

**MCL1-540**  
**Multi-Channel Lock-in**  
**Amplifier Measurement System**  
*Instruction Manual*

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This manual is subject to change. It is being checked regularly for accuracy and will be updated if necessary. For the latest versions, please refer to <http://support.synktek.com>.

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If you have questions after you read this manual or need technical assistance please contact

SynkTek AB  
Blockstupet 6  
163 42 Spånga, Sweden  
info@synktek.com

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# 1 Safety precautions

Please read this manual carefully. Please keep it in a safe place for later use or for subsequent users.

All safety precautions must be observed during all phases of operation, service, and repair of this measurement system. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instrument. The Manufacturer assumes no liability for Customer failure to comply with these requirements.

Check the system and all parts after removing it from the packaging. If it has suffered any damage in transport, do not connect the appliance, contact your re-seller and provide written notification of the damage caused within five working days upon receipt of the system, otherwise you will lose your right to any type of compensation.

This appliance must be installed according to the installation instruction included. Only use this appliance indoors with in the required environmental conditions specified in this manual.









Incorrect repairs and modifications are dangerous. Repairs may only be carried out by authorized service personal. A defective appliance may cause electric shock. If the appliance is defective, shows external damage or you suspect any other condition that may impair the safety of the appliance, unplug the appliance from the mains and contact your re-seller.

Component replacement and internal adjustments must be made by qualified maintenance personnel. Do not replace components with power cable connected. Always disconnect power and discharge circuits before touching them.

Do not install unauthorized substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an authorized representative for service and repair. Do not replace detachable mains supply cords by inadequately rated cords.

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired. The safety of any system incorporating the equipment is the responsibility of the assembler of the system.

## 2 Symbols used

Symbol	Description
	Caution, possibility of electric shock
	Caution, refer to documentation
	Earth (ground) terminal
	Chassis ground
	Fuse
	Alternating current
	Power off
	Power on



### 3 Protecting the environment

This appliance is labeled in accordance with European Directive 2012/19/EU concerning used electrical and electronic appliances (waste electrical and electronic equipment - WEEE). The guideline determines the framework for the return and recycling of used appliances as applicable throughout the EU.



Preserve the packaging material of the system for future transportation. For disposal of the system, contact the manufacturer or your distributor for a free-of-charge return.

## 4 General

The MCL1-540 multichannel lock-in system is a precision measurement system for measuring small AC signals in the presence of noise. It is intended for applications in research and development where current, voltage or resistance of analog devices/sensors needs to be measured synchronously on multiple terminals or different devices.



Do not connect voltages exceeding the specified input/output voltage of the terminals. Noncompliance may result in damage of the measurement system. Refer to the specification in the respective sections of the manual.

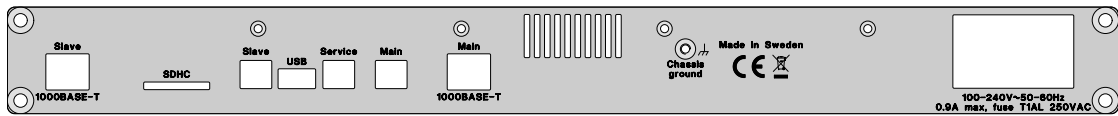


The measurement system is not designed, manufactured, or tested for use in life or safety critical systems, hazardous environments or any other environments requiring fail-safe performance, including in the operation of nuclear facilities; aircraft navigation; air traffic control systems; life saving or life sustaining systems or such other medical devices; or any other application in which the failure of the measurement system could lead to death, personal injury, severe property damage or environmental harm. Prudent steps to protect against failures, including providing backup and shut-down mechanisms, must be taken.

# 5 Parts overview

The MCL1 measurement system is a modular system consisting of a chassis, one to five input/output modules, an embedded main controller, and an optional slave system for real-time data processing of the raw data.

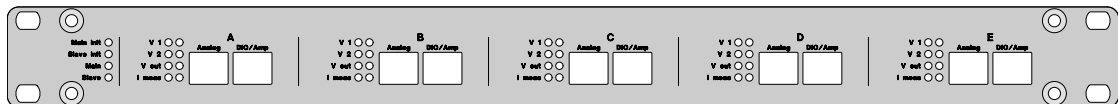
## 5.1 Rear panel



On the rear panel are terminals for the power supply, grounding and communication of the system. The terminals are, from right to left:

1. Mains: IEC 60320-C14 connector for power supply.
2. Chassis shield connector: M4
3. Primary Ethernet: 1000BASE-T Gigabit Ethernet of the Main processing system.
4. Primary USB: USB B 2.0 Hi-Speed of the Main processing system.
5. Service USB: USB B 2.0 HID of the integrated service monitor module.
6. USB: USB A 2.0 host for external data storage, optional.
7. Slave USB: USB B 2.0 Hi-Speed of the optional slave processing system.
8. SDHC: SDHC interface for external data storage, optional.
9. Slave Ethernet: 1000BASE-T Gigabit Ethernet of the optional slave processing system.

## 5.2 Front panel



## 5.2.1 Connectors

The front panel has connectors for the signals to the experiment. There are two 8-position 8-contact (8P8C) modular RJ45 connectors per module, totaling 10 connectors. Connection can be made with any shielded network patch cable of category 5 or higher. Usage of unshielded cables is not recommended as sharp trigger and high-frequency signals may lead to radio-frequency interference and reduced system performance. For best performance and minimal cross-talk, Cat 7 cables having individually shielded pairs are recommended.



When connected to a test object with improper shielding, the EMC emission levels might be exceeded.

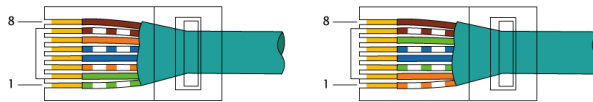


Figure 5.1: T568A versus T568B wiring

Each connector has 8 signal pins plus the cable shielding. The connector pinout follows the TIA/EIA-568 standard, featuring 4 differential signal pairs. The pin numbers and cable color codes for termination using the most common T568A and T568B pin/pair assignments is shown in the figures. The following table additionally shows the signal references used in this documentation.

Pin	Signal	T568A color	T568B color
1	1+	white/green stripe	white/orange stripe
2	1-	green solid	orange solid
3	2+	white/orange stripe	white/green stripe
4	3+	blue solid	blue solid
5	3-	white/blue stripe	white/blue stripe
6	2-	orange solid	green solid
7	4+	white/brown stripe	white/brown stripe
8	4-	brown solid	brown solid

The pin functionality is described in the respective section for each module type.

## 5.2.2 Status LEDs

The front panel features two status LEDs for each processing unit and 8 status LEDs per module. Each LED has the state off (O), green (G) or red (R). The states for the modules are described in the respective module section. If the embedded software is not running/starting, all module LEDs change between red and green every 5 seconds.

The processing unit LEDs for the Main/Slave unit are labeled Main/Slave Init and Main/Slave.

Main/Slave Init LED:

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Color	Pattern	Description
O	off	The system is running normally.
G	solid	The system is currently booting.
G	flashing	The system is in service or install mode, or unable to load the software.
R	solid	The CPU/FPGA or embedded system temperature has exceeded the internal minimum or maximum temperature specifications.

---

**Main/Slave LED:**

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Color	Pattern	Description
O	off	The system is not running or unconfigured.
G	solid	The system operating system is configured.

---

# 6 Installation

## 6.1 Hardware

Before the installation of the measurement system, make sure all safety precautions, environmental conditions and supply voltage requirements are met.

The system can be used both free-standing as well as mounted in a 19" rack. Ensure a steady placement of the system that prevents sliding due to tension in connected cables. Do not place any loads heavier than 5 kg on the system. Convection around the top cover of the instrument is needed for proper cooling, and a space of 40mm above the instrument and at least 10cm from the rear edge must be kept clear to prevent overheating. Adjacent rack units must be passive, and not produce additional heat. Observe that the main power switch might not be accessible when mounted in a rack, in this case other means of disconnecting the system from mains need to be provided.



After installation verify that the openings for the fan on the rear panel and at the sides are not covered and allow for a sufficient air convection.

Make sure the mains switch is in the off (0) position. Connect the power cable to the mains voltage using a three-conductor AC power cable. Assure that a proper protective earth grounding is provided to the system through the mains cable.

Connect the primary Ethernet to your local network and/or the primary USB to your control computer. By default, the network configuration mode is set to DHCP. The USB device will be recognized as a new network interface. For best performance, Ethernet is recommended. To avoid ground loops, the USB connection should be avoided, and the shield of the Ethernet should be interrupted.



The measurement system contains a complete complex embedded operating system. For security reasons, the system should (similar to other network devices like for example network printers) only be operated in a secured network restricting unauthorized network traffic.

Switch on the system. The system will need about one minute to start and initialize. If the system is running, all LEDs except for the Main/Slave LED are off.

## 6.2 Software

The MCL lock-in measurement system can be controlled through a LabVIEW-based binary application, a LabVIEW packed library, the webinterface and a Python library. The latest version of the software can be downloaded at <https://www.synktek.com/downloads>.

The LabVIEW-based software on the user side consists of the following parts:

- User application (compiled binary) for configuration and direct interaction with the instrument
- LabVIEW packed library (MCL.lvlib) and LabVIEW example code for LabVIEW control and system integration
- LabVIEW runtime engine

Both the user application and the LabVIEW packed library use the LabVIEW runtime engine, which will be installed together with the software.

### 6.2.1 Software requirements

- Windows: Windows 7 or later.
- MacOS: OSX 10 or later

If the user has LabVIEW installed, the software installation should match the version of the installed LabVIEW. If the software version is for a newer version than the LabVIEW installed, an updated version of the LabVIEW runtime engine will be installed. The MCL user application will run, but the installed LabVIEW will not be able to access the packed library.

