

HF2 User Manual

50 MHz Lock-in Amplifier



Zurich
Instruments

HF2 User Manual

Zurich Instruments AG

Revision 24.04

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CE Declaration of Conformity



The manufacturer

Zurich Instruments
Technoparkstrasse 1
8005 Zurich
Switzerland

declares that the product
HF2 Series (HF2LI, HF2IS), 50 MHz, 210 MSamples/s

is in conformity with the provisions of the relevant Directives and Regulations of the Council of the European Union:

Directive / Regulation	Conformity proven by compliance with the standards
2014/30/EU (Electromagnetic compatibility [EMC])	EN 61326-1:2006, EN 55011:2007 (Group 1, Class A and B equipment)
2014/35/EU (Low voltage equipment [LVD])	EN 61010-1:2010, EN 61010-1:2010/A1:2019, EN 61010-1:2010/A1:2019/AC:2019-04
2011/65/EU, as amended by 2015/863 and 2017/2102 (Restriction of the use of certain hazardous substances [RoHS])	EN IEC 63000:2018
(EC) 1907/2006 (Registration, Evaluation, Authorisation, and Restrictions of Chemicals [REACH])	-

Zurich, October 20th, 2022

Flavio Heer, CTO

UKCA Declaration of Conformity



The manufacturer

Zurich Instruments
Technoparkstrasse 1
8005 Zurich
Switzerland

declares that the product
HF2 Series (HF2LI, HF2IS), 50 MHz, 210 MSamples/s

is in conformity with the provisions of the relevant UK Statutory Instruments:

Statutory Instruments	Conformity proven by compliance with the standards
S.I. 2016/1091 (Electromagnetic Compatibility Regulations)	EN 61326-1:2006, EN 55011:2007 (Group 1, Class A and B equipment)
S.I. 2016/1101 (Electrical Equipment (Safety) Regulations)	EN 61010-1:2010, EN 61010-1:2010/A1:2019, EN 61010-1:2010/A1:2019/AC:2019-04
S.I. 2012/3032 (Restriction of the Use of Certain Hazardous Substances Regulations)	EN IEC 63000:2018

Zurich, October 20th, 2022

A handwritten signature in black ink, appearing to read 'Flavio Heer'.

Flavio Heer, CTO

1. Change Log

1.1. Release 24.04

Release date: 30-Apr-2024

1.2. Release 24.01

Release date: 31-Jan-2024

- ─ Sweeper: The sweeper grid now includes the exact start and stop sweeping points.

1.3. Release 23.10

Release date: 31-Oct-2023

- ─ Sweeper: Setting the start and stop points of the sweep parameter from the x-axis cursors in the Sweeper tab.

1.4. Release 23.06

Release date: 30-Jun-2023

1.5. Release 23.02

Release date: 28-Feb-2023

- ─ LabOne API: Added support of Python 3.11.
- ─ Sweeper Module: Improved phase unwrap feature.
- ─ LabOne: Dropped support for Windows 7 and Windows 8.1 as they have reached their end of life.

1.6. Release 22.08

Release date: 31-Aug-2022

- ─ LabOne UI: Improved the Spectral Density feature of Sweeper tab.

1.7. Release 22.02

Release date: 28-Feb-2022

- ─ LabOne Software: 'Flat Top' window function for FFT mode of Scope, DAQ, and Spectrum.
- ─ LabOne API: Support of Python 3.10.

1.8. Release 21.08

Release date: 31-Aug-2021

- ─ User Manual: HTML version available in LabOne user interface and [online documentation](#).
- ─ LabOne Software: Support for GNU/Linux and macOS on ARM64 and Apple M1 processors.

1.9. Release 21.02

Release date: 28-Feb-2021

- LabOne API: Added online Programming Manual and Documentation.
- Sweeper: Simultaneous display of standard and X-Y plots to visualize Nyquist and Bode plots at the same time.
- Sweeper: Improved rendering of sweeps with more than 2000 points.

1.10. Release 20.07

Release date: 20-Aug-2020

- LabOne: Trends plots to track readings from the Math sub-tab over time.
- LabOne: Device Information report in Device tab.
- LabOne: Improved colormaps available for 2D plots.
- PID Advisor: clamp maximum advised bandwidth to hardware limits to guard against instability.

1.11. Release 20.01

Release date: 28-Feb-2020

- LabOne: added linear fit to the Math sub-tab of Sweeper and DAQ tabs.
- LabOne: histogram data can be saved in CSV format.
- LabOne: added option to display a normal or Rice distribution fit in Plotter tab.
- LabOne: improved importing of saved SVG figures to main vector graphics editors.

2. Getting Started

This first chapter guides you through the initial set-up of your HF2 Instrument in order to make your first measurements. This chapter comprises of:

- Quick start guide
- Package content and accessories list
- Software installation instructions
- Powering-on the device, connecting the device via USB, and performing basic operation checks on the instrument
- List of essential handling and safety instructions

This chapter is delivered as a hard copy with the instrument upon delivery. It is also the first chapter of the HF2 User Manual.


2.1. Quick Start Guide

This page addresses all the people who have been impatiently awaiting their new gem to arrive and want to see it up and running quickly. Please proceed with the following steps:

1. Check the package content. Besides the Instrument there should be a country-specific power cable, a USB cable and a hard copy of the user manual [Getting Started](#).
2. Check the Handling and Safety Instructions in [Handling and Safety Instructions](#).
3. Download and install the latest LabOne software from the Zurich Instruments homepage <http://www.zhinst.com/downloads/>. More detailed instructions are found in [Software Installation](#).
4. Connect the Instrument to the power line, turn it on and connect it to the PC using the USB cable. The front panel LED will show a steady blue color. If the LED does not turn blue, please contact Zurich Instruments for assistance.
5. Start the LabOne User Interface. The default web browser will open and display your instrument in a start screen as shown below. Use Chrome, Edge, Firefox, or Opera for best user experience.



6. Click the **Open** button on the bottom right of the page. The default configuration will be loaded and the first measurements can be taken. If the user interface does not start up successfully, please refer to [Connecting to the Instrument](#).
7. The HF2LI User Manual is included in a LabOne installation and can be accessed in Windows 10 via ¹ **Start Menu → Zurich Instruments → User Manual HF2 - LabOne**.

If any problems occur whilst setting up the instrument and software please see the [Troubleshooting](#) at the end of this chapter. After use it is recommended to shut down the instrument using the soft power button on the front panel instrument or by clicking on the  button at the bottom left of the user interface screen before turning the power switch on the back panel of the instrument.

Once the Instrument is up and running we recommend going through some of the [Tutorials](#). Moreover, [Functional Overview](#) provides a general introduction to the various tools and settings tabs with tables in each section providing a detailed description of every UI element as well. For specific application know-how the [blog section](#) of the Zurich Instruments website will serve as a valuable resource that is constantly updated and expanded.

1. Under Windows 7 and 8, the User Manual can be found in **Start Menu → All programs / All apps → Zurich Instruments → User Manual HF2 - LabOne.**




2.2. Inspect the Package Contents





If the shipping container appears to be damaged, keep the container until you have inspected the contents of the shipment and have performed basic functional tests.

Please verify:

- You have received 1 Zurich Instruments HF2 Instrument
- You have received 1 power cord with a power plug suited to your country
- You have received 1 USB cable
- A printed version of the "Getting Started" section
- Additional cables have been added to the delivery if an HF2 pre-amplifier has been delivered at the same time
- The line voltage selector on the HF2 Instrument power inlet indicates the correct line voltage of your country (115 V/60 Hz, or 230 V/50 Hz). While Zurich Instruments configures the power system when an instrument is initially delivered, no liability derives from potential wrong configuration or incorrect configuration at any point in time during the lifetime of the instrument
- The "Next Calibration" sticker on the rear panel of the Instrument indicates approximately 2 years ahead in time. Zurich Instruments recommends calibration intervals of 2 years
- The serial number of the instrument are displayed on a sticker on the back panel
- For Japanese users only: you are supposed to operate the HF2 Instruments with an external 100 V to 110 V transformer in order to have reliable measurement results. Please verify having received the transformer included in your delivery.

Table 2.1: Package contents for the HF2 Instrument

	
	the power cord (e.g. EU norm)
	the USB cable
	the power inlet with selected 230 V/ 50 Hz power system Power inlet with selected 230 V/50 Hz power system (red circle) and fuse holder. Requires 2 x 20 mm fast-acting fuses with 800 mA current limit. To extract the fuse holder use a small screwdriver in the indicated spot (red arrow) to lift it out of the casing

	the power inlet with selected 230 V/ 60 Hz power system (red circle) and fuse holder. Requires 2 x 20 mm fast-acting fuses with 800 mA current limit. To extract the fuse holder use a small screwdriver in the indicated spot (red arrow) to lift it out of the casing
	the S/N sticker on the back panel of the instrument
	the "Next Calibration" sticker on the back panel of the instrument
	Japanese users only: 100 V to 110 V transformer

Carefully inspect your HF2 Instrument. If there is mechanical damage or the instrument does not seem to operate after the [Software Installation](#), please consult the [Handling and Safety Instructions](#) and the [Troubleshooting](#), then notify the Zurich Instruments support team at support@zhinst.com as soon as possible.

2.3. Handling and Safety Instructions

The HF2LI Instrument is a sensitive piece of electronic equipment, and under no circumstances should its casing be opened, as there are high-voltage parts inside which may be harmful to human beings. There are no serviceable parts inside the instrument. Do not install substitute parts or perform any unauthorized modification to the product. Opening the instrument immediately voids the warranty provided by Zurich Instruments.

Do not use this product in any manner not specified by the manufacturer. The protective features of this product may be affected if it is used in a way not specified in the operating instructions.

The following general safety instructions must be observed during all phases of operation, service, and handling of the instrument. The disregard of these precautions and all specific warnings elsewhere in this manual may negatively affect the operation of the equipment and its lifetime.

Zurich Instruments assumes no liability for the user's failure to observe and comply with the instructions in this user manual.

Table 2.2: Safety Instructions

Ground the instrument	The instrument chassis must be correctly connected to earth ground by means of the supplied power cord. The ground pin of the power cord set plug must be firmly connected to the electrical ground (safety ground) terminal at the mains power outlet. Interruption of the protective earth conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury and potential damage to the instrument. For more information on the ground and earth scheme, refer to section Ground and Earth Scheme .
Measurement category	This equipment is of measurement category I (CAT I). Do not use it for CAT II, III, or IV. Do not connect the measurement terminals to mains sockets.
Maximum ratings	The specified electrical ratings for the connectors of the instrument should not be exceeded at any time during operation. Please refer to the Specifications for a comprehensive list of ratings.





Do not service or adjust anything yourself	There are no serviceable parts inside the instrument.
Software updates	Frequent software updates provide the user with many important improvements as well as new features. Only the last released software version is supported by Zurich Instruments.
Overseas travel	Changing the power system without changing the orientation of the fuse holder will damage the fuses and may make the instrument behave unpredictably.
Warnings	Instructions contained in any warning issued by the instrument, either by the software, the graphical user interface, the notes on the instrument or mentioned in this manual, must be followed.
Notes	Instructions contained in the notes of this user manual are of essential importance for correctly interpreting the acquired measurement data.
High voltage transients due to inductive loads	When measuring devices with high inductance, take adequate measures to protect the Signal Input connectors against the high voltages of inductive load switching transients. These voltages can exceed the maximum voltage ratings of the Signal Inputs and lead to damage.
Location and ventilation	This instrument or system is intended for indoor use in an installation category II and pollution degree 2 environment as per IEC 61010-1. Do not operate or store the instrument outside the ambient conditions specified in the Specifications section. Do not block the ventilator opening on the back or the air intake on the chassis side and allow a reasonable space for the air to flow.
Cleaning	To prevent electrical shock, disconnect the instrument from AC mains power and disconnect all test leads before cleaning. Clean the outside of the instrument using a soft, lint-free cloth slightly dampened with water. Do not use detergent or solvents. Do not attempt to clean internally.
AC power connection and mains line fuse	For continued protection against fire, replace the line fuse only with a fuse of the specified type and rating. Use only the power cord specified for this product and certified for the country of use. Always position the device so that its power switch and the power cord are easily accessible during operation.
Main power disconnect	Unplug product from wall outlet and remove power cord before servicing. Only qualified, service-trained personnel should remove the cover from the instrument.
RJ45 sockets	The four RJ45 sockets on the back panel labeled "Peripheral ZCtrl 1/2" and "ZSync In/Out" are not intended for Ethernet LAN connection. Connecting an Ethernet device to these sockets may damage the instrument and/or the Ethernet device.
Operation and storage	Do not operate or store the instrument outside the ambient conditions specified in the Specifications section.
Handling	Handle with care. Do not drop the instrument. Do not store liquids on the device, as there is a chance of spillage resulting in damage.
Safety critical systems	Do not use this equipment in systems whose failure could result in loss of life, significant property damage or damage to the environment.

If you notice any of the situations listed below, immediately stop the operation of the instrument, disconnect the power cord, and contact the support team at Zurich Instruments, either through the website form or through [email](#).

Table 2.3: Unusual Conditions

Fan is not working properly or not at all	Switch off the instrument immediately to prevent overheating of sensitive electronic components.
Power cord or power plug on instrument is damaged	Switch off the instrument immediately to prevent overheating, electric shock, or fire. Please exchange the power cord only with one for this product and certified for the country of use.
Instrument emits abnormal noise, smell, or sparks	Switch off the instrument immediately to prevent further damage.
Instrument is damaged	Switch off the instrument immediately and ensure it is not used again until it has been repaired.

Table 2.4: Symbols

	Earth ground
	Chassis ground
	Caution. Refer to accompanying documentation
	DC (direct current)

2.4. Software Installation

The HF2 Series Instrument is operated from a host computer with the LabOne software. To install the LabOne software on a computer, administrator rights may be required. In order to simply run the software later, a regular user account is sufficient. Instructions for downloading the correct version of the software packages from the Zurich Instruments website are described below in the platform-dependent sections. It is recommended to regularly update to the latest software version provided by Zurich Instruments. Thanks to the Automatic Update check feature, the update can be initiated with a single click from within the user interface, as shown in [Software Update](#).

2.4.1. Installing LabOne on Windows

The installation packages for the Zurich Instruments LabOne software are available as Windows installer .msi packages. The software is available on the [Zurich Instruments Download Center](#). Please ensure that you have administrator rights for the PC on which the software is to be installed. See [LabOne compatibility](#) for a comprehensive list of supported Windows systems.

2.4.2. Windows LabOne Installation

1. The HF2 Series Instrument should not be connected to your computer during the LabOne software installation process.
2. Start the LabOne installer program with a name of the form **LabOne64-XX.XX.XXXXX.msi** by a double click and follow the instructions. Windows Administrator rights are required for installation. The installation proceeds as follows:
 - On the welcome screen click the **Next** button.

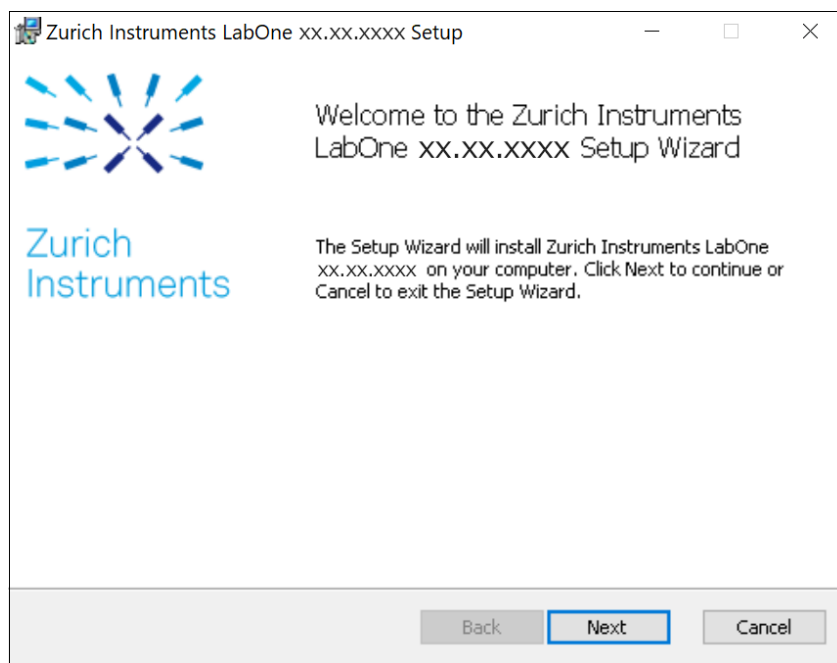


Figure 2.1: Installation welcome screen

- After reading through the Zurich Instruments license agreement, check the "I accept the terms in the License Agreement" check box and click the **Next** button.
- Review the features you want to have installed. For the HF2 Instrument the "HF2 Series Device", "LabOne User Interface" and "LabOne APIs" features are required. Please install the features for other device classes as well, if required. To proceed click the **Next** button.

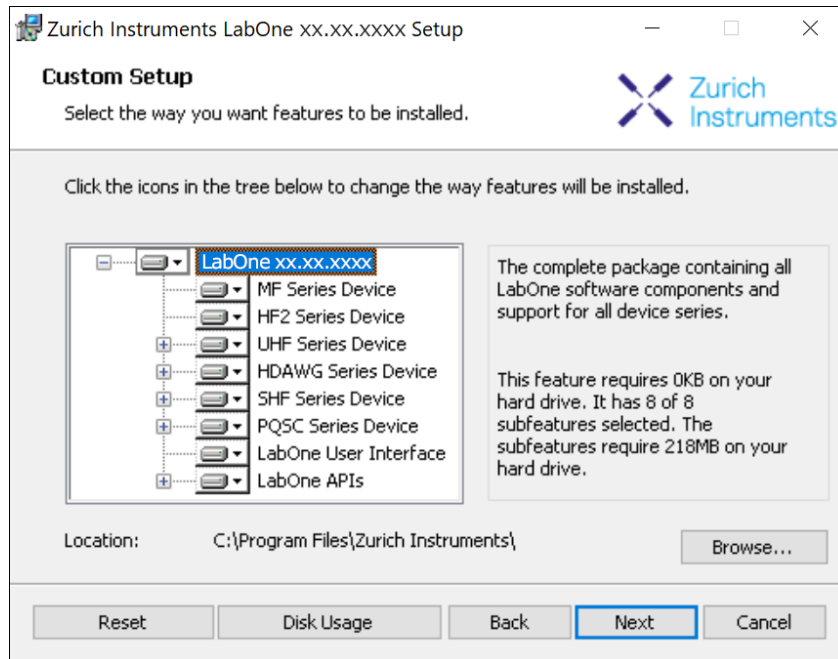


Figure 2.2: Custom setup screen

- Select whether the software should periodically check for updates. Note, the software will still not update automatically. This setting can later be changed in the user interface. If you would like to install shortcuts on your desktop area, select "Create a shortcut for this program on the desktop". To proceed click the **Next** button.

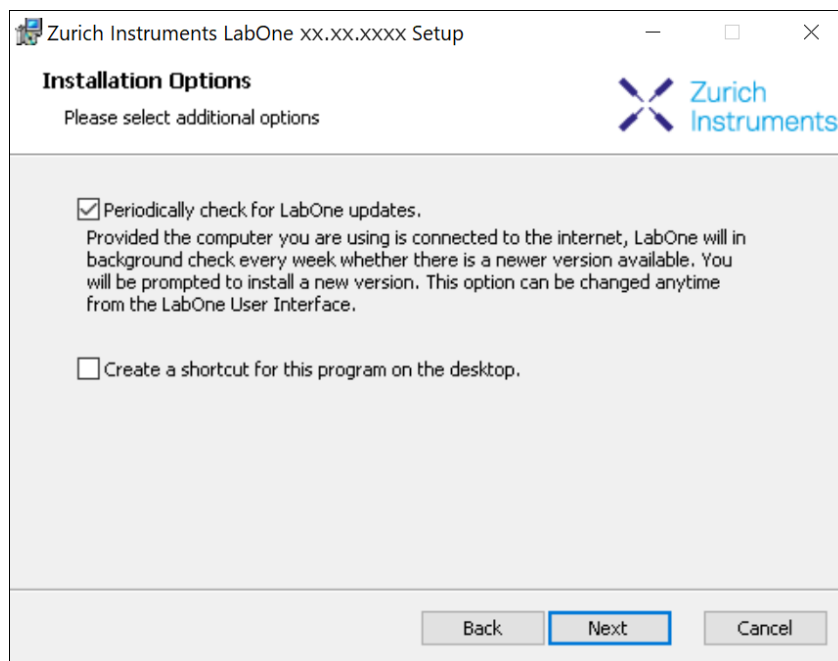


Figure 2.3: Automatic update check

- Click the **Install** button to start the installation process.
- Windows may ask up to two times to reboot the computer if you are upgrading. Make sure you have no unsaved work on your computer.

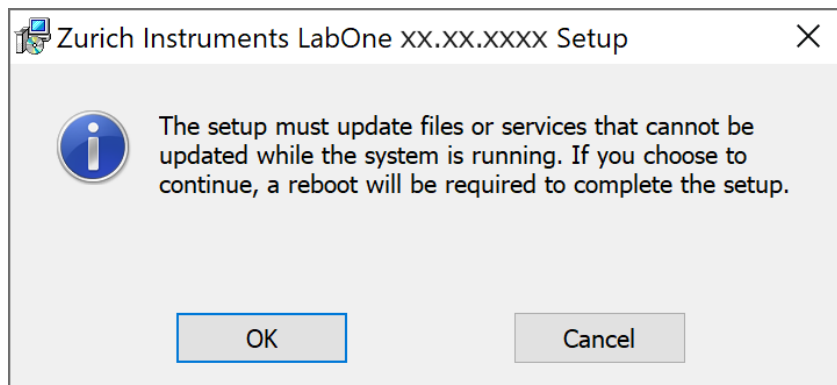


Figure 2.4: Installation reboot request

- During the first installation of LabOne, it is required to confirm the installation of some drivers from the trusted publisher Zurich Instruments. Click on **Install**.

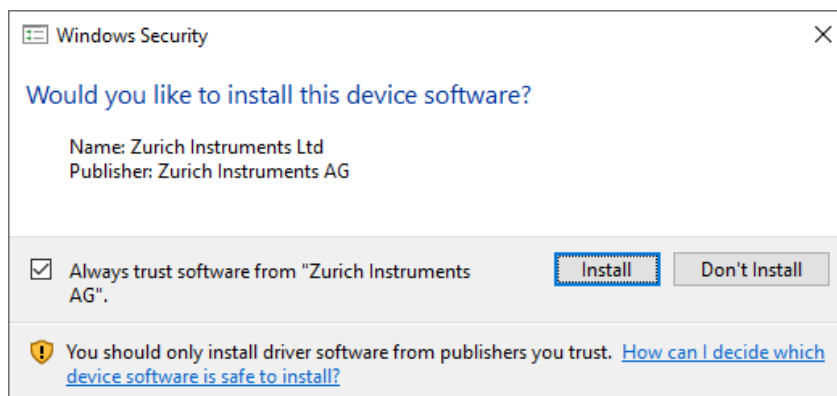


Figure 2.5: Installation driver acceptance

- Click **OK** on the following notification dialog.

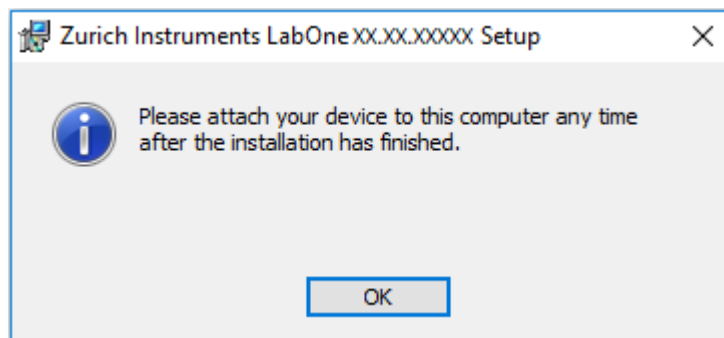


Figure 2.6: Installation completion screen

- Click **Finish** to close the Zurich Instruments LabOne installer.
- You can now start the LabOne User Interface as described in [LabOne Software Start-up](#) and choose an instrument to connect to via the Device Connection dialog shown in [Device Connection dialog](#).

Warning

Do not install drivers from another source other than Zurich Instruments.

2.4.3. Start LabOne Manually on the Command Line

After installing the LabOne software, the Web Server and Data Server can be started manually using the command-line. The more common way to start LabOne under Windows is described in [LabOne Software Start-up](#). The advantage of using the command line is being able to observe and change the behavior of the Web and Data Servers. To start the Servers manually, open a command-line

terminal (Command Prompt, PowerShell (Windows) or Bash (Linux)). For Windows, the current working directory needs to be the installation directory of the Web Server and Data Server. They are installed in the Program Files folder (usually: C:\Program Files) under \Zurich Instruments\LabOne in the WebServer and DataServer folders, respectively. The Web Server and Data Server (ziServer) are started by running the respective executable in each folder. Please be aware that only one instance of the Web Server can run at a time per computer. The behavior of the Servers can be changed by providing command line arguments. For a detailed list of all arguments see the command line help text:

```
$ ziWebServer --help
```

For the HF2 Data Server:

```
$ ziServer --help
```

One useful application of running the Webserver manually from a terminal window is to change the data directory from its default path in the user home directory. The data directory is a folder in which the LabOne Webserver saves all the measured data in the format specified by the user. Before running the Webserver from the terminal, the user needs to ensure there is no other instance of Webserver running in the background. This can be checked using the Tray Icon as shown below.

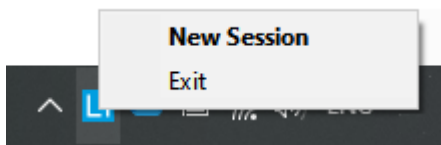


Figure 2.7: LabOne Tray Icon in Windows 10

The corresponding command line argument to specify the data path is **--data-path** and the command to start the LabOne Webserver with a non-default directory path, e.g., **C:\data** is

```
C:\Program Files\Zurich Instruments\LabOne\WebServer> ziWebServer --data-path "C:\data"
```

Windows LabOne Uninstallation

To uninstall the LabOne software package from a Windows computer, one can open the "Apps & features" page from the Windows start menu and search for LabOne. By selecting the LabOne item in the list of apps, the user has the option to "Uninstall" or "Modify" the software package as shown in Figure 2.8.

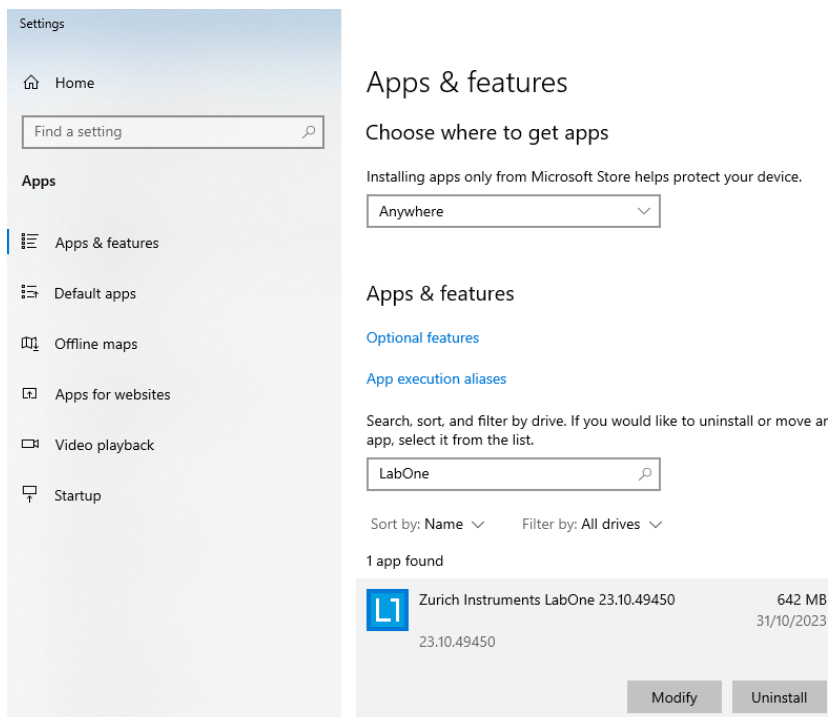


Figure 2.8: Uninstallation of LabOne on Windows computers

Warning

Although it is possible to install a new version of LabOne on a currently-installed version, it is highly recommended to first uninstall the older version of LabOne from the computer and then, install the new version. Otherwise, if the installation process fails, the current installation is damaged and cannot be uninstalled directly. The user will need to first repair the installation and then, uninstall it.

In case a current installation of LabOne is corrupted, one can simply repair it by selecting the option "Modify" in Figure 2.8. This will open the LabOne installation wizard with the option "Repair" as shown in Figure 2.9.

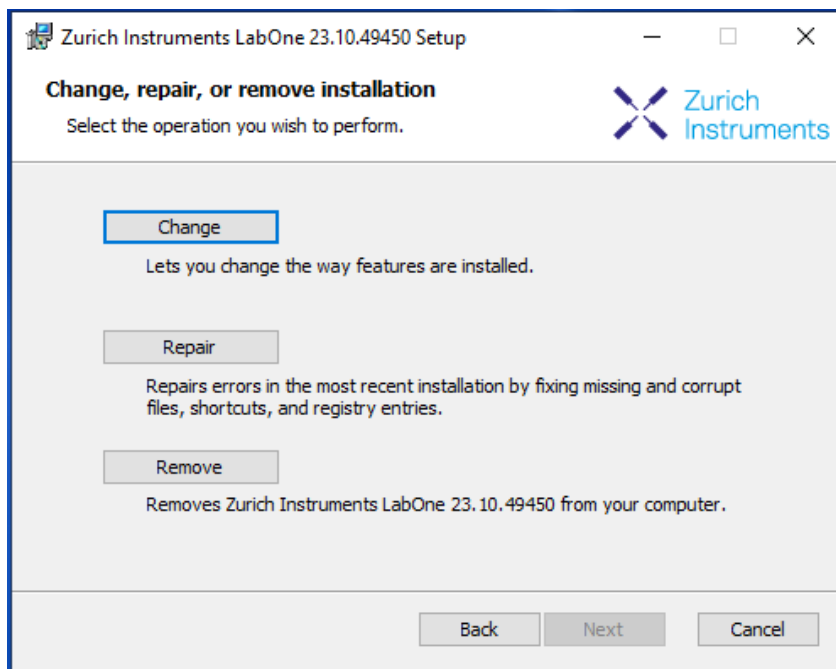


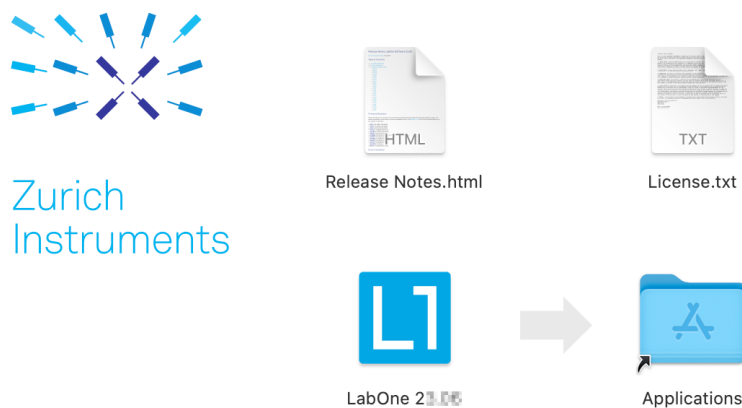
Figure 2.9: Repair of LabOne on Windows computers

After finishing the repair process, the normal uninstallation process described above can be triggered to uninstall LabOne.

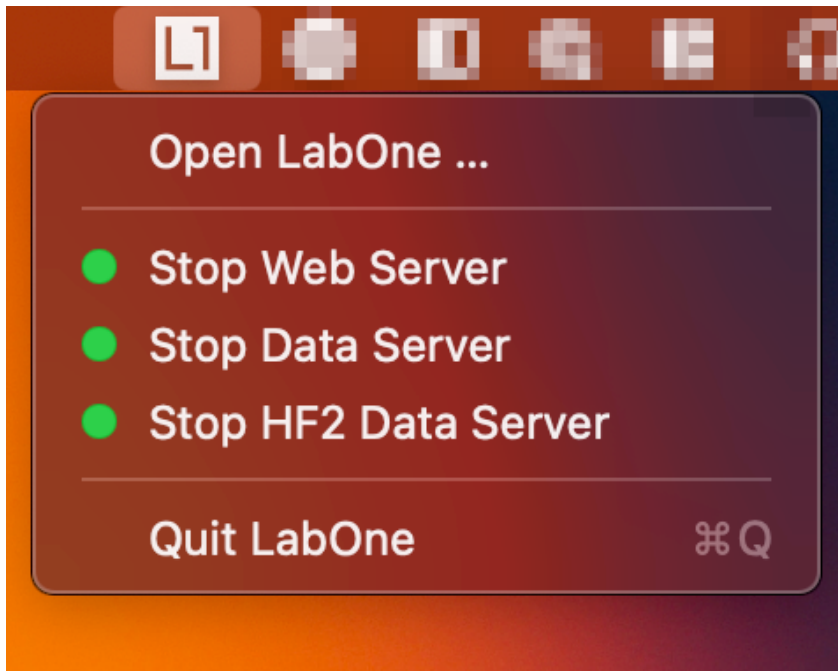
2.4.4. Installing LabOne on macOS

LabOne supports both Intel and ARM (M-series) architectures within a single universal disk image (DMG) file available in our Download Center.

- Download and double-click the DMG file to mount the image.



- The image contains a single LabOne application with all services needed.
- Once the application is started, a labone icon will appear in the menu bar. It allows the user to easily open a new session and shows the status of all services.



2.4.5. Uninstalling LabOne on macOS

To uninstall LabOne on macOS, simply drag the LabOne application to the trash bin.

2.4.6. Application Content

The LabOne application contains all resources available for macOS. This includes:

- The binaries for the Web Server and Data Servers.
- The binaries for the C, MATLAB, and LabVIEW APIs.
- An offline version of the user manuals.
- The latest firmware images for all instruments.

To access this content, right-click on the LabOne application and select "Show Package Contents". Then, go into Contents/Resources.

Note

Since the application name contains a space, one needs to escape it when using the command line to access the contents: `cd /Applications/LabOne\ 2X.XX.app/Contents/Resources`

2.4.7. Start LabOne Manually on the Command Line

To start the LabOne services like the data server and web server manually, one can use the command line.

The data server binary is called **ziServer** (**ziServer** for HF2 instruments) and is located at `Applications/LabOne\ 2X.XX.app/Contents/Resources/DataServer/`.

The web server binary is called **ziWebServer** and is located at `Applications/LabOne\ 2X.XX.app/Contents/Resources/DataServer/`.

Note

No special command line arguments are needed to start the LabOne services. Use the `--help` argument to see all available options.

2.4.8. Installing LabOne on Linux

2.4.9. Requirements

Ensure that the following requirements are fulfilled before trying to install the LabOne software package:

1. LabOne software supports typical modern GNU/Linux distributions (Ubuntu 14.04+, CentOS 7+, Debian 8+). The minimum requirements are glibc 2.17+ and kernel 3.10+.
2. You have administrator rights for the system.
3. The correct version of the LabOne installation package for your operating system and platform have been downloaded from the Zurich Instruments [Download Center](#):

```
LabOneLinux<arch>-<release>-<revision>.tar.gz,
```

Please ensure you download the correct architecture (x86-64 or arm64) of the LabOne installer. The `uname` command can be used in order to determine which architecture you are using, by running:

```
uname -m
```

in a command line terminal. If the command outputs **x86_64** the x86-64 version of the LabOne package is required, if it displays **aarch64** the ARM64 version is required.

2.4.10. Linux LabOne Installation

Proceed with the installation in a command line shell as follows:

1. Extract the LabOne tarball in a temporary directory:

```
tar xzvf LabOneLinux<arch>-<release>-<revision>.tar.gz
```

2. Navigate into the extracted directory.

```
cd LabOneLinux<arch>-<release>-<revision>
```

3. Run the install script with administrator rights and proceed through the guided installation, using the default installation path if possible:

```
sudo bash install.sh
```

The install script lets you choose between the following three modes:

- Type "a" to install the Data Server program, the Web Server program, documentation and APIs.
 - Type "u" to install **udev** support (only necessary if HF2 Instruments will be used with this LabOne installation and not relevant for other instrument classes).
 - Type "ENTER" to install both options "a" and "u".
4. Test your installation by running the software as described in the next section.

2.4.11. Running the Software on Linux

The following steps describe how to start the LabOne software in order to access and use your instrument in the User Interface.

1. Check whether the HF2 Data Server is already running using the "ziService" program:

```
$ ziService status
```

If **udev** support was installed, the HF2 Data Server program "ziServer" should already be running. If not, start the Data Server manually at a command prompt:

```
$ ziServer
```

If **udev** support was installed, then the HF2 Data Server program is automatically started upon plugging in the HF2's USB cable and powering the instrument. You should be able to access your instrument. In case of problems please consult the [Troubleshooting](#) at the end of this chapter. 2. Start the Web Server program at a command prompt:


```
$ ziWebServer
```

2. Start an up-to-date web browser and enter the **127.0.0.1:8006** in the browser's address bar to access the Web Server program and start the LabOne User Interface. The LabOne Web Server installed on the PC listens by default on port number 8006 instead of 80 to minimize the probability of conflicts.
3. You can now start the LabOne User Interface as described in [LabOne Software Start-up](#) and choose an instrument to connect to via the Device Connection dialog shown in [Device Connection dialog](#).

Danger

Do not use two Data Server instances running in parallel; only one instance may run at a time.

If your command log window is flooded with messages after starting the HF2LI Data Server stop the program; it is likely that another instance of the Data Server is already running. Verify whether a Data Server is already running as described above using the ziService program.

2.4.12. Uninstalling LabOne on Linux

The LabOne software package copies an uninstall script to the base installation path (the default installation directory is `/opt/zi/`). To uninstall the LabOne package please perform the following steps in a command line shell:

1. Navigate to the path where LabOne is installed, for example, if LabOne is installed in the default installation path:

```
$ cd /opt/zi/
```

2. Run the uninstall script with administrator rights and proceed through the guided steps:

```
$ sudo bash uninstall_LabOne<arch>-<release>-<revision>.sh
```

2.5. Connecting to the Instrument

The Zurich Instruments HF2LI Instrument is operated using the LabOne software. After installation of LabOne, the instrument is ready to be connected to a PC by the USB cable. The LabOne software is controlled via a web browser once suitable physical and logical connections to the instrument have been made.

Note

The following web browsers are supported (latest versions)



2.5.1. LabOne Software Architecture

The Zurich Instruments LabOne software gives quick and easy access to the instrument from a host PC. LabOne also supports advanced configurations with simultaneous access by multiple software clients (i.e., LabOne User Interface clients and/or API clients), and even simultaneous access by several users working on different computers. Here we give a brief overview of the architecture of the LabOne software. This will help to better understand the following chapters.

The software of Zurich Instruments equipment is server-based. The servers and other software components are organized in layers as shown in [Figure 2.10](#).

- ─ The lowest layer running on the PC is the LabOne Data Server, which is the interface to the connected instrument.
- ─ The middle layer contains the LabOne Web Server, which is the server for the browser-based LabOne User Interface.

- The graphical user interface, together with the programming user interfaces, are contained in the top layer.

The architecture with one central Data Server allows multiple clients to access a device with synchronized settings. The following sections explain the different layers and their functionality in more detail.

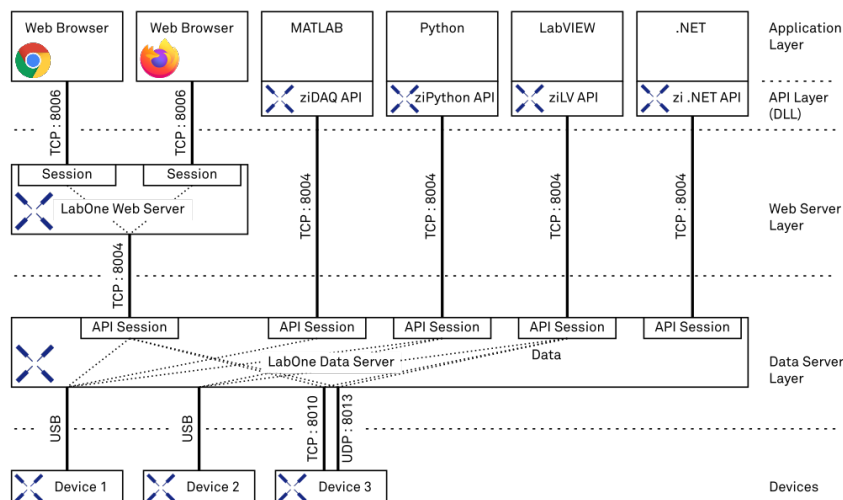


Figure 2.10: LabOne Software architecture

2.5.2. LabOne Data Server

The **LabOne Data Server** program is a dedicated server that is in charge of all communication to and from the device. The Data Server can control a single or also multiple instruments. It will distribute the measurement data from the instrument to all the clients that subscribe to it. It also ensures that settings changed by one client are communicated to other clients. The device settings are therefore synchronized on all clients. The HF2 Data Server is started automatically (on Windows via ziService, on Linux via udev) whenever a HF2 Instrument is connected to a PC via USB. On a PC, only a single instance of a LabOne Data Server should be running.

2.5.3. LabOne Web Server

The LabOne Web Server is an application dedicated to serving up the web pages that constitute the LabOne user interface. The user interface can be opened with any device with a web browser. Since it is touch enabled, it is possible to work with the LabOne User Interface on a mobile device - like a tablet. The LabOne Web Server supports multiple clients simultaneously. This means that more than one session can be used to view data and to manipulate the instrument. A session could be running in a browser on the PC on which the LabOne software is installed. It could equally well be running in a browser on a remote machine.

With a LabOne Web Server running and accessing an instrument, a new session can be opened by typing in a network address and port number in a browser address bar. In case the Web Server runs on the **same** computer, the address is the localhost address (both are equivalent):

- **127.0.0.1:8006**
- **localhost:8006**

In case the Web Server runs on a **remote** computer, the address is the IP address or network name of the remote computer:

- **192.168.x.y:8006**
- **myPC.company.com:8006**

The most recent versions of the most popular browsers are supported: Chrome, Firefox, Edge, Safari and Opera.

2.5.4. LabOne API Layer

The instrument can also be controlled via the application program interfaces (APIs) provided by Zurich Instruments. APIs are provided in the form of DLLs for the following programming environments:

- MATLAB
- Python
- LabVIEW
- .NET
- C

The instrument can therefore be controlled by an external program, and the resulting data can be processed there. The device can be concurrently accessed via one or more of the APIs and via the user interface. This enables easy integration into larger laboratory setups. See the LabOne Programming Manual for further information. Using the APIs, the user has access to the same functionality that is available in the LabOne User Interface.

2.5.5. LabOne Software Start-up

This section describes the start-up of the LabOne User Interface which is used to control the HF2 Series Instrument. If the LabOne software is not yet installed on the PC please follow the instructions in [Software Installation](#). If the device is not yet connected please find more information in [Visibility and Connection](#).

The LabOne User Interface start-up link can be found under the Windows 10 Start Menu (Under Windows 7 and 8, the LabOne User Interface start-up link can be found in **Start Menu → all programs / all apps → Zurich Instruments LabOne**). As shown in [Figure 2.11](#), click on **Start Menu → Zurich Instruments LabOne**. This will open the User Interface in a new tab in your default web browser and start the LabOne Data Server and LabOne Web Server programs in the background. A detailed description of the software architecture is found in [LabOne Software Architecture](#).

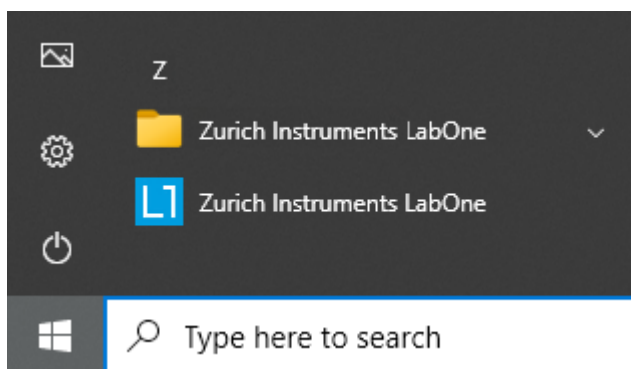


Figure 2.11: Link to the LabOne User Interface in the Windows 10 Start Menu

LabOne is an HTML5 browser-based program. This simply means that the user interface runs in a web browser and that a connection using a mobile device is also possible; simply specify the IP address (and port 8006) of the PC running the user interface.

Note

By creating a shortcut to Google Chrome on your desktop with the Target **path\to\chrome.exe -app=http://127.0.0.1:8006** set in Properties you can run the LabOne User Interface in Chrome in application mode, which improves the user experience by removing the unnecessary browser controls.

After starting LabOne, the Device Connection dialog [Figure 2.12](#) is shown to select the device for the session. The term "session" is used for an active connection between the user interface and the device. Such a session is defined by device settings and user interface settings. Several sessions can be started in parallel. The sessions run on a shared LabOne Web Server. A detailed description of the software architecture can be found in the [LabOne Software Architecture](#).

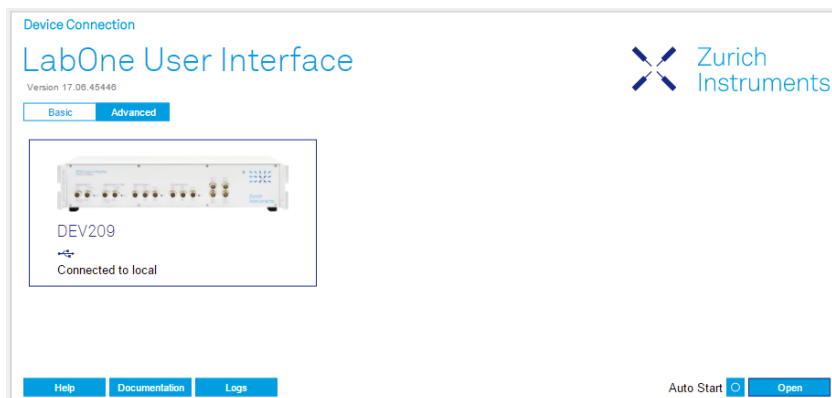


Figure 2.12: Device Connection dialog

The Device Connection dialog opens in the Basic view by default. In this view, all devices that are available for connection are represented by an icon with serial number and status information. If required, a button appears on the icon to perform a firmware upgrade. Otherwise, the device can be connected by a double click on the icon, or a click on the **Open** button at the bottom right of the dialog.

In some cases it's useful to switch to the Advanced view of the Device Connection dialog by clicking on the "Advanced" button. The Advanced view offers the possibility to select custom device and UI settings for the new session and gives further connectivity options that are particularly useful for multi-instrument setups.

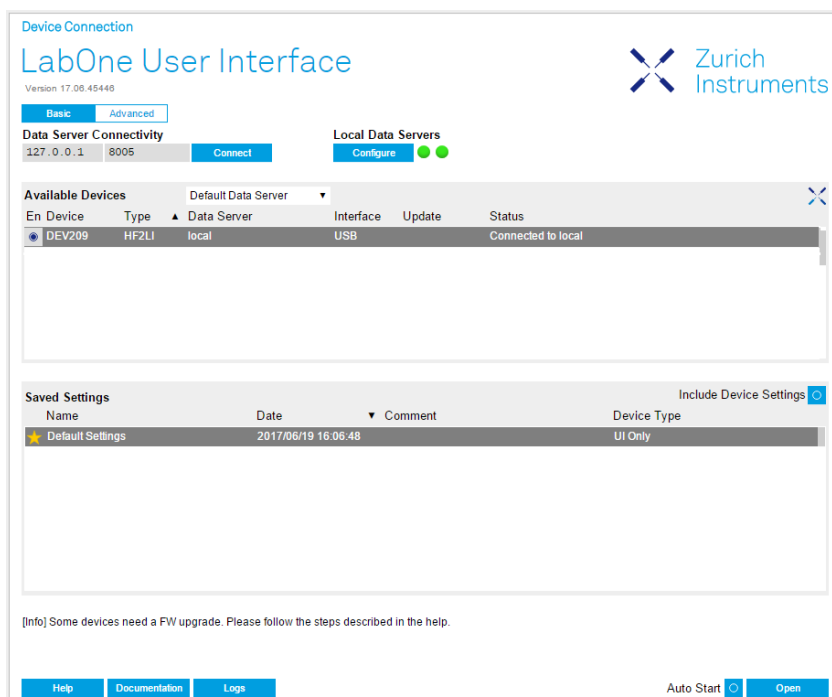


Figure 2.13: Device Connection dialog (Advanced view)

The Advanced view consists of three parts:

- Data Server Connectivity
- Available Devices
- Saved Settings

The Available Devices table has a display filter, usually set to **Default Data Server**, that is accessible by a drop-down menu in the header row of the table. When changing this to **Local Data Servers**, the Available Devices table will show only connections via the Data Server on the host PC and will contain all instruments directly connected to the host PC via USB or to the local network via 1GbE. When using the **All Data Servers** filter, connections via Data Servers running on other PCs in the network also become accessible. Once your instrument appears in the Available Devices table, perform the following steps to start a new session:

1. Select an instrument in the **Available Devices** table.
2. Select a setting file in the **Saved Settings** list unless you would like to use the Default Settings.

3. Start the session by clicking on [Open](#)

Note

By default, opening a new session will only load the UI settings (such as plot ranges), but not the device settings (such as signal amplitude) from the saved settings file. In order to include the device settings, enable the **Include Device Settings** checkbox. Note that this can affect existing sessions since the device settings are shared between them.

Note

In case devices from other Zurich Instruments series (UHF, HF2, MF, HDAWG, PQSC, GHF, or SHF) are used in parallel, the list in **Available Devices** section can contain those as well.

The following sections describe the functionality of the **Device Connection** dialog in detail.

2.5.6. Data Server Connectivity

The Device Connection dialog represents a Web Server. However, on start-up the Web Server is not yet connected to a LabOne Data Server. With the **Connect/Disconnect** button the connection to a Data Server can be opened and closed.

This functionality can usually be ignored when working with a single HF2 Instrument and a single host computer. Data Server Connectivity is important for users operating their instruments from a remote PC, i.e., from a PC different to the PC on which the Data Server is running or for users working with multiple instruments. The Data Server Connectivity function then gives the freedom to connect the Web Server to one of several accessible Data Servers. This includes Data Servers running on remote computers, and also Data Servers running on an MF Series instrument.

In order to work with a UHF, HF2, HDAWG, PQSC, GHF, or SHF instrument remotely, proceed as follows. On the computer directly connected to the instrument (Computer 1) open a User Interface session and change the Connectivity setting in the Config tab to "From Everywhere". On the remote computer (Computer 2), open the Device Connection dialog by starting up the LabOne User Interface and then go to the Advanced view by clicking on [Advanced](#) on the top left of the dialog. Change the display filter from Default Data Server to All Data Servers by opening the drop-down menu in the header row of the Available Devices table. This will make the Instrument connected to Computer 1 visible in the list. Select the device and connect to the remote Data Server by clicking on [Connect](#). Then start the User Interface as described above. In case you use UHF or MF Instruments in parallel with the HF2, please also refer to the UHF or MF documentation.

Note

When using the filter "All Data Servers", take great care to connect to the right instrument, especially in larger local networks. Always identify your instrument based on its serial number in the form DEV0000, which can be found on the instrument back panel.

2.5.7. Available Devices

The Available Devices table gives an overview of the visible devices. The first column of the list holds the **Enable** button controlling the connection between the device and a Data Server. For HF2 series instruments, this button is always greyed out since this connection is always established automatically. The second column indicates the serial number and the third column shows the instrument type (HF2, UHF, or MFLI). The fourth column indicates shows the host name of the LabOne Data Server controlling the device. The next column shows the interface type. For HF2 series instruments the type is always USB. The LabOne Data Server will scan for the available devices and interfaces once per second. If a device has just been switched on or physically connected it may take up to 20 s before it becomes visible to the LabOne Data Server. If an interface is physically connected but not visible please read [Device Connectivity](#). The last column indicates the status of the device which in the case of HF2 series instruments is always "Connected"

Table 2.5: Device Status Information


Connected	The device is connected to a LabOne Data Server, either on the same PC (indicated as local) or on a remote PC (indicated by its IP address). The user can start a session to work with that device.
Free	The device is not in use by any LabOne Data Server and can be connected by clicking the Open button.
In Use	The device is in use by a LabOne Data Server. As a consequence the device cannot be accessed by the specified interface. To access the device, a disconnect is needed.
Device FW upgrade required/available	The firmware of the device is out of date. Please first upgrade the firmware as described in Software Update .
Device not yet ready	The device is visible and starting up.

2.5.8. Saved Settings

Settings files can contain both UI and device settings. UI settings control the structure of the LabOne User Interface, e.g. the position and ordering of opened tabs. Device settings specify the set-up of a device. The device settings persist on the device until the next power cycle or until overwritten by loading another settings file.

The columns are described in [Table 2.6](#). The table rows can be sorted by clicking on the column header that should be sorted. The default sorting is by time. Therefore, the most recent settings are found on top. Sorting by the favorite marker or setting file name may be useful as well.

Table 2.6: Column Descriptions

	Allows favorite settings files to be grouped together. By activating the stars adjacent to a settings file and clicking on the column heading, the chosen files will be grouped together at the top or bottom of the list accordingly. The favorite marker is saved to the settings file. When the LabOne user interface is started next time, the row will be marked as favorite again.
Name	The name of the settings file. In the file system, the file name has the extension .md.
Date	The date and time the settings file was last written.
Comment	Allows a comment to be stored in the settings file. By clicking on the comment field a text can be typed in which is subsequently stored in the settings file. This comment is useful to describe the specific conditions of a measurement.
Device Type	The instrument type with which this settings file was saved.

Special Settings Files

Certain file names have the prefix "last_session_". Such files are created automatically by the LabOne Web Server when a session is terminated either explicitly by the user, or under critical error conditions, and save the current UI and device settings. The prefix is prepended to the name of the most recently used settings file. This allows any unsaved changes to be recovered upon starting a new session.

If a user loads such a last session settings file the "last_session_" prefix will be cut away from the file name. Otherwise, there is a risk that an auto-save will overwrite a setting which was saved explicitly by the user.

The settings file with the name "Default Settings" contains the default UI settings. See button description in [Table 2.7](#).

Table 2.7: Button Descriptions

Open	The settings contained in the selected settings file will be loaded. The button "Include Device Settings" controls whether only UI settings are loaded, or if device settings are included.
Include Device Settings	Controls which part of the selected settings file is loaded upon clicking on Open. If enabled, both the device and the UI settings are loaded.

Auto Start	Skips the session dialog at start-up if selected device is available. The default UI settings will be loaded with unchanged device settings.
-------------------	--

Note

The user setting files are saved to an application-specific folder in the directory structure. The best way to manage these files is using the File Manager tab.

Note

The factory default UI settings can be customized by saving a file with the name "default_ui" in the Config tab once the LabOne session has been started and the desired UI setup has been established. To use factory defaults again, the "default_ui" file must be removed from the user setting directory using the File Manager tab.

Note

Double clicking on a device row in the Available Devices table is a quick way of starting the default LabOne UI. This action is equivalent to selecting the desired device and clicking the **Open** button.

Double clicking on a row in the Saved Settings table is a quick way of loading the LabOne UI with those UI settings and, depending on the "Include Device Settings" checkbox, device settings. This action is equivalent to selecting the desired settings file and clicking the **Open** button.

2.5.9. Tray Icon

When LabOne is started, a tray icon appears by default in the bottom right corner of the screen, as shown in the figure below. By right-clicking on the icon, a new web server session can be opened quickly, or the LabOne Web and Data Servers can be stopped by clicking on Exit. Double-clicking the icon also opens a new web server session, which is useful when setting up a connection to multiple instruments, for example.

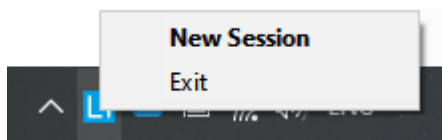


Figure 2.14: LabOne Tray Icon in Windows 10

2.5.10. Messages

The LabOne Web Server will show additional messages in case of a missing component or a failure condition. These messages display information about the failure condition. The following paragraphs list these messages and give more information on the user actions needed to resolve the problem.

Lost Connection to the LabOne Web Server

In this case the browser is no longer able to connect to the LabOne Web Server. This can happen if the Web Server and Data Server run on different PCs and a network connection is interrupted. As long as the Web Server is running and the session did not yet time out, it is possible to just attach to the existing session and continue. Thus, within about 15 seconds it is possible with **Retry** to recover the old session connection. The **Reload** button opens the Device Connection dialog shown in [Figure 2.12](#). The figure below shows an example of the Connection Lost dialog.

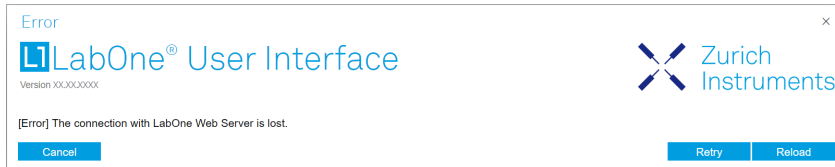


Figure 2.15: Dialog: Connection Lost

Reloading...

If a session error cannot be handled, the LabOne Web Server will restart to show a new Device Connection dialog as shown in Figure 2.12. During the restart a window is displayed indicating that the LabOne User Interface will reload. If reloading does not happen the same effect can be triggered by pressing F5 on the keyboard. The figure below shows an example of this dialog.

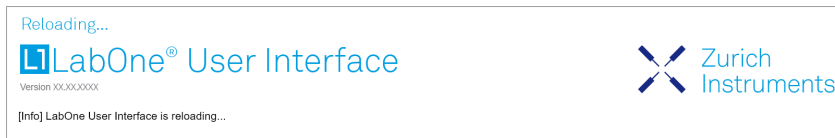


Figure 2.16: Dialog: Reloading

No Device Discovered

An empty "Available Devices" table means that no devices were discovered. This can mean that no LabOne Data Server is running, or that it is running but failed to detect any devices. The device may be switched off or the interface connection fails. For more information on the interface between device and PC see [Visibility and Connection](#). The figure below shows an example of this dialog.

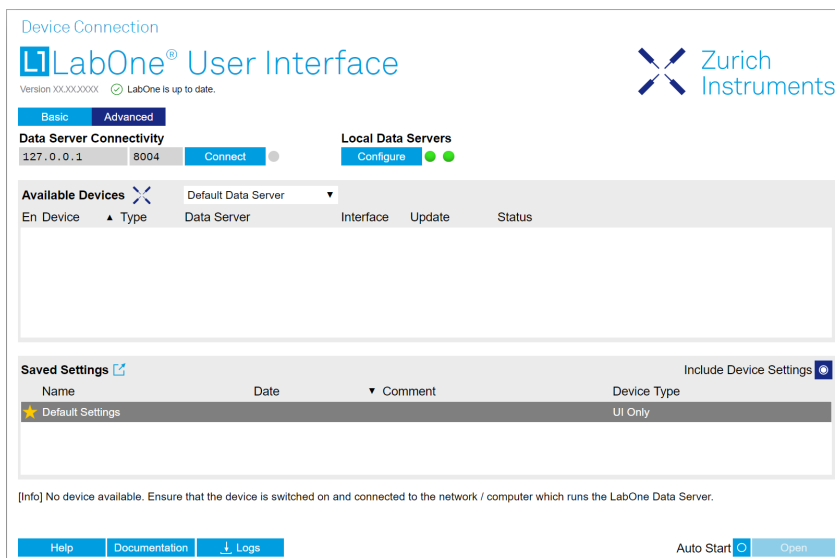


Figure 2.17: No Device Discovered

2.5.11. Device Connectivity

The device can be connected to a host computer by Universal Serial Bus (USB). The HF2 Instrument will then connect to the Data Server on the host PC. If the Data Server is not yet up and running, it is started up automatically when plugging in the USB connection. An instrument can be connected to one Data Server only, but a single Data Server and host computer can connect to several instruments at once.

If the host computer is in a local TCP/IP network, it's possible to control the device remotely and even from several computers simultaneously. Also in this remote configuration, there is a single LabOne Data Server connected to the instrument. This Data Server runs on the computer connected to the instrument via USB. The Data Server can serve one or more remote clients in the network. All clients can access the same measurement data. Changes in instrument settings done by one client will be seen by all other clients.

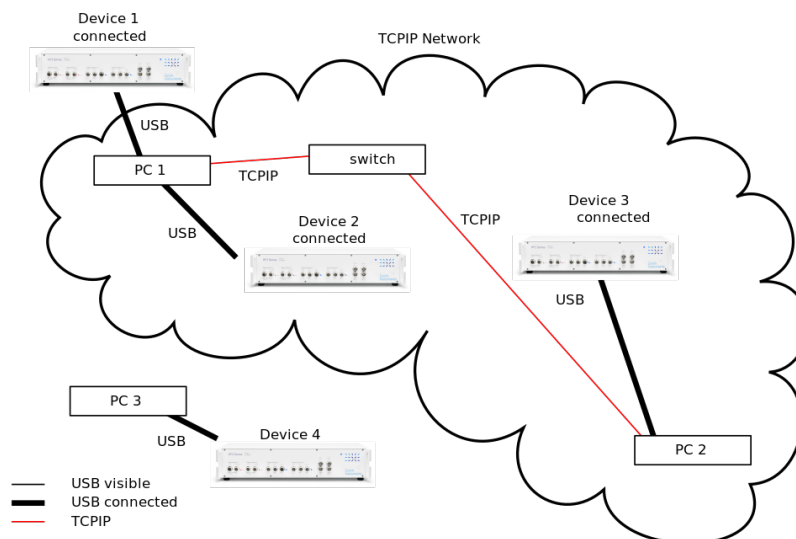


Figure 2.18: Connectivity

Figure 2.18 shows some examples of possible configurations of PC-to-device connectivity.

- Server on PC 1 is connected to device 1 (USB) and device 2 (USB).
- Server on PC 2 is connected to device 3 (USB).
- Server on PC 3 is connected to device 4.
- The devices 1, 2, and 3 are all visible to PC 1 and PC 2 over TCP/IP.

2.6. Software Update

2.7. Overview

It is recommended to regularly update the LabOne software on the HF2LI Instrument to the latest version. In case the Instrument has access to the internet, this is a very simple task and can be done with a single click in the software itself, as shown in [Updating LabOne using Automatic Update Check](#). If you use one of the LabOne APIs with a separate installer, don't forget to update this part of the software, too.

2.7.1. Updating LabOne using Automatic Update Check

Updating the LabOne software is done by downloading and installing the latest LabOne software from the Zurich Instruments downloads page, as shown in [Software Installation](#). In case "Periodically check for updates" has been enabled during the LabOne installation and LabOne has access to the internet, a notification will appear on the Device Connection dialog whenever a new version of the software is available for download. This setting can later be changed in the Config tab of the LabOne user interface. In case automatic update check is disabled, the user can manually check for updates at any time by clicking on the button [Check For Update](#) in the Device Connection dialog. In case an update is found, clicking on the button "Update Available" shown in [Figure 2.19](#) will start a download of the latest LabOne installer for Windows or Linux, see [Figure 2.20](#). After download, proceed as explained in [Software Installation](#) to update LabOne.

Device Connection



Figure 2.19: Device Connection dialog: LabOne update available

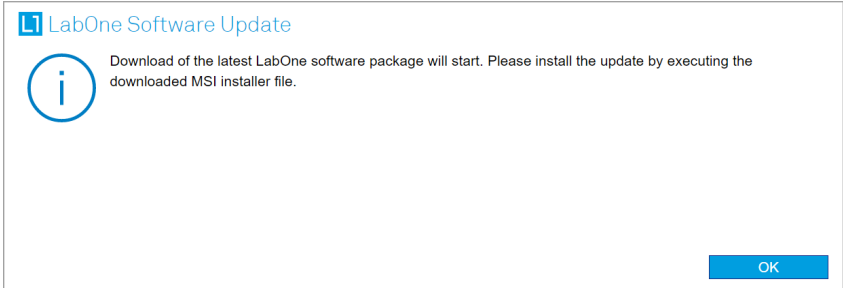


Figure 2.20: Download LabOne MSI using Automatic Update Check feature

2.8. Troubleshooting

This section aims to help the user solve and avoid problems while using the software and operating the instrument.

2.8.1. Common Problems

Your HF2 Series Instrument is an advanced piece of laboratory equipment which has many more features and capabilities than a traditional lock-in amplifier. In order to benefit from these, the user needs access to a large number of settings in the LabOne User Interface. The complexity of the settings might overwhelm a first-time user, and even expert users can get surprised by certain combinations of settings. To avoid problems, it's good to use the possibility to save and load settings in the Config Tab. This allows one to keep an overview by operating the instrument based on known configurations. This section provides an easy-to-follow checklist to solve the most common mishaps.

Table 2.8: Common Problems

Problem	Check item
The software cannot be installed or uninstalled	Please verify you have administrator/root rights.
The software cannot be updated	Please use the Modify option in Windows Apps & Features functionality. In the software installer select Repair, then uninstall the old software version, and install the new version.
The Instrument does not turn on	Please verify the power supply connection and inspect the fuse. The fuse holder is integrated in the power connector on the back panel of the instrument.
The HF2 Instrument turns on but delivers obviously wrong measurements	Please verify the power system setting on the back panel of the device is set to the power system of your country (110 V / 60 Hz, 220 V / 50 Hz). Make sure the fuse holder is set to the correct power supply position. This means that the wanted power supply label, 230 V or 115 V, must be positioned beside the edge of the power socket (e.g. not beside the power switch).
The HF2 Instrument performs poorly in a country with 100 V supply system (e.g. Japan)	if no 100 V to 110 V transformer is used, the internal power supplies might be below specifications and some circuits might perform worse than specification. Users in countries with 100 V supply system are warmly recommended to use an external transformer (delivered with the instrument).

Problem	Check item
The HF2 Instrument shows limited data throughput on USB	although the host computer requirements are not particularly demanding, highest performance in USB throughput will require a performing desktop. The USB might be limiting the data throughput, please see Maximum sample readout rate for more details. Many concurrent transfers on the USB will limit the individual transfer. In particular the Scope should be turned off when not needed by the application. The status of the USB transfer can be monitored in the STATUS_TAB.
The Instrument performs poorly in single-ended operation	the signal inputs of the instrument might be set to differential operation. Please ensure that differential input mode is turned off in the Lock-in Tab or In / Out Tab.
The HF2 Instrument has a high input noise floor	the USB cable connects the Instrument ground to computer ground, which might inject some unwanted noise to the measurements results. In order to decouple the computer from the Instrument consider using an electrically isolating USB range extender supporting 480 Mbit/s data transfer rate. Zurich Instruments recommends the models USB 2.0 Ranger 2201 (Icron technologies) and U-Link USB 2.0 extender (Sewell). The power supply delivered with the range extender may need to be exchanged with a more stable power supply for optimum noise performance.
The Instrument performs poorly at low frequencies	the signal inputs of the instrument might be set to AC operation. Please verify to turn off the AC switch in the Lock-in Tab or In / Out Tab.
The Instrument performs poorly during operation	the demodulator filters might be set too wide (too much noise) or too narrow (slow response) for your application. Please verify if the demodulator filter settings match your frequency versus noise plan.
The Instrument performs strangely when working with the HF2-MF Multi-frequency Option	it is easily possible to turn on more signal generators than intended. Check the generated Signal Output with the integrated oscilloscope and check the number of simultaneously activated oscillator voltages.
The Instrument performs close to specification, but higher performance is expected	After 2 years since the last calibration, a few analog parameters are subject to drift. This may cause inaccurate measurements. Zurich Instruments recommends re-calibration of the Instrument every 2 years.
The Instrument measurements are unpredictable	Please check the Status Tab to see if there is any active warning (red flag), or if one has occurred in the past (yellow flag).
The Instrument does not generate any output signal	verify that signal output switch has been activated in the Lock-in Tab or in the In / Out Tab.
The Instrument locks poorly using the digital I/O as reference	make sure that the digital input signal has a high slew rate and clean level crossings.
The Instrument locks poorly using the auxiliary analog inputs as reference	the input signal amplitude might be too small. Use proper gain setting of the input channel.

Problem	Check item
The sample stream from the Instrument to the host computer is not continuous	Check the communication (COM) flags in the status bar. The three flags indicate occasional sample loss, packet loss, or stall. Sample loss occurs when a sampling rate is set too high (the instrument sends more samples than the interface and the host computer can absorb). The packet loss indicates an important failure of the communications to the host computer and compromises the behavior of the instrument. Both problems are prevented by reducing the sample rate settings. The stall flag indicates that a setting was actively changed by the system to prevent UI crash.
The Instrument is connected but there is no communication to the computer	check the clock fail (CF) flag in the status bar. This abnormal situation can occur if "Clk 10 MHz" is selected as Clock Source but no clock signal is fed to the Instrument. If Internal clock source is selected and the flag is still active, then the situation might indicate a serious hardware failure. In this case contact Zurich Instruments support team at support@zhinst.com .
The LabOne User Interface does not start	Verify that the LabOne Data Server (ziServer.exe) and the LabOne Web Server (ziWebServer.exe) are running via the Windows Task Manager. The Data Server should be started automatically by ziService.exe and the Web Server should be started upon clicking "Zurich Instruments LabOne" in the Windows Start Menu. If both are running, but clicking the Start Menu does not open a new User Interface session in a new tab of your default browser then try to create a new session manually by entering 127.0.0.1:8006 in the address bar of your browser.
The user interface does not start or starts but remains idle	Verify that the ziServer HF2 Instrument has been started and are running on your host computer.
The user interface is slow and the web browser process consumes a lot of CPU power	Make sure that the hardware acceleration is enabled for the web browser that is used for LabOne. For the Windows operating system, the hardware acceleration can be enabled in Control Panel → Display → Screen Resolution . Go to Advanced Settings and then Troubleshoot. In case you use an NVIDIA graphics card, you have to use the NVIDIA control panel. Go to Manage 3 Settings, then Program Settings and select the program that you want to customize.

2.8.2. Location of the Log Files

The most recent log files of the LabOne Web and Data Server programs are most easily accessed by clicking on **Logs** in the **LabOne Device Connection dialog** of the user interface. The Device Connection dialog opens on software start-up or upon clicking on **Session Manager** in the Config tab of the user interface.

The location of the Web and Data Server log files on disk are given in the sections below.

Windows

The Web and Data Server log files on Windows can be found in the following directories.

- HF2 Data Server (**ziServer.exe**) started by the service (**ziService.exe**):

- ```
C:\Windows\ServiceProfiles\LocalService\AppData\Local\Temp\Zurich
Instruments\LabOne\ziServerLog
```
- HF2 Data Server started manually:  
C:\Users\[USER]\AppData\Local\Temp\Zurich Instruments\LabOne\ziServerLog
  - LabOne Web Server (ziWebServer.exe):  
C:\Users\[USER]\AppData\Local\Temp\Zurich Instruments\LabOne\ziWebServerLog

## Note

The `C:\Users\[USER]\AppData` folder is hidden by default under Windows. A quick way of accessing it is to enter `%AppData%\..` in the address bar of the Windows File Explorer.

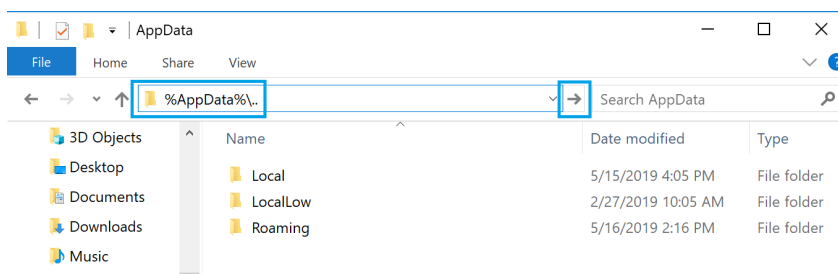


Figure 2.21: Using the

## Linux and macOS

The Web and Data Server log files on Linux or macOS can be found in the following directories.

- HF2 Data Server (ziServer) started manually:  
/tmp/ziServerLog\_[USER]
- HF2 Data Server if started automatically (Linux only, by the Zurich Instruments udev rule):  
/tmp/ziServerLog\_root
- LabOne Web Server (ziWebServer):  
/tmp/ziWebServerLog\_[USER]

### 2.8.3. Prevent web browsers from sleep mode

It often occurs that an experiment requires a long-time signal acquisition; therefore, the setup including the measurement instrument and LabOne software are left unattended. By default, many web browsers go to a sleep mode after a certain idle time which results in the loss of acquired data when using the web-based user interface of LabOne for measurement. Although it is recommended to take advantage of LabOne APIs in these situations to automate the measurement process and avoid using web browsers for data recording, it is still possible to adjust the browser settings to prevent it from entering the sleep mode. Below, you will find how to modify the settings of your preferred browser to ensure a long-run data acquisition can be implemented properly.

## Edge

- Open **Settings** by typing `edge://settings` in the address bar
- Select **System** from the icon bar.
- Find the **Never put these sites to sleep** section of the **Optimized Performance** tab.
- Add the IP address and the port of LabOne Webserver, e.g., `127.0.0.1:8006` or `192.168.73.98:80` to the list.

## Chrome

- While LabOne is running, open a tab in Chrome and type `chrome://discards` in the address bar.
- In the shown table listing all the open tabs, find LabOne and disable its **Auto Discardable** feature.
- This option avoids discarding and refreshing the LabOne tab as long as it is open. To disable this feature permanently, you can use an extension from the Chrome Webstore.

## Firefox

1. Open **Advanced Preferences** by typing `about:config` in the address bar.
2. Look for `browser.tabs.unloadOnLowMemory` in the search bar.
3. Change it to **false** if it is **true**.

## Opera

1. Open **Settings** by typing `opera://settings` in the address bar.
2. Locate the **User Interface** section in the **Advanced** view.
3. Disable the **Snooze inactive tabs to save memory** option and restart Opera.

## Safari

1. Open **Debug** menu.
2. Go to **Miscellaneous Flags**.
3. Disable **Hidden Page Timer Throttling**.

# 3. Functional Overview

This chapter helps you to quickly get acquainted with the main features, the panels, and the operating modes of the HF2 Series. A product selector is provided listing the key features of the products in order to support the selection and ordering. This section is intended as overview and therefore has a coarse level of detail without containing detailed descriptions.

## 3.1. Features

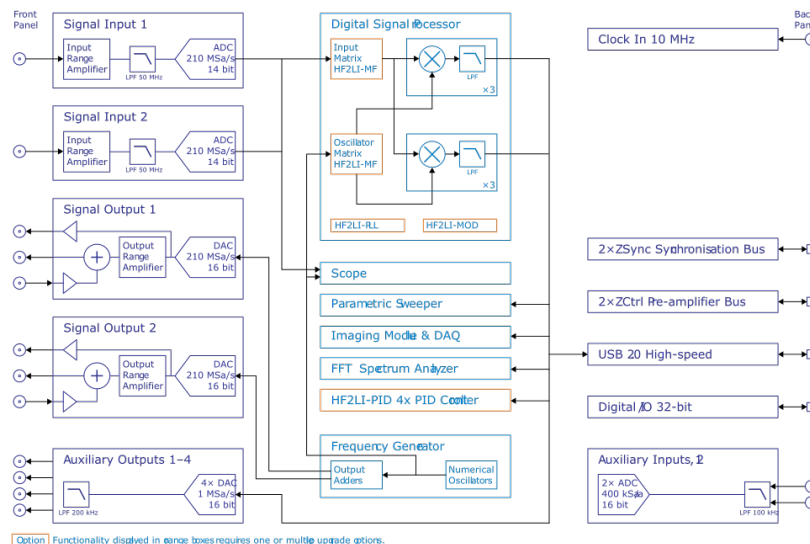


Figure 3.1: HF2 functional diagram

The HF2 Instrument as in Figure 3.1 consists of 4 high-frequency analog blocks, 2 low-frequency auxiliary blocks, the internal digital processing block (light-blue), and the hardware interfaces (mostly available on the back panel of the instrument).

The signal to be measured is connected to one of the two high-frequency analog inputs where it is amplified to a defined range, filtered, and digitized at very high speed. The resulting samples are fed into the digital signal processing block for demodulation by means of up to 8 dual-phase demodulators. The demodulators output samples flow into the embedded RISC processor for further processing or to be sent to the host computer. The samples are also sent to the auxiliary outputs in order to be available on the front panel of the HF2 Instrument.

The numerical oscillators generate sine and cosine signal pairs that are used for the demodulation of the input samples and also for the generation of the high-frequency output signals. For this purpose, the Output Mixers generate a weighted sum of the generator outputs to generate the multi-frequency signal that can be used as a stimulation signal. The 2 high-frequency output stages provide analog to digital conversion, signal scaling (range), add of an external AC or DC signal, and a synchronization signal.

### 3.1.1. Operating Modes

- Internal reference mode
- External reference mode
- Auto reference mode
- Dual-channel operation
- Dual-harmonic mode
- Multi-harmonic mode
- Arbitrary frequency mode

### 3.1.2. High-frequency Analog Inputs

- 2 low-noise high-frequency inputs

## 3.1. Features

- Differential & single-ended operation (A, -B, A-B)
- Variable input range
- Variable input impedance
- AC/DC coupling

### 3.1.3. High-frequency Analog Outputs

- 2 low-noise high-frequency outputs
- Large output range
- Variable output range settings
- 1 synchronization signal for each output
- 1 adder signal for each output

### 3.1.4. Auxiliary Analog Input/Outputs

- 4 auxiliary high-speed outputs
- 2 auxiliary high-speed inputs
- User defined signal on auxiliary output

### 3.1.5. Demodulators & Reference

- Up to 8 dual-phase demodulators
- Up to 8 programmable numerical oscillators
- Programmable demodulators filters
- Very-high resolution internal reference
- 64-bit resolution demodulator outputs

### 3.1.6. Measurement Tools

- Spectroscope
- Numerical
- Oscilloscope
- Frequency response analyzer
- FFT spectrum analyzer

### 3.1.7. User-programmable Embedded Processor (Option)

- Microblaze 32-bit RISC
- 64 MHz operation allows implementation of real-time control loops
- 32-bit floating-point unit
- 64 kB internal memory (maximum program size)
- 64 MB external memory DDR2

### 3.1.8. Other Interfaces

- USB 2.0 high-speed 480 Mbit/s host interface
- DIO: 32-bit digital input-output port
- ZSync: 2 ports for inter-instrument synchronization bus (ZI proprietary)
- ZCtrl: 2 ports for control/power bus for external pre-amplifiers (ZI proprietary)
- Clock input connector (10 MHz)

### 3.1.9. Software Features

- The LabOne User Interface, a powerful browser-based graphical interface
- ziServer multi-mode multi-connection server
- ziAPI for extended programmability in C, LabVIEW, MATLAB, and Python - programming examples included
- Console: text interface to connect virtually any programming language



## 3.2. Front Panel Tour

The front panel BNC connectors and control LEDs are arranged in 5 sections as shown in [Figure 3.2](#) and [Figure 3.3](#) and listed in . The HF2LI and HF2IS have the same connectors and connector functionality on their front and back panel.

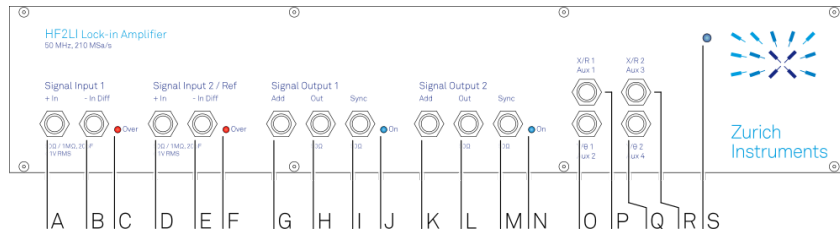


Figure 3.2: HF2LI front panel

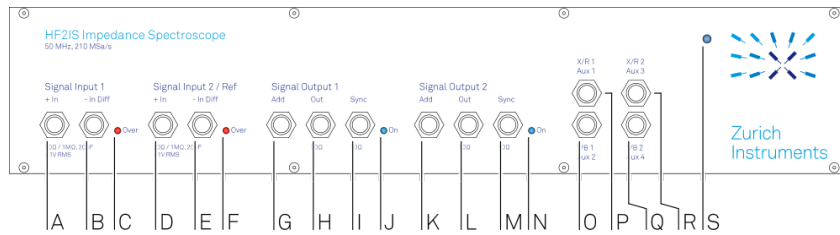


Figure 3.3: HF2IS front panel

Table 3.1: HF2 Series front panel description

| Position | Label / Name                      | Description                                                                                                                                                                                           |
|----------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A        | Signal Input 1<br>+ In            | single-ended input                                                                                                                                                                                    |
| B        | Signal Input 1<br>- In Diff       | negative input (when not used, has to be internally shorted to ground with switch on graphical user interface)                                                                                        |
| C        | Signal Input 1<br>Over            | this LED indicates that the input signal saturates the A/D converter                                                                                                                                  |
| D        | Signal Input 2 / Ref<br>+ In      | single ended input / reference input for external reference mode                                                                                                                                      |
| E        | Signal Input 2 / Ref<br>- In Diff | negative input (when not used, has to be internally shorted to ground with switch on graphical user interface)                                                                                        |
| F        | Signal Input 2<br>Over            | this LED indicates that the input signal saturates the A/D converter                                                                                                                                  |
| G        | Signal Output<br>1 Add            | the signal applied to the connector is added (analog add) to the output signal                                                                                                                        |
| H        | Signal Output<br>1 Out            | high-frequency output                                                                                                                                                                                 |
| I        | Signal Output<br>1 Sync           | the output signal before the output gain stage for use as synchronization or monitoring signal; the amplitude voltage calculates as ratio of the corresponding output amplitude and its range setting |
| J        | Signal Output<br>1 On             | this LED indicates that the signal output is turned on                                                                                                                                                |
| K        | Signal Output<br>2 Add            | the signal applied to the connector is added (analog add) to the output signal                                                                                                                        |
| L        | Signal Output<br>2 Out            | high-frequency output                                                                                                                                                                                 |
| M        | Signal Output<br>2 Sync           | the output signal before the output gain stage for use as synchronization or monitoring signal; the amplitude voltage calculates as ratio of the corresponding output amplitude and its range setting |
| N        | Signal Output<br>2 On             | this LED indicates that the signal output is turned on                                                                                                                                                |

| Position | Label / Name  | Description                                                                                                                         |
|----------|---------------|-------------------------------------------------------------------------------------------------------------------------------------|
| O        | Y/θ 1 / Aux 2 | this connector provides either the quadrature signal of the demodulator (Y1), the phase (θ1), or an auxiliary output signal Aux 2   |
| P        | X/R 1 / Aux 1 | this connector provides either the in-phase signal of the demodulator (X1), the magnitude (R1), or an auxiliary output signal Aux 1 |
| Q        | Y/θ 2 / Aux 4 | this connector provides either the quadrature signal of the demodulator (Y2), the phase (θ2), or an auxiliary output signal Aux 4   |
| R        | X/R 2 / Aux 3 | this connector provides either the in-phase signal of the demodulator (X2), the magnitude (R2), or an auxiliary output signal Aux 3 |
| S        | Power         | instrument mains power-on LED                                                                                                       |

## 3.3. Back Panel Tour

The back panel is the main interface for power, control, service and connectivity to other ZI instruments. Please refer to [Figure 3.4](#) and for the detailed description of the items.

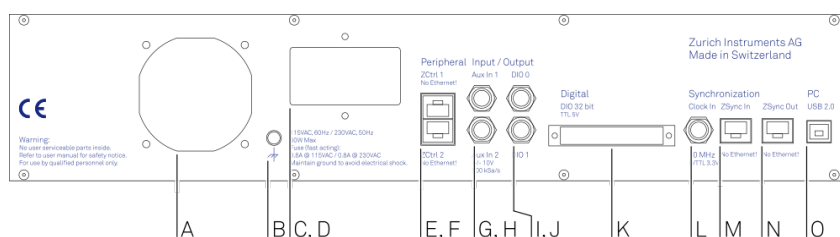


Figure 3.4: HF2 Series back panel

Table 3.2: HF2 Series back panel description

| Position | Label / Name | Description                                                                                                                                             |
|----------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| A        | -            | ventilator (important: keep clear from obstruction)                                                                                                     |
| B        | Earth ground | 4 mm banana jack connector for earth ground purpose, electrically connected to the chassis and the earth pin of the power inlet                         |
| C        | Power inlet  | power inlet with On/Off switch                                                                                                                          |
| D        | Power system | select between 115 V and 230 V power system                                                                                                             |
| E        | ZCtrl 1      | peripheral pre-amplifier power & control bus 1 - attention: this is not an Ethernet plug, connection to an Ethernet network might damage the instrument |
| F        | ZCtrl 2      | peripheral pre-amplifier power & control bus 2 - attention: this is not an Ethernet plug, connection to an Ethernet network might damage the instrument |
| G        | Aux In 1     | auxiliary high-sampling rate input 1                                                                                                                    |
| H        | Aux In 2     | auxiliary high-sampling rate input 2                                                                                                                    |
| I        | DIO 0        | digital input/output 0                                                                                                                                  |
| J        | DIO 1        | digital input/output 1                                                                                                                                  |
| K        | DIO          | digital input/output 0-31                                                                                                                               |
| L        | Clock In     | clock input (10 MHz)                                                                                                                                    |
| M        | ZSync In     | inter-instrument synchronization bus input - attention: this is not an Ethernet plug, connection to an Ethernet network might damage the instrument     |
| N        | ZSync Out    | inter-instrument synchronization bus output - attention: this is not an Ethernet plug, connection to an Ethernet network might damage the instrument    |
| O        | USB          | host computer connection                                                                                                                                |

## 3.4. Ordering Guide

The HF2 Series is a product line comprising an impedance spectroscopy and a digital lock-in amplifier covering advanced requirements for laboratory equipment. The HF2 Series provides best-in-class performance, wide operation range, intuitive handling and excellent accuracy. The HF2IS Impedance Spectroscopy is controlled with the ziControl user interface which is described in the ziControl Edition of the HF2 User Manual.

provides an overview of the available products in the HF2 Series. Upgradeable features are options that can be purchased anytime without need to send the instrument to Zurich Instruments - the upgradeable features consist of a firmware upgrade.

Table 3.3: HF2 Series product codes for ordering

| Product code | Product name                     | Description                                                      | Upgrade in the field possible |
|--------------|----------------------------------|------------------------------------------------------------------|-------------------------------|
| HF2LI        | HF2LI Lock-in Amplifier          | base lock-in amplifier                                           | -                             |
| HF2LI-MF     | HF2LI-MF Multi-frequency         | option                                                           | yes                           |
| HF2LI-PLL    | HF2LI-PLL Dual Phase-locked Loop | option                                                           | yes                           |
| HF2LI-PID    | HF2LI-PID Quad PID Controller    | option                                                           | yes                           |
| HF2LI-MOD    | HF2LI-MOD AM/FM Modulation       | option                                                           | yes                           |
| -            | -                                | -                                                                | -                             |
| HF2PLL       | HF2PLL Phase-locked Loop         | bundle of the HF2LI plus the HF2LI-PLL and the HF2LI-PID options | -                             |
| -            | -                                | -                                                                | -                             |
| HF2IS        | HF2IS Impedance Spectroscopy     | base impedance spectroscopy                                      | -                             |
| HF2IS-MF     | HF2IS-MF Multi-frequency         | option                                                           | yes                           |
| -            | -                                | -                                                                | -                             |
| HF2TA        | HF2TA Current Amplifier          | low-noise transimpedance amplifier                               | yes                           |

Table 3.4: Product selector

| Feature                                                  | HF2LI | HF2LI + HF2LI-MF | HF2IS   | HF2IS + HF2IS-MF |
|----------------------------------------------------------|-------|------------------|---------|------------------|
| Internal reference mode                                  | yes   | yes              | yes     | yes              |
| External reference mode                                  | yes   | yes              | -       | -                |
| Auto reference mode                                      | yes   | yes              | -       | -                |
| Dual-channel operation (2 independent measurement units) | yes   | yes              | yes     | yes              |
| Sinusoidal generators                                    | 2     | 2                | 2       | 2                |
| Superposed output sinusoidals per generator              | 1     | up to 6          | up to 4 | up to 8          |
| Dual-harmonic mode                                       | yes   | yes              | -       | -                |
| Multi-harmonic mode                                      | -     | yes              | -       | -                |
| Arbitrary frequency mode                                 | -     | yes              | yes     | yes              |
| Number of demodulators                                   | 6     | 6                | 4       | 8                |

| Feature                                               | HF2LI                                           | HF2LI + HF2LI-MF                                | HF2IS                               | HF2IS + HF2IS-MF                    |
|-------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------|-------------------------------------|
| Simultaneous freq. supported (fundamentals/harmonics) | 2/4                                             | 6/-                                             | 4/-                                 | 8/-                                 |
| Signal input select switch matrix                     | -                                               | yes                                             | yes                                 | yes                                 |
| Oscillator select switch matrix                       | -                                               | yes                                             | -                                   | -                                   |
| 50 MHz, 210 MS/s, 0.8 $\mu$ s TC                      | yes                                             | yes                                             | yes                                 | yes                                 |
| DSP technology                                        | 128 bit                                         | 128 bit                                         | 128 bit                             | 128 bit                             |
| Dynamic reserve                                       | 120 dB                                          | 120 dB                                          | -                                   | -                                   |
| Lock-in range                                         | 50 MHz                                          | 50 MHz                                          | -                                   | -                                   |
| USB 2.0 480 Mbit/s                                    | yes                                             | yes                                             | yes                                 | yes                                 |
| Instrument software                                   | LabOne User Interface, ziAPI, ziServer software | LabOne User Interface, ziAPI, ziServer software | ziControl, ziAPI, ziServer software | ziControl, ziAPI, ziServer software |
| Frequency response analyzer                           | yes                                             | yes                                             | yes                                 | yes                                 |
| Oscilloscope                                          | yes                                             | yes                                             | yes                                 | yes                                 |

## 3.5. Operating Modes

### 3.5.1. Internal Reference Mode

The internal reference mode takes advantage of the internal HF generators inside the HF2 Instrument. There are 6 frequency generators in the HF2LI and up to 8 frequency generators in the HF2IS. The output of these generators are added numerically inside the instrument avoiding complicated external analog signal adders and the resulting signal is fed to the device under test. The internal reference mode is the preferred mode as the signal recovery works at its best as the generated frequency is known inside of the instrument. The signal acquisition works immediately and there is no delay lock-time.

The internal reference mode is supported with single-channel and dual-channel operation. This is possible as the HF2 Instrument includes 2 independent measurement units that are working autonomously. Each of the measurement units provides analysis for one fundamental and 2 harmonic frequencies in parallel (sometimes called dual-harmonic mode). In total, the HF2LI can measure 2 fundamental and 4 harmonic frequencies, while the HF2IS can measure 4 frequencies. The number of frequencies increases with the multi-frequency options.

The demodulator samples are available in analog format on the auxiliary outputs of the HF2 Instrument and digitally on the connected computer transferred over the USB interface. The auxiliary outputs generate an analog signal after a linear digital to analog conversion at high sample rate. There are 2 pairs of analog signals allowing to output any 2 of the demodulation sample streams. All demodulator streams are available on the computer and can be further analyzed or stored in the local drives.

