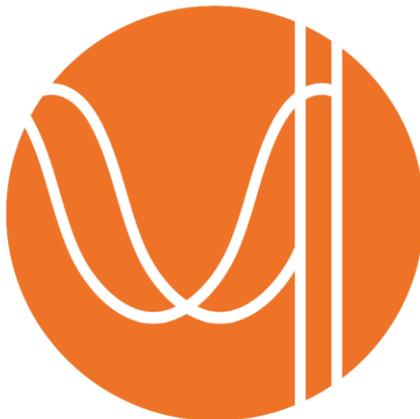


USER MANUAL

DELTA SENS





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### 3. Technical specifications

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## REVISION HISTORY

Version 0.1	Created February 1, 2018	A. Sielecki	New document
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Version 1.1	Updated March 11, 2019	N. Piva	Update
Version 1.2	Updated May 16, 2019	N. Piva	Update

# SAFETY

The DeltaSens interrogator is equipped with a class 1M laser device. The infrared laser light is coupled out via the optical fiber connector on the front panel. Do not stare into the laser beam or view it directly with optical instruments.



Before applying power to the instrument make sure that the voltage rating displayed next to the fuse port matches the voltage of your local supply. If not, the installed fuses need to be replaced by the user.



Except for the mains fuses, there are no user serviceable parts in this product.

All statements regarding safety of operation and technical data in this instruction manual will only apply when the unit is operated correctly.

The unit is equipped with a cord having an equipment-grounding conductor and grounding plug. Before applying power to the instrument make sure that the plug is connected into a properly installed and grounded outlet. Improper grounding can cause electric shock with damages to your health or even death. The instrument must not be operated in explosion-endangered environments.

Do not remove covers.

Refer servicing to qualified personnel only.

Do not obstruct the ventilation vents of the unit.



# INTRODUCTION

This document describes the DeltaSens system installation and usage. The first section describes system connections and installation, together with a brief introduction to the software and its first configuration steps. The second section includes a more detailed description of the software and all its functionalities. In the third section a brief overview of the capabilities of the system and its working principle are presented. The last section includes the technical specifications of the instrument.

# 1. INSTALLATION

This section describes the installation of the DeltaSens system. It provides an overview of the DeltaSens elements, wiring scheme and actions required to start up and configure the DeltaSens interrogator unit.

## 1.1. DeltaSens system overview

The central element of the DeltaSens system is the interrogator unit. It acquires the optical signal from the array of sensors, processes it and provides the user with both analog and digital outputs to analyze it. To configure the interrogator and setup the measurement parameters, the unit needs to be connected to a computer with the DeltaSens software installed on it.

### 1.1.1. DeltaSens operating principle

DeltaSens is a stand-alone system that simultaneously interrogates multiple Fabry-Pérot (FP) sensors connected through an optical fiber network. By using a single read-out to measure multiple transducers, DeltaSens provides a cost-effective sensing solution without compromising on performances. The distance between the sensors and the read-out can vary from centimeters up to several kilometers.

DeltaSens uses interferometry to measure multiple low-finesse Fabry-Pérot sensors, and therefore provides a reduced cost per sensor while maintaining high sensitivity and acquisition speed. In combination with Optics11 fiber-top technology, it can support the measurement of a broad range of physical parameters such as acceleration, pressure or temperature.

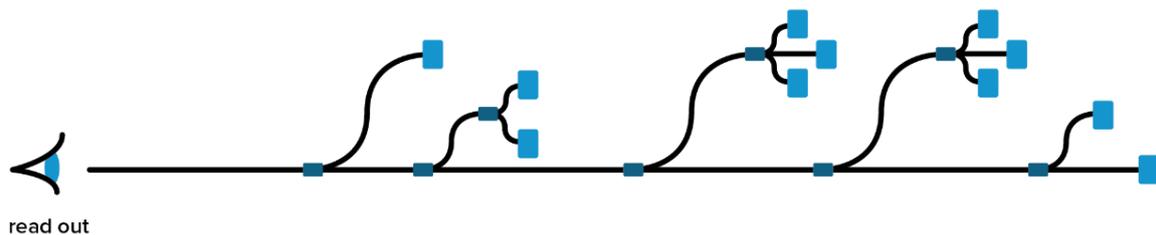


Figure 1: General schematic of operation



## 1.1.2. Connections

The DeltaSens unit houses an optical fiber connector on the front panel and several electrical connectors on the rear panel. The front panel connector is a FC/APC socket used to connect the sensing fiber. To connect multiple sensors to a single interrogator unit, one or more fiber splitters might be needed depending on the use case. The front and rear panels of the unit are presented in Figure 2.

The rear panel houses the following connectors:

- Power inlet with fuse port (note that to power the unit with 115 V AC, the fuses must be changed from 0.8 A to 1.6 A and the fuse holder should be reversed.)
- RJ-45 Ethernet port for computer connection.
- USB type A port for debug connection.
- RS232 port for debug connection.
- 8 BNC connectors for analog outputs.
- 3 BNC connectors for external clock and trigger.
- DB-9 connector for 4 additional analog outputs.

The device must be connected to the power supply with the provided power cable and to a computer or LAN with the provided Ethernet cable or equivalent ones.

The sensors can be connected to the front FC/APC port using compatible FC/APC fiber connectors. Both the interrogator FC/APC port and the sensor FC/APC connectors should be kept as clean as possible and protected with the provided protective cap when not connected. A periodic cleaning of the FC/APC connectors is required to ensure proper operation of the system. It is recommended to use tailored cleaning products such as fiber cleaning cloth spools.

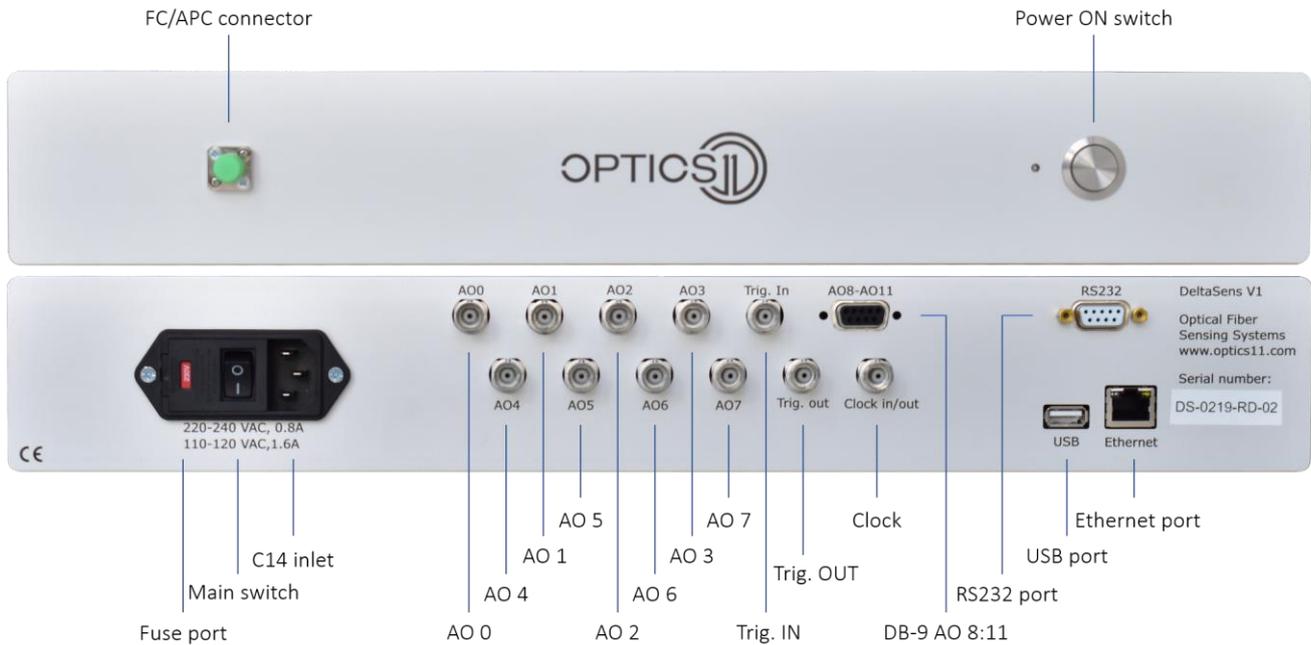


Figure 2: DeltaSens front and rear panels

The interrogator is a standalone device meaning it can operate without being connected to a computer. If not connected to a computer, the unit will operate according to the latest configurations set by the user. Such configurations can be edited only by connecting the unit to a computer with the DeltaSens software installed on it. The software also allows to control the measurement parameters, acquire and record signals and analyse them.

Before connecting the interrogator to the computer, please install the accompanying software and necessary drivers.

To configure the interrogator, connect it to the power supply and to the computer (or your LAN network) with the provided cables. After turning the device on, it will take it around 1 minute to boot and load the previous configurations. After booting, the device will start operating according to the latest configurations set via software by the user. It will acquire the signals and generate the digital and analog output signals according to the loaded settings. After booting, the device can be accessed via software to update and edit its configurations.

