MFLI User Manual

Zurich
Instruments

MFLI User Manual

Zurich Instruments AG

Publication date Revision 38200

Revision History

Revision 38200, 14-July-2016:

The entire document was updated to comply with the changes of the 16.04 LabOne release.

Highlights of the changes and additions to the MFLI product are:

- NEW option MF-IA Impedance Analyzer: accurate impedance measurements from 1 mΩ to 10 GΩ, Sweeper support, Compensation Advisor, Confidence Indicator
- NEW accessory MFITF Impedance Test Fixture: fixture and carriers for SMD and through-hole components designed for low parasitics and dissipation
- Software Trigger: new grid mode for 2D data capture and frame averaging supporting imaging applications
- Scope: new resample feature to eliminate trigger jitter when using averaging in combination with reduced sampling rate
- Ref inputs: new duty cycle reconstruction feature for improved locking to TTL reference signals with low duty cycle
- Config tab: update reminder for the LabOne software
- Config tab: new time zone setting to adjust the time information in saved data
- Specifications: added tabular Signal Output noise specification
- Specifications: added operating environment and altitude, removed environment policy
- Specifications: updated Supported Languages to Python 2.7, 3.5 (previously 2.6, 2.7); and to MATLAB 2009 (Windows) / MATLAB 2014 (Linux) (previously MATLAB 2009)
- Specifications: added reactance chart for measurement accuracy and temperature drift (related to MF-IA option)

A more detailed list of all technical changes can be found in the LabOne release notes.

Revision 34390, 22-Dec-2015:

The entire document was updated to comply with the changes of the 15.11 LabOne release.

Highlights of the changes and additions to the MFLI product are:

- New option MF-DIG Digitizer: increased sample memory and feature enhancement for the Scope
- New front panel for MF instruments
  - Concerns instruments with serial numbers MF-DEV3200 and above
  - BNC connectors Signal Input +V/-V are swapped
  - LabOne release 15.11 is compatible with all MFLI instruments also with serial numbers below MF-DEV3200
- Network discovery: automatic search of Data Server instances and instruments from all Zurich Instruments series in the local network
- Improved USB support: higher recording speed, improved interface stability

- Plotter: hardware trigger inputs can be displayed individually
- Specification change: Signal Input +V/-V damage threshold is now +12 V / -12 V (previously +10 V / -10 V)
- Specification change: analog adder input bandwidth is now 2 MHz (previously 10 MHz)

A more detailed list of all technical changes can be found in the LabOne release notes.

Revision 31421, 8-Jul-2015:

This is the first version of the MFLI user manual related to software release 15.05.

Table of Contents

Declaration of Conformity

The manufacturer

Zurich Instruments
Technoparkstrasse 1
8005 Zurich
Switzerland

declares that the product

MFLI Lock-in Amplifier, 500 kHz / 5 MHz, 60 MSa/s

fulfills the requirements of the European guidelines

- 2004/108/EC Electromagnetic Compatibility
- 2006/95/EC Low Voltage
- 2011/65/EU Restriction of Hazardous Substances

The assessment was performed using the directives according to Table 1.

Table 1. Conformity table

EN 61326-1:2006	Emissions for industrial environments, immunity for industrial environments
EN 61000-6-4	Emission standard for industrial environments
EN 61000-6-2	Immunity for industrial environments
EN 55011	Group 1, class A and B (the product was tested in typical configuration)
EN 61000-4-2	CD 4 kV, AD 8 kV
EN 61000-4-3	10 V/m 80% AM 80 MHz - 1 GHz
	3 V/m 80% AM 1 GHz - 2 GHz
	1 V/m 80% AM 2 GHz - 2.7 GHz
EN 61000-4-4	2 kV power line
	1 kV USB line
EN 61000-4-5	1 kV line-line, 2 kV line-earth
EN 61000-4-6	10 V 150 kHz - 80 MHz 80% AM, power line
EN 61000-4-11	100% dip (1 cycle), 30% dip (25 cycles), 60% dip (10 cycles), 100% short interruptions (250 cycles)
EN 61010-1:2010	Safety requirements for electrical equipment for measurement, control and laboratory use

Figure 1. CE Logo

Chapter 1. Getting Started

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

- A Quick Start Guide for the impatient.
- Inspecting the package content and accessories.
- List of essential handling and safety instructions.
- Connecting to the MFLI Instrument.
- Running the LabOne Web Server on a separate PC.
- Using the LabOne programming interfaces.
- Handy list of troubleshooting guidelines

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

1.1. Quick Start Guide

This page addresses all the people who impatiently are awaiting their new gem to arrive and want to see it up and running quickly. If the MFLI Instrument is to be integrated into a LAN with DHCP server, it is ready to go without further need of software installation. Please proceed along the following steps:

1. Inspect the package content. Besides the Instrument there should be a country-specific power cable, a USB cable, an Ethernet cable and a hard copy of the user manual Chapter 1.
2. Check the Handling and Safety Instructions in Section 1.3.
3. Connect the Instrument to the power line. Turn it on and connect it to a switch in the LAN using the Ethernet cable, or directly to the host computer with the USB cable. After flashing green for a short time, the front panel LED will show a steady blue color. If the LED remains flashing green, power-cycle the MFLI instrument again and wait for the LED to turn blue. If the LED does not turn blue, please contact Zurich Instruments for assistance.
4. **Ethernet**: open a web browser on a PC in the LAN and type the following text in the address bar:

   ```
   http://<instrument-serial>.<domain>/
   ```

   where `<instrument-serial>` is the serial number of the instrument (see label on back panel) and `<domain>` is the network domain in which the instrument is running. An example is shown below for the Chrome browser.

   An example of the serial number label on the back panel is shown below. In this particular example the serial number is `MF-DEV3026`.

   Alternative ways to address the instrument are: `http://<instrument-serial>/` (without domain name) and `http://192.168.11.2/`, the latter applies to cases where the IP address is known to the user. Using the `http` prefix and network domain name and trailing slash with the host name prevents the triggering of search engines.

   USB (Windows): when connected via USB, the MFLI provides a flash drive similar to a USB stick. Find the suitable USB driver for your operating system on that flash drive, and install it e.g. by double-clicking `MF-USB-Driver64.msi`. Section 1.4.2 contains more detailed instructions.

   Under Windows, the installation of the driver will create a Start Menu entry under `Start Menu` → `All programs / All apps` → `Zurich Instruments` → `LabOne User Interface MF USB`. Click this link to open the default web browser with the LabOne User Interface start-up screen.

   USB (Linux/Mac): Linux computers usually don't require a USB driver installation. On Macintosh computers, install the USB driver according to the installations in Section 1.4.2. Open a web browser and enter `http://<instrument-serial>/` into the address bar, where the instrument serial of the format `MF-DEV3026` is found on the back panel of your instrument.
5. The LabOne User Interface start-up screen will appear. Click the **Default UI** button on the lower 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 Section 1.4.

If any problems occur whilst setting up the instrument and software please see the troubleshooting section at the end of this chapter.

Once the Instrument is up and running we recommend going through some of the tutorials given in Chapter 3. Moreover, Chapter 2 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 web page will serve as a valuable resource that is constantly updated and expanded.

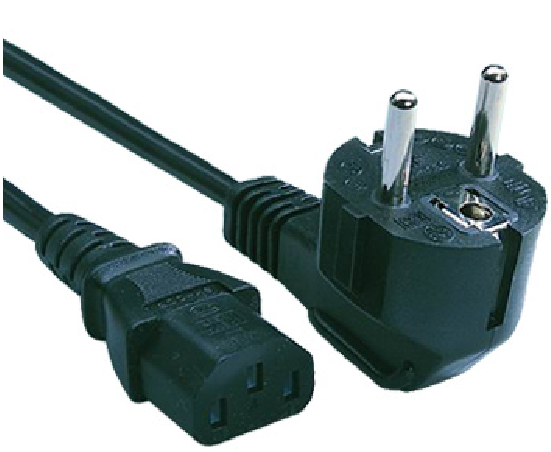
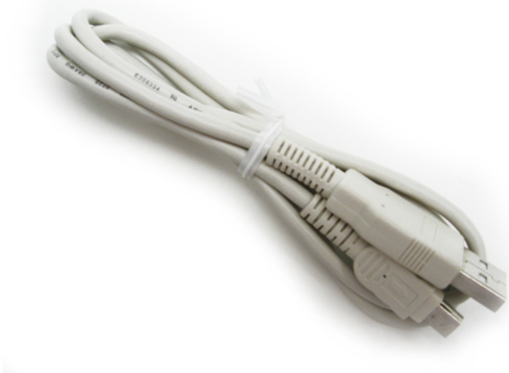
1.2. Inspect the Package Contents

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 MFLI Instrument
- You have received 1 power cord with a power plug suited to your country
- You have received 1 USB cable and/or 1 LAN cable (category 5/6 required)
- A printed version of the "Getting Started" section
- 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 MAC address of the instrument is displayed on a sticker on the back panel

Table 1.1. Package contents for the MFLI Instrument

<table>
<tr><td colspan="2">
</td></tr>
<tr><td>
the power cord (e.g. EU norm)</td><td>
the USB cable</td></tr>
</table>

 the power inlet, with power switch and fuse holder	 the LAN / Ethernet cable (category 5/6 required)
 the "Next Calibration" sticker on the back panel of your instrument	 the MAC address sticker on the back panel of your instrument

The MFLI Instrument is equipped with a multi-mains switched power supply, and therefore can be connected to most power systems in the world. The fuse holder is integrated with the power inlet, and can be extracted by grabbing the holder with two small screwdrivers at the top and at the bottom at the same time. A spare fuse is contained in the fuse holder. The fuse description is mentioned in the specifications chapter.

Carefully inspect your Instrument. If there is mechanical damage or the instrument does not pass the basic tests, then you should immediately notify the Zurich Instruments support team at `<support@zhinst.com>`.

1.3. Handling and Safety Instructions

The MFLI is a sensitive electronic instrument, which under no circumstances should 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 cancels 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 affect correct 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 1.2. 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.
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 Chapter 5 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.
Warnings	Instructions contained in any warning issued by the instrument, either by the software, the graphical user interface, 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

	the correct interpretation of the acquired measurement data.
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 Chapter 5. Do not block the ventilator opening on the back or the air intake on the side of the chassis 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 accessed 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.
Operation and storage	Do not operate or store at the instrument outside the ambient conditions specified in Chapter 5.
Handling	Do not drop the Instrument, handle with due care, do not store liquids on the device as there is a chance of spilling and damage.

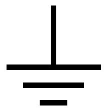
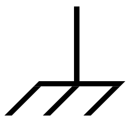
When you notice any of the situations listed below, immediately stop the operation of the Instrument, disconnect the power cord, and contact the support team at Zurich Instruments, either through the website form or by email at <support@zhinst.com>.

Table 1.3. 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 only with a power cord specified for this product and certified for the country of use.
Instrument emits abnormal noise, smell, or sparks	Switch off the Instrument immediately to prevent large damage.

Instrument is damaged	Switch off the Instrument immediately and secure it against unintended operation.

Table 1.4. Symbols

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

1.4. Connecting to the MFLI Instrument

The Zurich Instruments MFLI is designed to work out of the box with minimal effort on the part of the user. The Zurich Instruments LabOne software runs on an embedded PC in the MFLI instrument and is pre-installed before delivery. One of the programs running on the embedded PC is the LabOne Web Server, which can be connected to via a web browser once suitable physical and logical connections to the instrument have been established.

Note

The following web browsers are supported (latest versions)

Chrome Firefox **Opera** Internet Explorer Safari

There are two ways to physically connect to the instrument:

- Ethernet (no software installation required). Integrate the instrument into an existing local area network (LAN) by connecting the instrument to a switch in the LAN using an Ethernet cable. The instrument can then be accessed from a web browser running on any device in the same LAN. The Ethernet connection can also be point-to-point. This requires some adjustment of the network card settings of the client computer. Depending on the network configuration and the installed network card, one or the other connection scheme is better suited.
- Universal Serial Bus (USB). The USB connection is a point-to-point connection between the instrument and the host computer to which the USB cable is connected. This requires the installation of an RNDIS driver on the host computer. The driver is conveniently available from the instrument's flash memory. Once the instrument is connected by USB to you PC/MAC a new drive appears in the Explorer/Finder that contains this driver and also the user manuals.

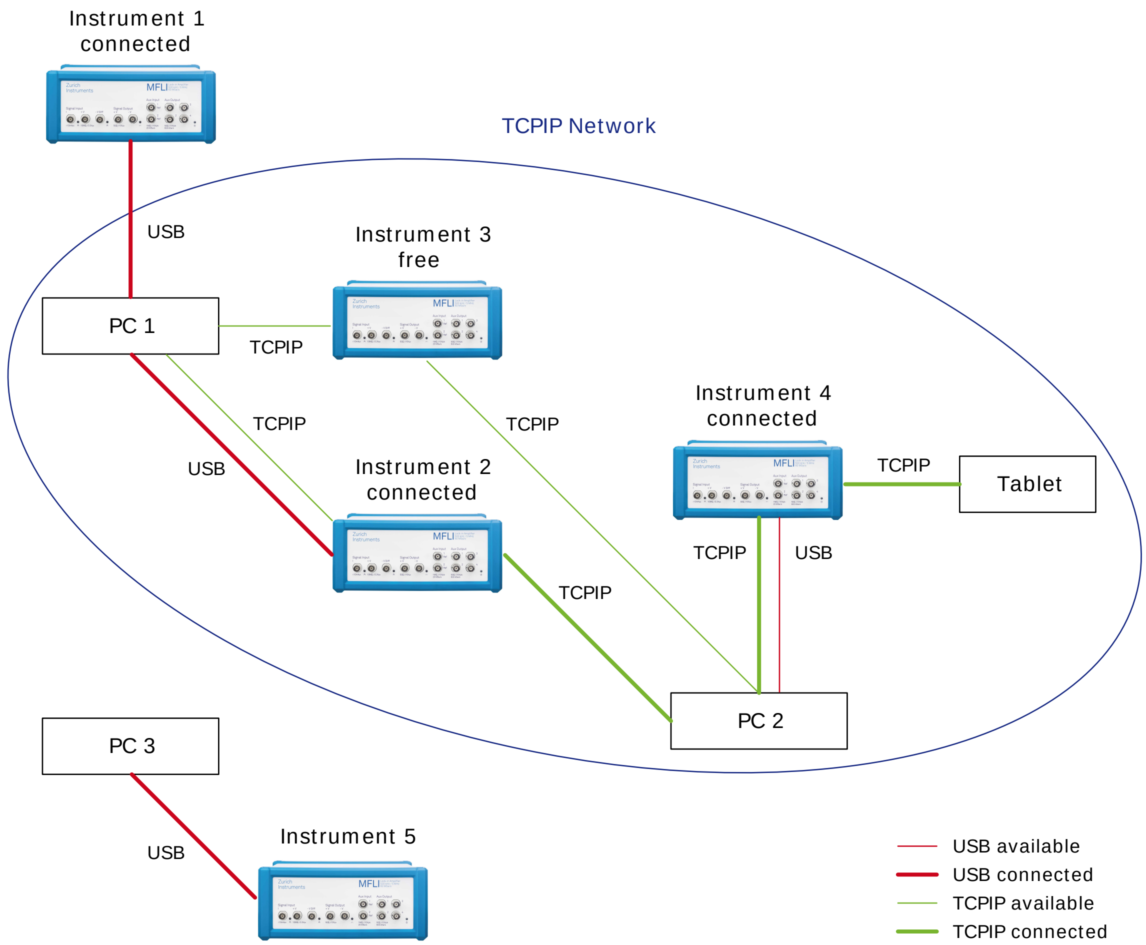


Figure 1.1. Connectivity

Figure 1.1 shows some examples of possible configurations of computer to instrument connectivity.

1.4.1. Ethernet TCP/IP Connection

The simplest connection method is to integrate the instrument into an existing LAN supporting the Domain Name System (DNS) and dynamic DNS update. In such a network the MFLI instrument can be addressed using its serial number instead of its IP address. Attach an Ethernet cable from the instrument to a LAN network switch. The LabOne User Interface can be started by typing the following text in the address bar of a web browser running on a computer in the LAN:

`http://<instrument-serial>.<domain>/`, or

`http://<instrument-serial>/`

where `<instrument-serial>` is the serial number of the instrument and `<domain>` is the network domain in which the instrument is running.

This approach uses DNS lookup to resolve the IP address of the instrument which is configured with this network name by default. It is possible that this approach fails due to special network policies or for other reasons. In that case, there are other options to configure the TCP/IP connection to the instrument. These are described in Section 1.4.3 Advanced TCP/IP Configuration.

With connection via LAN, multiple web browser and API client sessions have simultaneous access and control over the instrument. Therefore changes made to the settings of the instrument by say a Python program via the API will be seen by a web browser session connected to that instrument. The instrument data can be streamed to multiple client sessions simultaneously.

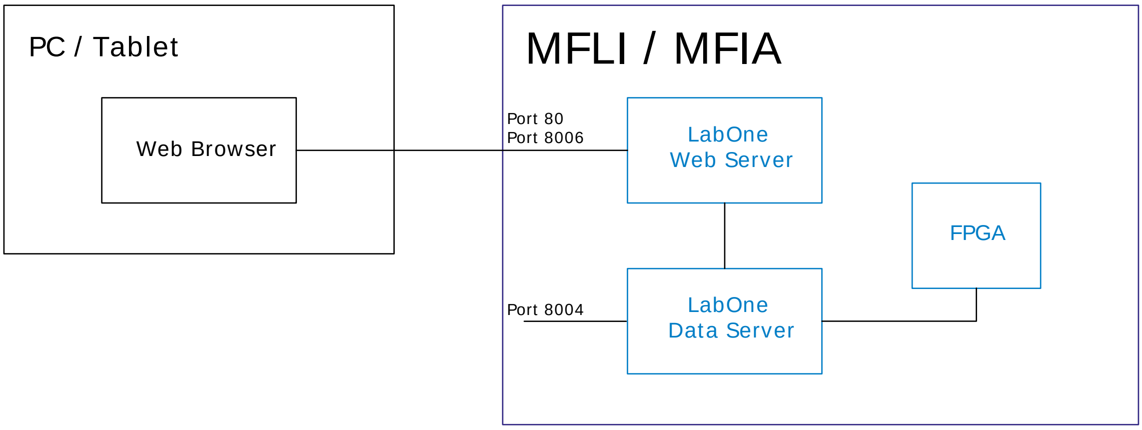


Figure 1.2. Simplest connection to MFLI instrument

1.4.2. Universal Serial Bus (USB) Connection

To control the instrument via USB, connect the instrument with the supplied USB cable to the PC you are using. Depending on the operating system you are using, it may be necessary to install a USB RNDIS device driver on the PC. The RNDIS provides a virtual Ethernet link to the instrument enabling it to be addressed using the normal IP address and host name mechanisms. The RNDIS driver installation procedure for various operating systems is described in the next sections.

USB RNDIS Device Driver Windows

Zurich Instruments provides a Microsoft MSI installer to simplify the Windows RNDIS driver installation. The MFLI Instrument is designed so that when the USB cable is plugged in, a flash disk partition appears with the label MFLI, containing the required Windows MSI installer for the USB RNDIS device driver, plus the instrument user manual in PDF form and a copy of this Getting Started chapter.

Proceed with the device driver installation as follows:

1. Log on to the PC as an administrator. Installing the USB RNDIS device driver requires administrator rights.
2. Ensure that the USB cable is connected from the PC to the MFLI Instrument.
3. Power cycle the MFLI Instrument and wait for approximately 20 seconds for the instrument initialization to complete. During this time an AutoPlay window will pop up showing the newly detected MFLI drive.
4. In the AutoPlay window, select **Open folder to view files**.
5. Two installers will be visible in Windows Explorer: Double click on the .msi installer appropriate for your operating system. This will be either

   `MF-USB-Driver64.msi` for 64 bit operating systems, or

   `MF-USB-Driver32.msi` for 32 bit operating systems.

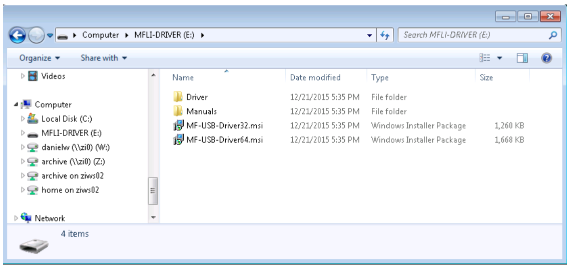


Figure 1.3. Read-only drive of the MFLI shown in the file explorer

6. In the welcome screen click the **Next** button.

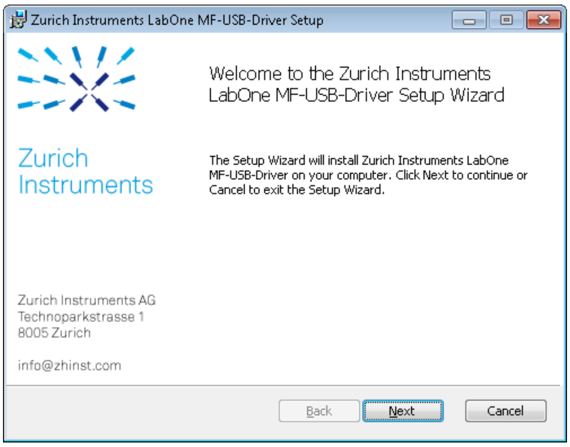


Figure 1.4. Installation welcome screen

7. 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.

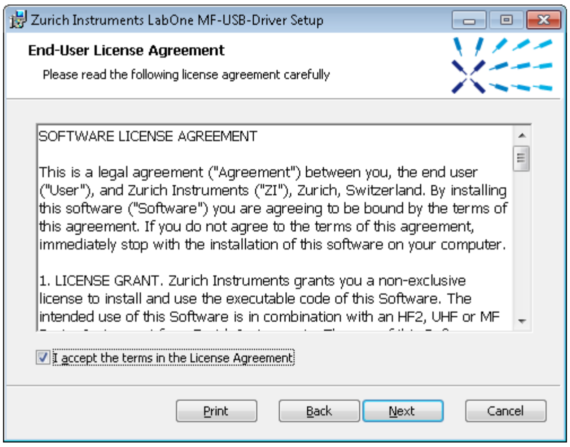


Figure 1.5. Installation license agreement

8. In the Custom Setup screen click the **Next** button.

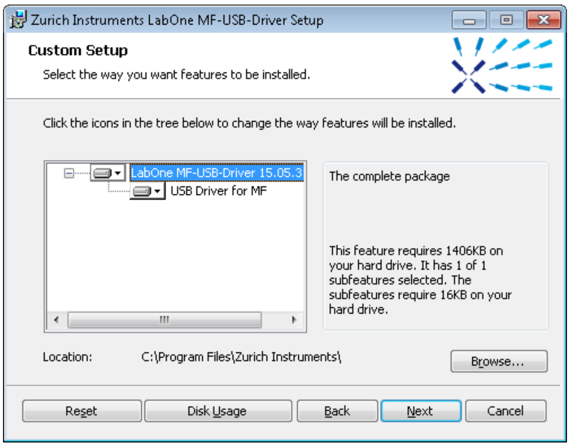


Figure 1.6. Custom setup screen

9. Click the **Install** button to start the installation.

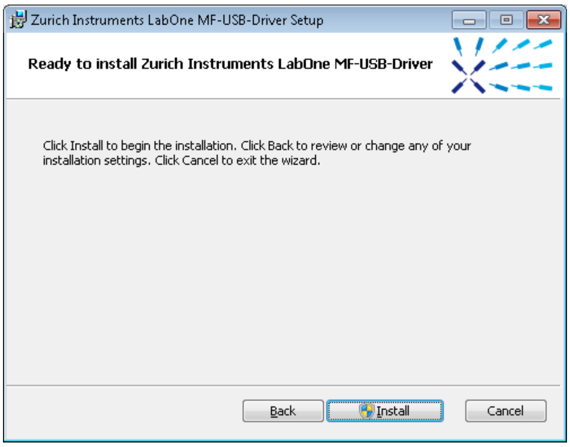


Figure 1.7. Installation confirmation

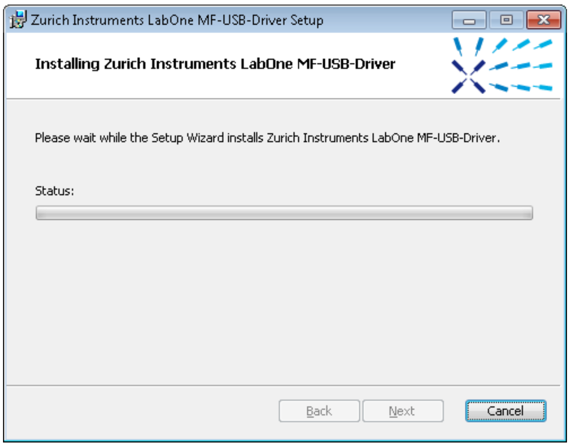


Figure 1.8. Installation progress

If the User Account Control pop-up window appears, click **Yes** to allow the installation program to make changes to the computer.

10. In the Windows Security pop-up window, click **Install**. You can also click the **Always trust software from "Zurich Instruments AG"** check box to prevent the message from appearing in the future.

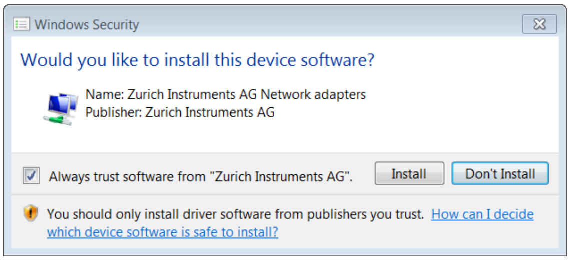


Figure 1.9. Installation driver acceptance

11. Click the **Finish** button to complete the installation.

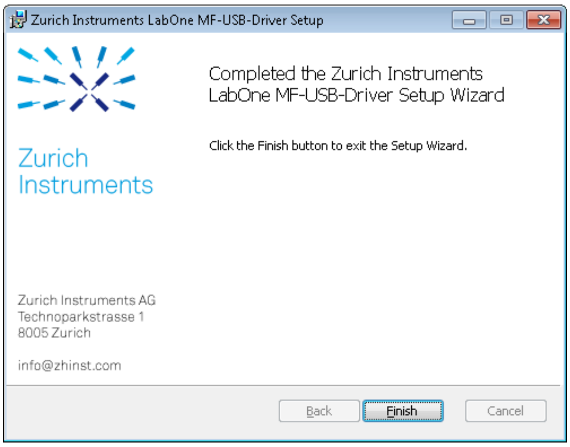


Figure 1.10. Installation complete

The installation of the driver will create a Windows Start Menu entry `LabOne User Interface MF USB` to start the LabOne User Interface on the default web browser. A locally installed application will detect the IP address of the instrument connected over USB and will start the browser with the IP address pointing to the LabOne Web Server running on the instrument. The Start Menu entry is found under `Start Menu → All programs / All apps → Zurich Instruments → LabOne User Interface MF USB`. This link will open the Device and Settings dialog shown in Figure 1.11. Click on Default UI on the bottom right of the screen to open a LabOne browser session with the default settings.

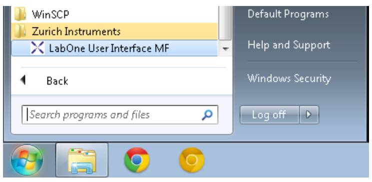


Figure 1.11. Windows Start Menu entry to start the LabOne User Interface (for USB interface only)

Note

The LabOne User Interface MF start menu entry should only be used together with USB. If you use 1GbE to connect to the Instrument, please follow the instructions in Section 1.4.1.

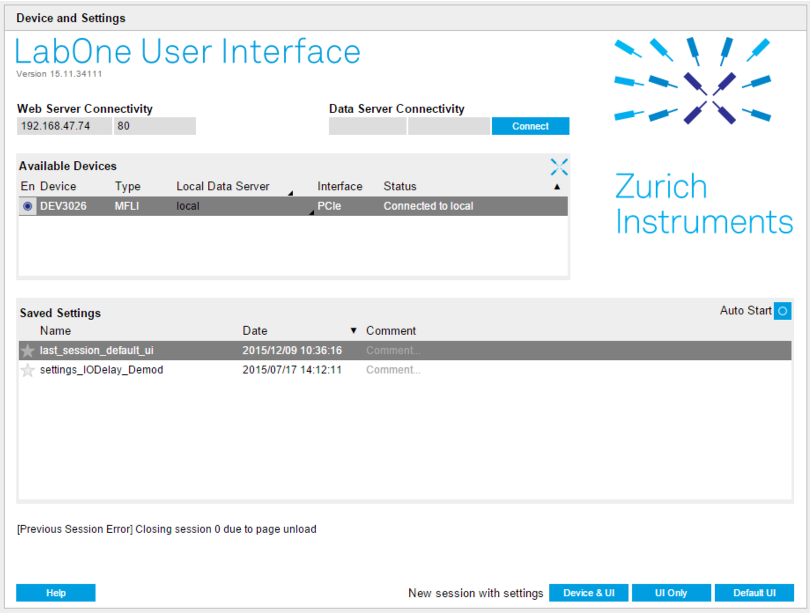


Figure 1.12. Device and Settings dialog after starting the LabOne User Interface MF

USB RNDIS Device Driver Linux

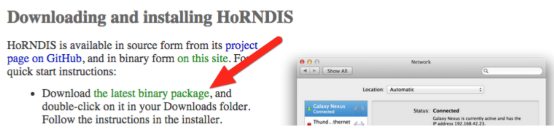
With an up-to-date version of a UBUNTU Linux distribution there is no special installation necessary, the USB connection works out of the box.

Other Linux distributions should also work but may require further installation steps. Detailed instructions cannot not given here due to the large number of Linux distributions available.

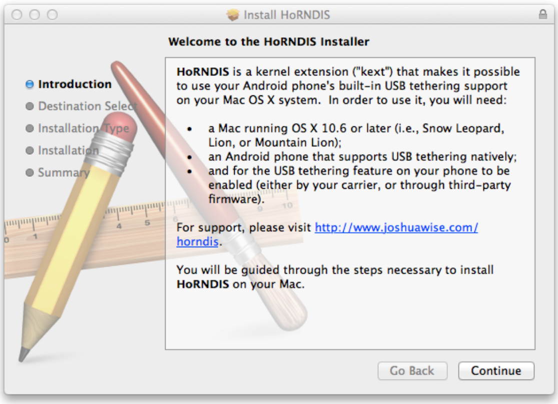
USB RNDIS Device Driver OS X

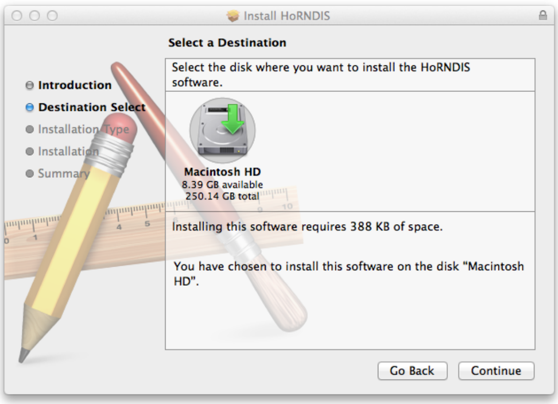
To install the required USB RNDIS device driver on a Macintosh computer, proceed as follows:

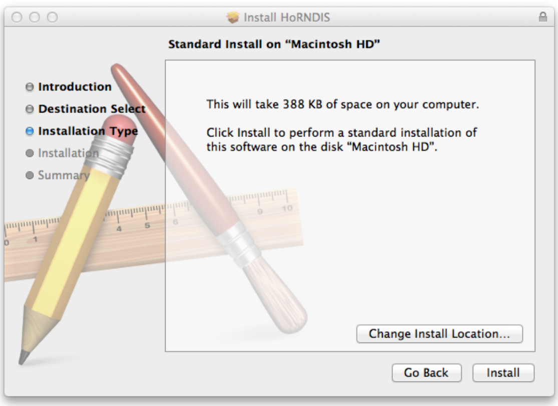
1. Open a web browser and go to http://joshuawise.com/horndis downloads page and click the link to download the latest binary package. At the time of writing, this link leads to the file `HoRNDIS-rel7.pkg`, which should be downloaded.



2. Locate the downloaded file using the Finder. The file can typically be found in the Downloads folder. Double click the file to run the installer.
3. The installer will guide you through the installation process. Select the standard option in each dialog and click **Continue** to proceed with the installation.

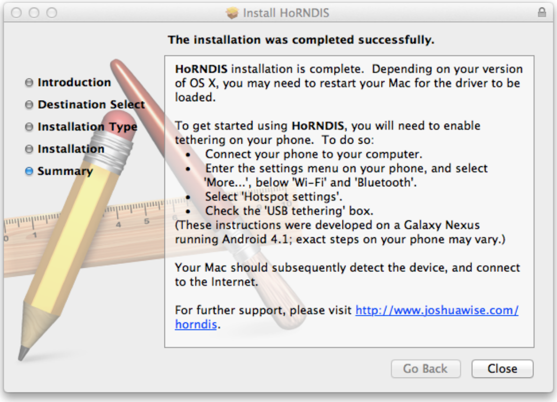




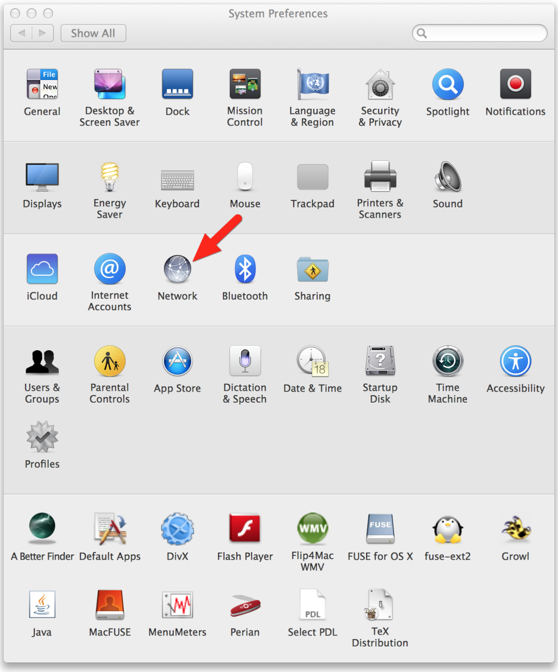


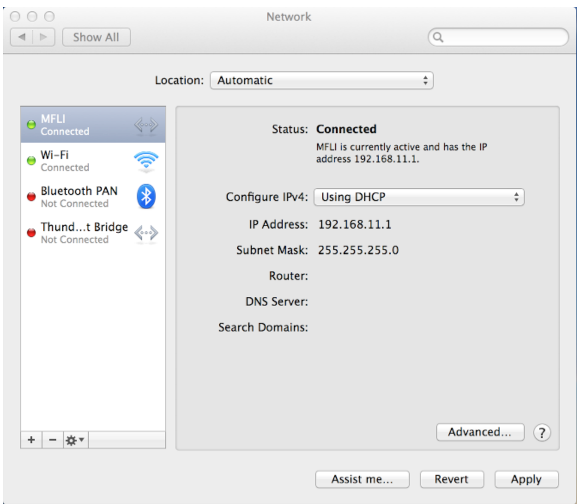
4. Before the installer can finalize the installation, it will request administrator permissions. Supply the necessary credentials to finish the installation.

5. A summary of the installation will be shown once it completes.



6. At this point it is advisable to restart the computer.
7. Connect the MFLI Instrument to the computer using the USB cable and power it up. Wait until the blue LED on the front-panel of the MFLI Instrument illuminates.
8. To verify that the MFLI is correctly detected by the computer open the **System Preferences** and select the **Network** category.





The MFLI device should now be shown in the interface list with a green icon and marked as `Connected`. When the interface is selected, the information in the right hand side pane should update to show that the interface uses DHCP and the IP address should take the form `192.168.x.x`.

9. It is now possible to connect to the device using a web browser either by entering the following in the address bar:

   `<instrument-serial>.local`

   where `<instrument-serial>` is the serial number of the instrument.

   Alternatively, the IP address of the instrument can be used. The IP address of the instrument is the IP address shown in the described in the previous step, with 1 added to the right-most octet. So for instance, if the IP address shown is `192.168.47.57`, the instrument IP address to enter in the address bar would be `192.168.47.58`.

1.4.3. Advanced TCP/IP Configuration

Various schemes are possible for logically connecting to the MFLI instrument via TCP/IP.

- DHCP (the simplest scheme for the user and the default)
- Static IP (the fallback if DHCP fails)
- Point-to-point (P2P)

DHCP is the simplest and preferred connection method. Other connection methods can become necessary when using network configurations that are in contradiction with the local policies.

DHCP

The most straightforward Ethernet connection method is to rely on a LAN configuration to recognize the MFLI Instrument. This is the MFLI Instrument's default configuration. By connecting the instrument in a LAN, a dynamic IP address is assigned to it like to any other PC by the DHCP server. In case of restricted networks, the network administrator may be required to register the instrument on the network by means of the MAC address. The MAC address is indicated on the back panel of the instrument. If the network configuration does not allow or does not support DHCP it is necessary to use a static IP setup as described below.

Static Instrument IP

The best way to assign the instrument a static IP address is to first connect via USB. This is especially necessary if DHCP is not available in the LAN.

1. Connect to the instrument via USB and start the LabOne User Interface MF USB as described in Section 1.4.2.
2. Open the Device tab.
3. In the Communication section, set the desired IP4 address.
4. Set the appropriate IP4 mask and Gateway
5. Click on the **Static IP** button to indicate the use of a static IP address.
6. Click on the **Program** button to save the changed parameters.
7. Connect an Ethernet cable from a switch in the LAN to the 1GbE port on the back panel of the MFLI Instrument.
8. Power-cycle the MFLI instrument.

9. (Optional) To verify the connection between the host computer and the MFLI Instrument, open a DOS command window and ping the IP address entered above.
10. Type the following in the address bar of a web browser on a computer within the LAN:

    ```
    http://<Static IP Address>/
    ```

    where <Static IP Address> is the static IP address entered above.

    The LabOne UI should now appear.

Requirements

- The chosen static IP address must be unique within the LAN.
- Needs network administrator support on networks with dynamic IP configuration (the static IP address will need to be reserved).

Point-to-Point (P2P)

Setting up a point-to-point network consisting only of the host computer and the MFLI avoids problems related to special network policies. Since it is nonetheless necessary to stay connected to the internet, it is recommended to install two network cards in your computer, one of them for network connectivity, the second one for connecting to the MFLI Instrument. Notebooks can generally profit from wireless LAN for internet connection.

1. Use one of the network cards and set it to static IP in TCP/IPv4 using the IP address `192.168.1.n`, where n=[2..9] and the mask `255.255.255.0`, see Figure 1.13 (go to `Control Panel → Internet Options → Network and Internet → Network and Sharing Center → Local Area Connection → Properties`).

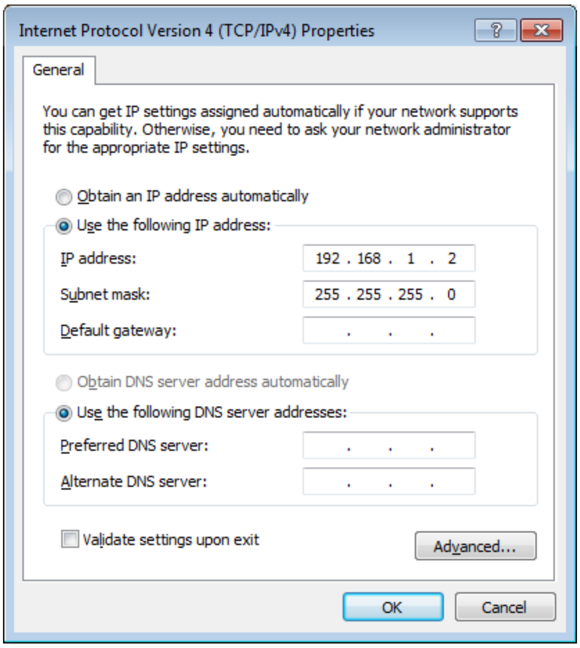


Figure 1.13. Static IP configuration of PC

2. Set the MFLI IP address to the static value `192.168.1.10` as described in the previous section. To connect to the MFLI Instrument and start the LabOne User Interface, type the following in the address bar of a web browser:

    ```
    http://192.168.1.10/
    ```

Requirements

- Two networks cards needed for additional connection to internet
- Network adapter connected to the instrument must be in static IP4 configuration

Note

A power cycle of the MFLI Instrument is required if it was previously connected to a network that provided an IP address to the instrument and then the user decides to run in static IP configuration.

Note

Only IP v4 is currently supported. There is no support for IP v6.

Warning

Changing the IP settings of your network adapters manually can interfere with its later use, as it can no longer be used for network connectivity until it is set again for dynamic IP.

1.5. Running the LabOne Web Server on a Separate PC

By default both the LabOne Web Server and the Data Server run on the embedded PC in the instrument. It can be advantageous to run the LabOne Web Server on a separate PC. This is particularly the case when using high data transfer rates. The higher processing power of laptop and desktop computers then gives improved UI responsiveness and generally a better user experience and reduces the probability of data loss.

To run the Web Server on a separate PC, the LabOne software must be installed on that PC. See Section 1.7 for LabOne installation instructions.

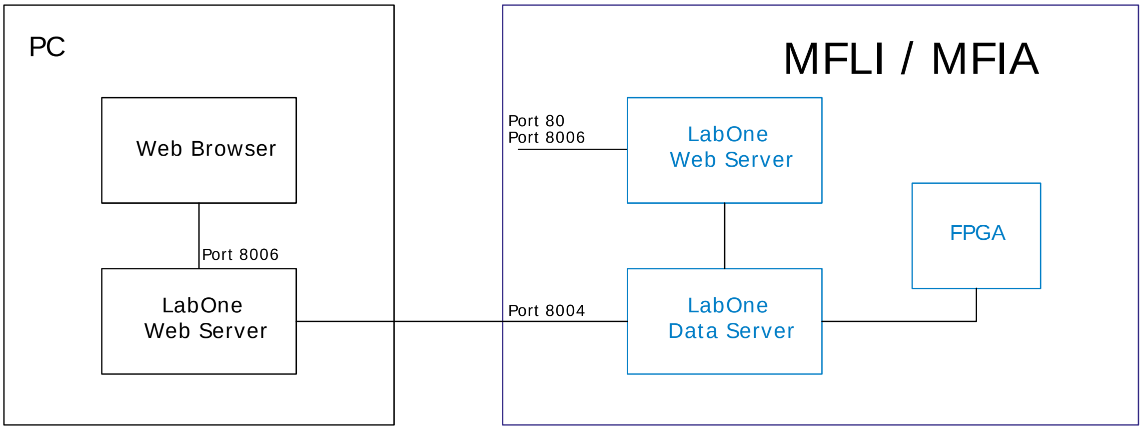


Figure 1.14. Zurich Instruments Web Server running on separate PC

1.5.1. LabOne Software Start-up

This section is only relevant if the LabOne Software has been installed on a PC, which is not strictly required for MFLI Instruments.

This section describes the LabOne User Interface start-up. If the LabOne Software is not yet installed on the PC please follow the instructions in Section 1.7 Software Installation.

The most straightforward method to control and obtain data from the instrument is to use the LabOne User Interface, which can be found under the Windows Start Menu (see Figure 1.15 and Figure 1.16): Click and select `Start Menu → All programs / All apps → Zurich Instruments → LabOne User Interface`. 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.

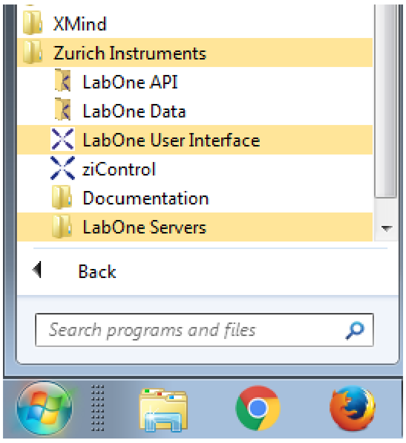


Figure 1.15. Link to the LabOne User Interface in the Windows 7 Start Menu (All programs)

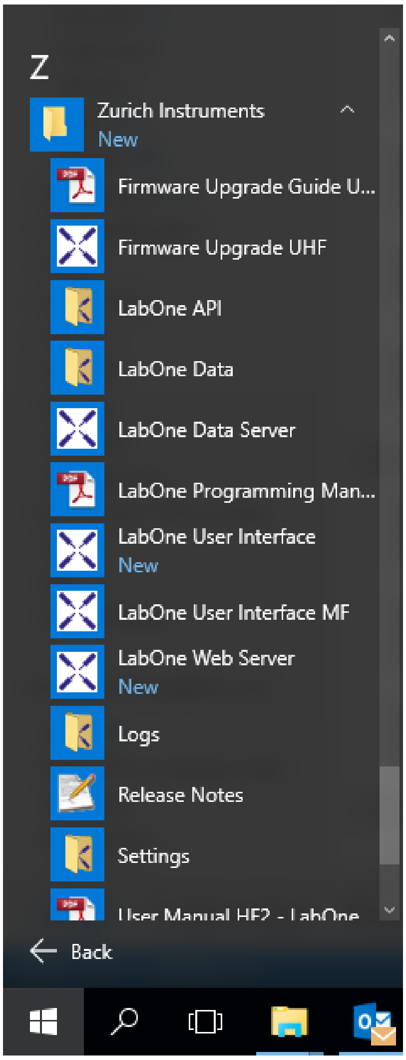


Figure 1.16. Link to the LabOne User Interface in the Windows 10 Start Menu (All apps)

Device and Settings Dialog

After starting the LabOne user interface software, a dialog is shown to select the device and settings 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.

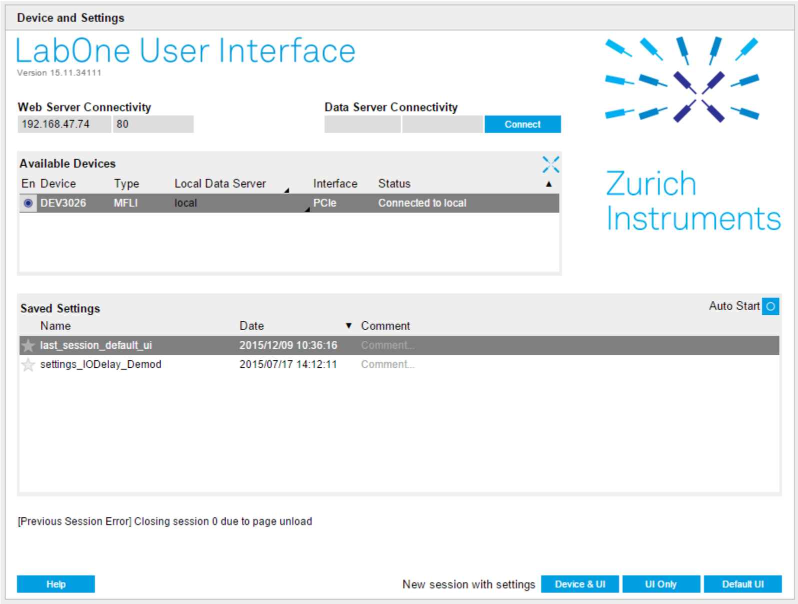


Figure 1.17. Dialog Device and Settings

The Device and Settings dialog consists of four sections: Web Server Connectivity, Data Server Connectivity, Available Devices, and Saved Settings. By default, the dialog is set to Local Data Server mode in the Available Devices section. In that case, the list of Available Devices will contain all instruments directly connected to the host PC via USB . To see devices connected to the LAN via 1GbE, change the dialog mode from **Local Data Server** to **All Data Servers** by opening the drop-down menu in the header row of the Available Devices table. Once your instrument appears in the Available Devices section, perform the following steps to start a new session:

1. Select an instrument in the Available Devices list.
2. Select a setting file in the Saved Settings list unless the **Default UI** is used.
3. Start the session by clicking **Device & UI**, **UI Only**, or **Default UI**.

If there are no setting files listed, starting the LabOne User Interface by clicking the button **Default UI** will start a session using factory defaults.

Note

Opening a new session with the **Device & UI** button can affect existing sessions since the device settings are shared between them. In that case, consider using the **UI Only** button to open a new session.

Note

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

The following sections describe the functionality of the Device and Settings dialog in detail.

Data Server Connectivity

The Device and Settings dialog represents a Web Server shown under Web Server Connectivity. However, on startup the Web Server is not yet connected to a LabOne Data Server, which is why the fields under Data Server Connectivity are empty. 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 MFLI 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 where 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 controlling UHF or HF2 Instruments, and also Data Servers running on an MF instrument.

On the remote computer (Computer 2), open the Device and Settings dialog by starting up the LabOne User Interface. Change the dialog mode from **Local 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 **Local Data Server** mode, all instruments accessible by a Data Server on the same computer and on an MFLI instrument connected to the PC via USB are visible. In **All Data Servers** mode, all accessible Data Servers in the network are shown. This includes Data Servers on MFLI instruments connected to the LAN via 1GbE.

Note

When using All Data Servers mode, take great care to connect to the right instrument especially in larger local networks. Always identify your instrument based on its device serial of the form DEV-xxxx which can be found on the instrument back panel.

Available Devices

The Available Devices section gives an overview of the visible devices. A device is ready for use if either marked free or connected. The first column of the list holds the **Enable** button controlling the connection between the device and a Data Server. This button is greyed out until a Data Server is connected to the LabOne Web Server using the **Connect** button. If the button is enabled the device is connected by the LabOne Data Server. In this case no other LabOne Data Server running on another PC can access the device. Only one interface and LabOne Data Server can access the device.

The second column indicates the device serial and the third column shows the instrument type (HF2, UHF, MFLI, or MFIA). The fourth column indicates shows the IP address of the LabOne Data Server controlling the device, if it is not a local one. The next column shows the interface type. For UHF Instruments the interfaces USB or 1GbE are available. The interface is listed if physically connected. For MF series instruments the interface is always indicated as PCIe (this corresponds to the interface between the embedded PC and the measurement unit inside the MF instrument) regardless of the connection to the host computer (which can be USB or 1GbE). The LabOne Data Server will scan for the available devices and interfaces every 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.