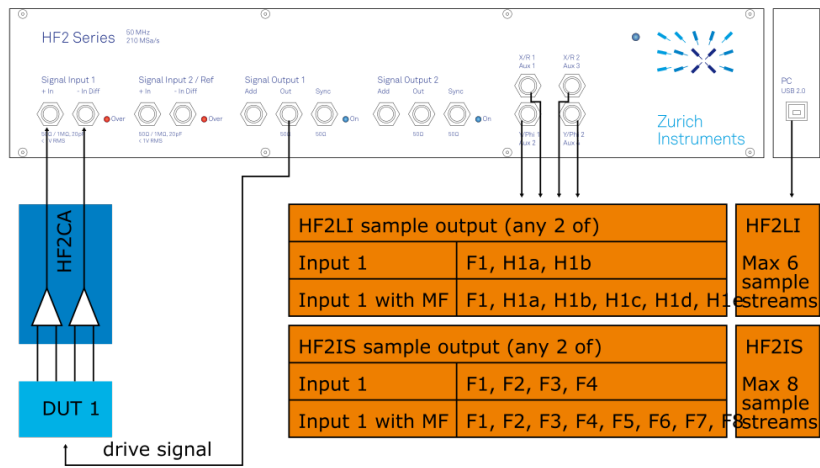


Figure 3.5: HF2 internal reference mode / single-channel

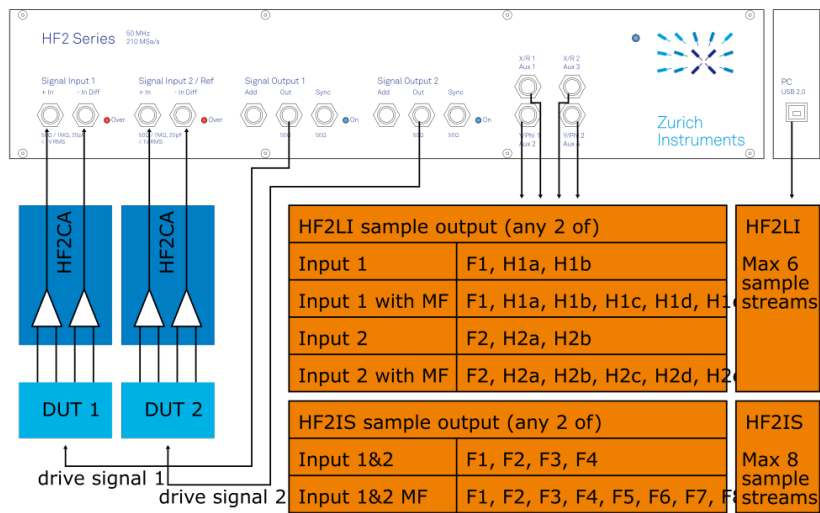


Figure 3.6: HF2 internal reference mode / dual-channel

### 3.5.2. External Reference Mode

The external reference mode uses external reference sources to recover the signal of interest inside the HF2 Instrument. In this mode, the internal frequency generators are not used to stimulate the DUT. As the signal reference is an arbitrary periodic signal, a certain amount of time is required for the HF2LI to lock on the reference and to be able to recover the signal of interest reliably. This lock time depends on several parameters, but most important on the level and phase noise of the reference.

The external reference mode is supported with single-channel and dual-channel operation. This is possible as the HF2 Instruments includes 2 independent measurement units that are working autonomously. In single-channel mode, the reference can be fed into the Input 2/Ref connector on the front panel. This alternative provides an unmatched capability to use references with small amplitudes as they can be amplified by the signal path of Input 2. In dual-channel operation, the external TTL references are fed into the HF2 by means of the DIO0 and DIO1 connectors on the back panel.

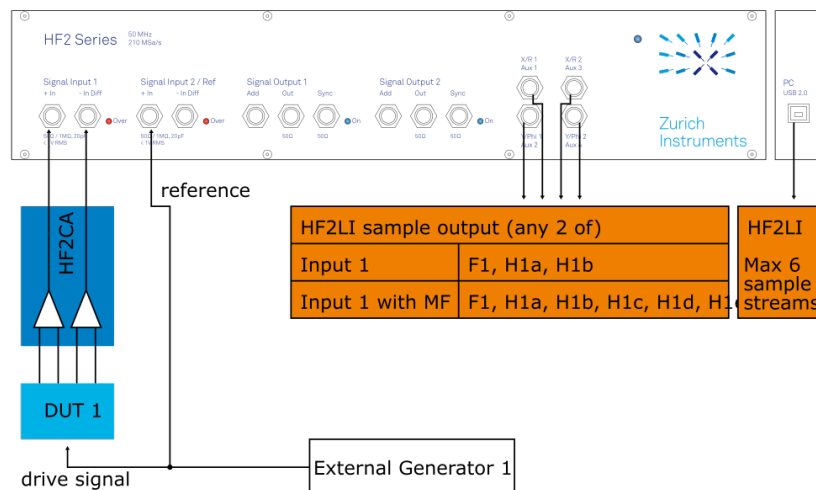


Figure 3.7: HF2 external reference mode / single-channel

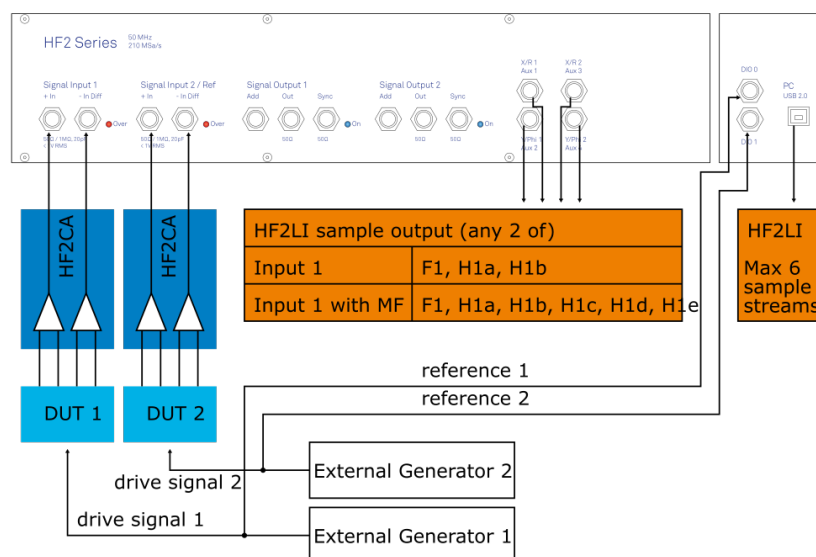


Figure 3.8: HF2 external reference mode / dual-channel

### 3.5.3. Auto Reference Mode

The auto reference mode makes use of the internal PLLs to recover the reference frequency directly from the signal coming from the DUT. In this mode, the internal frequency generators are not used to stimulate the DUT. As the reference is inherently contained in the sampled signal, a dedicated PLL is able to lock on the frequency and to inherently the reference and the signal of interest. This process is suited for signals with enough amplitude and signal-to-noise ratio. Further the reference recovery requires a certain amount of time that depends on several parameters like the level and the phase noise of the measured signal.

The auto reference mode is supported with single-channel and dual-channel operation. This is possible as the HF2 Instrument includes 2 independent measurement units that are working autonomously. In dual-channel mode it is sufficient to connect the signals captures at the DUTs to the Input 1 and Input 2 connectors of the HF2 Instrument. The HF2 Series support both single-ended and differential input signals ideal for fixed and floating ground applications.

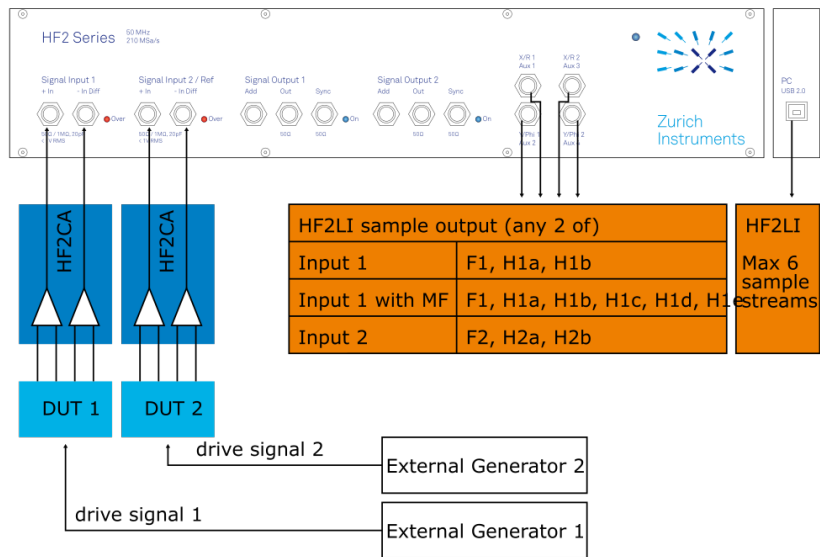


Figure 3.9: HF2 auto reference mode / dual-channel

3.5.4. Multi-frequency Operation

The multi-frequency operation is the powerful extension provided by the HF2 Series increasing the number of frequencies that can be analyzed in parallel. Moreover, the multi-frequency considerably expands the multiplexing options the user has with respect of input channels and demodulator clocks. Please note that the HF2IS-MF is different than the HF2LI-MF (see ) as different features and different number of demodulators are activated.

For the HF2LI the multi-harmonic mode and the arbitrary frequency mode are distinguished. In multi-harmonic mode it is possible to analyze a signal at the fundamental frequency and at 5 harmonics at the same time, and the arbitrary frequency mode is the extension to analyze a signal of interest at 6 completely independent frequencies.

For the HF2IS only the arbitrary frequency mode is relevant.

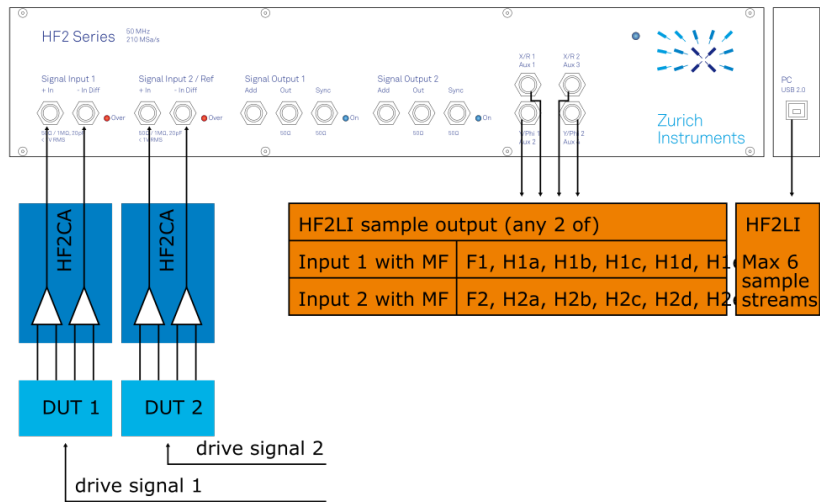


Figure 3.10: HF2 multi-harmonic mode

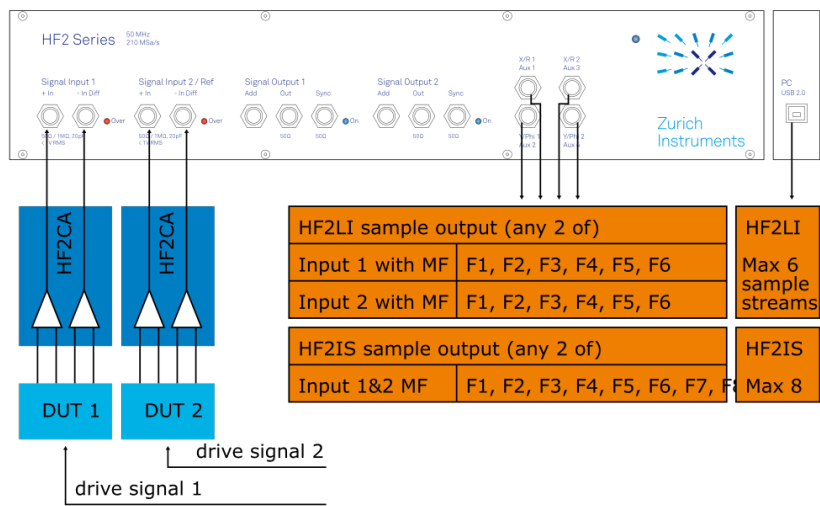


Figure 3.11: HF2 arbitrary frequency mode



# 4. Tutorials

The tutorials in this chapter aim to help users perform their initial measurements with HF2 lock-in amplifiers using the LabOne User Interface. The tutorials require some basic laboratory equipment and equipment handling knowledge. For the tutorials, you'll need the following material:

- 1 USB 2.0 cable (supplied with your HF2 Instrument)
- 3 BNC cables (2 optional)
- 1 male shorting cap (optional)
- 1 oscilloscope (optional)
- 1 T-piece (optional)

## Note

For all tutorials, you must have the LabOne software package installed as described in the [Getting Started Chapter](#). Start up the user interface as described in [Connecting to the Instrument](#).

## 4.1. HF2LI First Time User

This tutorial covers basic operation of the HF2LI lock-in amplifier with the LabOne User Interface.

The LabOne User Interface is provided as the primary interface to the HF2LI but it is not the only program that can run the instrument. Typically, the user will use LabOne UI to set up the instrument and then either use LabOne UI to take the measurements or run (possibly concurrently) some custom programs.

## Note

This tutorial aims to give a walk-through of the main features of the LabOne User Interface. Please also see [User Interface Overview](#) for an overview of the UI's layout and [Functional Description LabOne User Interface](#) in general for a thorough description of all the available settings available in LabOne UI for your instrument.

### 4.1.1. The Lock-in Tab

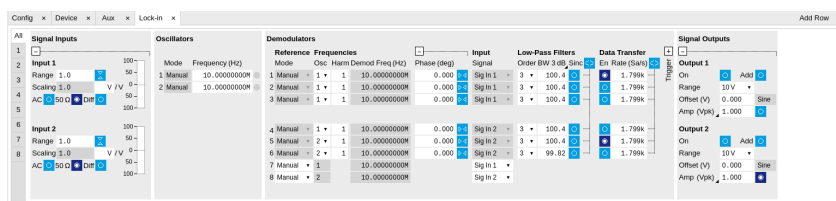


Figure 4.1: The Lock-in tab

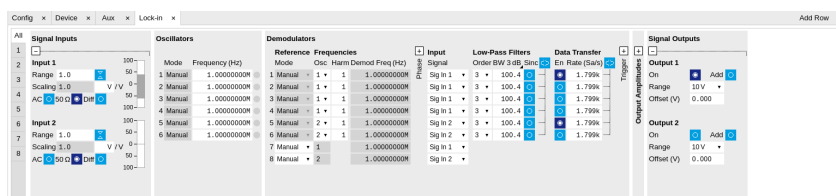


Figure 4.2: The Lock-in MF tab

Open the Lock-in tab by clicking on the Lock-in icon on the left side of the user interface. If you find the Lock-in MF tab, it means that the instrument has the HF2-MF option installed. [Lock-in Tab](#) provides the full documentation of the Lock-in tab while [Lock-in Tab \(HF2-MF option\)](#) describes the Lock-in MF tab.

The Signal Inputs section contains a Range that can be set to a value between 1 mV and 1.6 V, the largest amplification of the input signal is achieved for 1 mV. The input has protection diodes that clip signals with amplitude above 5 V.

## Warning

Please respect the compliance to the maximum ratings [Maximum ratings](#) to prevent damage to the instrument.

The AC button sets the coupling type: AC coupling has a cutoff frequency of 1 kHz. The AC coupling consists of a blocking capacitor between two input amplifier stages: this means that a DC signal larger than 5 V will saturate the front amplifier even if AC coupling is enabled. The Diff Differential mode button sets single-ended/differential measurement mode: in the differential mode, the voltage difference between the +In and -In is amplified whereas in single-ended mode, the voltage at the +In connector is amplified. The 50  $\Omega$  button toggles the input impedance

between low (50  $\Omega$ ) and high (approx 1 M $\Omega$ ) input impedance. 50  $\Omega$  input impedance should be selected for signal frequencies above 10 MHz to avoid artifacts generated by multiple signal reflections within the cable. With 50  $\Omega$  input impedance, one will expect a reduction of a factor of 2 in the measured signal if the signal source also has an output impedance of 50  $\Omega$ .

Next, one finds the Oscillators section used to control the frequency for the demodulation with an internal reference. For the purpose of this tutorial, set the frequency of oscillator 1 to 1 MHz.

Under the section Demodulators the user can select which harmonics and filter bandwidths to use for demodulation. It is not uncommon to need to measure different harmonics (integer multiples of the fundamental frequency, in this case 1 MHz). Select the harmonic (Harm) to 1 for the first demodulator (the first line), set the filter order to 4 (this corresponds to a filter steepness of 24 dB/oct or 80 dB/dec, an attenuation of  $10^4$  for a tenfold frequency increase) and type 10 Hz into the BW control (the digital filters of the HF2 are described in [Discrete-Time Filters](#)). Users are sometimes interested in the second harmonic that may be generated by nonlinear processes in their device under test: select harmonic 2 for the second demodulator and type the same values for the filter order and BW as in the previous case. You can also measure the same fundamental harmonic with a larger bandwidth: set harmonic to 1, order to 24 dB/oct and BW to 1 kHz for the third demodulator. Measuring with different bandwidths can provide the signal average and transient values. Click on the enable button next to the filters to read out the values from the 3 demodulators.

Next, set the Trigger to Continuous and the Rate to 7.20 kSa/s (rate settings can only be sub-multiples of 460 kSa/s, the maximum readout rate for one demodulator): in this case, the HF2LI will send the demodulated signal sampled at this rate through the USB. Due to the finite bandwidth of the USB connection the maximum cumulative demodulator sample rate is 700 kSa/s, which can be split over the active demodulators, see [Maximum sample readout rate](#). In this example we're using 3 active demodulators, therefore, since the sample rates are sub-multiples of 460 kSa/s the maximum possible readout rate for each demodulator is 230 kSa/s. Note that, according to the Nyquist sampling theorem, the sampling rate should be at least twice as fast as the maximum frequency present in the signal, in order to reconstruct the demodulated signal (this is not important if you only need one data point or the standard deviation of the demodulated signal). Since the low-pass filters do not have an infinite roll-off (the attenuation is not infinite past the filter's 3 dB frequency), it is common to set the sampling rate to about 8 times higher than the filter bandwidth.

Next, we configure the HF2 to output a 1 MHz signal on its Signal Output 1/Out connector. In case you have the HF2-MF Option installed, go to the Signal Outputs section, set the excitation amplitude Amp (Vpk) to 100 mV and the output range to be the smallest possible but at least twice as large as than the amplitude for minimum harmonic distortion. Connect Signal Output 1 to Signal Input 1 +In with a BNC cable and click on the On button in the LabOne Signal Outputs section of Output 1. With the HF2-MF Option installed, first go the Output Amplitudes section, set the signal amplitude Amp 1 (Vpk) of demodulator 7 to 100 mV and enable the button next to the amplitude field. Connect Signal Output 1 to Signal Input 1 +In with a BNC cable and click on the On button in the LabOne Signal Outputs section of Output 1.

### 4.1.2. The Numeric Tab

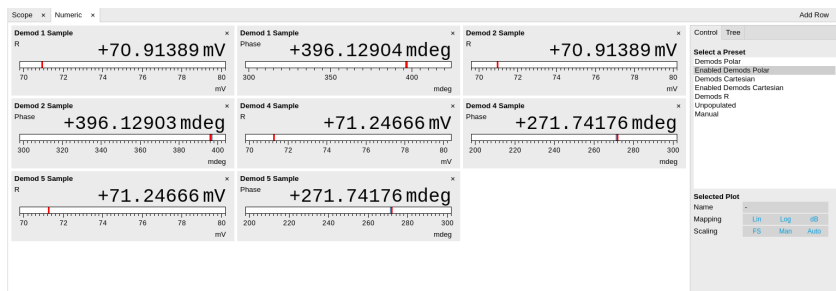
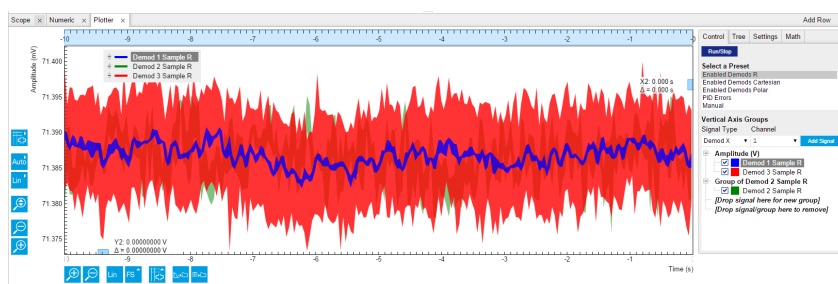


Figure 4.3: The Numeric Tab

In the Numeric tab, you should read 71 mV RMS for the R component of demodulator 1, (demodulating at 1 MHz). The RMS corresponds to the 100 mV divided by  $\sqrt{2}$ . The phase value will depend on the BNC cable length (for lengths shorter than one meter, the phase is approximately a few degrees). Demodulator 3 (also at 1 MHz) will show the same amplitude, but the digits fluctuate more, since the measurement bandwidth and therefore the noise, is larger. Demodulator 2 reads only a few MUV because at 2 MHz (the second harmonic) there is only a little component of the signal, coming from the harmonic distortion of the HF2LI output and input stages.

### 4.1.3. The Plotter Tab



Now open the Plotter tab. Here one can display the demodulated values over time. Select Enabled Demods R from the Presets and click on Run/Stop to start the acquisition. The demodulated traces for these three demodulators are displayed, offset to one another: as before, demodulators 1 and 3 have the same average value, but a larger noise amplitude is clearly visible in the third trace. In [Plot Functionality](#) you can find a detailed description of the functions of the plot window. For instance you can find there ways to change the horizontal and vertical scales, to remove offsets in the plot, and to use the cursors for exact measurements. The amount of stored data depends on the set Window Length in the Settings sub-tab.

### 4.1.4. The Scope Tab

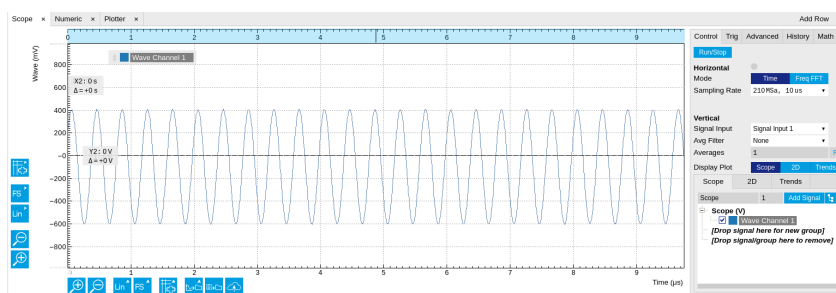


Figure 4.4: The Scope

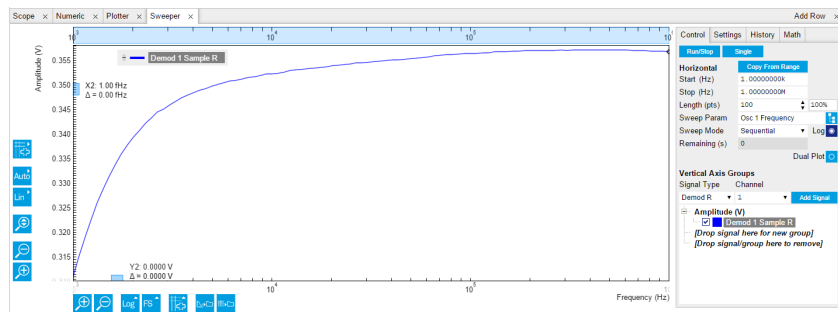
Let us proceed to the Scope tab. The Scope can be used to display the signal at the signal inputs and outputs of the HF2LI. It has a 2048 point wave memory that is useful for visualizing the raw signal. It also replaces the need for an external oscilloscope. Select Signal Input 1 in the Vertical section of the Control sub-tab, Signal Output 1 as the Signal in the Trigger sub-tab and press the Run/Stop button. The 1 MHz input signal is visible as 10 full cycles if the Sampling Rate is set to 210 MS, 10  $\mu$ s in the Control sub-tab. Decreasing the sampling rate to display a longer time interval should be done carefully because it may lead to aliasing: for instance setting the sampling rate to 26 kSa/s, 80 ms, will produce a correctly looking sinusoidal, but at the wrong frequency. The BW Limit button in the Advanced sub-tab may reduce aliasing effects without removing them completely.

The update rate of the oscilloscope frames is controlled by the Holdoff time in the Trigger sub-tab: the minimum interval between two traces is 10 ms. This is a low value which increases the load of

the USB bandwidth and may lead to USB sample loss - therefore avoid using small hold off values if not needed.

You can go from the time domain display to a frequency domain display by selecting the Freq Domain FFT Mode in the Control sub-tab. The frequency resolution is coarse because the time trace contains 2048 points. Averaging of the Fourier power spectra can be enabled to increase the SNR ratio.

### 4.1.5. The Sweeper Tool



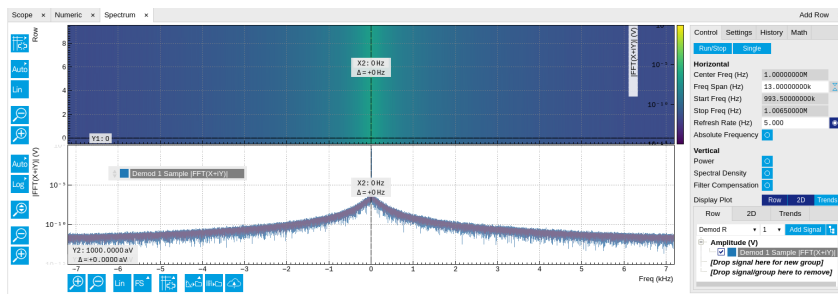
Next is the Sweeper tool: it turns the HF2LI into a frequency response analyzer, giving the transfer function of a device under test in the form of a Bode plot. In AFM applications this is useful to easily identify the resonance frequency of a cantilever as well as the phase delay. The sweeper tool can also be used to sweep parameters other than frequency: phase, time constant, amplitude and auxiliary output voltage.

As a frequency sweeper example, we will execute a logarithmic sweep of 100 points between 1 kHz and 1 MHz. In the Horizontal section, set the sweep range Start to 1 kHz and Stop to 1 MHz, 100 points and enable the Log Sweep. Click on Run/Stop for continuous sweeping or on Single for a single sweep. Toggle the AC input coupling in the Lock-in settings, and observe the attenuation in the response at 1 kHz in AC coupling, since the AC coupling has a cutoff frequency of approximately 1 kHz. In the History sub-tab, the measurement that is displayed can be saved to a data file in ASCII format. There it is also possible to declare one out of several measured traces as a reference by selecting the trace in the list and clicking on Reference. The selected trace then appears below the list, and next to it there is the enable button for the reference mode. In reference mode, all traces in the plot are divided by the reference trace.

During the logarithmic sweep the NEPBW (noise equivalent power bandwidth) is adjusted for each frequency point and displayed under the Filters BW field under the Lock-in tab. The adjustment is due to the fact that the sweep is logarithmic and the sweep frequency steps are not equally spaced. In order to account for all signal power (and power densities), the measurement bandwidth must be changed accordingly. This can be done automatically by going from Application Mode to Advanced mode in the Settings sub-tab, and there selecting Auto as the Bandwidth Mode. For an explanation of the NEPBW, see [Signal Bandwidth](#) chapter. Note that in this configuration, if the signal to noise ratio is large, there will not be any effect when disabling Auto BW, since the noise signal is negligible when measured with (almost) any NEP bandwidth. Averaging can also help to improve the signal-to-noise ratio during the sweep.

As an example of noise measurement, disconnect the BNC cable from Signal Output 1 and connect it to Signal Output 2. In the Lock-in tab, turn off the Signal Output 1, and generate a 100 kHz / 100 mV excitation Signal Output 2 (remember to turn on the output in the Signal Outputs section). In the frequency sweeper perform a single sweep with Auto BW enabled. A relatively wide peak will appear at 100 kHz, as the measurement was performed with wide NEPBW. Switch the X scaling to Manual and zoom into the region around 100 kHz; click the Copy From Range button to use the new boundaries for the sweep as selected in the graph and again perform a single sweep. The peak at 100 kHz will appear narrow, reflecting the change in the measurement bandwidth.

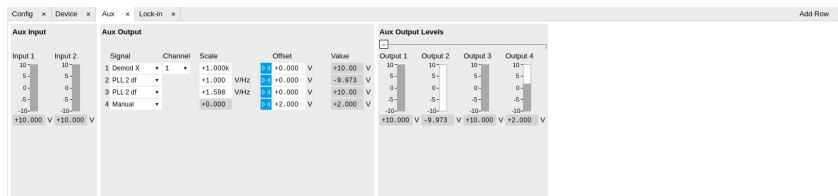
### 4.1.6. The Spectrum Tab




The Spectrum tool (more information (see [Zoom FFT](#))) allows the user to measure the frequency spectrum around a specific frequency: this is done by performing the Fourier transform of the demodulated X and Y (or in-phase and quadrature) components of the signal (more precisely of the quantity  $X+jY$ , where  $j$  is the imaginary unit). This method is called zoomFFT. The frequency resolution that can be achieved in this way is given by the sampling rate divided by the number of recorded samples, and is therefore much higher than the frequency resolution obtained in the Scope tab. The zoomFFT approach is more efficient than the FFT on raw samples in which one digitizes a long time trace, performs the Fourier transform and retains only the portion of the frequency spectrum of interest while discarding the rest.

We continue from the previous section with the BNC connecting Signal Output 2 to Signal Input 1, and 100 mV, 100 kHz sine wave. In the Lock-in tab, set the oscillator 1 frequency to 101 kHz. Set the Demodulator 1 parameters to filter order 4, filter bandwidth 500 Hz, and Data transfer rate 7.2 kSa/s. In the Spectrum tab, enable Filter Compensation and select Demodulator 1 for Signal Input. A peak appears at 1 kHz to the left of the center frequency. Increasing the number of lines in FFT will result in a finer frequency resolution. The Filter compensation button compensates for the demodulator filter, by dividing the measured spectrum by the demodulator filter transfer function. This is why the input signal does not appear attenuated despite being outside the filter bandwidth (1 kHz and 500 Hz respectively).

### 4.1.7. The Auxiliary Tab



The Auxiliary tab controls the 4 Auxiliary Outputs on the right side of the HF2LI front panel, as well as the 2 Auxiliary Inputs on the rear panel. Aux Output 1 is represented by the first line of controls in the Aux Output section. In order to output the lock-in signal on this connector, select Demod R from the Signal drop-down menu and set the channel (i.e., the demodulator number) to 1. Set the Scale factor to 10 V/V<sub>RMS</sub>: you should read 0.712 V in the output Value (V) field, which corresponds to the amplitude of the signal as you can read it in the Numeric tab multiplied by the scale factor. If one is interested in small variations of the signal amplitude, an offset can be applied to the output: type -0.712 in Offset (V) or click on the button  next to the Offset field: Value (V) should now read 0.

## 4.2. Simple Loop

## 4.3. Preparation

In this tutorial you generate a signal with the HF2 Instrument and measure that generated signal with the same Instrument. This is done by connecting Signal Output 1/Out with Signal Input 1/+In with a BNC cable. This tutorial shows a single-ended operation, meaning that there is no signal going into the Signal Input 1/-In connector. For proper operation, the Channel 1 must be set to single-ended operation, or alternatively the Input 1- connector must be shorted to ground using a male shorting cap. Optionally it is possible to connect the generated signal at Output 1 to an oscilloscope by using a T-piece and an additional BNC cable.

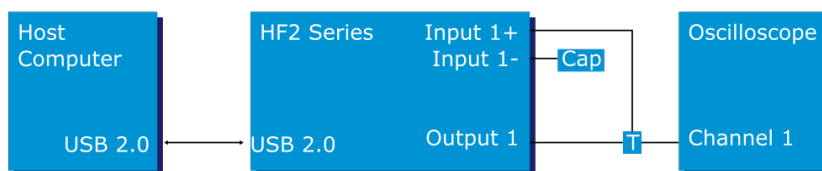


Figure 4.5: Tutorial

## Note

This tutorial is both for HF2LI Lock-in Amplifier and HF2IS Impedance Spectroscopy users.

Connect the cables as described above. Make sure the HF2 unit is powered on, and then connect the HF2 to your computer with a USB 2.0 cable. Finally launch LabOne (Start Menu/Programs/Zurich Instruments/LabOne User Interface HF2).

### 4.3.1. Generate the Test Signal

Apply the following settings in order to generate a 2.5 MHz signal of 0.5 V amplitude on Signal Output 1/Out.

- Open the Lock-in tab and set frequency of Oscillator 1 to 2.5 MHz: click on the field, enter "2.5 M" or "2.5E6" and press <TAB> on your keyboard to confirm the data
- In the Output 1 section, set the Range drop-down of 1 V
- Without HF2-MF option: In the Output 1 section, set the amplitude to 0.5 V by entering 0.5 followed by a <TAB>
- With HF2-MF option: In the Output Amplitudes section, set Amp 1 (Vpk) of demodulator 7 to 0.5 V by entering 0.5 followed by a <TAB>.
- By default all physical outputs of the HF2 are inactive to prevent damage to connected circuits. Now turn on the main output switch by clicking on the button labeled "On".
- If you have an oscilloscope connected to the setup, you are able to see your generated signal

Table 4.1: Settings: generate the test signal

|                        |         |
|------------------------|---------|
| Output 1 range         | 1 V     |
| Oscillator 1 Frequency | 2.5 MHz |
| Demodulator 7 Amp 1    | 0.5 V   |
| Output 1               | ON      |

### 4.3.2. Acquire the Test Signal

Next, you adjust the input parameters in order to acquire signals with the appropriate input range. To do this, you switch the signal source and the trigger of the Scope to Signal Input 1. Then you adjust the Signal Input 1 range to 1 V.

Table 4.2: Settings: acquire the test signal

|                               |                |
|-------------------------------|----------------|
| Scope Signal Input            | Signal Input 1 |
| Scope Trigger Signal          | Signal Input 1 |
| Scope Sampling Rate           | 210 MS, 10 us  |
| Run / Stop                    | RUN            |
| Signal Input 1 range          | 1 V            |
| Signal Input 1 AC / 50 / Diff | ON / OFF / OFF |



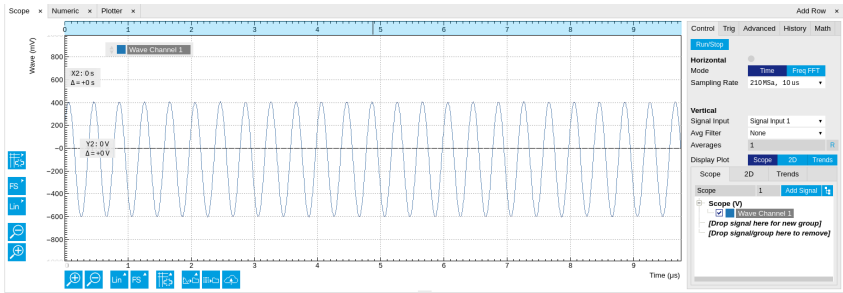


Figure 4.6: LabOne UI displaying the acquired signal

The Scope displays the measured signal at Input 1. Having set the input range to 1 V ensures that no signal clipping occurs. If you try and set the input range to 0.3 V you see the effect in the Scope window. Note how the red "Over" LEDs on the front panel of the HF2 indicates the error condition and the set OV (OVI) status flag on the right-bottom corner of the window. Set back the input range to 1 V and then clear the flag by clicking **c**. The Scope is a very handy tool to quickly check settings before proceeding to more advanced measurements, please refer to [Scope Tab](#) for a full description of features available in the Scope.

4.3.3. Measure the Test Signal

Next you use the demodulators of the HF2 to measure acquired test signal. You will use the Numeric and the Plotter tab from the LabOne user interface. First apply the following settings (choose any of the demodulators 1 to 6).

Table 4.3: Settings: measure the test signal

|                           |                                 |
|---------------------------|---------------------------------|
| Filter BW 3 dB            | 7 Hz (approximated to 6.8 Hz)   |
| Filter order              | 2                               |
| Data transfer rate        | 100 Hz (approximated to 112 Hz) |
| Data transfer enable (En) | ON                              |

These settings set the demodulation filter to second-order low-pass operation with a 7 Hz bandwidth. The corresponding time constant can be obtained easily by clicking on the label on top of the bandwidth setting column according to [Equation 3](#) provided in [Signal Processing Basics](#). The output of the demodulator filter is read out with 100 Hz, implying that 100 data samples are sent to the host PC per second. These samples are viewed in the Numeric and Plotter tab that we examine next.

The Numeric tool provides the space for 6 measurement panels corresponding to the 6 demodulators. Each of the panels has the option to display the samples in Cartesian (X,Y) or polar format (R,THETA). The unit of the (X,Y,R) values is  $V_{RMS}$ .

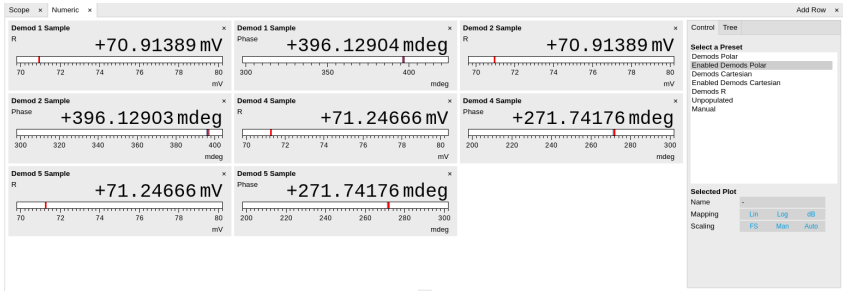


Figure 4.7: LabOne UI Numeric tab

If you wish to play around with the settings, you could now change the amplitude of the generated signal, and observe the effect on the demodulator output.

Next, we'll have a look at the tab. This tab provides a time plot of the demodulator outputs. It is possible to plot up to 6 signals continuously as (X,Y) or (R,THETA) pairs, to set different scales, or to make detailed measurements with 2 cursors. For a detailed description of the functionality available in the Plotter please see [Plotter Tab](#) and [Plot Functionality](#).

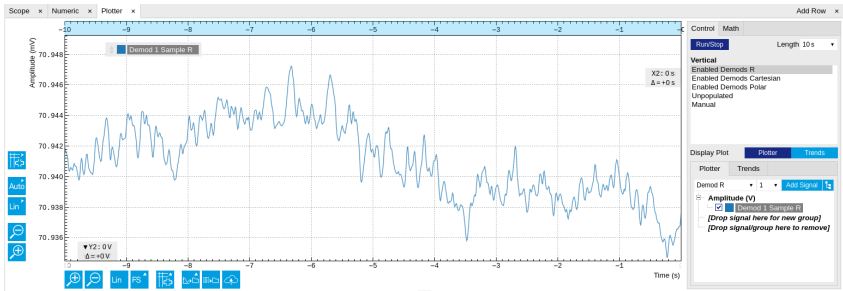


Figure 4.8: LabOne Plotter view with plot of demodulator 1 output (TC = 10 ms)

4.3.4. Different Filter Settings

As last step of this tutorial you change the filter settings and see the effect on the measurement results. For instance you change the time constant of the integration to 2 seconds.

Table 4.4: Settings: changing the filter settings

|                                      |           |
|--------------------------------------|-----------|
| Time constant (TC)                   | 2 s       |
| Filter slope                         | 12 dB/Oct |
| Resulting measurement bandwidth (BW) | ~51 mHz   |

Increasing the time constant increases the integration time of the demodulators smoothing out the demodulator outputs. This averages the noise over time and the output of the filters is more stable. This manifests itself in a smoother curve of the demodulator data but also in a larger number of stable digits in the Numeric tab.

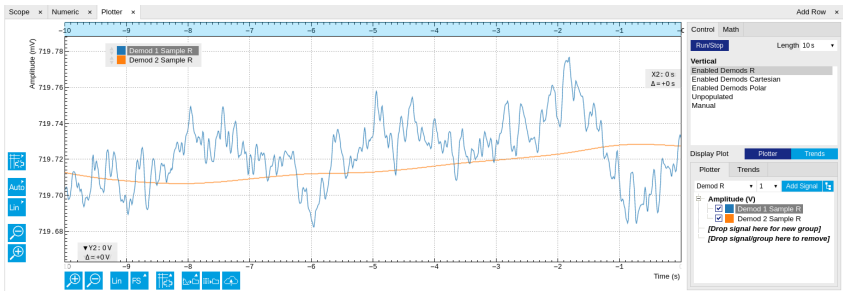


Figure 4.9: LabOne Plotter displaying the data of two demodulators with different time constants

4.4. Dynamic Signals

4.5. Preparation

In this tutorial we generate a test signal of 2.5 MHz with an amplitude modulated at a frequency of 1 Hz. Then we measure the test signal using two different filter settings.

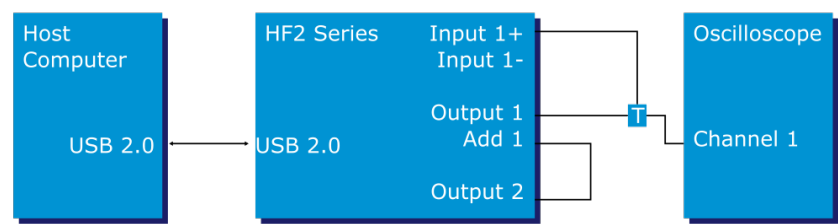


Figure 4.10: Tutorial dynamic signals setup



Note

This tutorial can be performed both on the HF2LI Lock-in Amplifier and on the HF2IS Impedance Spectroscope and will use the Input connector. The generation of multi-frequency signals is simple on the HF2LI with the HF2-MF option or on the HF2IS, where there is no need to make use of the ADD connector.

Connect the cables as described above. Make sure the HF2 unit is powered on, and then connect the HF2 to your computer with a USB 2.0 cable. Finally launch LabOne (Start Menu/Programs/Zurich Instruments/LabOne User Interface).

4.5.1. Generate the Test Signal

In this section you generate a 2.5 MHz sinusoidal signal whose amplitude oscillates at 1 Hz. This is also called the beat signal. In order to obtain this test signal you add two sinusoids of the same amplitude but with a 1 Hz difference in the frequency.

Table 4.5: Settings: generate the test signal

|                        |              |
|------------------------|--------------|
| Output 1 range         | 1 V / ON     |
| Output 2 range         | 1 V / ON     |
| Oscillator 1 frequency | 2'500'000 Hz |
| Demodulator 7 Amp 1    | 0.3 V / ON   |
| Oscillator 2 frequency | 2'500'001 Hz |
| Demodulator 8 Amp 2    | 0.3 V / ON   |
| Signal Output 1 Add    | ON           |

When connecting an oscilloscope to the Output 1 connector, you should be able to observe the superposition of the 2 sinusoids. To see the acquired signal inside the LabOne User Interface switch to the Scope tab. The Scope view looks like this with the following settings.

Table 4.6: Settings: acquire the test signal

|                               |                 |
|-------------------------------|-----------------|
| Scope Signal input            | Signal Input 1  |
| Scope Trigger signal          | Signal Input 1  |
| Scope sampling rate           | 6.4 kSa, 320 ms |
| Run/Stop                      | Run             |
| Signal Input 1 range          | 1 V             |
| Signal Input 1 AC / 50 / Diff | ON / OFF / OFF  |

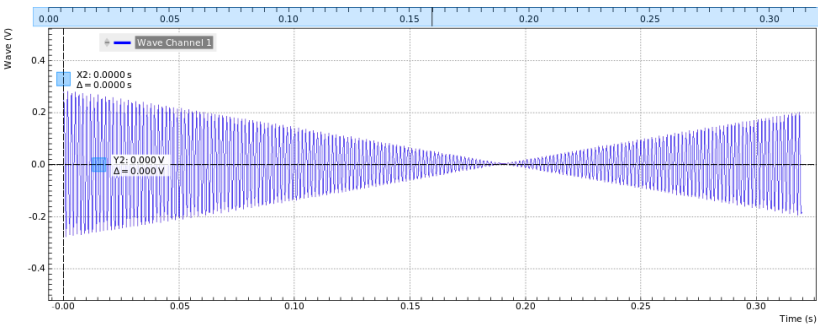


Figure 4.11: LabOne UI displaying the acquired signal

The beat signal has a maximum amplitude of 0.6 V, thus it falls within the set range of 1 V. The range setting will prevent any higher voltage than what is set - even if 2 sinusoids of 0.7 V amplitude each would be added like done in this section, the output would be clipping at 1 V which is the set range.

Try to change the output range to 0.1 V, and see how the output voltage is changed to prevent inconsistent settings.

4.5.2. Measure the Test Signal

First you change to the Plotter tab, set the scale in order to view an interesting set of data, and set the demodulator filters to a low time constant to measure the amplitude of the 2.5 MHz signal (Hull curve).

Table 4.7: Settings: filter with a low time constant

|                                          |                                 |
|------------------------------------------|---------------------------------|
| Time constant (TC)                       | 10 ms (approximated to 10.2 ms) |
| Filter order                             | 2                               |
| Resulting measurement bandwidth (BW 3dB) | \~10 Hz                         |
| Data transfer rate                       | 100 Hz (approximated to 112 Hz) |
| Data transfer enable (En)                | ON                              |

These settings set the demodulation low-pass filter to a 10 ms time constant (the corresponding bandwidth is around 10 Hz) and the filter slope to second order. The output of the filter is sampled at a rate of 100 Hz, and the samples are sent to the host computer.

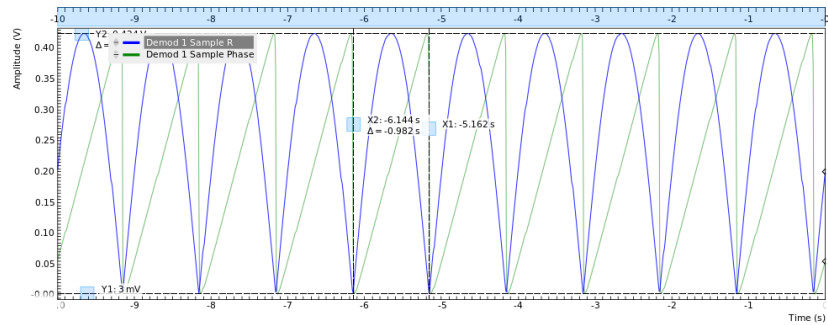


Figure 4.12: LabOne UI displaying the measured signal

If you stop the acquisition by pressing the button "Run/Stop" you can conveniently measure the amplitude of the 1 Hz signal by using the 2 cursors C1 and C2: 394.4 mV<sub>RMS</sub>, half period 498.1 ms. You can achieve higher measurement precision by using a even lower time constant (e.g. 1 ms), increasing the readout rate (e.g. 1.8 kHz), and zooming into the Plotter view.

Next you use a high time constant to separate the 2 original sinusoids even though they are superposed in one signal. In the Lock-in tab apply the following settings.

Table 4.8: Settings: filter with a high time constant

|                                          |                                 |
|------------------------------------------|---------------------------------|
| Time constant (TC)                       | 2 s                             |
| Filter order                             | 2                               |
| Resulting measurement bandwidth (BW 3dB) | \~35 mHz                        |
| Data transfer rate                       | 100 Hz (approximated to 112 Hz) |
| Data transfer enable (En)                | ON                              |

These settings set the demodulation low-pass filter to a time constant of 2 s, with a resulting measurement bandwidth of 35 mHz. With these settings the HF2 is able to distinguish between the signal component at 2'500'000 Hz and the signal component at 2'500'001 Hz as the measurement bandwidth is considerably less than the frequency spacing of the 2 signal components. The output of the demodulator is stable after a settling time.

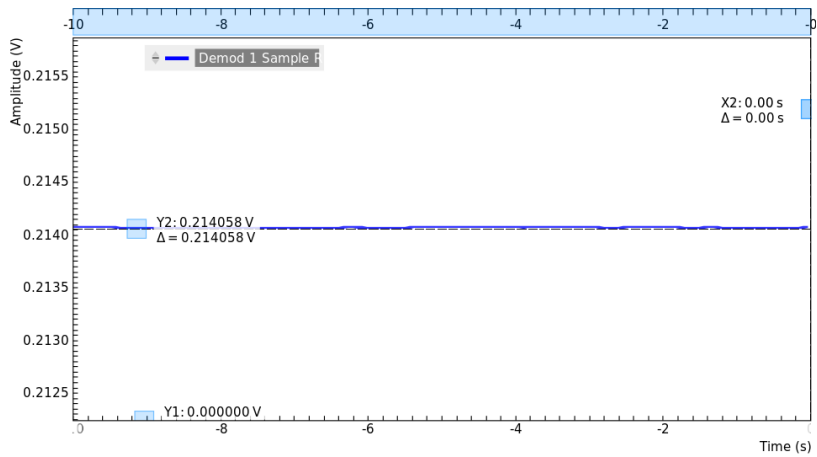


Figure 4.13: LabOne UI displaying the measured signal

The output of the demodulator does not show any oscillations like before: the numerical value is 214 mV<sub>RMS</sub>. If you switch to the oscilloscope view, you see that the signal at Input 1 is still beating as before, while the demodulator filter is set such to ignore the interferer at 2'500'001 Hz. Try to switch off the interferer.

Table 4.9: Settings: remove the interferer

|                        |     |
|------------------------|-----|
| Signal output 2 ON/OFF | OFF |
|------------------------|-----|

The time it takes to settle depends on various parameters like filter setting and switch-off timing. The difference in amplitude of the measurement at 2'500'000 Hz with or without interferer is in the range of 50 µV. With different filter settings it is possible to do better than that.

Consider this: you have 2 signals with relevant amplitude (0.3 V) interfering with each other as their frequency is very close (1 Hz at 2.5 MHz). The power of lock-in amplification consists of extracting the relevant signal energy at exactly one frequency. The "immunity" from nearby interferer is the capability to ignore them. This a simple definition of the dynamic reserve.

4.5.3. Filter Setting Discussion

This section aims to summarize a few basic concepts of filtering in connection with lock-in amplification. In this tutorial, you have used different filter settings to measure different signal properties.

Table 4.10: Settings: filter with a high time constant

| Time constant | Measurement bandwidth                         | Measurement noise                | Changes upon steady state change | Example                                                                                          |
|---------------|-----------------------------------------------|----------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------|
| Low setting   | High, capability to detect fast events        | More noise in measurement result | Fast adaptation of result        | BW = 10 kHz, capability to detect events at 2-5 kHz, prone to pick-up noise                      |
| High setting  | Low, capability to determine the steady state | Less noise in measurement result | Slow adaptation of result        | BW = 50 mHz, exact determination of steady state - events more frequent than 0.1 Hz are filtered |

Filtering constitutes a trade-off between measurement speed and measurement accuracy. In order to measure fast events, it is necessary to open up the filters allowing also more noise in the measurement result. The opposite is to measure with narrow filters which increases the signal-to-noise ratio, but limits the capability to detect the changes in the signal of interest. This trade-off is in common with any lock-in amplifier. The power of the HF2 is that it allows to do both at the same time thanks to the multiple demodulators per input channel.

# 4.6. External Reference

## 4.7. Preparation

In this tutorial we generate a test signal with the HF2 and use it as a reference signal for demodulation in the same way as we would do it with a reference signal coming from an external source.

This is done by connecting the Output 2 connector with the Input 2+ connector with a BNC cable. This tutorial shows a single-ended operation, meaning that there is no signal going into the Input 2- connector. Optionally, it is possible to connect the generated signal from Output 2 to an oscilloscope by using a T-piece and an additional BNC cable. The Output 1 connector is to be connected to the Input 1+ connector. This allows you to check the generated reference signal. The measurement setup is shown in the following figure.

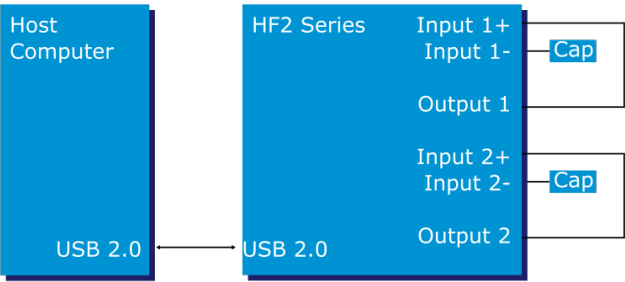


Figure 4.14: Tutorial external reference setup

Make sure the HF2 unit is powered on, and then connect the HF2 to your computer with a USB 2.0 cable. Finally, launch LabOne (Start Menu/Programs/Zurich Instruments/LabOne User Interface HF2).

### 4.7.1. Generate the Reference Signal

In this section you generate a 1.0 MHz signal with a 1 V amplitude on Output 2 for use as the external reference. The settings for generating the reference signal are shown in the following table.

Table 4.11: Settings: generate the reference signal

|                                       |                        |
|---------------------------------------|------------------------|
| Output 2 range                        | 1 V                    |
| Demodulator 8 Amplitude 2             | 1.0 V / ON             |
| Oscillator 2 frequency                | 1 MHz                  |
| Signal input 2 range / AC / Diff / 50 | 1.2 V / ON / OFF / OFF |

When connecting an oscilloscope to the Output 2 connector, you should be able to observe the sinusoid. Alternatively, you can look at the signal in the LabOne UI Scope with the following settings.

Table 4.12: Settings: acquire the reference signal

|                      |                |
|----------------------|----------------|
| Scope Signal Input   | Signal Input 2 |
| Scope Trigger Signal | Signal Input 2 |
| Scope Sampling rate  | 53 MSa, 39 us  |

### Note

In the Scope tab set the Horizontal Mode to Freq Domain FFT in order to see the frequency spectrum of the signal. This will also set a logarithmic Y scale by default. An Exponential Moving Average can be enabled in the Avg Filter field to reduce the noise floor in the display.

4.7.2. Activate the External Reference Mode

In this section we activate the external reference mode. Based on the external reference, we demodulate a separate signal of interest.

Table 4.13: Settings: generate the signal of interest

|                                       |                        |
|---------------------------------------|------------------------|
| Output 1 range                        | 1V                     |
| Demodulator 7 Amp 1                   | 1.0 V / ON             |
| Oscillator 1 frequency                | 1 MHz                  |
| Demodulator 1 En/Rate                 | ON / 100 Hz            |
| Signal Input 1 range / AC / 50 / Diff | 1.3 V / ON / OFF / OFF |

The external reference mode makes use of demodulators 7 and 8. These two demodulators can not be used for measurement. They serve as phase sensitive detectors to set up phase-locked loops locking an external reference and an internal oscillator. Demodulator 7 is assigned to oscillator 1, and demodulator 8 is assigned to oscillator 2. Previously we have chosen oscillator 2 as the source of the reference signal on Signal Output 2. Now we want lock oscillator 1 to this reference. In order to achieve that, we set the Mode field of demodulator 7 to ExtRef. In the drop-down selector in the Input column of demodulator 7, select Signal Input 2.

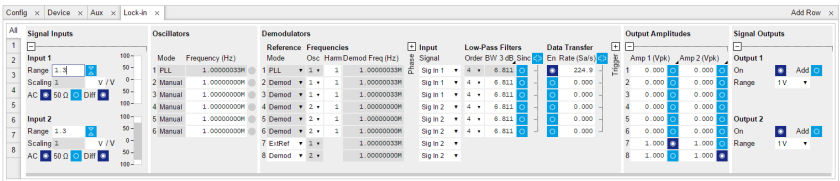


Figure 4.15: LabOne UI enabling external reference mode

Once the external reference mode has been enabled, the frequency of oscillator 1 changes continuously, adapting to the frequency of the external reference signal. This can be verified by changing the frequency of oscillator 2 and noting how the frequency of oscillator 1 follows. A green light next to the oscillator frequency field indicates that the instrument has locked to an external reference.

In the demodulation process, the measurement signal is not multiplied directly with the external reference signal. Instead, the measurement signal is multiplied with newly generated reference signal from the internal oscillator, using only the frequency and phase information of the external reference. The continuous toggling of the oscillator frequency shows that the newly generated reference is continuously adjusted to the external reference.

4.7.3. Change External Reference Input

In this section you will modify the setup to use DIO 0 as the external reference instead of Signal Input 2. This is useful in practice since it means that the two sensitive Signal Inputs of the Instrument remain available for actual measurements. The modified setup is shown on Figure 4.16. Note that the DIO 0 connector is located on the back panel of the HF2 Instrument.

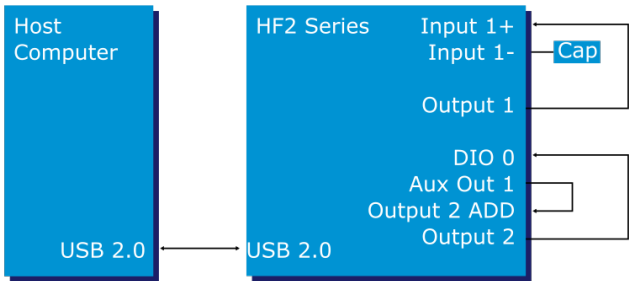


Figure 4.16: Tutorial external reference using DIO 0 setup

It is important to make sure that DIO 0 is configured as an input before connecting anything to it. This can done using the DIO tab in LabOne. Note that the button to the right of **bits 7...0** should be off.

When using the DIO 0 as the external reference signal, it should be taken into account that this is a digital I/O, which should be operated at TTL levels. Therefore the Aux 1 output is connected to the Add connector of Output 2, to provide a DC shift of the test signal and thus make it TTL compatible.

The settings used for generating the test signal are shown in the following tables. The resulting signal will have a DC offset of 1.5 V and an amplitude of 1 V and will thus oscillate between 0.5 V and 2.5 V, which is TTL compatible.

Table 4.14: Settings: generate the test signal

|                          |            |
|--------------------------|------------|
| Signal Output 1 range    | 1 V        |
| Signal Output 1 On / Add | ON / ON    |
| Demodulator 8 Amp 2      | 1.0 V / ON |
| Oscillator 2 Frequency   | 1 MHz      |

Table 4.15: Settings: generate the DC shift

|              |        |
|--------------|--------|
| Aux 1 Signal | Manual |
| Aux 1 Offset | 1.5 V  |

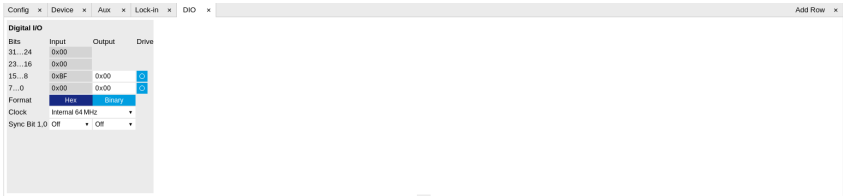


Figure 4.17: Configuring DIO 0 as reference input

Finally use the Input drop-down selector for demodulator 7 in the Lock-in tab and set it to "DIO 0". This makes oscillator 1 lock on DIO 0. The frequency of oscillator 1 should start updating similarly to what was described in [Activate the External Reference Mode](#).

# 4.8. Noise Measurement

Lock-in amplifiers can be used to measure the noise on a signal. By quantifying the noise of a system one can estimate the maximum achievable performance.

## 4.8.1. How Does a Lock-in Measure Noise?

A lock-in amplifier measures the signal amplitude close to a given reference frequency with a defined bandwidth around this reference frequency. The noise in an input signal near the reference frequency appears as noise in the lock-in amplifier signal output.

The noise is the standard deviation of the measured X or Y value and is measured by first calculating the average,  $X_{avg}$ , over a defined period of time. Then, this signal,  $X_{avg}$ , is subtracted from the X value to get the deviation. Finally, the RMS (root-mean-square) is calculated, corresponding to the total noise power of the input signal within a defined bandwidth around the reference frequency. The value is correct for input noise with Gaussian distribution of the noise power, which is normally the case.

Most of the times the noise spectral density is of interest, which is the normalization of the  $X_{noise}$  made independent of the filter bandwidth. To calculate the noise spectral density from the calculated RMS noise, one needs to divide the measured value by the square root of the bandwidth  $\sqrt{BW}$ . The noise spectral density has the units  $V/\sqrt{Hz}$ .

The related equations are  $X_{noise} = RMS(X - X_{avg})/\sqrt{BW}$ , and  $Y_{noise} = RMS(Y - Y_{avg})/\sqrt{BW}$  respectively. The X and Y noise are expected to be identical.

## 4.8.2. Measuring the Noise of the HF2LI/HF2IS

A LabVIEW example (ziExample-HF2-Noise.vi) is available to measure the noise in an input signal. To measure the equivalent input noise of the HF2, remove all BNC connectors from the input of the device and apply the following settings in the LabOne UI.

Table 4.16: Settings: Measure HF2 Noise

|                                       |                            |
|---------------------------------------|----------------------------|
| Signal Input 1 range / AC / Diff / 50 | 0.01 V / ON / OFF / ON     |
| Demodulator 1 Low-Pass Filter         | BW 3dB = 100 Hz, Order = 4 |
| Oscillator 1 Frequency                | 1 MHz                      |
| Signal Output 1 switch                | OFF                        |

Run the example, ziExample-HF2-Noise.vi. Make sure that the correct Demodulator is selected. The noise spectral density should now show a value close to 5 nV/√Hz. By changing the settings in the user interface, the noise behavior of the device can be analyzed in more detail. For example, changing the reference frequency to 10 kHz will slightly increase the spectral noise density, because of flicker noise that is larger at lower frequencies and generally present in all electronic circuits.

## 4.9. Amplitude Modulation

### Note

This tutorial is addressed to HF2LI lock-in amplifier users that have purchased both HF2-MF multi-frequency and HF2-MOD AM/FM modulation options.

Amplitude modulation (AM) and frequency modulation (FM) refer to the modulation of an oscillating signal  $s(t) = A \cos(\omega t + \phi)$ , the so-called carrier.  $A$  and  $\omega t + \phi$  are the amplitude and the phase of the signal, respectively. Figure 4.18 depicts the phasor representation of  $s(t)$ . The phasor follows a circle with radius  $A$ , and the phase wraps around after a full revolution of  $360^\circ$ . The signal  $s(t)$  is the projection of the phasor on the abscissa.

In the case of AM signals, the amplitude  $A$ , i.e. the phasor length, is time dependent, as in Figure 4.18(b). In the case of FM signals, the phase offset  $\phi$  is time dependent and the phasor has a constant amplitude, see Figure 4.18(c).

Amplitude and frequency modulation, best known from radio transmission, are also common lock-in detection techniques.

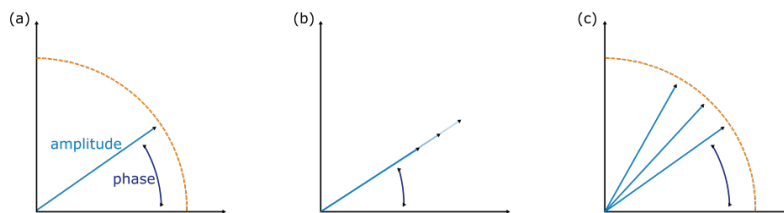


Figure 4.18: A sinusoidal signal represented as a phasor: the signal corresponds to the projection on the x axis. Amplitude (b) and frequency (c) modulated signals affect the amplitude of the phasor or its phase

### 4.9.1. What is Amplitude Modulation?

In the time domain, amplitude modulation of the carrier signal produces a variation of the carrier amplitude proportional to the amplitude of the modulating signal. For example, when the amplitude of a carrier with a frequency  $f_c = \omega_c/2\pi$  is modulated by a signal with frequency  $f_m = \omega_m/2\pi$  (where  $f_m < f_c$ ), the resulting signal has the form

$$\begin{aligned}
 s(t) &= [A + M \sin(\omega_m t)] \sin(\omega_c t + \phi) \\
 &= A \sin(\omega_c t + \phi) + \frac{M}{2} \cos[(\omega_c - \omega_m)t + \phi] - \frac{M}{2} \cos[(\omega_c + \omega_m)t + \phi]
 \end{aligned} \tag{1}$$

where  $A$  and  $M$  are the amplitudes of the fast and slow modulations respectively and  $\phi$  the phase offset. There is no restriction on the magnitude of  $M$  compared to  $A$ . The information of interest is encoded in these three parameters,  $A$ ,  $M$  and  $\phi$ .

In the frequency domain, the AM signal  $s(t)$  is composed of three frequencies: the carrier at  $f_c$  and two additional sidebands at  $f_c - f_m$  and  $f_c + f_m$ , as shown in Equation 1. The two sidebands have equal amplitude  $M/2$ , half of the modulating signal, and the carrier amplitude is independent on the modulation amplitude.

The traditional way of measuring an AM signal is called double (or tandem) demodulation and requires two lock-in amplifiers: the first one demodulates the signal at  $f_c$  with a bandwidth that is at least as large as  $f_m$  (but smaller than  $f_c - f_m$ ). This is to ensure that the full amplitude of the modulation signal is retained. The demodulated signal after the first lock-in becomes

$$s(t) \cdot \cos(\omega_c t) \xrightarrow[\text{filtering}]{\text{after}} d_1(t) = \frac{A + M \sin(\omega_m t)}{2} \cos(\phi) \quad (2)$$

In  $d_1(t)$ , the two sidebands are now located at the same frequency  $f_m$ , while the carrier appears as a DC component. When the demodulated signal  $d_1(t)$  is fed to a second lock-in amplifier, the result of the second demodulation at  $f_m$  is proportional to  $M \cos \phi$ .

In order to recover the amplitude  $M$  it is necessary to measure the  $\phi$  so one can divide the result by the factor  $\cos \phi$ . To measure the phase one can use a third lock-in to demodulate  $s(t)$  at the carrier frequency  $f_c$  with a bandwidth smaller than  $f_m$  as shown in Figure 4.19.

Instead of using a tandem configuration, the HF2-MOD option allows the user to demodulate directly at the three frequencies  $f_c$  and  $f_c \pm f_m$  simultaneously. The three parameters  $A$ ,  $M$  and  $\phi$  can be measured and displayed with a single instrument.

Internally, the HF2LI generates the phases  $\omega_c t$  and  $\omega_m t$  from which it produces  $(\omega_c - \omega_m) t$ ,  $\omega_c t$  and  $(\omega_c + \omega_m) t$ . This ensures the correct phase relationship for the demodulations of the sidebands.

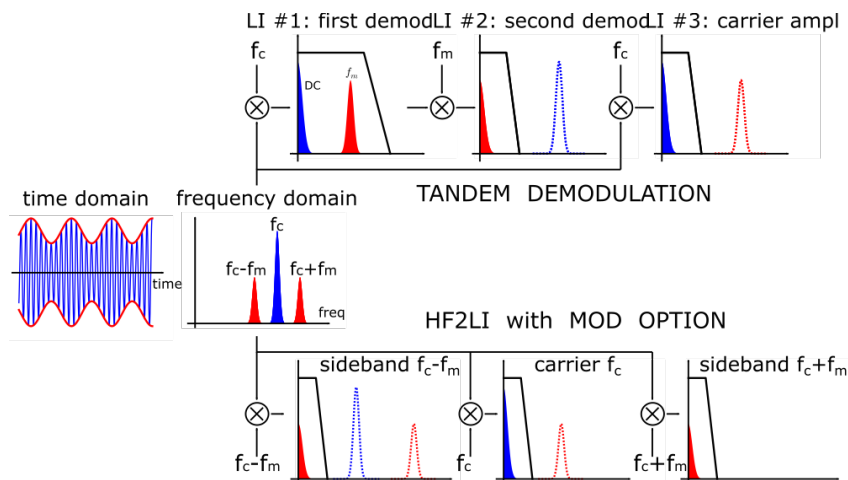


Figure 4.19: Comparison between tandem demodulation and the HF2-MOD option of an AM modulated signal

## 4.9.2. Generate the Test Signal

In this tutorial, you are going to generate an AM signal with a carrier frequency of 1 MHz and a modulation frequency of 100 kHz. The signal is generated at Signal Output 2 and is demodulated by the first lock-in unit by feeding it into Signal Input 1. The HF2-MOD option requires the HF2-MF Multi-frequency option because each modulated signal requires at least two oscillators. Note that changing the Modulation tab settings will modify some of the settings found in the Lock-in MF tab. The reader is kindly referred to [MOD Tab](#).

Start by enabling the Signal Output 2 in the Lock-in MF tab and disabling all demodulator Output Amplitudes. This will ensure that only the desired components of the amplitude-modulated signal appear on the output.

Table 4.17: Settings: generate the AM signal




|                                           |     |
|-------------------------------------------|-----|
| Signal Output 2 Enable                    | ON  |
| Signal Output Amplitudes Demodulators 1-8 | OFF |

In the Modulation tab, in the MOD 2 section, select the following parameters:

Table 4.18: Settings: generate the AM signal

|                                         |                 |
|-----------------------------------------|-----------------|
| Carrier Oscillator (Osc)/Frequency      | Osc 1 / 1 MHz   |
| Sideband 1 Oscillator (Osc)/Frequency   | Osc 2 / 100 kHz |
| Carrier Mode                            | AM              |
| Generation Carrier/Modulation Amplitude | 200 mV / 100 mV |
| Generation Carrier/Modulation Enable    | ON / ON         |
| MOD 2 Enable                            | ON              |

This generates an AM signal with two sidebands of equal amplitude. To look at this signal, connect Signal Output 2 to Signal Input 1 of the HF2LI. Select the correct input parameters: in the Lock-in tab, for Signal Input 1, make sure Differential mode and 50  $\Omega$  are disabled. Then click on the auto range button . In the Scope tab, select Source to be Signal Input 1, Trigger to be Signal Output 2 and click on Run to activate the Scope. Observe how the carrier amplitude is modulated at 100 kHz as seen in . In Frequency Domain FFT mode, the plot shows three peaks: the carrier at 1 MHz and two sidebands at 0.9 and 1.1 MHz (see the cursors in the frequency domain representation in [Figure 4.21](#)).

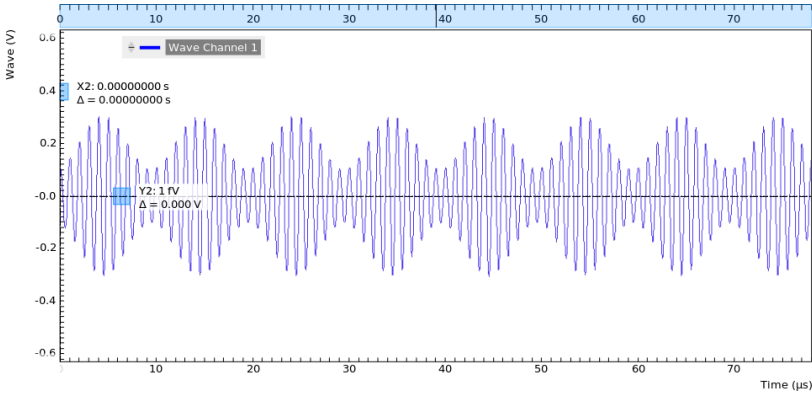


Figure 4.20: Time domain representation of the AM signal generated by MOD2 measured with the LabOne Scope

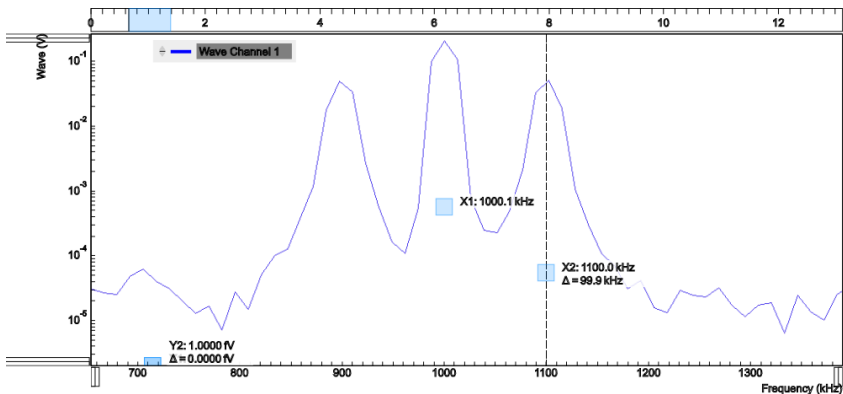


Figure 4.21: Frequency domain representation of the AM signal generated by MOD2 measured with the LabOne Scope

### 4.9.3. Measure the Test Signal

In the Modulation tab, in the MOD 1 section, select the following parameters:

Table 4.19: Settings: measure the AM signal

|                                                  |       |
|--------------------------------------------------|-------|
| Carrier oscillator (Osc)                         | 1     |
| Sideband 1 oscillator (Osc)                      | 2     |
| Carrier Mode                                     | AM    |
| Low-pass Filter BW (Carrier)                     | 10 Hz |
| Low-pass Filter BW (Sideband 1)                  | 10 Hz |
| MOD 1 Enable                                     | ON    |
| Demod 1, 2, 3 Data Transfer Enable (Lock-in tab) | ON    |

This sets the correct demodulation of the AM signal with the two sidebands. In the Numeric tab, look at the amplitude of the carrier,  $142 \text{ mV}_{\text{RMS}}$  and of the two sidebands,  $35 \text{ mV}_{\text{RMS}}$  each, one quarter of the carrier amplitude: this corresponds to a modulation index of 50%.

## 4.10. Frequency Modulation

### Note

This tutorial is addressed to HF2LI lock-in amplifier users that have purchased both HF2-MF multi-frequency and HF2-MOD AM/FM modulation options.

### 4.10.1. What is Frequency Modulation?

In frequency modulation (FM), the amplitude of the modulating signal is proportional to the instantaneous frequency deviation from a fixed frequency. In the simplest case shown in [Figure 4.22\(a\)](#), the modulated signal

$$s(t) = A \cos[\omega_c t + \frac{\omega_p}{\omega_m} \sin(\omega_m t) + \varphi] \quad (1)$$

is produced when a carrier signal of frequency  $f_c = \omega_c/2\pi$  is modulated by a sinusoidal modulation with frequency  $f_m = \omega_m/2\pi$ . The maximum variation of the frequency around the carrier frequency, the peak frequency deviation, is  $f_p = \omega_p/2\pi$ . The physical information is encoded in the parameters  $A$ ,  $f_p$  and  $\varphi$ .

Because the frequency is the time derivative of the phase (divided by  $2\pi$ ) and the phase is the argument of the cosine in [Equation 1](#), we can define the instantaneous frequency as

$$f(t) = f_c + f_p \cos(2\pi f_m t) \quad (2)$$

The spectrum of the FM signal of [Equation 1](#) is more complicated than in the case of amplitude modulation. It consists of the carrier and a series of pairs of sidebands at multiple integers of  $f_m$  around the carrier frequency, see [Figure 4.22\(d\)](#). The amplitudes of the carrier and sidebands are given by mathematical functions called Bessel functions usually indicated by  $J_n$  evaluated at the modulation index  $h = f_p/f_m$ . For instance, the  $n$ -th pair of sidebands is located symmetrically about  $f_m$  at  $f_c \pm n f_m$  and its amplitude is  $J_n(h)$ .

A peculiarity of the Bessel functions is that they oscillate around zero: even for the carrier, as the modulation index is increased, its amplitude  $J_0(h)$  decreases, crossing zero at  $h \approx 2.41$  and then it increases in amplitude (in anti-phase) before reaching zero again at  $h \approx 5.52$ .

At low modulation indexes, the amplitude of higher sidebands is very low and can thus be ignored: this is called the narrow-band approximation. In this limit (it is customary to assume  $h < 0.2$ ), only the two sidebands at  $f_c \pm f_m$  have non-negligible amplitude and the signal  $s(t)$  can be approximated by

$$\tilde{s}(t) = A[J_0(h)\sin(\omega_c t + \varphi) - J_1(h)\cos[(\omega_c + \omega_m)t + \varphi] + J_1(h)\cos[(\omega_c - \omega_m)t + \varphi]] \quad (3)$$

The first term is the carrier, the other two are the lower and upper sidebands. The problem of finding  $h$  (and the peak amplitude  $f_p$ ) reduces now to comparing the amplitude of the first pair of sidebands

and the carrier to the ratio  $J_1(h)/J_0(h)$ . A plot of the ratio  $J_1(h)/J_0(h)$  and  $J_2(h)/J_0(h)$  is shown in Figure 4.22(e).

Even though  $\tilde{S}(t)$  looks very similar to an AM signal, there is a subtle but substantial difference: the phases of the sidebands are offset with respect to that of the carrier. This results in the sidebands being in quadrature with the carrier. For example, assume that  $\phi = 0$ : demodulating  $\tilde{S}(t)$  with the carrier signal  $\sin(\omega_c t)$  gives the DC component (the carrier) but no sidebands; on the other hand, demodulating with the quadrature  $\cos(\omega_c t)$ , only the two sidebands at  $f_m$  are observed and no carrier is present. Because of this, FM detection can be done in a similar way as AM detection scheme, using the tandem configuration described previously in [Amplitude Modulation](#).

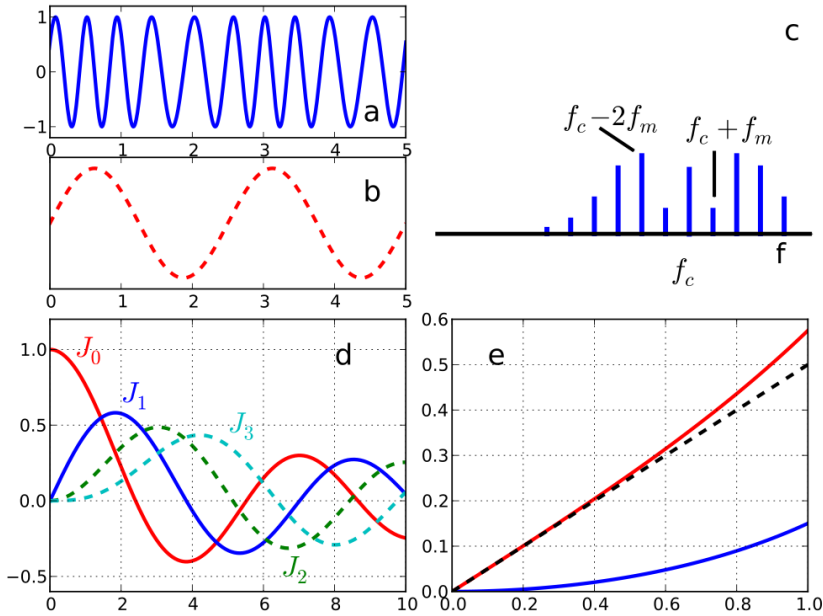


Figure 4.22: (a) A simple frequency modulated signal, (b) its instantaneous frequency, (c) the frequency domain spectrum of a FM signal is composed of an infinite series of sidebands, here depicted for  $h = 0.35$ , (d)  $n$ -th Bessel function versus  $h$ , (e) ratio  $J_1(h)/J_0(h)$  (red line),  $J_2(h)/J_0(h)$  (blue line), slope 0.5 line (black dashed line)

The HF2-MOD AM/FM Modulation option permits direct generation and demodulation of an FM signal. For demodulation, this option enables measurement of the parameters  $A$ ,  $f_p$ , and  $\phi$ .

Internally the HF2LI calculates the peak frequency  $f_p$  with the method described above, from the ratio  $J_1(h)/J_0(h)$ , proportional to the carrier and first sideband amplitude. Since this method is valid only for narrow-band frequency modulation, users are advised to work at small values of the modulation index  $h < 1$ .

Another, intuitive way of demodulating an FM signal would be to use the PLL to track the frequency deviation  $\Delta f$  and to further demodulate this signal. However, using sideband demodulation with the HF2-MOD AM/FM Modulation option provides a better signal-to-noise ratio. This is because the signal can be averaged over several modulation cycles while keeping the bandwidth small.

### 4.10.2. Generate the Test Signal

In this tutorial, you are going to generate an FM signal with a carrier frequency of 1 MHz, a modulation frequency of 100 kHz, and a modulation index of 0.1. The signal is generated at Signal Output 2 and is demodulated by the first lock-in unit by feeding it into Signal Input 1.

Start by enabling the Signal Output 2 in the Lock-in MF tab and disabling all demodulator Output Amplitudes. This will ensure that only the desired components of the frequency-modulated signal appear on the output.

Table 4.20: Settings: generate the AM signal

|                                           |     |
|-------------------------------------------|-----|
| Signal Output 2 Enable                    | ON  |
| Signal Output Amplitudes Demodulators 1-8 | OFF |

In the Modulation tab, in the MOD 2 section, select the following parameters:

Table 4.21: Settings: generate the FM signal

|                                       |                 |
|---------------------------------------|-----------------|
| MOD 2 Enable                          | ON              |
| Carrier Oscillator (Osc)/Frequency    | Osc 1 / 1 MHz   |
| Sideband 1 Oscillator (Osc)/Frequency | Osc 2 / 100 kHz |
| Carrier Mode/Enable                   | FM / ON         |
| Generation Carrier Amplitude/Enable   | 100 mV / ON     |
| Generation Index                      | 0.1             |

This generates an FM signal consisting of a carrier and two sidebands at  $f_c \pm f_m$ . To look at this signal, connect Signal Output 2 to Signal Input 1 of the HF2 Instrument. Select the correct input parameters in the Lock-in tab: for Signal Input 1, make sure Differential and 50  $\Omega$  are turned off. Then click the auto range button. In the Scope tab, select Signal Input 1 as Source, Signal Output 2 as Trigger, and click on Run/Stop to activate the Scope. Observe that the carrier amplitude is constant. The periodic frequency variation is hardly visible. In Frequency Domain FFT mode, the plot shows the carrier at 1 MHz and the two sidebands. You can increase the frequency resolution by selecting a smaller Sampling Rate and larger time scale in the Horizontal section of the Scope.

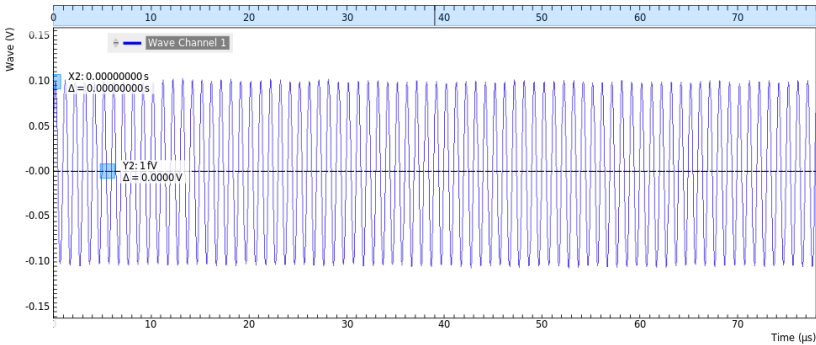


Figure 4.23: Time domain representation of the FM signal generated by MOD2 measured with the LabOne Scope

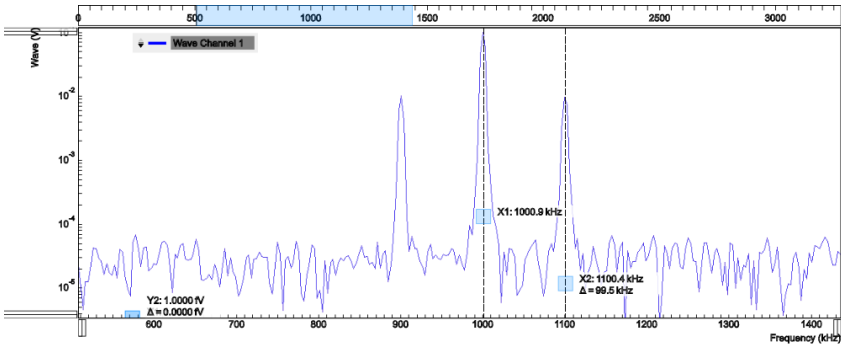


Figure 4.24: Frequency domain representation of the FM signal generated by MOD2 measured with the LabOne Scope

### 4.10.3. Measure the Test Signal

In the Modulation tab, in the MOD 1 section, select the following parameters:

Table 4.22: Measure the FM signal

|                                 |       |
|---------------------------------|-------|
| MOD 1 Enable                    | ON    |
| Carrier oscillator (Osc)        | 1     |
| Sideband 1 oscillator (Osc)     | 2     |
| Carrier Mode                    | FM    |
| Low-pass Filter BW (Carrier)    | 10 Hz |
| Low-pass Filter BW (Sideband 1) | 10 Hz |

|                                                  |    |
|--------------------------------------------------|----|
| Demod 1, 2, 3 Data Transfer Enable (Lock-in tab) | ON |
|--------------------------------------------------|----|

This sets the correct demodulation of the FM signal. In the Numerical tab, look at the amplitude of the carrier, 71 mV<sub>RMS</sub>. You can also see that the two sidebands have an amplitude of 3.5 mV<sub>RMS</sub>. This corresponds approximately to the carrier amplitude multiplied by the ratio  $J_1(h)/J_0(h)$ , see [Figure 4.22\(e\)](#) for our modulation index of h=0.1. Note that the phases of the two sidebands are 180° apart, which is typical for FM.

# 4.11. Phase-locked Loop

## Note

This tutorial is applicable to HF2 Instruments with the HF2-PID Quad PID Controller option installed.

### 4.11.1. Goals and Requirements

This tutorial explains how to track the resonance frequency shift of a resonator using a phase-locked loop (PLL). To follow this tutorial, one needs to connect a resonator between Signal Output 1 and Signal Input 1.

### 4.11.2. Preparation

Connect the cables as shown in the figure below. Make sure that the HF2 Instrument is powered on and connected by USB to your host computer or by Ethernet to your local area network (LAN) where the host computer resides. After starting LabOne the default web browser opens with the LabOne graphical user interface.

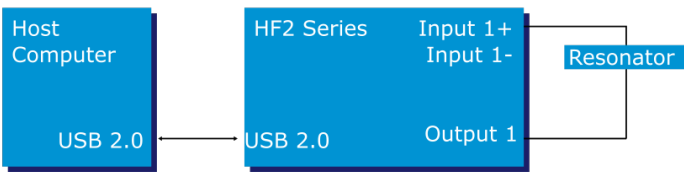


Figure 4.23: PLL connection with HF2 Instrument

The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (e.g. as is after pressing F5 in the browser).

### 4.11.3. Determine the Resonance of the Quartz

In this section you will learn first how to find the resonance of your resonator with the [Sweeper Tab](#) tool. In the Sweeper tab, one can start by defining a frequency sweep across the full instrument bandwidth and narrow down the range using multiple sweeps in order to find the resonance peak of interest. In our case, we know already that the resonance lies at around 1.8 MHz which saves us some time in finding the peak, knowing that its Q factor is rather high. The Sweeper tab and Lock-in tab settings are shown in the table below.

## Note

The table below applies to instruments without the HF2-MF Multi-frequency option installed. With the option installed, the output amplitude needs to be configured in the Output Amplitudes section of the Lock-in tab.

Table 4.23: Settings: sweep the measurement frequency

| Tab     | Sub-tab | Section        | # | Label   | Setting / Value / State |
|---------|---------|----------------|---|---------|-------------------------|
| Lock-in | All     | Signal Outputs | 1 | Amp (V) | 100.0 m / ON            |

| Tab     | Sub-tab | Section              | # | Label                 | Setting / Value / State |
|---------|---------|----------------------|---|-----------------------|-------------------------|
| Lock-in | All     | Signal Outputs       | 1 | Output 1              | ON                      |
| Lock-in | All     | Signal Inputs        | 1 | 50 $\Omega$           | ON                      |
| Lock-in | All     | Signal Inputs        | 1 | Diff                  | OFF                     |
| Lock-in | All     | Demodulators         | 1 | Osc                   | 1                       |
| Lock-in | All     | Demodulators         | 1 | Input                 | Sig In 1                |
| Lock-in | All     | Data Transfer        | 1 | Enable                | ON                      |
| Sweeper | Control | Horizontal           |   | Sweep Param.          | Osc 1 Frequency         |
| Sweeper | Control | Vertical Axis Groups |   | Signal Type / Channel | Demod 0 / 1             |
| Sweeper | Control | Vertical Axis Groups |   | Add Signal            | click                   |
| Sweeper | Control | Vertical Axis Groups |   | Signal Type / Channel | Demod R / 1             |
| Sweeper | Control | Vertical Axis Groups |   | Add Signal            | click                   |
| Sweeper | Control | Horizontal           |   | Start (Hz)            | 1 M                     |
| Sweeper | Control | Horizontal           |   | Stop (Hz)             | 3 M                     |
| Sweeper | History |                      |   | Length                | 2                       |
| Sweeper | Control | Settings             |   | Dual Plot             | ON                      |
| Sweeper | Control | Settings             |   | Run/Stop              | ON                      |

We use demodulator 1 to generate the sweep signal and to demodulate the signal transmitted through the resonator. The Lock-in settings ensure that the oscillator used both for the generation and the measurement is the same (oscillator 1). In addition, the input must be set to Signal Input 1 in accordance with the connection diagram.

Once the Sweeper **Run/Stop** button is clicked, the Sweeper will repeatedly sweep the frequency response of the quartz oscillator. The History Length of 2 allows you to keep one previous sweep on the screen while adjusting the sweep range. You can use the zoom tools to get a higher resolution on the resonance peak. To redefine the start and stop frequencies for a finer sweeper range, just click the **Copy From Range** button. This will automatically paste the plot frequency range into the Start and Stop fields of the Sweeper frequency range.

## Note

The sweep frequency resolution will get finer when zooming in horizontally using the **Copy From Range** button even without changing the number of points.

When a resonance peak has been found, you should get a measurement similar to the solid lines in the two figures below. The resonance fitting tool allows us to easily determine resonance parameters such as Q factor, center frequency, or peak amplitude. To use the tool, place the two X cursors to the left and right of the resonance, open the Math sub-tab of the Sweeper tab, select "Resonance" from the left drop-down menu, and click on **Add**. Repeat this operation, once with the demodulator amplitude as the active trace in the plot, and once with the demodulator phase (see Vertical Axis Groups). The tool will perform a least-squares fit to the response function of an LCR circuit. In the limit of large Q factors, this corresponds to a fit to the square root of a Lorentzian function for the amplitude, and to an inverse tangent for the phase. The exact fitting functions are documented in [the section called "Cursors and Math"](#).

The fitting curves are added as dashed lines to the plot as shown in [Figure 4.24](#) and [Figure 4.25](#). Since the two fits are independent, they may lead to different results if the resonance significantly deviates from a simple LCR circuit model, which often is the case if there is capacitive coupling between the leads. In this case, the fit to the phase curve which is clearly better than that to the amplitude curve yields a Q factor of about 12,800, and a center frequency of 1.8428 MHz.

The phase in [Figure 4.25](#) follows a typical resonator response going from  $+90^\circ$  to  $-90^\circ$  when passing through the resonance on a 50  $\Omega$  input. Directly at the resonance, the measured phase is close to  $0^\circ$ . We will use this value as a phase setpoint for the PLL. After having completed the Sweeper measurements, turn off sweeping by clicking on **Run/Stop**. This will release the oscillator frequency from the control by the Sweeper.



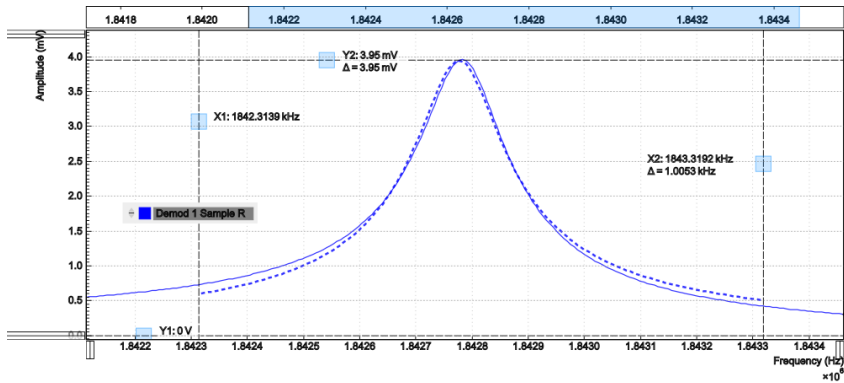


Figure 4.24: Amplitude of the resonator's frequency response measured with the LabOne Sweeper. Solid line are measurement data, dashed line is a fit to the response function of an LCR circuit model using the resonance fitting tool.

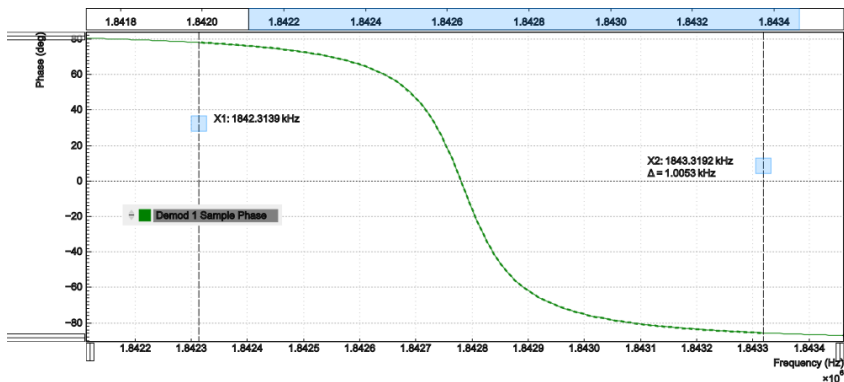


Figure 4.25: Phase of the resonator's frequency response measured with the LabOne Sweeper. Solid line are measurement data, dashed line is a fit to the response function of an LCR circuit model using the resonance fitting tool.

4.11.4. Resonance Tracking with the PLL

Now we know the resonance frequency and the phase measured at this frequency. We can track the drift in resonance frequency by locking on to this phase, hence the name phase-locked loop (PLL). The phase-locked loop is available in the PLL tab. There are two PLL controllers in each HF2 Series instrument. For this tutorial, we will use PLL 1. We first set up the basic PLL 1 fields as shown in the table below, using the values from the previous measurement.