## 1.2. Starting the software

### 1.2.1. Setting the unit IP address

The device connects with the computer using the Ethernet protocol. It can be connected through LAN or directly to the operating PC. In both cases the IP address of the device must be looked up and set in the software to allow remote control of the unit. While booting, the software will look for the interrogator unit at the latest IP address set by the user. If no unit is found at that address, the “IP Discovery” tool will appear to help the user identifying the unit IP address (see Figure 3).

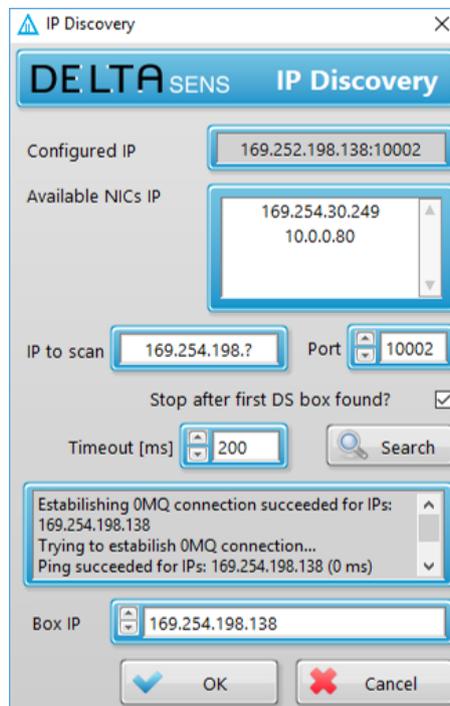


Figure 3: IP Discovery tool

- **Configured IP** – last IP address set by the user.
- **Available NICs IP** – interface controllers IPs available in the network.
- **IP to scan** – allows to specify the range of IP addresses to scan to search for the unit.
- **Port** – port used to try to ping with the unit, should be set to 10002 as default.
- **Timeout** – how long the software will wait for a response when pinging an IP address.
- **Box IP** – IP address at which the DeltaSens was found by the “Discovery Tool”.

Depending on how the unit is connected to the computer, its IP address might be assigned by the computer itself or by the LAN router:

- If the device is connected through LAN, you can limit the search to the IP addresses of your local network by setting the "IP to scan" field to 10.0.?.?
- If the device is connected directly to the computer running the DeltaSens software, limit the search to the internal IP addresses by setting the "IP to scan" field to 169.254.?.?

These are the most common subset of IP addresses to scan and they might vary depending on your local network settings.

By clicking on "Search" the tool will start scanning the range of IP addresses defined by the "IP to scan" field. This procedure might take some minutes. If the tool successfully locates the DeltaSens unit, the "Box IP" indicator will be updated with the discovered IP address. By clicking "OK" the user can exit the tool and store this address into the software settings and start interfacing with the unit.

The IP address used to communicate with the DeltaSens unit can also be set manually by accessing the "Dev. Mode" menu of the "Settings" panel. The user can manually enter the IP address and ports used to communicate with the DeltaSens unit under the "ZeroMQ" submenu (shown in Figure 4). The default ports are 10002 for cmd and 10003 for data. To save the changes click "Save" before quitting the menu. The lightning bolt indicator located on the right of the top bar indicates if the software is correctly interfacing with the DeltaSens unit. The indicator will turn yellow if everything is working correctly (see Figure 5) and grey in case of communication problems.

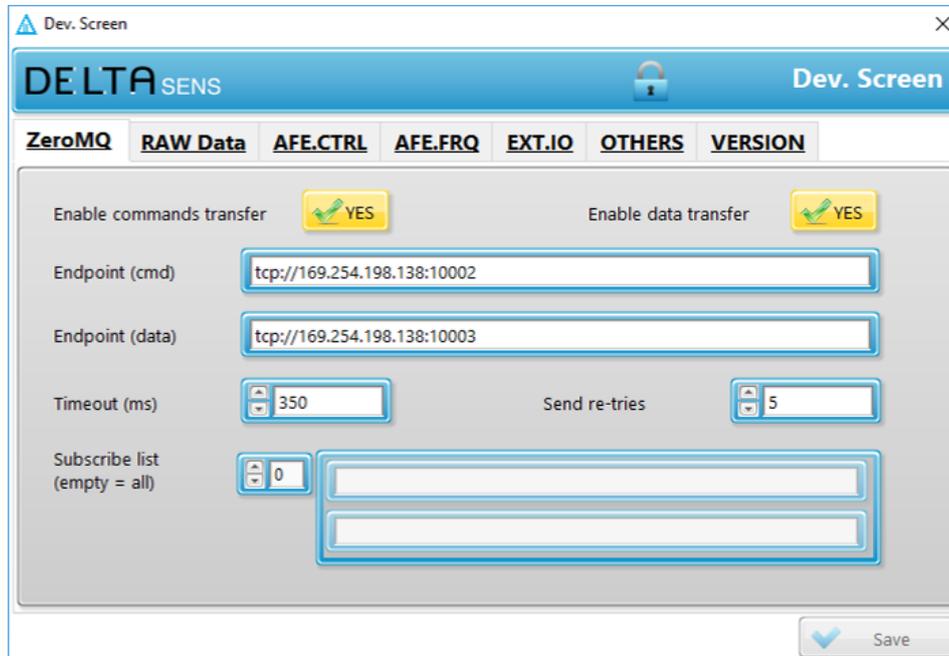


Figure 4: ZeroMQ configuration submenu



Figure 5: Connection lightning bolt indicator

## 1.2.2. Setting the SLD power

When a new sensor / network of sensors is connected to the unit, the output power of the Superluminescent Diode (SLD) and the conversion efficiency of the spectrometer must be tuned to ensure proper functioning of the system. The software integrates a tool to calculate and set the optimum levels of both these parameters. The Auto-power tool settings can be found under the "AFE.CTRL" submenu of the "Dev. Mode" menu. Make sure that the Auto-power is enabled as shown in Figure 6. The default settings are meant to ensure a fast and effective tuning and simplify the unit setup, refer to following section of these manual for a detailed description of them.

If enabled, the Auto-power tool will run automatically every time the user opens the "Sensors select" menu of the "Home" panel and clicks "OK". The "Sensors select" menu allows the user to define the sensors connected to the unit and edit their parameters to properly decode their signal. Before doing

this, the Auto-power tool must be run by opening the "Sensors select" menu and clicking OK. A popup window will appear to show the tuning progress and automatically close when the tuning is completed.

It is possible to check if the Auto-power tool correctly tuned the SLD power and the spectrometer conversion efficiency by analysing the live raw-data acquired by the spectrometer. These data can be displayed by opening the "RAW data" submenu of the "Dev. Mode" and clicking "Time domain". In case of proper tuning the raw signal should resemble the one shown in Figure 7. In case of multiple sensors connected to the unit, the raw-signal could slightly differ from the one here presented. However, the envelope shape and the maximum value of the signal should be comparable with the ones of Figure 7.

For experienced users, the SLD output power and the spectrometer conversion efficiency can also be set manually. To ensure proper operation of the system the user should tune these parameters in order to achieve a good Signal to Noise Ratio (SNR) while avoiding signal saturation. The following guidelines can help the user in performing such procedure manually:

- Remember to disable the "Auto-power" tool on the "AFE.CTRL" tab of the "Dev. Mode" menu before performing the following procedure.
- To display and keep track of the raw signal during the tuning process, open the "RAW data" submenu of the "Time domain" menu and click "Time domain".
- On the "Settings" panel the user can control the light output power. Under the "SLD (light source)" submenu set the source current to 600 mA and click save at the bottom right of the "Settings" panel.
- Now open the "AFE.CTRL" tab of the "Dev. Mode" to set the conversion efficiency of the spectrometer. Find the minimum value of conversion efficiency for which the raw signal still saturates. Remember to click "Save" to update the spectrometer settings.
- Now the SLD source current must be lowered in order to achieve a good signal level and avoid saturation. The "SLD (light source)" submenu of the "Settings" panel allows to display the maximum of the raw signal spectrum while tuning the SLD source current. Enable the "Display max" option to display the level at which the signal is saturating on the "Spectrum max" indicator.
- Tune down the SLD power in order to reach a "Spectrum max" level of around 80% of the saturation value. Remember to click "Save" on the bottom right of the "Settings" panel for changes to take place every time you enter a new SLD source current value.



