USER MANUAL

multiLane

Digital Sampling Oscilloscope User Manual

Connection | Installation | Calibration | Measurement | Troubleshooting

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Firmware Revision 3.2
GUI Revision 2.0.9

Innovation for the next generation

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Only qualified personnel should perform service procedures.

While using this product, you may need to access other parts of the system. Read the General Safety Summary in other system manuals for warnings and cautions related to operating the system.

To Avoid Fire or Personal Injury

Use Proper Power Cord. Only use the power cord specified for this product and certified for the country of use.

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Do Not Operate Without Covers.

Do not operate this product with covers or panels removed.

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Do Not Operate with Suspected Failures.

If you suspect there is damage to this product, have it inspected by qualified service personnel.

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⚠ *Caution statements identify conditions or practices that could result in damage to this product or other property.*

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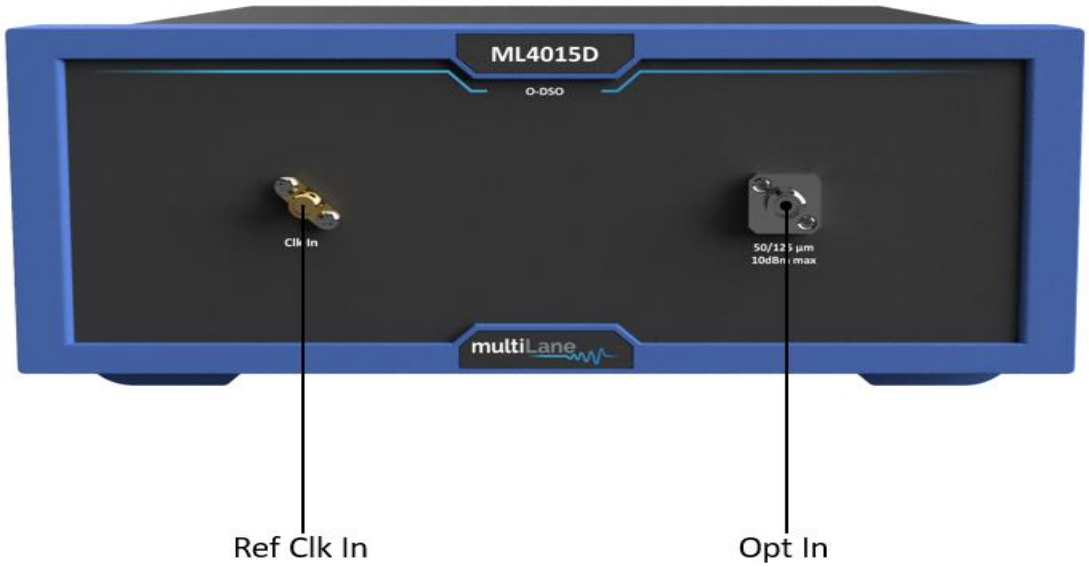
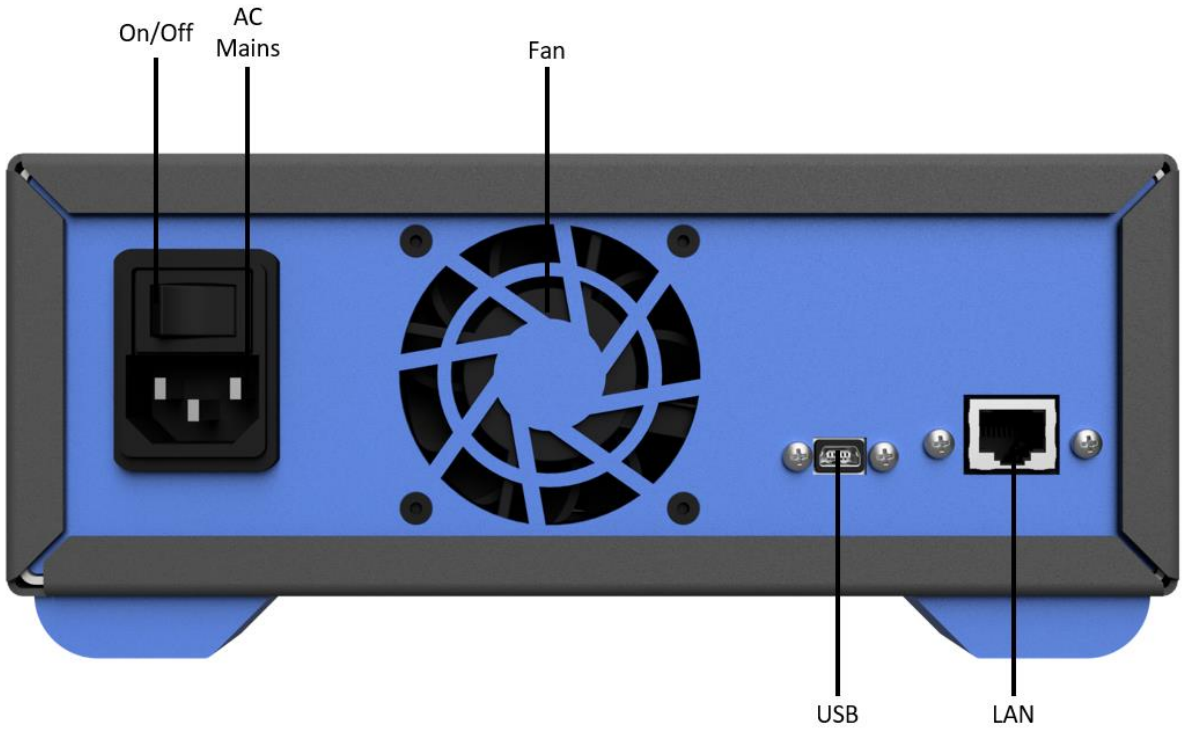
INTRODUCTION