### 6.2.2 Network/firewall requirements

If the system is connected over Ethernet, both system and user should be in the same network subnet. The following ports must be opened to the MCL system:

Port	Type	Description
80	TCP	HTTP web interface
1901-1904	UDP	Network discovery
2343	TCP	LabVIEW
6000-6010	UDP	LabVIEW
8002	TCP	HTTP web interface/REST API
46000-46001	TCP	Data read/write
59110-59120	TCP	LabVIEW

### 6.2.3 Installation

To install the user software, run the installation program. The installation program will install the user application, software library/example code, and LabVIEW runtime engine. If asked by

the Windows firewall, allow the user software to access the network.

## **6.2.4 Network configuration**

If the system is connected via USB, the system is recognized as a network interface and an IP address is automatically assigned.

In the default configuration, the Ethernet port is expecting to be assigned an IP address using DHCP. If no address is received, an arbitrary local link address in the 169.254.0.0/16 subnet is assigned. The default link local address can be found on the rear panel of the device. The usage of local link to operate the system is not recommended, a fixed IP address should be used instead.

The network settings can be changed in the user software. However, a working communication connection to the system is needed. This can be provided either by the local link, or by temporarily connecting the system using the USB.

1. Start the user software, select the TCP/IP.
2. Wait for the network scan to finish (check the network connectivity and re-scan if the system is not found, alternatively)
3. Select the desired measurement system and wait a few seconds for the information to update. Select the config tab.
4. In the adapters tab the current settings are for the Ethernet and USB are shown.
5. In the TCP/IP settings tab the settings of the Ethernet port can be changed.
6. When done, hit the save button and wait for the software re-scanning the network.



# 7 Modules

## 7.1 Connector pinout

Each module has two connectors on the front panel.

Connector	Pair	Type	Description	Maximum range/rating
left	1	analog input, differential	Voltage input 1	+/-10 V
left	2	analog input, differential	Voltage input 2	+/-10 V
left	3	analog output, single ended	Analog voltage output	+/-10 V, 50 mA
left	4	analog output, floating	Analog voltage output with return current measurement	+/-10 V, 50 mA
right	1	analog output, single ended	Amplified Voltage 1	+/-10 V, 1 mA
right	2	analog output, single ended	Amplified Voltage 2	+/-10 V, 1 mA
right	3	digital input, single ended	Trigger/phase marker in	5 V
right	4	digital output, single ended	Trigger/phase marker out	5 V, 600 $\Omega$

The right cable should be disconnected if is unused to minimize potential interference paths into the low-noise part of the system.

## 7.2 Status LEDs

Row	Color	Left LED	Right LED
V 1	off	input underrange	input grounded
	green	input in optimal range	input DC coupled
	red	input overrange	input AC coupled
V 2	off	input underrange	input grounded
	green	input in optimal range	input DC coupled
	red	input overrange	input AC coupled
V out	off	no output voltage	fixed output range
	green	output voltage > 0V, grounded	reserved (output auto-range)
	red	output voltage > 0V, floating	reserved (output underrange)
I meas	off	underrange	fixed current measurement range
	green	optimal range	current measurement auto-range
	red	overrange	reserved

## 7.3 Description

### 7.3.1 Analog input

Each module contains two identical differential analog inputs. At first, the signal passes a relay to select between DC and AC (high-pass filter) coupling. In the second step, the signal is passing through one of three parallel preamplifiers (1-20-500 amplification). The inputs are selected by signal relays, and unused amplifiers are grounded. The output is low-pass filtered (100  $\Omega$  & 1 nF,  $\sim$ 1.6 MHz) and selected by a digitally controlled CMOS switch. A second amplifier provides an additional amplification of 1-2-5-10. Finally, the ADC driver incorporates a second order Sallen-Key low-pass filter with a break frequency of  $\sim$ 600 kHz. The amplified signal is available at the front panel.



Activating AC coupling will load any connected sample with a discharged grounded capacitor (10  $\mu$ F for MCL1M-112-4 and MCL1M-112-18, 47  $\mu$ F for MCL1M-112-1.8). The current will be limited by the filter resistor only (232 k $\Omega$  for MCL1M-112-4 and MCL1M-112-18, 27 k $\Omega$  for MCL1M-112-1.8). In case of sensitive samples, bring the sample terminals to ground potential before switching to AC coupling.

Intentionally, the input has no additional input protection/radio frequency interference filter besides the preamplifiers internal protection (3 kV human body model) as these are compromising the input performance. Adequate ESD measures to protect the circuitry and proper signal shielding to avoid rectification of radio-frequency signals is required.

### 7.3.2 Analog output

The DAC generates a  $\pm$ 10 V analog signal using a 5 V voltage reference. This output is buffered and passes an active 2nd order Butterworth filter in a Sallen-Key configuration with a break frequency of about 520 kHz. Thereafter, the signal is optionally attenuated to a 1.0 V or 0.1 V full range and buffered again. This signal (single ended ground referenced) is available on pair 3 of the left connector.

The signal continues and is converted into a differential signal ( $>$ 4 k $\Omega$  insulation to ground, about 50dB CMRR  $<$ 100 Hz). The negative output is by default grounded through a solid state relay. The grounding impedance is non-zero and leads to a ground voltage if -100dB below 50 Hz and about -70...-75 dB at 1 kHz with respect to the output voltage.

The return current on the negative terminal of the floating voltage output is measured. The current is either measured over a 10  $\Omega$  shunt resistor, or over a feedback ammeter with a selectable feedback resistor of 2 M $\Omega$ , 100 k $\Omega$ , 5 k $\Omega$  or 250  $\Omega$ . This signal is low-pass filtered and preamplified with a gain of 20 and an additional gain of 1-2-5-10. As the current measurement is located close to the source, it might not necessarily correspond to the true sample current due to cable capacitance. Furthermore, in sample configurations with multiple connected bias terminals the current return path has to be evaluated carefully.

Connection leads to the sample should be kept as short as possible to reduce cable capacitance.

Cable capacitance degrades the noise performance of the ammeter strongly, as input voltage noise is amplified proportionally with the capacitance and becomes dominating over the current noise. In the worst case, excessive noise can lead to ringing effects. The effects can be reduced by decoupling the capacitance by a resistance close to the current return output.

### **7.3.3 Digital input/output**

Each module has a digital input (for PLL) and a digital output (as a phase marker).

The output voltage level is by factory default set to 5 V and can be switched to 3.3 V by a switch on the module. The output is pulled to the output level with a  $600\ \Omega$  ( $10\ \text{k}\Omega$ ) pull-up resistor, and periodically grounded by a MOSFET transistor. Therefore, the falling edge contains less jitter compared to the rising edge. Though the output contains a common mode filter, special care needs to be taken to avoid the sharp return currents of the falling edge to return through the analog signals.

# 8 Maintenance

## 8.1 Cleaning

Disconnect the system from mains power before cleaning, and prevent IPA from entering the system. The outside system can be carefully cleaned with a cleaning cloth and isopropanol (IPA).

Dust in the system prevents a sufficient cooling, which may result in overheating and malfunctioning of the system, and is a potential fire hazard. Inspect the system regularly. If needed, clean the inside of the measurement system by gently removing the dust. Follow the instructions and safety precautions for opening the system in the respective section of the manual. In case the fan needs a replacement contact the technical support. Do not use liquids. Do not touch any components or internal cables.

## 8.2 Calibration

The modules are factory calibrated, but can be re-calibrated by the user, using an automatic calibration routine and a high-precision resistor (10 k $\Omega$ , 0.01%). Factory calibration values will be loaded at start. User calibration needs to be loaded after start.

### 8.2.1 Calibration parameters

The calibration parameters for each module include:

- Input offset voltage (for 12 gains x 2 inputs)
- Input gain correction factor (for 12 gains x 2 inputs)
- Input gain frequency and phase correction parameters (for 12 gains x 2 inputs)
- Current measurement offset (for 20 gains x 1 output)
- Current measurement gain correction factor (for 20 gains x 1 output)
- Current measurement gain frequency and phase correction parameters (for 20 gains x 1 output)
- Output offset voltage (for 3 output ranges x 1 output)
- Output gain correction (for 3 output ranges x 1 output)

## 8.3 Installation of modules

### 8.3.1 Opening the system



Before opening the system verify that all cables to the systems terminals are disconnected as hazardous live parts may become accessible resulting in a danger for electric shock.



The system consists of very sensitive electronics. Adequate grounding and ESD protection measures need to be taken to protect the system from damage. The manufacturer is not responsible for damages and claims due to inappropriate service.

Disconnect any cables connected to the systems terminals. Unmount the system from the rack. Remove the 16 small screws on the top panel of the system. Lift out the top panel from the rear panel by using a small screw driver in one of the screw holes at the side, or by carefully tilting the system upside-down as the front edge of the panel is fixed in a slot engraved into the front panel.