Table 1.5. 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 **Enable** button. Alternatively, a session can also be started directly by clicking on **Device & UI**, **UI Only**, **Default UI** without prior connecting.
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. Only applies to UHF Instruments.
Device needs FW upgrade	The firmware of the device is out of date. Only applies to UHF Instruments.
Device not yet ready	The device is visible and starting up.

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.

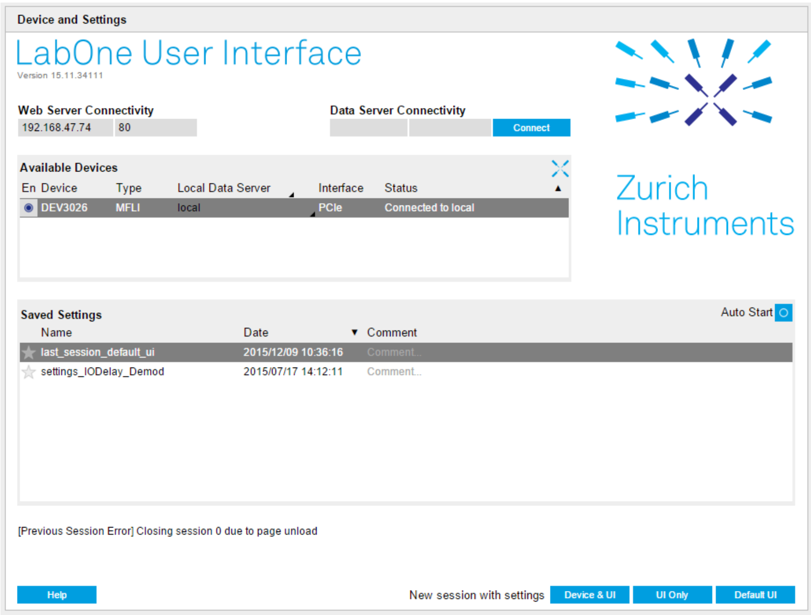
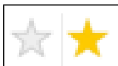


Figure 1.18. Dialog Device and Settings

The columns are described in Table 1.6. 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 1.6. 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 .xml.
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 very useful to describe the specific conditions of a measurement.

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_u`" 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_ui`" also has special meaning. As the name suggests this file contains the default UI settings. See button description in Table 1.7.

Table 1.7. Button Descriptions

Device & UI	The Device and UI settings contained in the selected settings file will be loaded.
UI Only	Only the UI settings contained in the selected settings file will be loaded. The device settings remain unchanged.
Default UI	Loads the default LabOne UI settings. The device settings remain unchanged.
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 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.

Note

The user setting files are saved to an application-specific folder in the user directory structure. On Windows, the folder can be opened in a file explorer by following the link in the Windows Start Menu: Click and select `Start Menu → Programs → Zurich Instruments → LabOne Servers → Settings`.

Note

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

Double clicking on a row in the Saved Settings block is a quick way of loading the LabOne UI with the those device and UI settings. This action is equivalent to selecting the desired settings file and clicking the **Device & UI** button.

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 dialog Device and Settings shown in Figure 1.17. The figure below shows an example of this dialog.

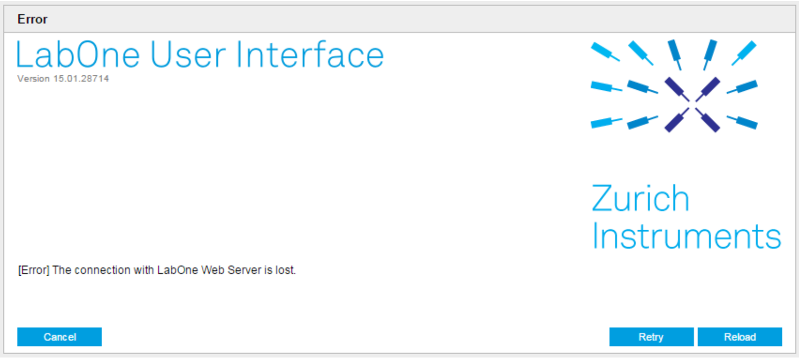


Figure 1.19. Dialog: Connection Lost

Reloading...

If a session error cannot be handled the LabOne Web Server will restart to show a new Dialog Device and Settings as shown in the section called "Device and Settings Dialog". 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.

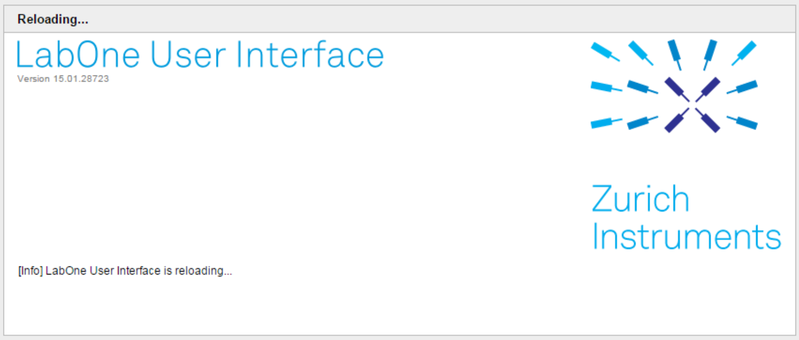


Figure 1.20. Dialog: Reloading

1.6. Using the LabOne Programming Interfaces

LabOne provides Application Programming Interfaces (APIs) for MATLAB, LabVIEW, Python and C. These APIs require installation on the PC where they will be used, see the next section for more details.

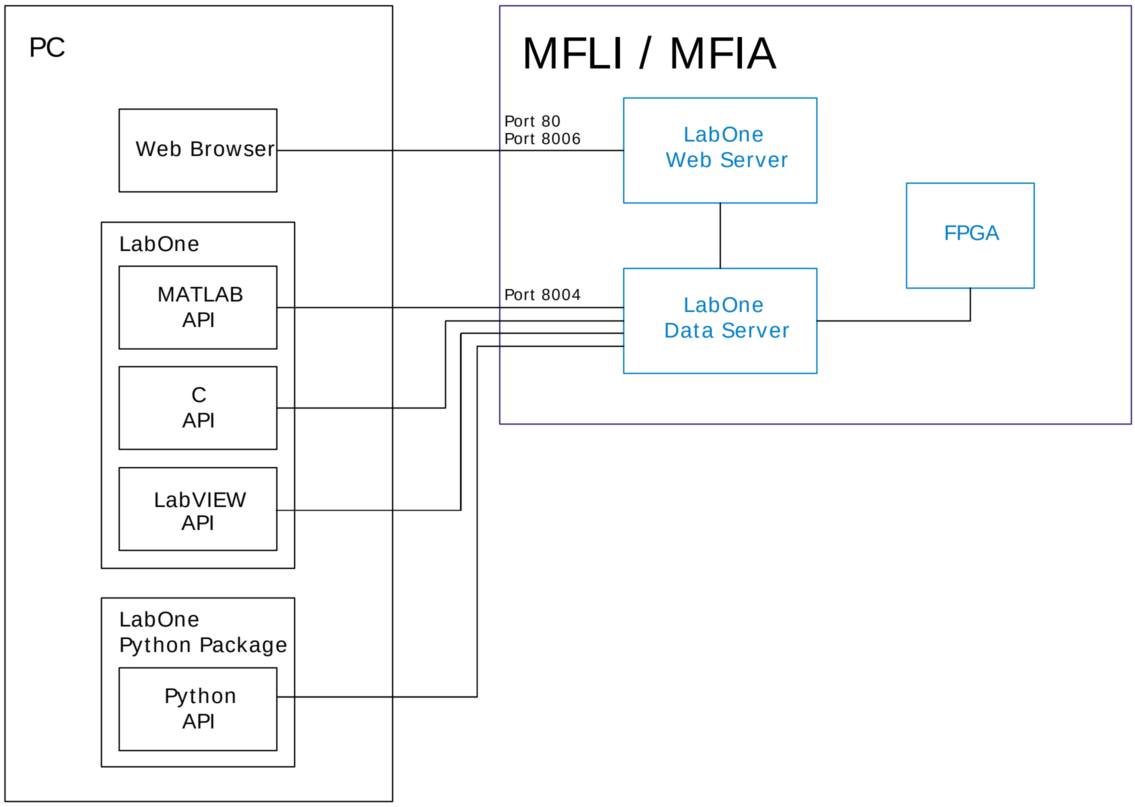


Figure 1.21. LabOne APIs installed on separate PC

The LabOne APIs communicate directly with the Data Server running on the MFLI Instrument via IP port 8004.

The device address can be `<instrument-serial>`, `mf-<instrument-serial>`, `mf-<instrument-serial>.<domain>`, or `<IP address>`. If the address is not fully qualified, means domain name is not added, the API will perform a network discovery with multicast to get the IP address. This ensures that devices connected by Ethernet over USB will be accessible by the same method as devices connected to LAN.

1.6.1. Using the LabOne MATLAB, LabVIEW and C APIs

The MATLAB, LabVIEW and C APIs must be installed on the PC where they will be used. There are two possibilities to install them on a PC. The first option is to install the main LabOne package which includes all the APIs (except the LabOne Python API). This is a good option if you would also like to run the Web Server on this PC as described above in Section 1.5. Installation of the main LabOne package is described in Section 1.7. The second option is to install only the required API's package. This is a better option if only this API will be used on the target PC. The individual API packages are available on the Zurich Instruments download page, www.zhinst.com/downloads.

Please refer to the LabOne Programming Manual for details on installing and using the MATLAB, LabVIEW and C APIs.

1.6.2. Using the LabOne Python API

To use the Python API, the separate Zurich Instruments LabOne Python package must installed. Please refer to the LabOne Programming Manual for details on installing and getting started with the LabOne Python API.

1.7. Software Installation and Update

The MFLI Instrument comes with the LabOne software pre-installed and is ready to work out of the box. Administrator rights are not required to update the LabOne software on the instrument. The LabOne software can also be installed on Windows and Linux PCs. This can be advantageous for performance reasons, and is necessary to use the MATLAB, LabVIEW or C APIs with the instrument. To install the LabOne software on a PC administrator rights are required. Following installation, to simply run the software, 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 Instrument as described in this section.

1.7.1. Updating LabOne on the MFLI Instrument

The LabOne software on the MFLI instrument can be updated by either a drag-and-drop procedure, or by using a USB mass storage device (e.g. a memory stick).

Note

Updating the LabOne software on the Instrument requires that the browser is connected to the Web Server running on the MFLI Instrument.

Drag-and-Drop LabOne Software Update

- Download the latest LabOne software version from the Zurich Instruments Download Center . Choose the version for the MFLI Instrument. The file has the form `LabOneMF-xx.xx.xxxxx.tar`.
- Open a Windows Explorer window and navigate to the location of the downloaded LabOne installation file (on Windows this is typically the Downloads folder). On Linux, the Files application or some other file manager utility supporting drag and drop, can be used. We will use the term explorer window henceforth in this description.
- Start the LabOne User Interface in a web browser (connect to the Web Server running on the Instrument by typing the serial number in the address bar).
- Open the LabOne Config tab.
- Position/Re-size the explorer window and the web browser such that the dotted rectangle under the File Upload section of the Config tab is visible.

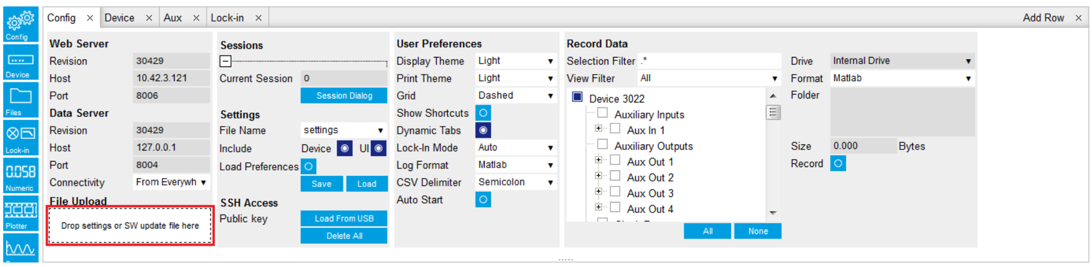


Figure 1.22. Config Tab showing drop zone for software update

- Drag and drop the downloaded LabOne installation file from the explorer window onto the dotted rectangle. An Upload pop-up window will appear indicating the progress of the upload. Once uploaded, The LabOne Software Update pop-up window will appear.

Figure 1.23. Upload pop-up window

Figure 1.24. LabOne Software Update pop-up window

- Click **OK** in the LabOne Software Update pop-up window. This completes the software update. The servers running on the instrument will now be restarted necessitating a reload of the LabOne User Interface. An Error pop-up window will appear containing the text "The connection with the LabOne Web Server is lost".
- Reload the LabOne User Interface by clicking on the **Reload** button.

USB Stick LabOne Software Update

- Download the latest LabOne software version from the Zurich Instruments Download Center and copy it onto a USB mass storage device. Choose the version for the MFLI Instrument. The file has the form `LabOneMF-xx.xx.xxxxx.tar`.
- Start the LabOne User Interface in a web browser (connect to the Web Server running on the Instrument by typing the serial number in the address bar).
- Insert the USB mass storage device into one of the USB sockets on the back of the MFLI Instrument.
- Open the LabOne File Manager tab.
- A folder labelled USB1 will be displayed in the File Manager tab, corresponding to the inserted USB device. Expand the USB1 branch to display its contents (double click on the folder icon).
- Right click the LabOne update .tar file and select **SW Update** to update the software.

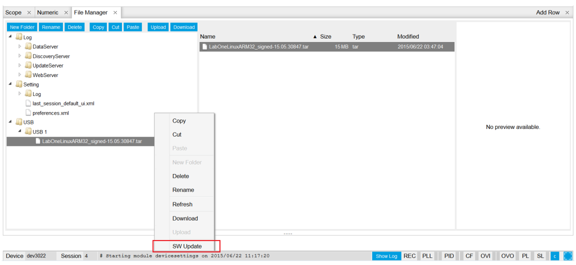


Figure 1.25. File Manager tab

An Upload pop-up window will appear indicating the progress of the upload. Once uploaded, The LabOne Software Update pop-up window will appear.

Figure 1.26. LabOne Software Update pop-up window

- Click **OK** in the LabOne Software Update pop-up window. This completes the software update. The servers running on the instrument will now be restarted necessitating a reload of the LabOne User Interface. An Error pop-up window will appear containing the text "The connection with the LabOne Web Server is lost".
- Reload the LabOne User Interface by clicking on the **Reload** button.

1.7.2. Installing LabOne on Windows

This section describes how to additionally install the LabOne Software on Windows. this is only necessary if you wish to access the User Interface with a Web Server running on a PC instead of on the MFLI itself (for performance reasons) or use one of the LabOne APIs (Matlab, Python, LabVIEW, C).

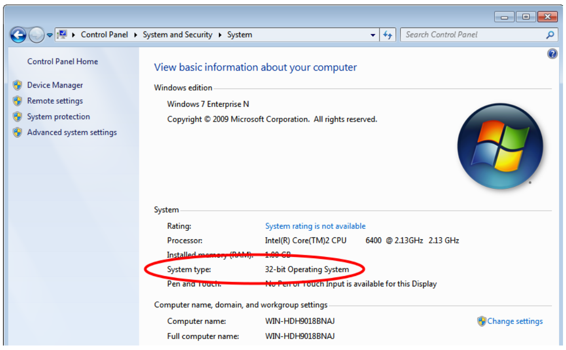
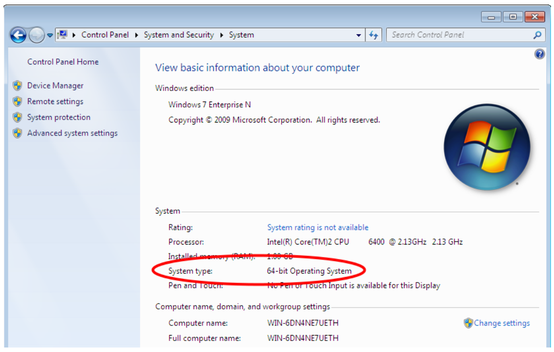
The installation packages for Zurich Instruments LabOne software are available as Windows installer .msi packages. The software is available on the Zurich Instruments download page, www.zhinst.com/downloads. Please ensure that you have administrator rights for the PC where the software is to be installed and that you download the correct software installer for the PC's processor architecture (32-bit or 64-bit), for help see the section called “Determining PC Architecture on Microsoft Windows”. See www.zhinst.com/labone/compatibility for a comprehensive list of supported Windows systems.

Determining PC Architecture on Microsoft Windows

In case you are unsure which Windows architecture you are using, it can be checked as follows:

- Windows 7: `Control panel → System and Security → System/System type`
- Windows 8: `Control panel → System → System/System type`

Table 1.8. Find out the OS addressing architecture (32-bit or 64-bit)

Windows 7 (32-bit: x86)	Windows 7 (64-bit: x64)
	

Windows LabOne Installation

1. The MFLI Instrument should not be connected to your computer during the LabOne software installation process

2. Start the `LabOne32/64-xx.xx.xxxxxx.msi` LabOne installer program by a double click and follow the instructions. Please note that Windows Administrator rights are required for installation. The installation proceeds as follows:

   - On the welcome screen click the **Next** button.

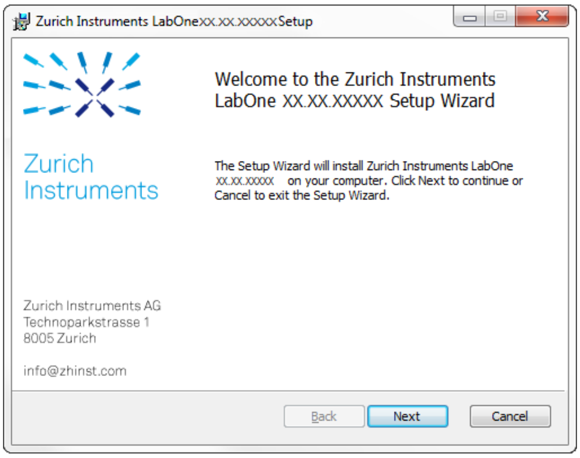


Figure 1.27. Installation welcome screen

   - 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 MFLI Instrument the `MFLI Series Device`, `Web Server` and `API` features are required. Please install the features for other device classes as well as required. If you would like to install shortcuts on your desktop area enable the feature `Desktop Shortcuts`. To proceed click the **Next** button.

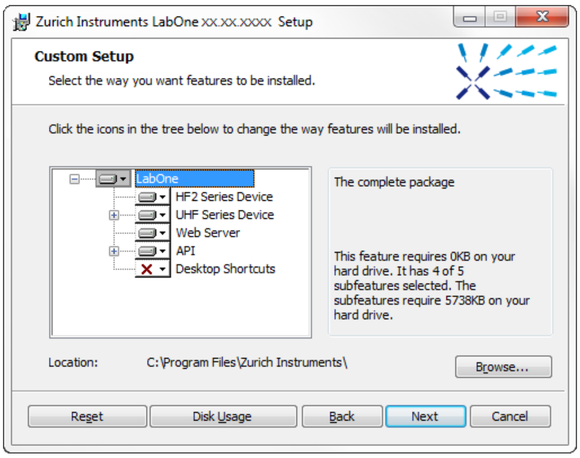


Figure 1.28. Custom setup screen

   - Click the **Install** button to start the installation process.
   - Windows will ask up to two times to reboot the computer. Make sure you have no unsaved work on your computer. Actually a reboot is practically never required, so that one may safely click **OK**.

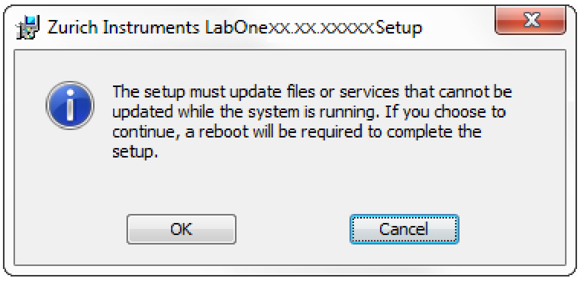


Figure 1.29. Installation reboot request

- On Windows Server 2008 and Windows 7 it is required to confirm the installation of up to 2 drivers from the trusted publisher Zurich Instruments. Click on **Install**.

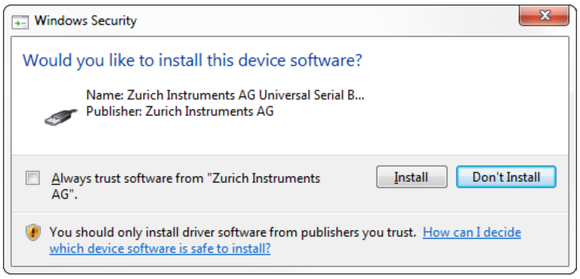


Figure 1.30. Installation driver acceptance

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

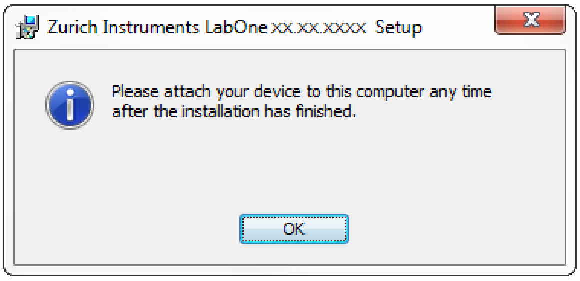


Figure 1.31. Installation completion screen

3. Click **Finish** to close the Zurich Instruments LabOne installer.

Warning

Do not install drivers from another source and therefore not trusted as originating from Zurich Instruments.

1.7.3. Installing LabOne on Linux

This section describes how to additionally install the LabOne Software on Linux. this is only necessary if you wish to run the Web Server on a PC instead of on the MFLI itself.

Requirements

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

1. Officially, Ubuntu 12.04 LTS and 14.04 LTS (i386, amd64) are supported although in practice LabOne software may work on other platforms. Please ensure that you are using a Linux distribution that is compatible with Ubuntu/Debian, but preferably Ubuntu 12.04 LTS or 14.04 LTS.
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 downloads page:
   - LabOneLinux<arch>-<release>.<revision>.tar.gz, for example:

     ```
     LabOneLinux32/64-xx.xx.xxxxx.tar.gz
     ```

   Please ensure you download the correct architecture (32-bit/64-bit) 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 " `x686`" the 32-bit version of the LabOne package is required, if it displays " `x86_64`" the 64-bit version is required.

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.

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. Start the Web Server program at a command prompt:

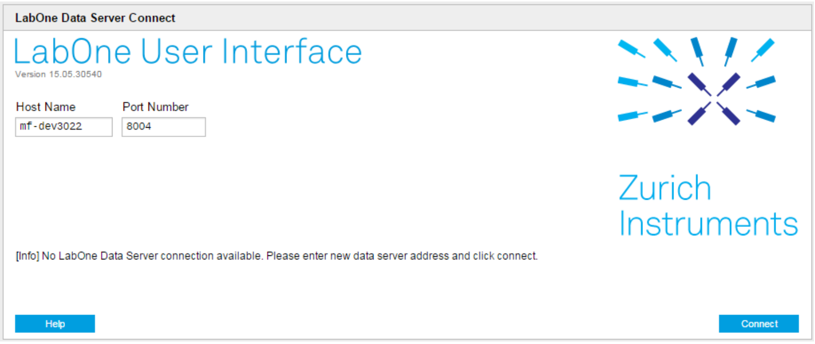
   ```
   $ startWebServer
   ```

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. In the LabOne DataServer Connect dialog that appears, type the following text in the Host Name field:

   ```
   <instrument-serial>.<domain>
   ```

   Where <instrument-serial> is the serial number of the MFLI Instrument and <domain> is the network domain in which the instrument is running. An example is given below.

   The port to use is 8004 which by default should already be correct (The LabOne Data Server running on the MFLI listens on port 8004).

   Click the **Connect** button. The Device and Settings dialog will appear allowing you to proceed as normal.