Acronym	Definition
BW	Bandwidth
NRZ	Non-Return to Zero
DUT	Device Under Test
SONET	Synchronous Optical Networking
SOC	System on a Chip
PCIe	Peripheral Component Interconnect Express
SATA	Serial Advanced Technology Attachment
PAM4	Pulse Amplitude Modulation
ORR	12G Wideband Optical Reference Receiver
Sim	Simulation
Conf	Configuration
PRD	Product Requirements Document
HW, FW, SW	Hardware, Firmware, Software
RF	Radio Frequency
Gbps	Gigabits per second
PC Mode	Pattern Capture Mode
GUI	Graphical User Interface
THD	Total Harmonic Distortions

Product Features





Power Requirements

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Current from +5 V Supply		External		1.5		**A**
The typical power dissipation for the DSO is 7.5 W; the module can be powered from an external source 5 V/1.5 A through a power cable.						

Ordering Information

Option	Description
ML4015D-	Single Channel DSO
25-SM	25 GHz optical, single-mode fiber
25-MM	25 GHz optical, multi-mode fiber
40-SM	40 GHz optical, single-mode fiber
E-32	32 GHz electrical
E-50	50 GHz electrical
E-50-24	50 GHz electrical, 2.4 mm connectors
3YW	3-year warranty

Product Description

- Installation explains how to configure and install the instrument as well as how to install the included system software
- Incoming Inspection provides a verification procedure for basic operation and functionality
- Accessories and Options lists the instrument options available along with the standard/optional accessories for this product.

Overview

The **DSO** Digital Sampling Oscilloscope (DSO) is a fully integrated, ultra-compact USB/ Ethernet controlled instrument that automatically performs accurate eye diagram and pattern capture analysis to characterize the quality of transmitters and receivers, interconnecting with a specified input BW. It is operational under Windows and Linux.

The **DSO** implements a statistical under-sampling technique with comprehensive software libraries for eye measurement, jitter analysis and processing of NRZ data, thus enabling:

- Eye measurements with the following classes of operation:
  - Oscilloscope Measurements
  - NRZ Measurements
  - PAM4 Measurements
  - Multiple measurements
  - Mask Test
- Advanced pattern acquisition with pre-emphasis measurements.
- Jitter component decomposition
- Filtering
- S-parameter generation & de-Embedding
- Frequency domain plots and THD measurements

Key Features

- High-value instrument grade sampling scope optimized for high speed data analysis.
- External reference clock input
- Single ended and differential electrical inputs supported
- Eye capture, jitter, rise/fall, histogram, mask measurement, pattern capture, S21 Capture & frequency domain, all in a single instrument.
- Multiple modules can be controlled via fast Ethernet 100Base-T
- The DSO tool can operate in a data acquisition only mode where the data is saved on multiple acquisitions for post processing.
- Supports high density parallel application with scalable concurrent testing.
- Ultra-compact form factor replaces conventional rack test solutions and solves impractical physical requirements of testing large lane counts. DSO can mount into the Verigy 93K.
- User friendly GUI enables zooming, markers, X/Y histograms, overlays, pre-emphasis with simultaneous measurement statistical captures
- Load and analyze data that was previously captured in simulation mode
- Capability to save statistical measurements, data files and configurations
- Color graded display for visualizing jitter and noise distributions
- Standard stress masks selection for LRM pre-cursor, LRM post-cursor, LRM symmetric and LRM Clean Eye
- Mask user defined, auto-detect mask support
- Percentage of failing points
- Save data and mask
- Load mask file

Scope Measurement Suite

- Mask margin, alternate mask margin rules available
- The mask margin (positive or negative) can be extracted for a defined number of points that fail, thus allowing for DUT quality assessment, control and binning
- The number of failed points for a region can be returned as well as the actual points that failed
- Eye opening, eye height and width, eye amplitude, top, base, hi, lo, peak to peak, max, min
- Rise/ fall time, single edge measurement in pattern capture
- Total edge jitter
- Statistical histogram measurements
- Crossing point, crossing percentage
- Advanced pattern measurements:
    - Eye measurements on specific bits of the pattern

- Single edge measurement in pattern capture
- Pre-emphasis (positive and negative, height and width)

- Jitter analysis
  - Deterministic jitter.
  - Random jitter.
- S-parameters & harmonic distortions

Target Applications

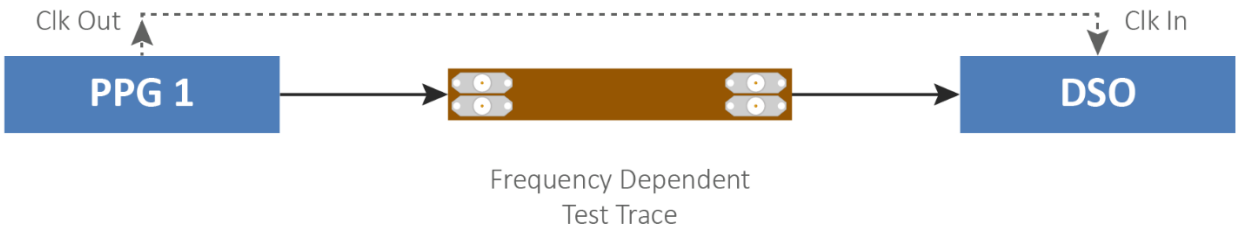


Figure 1: DSO Application

- Interconnect testing (SFP, SFP28, CFP, CFP2, CFP4, QSFP, QSFP28, ...)
- Backplane testing
- Interference and crosstalk testing
- Receiver sensitivity testing
- Receiver jitter tolerance testing equalizer characterization
- Electro-optical module testing
- Electrical stressed eye testing for 100 Gbps Ethernet, MLD/CAUI application, OIF CEI- 28G-VSR, CPPI-4, CAUI-4, 32G Fiber Channel chip to module (c2m)
- High speed SerDes testing & characterization
- Handheld 10G test equipment for field Installation and maintenance
- Multi-port or line card system testing
- In-Situ testing of high port count systems
- Can be mounted in Automatic Test Equipment (ATE) or in socketed load board
- Telecom equipment tests for installation and maintenance
- Fiber channel, Ethernet, PON, parallel optics, etc.
- High port count burn-in test
- Research and development applications