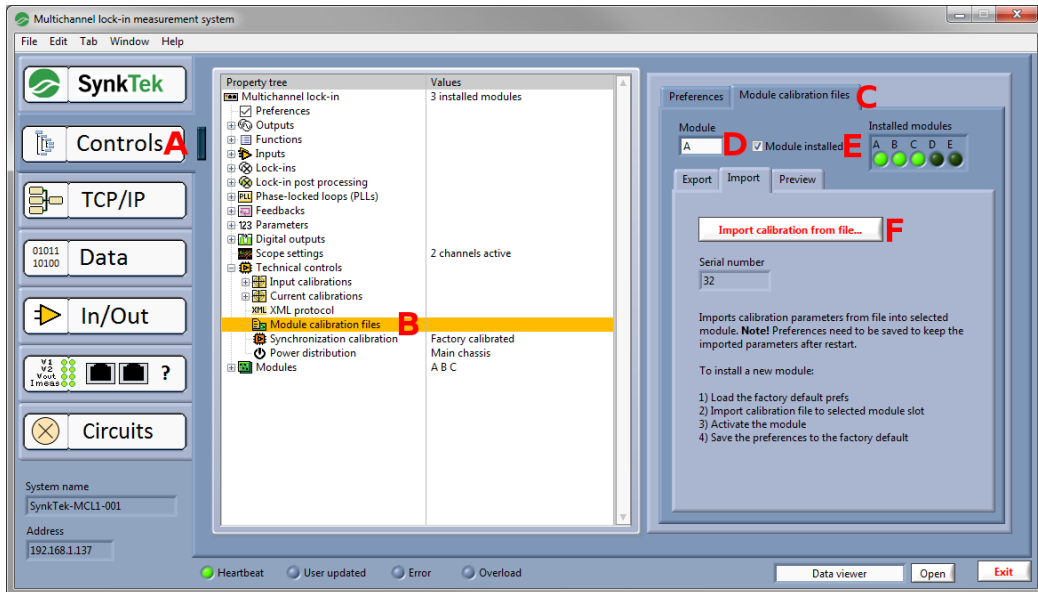
### 8.3.2 Closing the system

Place the top panel back onto the system and attach the 16 screws.

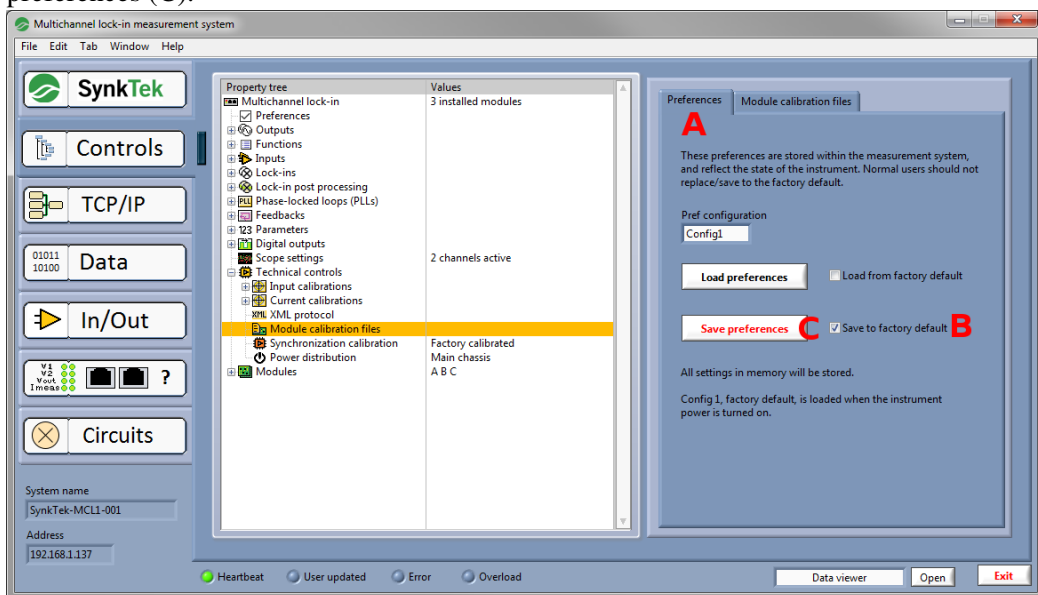
### 8.3.3 Loading module calibration files

This section applies to version 1.3 of the software only.

1. Start the lock-in and the user software and connect to the system
2. Go to the controls tab (A) and select Technical controls -> Module calibration files (B).
3. Select the module calibration files tab (C) and select the desired module (D).
4. Activate (or deactivate) the module (E)
5. Load the calibration file corresponding to the module (F), and verify that the correct module serial number is loaded.
6. Repeat steps 3-5 for all updated modules.



7. Go to the preferences tab (A), check the save to factory default checkbox (B) and Save the preferences (C).



## 8.4 Updating the embedded system

### 8.4.1 Version 1.4.14 and later

1. Copy the image file on a USB stick or SD-card and insert it into the system
2. Open the web interface.

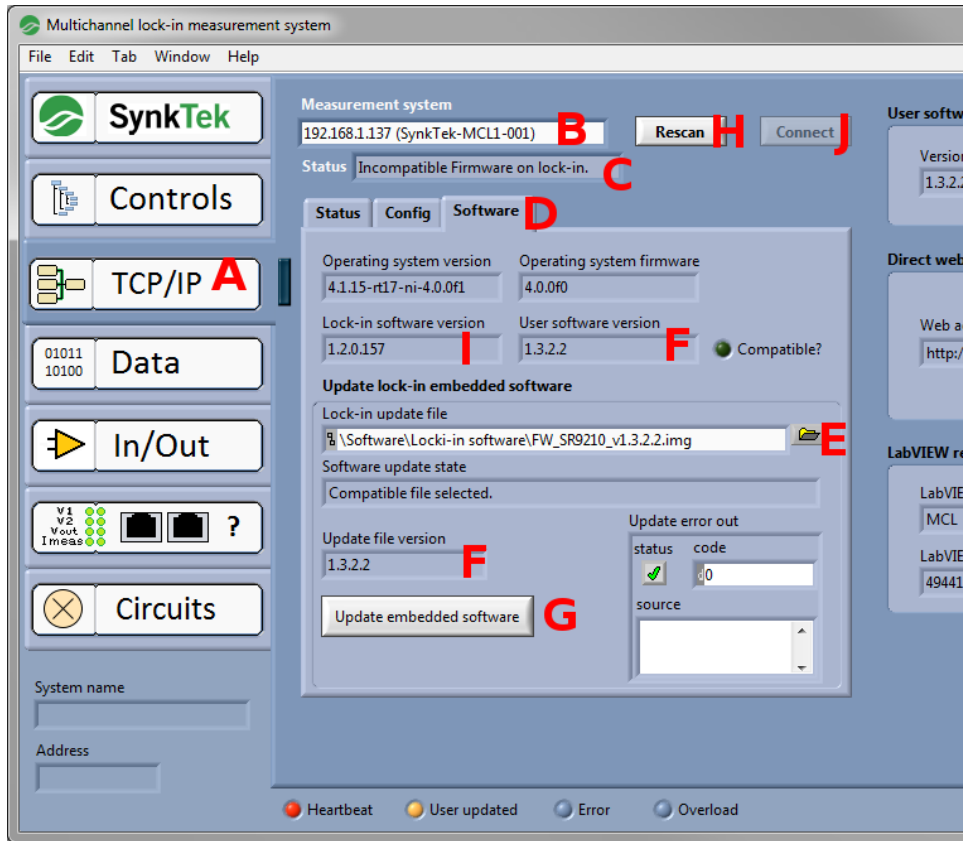
3. Go to System -> Update
4. Select the system image file in the selection list
5. Update the system

#### **8.4.2 Version 1.4.x**

1. Open the web interface.
2. Go to System -> Update
3. Upload the system image file
4. Select the system image file in the selection list
5. Update the system

#### **8.4.3 Version 1.3.x**

1. Download the latest version of both the user software executable and the latest system software image (.img-file).
2. Start the system and wait until the initialization is finished. Run the user software and go to the TCP/IP tab (A). Wait for the scan of the compatible network devices to finish.
3. Choose the instrument to update (B). The software might warn about an incompatible embedded software version (C). Proceed to the software tab (D).
4. Select the image file (E). Verify that the user software has the same or a newer version than the update image file.
5. Start the update of the software (G). The update will take approximately 5 minutes and the system will restart several times.
6. After the update is completed and the system is initialized, rescan to update the system information in the user software (H). The Lock-in software version should show the version number of the installed version (I). You may now connect to the system (J).





# 9 Software operation

## 9.1 Embedded system software design

The embedded software of the measurement system is running completely independently of any external control software. The system consists schematically of three related subsystems: an FPGA-based processing unit, a system configuration and communication unit (the so called "host"), and a front panel control unit that is also supervising system power distribution.

### 9.1.1 Processing unit

The processing unit handles all hardware control as well as all essential signal processing. This includes generation, data collection, calibration, demodulation, feedback, amplifier ranging, digital filtering, etc. The resulting data is transferred to the host through direct memory access.

### 9.1.2 Host: system configuration and communication unit

The host handles all user-configurable settings and all communication with the user computer. The host maintains a set of settings describing the system state and operation. When the power is turned on, the host system first boots and then loads its default set of configuration settings. During normal use, the host receives state changes both from the user and the processing unit, and forwards these changes to keep both user and processing unit updated. The host also updates the front panel control unit with the current system state. Measurement data that comes to the host from the processing unit are structured into a more user-friendly format and some additional post-conditioning, such as FFT and high-frequency corrections are performed. The measurement results are then pushed to the user computer if communication has been established. The host also publishes some measurement results to the network for other means of access.

### 9.1.3 Front panel control unit

The front panel control unit handles updates of front panel LEDs and monitors power distribution. The front panel updates are not performed in real time, but only a few times per second to avoid any cross-talk or other effects on the measurements. In case of system malfunction, the control unit can be accessed from the rear panel Service port.

## 9.2 Communication with the measurement system

The user control software first establishes a communication with the system. Once a communication has been established, new data and state changes are pushed to the user control software when they become available. The user control software connects to the system to access the data, receive updates of the configuration, and control the system.