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
   ```

1.8. Troubleshooting

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

1.8.1. Common Problems

Your MFLI Instrument is an advanced piece of laboratory equipment with many more functionalities 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.

The software cannot be installed or uninstalled: please verify you have Windows administrator rights. Windows systems: if prompted or required install the .NET Framework, see Section 1.8.3.

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 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 Instrument has a high input noise floor (when connected to host computer by USB): the USB cable connects the Instrument ground to computer ground, which might inject some unwanted noise to the measurements results. In this case it is recommended to use the Ethernet connection which is galvanically isolated using a UTP Cat 5 or 6 cable (UTP stands for “unshielded twisted pair”).

The Instrument performs poorly at low frequencies (below 100 Hz) : the signal inputs of the instrument might be set to AC operation. Please verify to turn off the AC switch in the Lock-in 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 poorly during operation: clipping of the input signal may be occurring. This is detectable by monitoring the red LEDs on the front panel of the instrument or the OVI flags on the status tab of the user interface. It can be avoided by adding enough margin on the input range setting (for instance 50% to 70% of the maximum signal peak).

The Instrument performs strangely when working with the MF-MD Multi-demodulator 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 measurements are unpredictable: please check the Status tab to see if any of the warning is occurring (red flag) or 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 / 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.

The sample stream from the Instrument to the host computer is not continuous: check the communication (COM) flags in the status bar. The three indicate occasional sample loss, packet loss, or stall. Sample loss occurs when a sampling rate is set too high (the instruments 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 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 Trouble Shoot. In case you use a NVIDIA graphics card, you have to use the NVIDIA control panel. Go to Manage 3D Settings, then Program Settings and select the program that you want to customize.

1.8.2. Location of the log files

The log files of the LabOne server programs are stored on the MFLI and can be accessed through the File Manager tab of the graphical user interface where they are found in the Log folder. In case the Web Server is run on the host computer and not on the embedded computer of the MFLI (see Section 1.5), the location of the Web Server log files is specified below.

On Windows, the log files can be accessed through the start menu (`All apps/all programs → Zurich Instruments → Logs`).

For Windows 7, 8, and 10 the log files are located in the following directories:

- LabOne Data Server: `C:\Users\[USER]\AppData\Local\Temp\Zurich Instruments\LabOne\ziDataServerLog`
- LabOne Web Server: `C:\Users\[USER]\AppData\Local\Temp\Zurich Instruments\LabOne\ziWebServerLog`

On Windows XP:

- LabOne Data Server: `C:\Documents and Settings\[USER]\Local Settings\Temp\Zurich Instruments\LabOne\ziDataServerLog`
- LabOne Web Server: `C:\Documents and Settings\[USER]\Local Settings\Temp\Zurich Instruments\LabOne\ziWebServerLog`

1.8.3. Windows .NET Framework Requirement

The Zurich Instruments LabOne software installer requires the Microsoft .NET Framework to be installed on Windows systems. This is normally already installed on most Windows systems but may need to be additionally installed on some computers running Windows XP and Vista. If the .NET Framework is not available a message will be shown that this requirement is missing when the LabOne installer is started.

It is possible to check whether and which version of the Microsoft .NET Framework is installed on your system under Windows Start -> Control panel -> Add and Remove Programs. The minimum requirement is Microsoft .NET Framework 3.5 Service Pack 1. In case the required version is not installed, it can be installed through Windows Update tool (Windows Start -> Control panel -> Windows Update).

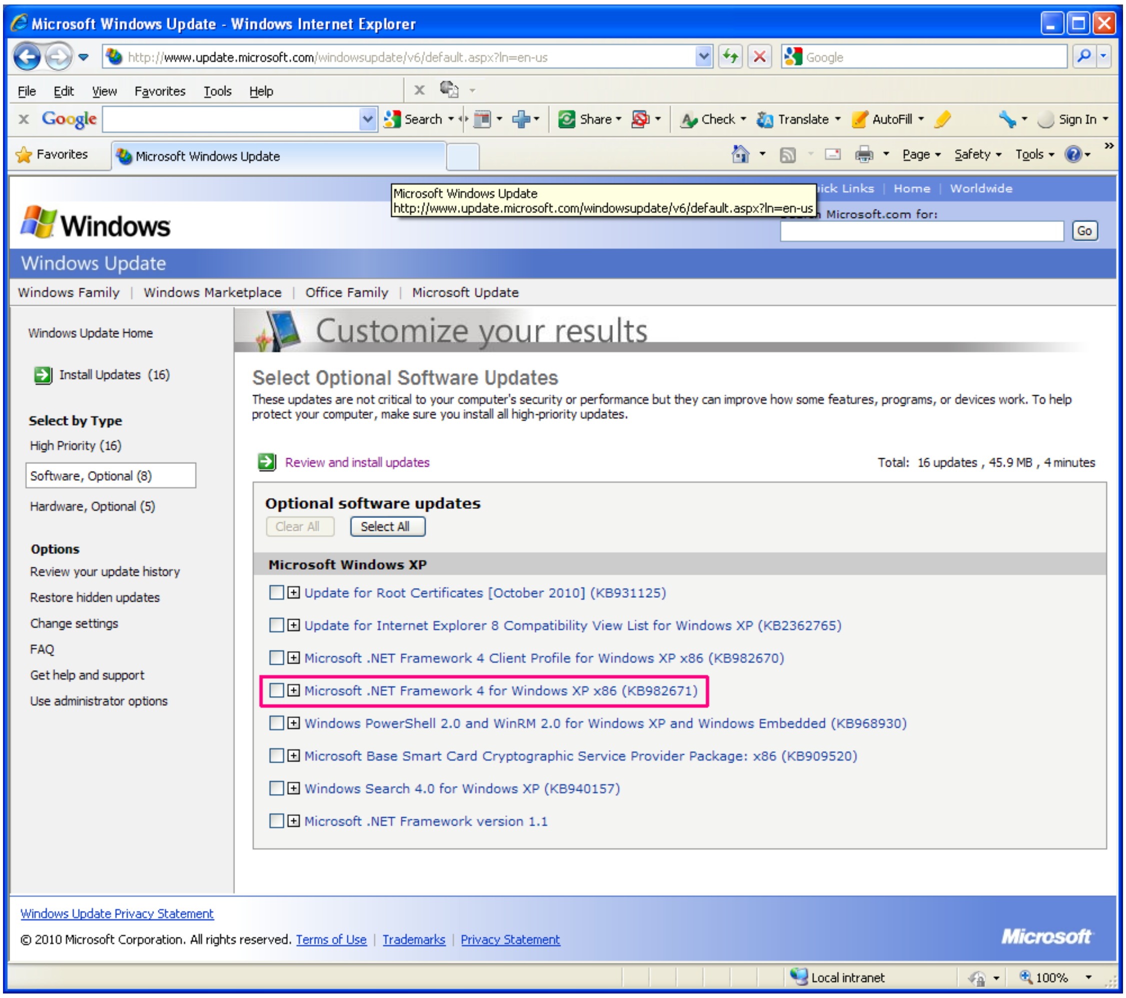


Figure 1.32. Installation of the .NET Framework.

Chapter 2. Functional Overview

This chapter provides the overview of the features of the MFLI Instrument. The first section contains the graphical overview as well as the hardware and software feature list. The next sections detail the front panel and the back panel of the measurement instrument. The last section provides product selection and ordering support.

2.1. Features

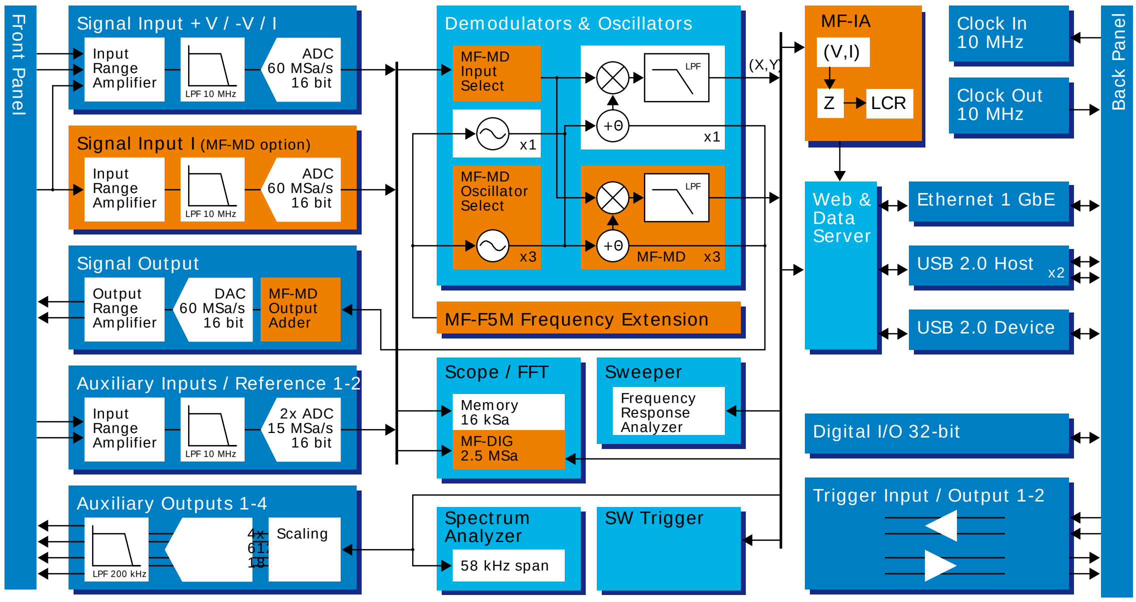


Figure 2.1. MFLI Instrument Overview

Every MF Instrument (MFLI, MFIA) described on Figure 2.1 consists of several internal units (light blue color) surrounded by several interface units (dark blue color) and the front panel on the left-hand side and the back panel on the right-hand side. The orange blocks are optional units that can be either ordered at the beginning or upgraded later in the field. The arrows between the panels and the interface units indicate the physical connections and the data direction flow. Only a small subset of internal connections is depicted.

The signal of interest is connected to the low-noise current or to the voltage input of the MF Instrument, where it is amplified to a defined range and digitized at very high speed. When the MF-MD option is installed, both inputs can be used simultaneously, enabling 4-terminal measurements for example. The resulting samples are fed into the digital signal processor consisting of up to 4 dual-phase demodulators. The demodulator output samples are further processed on the embedded processor that provides the LabOne web server, to which the user can connect from any device running a browser (PC, tablet or smart phone). No software installation is required. Both Ethernet and USB are supported. The demodulator samples are also available as analog signal on the auxiliary outputs on the front panel of the MF 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 MF output signals. When the MF-MD option is installed, the Output Adder can generate a linear combination of the oscillator outputs to generate a multi-frequency output signal: digital to analog conversion and signal scaling (range) are supported.

Hardware trigger and reference signals are used for various purposes inside the instrument, such as triggering demodulation, triggering oscilloscope data acquisition, or to generate external reference clocks or triggering signals to other equipment.

Lock-in Operating Modes

- Internal reference mode
- External reference mode
- Auto reference mode
- Impedance mode, measuring current input and voltage input simultaneously (optional)
- Multi-harmonic mode (optional, simultaneous measurement up to four harmonic frequencies)
- Arbitrary frequency mode (optional, simultaneous measurement at 4 arbitrary frequencies)

Medium Frequency Voltage Input

- 1 low-noise MF voltage input, single-ended, differential, 5 MHz bandwidth
- Variable input range
- Switchable input impedance
- Selectable AC/DC coupling
- Selectable instrument ground or floating

Medium Frequency Current Input

- 1 low-noise MF current input, single-ended, 5 MHz bandwidth
- Variable input range
- Switchable input impedance
- Selectable AC/DC coupling

Medium Frequency Signal Output

- Low-distortion MF outputs, single-ended, differential, 5 MHz bandwidth
- Variable output range
- Digital and analog offset

Demodulators & Reference

- Up to 4 dual-phase demodulators
- Up to 4 programmable numerical oscillators
- Up to 2 external reference signals
- Individually programmable demodulator filters
- 128-bit internal processing
- 64-bit resolution demodulator sample
- 48-bit internal reference resolution

Auxiliary Input, Outputs and Triggers

- 4 auxiliary outputs, user defined signals
- 2 auxiliary inputs, general purpose
- 2 input and 2 output trigger signals

High-speed Connectivity

- USB 2.0 Device high-speed 480 Mbit/s interface

- Dual USB 2.0 Host high-speed interface
- LAN 1 Gbit/s controller interface
- DIO: 32-bit digital input-output port
- Clock input connector (10 MHz)
- Clock output connector (10 MHz)

LabOne Toolset

- Sweeper
- Scope
- Numeric
- Spectrum
- Plotter
- SW trigger

Software Connectivity

- Data server with multi-client support
- API for C, LabVIEW, MATLAB, Python based instrument programming

2.2. Front Panel Tour

The front panel BNC connectors and control LEDs are arranged as shown in Figure 2.2 and listed in Table 2.1.

Note

Figure 2.2 shows the front panel of MF Instruments with **serial numbers MF-DEV3200 and higher** (see Table 1.1). On Instruments with smaller serial numbers, the +V and -V Diff connectors (C* and D*) are swapped and the spacing of several connectors is different.

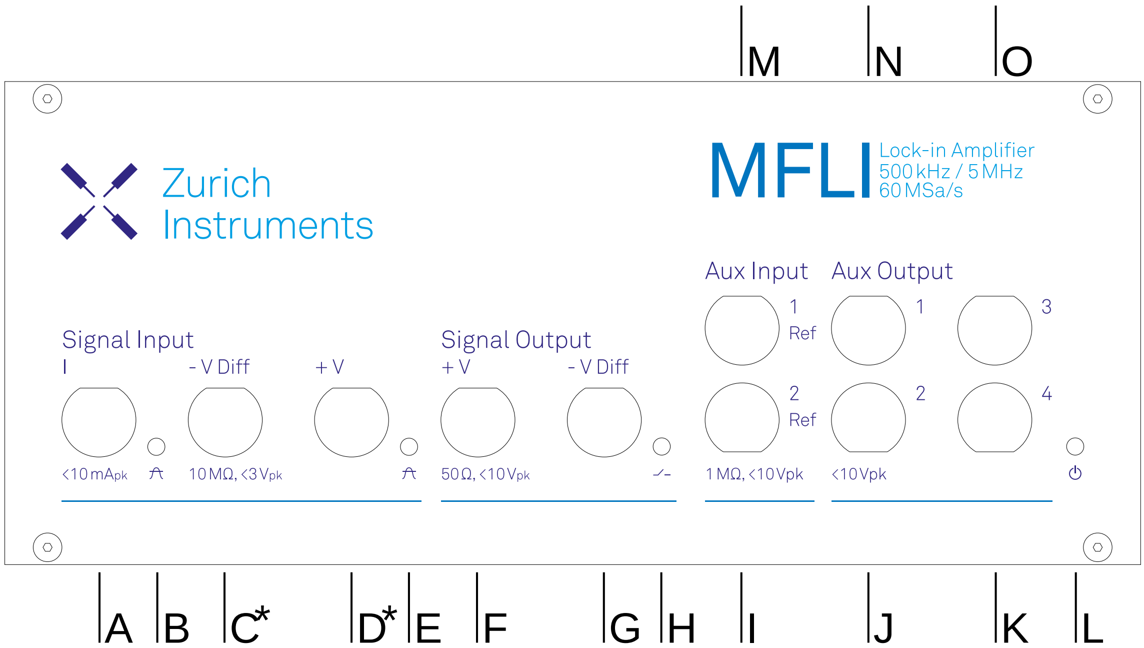


Figure 2.2. MF Instrument front panel

Table 2.1. MF Instrument front panel description

Position	Label / Name	Description
A	Signal Input I	single-ended current input
B	Current Input Signal Over	this red LED indicates that the current input signal saturates the A/D converter and therefore the current input range must be increased or the signal must be attenuated
C* (serial above 3200)	Signal Input –V Diff	voltage input
		single-ended mode: internally shorted to ground
		differential mode: negative voltage input
D* (serial above 3200)	Signal Input +V	voltage input
		in single-ended mode: single-ended voltage input
		differential mode: positive voltage input
C* (serial below 3200)	Signal Input +V	voltage input
		single-ended mode: single-ended voltage input
		differential mode: positive voltage input

Position	Label / Name	Description
D* (serial below 3200)	Signal Input −V Diff	voltage input
		single-ended mode: internally shorted to ground
		differential mode: negative voltage input
E	Voltage Input Signal Over	this red LED indicates that the voltage input signal saturates the A/D converter and therefore the voltage input range must be increased or the signal must be attenuated
F	Signal Output +V	voltage output
		single-ended mode: single-ended voltage output
		differential mode: positive voltage output
G	Signal Output −V Diff	voltage output
		single-ended mode: internally shorted to ground
		differential mode: negative voltage output
H	Signal Output ON	this blue LED indicates that the signal output is actively driven by the instrument
I	Aux Input 2 Ref	auxiliary input 2, can be used as external reference input supporting the full bandwidth of the device
J	Aux Output 2	auxiliary output 2, this connector provides a user defined signal, often used to output demodulated samples (X,Y) or (R,Θ)
K	Aux Output 4	auxiliary output 4, this connector provides a user defined signal, often used to output demodulated samples (X,Y) or (R,Θ)
L	Power	this LED indicates that the instrument is powered
		color blue: the device has an active connection to the LabOne data server and is ready for operation
		color green blinking: the firmware is ready, waiting for LabOne data server connection. This process takes around 20 seconds.
		color red: the device is not initialized respectively is performing the internal auto calibration process.
		color purple blinking: a firmware update is in progress
		color purple: the boot process failed
M	Aux Input 1 Ref	auxiliary input 1, can be used as external reference input supporting the full bandwidth of the instrument; the value of auxiliary input 1 can be added as offset to the signal output
N	Aux Output 1	auxiliary output 1, this connector provides a user-defined signal, often used to output demodulated samples (X,Y) or (R,Θ)
O	Aux Output 3	auxiliary output 3, this connector provides a user-defined signal, often used to output demodulated samples (X,Y) or (R,Θ)

Please refer to the troubleshooting section for further information regarding the meaning of the Power LED colors.

2.3. Back Panel Tour

The back panel is the main interface for power, control, service and connectivity to other ZI instruments. Please refer to Figure 2.3 and Table 2.2 for the detailed description of the items.

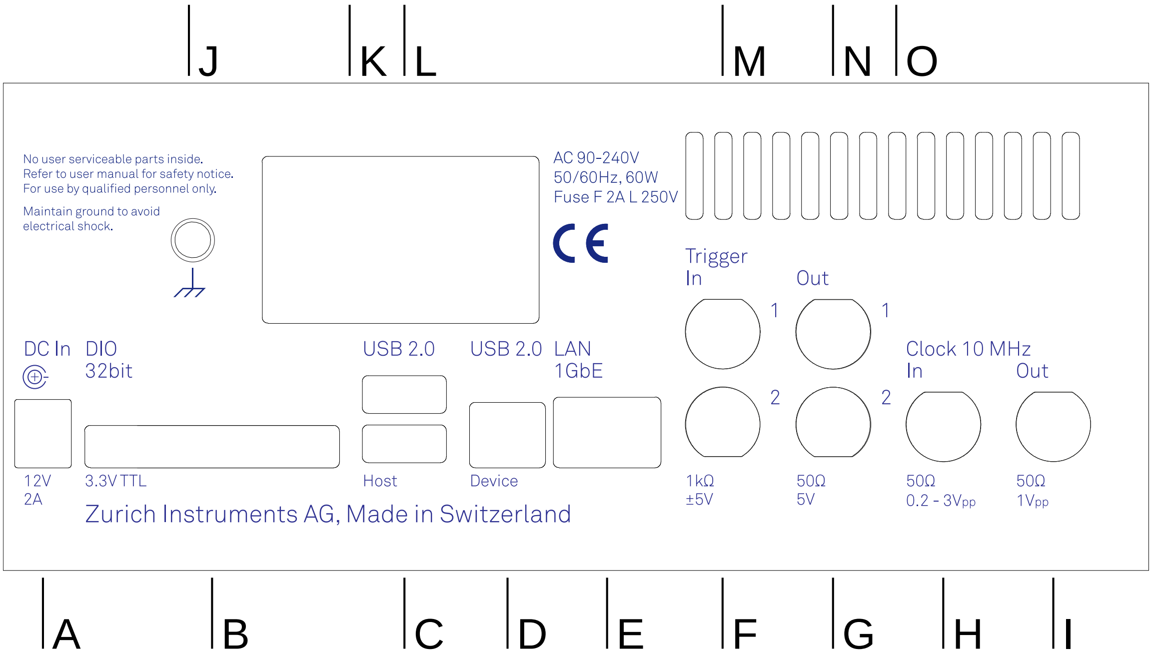


Figure 2.3. MF Instrument back panel

Table 2.2. MF Instrument back panel description

Position	Label / Name	Description
A	DC In	DC external 12 V power supply
B	DIO	32-bit digital input/output connector
C	USB 2.0 Host	universal serial bus host connector
D	USB 2.0 Device	universal serial bus device connector to computer
E	LAN 1GbE	1 Gbit Ethernet LAN connector
F	Trigger In 2	digital TTL trigger input 2
G	Trigger Out 2	digital TTL trigger output 2
H	Clk 10 MHz In	clock input (10 MHz) to be used for synchronization from external instruments
I	Clk 10 MHz Out	clock output (10 MHz) to be used for synchronization of external instruments
J	Earth ground	4 mm banana jack connector for earth ground, electrically connected to the chassis and the earth pin of the power inlet
K	USB 2.0 Host	universal serial bus host connector
L	Power inlet	power inlet with ON/OFF switch
M	Trigger In 1	digital TTL trigger input 1
N	Trigger Out 1	digital TTL trigger output 1
O	Cooling outlet	ventilator (important: keep clear from obstruction)

2.4. Ordering Guide

Table 2.3 provides an overview of the available MF products. Upgrade options can be purchased at any time without need to send the Instrument to Zurich Instruments.

Table 2.3. MF Instrument product codes for ordering

Product code	Product name	Description	Upgrade in the field possible
MFLI 500 kHz	MFLI 500 kHz Lock-in Amplifier	base product	-
MFLI 5 MHz	MFLI 5 MHz Lock-in Amplifier	bundle	-
MF-MD	MF-MD Multi-demodulator	option	yes
MF-F5M	MF-F5M Frequency Extension	option	yes
MF-DIG	MF-DIG Digitizer	option	yes
MF-IA	MF-IA Impedance Analyzer	option (can be purchased only together with MFITF)	yes
MFITF	Impedance Test Fixture	accessory (can be purchased only together with MF-IA)	-

The MF product line consists of the MFLI Lock-in Amplifier series and the MFIA Impedance Analyzer series. The combination MFLI 5 MHz + MF-IA is equivalent to the MFIA 5 MHz product, and the combination MFLI 500 kHz + MF-IA is equivalent to the MFIA 500 kHz product. The following table gives an overview of the features for the most important product configurations.

Table 2.4. Product selector

Feature	MFLI	MFLI +MF-MD	MFLI +MF-F5M	MFLI +MF-MD +MF-F5M
Internal reference mode	yes	yes	yes	yes
External reference mode	yes	yes	yes	yes
Auto reference mode	yes	yes	yes	yes
Impedance mode (independent measurement of voltage and current signal inputs)	-	yes	-	yes
Signal generators	1	1	1	1
Superposed output sinusoids per generator	1	up to 4	1	up to 4
Quad-harmonic mode	-	yes	-	yes
Multi-frequency mode	-	yes	-	yes
Arbitrary frequency mode	-	yes	-	yes
Number of demodulators	1	4	1	4
Simultaneous frequencies	1	4	1	4
Simultaneous harmonics	1	4	1	4

Feature	MFLI	MFLI +MF-MD	MFLI +MF-F5M	MFLI +MF-MD +MF-F5M
External references	1	2	1	2
Dynamic reserve	120 dB	120 dB	120 dB	120 dB
Frequency range	500 kHz	500 kHz	5 MHz	5 MHz
USB 2.0 480 Mbit/s	yes	yes	yes	yes
Ethernet 1 GbE	yes	yes	yes	yes

Chapter 3. Tutorials

The tutorials in this chapter have been created to allow users to become more familiar with the basic technique of lock-in amplification, the operation of host-based lock-in amplifiers, the LabOne web browser based user interface, as well as some more advanced lock-in measurement techniques. In order to successfully carry out the tutorials, users are required to have certain laboratory equipment and basic equipment handling knowledge. The equipment list is given below.

Note

For all tutorials, you must have LabOne installed as described in the Getting Started Chapter. We make use of a systematic nomenclature to describe the different controls and elements of the LabOne graphical user interface. This nomenclature is explained in Section 4.1.1.

- 1 LAN cable
- 5 BNC cables
- 1 oscilloscope (optional)
- 2 BNC T-pieces
- 1 optical chopper (for the External Reference tutorial)
- 1 infrared emitter/detector pair (for the External Reference tutorial)
- 1 field-effect transistor (for the Sweeper tutorial)
- 1 Kelvin probe cable set and through-hole resistors 1 Ω and 10 Ω (for the Compensation tutorial)
- 1 MΩ through-hole resistor and soldering equipment (for the Advanced Impedance Measurement tutorial)

3.1. Simple Loop

Note

This tutorial is applicable to all MFLI Instruments. No specific options are required.

3.1.1. Goals and Requirements

This tutorial is for people with no or little prior experience with Zurich Instruments lock-in amplifiers. By using a very basic measurement setup, this tutorial shows the most fundamental working principles of the MFLI Instrument and the LabOne UI in a step-by-step hands-on approach.

There are no special requirements for this tutorial.

3.1.2. Preparation

In this tutorial, you are asked to generate a single-ended signal with the MFLI Instrument and measure that generated signal with the same instrument using an internal reference. This is done by connecting Signal Output +V to Signal Input +V with a short BNC cable (ideally < 30 cm). Alternatively, it is possible to connect the generated signal at Signal Output +V to an oscilloscope by using a T-piece and an additional BNC cable. Figure 3.1 displays a sketch of the hardware setup.

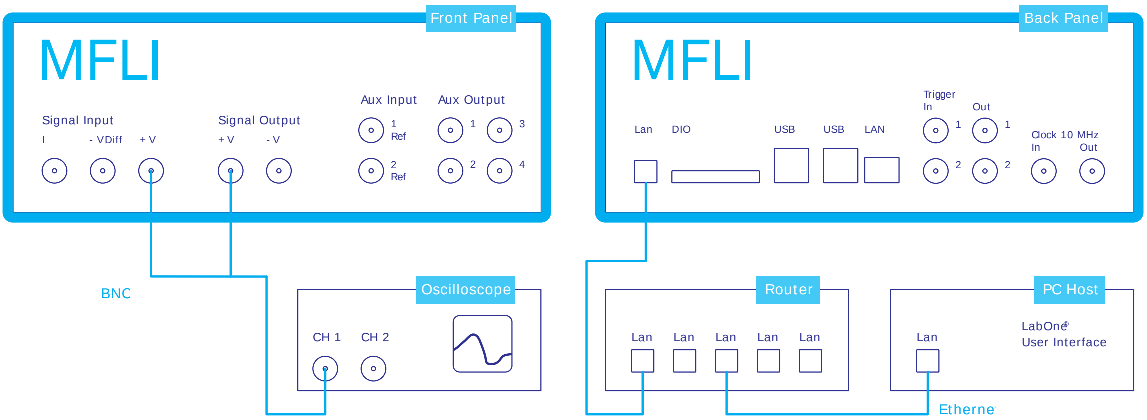


Figure 3.1. Setup for the Simple Loop Tutorial (LAN connection shown)

Note

This tutorial is for all MFLI irrespective of which particular option set is installed. Some changes in the description apply if the MF-MD Multi-demodulator option is installed.

Connect the cables as described above. Make sure that the MFLI Instrument is powered on and then connect the MFLI directly by USB to your host computer or by Ethernet to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

3.1.3. Generate the Test Signal

Perform the following steps in order to generate a 300 kHz signal of 0.5 V peak amplitude on Signal Output +V. We work with the graphical Lock-in tab. Note that the control elements in this tab dynamically adapt their appearance to the web browser window size. Be sure to work in full screen size for this test.

1. In the Lock-in tab, select the sub-tab 1 on the left-hand side of the screen. In the Reference section, change the frequency value of oscillator 1 to 300 kHz: click on the field, enter 300000 or 300 k in short and press either <TAB> or <ENTER> on your keyboard to activate the setting.
2. In the Output Amplitudes section, set the amplitude to 500 mV (peak value) and enable the signal by clicking on the button labeled "En". A single green LED on top indicates the enabled signal.
3. In the Signal Output 1 section (right hand side on the Lock-in tab), set the Range pull-down to 1 V and the Offset to 0 V. Keep the Add and Diff buttons unchecked.
4. By default, all physical outputs of the MFLI are inactive to prevent damage to the MFLI or to the devices connected to it. Now it is time to turn on the main output by clicking on the button labelled "On".

Table 3.1 summarizes the instrument settings to be made. If you have an oscilloscope connected to the setup, you should now be able to see the generated sinusoidal signal with a peak-to-peak amplitude of 1 V. Be sure to choose a high input impedance on the oscilloscope. But you can easily spare the extra equipment, as the MFLI comes with a built-in oscilloscope. In Section 3.1.4 we describe how to use it.

Table 3.1. Settings: generate the test signal

Tab	Section	#	Label	Setting / Value / State
Lock-in	Oscillator	1	Frequency	300 kHz
Lock-in	Output	1	Amplitude	500 mV
Lock-in	Output	1	Offset	0 V
Lock-in	Output	1	On	On

3.1.4. Check the Test Input Signal

Next, we configure the signal input side of the MFLI from the Lock-in tab, and then visualize the input signal using the Scope tab. In the Signal Input section of the Lock-in tab, select Sig In 1 from the pull-down menu. Set the range to 1.0 V, and be sure to have the AC, 50 Ω, Diff and Float buttons unchecked.

The range setting ensures that the analog amplification on the Signal Input +V is set such that the resolution of the input analog-to-digital converter is used efficiently without clipping the signal. This optimizes the dynamic range.

The incoming signal can now be observed over time by using the Scope tab. A Scope view can be placed in the web browser by clicking on the icon in the left sidebar or by dragging the Scope Icon to one of the open tab rows. Choose the following settings on the Scope tab to display the signal entering Signal Input +V:

Table 3.2. Settings: check the test signal

Tab	Section	#	Label	Setting / Value / State
Lock-in	Signal Input	1	Float	Off
Lock-in	Signal Input	1	Diff	Off

Tab	Section	#	Label	Setting / Value / State
Lock-in	Signal Input	1	50 Ω	Off
Lock-in	Signal Input	1	AC	Off
Scope	Horizontal		Sampling Rate	60 MHz
Scope	Horizontal		Length	4096 pts
Scope	Vertical		Channel 1	Signal Input 1
Scope	Trigger		Enable	On
Scope	Trigger		Level	0 V

The Scope tool now displays single shots of Signal Input +V with a temporal distance given by the Hold off Time. The scales on the top and on the left of the graphs indicate the zoom level for orientation. The icons on the left and below the figure give access to the main scaling properties and allow one to store the measurement data as a SVG image file or plain data text file. Moreover, panning can be achieved by clicking and holding the left mouse button inside the graph while moving the mouse.

Note

Zooming in and out along the horizontal dimension can by achieved with the mouse wheel. For vertical zooming, the shift key needs to be pressed and again the mouse wheel can by used for adjustments. Another, quick way of zooming in is to hold down the shift key and to use the right mouse button to define a horizontal, vertical, or box-like inside the graph area.

Having set the Input Range to 1 V ensures that no signal clipping occurs. If you set the Input Range to 0.1 V, clipping can be seen immediately on the scope window accompanied by a red OVI error flag on the status bar on the bottom of the LabOne User Interface. At the same time, the LED next to the Signal Input +V BNC connector on the instrument's front panel will turn red.

The Scope is a very handy tool to quickly check the quality of the input signal. Users can either use the Scope to adjust the optimal input range setting or to check if the software trigger level is set correctly. For the full description of the Scope tool please refer to the Functional Description.

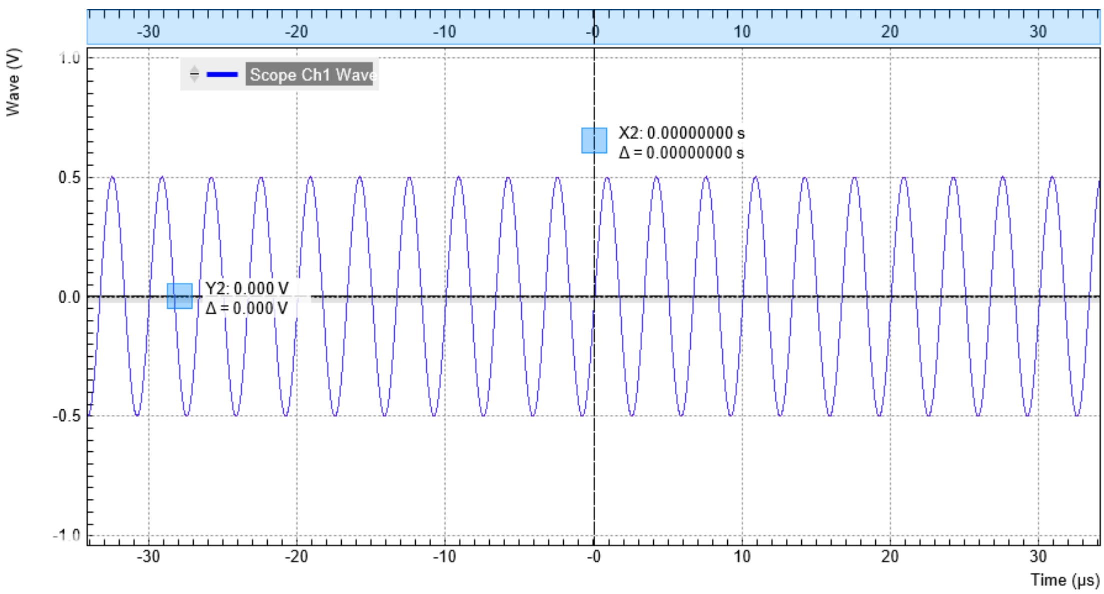


Figure 3.2. LabOne Scope showing the raw signal generated by the MFLI

3.1.5. Measure the Test Input Signal

Now, we are ready to use the MFLI to demodulate the input signal and measure its amplitude and phase. We will use two tools of the LabOne User Interface: the Numeric and the Plotter tab.

First, adjust the parameters listed in the following table on the graphical Lock-in tab for demodulator 1.

Table 3.3. Settings: generate the reference signal

Tab	Section	#	Label	Setting / Value / State
Lock-in	Signal Input	1		Signal Input 1
Lock-in	Low-Pass Filter	1	Sinc	Off
Lock-in	Low-Pass Filter	1	Order	3 (18 dB/Oct)
Lock-in	Low-Pass Filter	1	BW 3 dB	10.6 Hz
Lock-in	PC Data Transfer	1	En	On
Lock-in	PC Data Transfer	1	Rate	100 Sa/s (automatically adjusted to 104.6 Sa/s)
Lock-in	PC Data Transfer	1	Trigger	Continuous

These above settings configure the demodulation filter to the third-order low-pass operation with a 10.6 Hz 3 dB filter bandwidth (BW 3dB). Alternatively, the corresponding noise-equivalent bandwidth (BW NEP) or the integration time constant (TC) can be displayed and entered. The output of the demodulator filter is read out at a rate of 104.6 Hz, implying that 104.6 data samples are sent to the internal MFLI computer per second with equidistant spacing. These samples can be viewed in the Numeric and the Plotter tool which we will examine now.

Note

1. The rate should be about 7 to 10 times higher than the filter bandwidth chosen in the Low-Pass Filter section. When entering a number in the Rate field, the new rate is automatically set to the closest available value - in this case 104.6 Sa/s.
2. If you don't see any signal in the Plotter, Numeric, Spectrum, SW Trigger, or Sweeper tab, the first thing to check is whether the corresponding data stream is enabled

The Numeric tool provides the space for 16 or more measurement panels. Each of the panels has the option to display the samples in the Cartesian (X,Y) or in the polar format (R,Θ) plus other quantities such as the Oscillator Frequencies and Auxiliary Inputs. The unit of the (X,Y,R) values are by default given in V_{RMS}. The scaling and the displayed unit can be altered in the Signal Input section of the Lock-in tab. The numerical values are supported by graphical bar scale indicators to achieve better readability, e.g. for alignment procedures. Certain users may observe rapidly changing digits. This is due to the fact that you are measuring thermal noise that is maybe in the μV or even nV range depending on the filter settings. This provides a first glimpse of the level of measurement precision offered by your MFLI Instrument. If you wish to play around with the settings, you can now change the amplitude of the generated signal, and observe the effect on the demodulator output.

Next, we will have a look at the Plotter tool that allows users to observe the demodulator signals as a function of time. It is possible to adjust the scaling of the graph in both directions, or make detailed measurements with 2 cursors for each direction. You can find a variety of handy tools for immediate analysis in the Math sub-tab, allowing you to accurately measure noise amplitude, peak positions and heights, signal background and many more. Figure 3.3 shows the signal along with additional graphical elements that are dynamically added to the plot when e.g. using the histogram functionality from the Math sub-tab.

Signals of the same unit are automatically added to the same default y-axis group. This ensures that the axis scaling is identical. Signals can be moved between groups. More information on y-axis groups can be found in Section 4.1.3. Try zooming in along the time dimension using the mouse wheel or the icons below the plot to display about one second of the data stream. While zooming in, the mode in which the data are displayed will change from a min-max envelope plot to linear point interpolation. The LabOne Web Server makes this choice depending on the density of points along the horizontal axis as compared to the number of pixels available on the screen.

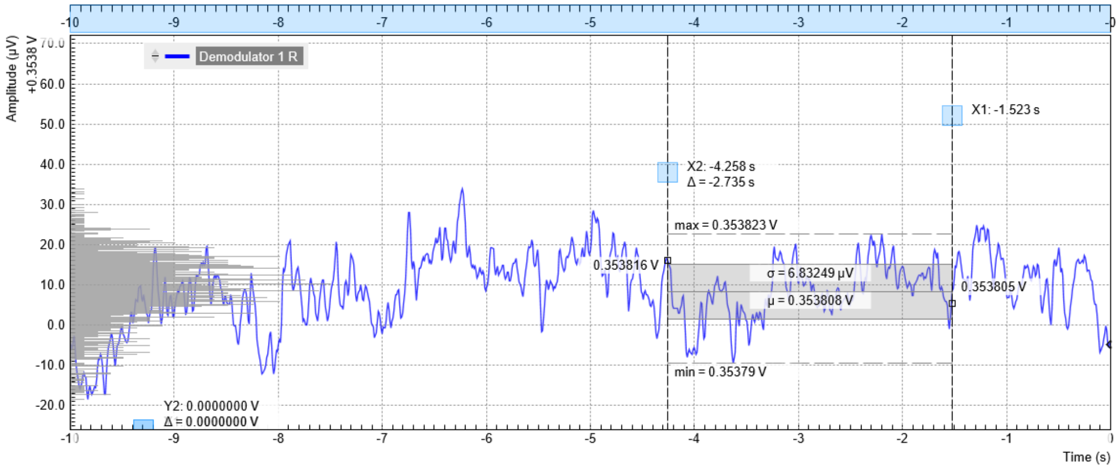


Figure 3.3. LabOne User Interface Plotter displaying demodulator results continuously over time (roll mode)

Data displayed in the Plotter can also be saved continuously to the instrument memory and easily transferred to the host computer. Please have a look at Section 4.1.4 for a detailed description of the data saving and recording functionality. Instrument and user interface settings can be saved and loaded using the Config tab (Settings section).

3.1.6. Different Filter Settings

As next step in this tutorial you will learn to change the filter settings and see their effect on the measurement results. For this exercise, change the 3 dB bandwidth to 1 kHz.

Table 3.4. Settings: change the filter parameters

Tab	Section	#	Label	Setting / Value / State
Lock-in	Low-Pass Filter	1	Order	3 (18 dB/Oct)
Lock-in	Low-Pass Filter	1	BW 3dB	1 kHz
Lock-in	PC Data Transfer	1	Rate	6.7 kSa/s

Increasing the filter bandwidth reduces the integration time of the demodulators. This will increase available time resolution but in turn make the signal noisier, as can be nicely observed in the Plotter tab. Note that it is recommended to keep the sample rate 7 to 10 times the filter 3 dB bandwidth. The sample rate will be rounded off to the next available sampling frequency. For example, typing 7 k in the Rate field will result in 6.7 kSa/s which is sufficient to not only properly resolve the signal, but also to avoid aliasing effects.

Moreover, you may for instance "disturb" the demodulator with a change of test signal amplitude, for example from 0.5 V to 0.7 V and back. The plot will go out of the display range which can be re-adjusted by pressing the "Rescale" button , cf. Section 4.1.3. With an increasing time constant, the demodulated data react more and more slowly to the change in the input signal. In addition, the number of stable significant digits in the Numeric tab will also be higher with a large time constant.

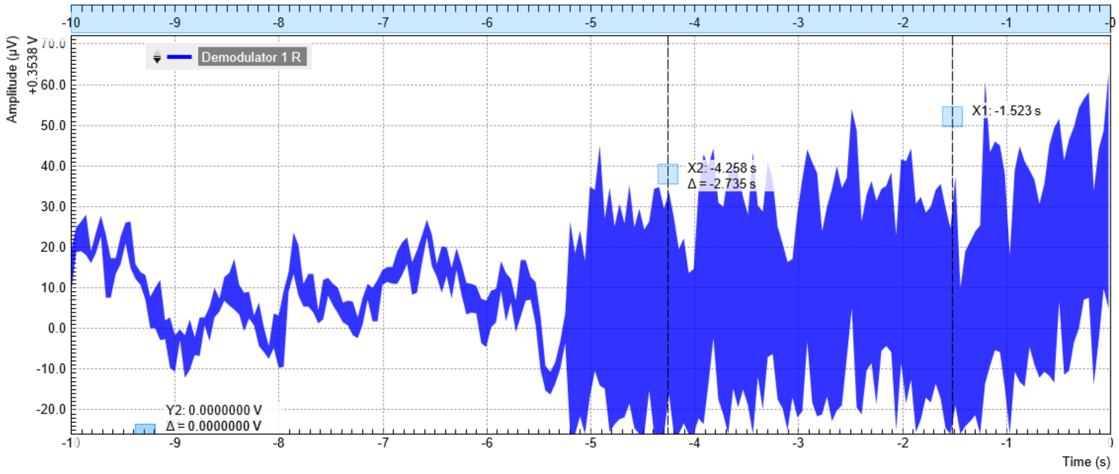


Figure 3.4. LabOne User Interface Plotter displaying demodulator results while changing the filter bandwidth from 10 Hz to 1 kHz

3.2. External Reference

Note

This tutorial is applicable to all MFLI Instruments. No specific options are required. The user interface has slight differences depending on whether the MF-MD Multi-demodulator option is installed or not. The tutorial provides separate instructions for both cases.

3.2.1. Goals and Requirements

This tutorial explains how to lock an internal oscillator to an external reference frequency, and then demodulate a measurement signal at a harmonic of this frequency. To follow this tutorial, you need an optical chopper as well as a standard optical detector/emitter pair. However, the tutorial applies to any comparable setup in which separate reference and signal channels are available. The reference channel should have a sufficiently large amplitude (e.g., TTL level) to allow for reliable locking.

3.2.2. Preparation

Connect the cables as shown in Figure 3.5. Make sure the MFLI is powered on, and then connect the MFLI through USB to your PC, or to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

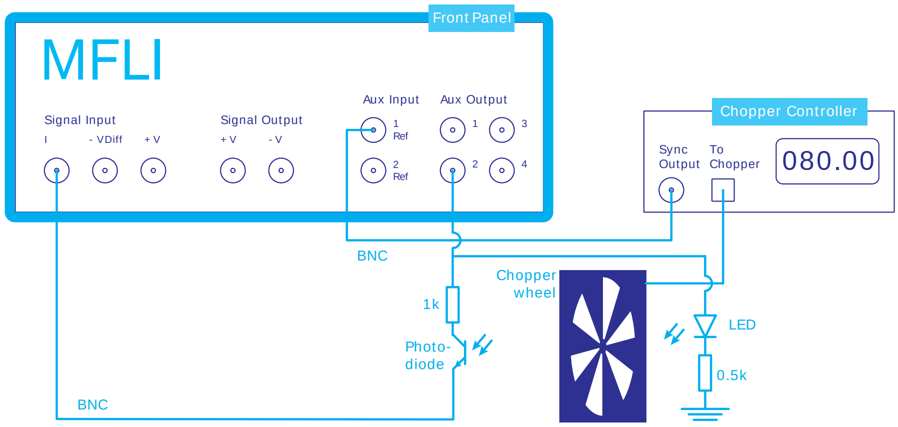


Figure 3.5. Setup for the external reference measurement with optical chopper, LED, and photo diode.

3.2.3. Activate the External Reference Mode

The reference signal is wired from the sync output of the optical chopper to the Aux Input 1/Ref of the MFLI. In our case, the reference signal is a square signal switching between 0 V and 5 V. We choose a base frequency of 80 Hz on the chopper. You can inspect the signal easily by going to the Scope tab and selecting Aux In 1 Ch 1 as the input signal.

Locking the internal oscillator to the external signal looks slightly different depending on the installed options, notably if the MF-MD Multi-demodulator option is installed or not. We therefore describe the required steps separately for both cases.

Without MF-MD Multi-demodulator option: Open the graphical Lock-in tab. In the Internal/External Reference section on the bottom row of that tab, the section label is actually a control which can be toggled between Internal Reference (default) and External Reference. Set it to External Reference. To the right of that control, you can now select the input signal. Select Aux In 1 as the input signal. These settings are also shown in Figure 3.6. The frequency value displayed in the center of the reference section should quickly convert to the 80 Hz of the chopper. The Lock-in settings used to lock to the external reference without MF-MD Multi-demodulator option are shown in the following table.

Table 3.5. Settings: set up external reference mode (without MF-MD option)

Tab	Section	#	Label	Setting / Value / State
Lock-in	Internal/External Reference	1	Internal/External Reference	External Reference
Lock-in	Internal/External Reference	1	Internal/External Reference	Aux In 1

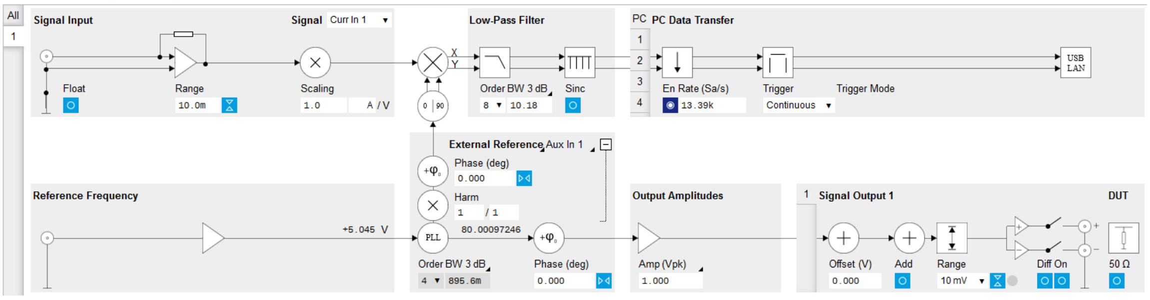


Figure 3.6. Lock-in tab with settings for external reference (without MF-MD option)

With MF-MD Multi-demodulator option: Open the graphical Lock-in tab of the second demodulator. We use this demodulator to establish the phase-locked loop (PLL) between the internal oscillator 1 and the external signal. In the Reference section at the bottom left of the Lock-in tab, select ExtRef in the Mode field and select oscillator number 1. In the Signal Input section top left, select Aux In 1 as the input signal. These settings are also shown in Figure 3.7. The frequency of oscillator 1 displayed in the Reference section should quickly converge to the 80 Hz of the chopper. The Lock-in settings for enabling the lock to the external reference with MF-MD Multi-demodulator option are shown in Table 3.6.

Table 3.6. Settings: set up external reference mode (with MF-MD option)

Tab	Section	#	Label	Setting / Value / State
Lock-in	Reference	2	Mode	ExtRef
Lock-in	Reference	2	Osc	1
Lock-in	Signal Input	2	Signal	Aux In 1

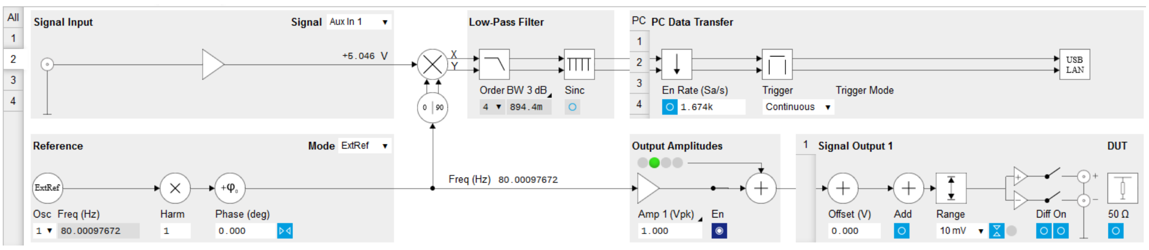


Figure 3.7. Lock-in tab with settings for external reference (with MF-MD option)

At this point, it is worth noting that the external reference signal is never used directly for demodulation. Instead, the frequency and phase of the external reference signal are mapped onto one of the internal oscillators through an internal phase-locked loop. This internal oscillator can then serve as a reference for any of the demodulators.

This mapping procedure is implemented with an automatic bandwidth adjustment that ensures quick locking over the whole instrument bandwidth. It covers a large variety of signal qualities in terms of frequency stability and signal-to-noise ratio. Over the course of automatic adjustment, the Low-Pass Filter bandwidth of the associated demodulators 2 or 4 usually ramps down until a final value is reached after a few seconds. The indicated bandwidth also marks an upper limit to the bandwidth of the phase-locked loop that does the mapping of the external signal to the internal oscillator. Figure 3.8 shows a typical result in the Plotter for the frequency tracking immediately after it is turned on. For such a measurement, open the Plotter tab and add the corresponding signal to the plot (Control sub-tab, Vertical Axis Groups, Frequency, Channel 1, Add Signal).

Note

With the MF-MD Multi-demodulator option installed, you can alternatively look at the phase error (Control sub-tab, Vertical Axis Groups, Demod Theta, Channel 2, Add Signal). Be sure to enable the corresponding data stream in the PC Data Transfer section of the corresponding Lock-in tab.

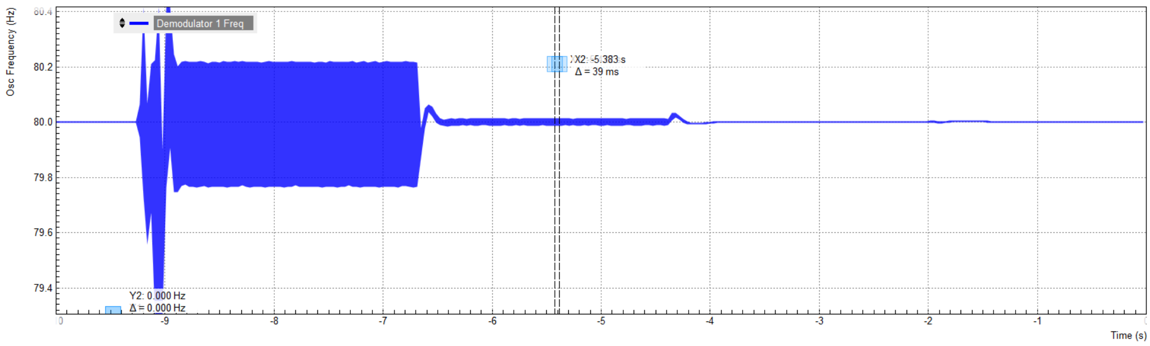


Figure 3.8. Frequency of the internal oscillator over time with stepwise automatic bandwidth adjustment

3.2.4. Measure at a Harmonic of the Reference Frequency

For our optical demonstration measurement, we use a Vishay TCRT5000 infrared detector/emitter pair whose light is passed through the optical chopper. The detector is a photo diode, the emitter an LED, and both are biased directly by the Auxiliary Output 2 through a simple circuit as shown in Figure 3.5. We current-bias the LED with 10 mA by applying 5 V across a 500 Ω resistor. The 1 kΩ resistor in series with the photo diode is merely a limiter. Note that the circuit by design can't exceed the damage threshold of the MFLI (5 V on the 50 Ω I input).

The current generated by the photo diode contains an offset contribution, typically due to ambient light, and a modulation contribution due to the chopper. Both are in the range of some μA in our case, allowing us to use the higher input sensitivity of 100 μA instead of 10 mA and thus improve the input noise. The chopper wheel used for this experiment has a multiplier of 10, so the optical signal is actually modulated at a frequency of 800 Hz. This places us further away from the 50/60 Hz utility frequency without having to use a high revolution speed of the chopper.

We will use the harmonics functionality to internally generate an 800 Hz demodulation reference from the 80 Hz external reference. Setting this up again presents slight difference depending on the installed options, so we describe the required steps with and without installed MF-MD Multi-demodulator option.

Without MF-MD Multi-demodulator option: In the Signal Input section of the graphical Lock-in tab, select Current Input 1 and change the input range to 100 μA. In the External Reference Section, set the Harmonic (Harm) to 10 / 1. Note that this setting is hidden by default. You can get access to this setting by expanding the section with a click on the + symbol on the top right of the section. You should now observe a numerical display of the demodulator reference frequency close to 800 Hz as shown in Figure 3.9. Finally, set the Low-Pass Filter to 100 Hz (3rd order) and enable the data stream in the PC Data Transfer section.

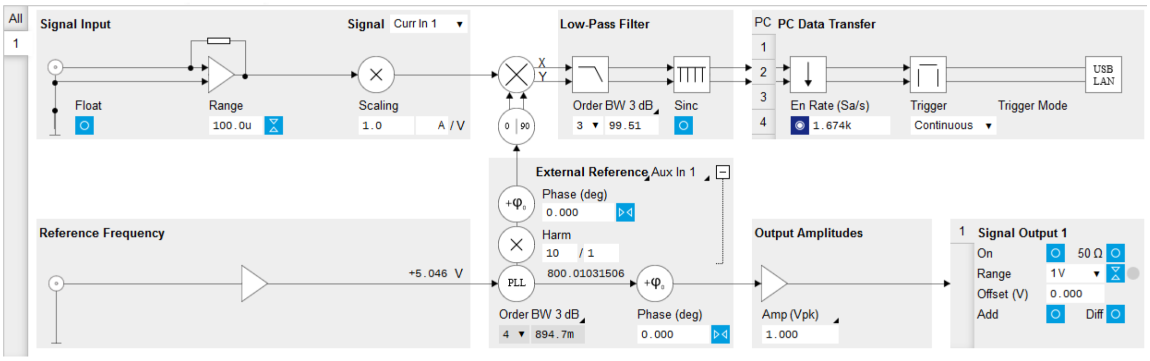


Figure 3.9. Lock-in tab set up for measurement at 800 Hz (without MF-MD option)

Table 3.7. Settings: lock-in detection at a harmonic of the external reference frequency (without MF-MD option)

Tab	Section	#	Label	Setting / Value / State
Lock-in	External Reference	1	Harm	10 / 1
Lock-in	Signal Input	1	Signal	Current Input 1
Lock-in	Signal Input	1	Range	100 μA

With MF-MD Multi-demodulator option: Open the graphical Lock-in tab of the first demodulator. We use this demodulator to perform the lock-in detection. In the Signal Input section of the graphical Lock-in tab, select Current Input 1 and change the input range to 100 μA. In the Reference section, choose Oscillator 1 and set the Harmonic (Harm) to 10, cf. Figure 3.10. In the circuit diagram of the graphical Lock-in tab, you should observe the numeric value of the demodulation frequency, 800 Hz. Set the Low-Pass Filter to 100 Hz (3rd order) and enable the data stream in the PC Data Transfer section.

Table 3.8. Settings: lock-in detection at a harmonic of the external reference frequency (with MF-MD option)

Tab	Section	#	Label	Setting / Value / State
Lock-in	Reference	1	Harm	10
Lock-in	Signal Input	1	Signal	Current Input 1
Lock-in	Signal Input	1	Range	100 μA

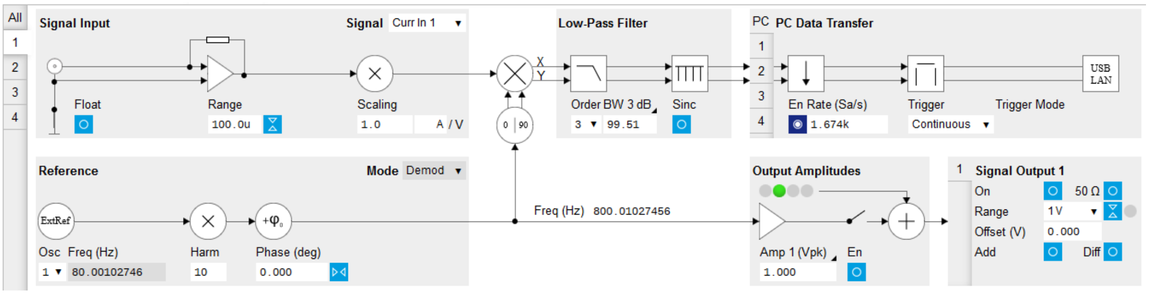


Figure 3.10. Lock-in tab setup for measurement at 800 Hz (with MF-MD option)

Note

The filter bandwidth should be well below the modulation frequency ω in order to suppress the 2ω signal component (see Section 6.5). Here we use a filter bandwidth of 100 Hz at a modulation frequency ω of 800 Hz.

3.2.5. Plot the Measurement Results

Having set up the demodulation at 800 Hz, we are ready to check the measurement data. Open the Plotter tab. In the Control sub-tab, select the Enabled Demods R setting in the Presets list. Figure 3.11 shows a plot of the photo diode current in which the light path between emitter and detector was manually intersected a number of times to show the measurement contrast. When the light path is open (except for the chopper wheel), we measure a constant rms current of about 15.5 µA, and whenever we block the light path the current drops to zero.

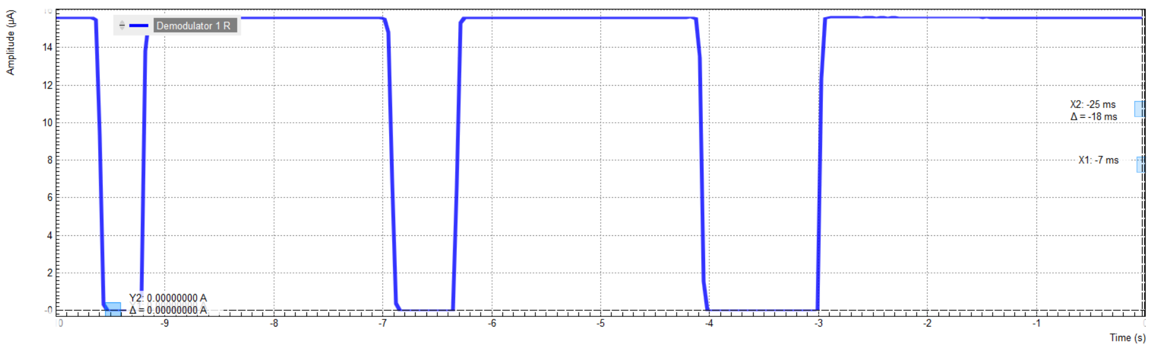


Figure 3.11. Photo diode signal continuously plotted with the LabOne Plotter

3.3. Sweeper

Note

This tutorial is applicable to all MFLI Instruments with the MF-MD Multi-demodulator option installed. The MD option is required for four-terminal measurements with simultaneous detection of voltage and current.

3.3.1. Goals and Requirements

This tutorial explains how to use the LabOne Sweeper to perform measurements on a MOSFET (Metal-oxide-semiconductor field-effect transistor). The goal of the tutorial is to demonstrate typical steps in the work flow of a lock-in measurement using the LabOne toolset using the MOSFET as a demonstration system. To follow this tutorial, you need a MOSFET with specifications similar to those of the IRLML2502. However, many of the working steps have a generic character and can be adopted to a multitude of transport measurement situations.