Product Software

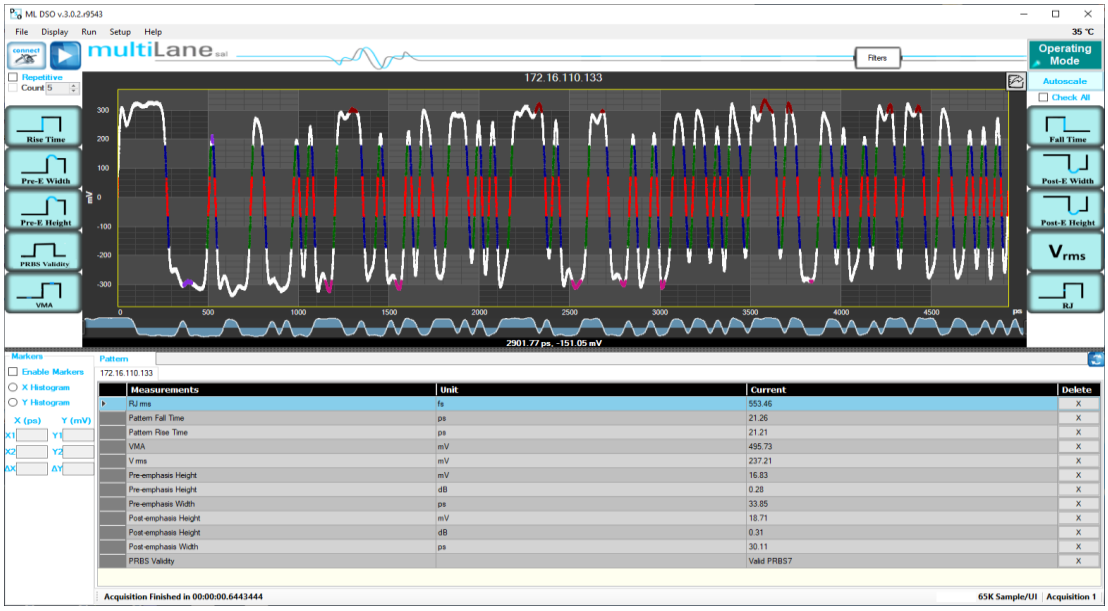


Figure 2: DSO GUI

Minimum PC Requirements

The Windows PC properties for the MultiLane software must meet the following specifications:

- Windows XP SP3 or greater
- Minimum 2 GB RAM
- 1 Ethernet card to establish connection with the device
- USB connector
- Pentium 4 processor 2.0 GHz or greater
- .NET Framework 4.0

NOTE: *It is recommended to connect the DSO via Ethernet to a single PC only, preventing conflict from multiple user commands.*

Installation

This section address installation and bring-up of the instrument, addressing the following topics:

- System start-up
- Connection guide

System Start-up

To use the **DSO** under Windows XP, Windows 7 and Vista, it is important that the correct start-up sequence is followed:

- Ensure Microsoft .NET Framework 4.0 is installed
- Install the DSO GUI software
- Connect the power cable to the power jack and field it with a +5 V/ 1.5 A supply
- Note power plug is already included in the package accessories.
- Communication through USB to the instrument is required to configure its own IP **only**
- Install the USB driver to the PC (Appendix I)
- Change the IP of the DSO to fit in the network range by and using the software DSO Conf (Appendix III)
- Communication through Ethernet port is required for data acquisition
- Connect the PC to the DSO through an Ethernet cable, no driver required
- Now the DSO is powered up, having the right IP, the Ethernet cable links the instrument to the PC with the GUI correctly installed
- To open the GUI, double click on the software icon located in the Desktop directory
- In order to characterize the signals fielding the instrument, check the Data and Connection configuration

NOTE: *This release supports Ethernet connection for the software applications, and the USB port is used only to configure the device IP Address (note that the IP should be in the same range of the network)*

DSO GUI Overview

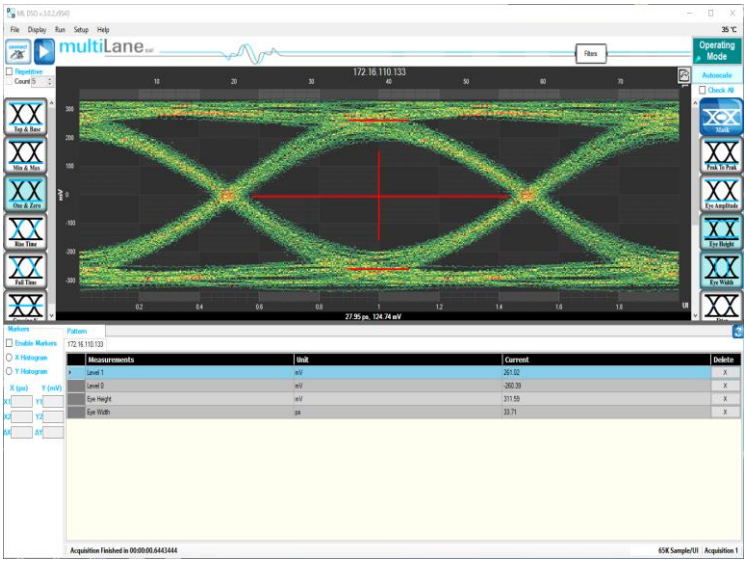


Figure 3: GUI

- Click the connect button at the top left of your screen
- The “Connect to DSO” window will pop up
- Click on the add button to add the virtual DSO
- The “DSO configuration” window opens