### 9.2.1 Finding the system on the network

Start the user control software. Under TCP/IP settings, scan the network for measurement systems. Consult the installation section of the manual if no systems are found. Select the system and connect to it for direct communication using the user control program, or set and record the TCP/IP settings and host name for programmatic access.

### 9.2.2 Establishing communication

The communication is established either through the TCP engine of the user interface program or programmatically using the TCP engine of the LabVIEW packed library. When communication is established with the system, two two parallel TCP channels are opened to the host. The communications are prevented from timing out through small ping packets on regular intervals to maintain shortest possible latency. As long as communication is established, changes of settings at the host are pushed to the user. When communication is established the `_App.vi` will ask the host for all current settings.

#### Parallel communication

Currently, the measurement system does not allow multiple TCP engines to connect to the system at the same time. The user should thus either use the user control software or the TCP engine of the LabVIEW packed library, not both. The `_App.vi` in the packed library replaces the user control software in case of programmatic access without loss of functionality.

### 9.2.3 Updating the system state

Normally, every time a setting is changed, the setting is sent to the host. It is possible to programmatically send several settings simultaneously to the host.

### 9.2.4 Receiving system state updates

The user communication software maintains a local mirror of the full system state, including all settings. In most cases the measurement system state is controlled by the user. If the user programmatically requests the value of a certain parameter, the communication software returns the local copy of this parameter, without any communication with the measurement system. Certain settings can, however, be changed by the measurement system itself, such as input voltage gains

when auto ranging, or when a saved user configuration is loaded. As long as communication has been established, such changes are automatically sent back to the user. To ensure that the user software is always reflecting the correct state of the measurement system, the full system state is sent to the user when communication is established, and later by request.

### **9.2.5 Receiving measurement data**

The measurement system automatically pushes new data to the user as soon as it is available, provided that communication has been established. The user can configure what the measurement system sends. By default all data are sent. Similarly, sampled waveforms and FFTs are pushed to the user.

# 10 User control software

## 10.1 Software layout

The user control software is built around a main parent window from which additional windows, graphs, etc. can be generated.

The main parent window of the user control software consists of three parts.

- Menu tabs on the left
- Main area
- Bottom status bar

The menu tabs on the left act as a main menu. Depending on the selection, the main area presents different configuration settings and/or information. Key status as well as a stand-alone panel launcher popup are found in the bottom status bar.

### 10.1.1 Menu tabs and main area

The menu tabs on the left have the following functionality:

- Info: Information about system and support
- Controls: Configuration of all functional settings
- TCP/IP: Configuration of network settings and system health monitoring
- Data: Measurement data readings
- In/Out: Input and output status information
- Front panel: Information about the meaning of front panel LEDs, connectors, and cabling
- Circuits: Diagram schematics describing various aspects of the system

### 10.1.2 Bottom status bar

The bottom status bar components have the following functionality:

- System name: Name of the measurement system for identification and communication purposes

- Heartbeat: Indicator that will blink green once per second when the measurement system is present
- Update user checkbox: Sends a command to the measurement system to update the user state
- User updated: Blinks green for a short while when the user has been updated
- Address: The IP address with which the user software tries to communicate
- Ovl: Overload indicator that indicates if any input or current measurement channel is overloading
- Popup menu: List of stand-alone windows that can be launched
- Open button: Opens an additional window of the specified type
- Exit: Exits the program

## 10.2 Software info

The info tab page displays software info and introductory information about the measurement system and support.

## 10.3 Controls

### 10.3.1 Tree structure

The controls are organized in a property tree structure. A single setting may appear at more than one place in the tree. Depending on the tree structure selection, the corresponding settings are accessible for configuration.

### 10.3.2 Relations between controls

To provide maximum flexibility, many settings are made in several steps. As an example, an output function has an amplitude that has a certain value. A different output function could be selected, the output function could change the amplitude parameter that it is using, or the value of the amplitude parameter could be changed. This means that several outputs can share the same functions, frequencies, or other parameters. As an example, Output A could output a square wave based on Frequency 1 and Amplitude 1 while Output B could output a sine wave based on Frequency 1 and Amplitude 2.

### 10.3.3 Control settings

Below is a short summary of the control settings of the property tree structure.

- Inputs: Configure voltage input ranging, grounding, and ac coupling.
- Outputs: Configure voltage output settings, including ranging, output functions, and current measurement ranging.
- Lock-ins: Configure the lock-in sets. As default, each set acts synchronously on all voltage inputs and current measurement channels.
- Phase-locked loops (PLLs): Configures the digital input and settings for the corresponding PLL frequency generator.
- Feedbacks: Configures the settings for real-time feedback. The feedback is not sent directly to the output, but is instead configuring a real-time offset parameter that can be used in any output function.
- Amplitudes: Configure the available amplitude parameters.
- Offsets: Configure the available offset parameters. The feedback parameter settings are added to the actual real-time offsets.
- Duty cycles: Configure the available duty cycle parameters, used for square waves etc.
- Frequencies: Configure the available frequency parameters.
- Phase shifts: Configure the available phase shift parameters, used for outputs and lock-ins.
- Functions: Configure the available functions, used for outputs.
- Digital outputs: Configure the digital outputs.
- Input calibrations: Configure the calibrations for voltage inputs.
- Current calibrations: Configure the calibrations for output current measurements.
- General controls: Configure advanced synchronization settings.
- Lock-in post processing: Configure host post processing of lock-in data, including data pushed to user.
- Waveform settings: Configure waveform settings and select waveforms that should be pushed to user.

The details of the controls are found under the section Control details.

## 10.4 TCP/IP

Under the TCP/IP tab, the user can search for measurement systems, select a measurement system to communicate with, configure the TCP/IP settings of a system, and monitor some system status information about the health of the system.

### **10.4.1 Searching for measurement systems**

Initially, the user software automatically scans the network for measurement systems. If no system is found, click Rescan to search again. Check network connection and possible firewall settings if no system is found.

### **10.4.2 Selecting a measurement system**

Select the measurement system in the Measurement system popup.

### **10.4.3 Connecting to a measurement system**

If a system is available, the Connect button should be enabled. Click Connect to connect to the system. The Heartbeat indicator should start to blink green.

### **10.4.4 TCP/IP configuration**

Once a measurement system has been found, its TCP/IP settings can be configured. It is not necessary to connect to the system to configure these setting. Relevant settings are found under the Config tab in the TCP/IP tab area.

#### **Verifying hardware/software info**

Hardware and software information for the selected measurement system are shown under the Config->Hardware/software info tab. This information includes the current network MAC address and IP address, hardware serial number, and software version information.

#### **Listing network adapters**

Under the Config->Adapters tab, the network adapters are listed. The system supports two network adapters:

- Ethernet: Connection through the Main Ethernet port
- USB: Connection through the Main USB port

#### **Configuring the TCP/IP settings**

The TCP/IP settings of the Ethernet adapter are modified under the Config->TCP/IP settings tab. The Hostname may be chosen freely to uniquely identify the system. Click the Save new TCP/IP settings button to update settings.

## **Service access**

Under the Config->Service tab, some service information is displayed. Possible system software errors are also shown. If the system needs to be restarted remotely, there is also a restart button.

## **10.4.5 Status information**

Central measurement system status information is found under the Status tab in the TCP/IP tab area.

### **Time settings**

The time settings are found under the Status->Time tab. Time settings include setting time and Time zone.

### **System temperature**

The system temperature is displayed under the Status->Temperatures tab. Under normal operation, the temperature should be well below the Max allowed temperature.

### **Available disk space**

The measurement system has a built-in disk storage, which is monitored under the Status->Disk tab. The available space should not change significantly during normal use.

### **Available memory**

The available memory is shown under the Status->Memory tab. The available free memory should not change significantly during normal use, but is affected by the number of scope channels active. Monitor the free memory if the system crashes after extended use. Activating all scope channels at maximum number of samples per channel will likely exceed available memory.

### **Host processor load**

The host processor has two CPUs that are monitored under the Status->CPU tab. The load should normally be below 50%. The system may become unstable in case the load is persistently high. To lower the CPU load in such case:

- Reduce the amount of waveforms sent to the user
- Reduce the waveform length and increase the waveform reduction factor correspondingly
- Increase the time constant per sample for both lock-in sets



## 10.5 Data

Under the Data tab, the current readings are shown. The readings are grouped in two parts, data readings and general readings.

### 10.5.1 Lock-in sets

Each lock-in set has its own readings. The readings from different lock-in sets are asynchronous if the lock-in sets are based on different frequency generators and synchronous if the lock-in sets are based on the same frequency generator and have the same time constant settings.

The data of each lock-in set is always synchronous. Each set consists of data readings and general readings.

### 10.5.2 Data readings

The data readings are organized as a cluster of arrays of data. Each array consists of 15 data elements.

#### Cluster components

The cluster contains the following arrays of measured data:

- DC: DC voltage, unit (V) or DC current, unit (A), depending on element
- X: In-phase component, unit (V) or (A) depending on element
- Y: Out-of-phase (quadrature) component, unit (V) or (A) depending on element
- R: Amplitude, unit (V) or (A) depending on element
- theta (deg): Phase in degrees

#### Standard measurement mode

In the standard measurement mode, the 15 elements of each array are in the following order:

- Module A, voltage V1
- Module A, voltage V2
- Module B, voltage V1
- ...
- Module E, voltage V2
- Module A, current

- ...
- Module E, current

### **Multiple harmonics mode**

In the multiple harmonics mode, the elements of each array are given by a specified, predefined order, where each of the 15 elements belongs to a specified module, input, and harmonic. This feature is not available on all software options.