The goal of the tutorial is not to provide instructions for MOSFET characterization. This is a sophisticated measurement task and lies beyond the scope of this tutorial.

3.3.2. Preparation

We perform these measurement on a IRLML2502 power MOSFET manufactured by International Rectifier, but many other MOSFETs allow similar measurements with certain adjustments to the parameters. Connect the cables as shown in Figure 3.12. Make sure the MFLI is powered on, and then connect the MFLI through USB to your PC, or through an Ethernet cable to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened in the browser. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

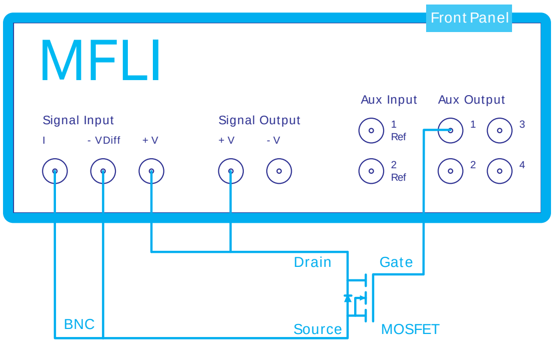


Figure 3.12. Setup for the MOSFET measurements.

3.3.3. Tune the Gate–Source Voltage

We start by configuring the lock-in to detect the source current of the MOSFET. Open the Lock-in tab of the first demodulator. In the Reference section choose oscillator 1 and set the frequency to 1 kHz. In the Signal Input section, select Current Input 1 as the signal and set the range to 10 mA. In the Low-Pass Filter section, set the filter 3 dB bandwidth to 10 Hz.

We will operate the MOSFET with a negative drain–source offset voltage. On top of that, we apply a small alternating drain–source voltage. This is an unusual regime for the MOSFET. But it allows to operate the device in a configuration of linear response to the alternating drain–source voltage while having offset currents within the range of the MFLI Signal Input I.

In the Output Amplitudes section, set Amplitude 1 to 10 mVrms and enable the output. In the Signal Output section, set Offset to −100 mV and turn on the output. Finally, enable the data transfer of demodulator 1 in the PC Data Transfer section. The following table summarizes the settings to be made.

Table 3.9. Settings: MOSFET source current measurement

Tab	Section	#	Label	Setting / Value / State
Lock-in	Reference	1	Osc	1
Lock-in	Reference	1	Freq	1 kHz
Lock-in	Signal Input	1	Signal Input	Curr In 1
Lock-in	Signal Input	1	Range	10 mA
Lock-in	Low-Pass Filter	1	BW 3dB	100 Hz
Lock-in	Output Amplitudes	1	Amp 1 (Vrms)	100 mVrms
Lock-in	Output Amplitudes	1	En	On
Lock-in	Signal Output	1	Offset	−100 mV
Lock-in	Signal Output	1	On	On
Lock-in	PC Data Transfer	1	En	On

The MOSFET gate is connected to the Auxiliary Output 1. Using the Aux tab, we can configure this output to generate a constant voltage. In the Aux Output section, set the Signal of the first Auxiliary Output to Manual. Now it is possible to output an arbitrary voltage using the Offset field. If you play around with that value while observing the MOSFET current in the Plotter or the Numeric tab, you can observe the behavior of the MOSFET as a tunable resistor. Our model is an n-channel device, therefore negative gate-source voltages lead to a suppression of the current and positive voltages of a few Volts open up the MOSFET channel. The following table summarizes the settings to be made.

Before we continue, let us shortly discuss the effect of series resistances in our measurement setup. Taking a quick glance at Figure 3.12keeping in mind that Signal Input I represents a virtual ground. We would conclude that the voltage on Signal Output +V is equal to the drain–source voltage of the MOSFET, and the voltage on Auxiliary Output 1 is equal to the gate-source voltage. In reality, this is not exact, since Signal Output +V, Signal Input I, and the Auxiliary Outputs have a 50 Ω impedance connected in series internally. As soon as there is significant current flow on either of the three connectors, the actual potential at the corresponding MOSFET contact is altered. This correction is negligible for the gate contact which is essentially isolating, but it can be important for the source and drain contacts.

In the first part of the tutorial we will focus on the region with partially closed MOSFET channel. In this high-impedance configuration, we can make the assumption that currents and corrections are small. In the second part of the tutorial we will focus on the region with open MOSFET channel. In this low-impedance configuration, we instead use a four-terminal measurement to properly account for the corrections.

3.3.4. Sweep the Gate–Source Voltage

We will now set up a sweep of the MOSFET gate voltage. Open the Sweeper tab and in the Control sub-tab, choose Aux Out 1 Offset as Sweep Parameter. Enter Start and Stop values of 0 V and 1 V, respectively, and set Length to 100 points. Disable the Log check box so the measurement points will be linearly distributed over the interval between 0 V and 1 V.

In a Sweeper measurement, some care has to be taken in choosing a sweep speed compatible with the measurement bandwidth. If the time per point is too short, systematic errors can occur due to insufficient settling of the measurement value. You can usually let the LabOne Sweeper take care of this. Choose Application Mode in the Filter field of the Settings sub-tab. The Sweeper then chooses useful sweep parameters and adjusts the demodulator filter settings for a number of pre-defined application cases. We select the general-purpose "Parameter Sweep Averaged" case in the Application field. Please refer to Section 4.9 for further information.

Note

It may be that the measurement bandwidth is limited by the device under test and not by the demodulator filter. The Sweeper can not account for this, as it only knows the demodulator filter bandwidth but not the properties of the device. If you're unsure whether the sweep is too fast, check for hysteresis in the measurement by setting the Sweep Mode to Bidirectional in the Control sub-tab. If custom sweep settings appear necessary, you can access them in the Advanced Mode from the Settings sub-tab.

Table 3.10. Settings: MOSFET gate voltage sweep

Tab	Section	#	Label	Setting / Value / State
Sweeper	Control		Sweep Param	Aux Out 1 Offset
Sweeper	Control		Start	0 V
Sweeper	Control		Stop	1 V
Sweeper	Control		Length	100 points
Sweeper	Control		Log	Off
Sweeper	Settings		Filter	Application Mode
Sweeper	Settings		Application	Parameter Sweep Averaged

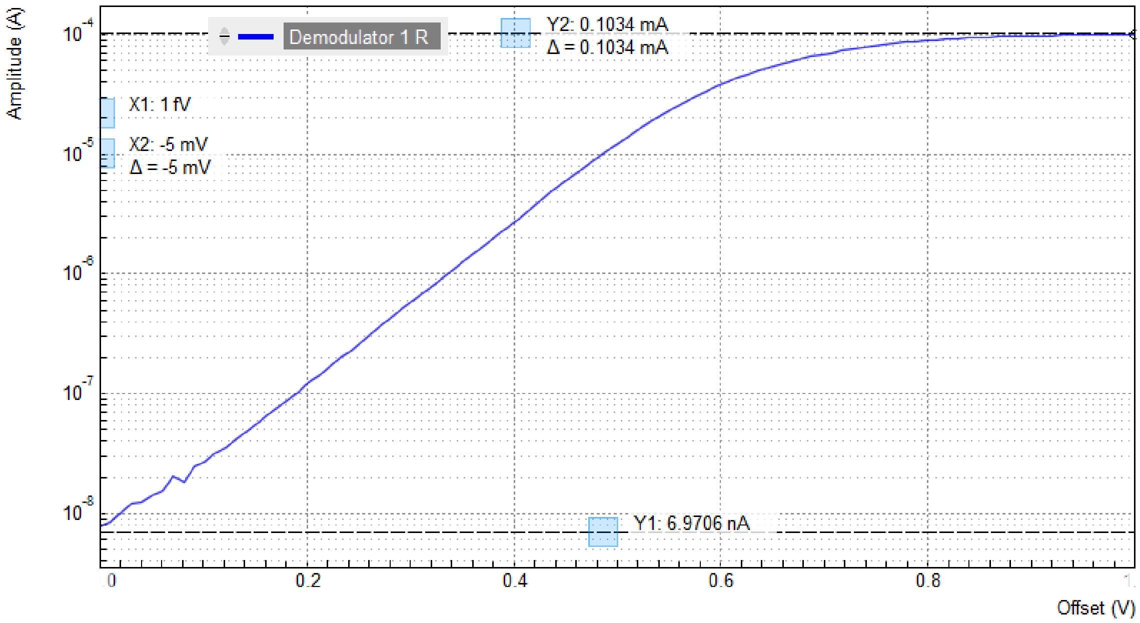


Figure 3.13. Gate voltage dependence of the MOSFET source current measured with the LabOne Sweeper

Figure 3.13 shows the result of the gate voltage sweep. For gate voltages below about 0.5 V, we observe an exponential suppression of the drain current. For higher voltages, the current eventually saturates at about 0.1 mA. This value is determined by the Signal Output +V amplitude of 10 mV and the cumulated 100 Ω series resistance of the MFLI input and output impedances, two times 50 Ω. Note that in this plot, the signal amplitude goes down to about 10 nA, a level of about -120 dB relative to the input range of 10 mA! This gives you an impression of the accessible dynamic range of the MFLI Instrument.

3.3.5. Four-Terminal Resistance Measurement

In the measurements shown so far in this tutorial, we effectively employed a two-terminal method. As long as the device under test has a large impedance, like the MOSFET with a partly closed channel, this is adequate and has the benefit of being simple. In the opposite case of small device impedance, the effect of series impedances in the cabling and Signal Outputs and Inputs, can become increasingly dominant. It is then more appropriate to employ a four-terminal method.

In our case, we may be interested in the MOSFET properties in the On state, in which its channel resistance is well below 1 Ω. In order to measure this On-resistance, we continue to measure the alternating current as we did up to now. We add a measurement of the alternating voltage drop across the MOSFET channel using the differential Signal Input of the MFLI.

We configure the second demodulator to perform this voltage measurement. Open the Lock-in tab of the second demodulator. In the Reference section, select Oscillator 1. In the Signal Input section, select Signal Input 1 and enable differential measurement by enabling the check box labeled Diff. Set the range to 1 mV and enable the data transfer of demodulator 1 in the PC Data Transfer section. The following table summarizes the settings to be made.

Table 3.11. Settings: MOSFET gate voltage sweep

Tab	Section	#	Label	Setting / Value / State
Lock-in	Signal Input	2		Sig In 1
Lock-in	Signal Input	2	Diff	ON

Tab	Section	#	Label	Setting / Value / State
Lock-in	Signal Input	2	Range	1 mV
Lock-in	Reference	2	Osc	1
Lock-in	PC Data Transfer		En	ON

In order to obtain a clean four-terminal measurement, the voltages probe on the MOSFET source and drain should be as close to the device under test as possible. The best is to use point probes directly on the MOSFET contacts to eliminate the effect of soldering joint resistances.

At a gate voltage (Aux Output 1) of 4 V and an excitation voltage of 100 mVrms (Signal Output 1), we can check the measurement data on the Numeric tab. We measure a source current of 1.00 mA and a source-drain voltage of 0.027 mV. This corresponds to an On-resistance of 27 mΩ in accordance with the device specifications. Figure 3.14 and Figure 3.15 show the source current and two-terminal drain–source voltage of the MOSFET over a larger gate voltage range.

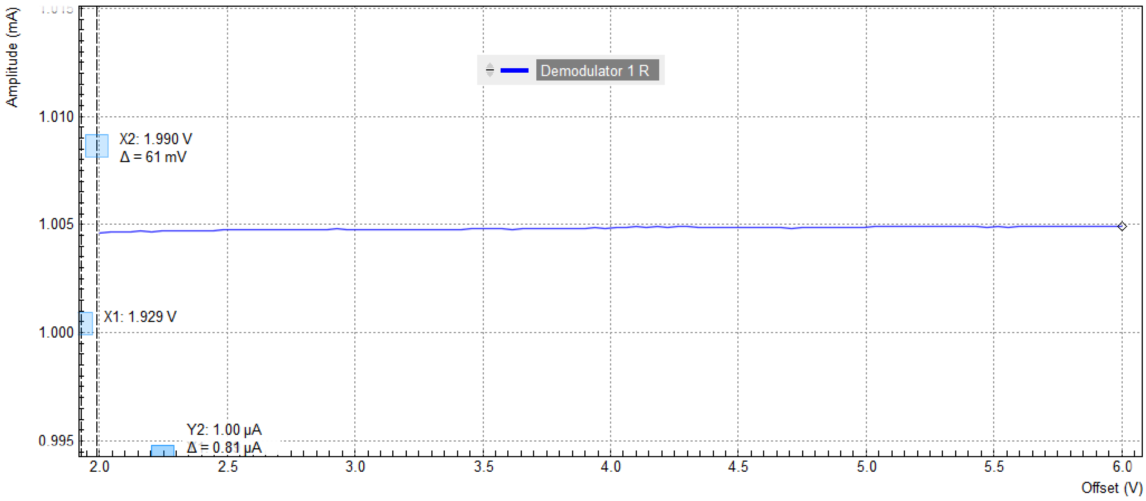


Figure 3.14. Gate voltage dependence of the MOSFET source current measured with the LabOne Sweeper in a four-terminal setup

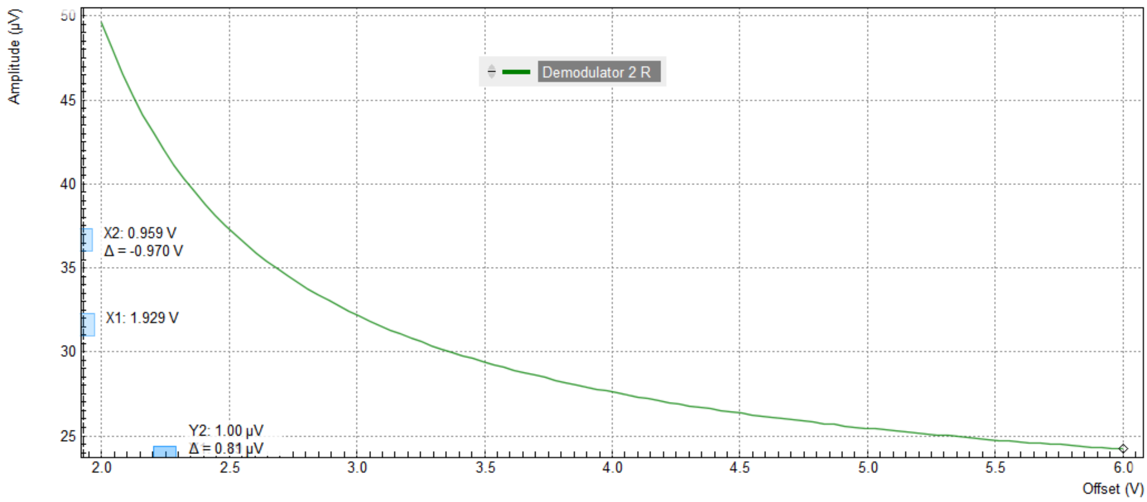


Figure 3.15. Gate voltage dependence of the MOSFET drain–source voltage measured with the LabOne Sweeper in a four-terminal setup

3.4. Impedance Measurement

Note

This tutorial is applicable to all MFIA Instruments and to MFLI Instruments with the MF-IA Impedance Analyzer option installed.

3.4.1. Goals and Requirements

This tutorial is for people with no or little prior experience with Zurich Instruments impedance analyzers. By using a very basic measurement setup, this tutorial shows the fundamental working principles of the MFLI Instrument and the LabOne user interface in a step-by-step hands-on approach.

The tutorial requires the MFITF Impedance Test Fixture.

3.4.2. Preparation

This tutorial guides you through the basic steps to perform a simple measurement of the 1 kΩ test resistor delivered with the MFITF Impedance Test Fixture. Start by connecting the MFITF to the BNC connectors on the front panel of the MFLI, and plug the resistor labeled "1k" and "4Pt" into the 8-pin connector on the front of the test fixture. Figure 3.16 shows a diagram of the hardware setup.

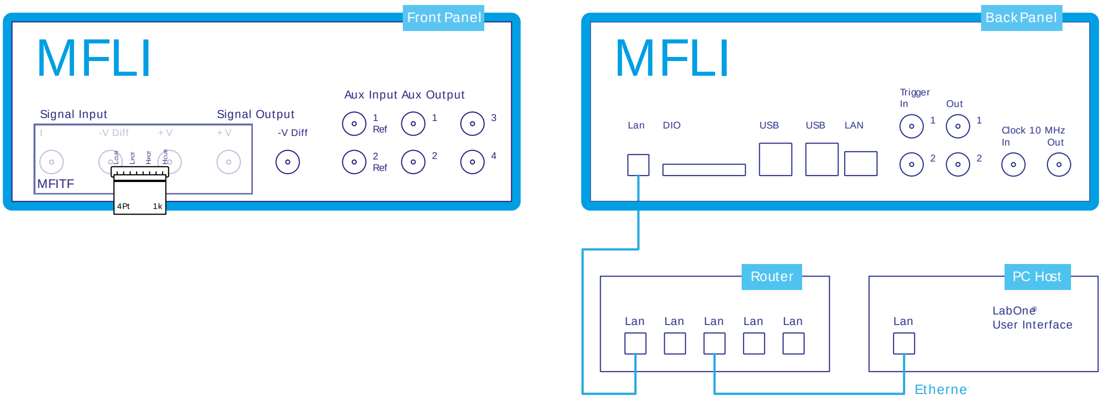


Figure 3.16. Setup for the Impedance Measurement Tutorial

Make sure that the MFLI Instrument is powered on and then connect the MFLI directly by USB to your host computer or by Ethernet to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

3.4.3. Configure the Impedance Analyzer

The Impedance Analyzer tab shown in Figure 3.17 provides you with the necessary settings to start measuring impedance. Open the tab by clicking on the corresponding icon on the left side of the user interface. For a quick measurement of the 1 kΩ device-under-test (DUT), the default settings are suitable. All we have to do is to click the Enable button on top left of the Impedance Analyzer tab in order to turn on the drive signal and start the measurement. This will override some of the settings made in the Lock-in tab. Since automatic range control is enabled by default, the current and voltage input ranges will be adjusted within a few seconds and the measurement starts.

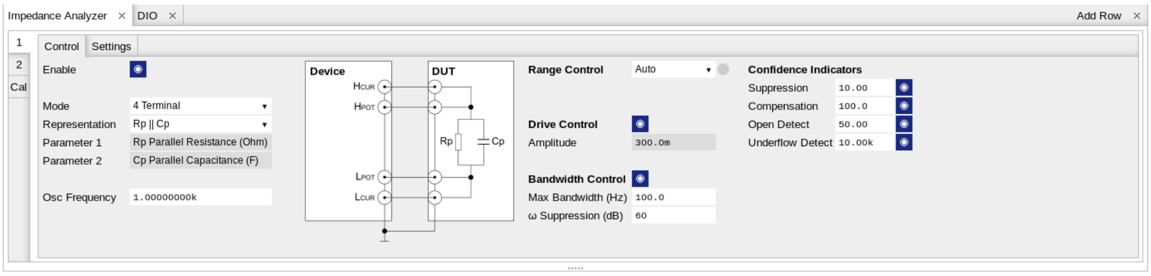


Figure 3.17. Impedance Analyzer tab

The measurement result is now shown in the Numeric tab. This tab is open in the bottom half of the screen by default. Select the Impedance preset in the Presets sub-tab. The Numeric tab shown in Figure 3.18 is organized in panels which display the impedance Z_{DUT} in Cartesian and in polar form and other parameters. You can add more panels using the Tree sub-tab on the right if you wish to monitor other quantities such as bias voltage. Every numerical value is supported by a graphical bar scale indicator for better readability. We read an impedance absolute value Abs(Z) of 999.8 Ω, and a complex phase Phase(Z) of nearly 0 degrees, nicely corresponding to the 1 kΩ DUT that we plugged in.

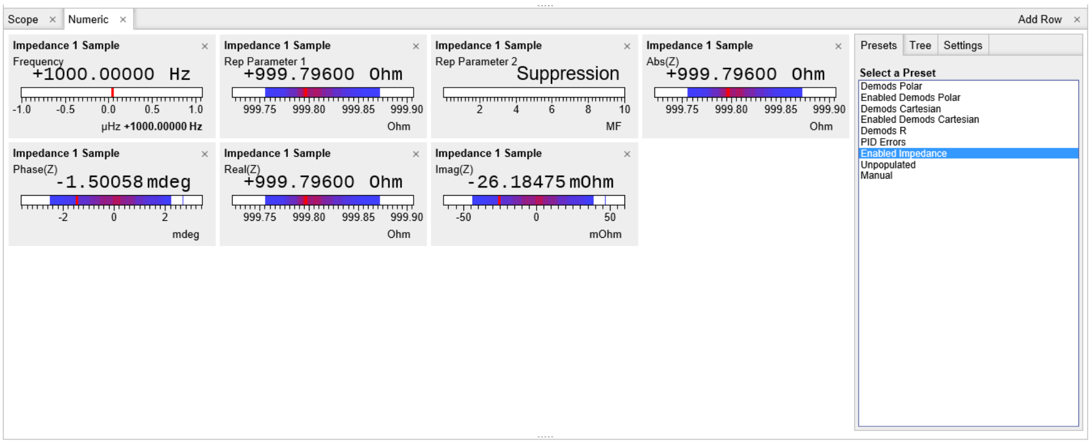


Figure 3.18. Numerical tab displaying measured impedance and circuit representation parameters

3.4.4. Measure Frequency Dependence

The frequency is a critical measurement parameter The frequency can be changed manually by clicking on the Osc Frequency field, typing a value such as 1000 or 1k in short press either <TAB> or <ENTER> on your keyboard to apply the setting. For a more systematic measurement of the frequency dependence, we'll turn to the Sweeper tool introduced previously in Section 3.3.4.

Open the Sweeper tab by clicking on the corresponding icon on the left side of the user interface. Select the Application Mode in the Settings sub-tab of the Sweeper, and Impedance as the Application.

Add the measured absolute value of the impedance to the plot by selecting "IA Abs(Z)" as Signal Type clicking on "Add Signal". In the Control sub-tab you can configure the sweep parameter, the sweep range and resolution. Set the start and stop frequency to 1 kHz and 1 MHz. By default, the sweeper is set to divide this span into 100 points on a logarithmic grid. Both of these settings are configurable, as well as the Sweep Parameter. The following table summarizes the Sweeper settings we use.

Table 3.12. Settings: configure the Sweeper for frequency dependence measurement

Tab	Sub-tab	Section	#	Label	Setting / Value / State
Sweeper	Settings			Filter	Application Mode
Sweeper	Settings			Application	Impedance
Sweeper	Control	Horizontal		Sweep Param	Osc 1 Frequency
Sweeper	Control	Horizontal		Start / Stop	1k / 1M
Sweeper	Control	Horizontal		Length	100 pts

Start the frequency sweep by clicking on Single. The screenshot in Figure 3.19 shows the measurement in the plot section of the Sweeper tab. It shows a perfectly flat curve for the real part of the impedance Abs(Z) within 0.05% of 1 kΩ as is indicated with the cursor for the vertical axis. Whereas our 1 kΩ DUT has no notable frequency dependence between 1 Hz and 1 MHz, very large or small resistors will typically show a change in Abs(Z) towards high frequencies due to the spurious capacitance or inductance.

The plot section features multi-trace and dual-plot functionalities for representing multiple curves with different units, such as Ohm (Ω) and Farad (F), or with very different magnitudes. The plot functionality in LabOne is described in more detail in Section 4.1.3. There you also find a description of the cursor and math functions for quick quantitative analysis of measurement data.

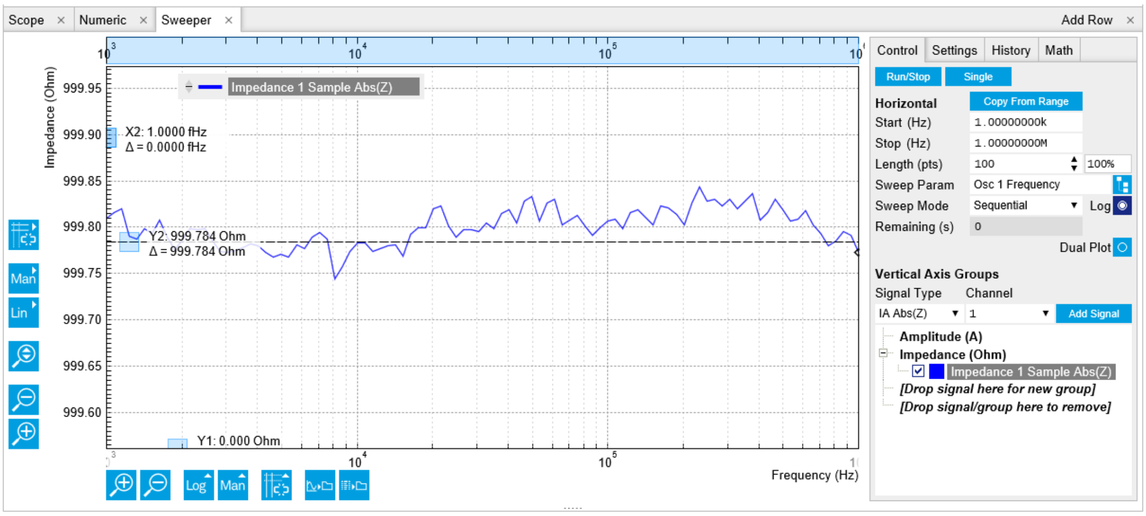


Figure 3.19. LabOne Sweeper showing the frequency dependence of a 1 kΩ DUT

3.4.5. Circuit Representation and Measurement Mode

There are two settings that any user should be aware of before continuing with own measurements: the Measurement Mode, and the DUT Representation. These settings determine the currently active measurement configuration. The configuration is graphically represented by a dynamically updated circuit diagram in the Impedance Analyzer tab.

1. The Measurement Mode (either 2 Terminal or 4 Terminal) corresponds to the way the DUT is wired to the instrument connectors. This determines where the DUT voltage V is measured: on

Signal Input -V and Signal Input +V, or on Signal Output +V. The voltage measurement together with the measurement of the current I on Signal Input I constitutes a measurement of the impedance Z=V/I. For the 1 kΩ DUT, the measurement mode is 4 Terminal because all four connectors Signal Output +V, Signal Input I, Signal Input +V and Signal Input -V are wired to the DUT.

2. The DUT Representation determines how the measured complex-valued impedance Z_{DUT}=V/I is converted into DUT circuit parameters such as resistance and capacitance. For our 1 kΩ resistor, a parallel resistor-capacitor representation Rp || Cp makes sense, even if the parallel capacitance is negligible.

The DUT representation parameters (in our case Representation Parameter 1 = Rp, and Representation Parameter 2 = Cp) are available for display elsewhere in the user interface, e.g. in the Numeric or in the Sweeper tab. In the Numeric tab shown in Figure 3.18, the Model Parameter 1 (Rp) reads 999.8 Ω. The panel of the Model Parameter 2 (Cp) shows no numerical reading but the message "Suppression" instead. This message of the LabOne Confidence Indicator informs you in situations when one of the Model Parameters cannot be determined reliably. In the present case, the current passing through the stray capacitance between the resistor electrodes is too small compared to the current through the resistor itself. Instead of displaying a calculated numeric value with no meaning, the "Suppression" warning prevents you from doing systematic measurement errors.

Apart from "Suppression", there are other Confidence Indicator warnings that can appear. The Confidence Indicator is for instance able to detect missing connections (e.g. when tying to measure a DUT in 4 Terminal mode when it is connected to 2 terminals only), or signal underflow and overflow conditions. The meanings of the different warnings are summarized in Table 4.42 in the Functional Description chapter.

3.4.6. Time Dependence and Filtering

Next, we will have a look at the Plotter tab that allows users to observe measurement data as a function of time, e.g. to measure the long-term stability of a component impedance. Open the Plotter tab by clicking on the corresponding icon on the left, and choose the Impedance preset in the Control sub-tab in order to add a selection of useful quantities to the plot. For a good overview, disable all traces except the resistance (Impedance 1 Representation Parameter 1) using the checkboxes in the Vertical Axis Group section.

The Plotter is a good tool to observe the noise in the measurement. Noise can be efficiently eliminated by low-pass filtering. The MFLI offers automatic bandwidth control which usually provides good noise reduction without unnecessarily slowing down the measurement. Nonetheless it can sometimes be beneficial to optimize the filtering manually, for instance in situations with strong electrical noise. For manual adjustment, disable the Auto Bandwidth Control in the Impedance Analyzer tab (Settings sub-tab). The Low-Pass Filters section now changes from a disabled (greyed-out) state to an editable (white) state. Try different filter bandwidths, e.g. 1 Hz and 100 Hz, to see the live effect on the data as seen in Figure 3.20. More information about filter parameters is found in the Signal Processing Basics Chapter.

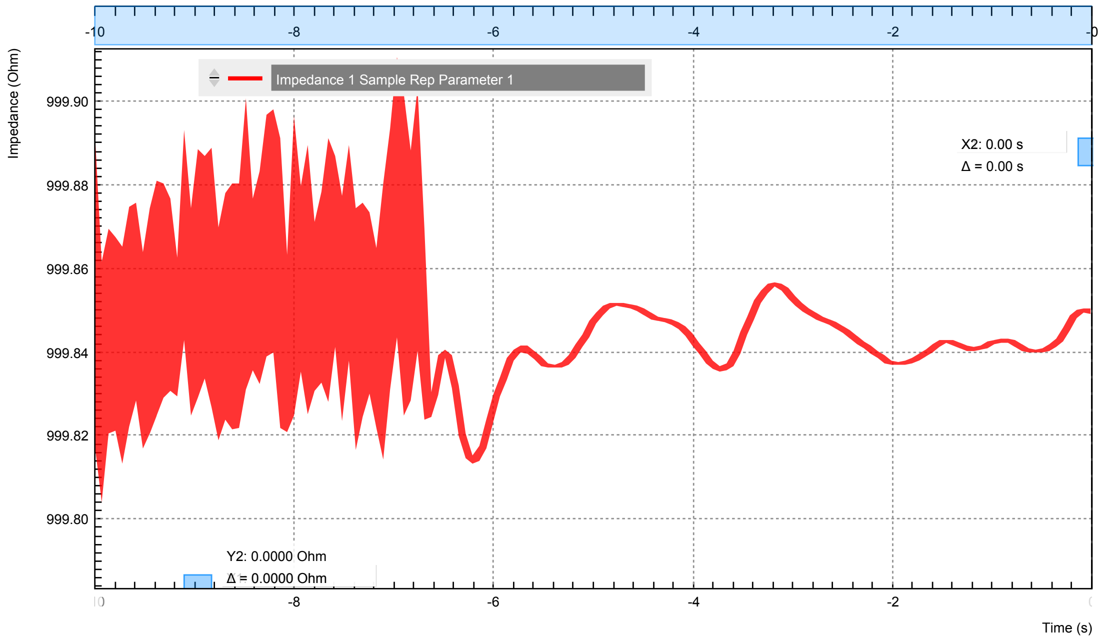


Figure 3.20. LabOne Plotter showing a resistance measurement over time. Changing the filter setting manually leads to a change in noise.

The following table summarizes the Plotter settings we use.

Table 3.13. Settings: configure the Sweeper for frequency dependence measurement

Tab	Sub-tab	Section	#	Label	Setting / Value / State
Plotter	Control	Select a Preset			Impedance
IA	Settings	Bandwidth Control		Auto	OFF
IA	Settings	Low-Pass Filters		BW 3dB	1 Hz / 100 Hz

3.4.7. Measurement Accuracy

The measurement accuracy is one of the key specifications of an impedance analyzer. It relates the measured and the real DUT impedance. The real impedance of the supplied 1 kΩ DUT is within 0.05% of an ideal 1 kΩ resistor in the frequency range of the MFLI, and is therefore suitable to judge the accuracy of the measurement result.

The measurement accuracy is not a universal number but depends on the frequency and on the absolute impedance $|Z_{DUT}|$. Figure 3.21 shows the accuracy across the full parameter space covered by the MFLI. This impedance accuracy chart is a handy tool not only to get the measurement accuracy, but also to quickly obtain the absolute impedance of a capacitance or inductance at a certain frequency. For 1 kΩ (vertical axis) and 1 kHz (horizontal axis), we land in a region with 0.05% accuracy.

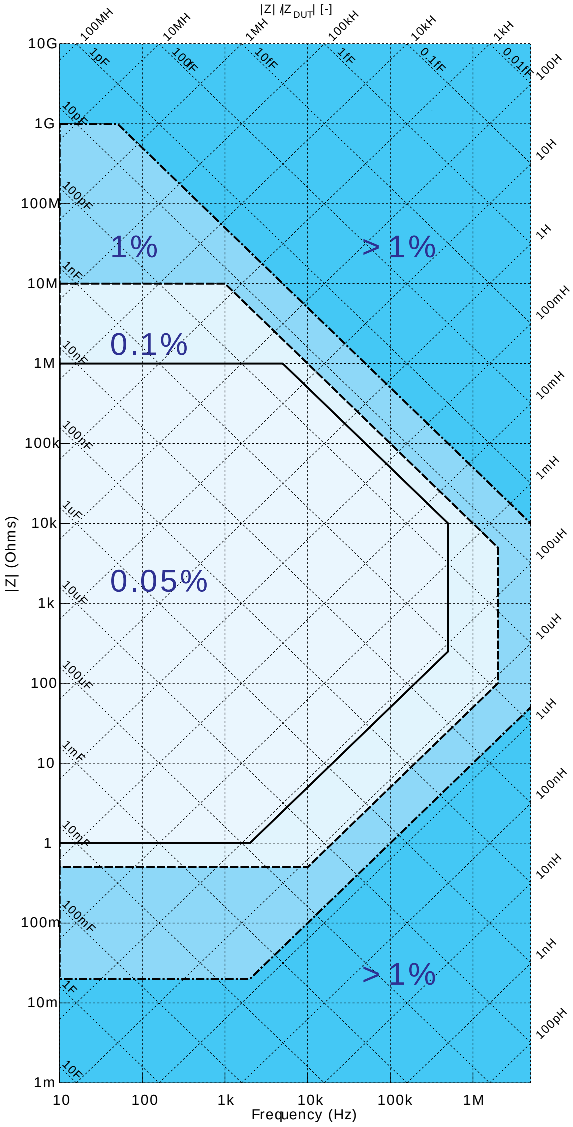


Figure 3.21. Impedance Accuracy chart

Note

The relative accuracy specification of the instrument applies to the measured **total** impedance. Neither does it apply to the real or imaginary parts of the impedance individually, nor to the circuit representation parameters. A 30 minute warm-up time is required to reach the maximum accuracy.

3.5. Advanced Impedance Measurements

Note

This tutorial is applicable to all MFIA Instruments and to MFLI Instruments with the MF-IA Impedance Analyzer option installed.

3.5.1. Goals and Requirements

The goal of this tutorial is to show some more advanced features of the LabOne user interface by guiding through a measurement of a frequency-dependent impedance. We introduce important practical aspects about impedance measurements such as the influence of parasitics, or the effect of parameter suppression.

This tutorial is for people with some starting experience with Zurich Instruments impedance analyzers. To follow this tutorial, you need a 1 MΩ DUT fitting on the MFITF Impedance Test Fixture, e.g. a through-hole resistor soldered to one of the DUT carriers delivered with the MFITF.

3.5.2. Preparation

Start by connecting the MFITF Test Fixture to the BNC connectors on the front panel of the MFLI, and plug the DUT into the 8-pin connector on the front of the test fixture. Figure 3.22 shows a diagram of the hardware setup.

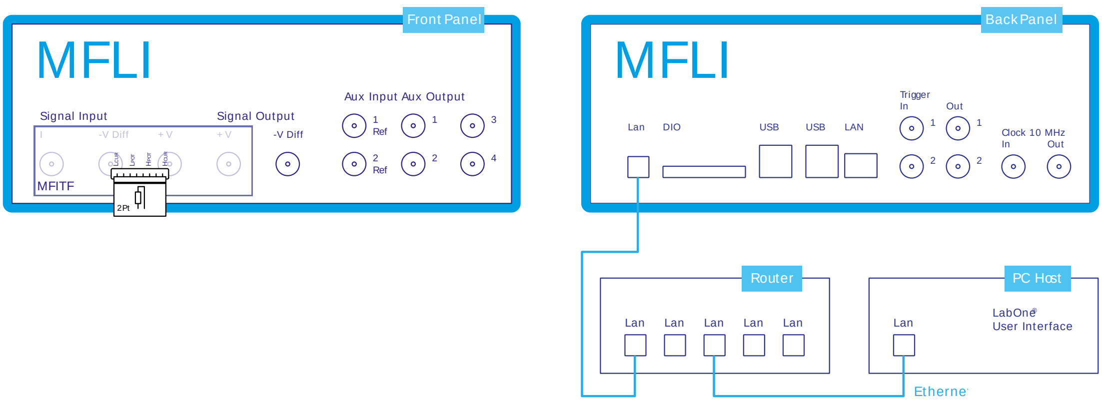


Figure 3.22. Setup for the Impedance Measurement Tutorial

Make sure that the MFLI Instrument is powered on and then connect the MFLI directly by USB to your host computer or by Ethernet to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

3.5.3. Impedance and Representation Parameters

The real impedance of a DUT like the 1 MΩ resistor is not necessarily equal to its nominal, or ideal, value. First of all, the DUT impedance value is only specified within some accuracy, e.g.

1%. In addition to that imperfection, there are spurious impedance components such as lead inductance, or parallel capacitance. For the given 1 MΩ resistor, the real impedance is indeed close to that of a parallel Rp||Cp circuit, with a parallel capacitor Cp of some hundreds of fF. This real impedance, including device imperfections, is what the MFLI measures.

In order to measure the 1 MΩ DUT, we configure the Impedance Analyzer with a suitable DUT Representation of Rp||Cp. Since the DUT carrier we use is connected to 2 leads only, we change the measurement mode to 2 Terminal. Furthermore, we set the Range Control to Impedance, and the range to 1 M. This will set the input current and voltage ranges to suitable values and keep them constant, preventing glitches in the subsequent frequency sweep.

Table 3.14 summarizes the instrument settings we use.

Table 3.14. Settings: configure and enable the impedance analyzer

Tab	Sub-tab	Section	#	Label	Setting / Value / State
IA	Control			Mode	2 Terminal
IA	Control			Representation	Rp || Cp
IA	Control			Osc Frequency	1 k
IA	Control	Auto		Range Control	Impedance
IA	Control	Auto		Range	1 M
IA	Control			Enable	ON

3.5.4. Measure the Frequency Dependence

Open the Sweeper tab (Settings sub-tab), select the Application Mode, and Impedance as the Application. In the Control sub-tab you can configure the sweep parameter, the sweep range and resolution. We choose parameters for a logarithmic frequency sweep from 1 kHz to 1 MHz. We start with a measurement of the absolute impedance $|Z_{DUT}|$. Add this parameter to the plot by selecting "IA Abs(Z)" as a Signal Type, and click on "Add Signal". The following table summarizes the Sweeper settings we use.

Table 3.15. Settings: configure the Sweeper for frequency dependence measurement

Tab	Sub-tab	Section	#	Label	Setting / Value / State
Sweeper	Settings			Filter	Application Mode
Sweeper	Settings			Application	Impedance
Sweeper	Control	Horizontal		Sweep Param	Osc 1 Frequency
Sweeper	Control	Horizontal		Start / Stop	1k / 1M
Sweeper	Control	Horizontal		Length	100 pts

Start the frequency sweep by clicking on Single. Display the absolute impedance $|Z_{DUT}|$ by selecting "Impedance 1 Sample Abs(Z)" in the Vertical Axis Groups section. Naively we'd expect this parameter to stay constant at 1 MΩ, but in fact it drops by about 50% at 500 kHz. The plot in Figure 3.23 shows the measurement of $|Z_{DUT}|$ as the red curve in the plot section of the Sweeper tab. The drop of the absolute impedance is due to the spurious parallel capacitance. At high enough frequencies, this capacitance forms a bypass for the current and therefore leads to a reduction of the impedance.

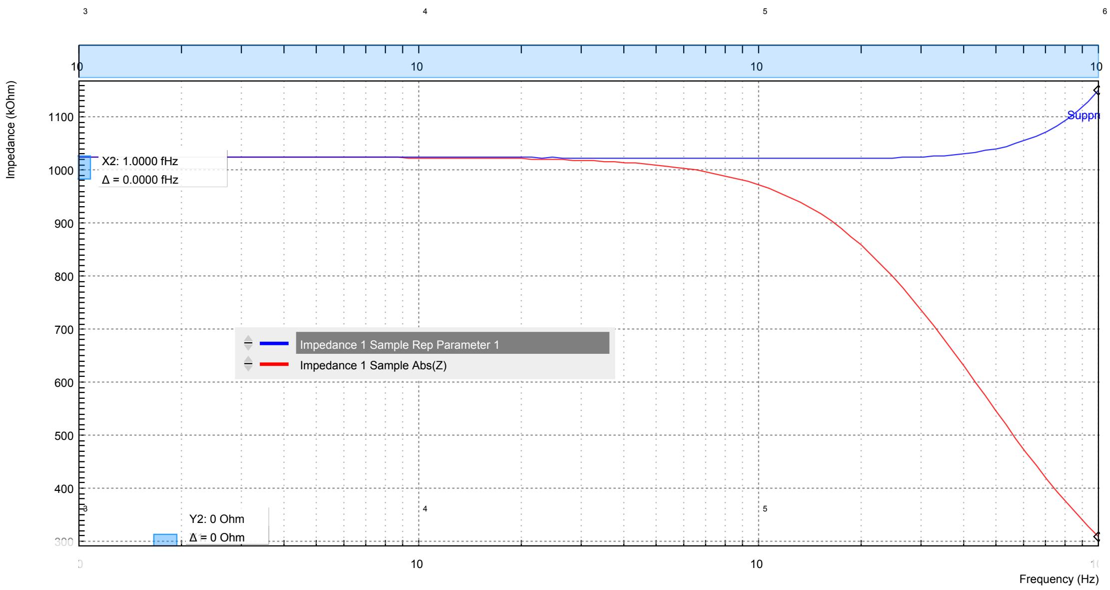


Figure 3.23. Absolute Impedance $|Z_{DUT}|$ and replacement circuit resistance of a 1 MΩ through-hole device measured with the LabOne Sweeper

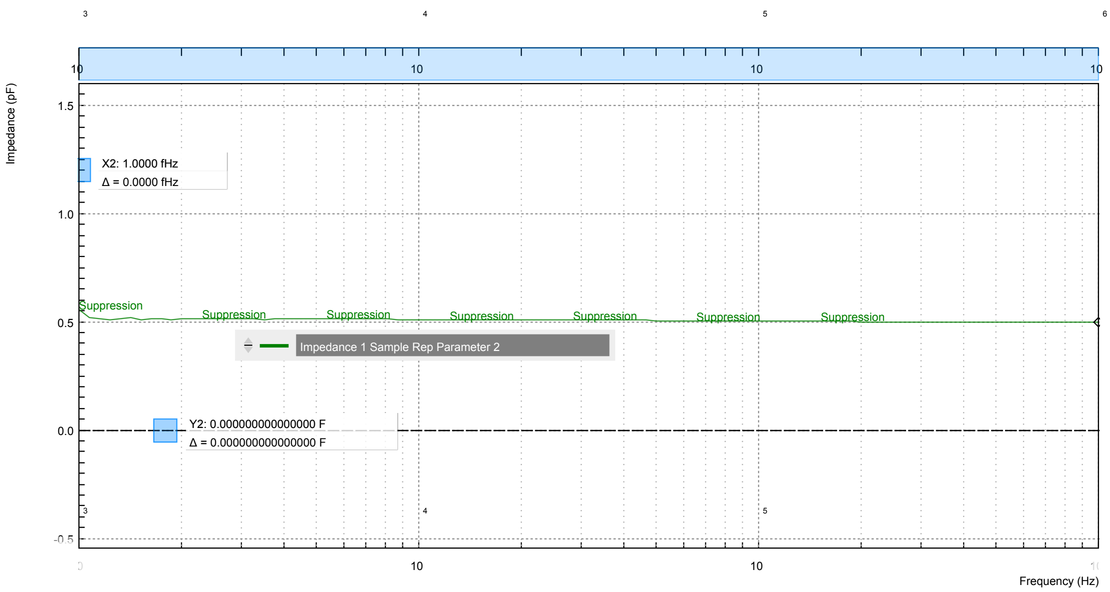


Figure 3.24. Replacement circuit capacitance of a 1 MΩ through-hole device measured with the LabOne Sweeper

The Rp || Cp circuit representation allows us to extract the parallel resistance Rp and capacitance Cp separately. Even after the Sweep has finished, we can add these signals to the plot by selecting IA Parameter 1 or IA Parameter 2 as Signal Type, and clicking on "Add Signal". Selecting the corresponding Impedance 1 Sample Rep Parameter 1 or 2 in the Vertical Axis Groups section will change the axis between a Farad (F) and an Ohm (Ω) scale.

Ideally, the resistance and capacitance are both frequency-independent. Looking at the blue curve in Figure 3.23 (Rp) and the green curve in Figure 3.24 (Cp), this is indeed mostly the case in the measurement: Rp stays flat at about 1 MΩ up to a few 100 kHz, and Cp stays at about 0.5 pF. However, parts of both curves are tagged by the Confidence Indicator warning "Suppression". It shows that the capacitance measurement is most reliable at high frequencies, and the resistance measurement is most reliable at low frequencies.

3.5.5. Saving and Exporting Data

Data acquired with the Sweeper can be easily saved to comma-separated value (CSV), Matlab, and ZView format. Particularly the ZView format is attractive for further equivalent circuit modeling with specialized software tools. Such an analysis often enables precise characterization of the DUT circuit, going much beyond the extraction of a pair of representation parameters. Select your preferred file format in the Config tab (Record Data section). This setting is global and also applies to the Plotter and the SW Trigger tab.

All past sweeps are listed in the History sub-tab of the Sweeper, up to a maximum number of list entry specified by the History Length parameter. Clicking on Save will store all the sweeps in the History list. The data are stored in a subfolder of the LabOne Data folder which can be conveniently accessed in the File Manager tab. The Enable button next to each History entry controls the plot display, but not which sweeps are saved. Find more information, for instance on how to use the Reference feature, in Section 4.9.

3.6. Compensation

Note

This tutorial is applicable to all MFIA Instruments and to MFLI Instruments with the MF-IA Impedance Analyzer option installed.

3.6.1. Goals and Requirements

The goal of this tutorial is to demonstrate a user compensation for impedance measurements with the MFLI instrument. A compensation improves the measurement accuracy when using a custom impedance fixture.

Some starting experience with Zurich Instruments impedance analyzers is required to follow the tutorial. You also need a Kelvin probe cable set and a 1 Ω through-hole resistor, a 10 Ω resistor, and a simple piece of wire. Instead of the Kelvin probe set, you can use a set of BNC cables and crocodile clamps.

3.6.2. Preparation

Start by connecting the Kelvin probe set to the BNC connectors on the front panel of the MFLI, paying attention not to mix up the connectors. One clamp should be electrically connected to Signal Output +V and Signal Input +V, the other clamp to Signal Input I and Signal Input -V. Fix the 1 Ω resistor with the two clamps. Figure 3.25 shows a diagram of the hardware setup.

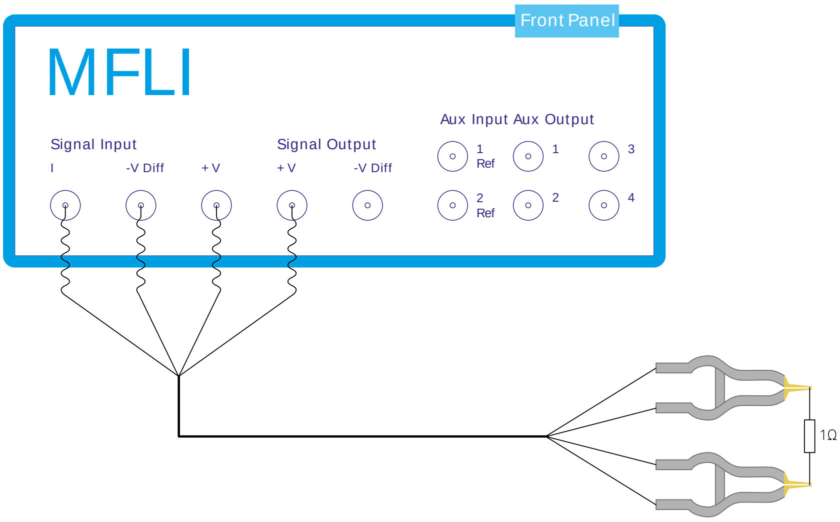


Figure 3.25. Setup for the Impedance Compensation Tutorial

Make sure that the MFLI Instrument is powered on and then connect the MFLI directly by USB to your host computer or by Ethernet to your local area network (LAN) where the host computer resides. After connecting to your Instrument through the web browser using its address, the LabOne graphical user interface is opened. Check the Getting Started Chapter for detailed instructions. The tutorial can be started with the default instrument configuration (e.g. after a power cycle) and the default user interface settings (i.e. as is after pressing F5 in the browser).

3.6.3. Configure the Impedance Analyzer

A measurement fixture like the Kelvin probe set affects the impedance measurement through its electrical properties, such as its stray capacitance, or the delay caused by its cables. A carefully executed compensation can practically eliminate the negative influence and thus improve measurement accuracy.

To get an idea of the Kelvin probe's influence, let's first make a quick measurement without compensation. We'll select the Rs+Ls Representation in the Impedance Analyzer tab, which is a good choice for small-valued resistors. The two representation parameters can be read in the Numeric tab with activated Impedance preset. We furthermore relax the threshold of the Suppression warning by setting the Suppression Ratio to 100 in the Impedance Analyzer tab. This is deemed sufficient for the level of accuracy that we can achieve with such a cable-based setup.

Let's start by reading some measurement values at different oscillator frequencies, which we change manually in the Impedance Analyzer tab.

Table 3.16. Measurement: 1 Ω through-hole resistor without compensation

Frequency	Rep. parameter 1 (resistance Rs)	Rep. parameter 2 (inductance Ls)
1 kHz	1.001 Ω	Suppression
500 kHz	0.986 Ω	110 nH
3 MHz (MF-5M option)	0.738 Ω	112 nH
5 MHz	Suppression	111 nH

The resistance (Rep. parameter 1) at 1 kHz looks quite reasonable. The inductance (Rep. parameter 2) is not reliably measurable at this frequency and is flagged with the "Suppression" warning. At higher frequencies such as 500 kHz, the inductance is measurable, but it seems unexpectedly large: 110 nH would correspond to 10 to 15 cm of wire, but the resistor leads are much shorter. The spurious series inductance Ls of a through-hole component is typically of the order of 5 nH. At 3 MHz the measured resistance drops to 0.738 Ω which does not seem realistic. At the maximum frequency 5 MHz, the resistance measurement finally fails. The following table summarizes the settings we used.

Table 3.17. Settings: quick measurement with uncompensated Kelvin Probe set

Tab	Sub-tab	Section	#	Label	Setting / Value / State
IA	Control			Representation	Rs + Ls
IA	Control			Enable	ON
IA	Control	Confidence Indicators		Suppression	100
IA	Control			Osc Frequency	1k, 500k, 3M, 5M

3.6.4. Carry out the Compensation

Some of the apparent problems seen before can be attributed to the uncompensated Kelvin probe set. In order to do a compensation, open the Cal side-tab in the Impedance Analyzer tab and select the SOL (short-open-load) Compensation Sequence. It's necessary to specify the parameters of the "load" DUT: 10 Ω, and since we don't know precisely the stray capacitance, we'll enter a value of 0 F as Load C. The three compensation steps can now be simply carried out by fixing the appropriate DUT (the wire for the S step, the 10 Ω resistor for the L step, or nothing for the O step) and clicking on the "Short", "Open", or "Load" button followed by "Compensate". For a precise calibration, try to keep the position of the clamps the same in all three steps and in the measurement itself. The spurious capacitance is very sensitive to the position of the clamps and the parts of the cables which are unshielded.

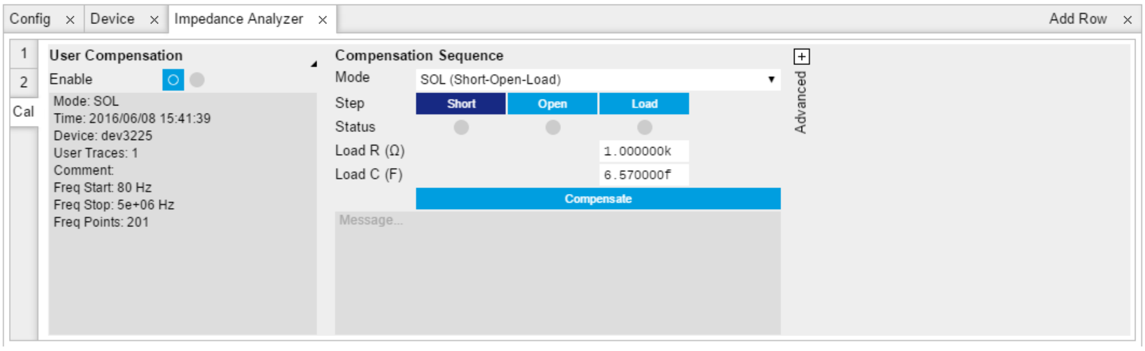


Figure 3.26. Impedance Analyzer tab: Cal side-tab

Each compensation step takes about a minute with the standard settings, and its progress and termination is reported in the text field below the "Compensate" button. The Status LEDs show which of the steps are completed. Once all three are done, the compensation data are transferred to the instrument.

Table 3.18. Settings: perform a user compensation

Tab	Sub-tab	Section	#	Label	Setting / Value / State
IA	Cal	Compensation Sequence		Mode	SOL (short-open-load)
IA	Cal	Compensation Sequence		Load R (Ω)	10
IA	Cal	Compensation Sequence		Load C (F)	0
IA	Cal	Compensation Sequence		Step	Short / Open / Load
IA	Cal	Compensation Sequence		Compensate	ON

The left section of the Cal sub-tab displays information and contains the enable button of the internal calibration and the current user compensation. The label Internal Calibration (or User Compensation) acts as a control to switch the display (the small black triangle to the bottom right of the label indicates the control). When switched to User Compensation, the compensation can easily be activated and deactivated with the Enable button. This has an immediate effect on the measurement data displayed in the Numeric, the Plotter, or the Sweeper tab.

Note

The internal calibration should normally be enabled at all times.

3.6.5. Measure with Compensation

In order to compare the results with and without compensation, we'll perform a sweep up to the maximum available frequency as shown in the previous tutorials. In the Sweeper tab, perform a linear frequency sweep from 1 kHz to 5 MHz. Repeat that once with and once without enabled compensation.

The plot in Figure 3.27We look at two selected quantities in the following plots. The Resistance (= Rep. Parameter 1) remains flat at 1.0 Ω with compensation (green), whereas it goes down below 0.4 Ω without compensation.

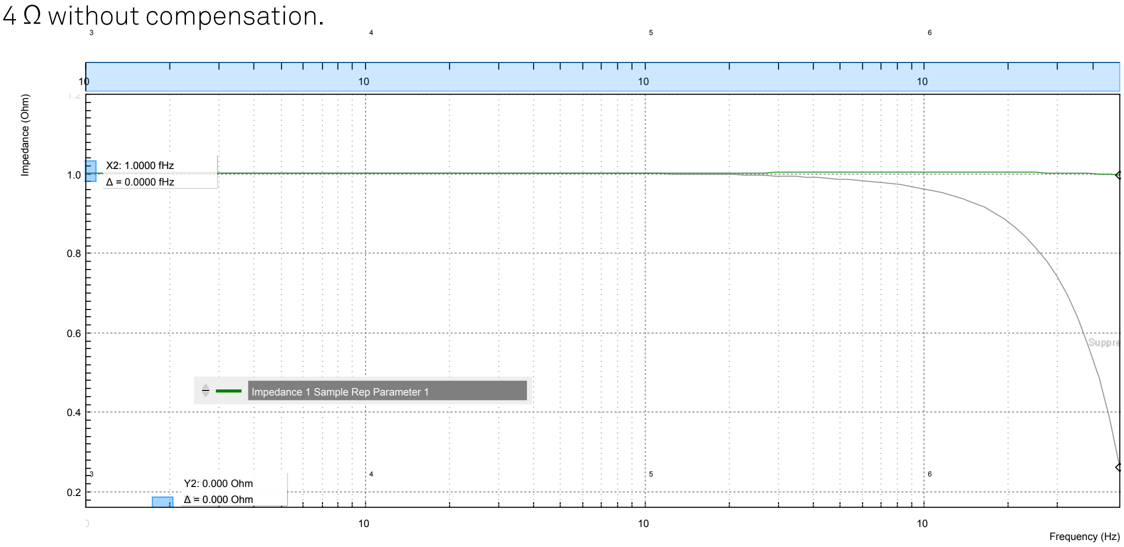


Figure 3.27. LabOne Sweeper showing the resistance of a 1 Ω DUT measured with compensation (green) and without (grey)

The Inductance (= Parameter 2) is relatively flat in frequency both with and without compensation, see Figure 3.28. But its value is much too large without compensation. With compensation the measured value is less than 10 nH which is the expected order of magnitude, in any case it is too small to be measured with high precision and is flagged with the "Suppression" warning. Note that the lead inductance of the resistor is about 8 nH/cm. Clamping the DUT at a slightly different position and measuring again will show an effect on the measured inductance Ls, whereas the resistance Rs is largely insensitive to that.

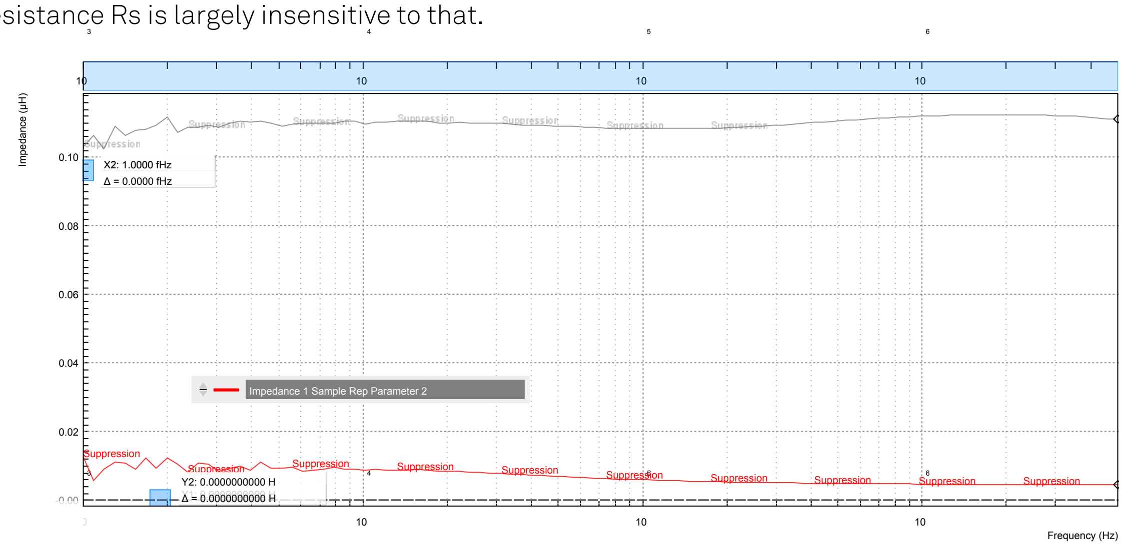


Figure 3.28. LabOne Sweeper showing the serial inductance of a 1 Ω DUT measured with compensation (red) and without (grey)

Chapter 4. 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 MFLI. 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.

4.1. User Interface Overview

4.1.1. 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 MFLI. 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 (possibly concurrently) by custom programs written in any of the supported languages (e.g. LabVIEW, MATLAB, Python, C) connecting through the LabOne APIs.

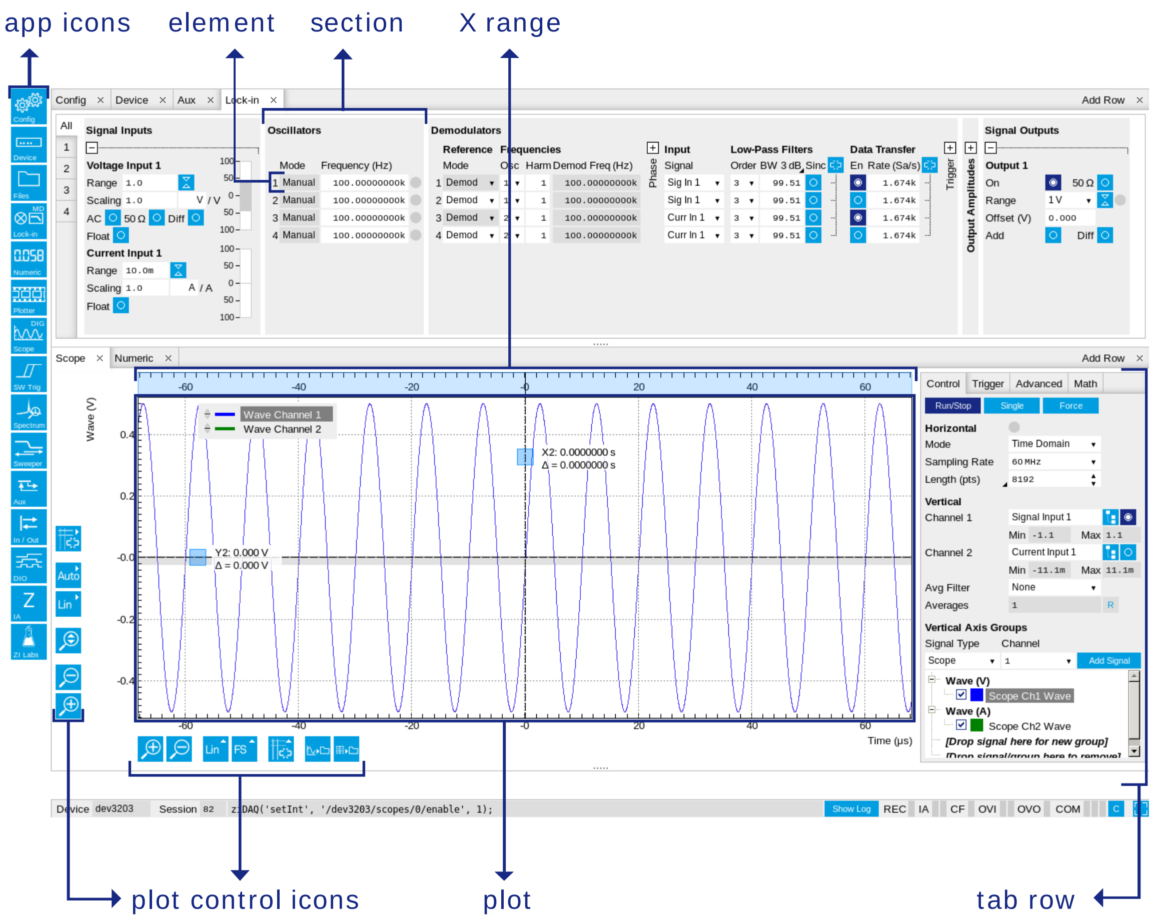


Figure 4.1. LabOne User Interface (default view)

Figure 4.1 shows the LabOne User Interface with the tabs opened by default after a new UI session has been started. The UI is by default 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 left side bar. A simple 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 simply be displaced by drag-and-drop within a row or across rows. Further items are highlighted in Figure 4.2.

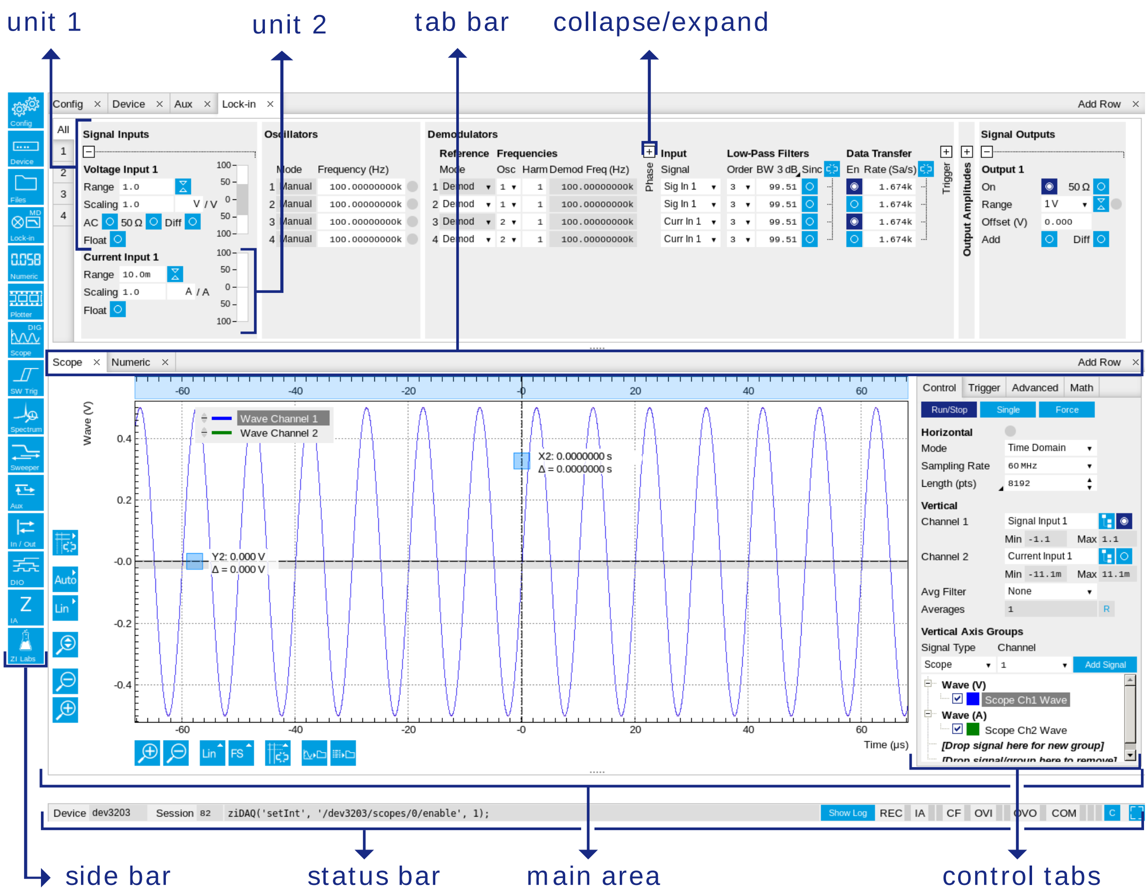


Figure 4.2. LabOne User Interface (more items)

Table 4.1 gives brief descriptions and naming conventions for the most important UI items.

Table 4.1. 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 indicators, warning lamps, 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	tab rows, each consisting of tab bar and the active tab area

Item name	Position	Description	Contains
		the top right corner of each tab row	
tab area	inside of each tab	provides the active part of each tab consisting of settings, controls and measurement tools	sections, plots, control tabs, unit selections

4.1.2. Unique Set of Analysis Tools

All Instruments feature a comprehensive tool set for time and frequency domain analysis for both raw signals and demodulated signals. Note that the selection of app icons is limited by the upgrade options installed on a particular instrument.

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 of 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. will the Sweeper change certain demodulator settings while performing a frequency sweep. Within the tools one can further discriminate between time domain and frequency domain analysis, moreover, a distinction between the analysis of fast input signals - typical sampling rate of 60 MSa/s - and the measurement of orders of magnitude slower data - typical sampling rate of <200 kSa/s - derived for instance from demodulator outputs and auxiliary inputs. Table 4.2 provides a brief classification of the tools.

Table 4.2. Tools for time domain and frequency domain analysis

	Time Domain	Frequency Domain
Fast signals (60 MSa/s)	Oscilloscope (Scope Tab)	FFT Analyzer (Scope Tab)
Slow signals (<200 kSa/s)	Numeric	Spectrum Analyzer (Spectrum Tab)
	Plotter	Sweeper
	Software Trigger	-

The following table gives the overview of all app icons.

Table 4.3. 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 MD		Quick overview and access to all the settings and properties for signal generation and demodulation.
Files		Access files on internal flash memory and USB drive.

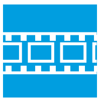
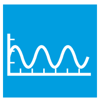
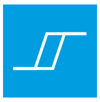
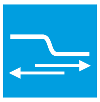
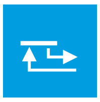
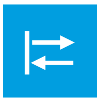
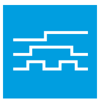
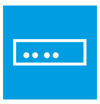
Control/Tool	Option/Range	Description
Numeric		Access to all continuously streamed measurement data as numerical values.
Plotter		Displays various continuously streamed measurement data as traces over time (roll-mode).
Scope		Displays shots of data samples in time and frequency domain (FFT) representation.
SW Trig		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		Allows to scan one variable (of a wide choice, e.g. frequency) 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		Access to all controls relevant for the main Signal Inputs and Signal Outputs on the instrument's front.
DIO		Gives access to all controls relevant for the digital inputs and outputs including the Ref/Trigger connectors.
Config		Provides access to software configuration.
Device		Provides instrument specific settings.
IA		Quick overview and access to all the settings and properties for impedance measurements.
ZI Labs		Experimental settings and controls.

Table 4.4 gives a quick overview over the different status bar elements along with a short description.

Table 4.4. 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 Log	Show the command log history in a separate browser window.