Figure 6: AFE.CTRL submenu

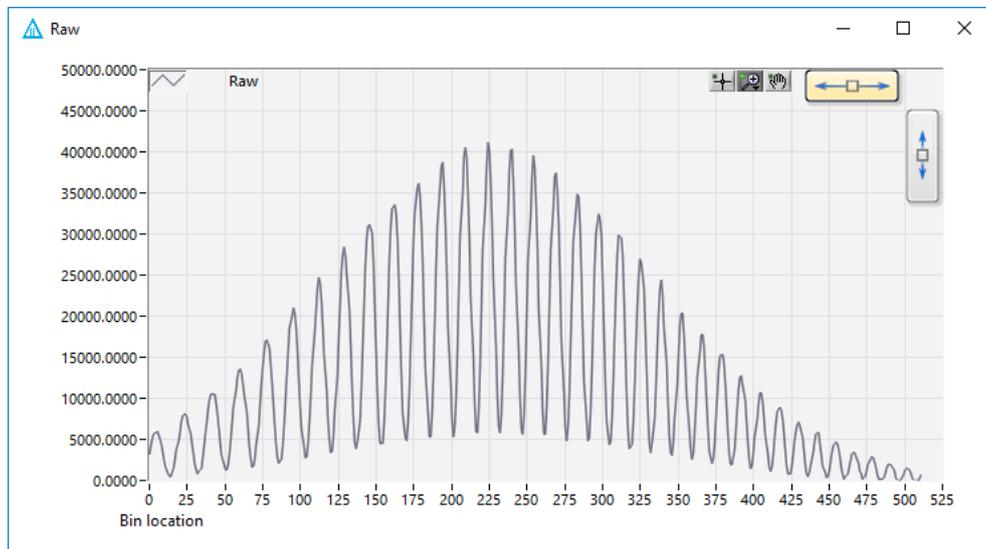


Figure 7: Raw time domain signal

### 1.2.3. Define sensors

The last step required to start measuring and acquiring data with the DeltaSens system is the definition of the sensors connected to the unit. To properly demodulate their signals, it is necessary to define each sensor and set its cavity size on the "Sensors Select" menu of the "Home" panel. If the interrogator is delivered together with a set of sensors, their settings will be already stored into the unit. If this is not the case, the following instructions shows how to define manually a set of sensors and decide what sensors signals the unit should decode. Open the "Sensors select" menu of the "Home" panel as shown in Figure 8.

- Click "Add" on the bottom left corner of the menu to open the "Sensor Add" window as shown in Figure 8 b). This popup window allows to define a new sensor connected to the unit.
- Fill the following fields:
  - **Name** – custom name of the sensor.
  - **Signal** – should be set to Relative as default.
  - **Gain** – scaling value used to convert the sensor cavity length into the measured physical quantity. This value can be found in the datasheet accompanying the sensor and it is assessed during the sensor calibration.
  - **Offset** – should be set to 0 as default.
  - **Phase IPM** – defines range and resolution of the sensor. It should be kept at 0 by default, more detailed description is provided in section 1.6.
  - **Type** – informative description of the sensor.
  - **Unit** – unit of measurement to display in the graphs of the demodulated signal (e.g. "g" for accelerometers)
- To save the changes and add the new sensor to the list click "OK". The new sensor will be now displayed in the list with a default cavity size of 0.
- To decode the signal of the new sensor its cavity size must be set. Double click on the sensor name to extend the "Sensor select" window as shown in Figure 8 c).
- Each peak of the graph displayed in the extended window corresponds to a sensor connected to the unit. Refer to the cavity size value provided in the sensor datasheet to locate the peak corresponding to your sensors.
- To select the sensor cavity size, use the cursor to move the yellow line indicator over this peak as shown in Figure 8 c). Click "Confirm" at the bottom right of the window to save the changes.
- The thick-boxes on the left of each sensor name, allow the user to select of what sensors the unit should acquire the signal. To add the new sensor to the acquired ones, thick the corresponding box.

- Click "OK" to close the window and save the changes.

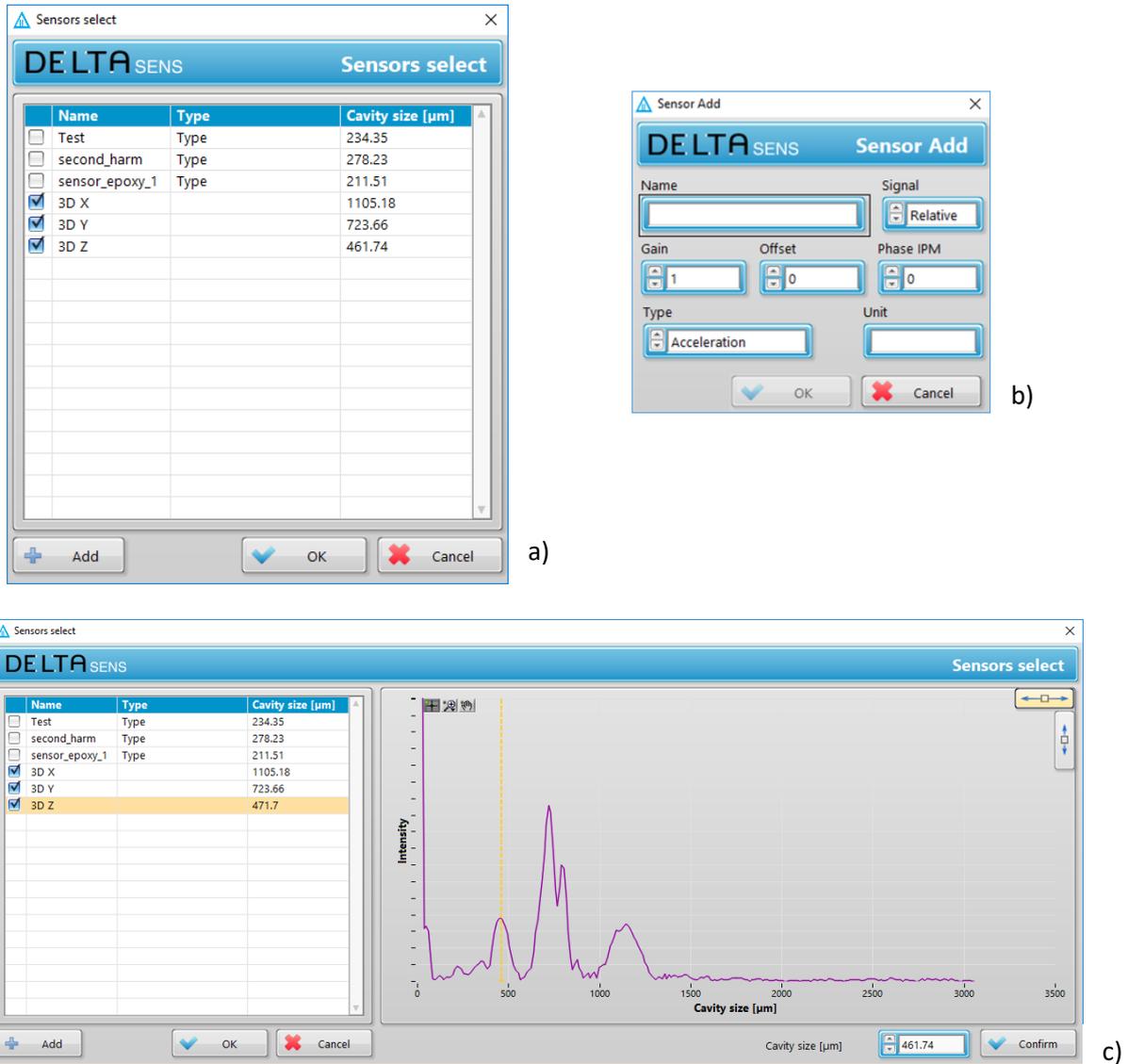


Figure 8: Sensor select and Sensor add windows

The sensor signal can be displayed by clicking the "Add graph" button on the right side of the "Home" panel and by selecting the sensor from the mouse-over menu on the left side of the graph.

A more detailed description of the software and its features is provided in the next section of this manual.