- Module, V1/V2/I, harmonic
- Module, V1/V2/I, harmonic
- ...

### **10.5.3 General readings**

The general readings contain the following data:

- Lock-in frequency for the lock-in set
- Number of frequency cycles per sample for the current data reading set
- Time for the current data reading
- A data point index
- A point number
- Module data
- PLL1, PLL2, and composite frequencies

The data point index and point number are two different indices. The data point index is FPGA-based and the point number is host-based.

The module data contains the following information for each module:

- Digital input frequency
- Digital output frequency
- Current output ac amplitude
- Current output dc offset

## **10.6 Preamps**

Under the Preamps tab, the user can get a quick overview of the input preamplifier stages, the output ranging, and the output current measurement amplifiers.

## 10.7 Front panel

Under the Front panel tab, the front panel indicators and connectors are described. Each module has a set of LED indicators, an Analog connector and a DIO/Amp connector.

### 10.7.1 LED indicators

The Front panel -> LED indicators tab gives a quick access to the meaning of the different indicators lights.

### 10.7.2 Analog connector

The Front panel -> Analog connector tab describes the analog connector. The connector has the following four pairs:

1. Analog input, differential: voltage input 1
2. Analog input, differential: voltage input 2
3. Analog output, single ended: analog voltage output
4. Analog output, differential: analog voltage output + return current

### 10.7.3 DIO/Amp connector

The Front panel -> DIO/Amp connector tab describes the connector for digital input/output and amplified input signals. The connector has the following four pairs:

1. Analog output, single ended: Amplified voltage input 1, +/- 10 V full range
2. Analog output, single ended: Amplified voltage input 2, +/- 10 V full range
3. Digital input: Trigger/PLL in, 3.3 V - 5 V
4. Digital output: Trigger/Phase marker out, 3.3 V or 5 V (hardware switch on module)

### 10.7.4 Cable description

There are two different versions of color coding for network cables, T-568A and T-568B. The T-568B is the most commonly used. Cables should be straight (T-568A to T-568A or T-568B to T-568B), not cross-over (T-568A to T-568B).

## 10.8 Circuits

Under the Circuits tab, the user can find functional schematics and short descriptions of the central hardware and software.

# 11 Control details

The measurement system controls are organized in a tree structure, where a certain control can occur at more than one place. Below, the details of each control is only described once. Parent groups that only group other controls are not described. Each set of controls typically belongs to a control specifier, such as an input channel.

## 11.1 Input

### Control specifier

[Input channel] enum {A1, A2, B1, ..., E2}

### Control(s)

[Voltage gain] enum {1, 2, 5, 10, 20, 40, 100, 200, 500, 1000, 2500, 5000}

[GND] boolean {F/T}

[ac coupling] boolean {F/T}

[Autorange] boolean {F/T}

### Description

Configures analog input stage. Each input has a voltage preamplifier stage. The voltage gain sets the input preamplifier gain if the gain is not auto ranging. When grounding [GND] is true, the input is grounded and both polarities of the connection to sample are broken. Each input can be selected to be ac or dc coupled. If auto ranging is active, the preamplifier gain will adjust automatically regardless of the voltage gain setting.

## 11.2 Output

### Control specifier

[Output module] enum {A, B, C, D, E}

### Control(s)

[Range Setting:Output range] enum {10V, 1V, 0.1V}

[Range Setting:Floating] boolean {F/T}

[Fx] enum {Function 1, ..., Function 8}

[Fy] enum {Function 1, ..., Function 8}

[Current Meas:Current range] enum {50mA, 25mA, 10mA, 5mA, 2mA, 1mA, ..., 25nA}

[Current Meas:Auto-range] boolean {F/T}

[Output enabled] boolean {F/T}

[Digital out phase marker (Fx)] boolean {F/T}

[Type] enum {Fx, Fx\*Fy, Fx+Fy, Fx-Fy, Fy}

### Description

Configures analog voltage output stage, including ranging, output functions, and current measurement ranging. Output is active only when [Output enabled] is true. The functions [Fx] and [Fy] are combined through [Type]. The digital output phase marker can also be activated. This phase marker is based on [Fx].

## 11.3 Lock-in

### Control specifier

[Lock-in set] enum {Lock-in set L1, Lock-in set L2}

### Control(s)

[Frequency generator] enum {Frequency 1, ..., Frequency 8}

[Harmonic] U16 {1, ..., 65535}

[Type] enum {Sine, Square, Boxcar}

[PhaseShift] enum {Phase 1, ..., Phase 7, Disabled}

[Duty cycle] enum {DutyCycle 1, ..., DutyCycle 7, Inactive}

[Time constant] double {100 s, ..., 1 ms, other}

[Exponential low-pass filter:Enabled] boolean {F/T}

[Exponential low-pass filter:Stage1 time const.] double {100 s, ..., 1 ms, other}

[Exponential low-pass filter:Stage2 time const.] double {100 s, ..., 1 ms, other}

### Description

Configures a lock-in set. Each lock-in set acts synchronously on all voltage inputs and current measurement channels. Different lock-in sets may be independent or based on the same frequency generator but with a different harmonic. If the lock-in [Type] is Sine or Square, the [Duty cycle] is neglected. If [Type] is Boxcar, the [Duty cycle] defines the

active window. The [PhaseShift] shifts the reference phase. [Time constant] is the data point rate time constant. This time constant also defines the synchronous filter. If [CIC filter:CIC filter] is enabled, two stages of exponential filters are applied with given time constants. These time constants could be both shorter or longer than the data point rate time constant.

## 11.4 Phase-locked loop (PLL)

### Control specifier

[PLL] enum {PLL 1: Frequency 6, PLL 2: Frequency 7}

### Control(s)

[Source] enum {DIO A, ..., DIO E}

[Falling edge] boolean {F/T}

[Trigger phase shift (deg)] double {}

### Description

Configures a phase-locked loop. The phase-locked loops use the digital input to determine the frequency and phase of a reference signal. The result is a PLL frequency generator that follows the digital input reference. The PLL frequency generator can be used both for lock-in settings and for output signal generation.

## 11.5 Feedback

### Control specifier

[Feedback] enum {Feedback 1: Offset 6, Feedback 2: Offset 7}

### Control(s)

[Feedback type] enum {Input, DC, X (in-phase), Y (Quadrature)}

[After low-pass] boolean {F/T}

[Signal] enum {AV1, AV2, BV1, ..., EV2, AI, ..., EI, Int.}

[Reference] enum {Lock-in set L1, Lock-in set L2}

[Output gain] enum {1V/V, 1V/100mV, 1V/10mV, 1V/mV, 1V/100uV, 1V/10uV, 1V/uV, 1V/100nV, 1V/10nV, 1V/nV}

### Description

Configures the settings for real-time feedback. The feedback is a real-time signal independent of the lock-in data point time constant with an update rate of 1 MS/s. The feedback is represented by a real-time offset parameter that can be used in any output function. The [Feedback type] determines the main behavior of the feedback. {Input} is the sampled analog input, {DC} is the dc-filtered input, {X} is the in-phase component after mixing with reference signal, and {Y} is the quadrature component after mixing with reference signal. The feedback signal can be accessed both before and after the low-pass filter stages. The [Signal] and [Reference] determines the source of the feedback. The resulting offset parameter is the feedback signal scaled by [Output gain].

## 11.6 Amplitude

### Control specifier

[Amplitude] enum {Amplitude 1, ..., Amplitude 5}

### Control(s)

[Amplitude] double {0 ... 7.071}

[Unit] enum {Vrms, Vp, Vpp}

[Ramp changes] boolean {F/T}

[Ramp rate (s/V)] double {1000, ..., 0.001, other}

### Description

Configures an amplitude parameter. The amplitude parameter is used in one or several output functions. The functions may be combined before being output. The actual output amplitude of a function scales with the output range. If [Ramp changes] is activated, the amplitude does not take a new value immediately, but changes with a ramp rate [Ramp rate (s/V)].

## 11.7 Offset

### Control specifier

[Offset] enum {Offset 1, ..., Offset 5, Offset 6: Feedback 1, Offset 7: Feedback 2}

### Control(s)

[Offset (V)] double {-10 ... 10}

[Ramp changes] boolean {F/T}

[Ramp rate (s/V)] double {1000, ..., 0.001, other}

### Description

Configures an offset parameter. The offset parameter is used in one or several output functions. For [Offset] set to {Offset 6} and {Offset 7}, the specified offset voltage is added to the results given by the feedback.

## 11.8 Duty cycle

### Control specifier

[Duty cycle] enum {DutyCycle 1, ..., DutyCycle 7, Inactive}

### Control(s)

[Duty cycle] double {}

[Unit] enum {deg,%}

### Description

Configures a duty cycle parameter. The duty cycle parameter is used in one or several square wave output functions and/or lock-in sets configured for box-car measurements.

## 11.9 Frequency

### Control specifier

[Frequency] enum {Frequency 1, ..., Frequency 5, Frequency 6: PLL 1, Frequency 7: PLL 2, Frequency 8:composite}

### Control(s)

[Frequency (Hz)] double {0 ... 5E5}

[Ramp changes] boolean {F/T}

[Ramp time const. (s)] double {100 s, ..., 1 ms, other}

### Description

Configures a frequency parameter. The frequency parameter can be used in output functions and lock-in references. If [Ramp changes] is activated, the frequency is changed continuously (no phase jumps) with a time constant given by [Ramp time const. (s)]. The frequency will then double or be reduced by half during one time constant. Frequency 6 and frequency 7 are controlled by the PLLs. Frequency 8 is a composite frequency.