Table 4.24: Settings: set up the phase-locked loop

| Tab | Sub-tab | Section | # | Label                    | Setting / Value / State  |
|-----|---------|---------|---|--------------------------|--------------------------|
| PLL | PLL     |         | 1 | Mode                     | PLL                      |
| PLL | PLL     |         | 1 | Auto Mode                | PID Coeff                |
| PLL | PLL     | Input   | 1 | Setpoint (deg)           | 0.0                      |
| PLL | PLL     | Output  | 1 | Output                   | Oscillator Frequency / 1 |
| PLL | PLL     | Output  | 1 | Center Freq (Hz)         | 1.8428 M                 |
| PLL | PLL     | Output  | 1 | Lower / Upper Limit (Hz) | -10k / +10 k             |

The upper and lower frequency (or range) relative to the Center Frequency should be chosen narrow enough so that the phase of the device follows a monotonous curve with a single crossing at the setpoint, else the feedback controller will fail to lock correctly. Now, we need to find suitable feedback gain parameters (P, I, D) which we do using the Advisor. Set the Target BW (Hz) to 1.0 kHz. The target bandwidth should be at least as large as the expected bandwidth of the frequency variations. In the present case, the resonator frequency is practically stable, so 1 kHz bandwidth is largely enough. Click on the **Advise** button to have the Advisor find a set of feedback gain parameters using a numerical optimization algorithm. Figure 4.26 shows a typical view of the PLL tab after the Advisor has finished. The Advisor tries to match or exceed the target bandwidth in its simulation. The achieved bandwidth can be read from the BW (Hz) field, or directly from the 3 dB point of the simulated Bode plot on the right. The Phase Margin value of the simulation is displayed



in the PM (deg) field and should exceed 45° to ensure stable feedback operation without oscillations. Once you are satisfied with the Advisor results, click on the **To PLL** button to transfer the feedback gain parameters to the physical PLL controller. To start PLL operation, click on the Enable button at the top of the PLL tab.

Table 4.25: Settings: set up and run the PID Advisor

| Tab | Sub-tab | Section   | # | Label              | Setting / Value / State |
|-----|---------|-----------|---|--------------------|-------------------------|
| PLL | Advisor | Advisor   | 1 | Target BW (Hz)     | 1 k                     |
| PLL | Advisor | DUT Model | 1 | DUT Model          | Resonator Frequency     |
| PLL | Advisor | DUT Model | 1 | Res Frequency (Hz) | 1.8 M                   |
| PLL | Advisor | DUT Model | 1 | Q                  | 12.8 k                  |
| PLL | Advisor | Advisor   | 1 | Advise             | click                   |

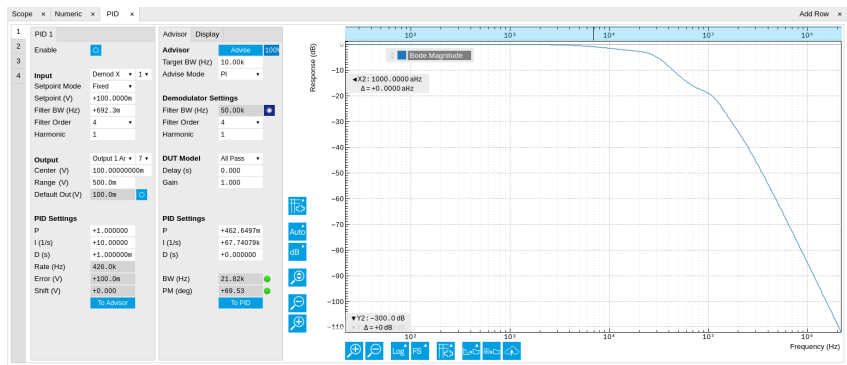


Figure 4.26: Settings and Advisor simulation in the PLL tab (typical – parameters may differ from the example)

When the PLL is locked, the green indicator next to the label Error/PLL Lock will be switched on. The actual frequency shift is shown in the field Freq Shift (Hz).

Note

At this point, it is recommended to adjust the signal input range by clicking the Auto Range button in the Lock-in tab. This often increases the signal-to-noise ratio which helps the PLL to lock to an input signal.

The easiest way to visualize the frequency drift is to use the Plotter tool. The frequency can be added to the display by using the Tree Selector to navigate to Demodulator 1 → Sample and selecting Frequency. The frequency noise increases with the PLL bandwidth, so for optimum noise performance the bandwidth should not be higher than what is required by the experiment. The frequency noise also scales inversely with the drive amplitude of the resonator.

4.12. Automatic Gain Control

Note

This tutorial is applicable to HF2 Instruments with the HF2-PID Quad PID Controller option installed.

4.12.1. Goals and Requirements

This tutorial explains how to set up a PID controller for automatic gain control. We use the PID Advisor to simulate the step response of a feedback loop and the Data Acquisition tool to capture the physical step response of the loop. We perform the test using a quartz resonator between Signal Output 1 and Signal Input 1.



4.12.2. Preparation

Connect the cables as illustrated below. Make sure the HF2 Instrument is powered on, and then connect the HF2 Instrument through the USB to your PC, or to your local area network (LAN) where the host computer resides. After starting LabOne the default web browser opens with the LabOne graphical user interface.

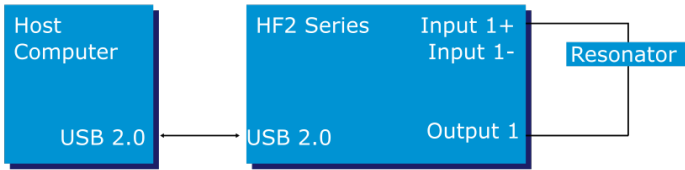


Figure 4.27: PID connection with HF2 instrument

The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (e.g. as is after pressing F5 in the browser).

4.12.3. Automatic Gain Control

In this section you will learn how to control the output amplitude of your device under test with a PID controller. We will use a quartz resonator driven at its resonance frequency by the signal generator of the instrument, and measured with a demodulator.

If you are continuing from the [Phase-locked Loop](#), then you can just leave the PLL enabled. Otherwise, you should know how to generate an excitation signal at the required frequency and how to measure the signal amplitude that you want to control. The device-under-test does not need to be a resonator.

As shown in the frequency response curve below, we are measuring an amplitude of about 4.0 mV at the peak of the resonance while driving with 100 mV<sub>pk</sub>. The goal is to have this amplitude programmable by the user on the fly.

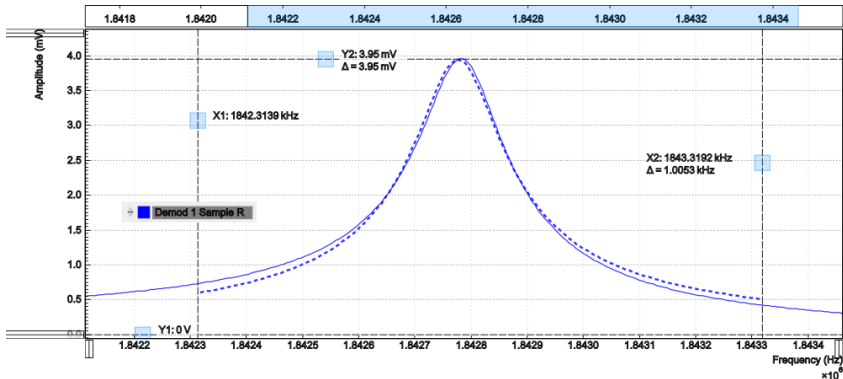


Figure 4.28: Amplitude of the resonator's frequency response measured with the LabOne Sweeper. Solid line are measurement data, dashed line is a fit to the response function of an LCR circuit model using the resonance fitting tool.

For setting up automatic gain control, open the PID tab in which the four available PID controllers are represented in different side-tabs. We'll use PID 3 for this tutorial. We'll define the Input of the controller as the measured lock-in R signal, and the Output as the drive amplitude. The settings are shown in the table below.

Note


The table below applies to instruments without the HF2-MF Multi-frequency option installed. With the option installed, the Output 1 Amplitude channel needs to be set to the number of the demodulator used to generate the signal in the Output Amplitudes section of the Lock-in tab.

Table 4.26: Settings: Set up the PID controller

| Tab | Sub-tab | Section | # | Label                 | Setting / Value / State |
|-----|---------|---------|---|-----------------------|-------------------------|
| PID | PID     |         | 3 | Mode                  | PID                     |
| PID | PID     | Input   | 3 |                       | Demod R / 1             |
| PID | PID     | Input   | 3 | Setpoint (V)          | 10 m                    |
| PID | PID     | Output  | 3 |                       | Output 1 Amplitude      |
| PID | PID     | Output  | 3 | Center (V)            | 0.5                     |
| PID | PID     | Output  | 3 | Lower/Upper Limit (V) | -0.5/+0.5               |
| PID | PID     | Output  | 3 | Range                 | 0.5                     |

The next step is to select the proper feedback gain parameters (P, I, D). On the HF2 instrument we can do this with the help of the PID Advisor. Based on a set of mathematical models for the device under test (DUT), it can simulate the step response for a certain set of feedback gain values. The PID Advisor numerically optimizes the feedback gain parameters to obtain a step response that matches or exceeds a user-specified target bandwidth.

The list of available DUT models is found in [PID Tab](#). In case your DUT is not well described by one of the models, the methods presented here are nonetheless useful to implement certain heuristic tuning method such as the Good Gain method (Finn Haugen, Telemark University College, Norway, 2010), as they enable measurement of the closed-loop step response.

The PID Advisor offers an efficient graphical tool for setting the feedback gain parameters manually. To access it, enable the Advanced Mode in the Display sub-tab and select PID from the Transfer Function menu. Three cursor lines will be added to the display section which represent the frequency dependence of the P, I, and D part of the PID controller transfer function. The cursors can be dragged, allowing you to define a target Bode plot. If you enable the Advisor Link button , the feedback gain parameters derived from the cursors are linked with the simulation parameters from the Advisor from where they can be transferred to the instrument.

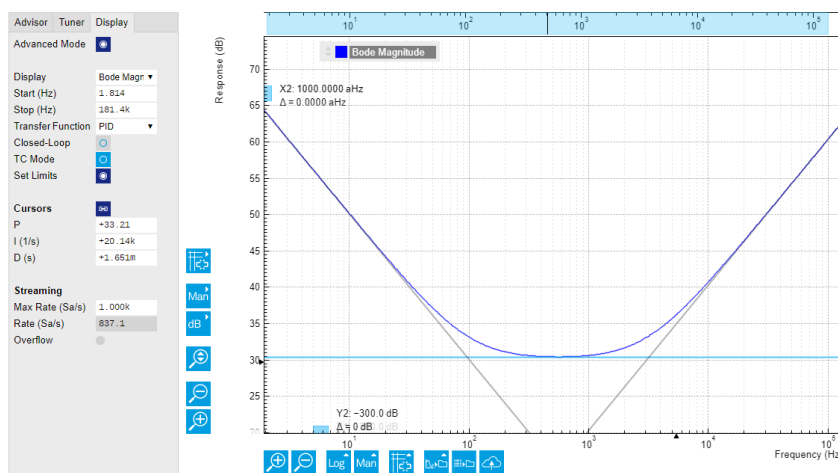



Figure 4.29: Graphical setting of the PID parameters using the cursors. The three cursor lines with negative, zero, and positive slope correspond to the frequency dependence of the P, I, and D parts of the controller, respectively.

#### 4.12.4. Simulating the Device Under Test

In the Advisor sub-tab, select "Resonator Amplitude" as the model of the DUT. This model is characterized by four parameters: delay, gain, center frequency, and Q. The latter two can easily be determined from a frequency response measurement in the Sweeper tab using the resonance fitting tool available in the [Math sub-tab](#) as described in [Determine the Resonance of the Quartz](#). We obtain a Q factor of  $\sim 12,800$  and a center frequency of 1.8428 MHz. The delay value represents extra delays such as those coming from cables (typically 4 to 5 ns per meter). Since we use short cables these are negligible and we can leave the delay parameter at 0 s. The gain value parametrizes overall signal gain or attenuation between PID controller output and input, including unit conversion. In our case, measuring an R amplitude of  $4.0 \text{ mV}_{\text{rms}}$  on resonance while the drive amplitude is set to  $100 \text{ mV}_{\text{pk}}$ , we have a gain of 0.040.

With the Mode selector in the Advisor sub-tab, you can define which of the feedback gain parameters the Advisor uses for his optimization. E.g., when you select PI advise mode, P and I parameters are varied but D is fixed at the value presently set. In this way you can choose the most efficient way of using the Advisor: you can have everything be done by the Advisor, you can control some of the parameters manually and have the Advisor deal with the rest, or you do all the adjustments manually and use the Advisor only to simulate the outcome.

We leave the D parameter at 0 and let the Advisor run in PI mode. Enter a target BW of 1 kHz and click on the  button. The Advisor will suggest some values for P and I. The BW field indicates the bandwidth of the simulated loop, with a green lamp showing that the target bandwidth was reached or exceeded. The PM field shows the phase margin, with a green lamp indicating a stable feedback loop.

In the given example, the resonator has a bandwidth of about 140 Hz, so the target bandwidth of 1 kHz is just about within reach. However, in order to reach this value, the corresponding demodulator filter bandwidth may need adjustment. It should be larger than the target bandwidth, but not larger than necessary in order to avoid excessive noise. When enabling Auto Bandwidth (the checkbox next to the Filter BW field in the Demodulator Settings), the PID Advisor selects a suitable demodulator bandwidth which later will be transferred automatically to the demodulator.

The Bode plot on the right-hand side of the tab corresponds to the simulated closed-loop frequency response based on the P, I, and D gain values and the DUT model presently set in the Advisor sub-tab. In order to show the simulated closed-loop step response for our example as in [Figure 4.30](#), set Display to Step Response in the Display sub-tab.

## Note

In case a demodulator measurement is selected as the PID input, the Advisor will control the corresponding demodulator filter bandwidth, but not the filter order. If you encounter problems with oscillating feedback, bear in mind that low-order filters often lead to more stable feedback loop behavior because of their smaller delay.

Table 4.27: Settings: set up and run the PID Advisor

| Tab | Sub-tab | Section              | # | Label                      | Setting / Value / State |
|-----|---------|----------------------|---|----------------------------|-------------------------|
| PID | Advisor | Advisor              | 3 | Target BW (Hz)             | 1 k                     |
| PID | Advisor | Advisor              | 3 | Advise Mode                | PI                      |
| PID | Advisor | Demodulator Settings | 3 | Filter BW / Auto Bandwidth | ON                      |
| PID | Advisor | DUT Model            | 3 | DUT Model                  | Resonator Amplitude     |
| PID | Advisor | DUT Model            | 3 | Delay                      | 0.0 s                   |
| PID | Advisor | DUT Model            | 3 | Gain                       | 0.040                   |
| PID | Advisor | DUT Model            | 3 | Center Frequency           | 1.8 M                   |
| PID | Advisor | DUT Model            | 3 | Q                          | 12.8 k                  |
| PID | Display |                      | 3 | Display                    | Step Response           |
| PID | Advisor | Advisor              | 3 | Advise                     | ON                      |



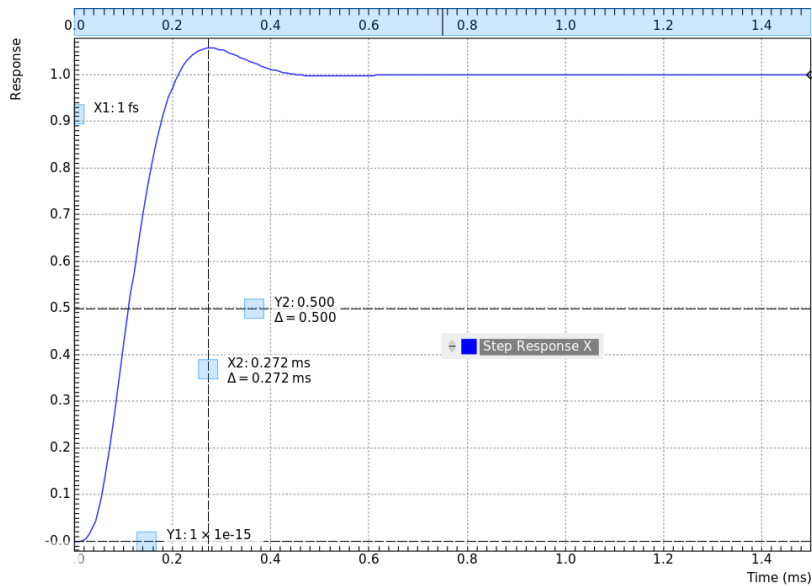


Figure 4.30: Closed-loop step response simulated with the PID Advisor

4.12.5. Measuring the Step Response

Once you are satisfied with the Advisor results, click on the **To PID** button to transfer the feedback gain parameters to the physical PID controller represented on the left. Enable the PID controller and check, e.g. using the **Plotter Tab**, whether demodulator 1 R has settled at the setpoint of 10 mV. Toggling the setpoint in the PID tab will then immediately be visible as a step in the Plotter. To capture the step response, the **Data Acquisition Tab** is the tool of choice. Open the DAQ tab and configure the trigger in the Settings and Grid sub-tabs according to the table below. .Settings: set up the Data Acquisition tool

Table 4.28: Settings: set up the Data Acquisition tool

| Tab     | Sub-tab  | Section          | # | Label              | Setting / Value / State |
|---------|----------|------------------|---|--------------------|-------------------------|
| DAQ     | Settings | Trigger Settings |   | Trigger Signal     | Demod 1 R               |
| DAQ     | Settings | Trigger Settings |   | Level (V)          | 11 m                    |
| DAQ     | Settings | Trigger Settings |   | Hysteresis (V)     | 0                       |
| DAQ     | Settings | Horizontal       |   | Delay (s)          | -1 m                    |
| DAQ     | Grid     | Grid Settings    |   | Mode               | Linear                  |
| DAQ     | Grid     | Grid Settings    |   | Duration (s)       | 5 m                     |
| Lock-in | All      | Data Transfer    | 1 | Rate (Hz) / Enable | 100 k / ON              |

We also increased the demodulator data transfer rate to get a high time resolution for this measurement. Start the Data Acquisition tool by clicking on **Run/Stop**. Any time you toggle the setpoint across the Trigger Level (e.g. from 10 mV to 12 mV), a single trace will be recorded and displayed in the DAQ tab as shown in the figure below.



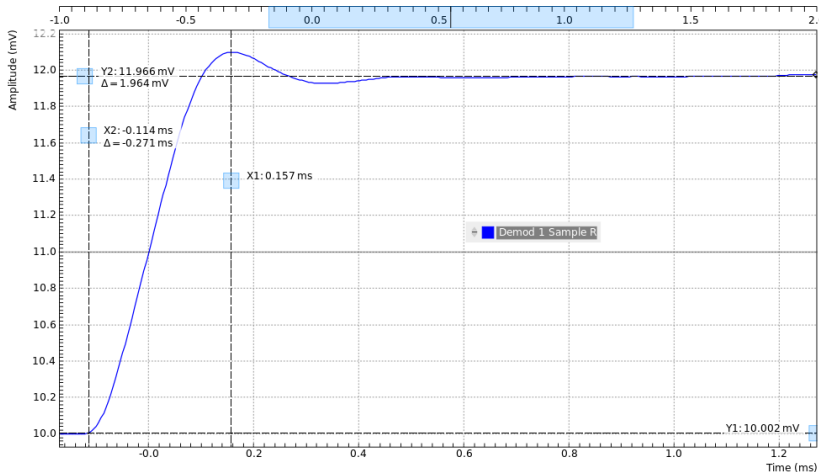


Figure 4.31: Closed-loop step response measured with the Data Acquisition tool

Comparing [Figure 4.31](#) with [Figure 4.30](#) demonstrates the excellent quantitative match between simulation and measurement.

## 4.13. Imaging

### Note

This tutorial is applicable to all HF2 Instruments.

### 4.13.1. Goals and Requirements

This tutorial explains how to capture and display an imaging signal, i.e., a signal structured in lines and frames that can be built up to a 2-dimensional data set. To follow this tutorial, one will require a 3<sup>rd</sup>-party programmable arbitrary waveform generator to generate a realistic imaging signal with line triggers, or access to a real imaging signal including line triggers or EOL triggers e.g. from an atomic force microscope.

### 4.13.2. Preparation

Connect the cables as shown in the figure below. Make sure that the HF2 Instrument is powered on and connected by USB to your host computer . After starting LabOne the default web browser opens with the LabOne graphical user interface.

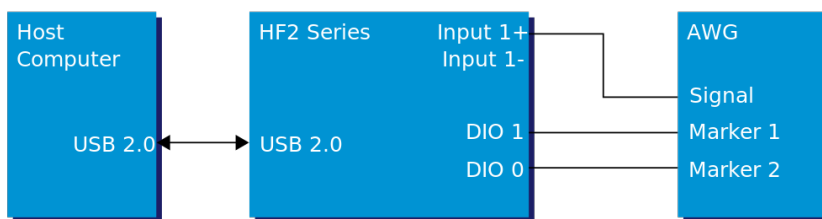


Figure 4.31: Setup for the imaging tutorial with HF2 Instrument

The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (e.g. as is after pressing F5 in the browser).

### 4.13.3. Imaging Signal Properties

In this section we discuss the properties of the external signal used in this tutorial. It is most illustrative to discuss the imaging functionality based on a realistic signal generated by an arbitrary waveform generator (AWG), or even a real imaging signal. The imaging functionality of the instrument can also be tried out without external equipment, but it's not easily possible to generate a nicely structured imaging signal with the HF2 instrument alone. In order to facilitate the phase-locking

between AWG and lock-in, an AWG with digital modulation capability and a possibility to output the phase reference signal separately from the AWG signal is helpful. Examples are the UHFAWG and the HDAWG from Zurich Instruments.

We will assume the following scanning parameters: a line scanning frequency of about 200 Hz and a line number of 256. We will furthermore assume that the imaging signal on the AWG signal output is an amplitude-modulated signal at a fixed carrier frequency of 300 kHz. This signal is wired to the Signal Input 1+In connector of the HF2 instrument. The carrier phase reference, a square wave at 300 kHz with about  $1\text{ V}_{\text{pk}}$  amplitude, is generated on the AWG marker output 1 and is connected to the lock-in reference input DIO 1. At the start of each line, the AWG generates a rising edge of a TTL signal generated on its marker output 2. This line trigger signal is connected to the DIO 0 connector of the HF2 instrument. The minimum trigger signal width required to correctly trigger the data acquisition is equal to the inverse demodulator sample rate used. The reason is that the state of the DIO 0 connector is transferred to the host computer together with the demodulator data which limits the time resolution and therefore the minimum trigger pulse width.

#### 4.13.4. Measure the Imaging Signal

For this example, we programmed the AWG to generate a signal with an amplitude varying between 0 and about  $0.6\text{ V}_{\text{rms}}$  which builds up to an image of the Zurich Instruments logo. We let the AWG run continuously, which means it will permanently generate this signal, the line trigger, and the phase reference signal. Here we will set up the lock-in amplifier with sufficiently high demodulator bandwidth and sampling rate in order to faithfully measure the imaging signal in external reference mode.

For locking to the external reference lock-in reference input, we need to select the reference input signal and change the lock-in amplifier to external reference mode. You can check in the [DIO Tab](#) whether the corresponding input connector shows a toggling signal. Setting up a measurement in external reference mode is more generally described in [External Reference](#).

Table 4.29: Settings: enable external reference mode

| Tab     | Sub-tab | Section      | # | Label  | Setting / Value / State |
|---------|---------|--------------|---|--------|-------------------------|
| Lock-in | All     | Demodulators | 7 | Signal | DIO D1                  |
| Lock-in | All     | Demodulators | 7 | Mode   | ExtRef                  |

We choose demodulator filter settings and sampling rate sufficiently high to measure the fast components in the signal up to several 10 kHz. You can find a more general description on selecting filter constants in [Dynamic Signals](#). The table below shows the settings to be made.

Table 4.30: Settings: configure the demodulator

| Tab     | Sub-tab | Section          | # | Label   | Setting / Value / State |
|---------|---------|------------------|---|---------|-------------------------|
| Lock-in | All     | Signal Input     | 1 | Range   | 1.2 V                   |
| Lock-in | All     | Low-pass Filters | 1 | BW 3 dB | 30 kHz                  |
| Lock-in | All     | Low-pass Filters | 1 | Order   | 8                       |
| Lock-in | All     | Data Transfer    | 1 | Rate    | 220 kSa/s               |
| Lock-in | All     | Data Transfer    | 1 | Enable  | ON                      |

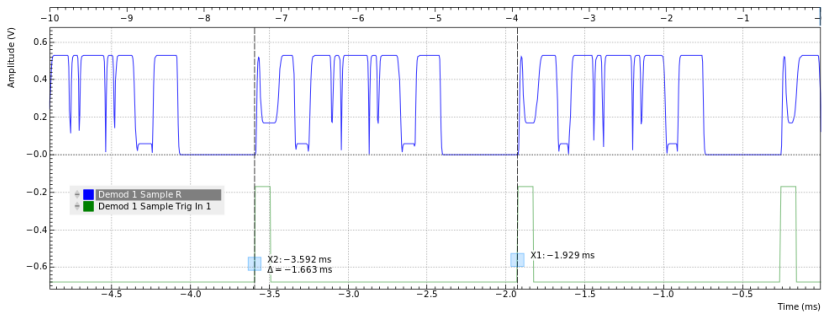
Now we can monitor the imaging signal as well as the line triggers in the [Plotter Tab](#). Open the Plotter tab and add the demodulator R signal as well as DIO 0 to the plot.

Table 4.31: Settings: measure imaging signal and line trigger in the Plotter

| Tab     | Sub-tab | Section              | # | Label         | Setting / Value / State      |
|---------|---------|----------------------|---|---------------|------------------------------|
| Plotter | Control | Vertical Axis Groups |   | Tree Selector | Demodulators/1/ Sample/R     |
| Plotter | Control | Vertical Axis Groups |   | Tree Selector | Demodulators/1/ Sample/DIO 0 |
| Plotter | Control |                      |   | Run / Stop    | ON                           |

The Plotter should now display the continuously streamed imaging data. The figure below shows in blue the demodulator R signal, and in green the line trigger signal marking the beginning of each line. The cursors indicate a line repetition period of about 1.66 ms, and In the following, instead of

displaying these data in a continuous stream in the Plotter, we would like to capture a full image frame.



4.13.5. Set up the Grid Mode

The [Data Acquisition Tab](#) with its Grid Mode is the suitable tool to capture images. In this section we go through the configuration of this tool.

The Data Acquisition tool in grid mode acquires 2-dimensional data sets with pre-defined rows and columns that are defined by a trigger timing for each line, a well-defined line number, and a well-defined line duration. The acquired data stream can be linearly interpolated to a well-defined number of data points (e.g. pixels) for each line, or it can be acquired exactly with the transfer rate of the demodulator in exact mode. It furthermore supports averaging over multiple frames.

Here we select the DIO 0 signal as trigger source in the Settings sub-tab. We set the hold-off time to 0 s to ensure that no triggers are lost in between successive lines. By changing the delay, we can compensate for a possible misalignment between trigger timing and line start, or to configure the Data Acquisition tool for a line end trigger, rather than line start trigger.

In the Grid sub-tab, we select a number of rows corresponding to what we have programmed on the AWG. In Exact (on-grid) mode, we select the number of columns such that the duration is sufficiently long to capture one line, but shorter than 1 line trigger period so the DAQ tool can re-arm for every new line. Here we select  $N = 300$  columns, corresponding to a duration of  $T = 1.36$  ms. The two numbers are related to the demodulator sampling rate  $f_s = 220$  kSa/s by  $T = N/f_s$ .

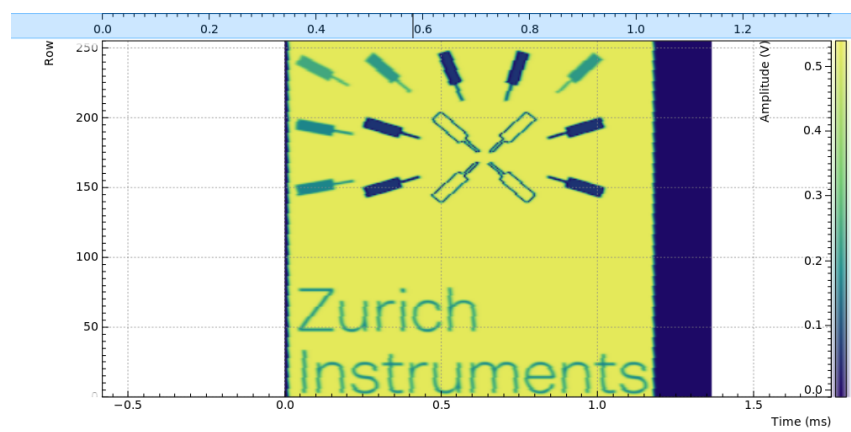
Finally, we select the 2D display in the Control sub-tab, and we make sure to add demodulator 1 R as a displayed signal in the [Vertical Axis Groups](#) section. The DAQ tab also supports multi-channel acquisition as more signals, e.g. the phase or other demodulators can be recorded. The table below summarizes the settings.

Table 4.32: Settings: set up the grid mode

| Tab | Sub-tab  | Section          | # | Label          | Setting / Value / State           |
|-----|----------|------------------|---|----------------|-----------------------------------|
| DAQ | Settings | Trigger Settings |   | Trigger Signal | Demod 1 DIO 0                     |
| DAQ | Settings | Horizontal       |   | Hold off time  | 0 s                               |
| DAQ | Settings | Horizontal       |   | Delay          | 0 s                               |
| DAQ | Grid     | Grid Settings    |   | Mode           | Exact (on-grid)                   |
| DAQ | Grid     | Grid Settings    |   | Columns        | 300                               |
| DAQ | Grid     | Grid Settings    |   | Duration       | 1.36 ms (read-only in Exact mode) |
| DAQ | Grid     | Grid Settings    |   | Rows           | 256                               |
| DAQ | Control  | Time Domain      |   | Plot Type      | 2D                                |

In order to capture one fresh frame, we shortly disable the AWG. We arm the Data Acquisition tool by clicking on [Single](#) to acquire a single frame with the exact number of rows specified before, and then restart the AWG. The figure below shows the captured image. The acquired data appear as an entry in the History sub-tab and can easily be saved from there.







# 5. Functional Description LabOne User Interface

This chapter gives a detailed description of the functionality available in the LabOne User Interface (UI) for the Zurich Instruments HF2 Series. LabOne provides a data server and a web server to control the Instrument with any of the most common web browsers (e.g. Firefox, Chrome, Edge, etc.). This platform-independent architecture supports interaction with the Instrument using various devices (PCs, tablets, smartphones, etc.) even at the same time if needed.

On top of standard functionality like acquiring and saving data points, this UI provides a wide variety of measurement tools for time and frequency domain analysis of measurement data as well as for convenient servo loop implementation.

## 5.1. User Interface Overview

## 5.2. UI Nomenclature

This section provides an overview of the LabOne User Interface, its main elements and naming conventions. The LabOne User Interface is a browser-based UI provided as the primary interface to the HF2 Series instrument. Multiple browser sessions can access the instrument simultaneously and the user can have displays on multiple computer screens. Parallel to the UI, the instrument can be controlled and read out by custom programs written in any of the supported languages (e.g. LabVIEW, MATLAB, Python, C) connecting through the LabOne APIs.

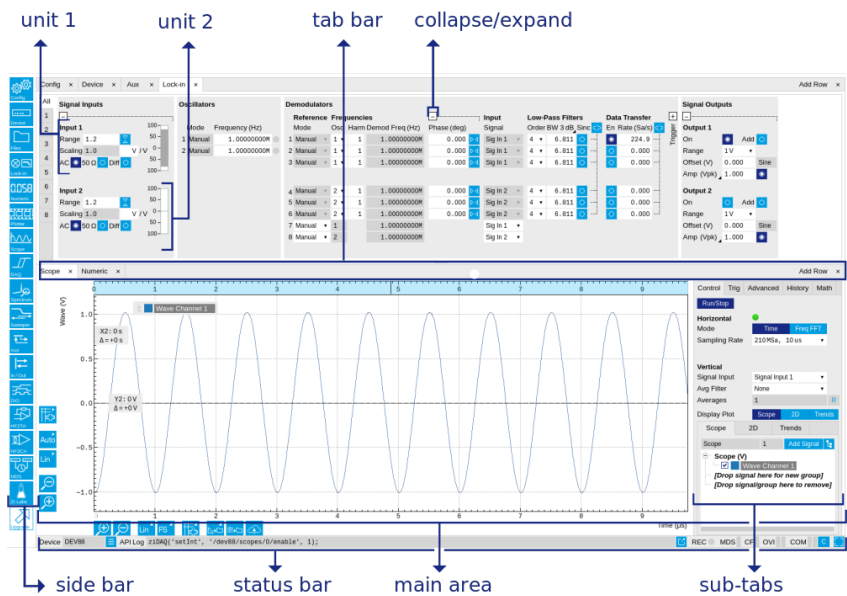


Figure 5.1: LabOne User Interface (default view)

The [LabOne User Interface](#) automatically opens some tabs by default after a new UI session has been started. At start-up, the UI is divided into two tab rows, each containing a tab structure that gives access to the different LabOne tools. Depending on display size and application, tab rows can be freely added and deleted with the control elements on the right-hand side of each tab bar. Similarly, the individual tabs can be deleted or added by selecting app icons from the side bar on the left. A click on an icon adds the corresponding tab to the display, alternatively the icon can be dragged and dropped into one of the tab rows. Moreover, tabs can be moved by drag-and-drop within a row or across rows.

[Table 5.1](#) gives a brief descriptions and naming conventions for the most important UI items.

Table 5.1: LabOne User Interface features

| Item name  | Position                 | Description                                                                                                                            | Contains                                                     |
|------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| side bar   | left-hand side of the UI | contains app icons for each of the available tabs - a click on an icon adds or activates the corresponding tab in the active tab row   | app icons                                                    |
| status bar | bottom of the UI         | contains important status and warning indicators, device and session information, and access to the command log                        | status indicators                                            |
| main area  | center of the UI         | accommodates all active tabs – new rows can be added and removed by using the control elements in the top right corner of each tab row | tab rows, each consisting of tab bar and the active tab area |
| tab area   | inside of each tab       | provides the active part of each tab consisting of settings, controls and measurement tools                                            | sections, plots, sub-tabs, unit selections                   |

Further items are highlighted in Figure 5.2.

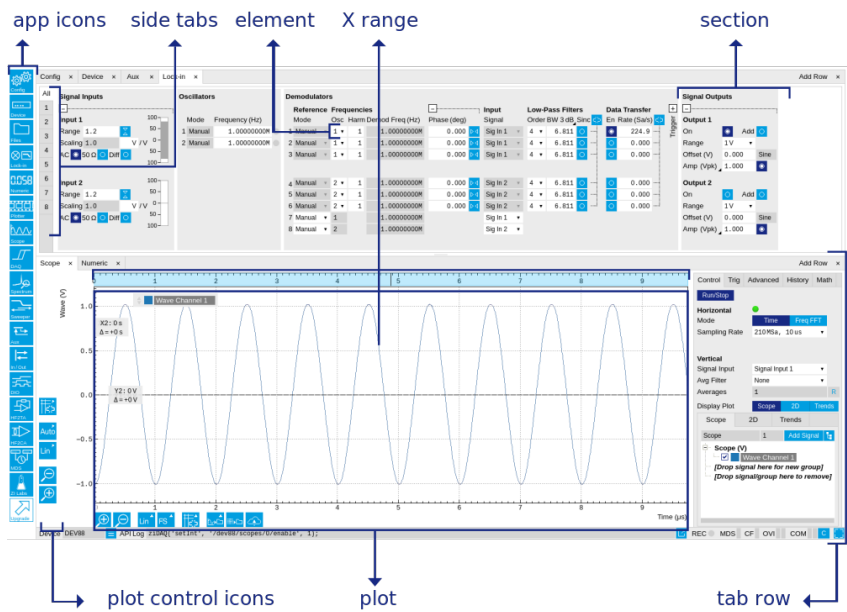


Figure 5.2: LabOne User Interface (more items)

5.2.1. Unique Set of Analysis Tools

All instruments feature a comprehensive tool set for time and frequency domain analysis for both raw and demodulated signals.

The app icons on the left side of the UI can be roughly divided into two categories: settings and tools.

**Settings**-related tabs are in direct connection to the instrument hardware, allowing the user to control all the settings and instrument states.

**Tools**-related tabs place a focus on the display and analysis of gathered measurement data.

There is no strict distinction between settings and tools, e.g. the Sweeper will change certain demodulator settings while performing a frequency sweep. Within the tools one can often further discriminate between time domain and frequency domain analysis. Moreover, a distinction can be made between the analysis of fast input signals - typical sampling rate of 210 MSa/s - and the measurement of orders of magnitude slower data - typical sampling rate of - derived for instance from demodulator outputs and auxiliary inputs. Table 5.2 provides a brief classification of the tools.

Table 5.2: Tools for time domain and frequency domain analysis

|                           | Time Domain              | Frequency Domain                 |
|---------------------------|--------------------------|----------------------------------|
| Fast signals (210 MSa/s)  | Oscilloscope (Scope tab) | FFT Analyzer (Scope tab)         |
| Slow signals (<200 kSa/s) | Numeric                  | Spectrum Analyzer (Spectrum tab) |
|                           | Plotter                  | Sweeper                          |
|                           | Data Acquisition         | -                                |

The following table gives the overview of all app icons. Note that the selection of app icons may depend on the upgrade options installed on a given instrument.

Table 5.3: Overview of app icons and short description


























| Control/Tool | Option/Range                                                                        | Description                                                                                                                                     |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Lock-in      |    | Quick overview and access to all the settings and properties for signal generation and demodulation.                                            |
| Lock-in MF   |    | Quick overview and access to all the settings and properties for signal generation and demodulation.                                            |
| Files        |    | Access settings and measurement data files on the host computer.                                                                                |
| Numeric      |    | Access to all continuously streamed measurement data as numerical values.                                                                       |
| Plotter      |    | Displays various continuously streamed measurement data as traces over time (roll mode).                                                        |
| Scope        |    | Displays shots of data samples in time and frequency domain (FFT) representation.                                                               |
| DAQ          |   | Provides complex trigger functionality on all continuously streamed data samples and time domain display.                                       |
| Spectrum     |  | Provides FFT functionality to all continuously streamed measurement data.                                                                       |
| Sweeper      |  | Sweep frequencies, voltages, and other quantities over a defined range and display various response functions including statistical operations. |
| Aux          |  | Controls all settings regarding the auxiliary inputs and auxiliary outputs.                                                                     |
| In/Out       |  | Gives access to all controls relevant for the Signal Inputs and Signal Outputs of each channel.                                                 |
| DIO          |  | Gives access to all controls relevant for the digital inputs and outputs including DIO, Trigger Inputs, Trigger Outputs, and Marker Outputs.    |
| Config       |  | Provides access to software configuration.                                                                                                      |
| Device       |  | Provides instrument specific settings.                                                                                                          |
| PID          |  | Features all control, analysis, and simulation capabilities of the PID controllers.                                                             |
| PLL          |  | Features all control, analysis, and simulation capabilities of the phase-locked loops.                                                          |
| MOD          |  | Control panel to enable (de)modulation at linear combinations of oscillator frequencies.                                                        |
| MDS          |  | Synchronize multiple instruments.                                                                                                               |
| HF2CA        |  | Remote control of the HF2CA Current Amplifier.                                                                                                  |
| HF2TA        |  | Remote control of the HF2TA Current Amplifier.                                                                                                  |
| ZI Labs      |  | Experimental settings and controls.                                                                                                             |

Table 5.4 provides a quick overview over the different status bar elements along with a short description.

Table 5.4: Status bar description

| Control/Tool    | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                 |
|-----------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Command log     | last command                                                                        | Shows the last command. A different formatting (MATLAB, Python, ..) can be set in the config tab. The log is also saved in [User] \Documents\Zurich Instruments\LabOne\WebServer\Log                                                                                                                        |
| Show Log        |    | Show the command log history in a separate browser window.                                                                                                                                                                                                                                                  |
| Errors          | Errors                                                                              | Display system errors in separate browser tab.                                                                                                                                                                                                                                                              |
| Device          | devXXX                                                                              | Indicates the device serial number.                                                                                                                                                                                                                                                                         |
| Identify Device |    | When active, device LED blinks                                                                                                                                                                                                                                                                              |
| MDS             | grey/green/red/yellow                                                               | Multiple device synchronization indicator. Grey: Nothing to synchronize - single device on the UI. Green: All devices on the UI are correctly synchronized. Yellow: MDS sync in progress or only a subset of the connected devices is synchronized. Red: Devices not synchronized or error during MDS sync. |
| REC             | grey/red                                                                            | A blinking red indicator shows ongoing data recording (related to global recording settings in the Config tab).                                                                                                                                                                                             |
| CF              | grey/yellow/red                                                                     | Clock Failure - Red: present malfunction of the external 10 MHz reference oscillator. Yellow: indicates a malfunction occurred in the past.                                                                                                                                                                 |
| OVI             | grey/yellow/red                                                                     | Signal Input Overload - Red: present overload condition on the signal input also shown by the red front panel LED. Yellow: indicates an overload occurred in the past.                                                                                                                                      |
| OVO             | grey/yellow/red                                                                     | Overload Signal Output - Red: present overload condition on the signal output. Yellow: indicates an overload occurred in the past.                                                                                                                                                                          |
| COM             | grey/yellow/red                                                                     | Packet Loss - Red: present loss of data between the device and the host PC. Yellow: indicates a loss occurred in the past.                                                                                                                                                                                  |
| COM             | grey/yellow/red                                                                     | Sample Loss - Red: present loss of sample data between the device and the host PC. Yellow: indicates a loss occurred in the past. A possible cause for sample loss may be the scope running in parallel.                                                                                                    |
| C               |  | Reset status flags: Clear the current state of the status flags                                                                                                                                                                                                                                             |
| MOD             | grey/green                                                                          | MOD - Green: indicates which of the modulation kits is enabled.                                                                                                                                                                                                                                             |
| PID             | grey/green                                                                          | PID - Green: indicates which of the PID units is enabled. Red: indicates PID unit is in PLL or ExtRef mode but is not locked. Yellow: indicates PID unit was not locked in the past.                                                                                                                        |
| PLL             | grey/green                                                                          | PLL - Green: indicates which of the PLLs is enabled.                                                                                                                                                                                                                                                        |
| Full Screen     |  | Toggles the browser between full screen and normal mode.                                                                                                                                                                                                                                                    |

## 5.2.2. Plot Functionality

Several tools provide a graphical display of measurement data in the form of plots. These are multi-functional tools with zooming, panning and cursor capability. This section introduces some of the highlights.

### Plot Area Elements

Plots consist of the plot area, the X range and the range controls. The X range (above the plot area) indicates which section of the wave is displayed by means of the blue zoom region indicators. The two ranges show the full scale of the plot which does not change when the plot area displays a zoomed view. The two axes of the plot area instead do change when zoom is applied.

The [mouse functionality](#) inside of a plot greatly simplifies and speeds up data viewing and navigation.

Table 5.5: Mouse functionality inside plots

| Name                       | Action                                     | Description                                      | Performed inside                                             |
|----------------------------|--------------------------------------------|--------------------------------------------------|--------------------------------------------------------------|
| Panning                    | left click on any location and move around | moves the waveforms                              | plot area                                                    |
| Zoom X axis                | mouse wheel                                | zooms in and out the X axis                      | plot area                                                    |
| Zoom Y axis                | shift + mouse wheel                        | zooms in and out the Y axis                      | plot area                                                    |
| Window zoom                | shift and left mouse area select           | selects the area of the waveform to be zoomed in | plot area                                                    |
| Absolute jump of zoom area | left mouse click                           | moves the blue zoom range indicators             | X and Y range, but outside of the blue zoom range indicators |
| Absolute move of zoom area | left mouse drag-and-drop                   | moves the blue zoom range indicators             | X and Y range, inside of the blue range indicators           |
| Full Scale                 | double click                               | set X and Y axis to full scale                   | plot area                                                    |










Each plot area contains a legend that lists all the shown signals in the respective color. The legend can be moved to any desired position by means of drag-and-drop.

The X range and Y range plot controls are described in [Table 5.6](#).

## Note

Plot data can be conveniently exported to other applications such as Excel or Matlab by using LabOne's Net Link functionality, see [Section 5.4.5](#) for more information.

Table 5.6: Plot control description

| Control/Tool         | Option/Range                                                                        | Description                                                                                                                                                                                                                                      |
|----------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Axis scaling mode    |  | Selects between automatic, full scale and manual axis scaling.                                                                                                                                                                                   |
| Axis mapping mode    |  | Select between linear, logarithmic and decibel axis mapping.                                                                                                                                                                                     |
| Axis zoom in         |  | Zooms the respective axis in by a factor of 2.                                                                                                                                                                                                   |
| Axis zoom out        |  | Zooms the respective axis out by a factor of 2.                                                                                                                                                                                                  |
| Rescale axis to data |  | Rescale the foreground Y axis in the selected zoom area.                                                                                                                                                                                         |
| Save figure          |  | Generates PNG, JPG or SVG of the plot area or areas for dual plots to the local download folder.                                                                                                                                                 |
| Save data            |  | Generates a CSV file consisting of the displayed wave or histogram data (when histogram math operation is enabled). Select full scale to save the complete wave. The save data function only saves one shot at a time (the last displayed wave). |
| Cursor control       |  | Cursors can be switch On/Off and set to be moved both independently or one bound to the other one.                                                                                                                                               |
| Net Link             |  | Provides a LabOne Net Link to use displayed wave data in tools like Excel, MATLAB, etc.                                                                                                                                                          |

## Cursors and Math

The plot area provides two X and two Y cursors which appear as dashed lines inside of the plot area. The four cursors are selected and moved by means of the blue handles individually by means of drag-and-drop. For each axis, there is a primary cursor indicating its absolute position and a secondary cursor indicating both absolute and relative position to the primary cursor.

Cursors have an absolute position which does not change upon pan or zoom events. In case a cursor position moves out of the plot area, the corresponding handle is displayed at the edge of the plot area. Unless the handle is moved, the cursor keeps the current position. This functionality is very effective to measure large deltas with high precision (as the absolute position of the other cursors does not move).









The cursor data can also be used to define the input data for the mathematical operations performed on plotted data. This functionality is available in the Math sub-tab of each tool. The [Table 5.7](#) gives an overview of all the elements and their functionality. The chosen Signals and Operations are applied to the currently active trace only.

### Note

Cursor data can be conveniently exported to other applications such as Excel or MATLAB by using LabOne's Net Link functionality, see [Section 5.4.5](#) for more information.

Table 5.7: Plot math description

| Control/Tool     | Option/Range                                      | Description                                                                                                                                                                                                                                                         |
|------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Source Select    |                                                   | Select from a list of input sources for math operations.                                                                                                                                                                                                            |
|                  | Cursor Loc                                        | Cursor coordinates as input data.                                                                                                                                                                                                                                   |
|                  | Cursor Area                                       | Consider all data of the active trace inside the rectangle defined by the cursor positions as input for statistical functions (Min, Max, Avg, Std).                                                                                                                 |
|                  | Tracking                                          | Display the value of the active trace at the position of the horizontal axis cursor X1 or X2.                                                                                                                                                                       |
|                  | Plot Area                                         | Consider all data of the active trace currently displayed in the plot as input for statistical functions (Min, Max, Avg, Std).                                                                                                                                      |
|                  | Peak                                              | Find positions and levels of up to 5 highest peaks in the data.                                                                                                                                                                                                     |
|                  | Trough                                            | Find positions and levels of up to 5 lowest troughs in the data.                                                                                                                                                                                                    |
|                  | Histogram                                         | Display a histogram of the active trace data within the x-axis range. The histogram is used as input to statistical functions (Avg, Std). Because of binning, the statistical functions typically yield different results than those under the selection Plot Area. |
|                  | Resonance                                         | Display a curve fitted to a resonance.                                                                                                                                                                                                                              |
|                  | Linear Fit                                        | Display a linear regression curve.                                                                                                                                                                                                                                  |
| Operation Select |                                                   | Select from a list of mathematical operations to be performed on the selected source. Choice offered depends on the selected source.                                                                                                                                |
|                  | Cursor Loc: X1, X2, X2-X1, Y1, Y2, Y2-Y1, Y2 / Y1 | Cursors positions, their difference and ratio.                                                                                                                                                                                                                      |
|                  | Cursor Area: Min, Max, Avg, Std                   | Minimum, maximum value, average, and bias-corrected sample standard deviation for all samples between cursor X1 and X2. All values are shown in the plot as well.                                                                                                   |
|                  | Tracking: Y(X1), Y(X2), ratioY, deltaY            | Trace value at cursor positions X1 and X2, the ratio between these two Y values and their difference.                                                                                                                                                               |
|                  | Plot Area: Min, Max, Pk Pk, Avg, Std              | Minimum, maximum value, difference between min and max, average, and bias-corrected sample standard deviation for all samples in the x axis range.                                                                                                                  |

| Control/Tool   | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                | Peak: Pos, Level                                                                    | Position and level of the peak, starting with the highest one. The values are also shown in the plot to identify the peak.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                | Histogram: Avg, Std, Bin Size, (Plotter tab only: SNR, Norm Fit, Rice Fit)          | A histogram is generated from all samples within the x-axis range. The bin size is given by the resolution of the screen: 1 pixel = 1 bin. From this histogram, the average and bias-corrected sample standard deviation is calculated, essentially assuming all data points in a bin lie in the center of their respective bin. When used in the plotter tab with demodulator or boxcar signals, there additionally are the options of SNR estimation and fitting statistical distributions to the histogram (normal and rice distribution).                                                                                           |
|                | Resonance: Q, BW, Center, Amp, Phase, Fit Error                                     | A curve is fitted to a resonator. The fit boundaries are determined by the two cursors X1 and X2. Depending on the type of trace (Demod R or Demod Phase) either a Lorentzian or an inverse tangent function is fitted to the trace. The Q is the quality factor of the fitted curve. BW is the 3dB bandwidth (FWHM) of the fitted curve. Center is the center frequency. Amp gives the amplitude (Demod R only), whereas Phase returns the phase at the center frequency of the resonance (demod Phase only). The fit error is given by the normalized root-mean-square deviation. It is normalized by the range of the measured data. |
|                | Linear Fit: Intercept, Slope, R <sup>2</sup>                                        | A simple linear least squares regression is performed using a QR decomposition routine. The fit boundaries are determined by the two cursors X1 and X2. The parameter outputs are the Y-axis intercept, slope and the R <sup>2</sup> -value, which is the coefficient of determination to determine the goodness-of-fit.                                                                                                                                                                                                                                                                                                                |
| Add            |    | Add the selected math function to the result table below.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Add All        |   | Add all operations for the selected signal to the result table below.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Clear Selected |  | Clear selected lines from the result table above.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Clear All      |  | Clear all lines from the result table above.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Copy           |  | Copy selected row(s) to Clipboard as CSV                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Unit Prefix    |                                                                                     | Adds a suitable prefix to the SI units to allow for better readability and increase of significant digits displayed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| CSV            |  | Values of the current result table are saved as a text file into the download folder.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Net Link       |  | Provides a LabOne Net Link to use the data in tools like Excel, MATLAB, etc.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Help           |  | Opens the LabOne User Interface help.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

## Note

The standard deviation is calculated using the formula  $\sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2}$  for the unbiased estimator of the sample standard deviation with a total of N samples  $x_i$  and an arithmetic average  $\bar{x}$ . The formula above is used as-is to calculate the standard deviation for the Histogram Plot Math tool. For large number of points (Cursor Area and Plot Area tools), the more accurate pairwise algorithm is used (Chan et al., "Algorithms for Computing the Sample Variance: Analysis and Recommendations", The American Statistician 37 (1983), 242-247).



## Note

The fitting functions used in the Resonance Plot Math tool depend on the selected signal source. The demodulator R signal is fitted with the following function:


$$R(f) = C + A \frac{f}{\sqrt{f^2 + \left(\frac{Q}{f_0}\right)^2 (f^2 - f_0^2)^2}} \quad (1)$$

where **C** accounts for a possible offset in the output, **A** is the amplitude, **Q** is the quality factor and  $f_0$  is the center frequency. The demodulator  $\phi$  signal is fitted with the following function:

$$\phi(f) = \tan^{-1} \left( Q \frac{1 - \left(\frac{f}{f_0}\right)^2}{\frac{f}{f_0}} \right) \quad (2)$$

using the same parameters as above.

## Tree Selector

The Tree selector allows one to access streamed measurement data in a hierarchical structure by checking the boxes of the signals that should be displayed. The tree selector also supports data selection from multiple instruments, where available. Depending on the tool, the Tree selector is either displayed in a separate Tree sub-tab, or it is accessible by a click on the  button.

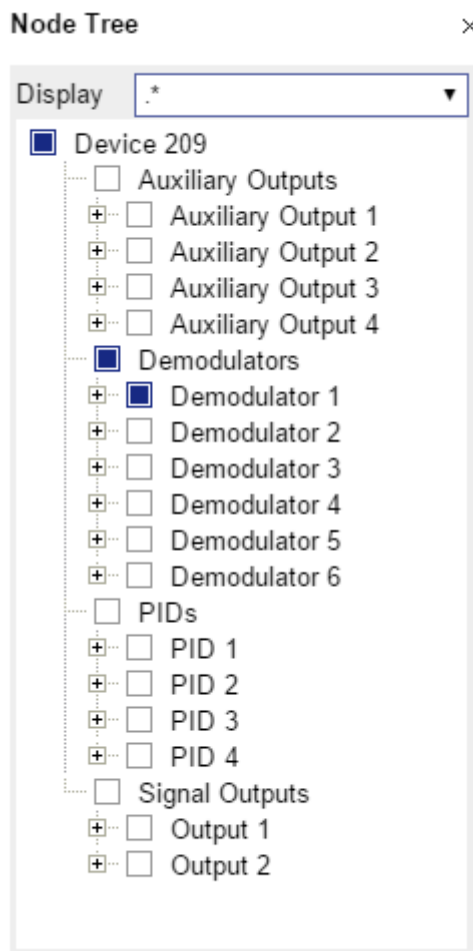


Figure 5.3: Tree selector with Display drop-down menu



## Vertical Axis Groups

Vertical Axis groups are available as part of the plot functionality in many of the LabOne tools. Their purpose is to handle signals with different axis properties within the same plot. Signals with different units naturally have independent vertical scales even if they are displayed in the same plot. However, signals with the same unit should preferably share one scaling to enable quantitative comparison. To this end, the signals are assigned to specific axis group. Each axis group has its own axis system. This default behavior can be changed by moving one or more signals into a new group.

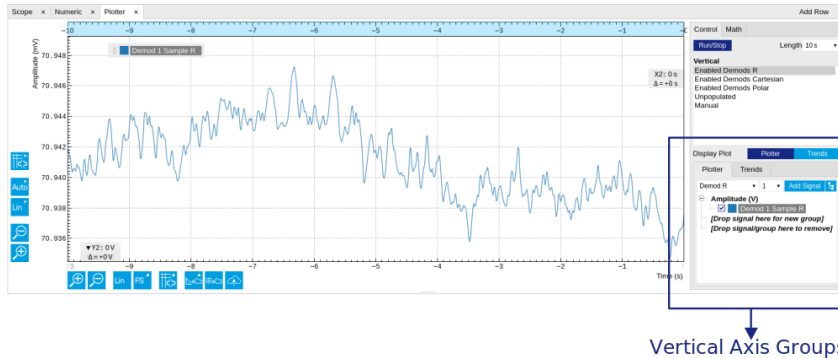


Figure 5.4: Vertical Axis Group in Plotter tool

The tick labels of only one axis group can be shown at once. This is the foreground axis group. To define the foreground group click on one of the group names in the Vertical Axis Groups box. The current foreground group gets a high contrast color.

### Select foreground group

Click on a signal name or group name inside the Vertical Axis Groups. If a group is empty the selection is not performed.

### Split the default vertical axis group

Use drag-and-drop to move one signal on the field [Drop signal here to add a new group]. This signal will now have its own axis system.

### Change vertical axis group of a signal

Use drag-and-drop to move a signal from one group into another group that has the same unit.

### Group separation

In case a group hosts multiple signals and the unit of some of these signals changes, the group will be split in several groups according to the different new units.

### Remove a signal from the group

In order to remove a signal from a group drag-and-drop the signal to a place outside of the Vertical Axis Groups box.

### Remove a vertical axis group

A group is removed as soon as the last signal of a custom group is removed. Default groups will remain active until they are explicitly removed by drag-and-drop. If a new signal is added that match the group properties it will be added again to this default group. This ensures that settings of default groups are not lost, unless explicitly removed.

### Rename a vertical axis group

New groups get a default name "Group of ...". This name can be changed by double-clicking on the group name.

### Hide/show a signal

Uncheck/check the check box of the signal. This is faster than fetching a signal from a tree again.

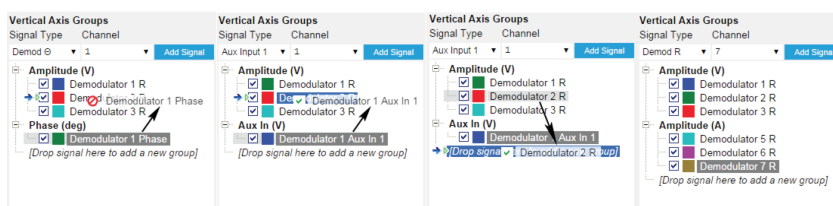


Figure 5.5: Vertical Axis Group typical drag and drop moves.

Table 5.8: Vertical Axis Groups description

| Control/Tool        | Option/Range         | Description                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Vertical Axis Group |                      | Manages signal groups sharing a common vertical axis. Show or hide signals by changing the check box state. Split a group by dropping signals to the field [Drop signal here to add new group]. Remove signals by dragging them on a free area.<br><br>Rename group names by editing the group label. Axis tick labels of the selected group are shown in the plot. Cursor elements of the active wave (selected) are added in the cursor math tab. |
| Signal Type         | HW Trigger           | Select signal types for the Vertical Axis Group.                                                                                                                                                                                                                                                                                                                                                                                                    |
|                     | Demod X, Y, R, Theta |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                     | Frequency            |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                     | Aux Input 1, 2       |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Channel             | integer value        | Selects a channel to be added.                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Signal              | integer value        | Selects signal to be added.                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Add Signal          | <b>Add Signal</b>    | Adds a signal to the plot. The signal will be added to its default group. It may be moved by drag and drop to its own group. All signals within a group share a common y-axis. Select a group to bring its axis to the foreground and display its labels.                                                                                                                                                                                           |
| Window Length       | 2 s to 12 h          | Window memory depth. Values larger than 10 s may cause excessive memory consumption for signals with high sampling rates. Auto scale or pan causes a refresh of the display for which only data within the defined window length are considered.                                                                                                                                                                                                    |

## Trends

The Trends tool lets the user monitor the temporal evolution of signal features such as minimum and maximum values, or mean and standard deviation. This feature is available for the Scope, Spectrum, Plotter, and DAQ tab. Using the Trends feature, one can monitor all the parameters obtained in the [Math sub-tab](#) of the corresponding tab.

The Trends tool allows the user to analyze recorded data on a different and adjustable time scale much longer than the fast acquisition of measured signals. It saves time by avoiding post-processing of recorded signals and it facilitates fine-tuning of experimental parameters as it extracts and shows the measurement outcome in real time.

To activate the Trends plot, enable the Trends button in the Control sub-tab of the corresponding main tab. Various signal features can be added to the plot from the Trends sub-tab in the [Vertical Axis Groups](#). The vertical axis group of Trends has its own Run/Stop button and Length setting independent from the main plot of the tab. Since the Math quantities are derived from the raw signals in the main plot, the Trends plot is only shown together with the main plot. The Trends feature is only available in the LabOne user interface and not at the API level.

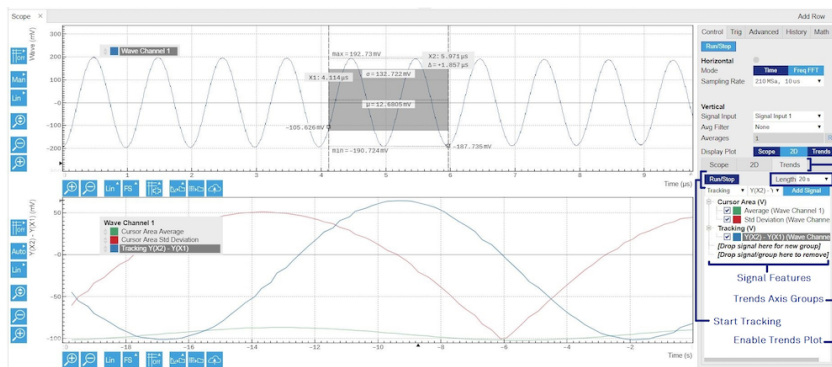


Figure 5.6: Top: main plot of the Scope tab showing the signal trace. Bottom: corresponding Trends plot tracking an average, standard deviation, and difference signal derived from the cursor positions in the main plot.

## 5.3. Saving and Loading Data



## 5.4. Overview

In this section we discuss how to save and record measurement data with the HF2 Series Instrument using the LabOne user interface. In the LabOne user interface, there are 3 ways to save data:

- Saving the data that is currently displayed in a plot
- Continuously recording data in the background
- Saving trace data in the History sub-tab

Furthermore, the History sub-tab supports loading data. In the following, we will explain these methods.


### 5.4.1. Saving Data from Plots

A quick way to save data from any plot is to click on the Save CSV icon  at the bottom of the plot to store the currently displayed curves as a comma-separated value (CSV) file to the download folder of your web browser. Clicking on  will save a graphics file instead.

### 5.4.2. Recording Data

The recording functionality allows you to store measurement data continuously, as well as to track instrument settings over time. The [Config Tab](#) gives you access to the main settings for this function. The Format selector defines which format is used: HDF5, CSV, or MATLAB. The CSV delimiter character can be changed in the User Preferences section. The default option is Semicolon.

The node tree display of the Record Data section allows you to browse through the different measurement data and instrument settings, and to select the ones you would like to record. For instance, the demodulator 1 measurement data is accessible under the path of the form **Device 0000/Demodulators/Demod 1/Sample**. An example for an instrument setting would be the filter time constant, accessible under the path **Device 0000/Demodulators/Demod 1/Filter Time Constant**.

The default storage location is the LabOne Data folder which can, for instance, be accessed by the Open Folder button . The exact path is displayed in the Folder field whenever a file has been written.

Clicking on the Record checkbox will initiate the recording to the hard drive. In case of demodulator and boxcar data, ensure that the corresponding data stream is enabled, as otherwise no data will be saved.

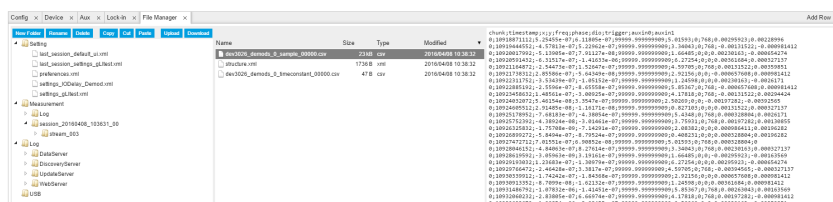


Figure 5.7: Browsing and inspecting files in the LabOne File Manager tab



In case HDF5 or MATLAB is selected as the file format, LabOne creates a single file containing the data for all selected nodes. For the CSV format, at least one file for each of the selected nodes is created from the start. At a configurable time interval, new data files are created, but the maximum size is capped at about 1 GB for easier data handling. The storage location is indicated in the Folder field of the Record Data section.

The [File Manager Tab](#) is a good place to inspect CSV data files. The file browser on the left of the tab allows you to navigate to the location of the data files and offers functionalities for managing files in the LabOne Data folder structure. In addition, you can conveniently transfer files between the folder structure and your preferred location using the Upload/Download buttons. The file viewer on the right side of the tab displays the contents of text files up to a certain size limit. [Figure 5.7](#) shows the Files tab after recording Demodulator Sample and Filter Time Constant for a few seconds. The file viewer shows the contents of the demodulator data file.

## Note

The structure of files containing instrument settings and of those containing streamed data is the same. Streaming data files contain one line per sampling period, whereas in the case of instrument settings, the file usually only contains a few lines, one for each change in the settings. More information on the file structure can be found in the LabOne Programming Manual.

### 5.4.3. History List

Tabs with a history list such as [Sweeper Tab](#), [Data Acquisition Tab](#), [Scope Tab](#), [Spectrum Analyzer Tab](#) support feature saving, autosaving, and loading functionality. By default, the plot area in those tools displays the last 100 measurements (depending on the tool, these can be sweep traces, scope shots, DAQ data sets, or spectra), and each measurement is represented as an entry in the History sub-tab. The button to the left of each list entry controls the visibility of the corresponding trace in the plot; the button to the right controls the color of the trace.<sup>1</sup> Double-clicking on a list entry allows you to rename it. All measurements in the history list can be saved with **Save All**. Clicking on the **Save Sel** button (note the dropdown button ) saves only those traces that were selected by a mouse click. Use the Control or Shift button together with a mouse click to select multiple traces. The file location can be accessed by the Open Folder button . Figure 5.10.8 illustrates some of these features. Figure 5.8 illustrates the data loading feature.

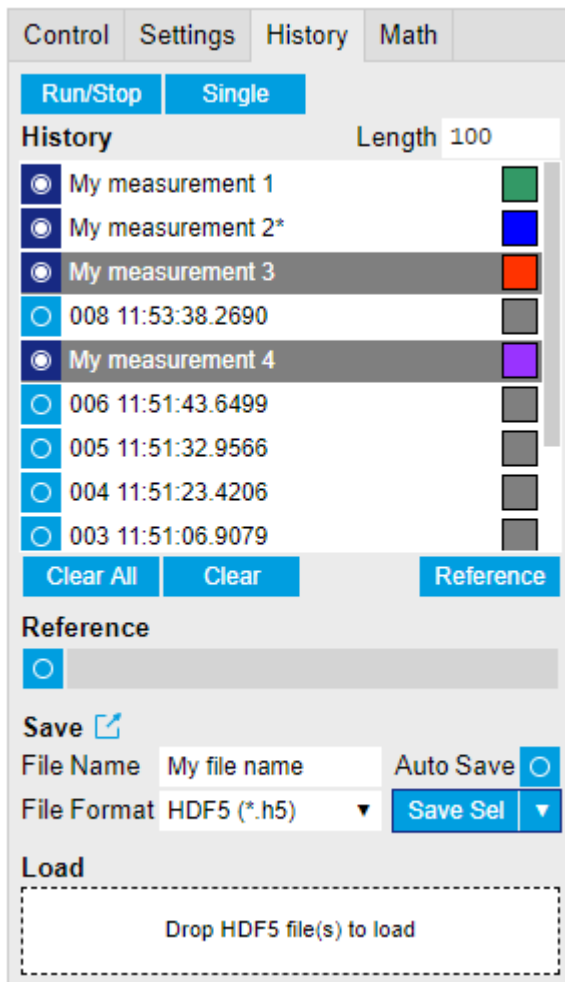


Figure 5.8: History sub-tab features. The entries "My measurement 1" etc. were renamed by the user. Measurement 1, 2, 3, 4 are currently displayed in the plot because their left-hand-side button is enabled. Clicking on Save Sel would save "My measurement 3" and "My measurement 4" to a file, because these entries were selected (gray overlay) by a Control key + mouse click action.

Which quantities are saved depends on which signals have been added to the Vertical Axis Groups section in the **Control** sub-tab. Only data from demodulators with enabled Data Transfer in the Lock-in tab can be included in the files.

The history sub-tab supports an **autosave** functionality to store measurement results continuously while the tool is running. Autosave directories are differentiated from normal saved directories by the text "autosave" in the name, e.g. sweep\_autosave\_000. When running a tool continuously (**Run/Stop** button) with Autosave activated, after the current measurement (history entry) is complete, all measurements in the history are saved. The same file is overwritten each time, which means that old measurements will be lost once the limit defined by the history Length setting has been reached. When performing single measurements (**Single** button) with Autosave activated, after each measurement, the elements in the history list are saved in a new directory with an incrementing count, e.g. **sweep\_autosave\_001**, **sweep\_autosave\_002**.

Data which was saved in HDF5 file format can be loaded back into the history list. Loaded traces are marked by a prefix "loaded " that is added to the history entry name in the user interface. The **createdtimestamp** information in the header data marks the time at which the data were measured.

- Only files created by the Save button in the History sub-tab can be loaded.
- Loading a file will add all history items saved in the file to the history list. Previous entries are kept in the list.
- Data from the file is only displayed in the plot if it matches the current settings in the Vertical Axis Group section the tool. Loading e.g. PID data in the Sweeper will not be shown, unless it is selected in the Control sub-tab.
- Files can only be loaded if the devices saving and loading data are of the same product family. The data path will be set according to the device ID loading the data.

Figure 5.9 illustrates the data loading feature.

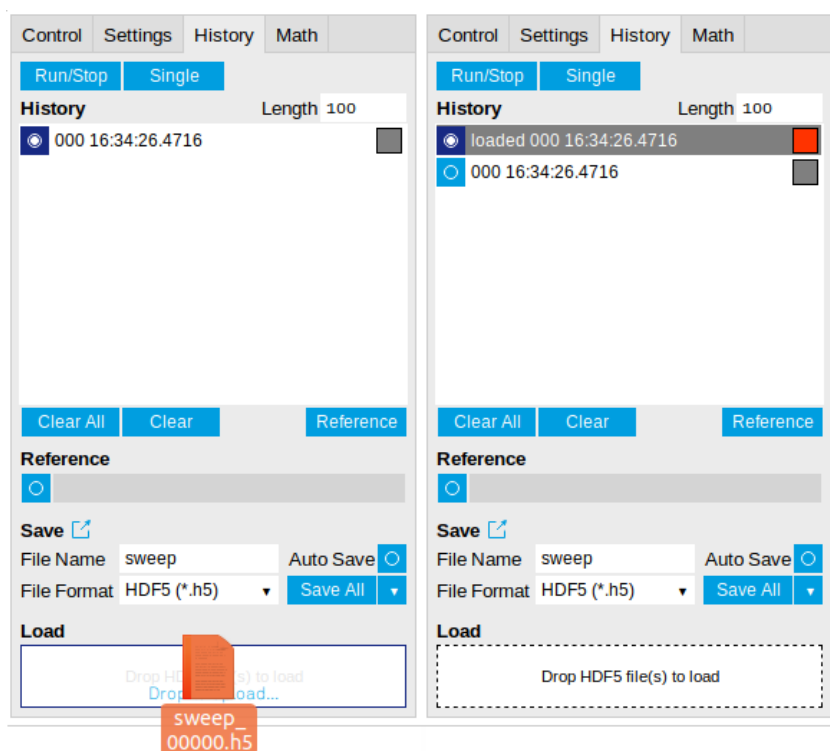


Figure 5.9: History data loading feature. Here, the file sweep\_00000.h5 is loaded by drag-and-drop. The loaded data are added to the measurements in the history list.

#### 5.4.4. Supported File Formats

##### HDF5

Hierarchical Data File 5 (HDF5) is a widespread memory-efficient, structured, binary, open file format. Data in this format can be inspected using the dedicated viewer [HDFview](#). HDF5 libraries or import tools are available for Python, MATLAB, LabVIEW, C, R, Octave, Origin, Igor Pro, and others. The following example illustrates how to access demodulator data from a sweep using the h5py library in Python:

```
import h5py
filename = 'sweep_00000.h5'
```

```
f = h5py.File(filename, 'r')
x = f['000/dev3025/demods/0/sample/frequency']
```

The data loading feature of LabOne supports HDF5 files, while it is unavailable for other formats.

## MATLAB

The MATLAB File Format (.mat) is a proprietary file format from MathWorks based on the open HDF5 file format. It has thus similar properties as the HDF5 format, but the support for importing .mat files into third-party software other than MATLAB is usually less good than that for importing HDF5 files.

## SXM

SXM is a proprietary file format by Nanonis used for SPM measurements.

### 5.4.5. LabOne Net Link

Measurement and cursor data can be downloaded from the browser as CSV data. This allows for further processing in any application that supports CSV file formats. As the data is stored internally on the web server it can be read by direct server access from other applications. Most up-to-date software supports data import from web pages or CSV files over the internet. This allows for automatic import and refresh of data sets in many applications. To perform the import the application needs to know the address from where to load the data. This link is supplied by the LabOne User Interface. The following chapter lists examples of how to import data into some commonly used applications.

The CSV data sent to the application is a snap-shot of the data set on the web server at the time of the request. Many applications support either manual or periodic refresh functionality.

Since tabs can be instantiated several times within the same user interface, the link is specific to the tab that it is taken from. Changing the session on the LabOne User Interface or removing tabs may invalidate the link.

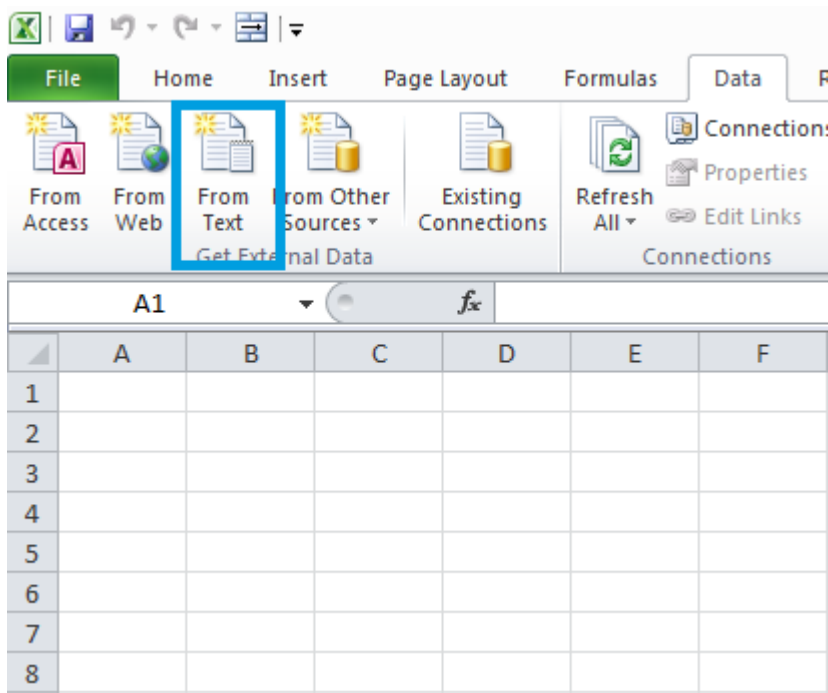
Supported applications:

- [Excel](#)
- [MATLAB](#)
- [Python](#)
- [C#.NET](#)
- [Igor Pro](#)
- [Origin](#)

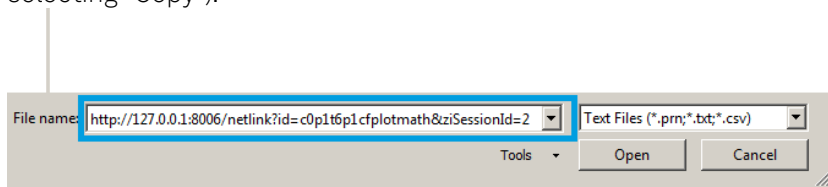
## Excel

These instructions are for Excel 2010 (English). The procedure for other versions may differ.

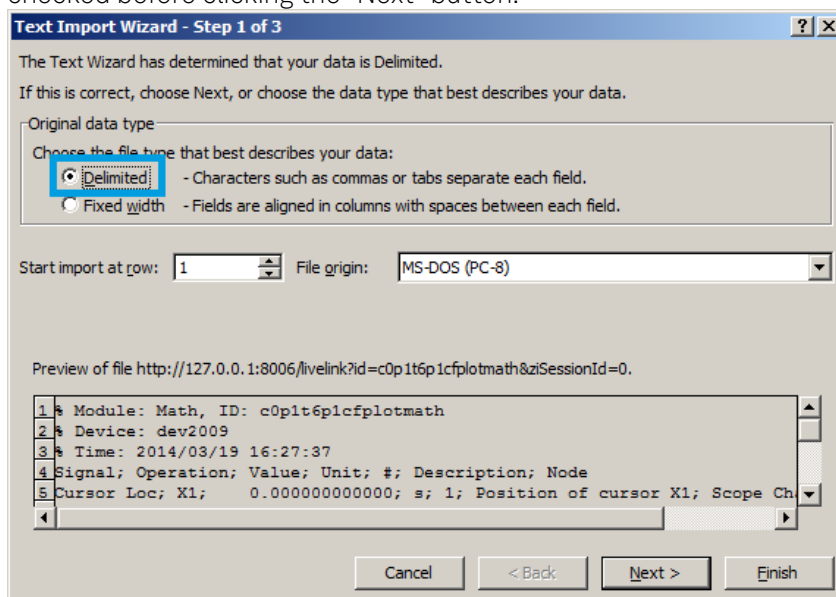
1. In Excel, click on the cell where the data is to be placed. From the Data ribbon, click the "From Text" icon. The "Import Text File" dialog will appear.



2. In LabOne, click the "Link" button of the appropriate Math tab. Copy the selected text from the "LabOne Net Link" dialog to the clipboard (either with Ctrl-C or by right clicking and selecting "Copy").

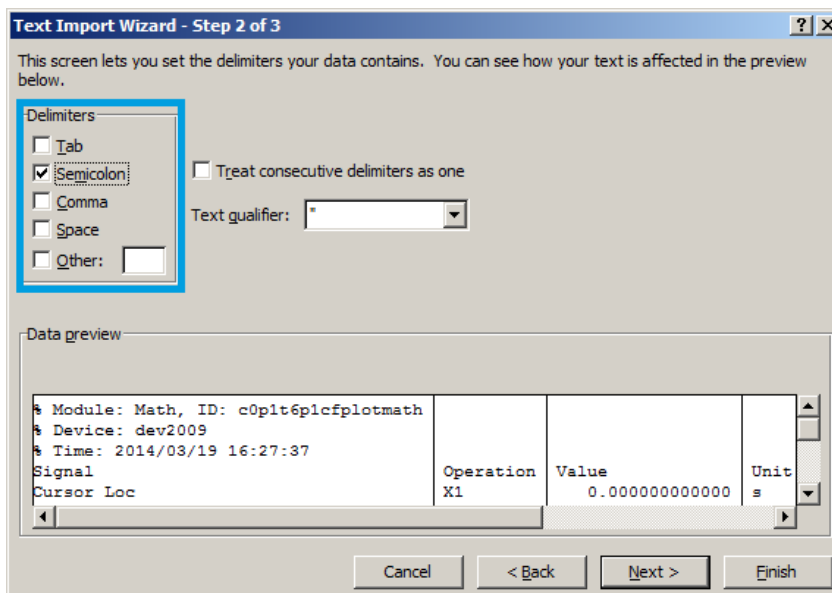


3. In Excel, paste the link into the "File name" entry field of the "Import Text File" dialog and click the "Open" button. This will start the text import wizard. Ensure that the "Delimited" button is checked before clicking the "Next" button.

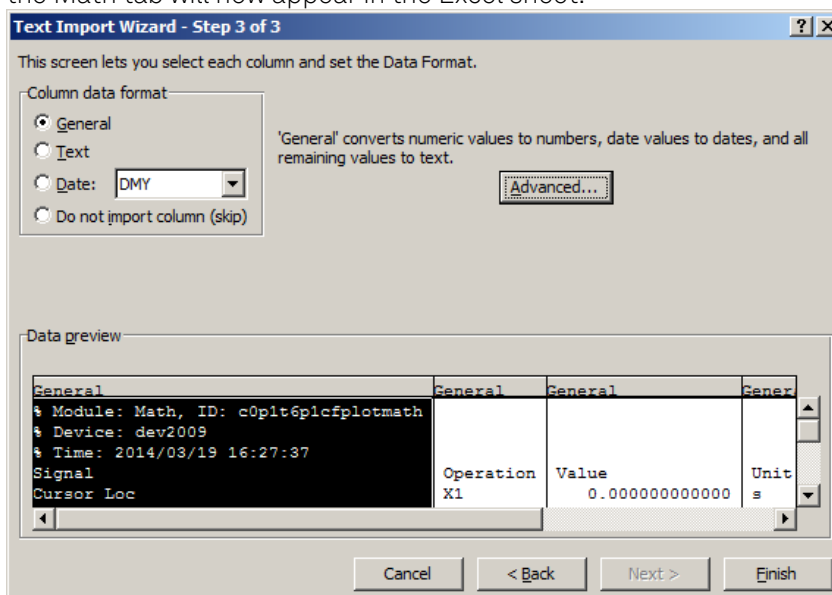


4. In the next dialog, select the delimiter character corresponding to that selected in LabOne (this can be found in the "Sessions" section of the Config tab). The default is semicolon. Click the "Next" button.

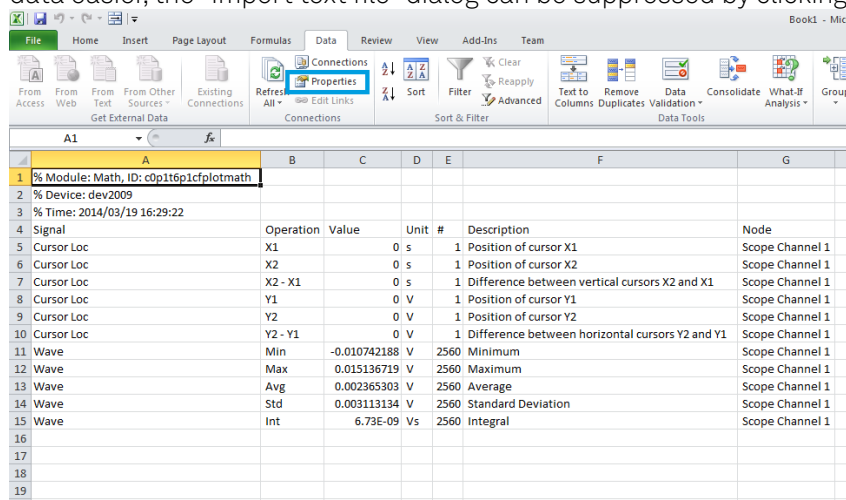




5. In the next dialog, click on "Finish" and then "OK" in the "Import Data" dialog. The data from the Math tab will now appear in the Excel sheet.

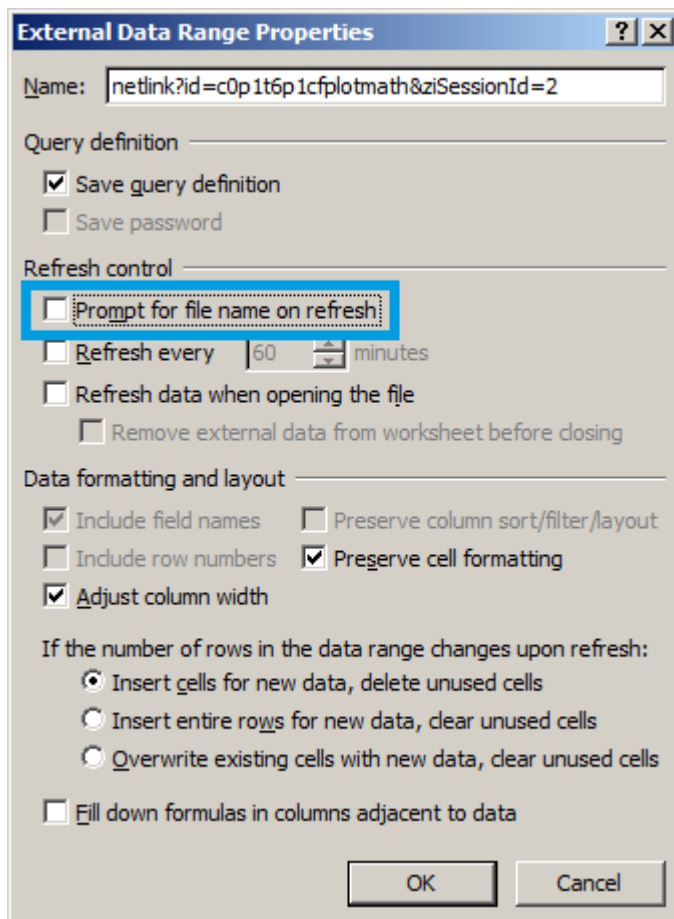


6. The data in the sheet can be updated by clicking the "Refresh All" icon. To make updating the data easier, the "Import text file" dialog can be suppressed by clicking on "Properties".



7. Deactivate the check box "Prompt for file name on refresh".





## MATLAB

By copying the link text from the "LabOne Net Link" dialog to the clipboard, the following code snippet can be used in MATLAB to read the data.

```
textscan(urlread(clipboard('paste')), '%s%f%s%d%s', 'Headerlines',
4, 'Delimiter', ';')
```

## Python

The following code snippet can be used in Python 2 to read the LabOne Net Link data, where "url" is assigned to the text copied from the "LabOne Net Link" dialog.

```
import csv
import urllib2
url = "http://127.0.0.1:8006/netlink?id=c0p5t6p1cfplotmath&ziSessionId=0"
webpage = urllib2.urlopen(url)
datareader = csv.reader(webpage)
data = []
for row in datareader:
 data.append(row)
```

## C#.NET

The .NET Framework offers a WebClient object which can be used to send web requests to the LabOne WebServer and download LabOne Net Link data. The string with comma separated content can be parsed by splitting the data at comma borders.

```

using System;
using System.Text;
using System.Net;

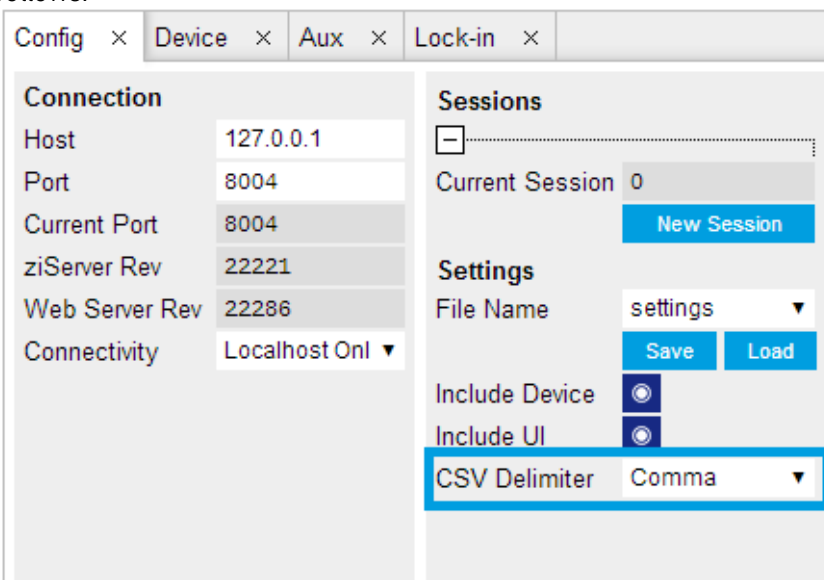
namespace ExampleCSV
{
 class Program
 {
 static void Main(string[] args)
 {
 try
 {
 WebClient wc = new WebClient();
 byte[] buffer = wc.DownloadData("http://127.0.0.1:8006/netlink?
id=c0p1t6p1cfplotmath&ziSessionId=0");
 String doc = Encoding.ASCII.GetString(buffer);
 // Parse here CSV lines and extract data
 // ...
 Console.WriteLine(doc);
 } catch (Exception e) {
 Console.WriteLine("Caught exception: " + e.Message);
 }
 }
 }
}

```

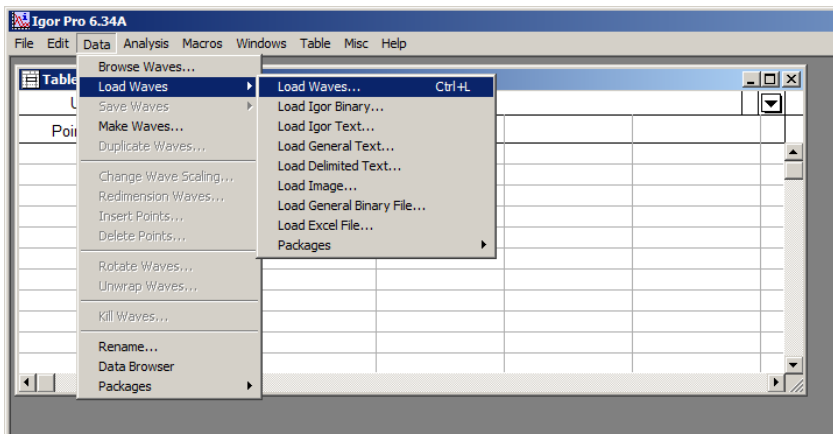
## Igor Pro

These instructions are for Igor Pro 6.34A English. The procedure for other versions may differ.

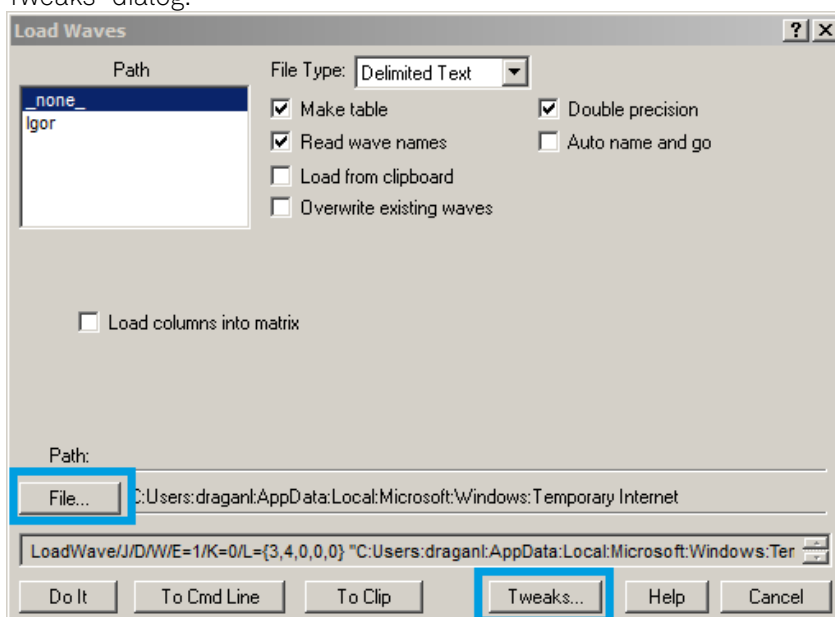
1. For Igor Pro, the CSV separator has to be the comma. Set this in the LabOne Config tab as follows:



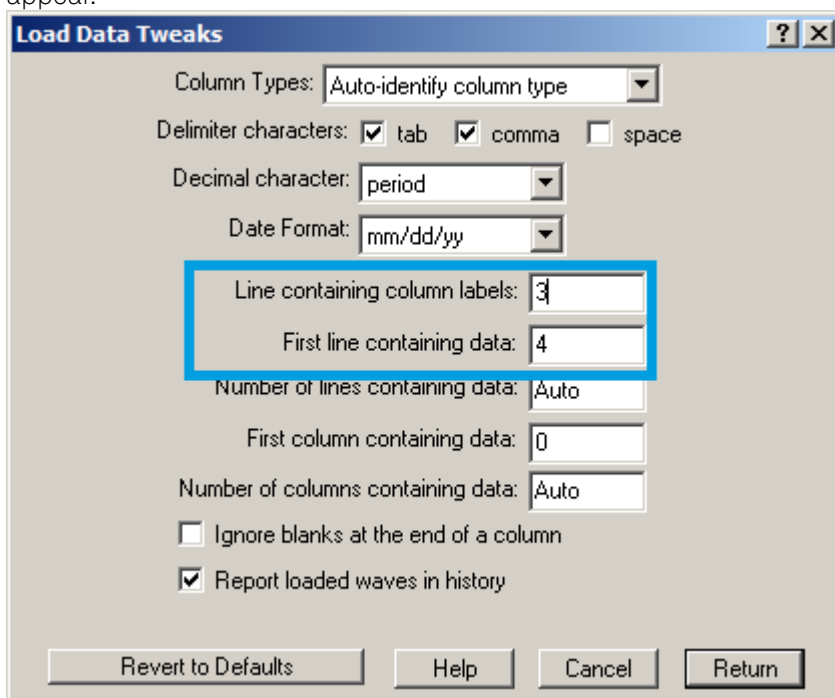
2. In Igor Pro, select the menu "Data→Load Waves→Load Waves...".