Session	integer value	Indicates the current session identifier.
Device	devXXX	Indicates the device serial number.
REC	grey/green	A green indicator shows ongoing data recording (related to global recording settings in the Config tab).
AWG	grey/green	Arbitrary Waveform Generator - Green: indicates that the AWG unit is enabled.
CNT	grey/green	Pulse Counter - Green: indicates which of the pulse counter modules is enabled.
IA	grey/green	Impedance Analyzer - Green: indicates which of the impedance analyzer modules is enabled.
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 Overflow - Red: present overflow condition on the signal input also shown by the red front panel LED. Yellow: indicates an overflow occurred in the past.
OVO	grey/yellow/red	Overflow Signal Output - Red: present overflow condition on the signal output. Yellow: indicates an overflow occurred in the past.
COM	grey/yellow/red	Warning flags related to instrument communication.

Control/Tool	Option/Range	Description
		Packet Loss - Red: present loss of data between the device and the host PC. Yellow: indicates a loss occurred in the past. Sample Loss - Red: present loss of sample data between the device and the host PC. Yellow: indicates a loss occurred in the past. Stall - Red: indicates that the sample transfer rates have been reset to default values to prevent severe communication failure. This is typically caused by high sample transfer rates on a slow host computer.
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.
PLL	grey/green	PLL - Green: indicates which of the PLLs is enabled.
Full Screen		Toggles the browser between full screen and normal mode.

4.1.3. Plot Functionality

Several tools - Plotter, Scope, SW Trigger, Spectrum and Sweeper - 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 plot is summarized in Table 4.5

Table 4.5. Mouse functionality inside plots

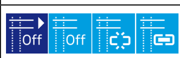
Name	Action	Description	Performed inside
Panning	left click on any location and move around	moves the waveforms	plot area
Zoom X axis	mouse wheel	zooms in and out the X axis	plot area

Name	Action	Description	Performed inside
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 4.6.

Table 4.6. 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 an SVG of the plot area or areas for dual plots to the local download folder.
Save data		Generates a TXT consisting of the displayed set of samples. 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.

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 by pan or zoom events. In case the cursors move out of the zoom area, the corresponding handle is displays on the related side 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 following Table 4.7 gives an overview of all the elements and their functionality. It is important to know that the Signals and Operations defined will always be performed only on the currently chosen active trace.

Table 4.7. 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 plot data inside the rectangle defined by the cursor coordinates as input for statistical functions (Min, Max, Avg, Std, Int).
	Tracking	Output plot value at current cursor position. Options are X1 and X2.
	Wave	Consider all plot data currently displayed in the Plot as input for statistical functions (Min, Max, Avg, Std, Int).
	Peak	Find and determine the various peaks in the plotted data and their associated values.
	Histogram	Select statistical data as Math input and display a histogram in the plot area.
Operation Select		Select from a list of mathematical operations to be performed on the selected signals. Choice offered depends on input signals selected.
	X1, X2, X2-X1, Y1, Y2, Y2-Y1	Cursors values and their differences.

Control/Tool	Option/Range	Description
	Min, Max, Avg, Std, Int	Statistical Functions applied to a set of samples.
	Pos, Level	Finds the Position (x-values) and the Levels (y-values) of Peaks on a set of samples.
Add	Add	Add the selected math function to the result table below.
Add All	Add All	Add all operations for the selected signal to the result table below.
Select All	Select All	Select all lines from the result table above.
Clear Selected	Clear Selected	Clear selected lines from the result table above.
Unit Prefix	Unit Prefix	Adds a suitable prefix to the SI units to allow for better readability and increase of significant digits displayed.
CSV	CSV	Values of the current result table are saved as a text file into the download folder.
Link	Link	Provides a LabOne Net Link to use the data in tools like Excel, Matlab, etc.
Help	Help	Opens the LabOne User Interface help.

Note

For calculation of the standard deviation the corrected sample standard deviation is used as defined by $\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$ with a total of N samples x_i and an arithmetic average $\overline{x}$.

Tree Sub-Tab

The Numeric tab and Plotter tab are able to display so many different types of signals that a number of different options are provided to access them. One of them is the Tree sub-tab that allows one to access all streamed measurement data in a hierarchical structure by checking the boxes of the signal that should be displayed.

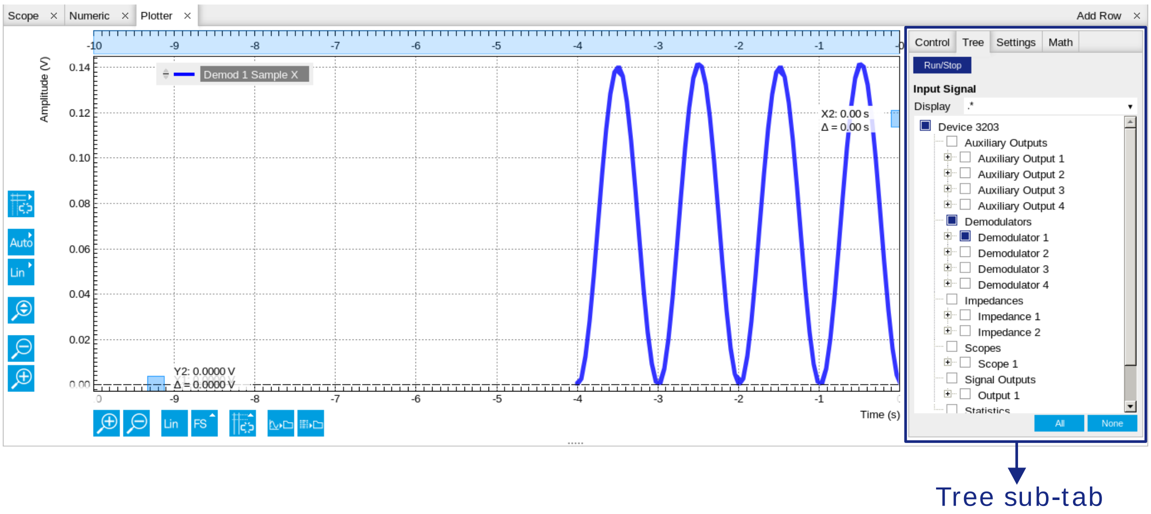


Figure 4.3. Tree sub-tab in Plotter tab

Table 4.8. Tree description

Control/Tool	Option/Range	Description
Display	Preset filter or regular expression	Predefined filters that limit the view to specific signal groups. The display filter does not select any nodes.
All	All	Select all nodes that can be selected in the relevant context.
None	None	Unselect all nodes.

Vertical Axis Groups

Vertical Axis groups are available in the Plotter tab, SW Trigger tab, and Sweeper tab. These tools are able to show signals with different axis properties within the same plot. As a frequency and amplitude axis have fundamentally different limits they have each their individual axis which allows for correct auto scaling. However, signals of the same type e.g. Cartesian demodulator results should preferably share one scaling. This allows for fast signal strength comparison. To achieve this 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.

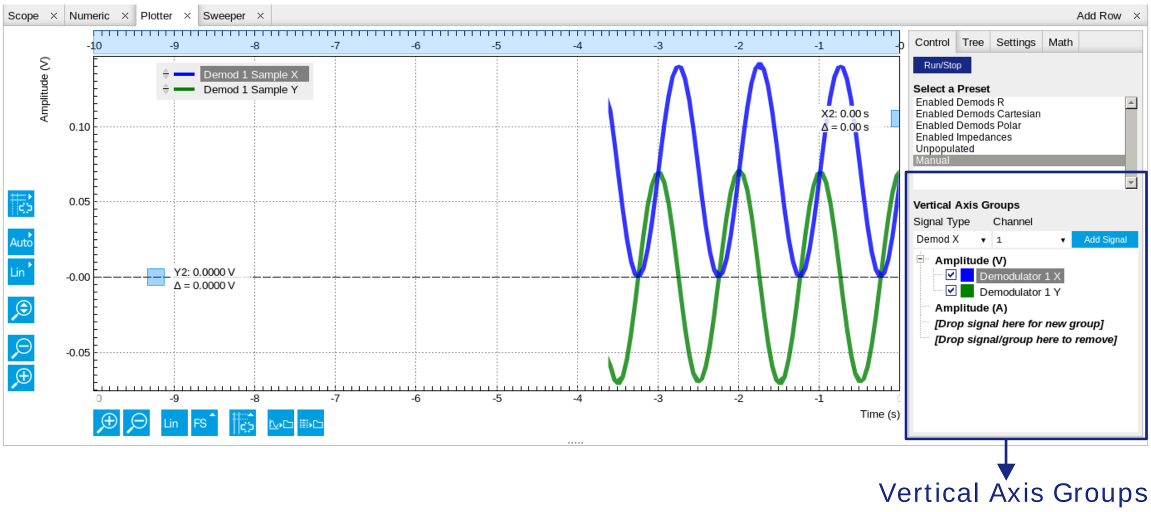


Figure 4.4. Vertical Axis Group in Plotter tool

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.

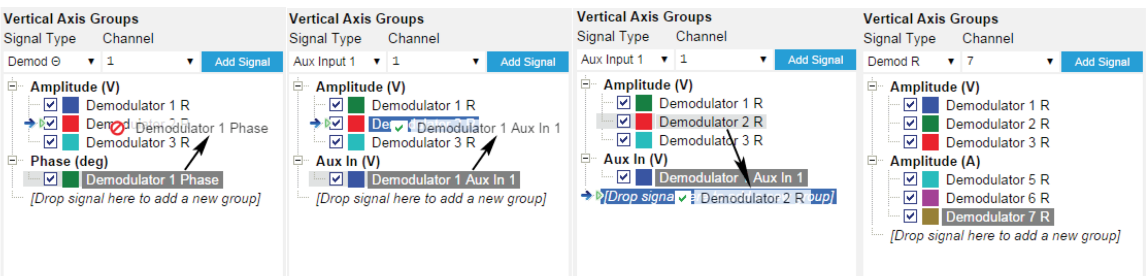


Figure 4.5. Vertical Axis Group typical drag and drop moves

Table 4.9. 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. 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	Demod X, Y, R, Theta	Select signal types for the Vertical Axis Group.
	Frequency	
	Aux Input 1, 2	
	HW Trigger	
Channel	integer value	Selects a channel to be added.
Add Signal	Add Signal	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.

4.1.4. Saving and Recording Data

In this section we discuss how to save and record measurement data with the MFLI Instrument using the LabOne user interface. A quick way of doing this was already introduced in the previous section: in any plot (in the Plotter, Scope, Spectrum, and other tabs), you can save the currently displayed curves as a comma-separated value (CSV) file to the download folder of your web browser. Just click on the corresponding icon at the bottom of the plot. Clicking on will save a vector graphics instead.

The record functionality in comparison allows you to monitor and 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: CSV or Matlab binary file format. This global setting also applies to the storage format used by the Sweeper and the Software Trigger tab. The CSV delimiter character can be changed in the User Preferences section. The default option is Semicolon. Finally, the Time Zone setting allows you to adjust the time stamps of the saved data.

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 DeviceXXXX/

Demodulators/Demod 1/Sample. An example for an instrument setting would be the filter time constant, accessible under the path DeviceXXXX/Demodulators/Demod 1/Filter Time Constant.

The storage location is selected in the Drive drop-down menu of the Record section. The default location is the internal hard drive of the MFLI. Alternatively, you can plug an external USB drive into one of the USB Device ports on the back panel of the MFLI. If you do so, an additional option USB 1 or USB 2 appears in the Drive drop-down menu.

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.

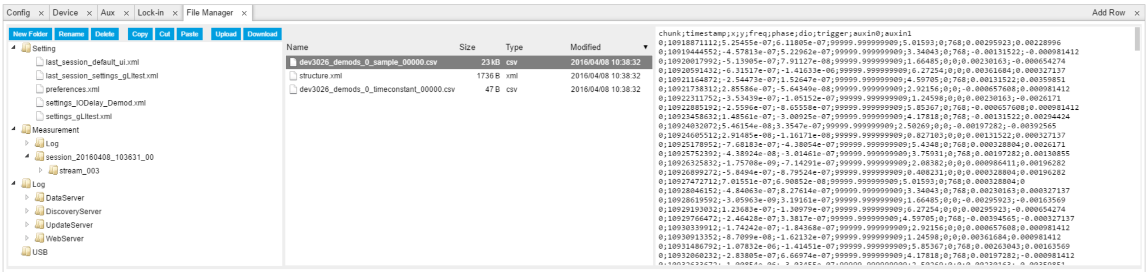


Figure 4.6. Browsing and inspecting files in the LabOne File Manager tab

For each of the selected nodes, at least one file is created. Its location is indicated in the Folder field of the Record Data section. For longer recording periods, LabOne may distribute the data over several files. The size of the files can be controlled using the Window Length parameter in the Settings of the Plotter tab.

The File Manager (Files) tab is a good place to inspect the resulting CSV data files. The file browser on the left of the tab allows you to navigate to the location of the data files and gives you the usual functionalities for managing files on the drive of the MF Instrument. In addition, you can conveniently transfer files between the MFLI and the host computer 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 4.6 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.

4.2. Lock-in Tab

This tab is the main lock-in amplifier control panel. Users with instruments with MF-MD Multi-demodulator option installed are kindly referred to Section 4.3.

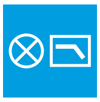
4.2.1. Features

- Functional block diagram with access to main input, output and demodulator controls
- Parameter table with main input, output and demodulator controls
- Control elements for 1 configurable demodulator
- Auto ranging, scaling, arbitrary input units for both input channels
- Control for 1 oscillator
- Settings for main signal inputs and signal outputs
- Flexible choice of reference source, trigger options and data transfer rates

4.2.2. 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 4.10. 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 4.7) consists of 4 sections: Signal Inputs, Oscillators, Demodulators and Signal Outputs. The Demodulator section consists of two rows where the upper row offers access to all the settings of the dual phase demodulator, the second row represents the phase detector for the PLL used for external reference. The user can obtain and change the filter settings but not transfer the data to the data server.

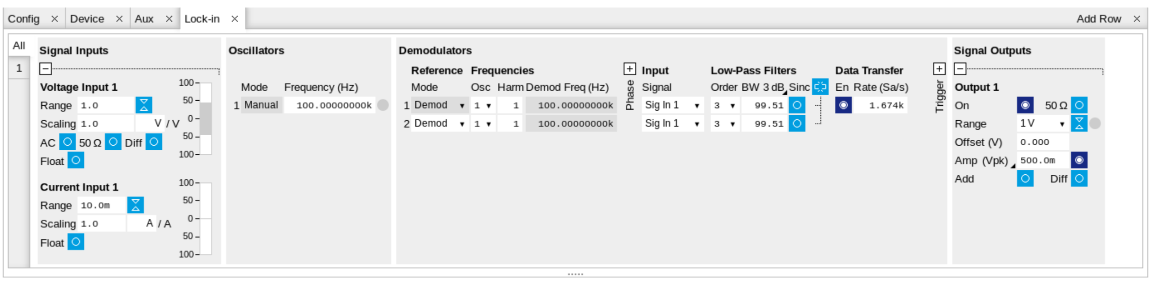


Figure 4.7. LabOne User Interface Lock-in tab - Parameter table (All)

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.

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.

Below the Scaling field there is the AC/DC button and the 50 Ω/10 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/10 MΩ button toggles the input impedance between low (50 Ω) and high (approx. 10 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.

Note

The Signal Inputs can be set to float which means that the BNC connector shield is no longer connected to the instrument ground. This setting affects both the current input and the voltage input.

The **Oscillator section** indicates the frequency of the internal oscillator. 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.

In the following, we discuss the **Demodulators settings** in more detail. The block diagram displayed in Figure 4.8 indicates the main demodulator components and their interconnection. The understanding of the wiring is essential for successfully operating the instrument.

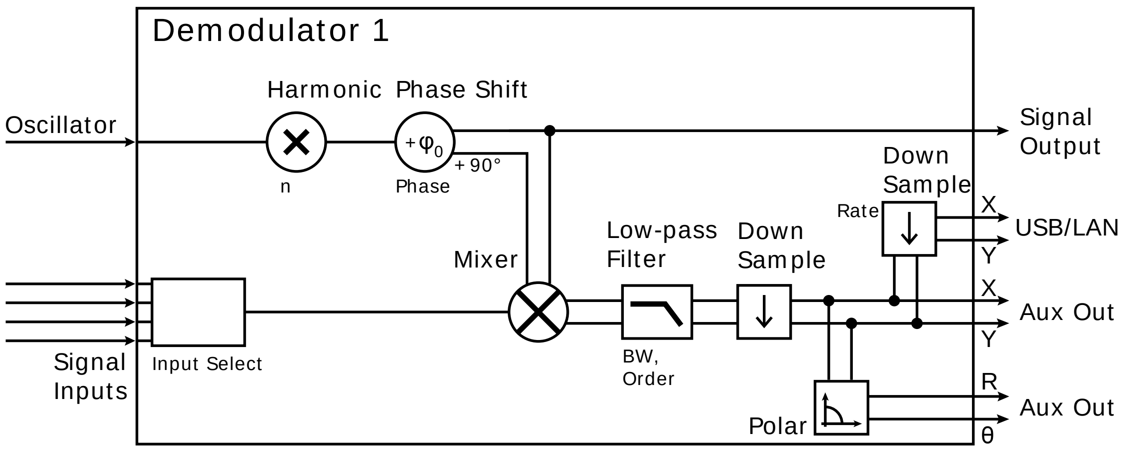


Figure 4.8. Demodulator block diagram without MF-MD Multi-demodulator option.

The first line in the Demodulators section represents the demodulator available for measurements. The Mode column is read-only set to internal reference (Demod). The second line represents an additional Demodulator that is reserved for the exclusive use as a phase detector when the mode is switched to external reference (ExtRef). The user can select from a number of different inputs to be used as external reference signals and the filter settings provide the user with an idea of the PLL speed. However, this second demodulator does not produce any output data that could be used for measurements.

In the Input Signal column one defines the signal that is taken as input for a given demodulator. A wide choice of signals can be selected: Signal Inputs, the Trigger Inputs, the Auxiliary Inputs and Auxiliary Outputs. This allows using 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 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 Section 4.4.

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 Trigger Input 1 or 2 on the instrument back panel.

In the **Signal Outputs section** the On buttons are used to activate the Signal Output. The Range drop-down list is used to select the proper output range setting. On the Signal Output an offset voltage (Offset) can be defined. The maximum output signal permitted is ±10 V.

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 4.9 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).

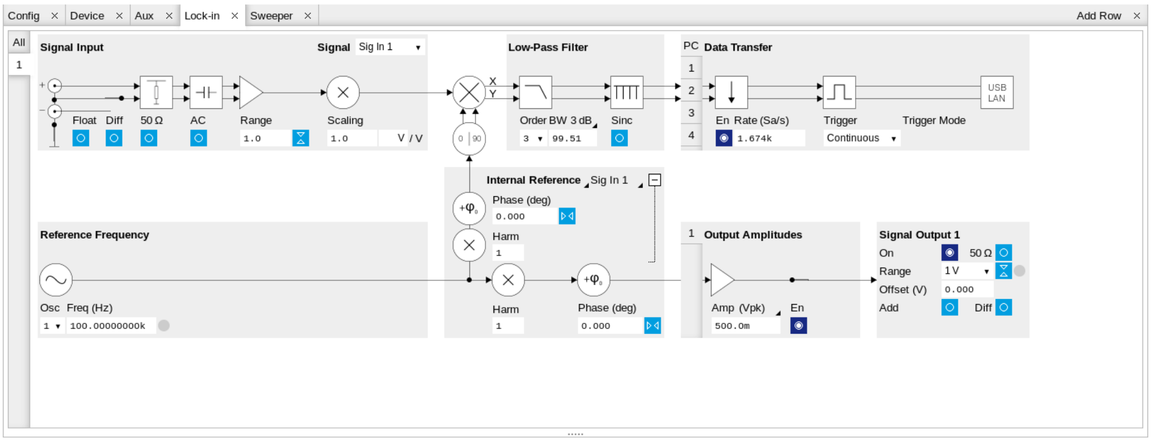


Figure 4.9. LabOne User Interface Lock-in tab - Graphical Lock-in tab in Internal Reference mode

The block diagram in Figure 4.10 shows the signal path through the instrument for the case when an external reference is used. The Signal Input is described on the left side, the core of demodulation with the mixer and low-pass filter as well as the External Reference 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.

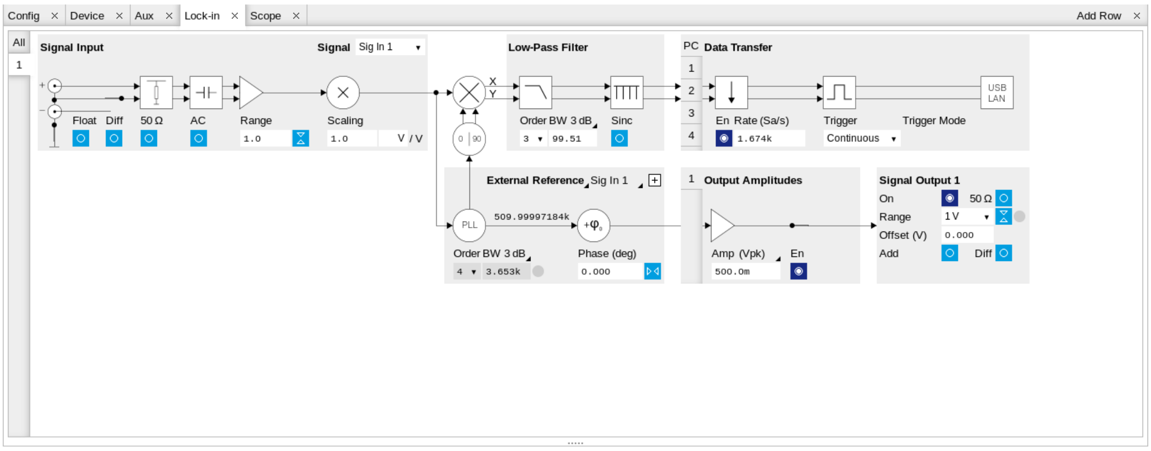


Figure 4.10. LabOne User Interface Lock-in tab - Graphical Lock-in tab in External Reference mode

Note

In order to switch between Internal Reference Mode and External Reference Mode click on the section label. The "+" symbol next to the label provides access to the phase settings of the reference.

4.2.3. Functional Elements

Table 4.11. Lock-in tab

Control/Tool	Option/Range	Description
Range	3.0 mV, 10 mV, 30 mV, 100 mV, 300 mV, 1 V, 3.0 V	Defines the gain of the analog input amplifier. The range should exceed the incoming

Control/Tool	Option/Range	Description
		signal by roughly a factor two including a potential DC offset. Note 1: the value inserted by the user may be approximated to the nearest value supported by the Instrument. Note 2: a proper choice of range setting is crucial in order to achieve good accuracy and best possible signal to noise ratio as it targets to use the full dynamic range of the input ADC.
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. 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.
AC	ON: AC coupling OFF: DC coupling	Defines the input coupling for the Signal Inputs. AC coupling inserts a high-pass filter.
50 Ω	ON: 50 Ω OFF: 10 MΩ	Switches between 50 Ω (ON) and 10 MΩ (OFF).
Float	ON: Floating OFF: GND connected	Switches between floating (ON) and connected grounds (OFF). This setting is shared for the voltage and current input.
Diff	OFF: Single ended voltage input ON: Differential voltage input	Switches between single ended (OFF) and differential (ON) measurements.
Range	10 nA 1 μA 100 μA	Defines the gain of the current input amplifier. The range should exceed the incoming

Control/Tool	Option/Range	Description
	10 mA	signal by roughly a factor two including a potential DC offset. Note 1: the value inserted by the user may be approximated to the nearest value supported by the Instrument. Note 2: a proper choice of range setting is crucial in order to achieve good accuracy and best possible signal to noise ratio as it targets to use the full dynamic range of the input ADC.
Auto		Automatic adjustment of the Range to about two times the maximum current input amplitude measured over about 100 ms.
Scaling	numeric value	Applies an arbitrary scale factor to the current input.
Measurement Unit	unit acronym	Defines the physical unit of the current input. Use *, / and ^ operators, e.g., m or m/s^2 The value in this field modifies the readout of all measurement tools in the user interface.
Mode		Indicates how the frequency of the corresponding oscillator is controlled (manual, external reference). Read only flag.
	Manual	The user setting defines the oscillator frequency.
	ExtRef	An external reference is mapped onto the oscillator frequency.
Frequency (Hz)	0 to 5 MHz	Frequency control for each oscillator.
Locked	ON / OFF	Oscillator locked to external reference when turned on.
Mode		Indicates the unit that uses the demodulator (Demod stands for regular lock-in amplifier or external reference)
	Demod	Default operating mode with demodulator used for lock-in demodulation.

Control/Tool	Option/Range	Description
	ExtRef	The demodulator is used for external reference mode and tracks the frequency of the selected reference input.
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	Multiplies the demodulator's reference frequency with the integer factor defined by this field. Multiplies the demodulator's reference frequency by an integer factor. 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.
Harm	1 to 1023	Divides the demodulator's reference frequency by an integer factor in external reference mode. Multiplies the demodulator's reference frequency by an integer factor. 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 5 MHz	Indicates the frequency used for demodulation and for output generation. The demodulation frequency is calculated with oscillator frequency times the harmonic factor. When the MF-MOD option is used linear combinations of oscillator frequencies including the harmonic factors define the demodulation frequencies.

Control/Tool	Option/Range	Description
Phase (deg)	-180° to 180°	Phase shift applied to the reference input of the demodulator.
Zero		Adjust the demodulator phase automatically in order to read zero degrees. Shifts the phase of the reference at the input of the demodulator in order to achieve zero phase at the demodulator output. This action maximizes the X output, zeros the Y output, zeros the Θ 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.
	Curr In 1	Current Input 1 is connected to the corresponding demodulator.
	Trigger 1	Trigger 1 is connected to the corresponding demodulator.
	Trigger 2	Trigger 2 is connected to the corresponding demodulator.
	Aux Out 1	Auxiliary Output 1 is connected to the corresponding demodulator.
	Aux Out 2	Auxiliary Output 2 is connected to the corresponding demodulator.
	Aux Out 3	Auxiliary Output 3 is connected to the corresponding demodulator.
	Aux Out 4	Auxiliary Output 4 is connected to the corresponding demodulator.
	Aux In 1	Auxiliary Input 1 is connected to the corresponding demodulator.
	Aux In 2	Auxiliary Input 2 is connected to the corresponding demodulator.
Order		Selects the filter roll off between 6 dB/oct and 48 dB/ oct.

Control/Tool	Option/Range	Description
	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), noise equivalent power bandwidth (BW NEP), 3 dB bandwidth (BW 3 dB).
	TC	Defines the low-pass filter characteristic using time constant of the filter.
	BW NEP	Defines the low-pass filter characteristic using the noise equivalent power bandwidth of the filter.
	BW 3 dB	Defines the low-pass filter characteristic using the cut-off frequency 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. 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.
Lock		Makes all demodulators filter settings equal (order, time constant, bandwidth). Pressing the lock copies the settings from demodulator one into the settings of all demodulators. When the lock is pressed, any modification to a field is immediately changing

Control/Tool	Option/Range	Description
		all other settings. Releasing the lock does not change any setting, and permits to individually adjust the filter settings for each demodulator.
Enable Streaming		Enables the data acquisition for the corresponding demodulator. Note: increasing number of active demodulators increases load on physical connection to the host computer.
	ON: demodulator active	Enables the streaming of demodulated samples in real time to the host computer. The streaming rate is defined in the field on the right hand side. As a consequence demodulated samples can be visualized on the plotter and a corresponding numeric entry in the numerical tool is activated.
	OFF: demodulator inactive	Disables the streaming of demodulated samples to the host computer.
Rate (Sa/s)	0.056 Sa/s to 857 kSa/s	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. 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.
Demodulator Output Rate Lock		Makes all demodulator output rates equal. Pressing the lock copies the settings from demodulator one into the settings of all demodulators. When the lock

Control/Tool	Option/Range	Description
		is pressed, any modification to a field is immediately changing all other settings. Releasing the lock does not change any setting, and permits to individually adjust the demodulator output rate for each demodulator.
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.
	Trigger 1	Selects external triggering by means of the Trigger 1 connector. Demodulated samples are sent to the host computer for each event defined in the Trig Mode field. When edge trigger is selected the rate field is greyed out and has no meaning.
	Trigger 2	Selects external triggering by means of the Trigger 2 connector. Demodulated samples are sent to the host computer for each event defined in the Trig Mode field. When edge trigger is selected the rate field is greyed out and has no meaning.
	Trigger 1|2	Same functionality as above, but triggering is based on a logical OR function of Trigger 1 and Trigger 2.
Trig 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.

Control/Tool	Option/Range	Description
	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, dBm	Select the unit of the displayed amplitude value. The dBm value is only valid for a system with 50 Ω termination.
Amp Enable	ON / OFF	Enables individual output signal amplitude. When the MF-MD 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.
50Ω	ON / OFF	Select the load impedance between 50Ω and HiZ. The impedance of the output is always 50Ω. For a load impedance of 50Ω the displayed voltage is half the output voltage to reflect the voltage seen at the load.

Control/Tool	Option/Range	Description
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. 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 Ω target source or differential output is enabled the possible maximal output range will be half.
	10 mV	Selects output range ±10 mV.
	100 mV	Selects output range ±100 mV.
	1 V	Selects output range ±1 V.
	10 V	Selects output range ±10 V.
Auto Range		Selects the most suited output range automatically.
Output Clipping	grey/red	Indicates that the specified output amplitude(s) exceeds the range setting. Signal clipping occurs and the output signal quality is degraded. Adjustment of the range or the output amplitudes is required.
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 Aux Input 1 is added to the signal output. For differential output the added signal is a common mode offset.
Diff	ON / OFF	Switch between single-ended output (OFF) and differential output (ON). In differential mode the signal swing is defined between Signal Output +V / -V.

Control/Tool	Option/Range	Description
Output	-range to range	Defines the output amplitude as rms or peak-to-peak value. A negative amplitude value is equivalent to a phase change of 180 degree.

4.3. Lock-in Tab (MF-MD option)

This tab is the main lock-in amplifier control panel for MFLI Instruments with the MF-MD Multi-demodulator option installed. Users with instruments without this option installed are kindly referred to Section 4.2.

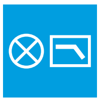
4.3.1. Features

- Functional block diagram with access to main input, output and demodulator controls
- Parameter table with main input, output and demodulator controls
- Controls for 4 individually configurable demodulators
- Auto ranging, scaling, arbitrary input units for both input channels
- Control for 4 oscillators
- Settings for main signal inputs and signal outputs
- Choice of reference source, trigger options and data transfer rates

4.3.2. 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 4.12. App icon and short description

Control/Tool	Option/Range	Description
Lock-in MD		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 4.11) consists of 5 sections: Signal Inputs, Oscillators, Demodulators, Output Amplitudes and Signal Outputs. The Demodulator section contains 4 rows each of them providing access to the settings of one dual phase demodulator. Demodulators 2 and 4 can be used for external referencing. Every demodulator can be connected to any of the possible inputs and oscillators.

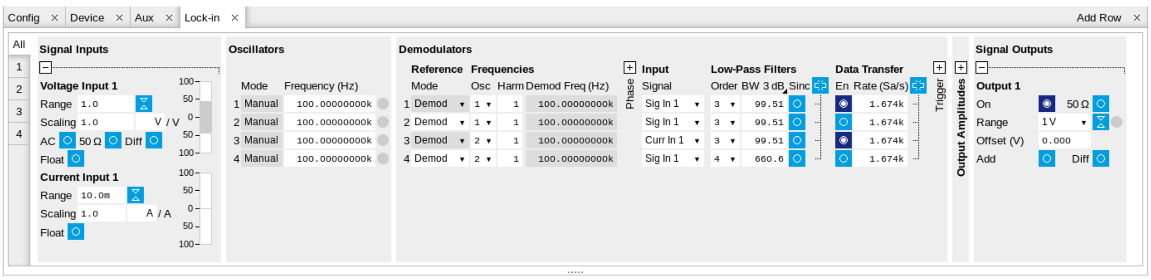


Figure 4.11. LabOne User Interface Lock-in tab with MF-MD Multi-demodulator option.

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/10 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/10 MΩ button toggles the input impedance between low (50 Ω) and high (approx. 10 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.

Note

The Signal Inputs can be set to float which means that the BNC connector shield is no longer connected to the instrument ground. It is important that this setting affects both the current input and the voltage input in the same way.

The **Oscillator section** indicates the frequency of the 4 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.

The next section contains the **Demodulators settings**. The block diagram displayed in Figure 4.12 indicates the main demodulator components and their interconnection. The understanding of the wiring is essential for successfully operating the instrument.

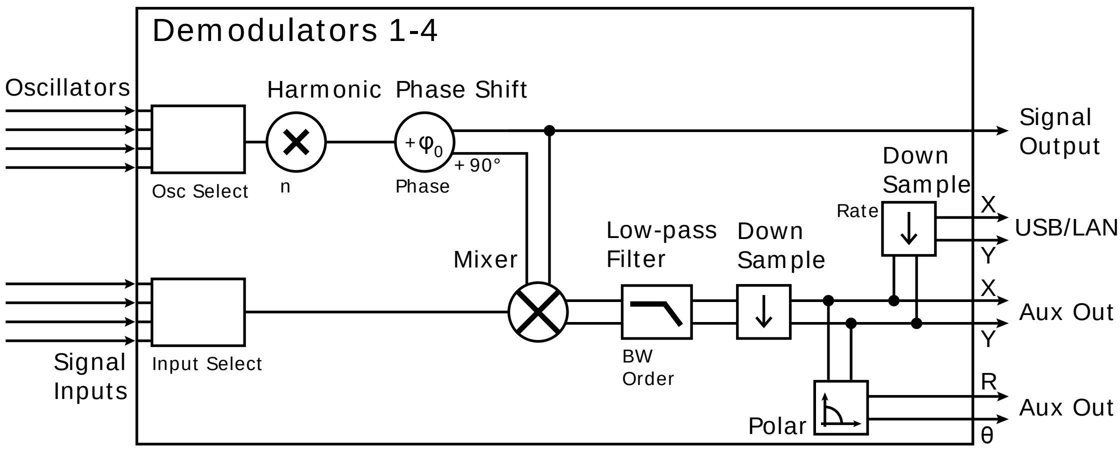


Figure 4.12. Demodulator block diagram with MF-MD Multi-demodulator option.

Every line in the Demodulators section represents one demodulator. The Mode column is read-only for all demodulators except 2 and 4, which can be to set to either internal reference (Demod) or external reference mode (ExtRef). When internal reference mode is selected, it is possible to demodulate the input signal with 4 demodulators simultaneously at 4 independent frequencies and using different filter settings. For external reference mode, one demodulator is used for the reference recovery and a few settings are greyed-out, and therefore 3 demodulators remain for simultaneous measurements.

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 Section 4.4.

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 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 1 or 2 on the back panel.

The **Output Amplitudes section** is only available for Instruments with the MF-MD option installed and allows for the flexible adjustment of output amplitudes of different demodulators and their summation on the Signal Output. In order to avoid signal clipping the sum of amplitudes of each signal output needs to be smaller than the range defined in the Signal Outputs section on the right. By clicking the headline of each column one can switch between amplitude definitions in terms of root mean square values, peak-to-peak values or even units of dBm, when the 50 Ω option in the Signal Output section is activated.

In the **Signal Outputs section** the On buttons allow to activate the Signal Output of the front panel. The Range drop down list is used to select the proper output range setting. On the Signal Output a digital offset voltage (Offset) can be defined. The maximum output signal permitted is ±10 V.

Block Diagram

The block diagram view of the main instrument functions is also sometimes referred to as the "Graphical Lock-in Tab". Depending how many demodulators are available in the instrument a set of numbered side-tabs occur 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 4.13 describes the signal path throughout the instrument for the case when the internal oscillator is used as reference. In this case the tab consists of 6 functional sections. The Signal Inputs and Reference/Internal Frequency are described on the left side, the core of demodulation with the mixer and low-pass 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.

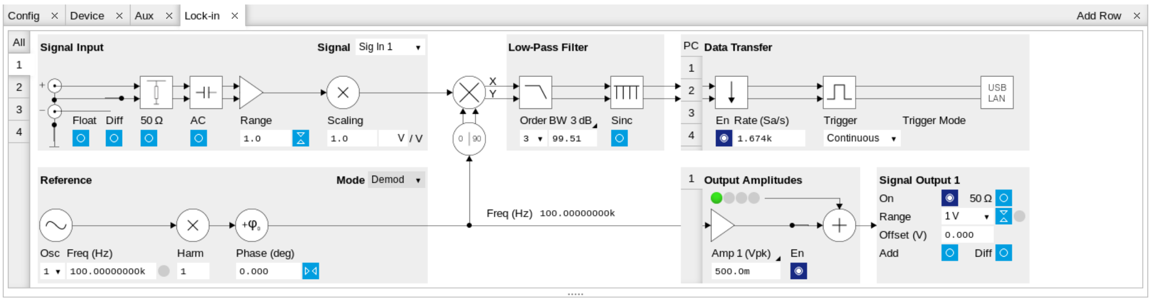


Figure 4.13. LabOne User Interface Lock-in tab - Graphical Lock-in tab in Internal Reference mode

The block diagram in Figure 4.14 describes the signal path throughout the instrument for the case when an external reference is used. This setting is only available for demodulators 2 and 4. In order to map an external frequency to any of the oscillators, go to the Reference section of demodulator 2 and 4 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.

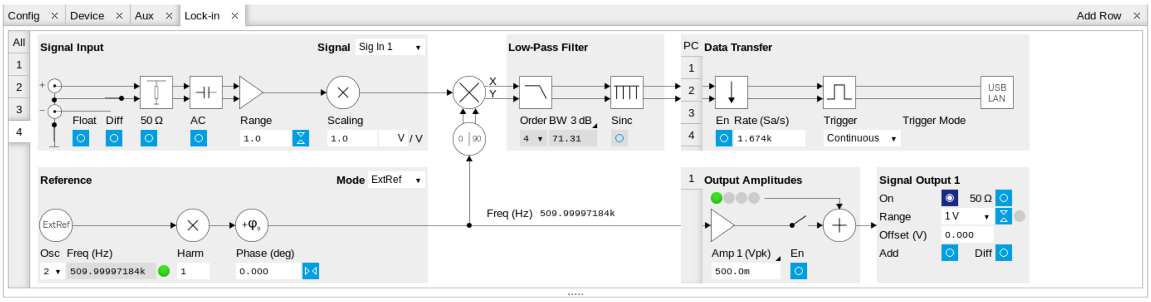


Figure 4.14. LabOne User Interface Lock-in tab - Graphical Lock-in tab in External Reference mode

4.3.3. Functional Elements

Table 4.13. Lock-in MF tab

Control/Tool	Option/Range	Description
Range	3.0 mV, 10 mV, 30 mV, 100 mV, 300 mV, 1 V, 3.0 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. Note 1: the value inserted by the user may be approximated to the nearest value supported by the Instrument. Note 2:

Control/Tool	Option/Range	Description
		a proper choice of range setting is crucial in order to achieve good accuracy and best possible signal to noise ratio as it targets to use the full dynamic range of the input ADC.
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. 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.
AC	ON: AC coupling OFF: DC coupling	Defines the input coupling for the Signal Inputs. AC coupling inserts a high-pass filter.
50 Ω	ON: 50 Ω OFF: 10 MΩ	Switches between 50 Ω (ON) and 10 MΩ (OFF).
Float	ON: Floating OFF: GND connected	Switches between floating (ON) and connected grounds (OFF). This setting is shared for the voltage and current input.
Diff	OFF: Single ended voltage input ON: Differential voltage input	Switches between single ended (OFF) and differential (ON) measurements.
Range	10 nA 1 µA 100 µA 10 mA	Defines the gain of the current input amplifier. The range should exceed the incoming signal by roughly a factor two including a potential DC offset. Note 1: the value inserted by the user may be approximated to the nearest value supported by the Instrument. Note 2: a proper choice of range

Control/Tool	Option/Range	Description
		setting is crucial in order to achieve good accuracy and best possible signal to noise ratio as it targets to use the full dynamic range of the input ADC.
Auto		Automatic adjustment of the Range to about two times the maximum current input amplitude measured over about 100 ms.
Scaling	numeric value	Applies an arbitrary scale factor to the current input.
Measurement Unit	unit acronym	Defines the physical unit of the current input. Use *, / and ^ operators, e.g., m or m/s^2 The value in this field modifies the readout of all measurement tools in the user interface.
Mode		Indicates how the frequency of the corresponding oscillator is controlled (manual, external reference). Read only flag.
	Manual	The user setting defines the oscillator frequency.
	ExtRef	An external reference is mapped onto the oscillator frequency.
Frequency (Hz)	0 to 5 MHz	Frequency control for each oscillator.
Locked	ON / OFF	Oscillator locked to external reference when turned on.
Mode		Indicates the unit that uses the demodulator (Demod stands for regular lock-in amplifier or external reference)
	Demod	Default operating mode with demodulator used for lock-in demodulation.
	ExtRef	The demodulator is used for external reference mode and tracks the frequency of the selected reference input.
Osc	oscillator index	Connects the selected oscillator with the demodulator corresponding to this line. Number of available

Control/Tool	Option/Range	Description
		oscillators depends on the installed options.
Harm	1 to 1023	Multiplies the demodulator's reference frequency with the integer factor defined by this field. Multiplies the demodulator's reference frequency by an integer factor. 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.
Harm	1 to 1023	Divides the demodulator's reference frequency by an integer factor in external reference mode. Multiplies the demodulator's reference frequency by an integer factor. 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 5 MHz	Indicates the frequency used for demodulation and for output generation. The demodulation frequency is calculated with oscillator frequency times the harmonic factor. When the MF-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.
Zero		Adjust the demodulator phase automatically in order to read zero degrees. Shifts the phase of the reference at the input of

Control/Tool	Option/Range	Description
		the demodulator in order to achieve zero phase at the demodulator output. This action maximizes the X output, zeros the Y output, zeros the Θ 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.
	Curr In 1	Current Input 1 is connected to the corresponding demodulator.
	Trigger 1	Trigger 1 is connected to the corresponding demodulator.
	Trigger 2	Trigger 2 is connected to the corresponding demodulator.
	Aux Out 1	Auxiliary Output 1 is connected to the corresponding demodulator.
	Aux Out 2	Auxiliary Output 2 is connected to the corresponding demodulator.
	Aux Out 3	Auxiliary Output 3 is connected to the corresponding demodulator.
	Aux Out 4	Auxiliary Output 4 is connected to the corresponding demodulator.
	Aux In 1	Auxiliary Input 1 is connected to the corresponding demodulator.
	Aux In 2	Auxiliary Input 2 is connected to the corresponding demodulator.
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

Control/Tool	Option/Range	Description
	8	8th order filter 48 dB/oct
TC/BW Select		Defines the display unit of the low-pass filters: time constant (TC), noise equivalent power bandwidth (BW NEP), 3 dB bandwidth (BW 3 dB).
	TC	Defines the low-pass filter characteristic using time constant of the filter.
	BW NEP	Defines the low-pass filter characteristic using the noise equivalent power bandwidth of the filter.
	BW 3 dB	Defines the low-pass filter characteristic using the cut-off frequency 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. 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.
Lock		Makes all demodulators filter settings equal (order, time constant, bandwidth). Pressing the lock copies the settings from demodulator one into the settings of all demodulators. When the lock is pressed, any modification to a field is immediately changing all other settings. Releasing the lock does not change any setting, and permits to individually adjust the filter settings for each demodulator.
Enable Streaming		Enables the data acquisition for the corresponding demodulator. Note: increasing number of active

Control/Tool	Option/Range	Description
		demodulators increases load on physical connection to the host computer.
	ON: demodulator active	Enables the streaming of demodulated samples in real time to the host computer. The streaming rate is defined in the field on the right hand side. As a consequence demodulated samples can be visualized on the plotter and a corresponding numeric entry in the numerical tool is activated.
	OFF: demodulator inactive	Disables the streaming of demodulated samples to the host computer.
Rate (Sa/s)	0.056 Sa/s to 857 kSa/s	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. 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.
Demodulator Output Rate Lock		Makes all demodulator output rates equal. Pressing the lock copies the settings from demodulator one into the settings of all demodulators. When the lock is pressed, any modification to a field is immediately changing all other settings. Releasing the lock does not change any setting, and permits to individually adjust the demodulator output rate for each demodulator.

Control/Tool	Option/Range	Description
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.
	Trigger 1	Selects external triggering by means of the Trigger 1 connector. Demodulated samples are sent to the host computer for each event defined in the Trig Mode field. When edge trigger is selected the rate field is greyed out and has no meaning.
	Trigger 2	Selects external triggering by means of the Trigger 2 connector. Demodulated samples are sent to the host computer for each event defined in the Trig Mode field. When edge trigger is selected the rate field is greyed out and has no meaning.
	Trigger 1|2	Same functionality as above, but triggering is based on a logical OR function of Trigger 1 and Trigger 2.
Trig 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.

Control/Tool	Option/Range	Description
	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, dBm	Select the unit of the displayed amplitude value. The dBm value is only valid for a system with 50 Ω termination.
Amp Enable	ON / OFF	Enables individual output signal amplitude. When the MF-MD option is used, it is possible to generate signals being the linear combination of the available demodulator frequencies.
Amp (V)	-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. 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.
AWG	AWG is ON	Indicates that the output amplitude is generated by the AWG.
On	ON / OFF	Main switch for the Signal Output corresponding to the

Control/Tool	Option/Range	Description
		blue LED indicator on the instrument front panel.
50Ω	ON / OFF	Select the load impedance between 50Ω and HiZ. The impedance of the output is always 50Ω. For a load impedance of 50Ω the displayed voltage is half the output voltage to reflect the voltage seen at the load.
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. 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 Ω target source or differential output is enabled the possible maximal output range will be half.
	10 mV	Selects output range ±10 mV.
	100 mV	Selects output range ±100 mV.
	1 V	Selects output range ±1 V.
	10 V	Selects output range ±10 V.
Auto Range		Selects the most suited output range automatically.
Output Clipping	grey/red	Indicates that the specified output amplitude(s) exceeds the range setting. Signal clipping occurs and the output signal quality is degraded. Adjustment of the range or the output amplitudes is required.
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 Aux Input 1 is added to the signal

Control/Tool	Option/Range	Description
		output. For differential output the added signal is a common mode offset.
Diff	ON / OFF	Switch between single-ended output (OFF) and differential output (ON). In differential mode the signal swing is defined between Signal Output +V / -V.

4.4. Numeric Tab

The Numeric Tab provides a powerful time domain based measurement display as introduced in Section 4.1.2. It is available in all MFLI Instruments.

4.4.1. 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

4.4.2. 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 4.14. 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 4.15) 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.

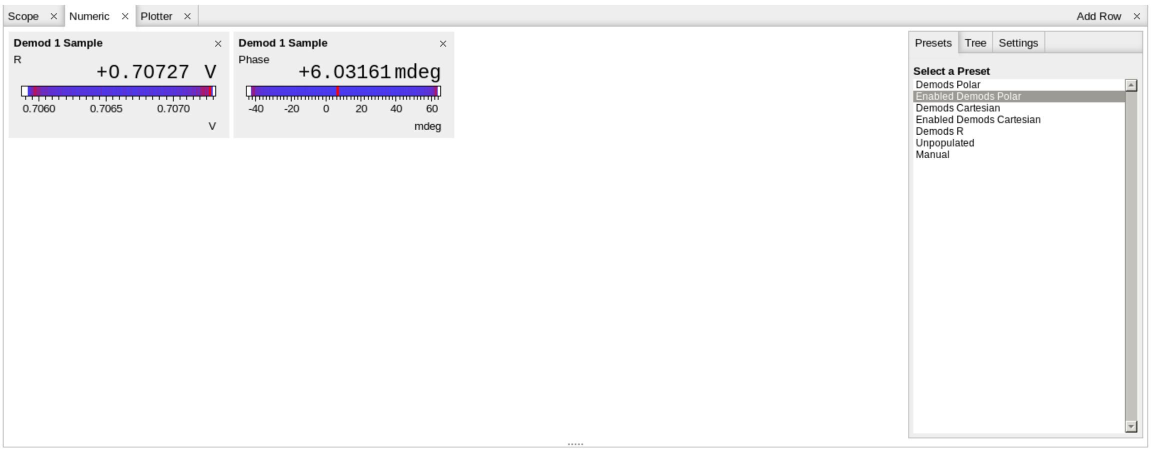


Figure 4.15. LabOne UI: Numeric tab

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, Θ) 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.

4.4.3. Functional Elements

Table 4.15. 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.
	Enabled Impedances	Shows impedance, model parameters, and frequency.
	Unpopulated	Shows no signals.
	Manual	If additional signals are added or removed the active preset gets manual.

For the Tree sub-tab please see Table 4.8 in the section called “Tree Sub-Tab”.