## 11.10 Composite frequency

### Control specifier



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**Control(s)**

[Frequency A] enum {Frequency 1, Frequency 2, ..., Frequency 7: PLL 2}

[Frequency B] enum {Frequency 1, Frequency 2, ..., Frequency 7: PLL 2}

[Frequency 8] enum {Freq. A + Freq. B, Freq. A - Freq. B}

**Description**

Configures Frequency 8. This frequency parameter is a composite frequency, given by either the sum or the difference of two other frequencies. The momentary phase of Frequency 8 (before any phase shift) is such that it is given by the phases of the constituent frequencies.

## 11.11 Phase shift

**Control specifier**

[Phase shift] enum {Phase 1, ..., Phase 7, Disabled}

**Control(s)**

[Phase shift (deg)] double {}

**Description**

Configure a phase shift parameter. The phase shift parameter is used to phase shift frequency generators used in output functions and lock-in references. The disabled parameter is always set to 0.

## 11.12 Function

**Control specifier**

[Function] enum {Function 1, ..., Function 10}

**Control(s)**

[Type] enum {Sine, Square, Sawtooth, Noise}

[Frequency] enum {Frequency 1, ..., Frequency 8}

[Harmonic] U16 {1 ... 65535}

[Amplitude] enum {Amplitude 1, ..., Amplitude 5}

[Reference level] enum {Top, Standard, Bottom}

[Duty cycle] enum {DutyCycle 1, ..., DutyCycle 7, Incactive}

[Offset] enum {Offset 1, ..., Offset 5, Offset 6: Feedback 1, Offset 7: Feedback 2}

[Phase shift] enum {Phase 1, ..., Phase 7, Disabled}

### **Description**

Configures an output function. The [Reference level] defines if a sine/square output is symmetric (Standard), on the positive side (Bottom), or negative side (Top) with respect to the offset and other functions.

## **11.13 Digital output**

### **Control specifier**

[Digital out] enum {A, B, C, D, E}

### **Control(s)**

[Enabled] Boolean {F/T}

### **Description**

Configures a digital output. The digital output will act as a phase marker if activated.

## **11.14 Input calibration**

### **Control specifier**

[Input] enum {A1, A2, B1, ..., E2}

### **Control(s)**

[Voltage calibrations] array[12] {Gain correction, Offset}

[Voltage calibrations:Gain correction] double {}

[Voltage calibrations:Offset] double {}

### **Description**

Configures the calibration parameters for a voltage input. Each item in the [Voltage calibrations] array corresponds to a preamplifier gain. The first item corresponds to Input [Voltage gain]=1. The [Voltage calibrations:Gain correction] is a correction factor that is factory calibrated. The [Voltage calibrations:Offset] is the preamplifier stage voltage offset specified as an input offset in V. It is factory calibrated, but should be recalibrated at regular intervals or when needed. Changes are not stored permanently unless preferences are saved.

## 11.15 Current calibration

### Control specifier

[Module] enum {A, B, C, D, E}

### Control(s)

[Current calibrations] array[20] {Gain correction, Offset}

[Current calibrations:Gain correction] double {}

[Current calibrations:Offset] double {}

### Description

Configures the calibration parameters for an output current measurement. Each item in the [Current calibrations] array corresponds to a preamplifier gain. The first item corresponds to Output [Current range]={50 mA}. The [Current calibrations:Gain correction] is a correction factor that is factory calibrated. The [Current calibrations:Offset] is the preamplifier stage current offset specified as an current input offset in A. It is factory calibrated, but should be recalibrated at regular intervals or when needed. Changes are not stored permanently unless preferences are saved.

## 11.16 System timing calibration

### Control specifier

—

### Control(s)

[FPGA calibration] cluster {Lock-in phase calib, Digital output delay, Digital input delay, Preamp calib}

[FPGA calibration:Lock-in phase calib (ticks)] U16 {0 ... 65535}

[FPGA calibration:Digital output delay (ticks)] U8 {0... 255}

[FPGA calibration:Digital input delay (ticks)] I16 {-32768... 32767}

[FPGA calibration:Preamp calib (5 MHz ticks)] U16 {0 ... 65535}

### Description

Configures advanced system calibration settings. Each tick corresponds to 12.5 ns (80 MHz ticks). The [Lock-in phase calib] is a calibration to compensate for the delay of the lock-in measurements with respect to internal phase generation. The [Digital output delay] is a calibration of the output delay to synchronize lock-in measurements with output signal. The [Digital input delay] is a calibration of the digital input delay to synchronize external PLL signal with internal lock-in. The [Preamp calib] is a delay to synchronize the timing

of physical relay switching with software gain changes of the ADC preamplifier stages. Configured correctly, the effect of input range changes should be minimized. All settings are factory calibrated and should not need to be modified.

## 11.17 Lock-in post processing

### 11.17.1 Host config

#### Control specifier

[Lockin] enum {Lockin L1, Lockin L2}

#### Control(s)

[Normalize dig ref] boolean {F/T}

[Averaging time (s)] double {}

[ReturnAllData] boolean {F/T}

[To Return] array[variable length] {Parameter, Return}

[To Return:Parameter] enum {enumerated options}

[To Return:Return] boolean {F/T}

#### Description

Configures host post processing of lock-in data, including data pushed to user. If [Normalize dig ref] is active, the lock-in data are normalized with a digital reference to compensate for low-pass filtering effects otherwise distorting results when frequency is suddenly changed. [Averaging time (s)] is controlling a host-based post-averaging. If [Averaging time (s)] is shorter than the lock-in time constant no post-averaging will take place. If [ReturnAllData] is true, the full set of lock-in data is sent to the user each time new data is available. If [ReturnAllData] is false, only the data specified in the [To Return] array are returned to the user.

### 11.17.2 RunningAvg

#### Control specifier

[Lockin] enum {Lockin L1, Lockin L2}

#### Control(s)

[Running average range] U16 {}

[Reset average] boolean {F/T}

#### Description

Configures a host-based running average of the lock-in data with a range given by [Running average range] data points. The actual running average range changes by 1 each data point, until it equals the set running average range. If [Reset average] is true, the [Running average range] is immediately set to 0 (no running average).

### 11.17.3 RangeCtrls

#### Control specifier

[Lockin] enum {Lockin L1, Lockin L2}

#### Control(s)

[Skip overloads] boolean {F/T}

[Skip range changes] boolean {F/T}

[Allow glitch] boolean {F/T}

#### Description

Configures to throw away data points if some input has overloaded or a range has changed. Reserved for future.

## 11.18 Scope

### 11.18.1 Scope settings

#### Control specifier

—

#### Control(s)

[Channels to return] cluster {A V1, ..., E V2, A Imeas, ..., E Imeas}

[Sampling reduction factor] U16 {1 ... 65535}

[#scope samples] enum {100, 1000, 10000, 100000}

[Average between samples] boolean {F/T}

[Return output instead of Imeas] boolean {F/T}

#### Description

Configures waveform sampling settings and selects waveforms that should be pushed to user. Activating average between samples will decrease noise, but may increase harmonic content. Activating Return output will return the set output signal rather than the measured current.

## 11.18.2 FFT settings

### Control specifier

—

### Control(s)

[Window] U8 / select values {Rectangle, Hanning, Hamming, ..., Gaussian}

[Average parameters] cluster {Mode, Weighting, Number of averages, Reset average}

[Average parameters:Mode] enum {No averaging, Vector averaging, RMS averaging, Peak hold}

[Average parameters:Weighting] enum {Linear, Exponential}

[Average parameters:Number of averages] U16 {}

[Average parameters:Reset average] boolean {F/T}

### Description

Configures the FFT settings.

## 11.19 Preferences

### 11.19.1 Load preferences

#### Control specifier

[Pref configuration] enum {Config 1, ..., Config 10}

#### Control(s)

[Load from default] boolean {F/T}

#### Description

Loads a stored state of the measurement system. This will replace all current settings in memory. The default configuration is loaded when the measurement system is powered on.

### 11.19.2 Save preferences

#### Control specifier

[Pref configuration] enum {Config 1, ..., Config 10}

#### Control(s)

[Save to default] boolean {F/T}

**Description**

Saves the state of the measurement system to a stored configuration. This will store all current settings to one of the pref configurations located on the measurement system. The default configuration is loaded when the measurement system is powered on.

# 12 Programmatic software access

## 12.1 LabVIEW library

The system can be fully controlled using the provided LabVIEW library "MCL.lvlib". The library and some sample code can be found in the LabVIEW project "UserProject.lvproj".

## 12.2 Python3 library

The system can be fully controlled using the Python3 library "MCLpy". The library and some sample code can be found on <https://github.com/synktek/MCLpy>. An example code can be found in the file "example.py". For access to the repository please contact the support.

## 12.3 Web API

### 12.3.1 General

The lock-in control and data can be accessed using the http-protocol under the URL `http://<IP>:8002/MCL/api`. Sets of data and configuration can be retrieved and set in XML-format while single parameters are accessed as plain text. The following parameters are supported:

#### **type**

Selects the type of the data. Possible values are "data" and "config". This parameter is compulsory.

#### **id**

Selects the set of data or configuration. Possible values are integer values or the name of the respective data set. If the parameter is not provided or empty, a list of possible parameters is provided. If necessary, spaces can be escaped with "\_", "+", or "%20".

#### **path**

Selects a specific value in the data set. If this parameter is provided, data is handled in plain text. For example, the grounding state of an input is set with the path parameter "InputCtrl/Input Setting/GND". The parameter is optional. If necessary, spaces can be escaped with "\_", "+", or "%20".