- If both software the DSO and simulator are hosted on the same computer, choose the “Simulation” mode
- If one of the GUI instances is being run on a different PC, choose “Hardware” instead of “Simulation” and enter the “IP” of the PC where the simulator is running
- Click on the refresh button in order to retrieve the simulator configuration, or configure the DSO by filling the “DSO configuration” window for the relevant IP address

NOTE: *Any data file that has already been saved using the* ***DSO*** *software can be loaded.*

DSO Configuration

Connection Configuration

Change the configuration as needed:

- The default display name of the target DSO can be edited as preferred
- The IP of the DSO connected by writing it next to “IP” label
- Name the DSO by populating the “Name” label
- Click on the hardware radio button to use the instrument; fill in IP and Channel

Data Configuration

The DSO has 3 SMA inputs (two for the differential data RF Input + and RF Input –, and one for the Clock input).

External Clock Operation

Clock Input in normal mode ranges between 5 and 525 MHz (710 MHz for certain models):

- Choose the Normal Operation radio button to use the onboard timing generator.
- Enter the target line rate less Line Rate (Gbps) into the **Gbit Rate** field or choose a Gbps value, example: 10.709, 10.625, 10.3125, 9.95328, 8.5, 6.25, 4.25 and 3.125
- Specify the number of packets; it can be 4, 8, 16, 32, 64, 128, 256 or 512

Each packet consists of 512 sample points per UI, which are duplicated when drawing the eye.

Eg: 256 packets correspond to 131072 points per pattern, and 262144 points per eye (131072 for each of the 2 UIs displayed in eye mode).

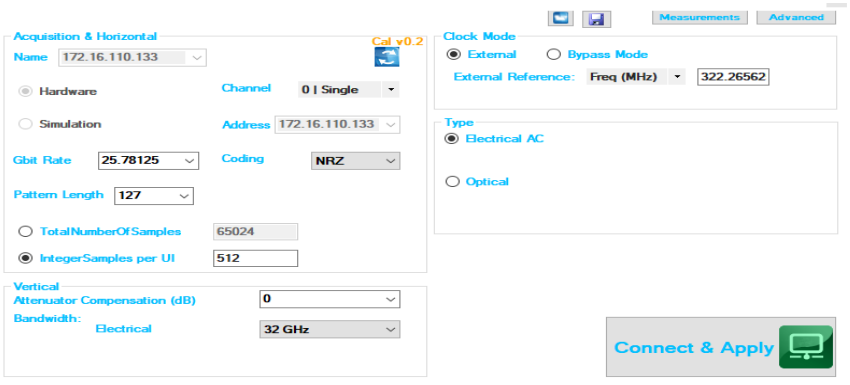


Figure 4. DSO Configuration

- Enter the percentage level of rising and falling times in the **NRZ Thresholds** field
- Enter the **External Reference Clock Frequency** in MHz or as a factor of the bit rate

- Clock rate can vary from 50 MHz to (525/710) MHz, with an amplitude range from 0.05 to 1.5 Vpp
- Typically, this will be rate / 16, 64, or 80, but can be any other rate as well
- Enter the **Pattern Length** of the data feeding the DSO to capture the full pattern
  Note: Incorrect pattern length would still display the eye capture, however full pattern capture is required for certain features of the software such as Jitter Decomposition, PTB and Filters.

E.G.: Pattern Length = 127 for PRBS-7, The Pattern length of PN(n) is $(2^{n}) - 1$.

- To get wander correction, check the box then choose between the 3 frequencies, 1024 or 2048 or 4096 Hz
- In order to retrieve the last configuration, enter the specified IP and then press the refresh button
- In order to scale the measured results, to remove the effect of an attenuator connected at the receiving end of the scope, enter the Attenuation value in dB. In optical mode, the value is doubled when the attenuator is at 3 dB. In electrical mode this is 6 dB.
- To capture more points for finer measurements, accumulate the number of points from all the acquisitions by entering the total number of points to persist in the accumulate field. This will set the number of points filling the entire eye diagram. For both UI's, half this number of points will be displayed in the pattern diagram. Accumulation works in infinite persistence mode, and unless the points are cleared or the connection is reset, all acquisitions will take part in the accumulated result with equal amounts of points randomly selected from each acquisition.

AOP Offset Correction

This field enables ML4015D users to offset (or shift) the actual power values reported from the photocurrent of the photodiode power supply which represents the actual AOP of the DUT signal with a reading resolution of 16 bits.

Attenuator Compensation

This field is specifically relevant to legacy platforms like the **ML4005D** and **ML4005C**, where the average of the captured 1 and 0 levels is used to determine the DUT measurement. These legacy systems featured a DC coupled O/E.

Wander Compensation

The time-base **Wander Compensation** checkbox enables or disables the Time Base Wander Correction for a measurement. Small variations in the DSO internal reference time base appear as low-frequency jitter (wander) in the acquired signal.

For mask tests and edge jitter measurements, the DSO analyzes the acquired samples and removes the effect of the temporal drift (wander). Wander correction improves the accuracy of DSO measurements but may increase the time to acquire data. For applications where measurement speed is important, disabling wander correction is suggested. Reducing the number of blocks to less than 128 significantly reduces the effect of wander and increases throughput.