Table 4.16. 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 scaling.
	Log	Enable logarithmic scaling.
	dB	Enable logarithmic scaling 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.

Control/Tool	Option/Range	Description
Stop Value	numeric value	Stop value of the selected plot(s). Only visible for manual scaling.

4.5. Plotter Tab

The Plotter is one of the powerful time domain measurement tools as introduced in Section 4.1.2 and is available in all MFLI Instruments.

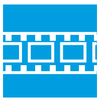
4.5.1. Features

- Plotting of all streamed data, e.g. demodulator data, auxiliary inputs, auxiliary outputs, etc.
- 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

4.5.2. 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 4.17. App icon and short description

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

The Plotter tab (see Figure 4.16) is divided into a display section on the left and a configuration section on the right.

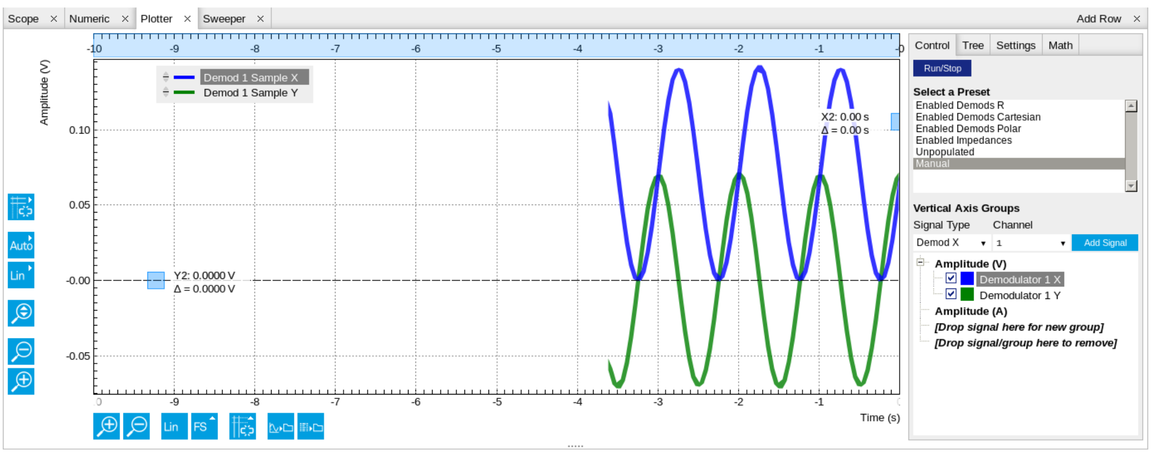


Figure 4.16. LabOne UI: Plotter tab

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, Θ, 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 Section 4.1.3.

The maximum duration data is kept in the memory can be defined as 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.

4.5.3. Functional Elements

Table 4.18. Plotter tab: Control sub-tab

Control/Tool	Option/Range	Description
Run/Stop	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. 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.
	Enabled Impedances	Shows impedance, model parameters, and frequency.
	Unpopulated	Shows no signals.
	Manual	Selects the signals as defined in the tree sub-tab.

For the Vertical Axis Groups, please see Table 4.9 in the section called “Vertical Axis Groups”.

For the Tree sub-tab please see Table 4.8 in the section called “Tree Sub-Tab”.

Table 4.19. Plotter tab: Settings sub-tab

Control/Tool	Option/Range	Description
Window Length	10 s to 12 h	Plotter 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.
Histogram	ON / OFF	Shows the histogram in the display.
Rate	27.5 kHz to 28.1 MHz	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.
Enable	ON / OFF	Enable scope streaming for the specified channel. This allows for continuous recording of scope data on the plotter and streaming to disk. Note: scope streaming requires the DIG option.

For the Math sub-tab please see Table 4.7 in the section called “Cursors and Math”.

4.6. Scope Tab

The Scope is a powerful time domain and frequency domain measurement tool as introduced in Section 4.1.2 and is available for all MFLI Instruments.

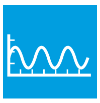
4.6.1. Features

- One input channel with 16 kSa of memory; upgradable to two channels with 2.5 MSa memory per channel (MF-DIG option)
- 16 bit nominal resolution
- 24 bit high-definition mode (MF-DIG option)
- Fast Fourier Transform (FFT): up to 60 MHz span, spectral density and power conversion, choice of window functions
- Sampling rates from 1.83 kSa/s to 60 MSa/s; up to 270 μs acquisition time at 60 MSa/s or 8.9 s at 1.83 kSa/s
- 8 signal sources including Signal Inputs (I/V) and Trigger Inputs; up to 8 trigger sources and 2 trigger methods
- Independent hold-off, hysteresis, pre-trigger and trigger level settings
- Support for Input Scaling and Input Units
- Segmented recording (requires MF-DIG option)

4.6.2. 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 4.20. App icon and short description

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

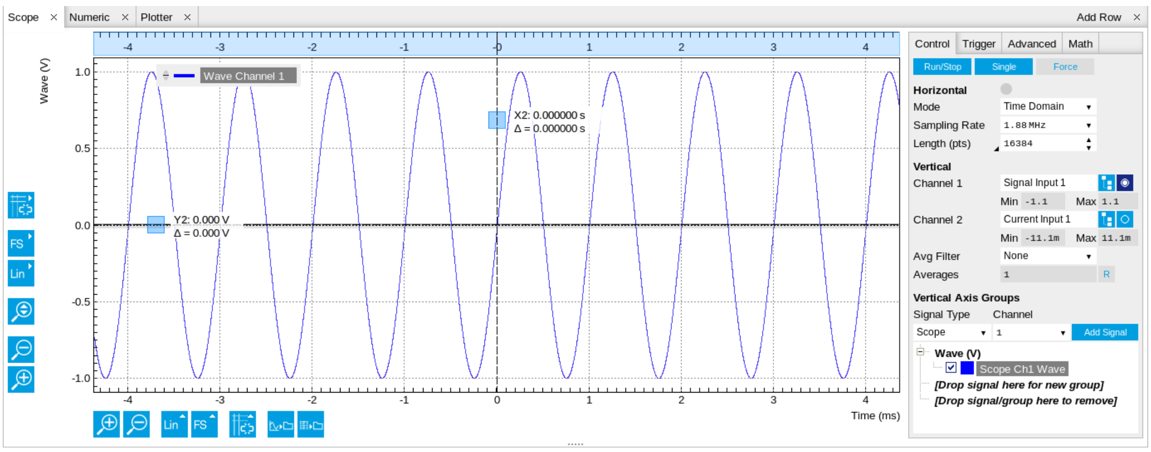


Figure 4.17. LabOne UI: Scope tab - Time domain

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 4 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 4.17) Ar frequency (for frequency domain display, Figure 4.19). It is possible to display the time trace and the associated FFT simultaneously by opening a second instance of the Scope tab. The Y axis displays the selected signal that can be modified and scaled using the arbitrary input unit feature found in the Lock-in tab.

The Scope records data from a single channel at up to 60 MSa/s. The channel can be selected among the two Signal Inputs, Auxiliary Inputs, Trigger Inputs and Demodulator Oscillator Phase. The Scope records data sets of up to 16 kSa samples in the standard configuration, which corresponds to an acquisition time of 270 μs at the highest sampling rate.

The product of the inverse sampling rate and the number of acquired points (Length) determines the total recording time for each shot. Hence, longer time intervals can be captured by reducing the sampling rate. The Scope can perform sampling rate reduction either using decimation or BW Limitation as illustrated in Figure 4.18. BW Limitation is activated by default, but it can be deactivated in the Advanced sub-tab. The figure shows an example of an input signal at the top, followed by the Scope output when the highest sample rate of 60 MSa/s is used. The next signal shows the Scope output when a rate reduction by a factor of 4 (i.e. 15 MSa/s) is configured and the rate reduction method of decimation is used. For decimation, a rate reduction by a factor of N is performed by only keeping every Nth sample and discarding the rest. The advantage to this method is its simplicity, but the disadvantage is that the signal is undersampled because the input filter bandwidth of the MFLI instrument is fixed at 7 MHz. As a consequence, the Nyquist sampling criterion is no longer satisfied and aliasing effects may be observed. The default rate reduction mechanism of BW Limitation is illustrated by the lowermost signal in the figure. BW Limitation means that for a rate reduction by a factor of N, each sample produced by the Scope is computed as the average of N samples acquired at the maximum sampling rate. The effective signal bandwidth is thereby reduced and aliasing effects are largely suppressed. As can be seen from the figure, with a rate reduction by a factor of 4, every output sample is simply computed as the average of 4 consecutive samples acquired at 60 MSa/s.

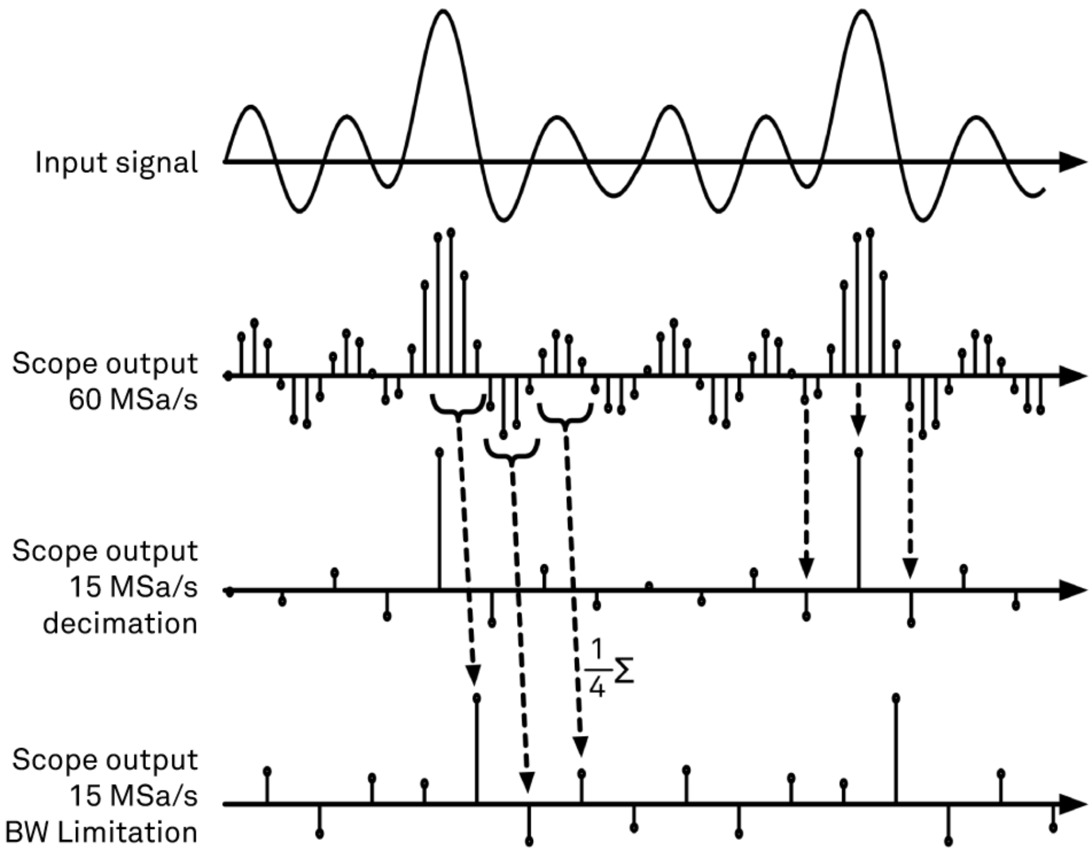


Figure 4.18. Illustration of how the Scope output is generated in BW Limitation and decimation mode when the sampling rate is reduced from the default of 60 MSa/s to 15 MSa/s .

The Scope also offers an averaging filter that works on a shot-to-shot basis. The functionality is implemented by means of an exponential moving average filter with configurable filter depth. The averaging filter can help suppress noise components that are uncorrelated with the main signal. It is particularly useful when the spectrum of the signal is considered as it can help to reveal harmonic signals and disturbances that might otherwise be hidden below the noise floor.

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.

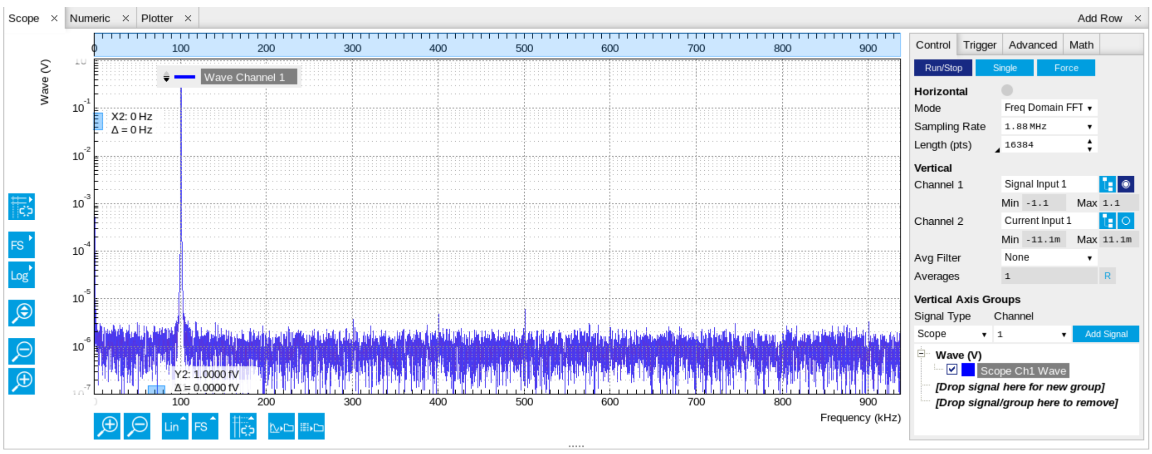


Figure 4.19. LabOne UI: Scope tab - Frequency domain

The Trigger sub-tab offers all the controls necessary for triggering on different signal sources. When the trigger is enabled, then oscilloscope shots are only acquired when 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.

Digitizer upgrade option

The MF-DIG Digitizer option greatly enhances the performance of the Scope with the addition of the following features

- Simultaneous recording of two Scope channels
- Memory depth of 5 MSa for both Scope channels
- Additional input signal sources (Demodulator X, Y, R, and Θ)
- Trigger gating
- Resolution increase up to 24 bit with high-definition (HD) mode
- Additional trigger input sources that allow for cross-domain triggering
- Additional trigger/marker output sources based on the state of the Scope
- Segmented data recording
- Continuous scope data streaming (Plotter tool)

This additional functionality can be enabled on any MFLI instrument by uploading an option key. Please contact Zurich Instruments to get more information. The following sections explain the Digitizer features in more detail.

Two channels and extended memory depth

With the MF-DIG option enabled it is possible to record two channels simultaneously. The two channels are sampled at the same time. This allows for very exact time difference measurements. Each channel can be assigned a different signal source. Enabled triggering will control when the recording of both channels start. The sampling rate and recording length settings are shared between both channels. A single shot length of up to 5 MSa can be recorded. Compared to the standard memory depth of 16 kSa this allows for longer recording times and FFTs with finer frequency resolution.

Additional input sources

Besides the Signal Input, Trigger Input, Auxiliary Input, and Oscillator Phase the MF-DIG option also allows for recording of Demodulator X, Y, R, and Θ signals. This functionality is very powerful in that it allows short bursts to be recorded with very high sampling rates. In order to achieve the best possible utilization of the scope vertical resolution the upper and lower limit of these input signals should be specified. Before sampling, a scaling and an offset are applied to the input signal in order to get 16 bit resolution between the lower and upper limit. The applied scaling and offset values are transferred together with the scope data, which allows for recovery of the original physical signal strength in absolute values. For directly sampled input signals like the Signal Inputs or Trigger Inputs, the limits are read-only values and reflect the selected input range.

High-definition mode

Sampling rate reduction with BW Limitation brings the advantage of increasing the available vertical resolution beyond the 16 bit resolution of the ADC up to 24 bit (high-definition mode). Table 4.21 shows the nominal scope resolution depending on the sampling rate.

Table 4.21. Scope resolution increase with MF-DIG Digitizer option

Scope Sampling Frequency	Scope vertical resolution (with MF-DIG option)
60 MSa/s	16 bits

Scope Sampling Frequency	Scope vertical resolution (with MF-DIG option)
30 MSa/s	16.5 bits
15 MSa/s	17 bits
7.5 MSa/s	17.5 bits
3.25 MSa/s	18 bits
1.625 MSa/s	18.5 bits
812 kSa/s	19 bits
406 kSa/s	19.5 bits
203 kSa/s	20 bits
101 kSa/s	20.5 bits
51 kSa/s	21 bits
25.3 kSa/s	21.5 bits
12.6 kSa/s	22 bits
6.3 kSa/s	22.5 bits
3.1 kSa/s	23 bits
1.5 kSa/s	23.5 bits
0.75 kSa/s	24 bits

Trigger gating

With the MF-DIG option installed the user can make full use of the Trigger Engine. If trigger gating is enabled, a trigger event will only be accepted if the gating input is active.

Additional trigger input sources

By using a Demodulator signal as trigger source, the Scope can be used in a cross-domain triggering mode. This allows, for example, for time domain signals to be recorded in a synchronous fashion triggered by the result from analyzing a signal in the frequency domain by means of a demodulator.

Note

Adjust a negative delay (pre-trigger) to compensate for the delay introduced by the Demodulator.

Segmented data recording

The scope sends the result of each shot to the PC over an interface with limited data transfer bandwidth. As a consequence, a hold-off time is required between individual scope shots to allow the recorded data to be transferred to the PC. The segmented data recording mode can be enabled if the user requires a small hold-off time between shots. The mode allows a burst of up to 16384 scope shots, called segments, to be recorded into the device memory. The hold-off time in this mode can be less than 100 μs between each shot, because the Scope does not have to wait for the data transfer to complete before the next shot can be started. The segmented data recording is most powerful when used over the API. The data of each shot will contain information on the segment number.

Scope state output on Trigger Output

The MF-DIG option extends the list of available Trigger Outputs by the six elements: Scope Trigger, Scope Armed, Scope Active and their logically inverse signals. The Trigger Output signals are controlled on the DIO tab (Section 4.12). Figure 4.20 shows an illustration of the signal that will be generated on the Trigger Output when one of the six new Scope-related sources is selected. An example input signal is shown at the top of the figure. It is assumed that the Scope is configured to trigger on this input signal on a rising edge crossing the level indicated by the stippled line.

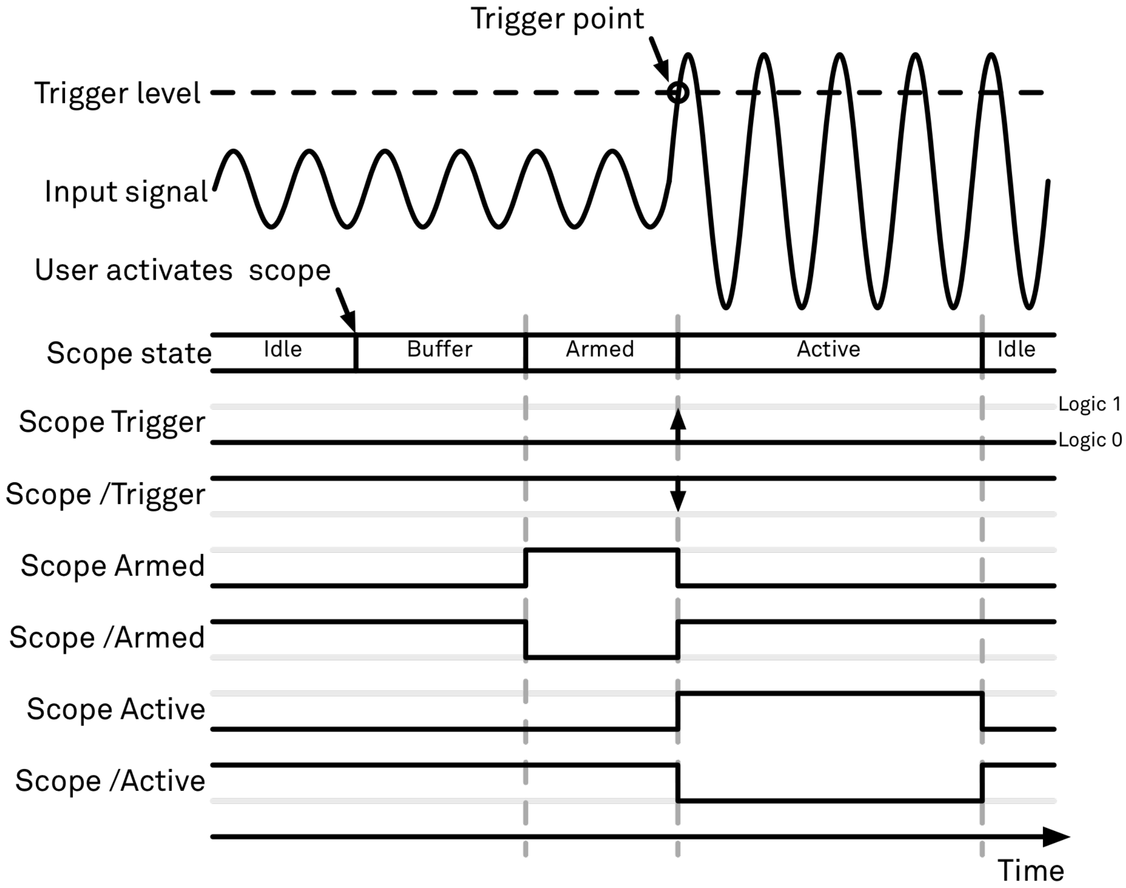


Figure 4.20. Illustration of the signal that will appear on the Trigger Output when one of the six Scope related sources is selected.

The Scope can be thought of as having a state, which changes over time. The state is shown below the input signal in the figure. When the Scope is completely inactive, it is said to be in the Idle state. When the user then activates the Scope, it will transition into a Buffer state. In this state the Scope will start to record the input signal. It will remain in this state until sufficient data has been recorded to fulfill the user requirement for recording data prior to the trigger point as controlled by the trigger Reference and Delay fields in the user interface. Once sufficient data has been recorded, the Scope will transition to the Armed state. In this state the Scope is ready to accept the trigger signal. Note that the Scope will continue to record data for as long as it is in the Armed state, and that if no trigger is defined, the Scope will simply pass straight through the Armed state. Once the input signal passes the Trigger level the Scope will trigger, and at the same time its state will change from Armed to Active. The Scope will remain in the Active state, where it also records data, until sufficient data has been recorded to fulfill the Length requirement configured in the user interface. Once enough data has been acquired, the Scope will transition back into the Idle state where it will wait for the time configured with the Hold-off time before it either starts the next measurement automatically (in case Run is active) or waits for the user to reactivate it.

The trigger source selector allows information about the Scope state to be reproduced on the Trigger Output in a number of ways. The signal that will appear on the output is shown with the six bottommost traces in the figure. Note that these traces are shown as digital signals with symbolic values of logic 0 and 1. These values will of course be actual voltages when measured on the device itself.

First, if Scope Trigger is selected then the trigger output will have a signal that is asserted, which means that it goes high, when the scope triggers, i.e. changes from the Armed to the Active state. The signal will normally have a very short duration and, therefore, it is shown with an arrow in the figure. The duration can be increased by means of the Width input field, which can be found next to the Output Signal selector on the DIO tab. If Scope/Trigger is selected, then the same signal will appear on the output, but it will simply be inverted logically.

Next, if the Scope Armed source is selected, the trigger output will be asserted as long as the Scope is in the Armed state. Again, this means that the Scope has recorded enough data to proceed with the acquisition and is waiting for the trigger condition to become satisfied. In this example, since a rising edge trigger is defined, the trigger condition becomes satisfied when the input signal goes from below the trigger level to above the trigger level.

Similarly, if Scope /Armed is selected, the trigger output will be asserted (i.e. at logic 1) whenever the Scope is in a state different from the Armed state. The same explanation holds for the remaining two configuration options, except here the trigger output is asserted when the Scope is in the Active state or when it is not in the Active state.

4.6.3. Functional Elements

Table 4.22. Scope tab: Control sub-tab

Control/Tool	Option/Range	Description
Run/Stop	Run/Stop	Runs the scope/FFT continuously.
Single	Single	Acquires a single shot of samples.
Force	Force	Force a trigger event.
Mode	Time Domain	Switches between time and frequency domain display.
	Freq Domain (FFT)	
Sampling Rate	1.83 kSa/s to 60 MS/s	Defines the sampling rate of the scope.
Length Mode		Switches between length and duration display.
	Length (pts)	The scope shot length is defined in number of samples. The duration is given by the number of samples divided by the sampling rate. The MF-DIG option greatly increases the available length.
	Duration (s)	The scope shot length is defined as a duration. The number of samples is given by the duration times the sampling rate.
Length (pts) or Duration (s)	numeric value	Defines the length of the recorded scope shot. Use the Length Mode to switch

Control/Tool	Option/Range	Description
		between length and duration display.
Channel 1/2	Signal Input, Current Input, Trigger Inputs, Auxiliary Inputs, Demodulator Oscillator Phase, Demodulator X/Y/R/Theta	Selects the source for scope channel. Navigate through the tree view that appears and click on the required signal. Note: Channel 2 requires the DIG option.
Min	numeric value	Lower limit of the scope full scale range. For demodulator, PID, Boxcar, and AU signals the limit should be adjusted so that the signal covers the specified range to achieve optimal resolution.
Max	numeric value	Upper limit of the scope full scale range. For demodulator, PID, Boxcar, and AU signals the limit should be adjusted so that the signal covers the specified range to achieve optimal resolution.
Enable	ON / OFF	Activates the display of the corresponding scope channel. Note: Channel 2 requires the DIG option.
Avg Filter		Selects averaging filter type that is applied when the average of several scope shots is computed and displayed.
	None	Averaging is turned off.
	Exponential Moving Avg	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.
Reset	R	Resets the averaging filter.

For the Vertical Axis Groups, please see Table 4.9 in the section called “Vertical Axis Groups”.

Table 4.23. 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

Control/Tool	Option/Range	Description
		disabled trigger is equivalent to continuous acquisition. Scope shots with data loss are indicated by yellow. Such an invalid scope shot is not processed.
Enable		When triggering is enabled scope data are acquired every time the defined trigger condition is met.
	ON	Trigger based scope shot acquisition
	OFF	Continuous scope shot acquisition
Signal	Signal Input	Selects the trigger source signal. Navigate through the tree view that appears and click on the required signal.
	Current Input	
	Trigger Inputs	
	Auxiliary Input	
	Demodulator Oscillator Phase	
	Demodulator X/Y/R/Theta	
Edge Rise	ON / OFF	Performs a trigger event when the source signal crosses the trigger level from low to high. For dual edge triggering, select also the falling edge.
Edge Fall	ON / OFF	Performs a trigger event when the source signal crosses the trigger level from high to low. For dual edge triggering, select also the rising edge.
Level (V)	trigger signal range (negative values permitted)	Defines the trigger level.
Hysteresis Mode		Selects the mode to define the hysteresis strength. The relative mode will work best over the full input range as long as the analog input signal does not suffer from excessive noise.
	Hysteresis (V)	Selects absolute hysteresis.
	Hysteresis (%)	Selects a hysteresis relative to the adjusted full scale signal input range.
Hysteresis (V)	trigger signal range (positive values only)	Defines the voltage the source signal must deviate from the trigger level before the trigger is rearmed again. Set to 0 to turn it off. The sign is defined by the Edge setting.

Control/Tool	Option/Range	Description
Hysteresis (%)	numeric percentage value (positive values only)	Hysteresis relative to the adjusted full scale signal input range. A hysteresis value larger than 100% is allowed.
Show Level	ON / OFF	If enabled shows the trigger level as grey line in the plot. The hysteresis is indicated by a grey box. The trigger level can be adjusted by drag and drop of the grey line.
Trigger Gating		Select the signal source used for trigger gating if gating is enabled. This feature requires the MF-DIG option.
	Trigger In 1 High	Only trigger if the Trigger Input 1 is at high level.
	Trigger In 1 Low	Only trigger if the Trigger Input 1 is at low level.
	Trigger In 2 High	Only trigger if the Trigger Input 2 is at high level.
	Trigger In 2 Low	Only trigger if the Trigger Input 2 is at low level.
Trigger Gating Enable	ON / OFF	If enabled the trigger will be gated by the trigger gating input signal. This feature requires the MF-DIG option.
Holdoff Mode		Selects the holdoff mode.
	Holdoff (s)	Holdoff is defined as time.
	Holdoff (events)	Holdoff is defined as number of events.
Holdoff (s)	numeric value	Defines the time before the trigger is rearmed after a recording event.
Holdoff (events)	1 to 1048575	Defines the trigger event number that will trigger the next recording after a recording event. A value one will start a recording for each trigger event.
Reference (%)	percent value	Trigger reference position relative to the plot window. Default is 50% which results in a reference point in the middle of the acquired data.
Delay (s)	numeric value	Trigger position relative to reference. A positive delay results in less data being acquired before the trigger point, a negative delay results

Control/Tool	Option/Range	Description
		in more data being acquired before the trigger point.
Enable	ON / OFF	Enable segmented scope recording. This allows for full bandwidth recording of scope shots with a minimum dead time between individual shots. This functionality requires the DIG option.
Segments	1 to 32768	Specifies the number of segments to be recorded in device memory. The maximum scope shot size is given by the available memory divided by the number of segments. This functionality requires the DIG option.
Shown Segment	integer value	Displays the number of recorded segments.
Shown Trigger	integer value	Displays the number of triggered events since last start.

Table 4.24. Scope tab: Advanced sub-tab

Control/Tool	Option/Range	Description
FFT Window	Rectangular	Four 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.
	Hann	
	Hamming	
	Blackman Harris	
Resolution (Hz)	mHz to Hz	Spectral resolution defined by the reciprocal acquisition time (sample rate, number of samples recorded).
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.

Control/Tool	Option/Range	Description
		The color scheme visualizes the number of occurrences at certain positions in time and amplitude by a multi-color scheme.
BW Limit Ch 1		Selects between sample decimation and sample averaging. Averaging avoids aliasing, but may conceal signal peaks.
	ON	Selects sample averaging for sample rates lower than the maximal available sampling rate.
	OFF	Selects sample decimation for sample rates lower than the maximal available sampling rate.
BW Limit Ch 2		Selects between sample decimation and sample averaging. Averaging avoids aliasing, but may conceal signal peaks. Channel 2 requires the DIG option.
	ON	Selects sample averaging for sample rates lower than the maximal available sampling rate. Channel 2 requires the DIG option.
	OFF	Selects sample decimation for sample rates lower than the maximal available sampling rate. Channel 2 requires the DIG option.

For the Math sub-tab please see Table 4.7 in the section called “Cursors and Math”.

4.7. Software Trigger Tab

The software trigger is one of the powerful time domain measurement tools as introduced in Section 4.1.2 and is available for all MFLI Instruments.

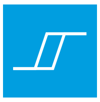
4.7.1. Features

- Time-domain data display for all continuously streamed data
- 6 different trigger types
- Automatic trigger level determination
- Display of multiple traces
- Adjustable record history
- Mathematical toolkit for signal analysis
- Grid mode for imaging support

4.7.2. Description

The Software Trigger tab provides display and recording of shot-wise data sets after configurable trigger events. 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 4.25. App icon and short description

Control/Tool	Option/Range	Description
SW Trig		Provides complex trigger functionality on all continuously streamed data samples and time domain display.

The Software Trigger tab (see Figure 4.21) 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.

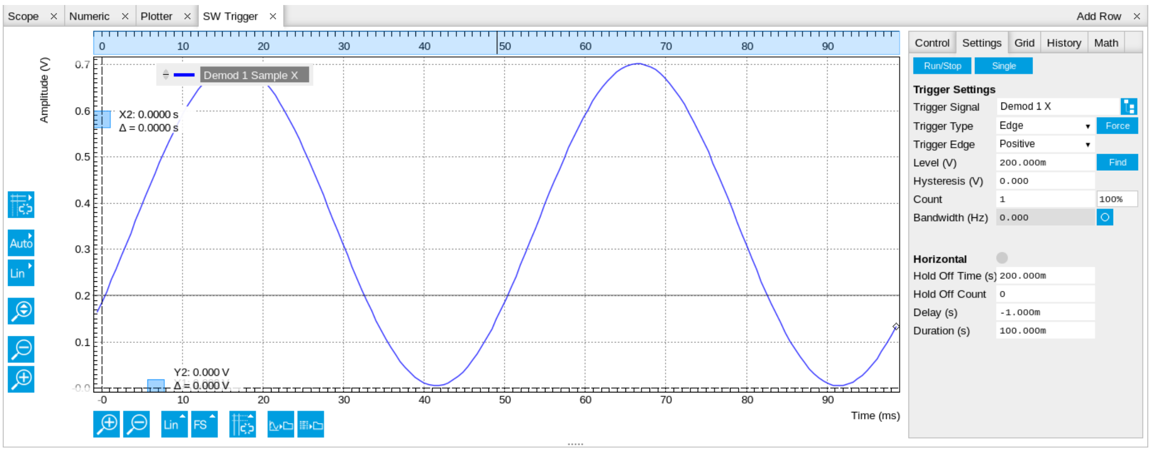


Figure 4.21. LabOne UI: Software trigger tab

The Software Trigger brings the trigger functionality of a scope to the continuously streamed data that can be viewed with the Plotter tool in a roll mode. The user can choose between a variety of different trigger options for the different signal inputs. Each trigger event is indicated by a green LED.

The trigger condition is configured in the **Settings** sub-tab. Among the selection of Trigger Types provided here, Edge and Pulse are most suited for analog trigger sources such as demodulator data, auxiliary voltages, or oscillator frequencies. 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 feature, be sure to choose a high enough bandwidth to let pass the feature that should be triggered upon, i.e., the signal edge or pulse. Note that the Bandwidth setting does not affect the recorded data itself.

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 intended for TTL signals on the Trigger Inputs or on the DIO lines. Using the Bits and Bit Mask setting, complex multi-bit trigger conditions on the DIO lines can be defined.

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 the functionality for capturing data for imaging applications. With enabled grid mode, the data recorded by the Software Trigger get organized in two-dimensional frames consisting of rows and columns. Every newly captured data shot is assigned to a row, and the total number of rows is defined by the Rows settings. 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 samples according to the Columns setting. If necessary, the streamed data are interpolated, resampled, and aligned with the trigger event. The data of a completed frame after averaging appears as a single entry in the History list. These data are available for saving, but can't be displayed in the plot section. The Software Trigger needs to run continuously for a sufficiently long time to complete the acquisition, and during that time the history entry contains only partial data

By default the plot area keeps the memory and display of the last 100 trigger shots represented in a list 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. Renaming a trace is easily possible by double clicking on a list entry. All measurements in the history can be stored in a file by clicking on Save. Which quantities are saved depends on which demodulator channels have been added to the Vertical Axis Groups section in the Control sub-tab. Naturally, only data from demodulators with enabled Data Transfer in the Lock-in tab can be included in the files. The file format, Matlab or comma-separated value (CSV) depends on the Format setting in the Config tab. The best way to access the saved files is via the File Manager tab.

4.7.3. Functional Elements

Table 4.26. SW Trigger tab: Control sub-tab

Control/Tool	Option/Range	Description
Run/Stop	Run/Stop	Start and stop the software trigger

Control/Tool	Option/Range	Description
Single	Single	Run the SW trigger once (record Count trigger events)
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 Table 4.9 in the section called "Vertical Axis Groups".

Table 4.27. SW Trigger tab: Settings sub-tab

Control/Tool	Option/Range	Description
Trigger Signal	Demodulator X/Y/R/Theta/ Frequency, Auxiliary Inputs, Trigger Inputs, Trigger Outputs, Demodulator 0 Degree Oscillator Phase Crossing	Source signal for trigger condition.
Trigger Type		Select the type of trigger to use. Selectable options depend on the selected trigger signal.
	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 conditions. The bit mask controls the bits that are used for trigger evaluation. For triggering just on DIO0 use a bit value 0x0001 and a bit mask 0x0001.
	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.
	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.

Control/Tool	Option/Range	Description
	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.
Force	Force	Forces a single trigger event.
Pulse Type	Positive/Negative/Both	Select between negative, positive or both pulse forms in the signal to trigger on.
Trigger Edge	Positive/Negative/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	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.

Control/Tool	Option/Range	Description
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 * 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	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	-2 s to 2 s	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)
Duration	up to 2 s	Recording length for each triggered data set.
Pulse Min	0 to 1 s	Minimum pulse width to trigger on.
Pulse Max	0 to 1 s	Maximum pulse width to trigger on.

Table 4.28. SW Trigger tab: Grid sub-tab

Control/Tool	Option/Range	Description
Mode		Enable the grid mode for two-dimensional data recording and select horizontal data resampling method.
	Off	Grid mode disabled.

Control/Tool	Option/Range	Description
	Nearest	Grid mode enabled. Resampling is performed using substitution by closest data point.
	Linear	Grid mode enabled. Resampling is performed using linear interpolation.
Operation		Select row update method.
	Replace	New row replaces old row.
	Average	The data for each row is averaged 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.
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
Repetitions	numeric value	Number of repetitions used for averaging

Table 4.29. SW Trigger tab: History sub-tab

Control/Tool	Option/Range	Description
History	History	Each entry in the list corresponds to a single trigger trace in the history. The number of triggers displayed in the plot is limited to 20. Use the toggle buttons to hide/ display individual traces. Use the color picker to change the color of a trace in the plot. Double click on an entry to edit its name.
Clear All	Clear All	Remove all records from the history list.
All	All	Select all records from the history list.
None	None	Deselect all records from the history list.

Control/Tool	Option/Range	Description
Length	integer value	Maximum number of entries stored in the measurement history. The number of entries displayed in the list is limited to the most recent 100.
Save	Save	Save all trigger event based traces in the history to file.Which data is saved depends on the demodulator channels present in the Vertical Axis Groups of the Control sub-tab

For the Math sub-tab please see Table 4.7 in the section called “Cursors and Math”.

4.8. Spectrum Analyzer Tab

The Spectrum Analyzer is one of the powerful frequency domain measurement tools as introduced in Section 4.1.2 and is available in all MFLI Instruments.

4.8.1. Features

- Fast, high-resolution FFT spectrum analyzer of demodulated data (X+iY, R, Θ, f and dΘ/dt/(2π))
- Variable center frequency, frequency resolution and frequency span
- Auto bandwidth, auto span (sampling rate)
- 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

4.8.2. Description

The Spectrum Analyzer allows frequency domain analysis of the demodulator data that are streamed to the data server with a user-defined rate. 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 4.30. 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 4.22) 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.

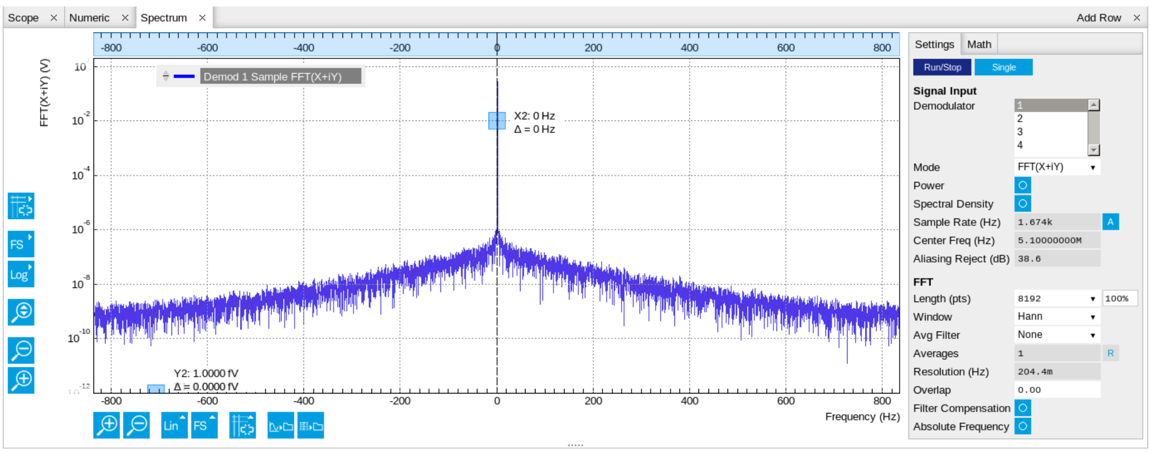


Figure 4.22. LabOne UI: Spectrum analyzer tab

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 described in Section 4.6. 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.

Another important property of the spectrum is the fact that the data samples 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 in a healthy ratio with respect to the filter bandwidth and order. When in doubt the user can always press the button labeled A next to the sampling rate in order to obtain a default setting that suits the filter settings.

Other than displaying the frequency spectrum of the complex demodulator samples X+iY, the user can also choose to apply an FFT to the polar demodulator values R and Theta. This allows to carefully discriminate between phase noise components and amplitude noise components present in the signal. As these samples are real numbers the spectrum is single-sided with minimum frequency of 0 Hz.

The last option in the drop-down list dΘ/dt allows one to apply the FFT on samples of demodulator frequencies. That is particularly useful when either the PLL or the ExtRef functionalities are used. 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.

4.8.3. Functional Elements

Table 4.31. Spectrum tab: Settings sub-tab

Control/Tool	Option/Range	Description
Run/Stop	Run/Stop	Run the FFT spectrum analysis continuously
Single	Single	Run the FFT spectrum analysis once
Demodulator	demodulator index	Select the input demodulator for FFT spectrum analysis
Mode		Select the source signal for FFT spectrum analysis. Enable spectral density to extract noise values. In order to extract peak values ensure that spectral density is disabled.
	FFT(X+iY)	Complex FFT of the demodulator result (zoom FFT). The center frequency is defined by the oscillator frequency of the demodulator. The span is twice the demodulator sampling rate.

Control/Tool	Option/Range	Description
	FFT(R)	FFT of the demodulator amplitude result $\mathrm{sqrt}(x^2 + y^2)$. The FFT is single sided as performed on real data.
	FFT(Θ)	FFT of the demodulator phase result atan2(y, x). The FFT is single sided as performed on real data.
	FFT(f)	FFT of the oscillator frequency of the selected demodulator. This mode is only interesting if the oscillator is controlled by a PID/PLL controller. The FFT is single sided as performed on real data.
	FFT($d\Theta/dt$)/(2π)	FFT of the demodulator phase derivative. This value is equivalent to the frequency noise observed on the demodulated signal. The FFT is single sided as performed on real data.
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.
Sample Rate (Hz)	numeric value	Equivalent to sampling rate of demodulator. The resulting frequency span is equal to the sample rate. Increase the sample rate to reduce aliasing.
Auto	A	Automatic adjustment of the sampling rate. The rate will be selected to achieve good enough anti-aliasing for the selected demodulator bandwidth.
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
Aliasing Reject (dB)	numeric value	Resulting aliasing rejection based on demodulator sampling rate and low-pass filter settings. If the value is too low either increase the sampling rate or lower the filter bandwidth.
Length (pts)	2^8 to 2^13	Number of lines of the FFT spectrum. A higher value increases the frequency resolution of the spectrum.
Sampling Progress	0% to 100%	The percentage of the FFT buffer already acquired.
Window	Rectangular	Four 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.
	Hann	
	Hamming	
	Blackman Harris	
Avg Filter	None	Selects the type of averaging.
	Exp Moving Avg	
Averages	integer value	Defines the number of spectra which are averaged and displayed.
Reset	R	Press once to reset the averaging filter.
Resolution (Hz)	mHz to Hz	Spectral resolution defined by the reciprocal acquisition time (sample rate, number of samples recorded).
Overlap	0 to 1	Overlap of demodulator data used for the FFT transform. Use 0 for no overlap and 0.99 for maximal overlap.
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.

For the Math sub-tab please see Table 4.7 in the section called “Cursors and Math”.

4.9. Sweeper Tab

The Sweeper is a highly versatile measurement tool available in all MFLI Instruments. The Sweeper allows one to scan one instrument parameter over a defined range and at the same time measure 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.

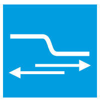
4.9.1. Features

- Full-featured parametric sweep tool for frequency, phase shift, output amplitude, DC output voltages, etc.
- Simultaneous display of data from different sources (Demodulators, frequencies, auxiliary inputs)
- 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
- Normalization of sweeps
- Auto bandwidth, averaging and display normalization
- Support for Input Scaling and Input Units
- Phase unwrap
- Full support of sinc filter

4.9.2. 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 4.23) 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 4.32. App icon and short description

Control/Tool	Option/Range	Description
Sweeper		Allows to scan one variable (of a wide choice, e.g. frequency) over a defined range and display various response functions including statistical operations.

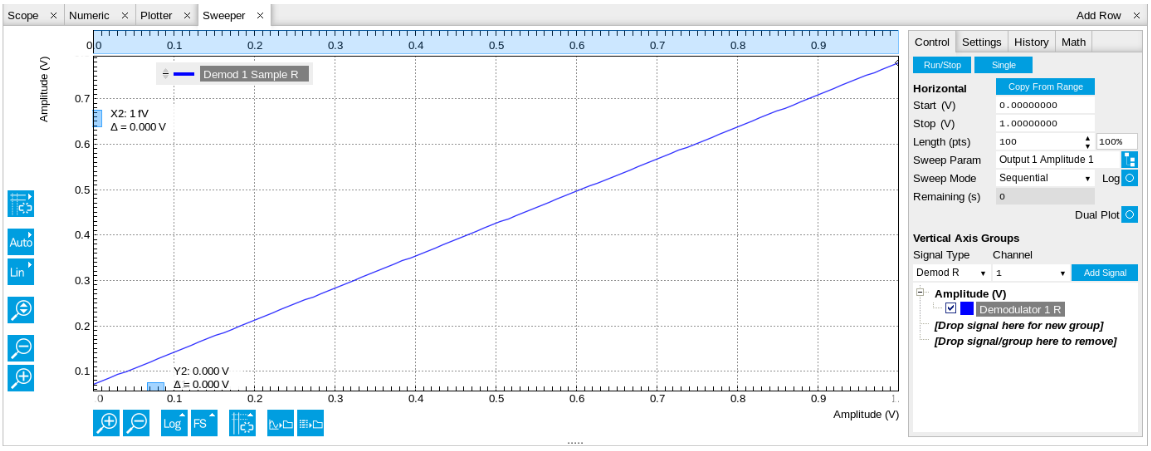


Figure 4.23. LabOne UI: Sweeper tab

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. Measurement parameters can be added 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.

For frequency sweeps the default sweep operation is logarithmic, i.e. with the Log button activated. In this mode, the sweep parameter points are distributed logarithmically - as opposed to equidistant for linear sweeps - between the start and stop values. This feature is particularly useful for sweeps over several decades, which is common for frequency sweeps. 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 +-180 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 Signal Processing chapter.

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 4th order filter and a 3 dB bandwidth of 100 Hz we obtain a step response the attains 90% after about 4.5 ms. This can be easily measured by using the SW Trigger as indicated in Figure 4.24. It is also explained in Section 6.3. 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 ω suppression. The ω 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.

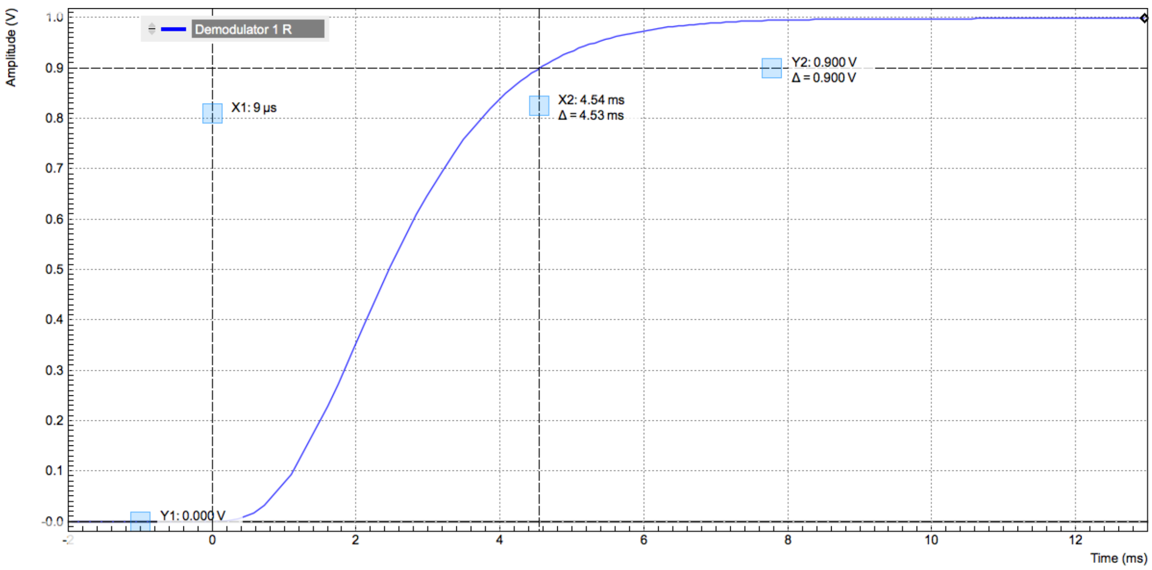


Figure 4.24. Demodulator settling time and inaccuracy

By default the plot area keeps the memory and display of the last 100 sweeps represented in a list 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. Renaming a trace is easily possible by double clicking on a list entry. All measurements in the history can be stored in a file by clicking on Save. Which quantities are saved depends on which demodulator channels have been added to the Vertical Axis Groups section in the Control sub-tab. Naturally, only data from demodulators with enabled Data Transfer in the Lock-in tab can be included in the files. The file format, Matlab or comma-separated value (CSV) depends on the Format setting in the Config tab. The best way to access the saved files is via the File Manager tab.

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).

4.9.3. Functional Elements

Table 4.33. Sweeper tab: Control sub-tab

Control/Tool	Option/Range	Description
Run/Stop	Run/Stop	Runs the sweeper continuously.
Single	Single	Runs the sweeper once.
Copy From Range	Copy From Range	Takes over start and stop value from the plot area.
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.	Oscillator Frequency	Selects the parameter to be swept. Navigate through the tree view that appears and click on the required parameter. Note: the available selection depends on the configuration of the device.
	Demodulator Phase	
	Signal Output Amplitude	
	Auxiliary Output Offset	
	Signal Output Offset	
Sweep Mode		Select the scanning type, default is sequential

Control/Tool	Option/Range	Description