# DESCRIPTION OF THE SOFTWARE

## 1.3. Home panel

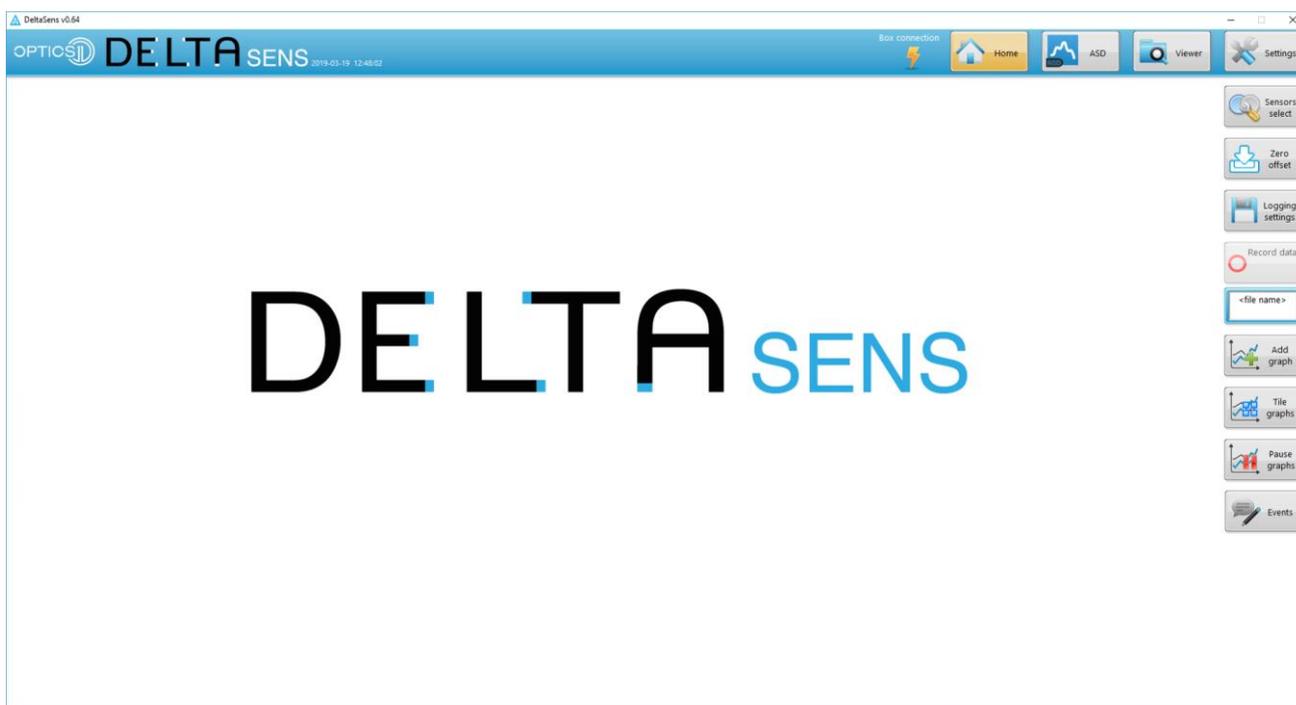


Figure 9: DeltaSens Home panel

Figure 9 presents the DeltaSens software “Home” panel. On the top bar there are 4 buttons to browse through the four main panel of the software: Home, Amplitude Spectral Density (ASD), Data Viewer and Settings. On their left is located a lightning bolt indicator, which lights up in yellow when the software is properly connected with the DeltaSens interrogator. On the right are located several action buttons:

- **Sensor select** – opens a window that allows to define and select sensors, edit their parameters, and visualize the spectral signal to choose the proper cavity length of each one. It is described more in detail in section 1.5
- **Zero offset** – in case of strong solicitation of the sensor (out of the dynamic range) the DeltaSens decoding system could reinitiate the signal acquisition with an unwanted offset. This action button allows the user to reset such offset to zero.

- **Logging settings** – opens a window that allow the user to set data logging preferences such as file location and acquisition length. It is described more in detail in section 1.5.
- **Record data** – allows the user to launch the data acquisition. From the moment this action button is activated the program will follow the settings specified in the “Logging settings” menu and record the signals acquired by the unit.
- **File name** – allows the user to specify a name for the recorded data to save. This name will be concatenated with a time stamp indicating the date and time of the acquisition.
- **Add graph** – allows to add a new graph to the Home and ALD panels. The software can display up to 12 graphs at the same time and each graph can display all the currently demodulated sensors or part of them depending on the user needs.
- **Tile graphs** – automatically arranges the currently displayed graphs in a default tile pattern.
- **Pause graphs** – freeze the graphs to allow the user to zoom and look into the data. This action button does not stop the signal acquisition and data logging which will continue in background. By unpausing, the graphs will update to their current state.
- **Events** – opens the events log window which lists any command sent to the box as well as warnings and errors. If there is any warning listed in the log flow, the “Event” button will turn orange and red in case of an error.

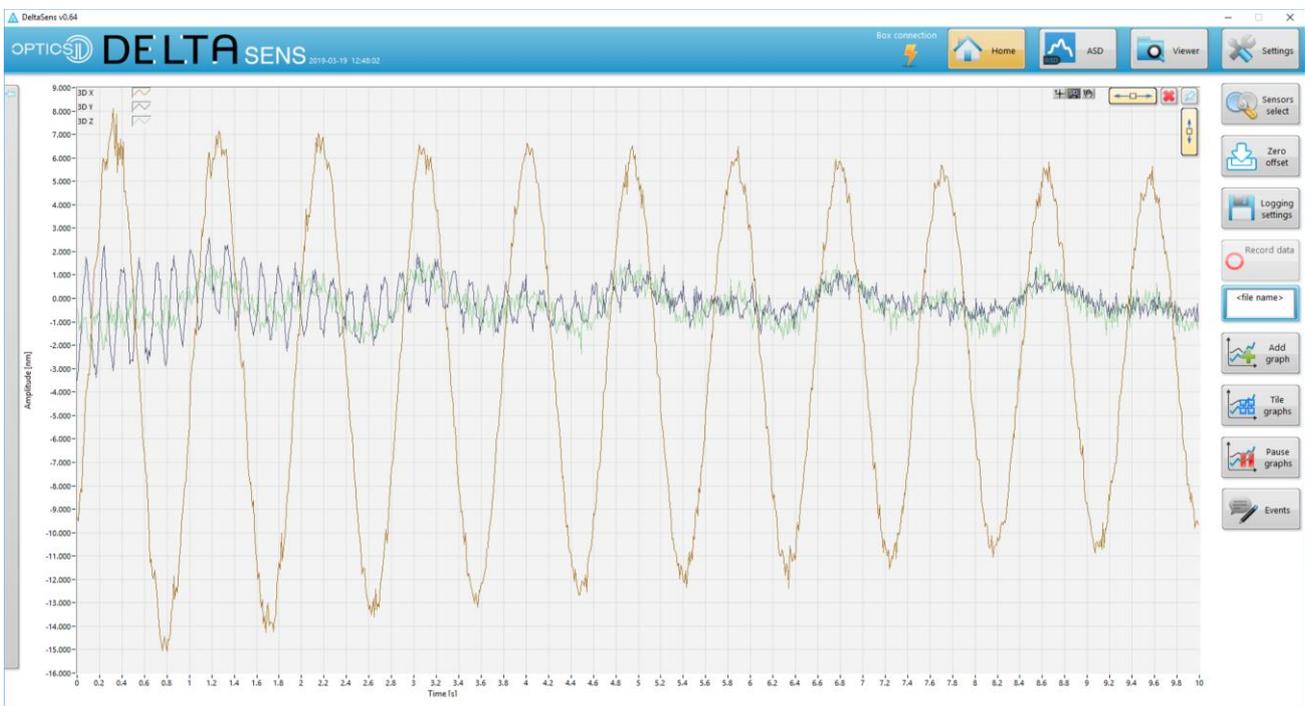


Figure 10: Home panel displaying a graph

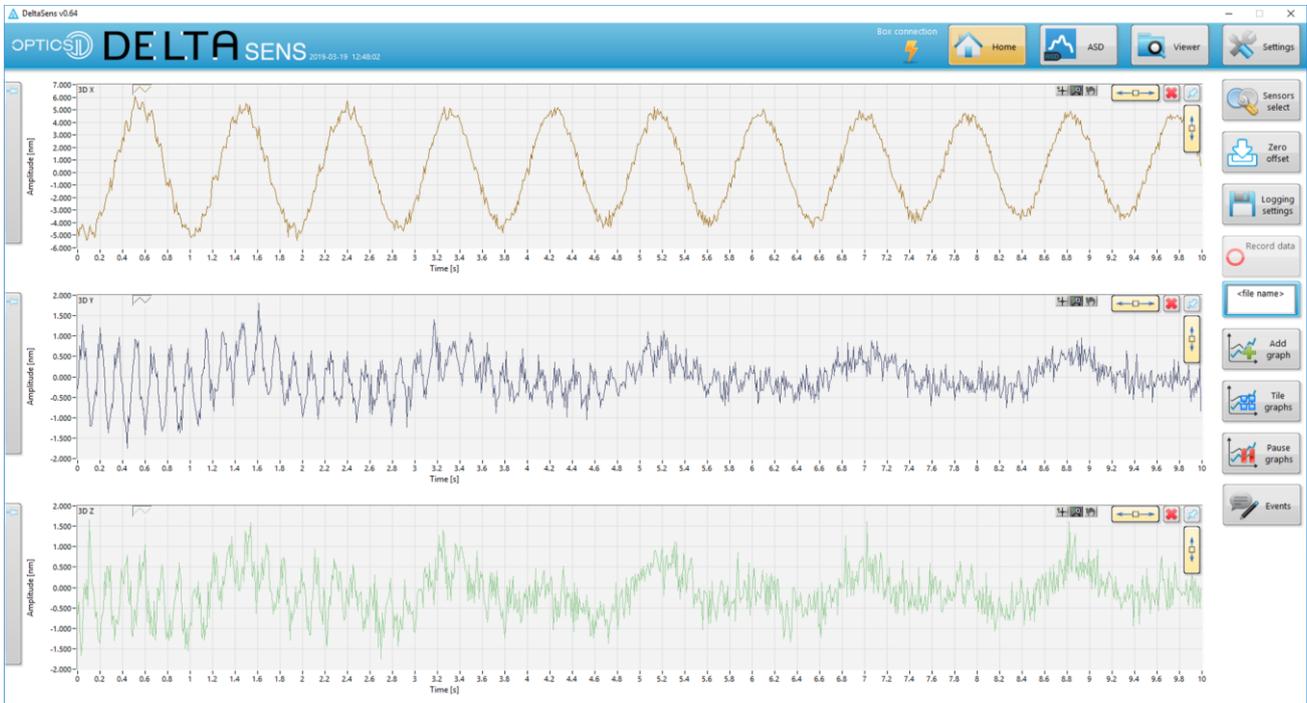


Figure 11: Home panel displaying multiple graphs

In Figure 11 is shown a typical use case of the software. The system is acquiring signals from 3 different sensors and displaying them in three different graphs on the “Home” panel. It is possible to select what signals to display on a graph by selecting the desired sensors from the mouse-over menu on the left side of each graph as shown in Figure 13.