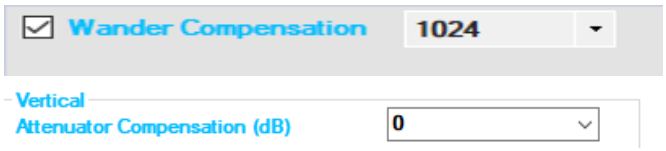


Figure 5: Wander Compensation

DSO Menu

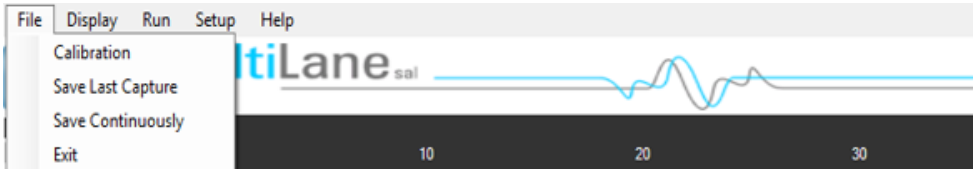


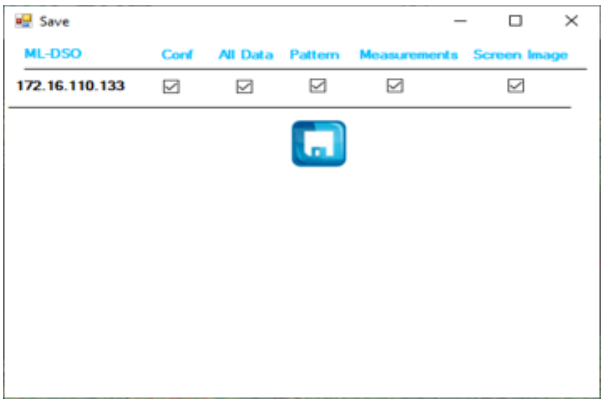
Figure 6: DSO menu bar

File Menu

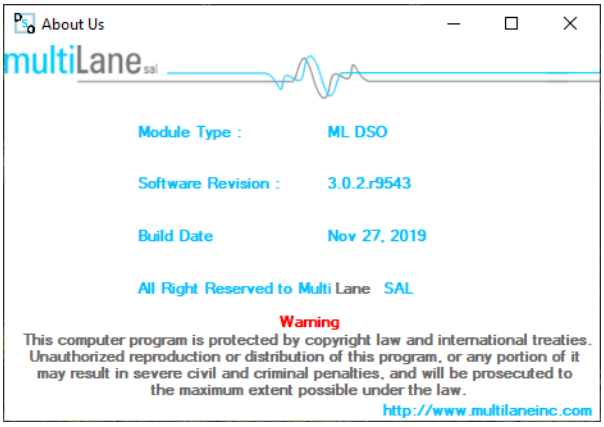
Save: after clicking on this icon, a save window appears enabling to save configurations, data and measurements files for each acquisition.

In the case of being connected to multiple DSOs, there are check boxes next to each DSO, check the one related to the needed DSO and save preferences. Each checked DSO has a separate folder. If the 3 options Conf, Data and Measurements are checked; in this folder 3 kinds of files will be found.

Conf: select to save the configuration file.
Data: select to save the data file.
Measurements: select to save the statistical measurements files.



The version for this software can be found after selecting the "**About Us**" under "**help**" menu option. Then, the following information will be displayed:



Zooming can be done by clicking on the graph and dragging, which would draw a dotted window. When the mouse is released, the graph will zoom to display only the content within the drawn box. This method of zooming may alter aspect ratio of the graph is the drawn box is of disproportional dimensions.

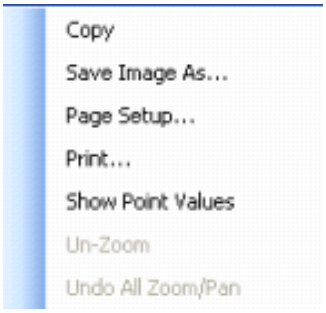
Zooming also can be done using the mouse wheel when the Ctrl button is held. This method will maintain the original aspect ratio of the graph.
In order to go back to the initial view, right click on the graph, and choose "**Undo All Zoom/ Plan**"

Panning

The position of the graph in the display window can be panned by dragging the graph with the mouse while the Ctrl key is held.

Copy, Save, Undo Zoom and Print a Graph

Right clicking the graph exposes these features:



Copy: copy the present graph as an image into clipboard.
Save Image As: save the present graph in the desired location.
Page Setup: view page information for printing.
Print: print the graph.
Show point values: display the coordinates of points when hovering over them in the graph.
Un-Zoom: undo the last zooming performed.
Undo All Zoom/ Plan: undo/reset all zoom actions.