		(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
Log	ON / OFF	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.
Dual Plot	ON / OFF	Toggle between single plot view and dual plot view

For the Vertical Axis Groups, please see Table 4.9 in the section called “Vertical Axis Groups”.

Table 4.34. Sweeper tab: Settings sub-tab

Control/Tool	Option/Range	Description
Filter		Application Mode: automatic mode. Advanced Mode: manual configuration.
	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).

Control/Tool	Option/Range	Description
	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 -> 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/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).

Control/Tool	Option/Range	Description
	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/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.
Order	numeric value	Selects the filter roll off to use for the sweep in fixed bandwidth mode. Range between 6 dB/oct and 48 dB/oct.
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

Control/Tool	Option/Range	Description
		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 Ω 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 this value and

Control/Tool	Option/Range	Description
		the next setting 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 this value and the previous setting 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 4.35. Sweeper tab: History sub-tab

Control/Tool	Option/Range	Description
History	History	Each entry in the list corresponds to a single sweep in the history. The number of displayed sweeps is limited to 20. Use the toggle buttons to hide/display individual sweeps. Use the color picker to change the color of a sweep. Double click on an entry to edit its name.
Clear All	Clear All	Remove all records from the history list.
All	All	Select all records from the history list.
None	None	Deselect all records from the history list.
Reference	Reference	Use the selected trace as reference for all active traces.
Length	integer value	Maximum number of entries stored in the measurement history. The number of entries

Control/Tool	Option/Range	Description
		displayed in the list is limited to the most recent 100.
Reference On	ON / OFF	Enable/disable the reference mode.
Reference name	name	Name of the reference trace used.
Save	Save	Save all sweeps in the history to file. Which data is saved depends on the demodulator channels present in the Vertical Axis Groups of the Control sub-tab.

For the Math sub-tab please see Table 4.7 in the section called “Cursors and Math”.

4.10. Auxiliary Tab

The Auxiliary tab provides access to the settings of the Auxiliary Inputs and Auxiliary Outputs; it is available for all MFLI Instruments.

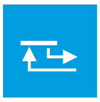
4.10.1. Features

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

4.10.2. Description

The Auxiliary tab serves mainly as a monitor and control of 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 4.36. 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 4.25) 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 buttons next to the Preoffset and 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.

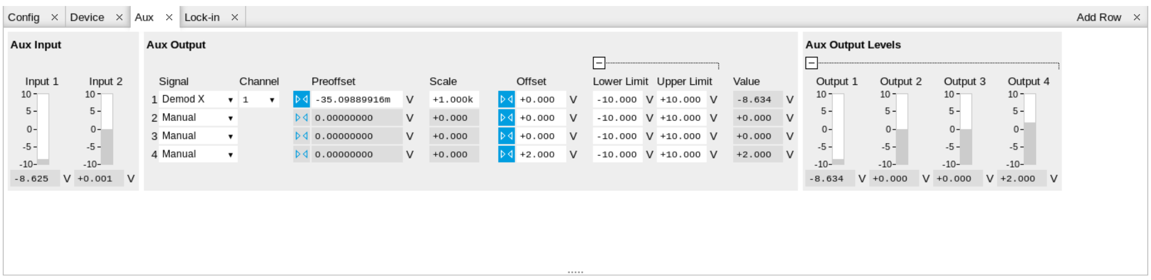


Figure 4.25. LabOne UI: Auxiliary tab

4.10.3. Functional Elements

Table 4.37. 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, Y, R, Θ	Select any of the 4 demodulator output quantities of any of the demodulators for auxiliary output.
	Manual	Manually define an auxiliary output voltage using the offset field.
Channel	index	Select the channel according to the selected signal source.
Preoffset	numerical value in signal units	Add an pre-offset to the signal before scaling is applied. Auxiliary Output Value = (Signal+Preoffset)*Scale + Offset
Auto-zero		Automatically adjusts the Pre-offset to set the Auxiliary Output Value to zero.
Scale	numerical value	Multiplication factor to scale the signal. Auxiliary Output Value = (Signal +Preoffset)*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+Preoffset)*Scale + Offset
Lower Limit	-10 V to 10 V	Lower limit for the signal at the Auxiliary Output. A smaller value will be clipped.
Upper Limit	-10 V to 10 V	Upper limit for the signal at the Auxiliary Output. A larger value will be clipped.
Value	-10 V to 10 V	Voltage present on the Auxiliary Output. Auxiliary Output Value = (Signal +Preoffset)*Scale + Offset

4.11. 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 for all MFLI Instruments.

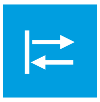
4.11.1. Features

- Signal input configuration
- Signal output configuration

4.11.2. 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 4.38. App icon and short description

Control/Tool	Option/Range	Description
In/Out		Access to all controls relevant for the main Signal Inputs and Signal Outputs on the instrument's front.

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 MF-MD Multi-demodulator option is installed or not. Figure 4.26)

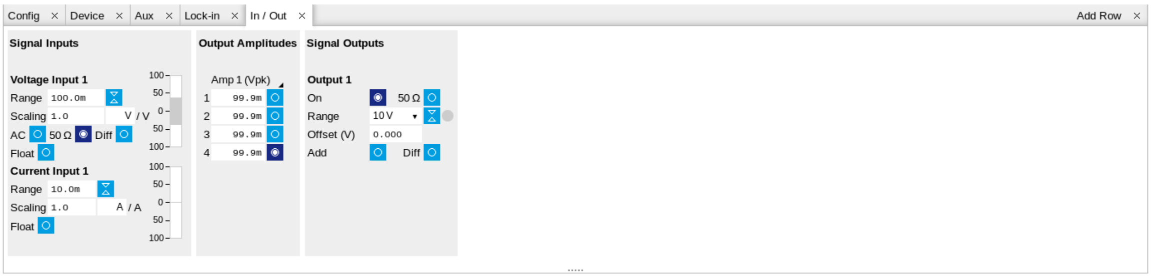


Figure 4.26. LabOne UI: Inputs/Outputs tab (with MF-MD Multi-demodulator option)

Figure 4.27. LabOne UI: Inputs/Outputs tab (without MF-MD Multi-demodulator option)

4.11.3. Functional Elements

All functional elements are equivalent to the ones on the Lock-in tab. See Section 4.2.2 or Section 4.3.2 for a detailed description of the functional elements.

4.12. 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 for all MFLI Instruments.

4.12.1. Features

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

4.12.2. 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 4.39. App icon and short description

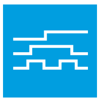
Control/Tool	Option/Range	Description
DIO		Gives access to all controls relevant for the digital inputs and outputs including the Ref/ Trigger connectors.

Figure 4.28. 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.

The Trigger section shows the settings for the 2 trigger inputs and 2 trigger outputs on the instrument back panel. The trigger outputs can be referenced to the demodulator frequencies and output a TTL signal with a 50% duty cycle.

Note

The Input Level determines the trigger threshold for trigger state discrimination. Also a 100 mV hysteresis is applied that cannot be adjusted such that a minimum amplitude of more than 100 mV is needed for the Trigger inputs to work reliably.

4.12.3. Functional Elements

Table 4.40. Digital input and output channels, reference and trigger

Control/Tool	Option/Range	Description
DIO mode		Select DIO mode
	Normal	Manual setting of the DIO output value.
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.
	hex	DIO view format is hexadecimal.
	binary	DIO view format is binary.
Clock		Select DIO internal or external clocking.
	Internal 60 MHz	The DIO is internally clocked with a fixed frequency of 60 MHz.
	Clk Pin 68	The DIO is externally clocked with a clock signal connected to DIO Pin 68. Available frequency range 1 Hz to 60 MHz.
Trigger level	-5 V to 5 V	Trigger voltage level at which the trigger input toggles between low and high. Use 50% amplitude for digital input and consider 100 mV hysteresis.
Trigger Input status		Indicates the current trigger state.
	high	A high state has been triggered.
	low	A low state has been triggered.
	toggling	The trigger signal is toggling.
Trigger output signal		Select the signal assigned to the trigger output.

Control/Tool	Option/Range	Description
	Off	The output trigger is disabled.
	Osc Phase Demod 2	Trigger event is output for each zero crossing of the oscillator phase used on demodulator 2.
	Osc Phase Demod 4	Trigger event is output for each zero crossing of the oscillator phase used on demodulator 4.
	Scope Trigger	Trigger output is asserted when the scope trigger condition is satisfied.
	Scope /Trigger	Trigger output is deasserted when the scope trigger condition is satisfied.
	Scope Armed	Trigger output is asserted when the scope is waiting for the trigger condition to become satisfied.
	Scope /Armed	Trigger output is deasserted when the scope is waiting for the trigger condition to become satisfied.
	Scope Active	Trigger output is asserted when the scope has triggered and is recording data.
	Scope /Active	Trigger output is deasserted when the scope has triggered and is recording data.
Width	0 s to 0.149 s	Defines the minimal pulse width for trigger events signaled on the trigger outputs of the device.

4.13. Impedance Analyzer Tab

The Impedance Analyzer tab is available on MFIA Impedance Analyzer instruments and on MFLI Lock-in Amplifier instruments with installed MF-IA Impedance Analyzer option (see Information section in the Device tab).

4.13.1. Features

- Control for impedance analyzer unit (2 units with MF-MD option)
- Auto ranging and auto bandwidth
- Graphical display of measurement mode: 2- and 4-terminal configuration
- Graphical display of DUT representation: Rp||Cp, Rs+Cs, Ls+Rs, C D,...
- 0.05 % basic accuracy
- 1 mΩ to 10 GΩ measurement range
- 20 ms measurement speed for basic accuracy
- Compensation Advisor for SOL and other compensation procedures
- Confidence Indicator
- Independent current and voltage measurement

4.13.2. Description

The Impedance Analyzer tab is the main control panel for impedance measurements. On MFIA Impedance Analyzer instruments, the tab is open 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 4.41. App icon and short description

Control/Tool	Option/Range	Description
IA		Quick overview and access to all the settings and properties for impedance measurements.

The Impedance Analyzer tab consists of one side-tab for each impedance analyzer unit, and the Cal side-tab giving access to the Compensation Advisor. The tab is further subdivided into a Control and a Settings sub-tab. The Control sub-tab (see Figure 4.29) is the main measurement interface. The main settings are accessible on the left and are visualized by a graphical circuit display in the center of the tab. With the Mode setting, the user selects between a 2- and a 4-terminal setup which has to correspond to the physical wiring of the device-under-test (DUT). The Representation setting allows the user to convert the measured impedance Z into a parameter pair of a DUT circuit representation, such as parallel resistance and capacitance (Rp || Cp), or serial resistance and inductance (Rs + Ls). The data appear as Representation Parameter 1 and 2 elsewhere in the UI, e.g. in the Numeric or the Plotter tab. The Enable button at the top initiates the measurement by turning on the drive voltage and starting the current and voltage measurement.

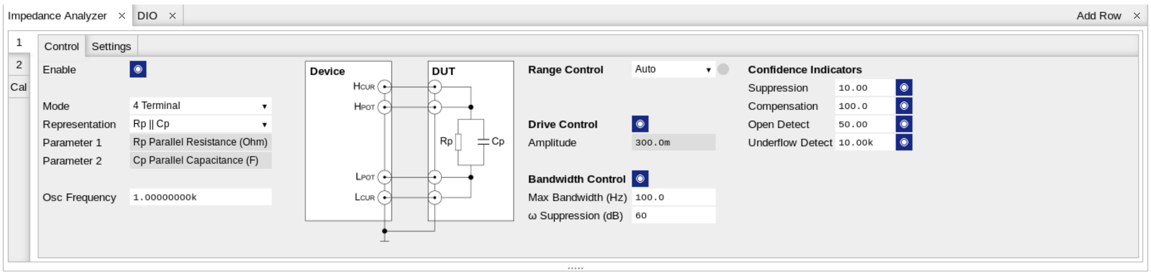


Figure 4.29. LabOne UI: Impedance Analyzer tab (Control sub-tab)

The center section of the tab contains settings related to measurement range, bandwidth, and output drive amplitude. By default, all of those parameters are under automatic control of the Impedance Analyzer providing suitable settings for most situations. Manual control is available and can be useful in some more advanced cases. Disabling automatic Range Control by setting it to Manual or Impedance can help preventing range changes in sweeper measurements. Manual Bandwidth Control can be advantageous in conditions with strong noise. The measurement bandwidth should then be chosen as a compromise between speed and precision. In auto bandwidth mode, the instrument selects an appropriate bandwidth for the desired ω suppression (see Section 6.5). Disabling automatic Drive Control allows the user to specify the drive amplitude when measuring an electrically sensitive DUT, for example. The numeric controls for bandwidth and drive amplitude are accessible in the Lock-in tab.

The Confidence Indicators section on the right side of the tab offer control of a number of features assisting in the measurement. The Indicators provide warning messages in the Sweeper, Plotter, and Numeric tab that prevent misinterpretation of measurement data. The different warning messages are explained in the table below. All Indicators can be individually enabled or disabled, and the numeric settings provide fine-tuning of the error thresholds.

Table 4.42. List of warning messages provided by the Confidence Indicator.

Confidence Indicator	Warning message	Situation	Corrective
Suppression	Suppression	The DUT is characterized by strongly differing impedance components. The calculation of the flagged Representation Parameter is unreliable.	Change measurement frequency, select appropriate representation corresponding to the DUT
Compensation	Strong Compensation	A measurement is carried out in a parameter range in which the user compensation enforces a large correction, making the measurement unreliable.	Check whether the test fixture is suitable for the measured impedance range and frequency. Check that the chosen compensation method is suitable for the impedance range. Consider including a "load" step with a load

Confidence Indicator	Warning message	Situation	Corrective
			close to the measurement range.
Open Detect	Open Detected	One of the terminals in a four-terminal is disconnected	Check the correct wiring of the DUT (e.g. 2-terminal DUT in a 4-terminal measurement). Check for broken connections.
Underflow Detect	Current Underflow, Voltage Underflow	Voltage or current reading is close to zero	Check for open connections. If connections are correctly closed, the DUT impedance may lie outside of the measurement range.

The Settings sub-tab (see Figure 4.30) contains further settings related to DC bias and compensation. Changing the Mode from Application to Advanced gives access to a larger number of controls for signal bandwidth, digital data transfer, and more.

Figure 4.30. LabOne UI: Impedance Analyzer tab (Settings sub-tab)

4.13.3. Compensation

The Compensation sub-tab (see Figure 4.31) provides user guidance through a compensation procedure. Compensation reduces the effect of test fixture parasitics and thus improves measurement accuracy. It requires a measurement of one or more reference devices under test (DUTs) with precisely known impedance values in a certain frequency range. The available compensation methods are combinations of measurements of short ("S", DUT with zero impedance), open ("O", DUT with infinite impedance), and load ("L", DUT with known impedance of arbitrary value). Please have a look at the Signal Processing chapter of the MFIA Impedance Analyzer user manual to learn more about the background and practicalities of the compensation, and at the Tutorial section in this document for step-by-step instructions for a specific example. The MFIA User Manual is available on the Zurich Instruments website.

To prepare a compensation, select the appropriate Mode, connect the reference DUT and click on Short, Open, or Load, corresponding to the connected DUT. The compensation measurement is started by clicking on Compensate. A green LED and a message indicates a successfully completed measurement. After all steps (up to three) have been completed, the compensation data is written to the instrument. The User Compensation Enable button activates or deactivates the compensation in subsequent measurements. The Advanced section on the right is collapsed by default and provides the frequency span and resolution setting among others.

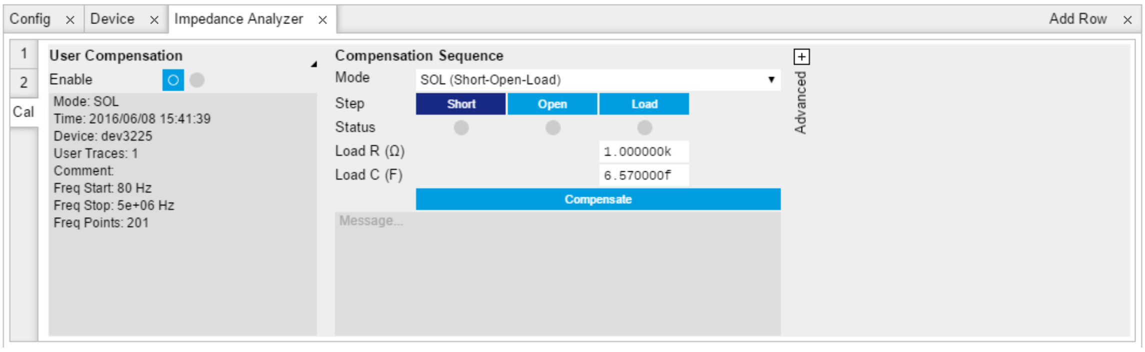


Figure 4.31. LabOne UI: Impedance Analyzer tab (Cal side-tab)

4.13.4. Functional Elements

Table 4.43. Impedance Analyzer tab: Control sub-tab

Control/Tool	Option/Range	Description
Enable	ON / OFF	Enable impedance calculation for demodulator data.
Mode		Select impedance measurement mode.
	4 Terminal	The 4 Terminal method uses the current and the voltage drop across the DUT to calculate the DUT impedance. This method results in very accurate measurements as influences of series resistors on the output and current input are excluded.
	2 Terminal	The 2 Terminal method uses the driving voltage and the measured current to calculate the DUT impedance. The 2 Terminal method can be beneficial when measuring very high impedance where the parasitics of the voltage measurement are limiting the frequency range.
Representation		Representation of the complex impedance value Z by two real values accessible as Parameter 1 and Parameter 2 on all user interface displays.
	Rp || Cp	Impedance value Z is represented by a resistive element Rp in parallel with a capacitive element Cp.

Control/Tool	Option/Range	Description
	Rs + Cs	Impedance value Z is represented by a resistive element Rs in series with a capacitive element Cs.
	Rs + Ls	Impedance value Z is represented by a resistive element Rs in series with a inductive element Ls.
	G B	Impedance value Z is represented by conductance G = Real(Y) and Susceptance B = Imag(Y) of the admittance Y = 1/Z.
	D Cs	Impedance value Z is represented by a dissipation factor D (loss tangent) and a capacitive element.
	Q Cs	Impedance value Z is represented by a quality factor Q = 1/D and a capacitive element.
	D Ls	Impedance value Z is represented by a dissipation factor D (loss tangent) and an inductive element.
	Q Ls	Impedance value Z is represented by a quality factor Q = 1/D and an inductive element.
Parameter 1	string	Currently active representation parameter 1. A representation is based on the measured impedance and the frequency. Representations are only valid within a specific frequency or impedance region.
Parameter 2	string	Currently active representation parameter 2. A representation is based on the measured impedance and the frequency. Representations are only valid within a specific frequency or impedance region.
Osc Frequency	0 to 5 MHz	Frequency control for the oscillator used for impedance measurement.
Range Control		Select input range control mode.

Control/Tool	Option/Range	Description
	Manual	In manual mode the current and voltage input ranges are adjusted manually and separately. Use this mode with care as overflow and underflow will result in inaccurate impedance results.
	Auto	Dynamically adjust the input range according to the measured input signal strength. This optimizes the dynamic range and precision of impedance measurements.
	Impedance	Impedance range is fixed. The current and voltage inputs are adjusted so that the selected impedance can be measured with the currently active excitation with best precision. Use this mode to avoid automatic range adjustments in a frequency sweep.
Suppressed	ON / OFF	Indicates disabled periodic auto range control. A running sweeper module takes over the range control and thus disables the periodic range checks.
Impedance Range	100, 1k, 10k, 100k, 1M, 10M, 100M, 1G, 10G	Select a fixed impedance range used for the measurement.
Current Range	100 nA, 1 μA, 10 μA, 100 μA, 1 mA, 10 mA	Input current range used for the impedance measurement. Small current input range have a reduced bandwidth. In the Range Control modes "Auto" and "Impedance", the current range is switched automatically to a higher range if the frequency is too high.
Voltage Range	10 mV, 30 mV, 100 mV, 300 mV, 1 V, 3.0 V	Input voltage range used for the impedance measurement.
Drive Control	ON / OFF	If enabled, the drive voltage amplitude is controlled by the device. If disabled it can be set manually.
Amplitude	numeric value	Drive amplitude on the Signal Output.
Bandwidth Control	ON / OFF	Enable automatic bandwidth control. If enabled the

Control/Tool	Option/Range	Description
		optimum bandwidth is calculated based on the frequency and measurement data.
Max Bandwidth (Hz)	positive numeric value	Limit of the maximum bandwidth used on the demodulator filter. Values above 1 kHz can heavily diminish measurement accuracy in the high-frequency region where the amplitude is no more constant over frequency.
ω Suppression (dB)	positive numeric value	Suppression of the omega and 2-omega components. Small omega suppression can diminish measurements of very low or high impedance because the DC component can become dominant. Large omega suppression will have a significant impact on sweep time especially for low filter orders.
Suppression Ratio	1 to 10000	Error amplification limit for which a secondary parameter is marked unreliable. Larger gain values mean larger warning tolerances. A gain value between 10 and 100 is best.
Suppression Enable	ON / OFF	The Suppression Confidence Indicator indicates if one of the two parameters of a circuit representation cannot be calculated reliably from the measured impedance. This is the case if a small variation in one (dominant) representation parameter creates a strong variation of the other (suppressed) representation parameter. Such an error amplification indicates that the measurement of the secondary parameter is unreliable.
Compensation	positive numeric value	Strength of the compensation that will trigger the strong compensation warning.
Compensation Enable	ON / OFF	Enables the indication of strong compensation in the plots. A strong compensation

Control/Tool	Option/Range	Description
		diminishes the measurement accuracy of the parameter.
Open Detect	positive numeric value	Open terminal detection ratio. An open terminal is reported if the excitation calculated from current and voltage drop differs more than the specified factor from the driving voltage.
Open Detect Enable	ON / OFF	Enables the open terminal detection for 4-terminal measurements. If enabled, an open terminal is indicated in the numeric tab and in plots.
Underflow Detect	positive numeric value	The underflow condition is met if the measured amplitude is lower than the specified ratio relative to full scale.
Underflow Detect Enable	ON / OFF	Enables the underflow detection for current and voltage. If enabled, an underflow will be shown in the numeric tab and in plots.

Table 4.44. Impedance Analyzer tab: Settings sub-tab

Control/Tool	Option/Range	Description
Mode		Switch between application-based or manually configured impedance settings. A parameter set given by an Application mode can be fine-tuned by changing to Advanced mode. Changing back to Application mode will reset the parameters.
	Application	The impedance settings are adjusted to fit best the selected application.
	Advanced	The impedance settings are manually configured.
Application		Select the Impedance application
	LCR Impedance Measurement	General-purpose settings for measuring components at finite frequency
	DC Impedance Measurement	Settings for measuring resistance at zero frequency.
Bias Control (V)	-3 V to 3 V	DC bias voltage applied across the device under test. Both positive and negative bias voltages are supported. In a

Control/Tool	Option/Range	Description
		4-terminal measurement, the bias voltage is limited by the maximum common voltage input range of the device. In a 2-terminal measurement, the bias voltage can be larger because the voltage inputs are not connected.
Bias Control Enable	ON / OFF	Enables bias control. The bias is generated by the additional offset applied on the output.
Current Input	Current Input 1	Select the current input used for two- and four-terminal impedance measurements.
Current Invert Enable	ON / OFF	If enabled, the current input signal is inverted. This is useful to switch the polarity of an input signal which can be caused by additional current amplifiers.
Voltage Input	Voltage Input 1	Select the voltage input used for a four-terminal impedance measurement.
Voltage Invert Enable	ON / OFF	If enabled, the voltage input signal is inverted.
AC	ON / OFF	Defines the input coupling for the Signal Inputs. AC coupling inserts a high-pass filter.
Current Demodulator	demodulator index	Demodulator used for current demodulation.
Voltage Demodulator	demodulator index	Demodulator used for voltage measurement in case of a four-terminal impedance measurement.
Output Demodulator	demodulator index	Demodulator unit used to generate the excitation voltage on the Signal Output.
Interpolation		Select the interpolation method of the compensation data. The interpolation method is particularly important if the derivative changes strongly e.g at cut-off frequencies.
	Linear	The linear interpolation is fastest but may create compensation errors in between the frequency points used for compensation.
	Piecewise Cubic Hermite (PCHIP)	The piecewise cubic Hermite interpolation will result in very

Control/Tool	Option/Range	Description
		accurate results but requires more calculation power.
Osc	oscillator index	Oscillator used to generate the frequency of the excitation voltage on the Hcur (+V) connector.
Harm	1 to 1023	Multiplies the demodulator's reference frequency with the integer factor defined by this field.
Order		Select the filter roll-off between 6 dB/oct and 48 dB/oct. High filter orders are beneficial for impedance measurements as they help to suppress DC offsets.
	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		Define the display unit of the low-pass filters: time constant (TC), noise-equivalent power bandwidth (BW NEP), 3 dB bandwidth (BW 3 dB).
	TC	Define the low-pass filter characteristic using time constant of the filter.
	BW NEP	Define the low-pass filter characteristic using the noise-equivalent power bandwidth of the filter.
	BW 3 dB	Define the low-pass filter characteristic using the cut-off frequency 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.
Rate	0.056 Sa/s to 857 kSa/s	Impedance data streaming rate. The same data rate is applied to the demodulators that are used for the impedance measurement.

Control/Tool	Option/Range	Description
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.
	10 mV	Selects output range ±10 mV.
	100 mV	Selects output range ±100 mV.
	1 V	Selects output range ±1 V.
	10 V	Selects output range ±10 V.

Table 4.45. Impedance Analyzer tab: Compensation sub-tab

Control/Tool	Option/Range	Description
Compensation Type Select		Displays information on either internal calibration or user compensation.
	Internal Calibration	The internal calibration matches all voltage and current ranges over the frequency range in order to achieve a high dynamic impedance range. The internal calibration is performed at Zurich instruments.
	User Compensation	The user compensation will correct for measurement setup influences like capacitive or inductive parasitics. It is applied on top of the internal calibration.
Internal	ON / OFF	Enables the internal calibration. This ensures that the input range gains match over the full frequency range. With enabled internal calibration the device fulfills the impedance accuracy specification. The internal calibration is a prerequisite to apply a user compensation.

Control/Tool	Option/Range	Description
Active	grey/green	Indicates if the internal calibration is applied to the measurement data.
Internal Calibration Info		Display of meta data saved together with the internal impedance calibration data.
User	ON / OFF	Enables the compensation of the impedance data. The user compensation is correcting parasitics and delays caused by the external setup. The user compensation is applied on top of the internal impedance calibration.
Active	grey/green	Indicates that a valid compensation is active. If active the impedance data streams deliver amplitude and phase corrected data based on the impedance compensation.
User Compensation Info		Display of meta data saved together with the user compensation.
Mode		Select the user compensation sequence. If the sequence involves a short or open condition, it is essential to keep the noise small by using auto range on the voltage and current inputs.
	None	No compensation is performed.
	SOL (Short-Open-Load)	Compensation of user setup using a short-open-load condition. This compensation method results in very accurate results over the whole impedance range under the condition of low-noise open and short compensation. Thus, this compensation should always be used with enabled auto range.
	OL (Open-Load)	The open-load compensation is suited for measuring high impedance. Use auto range to reduce the influence of noise for the open compensation step.

Control/Tool	Option/Range	Description
	SL (Short-Load)	The short-load compensation is suited for measuring low impedance.
	L (Load)	Compensation performed with a single load. This compensation is useful if the measured DUT is close to the load used for compensation.
	SO (Short-Open)	The short-open compensation corrects for inductive and capacitive parasitics of the user setup. This compensation method is suited if no load is available for the compensation. It will not correct gain errors.
	LLL (Load-Load-Load)	The compensation based on three load values results in very accurate results for a restricted impedance range. Use this method if the noise on the open or short condition is too strong.
Load R	numeric value	Resistance value of the compensation load.
Load C	numeric value	Capacitance value of the compensation load. In case of a resistor load the capacitance value is equivalent to its capacitive parasitics.
Step	Short, Open, Load	Compensation step to record. The sequence of the steps can be freely selected. Before starting the correct device needs to be connected to the setup.
Status	grey/green	Indicates a successful compensation step. If the status indicator does not indicate green after a compensation step, check the message box to learn more about the failure.
Compensate	Compensate	Start the compensation measurement for the selected condition. If a compensation measurement is completed successfully, the next pending condition is automatically selected. The message box will contain information on the quality of the completed

Control/Tool	Option/Range	Description
		compensation and failure messages in case of a fail. The progress of the currently active compensation run will be shown in the message box.
Message	string	The message pane displays information related to compensation. In case of a failed compensation, information on the root cause is reported. In case of successful compensation, representative parameters are reported to judge the quality of the compensation and measurement setup.
Comment	string	User comment that will be saved together with the compensation data. The comment string can also be changed between the different compensation steps.
Validation	ON / OFF	Perform a sanity check of the compensation result to detect outlier measurement results, overflow, or other error conditions. Validation should only be disabled for compensations performed in special conditions.
Auto Transfer	ON / OFF	If enabled, a successful compensation will be immediately transferred to the device, activated, and stored permanently. If automatic transfer is disabled, the transfer needs to be initiated manually.
On Device	On Device	Transfer and activate the recorded compensation manually.
Persistent	Persistent	Store the compensation data persistently on the device. The compensation will be loaded automatically on every power-up.
Start (Hz)	0 to 5 MHz	Lower frequency limit used for calibration. For measurements at lower frequencies than this value, an extrapolation is performed.

Control/Tool	Option/Range	Description
Stop (Hz)	0 to 5 MHz	Upper frequency limit used for calibration. This upper limit is essential for correct measurements.
Points	positive integer value	Number of frequency points used for compensation. For frequencies between two compensation frequencies the data will be interpolated.

4.14. Config Tab

The Config tab provides access to all major LabOne settings and is available for all MFLI Instruments.

4.14.1. 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

4.14.2. Description

The Config tab serves mainly as a control panel for all general LabOne related 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 4.46. App icon and short description

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

The Config tab (see Figure 4.32) is divided into four sections to control connections, sessions, user interface appearance and data recording.

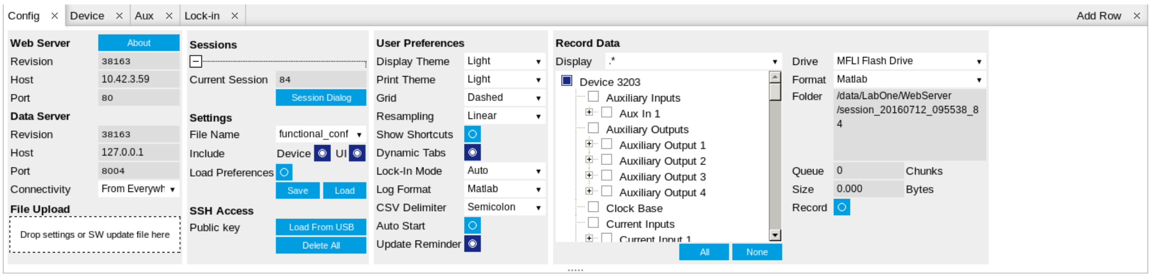


Figure 4.32. LabOne UI: Config tab

The Connection section provides information regarding 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 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 dialogue.

The User Preferences section contains the settings that are continuously stored and automatically reloaded the next time an MFLI is used from the same computer account. For low ambient light conditions the use of the dark display theme is recommended (see Figure 4.33).

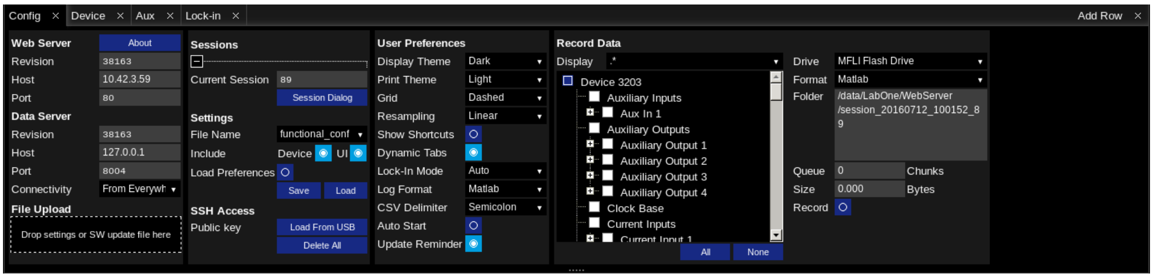


Figure 4.33. LabOne UI: Config tab - dark theme

The Record Data section contains all settings necessary to obtain hard copies of measurement data. The tree structure (see Tree Sub-Tab section) allows one to select among 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 as Matlab or comma-separated value (CSV) files. For each selected node at least one file gets generated, but the data may be distributed over several files during long recordings. The quickest way to inspect the files after recording is to use the File Manager tab described in Section 4.16. 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/(60 MHz). The timestamps are universal within one instrument and can e.g. be used to align the data from different files.

4.14.3. Functional Elements

Table 4.47. Config tab

Control/Tool	Option/Range	Description
About		Get information about LabOne software.
Web Server Rev	number	Web Server 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 Rev	number	Data Server 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.
Connectivity	Localhost Only	Forbid/Allow to connect to this Data Server from other computers.
	From Everywhere	

Control/Tool	Option/Range	Description
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. Supported files: Settings (*.xml), software update (LabOne*.tar). Uploading software updates will automatically trigger the update process if the file is valid and has a different revision than the currently installed software.
Current Session	integer number	Session identifier. A session is a connection between a client and LabOne Data Server. Also indicated in status bar.
Session Dialog	Session Dialog	Open the session dialog window. 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 Device	ON / OFF	Enable save/load of device settings.
Include UI	ON / OFF	Enable save/load of user interface settings.
Load Preferences	ON / OFF	Enable loading of user preferences from settings file.
Save	Save	Save the user interface and device setting to a file.
Load	Load	Load the user interface and device setting from a file.
Load From USB	Load From USB	Load public SSH keys from the USB mass storage connected to the device. Uploading of SSH keys enables SSH access to the device.
Delete All	Delete All	Delete all public SSH keys on the device.
Display Theme	Light Dark	Choose theme of the user interface.
Print Theme	Light Dark	Choose theme for printing SVG plots

Control/Tool	Option/Range	Description
Grid	Dashed	Select active grid setting for all graphs.
	Solid	
	None	
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.
Lock-In Mode	Auto	Select the display mode for the Graphical Lock-in tab. Auto format will select the format which fits best the current window width.
	Expanded	
	Collapsed	
Log Format	Telnet	Choose the command log format. See status bar and [User]\Documents \Zurich Instruments\LabOne \WebServer\Log
	Matlab	
	Python	
CSV Delimiter	Comma	Select which delimiter to insert for CSV files.
	Semicolon	
	Tab	
Auto Start	ON / OFF	Skip session dialog at start-up if selected device is available. In case of an error or disconnected device the session dialog will be reactivated.
Update Reminder	ON / OFF	Display a reminder on startup if the LabOne software wasn't updated in 180 days.
Drive		Select the drive for data saving.
	MFLI Flash Drive	Internal flash mass storage device of the MFLI.

Control/Tool	Option/Range	Description
	USB 1/2	Mass storage device connected on USB.
Format	Matlab	Data format of recorded data.
	CSV	
Folder	path indicating file location	Folder containing the saved data.
Queue	integer number	Number of data chunks not yet written to disk.
Size	integer number	Accumulated size of saved data.
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.
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 Table 4.8 in the section called “Tree Sub-Tab”.

4.15. Device Tab

The Device tab is the main settings tab for the connected instrument and is available in all MFLI Instruments.

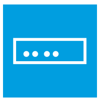
4.15.1. Features

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

4.15.2. 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 4.48. App icon and short description

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

The Device tab (see Figure 4.34) is divided into five sections: general instrument information, configuration, communication parameters, device presets, and a device monitor.

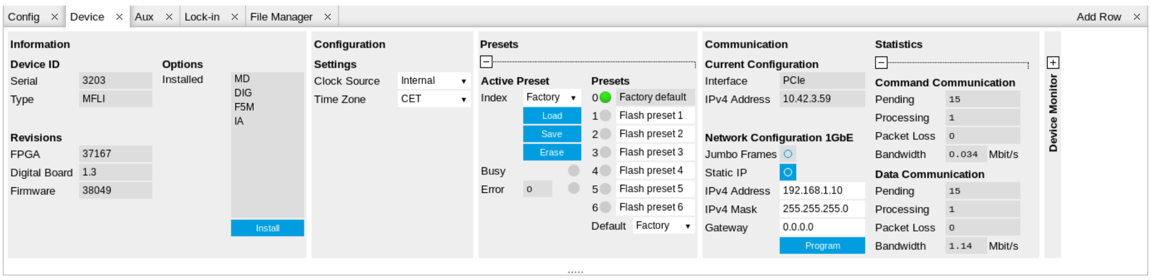


Figure 4.34. LabOne UI: Device tab

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 Presets section allows you to define a custom instrument start-up configuration different from the factory default. This configuration is stored in the instrument itself and are applied independently of the control PC. This saves time in cases where the control PC is not routinely needed, for instance when using only analog interfaces the instrument configuration is fixed.

The Communication section offers access to the instruments TCP/IP settings as well as choosing the connection type.

The Statistics section gives an overview on communication statistics. In particular the current data rate (Bandwidth) that is consumed.

Note

Packet loss on data streaming over UDP or USB: data packets may be lost if total bandwidth exceeds the available physical interface bandwidth. Data may also be lost if the host computer is not able to handle high-bandwidth data.

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

4.15.3. Functional Elements

Table 4.49. Device tab

Control/Tool	Option/Range	Description
Serial	1-4 digit number	Device serial number
Type	string	Device type
FPGA	integer number	HDL firmware revision
Digital Board	version number	Hardware revision of the FPGA base board
Firmware	integer number	Revision of the device internal controller software
Installed Options	short names for each option	Options that are installed on this device
Install	Install	Click to install options on this device. Requires a unique feature code and a power cycle after entry.
Clock Source		10 MHz reference clock source.
	Internal	Internal 10 MHz clock is used as the frequency and time base reference.
	Clk 10 MHz	An external 10-MHz clock is used as the frequency and time base reference. Provide a clean and stable 10 MHz reference to the appropriate back panel connector.
Time Zone	Timezone offset from UTC (Coordinated Universal Time).	Select the time zone in which the device is used. Settings, data and log files receive

Control/Tool	Option/Range	Description
		timestamps from this time zone. Requires a power cycle for changes to become effective.
Index		Select between factory preset or presets stored in internal flash memory.
	Factory	Select factory preset.
	Flash 1-6	Select one of the presets stored in internal flash memory 1-6.
Load	Load	Load the selected preset.
Save	Save	Save the actual setting as preset.
Erase	Erase	Erase the selected preset.
Busy	grey/green	Indicates that the device is busy with either loading, saving or erasing a preset.
Error		Returns a 0 if the last preset operation was successfully completed or 1 if the last preset operation was illegal.
	0	Last preset operation was successfully completed.
	1	Last preset operation was illegal.
Error LED	grey/red	Turns red if the last operation was illegal.
Valid LED	grey/green	Turns green if a valid preset is stored at the respective location.