When created, the graphs are automatically arranged by the software in a tile pattern (3 x 1 in this case). On the top right of each graph the user can find several control buttons:

-  Allows the user to unpin the graph from the Home / ALD panel and to manipulate it.
-  Allows the user to close a specific graph.
-  Allows the user to activate the auto-scale of each axis.
-  Allows to browse the graph data by zooming, panning and rescaling it.

The graph axes range can also be fixed manually by typing the desired maximum value at the end of the axis scale. In this case the auto-scaling option will turn off automatically.



The mouse-over menu allows also to apply a filter to the displayed signals. The filtering settings are located on the bottom of the mouse-over menu and can be set independently for each displayed signal of each graph. The available settings are:

- **Filter topology** – allows the user to turn ON and OFF the filtering and to select the optimum filter band-form.
- **Filter type** – allows to select the filter type between Low-pass, High-pass, Band-pass, Band-stop.
- **Order** – allows to control the filter order. Higher values of filter order will result in a filter approaching an ideal behaviour.
- **Cut-off frequencies** – controls the cut-off frequencies of the filter. If the “Filter type” is set to “High-pass” or “Low-pass” the second frequency control is automatically disabled and greyed out.

As mentioned before, note that each signal of each graph can be filtered independently. This allows for example to display at the same time in two different graphs the pristine and the filtered signals of a specific sensor. When a filter is applied to a sensor, a string indicator “(S fil)” will appear on the right of the sensor name on the mouse-over menu.

Note that the filters are applied only to the signal displayed by the software. The signals recorded into files and the analog outputs ones are always pristine signals.

## 1.4. Amplitude Spectral Distribution panel

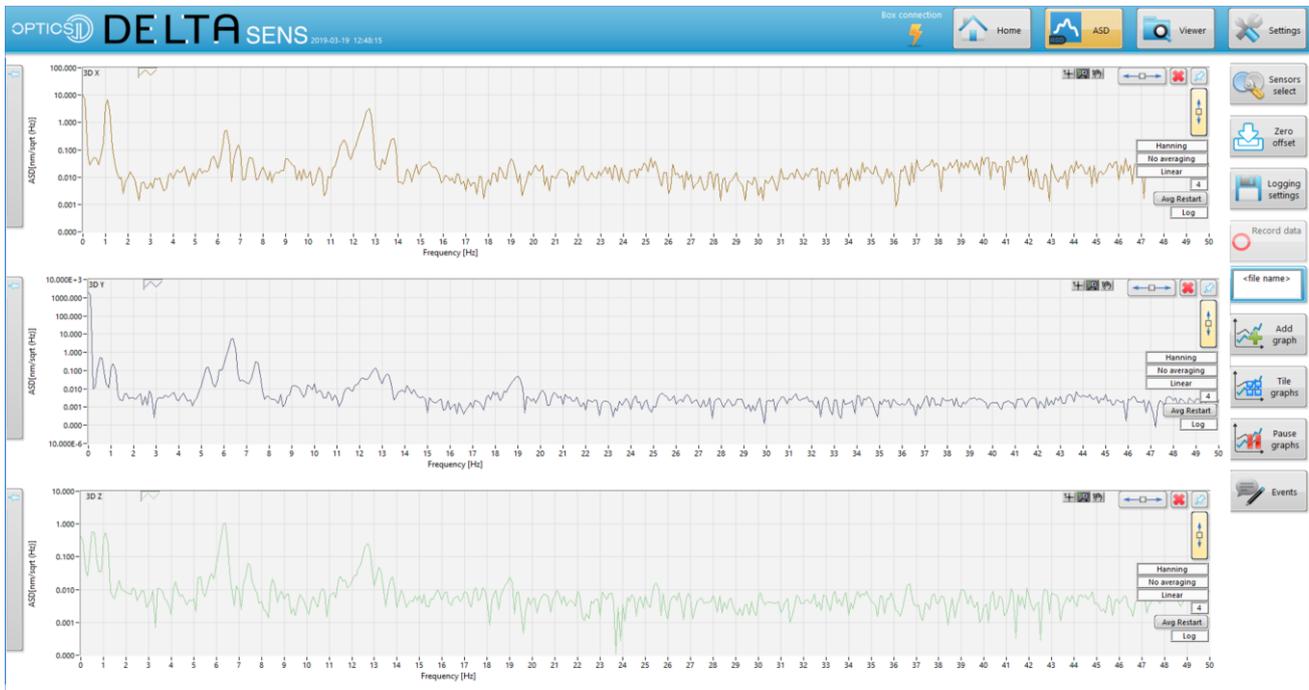


Figure 12: ASD panel displaying multiple graphs

The “ASD” panel is presented in Figure 12. This panel reproduces the same graphs and tile structure of the “Home” panel presented before. In this case the graphs display the Amplitude Spectral Density of the signals instead of their real time value. The graphs can be manipulated and rearranged in the same manner described previously. Like for the graph of the Home panel, it is possible to set what signals to display and add a filter in each graph. These options are available on the mouse-over menu on the left of the graphs. There are some additional controls on the right of each graph that allow to control the displayed ASD signal:

- **Window selection** - allows to choose which window is used to calculate the Fourier Transform. The Hanning window is selected by default but other options are available such as Hamming or Rectangular window.
- **Averaging** - allows to set the time averaging mode. The available options are No averaging, Vector averaging, RMS averaging or Peak hold.
- Below averaging selection there is an option to choose between **Linear** averaging or **Exponential** [moving] average.

- The next field allows to choose the **number of samples** used to calculate the average spectrum. If "Linear" is selected as averaging method, the software will acquire this number of points, calculate and display the average and stop updating the graph. In case of exponential averaging the data is weighted according to the following equation:

$$Y_i = \frac{N - 1}{N} Y_{i-1} + \frac{1}{N} X_i$$

where  $X_i$  is the result of the analysis performed on the  $i$ th block,  $Y_i$  is the result of the averaging process from  $X_1$  to  $X_i$ ,  $N = i$  for linear weighting, and  $N$  is a constant for exponential weighting ( $N = 1$  for  $i = 1$ ). (source: National Instruments).

- **Avg restart** allow to restart the averaging starting from next sample.
- The last control button allows to switch the Y axis scale between **linear** and **logarithmic**.

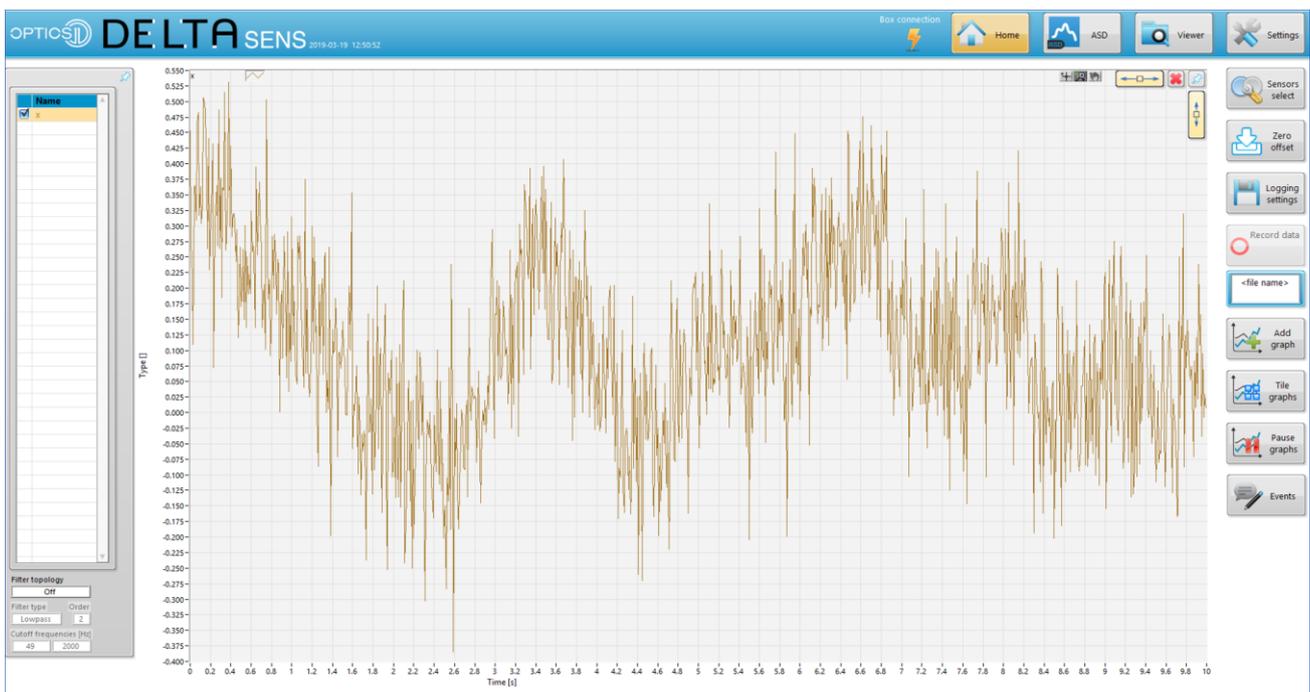


Figure 13: Home panel displaying mouse-over sensor select and filtering menu



datasheet will help locating the real cavity size on the spectrum of the extended window. After identifying the peak corresponding to the sensor cavity size, use the cursor to move the yellow line indicator over this peak and click "Confirm" at the bottom right of the window.