Operating Modes

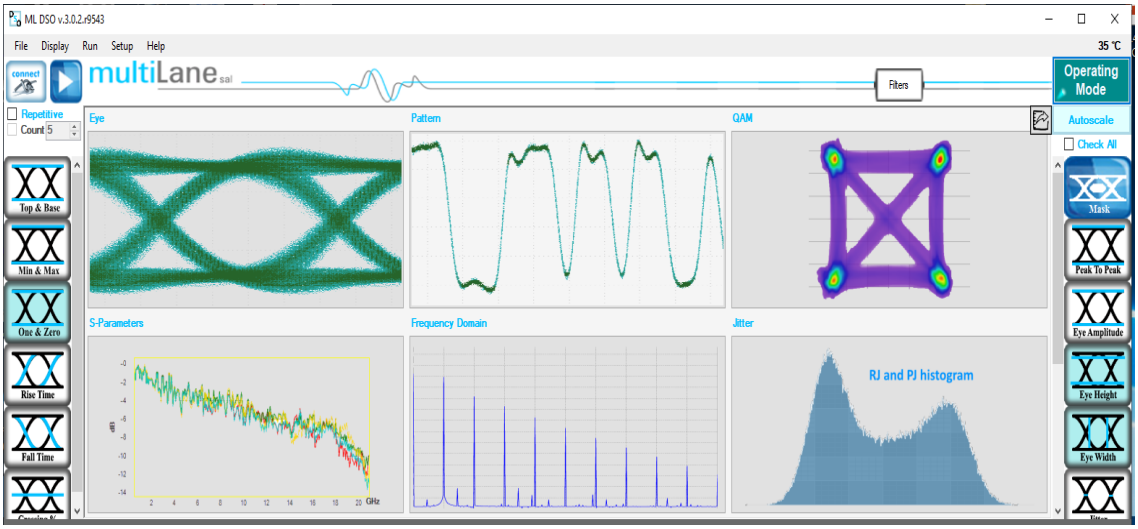


Figure 7: Supported DSO GUI Operating Modes

Selecting **Operating Modes** in upper right corner allows navigation between:

- Eye Measurement Mode:
  - Oscilloscope Measurements
  - Multiple measurements
  - NRZ Measurements
  - PAM4 Measurements
  - Mask Test
- Pattern Capture Mode including jitter decomposition
- S-Parameter Mode
- Frequency Domain Mode

Eye Measurement Mode

Regardless of hardware or simulation mode, it is possible to draw the eye and capture measurements after filling the configuration window and connecting to the instrument.
In Eye Mode, in order to draw the eye diagram, click on the **Start Data Acquisition** button

Check the **Check All** button to view all the eye measurements down the screen for one time or select the needed measurement only by pressing on the desired icons. Use the second option to reduce measurement operation time.

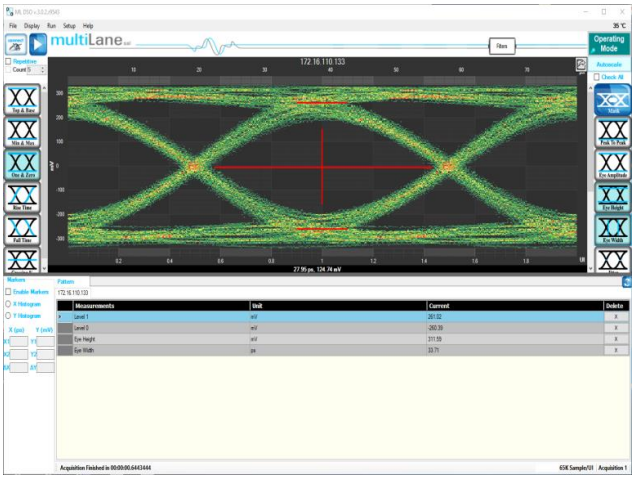


Figure 8: Measurements Mode

If a large number of acquisitions need to be captured, click on the **Repetitive** check box, then press the **Start Data Acquisition** button . Check the **Count** Text box and specify the number of acquisitions to automatically stop captures after a certain number of measurements.
By default, the measurements are displayed continuously. In this case, the eye diagram is frozen after the first acquisition.
By default, Eye Mode is chosen; if you are located in Pattern Capture mode, to move to the select **Switch to Eye Mode** to switch back.

During the acquisition phase the **Start Data Acquisition** button becomes a red stop acquisition functionality. Clicking on the red stop button will stop after completing the acquisition currently in progress and will display the eye and its statistical measurements.

In order to restart the acquisitions, click again on the **Start Data Acquisition** button; a new set of acquisitions begins. Accumulated data continues across several runs if not cleared.

In order to save data, statistical measurements and configuration files, check the **Saved Data** folder under the deployment directory. A folder is created for each ML-DSO and inside of this folder the user can find 3 different files; statistical measurements, configuration and the data file.

Status Bar

Number of Samples

The status bar displays the number of kilo-samples captured in the Eye mode.
'1K Samples' is equivalent to 1000 sample points in the Eye graph, including accumulated point when applicable.

Operation Status

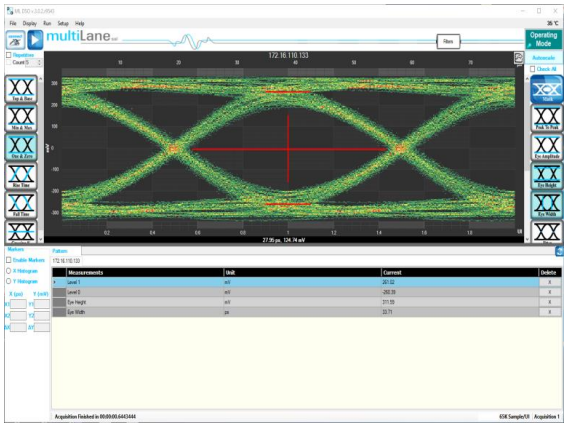
Operation Status	Status Description
Gathering Data	Acquiring data (reading from hardware)
Saving Data	Saving data in the data file
Error Connecting to DSO	A connection between SW and HW cannot be established
Error Applying Wander Compensation on DSO	Wander cannot be applied because an eye cannot be detected at the first place
Saving Results	Saving acquired data points and statistical measurements into their file
Displaying Results	Showing the statistical measurements and refreshing the graph
Acquisition Finished	Acquiring data and sampling is finished

Table 1: Operation Status Messages

How to add multiple ML-DSO Channels/Disconnect/Reconfigure

- To add a new ML-DSO channel, press the **Add New ML-DSO Channel** button in the **Connect to ML-DSO** configuration window; fill it and connect
- To disconnect from a specified ML-DSO, simply click on the **Close** button next to its name in the **Connect to ML-DSO** form
- To reconfigure the data, click the **Edit ML-DSO Configuration** icon, and then fill the configuration window as preferred
- To add multiple ML-DSOs, repeat the first step

Oscilloscope Measurements



While capturing the eye, a user can perform measurements by simply clicking the corresponding buttons: Top, Base, Min, Max, Fall time, Rise time, Peak to Peak, Eye Amplitude, Eye Height, Eye Width, Jitter, and the crossing percentage. The **Check All** text box can be selected to capture all the measurements in one action.