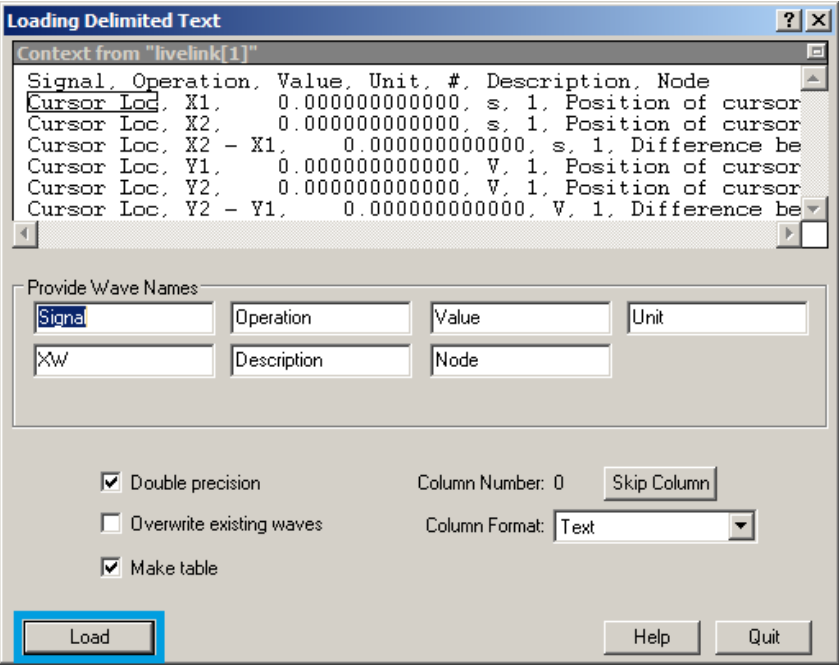
3. In the "Load Waves" dialog, click the "File..." button and paste the link text from the "LabOne Net Link" dialog into the entry field. Then click the "Tweaks..." button to open the "Load Data Tweaks" dialog.



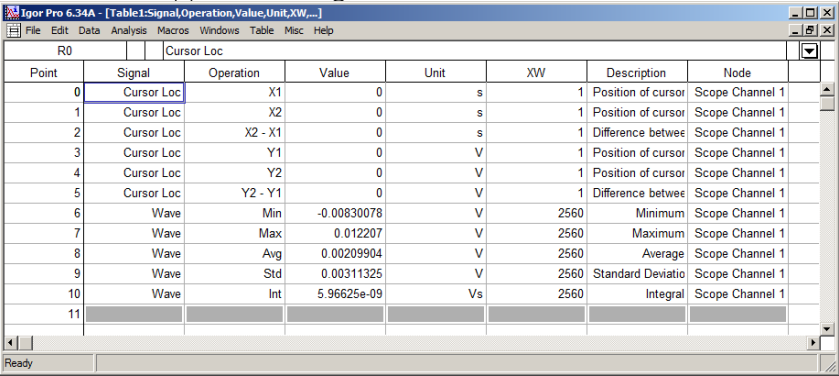
4. Adjust values as highlighted below and click "Return". The "Loading Delimited Data" dialog will appear.



5. Click the "Load" button to read the data.



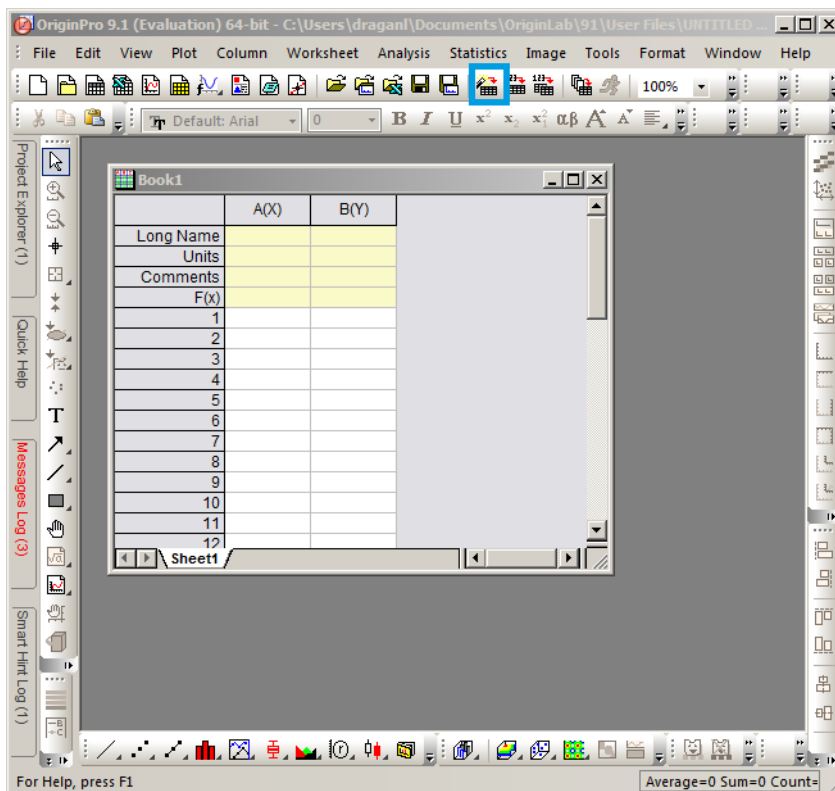
6. The data will appear in the Igor Pro main window.



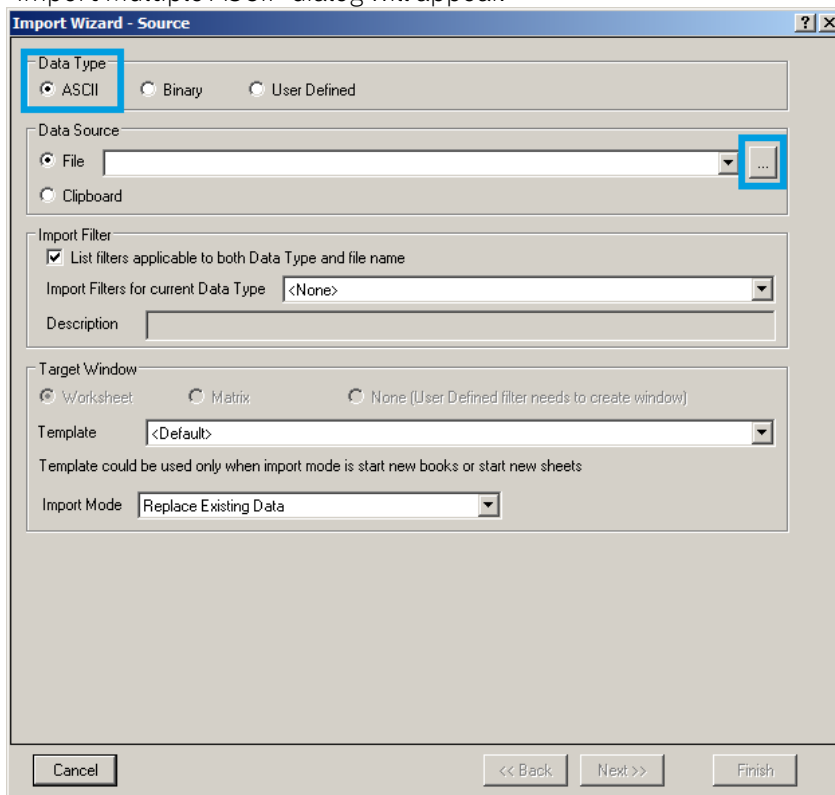
## Origin

These instructions are for Origin 9.1 English. The procedure for other versions may differ.

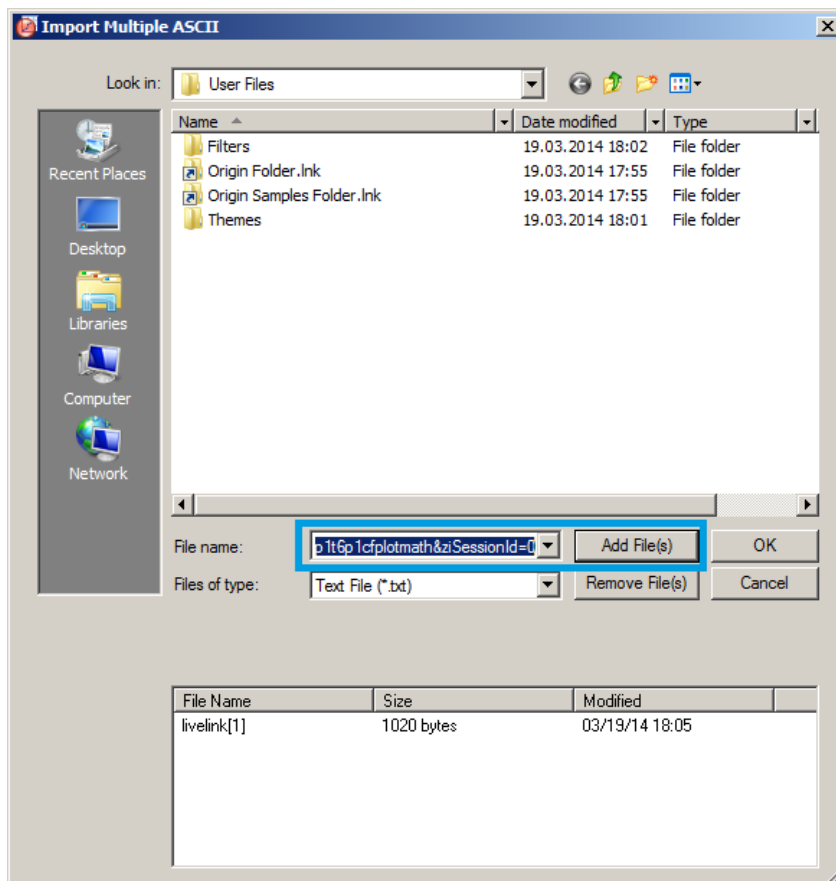
1. Open the import wizard by clicking on the icon highlighted below.



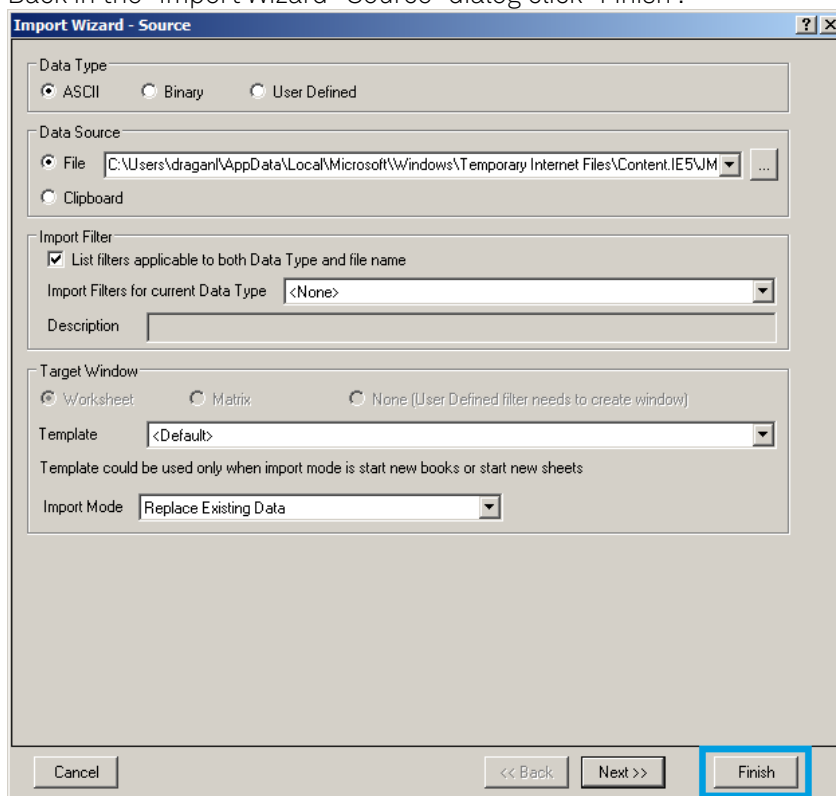
2. Ensure that the ASCII button is selected. Click the "..." button. See screenshot below. The "Import Multiple ASCII" dialog will appear.



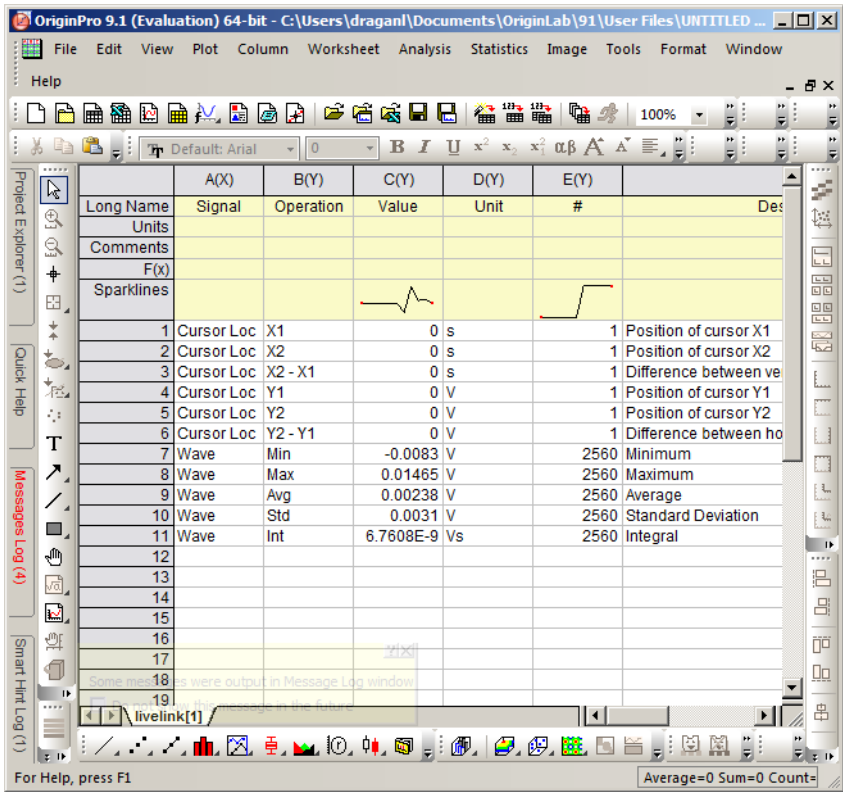
3. Paste the link text from the "LabOne Net Link" dialog into the entry field highlighted below. Then click "Add File(s)" followed by "OK".



4. Back in the "Import Wizard - Source" dialog click "Finish".



5. The data will appear in the Origin main window.



1. Among the mentioned tools, the Scope is exceptional: it displays the most recent acquisition, and its display color is fixed. However, the Persistence feature represents a more specialized functionality for multi-trace display. ↩

## 5.5. Lock-in Tab

This tab is the main lock-in amplifier control panel. Users with instruments with HF2-MF Multi-frequency option installed are kindly referred to [Lock-in Tab \(HF2-MF option\)](#)

### 5.5.1. Features

- Functional block diagram with access to main input, output and demodulator controls
- Parameter table with main input, output and demodulator controls
- Control elements for 6 configurable demodulators
- Auto ranging, scaling, arbitrary input units for both input channels
- Control for 2 oscillators
- Settings for main signal inputs and signal outputs
- Flexible choice of reference source, trigger options and data transfer rates

### 5.5.2. Description

The Lock-in tab is the main control center of the instrument and open after start up by default. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.9: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                                                          |
|--------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Lock-in      |  | Quick overview and access to all the settings and properties for signal generation and demodulation. |

The default view of the Lock-in tab is the parameter table view. It is accessible under the side tab labeled All and provides controls for all demodulators in the instrument. Moreover, for each

individual demodulator there is a functional block diagram available. It is accessible under the side tab labeled with the corresponding demodulator number.

## Parameter Table

The parameter table (see [Figure 5.10](#)) consists of 4 vertical sections: Signal Inputs, Oscillators, Demodulators and Signal Outputs. The Demodulators section gives access to all the settings of demodulators 1 to 6 that can be used for measurement, and of demodulators 7 and 8 that can be used for external referencing. Demodulators 1 to 3 (4 to 6) are connected to Signal Input 1 (2).

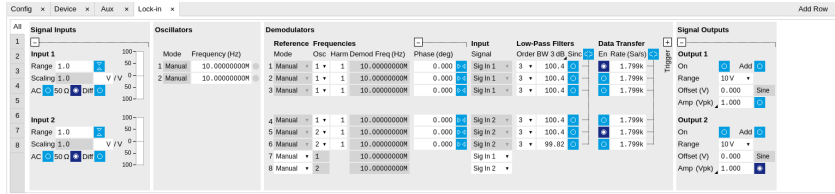


Figure 5.10: LabOne User Interface Lock-in tab - Parameter table (All)

The **Signal Inputs** section allows the user to define all relevant settings specific to the signal entered as for example input coupling, range, etc. Some of the available options like phase adjustment and the trigger functionality are collapsed by default. It takes one mouse click on the "+" icon in order to expand those controls. On the right-hand side of the Lock-in tab the Signal Outputs section allows defining signal amplitudes, offsets and range values.

Below the Scaling field there is the AC/DC button and the 50  $\Omega$  / 1 M $\Omega$  . The AC/DC button sets the coupling type: AC coupling has a high-pass cutoff frequency that can be used to block large DC signal components to prevent input signal saturation during amplification. The 50  $\Omega$  / 1 M $\Omega$  button toggles the input impedance between low (50  $\Omega$ ) and high (approx. 1 M $\Omega$ ) input impedance. With 50  $\Omega$  input impedance, one will expect a reduction of a factor of 2 in the measured signal if the signal source also has an output impedance of 50  $\Omega$ . Next to the 50  $\Omega$  button, there is the Diff button which switches the Signal Input between a single-ended measurement on the + Input and a differential measurement on the + and - Inputs.

The **Oscillator** section indicates the frequencies of both internal oscillators . Where the Mode indicator shows Manual, the user can define the oscillator frequency manually defined by typing a frequency value in the field. In case the oscillator is referenced to an external source, the Mode indicator will show ExtRef and the frequency field is set to read-only. External reference requires a PLL to do the frequency mapping onto an internal oscillator. Successful locking is indicated by a green light right next to the frequency field. When the Modulation unit or the PID controller determine the frequency value of an oscillator, MOD or PID are indicated in the Mode field and the user cannot change the frequency manually.

In the following, we discuss the **Demodulators settings** in more detail. The block diagram displayed in [Figure 5.11](#) indicates the main demodulator components and their interconnection. The understanding of the wiring is essential for successfully operating the instrument.



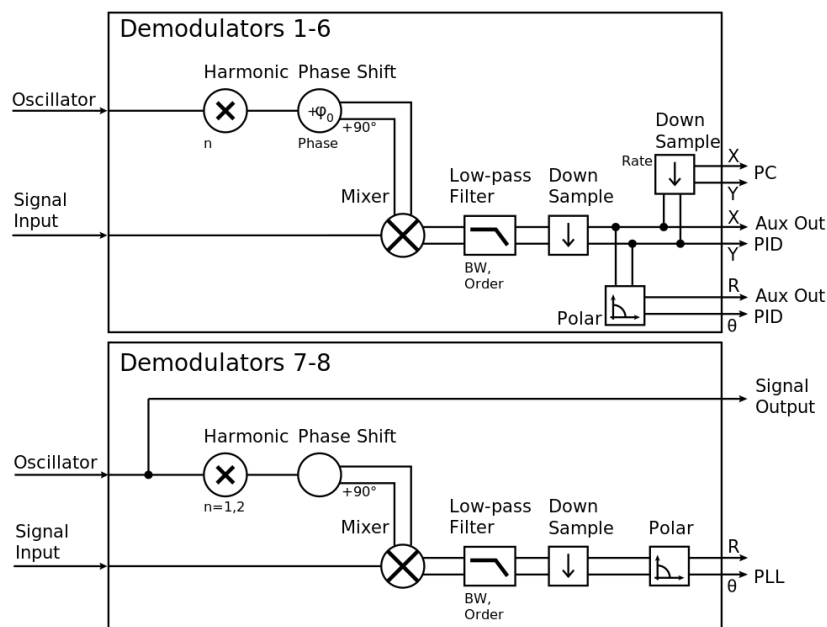


Figure 5.11: Demodulator block diagram without HF2-MF Multi-frequency option.

The first 6 lines in the Demodulators section represent the demodulators available for measurements. The Mode column is read-only set to internal reference (Demod). The 7th and 8th line represent a additional demodulators that are reserved for the exclusive use as phase detectors when the mode is switched to external reference (ExtRef). In ExtRef mode, the user can select from a number of different inputs to be used as external reference signal. However, the demodulators 7 and 8 do not produce any output data that could be used for measurements. In the Input Signal column one selects the signal that is taken as input for a given demodulator among the two Signal Inputs. For each demodulator an additional phase shift can be introduced to the associated oscillator by entering the phase offset in the Phase column. This phase is added both to the reference channel and to the output of the demodulator. Hence, when the frequency is generated and detected using the same demodulator, signal phase and reference phase change by the same amount and no change will be visible in the demodulation result. Demodulation of frequencies that are integer multiples of any of the oscillator frequencies is achieved by entering the desired factor in the Harm column. The result of the demodulation, i.e. the amplitude and phase can be read e.g. using the Numeric tab which is described in [Numeric Tab](#).

In the middle of the Lock-in tab is the Low-Pass Filters section where the filter order can be selected in the drop-down list for each demodulator and the filter bandwidth (BW 3dB) can be chosen by typing a numerical value. Alternatively, the time constant of the filter (TC) or the noise equivalent power filter bandwidth (BW NEP) can be chosen by clicking on the column's header. For example, setting the filter order to 4 corresponds to a roll off of 24 dB/oct or 80 dB/dec i.e. an attenuation of  $10^4$  for a tenfold frequency increase. If the Low-Pass Filter bandwidth is comparable to or larger than the demodulation frequency, the demodulator output may contain frequency components at the frequency of demodulation and its higher harmonics. In this case, the additional Sinc Filter should be enabled. It attenuates those unwanted harmonic components in the demodulator output. The Sinc Filter is useful when measuring at low frequencies, since it allows one to apply a Low-Pass Filter bandwidth closer to the demodulation frequency, thus speeding up the measurement time.

The data transfer of demodulator outputs is activated by the En button in the Data Transfer section where also the sampling rate (Rate) for each demodulator can be defined.

The Trigger section next to the Data Transfer allows for setting trigger conditions in order to control and initiate data transfer from the Instrument to the host PC by the application of logic signals (e.g. TTL) to either DIO 0 or 1 on the instrument back panel.

In the **Signal Outputs** section the On buttons are used to activate the Signal Outputs. This is also the place where the output amplitudes for the Signal Outputs can be set in adjustable units (Vpk, Vrms, or dBm). The Range drop-down list is used to select the proper output range setting. By enabling the Add button, one can add an external analog signal which is applied to the Add input to the Signal Output.

Block Diagram

The block diagram view of the main instrument functions is also sometimes called the "Graphical Lock-in Tab". A set of indexed side tabs in the Lock-in Tab give access to a block diagram for each demodulator. The block diagrams are fully functional and provide the user with a visual feedback of what is going on inside the instrument. All control elements that are available in the Parameter Table detailed in the previous section are also present in the graphical representation.

The block diagram in [Figure 5.12](#) shows the signal path through the instrument for the case when the internal oscillator is used as reference. The Signal Inputs and Reference/Internal Frequency are shown on the left-hand side. The actual demodulation, i.e. the mixing and low-pass filtering is represented in the center of the tab. On the bottom right the user can set Signal Output parameters. On the top right there are the settings related to the output of the measurement data, either by digital means (PC Data Transfer) or by analog means (Auxiliary Outputs 1 to 4).

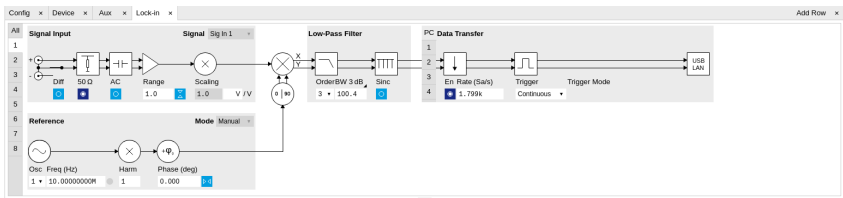


Figure 5.12: LabOne User Interface Lock-in tab - Graphical Lock-in tab in Internal Reference mode

The block diagram in [Figure 5.13](#) shows the signal path through the instrument for the case when an external reference is used. This setting is only available for demodulators 7 and 8. In order to map an external frequency to oscillator 1/2 go to the Reference section of demodulator 7/8 and change the mode to ExtRef. This demodulator will then be used as a phase detector within a phase locked loop. The software will choose the appropriate filter settings according to the frequency and properties of the reference signal.

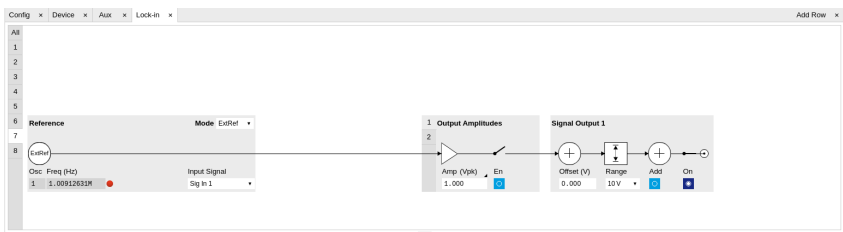




Figure 5.13: LabOne User Interface Lock-in tab - Graphical Lock-in tab in External Reference mode



5.5.3. Functional Elements

Table 5.10: Lock-in tab

| Control/Tool | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Range        | 1 mV to 1.5 V                                                                       | Defines the gain of the analog input amplifier. The range should exceed the incoming signal by roughly a factor two including a potential DC offset.<br><br>The instrument selects the next higher available range relative to a value inserted by the user. A suitable choice of this setting optimizes the accuracy and signal-to-noise ratio by ensuring that the full dynamic range of the input ADC is used. |
| On           | ON / OFF                                                                            | Enable Signal Input.                                                                                                                                                                                                                                                                                                                                                                                              |
| Auto         |  | Automatic adjustment of the Range to about two times the maximum signal input amplitude measured over about 100 ms.                                                                                                                                                                                                                                                                                               |
| Scaling      | numeric value                                                                       | Applies an arbitrary scale factor to the input signal.                                                                                                                                                                                                                                                                                                                                                            |

| Control/Tool     | Option/<br>Range                | Description                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Measurement Unit | unit acronym                    | <p>Defines the physical unit of the input signal. Use *, / and ^ operators, e.g., m or m/s^2.</p> <p>The value in this field modifies the readout of all measurement tools in the user interface. Typical uses of this field is to make measurements in the unit before the sensor/transducer, e.g. to take an transimpedance amplifier into account and to directly read results in Ampere instead of Volts.</p> |
| Coupling         | OFF: DC coupling                | Defines the input coupling for the Signal Inputs. AC coupling inserts a high-pass filter.                                                                                                                                                                                                                                                                                                                         |
|                  | ON: AC coupling                 |                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 50 Ω             | OFF: 1 MΩ                       | Switches between 50 Ω (ON) and 1 MΩ (OFF).                                                                                                                                                                                                                                                                                                                                                                        |
|                  | ON: 50 Ω                        |                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Diff             | ON: Differential voltage input  | Switches between single ended (OFF) and differential (ON) measurements.                                                                                                                                                                                                                                                                                                                                           |
|                  | OFF: Single ended voltage input |                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Mode             |                                 | Indicates how the frequency of the corresponding oscillator is controlled (manual, external reference, PLL, PID). Read only flag.                                                                                                                                                                                                                                                                                 |
|                  | Manual                          | The user setting defines the oscillator frequency.                                                                                                                                                                                                                                                                                                                                                                |
|                  | ExtRef                          | An external reference is mapped onto the oscillator frequency.                                                                                                                                                                                                                                                                                                                                                    |
|                  | PLL                             | The HF2-PLL option controls the oscillator frequency.                                                                                                                                                                                                                                                                                                                                                             |
|                  | PID                             | The HF2-PID option controls the oscillator frequency.                                                                                                                                                                                                                                                                                                                                                             |
| Frequency (Hz)   | 0 to 50 MHz                     | Frequency control for each oscillator.                                                                                                                                                                                                                                                                                                                                                                            |
| Locked           | ON / OFF                        | Oscillator locked to external reference when turned on.                                                                                                                                                                                                                                                                                                                                                           |
| Mode             |                                 | Select the reference mode (manual or external reference) or indicate the unit that uses the demodulator (e.g. PLL).                                                                                                                                                                                                                                                                                               |
|                  | Manual                          | Default lock-in operating mode with manually set reference frequency.                                                                                                                                                                                                                                                                                                                                             |
|                  | ExtRef                          | The demodulator is used for external reference mode and tracks the frequency of the selected reference input. The demodulator bandwidth is set automatically to adapt to the signal properties.                                                                                                                                                                                                                   |
|                  | Mod                             | The demodulator is used by the HF2-MOD option, e.g. for the direct demodulation of carrier and sideband signals.                                                                                                                                                                                                                                                                                                  |
| Osc              | oscillator index                | Connects the selected oscillator with the demodulator corresponding to this line. Number of available oscillators depends on the installed options.                                                                                                                                                                                                                                                               |
| Harm             | 1 to 1023                       | <p>Multiplies the demodulator's reference frequency with the integer factor defined by this field.</p> <p>If the demodulator is used as a phase detector in external reference mode (PLL), the effect is that the internal oscillator locks to the external frequency divided by the integer factor.</p>                                                                                                          |
| Demod Freq (Hz)  | 0 to 50 MHz                     | <p>Indicates the frequency used for demodulation and for output generation.</p> <p>The demodulation frequency is calculated with oscillator frequency times the harmonic factor. When the HF2LI-MOD option is used linear combinations of oscillator frequencies including the harmonic factors define the demodulation frequencies.</p>                                                                          |

| Control/Tool | Option/<br>Range                                                                  | Description                                                                                                                                                                                                                                                                                                                                    |
|--------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Phase (deg)  | -180° to 180°                                                                     | Phase shift applied to the reference input of the demodulator.<br><br>When the HF2LI-MF option is used, the phase shift is also applied to the Signal Outputs.                                                                                                                                                                                 |
| Zero         |  | Adjust the phase of the demodulator reference automatically in order to read zero degrees at the demodulator output.<br><br>This action maximizes the X output, zeros the Y output, zeros the $\Theta$ output, and leaves the R output unchanged.                                                                                              |
| Signal       |                                                                                   | Selects the signal source to be associated to the demodulator.                                                                                                                                                                                                                                                                                 |
|              | Sig In 1                                                                          | Signal Input 1 is connected to the corresponding demodulator.                                                                                                                                                                                                                                                                                  |
|              | Sig In 2                                                                          | Signal Input 2 is connected to the corresponding demodulator.                                                                                                                                                                                                                                                                                  |
|              | Aux In 1                                                                          | Auxiliary Input 1 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 20 kHz.                                                                                                                                          |
|              | Aux In 2                                                                          | Auxiliary Input 2 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 20 kHz.                                                                                                                                          |
|              | DIO D0                                                                            | DIO D0 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 2 MHz.                                                                                                                                                      |
|              | DIO D1                                                                            | DIO D1 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 2 MHz.                                                                                                                                                      |
| Order        |                                                                                   | Selects the filter roll off between 6 dB/oct and 48 dB/oct.                                                                                                                                                                                                                                                                                    |
|              | 1                                                                                 | 1st order filter 6 dB/oct                                                                                                                                                                                                                                                                                                                      |
|              | 2                                                                                 | 2nd order filter 12 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 3                                                                                 | 3rd order filter 18 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 4                                                                                 | 4th order filter 24 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 5                                                                                 | 5th order filter 30 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 6                                                                                 | 6th order filter 36 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 7                                                                                 | 7th order filter 42 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 8                                                                                 | 8th order filter 48 dB/oct                                                                                                                                                                                                                                                                                                                     |
| TC/BW Select |                                                                                   | Defines the display unit of the low-pass filters: time constant (TC) in seconds, noise equivalent power bandwidth (BW NEP) in Hz, 3 dB bandwidth (BW 3 dB) in Hz.                                                                                                                                                                              |
|              | TC                                                                                | Defines the low-pass filter characteristic using time constant (s) of the filter.                                                                                                                                                                                                                                                              |
|              | BW NEP                                                                            | Defines the low-pass filter characteristic using the noise equivalent power bandwidth (Hz) of the filter.                                                                                                                                                                                                                                      |
|              | BW 3 dB                                                                           | Defines the low-pass filter characteristic using the 3 dB cut-off frequency (Hz) of the filter.                                                                                                                                                                                                                                                |
| TC/BW Value  | numeric value                                                                     | Defines the low-pass filter characteristic in the unit defined above.                                                                                                                                                                                                                                                                          |
| Sinc         | ON / OFF                                                                          | Enables the sinc filter.<br><br>When the filter bandwidth is comparable to or larger than the demodulation frequency, the demodulator output may contain frequency components at the frequency of demodulation and its higher harmonics. The sinc is an additional filter that attenuates these unwanted components in the demodulator output. |

| Control/Tool                   | Option/Range                                                                      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Filter Lock                    |  | <p>Makes all demodulator filter settings equal (order, time constant, bandwidth).</p> <p>Enabling the lock copies the settings from demodulator 1 to all other demodulators. With locked filters, any modification to a filter setting is applied to all other filters, too. Releasing the lock does not change any setting.</p>                                                                                                                                                                                                            |
| Enable Streaming               | ON / OFF                                                                          | Enables the data acquisition and streaming of demodulated samples to the host computer for the corresponding demodulator. The streaming rate is defined in the field on the right hand side. Enabling a stream activates a corresponding element in the numeric tab and allows for demodulated samples to be visualized and analyzed in any of the LabOne measurement tools. Note: increasing number of active demodulators increases load on physical connection to the host computer.                                                     |
| Rate (Sa/s)                    | 0.22 Sa/s to 410 kSa/s                                                            | <p>Defines the demodulator sampling rate, the number of samples that are sent to the host computer per second. A rate of about 7-10 higher as compared to the filter bandwidth usually provides sufficient aliasing suppression.</p> <p>This is also the rate of data received by LabOne Data Server and saved to the computer hard disk. This setting has no impact on the sample rate on the auxiliary outputs connectors. Note: the value inserted by the user may be approximated to the nearest value supported by the instrument.</p> |
| Demodulator Sampling Rate Lock |  | <p>Makes all demodulator sampling rates equal.</p> <p>Enabling the lock copies the settings from demodulator 1 to all other demodulators. With locked sampling rates, any modification to a sampling rate is applied to all other sampling rate fields, too. Releasing the lock does not change any setting.</p>                                                                                                                                                                                                                            |
| Trigger                        |                                                                                   | Selects the acquisition mode of demodulated samples. Continuous trigger means data are streamed to the host computer at the Rate indicated.                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                | Continuous                                                                        | Selects continuous data acquisition mode. The demodulated samples are streamed to the host computer at the Rate indicated on the left hand side. In continuous mode the numerical and plotter tools are continuously receiving and display new values.                                                                                                                                                                                                                                                                                      |
|                                | DIO 0                                                                             | Samples are sent to the host computer depending on DIO 0 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                | DIO 1                                                                             | Samples are sent to the host computer depending on DIO 1 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                | DIO 0\1                                                                           | Samples are sent to the host computer depending on DIO 0 and 1 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Trigger Mode                   |                                                                                   | Defines the edge or level trigger mode for the selected Trigger input. Note: this field only appears when a non-continuous trigger is selected in the Trigger field.                                                                                                                                                                                                                                                                                                                                                                        |
|                                | Rising                                                                            | Selects triggered sample acquisition mode on rising edge of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                | Falling                                                                           | Selects triggered sample acquisition mode on falling edge of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                | Both                                                                              | Selects triggered sample acquisition mode on both edges of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                | High                                                                              | Selects continuous sample acquisition mode on high level of the selected Trigger input. In this selection, the sample rate field determines the frequency in which demodulated samples are sent to the host computer.                                                                                                                                                                                                                                                                                                                       |

| Control/Tool     | Option/Range    | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | Low             | Selects continuous sample acquisition mode on low level of the selected Trigger input. In this selection, the sample rate field determines the frequency in which demodulated samples are sent to the host computer.                                                                                                                                                                                                                                                                                                                                                                                                              |
| Amplitude Unit   | Vpk, Vrms       | Select the unit of the displayed amplitude value.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Amplitude Enable | ON / OFF        | Enables individual output signal amplitude.<br><br>When the HF2LI-MF option is used, it is possible to generate signals being the linear combination of the available demodulator frequencies.                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| On               | ON / OFF        | Main switch for the Signal Output corresponding to the blue LED indicator on the instrument front panel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Range            |                 | Defines the maximum output voltage that is generated by the corresponding Signal Output. This includes the potential multiple Signal Amplitudes and Offsets summed up. Select the smallest range possible to optimize signal quality.<br><br>This setting ensures that no levels or peaks above the setting are generated, and therefore it limits the values that can be entered as output amplitudes. Therefore selected output amplitudes are clipped to the defined range and the clipping indicator turns on. If 50 $\Omega$ target source or differential output is enabled the possible maximal output range will be half. |
|                  | 10 mV           | Selects output range $\pm 10$ mV.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                  | 100 mV          | Selects output range $\pm 100$ mV.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                  | 1 V             | Selects output range $\pm 1$ V.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                  | 10 V            | Selects output range $\pm 10$ V.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Offset           | -range to range | Defines the DC voltage that is added to the dynamic part of the output signal.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Add              | ON / OFF        | The signal supplied to the add input is added to the signal output.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Output           | -range to range | Defines the output amplitude for each demodulator frequency as rms or peak-to-peak value. A negative amplitude value is equivalent to a phase change of 180 degree. Demodulator 7 is the signal source for Signal Output 1, demodulator 8 is the source for Signal Output 2.                                                                                                                                                                                                                                                                                                                                                      |

## 5.6. Lock-in Tab (HF2-MF option)

This tab is the main lock-in amplifier control panel for HF2LI Instruments with the HF2-MF Multi-frequency option installed. Users with instruments without this option installed are kindly referred to [Lock-in Tab](#).

### 5.6.1. Features

- Functional block diagram with access to main input, output and demodulator controls
- Parameter table with main input, output and demodulator controls
- Controls for 6 (HF2LI) or 8 (HF2IS) individually configurable demodulators
- Auto ranging, scaling, arbitrary input units for both input channels
- Control for 6 oscillators
- Settings for main signal inputs and signal outputs
- Choice of reference source, trigger options and data transfer rates

### 5.6.2. Description

The Lock-in tab is the main control center of the instrument and open after start up by default. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.11: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                                                                          |
|--------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Lock-in MF   |  | Quick overview and access to all the settings and properties for signal generation and demodulation. |

The default view of the Lock-in tab is the parameter table view. It is accessible under the side tab labeled All and provides controls for all demodulators in the instrument. Moreover, for each individual demodulator there is a functional block diagram available. It is accessible under the side tab labeled with the corresponding demodulator number.

Parameter Table

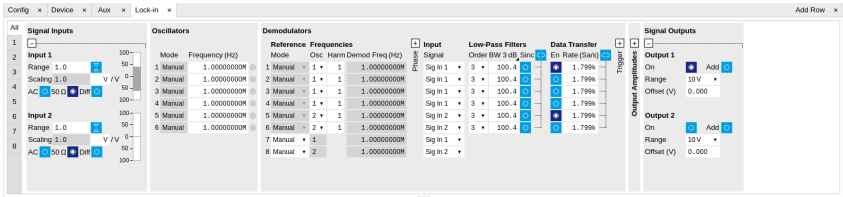


Figure 5.14: LabOne User Interface Lock-in tab with HF2-MF Multi-frequency option.

The **Signal Inputs** section allows the user to define all relevant settings specific to the signal entered as for example input coupling, range, etc. Some of the available options like phase adjustment and the trigger functionality are collapsed by default. It takes one mouse click on the "+" icon in order to expand those controls. On the right-hand side of the Lock-in tab the Signal Outputs section allows to define signal amplitudes, offsets and range values.

The Scaling field below the Range field can be used to multiply the Signal Input data for instance to account for the gain of an external amplifier. In case there is a transimpedance gain of 10 V/A applied to the input signal externally, then the Scaling field can be set to 0.1 and the Units field can be set to A in order to show the actual current readings through the entire user interface.

There are two buttons below the Scaling field that can be toggled: the AC/DC button and the 50 Ω/ 1 MΩ . The AC/DC button sets the coupling type: AC coupling has a high-pass cutoff frequency that can be used to block large DC signal components to prevent input signal saturation during amplification. The 50 Ω/ 1 MΩ button toggles the input impedance between low (50 Ω) and high (approx. 1 MΩ ) input impedance. With 50 Ω input impedance, one will expect a reduction of a factor of 2 in the measured signal if the signal source also has an output impedance of 50 Ω.

The **Oscillator** section indicates the . Where the Mode indicator shows Manual the user can define the oscillator frequency manually defined by typing a frequency value in the field. In case the oscillator is referenced to an external source the Mode indicator will show ExtRef and the frequency field is set to read-only. External reference requires a PLL to do the frequency mapping onto an internal oscillator. Successful locking is indicated by a green light right next to the frequency field.

The next section contains the **Demodulators settings**. The block diagram displayed in [Figure 5.15](#) indicates the main demodulator components and their interconnection. The understanding of the wiring is essential for successfully operating the instrument.



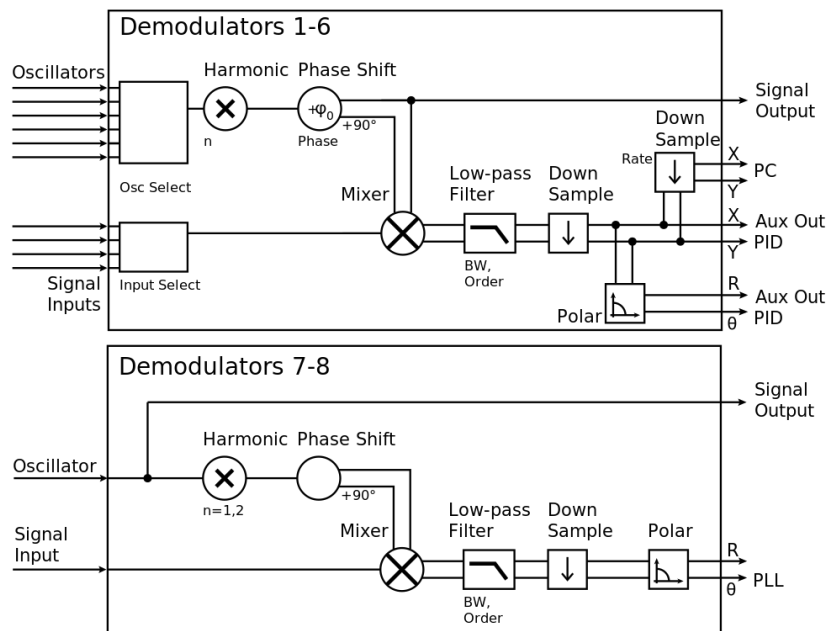


Figure 5.15: Demodulator block diagram with HF2-MF Multi-frequency option.

In the Input Signal column one defines the signal that is taken as input for the demodulator. A wide choice of signals can be selected: Signal Inputs, the Trigger Inputs, the Auxiliary Inputs and Auxiliary Outputs. This allows to use the instrument for many different measurement topologies.

For each demodulator an additional phase shift can be introduced to the associated oscillator by entering the phase offset in the Phase column. This phase is added both, to the reference channel and the output of the demodulator. Hence, when the frequency is generated and detected using the same demodulator, signal phase and reference phase change by the same amount and no change will be visible in the demodulation result. Demodulation of frequencies that are integer multiples of any of the oscillator frequencies is achieved by entering the desired factor in the Harm column. The demodulator readout can be obtained using the Numeric tab which is described in [Numeric Tab](#).

In the middle of the Lock-in tab is the Low-Pass Filters section where the filter order can be selected in the drop down list for each demodulator and the filter bandwidth (BW 3dB) can be chosen by typing a numerical value. Alternatively the time constant of the filter (TC) or the noise equivalent power filter bandwidth (BW NEP) can be chosen by clicking on the column's header. For example, setting the filter order to 4 corresponds to a roll off of 24 dB/oct or 80 dB/dec i.e. an attenuation of  $10^4$  for a tenfold frequency increase. If the Low-Pass Filter bandwidth is comparable to or larger than the demodulation frequency, the demodulator output may contain frequency components at the frequency of demodulation and its higher harmonics. In this case, the additional Sinc Filter can be enabled. It attenuates those unwanted harmonic components in the demodulator output. The Sinc Filter is also useful when measuring at low frequencies, since it allows to apply a Low-Pass Filter bandwidth closer to the demodulation frequency, thus speeding up the measurement time.

The data transfer of demodulator outputs is activated by the En button in the Data Transfer section where also the sampling rate (Rate) for each demodulator can be defined.

The Trigger section next to the Data Transfer allows for setting trigger conditions in order to control and initiate data transfer from the Instrument to the host PC by the application of logic signals (e.g. TTL) to either Trigger Input on the back panel.

## Block Diagram

The block diagram view of the main instrument functions is also sometimes called the "Graphical Lock-in Tab". Depending on how many demodulators are available in the instrument a set of numbered side tabs are available giving access to a Graphical Lock-in Tab for each demodulator. The block diagrams are fully functional and provide the user with a visual feedback of what is going on inside the instrument. All control elements that are available in the Parameter Table detailed in the previous section are also present in the graphical representation.

The block diagram in [Figure 5.16](#) describes the signal path throughout the instrument for the case when the internal oscillator is used as reference. The Signal Inputs and Reference/Internal Frequency are described on the left side, the core of demodulation with the mixer and low-pass



5.6. Lock-in Tab (HF2-MF option)

filter is located in the center of the tab and the Signal Outputs, the Auxiliary Outputs as well as the data transfer to the PC is sketched on the right.

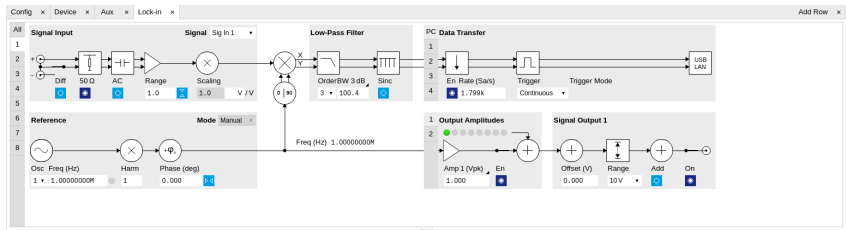


Figure 5.16: LabOne User Interface Lock-in tab - Graphical Lock-in tab in Internal Reference mode

The block diagram in [Figure 5.17](#) describes the signal path throughout the instrument for the case when an external reference is used. This setting is only available for demodulator 7/8. In order to map an external frequency to any of the oscillators, go to the Reference section of demodulator 7/8 and change the mode to ExtRef. This demodulator will then be used as a phase detector within the phase-locked loop. The software will choose the appropriate filter settings according to the frequency and properties of the reference signal. Once a demodulator is used to map an external frequency on to one of the internal oscillators, it is no longer available for other measurements.

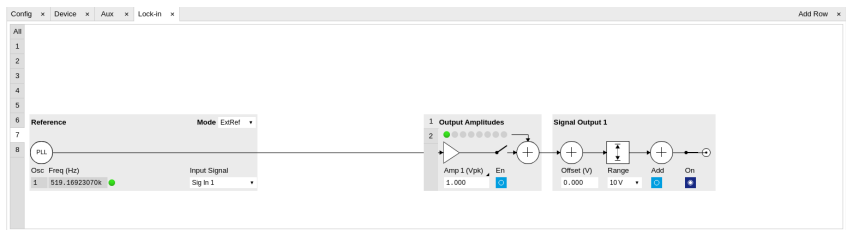





Figure 5.17: LabOne User Interface Lock-in tab - Graphical Lock-in tab in External Reference mode


5.6.3. Functional Elements

Table 5.12: Lock-in MF tab

| Control/Tool     | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Range            | 1 mV to 1.5 V                                                                       | Defines the gain of the analog input amplifier. The range should exceed the incoming signal by roughly a factor two including a potential DC offset.<br><br>The instrument selects the next higher available range relative to a value inserted by the user. A suitable choice of this setting optimizes the accuracy and signal-to-noise ratio by ensuring that the full dynamic range of the input ADC is used. |
| On               | ON / OFF                                                                            | Enable Signal Input.                                                                                                                                                                                                                                                                                                                                                                                              |
| Auto             |  | Automatic adjustment of the Range to about two times the maximum signal input amplitude measured over about 100 ms.                                                                                                                                                                                                                                                                                               |
| Scaling          | numeric value                                                                       | Applies an arbitrary scale factor to the input signal.                                                                                                                                                                                                                                                                                                                                                            |
| Measurement Unit | unit acronym                                                                        | Defines the physical unit of the input signal. Use *, / and ^ operators, e.g., m or m/s^2.<br><br>The value in this field modifies the readout of all measurement tools in the user interface. Typical uses of this field is to make measurements in the unit before the sensor/transducer, e.g. to take an transimpedance amplifier into account and to directly read results in Ampere instead of Volts.        |
| Coupling         | OFF: DC coupling<br>ON: AC coupling                                                 | Defines the input coupling for the Signal Inputs. AC coupling inserts a high-pass filter.                                                                                                                                                                                                                                                                                                                         |
| 50 Ω             | OFF: 1 MΩ                                                                           | Switches between 50 Ω (ON) and 1 MΩ (OFF).                                                                                                                                                                                                                                                                                                                                                                        |

| Control/Tool    | Option/<br>Range                                                                    | Description                                                                                                                                                                                                                                                                                                                       |
|-----------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                 | ON: 50 $\Omega$                                                                     |                                                                                                                                                                                                                                                                                                                                   |
| Diff            | ON:<br>Differential<br>voltage input                                                | Switches between single ended (OFF) and differential (ON) measurements.                                                                                                                                                                                                                                                           |
|                 | OFF: Single<br>ended<br>voltage input                                               |                                                                                                                                                                                                                                                                                                                                   |
| Mode            |                                                                                     | Indicates how the frequency of the corresponding oscillator is controlled (manual, external reference, PLL, PID). Read only flag.                                                                                                                                                                                                 |
|                 | Manual                                                                              | The user setting defines the oscillator frequency.                                                                                                                                                                                                                                                                                |
|                 | ExtRef                                                                              | An external reference is mapped onto the oscillator frequency.                                                                                                                                                                                                                                                                    |
|                 | PLL                                                                                 | The HF2-PLL option controls the oscillator frequency.                                                                                                                                                                                                                                                                             |
|                 | PID                                                                                 | The HF2-PID option controls the oscillator frequency.                                                                                                                                                                                                                                                                             |
| Frequency (Hz)  | 0 to 50 MHz                                                                         | Frequency control for each oscillator.                                                                                                                                                                                                                                                                                            |
| Locked          | ON / OFF                                                                            | Oscillator locked to external reference when turned on.                                                                                                                                                                                                                                                                           |
| Mode            |                                                                                     | Select the reference mode (manual or external reference) or indicate the unit that uses the demodulator (e.g. PLL).                                                                                                                                                                                                               |
|                 | Manual                                                                              | Default lock-in operating mode with manually set reference frequency.                                                                                                                                                                                                                                                             |
|                 | ExtRef                                                                              | The demodulator is used for external reference mode and tracks the frequency of the selected reference input. The demodulator bandwidth is set automatically to adapt to the signal properties.                                                                                                                                   |
|                 | Mod                                                                                 | The demodulator is used by the HF2-MOD option, e.g. for the direct demodulation of carrier and sideband signals.                                                                                                                                                                                                                  |
| Osc             | oscillator<br>index                                                                 | Connects the selected oscillator with the demodulator corresponding to this line. Number of available oscillators depends on the installed options.                                                                                                                                                                               |
| Harm            | 1 to 1023                                                                           | Multiplies the demodulator's reference frequency with the integer factor defined by this field.                                                                                                                                                                                                                                   |
|                 |                                                                                     | If the demodulator is used as a phase detector in external reference mode (PLL), the effect is that the internal oscillator locks to the external frequency divided by the integer factor.                                                                                                                                        |
| Demod Freq (Hz) | 0 to 50 MHz                                                                         | Indicates the frequency used for demodulation and for output generation.<br><br>The demodulation frequency is calculated with oscillator frequency times the harmonic factor. When the HF2LI-MOD option is used linear combinations of oscillator frequencies including the harmonic factors define the demodulation frequencies. |
| Phase (deg)     | -180° to 180°                                                                       | Phase shift applied to the reference input of the demodulator.<br><br>When the HF2LI-MF option is used, the phase shift is also applied to the Signal Outputs.                                                                                                                                                                    |
| Zero            |  | Adjust the phase of the demodulator reference automatically in order to read zero degrees at the demodulator output.<br><br>This action maximizes the X output, zeros the Y output, zeros the $\Theta$ output, and leaves the R output unchanged.                                                                                 |
| Signal          |                                                                                     | Selects the signal source to be associated to the demodulator.                                                                                                                                                                                                                                                                    |
|                 | Sig In 1                                                                            | Signal Input 1 is connected to the corresponding demodulator.                                                                                                                                                                                                                                                                     |
|                 | Sig In 2                                                                            | Signal Input 2 is connected to the corresponding demodulator.                                                                                                                                                                                                                                                                     |

| Control/Tool | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                                    |
|--------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|              | Aux In 1                                                                            | Auxiliary Input 1 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 20 kHz.                                                                                                                                          |
|              | Aux In 2                                                                            | Auxiliary Input 2 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 20 kHz.                                                                                                                                          |
|              | DIO D0                                                                              | DIO D0 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 2 MHz.                                                                                                                                                      |
|              | DIO D1                                                                              | DIO D1 is connected to the corresponding demodulator. This input is only available on demodulators 7 and 8 used for the External Reference mode. The input bandwidth is limited to 2 MHz.                                                                                                                                                      |
| Order        |                                                                                     | Selects the filter roll off between 6 dB/oct and 48 dB/oct.                                                                                                                                                                                                                                                                                    |
|              | 1                                                                                   | 1st order filter 6 dB/oct                                                                                                                                                                                                                                                                                                                      |
|              | 2                                                                                   | 2nd order filter 12 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 3                                                                                   | 3rd order filter 18 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 4                                                                                   | 4th order filter 24 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 5                                                                                   | 5th order filter 30 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 6                                                                                   | 6th order filter 36 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 7                                                                                   | 7th order filter 42 dB/oct                                                                                                                                                                                                                                                                                                                     |
|              | 8                                                                                   | 8th order filter 48 dB/oct                                                                                                                                                                                                                                                                                                                     |
| TC/BW Select |                                                                                     | Defines the display unit of the low-pass filters: time constant (TC) in seconds, noise equivalent power bandwidth (BW NEP) in Hz, 3 dB bandwidth (BW 3 dB) in Hz.                                                                                                                                                                              |
|              | TC                                                                                  | Defines the low-pass filter characteristic using time constant (s) of the filter.                                                                                                                                                                                                                                                              |
|              | BW NEP                                                                              | Defines the low-pass filter characteristic using the noise equivalent power bandwidth (Hz) of the filter.                                                                                                                                                                                                                                      |
|              | BW 3 dB                                                                             | Defines the low-pass filter characteristic using the 3 dB cut-off frequency (Hz) of the filter.                                                                                                                                                                                                                                                |
| TC/BW Value  | numeric value                                                                       | Defines the low-pass filter characteristic in the unit defined above.                                                                                                                                                                                                                                                                          |
| Sinc         | ON / OFF                                                                            | Enables the sinc filter.<br><br>When the filter bandwidth is comparable to or larger than the demodulation frequency, the demodulator output may contain frequency components at the frequency of demodulation and its higher harmonics. The sinc is an additional filter that attenuates these unwanted components in the demodulator output. |
| Filter Lock  |  | Makes all demodulator filter settings equal (order, time constant, bandwidth).<br><br>Enabling the lock copies the settings from demodulator 1 to all other demodulators. With locked filters, any modification to a filter setting is applied to all other filters, too. Releasing the lock does not change any setting.                      |

| Control/Tool                   | Option/Range                                                                      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Enable Streaming               | ON / OFF                                                                          | Enables the data acquisition and streaming of demodulated samples to the host computer for the corresponding demodulator. The streaming rate is defined in the field on the right hand side. Enabling a stream activates a corresponding element in the numeric tab and allows for demodulated samples to be visualized and analyzed in any of the LabOne measurement tools. Note: increasing number of active demodulators increases load on physical connection to the host computer.                                                     |
| Rate (Sa/s)                    | 0.22 Sa/s to 410 kSa/s                                                            | <p>Defines the demodulator sampling rate, the number of samples that are sent to the host computer per second. A rate of about 7-10 higher as compared to the filter bandwidth usually provides sufficient aliasing suppression.</p> <p>This is also the rate of data received by LabOne Data Server and saved to the computer hard disk. This setting has no impact on the sample rate on the auxiliary outputs connectors. Note: the value inserted by the user may be approximated to the nearest value supported by the instrument.</p> |
| Demodulator Sampling Rate Lock |  | <p>Makes all demodulator sampling rates equal.</p> <p>Enabling the lock copies the settings from demodulator 1 to all other demodulators. With locked sampling rates, any modification to a sampling rate is applied to all other sampling rate fields, too. Releasing the lock does not change any setting.</p>                                                                                                                                                                                                                            |
| Trigger                        |                                                                                   | Selects the acquisition mode of demodulated samples. Continuous trigger means data are streamed to the host computer at the Rate indicated.                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                | Continuous                                                                        | Selects continuous data acquisition mode. The demodulated samples are streamed to the host computer at the Rate indicated on the left hand side. In continuous mode the numerical and plotter tools are continuously receiving and display new values.                                                                                                                                                                                                                                                                                      |
|                                | DIO 0                                                                             | Samples are sent to the host computer depending on DIO 0 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                | DIO 1                                                                             | Samples are sent to the host computer depending on DIO 1 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                | DIO 0\1                                                                           | Samples are sent to the host computer depending on DIO 0 and 1 triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Trigger Mode                   |                                                                                   | Defines the edge or level trigger mode for the selected Trigger input. Note: this field only appears when a non-continuous trigger is selected in the Trigger field.                                                                                                                                                                                                                                                                                                                                                                        |
|                                | Rising                                                                            | Selects triggered sample acquisition mode on rising edge of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                | Falling                                                                           | Selects triggered sample acquisition mode on falling edge of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                | Both                                                                              | Selects triggered sample acquisition mode on both edges of the selected Trigger input.                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                | High                                                                              | Selects continuous sample acquisition mode on high level of the selected Trigger input. In this selection, the sample rate field determines the frequency in which demodulated samples are sent to the host computer.                                                                                                                                                                                                                                                                                                                       |
|                                | Low                                                                               | Selects continuous sample acquisition mode on low level of the selected Trigger input. In this selection, the sample rate field determines the frequency in which demodulated samples are sent to the host computer.                                                                                                                                                                                                                                                                                                                        |
| Amplitude Unit                 | Vpk, Vrms                                                                         | Select the unit of the displayed amplitude value.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Amplitude Enable               | ON / OFF                                                                          | <p>Enables individual output signal amplitude.</p> <p>When the HF2LI-MF option is used, it is possible to generate signals being the linear combination of the available demodulator frequencies.</p>                                                                                                                                                                                                                                                                                                                                       |

| Control/Tool  | Option/Range    | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Amplitude (V) | -range to range | Defines the output amplitude for each demodulator frequency as rms or peak-to-peak value.<br><br>A negative amplitude value is equivalent to a phase change of 180 degree. Linear combination of multiple amplitude settings on the same output are clipped to the range setting. Note: the value inserted by the user may be approximated to the nearest value supported by the Instrument.                                                                                                                                                                                                                                      |
| On            | ON / OFF        | Main switch for the Signal Output corresponding to the blue LED indicator on the instrument front panel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Range         |                 | Defines the maximum output voltage that is generated by the corresponding Signal Output. This includes the potential multiple Signal Amplitudes and Offsets summed up. Select the smallest range possible to optimize signal quality.<br><br>This setting ensures that no levels or peaks above the setting are generated, and therefore it limits the values that can be entered as output amplitudes. Therefore selected output amplitudes are clipped to the defined range and the clipping indicator turns on. If 50 $\Omega$ target source or differential output is enabled the possible maximal output range will be half. |
|               | 10 mV           | Selects output range $\pm 10$ mV.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|               | 100 mV          | Selects output range $\pm 100$ mV.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|               | 1 V             | Selects output range $\pm 1$ V.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|               | 10 V            | Selects output range $\pm 10$ V.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Offset        | -range to range | Defines the DC voltage that is added to the dynamic part of the output signal.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Add           | ON / OFF        | The signal supplied to the add input is added to the signal output.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

## 5.7. Numeric Tab

The Numeric tab provides a powerful time domain based measurement display as introduced in [Unique Set of Analysis Tools](#). It is available on all HF2LI instruments.


### 5.7.1. Features

- Display of demodulator output data and other streamed data, e.g. auxiliary inputs, demodulator frequencies
- Graphical and numerical range indicators
- Polar and Cartesian formats
- Support for Input Scaling and Input Units

### 5.7.2. Description

The Numeric tab serves as the main numeric overview display of multiple measurement data. The display can be configured by both choosing the values displayed and also rearrange the display tiles by drag-and-drop. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.13: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                               |
|--------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Numeric      |  | Access to all continuously streamed measurement data as numerical values. |

The numeric tab (see [Figure 5.18](#)) is divided into a display section on the left and a configuration section on the right. The configuration section is further divided into a number of sub-tabs.



Figure 5.18: LabOne UI: Numeric tab

The numeric tab can be deployed to display the demodulated signal, phase, frequency as well as the signal levels at the auxiliary inputs. By default, the user can display the demodulated data either in polar coordinates (R,  $\theta$ ) or in Cartesian coordinates (X, Y) which can be toggled using the presets. To display other measurement quantities as available from any of the presets simply click on the tree tab next to the preset tab. The desired display fields can be selected under each demodulator's directory tree structure.


5.7.3. Functional Elements

Table 5.14: Numeric tab: Presets sub-tab

| Control/Tool    | Option/Range             | Description                                                                                                           |
|-----------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Select a Preset |                          | Select numerical view based on a preset. Alternatively, the displayed value may also selected based on tree elements. |
|                 | Demods Polar             | Shows R and Phase of all demodulators.                                                                                |
|                 | Enabled Demods Polar     | Shows R and Phase of enabled demodulators.                                                                            |
|                 | Demods Cartesian         | Shows X and Y of all demodulators.                                                                                    |
|                 | Enabled Demods Cartesian | Shows X and Y of enabled demodulators.                                                                                |
|                 | Demods R                 | Shows R of all demodulators.                                                                                          |
|                 | Unpopulated              | Shows no signals.                                                                                                     |
|                 | Manual                   | If additional signals are added or removed the active preset gets manual.                                             |

For the Tree sub-tab please see [the section called "Tree Selector"](#).

Table 5.15: Numeric tab: Settings sub-tab

| Control/Tool   | Option/Range                                                                        | Description                                                                                   |
|----------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Name           | text label                                                                          | Name of the selected plot(s). The default name can be changed to reflect the measured signal. |
| Mapping        |                                                                                     | Mapping of the selected plot(s)                                                               |
|                | Lin                                                                                 | Enable linear mapping.                                                                        |
|                | Log                                                                                 | Enable logarithmic mapping.                                                                   |
|                | dB                                                                                  | Enable logarithmic mapping in dB.                                                             |
| Scaling        | Manual/Full Scale                                                                   | Scaling of the selected plot(s)                                                               |
| Zoom To Limits |  | Adjust the zoom to the current limits of the displayed histogram data.                        |
| Start Value    | numeric value                                                                       | Start value of the selected plot(s). Only visible for manual scaling.                         |
| Stop Value     | numeric value                                                                       | Stop value of the selected plot(s). Only visible for manual scaling.                          |

# 5.8. Plotter Tab

The Plotter is one of the powerful time-domain measurement tools as introduced in [Unique Set of Analysis Tools](#) and is available on all HF2LI instruments.


## 5.8.1. Features

- Vertical axis grouping for flexible axis scaling
- Polar and Cartesian data format
- Histogram and Math functionality for data analysis
- 4 cursors for data analysis
- Support for Input Scaling and Input Units

## 5.8.2. Description

The Plotter serves as graphical display for time domain data in a roll mode, i.e. continuously without triggering. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.16: App icon and short description

| Control/<br>Tool | Option/<br>Range                                                                  | Description                                                                              |
|------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Plotter          |  | Displays various continuously streamed measurement data as traces over time (roll mode). |

The Plotter tab (see [Figure 5.19](#)) is divided into a display section on the left and a configuration section on the right.

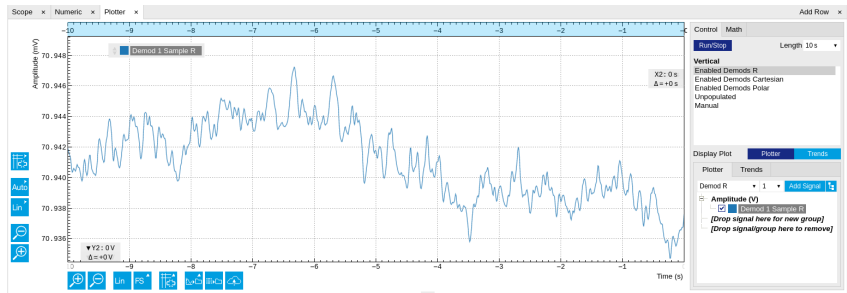


Figure 5.19: LabOne UI: Plotter tab

The Plotter can be used to monitor the evolution of demodulated data and other streamed data continuously over time. Just as in the numeric tab any continuously streamed quantity can be displayed, for instance  $R$ ,  $\theta$ ,  $X$ ,  $Y$ , frequency, and others. New signals can be added by either using the presets in the Control sub-tab or by going through the tree and selecting the signals of interest in the tree structure. The vertical and horizontal axis can be displayed in Lin, Log or dB scale. The Plotter display can be zoomed in and out with the magnifier symbols, or through Man (Manual), Auto (Automatic) and FS (Full Scale) button settings (see also [Plot Functionality](#)). The maximum duration data is kept in the memory can be defined through the window length parameter in the Settings sub-tab. The window length also determines the file size for the Record Data functionality.


## Note

Setting the window length to large values when operating at high sampling rates can lead to memory problems at the computer hosting the data server.

The sampling rate of the demodulator data is determined by the Rate value in Sa/s set in the Lock-in tab. The Plotter data can be continuously saved to disk by clicking the record button in the Config tab which will be indicated by a green Recording (REC) LED in the status bar. See [Saving and Loading Data](#) for more information on data saving.

### 5.8.3. Functional Elements

Table 5.17: Plotter tab: Control sub-tab

| Control/Tool    | Option/Range                                                                      | Description                                                                                                                                                                                                                               |
|-----------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Run/Stop        |  | Start and stop continuous data plotting (roll mode)                                                                                                                                                                                       |
| Select a Preset |                                                                                   | Select a pre-defined group signals. A signal group is defined by a common unit and signal type.<br><br>They should have the same scaling behavior as they share a y-axis. Split a group if the signals have different scaling properties. |
|                 | Enabled Demods R                                                                  | Selects the amplitude of all enabled demodulators.                                                                                                                                                                                        |
|                 | Enabled Demods Cartesian                                                          | Selects X and Y of all enabled demodulators.                                                                                                                                                                                              |
|                 | Enabled Demods Polar                                                              | Selects amplitude and phase of all enabled demodulators.                                                                                                                                                                                  |
|                 | Unpopulated                                                                       | Shows no signals.                                                                                                                                                                                                                         |
|                 | Manual                                                                            | Selects the signals as defined in the tree sub-tab.                                                                                                                                                                                       |

For the Vertical Axis Groups, please see [the table "Vertical Axis Groups description" in the section called "Vertical Axis Groups"](#).

For the Math sub-tab please see [the table "Plot math description" in the section called "Cursors and Math"](#).

## 5.9. Scope Tab

The Scope is a powerful time domain and frequency domain measurement tool as introduced in [Unique Set of Analysis Tools](#) and is available on all HF2 Series instruments.


### 5.9.1. Features

- One input channel with 2 kSa of memory
- 14 bit nominal resolution
- Fast Fourier Transform (FFT): up to 100 MHz span, spectral density and power conversion, choice of window functions
- Sampling rates from 6.4 kSa/s to 210 MSa/s; up to 10  $\mu$ s acquisition time at 210 MSa/s or 320 ms at 6.4 kSa/s
- 4 signal sources; up to 13 trigger sources and 2 trigger methods
- Independent hold-off and trigger level settings

### 5.9.2. Description

The Scope tab serves as the graphical display for time domain data. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.18: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                                       |
|--------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Scope        |  | Displays shots of data samples in time and frequency domain (FFT) representation. |



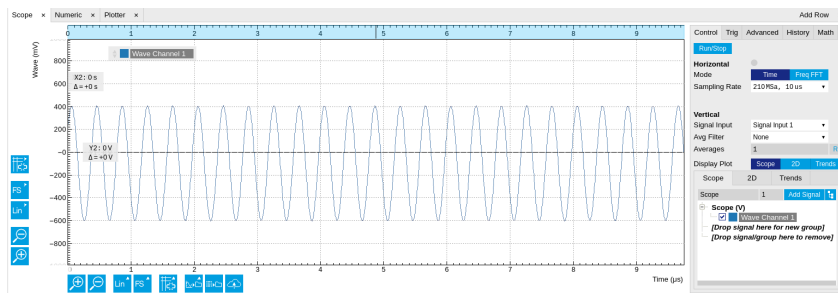


Figure 5.20: LabOne UI: Scope tab - Time domain

The Scope tab consists of a plot section on the left and a configuration section on the right. The configuration section is further divided into a number of sub-tabs. It gives access to a single-channel oscilloscope that can be used to monitor a choice of signals in the time or frequency domain. Hence the X axis of the plot area is time (for time domain display, [Figure 5.20](#)) or frequency (for frequency domain display, [Figure 5.22](#)). It is possible to display the time trace and the associated FFT simultaneously by opening a second instance of the Scope tab.

The Scope records data from a single channel at up to 210 MSa/s. The channel can be selected among the two Signal Inputs and the two Signal Outputs. The Scope records data sets of up to 2 kSa samples in the standard configuration, which corresponds to an acquisition time of 10  $\mu$ s at the highest sampling rate.

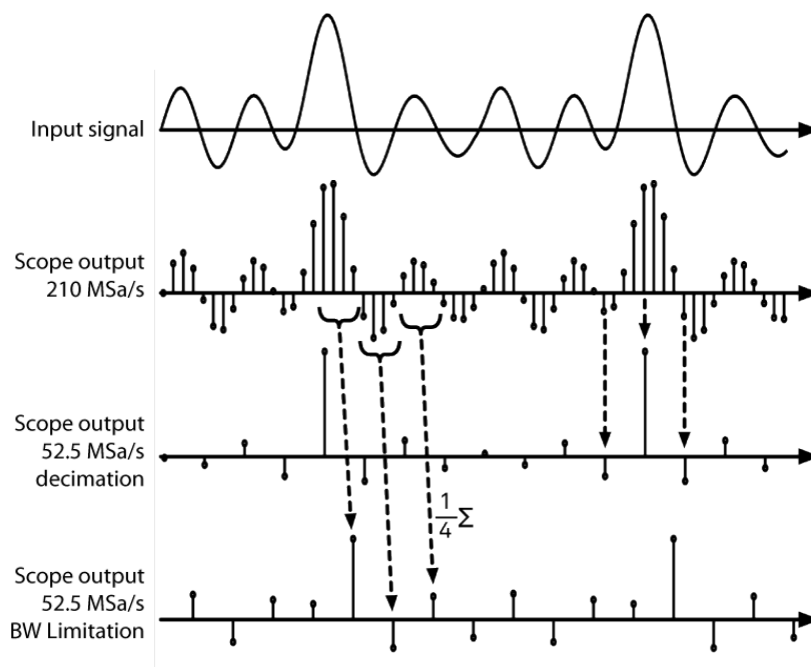


Figure 5.21: Illustration of how the Scope output is generated in BW Limitation and decimation mode when the sampling rate is reduced from the default of 210 MSa/s to 52.5 MSa/s

The frequency domain representation is activated in the Control sub-tab by selecting Freq Domain FFT as the Horizontal Mode. It allows the user to observe the spectrum of the acquired shots of samples. All controls and settings are shared between the time domain and frequency domain representations.

The Scope supports averaging over multiple shots. The functionality is implemented by means of an exponential moving average filter with configurable filter depth. Averaging helps to suppress noise components that are uncorrelated with the main signal. It is particularly useful in combination with the Frequency Domain FFT mode where it can help to reveal harmonic signals and disturbances that might otherwise be hidden below the noise floor.

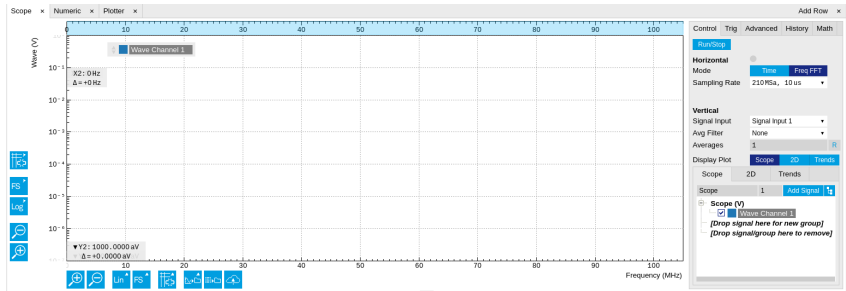


Figure 5.22: LabOne UI: Scope tab - Frequency domain

The Trigger sub-tab offers all the controls necessary for triggering on different signal sources. When the trigger is enabled, then oscilloscope shots are acquired whenever the trigger conditions are met. Trigger and Hysteresis levels can be indicated graphically in the plot. A disabled trigger is equivalent to continuous oscilloscope shot acquisition.

5.9.3. Functional Elements

Table 5.19: Scope tab: Control sub-tab

| Control/ Tool  | Option/ Range          | Description                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Run/Stop       | Run/Stop               | Runs the scope/FFT continuously.                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Mode           | Freq Domain (FFT)      | Switches between time and frequency domain display.                                                                                                                                                                                                                                                                                                                                                                                                   |
|                | Time Domain            |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Sampling Rate  | 6.4 kSa/s to 210 MSa/s | Defines the sampling rate of the scope. The numeric values are rounded for display purposes. The exact values are equal to the base sampling rate divided by 2^n, where n is an integer.                                                                                                                                                                                                                                                              |
| Sampling Rate  |                        | Defines the sampling rate of the scope. The numeric values are rounded for display purposes. The exact values are equal to the base sampling rate divided by 2^n, where n is an integer. Warning: Due to the lack of sample averaging feature, reduced sampling rates can cause aliasing and thus artifacts in the signal spectrum. Currently, the Scope tool only supports sample decimation, but in the future it will also offer sample averaging. |
| Signal Input   | Signal Output 2        | Selects the source for the scope input.                                                                                                                                                                                                                                                                                                                                                                                                               |
|                | Signal Input 1         |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                | Signal Input 2         |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                | Signal Output 1        |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Average Filter |                        | Enable Exponential Moving Average (EMA) filter that is applied when the average of several scope shots is computed and displayed. Depending on the mode, the source data for averaging is either the Time or the Freq FFT trace.                                                                                                                                                                                                                      |
|                | Off                    | Averaging is turned off.                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                | On                     | Consecutive scope shots are averaged with an exponential weight.                                                                                                                                                                                                                                                                                                                                                                                      |
| Averages       | integer value          | The number of shots required to reach 63% settling. Twice the number of shots yields 86% settling.                                                                                                                                                                                                                                                                                                                                                    |
| Averages       | integer value          | The number of shots to average on the device before returning the data.                                                                                                                                                                                                                                                                                                                                                                               |
| Reset          | R                      | Resets the averaging filter.                                                                                                                                                                                                                                                                                                                                                                                                                          |

For the Vertical Axis Groups, please see [the table "Vertical Axis Groups description"](#) in the section called "Vertical Axis Groups".

Table 5.20: Scope tab: Trigger sub-tab

| Control/Tool     | Option/Range                                         | Description                                                                                                                                                                                                                                                                                                                            |
|------------------|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trigger          | grey/green/yellow                                    | When flashing, indicates that new scope shots are being captured and displayed in the plot area. The Trigger must not necessarily be enabled for this indicator to flash. A disabled trigger is equivalent to continuous acquisition. Scope shots with data loss are indicated by yellow. Such an invalid scope shot is not processed. |
| Signal           |                                                      | Selects the trigger source signal.                                                                                                                                                                                                                                                                                                     |
|                  | Off                                                  | Switches the scope off.                                                                                                                                                                                                                                                                                                                |
|                  | Continuous                                           | A new waveform is acquired and displayed after the hold off time. The trigger source is ignored.                                                                                                                                                                                                                                       |
|                  | Signal Inputs 1/2                                    | A new waveform is acquired and displayed when the respective Signal Input is matching the trigger condition.                                                                                                                                                                                                                           |
|                  | Signal Outputs 1/2                                   | A new waveform is acquired and displayed when the respective Signal Output is matching the trigger condition.                                                                                                                                                                                                                          |
|                  | Oscillators 1-8                                      | A new waveform is acquired and displayed when the respective Oscillator is matching the trigger condition.                                                                                                                                                                                                                             |
|                  | DIO 0/1                                              | A new waveform is acquired and displayed when the respective DIO signal is matching the trigger condition.                                                                                                                                                                                                                             |
| Slope            | Falling edge trigger                                 | Select the signal edge that should activate the trigger.                                                                                                                                                                                                                                                                               |
|                  | Rising edge trigger                                  |                                                                                                                                                                                                                                                                                                                                        |
| Level (%)        | numeric percentage value (negative values permitted) | Defines the trigger level relative to signal full scale.                                                                                                                                                                                                                                                                               |
| Holdoff (s)      | numeric value                                        | Defines the time before the trigger is rearmed after a recording event.                                                                                                                                                                                                                                                                |
| Plot Type        |                                                      | Select the plot type.                                                                                                                                                                                                                                                                                                                  |
|                  | None                                                 | No plot displayed.                                                                                                                                                                                                                                                                                                                     |
|                  | 2D                                                   | Display defined number of grid rows as one 2D plot.                                                                                                                                                                                                                                                                                    |
|                  | Row                                                  | Display only the trace of index defined in the Active Row field.                                                                                                                                                                                                                                                                       |
|                  | 2D + Row                                             | Display 2D and row plots.                                                                                                                                                                                                                                                                                                              |
| Active Row       | integer value                                        | Set the row index to be displayed in the Row plot.                                                                                                                                                                                                                                                                                     |
| Track Active Row | ON / OFF                                             | If enabled, the active row marker will track with the last recorded row. The active row control field is read-only if enabled.                                                                                                                                                                                                         |
| Palette          | Solar                                                | Select the colormap for the current plot.                                                                                                                                                                                                                                                                                              |
|                  | Viridis                                              |                                                                                                                                                                                                                                                                                                                                        |
|                  | Inferno                                              |                                                                                                                                                                                                                                                                                                                                        |
|                  | Balance                                              |                                                                                                                                                                                                                                                                                                                                        |
|                  | Turbo                                                |                                                                                                                                                                                                                                                                                                                                        |
|                  | Grey                                                 |                                                                                                                                                                                                                                                                                                                                        |
| Colorscale       | ON / OFF                                             | Enable/disable the colorscale bar display in the 2D plot.                                                                                                                                                                                                                                                                              |
| Mapping          |                                                      | Mapping of colorscale.                                                                                                                                                                                                                                                                                                                 |
|                  | Lin                                                  | Enable linear mapping.                                                                                                                                                                                                                                                                                                                 |
|                  | Log                                                  | Enable logarithmic mapping.                                                                                                                                                                                                                                                                                                            |
|                  | dB                                                   | Enable logarithmic mapping in dB.                                                                                                                                                                                                                                                                                                      |
| Scaling          | Full Scale/<br>Manual/Auto                           | Scaling of colorscale.                                                                                                                                                                                                                                                                                                                 |




| Control/Tool   | Option/Range  | Description                                                                                                                                                                                                           |
|----------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Clamp To Color | ON / OFF      | When enabled, grid values that are outside of defined Min or Max region are painted with Min or Max color equivalents. When disabled, Grid values that are outside of defined Min or Max values are left transparent. |
| Start          | numeric value | Lower limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |
| Stop           | numeric value | Upper limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |

Table 5.21: Scope tab: Advanced sub-tab

| Control/Tool       | Option/Range               | Description                                                                                                                                                                                                                              |
|--------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| FFT Window         | Cosine squared (ring-down) | Several different FFT windows to choose from. Each window function results in a different trade-off between amplitude accuracy and spectral leakage. Please check the literature to find the window function that best suits your needs. |
|                    | Rectangular                |                                                                                                                                                                                                                                          |
|                    | Hann                       |                                                                                                                                                                                                                                          |
|                    | Hamming                    |                                                                                                                                                                                                                                          |
|                    | Blackman Harris            |                                                                                                                                                                                                                                          |
|                    | Flat Top                   |                                                                                                                                                                                                                                          |
|                    | Exponential (ring-down)    |                                                                                                                                                                                                                                          |
|                    | Cosine (ring-down)         |                                                                                                                                                                                                                                          |
| Resolution (Hz)    | mHz to Hz                  | Spectral resolution defined by the reciprocal acquisition time (sample rate, number of samples recorded).                                                                                                                                |
| Absolute Frequency | ON / OFF                   | Shifts x-axis labeling to show the absolute frequency in the center as opposed to 0 Hz, when turned off.                                                                                                                                 |
| Spectral Density   | ON / OFF                   | Calculate and show the spectral density. If power is enabled the power spectral density value is calculated. The spectral density is used to analyze noise.                                                                              |
| Power              | ON / OFF                   | Calculate and show the power value. To extract power spectral density (PSD) this button should be enabled together with Spectral Density.                                                                                                |
| Persistence        | ON / OFF                   | Keeps previous scope shots in the display.<br><br>The color scheme visualizes the number of occurrences at certain positions in time and amplitude by a multi-color scheme.                                                              |
| BW Limit           | ON / OFF                   | Select between scope sample decimation and averaging. Averaging avoids aliasing but may conceal single-sample peaks.                                                                                                                     |
| Rate               |                            | Streaming rate of the scope channels. The streaming rate can be adjusted independent from the scope sampling rate. The maximum rate depends on the interface used for transfer. Note: scope streaming requires the DIG option.           |

Table 5.22: Scope tab: History sub-tab

| Control/Tool | Option/Range | Description                                                                                                                                                                                                                                                                                                 |
|--------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| History      | History      | Each entry in the list corresponds to a single trace in the history. The number of traces displayed in the plot is limited to 20. Use the toggle buttons to hide or show individual traces. Use the color picker to change the color of a trace in the plot. Double click on a list entry to edit its name. |

| Control/Tool | Option/Range                                                                      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length       | integer value                                                                     | Maximum number of records in the history. The number of entries displayed in the list is limited to the 100 most recent ones.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Clear All    |  | Remove all records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Clear        |  | Remove selected records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Load file    |                                                                                   | Load data from a file into the history. Loading does not change the data type and range displayed in the plot, this has to be adapted manually if data is not shown.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Name         |                                                                                   | Enter a name which is used as a folder name to save the history into. An additional three digit counter is added to the folder name to identify consecutive saves into the same folder name.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Auto Save    |                                                                                   | Activate autosaving. When activated, any measurements already in the history are saved. Each subsequent measurement is then also saved. The autosave directory is identified by the text "autosave" in the name, e.g. "sweep_autosave_001". If autosave is active during continuous running of the module, each successive measurement is saved to the same directory. For single shot operation, a new directory is created containing all measurements in the history. Depending on the file format, the measurements are either appended to the same file, or saved in individual files. For HDF5 and ZView formats, measurements are appended to the same file. For MATLAB and SXM formats, each measurement is saved in a separate file. |
| File Format  |                                                                                   | Select the file format in which to save the data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Save         |  | Save the traces in the history to a file accessible in the File Manager tab. The file contains the signals in the Vertical Axis Groups of the Control sub-tab. The data that is saved depends on the selection from the pull-down list. Save All: All traces are saved. Save Sel: The selected traces are saved.                                                                                                                                                                                                                                                                                                                                                                                                                              |

For the Math sub-tab please see [the table "Plot math description"](#) in the section called "Cursors and Math".

## 5.10. Data Acquisition Tab

The Data Acquisition tool is one of the powerful time domain measurement tools as introduced in [Unique Set of Analysis Tools](#) and is available on all HF2LI instruments. This tab used to be named Software Trigger tab in previous versions of the LabOne software.


### 5.10.1. Features

- Time-domain and frequency domain display for all continuously streamed data
- Capture and color scale display of imaging data
- Frame averaging and pixel interpolation
- Automatic trigger level determination
- Display of multiple traces
- Adjustable record history
- Mathematical toolkit for signal analysis

### 5.10.2. Description

The Data Acquisition tab features display and recording of shot-wise and imaging data sets upon a trigger event. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.23: App icon and short description

| Control/<br>Tool | Option/<br>Range                                                                  | Description                                                                                               |
|------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| DAQ              |  | Provides complex trigger functionality on all continuously streamed data samples and time domain display. |

The Data Acquisition tab (see [Figure 5.23](#)) is divided into a display section on the left and a configuration section on the right. The configuration section is further divided into a number of sub-tabs.

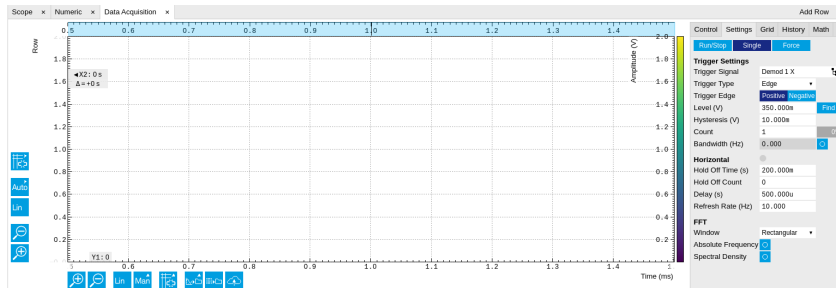


Figure 5.23: LabOne UI: Data Acquisition tab

The Data Acquisition tool brings the trigger functionality of a scope with FFT capability to the demodulator signals and other streamed data. The user can choose between a variety of different trigger and display options in the time and frequency domain.

Use the **Control** sub-tab to configure which signals are measured, both in time and in frequency domain. Measurement signals can be added to the Vertical Axis Groups section as described in [Vertical Axis Groups](#). There is one vertical axis group for each the time domain and the frequency domain data.

The trigger condition is configured in the **Settings** sub-tab. Among the selection of Trigger Types provided here, Edge and Pulse are applicable to analog trigger sources such as demodulator data, auxiliary voltages, or oscillator frequencies. The trigger time resolution is enhanced above the sampling rate of the analog data by using interpolation. Instead of manually setting a Trigger Level, you can click on **Find** to have LabOne find a value by analyzing the data stream. In case of noisy trigger sources, both the Bandwidth and the Hysteresis setting can help preventing false trigger events. The Bandwidth setting provides a configurable low-pass filter applied to the trigger source. When enabling this function, be sure to choose a sufficiently high bandwidth to resolve the signal feature that should be triggered upon, i.e., the signal edge or pulse. The Bandwidth setting does not affect the recorded data.

For trigger sources with a slowly varying offset, the Tracking Edge and Tracking Pulse Trigger Types provide continuous adjustment of the Level and Hysteresis. In Tracking mode, the Bandwidth setting plays a different role than for the Edge and Pulse trigger types. Here, the Bandwidth should be chosen sufficiently low to filter out all fast features and only let pass the slow offset. The Trigger Types HW Trigger and Digital are used for TTL signals on the DIO lines. Using the Bits and Bit Mask setting, complex multi-bit trigger conditions on the DIO lines can be defined. The timing resolution for digital triggers is given by the demodulator sample rate because the state of the DIO line is transferred together with demodulator data.

The Horizontal section of the Settings sub-tab contains the settings for shot Duration and Delay (negative delays correspond to pre-trigger time). Also minimum and maximum pulse width for the Pulse and Tracking Pulse trigger types are defined here.

The **Grid** sub-tab provides imaging functionality to capture and display two-dimensional data sets organized in frames consisting of rows and columns. By default, the number of rows is 1, which means the Data Acquisition tool operates similar to a scope. With a Rows setting larger than 1, every newly captured shot of data is assigned to a row until the number of rows is reached and the frame is complete. After completion of a full frame, the new data either replace the old or averaging is performed, according to the selected Operation and Repetitions setting. On the horizontal axis, the Duration of a shot is divided into a number of samples specified with the Columns setting. The Mode settings provides the functionality for post-processing of the streamed data for interpolation, resampling, and alignment with the trigger event. This is particularly helpful when capturing data from several sources, e.g. demodulators and PID controllers. As illustrated in [Figure 5.24](#), in such situation the streamed data don't lie on the same temporal grid by default. This can be changed by setting Mode to Linear or Nearest. In these modes, the streams from several sources will be up-sampled to match the sampling rate and temporal grid of the fastest data stream. This means data processing after saving becomes more convenient, however note that the actual streamed data rate is not increased, and the data don't gain in time resolution. A two-dimensional color scale image of

the data can be enabled and controlled in the Display section. The display features configurable scaling, range, and color scale.

With enabled grid mode, the data of a completed frame after averaging appear as a list entry in the **History** sub-tab. See [History List](#) for more details on how data in the history list can be managed and stored.

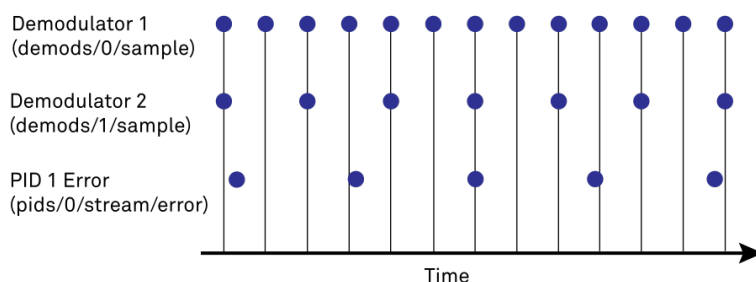


Figure 5.24: Samples from different sources configured with different rates: demodulator 1 at 2N kSa/s, demodulator 2 at N kSa/s and PID Error 1 at M kSa/s (N not divisible by M). Although each stream consists of equidistantly spaced samples in time, the sample timestamps from different streams are not necessarily aligned due to the different sampling rates

### 5.10.3. Functional Elements


Table 5.24: DAQ tab: Control sub-tab

| Control/Tool | Option/Range | Description                                                                                     |
|--------------|--------------|-------------------------------------------------------------------------------------------------|
| Run/Stop     |              | Start and stop the Data Acquisition tool                                                        |
| Single       |              | Run the Data Acquisition tool once (record Count trigger events)                                |
| Force        |              | Forces a single trigger event.                                                                  |
| Triggered    | grey/green   | When green, indicates that new trigger shots are being captured and displayed in the plot area. |

For the Vertical Axis Groups, please see [the table "Vertical Axis Groups description" in the section called "Vertical Axis Groups"](#).