The thick-boxes on the left of each sensor allow to set of which sensors the unit should demodulate the signal. The settings are update to the unit after clicking "OK".

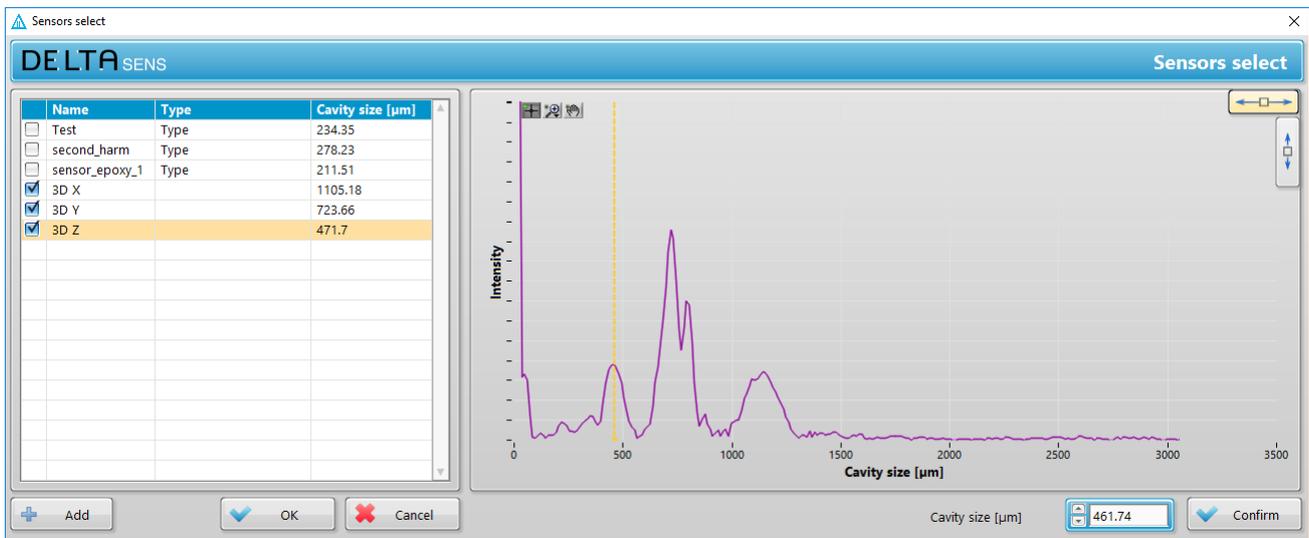


Figure 15: Extended sensors select window

## 1.5.2. Data logging settings

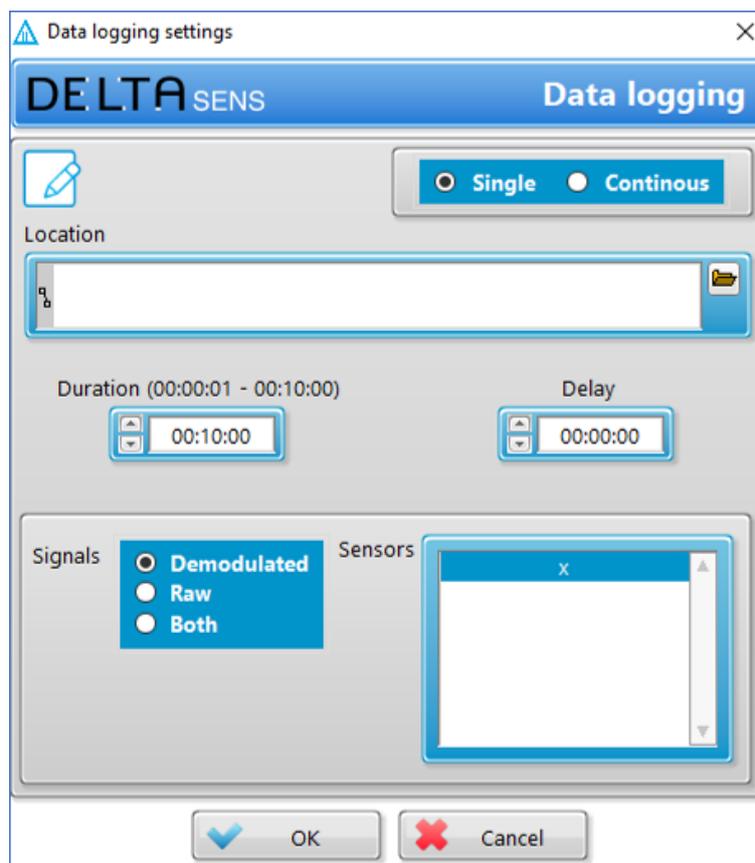


Figure 16: Data logging settings

The “Data logging” menu, presented in Figure 16, allows the user to edit the data logging settings. Such settings will be applied every time the user starts recording a signal by pressing the “Record” action button on the “Home” panel. The editable options are:

- **Single/Continuous** saving mode – The single mode will record the signals for a given timespan and save the data in a single file. The acquisition automatically stops when the set timespan is elapsed. The continuous mode will keep recording the signals till the user stops the acquisition by pressing again the “Record” action button. The software will create automatically multiple concatenated files. This mode allows to record signals for long timespans avoiding extremely big files.
- **Location** – Allow the user to enter the folder path where to save the acquired data.

- **Duration** – Specifies the length of the saved file in seconds. In single mode, this parameter controls the duration of the data acquisition. In continuous mode, it sets the duration length of a single file, after which the next one is started.
- **Delay** – Allows to set a delay for the data logging. After pressing “Record” the software will start saving the acquired data when the delay timespan is elapsed.
- **Sensors** – Presents a list of the currently demodulated sensors. It is possible to choose of which sensors the software will record the signal.

### 1.5.3.Events

The screenshot shows the 'Events' window for 'DELTA SENS'. The window title is 'Events' and it has a 'Pause' button. The main content is a table with three columns: 'Time', 'Level', and 'Message'. The table contains a list of events from 2018-03-26 12:55:33.4 to 2018-03-26 12:37:09.6. Most events are 'Info' level, but two are 'Error' level, highlighted in red. The 'Error' messages are: 'Comm.Data: Message counter issue (expected: 23301; received: 27453)' and 'Comm.Data: Message counter issue (expected: 16619; received: 16620)'. Other messages include 'Comm.Data Run: State Run', 'Comm.Data Config: Raw: TRUE; Demod: TRUE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000', 'Goertzel.Tune: Sensor 3D Z TRUE', 'Goertzel.Tune: Sensor 3D Y TRUE', 'Goertzel.Tune: Sensor 3D X TRUE', 'Goertzel.SetChannels: TRUE', 'Sensors selected', 'Goertzel compensate phase offset: finished', and 'Goertzel compensate phase offset: started'.