Presets		Shows a list of available presets including factory preset.
	0	Factory default preset. The name of the factory default preset is given and can not be edited.
	1	Flash preset 1. The name of this preset can be edited.
	2	Flash preset 2. The name of this preset can be edited.
	3	Flash preset 3. The name of this preset can be edited.
	4	Flash preset 4. The name of this preset can be edited.

Control/Tool	Option/Range	Description
	5	Flash preset 5. The name of this preset can be edited.
	6	Flash preset 6. The name of this preset can be edited.
Default		Indicates the preset which is used as default preset at start-up of the device.
	Factory	Select factory preset as default preset.
	Flash 1-6	Select one of the presets stored in internal flash memory 1-6 as default preset.
Interface	1. PCIe	Active interface between device and data server. In case multiple options are available, the priority as indicated on the left applies.
IPv4 Address	default 192.168.001.010	Current IP address of the device. This IP address is assigned dynamically by a DHCP server, defined statically, or is a fall-back IP address if the DHCP server could not be found (for point to point connections).
Jumbo Frames	ON / OFF	Enable jumbo frames for this device and interface as default.
Static IP	ON / OFF	Enable this flag if the device is used in a network with fixed IP assignment without a DHCP server.
IPv4 Address	default 192.168.001.010	Static IP address to be written to the device.
IPv4 Mask	default 255.255.255.000	Static IP mask to be written to the device.
Gateway	default 192.168.001.001	Static IP gateway
Program	Program	Click to program the specified IPv4 address, IPv4 Mask and Gateway to the device.
Pending	integer value	Number of buffers ready for receiving command packets from the device.
Processing	integer value	Number of buffers being processed for command packets. Small values indicate proper performance. For a TCP/IP interface, command packets are sent using the TCP protocol.

Control/Tool	Option/Range	Description
Packet Loss	integer value	Number of command packets lost since device start. Command packets contain device settings that are sent to and received from the device.
Bandwidth	numeric value	Command streaming bandwidth usage on the physical network connection between device and data server.
Pending	integer value	Number of buffers ready for receiving data packets from the device.
Processing	integer value	Number of buffers being processed for data packets. Small values indicate proper performance. For a TCP/IP interface, data packets are sent using the UDP protocol.
Packet Loss	integer value	Number of data packets lost since device start. Data packets contain measurement data.
Bandwidth	numeric value	Data streaming bandwidth usage on the physical network connection between device and data server.
FW Load	numeric value	Indicates the CPU load on the processor where the firmware is running.
CPU Load	numeric value	Indicates the total CPU load on the machine where the data server is running.
Memory Usage	numeric value	Indicates the total memory usage of the machine where the data server is running.

4.16. File Manager Tab

The File Manager tab provides a quick access to the files stored on the instrument flash drive as well as any mass storage attached to one of the USB connectors.

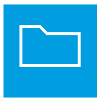
4.16.1. Features

- Download measurement data, instruments settings and log files to a local device
- Manage file structure (browse, copy, rename, delete) on instrument flash drive and attached USB mass storage devices
- Update instrument from USB mass storage
- File preview for settings files and log files

4.16.2. Description

The File Manager tab provides standard tools to see and organize the files on the instrument flash drive as well as on attached USB storage devices. Files can be conveniently copied, renamed, downloaded 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 4.50. App icon and short description

Control/Tool	Option/Range	Description
Files		Access files on internal flash memory and USB drive.

The Files tab (see Figure 4.35) 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.

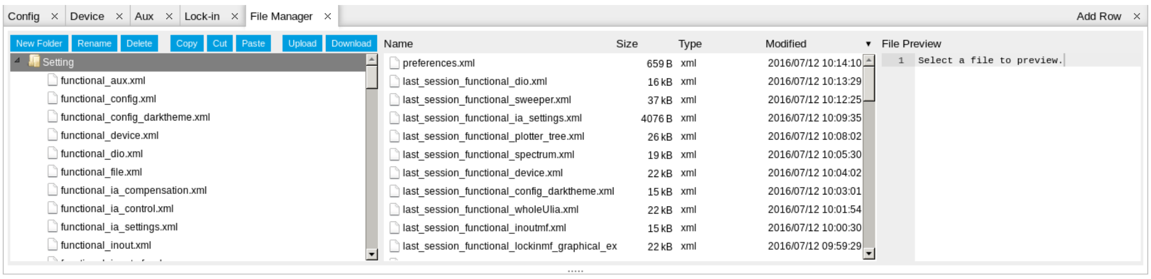


Figure 4.35. LabOne UI: File Manager tab

4.16.3. Functional Elements

Table 4.51. File tab

Control/Tool	Option/Range	Description
New Folder		Create new folder at current location.

Control/Tool	Option/Range	Description
Rename	Rename	Rename selected file or folder.
Delete	Delete	Delete selected file(s) and/or folder(s).
Copy	Copy	Copy selected file(s) and/or folder(s) to Clipboard.
Cut	Cut	Cut selected file(s) and/or folder(s) to Clipboard.
Paste	Paste	Paste file(s) and/or folder(s) from Clipboard to the selected directory.
Upload	Upload	Upload file(s) and/or folder(s) to the selected directory.
Download	Download	Download selected file(s) and/or folder(s).

4.17. 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 4.52. App Icon and short description

Control/Tool	Option/Range	Description
ZI Labs		Experimental settings and controls.

Chapter 5. Specifications

Important

Unless otherwise stated, all specifications apply after 30 minutes of instrument warm-up.

Important

Changes in the specification parameters are explicitly mentioned in the revision history of this document.

Important

Some specifications depend on the installed options. The options installed on a given instrument are listed in the Device tab of the LabOne user interface.

5.1. General Specifications

Table 5.1. General specifications

Parameter	Description
Storage temperature	+5°C to +65°C
Storage relative humidity	< 95%, non-condensing
Operating environment	IEC61010, indoor location, installation category II, pollution degree 2
Operating altitude	up to 2000 meters
Operating temperature	+5°C to +40°C
Operating relative humidity	< 90%, non-condensing
Specification temperature	+18°C to +28°C
Power consumption	<40 W
DC power inlet	12 V, 2 A Connector: Switchcraft 760BK, ID 2.5 mm, OD 5.5 mm
Power supply AC line	100–240 V (±10%), 50/60 Hz
Line power fuse	250 V, 2 A, fast, 5 x 20 mm, F 2 A L 250 V
Dimensions including bumper	28.3 x 23.2 x 10.2 cm 11.1 x 9.1 x 4.0 inch Rack mount on request
Weight including bumper	3.8 kg
Recommended calibration interval	2 years (see sticker on back panel)
Warranty	1 year, extensible

Table 5.2. Demodulators

Parameter	Description
Frequency range	DC to 500 kHz DC to 5 MHz, requires MF-F5M option
Number of demodulators	1 dual-phase (X, Y, R, Θ) 4 dual-phase, requires MF-MD option
Demodulator inputs	Signal Inputs (V/I), Auxiliary Inputs, Auxiliary Outputs, Trigger Inputs
Filter time constant	336 ns to 83 s
Filter bandwidth (-3 dB)	276 μHz – 206 kHz (4th order filter)
Harmonics	1 – 1023
Filter slope	6, 12, 18, 24, 30, 36, 42, 48 dB/oct
Additional filtering	Sinc filter
Phase resolution	10 μdeg
Frequency resolution	1 μHz
Output sample rate on Auxiliary Outputs	612 kSa/s (for each auxiliary output), 18 bit, ±10 V

Parameter	Description
Maximum transfer rate over 1 GbE	200 kSa/s (all demodulators), 48-bit full range
Maximum rate to store on local USB drive	50 kSa/s (all demodulators), 48-bit full range
Trigger modes for data transfer	Continuous, edge, gated

Table 5.3. Reference frequencies

Parameter	Description
External reference frequency range	1 Hz to 500 kHz 1 Hz to 5 MHz, requires MF-F5M option
External reference input	Auxiliary Inputs, Trigger Inputs, Auxiliary Outputs, Current Signal Input, Voltage Signal Input
Lock time for external reference	Typically less than max(100 cycles, 1.2 ms)
Number of external references	1; 2, requires MF-MD option
Internal reference frequency range	0 to 500 kHz 0 to 5 MHz, requires MF-F5M option

Table 5.4. Scope

Parameter	Description
Input channels	Signal Inputs (V,I), Auxiliary Inputs, Auxiliary Outputs, Trigger Inputs, Trigger Outputs, Signal Output, Oscillator Phase. Demodulator R, Theta, X, Y, requires MF-DIG option
Scope modes	Time domain, frequency domain (FFT)
Number display channels	1; 2, requires MF-DIG option
Trigger channels	Signal Inputs (V,I), Auxiliary Inputs, Auxiliary Outputs, Trigger Inputs, Trigger Outputs. Demodulator R, Theta, X, Y, requires MF-DIG option
Trigger modes	Edge
Trigger hysteresis	Full input range
Pre-trigger	Full sample range
Sampling rates	1.8 kSa/s to 60 MSa/s
Vertical resolution	16 bit
Maximum number of samples per shot	16 kSa; 5 MSa, requires MF-DIG option
Minimum hold time	1 ms
Bandwidth limit mode, vertical resolution increase	Downsampling by averaging; increase vertical resolution up to 24 bit, requires MF-DIG option
Cursor math	Location, Area, Wave, Peak, Tracking, Histogram

Table 5.5. Spectrum

Parameter	Description
Center frequency range	0 to 500 kHz

Parameter	Description
	0 to 5 MHz, requires MF-F5M option
Spectrum modes	FFT(X+iY), FFT(R), FFT(Θ), FFT(f) and FFT((dΘ/dt)/2π)
Statistical options	Amplitude, Spectral density, Power
Averaging modes	None, Exponential moving average
Maximum number of samples per spectrum	8 kSa
Maximum span	58 kHz
Window functions	Rectangular, Hann, Hamming, Blackman Harris
Cursor math	Location, Area, Tracking, Wave, Peak, Histogram

Table 5.6. Sweeper

Parameter	Description
Sweep parameters	Oscillator frequency, Demodulator phase, Auxiliary Offset, Signal Output Offset, etc.
Parameter sweep ranges	Full range, Linear and Logarithmic
Parameter sweep resolution	Arbitrary, defined by start/stop value and number of sweep points
Display parameters	Demodulator Output (X, Y, R, Θ, f), Auxiliary Input
Display options	Single Plot, Dual Plot (e.g. Bode Plot), Multi-trace
Statistical options	Amplitude, Spectral density, Power
Preset measurement modes	Parameter sweep, Noise amplitude measurement, Frequency response analyzer, 3-Omega-Sweep

Table 5.7. MF-IA Impedance Analyzer option

Parameter	Description
Frequency range	DC to 500 kHz DC to 5 MHz, requires MF-F5M option
Basic accuracy	0.05%
Basic temperature stability	<200 ppm/K
Test signal level	0 to 2.1 V_{rms} with monitoring
Bandwidth	276 µHz to 206 kHz
DC bias signal level	±10 V (2 Terminal); ±3 V (4 Terminal)
Compensation methods	SO, SOL, LLL, SL, L, OL
Impedance Z: range; basic accuracy	1 mΩ to 10 GΩ; 0.05%
Admittance Y: range; basic accuracy	100 pS to 1 kS; 0.05%
Resistance Rs, Rp: range; basic accuracy	1 mΩ to 10 GΩ; max(10 µΩ, 0.05%)[2]
Capacitance Cs, Cp: range; basic accuracy	10 fF to 1 F; max(10 fF, 0.05%)[2]
Inductance Ls, Lp: range; basic accuracy	100 nH to 1 H; max(10 nH, 0.05%)[2]

Parameter	Description
DC Resistance R_{DC}: range; basic accuracy	1 mΩ to 10 GΩ; 2%
Reactance X: range; basic accuracy	1 mΩ to 10 GΩ; 0.05%
Conductance G: range; basic accuracy	1 nS to 1 kS; max(100 nS, 0.05%)
Susceptance B: range; basic accuracy	1 nS to 1 kS; max(100 nS, 0.05%)
Loss coefficient D: range	10^{-4} to 10^{4}
Q factor: range	10^{-4} to 10^{4}

[2]Accuracy valid if parameter is the dominant value of the circuit representation.

Table 5.8. Voltage Signal Inputs

Parameter	Description
Connectors	2 BNC on front panel, single-ended or differential
Shield connectivity	Floating or ground
Maximum float voltage versus ground	±1 V
Input impedance	50 Ω and 10 MΩ 27 pF for range >=300 mV; 35 pF for range <=100 mV
Input frequency range	DC to 500 kHz; DC to 5 MHz, requires MF-F5M option
Input A/D conversion	16 bit, 60 MSa/s
Input noise amplitude	2.5 nV/√Hz for frequencies > 1 kHz 7 nV/√Hz at 10 Hz 40 nV/√Hz at 1 Hz 3.3 mV input range; shorting cap on input
Input noise corner frequency	Typically 100 Hz for range <=10 mV
Input bias current	Typically ±10 pA, max ±200 pA
Input full range sensitivity (10 V lock-in amplifier output)	1 nV to 3 V
Input AC ranges	1 mV to 3 V, 8 steps
AC coupling cutoff frequency	1.6 Hz
Maximum DC offset for AC coupling	±10 V
Input DC ranges	1 mV to 3 V, 8 steps
Input gain inaccuracy	< 1% (< 2 MHz); for higher frequencies limited by analog input filter
Analog input filter (anti-aliasing)	1 dB suppression at 5 MHz, 3 dB at 12 MHz; 3rd order roll-off
Input amplitude stability	0.1%/°C
Input offset amplitude	< max(0.5 mV, 1% of range)
Dynamic reserve	Up to 120 dB
Harmonic distortion	80 dBc for frequencies <=100 kHz 65 dBc for frequencies <=5 MHz

Parameter	Description
	carrier amplitude 1 dBFS
Coherent pickup	< −140 dB for frequencies <=5 MHz and 50 Ω input impedance; < −180 dB for frequencies <=100 kHz and 50 Ω input impedance

Table 5.9. Current Signal Input

Parameter	Description
Connector	BNC on front panel, float/ground
Shield connectivity	Floating or ground
Maximum float voltage versus ground	±1 V
Input impedance	see Table 5.10
Input frequency range	0 to 500 kHz 0 to 5 MHz, requires MF-F5M option
Input A/D conversion	16 bit, 60 MSa/s
Input noise amplitude	20 fA/√Hz at 100 Hz for 10 nA input range 200 fA/√Hz at 10 kHz for 1 μA input range 3.5 pA/√Hz at 1 MHz for 100 μA input range 300 pA/√Hz at 1 MHz for 10 mA input range
Input leakage current	±10 pA
Input full range sensitivity (10 V lock-in amplifier output)	10 fA to 10 mA
Input gain inaccuracy	< 1% (for frequencies below 10% of the input bandwidth)
Input offset amplitude	1% of range
Dynamic reserve	up to 120 dB
Coherent pickup	< 90 GΩ for frequencies <=5 MHz and 100 μA input range < 140 TΩ for frequencies <=100 kHz and 10 nA input range

Table 5.10. Current Signal Input: input ranges, transimpedance gain, bandwidth, input impedance

Current input range	Transimpedance gain	Bandwidth (-3 dB)	Input impedance at DC
10 mA	100 V/A	5 MHz	50 Ω
100 μA	10 kV/A	5 MHz	50 Ω
1 μA	1 MV/A	150 kHz	500 Ω
10 nA	100 M/A	2 kHz	10 kΩ

Table 5.11. Signal Output

Parameter	Description
Connectors	2 BNC on front panel, single ended and differential
Output impedance	50 Ω
Output frequency range	DC to 500 kHz DC to 5 MHz (with MF-F5M option)

Parameter	Description
Output frequency resolution	1 µHz
Output phase range	±180°
Output phase resolution	10 µdeg
Differential outputs	Sine waves shifted by 180°
Output D/A conversion	16 bit, 60 MSa/s
Output amplitude ranges	±10 mV, ±100 mV, ±1 V, ±10 V (single ended on high-impedance)
Output power	24 dBm (±10 V, 250 mW), for each BNC
Output gain inaccuracy	< 1% at 100 kHz for all output ranges
Maximum output drive current	100 mA
Output offset amplitude	±1 mV or 1% of range, whichever is bigger
Harmonic distortion	85 dBc for f < 100 kHz, 60 dBc for f < 5 MHz; for output ranges <=1 V; 80 dBc for f < 100 kHz, 50 dBc for f < 5 MHz; for output range 10 V; carrier amplitude 1 dBFS
Analog adder	Auxiliary Input 1 can be added to the signal output , +/- 10 V, DC–2 MHz

Table 5.12. Signal Output: voltage noise, ranges

Output range	Output noise density (high load impedance setting)	RMS output noise at 12 MHz bandwidth
10 mV	43 nV/√Hz	145 µVrms
100 mV	43 nV/√Hz	145 µVrms
1 V	48 nV/√Hz	161 µVrms
10 V	104 nV/√Hz	310 µVrms

Table 5.13. Auxiliary Inputs

Parameter	Description
Connectors	2 BNC on the front panel
A/D converter	16 bit, 15 MSa/s
A/D analog bandwidth	5 MHz
Input impedance	1 MΩ
Amplitude	±10 V
Resolution	0.335 mV

Table 5.14. Auxiliary Outputs

Parameter	Description
Connectors	4 BNC on the front panel
D/A converter	18 bit, 612 kSa/s
D/A analog bandwidth	200 kHz
Output impedance	50 Ω
Amplitude	±10 V

Parameter	Description
Resolution	< 85 μV
Drive current	20 mA

Table 5.15. Trigger Inputs

Parameter	Description
Connectors	2 BNC on the back panel
Trigger input impedance	1 kΩ
Frequency range external reference	1 Hz to 500 kHz; 1 Hz to 5 MHz, requires MF-F5M option
Trigger amplitude range	±5 V
Minimum pulse width	35 ns
Trigger level	±5 V, 3.66 mV resolution
Trigger hysteresis	< 20 mV

Table 5.16. Trigger Outputs

Parameter	Description
Connectors	2 BNC on the back panel
Trigger output impedance	50 Ω
Frequency range external reference	1 μHz to 500 kHz; 1 μHz to 5 MHz, requires MF-F5M option
Trigger amplitude	5 V

Table 5.17. 10 MHz clock synchronization

Parameter	Description
Connectors	2 BNC, 10 MHz clock input and output on the back panel
10 MHz input, impedance	50 Ω
10 MHz input, frequency range	9.98 to 10.02 MHz
10 MHz input, amplitude range	200 mV to 3 V
10 MHz output, impedance	50 Ω
10 MHz output, amplitude	1 Vpp into 50 Ω, sinusoidal

Table 5.18. Internal frequency reference

Parameter	Description
Type	TCXO
Initial accuracy	< ±1.5 ppm
Long term accuracy/aging	< ±1 ppm in the first year
Short term stability (0.1 s)	$< 2{\cdot}10^{-10}$
Temperature coefficient	0.05 ppm/°C (@23°C)
Phase noise at 1 kHz	−140 dBc/Hz
Phase noise at 10 kHz	−150 dBc/Hz

Table 5.19. Connectivity and others

Parameter	Description
Host connection	LAN, 1 GbE; USB 2.0, 480 Mbit/s
Internal drive data storage capacity	4.5 GB
USB host	2 connectors on the back panel for mass storage or WLAN modules
DIO, digital I/O	4 x 8 bit, general purpose digital input/output port, 3.3 V TTL VHDCI 68 pin female connector

Table 5.20. Maximum ratings

Parameter	Lower	Upper
Damage threshold Current Signal Input I	−5 V	+ 5 V
Damage threshold Voltage Input +V/-V Diff	−12 V	+12 V
Damage threshold Signal Output +V/-V	−12 V	+12 V
Damage threshold Aux Input 1,2	−12 V	+12 V
Damage threshold Aux Outputs 1,2,3,4	−12 V	+12 V
Damage threshold Clock 10 MHz In/Out	−5 V	+5 V
Damage threshold Trigger Out 1,2	−1 V	+6 V
Damage threshold Trigger In 1,2	−8 V	+8 V
Damage threshold DIO 32 bit	−1 V	+6 V
Damage threshold DC In	0 V	26 V

Table 5.21. LabOne UI requirements

Parameter	Description
Operating systems	Any, web browser based
Input device	Touch screen, keyboard, mouse
CPU	2+ cores, hardware accelerated rendering on browser
Browser	Internet Explorer 10+, Firefox 27+, Chrome 36+, Safari 6+, Opera 23+
Connectivity	1 GbE, 100 MbE, USB 2.0

Table 5.22. LabOne API requirements

Parameter	Description
Operating systems	Windows 8.x 64-bit, Windows 7 64-bit 32-bit and 64-bit of Linux, Ubuntu 12.04 LTS (i386, AMD64), 64-bit systems require the IA32 extension Mac OS X
CPU	AMD K8 (Athlon 64, Sempron 64, Turion 64, etc.), AMD Phenom, Intel Pentium 4, Xeon, Celeron, Celeron D, Pentium M, Celeron M, Core, Core 2, Core i5, Core i7, Atom
RAM	4 GB+
Connectivity	1 GbE, 100 MbE, USB 2.0

Parameter	Description
Supported languages	LabVIEW 2009 (32bit, 64-bit) and later; Python 2.7, 3.5 (32bit, 64-bit); MATLAB 2009 (Windows) / MATLAB 2014 (Linux) and later; C/C++

The DIO port is a VHDCI 68 pin connector as introduced by the SPI-3 document of the SCSI-3 specification. It is a female connector that requires a 32 mm wide male connector. The DIO port features 32 bits that can be configured byte-wise as inputs or outputs.

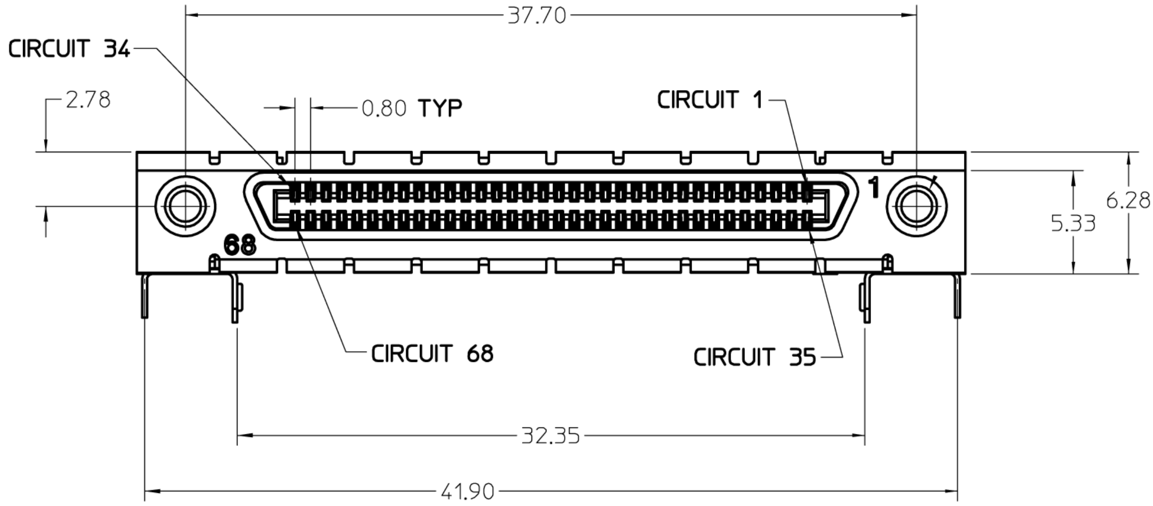


Figure 5.1. DIO HD 68 pin connector

Table 5.23. 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, 56.25 MHz clock signal, the digital outputs are synchronized to the falling edge of this signal	5 V CMOS
66-59	DI[31:24]	digital input or output (set by user)	output CMOS 5 V, input is CMOS/TTL
58-51	DIO[23:16]	digital input or output (set by user)	output CMOS 5 V, input is CMOS/TTL
50-43	DIO[15:8]	digital input or output (set by user)	output CMOS 5 V, input is CMOS/TTL
42-35	DIO[7:0]	digital input or output (set by user)	output CMOS 5 V, input is CMOS/TTL
34-30	-	do not connect, for internal use only	-
29-1	GND	digital ground	-

The figure below shows the architecture of the DIO input/output. The DIO port features 32 bits that can be configured byte-wise as inputs or outputs by means of a drive signal. The digital output data is latched synchronously with the falling edge of the internal clock, which is running at 56.25 MHz. The internal sampling clock is available at the DOL pin of the DIO connector. Digital input data can either be sampled by the internal clock or by an external clock provided through the CLKI pin. A decimated version of the input clock is used to sample the input data. The Decimation unit counts the clocks to decimation and then latches the input data. The default decimation is 5625000, corresponding to a digital input sampling rate of 1 sample per second.

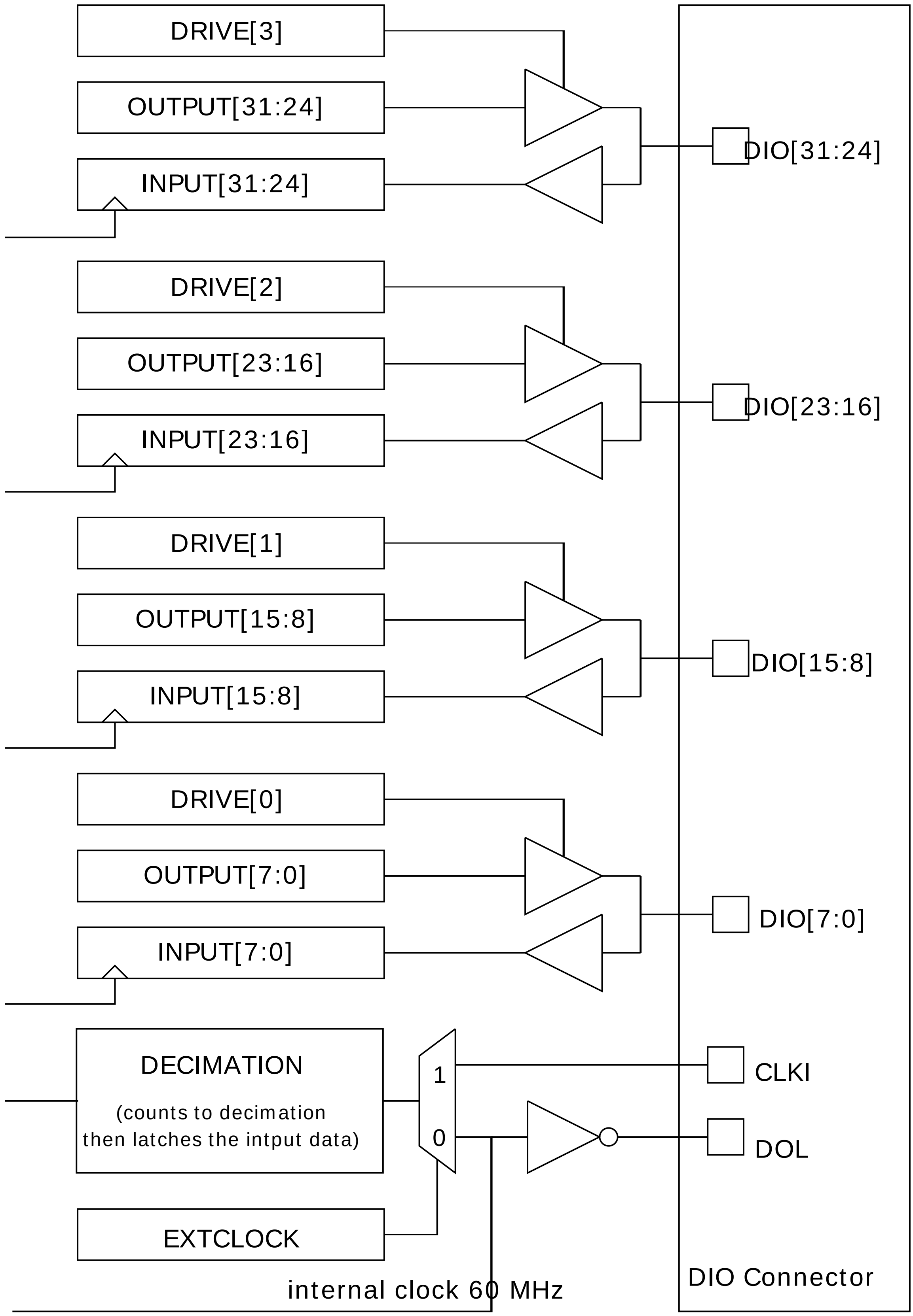


Figure 5.2. DIO input/output architecture

5.2. Performance Diagrams

Input noise amplitude depends on several parameters, and in particular on the frequency and on the input range setting. The input noise is lower for smaller input ranges, and it is recommended to use small ranges especially for noise measurements. Only the noise with DC input coupling is shown in Figure 5.3 since the input noise with AC coupling is the same, as long as the frequency is higher than the AC cutoff frequency (see Table 5.8). The noise is independent of the input impedance setting, 50 Ω or 10 MΩ. The corner frequency of the 1/f noise is in the range of 100 Hz and the white-noise floor is typically 2.5 nV/√Hz for the smallest input ranges.

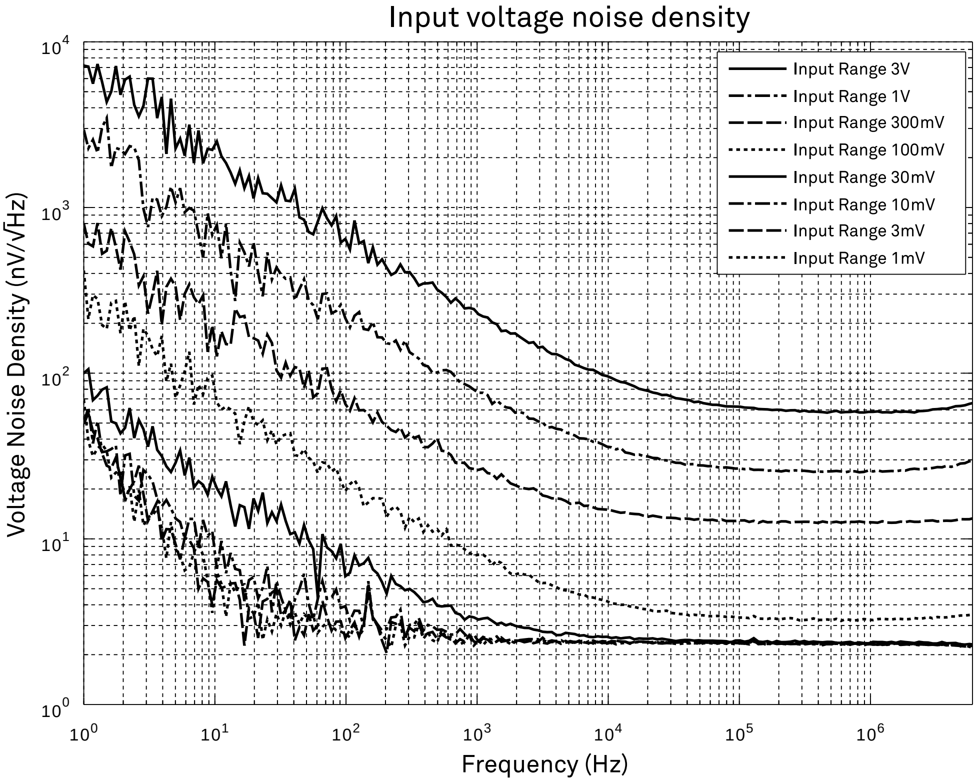


Figure 5.3. MFLI input voltage noise density

Chapter 6. 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.

6.1. Principles of Lock-in Detection

Lock-in demodulation is a technique to measure the amplitude A_S and the phase Θ 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 6.1 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.

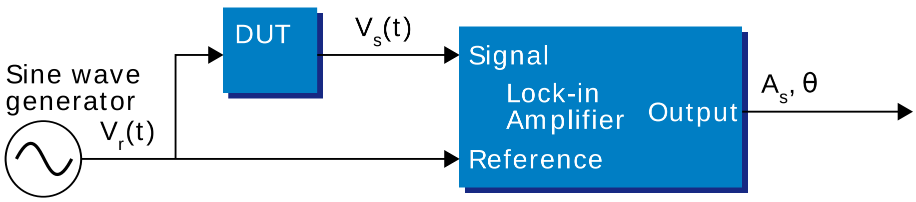


Figure 6.1. Basic measurement setup incorporating a lock-in amplifier

For practical reasons, most lock-in amplifiers implement the band-pass filter with a mixer and a low-pass filter (depicted in Figure 6.2): the mixer shifts the signal of interest into the baseband, ideally to DC, and the low-pass filter cuts all unwanted higher frequencies.

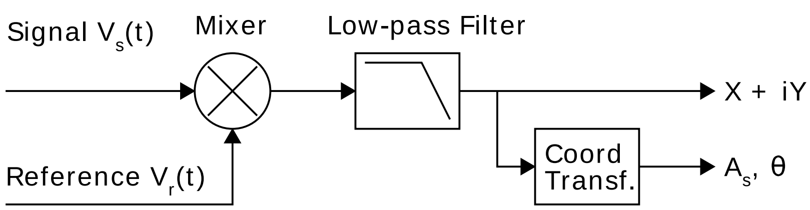


Figure 6.2. Mixing and low-pass filtering performed by the lock-in amplifier

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°) 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

$$V_s(t)\cdot V_r(t) = V_s(t)\cdot\sqrt{2}\,e^{-i\omega_r t} = \frac{A_s}{\sqrt{2}}e^{+i[(\omega_s-\omega_r)t+\Theta]} + \frac{A_s}{\sqrt{2}}e^{-i[(\omega_s+\omega_r)t+\Theta]}$$

Equation 6.1. Multiplication of signal of interest with reference signal

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 $\langle \cdot \rangle$. The frequency response of the filter F(ω) 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.

$$X + iY = \left\langle V_s(t) \cdot \sqrt{2}\, e^{-i\omega_r t} \right\rangle \approx F(\omega_s - \omega_r) \frac{A_s}{\sqrt{2}} e^{i[(\omega_s - \omega_r)t + \Theta]}$$

Equation 6.2. Averaging the result of the signal multiplication

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 Θ 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, Θ) encoded in a range of −10 V to +10 V of the auxiliary output signals.

6.1.1. 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 6.3 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.

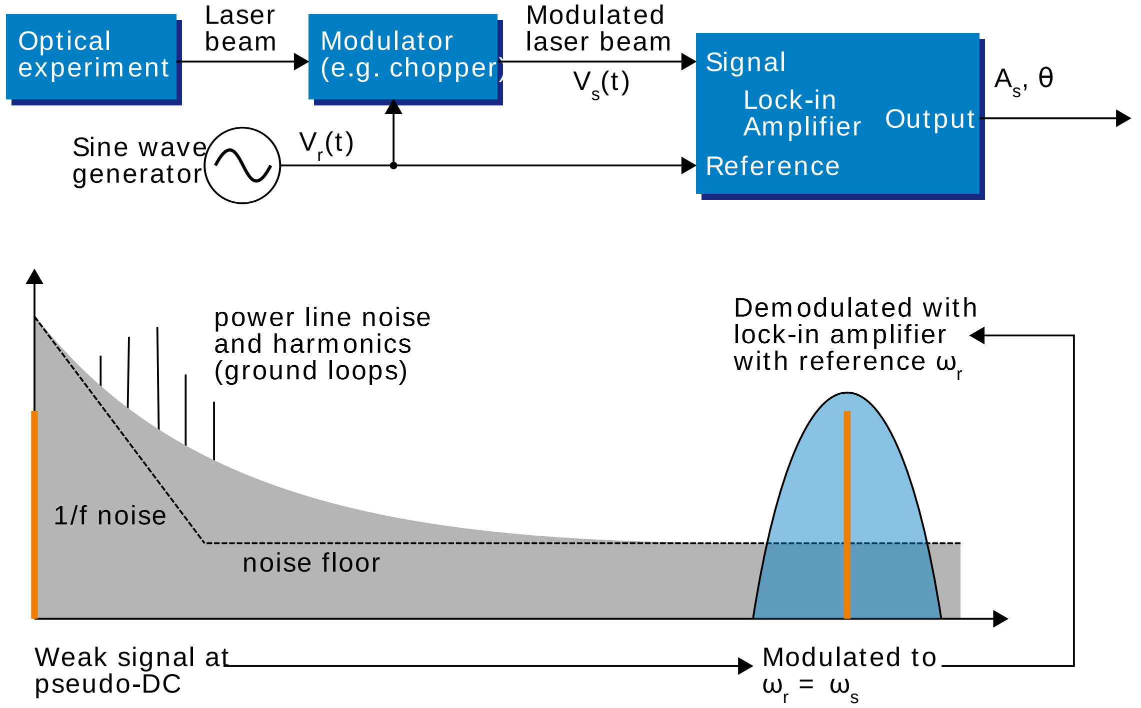


Figure 6.3. Lock-in measurement of a noisy DC signal

6.2. 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 = $f_{\text{cut-off}}$ = $f_{\text{-3dB}}$); that is, the signal power at $f_{\text{-3dB}}$ 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 a imaging application, 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 6.4. 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_{NEPBW}. The orange and blue areas in Figure 6.4 then are exactly equal in a linear scale.

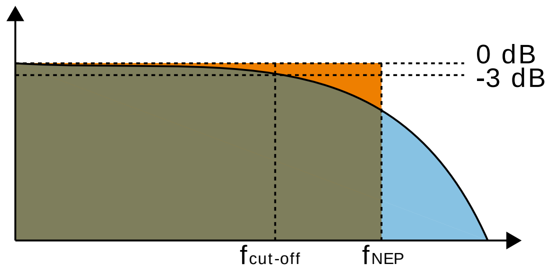


Figure 6.4. Signal bandwidth and noise equivalent power bandwidth

It is possible to establish a simple relation between the $f_{\text{cut-off}}$ and the f_{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_{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

$$\mathrm{TC} = \frac{\mathrm{FO}}{2\pi f_{\text{cut-off}}} \tag{6.3}$$

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 6.1. Summary of conversion factors for bandwidth definitions

filter order	filter roll-off	FO	$f_{\text{cut-off}}$	f_{NEPBW}	f_{NEPBW} / $f_{\text{cut-off}}$
1st	6 dB/oct	1.000	0.159 / TC	0.250 / TC	1.57
2nd	12 dB/oct	0.644	0.102 / TC	0.125 / TC	1.22
3rd	18 dB/oct	0.510	0.081 / TC	0.094 / TC	1.15
4th	24 dB/oct	0.435	0.068 / TC	0.078 / TC	1.12
5th	30 dB/oct	0.386	0.062 / TC	0.068 / TC	1.11

filter order	filter roll-off	FO	$f_{cut\text{-}off}$	f_{NEPBW}	f_{NEPBW} / $f_{cut\text{-}off}$
6^{th}	36 dB/oct	0.350	0.056 / TC	0.062 / TC	1.10
7^{th}	42 dB/oct	0.323	0.051 / TC	0.056 / TC	1.10
8^{th}	48 dB/oct	0.301	0.048 / TC	0.052 / TC	1.09

6.3. Discrete-Time Filters

6.3.1. 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 TC = τ_N as its only adjustable parameter. It operates on an input signal $X_{in}[n,T_S]$ 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,

$$X_{out}[n,T_S] = e^{-T_S/\tau_N} X_{out}[n-1,T_S] + \left(1-e^{-T_S/\tau_N}\right) X_{in}[n,T_S]$$

Equation 6.4. Time domain response of the discrete-time RC filter

The response of that filter in the frequency domain is well approximated by the formula

$$H_1(\omega) = \frac{1}{1+i\cdot\omega\cdot\tau_N}$$

Equation 6.5. Frequency domain response of the first-order discrete-time RC filter

The exponential filter is a first-order filter. Higher-order filters can easily be implemented by cascading several filters. For instance the 4th order filter is implemented by chaining 4 filters with the same time constant TC = τ_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

$$H_n(\omega) = \frac{1}{(1+i\cdot\omega\cdot\tau_N)^n}$$

Equation 6.6. Frequency domain response of the n-th order discrete-time RC filter

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 $\arg[H_n(\omega)]$.

6.3.2. Filter Settling Time

The low-pass filters after the demodulator cause a delay to measured signals depending on the filter order and time constant TC = τ_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 6.5 where the response of cascaded filters to a step input signal this is shown.

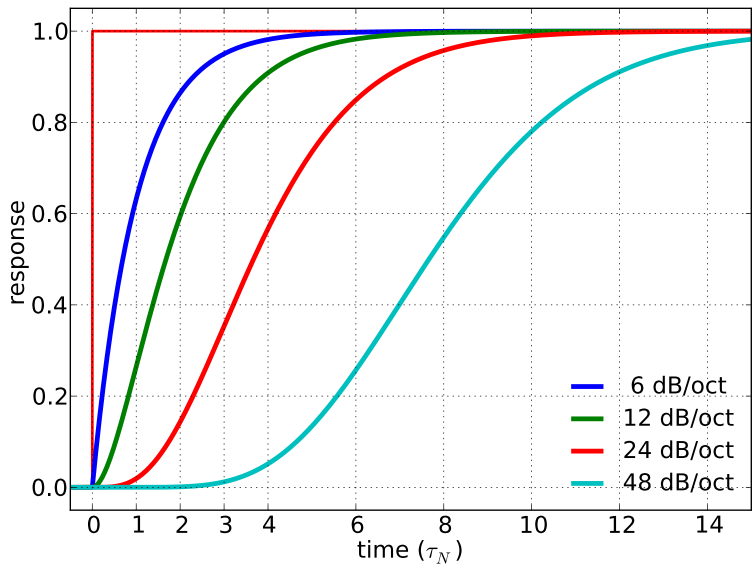


Figure 6.5. Time domain step response of the RC low-pass filters

More quantitative information on the settling time can be obtained from Table 6.2. In this table, you find settling times in units of the filter time constant τ_N for all filter orders available with the MFLI Lock-in Amplifier. The values tell the time you need to wait for the filtered demodulator signal to reach 5%, 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 6.2. Summary of Filter Rise Times

filter order	Setting time to		
	5%	95%	99%
1st	0.025 · TC	3.0 · TC	4.6 · TC
2nd	0.36 · TC	4.7 · TC	6.6 · TC
3rd	0.82 · TC	6.3 · TC	8.4 · TC
4th	1.4 · TC	7.8 · TC	10 · TC
5th	2.0 · TC	9.2 · TC	12 · TC
6th	2.6 · TC	11 · TC	12 · TC
7th	3.3 · TC	12 · TC	15 · TC
8th	4.0 · TC	13 · TC	16 · TC

6.4. 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.

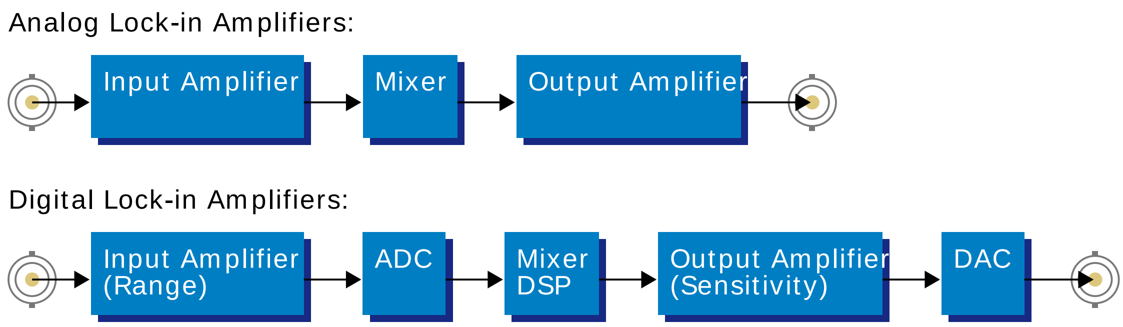


Figure 6.6. Sensitivity from signal input to signal output

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 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 mV)·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.

6.5. Sinc Filtering

As explained in Section 6.1, 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 2ω component) is effectively removed by regular low-pass filtering. By selecting filters with small bandwidth and faster roll-offs, the 2ω 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 2ω 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 ω 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 ω and 2ω components can affect the measurement result. Sinc filtering allows for strong attenuation of the ω and 2ω components. Technically the sinc filter is a comb filter with notches at integer multiples of the demodulation frequency (ω, 2ω, 3ω, etc.). It removes the ω component with a suppression factor of around 80 dB. The amount of 2ω 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.

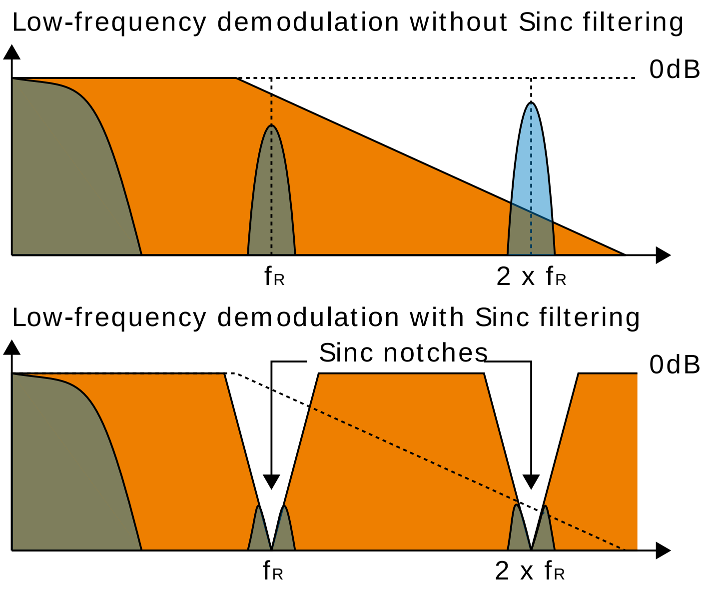


Figure 6.7. Effect of sinc filtering

Table 6.3. Artifacts in the demodulation signal

Input signal	Demodulation result before low-pass filter	Result
Signal at ω	DC component	Amplitude and phase information (wanted signal)
	2ω component	Unwanted component (can additionally be attenuated by sinc filter)

Input signal	Demodulation result before low-pass filter	Result
DC offset	ω 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 MFLI 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 ω component.

Figure 6.8 shows a spectrum with the sinc filter disabled, whereas for Figure 6.9 the sinc filter is enabled. The comparison of the two clearly shows how the sinc options dampens both the ω and 2ω components by about 100 dB.

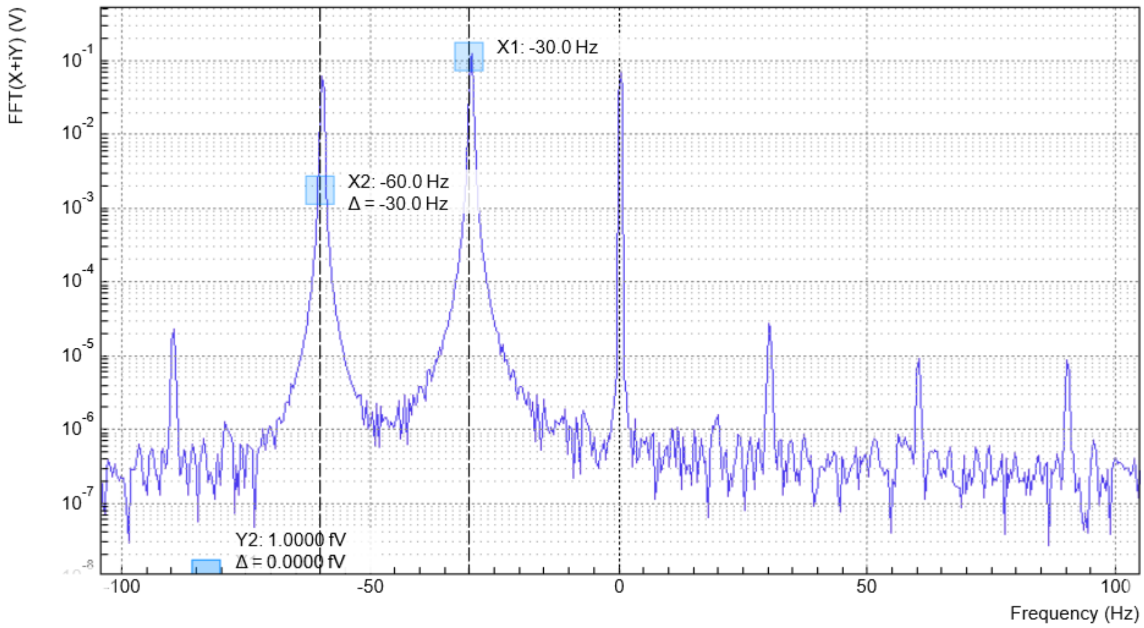


Figure 6.8. Spectrum of a demodulated 30 Hz signal without sinc filter

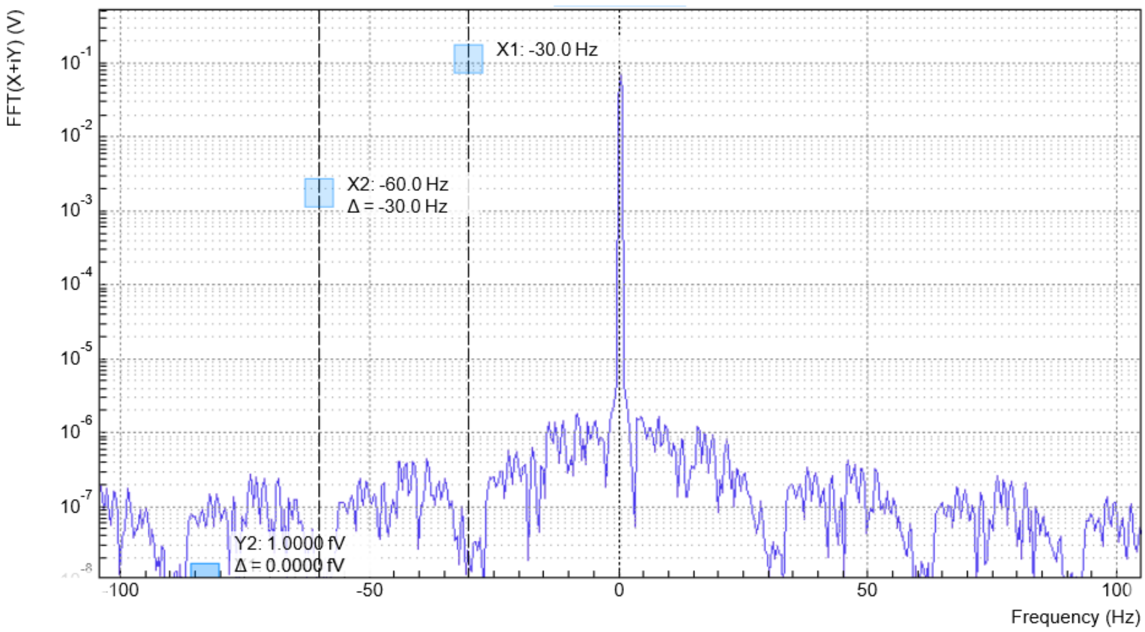


Figure 6.9. Spectrum of a demodulated 30 Hz signal with sinc filter

Note

In order to put the notches of the digital filter to ω and 2ω, 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.

6.6. 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 $V_s(t) = A_s\cos(\omega_s t + \Theta)$, the output signal is $X + iY = F(\omega_s - \omega_r)(A_s/\sqrt{2})e^{i[(\omega_s-\omega_r)t+\Theta]}$ where F(ω) 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 $(|A_s|^2/2)\cdot|F(\omega_r - \omega_s)|^2$ at $\omega_s-\omega_r$: this tells us the spectral power distribution of the input signal at frequencies close to ω_r within the demodulation bandwidth set by the filters F(ω).

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(−ω)=G*(ω) holds for the Fourier transform G(ω) 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 diving 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 originates when the signal frequencies higher than the sampling rate Ω are not sufficiently suppressed. Remember that Ω is the user settable readout rate, not the 60 MSa/s sampling rate of the MFLI input. Since the discrete-time Fourier transform extends between −Ω/2 and +Ω/2, the user has to make sure that at ±Ω/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 (2π/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 Ω, the discrete Fourier transform has a frequency resolution of Ω/N.

Glossary

This glossary provides easy to understand descriptions for many terms related to measurement instrumentation including the abbreviations used inside this user manual.

A

A/D
: Analog to Digital
See Also ADC.

AC
: Alternate Current

ADC
: Analog to Digital Converter

AM
: Amplitude Modulation

Amplitude Modulated AFM (AM-AFM)
: AFM mode where the amplitude change between drive and measured signal encodes the topography or the measured AFM variable.
See Also Atomic Force Microscope.

API
: Application Programming Interface

ASCII
: American Standard Code for Information Interchange

Atomic Force Microscope (AFM)
: Microscope that scans surfaces by means an oscillating mechanical structure (e.g. cantilever, tuning fork) whose oscillating tip gets so close to the surface to enter in interaction because of electrostatic, chemical, magnetic or other forces. With an AFM it is possible to produce images with atomic resolution.
See Also Amplitude Modulated AFM, Frequency Modulated AFM, Phase modulation AFM.

AVAR
: Allen Variance

B

Bandwidth (BW)
: The signal bandwidth represents the highest frequency components of interest in a signal. For filters the signal bandwidth is the cut-off point, where the transfer function of a system shows 3 dB attenuation versus DC. In this context the bandwidth is a synonym of cut-off frequency $f_{cut-off}$ or 3dB frequency f_{-3dB}. The concept of bandwidth is used when the dynamic behavior of a signal is important or separation of different signals is required.

In the context of a open-loop or closed-loop system, the bandwidth can be used to indicate the fastest speed of the system, or the highest signal update change rate that is possible with the system.

Sometimes the term bandwidth is erroneously used as synonym of frequency range.
See Also Noise Equivalent Power Bandwidth.

BNC
: Bayonet Neill-Concelman Connector

C

CF
: Clock Fail (internal processor clock missing)

Common Mode Rejection Ratio (CMRR)	Specification of a differential amplifier (or other device) indicating the ability of an amplifier to obtain the difference between two inputs while rejecting the components that do not differ from the signal (common mode). A high CMRR is important in applications where the signal of interest is represented by a small voltage fluctuation superimposed on a (possibly large) voltage offset, or when relevant information is contained in the voltage difference between two signals. The simplest mathematical definition of common-mode rejection ratio is: CMRR = 20 * log(differential gain / common mode gain).
CSV	Comma Separated Values

D

D/A	Digital to Analog
DAC	Digital to Analog Converter
DC	Direct Current
DDS	Direct Digital Synthesis
DHCP	Dynamic Host Configuration Protocol
DIO	Digital Input/Output
DNS	Domain Name Server
DSP	Digital Signal Processor
DUT	Device Under Test
Dynamic Reserve (DR)	The measure of a lock-in amplifier's capability to withstand the disturbing signals and noise at non-reference frequencies, while maintaining the specified measurement accuracy within the signal bandwidth.

E

XML	Extensible Markup Language. See Also XML.

F

FFT	Fast Fourier Transform
FIFO	First In First Out
FM	Frequency Modulation
Frequency Accuracy (FA)	Measure of an instrument's ability to faithfully indicate the correct frequency versus a traceable standard.
Frequency Modulated AFM (FM-AFM)	AFM mode where the frequency change between drive and measured signal encodes the topography or the measured AFM variable. See Also Atomic Force Microscope.
Frequency Response Analyzer (FRA)	Instrument capable to stimulate a device under test and plot the frequency response over a selectable frequency range with a fine granularity.

Frequency Sweeper	See Also Frequency Response Analyzer.

G

Gain Phase Meter	See Also Vector Network Analyzer.
GPIB	General Purpose Interface Bus
GUI	Graphical User Interface

I

I/O	Input / Output
Impedance Spectroscope (IS)	Instrument suited to stimulate a device under test and to measure the impedance (by means of a current measurement) at a selectable frequency and its amplitude and phase change over time. The output is both amplitude and phase information referred to the stimulus signal.
Input Amplitude Accuracy (IAA)	Measure of instrument's capability to faithfully indicate the signal amplitude at the input channel versus a traceable standard.
Input voltage noise (IVN)	Total noise generated by the instrument and referred to the signal input, thus expressed as additional source of noise for the measured signal.
IP	Internet Protocol

L

LAN	Local Area Network
LED	Light Emitting Diode
Lock-in Amplifier (LI, LIA)	Instrument suited for the acquisition of small signals in noisy environments, or quickly changing signal with good signal to noise ratio - lock-in amplifiers recover the signal of interest knowing the frequency of the signal by demodulation with the suited reference frequency - the result of the demodulation are amplitude and phase of the signal compared to the reference: these are value pairs in the complex plane (X, Y), (R, Θ).

M

Media Access Control address (MAC address)	Refers to the unique identifier assigned to network adapters for physical network communication.
Multi-frequency (MF)	Refers to the simultaneous measurement of signals modulated at arbitrary frequencies. The objective of multi-frequency is to increase the information that can be derived from a measurement which is particularly important for one-time, non-repeating events, and to increase the speed of a measurement since different frequencies do not have to be applied one after the other. See Also Multi-harmonic.
Multi-harmonic (MH)	Refers to the simultaneous measurement of modulated signals at various harmonic frequencies. The objective of multi-frequency is to increase the

information that can be derived from a measurement which is particularly important for one-time, non-repeating events, and to increase the speed of a measurement since different frequencies do not have to be applied one after the other.
See Also Multi-frequency.

N

Noise Equivalent Power Bandwidth (NEPBW)	Effective bandwidth considering the area below the transfer function of a low-pass filter in the frequency spectrum. NEPBW is used when the amount of power within a certain bandwidth is important, such as noise measurements. This unit corresponds to a perfect filter with infinite steepness at the equivalent frequency. See Also Bandwidth.
Nyquist Frequency (NF)	For sampled analog signals, the Nyquist frequency corresponds to two times the highest frequency component that is being correctly represented after the signal conversion.

O

Output Amplitude Accuracy (OAA)	Measure of an instrument's ability to faithfully output a set voltage at a given frequency versus a traceable standard.
OV	Over Volt (signal input saturation and clipping of signal)

P

PC	Personal Computer
PD	Phase Detector
Phase-locked Loop (PLL)	Electronic circuit that serves to track and control a defined frequency. For this purpose a copy of the external signal is generated such that it is in phase with the original signal, but with usually better spectral characteristics. It can act as frequency stabilization, frequency multiplication, or as frequency recovery. In both analog and digital implementations it consists of a phase detector, a loop filter, a controller, and an oscillator.
Phase modulation AFM (PM-AFM)	AFM mode where the phase between drive and measured signal encodes the topography or the measured AFM variable. See Also Atomic Force Microscope.
PID	Proportional-Integral-Derivative
PL	Packet Loss (loss of packets of data between the instruments and the host computer)

R

RISC	Reduced Instruction Set Computer
Root Mean Square (RMS)	Statistical measure of the magnitude of a varying quantity. It is especially useful when variates are positive and negative, e.g., sinusoids, sawtooth, square waves. For a sine wave the following relation holds between the

amplitude and the RMS value: $U_{RMS} = U_{PK} / \sqrt{2} = U_{PK} / 1.41$. The RMS is also called quadratic mean.

RT	Real-time

S

Scalar Network Analyzer (SNA)	Instrument that measures the voltage of an analog input signal providing just the amplitude (gain) information. See Also Spectrum Analyzer, Vector Network Analyzer.
SL	Sample Loss (loss of samples between the instrument and the host computer)
Spectrum Analyzer (SA)	Instrument that measures the voltage of an analog input signal providing just the amplitude (gain) information over a defined spectrum. See Also Scalar Network Analyzer.
SSH	Secure Shell

T

TC	Time Constant
TCP/IP	Transmission Control Protocol / Internet Protocol
Thread	An independent sequence of instructions to be executed by a processor.
Total Harmonic Distortion (THD)	Measure of the non-linearity of signal channels (input and output)
TTL	Transistor to Transistor Logic level

U

UHF	Ultra-High Frequency
UHS	Ultra-High Stability
USB	Universal Serial Bus

V

VCO	Voltage Controlled Oscillator
Vector Network Analyzer (VNA)	Instrument that measures the network parameters of electrical networks, commonly expressed as s-parameters. For this purpose it measures the voltage of an input signal providing both amplitude (gain) and phase information. For this characteristic an older name was gain phase meter. See Also Gain Phase Meter, Scalar Network Analyzer.

X

XML	Extensible Markup Language: Markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable.

Z

ZCtrl	Zurich Instruments Control bus
ZoomFFT	This technique performs FFT processing on demodulated samples, for instance after a lock-in amplifier. Since the resolution of an FFT depends on the number of point acquired and the spanned time (not the sample rate), it is possible to obtain very highly resolution spectral analysis.
ZSync	Zurich Instruments Synchronization bus

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