Table 5.25: DAQ tab: Settings sub-tab

| Control/Tool   | Option/Range | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trigger Signal |              | Source signal for trigger condition. Navigate through the tree view that appears and click on the required signal.                                                                                                                                                                                                                                                                                                                                                                                             |
| Trigger Type   |              | Select the type of trigger to use. Selectable options depend on the selected trigger signal.                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                | Continuous   | Continuous triggering.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                | Edge         | Analog edge triggering based on high and low level. Hysteresis on the levels and low-pass filtering can be used to reduce the risk of wrong trigger for noisy trigger signals.                                                                                                                                                                                                                                                                                                                                 |
|                | Digital      | Digital triggering on the 32-bit DIO lines. The bit value defines the trigger condition. The bit mask controls the bits that are used for trigger evaluation. When using a Positive Edge trigger setting, a trigger event occurs as soon as the equality $(DIO\ Value) \text{ AND } (Bit\ Mask) = (Bits) \text{ AND } (Bit\ Mask)$ is fulfilled (and was not previously fulfilled). In order to trigger on DIO0 set bit value to 1 and bit mask to 1; to trigger on DIO1 set bit value to 2 and bit mask to 2. |
|                | Pulse        | Triggers if a pulse on an analog signal is within the min and max pulse width. Pulses can be defined as either low to high then high to low (positive), the reverse (negative) or both.                                                                                                                                                                                                                                                                                                                        |

| Control/Tool      | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                        |
|-------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   | Tracking Edge                                                                       | Edge triggering with automatic adjustment of trigger levels to compensate for drifts. The tracking speed is controlled by the bandwidth of the low-pass filter. For this filter noise rejection can only be achieved by level hysteresis.                                                                                          |
|                   | HW Trigger                                                                          | Trigger on one of the four trigger inputs. Ensure that the trigger level and the trigger coupling is correctly adjusted. The trigger input state can be monitored on the plotter.                                                                                                                                                  |
|                   | Tracking Pulse                                                                      | Pulse triggering with automatic adjustment of trigger levels to compensate for drifts. The tracking speed is controlled by the bandwidth of the low-pass filter. For this filter noise rejection can only be achieved by level hysteresis.                                                                                         |
| Pulse Type        | Positive/<br>Negative/<br>Both                                                      | Select between negative, positive or both pulse forms in the signal to trigger on.                                                                                                                                                                                                                                                 |
| Trigger Edge      | Positive/<br>Negative/<br>Both                                                      | Triggers when the trigger input signal is crossing the trigger level from either high to low, low to high or both. This field is only displayed for trigger type Edge, Tracking Edge and Event Count.                                                                                                                              |
| Bits              | 0 to $2^{32}-1$                                                                     | Specify the value of the DIO to trigger on. All specified bits have to be set in order to trigger. This field is only displayed for trigger type Digital.                                                                                                                                                                          |
| Bit Mask          | 0 to $2^{32}-1$                                                                     | Specify a bit mask for the DIO trigger value. The trigger value is bits AND bit mask (bitwise). This field is only displayed for trigger type Digital.                                                                                                                                                                             |
| Level             | full signal range                                                                   | Specify the trigger level value.                                                                                                                                                                                                                                                                                                   |
| Find              |  | Automatically find the trigger level based on the current signal.                                                                                                                                                                                                                                                                  |
| Hysteresis        | full signal range                                                                   | The hysteresis is important to trigger on the correct edge in the presence of noise. The hysteresis is applied below the trigger level for positive trigger edge selection. It is applied above for negative trigger edge selection, and on both sides for triggering on both edges.                                               |
| Count             | integer number                                                                      | Number of trigger events to record (in Single mode)                                                                                                                                                                                                                                                                                |
| Trigger progress  | 0% to 100%                                                                          | The percentage of triggers already acquired (in Single mode)                                                                                                                                                                                                                                                                       |
| Bandwidth (Hz)    | 0 to $0.5 * \text{Sampling Rate}$                                                   | Bandwidth of the low-pass filter applied to the trigger signal. For edge and pulse trigger use a bandwidth larger than the signal sampling rate divided by 20 to keep the phase delay. For tracking filter use a bandwidth smaller than signal sampling frequency divided by 100 to just track slow signal components like drifts. |
| Enable            | ON / OFF                                                                            | Enable low-pass filtering of the trigger signal.                                                                                                                                                                                                                                                                                   |
| Hold Off Time (s) | positive numeric value                                                              | Hold off time before the trigger is rearmed. A hold off time smaller than the duration will lead to overlapping trigger frames.                                                                                                                                                                                                    |
| Hold Off Count    | integer value                                                                       | Number of skipped triggers until the next trigger is recorded again.                                                                                                                                                                                                                                                               |
| Delay (s)         | -Duration to Duration                                                               | Time delay of trigger frame position (left side) relative to the trigger edge. For delays smaller than 0, trigger edge inside trigger frame (pre trigger). For delays greater than 0, trigger edge before trigger frame (post trigger)                                                                                             |
| Refresh Rate      | 100 mHz to 10 Hz                                                                    | Set the maximum refresh rate for plot updates. The actual refresh rate depends on other factors such as the hold-off time and duration.                                                                                                                                                                                            |
| Pulse Min (s)     | 0 to Duration                                                                       | Minimum pulse width to trigger on.                                                                                                                                                                                                                                                                                                 |
| Pulse Max (s)     | 0 to Duration                                                                       | Maximum pulse width to trigger on.                                                                                                                                                                                                                                                                                                 |



| Control/Tool       | Option/Range               | Description                                                                                                                                                                                                                     |
|--------------------|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Window             | Cosine squared (ring-down) | Several different FFT windows to choose from. Depending on the application it makes a huge difference which of the provided window function is used. Please check the literature to find out the best trade off for your needs. |
|                    | Rectangular                |                                                                                                                                                                                                                                 |
|                    | Hann                       |                                                                                                                                                                                                                                 |
|                    | Hamming                    |                                                                                                                                                                                                                                 |
|                    | Blackman Harris            |                                                                                                                                                                                                                                 |
|                    | Flat Top                   |                                                                                                                                                                                                                                 |
|                    | Exponential (ring-down)    |                                                                                                                                                                                                                                 |
|                    | Cosine (ring-down)         |                                                                                                                                                                                                                                 |
| Absolute Frequency | ON / OFF                   | Shifts x-axis labeling to show the demodulation frequency in the center as opposed to 0 Hz, when turned off.                                                                                                                    |
| Spectral Density   | ON / OFF                   | Calculate and show the spectral density. If power is enabled the power spectral density value is calculated. The spectral density is used to analyze noise.                                                                     |




Table 5.26: DAQ tab: Grid sub-tab

| Control/Tool     | Option/Range    | Description                                                                                                                                                                                                                                                                  |
|------------------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mode             |                 | Select resampling method for two-dimensional data recording.                                                                                                                                                                                                                 |
|                  | Off             | Two-dimensional data recording is disabled.                                                                                                                                                                                                                                  |
|                  | Nearest         | Resampling is performed using substitution by closest data point.                                                                                                                                                                                                            |
|                  | Linear          | Resampling is performed using linear interpolation.                                                                                                                                                                                                                          |
|                  | Exact (on-grid) | Adjust the duration so that the grid distance matches the maximal sampling rate of the selected signals. This allows for on-grid sampling of measurement data. If a signal uses lower sampling rate it will be up-sampled by linear interpolation.                           |
| On Grid Sampling | Green or yellow | When green, indicates that all the captured data is aligned to the grid. When yellow, indicates that some data is not aligned to the grid and is interpolated. This can happen when one or more data sources have different sampling rates, or when a sampling rate changes. |
| Operation        |                 | Select row update method.                                                                                                                                                                                                                                                    |
|                  | Replace         | New row replaces old row.                                                                                                                                                                                                                                                    |
|                  | Average         | The data for each row is averaged over a number of repetitions.                                                                                                                                                                                                              |
|                  | Std             | The data for each row is the standard deviation over a number of repetitions.                                                                                                                                                                                                |
| Columns          | numeric value   | Number of columns. The data along the horizontal axis are resampled to a number of samples defined by this setting.                                                                                                                                                          |
| Duration         | up to 1000 s    | Recording length for each triggered data set. In exact sampling mode the duration is a read-only field. The duration is then defined by the maximal sampling rate and column size.                                                                                           |
| Rows             | numeric value   | Number of rows                                                                                                                                                                                                                                                               |
| Scan Direction   |                 | Select the scan direction and mode                                                                                                                                                                                                                                           |
|                  | Forward         | Scan direction from left to right                                                                                                                                                                                                                                            |
|                  | Reverse         | Scan direction from right to left                                                                                                                                                                                                                                            |
|                  | Bidirectional   | Alternate scanning in both directions                                                                                                                                                                                                                                        |

| Control/Tool        | Option/Range               | Description                                                                                                                                                                                                           |
|---------------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Repetitions         | numeric value              | Number of repetitions used for averaging                                                                                                                                                                              |
| Row-wise repetition | ON / OFF                   | Enable row-wise repetition. With row-wise repetition, each row is calculated from successive repetitions before starting the next row. With grid-wise repetition, the entire grid is calculated with each repetition. |
| Waterfall           | ON / OFF                   | Enable to show the 2D plot in waterfall mode. It will always update the last line.                                                                                                                                    |
| Overwrite           | ON / OFF                   | Enable to overwrite the grid in continuous mode. History will not be collected. A history element will only be created when the analysis is stopped.                                                                  |
| Plot Type           |                            | Select the plot type.                                                                                                                                                                                                 |
|                     | None                       | No plot displayed.                                                                                                                                                                                                    |
|                     | 2D                         | Display defined number of grid rows as one 2D plot.                                                                                                                                                                   |
|                     | Row                        | Display only the trace of index defined in the Active Row field.                                                                                                                                                      |
|                     | 2D + Row                   | Display 2D and row plots.                                                                                                                                                                                             |
| Active Row          | integer value              | Set the row index to be displayed in the Row plot.                                                                                                                                                                    |
| Track Active Row    | ON / OFF                   | If enabled, the active row marker will track with the last recorded row. The active row control field is read-only if enabled.                                                                                        |
| Palette             | Solar                      | Select the colormap for the current plot.                                                                                                                                                                             |
|                     | Viridis                    |                                                                                                                                                                                                                       |
|                     | Inferno                    |                                                                                                                                                                                                                       |
|                     | Balance                    |                                                                                                                                                                                                                       |
|                     | Turbo                      |                                                                                                                                                                                                                       |
|                     | Grey                       |                                                                                                                                                                                                                       |
| Colorscale          | ON / OFF                   | Enable/disable the colorscale bar display in the 2D plot.                                                                                                                                                             |
| Mapping             |                            | Mapping of colorscale.                                                                                                                                                                                                |
|                     | Lin                        | Enable linear mapping.                                                                                                                                                                                                |
|                     | Log                        | Enable logarithmic mapping.                                                                                                                                                                                           |
|                     | dB                         | Enable logarithmic mapping in dB.                                                                                                                                                                                     |
| Scaling             | Full Scale/<br>Manual/Auto | Scaling of colorscale.                                                                                                                                                                                                |
| Clamp To Color      | ON / OFF                   | When enabled, grid values that are outside of defined Min or Max region are painted with Min or Max color equivalents. When disabled, Grid values that are outside of defined Min or Max values are left transparent. |
| Start               | numeric value              | Lower limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |
| Stop                | numeric value              | Upper limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |

Table 5.27: DAQ tab: History sub-tab

| Control/Tool | Option/Range | Description                                                                                                                                                                                                                                                                                                 |
|--------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| History      | History      | Each entry in the list corresponds to a single trace in the history. The number of traces displayed in the plot is limited to 20. Use the toggle buttons to hide or show individual traces. Use the color picker to change the color of a trace in the plot. Double click on a list entry to edit its name. |

| Control/Tool | Option/Range                                                                      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Length       | integer value                                                                     | Maximum number of records in the history. The number of entries displayed in the list is limited to the 100 most recent ones.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Clear All    |  | Remove all records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Clear        |  | Remove selected records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Load file    |                                                                                   | Load data from a file into the history. Loading does not change the data type and range displayed in the plot, this has to be adapted manually if data is not shown.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Name         |                                                                                   | Enter a name which is used as a folder name to save the history into. An additional three digit counter is added to the folder name to identify consecutive saves into the same folder name.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Auto Save    |                                                                                   | Activate autosaving. When activated, any measurements already in the history are saved. Each subsequent measurement is then also saved. The autosave directory is identified by the text "autosave" in the name, e.g. "sweep_autosave_001". If autosave is active during continuous running of the module, each successive measurement is saved to the same directory. For single shot operation, a new directory is created containing all measurements in the history. Depending on the file format, the measurements are either appended to the same file, or saved in individual files. For HDF5 and ZView formats, measurements are appended to the same file. For MATLAB and SXM formats, each measurement is saved in a separate file. |
| File Format  |                                                                                   | Select the file format in which to save the data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Save         |  | Save the traces in the history to a file accessible in the File Manager tab. The file contains the signals in the Vertical Axis Groups of the Control sub-tab. The data that is saved depends on the selection from the pull-down list. Save All: All traces are saved. Save Sel: The selected traces are saved.                                                                                                                                                                                                                                                                                                                                                                                                                              |

For the Math sub-tab please see [the table "Plot math description"](#) in the section called "Cursors and Math".

## 5.11. Spectrum Analyzer Tab

The Spectrum Analyzer is one of the powerful frequency domain measurement tools as introduced in [Unique Set of Analysis Tools](#) and is available on all HF2 Series instruments.

### 5.11.1. Features

- Fast, high-resolution FFT spectrum analyzer
- Signals: demodulated data ( $X+iY$ ,  $R$ ,  $\theta$ ,  $f$  and  $d\theta/dt/(2\pi)$ ), PID, Boxcar, Auxiliary Inputs, and more
- Variable center frequency, frequency resolution and frequency span
- Auto bandwidth
- Waterfall display
- Choice of 4 different FFT window functions
- Continuous and block-wise acquisition with different types of averaging
- Detailed noise power analysis
- Support for Input Scaling and Input Units
- Mathematical toolbox for signal analysis

### 5.11.2. Description

The Spectrum Analyzer provides frequency domain analysis of demodulator data. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.28: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                                               |
|--------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Spectrum     |  | Provides FFT functionality to all continuously streamed measurement data. |

The Spectrum tab (see [Figure 5.25](#)) is divided into a display section on the left and a configuration section on the right. The configuration section is further divided into a number of sub-tabs.

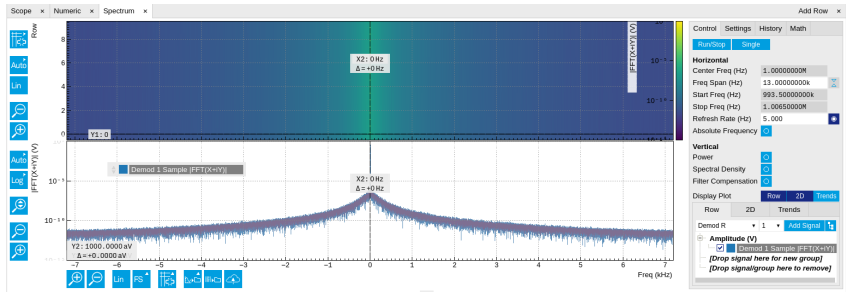



Figure 5.25: LabOne UI: Spectrum analyzer tab



The Spectrum Analyzer allows for spectral analysis of all the demodulator data by performing the fast Fourier transform (FFT) on the complex demodulator data samples  $X+iY$  (with  $i$  as the imaginary unit). The result of this FFT is a spectrum centered around the demodulation frequency, whereas applying a FFT directly on the raw input data would produce a spectrum centered around zero frequency. The latter procedure corresponds to the Frequency Domain operation in the [Scope Tab](#). The main difference between the two is that the Spectrum Analyzer tool can acquire data for a much longer periods of time and therefore can achieve very high frequency resolution around the demodulation frequency. By default, the spectrum is displayed centered around zero. Sometimes however it is convenient to shift the frequency axis by the demodulation frequency which allows one to identify the frequencies on the horizontal axis with the physical frequencies at the signal inputs. This can be done by activating Absolute Frequency on the Settings sub-tab.


By default, the display section contains a line plot of the spectrum together with a color waterfall plot of the last few acquired spectra. The waterfall plot makes it easier to see the evolution of the spectrum over time. The display layout as well as the number of rows in the color plot can be configured in the Settings sub-tab.

Data shown in the Spectrum tab have passed a low-pass filter with a well-defined order and bandwidth. This is most clearly noted by the shape of the noise floor. One has to take care that the selected frequency span, which equals the demodulator sampling rate, is 5 to 10 times higher than the filter bandwidth in order to prevent measurement errors due to aliasing. The Auto Bandwidth button  adjusts the sampling rate so that it suits the filter settings. The Spectrum tab features FFT display of a selection of data available in the Signal Type drop-down list in addition to the complex demodulator samples  $X+iY$ . Looking at the FFT of polar demodulator values  $R$  and  $\Theta$  allows one to discriminate between phase noise components and amplitude noise components in the signal. The FFT of the phase derivative  $d\Theta/dt$  provides a quantitative view of the spectrum of demodulator frequencies. That is particularly useful in conjunction with the PLL or the ExtRef functionalities. The FFT of the frequency samples then provide a quantitative view of what frequency noise components are present in the reference signal and also helps to find the optimal PLL bandwidth to track the signal. Note that many of the signals in the Signal Type list are real-valued, rather than complex-valued. Their spectra are single-sided with minimum frequency of 0 Hz.

5.11.3. Functional Elements

Table 5.29: Spectrum tab: Settings sub-tab

| Control/Tool     | Option/Range                                                                        | Description                                                                                                                                                                                |
|------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Run/Stop         |  | Run the FFT spectrum analysis continuously                                                                                                                                                 |
| Single           |  | Run the FFT spectrum analysis once                                                                                                                                                         |
| Center Freq (Hz) | numeric value                                                                       | Demodulation frequency of the selected demodulator used as input for the spectrum. For complex FFT( $X+iY$ ) the demodulation frequency defines the center frequency of the displayed FFT. |

| Control/Tool         | Option/Range                                                                      | Description                                                                                                                                                                                                                     |
|----------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Frequency Span (Hz)  | numeric value                                                                     | Set the frequency span of interest for the complex FFT. A FFT based on real input data will display half of the frequency span up to the Nyquist frequency.                                                                     |
| Auto Bandwidth       |  | Automatic adjustment of the demodulator bandwidths to obtain optimal alias rejection for the selected frequency span which is equivalent to the sampling rate. The functionality is only available if the spectrum is enabled.  |
| Start Frequency (Hz) | numeric value                                                                     | Indicates the start frequency of the FFT.                                                                                                                                                                                       |
| Stop Frequency (Hz)  | numeric value                                                                     | Indicates the end frequency of the FFT.                                                                                                                                                                                         |
| Refresh Rate (Hz)    | numeric value                                                                     | Set the maximum plot refresh rate. The actual refresh rate also depends on other parameters such as FFT length. In overlapped mode the refresh rate defines the amount of overlapping.                                          |
| Overlapped FFT       | ON / OFF                                                                          | Enable overlapped FFTs. If disabled, FFTs are performed on distinct abutting data sets. If enabled, the data sets of successive FFTs overlap based on the defined refresh rate.                                                 |
| Power                | ON / OFF                                                                          | Calculate and show the power value. To extract power spectral density (PSD) this button should be enabled together with spectral density.                                                                                       |
| Spectral Density     | ON / OFF                                                                          | Calculate and show the spectral density. If power is enabled the power spectral density value is calculated. The spectral density is used to analyze noise.                                                                     |
| Filter Compensation  | ON / OFF                                                                          | Spectrum is corrected by demodulator filter transfer function. Allows for quantitative comparison of amplitudes of different parts of the spectrum.                                                                             |
| Absolute Frequency   | ON / OFF                                                                          | Shifts x-axis labeling to show the demodulation frequency in the center as opposed to 0 Hz, when turned off.                                                                                                                    |
| FFT length           | numeric value                                                                     | The number of samples used for the FFT. Values entered that are not a binary power are truncated to the nearest power of 2.                                                                                                     |
| Sampling Progress    | 0% to 100%                                                                        | The percentage of the FFT buffer already acquired. The progress includes the number of rows and averages.                                                                                                                       |
| FFT Duration (s)     | numeric value                                                                     | Indicates the length in time of the samples used for a single FFT.                                                                                                                                                              |
| Window               | Cosine squared (ring-down)                                                        | Several different FFT windows to choose from. Depending on the application it makes a huge difference which of the provided window function is used. Please check the literature to find out the best trade off for your needs. |
|                      | Rectangular                                                                       |                                                                                                                                                                                                                                 |
|                      | Hann                                                                              |                                                                                                                                                                                                                                 |
|                      | Hamming                                                                           |                                                                                                                                                                                                                                 |
|                      | Blackman Harris                                                                   |                                                                                                                                                                                                                                 |
|                      | Flat Top                                                                          |                                                                                                                                                                                                                                 |
|                      | Exponential (ring-down)                                                           |                                                                                                                                                                                                                                 |
|                      | Cosine (ring-down)                                                                |                                                                                                                                                                                                                                 |
| Resolution (Hz)      | mHz to Hz                                                                         | Spectral resolution defined by the reciprocal acquisition time (sample rate, number of samples recorded).                                                                                                                       |
| Rows                 | numeric value                                                                     | Number of rows                                                                                                                                                                                                                  |
| Averages             | numeric value                                                                     | Number of FFT averaged for each row. Setting the value to 1 will disable any averaging.                                                                                                                                         |
| Waterfall            | ON / OFF                                                                          | Enable to show the 2D plot in waterfall mode. It will always update the lowest line.                                                                                                                                            |

| Control/Tool     | Option/Range               | Description                                                                                                                                                                                                           |
|------------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overwrite        | ON / OFF                   | Enable to overwrite the grid in continuous mode. History will not be collected. A history element will only be created when the analysis is stopped.                                                                  |
| Plot Type        |                            | Select the plot type.                                                                                                                                                                                                 |
|                  | None                       | No plot displayed.                                                                                                                                                                                                    |
|                  | 2D                         | Display defined number of grid rows as one 2D plot.                                                                                                                                                                   |
|                  | Row                        | Display only the trace of index defined in the Active Row field.                                                                                                                                                      |
|                  | 2D + Row                   | Display 2D and row plots.                                                                                                                                                                                             |
| Active Row       | integer value              | Set the row index to be displayed in the Row plot.                                                                                                                                                                    |
| Track Active Row | ON / OFF                   | If enabled, the active row marker will track with the last recorded row. The active row control field is read-only if enabled.                                                                                        |
| Palette          | Solar                      | Select the colormap for the current plot.                                                                                                                                                                             |
|                  | Viridis                    |                                                                                                                                                                                                                       |
|                  | Inferno                    |                                                                                                                                                                                                                       |
|                  | Balance                    |                                                                                                                                                                                                                       |
|                  | Turbo                      |                                                                                                                                                                                                                       |
|                  | Grey                       |                                                                                                                                                                                                                       |
| Colorscale       | ON / OFF                   | Enable/disable the colorscale bar display in the 2D plot.                                                                                                                                                             |
| Mapping          |                            | Mapping of colorscale.                                                                                                                                                                                                |
|                  | Lin                        | Enable linear mapping.                                                                                                                                                                                                |
|                  | Log                        | Enable logarithmic mapping.                                                                                                                                                                                           |
|                  | dB                         | Enable logarithmic mapping in dB.                                                                                                                                                                                     |
| Scaling          | Full Scale/<br>Manual/Auto | Scaling of colorscale.                                                                                                                                                                                                |
| Clamp To Color   | ON / OFF                   | When enabled, grid values that are outside of defined Min or Max region are painted with Min or Max color equivalents. When disabled, Grid values that are outside of defined Min or Max values are left transparent. |
| Start            | numeric value              | Lower limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |
| Stop             | numeric value              | Upper limit of colorscale.<br><br>Only visible for manual scaling.                                                                                                                                                    |

For the Math sub-tab please see [the table "Plot math description"](#) in the section called "Cursors and Math".

## 5.12. Sweeper Tab

The Sweeper is a highly versatile measurement tool available on all HF2LI instruments. The Sweeper enables scans of an instrument parameter over a defined range and simultaneous measurement of a selection of continuously streamed data. In the special case where the sweep parameter is an oscillator frequency, the Sweeper offers the functionality of a frequency response analyzer (FRA), a well-known class of instruments.

### 5.12.1. Features


- Full-featured parametric sweep tool for frequency, phase shift, output amplitude, DC output voltages, etc.

- Simultaneous display of data from different sources (Demodulators, PIDs, auxiliary inputs, and others)
- Different application modes, e.g. Frequency response analyzer (Bode plots), noise amplitude sweeps, etc.
- Different sweep types: single, continuous (run / stop), bidirectional, binary
- Persistent display of previous sweep results
- XY Mode for Nyquist plots or I-V curves
- Normalization of sweeps
- Auto bandwidth, averaging and display normalization
- Support for Input Scaling and Input Units
- Phase unwrap
- Full support of sinc filter

5.12.2. Description

The Sweeper supports a variety of experiments where a parameter is changed stepwise and numerous measurement data can be graphically displayed. Open the tool by clicking the corresponding icon in the UI side bar. The Sweeper tab (see Figure 5.26) is divided into a plot section on the left and a configuration section on the right. The configuration section is further divided into a number of sub-tabs.

Table 5.30: App icon and short description

| Control/<br>Tool | Option/<br>Range                                                                  | Description                                                                                                                                     |
|------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Sweeper          |  | Sweep frequencies, voltages, and other quantities over a defined range and display various response functions including statistical operations. |

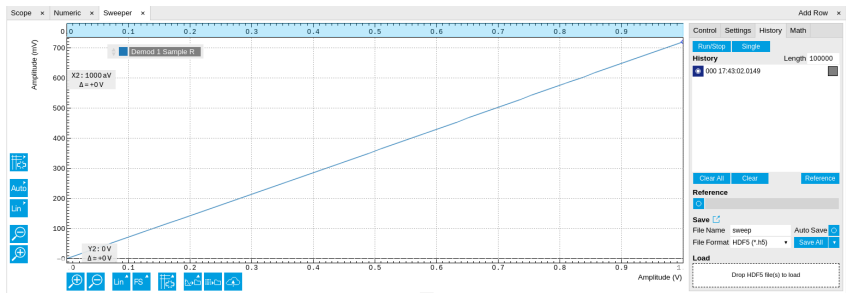


Figure 5.26: LabOne UI: Sweeper tab

The **Control** sub-tab holds the basic measurement settings such as Sweep Parameter, Start/Stop values, and number of points (Length) in the Horizontal section. Measurement signals can be added in the Vertical Axis Groups section. A typical use of the Sweeper is to perform a frequency sweep and measure the response of the device under test in the form of a Bode plot. As an example, AFM and MEMS users require to determine the resonance frequency and the phase delay of their oscillators. The Sweeper can also be used to sweep parameters other than frequency, for instance signal amplitudes and DC offset voltages. A sweep of the Auxiliary Output offset can for instance be used to measure current-voltage (I-V) characteristics. The XY Mode allows one to use a measured signal, rather than the sweep parameter, on the horizontal axis. This is useful to obtain Nyquist plots in impedance measurements, or to display an I-V curve in a four-probe measurement of a nonlinear device.

For frequency sweeps, the sweep points are distributed logarithmically, rather than linearly, between the start and stop values by default. This feature is particularly useful for sweeps over several decades and can be disabled with the Log checkbox. The Sweep Mode setting is useful for identifying measurement problems caused by hysteretic sample behavior or too fast sweeping speed. Such problems would cause non-overlapping curves in a bidirectional sweep.

Note

The Sweeper actively modifies the main settings of the demodulators and oscillators. So in particular for situations where multiple experiments are served maybe even from different control computers great care needs to be taken so that the parameters altered by the sweeper module do not have unwanted effects elsewhere.

The Sweeper offers two operation modes differing in the level of detail of the accessible settings: the Application Mode and the Advanced Mode. Both of them are accessible in the **Settings** sub-tab.

The Application Mode provides the choice between six measurement approaches that should help to quickly obtain correct measurement results for a large range of applications. Users who like to be in control of all the settings can access them by switching to the Advanced Mode.

In the Statistics section of the Advanced Mode one can control how data is averaged at each sweep point: either by specifying the Sample count, or by specifying the number of filter time constants (TC). The actual measurement time is determined by the larger of the two settings, taking into account the demodulator sample rate and filter settings. The Algorithm settings determines the statistics calculated from the measured data: the average for general purposes, the deviation for noise measurements, or the mean square for power measurements. The Phase Unwrap features ensures continuity of a phase measurement curve across the PM180 degree boundary. Enabling the Sinc Filter setting means that the demodulator Sinc Filter gets activated for sweep points below 50 Hz in Auto and Fixed mode. This speeds up measurements at small frequencies as explained in the [Sinc Filtering](#).

In the Settling section one can control the waiting time between a parameter setting and the first measurement. Similarly to the Statistics setting, one has the choice between two different representations of this waiting time. The actual settling time is the maximum of the values set in units of absolute time and a time derived from the demodulator filter and a desired inaccuracy (e.g. 1 m for 0.1%). Let's consider an example. For a 4<sup>th</sup> order filter and a 3 dB bandwidth of 100 Hz we obtain a step response that attains 90% after about 4.5 ms. This can be easily measured by using the Data Acquisition tool as indicated in [Figure 5.27](#). It is also explained in [Discrete-Time Filters](#). In case the full range is set to 1 V this means a measurement has a maximum error caused by imperfect settling of about 0.1 V. However, for most measurements the neighboring values are close compared to the full range and hence the real error caused is usually much smaller.

In the Filter section of the Advanced mode, the Bandwidth Mode setting determines how the filters of the activated demodulators are configured. In Manual mode, the current setting (in the Lock-in tab) remains unchanged by the Sweeper. In Fixed mode, the filter settings can be controlled from within the Sweeper tab. In Auto mode, the Sweeper determines the filter bandwidth for each sweep point based on a desired  $\omega$  suppression. The  $\omega$  suppression depends on the measurement frequency and the filter steepness. For frequency sweeps, the bandwidth will be adjusted for every sweep point within the bound set by the Max Bandwidth setting. The Auto mode is particularly useful for frequency sweeps over several decades, because the continuous adjustment of the bandwidth considerably reduces the overall measurement time.

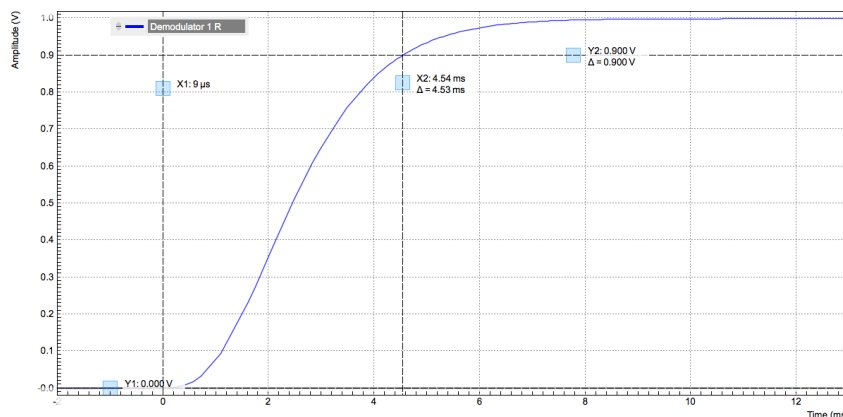


Figure 5.27: Demodulator settling time and inaccuracy: measurement carried out with the Data Acquisition tool to illustrate the settling time for a 4

By default the plot area keeps the memory and display of the last 100 sweeps represented in a list in the **History** sub-tab. See [History List](#) for more details on how data in the history list can be managed and stored. With the Reference feature, it is possible to divide all measurements in the history by a reference measurement. This is useful for instance to eliminate spurious effects in a frequency response sweep. To define a certain measurement as the reference, mark it in the list and click on [Reference](#). Then enable the Reference mode with the checkbox below the list to update the plot display. Note that the Reference setting does not affect data saving: saved files always contain raw data.

## Note

The Sweeper can get stuck whenever it does not receive any data. A common mistake is to select to display demodulator data without enabling the data transfer of the associated demodulator in the Lock-in tab.







## Note

Once a sweep is performed the sweeper stores all data from the enabled demodulators and auxiliary inputs even when they are not displayed immediately in the plot area. These data can be accessed at a later point in time simply by choosing the corresponding signal display settings (Input Channel).

### 5.12.3. Functional Elements

Table 5.31: Sweeper tab: Control sub-tab

| Control/Tool        | Option/Range                                                                        | Description                                                                                                                                                                                                 |
|---------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Run/Stop            |    | Runs the sweeper continuously.                                                                                                                                                                              |
| Single              |    | Runs the sweeper once.                                                                                                                                                                                      |
| Copy From X-Axis    |                                                                                     | Takes over start and stop value from the X-axis.                                                                                                                                                            |
| Copy From X-Cursors |                                                                                     | Takes over start and stop value from X-cursors. Button is disabled when one or both X cursors are not visible.                                                                                              |
| Start (unit)        | numeric value                                                                       | Start value of the sweep parameter. The unit adapts according to the selected sweep parameter.                                                                                                              |
| Stop (unit)         | numeric value                                                                       | Stop value of the sweep parameter. The unit adapts according to the selected sweep parameter.                                                                                                               |
| Length              | integer value                                                                       | Sets the number of measurement points.                                                                                                                                                                      |
| Progress            | 0 to 100%                                                                           | Reports the sweep progress as ratio of points recorded.                                                                                                                                                     |
| Sweep Param         |  | Selects the parameter to be swept. Navigate through the tree view that appears and click on the required parameter. The available selection depends on the configuration of the device.                     |
| Sweep Mode          |                                                                                     | Select the scanning type, default is sequential (incremental scanning from start to stop value)                                                                                                             |
|                     | Sequential                                                                          | Sequential sweep from Start to Stop value                                                                                                                                                                   |
|                     | Binary                                                                              | Non-sequential sweep continues increase of resolution over entire range                                                                                                                                     |
|                     | Bidirectional                                                                       | Sequential sweep from Start to Stop value and back to Start again                                                                                                                                           |
|                     | Reverse                                                                             | Reverse sweep from Stop to Start value                                                                                                                                                                      |
| X Distribution      | Linear / Logarithmic                                                                | Selects between linear and logarithmic distribution of the sweep parameter.                                                                                                                                 |
| Remaining           | numeric value                                                                       | Reporting of the remaining time of the current sweep. A valid number is only displayed once the sweeper has been started. An undefined sweep time is indicated as NaN.                                      |
| Invert Y Axis       | ON / OFF                                                                            | The xy-plot is displayed with inverted y-axis. This mode is used for Nyquist plots that allow for displaying $-\text{imag}(z)$ on the y-axis and $\text{real}(z)$ on the x-axis.                            |
| X Signal            |  | Selects the signal that defines the x-axis for xy-plots. The available selection depends on the configuration of the device. Displaying the selected signal source will result in a diagonal straight line. |

For the Vertical Axis Groups, please see [the table "Vertical Axis Groups description" in the section called "Vertical Axis Groups"](#).





Table 5.32: Sweeper tab: Settings sub-tab

| Control/Tool | Option/Range | Description                                                                  |
|--------------|--------------|------------------------------------------------------------------------------|
| Filter       |              | Application Mode: preset configuration. Advanced Mode: manual configuration. |

| Control/<br>Tool                   | Option/<br>Range         | Description                                                                                                                                                                                                                                 |
|------------------------------------|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                    | Application Mode         | The sweeper sets the filters and other parameters automatically.                                                                                                                                                                            |
|                                    | Advanced Mode            | The sweeper uses manually configured parameters.                                                                                                                                                                                            |
| Application                        |                          | Select the sweep application mode                                                                                                                                                                                                           |
|                                    | Parameter Sweep          | Only one data sample is acquired per sweeper point.                                                                                                                                                                                         |
|                                    | Parameter Sweep Averaged | Multiple data samples are acquired per sweeper point of which the average value is displayed.                                                                                                                                               |
|                                    | Noise Amplitude Sweep    | Multiple data samples are acquired per sweeper point of which the standard deviation is displayed (e.g. to determine input noise). For accurate noise measurement, the signal amplitude R is replaced by its quadrature components X and Y. |
|                                    | Freq Response Analyzer   | Narrow band frequency response analysis. Averaging is enabled.                                                                                                                                                                              |
|                                    | 3-Omega Sweep            | Optimized parameters for 3-omega application. Averaging is enabled.                                                                                                                                                                         |
|                                    | FRA (Sinc Filter)        | The sinc filter helps to speed up measurements for frequencies below 50 Hz in FRA mode. For higher frequencies it is automatically disabled. Averaging is off.                                                                              |
|                                    | Impedance                | This application mode uses narrow bandwidth filter settings to achieve high calibration accuracy.                                                                                                                                           |
| Precision                          |                          | Choose between a high speed scan speed or high precision and accuracy.                                                                                                                                                                      |
|                                    | Low -> fast sweep        | Medium accuracy/precision is optimized for sweep speed.                                                                                                                                                                                     |
|                                    | High -> standard speed   | Medium accuracy/precision takes more measurement time.                                                                                                                                                                                      |
|                                    | Very high -> slow sweep  | High accuracy/precision takes more measurement time.                                                                                                                                                                                        |
| Bandwidth Mode                     |                          | Automatically is recommended in particular for logarithmic sweeps and assures the whole spectrum is covered.                                                                                                                                |
|                                    | Auto                     | All bandwidth settings of the chosen demodulators are automatically adjusted. For logarithmic sweeps the measurement bandwidth is adjusted throughout the measurement.                                                                      |
|                                    | Fixed                    | Define a certain bandwidth which is taken for all chosen demodulators for the course of the measurement.                                                                                                                                    |
|                                    | Manual                   | The sweeper module leaves the demodulator bandwidth settings entirely untouched.                                                                                                                                                            |
| Time Constant/<br>Bandwidth Select |                          | Defines the display unit of the low-pass filter to use for the sweep in fixed bandwidth mode: time constant (TC), noise equivalent power bandwidth (NEP), 3 dB bandwidth (3 dB).                                                            |
|                                    | TC                       | Defines the low-pass filter characteristic using time constant of the filter.                                                                                                                                                               |
|                                    | Bandwidth NEP            | Defines the low-pass filter characteristic using the noise equivalent power bandwidth of the filter.                                                                                                                                        |
|                                    | Bandwidth 3 dB           | Defines the low-pass filter characteristic using the cut-off frequency of the filter.                                                                                                                                                       |
| Time Constant/<br>Bandwidth        | numeric value            | Defines the measurement bandwidth for Fixed bandwidth sweep mode, and corresponds to either noise equivalent power bandwidth (NEP), time constant (TC) or 3 dB bandwidth (3 dB) depending on selection.                                     |

| Control/Tool           | Option/Range       | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Order                  | numeric value      | Selects the filter roll off to set on the device in Fixed and Auto bandwidth modes. It ranges from 1 (6 dB/octave) to 8 (48 dB/octave).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Max Bandwidth (Hz)     | numeric value      | Maximal bandwidth used in auto bandwidth mode. The effective bandwidth will be calculated based on this max value, the frequency step size, and the omega suppression.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| BW Overlap             | ON / OFF           | If enabled the bandwidth of a sweep point may overlap with the frequency of neighboring sweep points. The effective bandwidth is only limited by the maximal bandwidth setting and omega suppression. As a result, the bandwidth is independent of the number of sweep points. For frequency response analysis bandwidth overlap should be enabled to achieve maximal sweep speed.                                                                                                                                                                                                                                                                                                     |
| Omega Suppression (dB) | numeric value      | Suppression of the omega and 2-omega components. Large suppression will have a significant impact on sweep time especially for low filter orders.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Min Settling Time (s)  | numeric value      | Minimum wait time in seconds between a sweep parameter change and the recording of the next sweep point. This parameter can be used to define the required settling time of the experimental setup. The effective wait time is the maximum of this value and the demodulator filter settling time determined from the Inaccuracy value specified.                                                                                                                                                                                                                                                                                                                                      |
| Inaccuracy             | numeric value      | Demodulator filter settling inaccuracy defining the wait time between a sweep parameter change and recording of the next sweep point. The settling time is calculated as the time required to attain the specified remaining proportion [1e-13, 0.1] of an incoming step function. Typical inaccuracy values: 10 m for highest sweep speed for large signals, 100 u for precise amplitude measurements, 100 n for precise noise measurements. Depending on the order the settling accuracy will define the number of filter time constants the sweeper has to wait. The maximum between this value and the settling time is taken as wait time until the next sweep point is recorded. |
| Settling Time (TC)     | numeric value      | Calculated wait time expressed in time constants defined by the specified filter settling inaccuracy.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Algorithm              |                    | Selects the measurement method.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                        | Averaging          | Calculates the average on each data set.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                        | Standard Deviation | Calculates the standard deviation on each data set.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                        | Average Power      | Calculates the electric power based on a 50 $\Omega$ input impedance.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Count (Sa)             | integer number     | Sets the number of data samples per sweeper parameter point that is considered in the measurement. The maximum between samples, time and number of time constants is taken as effective calculation time.                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Count (s)              | numeric value      | Sets the time during which data samples are processed. The maximum between samples, time and number of time constants is taken as effective calculation time.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Count (TC)             | 0/5/15/50/100 TC   | Sets the effective measurement time per sweeper parameter point that is considered in the measurement. The maximum between samples, time and number of time constants is taken as effective calculation time.                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Phase Unwrap           | ON / OFF           | Allows for unwrapping of slowly changing phase evolutions around the +/-180 degree boundary.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Spectral Density       | ON / OFF           | Selects whether the result of the measurement is normalized versus the demodulation bandwidth.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Sinc Filter            | ON / OFF           | Enables sinc filter if sweep frequency is below 50 Hz. Will improve the sweep speed at low frequencies as omega components do not need to be suppressed by the normal low-pass filter.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

Table 5.33: Sweeper tab: History sub-tab

| Control/Tool   | Option/Range                                                                        | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| History        | History                                                                             | Each entry in the list corresponds to a single trace in the history. The number of traces displayed in the plot is limited to 20. Use the toggle buttons to hide or show individual traces. Use the color picker to change the color of a trace in the plot. Double click on a list entry to edit its name.                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Length         | integer value                                                                       | Maximum number of records in the history. The number of entries displayed in the list is limited to the 100 most recent ones.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Clear All      |    | Remove all records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Clear          |    | Remove selected records from the history list.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Load file      |                                                                                     | Load data from a file into the history. Loading does not change the data type and range displayed in the plot, this has to be adapted manually if data is not shown.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Name           |                                                                                     | Enter a name which is used as a folder name to save the history into. An additional three digit counter is added to the folder name to identify consecutive saves into the same folder name.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Auto Save      |                                                                                     | Activate autosaving. When activated, any measurements already in the history are saved. Each subsequent measurement is then also saved. The autosave directory is identified by the text "autosave" in the name, e.g. "sweep_autosave_001". If autosave is active during continuous running of the module, each successive measurement is saved to the same directory. For single shot operation, a new directory is created containing all measurements in the history. Depending on the file format, the measurements are either appended to the same file, or saved in individual files. For HDF5 and ZView formats, measurements are appended to the same file. For MATLAB and SXM formats, each measurement is saved in a separate file. |
| File Format    |                                                                                     | Select the file format in which to save the data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Save           |  | Save the traces in the history to a file accessible in the File Manager tab. The file contains the signals in the Vertical Axis Groups of the Control sub-tab. The data that is saved depends on the selection from the pull-down list. Save All: All traces are saved. Save Sel: The selected traces are saved.                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Reference      |  | Use the selected trace as reference for all active traces.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Reference On   | ON / OFF                                                                            | Enable/disable the reference mode.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Reference name | name                                                                                | Name of the reference trace used.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

For the Math sub-tab please see [the table "Plot math description"](#) in the section called "Cursors and Math".

## 5.13. Auxiliary Tab

The Auxiliary tab provides access to the settings of the Auxiliary Inputs and Auxiliary Outputs; it is available on all HF2 Series instruments.


### 5.13.1. Features

- Monitor signal levels of auxiliary input connectors
- Monitor signal levels of auxiliary output connectors
- Auxiliary output signal sources: Demodulators, PLLs and manual setting
- Define Offsets and Scaling for auxiliary output values
- Control auxiliary output range limitations

5.13.2. Description

The Auxiliary tab serves mainly to monitor and control the auxiliary inputs and outputs. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.34: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                                                 |
|--------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Aux          |  | Controls all settings regarding the auxiliary inputs and auxiliary outputs. |

The Auxiliary tab (see [Figure 5.28](#)) is divided into three sections. The Aux Input section gives two graphical and two numerical monitors for the signal amplitude applied to the auxiliary inputs on the back panel. In the middle of the tab the Aux Output section allows to associate any of the measured signals to one of the 4 auxiliary outputs on the instrument front panel. With the action button next to the Offset values the effective voltage on the auxiliary outputs can be automatically set to zero. The analog output voltages can be limited to a certain range in order to avoid damaging the parts connected to the outputs.

Note

Please note the change of units of the scaling factor depending on what measurement signal is chosen.

Two Aux Output Levels on the right provides 4 graphical and 4 numerical indicators to monitor the voltages currently set on the auxiliary outputs.

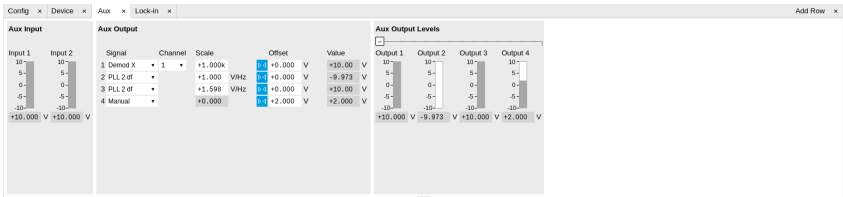



Figure 5.28: LabOne UI: Auxiliary tab

5.13.3. Functional Elements

Table 5.35: Auxiliary tab

| Control/Tool            | Option/Range  | Description                                                                        |
|-------------------------|---------------|------------------------------------------------------------------------------------|
| Auxiliary Input Voltage | -10 V to 10 V | Voltage measured at the Auxiliary Input.                                           |
| Signal                  |               | Select the signal source to be represented on the Auxiliary Output.                |
|                         | X             | Select the demodulator X component for auxiliary output.                           |
|                         | Y             | Select the demodulator Y component for auxiliary output.                           |
|                         | R             | Select the demodulator magnitude component for auxiliary output.                   |
|                         | $\theta$      | Select the demodulator phase component for auxiliary output.                       |
|                         | PLL 1 df      | Select the PLL 1 delta frequencies result. HF2LI-PLL option needs to be installed. |
|                         | PLL 2 df      | Select the PLL 2 delta frequencies result. HF2LI-PLL option needs to be installed. |
|                         | PID 1 Out     | Select the PID 1 controller's output. HF2LI-PID option needs to be installed.      |

| Control/Tool | Option/Range                                                                      | Description                                                                                                  |
|--------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
|              | PID 2 Out                                                                         | Select the PID 2 controller's output. HF2LI-PID option needs to be installed.                                |
|              | PID 3 Out                                                                         | Select the PID 3 controller's output. HF2LI-PID option needs to be installed.                                |
|              | PID 4 Out                                                                         | Select the PID controller's output. HF2LI-PID option needs to be installed.                                  |
|              | Manual                                                                            | Manually define an auxiliary output voltage using the offset field.                                          |
| Channel      | index                                                                             | Select the channel according to the selected signal source.                                                  |
| Scale        | numerical value                                                                   | Multiplication factor to scale the signal. Auxiliary Output Value = Signal*Scale + Offset                    |
| Auto-zero    |  | Automatically adjusts the Offset to set the Auxiliary Output Value to zero.                                  |
| Offset       | numerical value in Volts                                                          | Add the specified offset voltage to the signal after scaling. Auxiliary Output Value = Signal*Scale + Offset |
| Value        | -10 V to 10 V                                                                     | Voltage present on the Auxiliary Output. Auxiliary Output Value = Signal*Scale + Offset.                     |

## 5.14. Inputs/Outputs Tab

The In / Out tab provides access to the settings of the Instrument's main Signal Inputs and Signal Outputs. It is available on all HF2 Series instruments.


### 5.14.1. Features

- Signal input configuration
- Signal output configuration

### 5.14.2. Description

The In / Out tab gives access to the same settings as do the left-most and the right-most sections of the Lock-in tab. It is mainly intended to be used on small screens that can not show the entire the Lock-in tab at once. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.36: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                                                     |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| In/Out       |  | Gives access to all controls relevant for the Signal Inputs and Signal Outputs of each channel. |

The In / Out tab contains one section for the signal inputs and one for the signal outputs. All of the corresponding connectors are placed on the instrument front panel. The In / Out tab looks differently depending on whether the HF2-MF Multi-frequency option is installed or not.

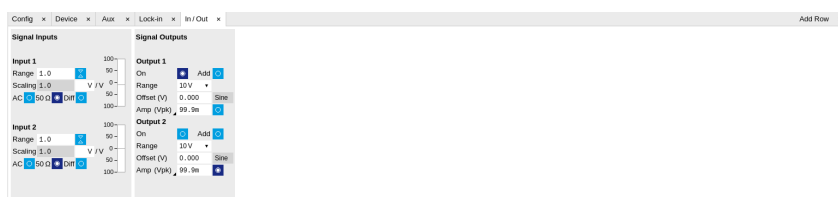


Figure 5.29: LabOne UI: Inputs/Outputs tab (base configuration)

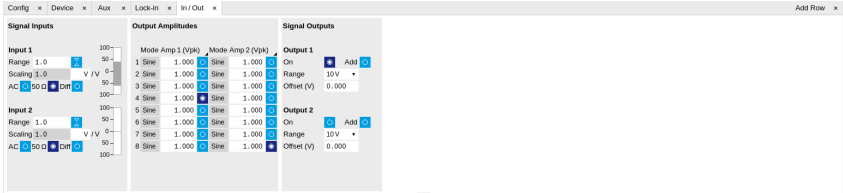


Figure 5.30: LabOne UI: Inputs/Outputs tab (with HF2-MF Multi-frequency option)

5.14.3. Functional Elements

All functional elements are equivalent to the ones on the Lock-in tab. See [the Lock-in Tab](#) or [Lock-in MF Tab](#) for a detailed description of the functional elements.

5.15. DIO Tab

The DIO tab provides access to the settings and controls of the digital I/O as well as the Trigger channels and is available on all HF2 Series instruments.

5.15.1. Features

- Monitor and control of digital I/O connectors
- Control settings for external reference and triggering

5.15.2. Description

The DIO tab is the main panel to control the digital inputs and outputs as well as the trigger levels and external reference channels . Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.37: App icon and short description

| Control/ Tool | Option/ Range                                                                       | Description                                                                                                                                  |
|---------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| DIO           |  | Gives access to all controls relevant for the digital inputs and outputs including DIO, Trigger Inputs, Trigger Outputs, and Marker Outputs. |

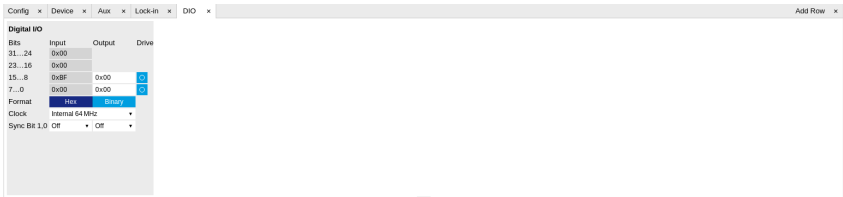


Figure 5.31: LabOne UI: DIO tab

The Digital I/O section provides numerical monitors to observe the states of the digital inputs and outputs. Moreover, with the values set in the Output column and the Drive button activated the states can also be actively set in different numerical formats.

With the Sync Bit 1,0 setting it's possible to activate a TTL synchronization signal on one of the DIO BNC connectors on the instrument back panel.

5.15.3. Functional Elements

Table 5.38: Digital input and output channels, reference and trigger

| Control/Tool       | Option/Range                                         | Description                                                                                                                                                                                                                                 |
|--------------------|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| QA Result Overflow | grey/yellow/red                                      | Red: present overflow condition on the DIO interface during readout. Yellow: indicates an overflow occurred in the past. An overflow can happen if readouts are triggered faster than the maximum possible data-rate of the DIO interface.  |
| DIO bits           | label                                                | Partitioning of the 32 bits of the DIO into 4 buses of 8 bits each. Each bus can be used as an input or output.                                                                                                                             |
| DIO input          | numeric value in either Hex or Binary format         | Current digital values at the DIO input port.                                                                                                                                                                                               |
| DIO output         | numeric value in either hexadecimal or binary format | Digital output values. Enable drive to apply the signals to the output.                                                                                                                                                                     |
| DIO drive          | ON / OFF                                             | When on, the corresponding 8-bit bus is in output mode. When off, it is in input mode.                                                                                                                                                      |
| Format             |                                                      | Select DIO view format.                                                                                                                                                                                                                     |
|                    | Hexadecimal                                          | DIO view format is hexadecimal.                                                                                                                                                                                                             |
|                    | Binary                                               | DIO view format is binary.                                                                                                                                                                                                                  |
| Clock              |                                                      | Select DIO internal or external clocking.                                                                                                                                                                                                   |
|                    | Internal 64 MHz                                      | The DIO is internally clocked with a fixed frequency of 64 MHz.                                                                                                                                                                             |
|                    | Clk Pin 68                                           | The DIO is externally clocked with a clock signal connected to DIO Pin 68.<br><br>Available frequency range 1 Hz to 64 MHz.                                                                                                                 |
| Sync Bit 1         |                                                      | Select a demodulator reference signal to be applied on DIO 1.                                                                                                                                                                               |
|                    | Off                                                  | DIO output 1 (BNC connector) is not used for sync output and is free for other purposes.                                                                                                                                                    |
|                    | Demod 1 to 8                                         | Reference signal of the selected demodulator is output on DIO 1. Note: there is a 166 ns delay between the sync on DIO 1 and the front panel outputs (sync on DIO 1 comes first) which leads to a relevant phase shift at high frequencies. |
| Sync Bit 0         |                                                      | Select a demodulator reference signal to be applied on DIO 0.                                                                                                                                                                               |
|                    | Off                                                  | DIO output 0 (BNC connector) is not used for sync output and is free for other purposes.                                                                                                                                                    |
|                    | Demod 1 to 8                                         | Reference signal of the selected demodulator is output on DIO 0. Note: there is a 166 ns delay between the sync on DIO 0 and the front panel outputs (sync on DIO 0 comes first) which leads to a relevant phase shift at high frequencies. |
| Delay (s)          |                                                      | This delay adds an offset that acts only on the trigger/marker output. The total delay to the trigger/marker output is the sum of this value and the value of the output delay node.                                                        |

## 5.16. Config Tab

The Config tab provides access to all major LabOne settings and is available on all HF2LI instruments.

### 5.16.1. Features


- define instrument connection parameters
- browser session control
- define UI appearance (grids, theme, etc.)
- store and load instrument settings and UI settings
- configure data recording



5.16.2. Description

The Config tab serves as a control panel for all general LabOne settings and is opened by default on start-up. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.39: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                |
|--------------|-----------------------------------------------------------------------------------|--------------------------------------------|
| Config       |  | Provides access to software configuration. |

The Config tab (see [Figure 5.32](#)) is divided into four sections to control connections, sessions, settings, user interface appearance and data recording.

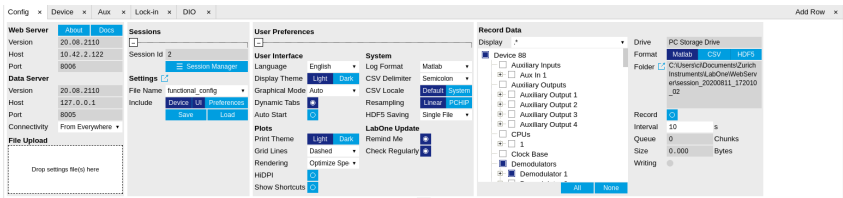


Figure 5.32: LabOne UI: Config tab

The **Connection** section provides information about connection and server versions. Access from remote locations can be restricted with the connectivity setting.

The **Session** section provides the session number which is also displayed in the status bar. Clicking on Session Dialog opens the session dialog window (same as start up screen) that allows one to load different settings files as well as to connect to other instruments.

The **Settings** section allows one to load and save instrument and UI settings. The saved settings are later available in the session dialog.

The **User Preferences** section contains the settings that are continuously stored and automatically reloaded the next time an HF2 Series instrument is used from the same computer account.

For low ambient light conditions the use of the dark display theme is recommended (see [Figure 5.33](#)).

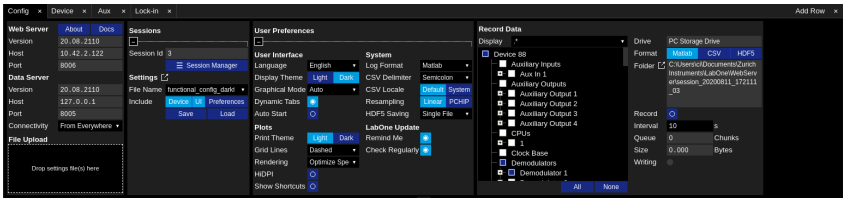






Figure 5.33: LabOne UI: Config tab - dark theme

The **Record Data** section contains all settings necessary to obtain hard copies of measurement data. The tree structure (see [Tree Selector](#) section) provides access to a large number of signals and instrument settings. Use the View Filter in order to reduce the tree structure to the most commonly used nodes such as the demodulator sample nodes. Whenever the Record button is enabled, all selected nodes get saved continuously in MATLAB, comma-separated value (CSV), or other supported file formats. For each selected node at least one file gets generated, but the data may be distributed over several files during long recordings. See [Saving and Loading Data](#) for more information on data saving. The quickest way to inspect the files after recording is to use the File Manager tab described in [File Manager Tab](#). Apart from the numerical data and settings, the files contain timestamps. These integer numbers encode the measurement time in units of the instrument clock period 1/(210 MHz). The timestamps are universal within one instrument and can be used to align the data from different files.

5.16.3. Functional Elements

Table 5.40: Config tab

| Control/Tool | Option/Range                                                                        | Description                            |
|--------------|-------------------------------------------------------------------------------------|----------------------------------------|
| About        |  | Get information about LabOne software. |

| Control/Tool                     | Option/Range                                                                        | Description                                                                                                                                                                                          |
|----------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Web Server Version and Revision  | string                                                                              | Web Server version and revision number                                                                                                                                                               |
| Host                             | default is localhost: 127.0.0.1                                                     | IP-Address of the LabOne Web Server                                                                                                                                                                  |
| Port                             | 4 digit integer                                                                     | LabOne Web Server TCP/IP port                                                                                                                                                                        |
| Data Server Version and Revision | string                                                                              | Data Server version and revision number                                                                                                                                                              |
| Host                             | default is localhost: 127.0.0.1                                                     | IP-Address of the LabOne Data Server                                                                                                                                                                 |
| Port                             | default is 8004                                                                     | TCP/IP port used to connect to the LabOne Data Server.                                                                                                                                               |
| Connect/Disconnect               |                                                                                     | Connect/disconnect the LabOne Data Server of the currently selected device. If a LabOne Data Server is connected only devices that are visible to that specific server are shown in the device list. |
| Status                           | grey/green                                                                          | Indicates whether the LabOne User Interface is connected to the selected LabOne data server. Grey: no connection. Green: connected. Red: error while connecting.                                     |
| Connectivity                     | From Everywhere                                                                     | Forbid/Allow to connect to this Data Server from other computers.                                                                                                                                    |
|                                  | Localhost Only                                                                      |                                                                                                                                                                                                      |
| File Upload                      | drop area                                                                           | Drag and drop files in this box to upload files. Clicking on the box opens a file dialog for file upload.<br><br>Supported files: Settings (*.xml).                                                  |
| Session Id                       | integer number                                                                      | Session identifier. A session is a connection between a client and LabOne Data Server.                                                                                                               |
| Session Manager                  |  | Open the session manager dialog. This allows for device or session change. The current session can be continued by pressing cancel.                                                                  |
| File Name                        | selection of available file names                                                   | Save/load the device and user interface settings to/from the selected file on the internal flash drive. The setting files can be downloaded/uploaded using the Files tab.                            |
| Include                          |                                                                                     | Enable Save/Load of particular settings.                                                                                                                                                             |
|                                  | No Include Settings                                                                 | Please enable settings type to be included during Save/Load.                                                                                                                                         |
|                                  | Include Device                                                                      | Enable Save/Load of Device settings.                                                                                                                                                                 |
|                                  | Include UI                                                                          | Enable Save/Load of User Interface settings.                                                                                                                                                         |
|                                  | Include UI and Device                                                               | Enable Save/Load of User Interface and Device settings.                                                                                                                                              |
|                                  | Include Preferences                                                                 | Enable loading of User Preferences from settings file.                                                                                                                                               |
|                                  | Include UI, Device and Preferences                                                  | Enable Save/Load of User Interface, Device and User Preferences.                                                                                                                                     |
| Save                             |  | Save the user interface and device setting to a file.                                                                                                                                                |
| Load                             |  | Load the user interface and device setting from a file.                                                                                                                                              |
| Language                         |                                                                                     | Choose the language for the tooltips.                                                                                                                                                                |
| Display Theme                    | Dark                                                                                | Choose theme of the user interface.                                                                                                                                                                  |
|                                  | Light                                                                               |                                                                                                                                                                                                      |
| Plot Print Theme                 | Dark                                                                                | Choose theme for printing SVG plots.                                                                                                                                                                 |
|                                  | Light                                                                               |                                                                                                                                                                                                      |
| Plot Grid                        | None                                                                                | Select active grid setting for all SVG plots.                                                                                                                                                        |

| Control/Tool      | Option/Range                                                                           | Description                                                                                                                                                                                                                                                                                                                 |
|-------------------|----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   | Dashed                                                                                 |                                                                                                                                                                                                                                                                                                                             |
|                   | Solid                                                                                  |                                                                                                                                                                                                                                                                                                                             |
| Plot Rendering    |                                                                                        | Select rendering hint about what tradeoffs to make as the browser renders SVG plots. The setting has impact on rendering speed and plot display for both displayed and saved plots.                                                                                                                                         |
|                   | Auto                                                                                   | Indicates that the browser shall make appropriate tradeoffs to balance speed, crisp edges and geometric precision, but with geometric precision given more importance than speed and crisp edges.                                                                                                                           |
|                   | Optimize Speed                                                                         | The browser shall emphasize rendering speed over geometric precision and crisp edges. This option will sometimes cause the browser to turn off shape anti-aliasing.                                                                                                                                                         |
|                   | Crisp Edges                                                                            | Indicates that the browser shall attempt to emphasize the contrast between clean edges of artwork over rendering speed and geometric precision. To achieve crisp edges, the user agent might turn off anti-aliasing for all lines and curves or possibly just for straight lines which are close to vertical or horizontal. |
|                   | Geometric Precision                                                                    | Indicates that the browser shall emphasize geometric precision over speed and crisp edges.                                                                                                                                                                                                                                  |
| Resampling Method |                                                                                        | Select the resampling interpolation method. Resampling corrects for sample misalignment in subsequent scope shots. This is important when using reduced sample rates with a time resolution below that of the trigger.                                                                                                      |
|                   | Linear                                                                                 | Linear interpolation                                                                                                                                                                                                                                                                                                        |
|                   | PCHIP                                                                                  | Piecewise Cubic Hermite Interpolating Polynomial                                                                                                                                                                                                                                                                            |
| Show Shortcuts    | ON / OFF                                                                               | Displays a list of keyboard and mouse wheel shortcuts for manipulating plots.                                                                                                                                                                                                                                               |
| Dynamic Tabs      | ON / OFF                                                                               | If enabled, sections inside the application tabs are collapsed automatically depending on the window width.                                                                                                                                                                                                                 |
| Graphical Mode    | Collapsed                                                                              | Select the display mode for the graphical elements. Auto format will select the format which fits best the current window width.                                                                                                                                                                                            |
|                   | Auto                                                                                   |                                                                                                                                                                                                                                                                                                                             |
|                   | Expanded                                                                               |                                                                                                                                                                                                                                                                                                                             |
| Log Format        | .NET                                                                                   | Choose the command log format. See status bar and [User] \Documents\Zurich Instruments\LabOne\WebServer\Log                                                                                                                                                                                                                 |
|                   | Telnet                                                                                 |                                                                                                                                                                                                                                                                                                                             |
|                   | MATLAB                                                                                 |                                                                                                                                                                                                                                                                                                                             |
|                   | Python                                                                                 |                                                                                                                                                                                                                                                                                                                             |
| CSV Delimiter     | Tab                                                                                    | Select which delimiter to insert for CSV files.                                                                                                                                                                                                                                                                             |
|                   | Comma                                                                                  |                                                                                                                                                                                                                                                                                                                             |
|                   | Semicolon                                                                              |                                                                                                                                                                                                                                                                                                                             |
| CSV Locale        | System locale. Use the symbols set in the language and region settings of the computer | Select the locale used for defining the decimal point and digit grouping symbols in numeric values in CSV files. The default locale uses dot for the decimal point and no digit grouping, e.g. 1005.07. The system locale uses the symbols set in the language and region settings of the computer.                         |
|                   | Default locale. Dot for the decimal point and no digit grouping, e.g. 1005.07          |                                                                                                                                                                                                                                                                                                                             |
| HDF5 Saving       | Multiple files. Each measurement goes in a separate file                               | For HDF5 file format only: Select whether each measurement should be stored in a separate file, or whether all measurements should be saved in a single file.                                                                                                                                                               |

| Control/Tool    | Option/Range                                 | Description                                                                                                                                                                                                                                                                               |
|-----------------|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                 | Single file. All measurements go in one file |                                                                                                                                                                                                                                                                                           |
| Auto Start      | ON / OFF                                     | Skip session manager dialog at start-up if selected device is available.<br><br>In case of an error or disconnected device the session manager will be reactivated.                                                                                                                       |
| Update Reminder | ON / OFF                                     | Display a reminder on start-up if the LabOne software wasn't updated in 180 days.                                                                                                                                                                                                         |
| Update Check    | ON / OFF                                     | Periodically check for new LabOne software over the internet.                                                                                                                                                                                                                             |
| Drive           |                                              | Select the drive for data saving.                                                                                                                                                                                                                                                         |
|                 | PC Storage Drive                             | Storage of the PC on which the LabOne Web Server is running.                                                                                                                                                                                                                              |
| Format          | HDF5                                         | File format of recorded and saved data.                                                                                                                                                                                                                                                   |
|                 | MATLAB                                       |                                                                                                                                                                                                                                                                                           |
|                 | CSV                                          |                                                                                                                                                                                                                                                                                           |
| Open Folder     |                                              | Open recorded data in the system File Explorer.                                                                                                                                                                                                                                           |
| Folder          | path indicating file location                | Folder containing the recorded data.                                                                                                                                                                                                                                                      |
| Save Interval   | Time in seconds                              | Time between saves to disk. A shorter interval means less system memory consumption, but for certain file formats (e.g. MATLAB) many small files on disk. A longer interval means more system memory consumption, but for certain file formats (e.g. MATLAB) fewer, larger files on disk. |
| Queue           | integer number                               | Number of data chunks not yet written to disk.                                                                                                                                                                                                                                            |
| Size            | integer number                               | Accumulated size of saved data in the current session.                                                                                                                                                                                                                                    |
| Record          | ON / OFF                                     | Start and stop saving data to disk as defined in the selection filter. Length of the files is determined by the Window Length setting in the Plotter tab.                                                                                                                                 |
| Writing         | grey/green                                   | Indicates whether data is currently written to disk.                                                                                                                                                                                                                                      |
| Display         | filter or regular expression                 | Display specific tree branches using one of the preset view filters or a custom regular expression.                                                                                                                                                                                       |
| Tree            | ON / OFF                                     | Click on a tree node to activate it.                                                                                                                                                                                                                                                      |
| All             |                                              | Select all tree elements.                                                                                                                                                                                                                                                                 |
| None            |                                              | Deselect all tree elements.                                                                                                                                                                                                                                                               |

For more information on the tree functionality in the Record Data section, please see [Tree Selector](#).

## 5.17. Device Tab

The Device tab is the main settings tab for the connected instrument and is available on all HF2 Series instruments.


### 5.17.1. Features

- Option and upgrade management
- External clock referencing (10 MHz)
- Instrument connectivity parameters
- Device monitor

5.17.2. Description

The **Device tab** serves mainly as a control panel for all settings specific to the instrument that is controlled by LabOne in this particular session. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.41: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                            |
|--------------|-----------------------------------------------------------------------------------|----------------------------------------|
| Device       |  | Provides instrument specific settings. |

The Device tab (see [Figure 5.34](#)) is divided into four sections: general instrument information, configuration, communication parameters, and a device monitor.

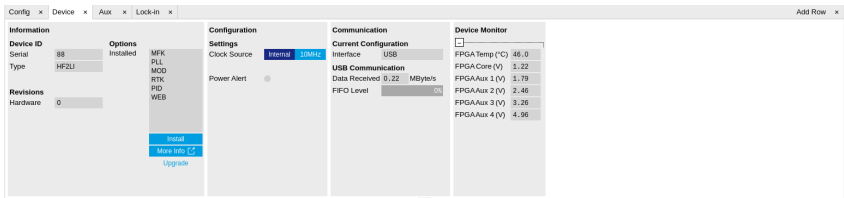


Figure 5.34: LabOne UI: Device tab

The **Information** section provides details about the instrument hardware and indicates the installed upgrade options. This is also the place where new options can be added by entering the provided option key.

The **Configuration** section allows one to change the reference from the internal clock to an external 10 MHz reference. The reference is to be connected to the Clock Input on the instrument back panel.

The **Communication** section serves to display the current data transfer rate over the USB interface.


Note

Packet loss on command streaming over TCP or USB: command packets should never be lost as it creates an invalid state.

The **Device Monitor** section is collapsed by default and generally only needed for servicing. It displays vitality signals of some of the instrument's hardware components.

5.17.3. Functional Elements

Table 5.42: Device tab

| Control/Tool           | Option/Range                                                                        | Description                                                                                            |
|------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Serial                 | 1-4 digit number                                                                    | Device serial number                                                                                   |
| Type                   | string                                                                              | Device type                                                                                            |
| Hardware               | integer number                                                                      | Hardware revision of the instrument                                                                    |
| Installed Options      | short names for each option                                                         | Options that are installed on this device.                                                             |
| Install                |  | Click to install options on this device. Requires a unique feature code and a power cycle after entry. |
| More Information       |                                                                                     | Display additional device information in a separate browser tab.                                       |
| Upgrade Device Options |                                                                                     | Display available upgrade options.                                                                     |
| Clock Source           |                                                                                     | 10MHz reference clock source.                                                                          |

| Control/Tool         | Option/Range | Description                                                                                                                                                                  |
|----------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      | Internal     | The internal 10MHz clock is used as the frequency and time base reference.                                                                                                   |
|                      | Clk 10MHz    | An external 10MHz clock is intended to be used as the frequency and time base reference. Provide a clean and stable 10MHz reference to the appropriate back panel connector. |
| Power Alert          |              | Check 115 V/230 V settings if active. Active if 5 V supply drops below 4.8 V.                                                                                                |
| Interface            |              | Active interface between device and data server. In case multiple options are available, the priority as indicated on the left applies.                                      |
| Data received (MB/s) |              | USB data rate: Current USB data rate from the device to the host PC                                                                                                          |
| USB FIFO Level (%)   |              | USB FIFO level: Indicates the USB FIFO fill level inside the device. When 100%, data is lost                                                                                 |

## 5.18. File Manager Tab


## 5.19. Features

- Quick access to measurement files, log files and settings files
- File preview for settings files and log files

### 5.19.1. Description

The File Manager tab provides standard tools to see and organize the files relevant for the use of the instrument. Files can be conveniently copied, renamed and deleted. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.43: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                      |
|--------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Files        |  | Access settings and measurement data files on the host computer. |

The Files tab (see [Figure 5.35](#)) provides three windows for exploring. The left window allows one to browse through the directory structure, the center window shows the files of the folder selected in the left window, and the right window displays the content of the file selected in the center window, e.g. a settings file or log file.

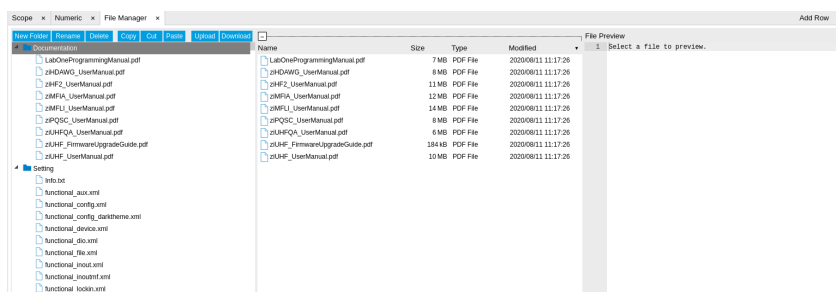










Figure 5.35: LabOne UI: File Manager tab

### 5.19.2. Functional Elements

Table 5.44: File tab

| Control/Tool | Option/Range                                                                      | Description                                                              |
|--------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| New Folder   |  | Create new folder at current location.                                   |
| Rename       |  | Rename selected file or folder.                                          |
| Delete       |  | Delete selected file(s) and/or folder(s).                                |
| Copy         |  | Copy selected file(s) and/or folder(s) to Clipboard.                     |
| Cut          |  | Cut selected file(s) and/or folder(s) to Clipboard.                      |
| Paste        |  | Paste file(s) and/or folder(s) from Clipboard to the selected directory. |
| Upload       |  | Upload file(s) and/or folder(s) to the selected directory.               |
| Download     |  | Download selected file(s) and/or folder(s).                              |

## 5.20. PID Tab

The PID tab is only available if the HF2-PID Quad PID Controller option is installed on the HF2 Series Instrument (the installed options are displayed in the Device tab).

### Note

Some settings in the PID tab are interdependent with settings that are accessible from other tabs. If the PID output controls a certain variable, e.g. Signal Output Offset, this variable will be shown as read-only where it appears in other tabs (i.e. in the Lock-in tab for this case).


### 5.20.1. Features

- Four fully programmable proportional, integral, derivative (PID) controllers
- PID Advisor with multiple DUT models, transfer function, and step function modeling
- More than 5 kHz regulation bandwidth
- Input parameters: demodulator data, auxiliary inputs, oscillator frequency
- Output parameters: output amplitudes, oscillator frequencies, auxiliary outputs and DIO

### 5.20.2. Description

The PID tab is the main control center for the feedback loop controllers in the instrument. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.45: App icon and short description

| Control/Tool | Option/Range                                                                        | Description                                                                         |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| PID          |  | Features all control, analysis, and simulation capabilities of the PID controllers. |

The PID tab (see [Figure 5.36](#)) consists of four identical side-tabs, each of them providing access to the functionality of one of the four PID controllers and the associated PID Advisor.

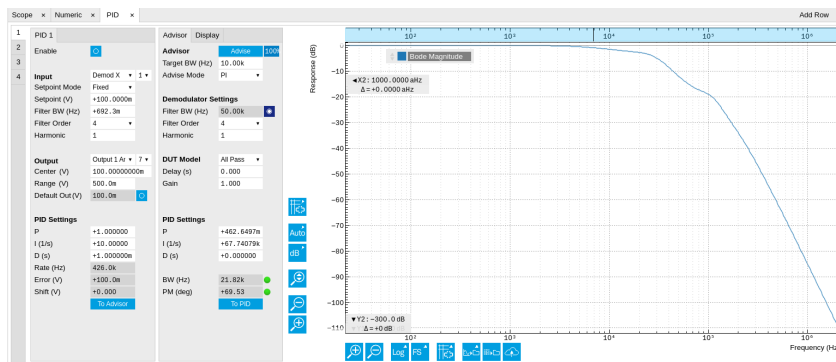


Figure 5.36: LabOne UI: PID tab

With their variety of different input and output connections, the LabOne PID controllers are extremely versatile and can be used in a wide range of different applications including laser locking or high-speed SPM. Figure 5.37 shows a block diagram of all PID controller components, their interconnections and the variables to be specified by the user.

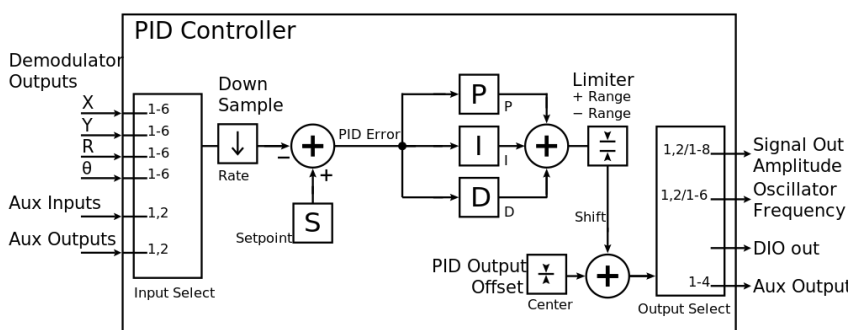


Figure 5.37: PID controller block diagram

## Setting up a Control Loop

Depending on the application there are a number of ways to set up a control loop. Let's consider a few different approaches and see how the Advisor can help to reduce the effort and improve on the result and understanding of the setup.

## Manual Setup

In cases where the transfer function of the device under test (DUT) is unknown and only little noise couples into the system from the environment, a manual approach is often the quickest way to get going. For manual configuration of a new control loop it is recommended to start with a small value for P and set the other parameters (I, D) to zero. By enabling the controller one will then immediately see if the sign of P is correct and if the feedback is acting on the correct output parameter for instance by checking the numbers (Error, Shift, Out) displayed in the PID tab. A stepwise increase of the integral gain I will then help to zero the PID error signal completely. Enabling the derivative gain D can increase the speed of the feedback loop, but it can also cause an instable feedback loop behavior. Monitoring the PID error in the [Plotter Tab](#) in parallel can be a great help at this stage. The math tools offered by the Plotter allow us to display the standard deviation and the average value of the error. These values should be minimized by tweaking the PID parameters and the associated histogram should have a symmetric (ideally Gaussian) envelope.

In order to characterize the feedback loop quantitatively, you can measure the step response in the [Data Acquisition Tab](#). To do that measurement, change the PID setpoint manually after you have configured the DAQ Trigger level half way in between the old and new setpoint. DAQ Delay and Duration are chosen to roughly match the expected bandwidth. For a step response curve with fine time resolution, the PID data rate should be high enough.



## PID Advisor

For many experimental situations the external device or DUT can be well approximated by a simple model. The LabOne PID Advisor allows you to simulate the behavior of a number of different DUT types in a feedback loop and choose feedback gain parameters based on the simulation. The DUTs are characterized by a model function with a number of parameters found on the Advisor sub-tab. All models include a setting for the delay that occurs outside the instrument. Depending on the targeted servo bandwidth, the external delay can often be the limiting factor and should be sensibly chosen.

### Note

The delay specified for each model is the earliest possible response to a stepwise change of the instrument output to be seen on the instrument input. It describes the causality of the system and does not affect the shape of the DUT transfer function. Standard coaxial cables cause a signal delay of about 5 ns/m.

The most simple approach to modeling is to assume a DUT with a unity transfer function by using All Pass. The low-pass filters allow for limiting the bandwidth, to set an overall gain and a damping for the second order filter. With a Gain set to 1 and a Delay set to 0, All Pass can be used to model the PID controller independent of the external device. Resonator Frequency is a model that applies well in situations with a passive external component, e.g. a AFM cantilever or a quartz resonator, whose frequency should be tracked by a PLL over time. In cases where the amplitude of the resonator signal needs to be stabilized with a second control loop (automatic gain control), the Resonator Amplitude model is the right choice. Setting the resonance frequency and the Q factor, both can be obtained before by a frequency scan over the resonance using the [Sweeper Tab](#), allows the Advisor to estimate the gain and low-pass behavior of the resonator. Internal PLL is used whenever an external oscillating signal is provided that shall be followed by one of the internal oscillators. The VCO setting describes a situation where the input variable of the DUT is a voltage and the output is a frequency. The gain parameter specifies how much voltage change on the input causes how much frequency shift on the VCO output. In case the frequency of the VCO can be tracked by using the external reference mode, one can easily measure this gain with the [Sweeper Tab](#) by scanning the Auxiliary Output voltage and displaying the resulting oscillator frequency. The gain is given by the slope of the resulting line at the frequency of interest.

With a model and parameters set to best describe the actual measurement situation, one can now continue by defining a target bandwidth for the entire control loop and the Advise Mode, i.e. the feedback gain parameters that shall be used for the control operation. Whenever the input signal is derived from one of the demodulators it is convenient to activate the box next to target bandwidth. With that in place the Advise algorithm will automatically adjust the demodulator bandwidth to a value about 5 times higher than the target bandwidth in order to avoid to be limited by demodulation speed. The Advisor algorithm will now calculate a target step response function that it will try to achieve by adjusting the feedback gain parameters in the next step. Before doing so in case of a newly set up DUT model, the algorithm will first try to estimate the PID parameters by using the Ziegler-Nichols method. When there has been a previous run, the user can also change the parameters in the model manually which will be used as new start parameters of the next Advise run. Starting from the initial parameters, the Advisor will then perform a numerical optimization in order to achieve a least-squares fit of the calculated step response to a target step response determined from the Target Bandwidth. The result is numerically characterized by an achieved bandwidth (BW) and a phase margin (PM). Moreover, the large plot area on the right can be used to characterize the result by displaying transfer functions, magnitude and phase, and step responses between different signal nodes inside the loop. Once the modeling is completed one can copy the resulting parameters to the physical PID by clicking on [To PID](#).

Table 5.46: DUT transfer functions

| Name         | Function                                                            | Parameters                                                           |
|--------------|---------------------------------------------------------------------|----------------------------------------------------------------------|
| All pass     | $H(s) = g$                                                          | 1. Gain $g$                                                          |
| Low-pass 1st | $H(s) = g \frac{1}{\tau_c s + 1} = g \frac{\omega_n}{s + \omega_n}$ | 1. Gain $g$<br>2. Filter bandwidth (BW) $f_{-3dB} = \omega_n / 2\pi$ |

| Name                | Function                                                                                                  | Parameters                                                                                                                                                                                                                                            |
|---------------------|-----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Low-pass 2nd        | $H(s) = g \frac{\omega_n^2}{s^2 + 2\omega_n\zeta s + \omega_n^2}$                                         | <ol style="list-style-type: none"> <li>1. Gain <b>g</b></li> <li>2. Resonance frequency <math>f_{\text{res}} = \omega_n/2\pi</math></li> <li>3. Damping ratio <math>\zeta</math> with <math>f_{-3\text{dB}} = 2\zeta f_{\text{res}}</math></li> </ol> |
| Resonator frequency | $H(s) = -360^\circ \frac{t_c}{t_c s + 1}$ with $t_c = \frac{1}{2\pi BW} = \frac{2Q}{2\pi f_{\text{res}}}$ | <ol style="list-style-type: none"> <li>1. Resonance frequency <math>f_{\text{res}}</math></li> <li>2. Quality factor <b>Q</b></li> </ol>                                                                                                              |
| Resonator amplitude | $H(s) = g \frac{\omega/(2Q)}{s + \omega/(2Q)}$ with $\omega = 2\pi f_{\text{res}}$                        | <ol style="list-style-type: none"> <li>1. Gain <b>g</b></li> <li>2. Resonance frequency <math>f_{\text{res}}</math></li> <li>3. Quality factor <b>Q</b></li> </ol>                                                                                    |
| Internal PLL        | $H(s) = -\frac{360^\circ}{s}$                                                                             |                                                                                                                                                                                                                                                       |
| VCO                 | $H(s) = g \frac{360^\circ}{s(t_c s + 1)}$ with $t_c = \frac{1}{2\pi f_{\text{res}}}$                      | <ol style="list-style-type: none"> <li>1. Gain <b>g</b> (Hz/V)</li> <li>2. Bandwidth (BW) <math>f_{-3\text{dB}}</math></li> </ol>                                                                                                                     |

## Note

It is recommended to use the Advisor in a stepwise approach where one increases the free parameters from P to PI, to PID. This can save time because it prevents optimizing into local minima. Also it can be quite illustrative to see which of the feedback parameters leads to which effect in the feedback behavior.

## Note

The low-pass filter in the differential part is implemented as an exponential moving average filter described by  $y_t = (1 - \alpha) \cdot y_{t-1} + \alpha x_t$  with  $\alpha = 2^{-\text{dshift}}$ ,  $x_t$  the filter input, and  $y_t$  the filter output. The default value for dshift is 0 which corresponds to a disabled filter. On the UI the filter properties can be changed in units of bandwidth or a time constant.

In case the feedback output is a voltage applied to sensitive external equipment it is recommended to make use of the center value and the upper and lower limit values. This will guarantee that the output stays in the defined range even when the lock fails and the integrator goes into saturation.

### 5.20.3. Functional Elements

Table 5.47: PID tab: PID section

| Control/Tool | Option/Range      | Description                           |
|--------------|-------------------|---------------------------------------|
| Enable       | ON / OFF          | Enable the PID controller             |
| Input        |                   | Select input source of PID controller |
|              | Demodulator X     | Demodulator cartesian X component     |
|              | Demodulator Y     | Demodulator cartesian Y component     |
|              | Demodulator R     | Demodulator magnitude component       |
|              | Demodulator Theta | Demodulator phase                     |
|              | Aux Input         | Auxiliary Input                       |

| Control/Tool   | Option/Range                                                                      | Description                                                                                                  |
|----------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
|                | Aux Output                                                                        | Internal value of Auxiliary Output                                                                           |
|                | Modulation Index                                                                  | Modulation depth                                                                                             |
|                | Dual Frequency Tracking $\backslash Z(i+1)\backslash - \backslash Z(i)\backslash$ | Used in dual frequency tracking applications                                                                 |
|                | Demod $X(i+1)-X(i)$                                                               | Used in dual frequency tracking applications                                                                 |
|                | Demod $\backslash Z(i+1)-Z(i)\backslash$                                          | Used in dual frequency tracking applications                                                                 |
|                | Oscillator Frequency                                                              | Oscillator frequency                                                                                         |
| Input Channel  | index                                                                             | Select input channel of PID controller.                                                                      |
| Setpoint Mode  |                                                                                   | Defines the source of the PID setpoint value.                                                                |
|                | Fixed                                                                             | Setpoint is manually set.                                                                                    |
|                | Aux Input 1                                                                       | Setpoint is supplied by Auxiliary Input 1.                                                                   |
|                | Aux Input 2                                                                       | Setpoint is supplied by Auxiliary Input 2.                                                                   |
|                | PID Output 4                                                                      | Setpoint is supplied by the output of another PID.                                                           |
| Setpoint       | numeric value                                                                     | PID controller setpoint                                                                                      |
| Filter BW      | numeric value                                                                     | Bandwidth of the demodulator filter used as an input.                                                        |
| Filter Order   |                                                                                   | Selects the filter roll off between 6 dB/oct and 48 dB/oct of the current demodulator.                       |
|                | 1                                                                                 | 1st order filter 6 dB/oct                                                                                    |
|                | 2                                                                                 | 2nd order filter 12 dB/oct                                                                                   |
|                | 3                                                                                 | 3rd order filter 18 dB/oct                                                                                   |
|                | 4                                                                                 | 4th order filter 24 dB/oct                                                                                   |
|                | 5                                                                                 | 5th order filter 30 dB/oct                                                                                   |
|                | 6                                                                                 | 6th order filter 36 dB/oct                                                                                   |
|                | 7                                                                                 | 7th order filter 42 dB/oct                                                                                   |
|                | 8                                                                                 | 8th order filter 48 dB/oct                                                                                   |
| Harmonic       | 1 to 1023                                                                         | Multiplier of the for the reference frequency of the current demodulator.                                    |
| Output         |                                                                                   | Select output of the PID controller                                                                          |
|                | Output 1 Amplitude                                                                | Feedback to the main signal output amplitude 1                                                               |
|                | Output 2 Amplitude                                                                | Feedback to the main signal output amplitude 2                                                               |
|                | Oscillator Frequency                                                              | Feedback to any of the internal oscillator frequencies                                                       |
|                | Aux Output Offset                                                                 | Feedback to any of the 4 Auxiliary Output's Offset                                                           |
|                | DIO (int16)                                                                       | Feedback to the DIO as a 16 bit word                                                                         |
| Output Channel | index                                                                             | Select output channel of PID controller.                                                                     |
| Center         | numeric value                                                                     | After adding the Center value to the PID output, the signal is clamped to Center + Range and Center - Range. |
| Range          | numeric value                                                                     | Set the range of the PID controller output relative to the center                                            |
| Default Out    | numeric value                                                                     | Set the value for the default output if the PID is disabled.                                                 |

| Control/Tool       | Option/Range      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Default Out Enable | ON / OFF          | Enable the default value when PID is off.                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| P (Hz/deg)         | numeric value     | PID proportional gain P                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| I (Hz/deg/s)       | numeric value     | PID integral gain I                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| D (Hz/deg*s)       | numeric value     | PID derivative gain D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Rate               | RT load dependent | <p>PID sampling rate and update rate of PID outputs. Needs to be set substantially higher than the targeted loop filter bandwidth.</p> <p>The numerical precision of the controller is influenced by the loop filter sampling rate. If the target bandwidth is below 1 kHz it starts to make sense to adjust this rate to a value of about 100 to 500 times the target bandwidth. If the rate is set too high for low bandwidth applications, integration inaccuracies can lead to non linear behavior.</p> |
| Error              | numeric value     | Error = Set point - PID Input                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Shift              | numeric value     | <p>Difference between the current output value Out and the Center.</p> $\text{Shift} = P * \text{Error} + I * \text{Int}(\text{Error}, dt) + D * d\text{Error}/dt$                                                                                                                                                                                                                                                                                                                                          |
| To Advisor         | To Advisor        | Copy the current PID settings to the PID Advisor.                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

Table 5.48: PID tab: Advisor sub-tab


| Control/Tool   | Option/Range  | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Advise         | Advise        | <p>Calculate the PID coefficients based on the used DUT model and the given target bandwidth. If optimized values can be found the coefficients are updated and the response curve is updated on the plot.</p> <p>Only PID coefficients specified with the advise mode are optimized. The Advise mode can be used incremental, means current coefficients are used as starting point for the optimization unless other model parameters are changed in-between.</p> |
| Progress       |               | The percentage of design algorithm already done when the Advisor is in progress.                                                                                                                                                                                                                                                                                                                                                                                    |
| Target BW (Hz) | numeric value | Target bandwidth for the closed loop feedback system which is used for the advising of the PID parameters. This bandwidth defines the trade-off between PID speed and noise.                                                                                                                                                                                                                                                                                        |
| Advise Mode    |               | <p>Select the PID coefficients that are optimized. The other PID coefficients remain unchanged but are used during optimization. This enables keeping selected coefficients at a fixed value while optimizing the rest.</p> <p>The advise time will increase significantly with the number of parameters to be optimized.</p>                                                                                                                                       |
|                | P             | Only optimize the proportional gain.                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                | I             | Only optimize the integral gain.                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                | PI            | Only optimize the proportional and the integral gain.                                                                                                                                                                                                                                                                                                                                                                                                               |
|                | PID           | Optimize the proportional, integral, and derivative gains.                                                                                                                                                                                                                                                                                                                                                                                                          |
| Filter BW      | numeric Value | Defines the low-pass filter characteristic of the selected demodulator input.                                                                                                                                                                                                                                                                                                                                                                                       |

| Control/Tool   | Option/Range        | Description                                                                                                                                                                                                                                                                                                               |
|----------------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Auto Bandwidth | ON / OFF            | Adjusts the demodulator bandwidth to fit best to the specified target bandwidth of the full system. If disabled, a demodulator bandwidth too close to the target bandwidth may cause overshoot and instability.<br><br>In special cases the demodulator bandwidth can also be selected smaller than the target bandwidth. |
| Filter Order   |                     | Selects the filter roll off between 6 dB/oct and 48 dB/oct of the modelled demodulator.                                                                                                                                                                                                                                   |
|                | 1                   | 1st order filter 6 dB/oct                                                                                                                                                                                                                                                                                                 |
|                | 2                   | 2nd order filter 12 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 3                   | 3rd order filter 18 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 4                   | 4th order filter 24 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 5                   | 5th order filter 30 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 6                   | 6th order filter 36 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 7                   | 7th order filter 42 dB/oct                                                                                                                                                                                                                                                                                                |
|                | 8                   | 8th order filter 48 dB/oct                                                                                                                                                                                                                                                                                                |
| Harmonic       | 1 to 1023           | Multiplier of the for the reference frequency of the modelled demodulator.                                                                                                                                                                                                                                                |
| DUT Model      |                     | Type of model used for the external device to be controlled by the PID.<br><br>A detailed description of the transfer function for each model is found in the previous section.                                                                                                                                           |
|                | All Pass            | The external device is modelled by an all pass filter. Parameters to be configured are delay and gain.                                                                                                                                                                                                                    |
|                | LP 1st              | The external device is modelled by a first-order low-pass filter. Parameters to be configured are delay, gain and filter bandwidth.                                                                                                                                                                                       |
|                | LP 2nd              | The external device is modelled by a second-order low-pass filter. Parameters to be configured are delay, gain, resonance frequency and damping ratio.                                                                                                                                                                    |
|                | Resonator Frequency | The external device is modelled by a resonator. Parameters to be configured are delay, center frequency and quality factor.                                                                                                                                                                                               |
|                | Internal PLL        | The DUT is the internal oscillator locked to an external signal through a phase-locked loop. The parameter to be configured is the delay.                                                                                                                                                                                 |
|                | VCO                 | The external device is modelled by a voltage controlled oscillator. Parameters to be configured are delay, gain and bandwidth.                                                                                                                                                                                            |
|                | Resonator Amplitude | The external device is modelled by a resonator. Parameters to be configured are delay, gain, center frequency and quality factor.                                                                                                                                                                                         |
| Delay          | numeric value       | Parameter that determines the earliest response for a step change. This parameter does not affect the shape of the DUT transfer function.                                                                                                                                                                                 |
| Gain           | numeric value       | Parameter that determines the gain of the DUT transfer function.                                                                                                                                                                                                                                                          |
| BW (Hz)        | numeric value       | Parameter that determines the bandwidth of the first-order low-pass filter respectively the bandwidth of the VCO.                                                                                                                                                                                                         |
| Damping Ratio  | numeric value       | Parameter that determines the damping ratio of the second-order low-pass filter.                                                                                                                                                                                                                                          |
| Res Freq       | numeric value       | Parameter that determines the resonance frequency of the of the modelled resonator.                                                                                                                                                                                                                                       |
| Q              | numeric value       | Parameter that determines the quality factor of the modelled resonator.                                                                                                                                                                                                                                                   |

| Control/Tool  | Option/Range  | Description                                                                                                                                                                                                                                                                     |
|---------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P (Hz/deg)    | numeric value | Proportional gain P coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.                                          |
| I (Hz/deg/s)  | numeric value | Integral gain I coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.                                              |
| D (Hz/deg*s)  | numeric value | Derivative gain D coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.                                            |
| BW (Hz)       | numeric value | Simulated bandwidth of the full close loop model with the current PID settings. This value should be larger than the target bandwidth.                                                                                                                                          |
| Target BW LED | green/red     | Green indicates that the target bandwidth can be achieved. For very high PID bandwidth the target bandwidth might be only achieved using marginal stable PID settings. In this case, try to lower the bandwidth or optimize the loop delays of the PID system.                  |
| PM (deg)      | numeric value | Simulated phase margin of the PID with the current settings. The phase margin should be greater than 45 deg for internal PLL and 60 deg for all other DUT for stable conditions. An Infinite value is shown if no unity gain crossing is available to determine a phase margin. |
| Stable LED    | green/red     | Green indicates that the phase margin is fulfilled and the PID system should be stable.                                                                                                                                                                                         |
| To PID        | To PID        | Copy the PID Advisor settings to the PID.                                                                                                                                                                                                                                       |

Table 5.49: PID tab: Display sub-tab

| Control/Tool               | Option/Range   | Description                                                                                                                                                                                                    |
|----------------------------|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Advanced Mode              | ON / OFF       | Enables manual selection of display and advice properties. If disabled the display and advice settings are automatically with optimized default values.                                                        |
| Display                    |                | Select the display mode used for rendering the system frequency or time response.                                                                                                                              |
|                            | Bode Magnitude | Display the Bode magnitude plot.                                                                                                                                                                               |
|                            | Bode Phase     | Display the Bode phase plot.                                                                                                                                                                                   |
|                            | Step Resp      | Display the step response plot.                                                                                                                                                                                |
| Start (Hz)                 | numeric value  | Start frequency for Bode plot display. For disabled advanced mode the start value is automatically derived from the system properties and the input field is read-only.                                        |
| Stop (Hz)                  | numeric value  | Stop frequency for Bode plot display. For disabled advanced mode the stop value is automatically derived from the system properties and the input field is read-only.                                          |
| Start (s)                  | numeric value  | Start time for step response display. For disabled advanced mode the start value is zero and the field is read-only.                                                                                           |
| Stop (s)                   | numeric value  | Stop time for step response display. For disabled advanced mode the stop value is automatically derived from the system properties and the input field is read-only.                                           |
| Transfer Function Selector |                | Selection of the displayed transfer function of the loop. 2 presets and a manual selection are possible. In closed loop configuration all elements from output to input will be included as feedback elements. |
|                            | System         | From Setpoint to System Output.                                                                                                                                                                                |
|                            | PID            | From Setpoint to PID Output.                                                                                                                                                                                   |

| Control/Tool | Option/Range                                                                        | Description                                                                                                                                                                                                                                           |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|              | Manual                                                                              | Any transfer function in the open or closed loop can be visualized.                                                                                                                                                                                   |
| Response In  |                                                                                     | Start point for the plant response simulation for open or closed loops. In closed loop configuration all elements from output to input will be included as feedback elements.                                                                         |
|              | Demod Input                                                                         | Start point is at the demodulator input.                                                                                                                                                                                                              |
|              | Setpoint                                                                            | Start point is at the setpoint in front of the PID.                                                                                                                                                                                                   |
|              | PID Output                                                                          | Start point is at PID output.                                                                                                                                                                                                                         |
|              | Instrument Output                                                                   | Start point is at the instrument output.                                                                                                                                                                                                              |
|              | DUT Output                                                                          | Start point is at the DUT output and instrument input.                                                                                                                                                                                                |
| Response Out |                                                                                     | End point for the plant response simulation for open or closed loops. In closed loop configuration all elements from output to input will be included as feedback elements.                                                                           |
|              | PID Output                                                                          | End point is at PID output.                                                                                                                                                                                                                           |
|              | Instrument Output                                                                   | End point is at the instrument output.                                                                                                                                                                                                                |
|              | DUT Output                                                                          | End point is at the DUT output and instrument input.                                                                                                                                                                                                  |
|              | Demod Input                                                                         | End point is at the demodulator input.                                                                                                                                                                                                                |
|              | System Output                                                                       | End point is at the output of the controlled system.                                                                                                                                                                                                  |
| Closed-Loop  | ON / OFF                                                                            | Switch the display of the system response between closed or open loop.                                                                                                                                                                                |
| TC Mode      | ON / OFF                                                                            | Enables time constant representation of PID parameters.                                                                                                                                                                                               |
| Set Limits   | ON / OFF                                                                            | Switch the writing of PID limits when 'To PID' is pressed. Only applies in case of internal PLL.                                                                                                                                                      |
| Advisor Link |  | Automatically copy cursor values displayed below to the PID advisor. To enable cursor helpers, switch Advanced Mode on and set Display to Bode Magnitude with PID Transfer Function. Cursors will be displayed in Log and dB axis scale combinations. |
| P            |                                                                                     | Cursor value representing PID proportional gain P. Drag the plot cursor with the mouse pointer or directly insert numerical value here.                                                                                                               |
| I            |                                                                                     | Cursor value representing PID integral gain I. Drag the plot cursor with the mouse pointer or directly insert numerical value here.                                                                                                                   |
| D            |                                                                                     | Cursor value representing PID derivative gain D. Drag the plot cursor with the mouse pointer or directly insert numerical value here.                                                                                                                 |

## 5.21. PLL Tab

The PLL tab allows convenient setup of a two independent phase-locked loop for high-speed tracking of frequency modulated signals. This tab is only available when the HF2-PLL Dual Phase-locked Loop option is installed on the HF2 Instrument (see Information section in the Device tab).