When multiple DSOs are connected, and after drawing all the eyes or patterns, the measurements are displayed for all DSOs down the screen in the tables.

Markers

This feature by default is off; in order to use it, switch it to on by choosing the **On** radio button, under the **Markers** group box.
A pair of movable markers in both X-axis and Y-axis is displayed. The horizontal and vertical markers help bound the measurement region by giving the difference between the 2 horizontal and vertical markers.
The results are displayed in the top of the graph. Picosecond or UI is the unit of the X axis; mV is the unit of the Y axis.

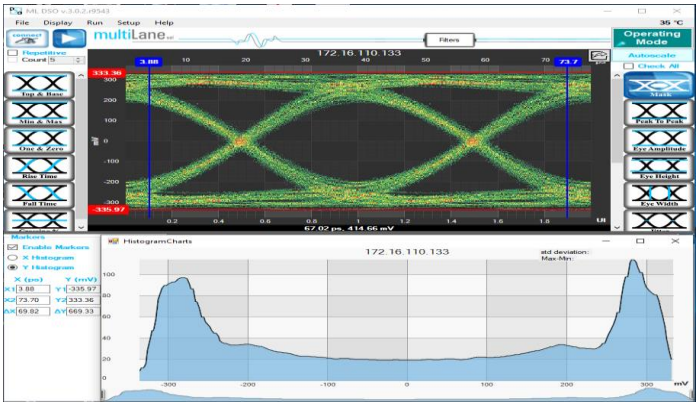
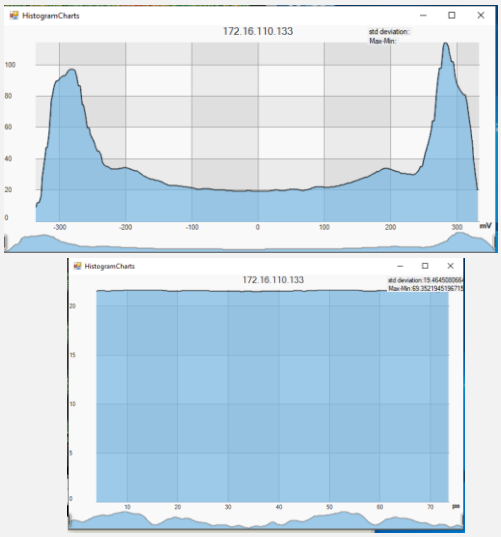