**action**

The default action is "get". With the value "set", non-readonly settings can be changed. The parameter is optional.

**value**

Provides the value to be set. The parameter is compulsory for action=set. Full datasets are provided in XML-format, single parameters as plain text.

**xsl**

Overrides the provided XSLT-sheet rendering the XML-response.

**12.3.2 Examples**

- retrieve full dataset of lock-in set 1:  
`http://<ip>:8002/MCL/api?type=data&id=L1`  
or  
`http://<ip>:8002/MCL/api?type=data&id=1`  
or  
`http://<ip>:8002/MCL/api?type=data&id=1&action=get`
- retrieve digital input frequency on module A:  
`http://<ip>:8002/MCL/api?type=data&id=1&path=outputcluster/GeneralReadings/Moduledata[2]/Module/Digitalinf(Hz)`  
A corresponding XPath expression on the full data set is  
`/*/Name[text()='outputcluster']/../*/Name[text()='GeneralReadings']/../*/Name[text()='Moduledata']/../*[2+3]/Name[text()='Module']/../*/Name[text()='Digitalinf(Hz)']/../Val/text()`
- retrieve the output current reading R on module A:  
`http://<ip>:8002/MCL/api?type=data&id=1&path=output_cluster/DataReadings/R[10]`  
A corresponding XPath expression on the full data set is  
`/*/Name[text()='outputcluster']/../*/Name[text()='DataReadings']/../*/Name[text()='R']/../*[10+3]/Val/text()`
- unground input A1:  
`http://<ip>:8002/MCL/api?type=config&id=8&action=set&path=InputCtrl/Input_Setting/GND&value=0`

### 12.3.3 Python example

```
import urllib.request
content=urllib.request.urlopen("<ip>:8002/MCL/api?type=config&id
=Freq_1").read()
print(content)
```

### 12.3.4 Config IDs and strings

id	name	Description
0	Config_L1	<a href="#">Lock-in host config settings</a>
1	Config_L2	...
2	RunningAvg_L1	<a href="#">Running average settings</a>
3	RunningAvg_L2	...
4	Range_L1	<a href="#">Range control settings</a>
5	Range_L2	...
6	Lockin_L1	<a href="#">Lock-in settings</a>
7	Lockin_L2	...
8	Input_A1	<a href="#">Input settings</a>
9	Input_A2	...
10	Input_B1	...
11	Input_B2	...
12	Input_C1	...
13	Input_C2	...
14	Input_D1	...
15	Input_D2	...
16	Input_E1	...
17	Input_E2	...
18	Output_A	<a href="#">Output settings</a>
19	Output_B	...
20	Output_C	...
21	Output_D	...
22	Output_E	...
23	General	General control
24	Calib_A1	<a href="#">Input calibration settings</a>
25	Calib_A2	...
26	Calib_B1	...
27	Calib_B2	...
28	Calib_C1	...
29	Calib_C2	...
30	Calib_D1	...
31	Calib_D2	...
32	Calib_E1	...
33	Calib_E2	...
34	Freq_1	<a href="#">Frequency settings</a>
35	Freq_2	...
36	Freq_3	...
37	Freq_4	...
38	Freq_5	...
39	Freq_6_PLL1	...
40	Freq_7_PLL2	...

id	name	Description
41	Freq_8_composite1	...
42	PLL_1	<a href="#">Phase-locked loop (PLL) settings</a>
43	PLL_2	...
44	GeneralLocal	Reserved for user app
45	PowerDiagnostics	System power supply readings
46	CurrCalib_A	<a href="#">Current calibration settings</a>
47	CurrCalib_B	...
48	CurrCalib_C	...
49	CurrCalib_D	...
50	CurrCalib_E	...
51	OutputState_A	<a href="#">Output current state and range indicator</a>
52	OutputState_B	...
53	OutputState_C	...
54	OutputState_D	...
55	OutputState_E	...
56	InputState_A1	<a href="#">Input preamp state and range indicator</a>
57	InputState_A2	...
58	InputState_B1	...
59	InputState_B2	...
60	InputState_C1	...
61	InputState_C2	...
62	InputState_D1	...
63	InputState_D2	...
64	InputState_E1	...
65	InputState_E2	...
66	Offset_1	<a href="#">Offset settings</a>
67	Offset_2	...
68	Offset_3	...
69	Offset_4	...
70	Offset_5	...
71	Offset_6_Feed1	...
72	Offset_7_Feed2	...
73	Feedback_1	<a href="#">Feedback settings</a>
74	Feedback_2	...
75	Amplitude_1	<a href="#">Amplitude settings</a>
76	Amplitude_2	...
77	Amplitude_3	...
78	Amplitude_4	...
79	Amplitude_5	...
80	Function_1	<a href="#">Function settings</a>
81	Function_2	...
82	Function_3	...
83	Function_4	...
84	Function_5	...
85	Function_6	...
86	Function_7	...
87	Function_8	...
88	Function_9	...
89	Function_10	...
90	PhaseShift_1	<a href="#">Phase shift settings</a>
91	PhaseShift_2	...
92	PhaseShift_3	...

id	name	Description
93	PhaseShift_4	...
94	PhaseShift_5	...
95	PhaseShift_6	...
96	PhaseShift_7	...
97	PhaseShift_8	...
98	DutyCycle_1	<a href="#">Duty cycle settings</a>
99	DutyCycle_2	...
100	DutyCycle_3	...
101	DutyCycle_4	...
102	DutyCycle_5	...
103	DutyCycle_6	...
104	DutyCycle_7	...
105	DutyCycle_8	...
106	Scope	<a href="#">Scope settings</a>
107	MultiHarm_L1	<a href="#">Multiple harmonics mode settings</a>
108	MultiHarm_L2	...
109	Timing	<a href="#">System timing calibration settings</a>
110	Composite_1	<a href="#">Composite frequency settings</a>
111	FrequencyCal_A1	Frequency calibration
112	FrequencyCal_A2	...
113	FrequencyCal_B1	...
114	FrequencyCal_B2	...
115	FrequencyCal_C1	...
116	FrequencyCal_C2	...
117	FrequencyCal_D1	...
118	FrequencyCal_D2	...
119	FrequencyCal_E1	...
120	FrequencyCal_E2	...
121	FrequencyCal_Imeas_A	Frequency calibration for current measurement
122	FrequencyCal_Imeas_B	...
123	FrequencyCal_Imeas_C	...
124	FrequencyCal_Imeas_D	...
125	FrequencyCal_Imeas_E	...
126	ModuleInfo_A	Module hardware information
127	ModuleInfo_B	...
128	ModuleInfo_C	...
129	ModuleInfo_D	...
130	ModuleInfo_E	...
131	OutputCal_A	Output calibration
132	OutputCal_B	...
133	OutputCal_C	...
134	OutputCal_D	...
135	OutputCal_E	...
136	FFT	<a href="#">FFT settings</a>

## 13 Calibration

The modules are factory calibrated. Under normal conditions it should be enough for the user to recalibrate offsets if environmental conditions have changed. The modules can, however, be partly re-calibrated by the user, using a semi-automatic calibration routine. A high-precision resistor (10 k $\Omega$ , 0.01%) is needed for current measurement gain calibration. Factory calibration values will be loaded at start. User calibration needs to be loaded after start.

### 13.1 Calibration parameters

The calibration parameters for each module include:

- Input offset voltage (for 12 gains x 2 inputs)
- Input gain correction factor (for 12 gains x 2 inputs)
- Current measurement offset (for 20 gains x 1 output)
- Current measurement gain correction factor (for 20 gains x 1 output)
- Output offset voltage (for 3 output ranges x 1 output)
- Output gain correction (for 3 output ranges x 1 output)

### 13.2 Hardware requirements

For a full calibration, a low-frequency (1-10 Hz), precision ac voltage source is needed. The low-noise (pair 3) output voltage of a functioning module can be used as such a voltage source for user calibration. A high-precision (0.01%) 10 k $\Omega$  resistor is needed for calibration of the current measurement gains.

### 13.3 Calibration order

The calibration should be performed in the following order:

1. Input offsets
2. Current measurement offsets
3. Output offsets

4. Input gains 1 through 10
5. Output gains for 10 V and 1.0 V ranges
6. Input gains 20 through 200
7. Output gain for 0.1 V range
8. Input gains 500 through 5000
9. Current measurement gains

## **13.4 Calibration routine**

### **13.4.1 Input offset calibration**

The input offset is calibrated by setting the input to ground and reading the dc offset of the input.

### **13.4.2 Current measurement offset calibration**

The current measurement offset is calibrated by disconnecting any cabling and reading the current measurement dc offset.

### **13.4.3 Output offset calibration**

The normal output offset (pair 4) is calibrated by connecting the normal output (pair 4) to an input. The input should be ungrounded and in auto-range. The output offset is adjusted to read zero dc input voltage. Note that the low-noise output (pair 3) cannot be calibrated independently from the normal output (pair 4).

### **13.4.4 Input gain 1 through 10 calibration**

The input gain is calibrated by connecting the external voltage reference or the low-noise (pair 3) output to the input set at gain 1 (not auto-ranging). If the module output is used for input calibration, the 10 V range output gain correction is assumed to be 1. This should be verified or adjusted. Any uncalibrated deviations from 1 will give a corresponding overall gain error. The output frequency is set to 1 Hz. Adjust gain correction factor using the input R reading.

- Gain 1: Use 5Vrms output.
- Gain 2: Use 2.5 Vrms output.
- Gain 5: Use 1 Vrms output.
- Gain 10: Use 0.5 Vrms output.