### Note

Demodulators that are used by an active PLL are set to read-only values on the Lock-in tab.

### 5.21.1. Features


- Two fully programmable 50 MHz phased-locked loops

- Programmable PLL center frequency and phase setpoint
- 50 kHz PLL bandwidth
- Programmable PLL phase detector filter settings and PID controller parameters
- PLL Advisor for model-based parameter suggestion and transfer function analysis
- Auto-zero functions for center frequency and setpoint
- Advanced 2- $\omega$  PLL mode (requires HF2-MF option)

5.21.2. Description

The PLL tab offers a convenient way to set up a phase-locked loop. In this way the frequency of an external signal can be mapped onto one of the instrument's internal oscillators. An advisor functionality based on mathematical models helps the user finding and optimizing the PID parameters and quickly optimizing the servo bandwidth for the application. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.50: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                                                            |
|--------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| PLL          |  | Features all control, analysis, and simulation capabilities of the phase-locked loops. |

The PLL tab (see [Figure 5.38](#)) is divided into two side-tabs corresponding to the two PLL units. It contains a settings section on the left and an advisor section with graphical display on the right.

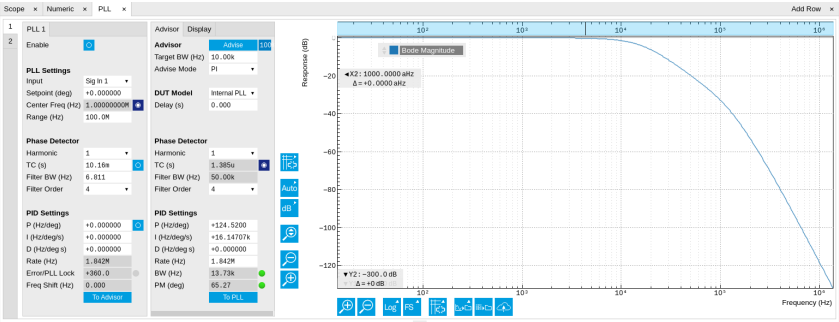


Figure 5.38: LabOne UI: PLL tab

[Figure 5.39](#) shows a block diagram of the PLL with its components, their interconnections and the variables to be specified by the user. The demodulator is slightly simplified for this sketch. Its full block diagram is given in [Demodulator block diagram \(without HF2-MF option\)](#) or [Demodulator block diagram \(HF2-MF option\)](#).

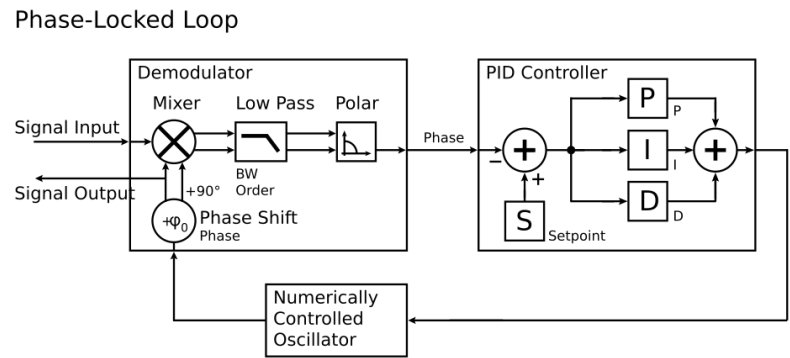


Figure 5.39: Phase-Locked Loop block diagram (components simplified)

In a typical work flow to set up a PLL one would first define the center frequency, frequency range, and the phase setpoint in the left section. If the frequency is not know beforehand, it can often be measured using the Sweeper or Spectrum tool. Then one would set a target bandwidth in the Advisor sub-tab and subsequently click on the **To PLL** button, and then enable the PLL. If the Error field now displays very small values, the phase lock has been successful. One can now iterate the process and e.g. play with the target bandwidth in the PLL Advisor to calculate a new set of feedback parameters. Displaying the oscillator frequency in the Plotter along with a Histogram and Math function (e.g. standard deviation) can help to characterize residual phase deviations and further improve lock performance by manual tweaking.



## Note

The frequency range in the PLL Settings section should exceed the target bandwidth by at least a factor of 5 to 10.

## Note

PLL 1 uses demodulator 7 as phase detector, and PLL 2 uses demodulator 8. The Input selection determines which signal is connected to the corresponding demodulator. This setting is the same as the Input Signal setting in the Lock-in tab.

### 5.21.3. Functional Elements

Table 5.51: PLL tab: PLL section

| Control/Tool                             | Option/Range                     | Description                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Enable                                   | ON / OFF                         | Enable the PLL                                                                                                                                                                                                                                                                                                                                                                                                           |
| Input                                    | Sig In 1/2, Aux In 1/2, DIO D0/1 | Select the input signal of the PLL controller                                                                                                                                                                                                                                                                                                                                                                            |
| Center Freq (Hz)                         | 0 to 50 MHz                      | Center frequency of the PLL oscillator. The PLL frequency shift is relative to this center frequency.                                                                                                                                                                                                                                                                                                                    |
| Auto Center Frequency                    | ON / OFF                         | The PLL Center Frequency is determined automatically. In this mode, the instrument sweeps the operating range until it finds a suitable frequency. Note: Auto Center Frequency works only for open loop systems. Closed loop systems require manual mode.                                                                                                                                                                |
| Range                                    | numeric value                    | Set the frequency range of the PLL controller output relative to the center frequency                                                                                                                                                                                                                                                                                                                                    |
| Harmonic                                 | 1, 2                             | Set the harmonic used in the phase detector. A setting of 2 means the PLL generates a sub-harmonic of the external reference.                                                                                                                                                                                                                                                                                            |
| TC (s)                                   | numeric value                    | Filter time constant of the demodulator used as the phase detector.                                                                                                                                                                                                                                                                                                                                                      |
| Auto TC Enable                           | ON / OFF                         | When On, the PLL is running at full bandwidth. Use manual mode (off) for low-noise performance.                                                                                                                                                                                                                                                                                                                          |
| Filter BW (Hz)                           | numeric value                    | Filter bandwidth of the demodulator used as the phase detector.                                                                                                                                                                                                                                                                                                                                                          |
| Filter Order                             | 1-8                              | Filter order of the demodulator used as the phase detector.                                                                                                                                                                                                                                                                                                                                                              |
| Setpoint (deg)                           | numeric value                    | Phase set point in degrees (i.e. PID setpoint). Controls the phase difference between the input signal and the generated signal.                                                                                                                                                                                                                                                                                         |
| Automated adjustment of PID coefficients | ON / OFF                         | If turned on together with Auto TC Enable and Auto Center Frequency, the PLL is in ExtRef mode                                                                                                                                                                                                                                                                                                                           |
| P (Hz/deg)                               | numeric value                    | PID proportional gain P                                                                                                                                                                                                                                                                                                                                                                                                  |
| I (Hz/deg/s)                             | numeric value                    | PID integral gain I                                                                                                                                                                                                                                                                                                                                                                                                      |
| D (Hz/deg*s)                             | numeric value                    | PID derivative gain D                                                                                                                                                                                                                                                                                                                                                                                                    |
| Rate (Hz)                                | numeric value                    | Current sampling rate of the PLL control loop.<br><br>Note: The numerical precision of the controller is influenced by the loop filter sampling rate. If the target bandwidth is below 1 kHz is starts to make sense to adjust this rate to a value of about 100 to 500 times the target bandwidth. If the rate is set too high for low-bandwidth applications, integration inaccuracies can lead to nonlinear behavior. |
| Error (deg)                              | numeric value                    | Current phase error of the PLL (Set Point - PID Input).                                                                                                                                                                                                                                                                                                                                                                  |

| Control/Tool    | Option/Range  | Description                                                                                                                                                                         |
|-----------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PLL lock LED    | grey/green    | Indicates when the PLL is locked.<br><br>The PLL error is sampled at 5 Sa/s and its RMS value is calculated. If the result is smaller than 5 degrees the loop is considered locked. |
| Freq Shift (Hz) | numeric value | Current frequency shift of the PLL (Oscillator Freq - Center Freq).                                                                                                                 |
| To Advisor      | To Advisor    | Copy the current PLL settings to the PLL Advisor.                                                                                                                                   |

Table 5.52: PLL tab: Advisor sub-tab

| Control/Tool   | Option/Range  | Description                                                                                                                                                                                                                                                                                                                   |
|----------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Advise         | Advise        | Calculate PID coefficients based on application mode and given settings.<br><br>Only PID coefficients specified with the advise mode are optimized. The Advise mode can be used incremental, means current coefficients are used as starting point for the optimization unless other model parameters are changed in-between. |
| Progress       |               | The percentage of design algorithm already done when the Advisor is in progress.                                                                                                                                                                                                                                              |
| Target BW (Hz) | numeric value | Target bandwidth for the PLL closed loop feedback system which is used for the advising of the PID parameters. This bandwidth defines the trade-off between PLL speed and phase noise.                                                                                                                                        |
| Advise Mode    |               | Select the PID coefficients that are optimized. The other PID coefficients remain unchanged but are used during optimization. This enables holding selected coefficients at a fixed value while optimizing the rest.<br><br>The advise time will increase significantly with the number of parameters to be optimized.        |
|                | P             | Only optimize the proportional gain.                                                                                                                                                                                                                                                                                          |
|                | I             | Only optimize the integral gain.                                                                                                                                                                                                                                                                                              |
|                | PI            | Only optimize the proportional and the integral gain.                                                                                                                                                                                                                                                                         |
|                | PID           | Optimize the proportional, integral, and derivative gains.                                                                                                                                                                                                                                                                    |
| DUT Model      |               | The model to use for the parameter calculation.                                                                                                                                                                                                                                                                               |
| Harmonic       | 1 to 1023     | Multiplier of the for the reference frequency of the modelled demodulator.                                                                                                                                                                                                                                                    |
| TC (s)         | numeric value | Defines the low-pass filter time constant of the selected demodulator input.                                                                                                                                                                                                                                                  |
| Auto Bandwidth | ON / OFF      | Adjusts the demodulator bandwidth to fit best to the specified target bandwidth of the full system. If disabled, a demodulator bandwidth too close to the target bandwidth may cause overshoot and instability.<br><br>In special cases the demodulator bandwidth can also be selected smaller than the target bandwidth.     |
| Filter BW      | numeric Value | Defines the low-pass filter characteristic of the selected demodulator input.                                                                                                                                                                                                                                                 |
| Filter Order   |               | Selects the filter roll off between 6 dB/oct and 48 dB/oct of the modelled demodulator.                                                                                                                                                                                                                                       |
|                | 1             | 1st order filter 6 dB/oct                                                                                                                                                                                                                                                                                                     |
|                | 2             | 2nd order filter 12 dB/oct                                                                                                                                                                                                                                                                                                    |
|                | 3             | 3rd order filter 18 dB/oct                                                                                                                                                                                                                                                                                                    |
|                | 4             | 4th order filter 24 dB/oct                                                                                                                                                                                                                                                                                                    |


| Control/Tool  | Option/Range                                                                        | Description                                                                                                                                                                                                                                      |
|---------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               | 5                                                                                   | 5th order filter 30 dB/oct                                                                                                                                                                                                                       |
|               | 6                                                                                   | 6th order filter 36 dB/oct                                                                                                                                                                                                                       |
|               | 7                                                                                   | 7th order filter 42 dB/oct                                                                                                                                                                                                                       |
|               | 8                                                                                   | 8th order filter 48 dB/oct                                                                                                                                                                                                                       |
| P (Hz/deg)    | numeric value                                                                       | Proportional gain P coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.           |
| I (Hz/deg/s)  | numeric value                                                                       | Integral gain I coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.               |
| D (Hz/deg*s)  | numeric value                                                                       | Derivative gain D coefficient used for calculation of the response of the PID model. The parameter can be optimized with PID advise or changed manually. The parameter only gets active on the PID after pressing the button To PLL.             |
| Rate (Hz)     | RT load dependent                                                                   | PID sampling rate used for simulation.<br><br>The advisor will update the rate to match with the specified target bandwidth. A sampling rate close to the target bandwidth and excessive higher bandwidth will results in a simulation mismatch. |
| BW (Hz)       | numeric value                                                                       | Simulated bandwidth of the full close loop PLL with the current PID settings. This value should be larger than the target bandwidth.                                                                                                             |
| Target BW LED | green/red                                                                           | Green indicates that the target bandwidth can be achieved. For very high PLL bandwidth the target bandwidth might be only achieved using marginal stable PID settings.                                                                           |
| PM (deg)      | numeric value                                                                       | Simulated phase margin of the PID with the current settings. The phase margin should be greater than 45 deg for stable conditions. An Infinite value is shown if no unity gain crossing is available to determine a phase margin.                |
| Stable LED    | green/red                                                                           | Green indicates that the phase margin is fulfilled and the PID system should be stable.                                                                                                                                                          |
| To PLL        |  | Copy the PLL Advisor settings to the PLL.                                                                                                                                                                                                        |

Table 5.53: PLL tab: Display sub-tab

| Control/Tool | Option/Range   | Description                                                                                                                                                             |
|--------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Advanced     | ON / OFF       | Enables manual selection of display and advice properties. If disabled the display and advice settings are automatically with optimized default values.                 |
| Display      |                | Select the display mode used for rendering the system frequency or time response.                                                                                       |
|              | Bode Magnitude | Display the Bode magnitude plot.                                                                                                                                        |
|              | Bode Phase     | Display the Bode phase plot.                                                                                                                                            |
|              | Step Resp      | Display the step response plot.                                                                                                                                         |
| Start (Hz)   | numeric value  | Start frequency for Bode plot display. For disabled advanced mode the start value is automatically derived from the system properties and the input field is read-only. |
| Stop (Hz)    | numeric value  | Stop frequency for Bode plot display. For disabled advanced mode the stop value is automatically derived from the system properties and the input field is read-only.   |
| Start (s)    | numeric value  | Start time for step response display. For disabled advanced mode the start value is zero and the field is read-only.                                                    |

| Control/Tool | Option/Range      | Description                                                                                                                                                                   |
|--------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stop (s)     | numeric value     | Stop time for step response display. For disabled advanced mode the stop value is automatically derived from the system properties and the input field is read-only.          |
| Response In  |                   | Start point for the plant response simulation for open or closed loops. In closed loop configuration all elements from output to input will be included as feedback elements. |
|              | Demod Input       | Start point is at the demodulator input.                                                                                                                                      |
|              | Setpoint          | Start point is at the setpoint in front of the PID.                                                                                                                           |
|              | PID Output        | Start point is at PID output.                                                                                                                                                 |
|              | Instrument Output | Start point is at the instrument output.                                                                                                                                      |
|              | DUT Output        | Start point is at the DUT output and instrument input.                                                                                                                        |
| Response Out |                   | End point for the plant response simulation for open or closed loops. In closed loop configuration all elements from output to input will be included as feedback elements.   |
|              | PID Output        | End point is at PID output.                                                                                                                                                   |
|              | Instrument Output | End point is at the instrument output.                                                                                                                                        |
|              | DUT Output        | End point is at the DUT output and instrument input.                                                                                                                          |
|              | Demod Input       | End point is at the demodulator input.                                                                                                                                        |
|              | System Output     | End point is in front of the PID error calculation (Setpoint-System Output).                                                                                                  |
| Closed-Loop  | ON / OFF          | Switches the display of the system response between closed or open loop.                                                                                                      |
| TC Mode      | ON / OFF          | Switch between display of gain parameters (I, D) and time constants (Ti, Td) for the integral and differential parts. The following relations hold: $I=P/T_i$ , $D=P*T_d$ .   |

## 5.22. MOD Tab

The MOD tab provides access to the settings of the amplitude and frequency modulation units. This tab is only available when the HF2-MOD AM/FM Modulation is installed on the Instrument (see Information section in the Device tab).

### Note

The HF2-MOD AM/FM Modulation requires the HF2-MF Multi-frequency option.


### 5.22.1. Features

- Phase coherently add and subtract oscillator frequencies and their multiples
- Control for AM and FM demodulation
- Control for AM and narrow-band FM generation
- Direct analysis of higher order carrier frequencies and sidebands

### 5.22.2. Description

The MOD tab offers control in order to phase coherently add and subtract the frequencies of multiple numerical oscillators. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.54: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                                                                              |
|--------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| MOD          |  | Control panel to enable (de)modulation at linear combinations of oscillator frequencies. |

The MOD tab (see [Figure 5.40](#)) is divided into two horizontal sections, one for each modulation unit.

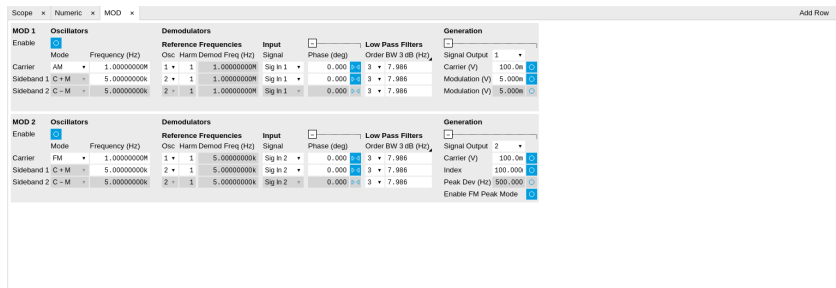


Figure 5.40: LabOne UI: MOD tab

The modulation units are designed for experiments involving multiple frequencies. For many of such experiments the associated spectrum reveals a dominant center frequency, often called the carrier, and one or multiple sidebands symmetrically placed around the carrier. Typical examples are amplitude modulated (AM) signals with one carrier and two sidebands separated from the carrier by the AM modulation frequency. Another example is frequency modulation (FM) where multiple sidebands to the left and right of the carrier can appear. The relative amplitude of the sideband for both AM and FM depends on the modulation depth, which is often expressed by the modulation index.

The classical approach of analyzing such signals (in particular when only analog instruments are available) is to use a configuration called tandem demodulation. This is essentially the serial cascading of lock-in amplifiers. The first device is referenced to the carrier frequency and outputs the in-phase component. This is then fed into the subsequent lock-in amplifiers in order to extract the different sideband components. There are several downsides to this scheme:

- The quadrature component of the first lock-in tuned to the carrier has to be continuously zeroed out by adjusting the reference phase. Otherwise a serious part of the signal power is lost for the analysis which usually leads to a drop in SNR.
- The scheme scales badly in terms of the hardware resources needed, in particular if multiple sideband frequencies need to be extracted.
- Every time a signal enters or exits an instrument the SNR gets smaller (e.g. due to the instrument inputs noise). Multiple such steps can deteriorate signal quality significantly.

All these shortcomings are nicely overcome by providing the ability to generate linear combinations of oscillator frequencies and use these combinations as demodulation references.

The MOD tab contains two sections MOD 1 and MOD 2. Both are identical in all aspects except that MOD 1 is linked to demodulators 1, 2 and 3, whereas MOD 2 is linked to demodulators 4, 5, and 6. Each of the MOD units can make use of up to 3 oscillators, which can be even referenced to an external source by using ExtRef or a PLL. [Figure 5.41](#) gives an overview of the different components involved and their interconnections.

#### HF2-MOD Option

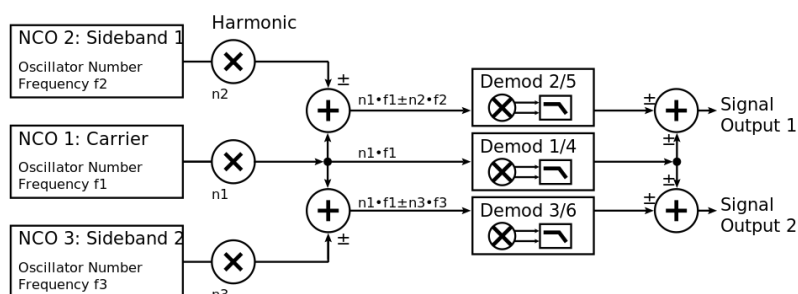


Figure 5.41: Modulation Option block diagram

For convenience the UI provides access to presets for AM and FM in the Mode column. In Manual Mode all settings can be chosen freely.

## Note

Whenever a MOD unit is enabled, all the settings in the Lock-in tab that are controlled by this unit will be set to read-only.

## Note

When using the Sweeper to vary a parameter of a MOD unit, it is recommended to manually set the minimum settling time to 500 ms (Settings sub-tab, Advanced Mode). Otherwise the measurement may yield invalid data.

On top of signal analysis the HF2-MOD AM/FM Modulation can also be utilized for signal generation. The Generation section provides all the necessary controls to adjust the carrier and sideband amplitudes.

## Note



FM signals are generated by coherent superposition of the carrier signal with two sideband frequencies on either side that have the same amplitudes but opposite phases. The phase shift is achieved by using negative amplitudes as displayed in the Lock-in tab. This FM generation method approximates true FM as long as the modulation index is well below 1, i.e. higher-order sidebands can be neglected. For a modulation index of 1 true FM provides more than 13% of signal power in the second and higher order sidebands.

More details regarding AM and FM signal analysis and generation can be found on the Zurich Instruments web page.

### 5.22.3. Functional Elements

Table 5.55: MOD tab

| Control/Tool   | Option/Range     | Description                                                                                                                      |
|----------------|------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Enable         | ON / OFF         | Enable the modulation                                                                                                            |
| Mode           | AM/FM/manual     | Select the modulation mode.                                                                                                      |
| Mode           |                  | Enabling of the first sideband and selection of the position of the sideband relative to the carrier frequency for manual mode.  |
|                | Off              | First sideband is disabled. The sideband demodulator behaves like a normal demodulator.                                          |
|                | C + M            | First sideband to the right of the carrier                                                                                       |
|                | C - M            | First sideband to the left of the carrier                                                                                        |
| Mode           |                  | Enabling of the second sideband and selection of the position of the sideband relative to the carrier frequency for manual mode. |
|                | Off              | Second sideband is disabled. The sideband demodulator behaves like a normal demodulator.                                         |
|                | C + M            | Second sideband to the right of the carrier                                                                                      |
|                | C - M            | Second sideband to the left of the carrier                                                                                       |
| Frequency (Hz) | 0 to 50 MHz      | Sets the frequency of the carrier.                                                                                               |
| Frequency (Hz) | 0 to 50 MHz      | Frequency offset to the carrier from the first sideband.                                                                         |
| Frequency (Hz) | 0 to 50 MHz      | Frequency offset to the carrier from the second sideband.                                                                        |
| Carrier        | oscillator index | Select the oscillator for the carrier signal.                                                                                    |
| Sideband 1     | oscillator index | Select the oscillator for the first sideband.                                                                                    |
| Sideband 2     | oscillator index | Select the oscillator for the second sideband.                                                                                   |

| Control/Tool        | Option/Range                                                                        | Description                                                                                                                                                                                                                                           |
|---------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Harm                | 1 to 1023                                                                           | Set harmonic of the carrier frequency. 1=Fundamental                                                                                                                                                                                                  |
| Harm                | 1 to 1023                                                                           | Set harmonic of the first sideband frequency. 1 = fundamental                                                                                                                                                                                         |
| Harm                | 1 to 1023                                                                           | Set harmonic of the second sideband frequency. 1 = fundamental                                                                                                                                                                                        |
| Demod Freq (Hz)     | 0 to 50 MHz                                                                         | Carrier frequency used for the demodulation and signal generation on the carrier demodulator.                                                                                                                                                         |
| Demod Freq (Hz)     | 0 to 50 MHz                                                                         | Absolute frequency used for demodulation and signal generation on the first sideband demodulator.                                                                                                                                                     |
| Demod Freq (Hz)     | 0 to 50 MHz                                                                         | Absolute frequency used for demodulation and signal generation on the second sideband demodulator.                                                                                                                                                    |
| Channel             | Signal Input 1, Signal Input 2                                                      | Select Signal Input for the carrier demodulation                                                                                                                                                                                                      |
| Channel             | Signal Input 1, Signal Input 2                                                      | Select Signal Input for the sideband demodulation                                                                                                                                                                                                     |
| Phase               | -180° to 180°                                                                       | Phase shift applied to the reference input of the carrier demodulator and also to the carrier signal on the Signal Outputs                                                                                                                            |
| Phase               | -180° to 180°                                                                       | Phase shift applied to the reference input of the sideband demodulator and also to the sideband signal on the Signal Outputs                                                                                                                          |
| Zero                |    | Adjust the carrier demodulator's reference phase automatically in order to read zero degrees at the demodulator output.<br><br>This action maximizes the X output, zeros the Y output, zeros the $\Theta$ output, and leaves the R output unchanged.  |
| Zero                |  | Adjust the sideband demodulator's reference phase automatically in order to read zero degrees at the demodulator output.<br><br>This action maximizes the X output, zeros the Y output, zeros the $\Theta$ output, and leaves the R output unchanged. |
| Order               | 1 to 8                                                                              | Filter order used for carrier demodulation                                                                                                                                                                                                            |
| Order               | 1 to 8                                                                              | Filter order used for sideband demodulation                                                                                                                                                                                                           |
| TC/BW Value         | numeric value                                                                       | Defines the low-pass filter characteristic in the unit defined above for the carrier demodulation                                                                                                                                                     |
| TC/BW Value         | numeric value                                                                       | Defines the low-pass filter characteristic in the unit defined above for the sideband demodulation                                                                                                                                                    |
| Signal Output       | 1, 2 or both                                                                        | Select Signal Output 1, 2 or none                                                                                                                                                                                                                     |
| Carrier (V)         | -range to range                                                                     | Set the carrier amplitude                                                                                                                                                                                                                             |
| Modulation (V)      | -range to range                                                                     | Set the amplitude of the first sideband component.                                                                                                                                                                                                    |
| Modulation (V)      | -range to range                                                                     | Set the amplitude of the second sideband component.                                                                                                                                                                                                   |
| Index               | -range to range                                                                     | In FM mode, set modulation index value. The modulation index equals peak deviation divided by modulation frequency.                                                                                                                                   |
| Peak Dev (Hz)       | -range to range                                                                     | In FM mode, set peak deviation value.                                                                                                                                                                                                                 |
| Enable FM Peak Mode | ON / OFF                                                                            | In FM mode, choose to work with either modulation index or peak deviation. The modulation index equals peak deviation divided by modulation frequency.                                                                                                |
| Enable              | ON / OFF                                                                            | Enable the signal generation for the first sideband                                                                                                                                                                                                   |
| Enable              | ON / OFF                                                                            | Enable the signal generation for the second sideband                                                                                                                                                                                                  |
| Enable              | ON / OFF                                                                            | Enable the carrier signal                                                                                                                                                                                                                             |

# 5.23. Multi Device Sync Tab

The Multi Device Sync (MDS) tab gives access to the automatic timing synchronization of measurement data from multiple HF2 instruments. This functionality and tab is available on all HF2 instruments.

## 5.23.1. Features

- Automatic timing synchronization across instruments
- Periodic check of synchronization
- Selectable instrument subgroup
- Status display

## 5.23.2. Description

The Multi Device Sync tab contains the controls and status information for synchronized measurements on multiple instruments. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.56: App icon and short description

| Control/Tool | Option/Range                                                                      | Description                       |
|--------------|-----------------------------------------------------------------------------------|-----------------------------------|
| MDS          |  | Synchronize multiple instruments. |

The Multi Device Sync tab shown in [Figure 5.42](#) consists of the Available Devices section, a Status section, and a wiring diagram.

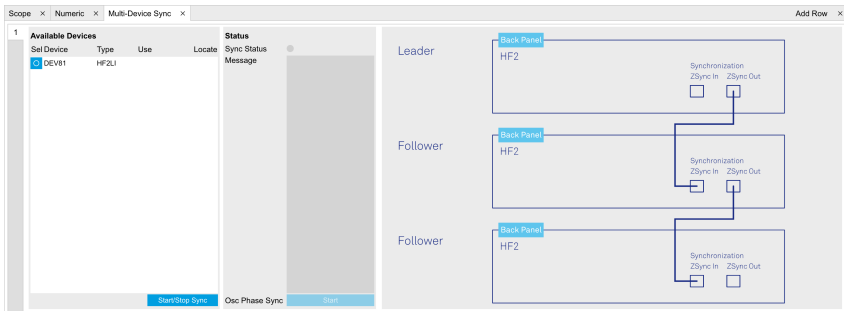


Figure 5.42: LabOne UI: Multi Device Sync tab

The Multi Device Synchronization feature provides an automated functionality to remove the clock offset of separate HF2 instruments. This enables a correct simultaneous display of their data in the [Plotter Tab](#) and helps when analyzing recorded data. In multi-channel applications that require sub-microsecond timing precision, the user can therefore benefit from having synchronized data from the start, rather than having to manually measure and compensate the clock offset in post-processing.

The first prerequisite for automatic synchronization is that all instruments are connected to the same LabOne Data Server (see [Connecting to the Instrument](#)).

These connections are automatically established with all HF2 instruments physically connected to the same host computer. Once all instruments are connected, they are selectable in the [Tree Selector](#) of a newly opened Plotter tab allowing you to visualize their data simultaneously, though by default these data are not synchronized yet. The settings of multiple instruments can be accessed in parallel by opening a new Web Server session for each of them. This is done by opening a new browser tab and connecting to `localhost:8006` or `127.0.0.1:8006`, respectively, and then double-clicking the respective instrument entry in the Available Devices list. With multiple instruments connected to the same Data Server, tabs that are available for several instruments will feature a device selector as shown in [Figure 5.43](#).

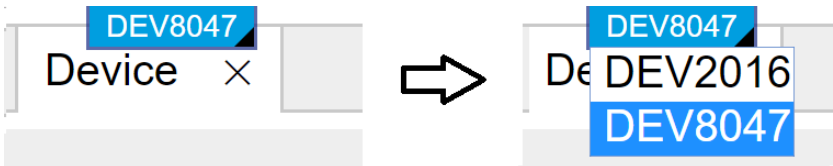


Figure 5.43: Example of the device selector for the Device tab



The second prerequisite for automatic synchronization is correct cabling of the instruments explained in the diagram in [Figure 5.44](#). The instruments need to be arranged in the form of a "daisy-chain" where the ZSync Out connector of the first instrument is connected to the ZSync In connector of the second instrument, and so forth.

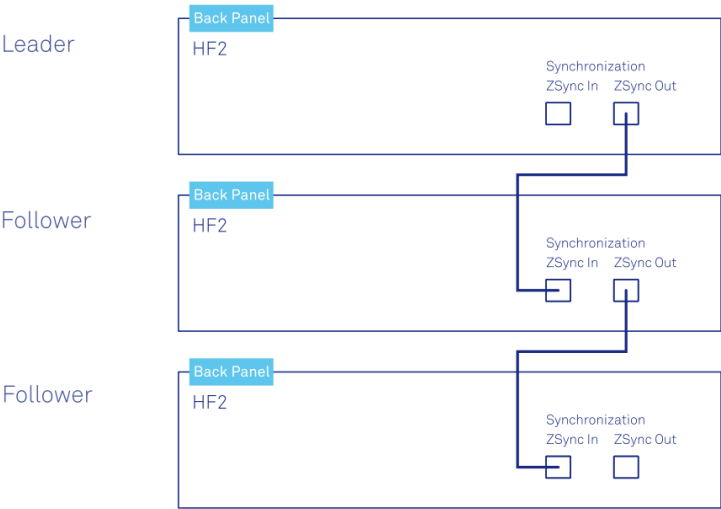


Figure 5.44: Cabling for automatic synchronization of multiple HF2 instruments

Once the cabling and the connectivity is set up correctly, automatic synchronization is started in the Multi Device Sync tab by checking the Enable button on the instruments in the Available Devices list, and then clicking on [Start/Stop Sync](#). The sequence assignment of the instruments (Leader, Follower 1, Follower 2,...) can be defined by the order in which the Enable button is clicked. This assignment has to agree with the way the cabling is made. The Message display on the right will then report on the progress, and the Sync Status LED will turn green if the synchronization was successful. In that case, visualizing a time-dependent measurement of multiple instruments in the Plotter will demonstrate the timing synchronization.

5.23.3. Functional Elements

Table 5.57: Multi Device Sync tab

| Control/Tool          | Option/Range                    | Description                                                                                                                                                      |
|-----------------------|---------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Start Sync            | <a href="#">Start/Stop Sync</a> | Start the automatic synchronization of the selected devices.                                                                                                     |
| Sync Status           |                                 | Indicates the status of the synchronization within this group. Green: synchronization successful. Yellow: synchronization in progress. Red: error (see message). |
| Message               |                                 | Displays a status message of the synchronization group.                                                                                                          |
| Cabling               |                                 | This image shows how to connect the devices for device synchronization.                                                                                          |
| Phase Synchronization |                                 | Reset phases of all oscillators on all synchronized devices.                                                                                                     |
| Identify Device       |                                 | Make device's front LED blink                                                                                                                                    |

5.24. Real-time Tab

Note

The Real-time Tab is unavailable in the LabOne UI. Please use ziControl to work with the Real-time Option.

# 5.25. HF2CA Tab

The HF2CA tab provides remote control over the HF2CA Current Amplifier which is available as an accessory to the HF2LI Lock-in amplifier. The HF2CA tab dynamically adapts its content depending on whether or not a HF2CA is connected to one of the ZCtrl connectors of the HF2LI.

## 5.25.1. Features

- Input impedance range from 10 V/A to 1 M V/A (R1, R2)
- Input mode differential or single-ended (Diff, Single)
- Input signal coupling mode (AC, DC)
- Output stage gain (G=1 or G=10)

## 5.25.2. Description

The HF2CA tab contains an interactive circuit diagram allowing the user to control the input settings, grounding, and gain of the preamplifier. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.58: App Icon and short description

| Control/Tool | Option/Range                                                                      | Description                                    |
|--------------|-----------------------------------------------------------------------------------|------------------------------------------------|
| HF2CA        |  | Remote control of the HF2CA Current Amplifier. |

The HF2CA tab consists of two side-tabs corresponding to the two ZCtrl inputs of the HF2 instrument. Each side-tab is horizontally divided into two identical sections corresponding to the two Signal Inputs of the HF2CA as shown in [Figure 5.45](#).

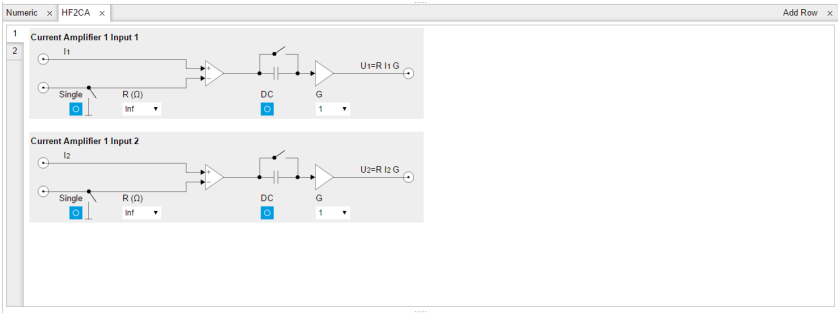


Figure 5.45: HF2CA tab

Additional HF2CA specification can be found in the [HF2CA Current Amplifier Data Sheet](#).

## 5.25.3. Functional Elements

Table 5.59: HF2CA tab

| Control/Tool | Option/Range                    | Description                                                           |
|--------------|---------------------------------|-----------------------------------------------------------------------|
| Single       | ON / OFF                        | Switch between differential and single-ended input configurations     |
| R (Ω)        | 10, 100, 1k, 10k, 100k, 1M, Inf | Select input impedance                                                |
| DC           | ON / OFF                        | Switch between DC and AC coupling after the first amplification stage |
| G1 / G2      | 1, 10                           | Set the voltage gain of the second amplification stage                |

# 5.26. HF2TA Tab

The HF2TA tab provides remote control over the HF2TA Current Amplifier which is available as an accessory to the HF2LI Lock-in amplifier. The HF2TA tab dynamically adapts its content depending on whether or not a HF2TA is connected to one of the ZCtrl connectors of the HF2LI.

## 5.26.1. Features

- Input offset +/- 10 V
- Transimpedance gain from 100 V/A to 100 MV/A (R1, R2)
- Input signal coupling mode (AC, DC)
- Addition gain (1, 10)
- Total gain display ( $R1 \cdot G$ ,  $R2 \cdot G$ )
- Input Shield (GND, EXT Bias)
- Auxiliary output +/- 10 V

## 5.26.2. Description

The HF2TA tab contains an interactive circuit diagram allowing the user to control the input settings, grounding, gain and offset of the preamplifier. Whenever the tab is closed or an additional one of the same type is needed, clicking the following icon will open a new instance of the tab.

Table 5.60: App Icon and short description

| Control/Tool | Option/Range                                                                      | Description                                    |
|--------------|-----------------------------------------------------------------------------------|------------------------------------------------|
| HF2TA        |  | Remote control of the HF2TA Current Amplifier. |

The HF2TA tab contains two side-tabs corresponding to the two ZCtrl inputs of the HF2 instrument. Each side-tab is horizontally divided into three sections as shown in [Figure 5.46](#). The two upper sections are identical and correspond to the two Signal Inputs of the HF2TA. The lowest section contains the setting of the Aux Output voltage of the HF2TA.

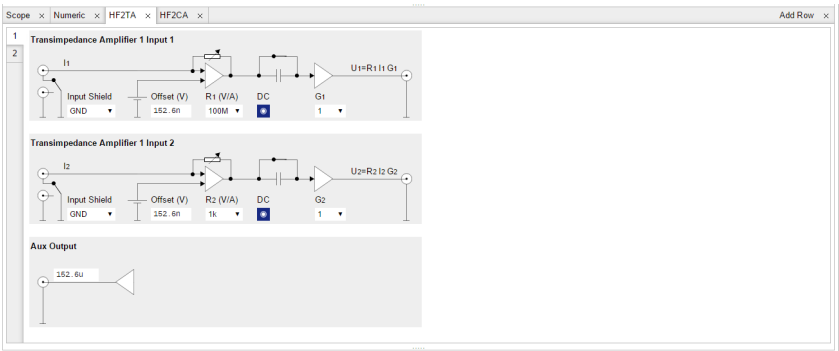


Figure 5.46: HF2TA tab

Detailed HF2TA specifications can be found in the [HF2TA Current Amplifier Data Sheet](#).

## 5.26.3. Functional Elements

Table 5.61: HF2TA tab


| Control/Tool  | Option/Range                      | Description                                                                               |
|---------------|-----------------------------------|-------------------------------------------------------------------------------------------|
| Input Shield  | GND, Ext Bias                     | Select the shield of Input 1 and 2 to be either grounded or biased by an external voltage |
| Offset (V)    | -10 mV to +10 mV                  | Set the offset voltage applied to the current input.                                      |
| R1 / R2 (V/A) | 100, 1k, 10k, 100k, 1M, 10M, 100M | Set the transimpedance gain of the amplifier                                              |
| DC            | ON / OFF                          | Switch between DC and AC coupling after the first amplification stage                     |
| G1 / G2       | 1, 10                             | Set the voltage gain of the second amplification stage                                    |

| Control/Tool | Option/Range   | Description                                   |
|--------------|----------------|-----------------------------------------------|
| Aux Output   | -10 V to +10 V | Set the auxiliary output voltage of the HF2TA |

## 5.27. ZI Labs Tab

The ZI Labs tab contains experimental LabOne functionalities added by the ZI development team. The settings found here are often relevant to special applications, but have not yet found their definitive place in one of the other LabOne tabs. Naturally this tab is subject to frequent changes, and the documentation of the individual features would go beyond the scope of this user manual. Clicking the following icon will open a new instance of the tab.

Table 5.62: App Icon and short description

| Control/Tool | Option/Range                                                                      | Description                         |
|--------------|-----------------------------------------------------------------------------------|-------------------------------------|
| ZI Labs      |  | Experimental settings and controls. |

## 5.28. Upgrade Tab

The Upgrade tab serves as a source of information about the possible upgrade options for the instrument in use. The tab has no functional purpose but provides the user with a quick link to further information about the upgrade options online.

# 6. Communication and Connectivity

This chapter describes the different possibilities to interface with an HF2 Instrument. The HF2 Series was designed with the concept that "the computer is the cockpit"; there are no controls on the front panel of the HF2 Instrument, instead the user has the freedom to configure and stream data from the instrument directly from their computer. The aim of this approach is to give the user the freedom to choose where they connect to, and how they control, their HF2 Instrument. The user can connect directly from a computer connected to the HF2 Instrument via USB or remotely from a different computer on the network, away from their experimental setup. Then, on either computer, the user can configure and retrieve data from their HF2 Instrument via a number of different interfaces, i.e. via the LabOne UI and/or their own custom programs. In this way the user can decide which connectivity setup and combination of interfaces best suits their experimental setup and data processing needs.

We first provide an overview of how the user connects an HF2 Instrument to a PC in [Instrument Connectivity Overview](#) and then give an overview of how to quickly modify instrument settings using the text-based console in [ziServer's Text-based Interface](#). Finally, at the end of this chapter, we explain how to connect to an HF2 instrument over a public network, [Connecting to ziServer over insecure or networks behind firewalls](#).

## Note

It is also possible to configure and obtain data from an HF2 Instrument via one of our APIs. Currently LabVIEW, Matlab, Python or C are available. These topics are covered in a separate document, The LabOne Programming Manual.

## Note

New users could benefit by first familiarizing themselves with the instrument using the LabOne UI, see [Tutorials](#).

## Note

Programming using the Real-time Option (ziRTK) is dealt with in [Real-time Option](#).

## 6.1. Instrument Connectivity Overview

The HF2 Series supports a server-based connectivity methodology for multi-user, multi-device operation. This means that it is possible to operate more than one HF2 Instrument from a single computer, that multiple users may access the same instrument, and that an instrument may be made available on a local area network. Server-based means that all communication between the user and the HF2 is via a computer program called a server, in our case ziServer. The ziServer program recognizes the device and manages all communication between the instrument and the host computer over the USB connection on one side, and the different available interfaces on the other side.

Before going into more detail, the terminology used in this chapter is explained.

- **Host computer:** The computer that is directly connected to the HF2 by USB. An HF2 can only be connected to one host computer, but to multiple remote computers on a local area network via ziServer running on the host.
- **ziServer:** A computer program that runs on the host computer and manages settings on, and data transfer to and from the HF2 by receiving commands from clients. It always has the most up-to-date configuration of the device and ensures that the configuration is synchronized between different clients.
- **Remote computer:** A computer, available on the same network as the host computer, that can communicate with the HF2 via the ziServer program running on the host.
- **Client:** A computer program that communicates with the HF2 via the server. The client can be running either on the host or the remote computer.

- **API (Application Programming Interface):** a collection of functions and data structures which enable communication between software components. In our case, the various APIs (e.g., LabVIEW, MATLAB®) for the HF2 provide functions to configure the device and receive measured experimental data.
- **Interface:** Either a client or an API.
- **TCP/IP:** Network communication protocols. In our case, ziServer communicates to the base API (ziAPI) using TCP/IP. This can happen either locally (entirely on the host computer) or between the host computer and remote computers.
- **GUI (Graphical User Interface):** A computer program that the user can operate via images as opposed to text-based commands.
- **Modules:** Software components that provide a unified interface to APIs to perform high-level common tasks such as sweeping data.

An overview of HF2 Instrument connectivity is shown in Figure 6.1.

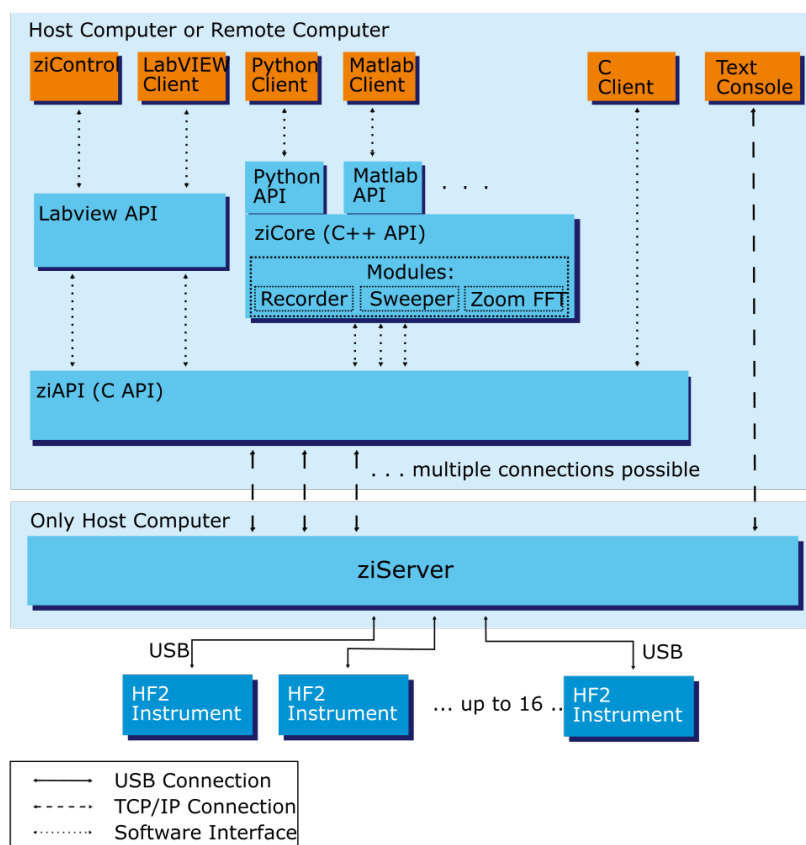


Figure 6.1: Instrument Connectivity

### 6.1.1. Physical Connectivity: Host and Remote Computers

In a commonly used configuration, the HF2 Instrument is connected to a host computer where both the server and the clients (denoted by the orange boxes in Figure 6.1) run. The ziServer program acts as bridge from the instrument to the various clients. For example, a user may use two clients in parallel: the LabOne UI to configure the device and their own program created using the LabVIEW API to plot custom results streamed from the instrument. Both these clients communicate data via the same instance of ziServer and ziServer ensures that both clients are always updated with the current instrument configuration. Note however, that any combination of clients shown in Figure 6.1 may be used in parallel, limited only by the performance of the host computer and by the load from requests to ziServer. In this configuration, the top and bottom block of Figure 6.1 (denoted by the light blue box) are both running on the host computer.

Sometimes, the user wishes to use a client to control the HF2 on a remote computer. In this case, the software in the top block of Figure 6.1 runs on the remote computer, connecting via TCP/IP over the local area network to the instance of ziServer running on the host computer (which is connected to the HF2 via USB).

In total, there are three possibilities of physically connecting to an HF2 Instrument:

- On the host computer, i.e., all the software (ziServer, interfaces) is running on the same computer that is connected to the instrument via USB. This is the simplest and most common setup.

- On a remote computer connected to the host computer over a secure local area network. If a private network is available this is a simple setup, ziServer only needs to allow remote connections, see [Enabling a Remote Connection to ziServer](#).
- On a remote computer connected to the host computer over a public, insecure network. This is a more advanced topic covered in [Connecting to ziServer over insecure or networks behind firewalls](#).

As you can now imagine, there are many possibilities to connect to an HF2 instrument. The following methods of connecting with HF2 Instruments are supported:

- Connection to and operation of an HF2 Instrument from multiple clients on different computers in parallel with automatic background update of instrument settings on all connected clients.
- Connection to and operation of up to 16 HF2 Instruments from a single host computer.
- Connection to and Operation of multiple remote HF2 Instruments that are connected on a TCP/IP LAN via a (or multiple) host computer(s), the number of which is limited by the performance of the remote computer. Note, there can only be one instance of ziServer running for one HF2 Instrument.

## 6.1.2. Software Connectivity: ziServer

The ziServer program provides a gateway to your HF2 Instrument from any of the programming interfaces described in this chapter. The ziServer program recognizes the device and manages all communication between the instrument and the host computer over the USB connection on one side, and the different available interfaces on the other side. Since ziServer is responsible for all communication to the instrument, it's important that only one instance of ziServer is running at any one time. This is how you can check that only one instance of ziServer is running, or is indeed running at all:

- **Windows:** Open Windows Task Manager with CTRL-SHIFT-ESC and check that both the processes **ziServer.exe** and **ziService.exe** are running.
- **Linux:** Either check manually that the process **ziServer** is running or alternatively use the `ziService` command

```
$ ziService status
```

in a terminal. You should see the output:

```
Status : ziServer is running.
```

## Enabling a Remote Connection to ziServer

In order to enable connections to ziServer from a remote computer, the node `/zi/config/open` must be set to **1**. To set this in the LabOne UI go to the Config Tab and under the Connectivity setting enable "From Everywhere".

## 6.1.3. Instrument Communication: The Node Hierarchy

In order to communicate with an HF2 Instrument via text-based commands, it is necessary to understand how the settings and measurement data of the instrument are accessed. All settings of the HF2 Instrument are organized in a file-system-like hierarchical structure. This means that it is possible to plot a consistent tree of nodes, where the instrument settings are leaves of the tree. It is also possible to browse branches inside the tree as if the user were navigating in a file-system. This hierarchy is used, no matter which interface you use when performing measurements.

An example demonstrating the hierarchy is the representation of the first demodulator on the device, given by the node:

```
/devX/demods/0
```

which, as we've already noted, is very similar to a **path** on a computer's file-system. Note that, the top level of the path is the device that you are connected to. The demodulators are then given as a top-level `*_node__` under your device-node and the node of the first demodulator is indexed by **0**. This path represents a branch in the node hierarchy which, in this case, if we explore further, has the following nodes:

```
/devX/demods/0/adselect
/devX/demods/0/order
```

```

/devX/demods/0/timeconstant
/devX/demods/0/rate
/devX/demods/0/trigger
/devX/demods/0/oscsselect
/devX/demods/0/harmonic
/devX/demods/0/phaseshift
/devX/demods/0/sinc
/devX/demods/0/sample

```

These nodes are \*\_leaves, the most bottom-level nodes which represent a setting of an instrument or a field that can be read to retrieve measurement data. For example, `/devX/demods/0/adcselect` is the leaf that controls the setting corresponding to the choice of signal input for the first demodulator. To set the index of the signal input the user writes to this node. The leaf `/devX/demods/0/sample` is the leaf where the demodulator's output (timestamp, demodulated x-value, demodulated y-value) are written at the frequency specified by `/devX/demods/0/rate`. In order to obtain the demodulator output you read the values from this node by \*\_polling this node. Polling a node sends a request from the client to ziServer to obtain the data from the node at that particular point in time.

[Device Node Tree](#) provides a full reference of nodes on HF2 Instruments and details which settings or measurement data they correspond to, whether they are read-only and, if they are writable, which values they may take (e.g., boolean, integer, floating point).

## Note

The numbering on the front panel of the HF2 Instrument and the block numbering on the LabOne UI generally start with 1, whereas the underlying instrument using the programming interfaces has a numbering notation starting with 0.

## Note

A useful method to learn about paths in your HF2 Instrument is to look at the output of the history in the bottom of the LabOne UI. The status line always shows the last applied command and you can view the entire history by clicking the "Show History" button. You will find paths like

```
/devx/sigins/0/ac = 1
```

after you switched on the AC mode for signal input 1, or

```

/devx/demods/1/rate =
7200.000000

```

after setting the readout rate of demodulator 2 to 7.2 kHz.

You can obtain a list of nodes available on your instrument as a text-file in the LabOne UI by saving the instrument settings. Go to the Config tab in the Settings section click the Save button.

## Note

We recommend that users who want to program their HF2 Instruments first familiarize themselves with the node hierarchy by browsing nodes via ziServer's text-based interface described in the next chapter. The text-based interface is an indispensable tool for HF2 programmers.

## 6.2. ziServer's Text-based Interface

The text-based interface is the simplest and most direct way of communicating with an HF2 Instrument and doesn't require any previous programming experience. Browsing the text interface physically happens within ziServer and since it makes use of TCP/IP sockets the user can also connect remotely over a network connection via telnet or ssh. In contrast to the LabOne UI, this is a geeky way of using an HF2 Instrument.



After connecting to the text-based interface via telnet, you find yourself in a DOS or Unix terminal-like program, where you can browse instrument settings in the node hierarchy ([Instrument Communication: The Node Hierarchy](#)). The terminal responds to known command syntax like `ls` (list all nodes in the current directory) and `cd` (select path to navigate in the directory hierarchy).

The text interface is a very powerful tool for users programming an HF2 Instrument with other interfaces such as Zurich Instrument’s LabVIEW or MATLAB® API. It is a convenient way to verify the instrument’s node paths and check that values have been set correctly by the interface you are actually programming with. It is also helpful for budding HF2 hackers who can use it to browse the node hierarchy and familiarize themselves with its structure.

Note

In theory, it would be possible to use the text-based interface to communicate with an HF2 Instrument from an arbitrary programming environment. However, this would require the implementation of a socket connection and a parser, and there is no exception handling should a command fail. Also, since it’s a text interface, as opposed to a binary interface, data transfer is slower. Therefore, in general, we strongly encourage the user to instead use one of the existing binary interfaces documented later in this chapter as their primary programming interface.

6.2.1. Getting Started with the Text-based Interface

Preparation

The purpose of this section is to get quickly acquainted with the text interface to the ziServer. For this you will need to have installed LabOne (see [Software Installation](#)) and have your HF2 Instrument connected to your host computer via USB. In order to access the text-based interface within ziServer, a telnet or SSH client providing a console is required.

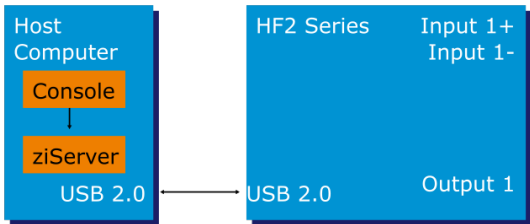


Figure 6.2: Setup for using the text-based interface

Connecting to ziServer on Windows

Zurich Instruments recommends to use the freeware PuTTY as a telnet client. PuTTY has to be configured with the following settings to connect with ziServer.

Table 6.1: PuTTY settings on Windows

|                                            |           |
|--------------------------------------------|-----------|
| Terminal category, Implicit CR in every LF | set       |
| Session category, Host Name                | localhost |
| Session category, Port                     | 8005      |
| Session category, Connection type          | Telnet    |

Users connecting to a remote ziServer (a ziServer which is not running on the local machine, but on the host computer available on the LAN) have to configure the host name accordingly (e.g. computer.domain.com) after allowing remote connections to ziServer, see [Software Connectivity: ziServer](#).

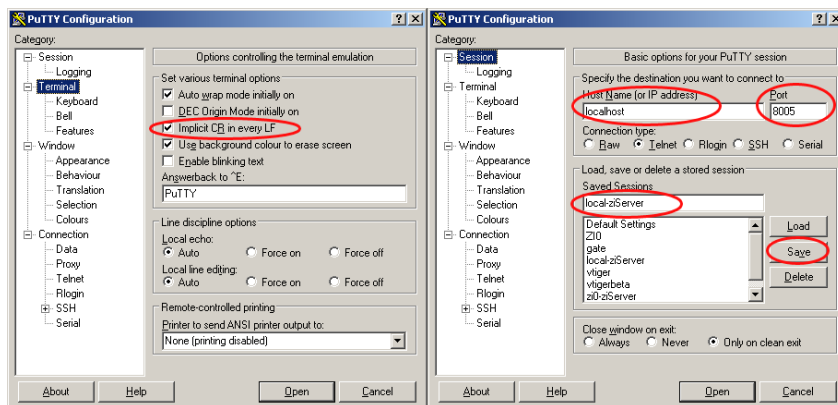


Figure 6.3: PuTTY configuration to connect to ziServer

Save the session settings with a suitable name, so that you can connect faster next time. After pressing the Open button, the following screen will appear: this message confirms successful connection to the ziServer. If the screen does not appear, or the text is missing, please check whether ziServer is running (Windows task manager, see [Software Connectivity: ziServer](#)) or check your PuTTY settings.

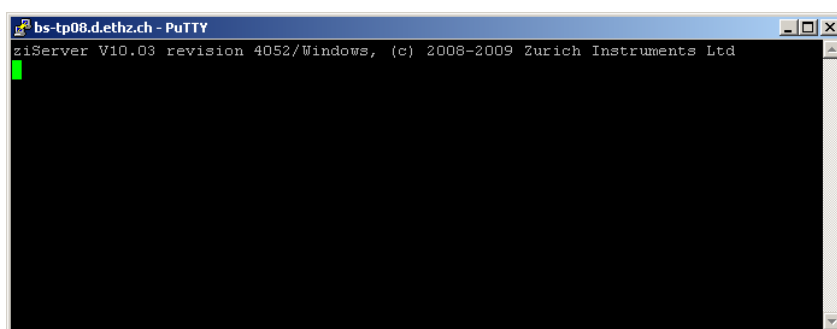


Figure 6.4: PuTTY successful ziServer connection

## Connecting to ziServer on Linux

You may connect to a running ziServer from the host computer by invoking telnet in a shell:

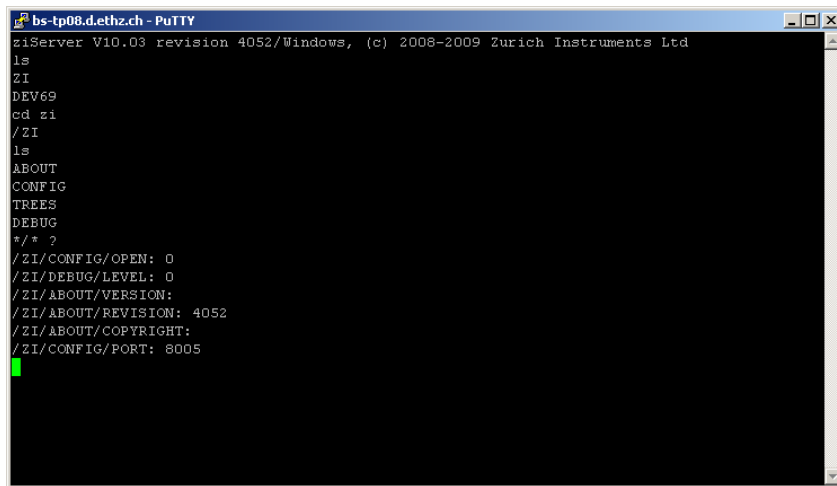
```
user@zi:~$ telnet localhost 8005
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
ziServer V19.05 revision 62216/Linux, (c) 2008-2021 Zurich Instruments AG
```

Or by using netcat:

```
user@zi:~$ nc localhost 8005
ziServer V19.05 revision 62216/Linux, (c) 2008-2021 Zurich Instruments AG
```

## A Tour of the Text-based Interface

We start our tour with some basic commands. After successful connection, it's nice to see which instruments are connected to ziServer. An `ls` will do the job. This yields the information that we have a ZI node (the node for ziServer) and a DEVX node (denoting your HF2 Instrument). The DEVX is the serial number of the HF2 Instrument in front of you. Let's select the ziServer node with `cd zi`, list the nodes with `ls`, and then read all values of the node inside the `/ZI/` tree with `/ ?`. Not very impressive so far.



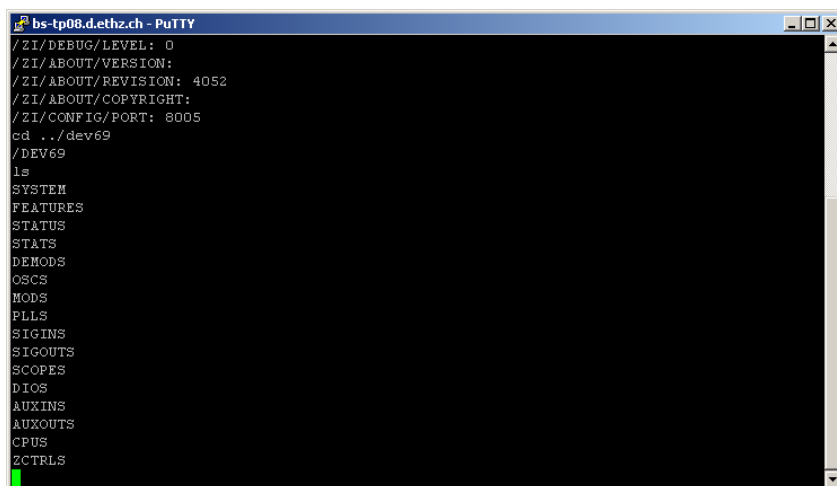
```

bs-tp08.d.ethz.ch - PuTTY
ziServer V10.03 revision 4052/Windows, (c) 2008-2009 Zurich Instruments Ltd
ls
ZI
DEV69
cd zi
/ZI
ls
ABOUT
CONFIG
TREES
DEBUG
*/ * ?
/ZI/CONFIG/OPEN: 0
/ZI/DEBUG/LEVEL: 0
/ZI/ABOUT/VERSION:
/ZI/ABOUT/REVISION: 4052
/ZI/ABOUT/COPYRIGHT:
/ZI/CONFIG/PORT: 8005

```

Figure 6.5: PuTTY tour: check server version

Let us move into the DEVX hierarchy by using the relative path `cd ../devx` (it's also possible to specify absolute paths, e.g., `cd /devx/` and investigate the structure of the node hierarchy with the `ls` command). This lists all the leaves inside of your device. Each leaf represents a setting that can be made inside of the instrument or a field that can be read to retrieve measurement data. The first level hierarchy inside the instrument is displayed in Figure 6.6.



```

bs-tp08.d.ethz.ch - PuTTY
/ZI/DEBUG/LEVEL: 0
/ZI/ABOUT/VERSION:
/ZI/ABOUT/REVISION: 4052
/ZI/ABOUT/COPYRIGHT:
/ZI/CONFIG/PORT: 8005
cd ../dev69
/DEV69
ls
SYSTEM
FEATURES
STATUS
STATS
DEMODS
OSCS
MODS
PLLS
SIGINS
SIGOUTS
SCOPES
DIOS
AUXINS
AUXOUTS
CPUS
ZCTRLS

```

Figure 6.6: PuTTY tour: first instrument hierarchy

This list gives a top-level insight into an HF2 Instrument showing its building blocks such as DEMODS (demodulators), OSCS (oscillators), SIGINS (signal inputs), SIGOUTS (signal outputs), SCOPES (oscilloscopes), AUXINS (auxiliary inputs), AUXOUTS (auxiliary outputs), CPUS (integrated processors), and so on. The branches and leaves that you see will depend on the options installed in your device: for instance, you will not see PLLS if you do not have the HF2PLL option installed.

It is time to dive into one branch of the instrument. Let us take oscillator 0: type `cd oscs`, then `ls` to see the branches at that level, then type `cd 0` to select the first oscillator, then list the leaves at that level, and use `* ?` to return the values of all leaves. We see for instance that `/DEVX/OSCS/0/FREQ` has a value of 2.5 MHz, see Figure 6.7.

It is now possible to check that the LabOne UI actually has the same value in the corresponding field. Note, that the block numbering notation inside of the GUI starts with 1, whereas the underlying instrument has a numbering notation starting with 0. It is also possible to change the frequency of the lock-in channel 1 inside of the GUI to 2.1 MHz, and then check the value inside the text interface by typing `* ?`. You notice that the settings changes are transparent to all clients connected to a ziServer. You can always rely on setting and data consistency.

```

bs-tp08.d.ethz.ch - PuTTY
SIGOUTS
SCOPES
DIOS
AUXINS
AUXOUTS
CPUS
ZCTRLS
cd oscs
/DEV69/OSCS
ls
0
1
2
3
4
5
cd 0
/DEV69/OSCS/0
ls
FREQ
* ?
/DEV69/OSCS/0/FREQ: 2500000.00000
* ?
/DEV69/OSCS/0/FREQ: 2100000.00000

```

Figure 6.7: PuTTY tour: leaves of an oscillator

Next, to change the value of the oscillator frequency, for instance to 4.5 MHz, type `freq 4500000`. The same effect can be achieved by using the absolute path `/DEV8/OSCS/0/FREQ 4500000`. Please note that the value in the GUI has changed from 2.1 MHz to 4.5 MHz in the meantime.

The wildcard symbol `*` can simplify life when many similar settings need to be made. Lets for instance check the frequency of all oscillators at once: type `cd ..`, and then `*/freq ?`, and then change all frequencies to 3.6 MHz with `\*/freq 3600000`. This is where the text interface is becoming pretty powerful.

```

bs-tp08.d.ethz.ch - PuTTY
* ?
/DEV69/OSCS/0/FREQ: 2500000.00000
* ?
/DEV69/OSCS/0/FREQ: 2100000.00000
freq 4500000
/DEV69/OSCS/0/FREQ: 4500000.00000
/dev69/oscs/0/freq 4500000
/DEV69/OSCS/0/FREQ: 4500000.00000
cd ..
/DEV69/OSCS
*/freq ?
/DEV69/OSCS/4/FREQ: 1000000.00000
/DEV69/OSCS/2/FREQ: 1000000.00000
/DEV69/OSCS/1/FREQ: 2500001.00000
/DEV69/OSCS/5/FREQ: 1000000.00000
/DEV69/OSCS/0/FREQ: 4500000.00000
/DEV69/OSCS/3/FREQ: 1000000.00000
*/freq 3600000
/DEV69/OSCS/4/FREQ: 3600000.00000
/DEV69/OSCS/2/FREQ: 3600000.00000
/DEV69/OSCS/1/FREQ: 3600000.00000
/DEV69/OSCS/5/FREQ: 3600000.00000
/DEV69/OSCS/0/FREQ: 3600000.00000
/DEV69/OSCS/3/FREQ: 3600000.00000

```

Figure 6.8: PuTTY tour: using the wildcard symbol

One word on scripting. It is possible to manually compile several settings in a file using the syntax `path value`, then to copy-paste them into the terminal window. The sequence will be recognized by the ziServer and all defined settings will be made.

Note, another useful method to learn about the paths in your HF2 Instrument is to look at the bottom of the LabOne UI after changing configuration (see this [note](#)). The complete command history of a session is stored in the LabVIEW Data directory, file `com.zhinst.ziControlStatusLog.txt`.

This concludes getting started with text-based programming. Zurich Instruments hopes you found it useful, and hopes you are going to perform some tutorials in [Tutorials](#). Thank you for measuring with Zurich Instruments.

## 6.2.2. Command Reference

### Commands

A complete lists of all available commands in the text-based interface can be viewed in the interface by typing `help`.

## Note

The text-based interface is case insensitive.

## Nodes, Leaves and Paths

Every setting of the instrument is represented by a leaf as a terminal of a tree of nodes. There are also leaves which are not settings, but for instance used to retrieve data from the instrument. For each leaf there is a path and the related value.

```
path_list = path [path]
path = [/ | / . . | *] name [/ name | * | **]
```

In the syntax above a name is a string, and the path is a list of names separated by a slash. If a path starts with a slash, it is an absolute path starting at the root of the hierarchy. The asterisk is a wildcard meaning all nodes at a given hierarchy, and two points in a row means one hierarchy higher.

## Navigation and Trees

The navigation inside the text interface is performed with the **sel**/**cd**/**ls**/**tr** commands.

```
sel or cd [?|..|path]
ls [path]
tr [path]
info [path]
```

The command **cd ?** feedbacks the current path, **cd ..** moves up one tree level, **cd path** moves down one tree level. **sel** and **cd** are equivalent commands. **ls** lists the tree available on the current path, **ls path** lists the tree available on the specified path, **tr** lists the complete tree on the current path, **tr path** lists the complete tree on the specified path, **info** feedbacks the help string of the current path, and **info path** reports the help string of a given path.

## Get and Set Node Values

The values of nodes are read and changed with the following syntax.

```
path ?
path_list value
```

The command **path ?** returns the value of path, **path value** sets the specified node to value, and **path\_list value** sets several nodes to value. Some examples:

```
about/* ? // return values of leaves at path
devx/demods/0/* ?
/zi/config/* ?

/devx/demods/0/adcselct ? // return value at path
/devx/demods/0/adcselct 0 // set value of leaf

/devx/demods/0/adcselct /devx/demods/1/adcselct 1
 // multiple set value
```

## Subscriptions

The ziServer provides a mechanism to automatically send all changes to a leaf to a subscribed client. This mechanism efficiently informs a client whenever a setting or a data of the instrument has changed without the need of active polling. It is possible to subscribe to single leaves, or full trees.

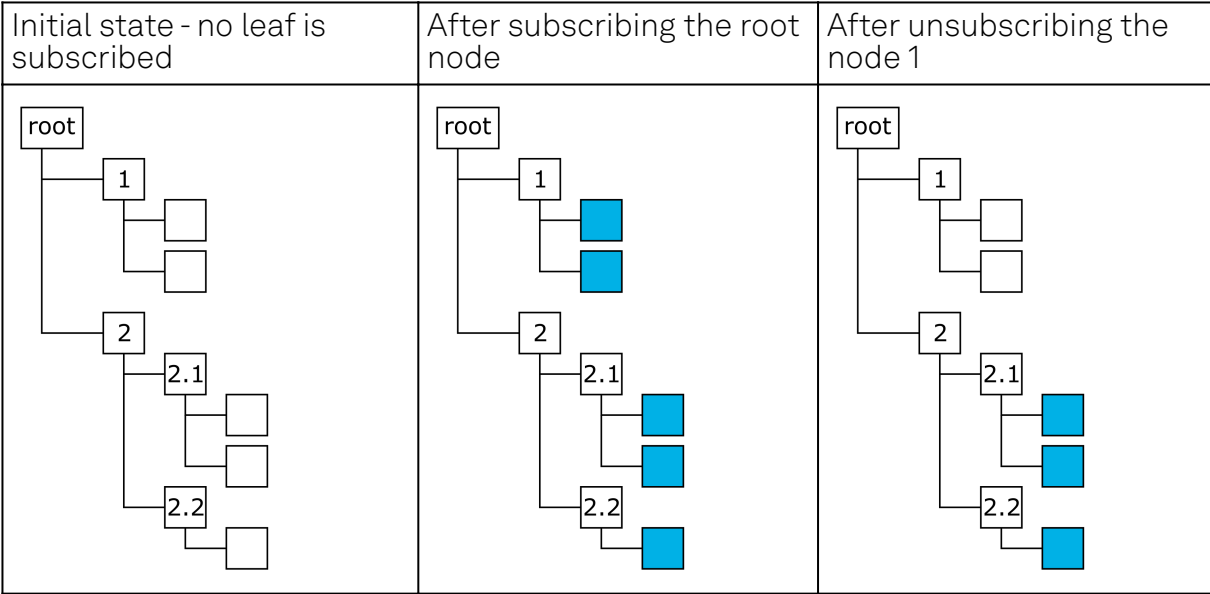
When a value of a subscribed leaf changes, the updated value is sent to the client. Most often samples, error and status nodes are subscribed. If one needs to maintain a user interface, then this can be done using subscriptions.

If you subscribe or unsubscribe from a node which is not a leaf, the subscription propagates to all nodes of the subtree. For example, you could first subscribe a subtree and then unsubscribe specific nodes within this subtree and still receive events for all nodes except for unsubscribed ones.

```
subs path_list // subscribe
unsubs path_list // unsubscribe

path value // return value for subscribed leaf
```

The following sequence illustrates subscribe and unsubscribe commands following each other, where turquoise leaves denote subscribed leaves.



The first image shows the initial state with no leaf subscribed. This state corresponds to a newly initiated ziServer session. After subscribing the root node, all leaves become subscribed. Then it is for instance possible to unsubscribe node 1 in order to leave just the leaves below node 2 subscribed.

Scripting

It is possible prepare a sequence of commands in a text editor and copy-paste them into the terminal session. The console will send all commands to the ziServer and the server will interpret them one by one.

Note

Use the right-mouse button in order to copy-paste into a Windows Putty session.

```
cd [.zinode]#/DEVX#
SIGOUTS/*/ON 0
SIGOUTS/0/RANGE 1
SIGOUTS/0/AMPLITUDES/0 1
SIGOUTS/0/ENABLES/* 0
SIGOUTS/0/ENABLES/0 1
OSCS/0/FREQ 300000
SIGINS/0/RANGE 10
DEMODS/0/ORDER 2
DEMODS/0/RATE 1000
```

## 6.3. Connecting to ziServer over insecure or networks behind firewalls

If you want to connect to the ziServer over insecure, public networks like the public internet, you need to consider that the TCP/IP connection to the ziServer is unsecured. Also many firewalls will not allow traffic to port 8005. There are two common solutions to this problem. Either a VPN or a ssh port tunneling/forwarding. In this section ssh port tunneling/forwarding is described.

### 6.3.1. SSH port forwarding

You can use ssh to connect to a remote computer and use this connection to tunnel ziServer traffic between the local and remote computer.

To illustrate how port forwarding works, let us use an example. Suppose you have two buildings. In Lab #1, there is the lab with computers residing in the subnet 10.1.1.\* and the HF2 is connected to one of these computers. At your Home, there are office computers residing in the subnet 10.2.2.\*. The computers in Lab #1 are running the ziServer application that uses an unencrypted TCP/IP session to communicate data with, e.g., the LabOne UI at your home. The firewall of the Lab and your Home might not permit this connection to be initiated. There are two kinds of port forwarding: local and remote forwarding. They are also called outgoing and incoming tunnels, respectively. Local port forwarding forwards traffic coming to a local port to a specified remote port. For example, all traffic coming to port 1234 on the client could be forwarded to port 8005 on the server (host).

The value of localhost is resolved after the Secure Shell connection has been established – so when defining local forwarding (outgoing tunnels), localhost refers to the server (remote host computer) you have connected to. Remote port forwarding does the opposite: it forwards traffic coming to a remote port to a specified local port. For example, all traffic coming to port 1234 on the server (host) could be forwarded to port 8005 on the client (localhost).

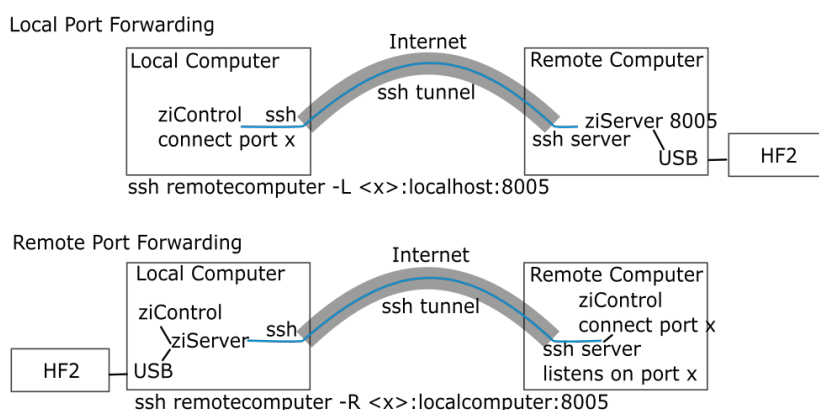


Figure 6.9: Secure connectivity

### 6.3.2. Local port forwarding

Accessing a service (in this example ziServer port TCP/8005) on a machine in the laboratory (10.1.1.) **from your machine at home (10.2.2.)**, simply by connecting to the server **work.example.org** at work:

```
$ssh user@work.example.org -L 10000:172.16.10.10:8005
```

We see the ziServer is available on the loop back interface only, listening on port TCP/10000:

```
$ netstat -tunelp | grep 10000
```

```
tcp 0 0 127.0.0.1:10000 0.0.0.0:* LISTEN 1000 71679 12468/ssh
```

From your home machine, you should be able to connect to the machine at work:

```
$ telnet localhost 10000
```

By specifying localhost and port 10000 in the LabOne UI you can connect with the LabOne UI. Note that port 10000 is chosen arbitrarily.

### 6.3.3. Local port forward for anyone at home

If you want other people on your home subnet to be able to reach the machine at work by SSH, add the global option `-g`:

```
$ ssh user@work.example.org -L 10000:172.16.10.10:22 -g
```

We now see the service is available on all interfaces on your home computer (10.2.2.5), available for anyone to connect to on the local subnet:

```
$ netstat -tunelp | grep 10000 tcp 0 0 0.0.0.0:10000 0.0.0.0:* LISTEN 1000 72265
12543/ssh
```

Anyone on your local subnet should be able to connect to the machine at work by doing this:

```
$ telnet 10.2.2.5 10000
```

By specifying host 10.2.2.5 and port 10000 in the LabOne UI you can connect with the LabOne UI.

### 6.3.4. Remote port forwarding

Giving access to a ziServer (port TCP/8005) on your home machine (10.2.2.5) to people at work:

```
$ ssh user@work.example.org -R 10000:10.2.2.5:8005
```

We see on our server at work (on the loop back interface on port TCP/10000) that we have access to our SSH server at home:

```
work.example.org$ netstat -tunelp | grep 10000 tcp 0 0 127.0.0.1:10000 0.0.0.0:*
LISTEN 0 73719534 3809/1
```

People logged in on the machine `work.example.org` now should be able to SSH into your home machine by doing:

```
work.example.org$ telnet localhost 10000
```

### 6.3.5. Remote port forwarding for anyone at work

If you want everybody on the subnet at work to be able to SSH into your home machine, there is no `-g` option for remote forward, so you need to change the SSH configuration of `work.example.org`, add to `sshd_config`:

```
GatewayPorts yes
```

Connect just as before:

```
home$ ssh user@work.example.org -R 10000:10.2.2.5:8005
```

Now, it is listening on all interfaces on the server at work:

```
work.example.org$ netstat -tunelp | grep 10000 tcp 0 0 0.0.0.0:10000 0.0.0.0:*
LISTEN 0 73721060 4426/1
```

Anyone at work can now connect to your home machine by SSH via the server:

```
anyone.example.org$ telnet work.example.org 10000
```



# 7. Device Node Tree

This chapter contains reference documentation for the settings and measurement data available on HF2LI Instruments. Whilst [Functional Description](#) describes many of these settings in terms of the features available in the LabOne User Interface, this chapter describes them on the device level and provides a hierarchically organized and comprehensive list of device functionality.

Since these settings and data streams may be written and read using the LabOne APIs (Application Programming Interfaces) this chapter is of particular interest to users who would like to perform measurements programmatically via LabVIEW, Python, MATLAB, .NET or C.

Please see:

- [Introduction](#) for an introduction of how the instrument's settings and measurement data are organized hierarchically in the Data Server's so-called "Node Tree".
- [Reference Node Documentation](#) for a reference list of the settings and measurement data available on HF2 Instruments, organized by branch in the Node Tree.

## 7.1. Introduction

This chapter provides an overview of how an instrument's configuration and output is organized by the Data Server.

All communication with an instrument occurs via the Data Server program the instrument is connected to (see [LabOne Software Architecture](#) for an overview of LabOne's software components). Although the instrument's settings are stored locally on the device, it is the Data Server's task to ensure it maintains the values of the current settings and makes these settings (and any subscribed data) available to all its current clients. A client may be the LabOne User Interface or a user's own program implemented using one of the LabOne Application Programming Interfaces, e.g., Python.

The instrument's settings and data are organized by the Data Server in a file-system-like hierarchical structure called the node tree. When an instrument is connected to a Data Server, its device ID becomes a top-level branch in the Data Server's node tree. The features of the instrument are organized as branches underneath the top-level device branch and the individual instrument settings are leaves of these branches.

For example, the auxiliary outputs of the instrument with device ID "dev2006" are located in the tree in the branch:

```
/dev1000/auxouts/
```

In turn, each individual auxiliary output channel has its own branch underneath the "AUXOUTS" branch.

```
/dev1000/auxouts/0/
/dev1000/auxouts/1/
/dev1000/auxouts/2/
/dev1000/auxouts/3/
```

Whilst the auxiliary outputs and other channels are labelled on the instrument's panels and the User Interface using 1-based indexing, the Data Server's node tree uses 0-based indexing. Individual settings (and data) of an auxiliary output are available as leaves underneath the corresponding channel's branch:

```
/dev1000/auxouts/0/demodselect
/dev1000/auxouts/0/limitlower
/dev1000/auxouts/0/limitupper
/dev1000/auxouts/0/offset
/dev1000/auxouts/0/outputselect
/dev1000/auxouts/0/preoffset
/dev1000/auxouts/0/scale
/dev1000/auxouts/0/value
```

These are all individual node paths in the node tree; the lowest-level nodes which represent a single instrument setting or data stream. Whether the node is an instrument setting or data-stream and

which type of data it contains or provides is well-defined and documented on a per-node basis in the Reference Node Documentation section in the relevant instrument-specific user manual. The different properties and types are explained in [Node Properties and Data Types](#).

For instrument settings, a Data Server client modifies the node's value by specifying the appropriate path and a value to the Data Server as a (path, value) pair. When an instrument's setting is changed in the LabOne User Interface, the path and the value of the node that was changed are displayed in the Status Bar in the bottom of the Window. This is described in more detail in [Exploring the Node Tree](#).

## Module Parameters

LabOne Core Modules, such as the Sweeper, also use a similar tree-like structure to organize their parameters. Please note, however, that module nodes are not visible in the Data Server's node tree; they are local to the instance of the module created in a LabOne client and are not synchronized between clients.

### 7.1.1. Node Properties and Data Types

A node may have one or more of the following properties:

|           |                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Read      | Data can be read from the node.                                                                                                                                                                                                                                                                                                                                                                                                         |
| Write     | Data can be written to the node.                                                                                                                                                                                                                                                                                                                                                                                                        |
| Setting   | The node corresponds to a writable instrument configuration. The data of these nodes are persisted in snapshots of the instrument and stored in the LabOne XML settings files.                                                                                                                                                                                                                                                          |
| Streaming | A node with the read attribute that provides instrument data, typically at a user-configured rate. The data is usually a more complex data type, for example demodulator data is returned as <b>ZIDemodSample</b> . A full list of streaming nodes is available in the Programming Manual in the Chapter Instrument Communication. Their availability depends on the device class (e.g. MF) and the option set installed on the device. |

A node may contain data of the following types:

|                      |                                                                                                                                                                                                                                                                            |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Integer              | Integer data.                                                                                                                                                                                                                                                              |
| Double               | Double precision floating point data.                                                                                                                                                                                                                                      |
| String               | A string array.                                                                                                                                                                                                                                                            |
| Integer (enumerated) | As for Integer, but the node only allows certain values.                                                                                                                                                                                                                   |
| Composite data type  | For example, <b>ZIDemodSample</b> . These custom data types are structures whose fields contain the instrument output, a timestamp and other relevant instrument settings such as the demodulator oscillator frequency. Documentation of custom data types is available in |

## 7.1.2. Exploring the Node Tree

### In the LabOne User Interface

A convenient method to learn which node is responsible for a specific instrument setting is to check the Command Log history in the bottom of the LabOne User Interface. The command in the Status Bar gets updated every time a configuration change is made. [Figure 71](#) shows how the equivalent MATLAB command is displayed after modifying the value of the auxiliary output 1's offset. The format of the LabOne UI's command history can be configured in the Config Tab (MATLAB, Python and .NET are available). The entire history generated in the current UI session can be viewed by clicking the "Show Log" button.

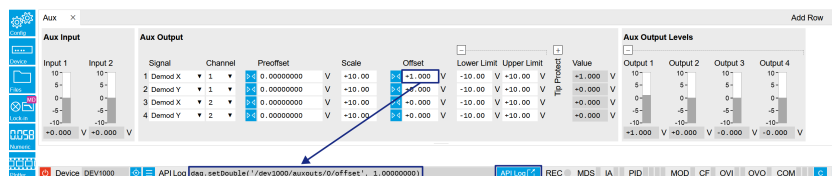


Figure 71: When a device's configuration is modified in the LabOne User Interface, the Status Bar displays the equivalent command to perform the same configuration via a LabOne programming interface. Here, the MATLAB code to modify auxiliary output 1's offset value is provided. When "Show Log" is clicked the entire configuration history is displayed in a new browser tab.

### In a LabOne Programming Interface

A list of nodes (under a specific branch) can be requested from the Data Server in an API client using the `listNodes` command (MATLAB, Python, .NET) or `ziAPIListNodes()` function (C API). Please see each API's command reference for more help using the `listNodes` command. To obtain a list of all the nodes that provide data from an instrument at a high rate, so-called streaming nodes, the `streamingonly` flag can be provided to `listNodes`. More information on data streaming and streaming nodes is available in the LabOne Programming Manual.

The detailed descriptions of nodes that is provided in [Reference Node Documentation](#) is accessible directly in the LabOne MATLAB or Python programming interfaces using the "help" command. The `help` command is `daq.help(path)` in Python and `ziDAQ('help', path)` in MATLAB. The command returns a description of the instrument node including access properties, data type, units and available options. The "help" command also handles wildcards to return a detailed description of all nodes matching the path. An example is provided below.

```
daq = zhinst.core.ziDAQServer('localhost', 8004, 6)
daq.help('/dev2006/auxouts/0/offset')
Out:
/dev1000/auxouts/0/offset#
Add the specified offset voltage to the signal after scaling. Auxiliary
Output
Value = (Signal+Preoffset)*Scale + Offset
Properties: Read, Write, Setting
Type: Double
Unit: V
```

## 7.1.3. Data Server Nodes

The Data Server has nodes in the node tree available under the top-level `/ZI/` branch. These nodes give information about the version and state of the Data Server the client is connected to. For example, the nodes:

- `/ZI/ABOUT/VERSION`
- `/ZI/ABOUT/REVISION`

are read-only nodes that contain information about the release version and revision of the Data Server. The nodes under the `/ZI/DEVICES/` list which devices are connected, discoverable and visible to the Data Server.

The nodes:

- /ZI/CONFIG/OPEN
- /ZI/CONFIG/PORT

are settings nodes that can be used to configure which port the Data Server listens to for incoming client connections and whether it may accept connections from clients on hosts other than the localhost.

Nodes that are of particular use to programmers are:

- /ZI/DEBUG/LOGPATH - the location of the Data Server's log in the PC's file system,
- /ZI/DEBUG/LEVEL - the current log-level of the Data Server (configurable; has the Write attribute),
- /ZI/DEBUG/LOG - the last Data Server log entries as a string array.

The Global nodes of the LabOne Data Server are listed in the Instrument Communication chapter of the LabOne Programming Manual

## 7.2. Reference Node Documentation

This section describes all the nodes in the data server's node tree organized by branch.

### 7.2.1. AUXINS

#### /dev..../auxins/n/averaging

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Averaging of the samples.

#### /dev..../auxins/n/sample

**Properties:** Read, Stream  
**Type:** ZIAuxInSample  
**Unit:**

Auxiliary input samples.

#### /dev..../auxins/n/values/n

**Properties:** Read  
**Type:** Double  
**Unit:** V

Input 0 value.

#### /dev..../auxins/n/values/1

**Properties:** Read  
**Type:** Double  
**Unit:** V

Input 1 value.

## 7.2.2. AUXOUTS

### /dev..../auxouts/n/demodselect

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Index

Source demodulator.

### /dev..../auxouts/n/offset

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** V

Value to be added to the output. The offset value is applied after scaling.

### /dev..../auxouts/n/outputselect

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Signal to be given out.

|    |                                    |
|----|------------------------------------|
| -1 | Manual                             |
| 0  | X                                  |
| 1  | Y                                  |
| 2  | R                                  |
| 3  | Theta                              |
| 4  | PLL 1 (with installed PLL option)) |

### /dev..../auxouts/n/scale

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**

Scaling of the signal which is given out.

### /dev..../auxouts/n/value

**Properties:** Read  
**Type:** Double  
**Unit:** V

Output value.

## 7.2.3. CLOCKBASE

### /dev..../clockbase

**Properties:** Read  
**Type:** Integer  
**Unit:**

Provides clockbase value for the device

## 7.2.4. CPUS

### /dev..../cpus/n/output

**Properties:** Read  
**Type:** ZIVectorData  
**Unit:**

Node containing the standard output stream written by the real time program.

### /dev..../cpus/n/program

**Properties:** Write  
**Type:** String  
**Unit:**

Node to write user programs to.

### /dev..../cpus/n/userregs/n

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

General purpose register.

### /dev..../cpus/n/workload

**Properties:** Read  
**Type:** Double  
**Unit:**

Usage of the processor-time.