Time	Level	Message
2018-03-26 12:55:33.4	Info	Comm.Data Run: State Run
2018-03-26 12:55:33.2	Info	Comm.Data Config: Raw: TRUE; Demod: TRUE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:55:33.2	Info	Comm.Data Run: State Run
2018-03-26 12:55:29.4	Error	Comm.Data: Message counter issue (expected: 23301; received: 27453)
2018-03-26 12:55:29.2	Info	Comm.Data Run: State Run
2018-03-26 12:46:16.2	Info	Comm.Data Run: State Ready
2018-03-26 12:45:32.7	Info	Comm.Data Run: State Run
2018-03-26 12:45:32.5	Info	Comm.Data Config: Raw: FALSE; Demod: TRUE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:45:32.5	Info	Comm.Data Run: State Run
2018-03-26 12:44:59.5	Info	Comm.Data Run: State Run
2018-03-26 12:44:59.1	Info	Comm.Data Config: Raw: TRUE; Demod: FALSE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:44:59.1	Info	Comm.Data Run: State Run
2018-03-26 12:44:58.5	Info	Comm.Data Run: State Run
2018-03-26 12:44:58.3	Info	Comm.Data Config: Raw: FALSE; Demod: TRUE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:44:58.3	Info	Comm.Data Run: State Run
2018-03-26 12:44:57.4	Info	Goertzel.CompensatePhaseOffset: TRUE
2018-03-26 12:44:57.1	Info	Goertzel.CompensatePhaseOffset: started
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D Z TRUE
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D Z started
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D Y TRUE
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D Y started
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D X TRUE
2018-03-26 12:44:57.1	Info	Goertzel.Tune: Sensor 3D X started
2018-03-26 12:44:57.0	Info	Goertzel.SetChannels: TRUE
2018-03-26 12:44:56.9	Info	Sensors selected
2018-03-26 12:44:56.9	Info	Comm.Data Run: State Ready
2018-03-26 12:44:56.8	Info	Comm.Data Config: Raw: FALSE; Demod: FALSE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:44:56.8	Info	Comm.Data Run: State Ready
2018-03-26 12:43:58.9	Info	Comm.Data Run: State Run
2018-03-26 12:43:58.7	Info	Comm.Data Config: Raw: TRUE; Demod: FALSE; Chans: 3; Samp: 500; AbsPart: 0.00000; 0.00000; 0.00000
2018-03-26 12:43:58.7	Info	Comm.Data Run: State Run
2018-03-26 12:37:24.2	Error	Comm.Data: Message counter issue (expected: 16619; received: 16620)
2018-03-26 12:37:24.1	Info	Goertzel compensate phase offset: finished
2018-03-26 12:37:23.8	Info	Goertzel compensate phase offset: started
2018-03-26 12:37:09.6	Info	Comm.Data Run: State Run

Figure 17: Events window

The “Events” window, presented in Figure 17, shows log of all the events occurred in the software and all the commands sent to the box. It also shows warning and errors when software is not working as intended.

## 1.6. Settings panel

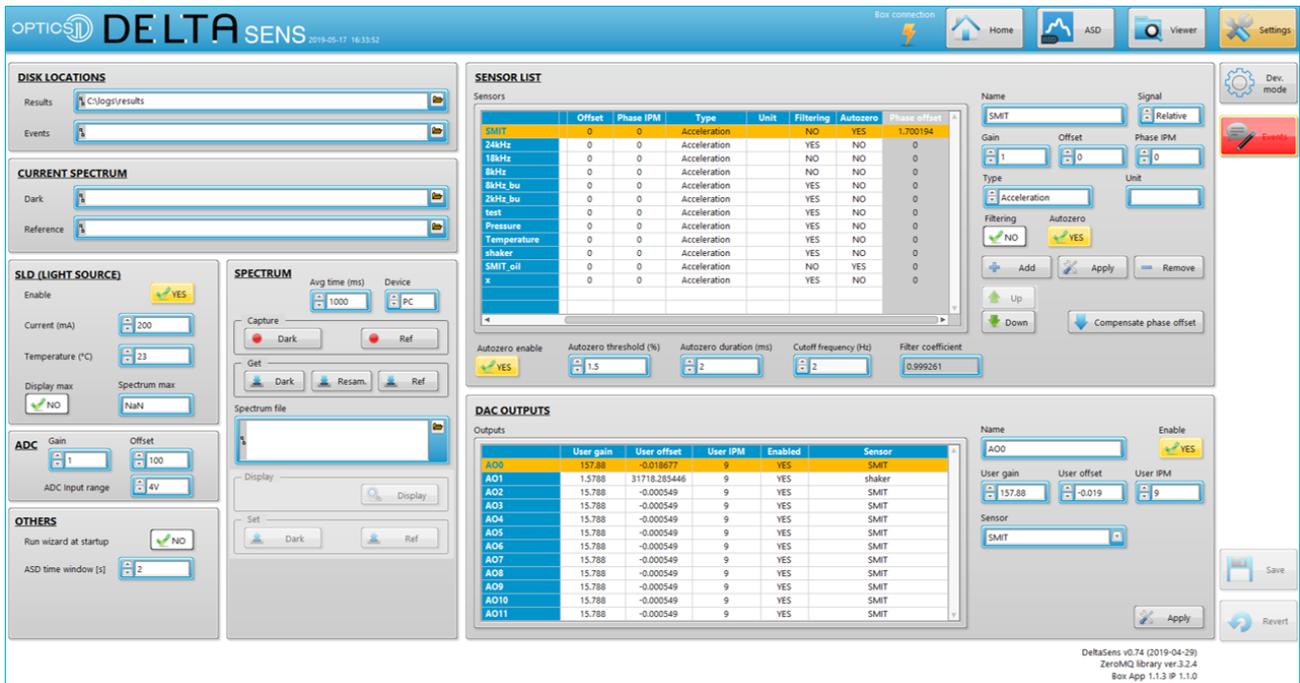


Figure 18: Settings panel

In Figure 18 is presented the “Settings” panel. Here the user can edit and update most of the software and interrogator options.

- **Disk Locations**
  - **Results** – Default location for saving measurement files.
  - **Events** – Default location for saving log events file.
- **Current Spectrum**
  - **Dark** – Default location to save and load dark spectrum file.
  - **Reference** – Default location to save and load reference spectrum file.
- **SLD (Light Source)**
  - **Enable** – Button to turn on and off the SLD.
  - **Current** – Value of the SLD source current.
  - **Temperature** – Set a temperature value for the SLD.
  - **Display max** – Button to enable the display of the maximum value of the spectrum.
  - **Spectrum max** – Field showing maximum value acquired by the spectrometer.

- ADC
  - **Gain** – Can be set in the range between 1 and 6. Can be used to modify sensitivity/power in special cases, otherwise it should be set to 1 as default.
  - **Offset** – Allows to adjust the offset of the ADC in case of a high DC value on the spectrometer, otherwise it should be set to 0 as default.
  - **ADC input range** – 2 or 4 V, it should be set to 4V as default.
- Others
  - **Run wizard at start-up** – Allows to choose if the “Sensor select” window should be displayed at the start-up of the software.
  - **ASD time window** – Allows to specify the time window used to calculate the ASD and therefore defines the ASD resolution. For time windows shorter than ( $< 5$  s) the ASD graphs will be refreshed with the given frequency. For longer windows the graph will be refreshed every second with a circular buffer. For example, if time window is set to “1 s”, the ASD resolution will be 1 Hz and the graphs will refresh every second with new data. If time window is set to “10 s”, the ASD resolution will be 100 mHz and the graphs will refresh every second with data acquired in the last 10 seconds.
- **Spectrum** – This pane allows to record, display, set and load the spectrum files
  - **Capture** – Allows to record the selected spectrum (Dark or Ref). To properly acquire the dark spectrum the SLD should be turned off. To acquire the reference one, the reference fiber should be connected to the unit and the SLD source current properly set.
  - **Get** – Uploads the chosen spectrum to the software
  - **Display** – Displays currently loaded/acquired spectrum
  - **Set** – Sets selected spectrum in the device
- **Sensor List** – Displays the full list of configured sensors along with their parameters
  - **Name** – Custom name of the sensor
  - **Signal** – Can be set to absolute or relative. In the current version of the software it must be set to relative as default.
  - **Gain** – Scaling value used to convert the sensor cavity length into the measured physical quantity. This value can be found in the datasheet accompanying the sensor and it is assessed during the sensor calibration.
  - **Offset** – Applies an offset to the demodulated signal. Should be set to 0 as default.
  - **Phase IPM** – Defines range and resolution of the signal in powers of 2. It can be changed and adjusted for different calibration factors, based on the range and resolution of the given signal. Default value of 0 allows for range of 65536 ( $2^{16}$ ) and resolution of  $3 \times 10^{-5}$ . Every step-up halves the range and the resolution, so e.g. value of IPM=1 results in range of 32768 and resolution of  $1.5 \times 10^{-5}$  and IPM=5 results in range up to 2048 and resolution down to  $1 \times 10^{-6}$ . IPM scale works independently of signal gain and applies only to the displayed signal.