### **13.4.5 Output gain calibration 10 V, 1.0V ranges**

The normal (pair 4) output is connected to the input. Adjust the output gain.

- 10 V range: Use 5 Vrms output and input gain 1.
- 1 V range: Use 0.5 Vrms output and input gain 10.

Note that the 10 V output gain correction should be set to 1 before the input gain is calibrated if the low-noise module output (pair 3) is used for input calibration. The parameter could change here, but should be reset to 1 again whenever the low-noise (pair 3) is used for calibration.

### **13.4.6 Input gain 20 through 200 calibration**

Use 1.0 V output range. Connect the normal output (pair 4) to the input with fixed gain. Adjust input gain correction.

- Gain 20: Use 0.25 Vrms output.
- Gain 40: Use 0.125 Vrms output.
- Gain 100: Use 0.05 Vrms output.
- Gain 200: Use 0.025 Vrms output.

### **13.4.7 Output gain calibration 0.1V range**

Adjust the output gain.

- 0.1 V range: Use 0.05 Vrms output and input gain 100.

### **13.4.8 Input gain 500 through 5000 calibration**

Use 0.1 V output range. Connect the normal output (pair 4) to the input with fixed gain. Adjust input gain correction.

- Gain 500: Use 0.010 Vrms output.
- Gain 1000: Use 0.005 Vrms output.
- Gain 2500: Use 0.002 Vrms output.
- Gain 5000: Use 0.001 Vrms output.

### **13.4.9 Current measurement gain calibration**

Connect a 10 k $\Omega$  precision resistor to input 1 and to the normal output (pair 4). Set input to auto-range. Set the output frequency to 1 Hz. Measure the ratio of the R readings for input 1

and current, representing the measured resistance. Adjust current measurement gain correction to give 10 k $\Omega$  reading.

- 5 mA: Use 10V output range, 5 Vrms output. Apply the same calibration correction to ranges 50 mA, 25 mA, 10 mA
- 1 mA: Use 10V output range, 5 Vrms output. Apply the same calibration correction to ranges 2 mA, 0.4 mA, 0.2 mA
- 100  $\mu$ A: Use 1.0 V output range, 0.5 Vrms output. Apply the same calibration correction to ranges 50  $\mu$ A, 20  $\mu$ A, 10  $\mu$ A
- 5  $\mu$ A: Use 0.1 V output range, 0.025 Vrms output. Apply the same calibration correction to ranges 2.5  $\mu$ A, 1  $\mu$ A, 0.5  $\mu$ A
- 0.25  $\mu$ A: Use 0.1 V output range, 0.002 Vrms output. Apply the same calibration correction to ranges 125 nA, 50 nA, 25 nA

Note: For each range of gains, the correction due to the subsequent 1-2-5-10 amplifier should be within calibration resolution. The highest and lowest current ranges (50 mA through 5 mA and 125 nA through 25 nA) are calibrated at a relatively low signal level. The signal level could be increased by using a different precision resistor during calibration of these ranges, but getting one and the same resistance reading for different current ranges is usually preferred rather than getting a somewhat better absolute accuracy at the highest and lowest currents.



# 14 Specifications

## 14.1 Technical data

- Weight:
  - Chassis: 2.3 kg
  - Module: 85 g
- Dimensions:
  - Chassis: 482 mm x 256 mm x 42 mm
  - Module: 152 mm x 78 mm x 23 mm
- Mains operating voltage:
  - 100-240 VAC, 50-60 Hz
  - 0.9 A max, 0.860 A typ at  $V_{in} = 115 \text{ Vac}$ , 0.460 A at  $V_{in} = 230 \text{ Vac}$
  - fuse: T1AL 250VAC

## 14.2 Environmental

- indoor use only
- Temperature: 15°C to 35°C
- Humidity: maximum relative humidity 80% for temperatures up to 31°C decreasing linearly to 50% relative humidity at 40°C;
- Operation altitude: 0-2000 m
- Pollution environment: Pollution Degree 2 (IEC 61010-1)
- Ingress Protection: IP30 (IEC 60529)

## 14.3 Module specification

Note: Specifications are subject to change without notice due to design improvement.

### 14.3.1 Analog input

Parameter	condition	Unit	MCL1M- 112-1.8	MCL1M- 112-4	MCL1M- 112-18
input voltage noise	> 10 Hz	nV/ $\sqrt{\text{Hz}}$	< 1.8	< 4	< 18
input current noise	1 kHz	pA/ $\sqrt{\text{Hz}}$	< 20		
input impedance	dc coupling	G $\Omega$	1	30	~1000
	ac coupling, $V_{\text{CM}}=0$	$\mu\text{F}+\text{k}\Omega$	47 + 27	10 + 232	10 + 232
input bias current	typ	nA	15	0.1	0.01
	max	nA	150	6	0.3
input offset current	typ	nA	0.5	0.1	0.0006
	max	nA	< 30	< 0.8	< 0.005
DC offset stability	$G \geq 500$	$\mu\text{V}/^\circ\text{C}$	~0.5	~0.2	~5
DC offset, uncalibrated	$G \geq 500$	$\mu\text{V}$	<50	<45	<125
input coupling	-	-	DC, AC		
AC coupling frequency cutoff	-5%	Hz	~0.5	~0.2	~0.2
Analog bandwidth	$G \leq 200, \pm 5\%$	kHz	> 300	> 300	> 50
Analog bandwidth	$G \geq 500, \pm 5\%$	kHz	> 100	> 100	> 10
ADC resolution	-	bit	18		
ADC sampling speed	-	MSPS	1		
full scale	$V_{\text{CM}}=0$	V	$\pm 10$		
CMRR	dc coupling, $G = 5000,$ $f = 10 \text{ Hz}$	dB	~140		
	ac coupling, $G = 5000,$ $f = 10 \text{ Hz}$	dB	~80		
	ac coupling, $G = 5000,$ $f = 1 \text{ kHz}$	dB	~100		
	separation from output				
channel separation	$G = 1, f < 10\text{kHz}$	dB	~150		
	$G = 1, f = 10 \text{ kHz}-100$ kHz	dB	120		
	$G = 5000$	dB	~180		
	$G = 1, f < 10\text{kHz}$	dB			
	$G = 1, f = 10 \text{ kHz}-100$ kHz	dB			
	$G = 5000$	dB			

### 14.3.2 Analog output

Parameter	condition	Unit	MCL1M-112-1.8, -4, -18
output	signal pair 3	-	ground referenced
	signal pair 4	-	floating
DAC resolution	-	bit	20
DAC sampling speed	-	MSPS	1.33
Analog bandwidth	signal pair 3, $\pm 5\%$	kHz	$\sim 110$
	signal pair 4, $\geq 10\mu\text{A}$ , $\pm 5\%$	kHz	$\sim 90$
	signal pair 4, $0.5\text{-}5\mu\text{A}$ , $\pm 5\%$	kHz	$> 5$
	signal pair 4, $\leq 0.25\mu\text{A}$ , $\pm 5\%$	kHz	$> 0.25$
full scale	-	V	$\pm 10$
max current	-	mA	$\pm 50$
output ranges	-	V	$\pm 10, \pm 1, \pm 0.1$
typ output noise floor	$\pm 10\text{ V}$ , 100 Hz-500 kHz	nV/ $\sqrt{\text{Hz}}$	60
	$\pm 0.1\text{ V}$ , 100 Hz-500 kHz, pair 3	nV/ $\sqrt{\text{Hz}}$	$< 5$
	$\pm 0.1\text{ V}$ , 100 Hz-500 kHz, pair 4	nV/ $\sqrt{\text{Hz}}$	$\sim 30$
typ output capacitance current measurement	-	pF	$< 10$
typ output impedance	signal pair 3	$\Omega$	$< 1$
	signal pair 4, $\geq 5\text{ mA}$ range	$\Omega$	$\sim 20$
	signal pair 4 $\leq 2\text{ mA}$ range	$\Omega$	$\sim 50$

### 14.3.3 Current measurement

Parameter	condition	Unit	MCL1M-112-1.8, -4, -18
ADC resolution	-	bit	18
ADC sampling speed	-	MSPS	1
shunt ammeter resistance	-	$\Omega$	10
shunt ammeter full scales	$R_f = 10\ \Omega$ , $f < 100\text{ kHz}$	mA	$\pm 50, \pm 25, \pm 10, \pm 5$
feedback ammeter transimpedance	-	$\Omega$	2 M / 100 k / 5 k / 250
feedback ammeter full scales	$R_f = 250\ \Omega$ , $f < 90\text{ kHz}$	mA	$\pm 2, \pm 1, \pm 0.5, \pm 0.2$
	$R_f = 5\text{ k}\Omega$ , $f < 90\text{ kHz}$	$\mu\text{A}$	$\pm 100, \pm 50, \pm 20, \pm 10$
	$R_f = 100\text{ k}\Omega$ , $f < 5\text{ kHz}$	$\mu\text{A}$	$\pm 5, \pm 2.5, \pm 1, \pm 0.5$
	$R_f = 2\text{ M}\Omega$ , $f < 0.25\text{ kHz}$	nA	$\pm 250, \pm 125, \pm 50, \pm 25$
Analog bandwidth	-	-	see analog output signal pair 4

### 14.3.4 Digital Input/Output

Parameter	condition	Unit	MCL1M-112-1.8, -4, -18
Input voltage	-	V	0 - 5
Output voltage	-	V	0 - 5 or 3.3

## **14.4 Guarantee conditions and legal requirements**

- The manufacturer is not responsible for accidents or faults caused by improper use of the system or parts of it.
- The guarantee period is 12 months after delivery on parts and labor on defects in materials and workmanship unless otherwise specified.