## 7.2.5. DEMODS

### /dev..../demods/n/adselect

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Index

Selects the index of the signal input for the demodulator.

|   |                |
|---|----------------|
| 0 | Signal input 0 |
| 1 | Signal input 1 |
| 2 | Aux Input 0    |
| 3 | Aux Input 1    |
| 4 | DIO 0          |
| 5 | DIO 1          |

**/dev..../demods/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the demodulator data stream.

|   |                        |
|---|------------------------|
| 0 | Demodulator stream off |
| 1 | Demodulator stream on  |

**/dev..../demods/n/freq**

**Properties:** Read  
**Type:** Double  
**Unit:** Hz

Frequency to of the demodulator.

**/dev..../demods/n/harmonic**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Harmonic

The harmonic of the base frequency to be used. Selecting 1 chooses the fundamental frequency.

**/dev..../demods/n/order**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Order

Selects the order of the low-pass filter.

|   |                 |
|---|-----------------|
| 1 | 6 dB/oct slope  |
| 2 | 12 dB/oct slope |
| 3 | 18 dB/oct slope |
| 4 | 24 dB/oct slope |
| 5 | 30 dB/oct slope |
| 6 | 36 dB/oct slope |
| 7 | 42 dB/oct slope |
| 8 | 48 dB/oct slope |

**/dev..../demods/n/osctest**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Index

Index of the oscillator used to demodulate the signal.

**/dev..../demods/n/phaseshift**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** deg

The phase shift of the demodulator.

**/dev..../demods/n/rate**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz

The number of output values sent to the computer per second.

**/dev..../demods/n/sample**

**Properties:** Read, Stream  
**Type:** ZIDemodSample  
**Unit:**

Samples of the demodulator are given out at this node.

**/dev..../demods/n/sinc**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value enabling Sinc filter functionality.

|   |                         |
|---|-------------------------|
| 0 | Sinc filtering disabled |
| 1 | Sinc filtering enabled  |

**/dev..../demods/n/timeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Sets the time constant of the low-pass filter. The time constant is set for each stage of the low-pass filter. The total time constant and bandwidth depends on the selected order.

**/dev..../demods/n/trigger**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** bit-coded

Sets the trigger- and gating-functionality of the demodulator. The triggers are configured by the bits of an integer. When multiple bits/triggers are set, they are or-ed. If trigger is set to 0 then demodulator data is sent continuously.

|     |                         |
|-----|-------------------------|
| 1   | "b0": DIO0 rising edge  |
| 2   | "b1": DIO0 falling edge |
| 4   | "b2": DIO1 rising edge  |
| 8   | "b3": DIO1 falling edge |
| 16  | "b4": DIO0 high         |
| 32  | "b5": DIO0 low          |
| 64  | "b6": DIO1 high         |
| 128 | "b7": DIO1 low          |



## 7.2.6. DIOS

**/dev..../dios/n/decimation**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Decimation for the sample rate of the DIO.

**/dev..../dios/n/drive**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Selects if the outputs should be driven.

|   |                     |
|---|---------------------|
| 0 | Drive off           |
| 1 | Drive lower 8 bits  |
| 2 | Drive higher 8 bits |
| 3 | Drive all 16 bits   |

**/dev..../dios/n/extclk**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Selects whether an external clock source should be used. The external clock needs to be applied to the DIO connector when this node is set to 1.

|   |                |
|---|----------------|
| 0 | Internal clock |
| 1 | External clock |

**/dev..../dios/n/input**

**Properties:** Read, Stream  
**Type:** ZIDIOSample  
**Unit:**

Samples of the input.

**/dev..../dios/n/output**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Bits to output.

**/dev..../dios/n/syncselect0**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Source to output the sync signal on bit 0.

**/dev..../dios/n/syncselect1**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Source to output the sync signal on bit 1.

## 7.2.7. FEATURES

**/dev..../features/code**

**Properties:** Write  
**Type:** String  
**Unit:**

Node providing a mechanism to write feature codes.

**/dev..../features/devtype**

**Properties:** Read  
**Type:** String  
**Unit:**

Node providing a string about the type of device.

**/dev..../features/options**

**Properties:** Read  
**Type:** String  
**Unit:**

Node giving information on enabled options. Reading this node returns a string containing a newline-separated list of all installed options.

**/dev..../features/serial**

**Properties:** Read  
**Type:** String  
**Unit:**

Node providing the serial number of the device.

## 7.2.8. MODS

**/dev..../mods/n/carrier/amplitude**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Gain

Carrier amplitude. Fraction of the output range added to the output signal. Multiply this value with the range setting to obtain voltage in V.

**/dev..../mods/n/carrier/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the carrier data stream.

|   |                        |
|---|------------------------|
| 0 | Demodulator stream off |
| 1 | Demodulator stream on  |

**/dev..../mods/n/carrier/harmonic**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Harmonic

Harmonic of the carrier frequency. Selecting 1 chooses the fundamental frequency.

**/dev..../mods/n/carrier/inputselect**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Signal Input for the carrier demodulation.

|   |          |
|---|----------|
| 0 | Sig In 1 |
| 1 | Sig In 2 |

**/dev..../mods/n/carrier/order**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Order

Filter order for carrier demodulation.

|   |                 |
|---|-----------------|
| 1 | 6 dB/oct slope  |
| 2 | 12 dB/oct slope |
| 3 | 18 dB/oct slope |
| 4 | 24 dB/oct slope |
| 5 | 30 dB/oct slope |
| 6 | 36 dB/oct slope |
| 7 | 42 dB/oct slope |
| 8 | 48 dB/oct slope |

**/dev..../mods/n/carrier/oscselect**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Index

Index of the oscillator used to demodulate the signal.

**/dev..../mods/n/carrier/phaseshift**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** deg

The phase shift of the carrier demodulator.

**/dev..../mods/n/carrier/timeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Sets the time constant of the carrier low-pass filter. The time constant is set for each stage of the low-pass filter. The total time constant and bandwidth depends on the selected order.

**/dev..../mods/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the modulation.

|   |                |
|---|----------------|
| 0 | Modulation Off |
| 1 | Modulation On  |

**/dev..../mods/n/freqdev**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** V

In FM mode, set peak deviation value.

**/dev..../mods/n/freqdevenable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

In FM mode, enable peak deviation.

|   |                    |
|---|--------------------|
| 0 | Peak deviation off |
| 1 | Peak deviation on  |

**/dev..../mods/n/index**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**

In FM mode, set modulation index value. The modulation index equals peak deviation divided by modulation frequency.

**/dev..../mods/n/mode**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Modulation mode.

|   |                      |
|---|----------------------|
| 0 | Amplitude modulation |
| 1 | Frequency modulation |
| 2 | Manual               |

**/dev..../mods/n/output**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Modulation output.

|   |         |
|---|---------|
| 0 | none    |
| 1 | 1       |
| 2 | 2       |
| 3 | 1 and 2 |

**/dev..../mods/n/rate**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz

The number of output values sent to the computer per second.

**/dev..../mods/n/rawfmcoeff**

**Properties:** Read, Write  
**Type:** Double  
**Unit:**

Frequency Modulation Coefficient. This node is only active in FM-mode (MODE=3)

**/dev..../mods/n/rawmode**

**Properties:** Read, Write  
**Type:** Integer (enumerated)  
**Unit:**

Modulation mode.

|   |                        |
|---|------------------------|
| 0 | Off                    |
| 1 | Amplitude modulation   |
| 2 | Frequency demodulation |
| 3 | Frequency modulation   |

**/dev..../mods/n/rawsideband**

**Properties:** Read, Write  
**Type:** Integer (enumerated)  
**Unit:**

Sideband selector.

|   |       |
|---|-------|
| 0 | Both  |
| 1 | Upper |
| 2 | Lower |

**/dev..../mods/n/sample**

**Properties:** Read, Stream  
**Type:** ZIDemodSample  
**Unit:**

Modulation Samples.

**/dev..../mods/n/sidebands/n/amplitude**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Gain

Sideband amplitude, Fraction of the output range added to the output signal. Multiply this value with the range setting to obtain voltage in V.

**/dev..../mods/n/sidebands/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the sideband data stream.

|   |                        |
|---|------------------------|
| 0 | Demodulator stream off |
| 1 | Demodulator stream on  |

**/dev..../mods/n/sidebands/n/harmonic**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Harmonic

Harmonic of the sideband frequency. Selecting 1 chooses the fundamental frequency.

**/dev..../mods/n/sidebands/n/inputselect**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Signal Input for the sideband demodulation.

|   |          |
|---|----------|
| 0 | Sig In 1 |
| 1 | Sig In 2 |

**/dev..../mods/n/sidebands/n/mode**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Sideband selector.

|   |       |
|---|-------|
| 0 | Off   |
| 1 | C + M |
| 2 | C - M |

**/dev..../mods/n/sidebands/n/order**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Order

Filter order for sideband demodulation.

|   |                 |
|---|-----------------|
| 1 | 6 dB/oct slope  |
| 2 | 12 dB/oct slope |
| 3 | 18 dB/oct slope |
| 4 | 24 dB/oct slope |
| 5 | 30 dB/oct slope |
| 6 | 36 dB/oct slope |
| 7 | 42 dB/oct slope |
| 8 | 48 dB/oct slope |

**/dev..../mods/n/sidebands/n/osctest**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Index

Index of the oscillator used to demodulate the signal.

**/dev..../mods/n/sidebands/n/phaseshift**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** deg

The phase shift of the sideband demodulator.

**/dev..../mods/n/sidebands/n/timeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Sets the time constant of the sideband low-pass filter. The time constant is set for each stage of the low-pass filter. The total time constant and bandwidth depends on the selected order.

**/dev..../mods/n/trigger**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** bit-coded

Sets the trigger- and gating-functionality of the demodulator.

|     |                         |
|-----|-------------------------|
| 1   | "b0": DIO0 rising edge  |
| 2   | "b1": DIO0 falling edge |
| 4   | "b2": DIO1 rising edge  |
| 8   | "b3": DIO1 falling edge |
| 16  | "b4": DIO0 high         |
| 32  | "b5": DIO0 low          |
| 64  | "b6": DIO1 high         |
| 128 | "b7": DIO1 low          |

**7.2.9. OSCS****/dev..../oscs/n/freq**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz

Frequency to of the oscillator.

**7.2.10. PIDS****/dev..../pids/n/center**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [OUTPUT Unit]

Sets the output center point.

**/dev..../pids/n/d**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [OUTPUT Unit]/[INPUT Unit]\*s

Proportional gain for differentiator. Sets the proportional gain for the differentiated error signal. Negative feedback corresponds to a negative gain.

**/dev..../pids/n/demod/adselect**

**Properties:** Read, Write  
**Type:** Integer (enumerated)  
**Unit:** Index

Selects the index of the signal input for the demodulator.

|   |                |
|---|----------------|
| 0 | Signal input 0 |
| 1 | Signal input 1 |
| 2 | Aux Input 0    |
| 3 | Aux Input 1    |
| 4 | DIO 0          |
| 5 | DIO 1          |



**/dev..../pids/n/demod/harmonic**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Harmonic

The harmonic of the base frequency to be used. Selecting 1 chooses the fundamental frequency.

**/dev..../pids/n/demod/order**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Order

Selects the order of the low-pass filter.

|   |                 |
|---|-----------------|
| 1 | 6 dB/oct slope  |
| 2 | 12 dB/oct slope |
| 3 | 18 dB/oct slope |
| 4 | 24 dB/oct slope |
| 5 | 30 dB/oct slope |
| 6 | 36 dB/oct slope |
| 7 | 42 dB/oct slope |
| 8 | 48 dB/oct slope |

**/dev..../pids/n/demod/timeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Sets the time constant of the low-pass filter. The time constant is set for each stage of the low-pass filter. The total time constant and bandwidth depends on the selected order.

**/dev..../pids/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enable PID controller.

|   |     |
|---|-----|
| 0 | OFF |
| 1 | ON  |

**/dev..../pids/n/error**

**Properties:** Read  
**Type:** Double  
**Unit:** [OUTPUT Unit]

Shows the error value. The calculated error is :  $ERROR = SETPOINT - IN$ .

**/dev..../pids/n/i**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [OUTPUT Unit]/[INPUT Unit]/s

Proportional gain for integrator. Sets the proportional gain for the integrated (accumulated) error signal. Negative feedback corresponds to a negative gain.

**/dev..../pids/n/input**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Selects the input for the PID.

|    |                                                   |
|----|---------------------------------------------------|
| 0  | Demodulator X value [Vrms]                        |
| 1  | Demodulator Y value [Vrms]                        |
| 2  | Demodulator R value [Vrms]                        |
| 3  | Demodulator Theta value [deg]                     |
| 4  | Auxiliary Input [V]                               |
| 5  | Auxiliary Output (as input) [V]                   |
| 6  | Modulation Index [0,1]                            |
| 7  | Dual Frequency Tracking $ Z(n+)  -  Z(n) $ [Vrms] |
| 8  | Demodulator $x(n+1) - x(n)$ [Vrms]                |
| 9  | Demodulator $ z(n+1) - z(n) $ [Vrms]              |
| 10 | Oscillator Frequency [Hz]                         |

**/dev..../pids/n/inputchannel**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

If applicable, selects the channel of the selected INPUT. Sets the input channel index for the selected INPUT, i.e. 0,1,2 etc.. The available channels depend on the input type.

**/dev..../pids/n/monitoroffset**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**

Offset for the monitor output.

**/dev..../pids/n/monitorscale**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**

Scale for the monitor output.

**/dev..../pids/n/output**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Selects the output for the PID.

|   |                                    |
|---|------------------------------------|
| 0 | Signal Output 1 [Vrms]             |
| 1 | Signal Output 2 [Vrms]             |
| 2 | Oscillator frequency [Hz]          |
| 3 | Auxiliary Output (manual mode) [V] |
| 4 | DIO [5 Volt TTL]                   |

**/dev..../pids/n/outputchannel**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

If applicable, selects the channel of the selected OUTPUT. Sets the input channel index for the selected OUTPUT, i.e. 0,1,2 etc.. The available channels depend on the output type

**/dev..../pids/n/outputdefault**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**

If OUTPUTDEFAULTENABLE is set, this node specifies the value to be applied.

**/dev..../pids/n/outputdefaultenable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

If OUTPUTDEFAULTENABLE is set, the value specified by OUTPUTDEFAULT will be applied when the PID is switched off.

|   |     |
|---|-----|
| 0 | OFF |
| 1 | ON  |

**/dev..../pids/n/p**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [OUTPUT Unit]/[INPUT Unit]

Proportional gain. Sets the proportional gain for the error signal. Negative feedback corresponds to a negative gain.

**/dev..../pids/n/range**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [OUTPUT Unit]

Sets the output range. The limits for the output are :  $OUT = [CENTER - RANGE, CENTER + RANGE]$  with  $RANGE > 0.0$ .

**/dev..../pids/n/rate**

**Properties:** Read  
**Type:** Double  
**Unit:** Samples/s

Control update rate.

**/dev..../pids/n/setpoint**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** [INPUT Unit]

Target settle point.

**/dev..../pids/n/setpointselect**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Set point selection.

|   |                   |
|---|-------------------|
| 0 | Manual Setpoint   |
| 1 | Auxiliary Input 1 |
| 2 | Auxiliary Input 2 |
| 3 | PID n             |

**/dev..../pids/n/shift**

**Properties:** Read  
**Type:** Double  
**Unit:** [OUTPUT Unit]

Shows the output shift. The calculated output value is :  $OUT = CENTER + SHIFT$ .

**/dev..../pids/n/tipprotect/active**

**Properties:** Read  
**Type:** Integer  
**Unit:** Boolean

Indicates whether TipProtect is active.

**/dev..../pids/n/tipprotect/activethreshold**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:**  $\text{deg}^2$

Threshold for the active state. Threshold for PLL error<sup>2</sup> when TipProtect is active, i.e. when waiting to re-enable the PID controller.

**/dev..../pids/n/tipprotect/activetimeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Time constant when TipProtect is active. Time constant for low-pass filtering the PLL error<sup>2</sup> when TipProtect is active, i.e. when waiting to re-enable the PID controller.

**/dev..../pids/n/tipprotect/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enable TipProtect for the PID controller.

|   |     |
|---|-----|
| 0 | OFF |
| 1 | ON  |

**/dev..../pids/n/tipprotect/inactivethreshold**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** deg<sup>2</sup>

Threshold for the inactive state. Threshold for PLL error<sup>2</sup> when TipProtect is inactive, i.e. when waiting to disable the PID controller.

**/dev..../pids/n/tipprotect/inactivetimeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Time constant when TipProtect is inactive. Time constant for low-pass filtering the PLL error<sup>2</sup> when TipProtect is inactive, i.e. when waiting to disable the PID controller.

**/dev..../pids/n/tipprotect/pll**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Selects a PLL for TipProtect.

## 7.2.11. PLLS

**/dev..../plls/n/adselect**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Index

Selects an input for the PLL.

|   |                |
|---|----------------|
| 0 | Signal Input 1 |
| 1 | Signal Input 2 |
| 2 | Aux Input 1    |
| 3 | Aux Input 2    |
| 4 | DIO 0          |
| 5 | DIO 1          |

**/dev..../plls/n/adcthreshold**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Threshold for edge detection. Full scale corresponds to -4096 and 4095.

**/dev..../plls/n/autocenter**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches auto-center.

|   |                 |
|---|-----------------|
| 0 | Auto-center off |
| 1 | Auto-center on  |

**/dev..../plls/n/autopid**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches external PID.

|   |                  |
|---|------------------|
| 0 | External PID off |
| 1 | External PID on  |

**/dev..../plls/n/autotimeconstant**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches external time constant control.

|   |                            |
|---|----------------------------|
| 0 | External time constant off |
| 1 | External time constant on  |

**/dev..../plls/n/auxavg**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Delta frequency averaging control.

**/dev..../plls/n/d**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** 1/deg

Derivative gain of the PID.

**/dev..../plls/n/demodselect**

**Properties:** Read  
**Type:** Integer  
**Unit:** Index

Source demodulator.

**/dev..../plls/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the PLL.

0 PLL off  
 1 PLL on

**/dev..../plls/n/error**

**Properties:** Read  
**Type:** Double  
**Unit:** deg

Error of the PLL.

**/dev..../plls/n/freqcenter**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz

Selects a center frequency.

**/dev..../plls/n/freqdelta**

**Properties:** Read  
**Type:** Double  
**Unit:** Hz

Frequency deviation from center frequency.

**/dev..../plls/n/freqrange**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz

Selects a frequency range for the PLL.

**/dev..../plls/n/harmonic**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** Harmonic

The harmonic of the base frequency to be used. Selecting 1 chooses the fundamental frequency.

**/dev..../plls/n/i**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz<sup>2</sup>/deg

Integral gain of the PID controller.

**/dev..../plls/n/locked**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Lock indicator for the PLL.

|   |                |
|---|----------------|
| 0 | PLL not locked |
| 1 | PLL locked     |

**/dev..../plls/n/order**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Order

Selects the order of the low-pass filter.

|   |                 |
|---|-----------------|
| 1 | 6 dB/oct slope  |
| 2 | 12 dB/oct slope |
| 3 | 18 dB/oct slope |
| 4 | 24 dB/oct slope |
| 5 | 30 dB/oct slope |
| 6 | 36 dB/oct slope |
| 7 | 42 dB/oct slope |
| 8 | 48 dB/oct slope |

**/dev..../plls/n/oscselect**

**Properties:** Read  
**Type:** Integer  
**Unit:** Index

Index of the oscillator used.

**/dev..../plls/n/p**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Hz/deg

Proportional gain of the PID controller.

**/dev..../plls/n/rate**

**Properties:** Read  
**Type:** Double  
**Unit:** Samples/s

Update rate information.



**/dev..../plls/n/setpoint**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** deg

The setpoint in degrees of the PLL.

**/dev..../plls/n/timeconstant**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

The external time constant.

## 7.2.12. SCOPES

**/dev..../scopes/n/bwlimit**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

The bandwidth-limit for the scope.

|   |              |
|---|--------------|
| 0 | BW-limit off |
| 1 | BW-limit on  |

**/dev..../scopes/n/channel**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Index

Selects the channel for which scope data should be provided.

|   |                 |
|---|-----------------|
| 0 | Signal Input 1  |
| 1 | Signal Input 2  |
| 2 | Signal Output 1 |
| 3 | Signal Output 2 |

**/dev..../scopes/n/enable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Enables the scope.

|   |           |
|---|-----------|
| 0 | Scope off |
| 1 | Scope on  |

**/dev..../scopes/n/time**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:**

Timescale of the scope wave (logarithmic decimation). Determines the decimation of the sample rate. The following formulas apply:  $\text{span} = 2^{\text{val}} * 10 \text{ us}$ ,  $\text{sample rate} = 210 \text{ MSamples}/2^{\text{val}}$

**/dev..../scopes/n/trigchannel**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Index

Selects the channel which should be used as source for the scope's trigger.

|    |                    |
|----|--------------------|
| -2 | Continuous         |
| -1 | Off                |
| 0  | Oscillator 7 phase |
| 1  | Signal Input 2     |
| 2  | Signal Output 1    |
| 3  | Signal Output 2    |
| 4  | Oscillator 1 phase |
| 5  | Oscillator 2 phase |
| 6  | Oscillator 3 phase |
| 7  | Oscillator 4 phase |
| 8  | Oscillator 5 phase |
| 9  | Oscillator 6 phase |
| 11 | Oscillator 8 phase |
| 12 | DIO 0              |
| 13 | DIO 1              |

**/dev..../scopes/n/trigedge**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Selects whether the scope should trigger on rising or falling edge.

|   |              |
|---|--------------|
| 0 | Falling edge |
| 1 | Rising edge  |

**/dev..../scopes/n/trigholdoff**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** s

Time to wait for re-arming the trigger after one occurred.

**/dev..../scopes/n/triglevel**

**Properties:** Read, Write, Setting  
**Type:** Integer  
**Unit:** LSB

Level at which a trigger is raised. Full scale is covered by min and max values

**/dev..../scopes/n/wave**

**Properties:** Read, Stream  
**Type:** ZIScopeWave  
**Unit:**

Samples of scope-waveforms.

## 7.2.13. SIGINS

**/dev..../sigins/n/ac**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value setting for AC coupling of the Signal Input.

|   |             |
|---|-------------|
| 0 | DC coupling |
| 1 | AC coupling |

**/dev..../sigins/n/diff**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value switching differential input mode.

|   |                     |
|---|---------------------|
| 0 | Single-ended inputs |
| 1 | Differential inputs |

**/dev..../sigins/n/imp50**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value enabling 50 Ohm input impedance termination.

|   |                  |
|---|------------------|
| 0 | High impedance   |
| 1 | 50 Ohm impedance |

**/dev..../sigins/n/range**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** V

Voltage range for the signal input.

## 7.2.14. SIGOUTS

**/dev..../sigouts/n/add**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches the output adder on and off.

|   |           |
|---|-----------|
| 0 | Adder off |
| 1 | Adder on  |

**/dev..../sigouts/n/amplitudes/n**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Gain

Fraction of the output range added to the output signal. Multiply this value with the range setting to obtain voltage in V.

**/dev..../sigouts/n/enables/n**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Switches a channel in the mixer on and off.

|   |                                                                                   |
|---|-----------------------------------------------------------------------------------|
| 0 | Channel off (unconditionally)                                                     |
| 1 | Channel on (unconditionally)                                                      |
| 2 | Channel off (will be turned off on next change of sign from negative to positive) |
| 3 | Channel on (will be turned on on next change of sign from negative to positive)   |

**/dev..../sigouts/n/offset**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** Gain

Offset added to the Signal Output. Multiply this value with the range setting to obtain offset voltage in V.

**/dev..../sigouts/n/on**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches the output on and off.

|   |            |
|---|------------|
| 0 | Output off |
| 1 | Output on  |

**/dev..../sigouts/n/range**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** V

Selects the output range for the Signal Output.

|      |              |
|------|--------------|
| 0.01 | 0.01 V range |
| 0.1  | 0.1 V range  |
| 1    | 1 V range    |
| 10   | 10 V range   |

**/dev..../sigouts/n/waveforms/n**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:**

Waveforms for a channel in the mixer. For hardware revisions 1.4 and lower, the output signal range for rectangular output is limited to 1 V.

|   |        |
|---|--------|
| 0 | Sine   |
| 1 | Square |

## 7.2.15. STATS

**/dev..../stats/bytesreceived**

**Properties:** Read  
**Type:** Integer  
**Unit:** Bytes

Total amount of bytes received via USB.

**/dev..../stats/bytessent**

**Properties:** Read  
**Type:** Integer  
**Unit:** Bytes

Total amount of bytes sent via USB.

**/dev..../stats/meanmsgcnt**

**Properties:** Read  
**Type:** Double  
**Unit:** Messages/Second

Average message-count.

**/dev..../stats/meanpollcnt**

**Properties:** Read  
**Type:** Double  
**Unit:** Polls/Second

Average poll-count.

**/dev..../stats/physical/1v2**

**Properties:** Read  
**Type:** Double  
**Unit:** Volts

Actual voltage of the 1.2 Volts supply.

**/dev..../stats/physical/1v8**

**Properties:** Read  
**Type:** Double  
**Unit:** Volts

Actual voltage of the 1.8 Volts supply.

**/dev..../stats/physical/2v5**

**Properties:** Read  
**Type:** Double  
**Unit:** Volts

Actual voltage of the 2.5 Volts supply.

**/dev..../stats/physical/3v3**

**Properties:** Read  
**Type:** Double  
**Unit:** Volts

Actual voltage of the 3.3 Volts supply.

**/dev..../stats/physical/5v0**

**Properties:** Read  
**Type:** Double  
**Unit:** Volts

Actual voltage of the 5.0 Volts supply.

**/dev..../stats/physical/overtemperature**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Too high FPGA temperature detected during session.

|   |                          |
|---|--------------------------|
| 0 | No overtemperature       |
| 1 | Overtemperature detected |

**/dev..../stats/physical/temp**

**Properties:** Read  
**Type:** Double  
**Unit:** Degrees Celsius

Actual temperature.

## 7.2.16. STATUS

**/dev..../status/adc0max**

**Properties:** Read  
**Type:** Integer  
**Unit:**

The maximum value on Signal Input 1 (ADC0) during 100 ms.

**/dev..../status/adc0min**

**Properties:** Read  
**Type:** Integer  
**Unit:**

The minimum value on Signal Input 1 (ADC0) during 100 ms.

**/dev..../status/adc1max**

**Properties:** Read  
**Type:** Integer  
**Unit:**

The maximum value on Signal Input 2 (ADC1) during 100 ms.

**/dev..../status/adc1min**

**Properties:** Read  
**Type:** Integer  
**Unit:**

The minimum value on Signal Input 2 (ADC1) during 100 ms.

**/dev..../status/echoread**

**Properties:** Read  
**Type:** Integer  
**Unit:**

32 bits written to ECHOWRITE node are echoed here.

**/dev..../status/echowrite**

**Properties:** Write  
**Type:** Integer  
**Unit:**

32 bits written to this node will be echoed back via ECHOREAD node.

**/dev..../status/fifolevel**

**Properties:** Read  
**Type:** Double  
**Unit:** Percent

Percentage of TX FIFO used.

**/dev.... /status/flags/adccclip/n**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating that this ADC-channel is clipping.

|   |             |
|---|-------------|
| 0 | no clipping |
| 1 | clipping    |

**/dev.... /status/flags/binary**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** bit-coded

A binary representation of all flags. When multiple flags are set the values are or-ed.

|         |                                                   |
|---------|---------------------------------------------------|
| 1       | "b0": PLL unlocked                                |
| 2       | "b1": HF clock unlocked                           |
| 4       | "b2": FX2 RX error                                |
| 8       | "b3": Package loss                                |
| 16      | "b4": Output 1 clipped                            |
| 32      | "b5": Output 2 clipped                            |
| 64      | "b6": Input 1 clipped                             |
| 128     | "b7": Input 2 clipped                             |
| 256     | "b8": Scope skipped a shot                        |
| 512     | "b9": FX2 TX buffer almost full                   |
| 1024    | "b10": 0                                          |
| 2048    | "b11": PLL unlocked (version without de-bouncing) |
| 4096    | "b12": FX2 TX package lost                        |
| 1048576 | "b20": PLL 1 locked                               |
| 2097152 | "b21": PLL 2 locked                               |

**/dev.... /status/flags/dcmlock**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating if the internal digital clock manager (DCM) has locked.

|   |                |
|---|----------------|
| 0 | DCM locked     |
| 1 | DCM not locked |

**/dev.... /status/flags/demodsampleloss**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating that demodulator data has been lost.

|   |                          |
|---|--------------------------|
| 0 | no demodulator data lost |
| 1 | demodulator data lost    |



**/dev.... /status/flags/fx2rx**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating if the device receives data via USB.

|   |                         |
|---|-------------------------|
| 0 | Device receives         |
| 1 | Device does not receive |

**/dev.... /status/flags/mixerclip/n**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating that this mixer-channel is clipping.

|   |             |
|---|-------------|
| 0 | no clipping |
| 1 | clipping    |

**/dev.... /status/flags/pkgloss**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating that the device lost data when sending via USB.

|   |                  |
|---|------------------|
| 0 | no packet loss   |
| 1 | packets are lost |

**/dev.... /status/flags/plllock**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating if the internal PLL for clock generation has locked.

|   |                |
|---|----------------|
| 0 | PLL locked     |
| 1 | PLL not locked |

**/dev.... /status/flags/scopeskipped**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Flag indicating that scope data has been skipped. This happens when too much data is being sent over USB.

|   |                 |
|---|-----------------|
| 0 | no data skipped |
| 1 | data skipped    |

**/dev.... /status/time**

**Properties:** Read  
**Type:** Double  
**Unit:** s

The current timestamp.

## 7.2.17. SYSTEM

**/dev.... /system/activeinterface**

**Properties:** Read  
**Type:** String  
**Unit:**

Node providing the active interface of the device.

**/dev.... /system/extclk**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value switching from internal to external clock. When using external clock, make sure that a clock generator is connected to the Clock In connector.

0 Internal clock  
 1 External clock

**/dev.... /system/hwrevision**

**Properties:** Read  
**Type:** Integer  
**Unit:**

The revision of the main-board.

**/dev.... /system/properties/negativefreq**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Device does support negative frequencies.

0 Negative frequencies not supported.  
 1 Negative frequencies supported.

**/dev.... /system/properties/freqresolution**

**Properties:** Read  
**Type:** Integer  
**Unit:** bits

Frequency resolution of the device.

**/dev..../system/properties/maxfreq**

**Properties:** Read  
**Type:** Double  
**Unit:** Hz

Maximum oscillator frequency of the device.

**/dev..../system/properties/maxtimeconstant**

**Properties:** Read  
**Type:** Double  
**Unit:** s

Maximum filter time constant of the device.

**/dev..../system/properties/minfreq**

**Properties:** Read  
**Type:** Double  
**Unit:** Hz

Minimum oscillator frequency of the device.

**/dev..../system/properties/mintimeconstant**

**Properties:** Read  
**Type:** Double  
**Unit:** s

Minimum filter time constant of the device.

**/dev..../system/properties/timebase**

**Properties:** Read  
**Type:** Double  
**Unit:** s

Time base of the device.

**/dev..../system/syncenable**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value enabling multi-device timestamp synchronization over ZSync. When synchronizing timestamps between devices make sure that an appropriate cable is connected between the ZSync ports of the leader and follower devices.

0 Default  
 1 Timestamp synchronization enabled

**/dev..../system/syncreset**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Boolean value activating timestamp reset over ZSync. When synchronizing timestamps between devices make sure that an appropriate cable is connected between the ZSync ports of the leader and follower devices.

0 Default  
 1 Timestamp reset activated

**/dev..../system/synctime**

**Properties:** Read  
**Type:** Double  
**Unit:** s

The timestamp to load when timestamp reset is activated.

## 7.2.18. ZCTRLS

**/dev..../zctrls/n/camp/available**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

1 when HF2CA is connected to the corresponding ZCtrl port.

0 HF2CA is not connected  
 1 HF2CA is connected

**/dev..../zctrls/n/camp/dc**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches between AC coupling and DC coupling.

0 AC coupling  
 1 DC coupling

**/dev..../zctrls/n/camp/gain**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Gain

Switches between factor 1 and 10 gain.

1 Factor 1 gain  
 10 Factor 10 gain

**/dev..../zctrls/n/camp/r**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Ohm

Chooses a value for the shunt-resistor.

|         |                  |
|---------|------------------|
| 0       | open, high ohmic |
| 10      | 10 Ohm           |
| 100     | 100 Ohm          |
| 1000    | 1 kOhm           |
| 10000   | 10 kOhm          |
| 100000  | 100 kOhm         |
| 1000000 | 1 MOhm           |

**/dev..../zctrls/n/camp/singleended**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches between differential and single-ended input.

|   |                     |
|---|---------------------|
| 0 | Differential inputs |
| 1 | Single-ended inputs |

**/dev..../zctrls/n/tamp/n/currentgain**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Gain

Chooses a value for the current gain.

|           |              |
|-----------|--------------|
| 100       | Factor 100   |
| 1000      | Factor 1 k   |
| 10000     | Factor 10 k  |
| 100000    | Factor 100 k |
| 1000000   | Factor 1 M   |
| 10000000  | Factor 10 M  |
| 100000000 | Factor 100 M |

**/dev..../zctrls/n/tamp/n/dc**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches between AC and DC Mode.

|   |         |
|---|---------|
| 0 | AC Mode |
| 1 | DC Mode |

**/dev..../zctrls/n/tamp/n/offset**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** V

Adjust offset value.

**/dev..../zctrls/n/tamp/n/voltagegain**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Gain

Chooses a value for the voltage gain.

|    |      |
|----|------|
| 1  | 1 x  |
| 10 | 10 x |

**/dev..../zctrls/n/tamp/available**

**Properties:** Read  
**Type:** Integer (enumerated)  
**Unit:** Boolean

1 when HF2TA is connected to the corresponding ZCtrl port.

|   |                        |
|---|------------------------|
| 0 | HF2TA is not connected |
| 1 | HF2TA is connected     |

**/dev..../zctrls/n/tamp/biasout**

**Properties:** Read, Write, Setting  
**Type:** Double  
**Unit:** V

Switches between internal and external bias.

**/dev..../zctrls/n/tamp/extbias**

**Properties:** Read, Write, Setting  
**Type:** Integer (enumerated)  
**Unit:** Boolean

Switches the external bias.

|   |                   |
|---|-------------------|
| 0 | External bias off |
| 1 | External bias on  |

# 8. Real-time Option

The Real-time option provides the capability to execute programs written in the C programming language on the RISC microprocessor of the HF2 Instrument with predictable latency and comes with an extensive programming environment.

This chapter describes:

- Installation of the Real-time programming environment, in [Installation of the Real-time Development Environment](#). See [Installation on Windows](#) and [Installation on Linux](#) for the installation process on Windows and Linux, respectively. [Accessing the Documentation](#) explains where to find the documentation in HTML format.

## Note

RT programming can be used only if the HF2LI-RT / HF2IS-RT option has been purchased and activated. This option is no further available for purchase from Zurich Instruments.

## Note

The LabOne User Interface does not have a tab for configuring and working with the Real-time Option. Please use the ziControl graphical user interface to use the Real-time Option and refer to the ziControl Edition of the HF2 User Manual for more details.

## Note

The Real-time Option programming reference guide is also available as HTML. The HTML documentation is bundled with the Real-time installation zip-file available from the Zurich Instruments [download page](#).

## 8.1. Installation of the Real-time Development Environment

In this section we describe the installation process of the HF2's real-time development environment, see [Installation on Windows](#) for Windows and [Installation on Linux](#) for Linux. The real-time development environment is available from the Zurich Instruments [download page](#).

## Note

The RT development environment does not include a special editor. Please use an editor of your choice, for example:

- [notepad++](#) or [PSPad](#) on Windows,
- [emacs](#), [vim](#), etc. on Linux.

### 8.1.1. Installation on Windows

#### Software Requirements

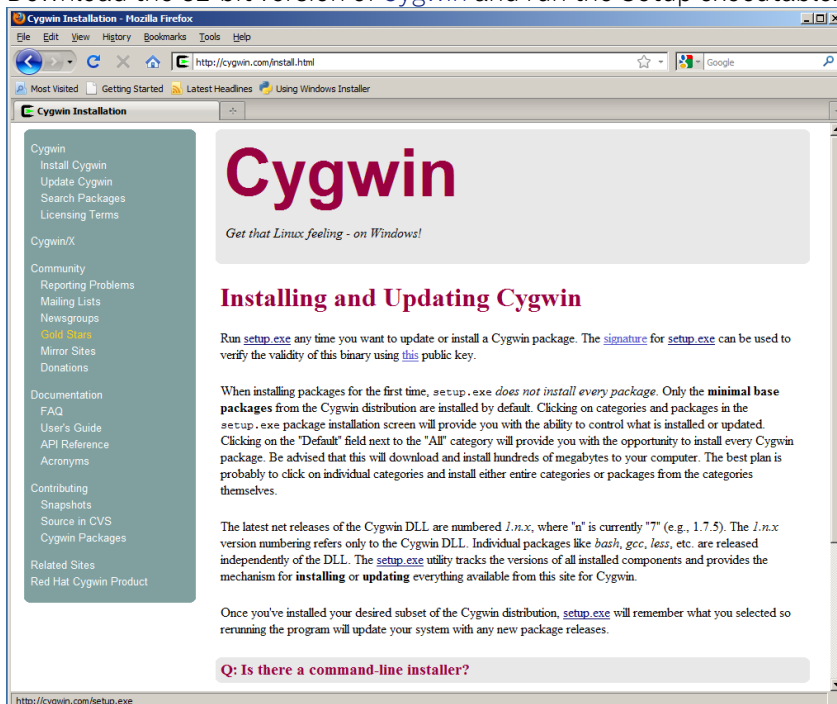
To use the compilation tools on Windows the RT development environment requires the 32-bit version of Cygwin which provides a Linux-like environment. Cygwin is free and open source software, for more details see the [Cygwin website](#). The only Cygwin package necessary is the **make** package. Installation of Cygwin is also detailed below.

## Note

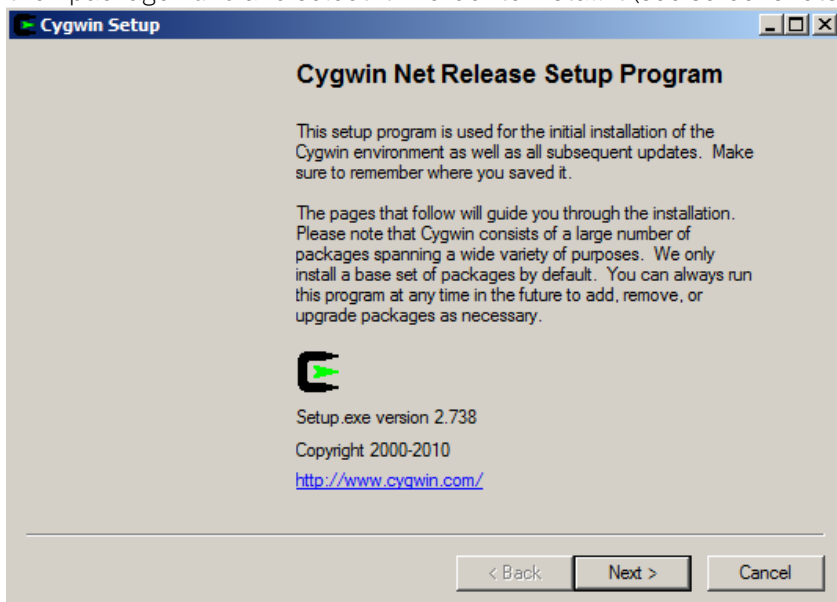
Even if your PC is natively 64-bit, the 32-bit version of Cygwin is required to run the compiler tools distributed with the RT development environment.

## Installation Steps

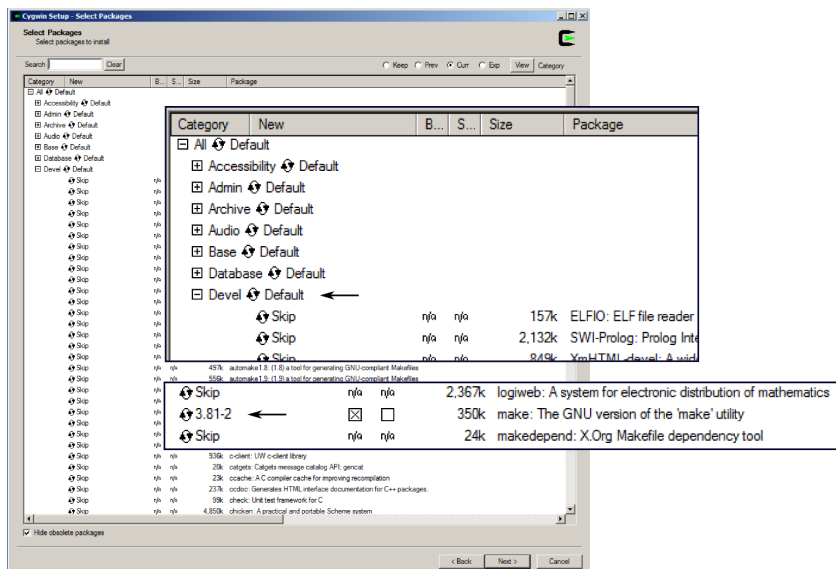
1. Download the 32-bit version of [Cygwin](http://cygwin.com) and run the Setup executable.



2. Go through the installation and, if possible, use default installation settings. There is one mandatory development package that must be installed in addition to the default installation. The package is called **make**. Select the package at the end of the installation. Select **devel**, then package **make** and select it in order to install it (see screenshots below).







3. When the Cygwin installation has been finished, download the ziRTK software bundle and unzip it in your Cygwin home folder.  
The home folder is located at: **[Cygwin installation path]\home**  
The default path is: **C:\cygwin\home**
4. Now open the Cygwin shell by clicking either by navigating to the Cygwin start menu entry or by clicking on the Desktop icon.
5. Navigate into the extracted directory. The install script is called "install.sh".  
**cd ziRTK-Win-[VERSION]**
6. Run the install script and go through the guided installation.  
**bash install.sh**  
Alternatively, you can also give executable rights to the install script and run it directly.  
If possible, use default installation paths.

## Note

You need not edit your code inside Cygwin, it's just used for compilation and loading your real-time programs onto the HF2 Instrument.

## 8.1.2. Installation on Linux

### Software Requirements

Officially, only Ubuntu 10.04 LTS is supported, but it should be possible to run the tools on any recent Linux distribution. The program GNU make is required to compile the examples. Since the RT tools were compiled on a 32-bit architecture, you need the package **ia32\_libs** installed on a 64-bit architecture in order to execute 32-bit programs on a 64-bit architecture. On a Debian-based system, both packages can be installed with:

```
sudo apt-get install ia32_libs make
```

### Installation Steps

1. Before you begin with the ziRTK installation make sure that the development package "make" is installed.  
**sudo apt-get install make**
2. Extract the ziRTK bundle in a temporary directory.  
**tar xzf ziRTK-[build number]-linux.tar.gz**
3. Navigate into the extracted directory. The install script is called "install.sh".  
**cd ziRTK-Linux-[VERSION]**
4. Run the install script with root rights and go through the guided installation.  
**sudo bash install.sh**  
Alternatively, you can also give executable rights to the install script and run it directly.  
If possible, use default installation paths.

### 8.1.3. Accessing the Documentation

The developers of Zurich Instruments now happily recommend you to browse remaining examples and reference documentation in HTML format, which duplicates the following section of the user manual. You can find the HTML version of the documentation in

`[INSTALLPATH]/ziRTK/doc/html/index.html`,

which is typically found at

`C:\cygwin\usr\share\zi\ziRTK-XX.XX\doc\html\index.html`

on Windows or

`/opt/zi/ziRTK/doc/html/index.html`

on Linux.

# 9. Specifications

## Warning

Unless otherwise stated, all specifications apply after 30 minutes of instrument warm-up.

## Warning

Important changes in the specification parameters are explicitly noted in the revision history of this document.

## 9.1. General Specifications

Table 9.1: General and storage

| Parameter                                    | min                                                                                              | typ | max   |
|----------------------------------------------|--------------------------------------------------------------------------------------------------|-----|-------|
| storage temperature                          | –25 °C                                                                                           | –   | 65 °C |
| storage relative humidity (non-condensing)   | –                                                                                                | –   | 95%   |
| operating temperature                        | 5 °C                                                                                             | –   | 40 °C |
| operating relative humidity (non-condensing) | –                                                                                                | –   | 90%   |
| specification temperature                    | 18 °C                                                                                            | –   | 28 °C |
| power consumption                            | –                                                                                                | –   | 60 W  |
| operating environment                        | IEC61010, indoor location, installation category II, pollution degree 2                          |     |       |
| operating altitude                           | up to 2000 meters                                                                                |     |       |
| power supply AC line                         | 110–120/220–240 V, 50/60 Hz                                                                      |     |       |
| power supply Japan                           | requires external 100 V to 110 V transformer (50/60 Hz) for operation according to specification |     |       |
| dimensions with handles and feet             | 45 x 34 x 10 cm, 17.7 x 13.6 x 4.0 inch, 19 inch rack compatible                                 |     |       |
| weight                                       | 6.2 kg                                                                                           |     |       |
| recommended calibration interval             | 2 years                                                                                          |     |       |

Table 9.2: Maximum ratings

| Parameter                                                               | min   | typ | max  |
|-------------------------------------------------------------------------|-------|-----|------|
| damage threshold HF inputs (Input 1, Input 2)                           | –5 V  | –   | 5 V  |
| damage threshold HF outputs (Output 1, Output 2)                        | –12 V | –   | 12 V |
| damage threshold Add inputs (Add 1, Add 2)                              | –12 V | –   | 12 V |
| damage threshold Sync output (Sync 1, Sync 2)                           | –12 V | –   | 12 V |
| damage threshold auxiliary outputs                                      | –12 V | –   | 12 V |
| damage threshold auxiliary inputs                                       | –12 V | –   | 12 V |
| damage threshold digital I/O (including DIO 0 and DIO 1 BNC connectors) | 0 V   | –   | 5 V  |
| damage threshold Clock input                                            | 0 V   | –   | 5 V  |

Table 9.3: Host system requirements

| Parameter                           | Description                                                                 |
|-------------------------------------|-----------------------------------------------------------------------------|
| supported Windows operating systems | Windows 10, 11 on x86-64                                                    |
| supported macOS operating systems   | macOS 10.11+ on x86-64 and ARMv8                                            |
| supported Linux distributions       | GNU/Linux (Ubuntu 14.04+, CentOS 7+, Debian 8+) on x86-64 and ARMv8         |
| supported processors                | x86-64 (Intel, AMD), ARMv8 (e.g., Raspberry Pi 4 and newer, Apple M-series) |

Table 9.4: Maximum sample readout rate

| Active demodulators | Maximum sample readout rate | Comments                                                                                                                                                                                                                   |
|---------------------|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                   | 460 kSamples/s              | To achieve highest rates, it is advised to remove all other data transfer that loads the USB. It is recommended to check the sample loss flag (in the status tab) from time to time when using high readout rate settings. |
| 2 – 3               | 230 kSamples/s              |                                                                                                                                                                                                                            |
| 4 – 6               | 115 kSamples/s              |                                                                                                                                                                                                                            |
| 7 – 8               | 57 kSamples/s               |                                                                                                                                                                                                                            |

## Note

The sample readout rate is the rate at which demodulated samples are transferred from the Instrument to the host computer. This rate has to be set to at least 2 times the signal bandwidth of the related demodulator in order to satisfy the Nyquist sampling theorem. As the total rate is limited by the USB interface, the maximum rate becomes smaller when the number of active demodulators is increased. This is summarized in the table above for HF2LI / HF2PLL (6 demodulators) and HF2IS (8 demodulators). An up-to-date and performing host computer is required to achieve these rates.

## 9.2. Analog Interface Specifications

Table 9.5: HF signal inputs

| Parameter                                                                                                                             | min                                           | typ                         | max                          |
|---------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|-----------------------------|------------------------------|
| connectors                                                                                                                            | front-panel single-ended/<br>differential BNC |                             |                              |
| input impedance (low value)                                                                                                           | –                                             | 50 $\Omega$                 | –                            |
| input impedance (high value)                                                                                                          | 500 k $\Omega$                                | 1 M $\Omega$                | –                            |
| input frequency range                                                                                                                 | 0.7 $\mu$ Hz                                  | –                           | 50 MHz                       |
| input A/D conversion                                                                                                                  | 14 bit, 210 MSamples/s                        |                             |                              |
| input noise amplitude (> 10 kHz, AC coupling, 50 $\Omega$ and 1 M $\Omega$ ), for detailed information see <a href="#">Figure 9.5</a> | –                                             | 5 nV/<br>$\sqrt{\text{Hz}}$ | –                            |
| input amplitude accuracy (5 MHz), for detailed information see <a href="#">Figure 9.10</a>                                            | –                                             | –                           | 5%                           |
| input amplitude accuracy (10 MHz), for detailed information see <a href="#">Figure 9.10</a>                                           | –                                             | –                           | 10%                          |
| input amplitude stability                                                                                                             | –                                             | –                           | 0.2 %/<br>$^{\circ}\text{C}$ |
| input DC offset (<1 V input range)                                                                                                    | –                                             | –                           | 20 mV                        |
| input DC offset (>1 V input range)                                                                                                    | –                                             | –                           | 2%                           |
| input bias current – note: the bias current can lead to a DC offset voltage with input impedance high                                 | –                                             | 100 nA                      | 6 $\mu$ A                    |

| Parameter                                                                             | min    | typ    | max    |
|---------------------------------------------------------------------------------------|--------|--------|--------|
| input range settings                                                                  | 1 mV   | –      | 1.5 V  |
| input full range sensitivity (10 V lock-in amplifier output)                          | 1 nV   | –      | 1.5 V  |
| input range (AC) with AC coupling                                                     | –0.6 V | –      | 0.6 V  |
| input range (AC) with DC coupling                                                     | –1.5 V | –      | 1.5 V  |
| input range (common mode)                                                             | –3.0 V | –      | 3.0 V  |
| input range (AC + common mode)                                                        | –3.3 V | –      | 3.3 V  |
| dynamic reserve                                                                       | –      | 100 dB | 120 dB |
| common mode rejection (CMRR), for detailed information see <a href="#">Figure 9.9</a> | –      | 75 dB  | –      |
| AC coupling cutoff frequency                                                          | –      | 1 kHz  | –      |

Table 9.6: Reference

| Parameter                                                                                                                                                                        | min                                             | typ | max                                               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|-----|---------------------------------------------------|
| internal reference frequency rangeInternal reference                                                                                                                             | 0.7 $\mu$ Hz                                    | –   | 100 MHz                                           |
| internal reference frequency resolution                                                                                                                                          | 0.7 $\mu$ Hz                                    | –   | –                                                 |
| internal reference phase range                                                                                                                                                   | –180 °                                          | –   | 180 °                                             |
| internal reference phase resolution                                                                                                                                              | 0.1 $\mu$ °                                     | –   | –                                                 |
| internal reference acquisition time (lock time)                                                                                                                                  | instantaneous                                   |     |                                                   |
| internal reference orthogonality                                                                                                                                                 | –                                               | 0 ° | –                                                 |
| external reference at Input 2/Ref, signal type                                                                                                                                   | arbitrary, active at rising edge                |     |                                                   |
| external reference at Input 2/Ref, frequency rangeExternal reference                                                                                                             | 1 Hz                                            | –   | 50 MHz                                            |
| external reference at Input 2/Ref, amplitude – note: for low-swing input signals the gain should be set to full-swing range to achieve best performance                          | 100 mV                                          | –   | 1 V                                               |
| external reference at Input 2/Ref, amplitude (using HF2LI-PLL option) – note: for low-swing input signals the gain should be set to full-swing range to achieve best performance | 10 mV                                           | –   | 1 V                                               |
| external reference at Input 2/Ref, reference acquisition time (lock time)                                                                                                        | –                                               | –   | 100 reference cycles or 1.2 ms whatever is larger |
| external reference at DIO0/DIO 1, signal type                                                                                                                                    | digital TTL versus ground                       |     |                                                   |
| external reference at DIO0/DIO1, frequency range                                                                                                                                 | 1 Hz                                            | –   | 2 MHz                                             |
| external reference at DIO0/DIO1, high level                                                                                                                                      | 2.0 V                                           | –   | 5 V                                               |
| external reference at DIO0/DIO1, low level                                                                                                                                       | 0 V                                             | –   | 0.8 V                                             |
| external reference at DIO0/DIO1, reference acquisition time (lock time)                                                                                                          | –                                               | –   | 100 reference cycles or 1.2 ms whatever is larger |
| external reference at AUXIN1/AUXIN2, signal type                                                                                                                                 | sine or rectangular                             |     |                                                   |
| external reference at AUXIN1/AUXIN2, frequency range                                                                                                                             | 1 Hz                                            | –   | 20 kHz                                            |
| external reference at AUXIN1/AUXIN2, amplitude                                                                                                                                   | 0.5 V                                           | –   | 1 V                                               |
| external reference at AUXIN1/AUXIN2, reference acquisition time (lock time)                                                                                                      | –                                               | –   | 100 reference cycles                              |
| auto reference at Input 1/Input 2, signal type                                                                                                                                   | AC signal with zero crossings, AC input setting |     |                                                   |
| auto reference at Input 1/Input 2, frequency range                                                                                                                               | 1 Hz                                            | –   | 50 MHz                                            |

| Parameter                                                                 | min | typ | max                                               |
|---------------------------------------------------------------------------|-----|-----|---------------------------------------------------|
| auto reference at Input 1/Input 2, reference acquisition time (lock time) | –   | –   | 100 reference cycles or 1.2 ms whatever is larger |

Table 9.7: Demodulators

| Parameter                                                                    | Description                                                                                   |
|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| demodulator number                                                           | HF2IS: 4 dual-phase, 8 dual-phase with multi-frequency kit                                    |
|                                                                              | HF2LI: 6                                                                                      |
|                                                                              | HF2PLL: 6                                                                                     |
| demodulator harmonic setting range                                           | 1 to 1023                                                                                     |
| demodulator filter time constant                                             | 0.8 $\mu$ s to 580 s                                                                          |
| demodulator filter slope / roll-off                                          | 6, 12, 18, 24, 30, 36, 42, 48 dB/oct, consisting of up to 8 cascaded critical damping filters |
| demodulator output resolution                                                | X, Y, R, THETA with 64-bit resolution                                                         |
| demodulator output rate (readout rate), for detailed specifications refer to | on Aux outputs: 921 kSamples/s                                                                |
|                                                                              | on USB to host PC: maximum cumulative 700 kSamples/s                                          |
| demodulator measurement bandwidth                                            | 83 $\mu$ Hz to 200 kHz                                                                        |
| demodulator harmonic rejection                                               | max –90 dB                                                                                    |
| demodulator sinc filter operating range                                      | 0.1 Hz to 10 kHz                                                                              |

Table 9.8: HF signal outputs

| Parameter                                                                                                                                | min                                              | typ                       | max    |
|------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|---------------------------|--------|
| connectors                                                                                                                               | front-panel single-ended BNC                     |                           |        |
| output impedance (Out and Sync)                                                                                                          | 50 $\Omega$                                      |                           |        |
| input impedance (Add)                                                                                                                    | 1 M $\Omega$                                     |                           |        |
| output frequency range                                                                                                                   | DC                                               | –                         | 50 MHz |
| output frequency range with 10 V amplitude. see also <a href="#">Figure 9.11</a>                                                         | DC                                               | –                         | 5 MHz  |
| output D/A conversion                                                                                                                    | 16 bit, 210 MSamples/s                           |                           |        |
| output amplitude ranges (restrictions apply for high amplitudes and high frequencies, see <a href="#">Figure 9.11</a> )                  | $\pm 10$ mV, $\pm 100$ mV, $\pm 1$ V, $\pm 10$ V |                           |        |
| output maximum current                                                                                                                   | –                                                | –                         | 100 mA |
| output amplitude accuracy @ 3 MHz, < 5 V (restrictions apply for high amplitudes and high frequencies, see <a href="#">Figure 9.11</a> ) | –                                                | –                         | 1%     |
| output total harmonic distortion THD (1 V, < 10 MHz), see <a href="#">Figure 9.12</a>                                                    | –50 dB                                           | –                         | –      |
| output total harmonic distortion THD (0.1 V, < 10 MHz), see <a href="#">Figure 9.12</a>                                                  | –60 dB                                           | –                         | –      |
| output noise amplitude (frequencies > 10 kHz), 50 $\Omega$ termination                                                                   | –                                                | 25 nV/ $\sqrt{\text{Hz}}$ | –      |
| output phase noise @ 10 MHz, BW = 0.67 Hz, offset 100 Hz                                                                                 | –100 dBc/Hz                                      | –                         | –      |
| output phase noise @ 10 MHz, BW = 0.67 Hz, offset 1 kHz                                                                                  | –120 dBc/Hz                                      | –                         | –      |
| output offset amplitude (range setting < 1 V)                                                                                            | –                                                | –                         | 10 mV  |
| output offset amplitude (range setting > 1 V)                                                                                            | –                                                | –                         | 200 mV |

| Parameter                                                                                             | min   | typ              | max    |
|-------------------------------------------------------------------------------------------------------|-------|------------------|--------|
| input Add signal range                                                                                | –10 V | –                | +10 V  |
| input Add signal bandwidth                                                                            | DC    | –                | 50 MHz |
| output Sync signal range (effective range = $\pm 1 \cdot \text{set\_amplitude} / \text{set\_range}$ ) | –1 V  | –                | 1 V    |
| output synchronization signal resolution                                                              | –     | 30 $\mu\text{V}$ | –      |

Table 9.9: Auxiliary Inputs and Outputs

| Parameter                                                | Description                                               |
|----------------------------------------------------------|-----------------------------------------------------------|
| auxiliary output connectors                              | front-panel single-ended BNC                              |
| auxiliary output impedance                               | 50 $\Omega$                                               |
| auxiliary output number and type of signals              | 4, amplitude, phase, frequency, X/Y, manual               |
| auxiliary output specification                           | $\pm 10$ V, 200 kHz, 16-bit, 921 kSamples/s               |
| auxiliary output resolution                              | 0.3 mV                                                    |
| auxiliary input connectors                               | back-panel single-ended BNC                               |
| auxiliary input impedance                                | 1 M $\Omega$                                              |
| auxiliary input number                                   | 2                                                         |
| auxiliary input specification                            | $\pm 10$ V, 100 kHz <sup>4</sup> , 16-bit, 400 kSamples/s |
| auxiliary input resolution                               | 0.3 mV                                                    |
| group delay (lag time from HF input to auxiliary output) | 7 $\mu\text{s}$ (typical), 10 $\mu\text{s}$ (maximum)     |

Table 9.10: Oscillator and clocks

| Parameter                                                                                                                                        | min         | typ         | max                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|------------------------------|
| internal oscillator frequency                                                                                                                    | –           | 10 MHz      | –                            |
| internal oscillator output (sine)                                                                                                                | –1 V        | –           | +1 V                         |
| internal oscillator initial accuracy (serial number HF2-DEV1141 and lower) <sup>1</sup>                                                          | –           | –           | $\pm 30$ ppm                 |
| internal oscillator aging (stability; serial number HF2-DEV1141 and lower) <sup>1</sup>                                                          | –           | –           | $\pm 5$ ppm/year             |
| internal oscillator temperature stability (23 $^{\circ}\text{C} \pm 5$ $^{\circ}\text{C}$ ; serial number HF2-DEV1141 and lower) <sup>1</sup>    | –           | –           | $\pm 30$ ppm                 |
| internal oscillator initial accuracy (serial number HF2-DEV1142 and higher) <sup>2</sup>                                                         | –           | –           | $\pm 1.5$ ppm                |
| internal oscillator temperature coefficient (23 $^{\circ}\text{C} \pm 5$ $^{\circ}\text{C}$ ; serial number HF2-DEV1142 and higher) <sup>2</sup> | –           | –           | 0.05 ppm/ $^{\circ}\text{C}$ |
| internal oscillator phase noise (at 100 Hz)                                                                                                      | –           | –125 dBc/Hz | –                            |
| internal oscillator phase noise (at 1 kHz)                                                                                                       | –           | –140 dBc/Hz | –                            |
| UHS (option) oscillator initial accuracy <sup>3</sup>                                                                                            | –           | –           | $\pm 0.5$ ppm                |
| UHS (option) oscillator aging (stability) <sup>3</sup>                                                                                           | –           | –           | $\pm 0.4$ ppm/year           |
| UHS (option) oscillator temperature stability (23 $^{\circ}\text{C} \pm 5$ $^{\circ}\text{C}$ ) <sup>3</sup>                                     | –           | –           | $\pm 0.03$ ppm               |
| UHS (option) oscillator phase noise (at 100 Hz) <sup>3</sup>                                                                                     | –130 dBc/Hz | –           | –                            |

| Parameter                                                            | min                         | typ    | max       |
|----------------------------------------------------------------------|-----------------------------|--------|-----------|
| UHS (option) oscillator phase noise (at 1 kHz) <sup>3</sup>          | -140 dBc/Hz                 | –      | –         |
| UHS (option) oscillator reference stability (over 30 s) <sup>3</sup> | 0.00005 ppm                 | –      | –         |
| UHS (option) oscillator time to reach specification <sup>3</sup>     | –                           | –      | 60 s      |
| external clock connector                                             | back-panel single-ended BNC |        |           |
| external clock input impedance                                       | 1 MΩ                        |        |           |
| external clock input voltage                                         | 0 V                         | –      | +3.3 V    |
| external clock frequency                                             | 9.98 MHz                    | 10 MHz | 10.02 MHz |

## 9.3. Digital Interface Specifications

Table 9.11: Digital interfaces

| Parameter                       | Description                                            |
|---------------------------------|--------------------------------------------------------|
| host computer connection        | USB 2.0 high-speed, 480 Mbit/s                         |
| ZCtrl pre-amplifier control bus | proprietary bus to control external pre-amplifiers     |
| ZSync synchronization bus       | proprietary bus to locally interconnect ZI instruments |
| DIO connector                   | 32 bit, general purpose                                |

The DIO connector is a HD 68 pin connector, typically also used by SCSI-2 and SCSI-3 interfaces, 47 mm wide male connector. The DIO port features 16 bits that can be configured byte-wise as inputs or outputs, as well as 16 input only bits. The digital signals follow the CMOS/TTL specification.

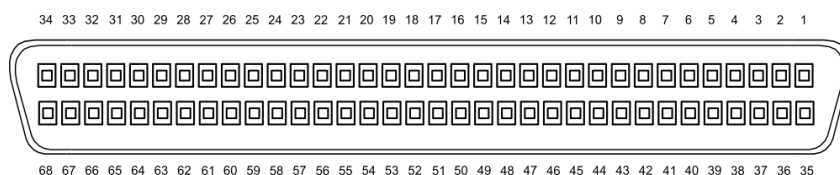


Figure 9.1: DIO HD 68 pin connector

Table 9.12: DIO pin assignment

| Pin   | Name      | Description                                                                                                                                                        | Range specification                |
|-------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| 68    | CLKI      | clock input, used to latch signals at the digital input ports - can also be used to retrieve digital signals from the output port using an external sampling clock | 5 V CMOS/TTL                       |
| 67    | DOL       | DIO output latch, 64 MHz clock signal, the digital outputs are synchronized to the falling edge of this signal                                                     | 5 V CMOS                           |
| 66–51 | DI[31:16] | digital input                                                                                                                                                      | digital input CMOS/TTL level       |
| 50–35 | DIO[15:0] | digital input or output (set by user)                                                                                                                              | output CMOS 5 V, input is CMOS/TTL |
| 34–3  | GND       | digital ground                                                                                                                                                     | –                                  |
| 2–1   | PWR       | 5 V supply (100 mA max)                                                                                                                                            | –                                  |



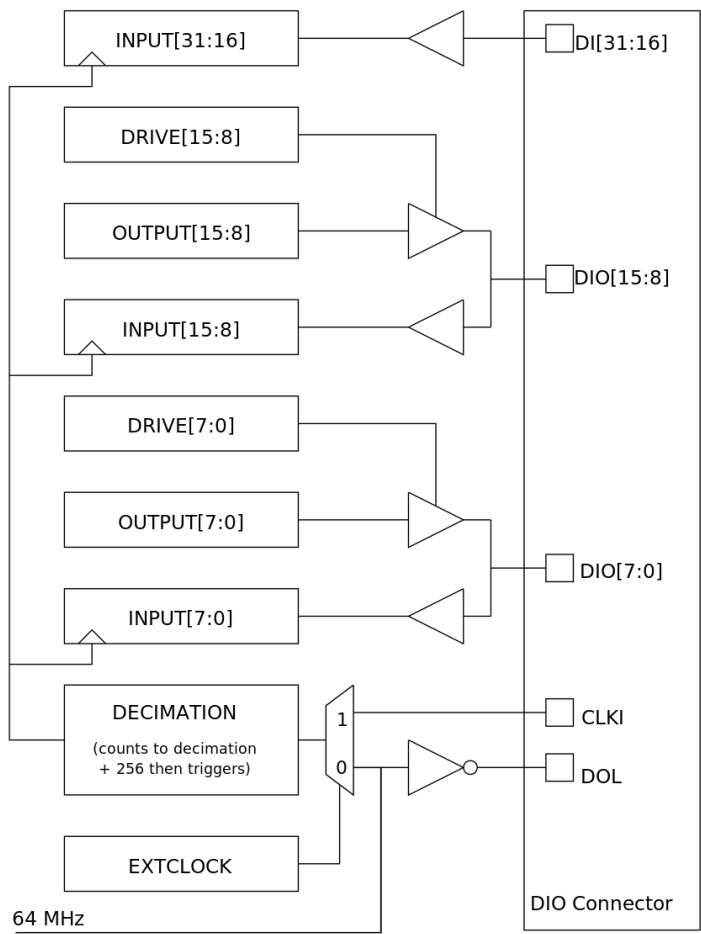


Figure 9.2: DIO input/output architecture

The HF2 Digital I/O Breakout Board provides an easy way to access all pins of the DIO Connector. The board consists of 68 pin headers and a 68-pin female socket to be connected to the HF2 using a ribbon cable. For description of the pins, refer to the [Table 9.12](#). The HF2 DIO Breakout Board is available with Zurich Instruments on demand.

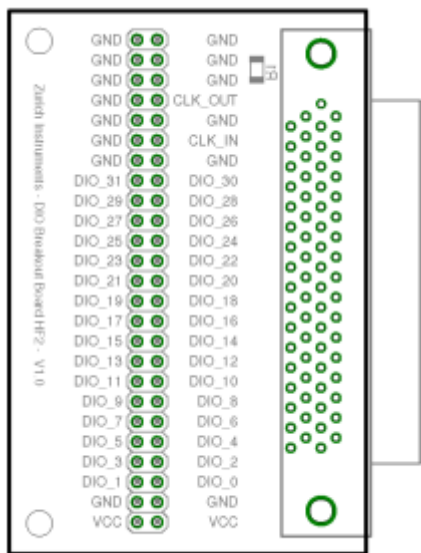


Figure 9.3: HF2 digital I/O breakout board

The internally generated 10 MHz clock is made available for external synchronization at the ZSync Out RJ45 connector. The clock signal is at pin 1, ground at pin 2. To connect: simply prepare a cable assembly that allows you to connect the 10 MHz signal from the HF2 to the BNC input of the other device external clock.

# ZSyncOut

1 CLK

2 GND

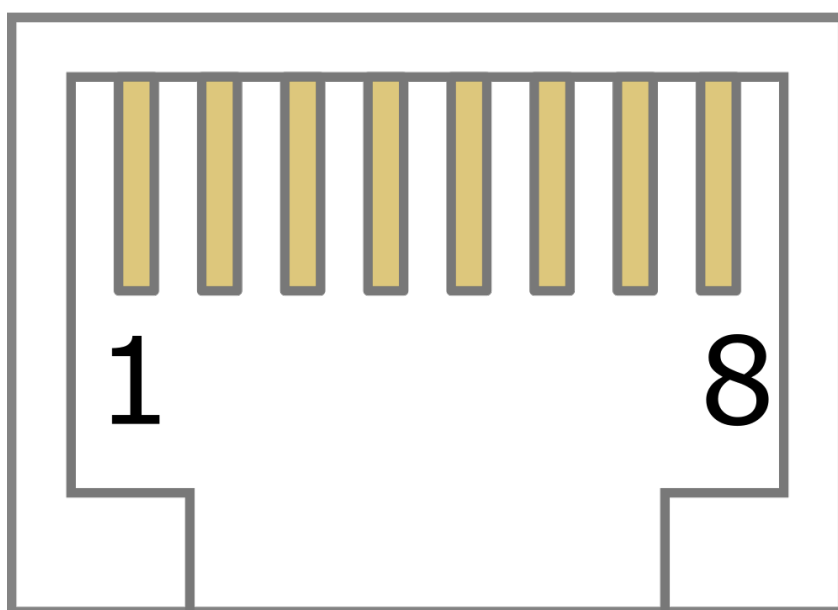


Figure 9.4: The pinout of the RJ45 jack

## 9.4. Performance Diagrams

Many parameters mentioned in [Analog Interface Specifications](#) are valid without specific conditions. Other parameters instead are typical specifications because they depend on several parameters, such as range settings, and frequency. This section completes the previous chapters with detailed performance diagrams in order to support the validation of applications.

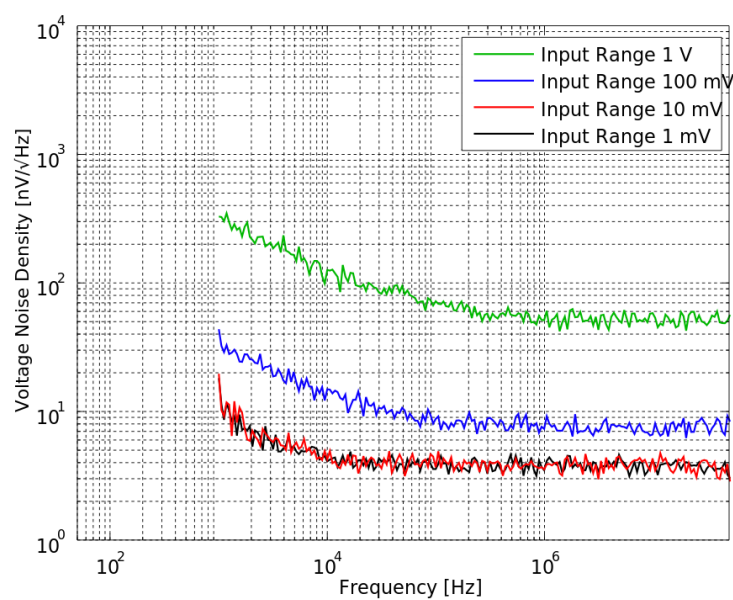


Figure 9.5: HF input noise with AC coupling

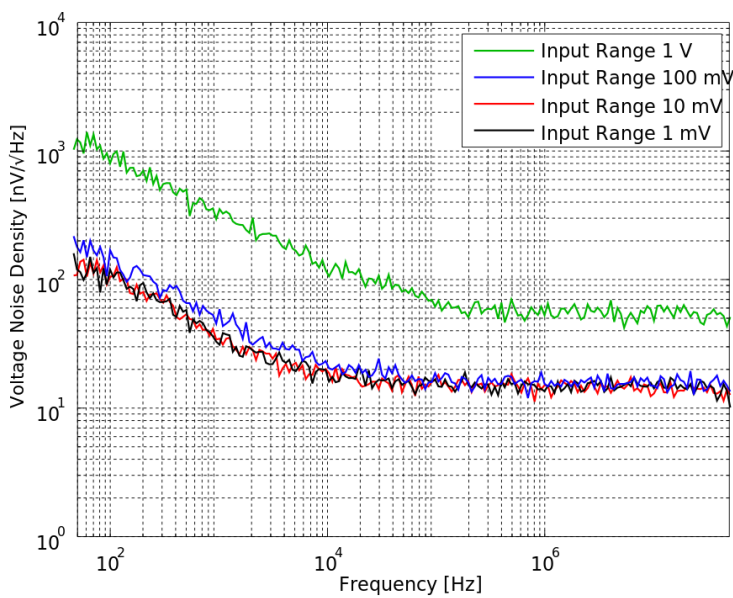


Figure 9.6: HF input noise with DC coupling

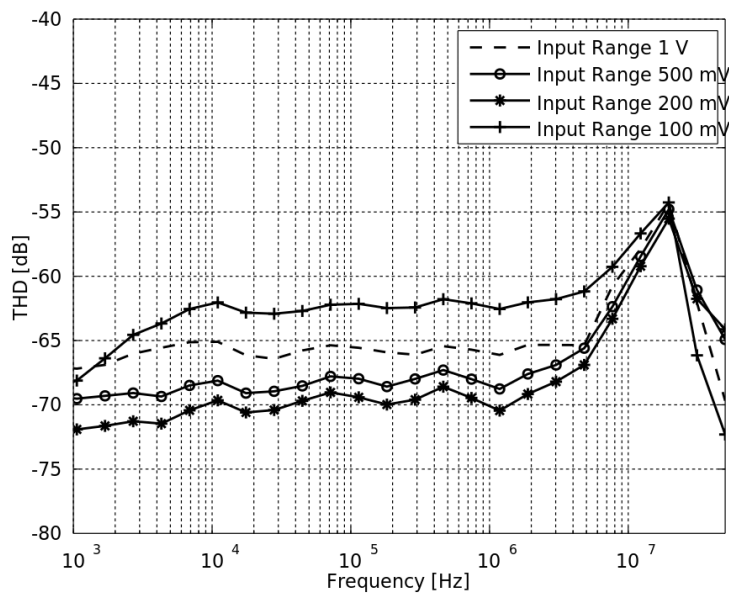


Figure 9.7: HF input total harmonic distortion with AC coupling

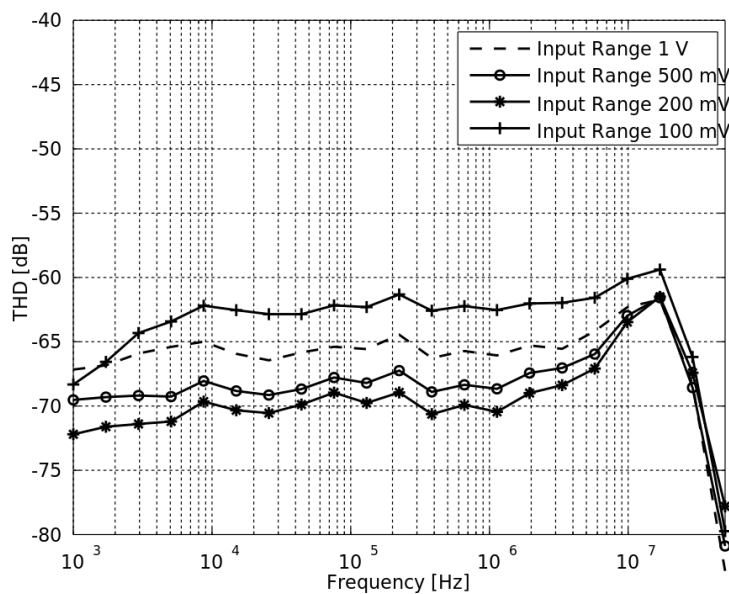


Figure 9.8: HF input total harmonic distortion with DC coupling

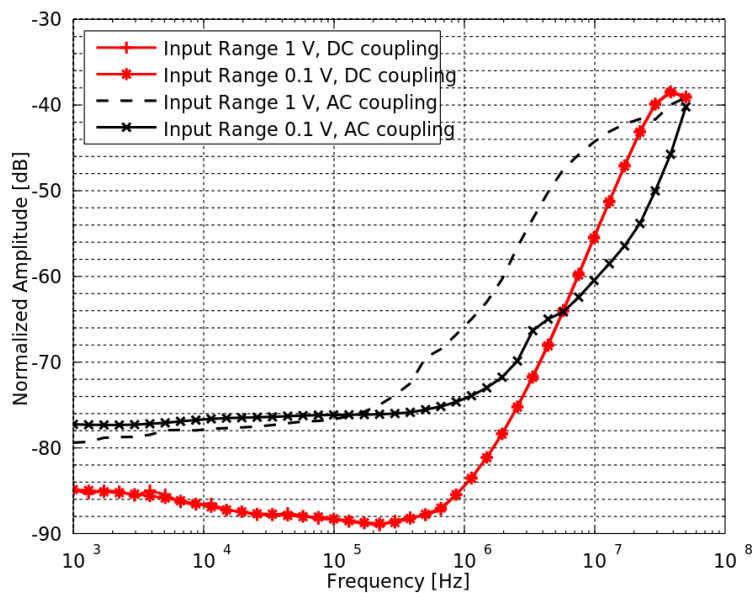


Figure 9.9: HF input common mode rejection ratio

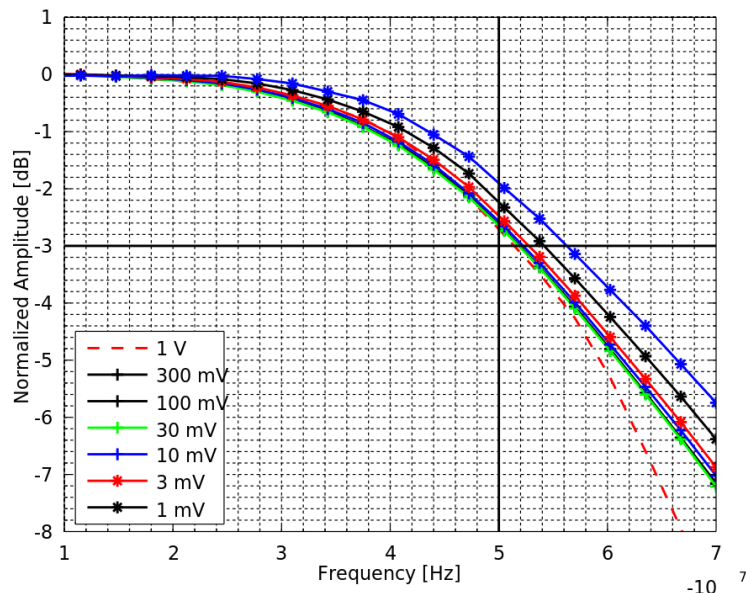


Figure 9.10: HF input bandwidth

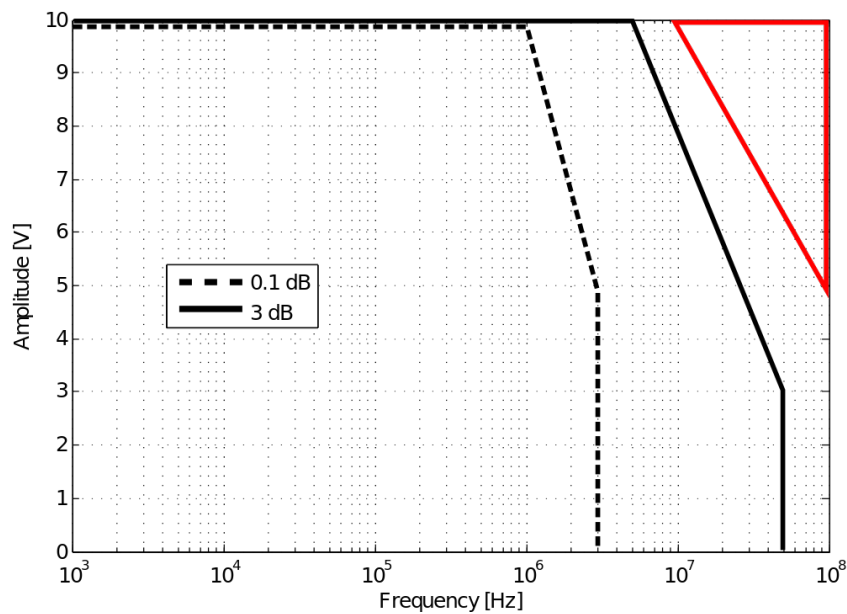


Figure 9.11: HF output amplitude accuracy

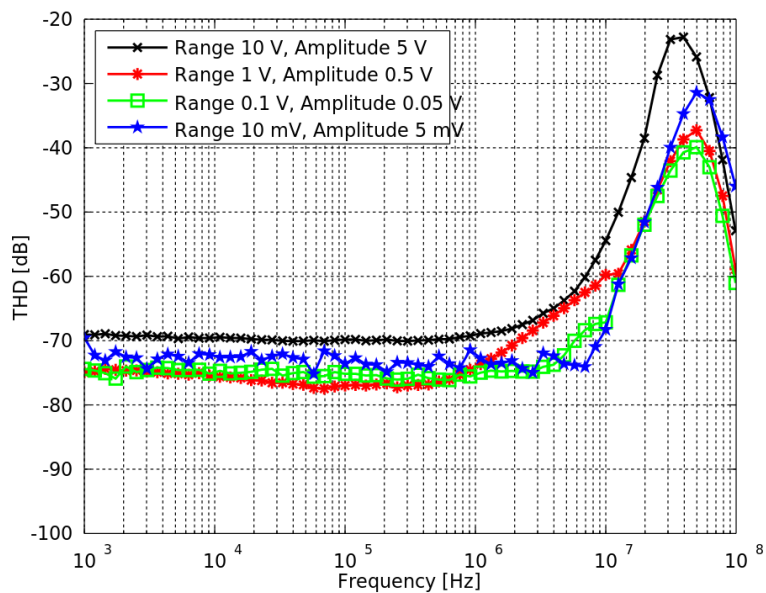


Figure 9.12: HF output total harmonic distortion

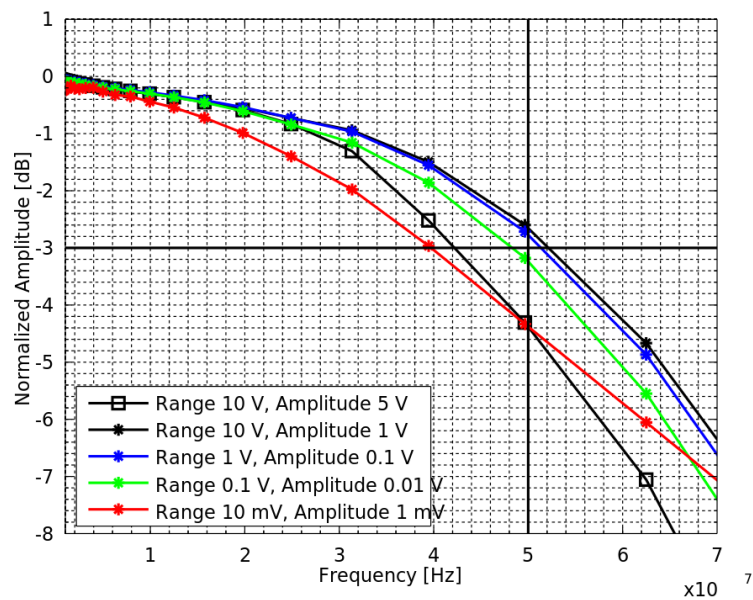


Figure 9.13: HF output bandwidth

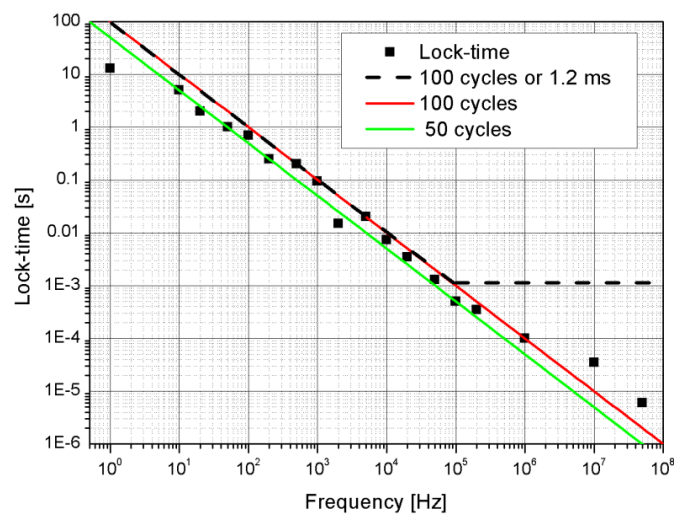


Figure 9.14: Lock time

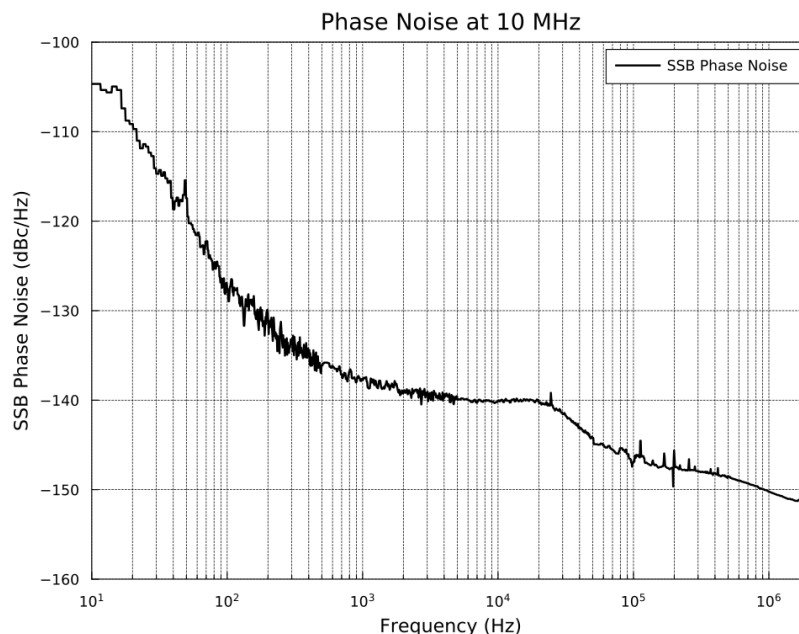


Figure 9.15: HF2 signal output phase noise

## 9.5. Ground and Earth Scheme

Ground loops may introduce noise at the line frequency (mostly 50/60 Hz) and its harmonics, and aliasing in the demodulated signal that is measurable for frequencies up to 10 MHz. Some lock-in amplifiers implement a line filter which has the effect to exclude low frequency measurements. This is not the case for the HF2 Instruments where an effective ground strategy is implemented.

In order to suppress large signal components at line frequency and higher harmonics avoiding ground loops within the measurement setup is required. Possible reasons for line frequency components include parasitics resistances between the different signal grounds, inductive coupling from line transformers and other electrical apparatus into the signal paths, and pre-amplifiers that generate additional loops.

Counter measures are to break loops using differential wiring, by implementing star ground connections in the measurement setup, with the main ground closest to the setup as possible, connect all instrument casing to earth, and using optocouplers and transformers that provide a galvanic decoupling in the signal path.

The grounding of the HF2 Instrument is implemented connecting analog ground and digital ground in a star network. This reduces the digital ground noise that flows into the analog domain considerably. All analog grounds are connected together before they are connected to the digital ground (e.g. USB ground). All grounds are decoupled by the Earth by means of a 1 M $\Omega$  resistor, which is however generally shorted by a PC connected by means of a USB cable. The earth connection of the power plug connects at the same time the chassis and the banana plug on the rear Instrument panel.

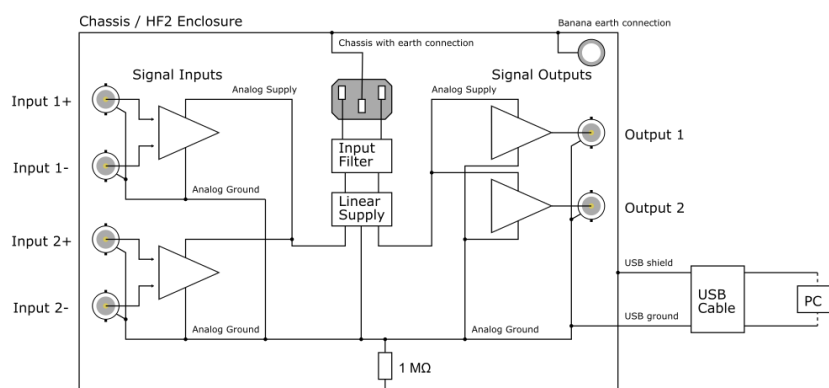


Figure 9.16: Instrument ground and earth connection scheme



For applications that require floating ground, it is suggested to make use of the differential inputs by connecting the BNC shield to the negative BNC connector. The limitation for this strategy is that the floating ground should not exceed the specified maximum input common mode offset.

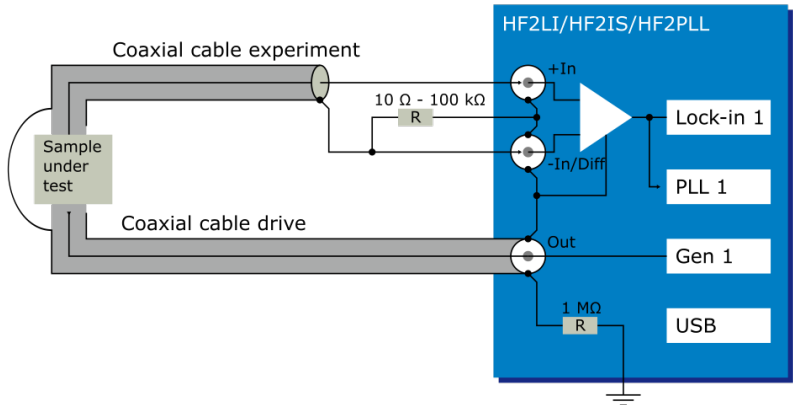


Figure 9.17: Differential connection scheme reducing ground loops

When using ZSync to synchronize two HF2 Instruments, the 10 MHz clock may couple into the signal path and disturb the lock-in measurement at certain frequencies. Below are two measures to counteract this potential problem.

- Connect the Clock In connectors on the back panel of the instruments with a short BNC cable. This cable has the sole purpose of connecting the digital grounds of the instruments and has no effect on the 10 MHz clock.
- Wind the Ethernet cable used to connect the ZSync ports into small coils and/or attach a ferrite bead to the cable.

## 9.6. Reference Images

The following figures are intended for advanced users with programming projects on the HF2 Instruments.

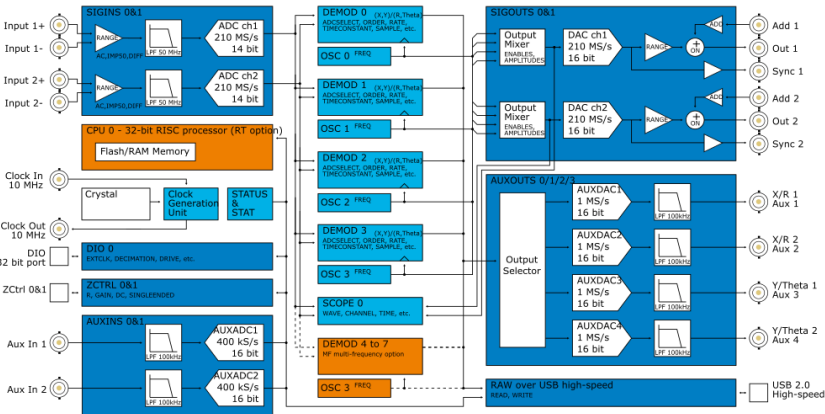


Figure 9.18: hf2is block diagram

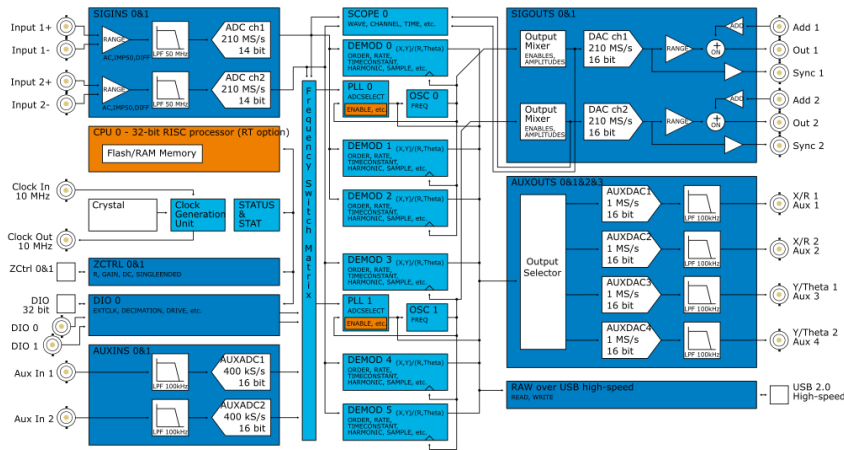


Figure 9.19: hf2li block diagram

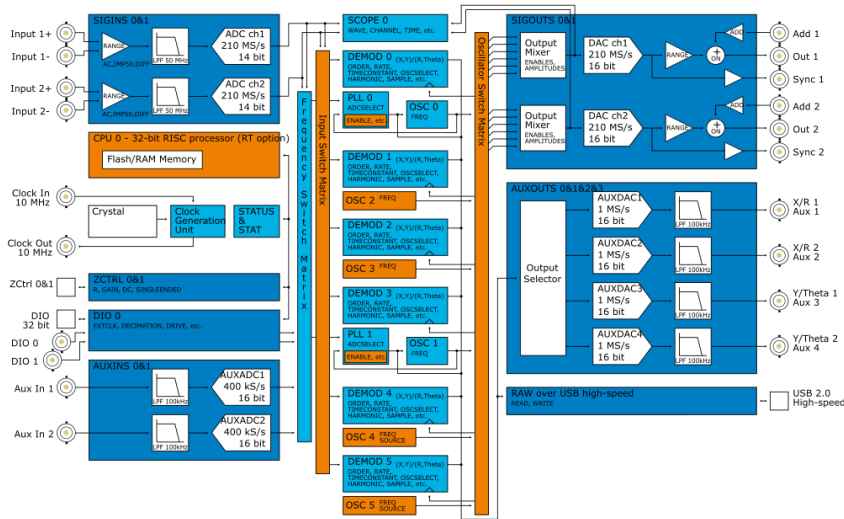


Figure 9.20: hf2limfk block diagram

## 9.7. Test Specifications

Users are encouraged to verify that the Instrument performs as specified, not only after shipping but also to ensure continuous performance over time. Recommended procedures for measuring key specification parameters are based on the Zurich Instruments *ziControl* software. For detailed instructions please refer to the Specifications chapter of the HF2 User Manual (*ziControl* Edition) available at <https://www.zhinst.com/products/hf2li-lock-amplifier>.