- **Type** – informative description of the sensor.
- **Unit** – unit of measurement to display in the graphs of the demodulated signal (e.g. “g” for accelerometers).
- **Add** – Allows to add new sensors to the list. It allows to define a sensor and its main parameters but not to set its cavity size. The cavity size must be set in the “Sensor select” window as described in the previous section.
- **Filtering** – Allows to enable the High-pass filter function integrated in the DeltaSens unit. Such function can be turned ON or OFF for each sensor individually. The cut-off frequency of the HP filter can be set with the “Cutoff frequency (Hz)” control located at the bottom of the sensor list. Unlike the filters available on the mouse-over menu of the “Home” and “ASD” panels, the HP filter function also affects the recorded data.
- **Autozero** – Allows to enable the Autozero function integrated in the DeltaSens unit. In case of strong solicitation of the sensor (out of the dynamic range) the DeltaSens decoding system could reinitiate the signal acquisition with an unwanted offset. The Autozero function allows to avoid signal saturation caused by the multiple offsets accumulated during the measurements. If the signal reaches a certain percentage of the maximum dynamic range, the Autozero function will re-center automatically the sensor signal around 0. The threshold that triggers the Autozero function can be set by the user using the control “Autozero threshold (%)”. The Autozero function is triggered only when the signal falls over such threshold for longer than a given timespan which can be set by the user using the control “Autozero duration (ms)”. This function can be turned ON or OFF for each sensor individually. The Autozero function also affects the recorded data and the analog outputs associated to the sensors for which the function is switched ON.
- **Apply** – Allow to save the changes. After pressing apply, the “Save” button on the bottom right of the “Settings” panel must be pressed as well to upload the changes to the DeltaSens unit.
- **Compensate phase offset** – This button is used to remove unwanted offset from the sensor signal. The moment the button is pressed, the chosen sensor signal will be reset to zero. This compensation affects the general phase signal and therefore also the analog outputs assigned to the sensor just reset.
- **Autozero enable** – Allows to enable or disable the Autozero function for all the demodulated signals. Note that if the “Autozero enable” switch is turned OFF, the Autozero function will not be applied to any of the demodulated signals, even if the “Autozero” option was selected for a specific sensor.
- **Autozero threshold (%)** – Allows to set the threshold that triggers the Autozero function.

- **Autozero duration (ms)** – Allows to set the timespan that triggers the Autozero function. If the sensor signal falls such threshold for longer than this timespan the Autozero function will be triggered.
- **Cutoff frequency (Hz)** – Allows the user to set the cut-off frequency of the HP pass filter function.
- **DAC Outputs** – This pane allows to set the analog outputs of the DeltaSens unit. Each analog output can be assigned to one of the demodulated sensors. The analog signal is generated by the DeltaSens DAC with a maximum range of (-10 V, 10 V) and 16-bit resolution. The scale from default units to nm or other units must be defined with user gain and User IPM
  - **Name** – Arbitrary name given to the analog output
  - **Enable** – Button to enable/disable each analog output
  - **User gain** – Scaling factor applied to the analog output. It must be defined together with the “User IPM” value to get an accurate signal on the analog outputs. Table 1 lists some typical values of gain and IPM values for various scaling factors. The gain value can be multiplied by the sensor sensitivity to achieve signal output in scaled value (e.g. 100  $\mu\text{G/V}$ )
  - **User offset** – Allows to set a custom offset to the analog output. It can be used to compensate a drift of the signal or to center a signal in the analog output range. It is set automatically for a given sensor when the “Compensate zero” button is pressed.
  - **User IPM** – As described in User gain, this parameter sets correct scaling and range of the analog output. It should be used in combination with proper, calculated offset.
  - **Sensor** – Allows to pick which sensor is mapped to the analog output. The signal of a sensor can be mapped to any chosen output, also to multiple ones with different offsets and gains.
  - **Apply** – Allows to save and apply the changed settings of a given analog output. After pressing apply, the “Save” button on the bottom right of the “Settings” panel must be pressed as well to upload the changes to the DeltaSens unit.

In the bottom right corner of the “Settings” panel are located two buttons: **Save** and **Revert**. After modifying the settings, the Save button must be clicked in order to upload the changes to the DeltaSens unit and apply them during measurements. The changes can also be reverted to previous state by clicking the Revert button.

There are two exceptions to this rule which are the “Compensate zero” and “Compensate phase offset” buttons. Once pressed their effects are applied immediately.

Table 1: Suggested User Gain and User IPM values

SCALING VALUE	HALF SCALE	USER GAIN	USER IPM
10 nm/V	100 nm	2.470	3
100 nm/V	1 $\mu$ m	1.976	6
1 $\mu$ m/V	10 $\mu$ m	1.581	9

## 1.7. Data Viewer panel



Figure 19: Data Viewer panel

The “Data Viewer” panel is presented in Figure 19. It allows the user to load saved data and analyse them in the software. The software saves the files in the TDMS standard format, which can be read by many data analysis software and converted to other common formats (e.g. .mat).

In the Viewer user can load a recorded file by pressing the “Load file” button located on the top right of the “Data viewer” panel. The parameters of the opened file can be displayed by pressing the “Display params” button. The viewer consists of two graphs: the top one displays the acquired signal over time and the bottom one the frequency spectrum of the signal. The frequency spectrum is calculated over a time window of the recorded signal. Such window can be modified by the user by moving the two yellow bars located on the top graph. This allows the user to calculate and analyse the signal frequency spectrum with very high resolutions (e.g. 100 s measurement will result in 10 mHz resolution).

On the top right of the graph are located the controls that allows to scale and manipulate the displayed signals and on the top left corner the user can choose which sensor signals to display. The filtering options described in the previous section are available also for data imported from a file. The

controls are located on the top of the first graph. Filters can be set independently for each signal displayed by the data viewer.





## 2. TECHNOLOGY PRINCIPLE

### 2.1. Principle of operation

DeltaSens uses interferometry to interrogate multiple Fabry-Perot cavities. The heart of the system consists of a broadband light source (SLD) and a spectrometer. The light from the SLD is coupled in the optical fiber and then travels to the sensor. In the low finesse FP cavity, the light is reflected from the fiber end (reference beam) and from a transducing element (signal beam) such as a cantilever, a membrane, or another fiber. The two beams then are combined in the fiber and travel back to the interrogator to be acquired by the spectrometer.

The combined beams are then imaged by the spectrometer. Based on the optical path difference (OPD) between the two beams a pattern is formed on the spectrometer array of detectors. Using a broadband light source, the interference of the two beams results in a fringe pattern on the wavelength space. The frequency of these fringes depends on the size of the measured cavities. By applying a Fourier Transform (FT) to the signal, such fringe frequencies are converted in peaks in the FT domain which represent the size of the cavity. Such peaks are then traced to measure the changes of each cavity size.

By using an innovative algorithm, this peak can be traced with an exceptional resolution (down to single picometers) and multiple sensors (with different cavity sizes) can be interrogated simultaneously using not only the same interrogator, but the same fiber. They can be connected in parallel or serial configuration as long as the amount of light reflected from each sensor has the same intensity. A proper balancing of the sensors in a network ensures the best performances and low noise levels.

### 2.2. Correction spectra

To properly demodulate the signal and achieve a low noise floor, it is important to set proper dark and reference spectra. These reference spectra are already uploaded into the unit along with other factory settings. It is possible to reset them in case the unit needs to be re-calibrated.

The dark spectrum can be acquired by turning off the SLD source and measuring the current signal of the spectrometer in dark conditions. Reference spectrum can be acquired by connecting a cleaved fiber in place of the sensor and setting the SLD source current in order to achieve on the spectrometer power values typically used during normal measurements. These spectra allow to compensate

background interferences and pixel-by-pixel non-uniformities of the spectrometer gain and therefore to improve the signal to noise ratio.

### 2.3. Internal calibration method

The main sensing component of the DeltaSens interrogator is the high-precision spectrometer. Such device is calibrated using a reference laser and its readings are compensated in the DeltaSens system considering the unit temperature. Thanks to the high manufacturing standards and the inherent properties of the DeltaSens sensing method, the spectrometer does not require to be calibrated, granting high-performance and accuracy during the whole product lifetime.



## 3. TECHNICAL SPECIFICATIONS

Performance	
Number of optical channels	1
Noise floor <sup>1</sup>	1 pm/√Hz
Sampling speed	17 kHz
Frequency response sensors <sup>2</sup>	DC to 8,5 kHz
Operation wavelength range	1510 nm to 1590 nm
Signal acquiring	True simultaneous
Sensors per channel	12
Signal resolution	64 bit digital / 16 bit analog
Dynamic range	140 dB
Environmental	
Operating temperature	0 to 45 °C
Storage temperature	-10 to 70 °C
Maximum humidity	85% (non-condensing)
Recommended warm-up time	15 minutes
IP rating	IP52
Physical	
Dimensions (W x H x L)	444 mm x 66 mm x 306 mm (19 inch 1,5 U version available)
Max. weight	8 kg
Housing material	Aluminum
Input voltage	220 – 240 VAC, 0.8A 110 – 120 VAC, 1.6A
Power consumption <sup>3</sup>	20 W
Input voltage frequency	50 – 60 Hz
Output interface / Port	Ethernet / RJ-45 Analog / BNC
Fiber port	FC/APC, 2.0 mm Narrow Key
Trigger interface	BNC
Trigger input /output	5V TTL, rising edge

<sup>1</sup> The final noise floor of the system is a combination of the readout and the sensor.

<sup>2</sup> Independent to the amount of sensors connected to the readout

<sup>3</sup> At room temperature

<a href="#">Data properties</a>	
Data output	Digital file (TDMS) and analog signal ( $\pm 10$ V)
Software requirements	Intel Core i5 or equivalent, min. 4 GB RAM, display resolution min. 1920 x 1080