# 10. Signal Processing Basics

This chapter provides insights about several lock-in amplifier principles not necessarily linked to a specific instrument from Zurich Instruments. Since the appearance of the first valve-based lock-in amplifiers in the 1930s the physics have not changed, but the implementation and the performance have evolved greatly. Many good lock-in amplifier primers have appeared in the past decades, and some of them appear outdated now because they were written with analog instruments in mind. This section does not aim to replace any existing primer, but to complete them with a preferred emphasis on digital lock-in amplifiers.

The first subsection describes the principles of lock-in amplification, followed by the description of the function of discrete-time filters. After, we discuss the definition of the full range sensitivity, a specification parameter particularly important for analog lock-in amplifiers but with somewhat reduced importance for digital instruments. In the following, we describe the function and use of sinc filtering in particular for low-frequency lock-in measurements. The last section is dedicated to the zoom FFT feature. Innovative in the context of lock-in amplifiers, zoom FFT offers a fast and high-resolution spectral analysis around the lock-in operation frequency.

## 10.1. Principles of Lock-in Detection

Lock-in demodulation is a technique to measure the amplitude  $A_s$  and the phase  $\theta$  of a periodic signal with the frequency  $\omega_s = 2\pi f_s$  by comparing the signal to a reference signal. This technique is also called phase-sensitive detection. By averaging over time the signal-to-noise ratio (SNR) of a signal can be increased by orders of magnitude, allowing very small signals to be detected with a high accuracy making the lock-in amplifier a tool often used for signal recovery. For both signal recovery and phase-sensitive detection, the signal of interest is isolated with narrow band-pass filtering therefore reducing the impact of noise in the measured signal.

Figure 10.1 shows a basic measurement setup: a reference  $V_r$  signal is fed to the device under test. This reference signal is modified by the generally non-linear device with attenuation, amplification, phase shifting, and distortion, resulting in a signal  $V_s = A_s \cos(\omega_s t + \theta_s)$  plus harmonic components.

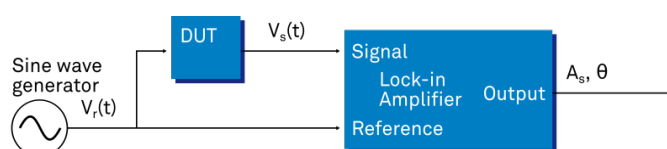


Figure 10.1: Basic measurement setup incorporating a lock-in amplifier

For practical reasons, most lock-in amplifiers implement the band-pass filter with a mixer and a low-pass filter (depicted in Figure 10.2): the mixer shifts the signal of interest into the baseband, ideally to DC, and the low-pass filter cuts all unwanted higher frequencies.

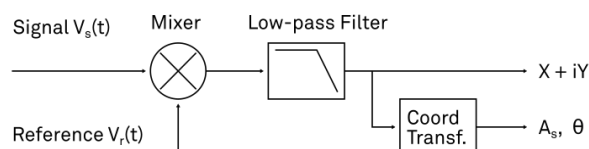


Figure 10.2: Mixing and low-pass filtering performed by the lock-in amplifier

The input signal  $V_s(t)$  is multiplied by the reference signal  $V_r(t) = \sqrt{2}e^{-i\omega_r t}$ , where  $\omega_r = 2\pi f_r$  is the demodulation frequency and  $i$  is the imaginary unit. This is the complex representation of a sine and cosine signal (phase shift  $90^\circ$ ) forming the components of a quadrature demodulator, capable of measuring both the amplitude and the phase of the signal of interest. In principle it is possible to multiply the signal of interest with any frequency, resulting in a heterodyne operation. However the objective of the lock-in amplifier is to shift the signal as close as possible to DC, therefore the frequency of the reference and the signal is chosen similar. In literature this is called homodyne detection, synchrodyne detection, or zero-IF direct conversion.

The result of the multiplication is the signal

$$V_s(t) \cdot V_r(t) = V_s(t) \cdot \sqrt{2}e^{-i\omega_r t} = \frac{A_s}{\sqrt{2}}e^{i[(\omega_s - \omega_r)t + \theta]} + \frac{A_s}{\sqrt{2}}e^{-i[(\omega_s + \omega_r)t + \theta]} \quad (1)$$

It consists of a slow component with frequency  $\omega_s - \omega_r$  and a fast component with frequency  $\omega_s + \omega_r$ .

The demodulated signal is then low-pass filtered with an infinite impulse response (IIR) RC filter, indicated by the symbol  $(\cdot)$ . The frequency response of the filter  $F(\omega)$  will let pass the low frequencies  $F(\omega_s - \omega_r)$  while considerably attenuating the higher frequencies  $F(\omega_s + \omega_r)$ . Another way to consider the low-pass filter is an averager.

$$X + iY = (V_s(t) \cdot \sqrt{2}e^{-i\omega_r t}) \approx F(\omega_s - \omega_r) \frac{A_s}{\sqrt{2}}e^{i[(\omega_s - \omega_r)t + \theta]} \quad (2)$$

The result after the low-pass filter is the demodulated signal  $X + iY$ , where  $X$  is the real and  $Y$  is the imaginary part of a signal depicted on the complex plane. These components are also called in-phase and quadrature components. The transformation of  $X$  and  $Y$  into the amplitude  $R$  and phase  $\theta$  information of  $V_s(t)$  can be performed with trigonometric operations.

It is interesting to note that the value of the measured signal corresponds to the RMS value of the signal, which is equivalent to  $R = A_s/\sqrt{2}$ .

Most lock-in amplifiers output the values  $(X, Y)$  and  $(R, \theta)$  encoded in a range of  $-10$  V to  $+10$  V of the auxiliary output signals.

### 10.1.1. Lock-in Amplifier Applications

Lock-in amplifiers are employed in a large variety of applications. In some cases the objective is measuring a signal with good signal-to-noise ratio, and then that signal could be measured even with large filter settings. In this context the word phase sensitive detection is appropriate. In other applications, the signal is very weak and overwhelmed by noise, which forces to measure with very narrow filters. In this context the lock-in amplifier is employed for signal recovery. Also, in another context, a signal modulated on a very high frequency (GHz or THz) that cannot be measured with standard approaches, is mixed to a lower frequency that fits into the measurement band of the lock-in amplifier.

One example for measuring a small, stationary or slowly varying signal which is completely buried in the  $1/f$  noise, the power line noise, and slow drifts. For this purpose a weak signal is modulated to a higher frequency, away from these sources of noise. Such signal can be efficiently mixed back and measured in the baseband using a lock-in amplifier. In Figure 10.3 this process is depicted. Many optical applications perform the up-mixing with a chopper, an electro-optical modulator, or an acousto-optical modulator. The advantage of this procedure is that the desired signal is measured in a spectral region with comparatively little noise. This is more efficient than just low-pass filtering the DC signal.

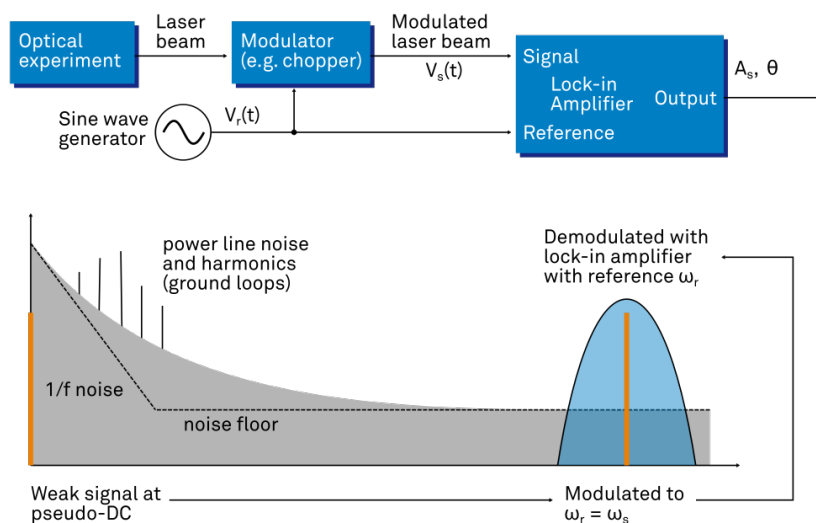


Figure 10.3: Lock-in measurement of a noisy DC signal

## 10.2. Signal Bandwidth

The signal bandwidth (BW) theoretically corresponds to the highest frequency components of interest in a signal. In practical signals, the bandwidth is usually quantified by the cut-off frequency. It is the frequency at which the transfer function of a system shows 3 dB attenuation relative to DC ( $BW = f_{\text{cut-off}} = f_{-3\text{dB}}$ ); that is, the signal power at  $f_{-3\text{dB}}$  is half the power at DC. The bandwidth, equivalent to cut-off frequency, is used in the context of dynamic behavior of a signals or separation of different signals. This is for instance the case for fast-changing amplitudes or phase values like in a PLL or in imaging applications, or when signals closely spaced in frequency need to be separated.

The noise equivalent power bandwidth (NEPBW) is also a useful figure, and it is distinct from the signal bandwidth. This unit is typically used for noise measurements: in this case one is interested in the total amount of power that passes through a low-pass filter, equivalent to the area under the solid curve in Figure 10.4. For practical reasons, one defines an ideal brick-wall filter that lets pass the same amount of power under the assumption that the noise has a flat (white) spectral density. This brick-wall filter has transmission 1 from DC to  $f_{\text{NEPBW}}$ . The orange and blue areas in Figure 10.4 then are exactly equal in a linear scale.

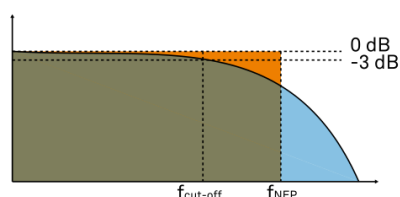


Figure 10.4: Signal bandwidth and noise equivalent power bandwidth

It is possible to establish a simple relation between the  $f_{\text{cut-off}}$  and the  $f_{\text{NEPBW}}$  that only depends on the slope (or roll-off) of the filter. As the filter slope actually depends on the time constant (TC) defined for the filter, it is possible to establish the relation also to the time constant. It is intuitive to understand that for higher filter orders, the  $f_{\text{cut-off}}$  is closer to the  $f_{\text{NEPBW}}$  than for smaller orders.

The time constant is a parameter used to interpret the filter response in the time domain, and relates to the time it takes to reach a defined percentage of the final value. The time constant of a low-pass filter relates to the bandwidth according to the formula

$$TC = \frac{FO}{2\pi f_{\text{cut-off}}} \quad (3)$$

where FO is said factor that depends on the filter slope. This factor, along with other useful conversion factors between different filter parameters, can be read from the following table.

Table 10.1: Summary of conversion factors for bandwidth definitions

| filter order    | filter roll-off | FO     | $f_{\text{cut-off}}$ | $f_{\text{NEPBW}}$ | $f_{\text{NEPBW}} / f_{\text{cut-off}}$ |
|-----------------|-----------------|--------|----------------------|--------------------|-----------------------------------------|
| 1 <sup>st</sup> | 6 dB/oct        | 1.0000 | 0.1592 / TC          | 0.2500 / TC        | 1.5708                                  |
| 2 <sup>nd</sup> | 12 dB/oct       | 0.6436 | 0.1024 / TC          | 0.1250 / TC        | 1.2203                                  |
| 3 <sup>rd</sup> | 18 dB/oct       | 0.5098 | 0.0811 / TC          | 0.0937 / TC        | 1.1554                                  |
| 4 <sup>th</sup> | 24 dB/oct       | 0.4350 | 0.0692 / TC          | 0.0781 / TC        | 1.1285                                  |
| 5 <sup>th</sup> | 30 dB/oct       | 0.3856 | 0.0614 / TC          | 0.0684 / TC        | 1.1138                                  |
| 6 <sup>th</sup> | 36 dB/oct       | 0.3499 | 0.0557 / TC          | 0.0615 / TC        | 1.1046                                  |
| 7 <sup>th</sup> | 42 dB/oct       | 0.3226 | 0.0513 / TC          | 0.0564 / TC        | 1.0983                                  |
| 8 <sup>th</sup> | 48 dB/oct       | 0.3008 | 0.0479 / TC          | 0.0524 / TC        | 1.0937                                  |

## 10.3. Discrete-Time Filters

### 10.3.1. Discrete-Time RC Filter

There are many options how to implement digital low-pass filters. One common filter type is the exponential running average filter. Its characteristics are very close to those of an analog resistor-capacitor RC filter, which is why this filter is sometimes called a discrete-time RC filter. The exponential running average filter has the time constant  $\mathbf{TC} = \tau_N$  as its only adjustable parameter. It operates on an input signal  $X_{in}[n, ]$  defined at discrete times  $nT_s$ ,  $(n + 1)T_s$ ,  $(n + 2)T_s$ , etc., spaced at the sampling time  $T_s$ . Its output  $X_{out}[n, T_s]$  can be calculated using the following recursive formula,

$$X_{out}[n, T_s] = e^{-T_s/\tau_N} X_{out}[n - 1, T_s] + (1 - e^{-T_s/\tau_N}) X_{in}[n, T_s] \quad (4)$$

The response of that filter in the frequency domain is well approximated by the formula

$$H_1(\omega) = \frac{1}{1 + i \cdot \omega \cdot \tau_n} \quad (5)$$

The exponential filter is a first-order filter. Higher-order filters can easily be implemented by cascading several filters. For instance the 4<sup>th</sup> order filter is implemented by chaining 4 filters with the same time constant  $\mathbf{TC} = \tau_n$  one after the other so that the output of one filter stage is the input of the next one. The transfer function of such a cascaded filter is simply the product of the transfer functions of the individual filter stages. For an n-th order filter, we therefore have

$$H_n(\omega) = \frac{1}{(1 + i \cdot \omega \cdot \tau_n)^n} \quad (6)$$

The attenuation and phase shift of the filters can be obtained from this formula. Namely, the filter attenuation is given by the absolute value squared  $|H_n(\omega)|^2$ . The filter transmission phase is given by the complex argument  $\arg[H_n(\omega)]$ .

### 10.3.2. Filter Settling Time

The low-pass filters after the demodulator cause a delay to measured signals depending on the filter order and time constant  $\mathbf{TC} = \tau_n$ . After a change in the signal, it will therefore take some time before the lock-in output reaches the correct measurement value. This is depicted in [Figure 10.5](#) where the response of cascaded filters to a step input signal is shown.

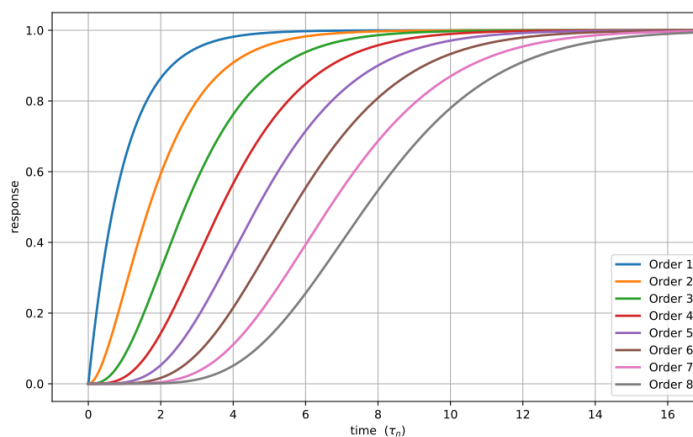


Figure 10.5: Time-domain step response of the demodulator low-pass filter for orders from 1 to 8.

More quantitative information on the settling time can be obtained from [Table 10.2](#). In this table, you find settling times in units of the 1st-order filter's time constant ( $\mathbf{TC}$ ) for all filter orders available with the HF2 Lock-in Amplifier. The values tell the time you need to wait for the filtered demodulator signal to reach 50%, 63%, 95% and 99% of the final value. This can help in making a quantitatively correct choice of filter parameters for example in a measurement involving a parameter sweep.

Table 10.2: Summary of Filter Settling Times

| Filter order    | 50%            | 63% (1-1/e)    | 90%             | 95%             | 99%             |
|-----------------|----------------|----------------|-----------------|-----------------|-----------------|
| 1 <sup>st</sup> | $0.7 \cdot TC$ | $1.0 \cdot TC$ | $2.3 \cdot TC$  | $3.0 \cdot TC$  | $4.6 \cdot TC$  |
| 2 <sup>nd</sup> | $1.7 \cdot TC$ | $2.1 \cdot TC$ | $3.9 \cdot TC$  | $4.7 \cdot TC$  | $6.6 \cdot TC$  |
| 3 <sup>rd</sup> | $2.7 \cdot TC$ | $3.3 \cdot TC$ | $5.3 \cdot TC$  | $6.3 \cdot TC$  | $8.4 \cdot TC$  |
| 4 <sup>th</sup> | $3.7 \cdot TC$ | $4.4 \cdot TC$ | $6.7 \cdot TC$  | $7.8 \cdot TC$  | $10.0 \cdot TC$ |
| 5 <sup>th</sup> | $4.7 \cdot TC$ | $5.4 \cdot TC$ | $8.0 \cdot TC$  | $9.2 \cdot TC$  | $11.6 \cdot TC$ |
| 6 <sup>th</sup> | $5.7 \cdot TC$ | $6.5 \cdot TC$ | $9.3 \cdot TC$  | $10.5 \cdot TC$ | $13.1 \cdot TC$ |
| 7 <sup>th</sup> | $6.7 \cdot TC$ | $7.6 \cdot TC$ | $10.5 \cdot TC$ | $11.8 \cdot TC$ | $14.6 \cdot TC$ |
| 8 <sup>th</sup> | $7.7 \cdot TC$ | $8.6 \cdot TC$ | $11.8 \cdot TC$ | $13.1 \cdot TC$ | $16.0 \cdot TC$ |

## 10.4. Full Range Sensitivity

The sensitivity of the lock-in amplifier is the RMS value of an input sine that is demodulated and results in a full scale analog output. Traditionally the X, Y, or R components are mapped onto the 10 V full scale analog output. In such a case, the overall gain from input to output of the lock-in amplifier is composed of the input and output amplifier stages. Many lock-in amplifiers specify a sensitivity between 1 nV and 1 V. In other words the instrument permits an input signal between 1 nV and 1 V to be amplified to the 10 V full range output.

Analog Lock-in Amplifiers:



Digital Lock-in Amplifiers:



Figure 10.6: Sensitivity from signal input to signal output

In analog lock-in amplifiers the sensitivity is simple to understand. It is the sum of the analog amplification stages between in the input and the output of the instrument: in particular the input amplifier and the output amplifier.

In digital lock-in amplifiers the sensitivity is less straightforward to understand. Analog-to-digital converters (ADC) operate with a fixed input range (e.g. 1 V) and thus require a variable-gain amplifier to amplify the input signal to the range given by the ADC. This variable-gain amplifier must be in the analog domain and its capability determines the minimum input range of the instrument. A practical analog input amplifier provides a factor 1000 amplification, thus 1 V divided by 1000 is the minimum input range of the instrument.

The input range is the maximum signal amplitude that is permitted for a given range setting. The signal is internally amplified with the suited factor, e.g.  $(1 \text{ mV}) \cdot 1000$  to result in a full swing signal at the ADC. For signals larger than the range, the ADC saturates and the signal is distorted – the measurement result becomes useless. Thus the signal should never exceed the range setting.

But the input range is not the same as the sensitivity. In digital lock-in amplifiers the sensitivity is only determined by the output amplifier, which is an entirely digital signal processing unit which performs a numerical multiplication of the demodulator output with the scaling factor. The digital output of this unit is then fed to the output digital-to-analog converter (DAC) with a fixed range of 10 V. It is this scaling factor that can be retrofitted to specify a sensitivity as known from the analog lock-in amplifiers. A large scaling factor, and thus a high sensitivity, comes at a relatively small expense for digital amplification.

One interesting aspect of digital lock-in amplifiers is the connection between input resolution and sensitivity. As the ADC operates with a finite resolution, for instance 14 bits, the minimum signal that can be detected and digitized is for instance 1 mV divided by the resolution of the ADC. With 14 bits the minimum level that can be digitized would be 122 nV. How is it possible to reach 1 nV sensitivity without using a 21 bit analog-to-digital converter? In a world without noise it is not possible.



Inversely, thanks to noise and current digital technology it is possible to achieve a sensitivity even below 1 nV.

Most sources of broadband noise, including the input amplifier, can be considered as Gaussian noise sources. Gaussian noise is equally distributed in a signal, and thus generates equally distributed disturbances. The noise itself can be filtered by the lock-in amplifier down to a level where it does not impact the measurement. Still, in the interplay with the signal, the noise does have an effect on the measurement. The input of the ADC is the sum of the noise and the signal amplitude. Every now and then, the signal amplitude on top of the large noise will be able to toggle the least significant bits even for very small signals, as low as 1 nV and below. The resulting digital signal has a component at the signal frequency and can be detected by the lock-in amplifier.

There is a similar example from biology. Rod cells in the human eye permit humans to see in very low light conditions. The sensitivity of rod cells in the human eye is as low as a single photon. This sensitivity is achieved in low light conditions by a sort of pre-charging of the cell to be sensitive to the single photon that triggers the cell to fire an impulse. In a condition with more surround light, rod cells are less sensitive and need more photons to fire.

To summarize, in digital lock-in amplifiers the full range sensitivity is only determined by the scaling factor capability of the digital output amplifier. As the scaling can be arbitrary big, 1 nV minimum full range sensitivity is achievable without a problem. Further, digital lock-in amplifiers exploit the input noise to heavily increase the sensitivity without impacting the accuracy of the measurement.

# 10.5. Sinc Filtering

As explained in [Principles of Lock-in Detection](#), the demodulated signal in an ideal lock-in amplifier has a signal component at DC and a spurious component at twice the demodulation frequency. The components at twice the demodulation frequency (called the  $2\omega$  component) is effectively removed by regular low-pass filtering. By selecting filters with small bandwidth and faster roll-offs, the  $2\omega$  component can easily be attenuated by 100 dB or more. The problem arises at low demodulation frequencies, because this forces the user to select long integration times (e.g. >60 ms for a demodulation frequency of 20 Hz) in order to achieve the same level of  $2\omega$  attenuation.

In practice, the lock-in amplifier will modulate DC offsets and non-linearities at the signal input with the demodulation frequency, resulting in a signal at the demodulation frequency (called  $\omega$  component). This component is also effectively removed by the regular low-pass filters at frequencies higher than 1 kHz.

At low demodulation frequencies, and especially for applications with demodulation frequencies close to the filter bandwidth, the  $\omega$  and  $2\omega$  components can affect the measurement result. Sinc filtering allows for strong attenuation of the  $\omega$  and  $2\omega$  components. Technically the sinc filter is a comb filter with notches at integer multiples of the demodulation frequency ( $\omega$ ,  $2\omega$ ,  $3\omega$ , etc.). It removes the  $\omega$  component with a suppression factor of around 80 dB. The amount of  $2\omega$  component that gets removed depends on the input signal. It can vary from entirely (e.g. 80 dB) to slightly (e.g. 5 dB). This variation is not due to the sinc filter performance but depends on the bandwidth of the input signal.

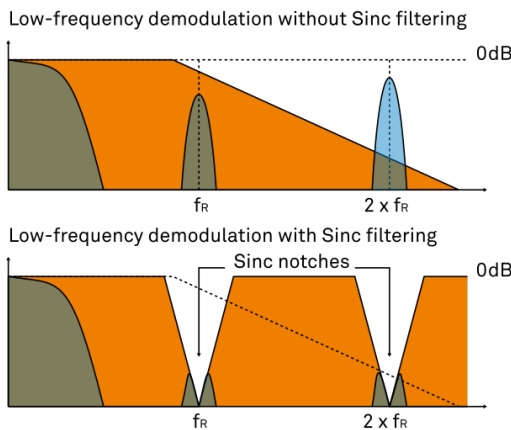


Figure 10.7: Effect of sinc filtering

Table 10.3: Artifacts in the demodulation signal



| Input signal       | Demodulation result before low-pass filter | Result                                                             |
|--------------------|--------------------------------------------|--------------------------------------------------------------------|
| Signal at $\omega$ | DC component                               | Amplitude and phase information (wanted signal)                    |
|                    | $2\omega$ component                        | Unwanted component (can additionally be attenuated by sinc filter) |
| DC offset          | $\omega$ component                         | Unwanted component (can additionally be attenuated by sinc filter) |

We can observe the effect of the sinc filter by using the Spectrum Analyzer Tool of the HF2 Lock-in Amplifier. As an example, consider a 30 Hz signal with an amplitude of 0.1 V that demodulated using a filter bandwidth of 100 Hz and a filter order 8. In addition 0.1 V offset is added to the signal so that we get a significant  $\omega$  component.

Figure 10.8 shows a spectrum with the sinc filter disabled, whereas for Figure 10.9 the sinc filter is enabled. The comparison of the two clearly shows how the sinc options dampens both the  $\omega$  and  $2\omega$  components by about 100 dB.

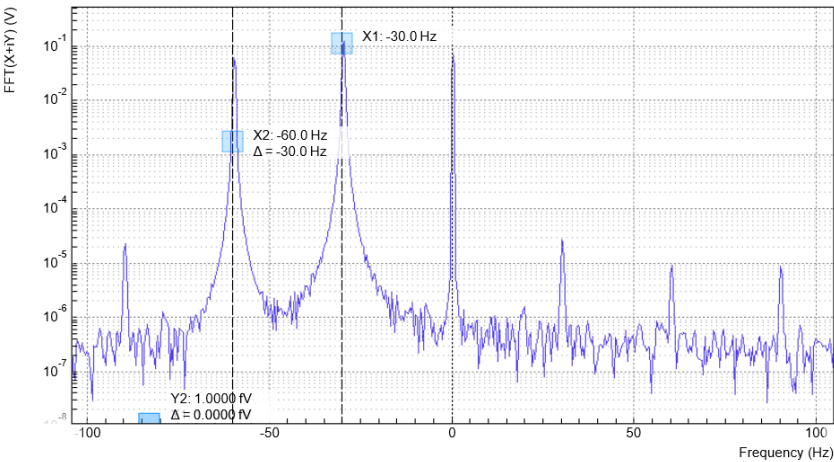


Figure 10.8: Spectrum of a demodulated 30 Hz signal without sinc filter

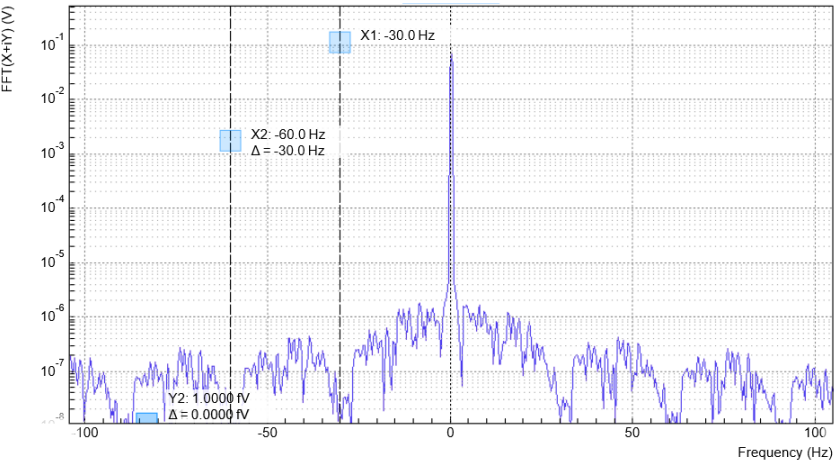


Figure 10.9: Spectrum of a demodulated 30 Hz signal with sinc filter

Note

In order to put the notches of the digital filter to  $\omega$  and  $2\omega$ , the sampling rate of the filter would have to be precisely adjusted to the signal frequency. As this is technically not feasible, the generated signal frequency is adjusted instead by a very small amount.

## 10.6. Zoom FFT

The concept of zoom FFT allows the user to analyze the spectrum of the input signal around a particular frequency by zooming in on a narrow frequency portion of the spectrum. This is done by performing a Fourier transform of the demodulated in-phase and quadrature (X and Y) components or more precisely, on the complex quantity  $X+iY$ , where  $i$  is the imaginary unit. In the LabOne user interface, this functionality is available in the Spectrum tab.

In normal FFT, the sampling rate determines the frequency span and the total acquisition time determines the frequency resolution. Having a large span and a fine resolution at the same time then requires long acquisition times at high sample rates. This means that a lot of data needs to be acquired, stored, and processed, only to retain a small portion of the spectrum and discard most of it in the end. In zoom FFT, the lock-in demodulation is used to down-shift the signal frequency, thereby allowing one to use both a much lower sampling rate and sample number to achieve the same frequency resolution. Typically, to achieve a 1 Hz frequency resolution at 1 MHz, FFT would require to collect and process approximately  $10^6$  points, while zoom FFT only processes  $10^3$  points. (Of course the high rate sampling is done by the lock-in during the demodulation stage, so the zoom FFT still needs to implicitly rely on a fast ADC.)

In order to illustrate why this is so and what benefits this measurement tool brings to the user, it is useful to remind that at the end of the demodulation of the input signal  $V_s(t) = A_s \cos(\omega_s t + \tau)$ , the output signal is  $X + iY = F(\omega_s - \omega_r)(A_s/\sqrt{2})e^{i[(\omega_s - \omega_r)t + \tau]}$  where  $F(\omega)$  is the frequency response of the filters.

Since the demodulated signal has only one component at frequency  $\omega_s - \omega_r$ , its power spectrum (Fourier transform modulus squared) has a peak of height  $(|A_s|^2/2) \cdot |F(\omega_s - \omega_r)|^2$  at  $\omega_s - \omega_r$ : this tells us the spectral power distribution of the input signal at frequencies close to  $\omega_r$  within the demodulation bandwidth set by the filters  $F(\omega)$ .

Note that:

- the ability of distinguish between positive and negative frequencies works only if the Fourier transform is done on  $X+iY$ . Had we taken  $X$  for instance, the positive and negative frequencies of its power spectrum would be equal. The symmetry relation  $G(-\omega)=G^*(\omega)$  holds for the Fourier transform  $G(\omega)$  of a real function  $g(t)$  and two identical peaks would appear at  $\pm|\omega_s - \omega_r|$ .
- one can extract the amplitude of the input signal by dividing the power spectrum by  $|F(\omega)|^2$ , the operation being limited by the numerical precision. This is implemented in LabOne and is activated by the Filter Compensation button: with the Filter Compensation enabled, the background noise appears white; without it, the effect of the filter roll-off becomes apparent.

The case of an input signal containing a single frequency component can be generalized to the case of multiple frequencies. In that case the power spectrum would display all the frequency components weighted by the filter transfer function, or normalized if the Filter Compensation is enabled.

When dealing with discrete-time signal processing, one has to be careful about aliasing which occurs when the signal frequencies higher than the sampling rate  $\omega$  are not sufficiently suppressed. Remember that  $\omega$  is the user settable readout rate, not the 2 GSa/s sampling rate of the GHFLI input. Since the discrete-time Fourier transform extends between  $-\omega/2$  and  $+\omega/2$ , the user has to make sure that at  $\pm\omega/2$  the filters provide the desired attenuation: this can be done either by increasing the sampling rate or resolving to measure a smaller frequency spectrum (i.e. with a smaller filter bandwidth).

Similarly to the continuous case, in which the acquisition time determines the maximum frequency resolution ( $2\pi/T$  if  $T$  is the acquisition time), the resolution of the zoom FFT can be increased by increasing the number of recorded data points. If  $N$  data points are collected at a sampling rate  $\omega$ , the discrete Fourier transform has a frequency resolution of  $\omega/N$ .

# 11. HF2CA Current Amplifier Data Sheet

This chapter contains the data sheet of the HF2CA Current Amplifier which is a preamplifier dedicated to the HF2 Series instruments. This data sheet is distributed only as part of the HF2 User Manual, and therefore not available separately.

The content of the chapter starts with the list of key features of the preamplifier, and continues with sections including the specifications, the detailed functional description, several possible applications, and finally an extended recommendation for 3rd party cables and connectors.

## 11.1. Key Features

- Current amplifier for high capacitive loads - shunt resistor based
- Voltage amplifier with selectable gain 1 or 10
- Input impedance switchable between 10 V/A and 1 MV/A
- Bandwidth from DC up to 100 MHz
- 2 differential amplification channels with switchable AC/DC coupling
- Adjustable output gain of 1 or 10
- Very low noise and small input leakage
- Single connector for power supply and control

The HF2CA current amplifier converts a differential input current to a differential output voltage in a wide frequency range. This device functions as an active probe and is conveniently placed close to the measurement setup. It supports applications with high capacitive loads such as dielectric impedance spectroscopy. When no shunt resistor is selected, the current amplifier works as a voltage amplifier. The careful design of the HF2CA insures stable operation over the entire frequency range.

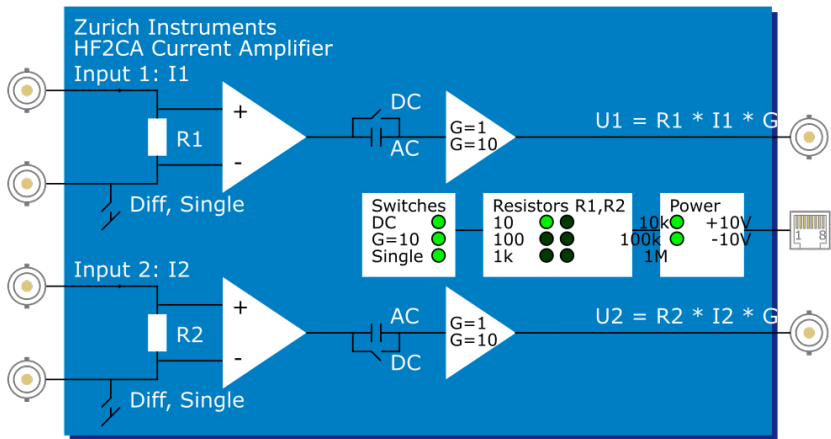


Figure 11.1: HF2CA functional overview

## 11.2. Specifications

Unless otherwise stated, all specifications apply after 30 minutes of device warming up.

Table 11.1: General

| Parameter             | Description      |
|-----------------------|------------------|
| dimensions            | 100 x 60 x 25 mm |
| weight                | 0.4 kg           |
| storage temperature   | -20 °C to 65 °C  |
| operating temperature | 5 °C to 40 °C    |

| Parameter                    | Description                                       |
|------------------------------|---------------------------------------------------|
| specification temperature    | 25 °C                                             |
| specification supply voltage | 12 V                                              |
| connectors                   | 4 SMB inputs, 2 SMB outputs, 1 RJ45 (no Ethernet) |

Table 11.2: Specifications

| Parameter                                                                                    | min     | typ          | max     |
|----------------------------------------------------------------------------------------------|---------|--------------|---------|
| positive supply voltage VDD+                                                                 | 12 V    | 15 V         | 20 V    |
| negative supply voltage VDD-                                                                 | -20 V   | -15 V        | -12 V   |
| supply current                                                                               | 60 mA   | 80 mA        | 120 mA  |
| <b>frequency response</b>                                                                    |         |              |         |
| frequency range                                                                              | DC      | -            | 100 MHz |
| frequency range (AC coupled)                                                                 | 100 Hz  | -            | 100 MHz |
| small signal bandwidth / 3dB cut-off (0.1 V <sub>pp</sub> input, 50 pF output load, gain 1)  | 100 MHz | -            | -       |
| small signal bandwidth / 3dB cut-off (0.1 V <sub>pp</sub> input, 50 pF output load, gain 10) | 25 MHz  | -            | -       |
| large signal bandwidth / 3dB cut-off (1 V <sub>pp</sub> , 50 pF)                             | 40 MHz  | -            | -       |
| <b>input</b>                                                                                 |         |              |         |
| input voltage noise (10 kHz)                                                                 | -       | 7 nV/<br>√Hz | -       |
| input voltage noise (10 MHz)                                                                 | -       | 6 nV/<br>√Hz | -       |
| input bias current                                                                           | -       | 2 pA         | 10 pA   |
| transimpedance gain (equivalent to input impedance)                                          | 10 V/A  | -            | 1 MV/A  |
| transimpedance gain accuracy (G=1)                                                           | -       | ±0.1 %       | -       |
| transimpedance gain accuracy (G=10)                                                          | -       | ±1 %         | -       |
| input offset voltage                                                                         | -       | -            | 1 mV    |
| common-mode offset range                                                                     | -10 V   | -            | 7.5 V   |
| <b>output</b>                                                                                |         |              |         |
| output voltage gain                                                                          | 1       | -            | 10      |
| <b>control interface</b>                                                                     |         |              |         |
| input high level                                                                             | 2.0 V   | -            | 5 V     |
| input low level                                                                              | 0 V     | -            | 0.8 V   |
| all transitions on SDI, SDO, SCK, SLC                                                        | -       | -            | 1 μs    |
| SCK clock period                                                                             | 10 μs   | -            | -       |
| SDI data to clock setup t <sub>DS</sub>                                                      | 2 μs    | -            | -       |
| SDI data hold from clock t <sub>DH</sub>                                                     | 1 μs    | -            | -       |
| SLC clock to latch setup t <sub>LS</sub>                                                     | 1 μs    | -            | -       |
| SLC latch hold t <sub>LH</sub>                                                               | 10 μs   | -            | 20 μs   |
| SCK clock free time t <sub>CF</sub>                                                          | 20 μs   | -            | -       |

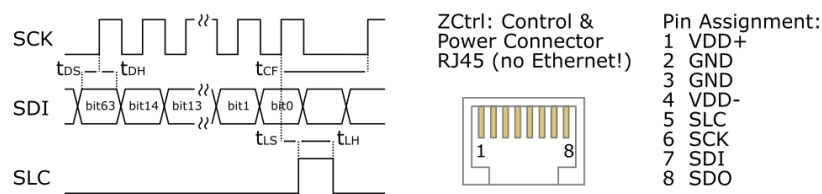


Figure 11.2: Digital control timing

Some parameters depend on the transimpedance gain settings. The following table provides an overview. The values in this table are typical values, they depend on the source capacitance, on the input signal swing, and as well as on the capacitive load on the output of the amplifier.

Table 11.3: Gain dependent parameters

| Input impedance setting | Bandwidth / 3dB cut-off frequency | Maximum input current range | Maximum input current noise |
|-------------------------|-----------------------------------|-----------------------------|-----------------------------|
| 10 V/A                  | 100 MHz                           | ±160 mA                     | 400 pA/√Hz                  |
| 100 V/A                 | 50 MHz                            | ±16 mA                      | 42 pA/√Hz                   |
| 1 kV/A                  | 5 MHz                             | ±1.6 mA                     | 5.6 pA/√Hz                  |
| 10 kV/A                 | 500 kHz                           | ±160 µA                     | 1.3 pA/√Hz                  |
| 100 kV/A                | 50 kHz                            | ±16 µA                      | 400 fA/√Hz                  |
| 1 MV/A                  | 5 kHz                             | ±1.6 µA                     | 128 fA/√Hz                  |

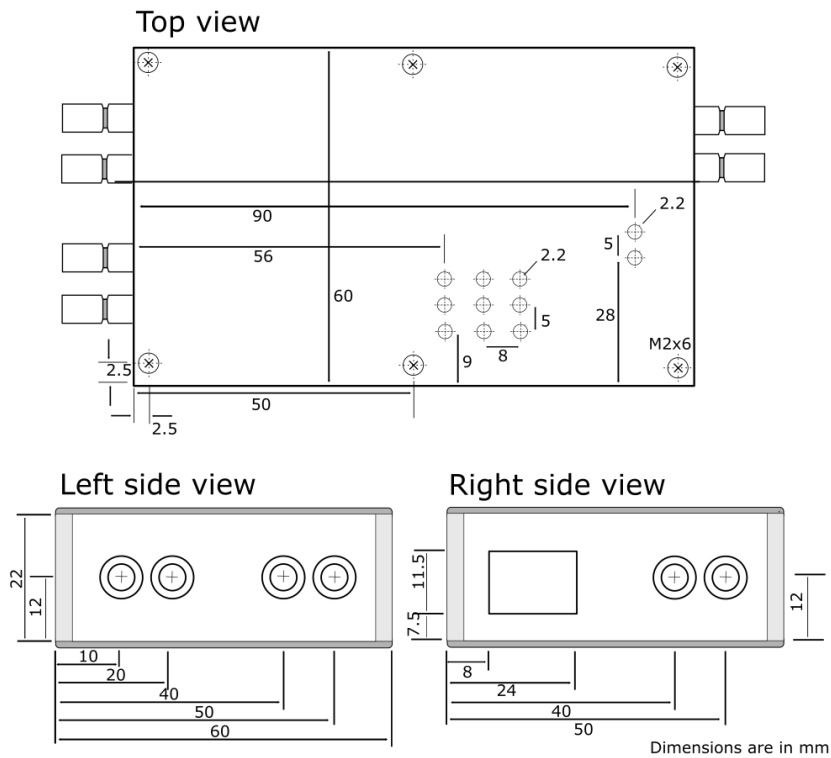


Figure 11.3: Casing dimensions of the HF2CA

## 11.3. Functional Description

The HF2CA external amplifier can be placed close to the signal source whereas the HF2 Instrument can be several meters away. Such a setup significantly improves the measurement quality due to less parasitics effects and to smaller interferences.

The two signal channels of the HF2CA can be used as separate amplification channels, or alternatively, in differential mode connected to the differential input of the HF2 Instrument.

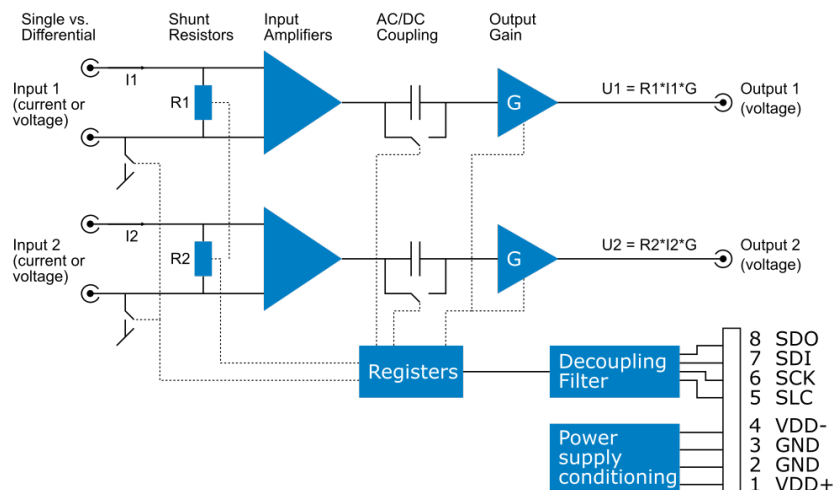


Figure 11.4: Detailed block diagram

### 11.3.1. Input and Output

**Shunt resistors:** HF2CA measures the current between the positive and the negative input terminal by measuring the voltage drop across a resistor, that is shunted between the inputs (see [Figure 11.4](#)). The supported resistor values are given in [Table 11.3](#). It is also possible to remove all internal resistors and to support any custom resistor that is externally connected (see [Custom Input Impedance](#)). When all resistors are removed (infinite impedance), then the HF2CA becomes a voltage amplifier with selectable gains 1 and 10.

**JFET input amplifiers:** the HF2CA is based on JFET input amplifiers that provide very low-noise over a wide frequency range. Additionally, the ultra-low input bias current of typically 2 pA allows for precise current measurements at small signal amplitudes. The input voltage range of the JFET input amplifiers is -10 V to 7.5 V for each input which is also the common mode offset range.

**Single vs. differential mode:** a selectable switch to amplifier ground allows the user to earth the negative terminal of each input and to operate in single-ended mode without needing external circuits. Alternatively, when leaving the ground switches open, it is possible to use a differential input signal or to connect the negative terminals to local ground externally.

**AC vs. DC mode:** a selectable switch after the input amplifiers allows the user to measure DC or close to DC signals, or when this is not required, to select AC coupling with a cut-off frequency at 100 Hz and eliminate potential 50/60 Hz noise from the measured signal.

### 11.3.2. Power Supply and Remote Control

The HF2CA is designed for use with the HF2 Series with its differential signal for improved signal-to-noise, and a single cable that provides power and control signals. A straight-through (as opposed to cross-over) Ethernet cable must be used. The cable carries the following signals: - **Power:** positive and negative supply, ground - **Digital control:** SDI digital input signal to control the preamplifier settings, SDO output signal for device detection (details of function not disclosed to users), SCK clock signal, and SLC latch signal. SDI, SCK and SLC are used to program the shift registers on the amplifier and thereby adjust the correct settings. The setting bits are given in [Table 11.4](#). The timing diagram of the digital interface is given in [Figure 11.2](#). The MSB of the register settings is shifted in first.

Table 11.4: HF2CA register settings

| Register bit | Name      | Description                                                      |
|--------------|-----------|------------------------------------------------------------------|
| 15 to 10     | -         | unused                                                           |
| 9            | gain      | 0: set output gain to 1<br>1: set output gain to 10              |
| 8            | dcswitch2 | 0: set AC coupling for input 2<br>1: set DC coupling for input 2 |
| 7            | dcswitch1 | 0: set AC coupling for input 1                                   |

| Register bit | Name         | Description                    |
|--------------|--------------|--------------------------------|
|              |              | 1: set DC coupling for input 1 |
| 6            | singleswitch | 0: set differential operation  |
|              |              | 1: set single-ended operation  |
| 5            | res1m        | 1: set resistor 1 MV/A         |
| 4            | res100k      | 1: set resistor 100 kV/A       |
| 3            | res10k       | 1: set resistor 10 kV/A        |
| 2            | res1k        | 1: set resistor 1 kV/A         |
| 1            | res100       | 1: set resistor 100 V/A        |
| 0            | res10        | 1: set resistor 10 V/A         |

## 11.4. Applications

- Impedance spectroscopy
- Large capacitive loads
- Wheatstone-bridge configuration
- Preamplifier for HF2IS impedance spectroscopy and HF2LI lock-in amplifier

### 11.4.1. Differential Current Measurement with Common-mode Offset

The resistors at the input of the amplifier can be inserted in a current path as shown in the figures. With this, fast current transients can be measured at large common-mode voltages, which are in the range from -10 V to 7.5 V are possible. This is used in, e.g., high-energy physics to record the radiation-induced current in a photo diode.

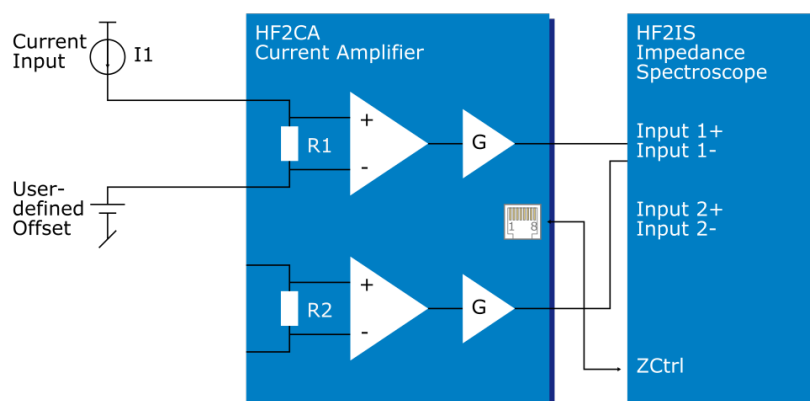


Figure 11.5: HF2CA differential current measurement

### 11.4.2. Multi-frequency Impedance Spectroscopy

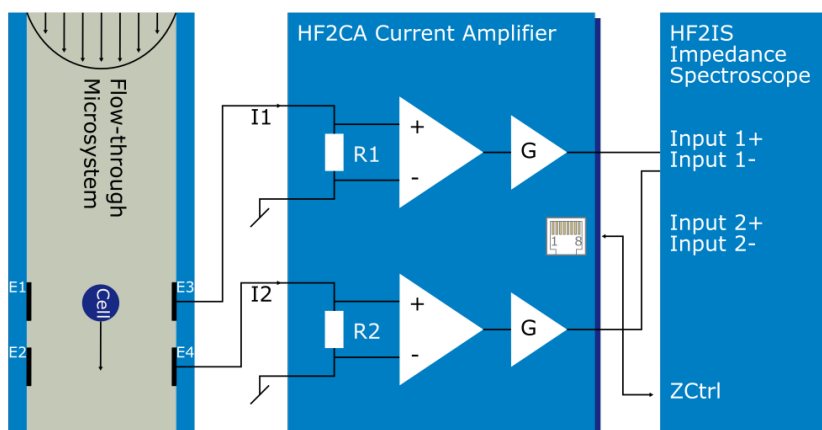


Figure 11.6: HF2CA impedance spectroscopy

The HF2CA in combination with the HF2IS impedance spectrometer is the solution to measure impedance in, for example, flow-through microsystems. The challenge here is to measure the channel impedance at high frequencies (>10 MHz). The large capacitance occurring at electrode electrolyte interfaces can lead to stability issues in a transimpedance amplifier. A solution is to use the electrodes in a Wheatstone bridge configuration with shunt resistors. The HF2CA offers this solution.

As shown in the figure, electrodes are placed on the channel walls of a microfluidic channel (width in the order of 20 to 50  $\mu\text{m}$ ). Electrodes E1 and E2 are stimulated with a sinusoidal voltage, the electrodes E3 and E4 are connected to the positive amplifier inputs and thus shunted to GND via resistors R1 and R2. The resulting voltage drops across R1 and R2 are given by the channel impedance. This impedance varies when a particle or a living cell passes the electrode area. An analysis at multiple frequencies at the same time (which is supported by the HF2IS and the HF2CA) allows for concurrently analyzing cell size and dielectric properties. With this information biologists, e.g. sort their cells and detect cell viability or health.

### 11.4.3. Impedance Measurement

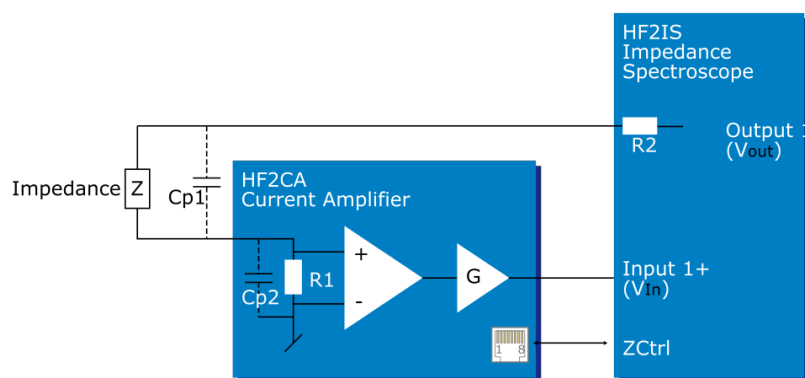


Figure 11.7: Measure an impedance using the HF2CA

The HF2 in conjunction with the HF2CA can be used to measure impedances at various frequencies. The connection diagram is shown in the figure above. The impedance of interest,  $Z$ , is connected to the input resistor in the HF2CA preamplifier. For optimal signal-to-noise, the input resistor,  $R_1$ , is set to a value close to the impedance  $Z$ . The HF2 generates an output signal of amplitude  $V_{\text{Out}}$  and the output signal from the preamplifier is connected to the positive input (Input +) of the HF2, which is here called  $V_{\text{In}}$ . With this setup, the impedance  $Z$  can be calculated using the following equation:

$$Z = R(V_{\text{Out}}V_{\text{In}})/V_{\text{In}}$$

Here we neglected the output resistance,  $R_2$ , of the HF2 device. This is valid as long as  $Z \gg R_1 = 50 \text{ } \Omega$ . Furthermore, at high frequencies the parasitic capacitances  $C_{p1}$  and  $C_{p2}$  will have to be included in the calculation. At even higher frequencies,  $C_{p1}$  and  $C_{p2}$  will be dominant.

### 11.4.4. Custom Input Impedance



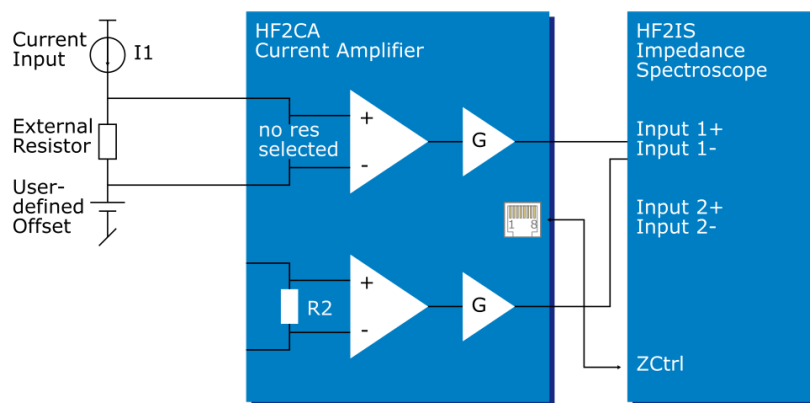


Figure 11.8: HF2CA custom input impedance

Sometimes it is useful to choose a special resistance value in order to optimize the signal to noise by, e.g. impedance matching. In this case, an external resistor can be used instead of using the standard values inside the preamplifier. All internal resistors need to be disconnected in this case, which can be done using the standard preamplifier user interface.

## 11.5. Cable Recommendation

Table 11.5: HF2CA cable recommendation

| Function                               | Connector / cable type   | Vendor / part number         |
|----------------------------------------|--------------------------|------------------------------|
| <b>SMB to BNC connection</b>           |                          |                              |
| SMB to BNC cable                       | BNC jack to SMB plug     | Farnell / Newark 1351896     |
| SMB to BNC adapter                     | BNC jack to SMB plug     | Digikey ACX1386-ND           |
| BNC jack to SMB jack                   | Farnell / Newark 4195930 |                              |
| <b>Custom access or cable assembly</b> |                          |                              |
| Cable                                  | Cable type RG-174        | Digikey A307-100-ND          |
|                                        |                          | Farnell / Newark 1387745     |
| SMB to cable                           | SMB plug to RG-174 cable | Tyco Electronics 413985-1    |
|                                        |                          | Digikey A4026-ND             |
|                                        |                          | Farnell / Newark 2141206     |
| BNC to cable                           | BNC plug to RG-174 cable | Tyco Electronics 1-5227079-6 |
|                                        |                          | Digikey A32212-ND            |

# 12. HF2TA Current Amplifier Data Sheet

This chapter contains the data sheet of the HF2TA Current Amplifier which is a preamplifier dedicated to the HF2 Series instruments. This data sheet is distributed only as part of the HF2 User Manual, and therefore not available separately.

The content of the chapter starts with the list of key features of the preamplifier, and continues with sections including the specifications, the detailed functional description, several possible applications, information how to test the specified performance, and finally an extended recommendation for 3rd party cables and connectors.

## 12.1. Key Features

- 50 MHz operation range
- 2 independent amplification channels with selectable AC/DC coupling
- Wide range of current gain settings (100 V/A to 100 MV/A)
- Impedance measurements from 1  $\mu\Omega$  to 100 M $\Omega$
- Input offset voltage adjustment
- Voltage output amplifier with selectable gain 1 or 10
- Very low noise and low input leakage
- Single connector for power supply and control

The HF2TA current amplifier converts 2 input currents to output voltages in a frequency range up to 50 MHz. This device is an active probe which can be conveniently placed close to the measurement setup. It supports most applications where a current must be converted to a voltage. The advanced design of the HF2TA ensures stability and a smooth operation over the entire frequency range. The HF2TA transimpedance current amplifier with the HF2 Series signal analyzers allows for very high performance measurements and insensitivity to interferences thanks to reduced parasitics.

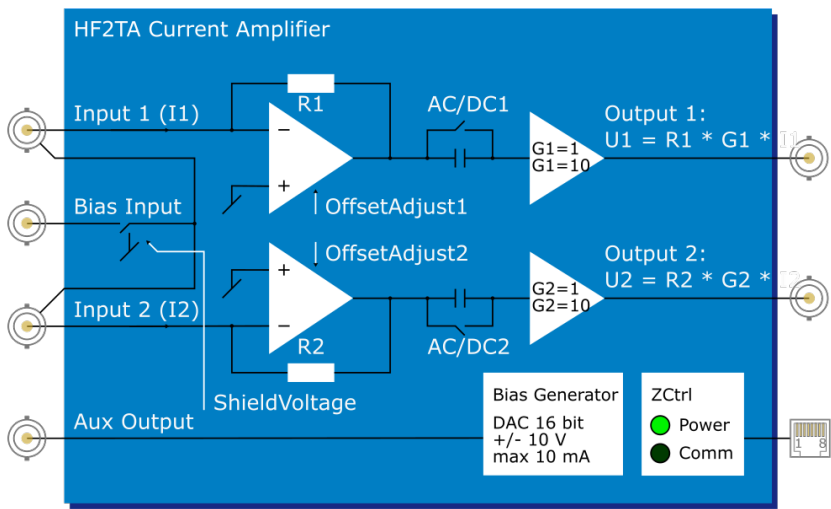


Figure 12.1: HF2TA functional overview

## 12.2. Specifications

Unless otherwise stated, all specifications apply after 30 minutes of device warming up.

Table 12.1: General

| parameter  | description      |
|------------|------------------|
| dimensions | 101 x 78 x 23 mm |
| weight     | 0.4 kg           |

| parameter                 | description                                                     |
|---------------------------|-----------------------------------------------------------------|
| storage temperature       | -20 °C to 65 °C                                                 |
| operating temperature     | 5 °C to 40 °C                                                   |
| specification temperature | 25 °C                                                           |
| connectors                | 3 SMA inputs female, 3 SMA outputs female, 1 RJ45 (no Ethernet) |

Table 12.2: Specifications

| parameter                                                                                    | min                                | typ          | max          |
|----------------------------------------------------------------------------------------------|------------------------------------|--------------|--------------|
| positive supply voltage VDD+                                                                 | 12 V                               | 13 V         | 15 V         |
| negative supply voltage VDD-                                                                 | -15 V                              | -13 V        | -12 V        |
| supply current                                                                               | 50 mA                              | 60 mA        | 100 mA       |
| <b>frequency response</b>                                                                    |                                    |              |              |
| frequency range                                                                              | DC                                 | -            | 50 MHz       |
| frequency range (AC coupled)                                                                 | 10 Hz                              | -            | 50 MHz       |
| small signal bandwidth / 3dB cut-off (0.1 V <sub>pp</sub> input, 50 pF output load, gain 1)  | -                                  | -            | 50 MHz       |
| small signal bandwidth / 3dB cut-off (0.1 V <sub>pp</sub> input, 50 pF output load, gain 10) | -                                  | -            | 50 MHz       |
| large signal bandwidth / 3dB cut-off (1 V <sub>pp</sub> , 50 pF)                             | -                                  | -            | 40 MHz       |
| <b>input</b>                                                                                 |                                    |              |              |
| input current range                                                                          | depends on R1, R2, G1, G2 settings |              |              |
| input current noise                                                                          | depends on R1, R2, G1, G2 settings |              |              |
| input voltage noise (10 kHz)                                                                 | -                                  | 7 nV/<br>√Hz | -            |
| input voltage noise (10 MHz)                                                                 | -                                  | 5 nV/<br>√Hz | -            |
| input leakage current                                                                        | -                                  | 2 pA         | 20 pA        |
| input voltage offset compensation range                                                      | -10 mV                             | -            | 10 mV        |
| input impedance range (Z // 15 pF)                                                           | 50 Ω                               | -            | 70 kΩ        |
| input bias voltage range                                                                     | -10 V                              | -            | 10 V         |
| input signal level (damage threshold)                                                        | -5 V                               | -            | 5 V          |
| <b>output</b>                                                                                |                                    |              |              |
| output voltage gain (G1,G2)                                                                  | 1                                  | -            | 10           |
| transimpedance gain (R1,R2)                                                                  | 100 V/A                            | -            | 100 MV/<br>A |
| transimpedance gain accuracy (R1,R2)                                                         | -                                  | ±1 %         | -            |
| <b>digital control interface timing</b>                                                      |                                    |              |              |
| input high level                                                                             | 2.2 V                              | -            | 5 V          |
| input low level                                                                              | 0 V                                | -            | 0.8 V        |
| all transitions on SDI, SDO, SCK, SLC                                                        | -                                  | -            | 1 μs         |
| SCK clock period                                                                             | 10 μs                              | -            | -            |
| SDI data to clock setup t <sub>DS</sub>                                                      | 2 μs                               | -            | -            |
| SDI data hold from clock t <sub>DH</sub>                                                     | 1 μs                               | -            | -            |

| parameter                         | min        | typ | max        |
|-----------------------------------|------------|-----|------------|
| SLC clock to latch setup $t_{LS}$ | 1 $\mu$ s  | -   | -          |
| SLC latch hold $t_{LH}$           | 10 $\mu$ s | -   | 20 $\mu$ s |
| SCK clock free time $t_{CF}$      | 20 $\mu$ s | -   | -          |

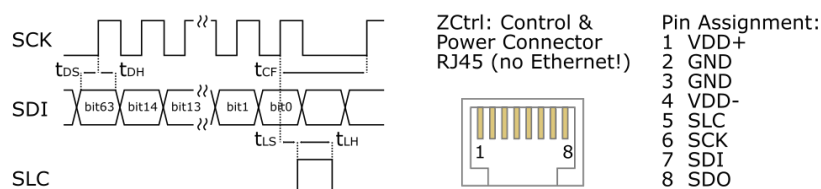


Figure 12.2: Digital control interface timing

Some parameters depend on the transimpedance gain settings. The following table provides an overview. The values in this table are typical values, they depend on the source capacitance, on the input signal swing, and also on the capacitive load on the output of the amplifier.

Table 12.3: Gain dependent parameters 1

| input impedance setting | bandwidth / 3dB cut-off | maximum input current range (G=1) | maximum input current range (G=10) |
|-------------------------|-------------------------|-----------------------------------|------------------------------------|
| 100 V/A                 | 50 MHz                  | $\pm 10$ mA                       | $\pm 1$ mA                         |
| 1 k V/A                 | 50 MHz                  | $\pm 1$ mA                        | $\pm 100$ $\mu$ A                  |
| 10 kV/A                 | 8 MHz                   | $\pm 100$ $\mu$ A                 | $\pm 10$ $\mu$ A                   |
| 100 kV/A                | 1.5 MHz                 | $\pm 10$ $\mu$ A                  | $\pm 1$ $\mu$ A                    |
| 1 MV/A                  | 250 kHz                 | $\pm 1$ $\mu$ A                   | $\pm 100$ nA                       |
| 10 MV/A                 | 25 kHz                  | $\pm 100$ nA                      | $\pm 10$ nA                        |
| 100 MV/A                | 12 kHz                  | $\pm 10$ nA                       | $\pm 1$ nA                         |

Table Gain dependent parameters 2

| input impedance setting | input impedance | maximum input current noise | measured at |
|-------------------------|-----------------|-----------------------------|-------------|
| 100 V/A                 | 50 $\Omega$     | 150 pA/ $\sqrt{\text{Hz}}$  | 1 MHz       |
| 1 k V/A                 | 50 $\Omega$     | 15 pA/ $\sqrt{\text{Hz}}$   | 1 MHz       |
| 10 kV/A                 | 50 $\Omega$     | 2 pA/ $\sqrt{\text{Hz}}$    | 1 MHz       |
| 100 kV/A                | 100 $\Omega$    | 500 fA/ $\sqrt{\text{Hz}}$  | 100 kHz     |
| 1 MV/A                  | 300 $\Omega$    | 250 fA/ $\sqrt{\text{Hz}}$  | 100 kHz     |
| 10 MV/A                 | 1.6 k $\Omega$  | 100 fA/ $\sqrt{\text{Hz}}$  | 10 kHz      |
| 100 MV/A                | 70 k $\Omega$   | 50 fA/ $\sqrt{\text{Hz}}$   | 10 kHz      |

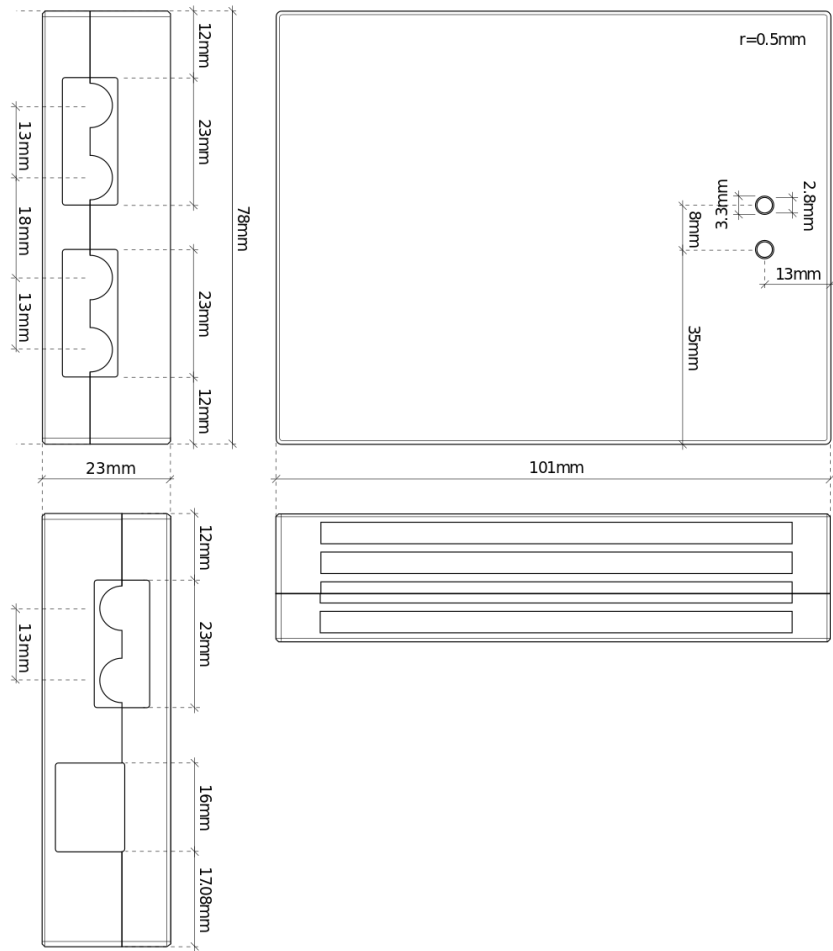


Figure 12.3: Casing dimensions of the HF2TA

## 12.3. Functional Description

The HF2TA is an external current preamplifier for the HF2 Series instruments from Zurich Instruments. The preamplifier can be placed close to the signal source, which significantly improves the measurement quality due to less parasitics effects and to smaller interferences.

The two signal channels of the HF2TA can be used as separate current amplification channels, or alternatively, in differential mode connected to the differential input of the HF2 Instrument. The channels settings can be set independently.

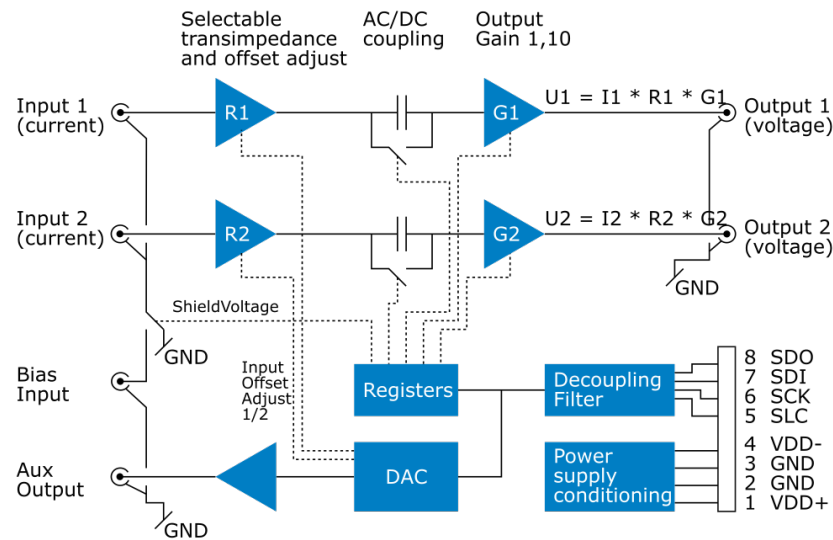


Figure 12.4: Detailed block diagram

### 12.3.1. Input and Output

**Transimpedance stage:** the HF2TA measures the current flowing at the two input terminals. The current amplifier uses a standard transimpedance stage to convert the current to a voltage output. The input terminal is matched to 50 Ohms to allow for proper impedance matching at high frequencies. At high current gains, or low input currents, respectively, the input terminal acts like a low-impedance virtual ground. The input impedance depends on the gain settings as described in the table above.

**Voltage gain 1 or 10:** the HF2TA offers a voltage gain of either 1 or 10 after the transimpedance amplifier. This allows to optimize the signal-to-noise at small amplitudes and high bandwidths. The transimpedance gain often has to be kept small in order to meet the required bandwidth. A voltage amplifier helps in this case to improve the measurement quality.

**JFET input amplifiers:** the HF2TA is based on JFET input amplifiers that provide very low-noise over a wide frequency range. Additionally, the ultra-low input bias current of typically 2 pA allows for precise current measurements at small signal amplitudes. The input voltage range of the JFET input amplifiers is -5 V to 2 V for each input which is also the common mode offset range.

**Offset adjustment:** the offset of the input amplifier can be manually compensated. For this purpose, disconnect any signal from the input of the current amplifier and measure the output voltage. Change the offset voltage until the output is close to zero. All remaining offset should now come from other sources (like offset current or leakage from the device under test).

**AC vs. DC mode:** a selectable switch after the input amplifiers allows the user to measure DC signals, or when this is not required, to select AC coupling with a cut-off frequency at around 10 Hz to remove the DC offset. When working in AC, make sure that the first amplifier is not saturating. This can be checked by switching to DC and gain 1.

**Aux output:** the HF2TA comprises a general purpose low-noise analog output. This output can be used as a power supply for, e.g., photo diodes. The photo diode is connected to the auxiliary output and the virtual ground of the input, no additional power supply is needed.

**Signal shield voltage:** the bias input connector can be used to apply a bias voltage to the signal shield. This can be used, for instance, to power a remote sensor over the signal shield without introducing an additional ground loop. If this option is not used, the signal shield should be conveniently grounded with the control setting "Shield Voltage".

### 12.3.2. Power Supply and Remote Control

The HF2TA is designed for use with the HF2 Series devices. It has to be connected to the ZCtrl 1/2 connectors of the host device using a single Ethernet cable which provides both power and control signals. A standard straight-through (as opposed to cross-over) cable must be used. The cable carries the following signals:

- **Power:** positive and negative supply, ground
- **Digital control:** SDI digital input signal to control the preamplifier settings, SDO output signal for device detection (details of function not disclosed to users), SCK clock signal, and SLC latch signal. SDI, SCK and SLC are used to program the shift registers on the amplifier and the DAC and thereby adjust the correct settings.

## 12.4. Applications

- Low-noise and high-speed current amplification
- Photo diode preamplifier
- Impedance measurement
- Semiconductor testing
- Impedance spectroscopy

### 12.4.1. Recommended Settings

In order to get the maximum performance out of your HF2TA, the following guidelines should be followed.

- low and high input current measurement

The HF2TA gain setting should be selected properly in the measurement path. The gain setting can be set according to . As one can see, each input impedance and G setting has a maximum input current range specified. With each recommended input impedance and G setting, the maximum current will produce the maximum voltage swing of  $\pm 1$  V at the output of the HF2TA. At this level the input digitizer of the HF2 input channel will run close to its full dynamic range which results in the optimal SNR.

- low and high bandwidth measurement  
HF2TA is specified to work up to the 3dB bandwidth of 50 MHz. Nevertheless, care must be taken when selecting input impedance gain settings. details as well the maximum 3dB signal bandwidth for each gain setting. For example, with an input current containing frequency components of less than 12 kHz in frequency, the maximum transimpedance gain of 100 MV/A can be selected. At 50 MHz, only 100 V/A of transimpedance gain is available.  $G=10$  can also be selected as well if more gain is required at high input signal frequencies.
- minimize cross-talk and parasitics effects  
With the measured impedance placed closely to the input of the HF2TA and the HF2 device, four point measurement setup can help to minimize parasitic effect as well as the noise pickups from the cable. Furthermore, using shielded cable can greatly reduce the high frequency noise pickups from the surrounding environment.
- avoid HF2TA instability  
Since HF2TA is a negative feedback amplifier, its feedback loop stability can be sensitive to input capacitance, especially at low R settings. In order to avoid possible under-damped behavior (i.e. oscillation) in the measurement, it is recommended to use as high as possible the selected transimpedance gain R when measuring a capacitive circuit. A short cable to the HF2TA input can also help to reduce the parasitic capacitance seen at the HF2TA input.

### 12.4.2. Photo Diode Amplifier with HF2LI

The HF2TA current amplifier is suited to read out the current from a photo diode. The following figures shows three possible ways to use the device. In the first option, the photo diode is grounded on one side and connected to the current amplifier on the other side. The recorded signal is amplified and sent to the HF2 Instrument.

The second option provides a solution when it is necessary to apply a bias voltage across the photo diode. For this purpose the auxiliary output of the HF2TA can be used. Voltages in the range of  $\pm 10$  V and currents up to 10 mA can be delivered by this connector. Alternatively the bias can be provided by another voltage source.

The third option supports the drive of the photo diode by means of the shield of the signal cable. This shield can be conveniently driven by the HF2TA by shorting the auxiliary output to the bias input. This option permits the user to connect the remote sensor with one single coaxial cable and while avoiding to introduce a ground loop in the system.

All HF2TA settings can be conveniently programmed inside the graphical user interface of the HF2 Instrument.

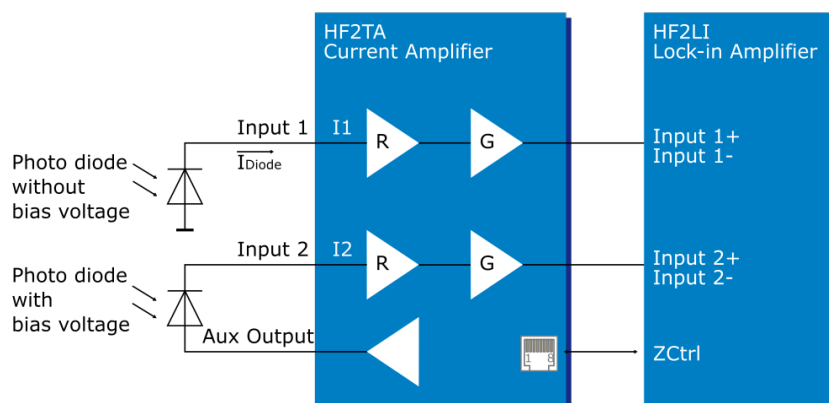


Figure 12.5: HF2TA photo diode amplifier

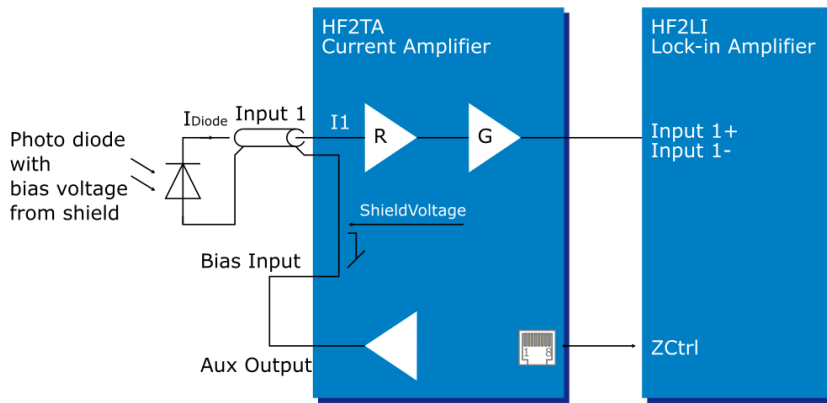


Figure 12.6: HF2TA photo diode amplifier with single coaxial cable

### 12.4.3. Impedance Measurement with HF2IS

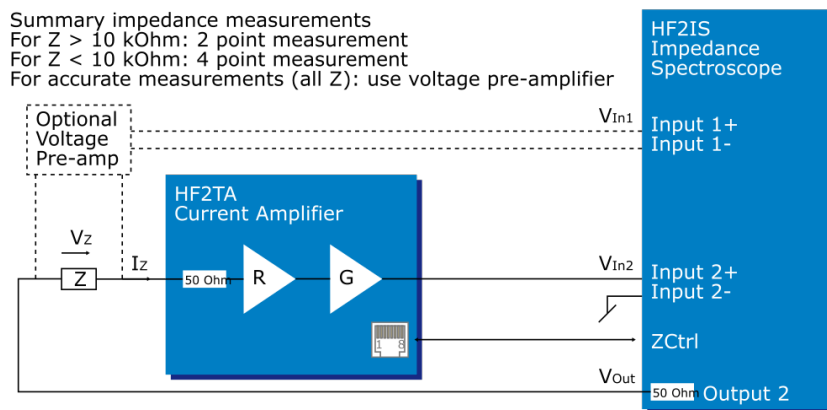
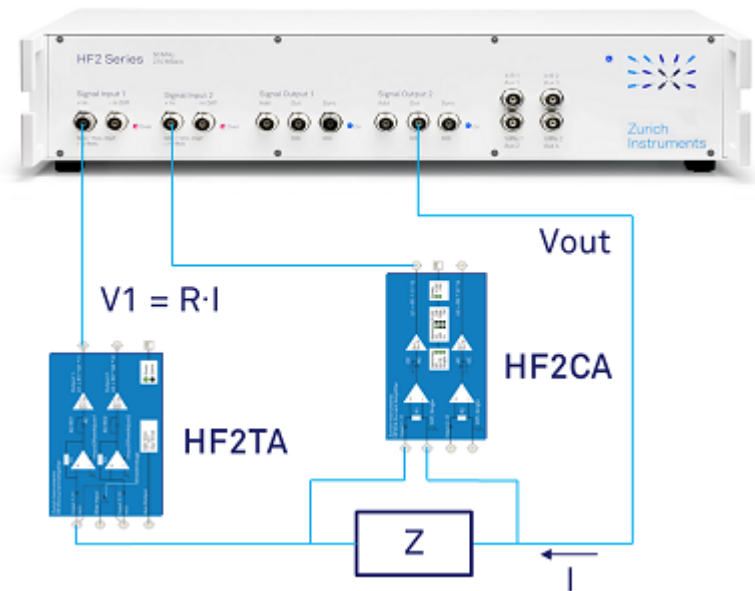


Figure 12.7: Measure an impedance using the HF2TA

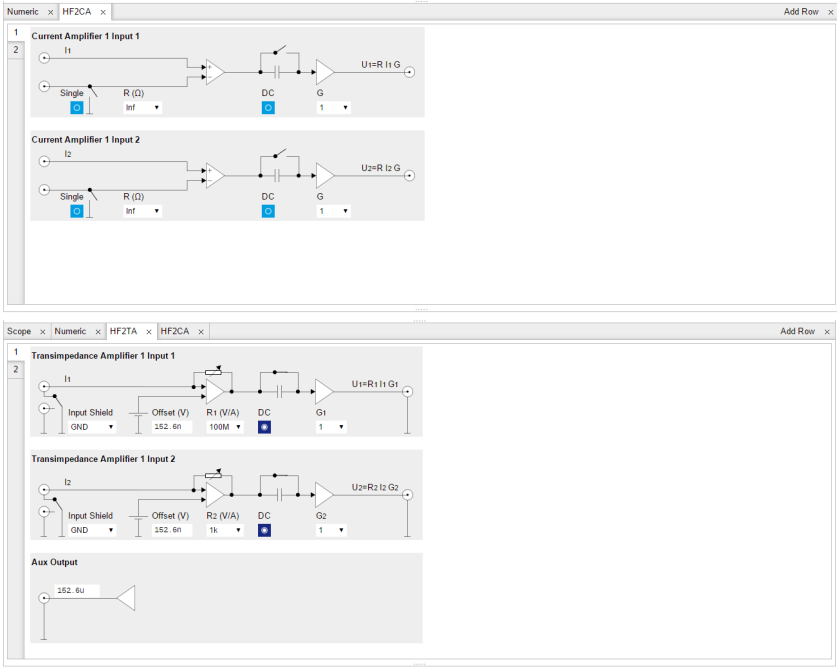
The HF2TA current amplifier can be used in conjunction with the HF2IS instrument to measure impedances in a very wide range at frequencies up to 50 MHz. The connection diagram in the figure above shows how the impedance of interest  $Z$  is connected to the input of the HF2TA. For optimal amplification versus bandwidth setting, the table in the specification section may be consulted. Three cases and applications need to be distinguished.

- Measuring an impedance  $Z > 10 \text{ k}\Omega$   
For large impedances it is possible to neglect the output resistance of the HF2IS Instrument and the input resistance of the preamplifier, thus the simple setup provides good accuracy. The HF2IS generates an output signal of amplitude  $V_{\text{Out}}$  and the output signal from the preamplifier is connected to the positive Input 2+ of the HF2, called  $V_{\text{In}}$ . With this setup, the impedance  $Z$  can be calculated using the following equation:  
$$Z = R \cdot G \cdot V_{\text{Out}} / V_{\text{In2}}$$
- Measuring an impedance  $Z < 10 \text{ k}\Omega$   
For small impedances and higher precision a four point measurement setup is required. For accuracy in the range of 1%, the voltage  $V_Z$  can be measured directly by the second differential Input 1+ and Input 1- of the HF2. In this case it is important to select the high ohmic input impedance option (1 M $\Omega$ ) as otherwise too much current is dissipated in the measurement instrument. Also the HF2 should be configured for differential measurement. The resulting impedance  $Z$  is calculated using the following equation:  
$$Z = R \cdot G \cdot V_Z / V_{\text{In2}} = R \cdot G \cdot V_{\text{In1}} / V_{\text{In2}}$$
- Measuring impedances with high accuracy (all values of  $Z$ )  
Four point measurement setup allows the most accurate measurement by taking into account simultaneously the current flowing through the measured impedance and the voltage drop caused by the current flow. For an accuracy better than 1%, it is recommended to use a voltage preamplifier with high-ohmic input stage to measure the voltage across the impedance  $V_Z = V_{\text{In1}}$ . Assuming  $V_{\text{In2}}$ ,  $R$  and  $G$  are the output, the resistor setting and the gain of the HF2TA, respectively, the resulting equation to calculate the impedance will be similar to the previous case:  
$$Z = R \cdot G \cdot V_Z / V_{\text{In2}} = R \cdot G \cdot V_{\text{In1}} / V_{\text{In2}} \text{ (assuming voltage pre-amp gain = 1)}$$
  
A pictorial representation of how to set up the four-point measurement is shown below.





Note that the voltage measurement is made differentially through HF2CA then converted to single-ended input to the HF2IS while the current measurement remains single-ended throughout the current measurement path. Both HF2TA and HF2CA can be controlled using the LabOne UI. When they are connected through Ethernet cables to the back of the HF2IS instrument, LabOne will automatically add an HF2TA or HF2CA tab as shown in the screen shots below.



Both HF2TA and HF2CA can operate in AC-coupled or DC input. The HF2TA has a high-pass cutoff of 10 Hz while the HF2CA has a high-pass cutoff of 100 Hz. It is recommended that no R1 and R2 values are selected for the HF2CA to obtain maximum input impedance (i.e. no signal current loss through the HF2CA input ports) and therefore the most accurate current measurement.

## 12.5. Performance Tests

In this section two tests are described that can be used to measure the DC leakage and the AC noise of the HF2TA. They can be performed by the user to do a sanity check on the validity of the measurement with HF2TA.

Table 12.4: Necessary equipment

| Required equipment | Specifications | Recommended equipment |
|--------------------|----------------|-----------------------|
|--------------------|----------------|-----------------------|

|                         |                                             |                                |
|-------------------------|---------------------------------------------|--------------------------------|
| HF2 Instrument          | No additional installation options required | HF2LI or HF2IS                 |
| HF2TA Current Amplifier | <a href="#">HF2TA Specifications</a>        | HF2TA                          |
| Digital multimeter      | 0.1 mV Resolution, 20 V range               | Agilent 34410A                 |
| SMA to BNC cables       | 2 x 50 $\Omega$ , male-to-male connectors   | supplied by Zurich Instruments |
| Ethernet cable          | Category 5 or 6                             | supplied by Zurich Instruments |

The following conditions have to be fulfilled:

1. The test equipment must be connect to the same AC power circuit. If you are unsure of the AC power circuit distribution, use a common power strip and connect all test equipment into it. Connecting the test equipment into separate AC power circuits can result in offset voltages between equipment, which can invalidate the verification test.
2. For accurate results, allow the test equipment to warm up for at least 30 minutes.
3. The HF2 Instrument as well as the HF2TA transimpedance amplifier are controlled by the LabOne software. Please make sure that the latest version of the LabOne software package is installed on the host computer. Please refer to the [Getting Started](#) for software installation instructions.

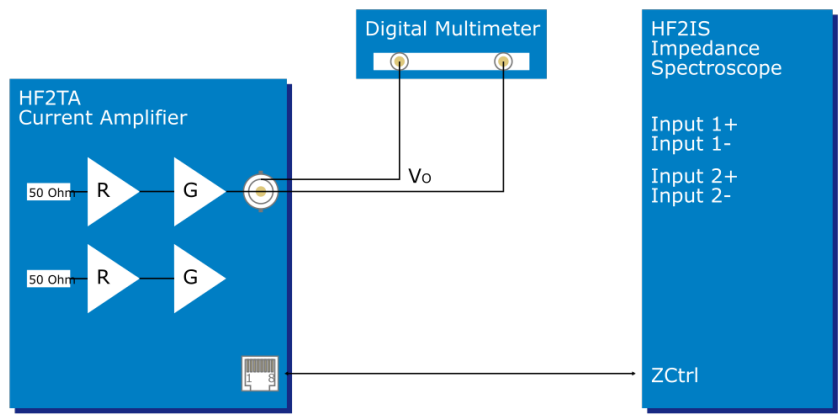
The HF2TA transimpedance amplifier has 2 analog input channels, 2 analog output channels and 1 external bias input and 1 auxiliary output. For the purpose of the following tests, the external bias input will not be used. The test setup for one channel is equally valid for the other channel.

12.5.1. Input Leakage Test

Definition

This test measures the DC input leakage current of the HF2TA.

Setup



The HF2TA is connected to the HF2 Instrument via the Ethernet cable for the purpose of configuring the HF2TA. The HF2 Instrument is not used for the measurement.

Table 12.5: HF2TA settings

|                |               |
|----------------|---------------|
| Ch1 Offset (V) | 0.0 V         |
| Ch1 R (V/A)    | 1 k and 100 M |
| Ch1 AC         | OFF           |
| G              | 1             |

|                |       |
|----------------|-------|
| Input Shield   | GND   |
| Aux Output (V) | 0.0 V |

Measurement

The DC leakage current can be estimated by subtracting the inherent DC offset  $V_{O1}$  of the amplifier from the total offset  $V_{O2}$  due to both the internal offset and the input leakage. For this test the input of the HF2TA is left open. Then the output is measured with a digital multimeter as shown . The input offset  $V_{O1}$  can be estimated by setting the transimpedance resistor R to 1 k. The sum of the input offset plus leakage  $V_{O2}$  can be estimated by setting the transimpedance resistor R to 100 M. Then, the approximate leakage can be found by:

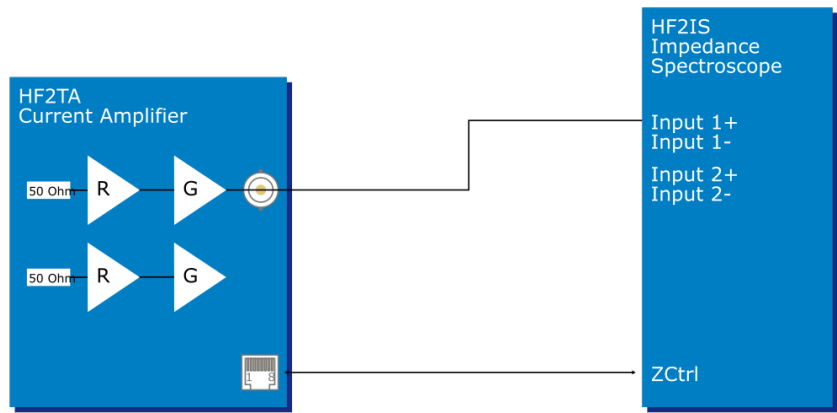
$$I_{\text{leakage}} = \frac{|V_{O2}-V_{O1}|}{100 \text{ M}\Omega}$$

12.5.2. Input Noise Test

Definition

The noise generated by the HF2TA transimpedance amplifier itself can be expressed as input referred current noise. The following setup description enables users to verify through measurement if their HF2TA units have indeed the same noise level as specified in

Setup



For this test the HF2TA transimpedance amplifier input is left open. The goal is to refer the total contribution of out noise from the amplifier itself to the input and not from any other external circuits. Since the input of the HF2TA is left open, it is only necessary to define the sweep range in the HF2 instrument since no drive voltage is required.

The HF2 instrument settings for the test are given in the table below.

Table 12.6: HF2 instrument settings

|                                |                                    |
|--------------------------------|------------------------------------|
| Ch1 Signal Inputs Range        | auto range                         |
| Ch1 Signal Inputs AC/ Diff/ 50 | ON                                 |
| Ch1 Scale                      | 1/R                                |
| Filter BW setting type         | BW NEP (noise equivalent power BW) |
| Filter BW                      | 1 Hz                               |

Notice that Scale has been set to  $1/R$  where  $R$  is the HF2TA transimpedance value. This is to obtain the noise current referred back to input.

## Measurement

The Sweeper will be used for the measurement with the following settings:

Table 12.7: Frequency sweeper settings

|                       |        |
|-----------------------|--------|
| Sweep Range Start     | 1 kHz  |
| Sweep Range Stop      | 50 MHz |
| Sweep Range Points    | 50     |
| Sweep Range Log Sweep | ON     |

To have LabOne choose suitable filtering, averaging, and display settings, simply choose Noise Amplitude Sweep as the Application in the Settings sub-tab. Set Precision to High and start the sweep to measure the noise over the specified frequency. After division by the HF2TA transimpedance gain, the result can then be compared to the values in the input referred noise table.

## 12.6. Cable Recommendation

Table 12.8: HF2TA cable recommendation

| Table 12.10: RF 27A cable recommendations |                          |                              |
|-------------------------------------------|--------------------------|------------------------------|
| Function                                  | Connector / cable type   | Vendor / part number         |
| SMA to BNC connection                     |                          |                              |
| SMA to BNC cable                          | BNC jack to SMA plug     | Digikey J3606-ND             |
| SMA to BNC adapter                        | BNC jack to SMA plug     | Digikey J10098-ND            |
|                                           |                          | Farnell / Newark 4195930     |
|                                           | BNC plug to SMB plug     | Farnell / Newark 1654647     |
|                                           |                          | Digikey ACX1324-ND           |
| Custom access or cable assembly           |                          |                              |
| Cable                                     | Cable type RG-174        | Digikey A307-100-ND          |
|                                           |                          | Farnell / Newark 1387745     |
| SMA to cable                              | SMA plug to RG-174 cable | Digikey A32326-ND            |
|                                           |                          | Farnell /Newark 2112459      |
| BNC to cable                              | BNC plug to RG-174 cable | Tyco Electronics 1-5227079-6 |
|                                           |                          | Digikey A32212-ND            |
|                                           |                          | Farnell / Newark 1831701     |