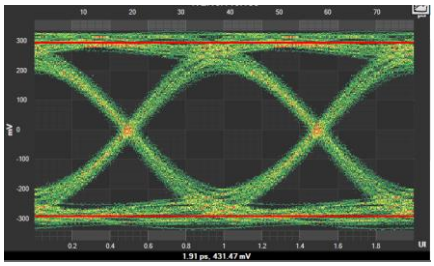
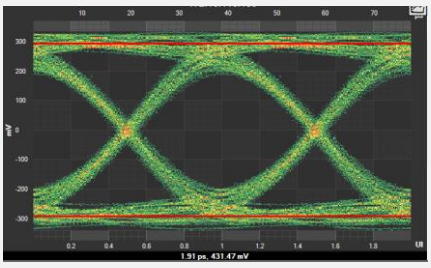
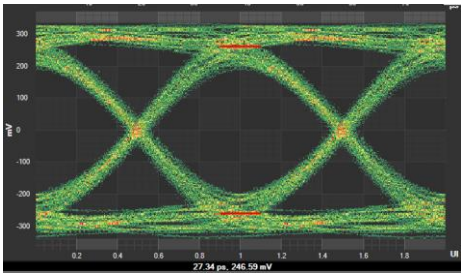
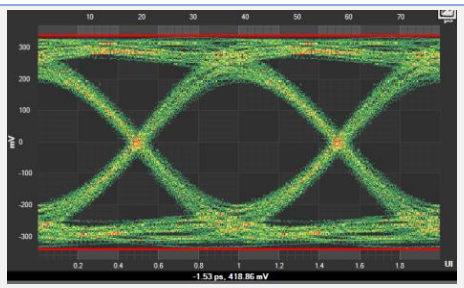
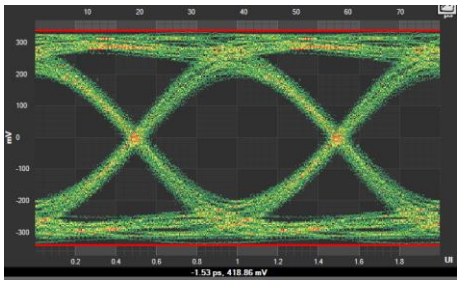
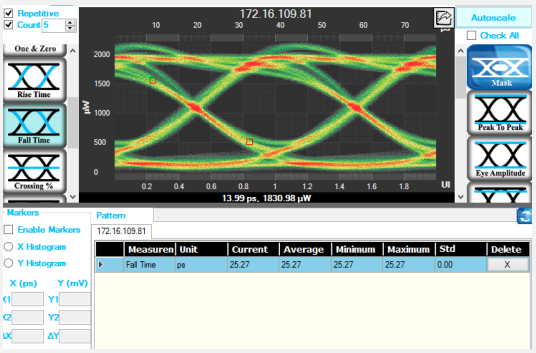
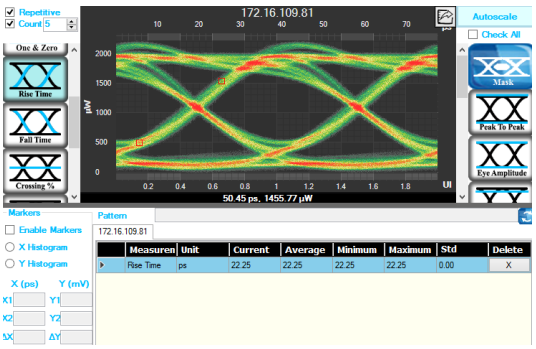
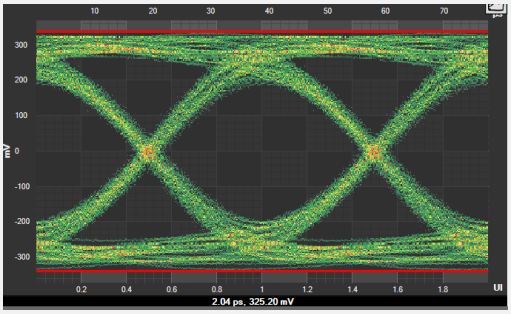
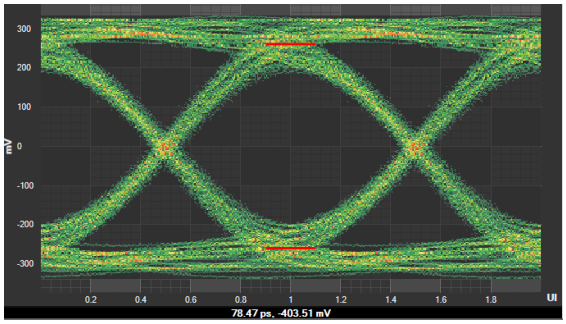
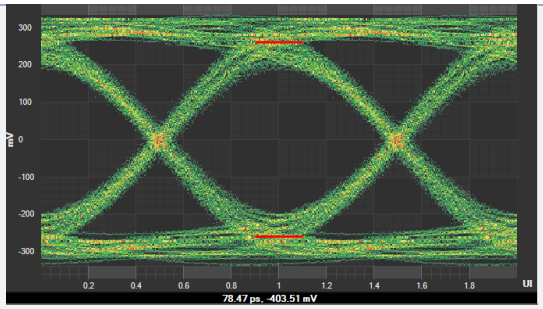
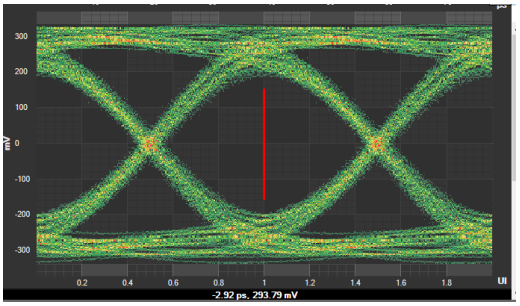
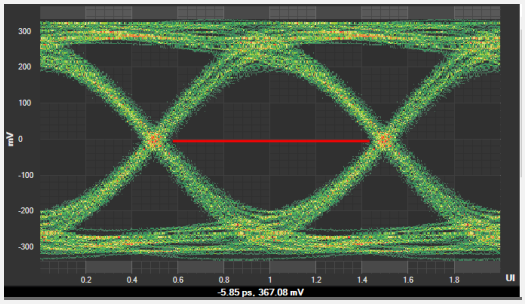
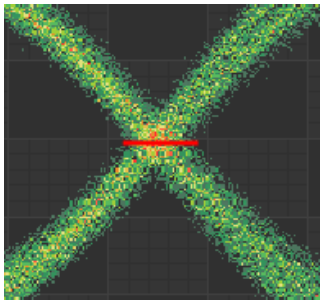
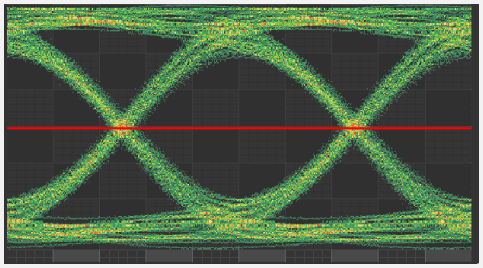
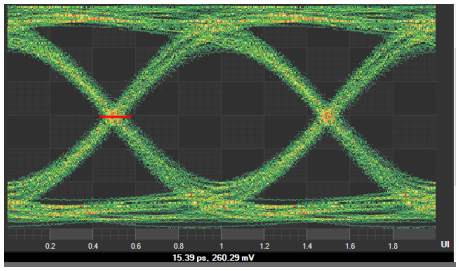


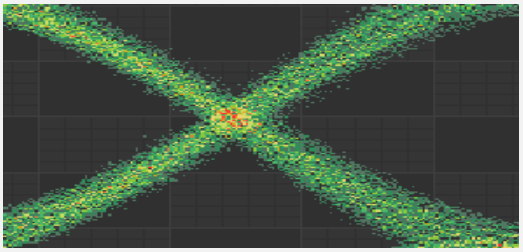
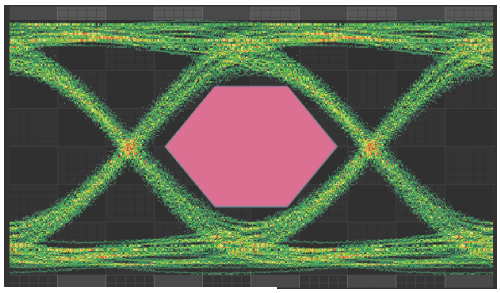
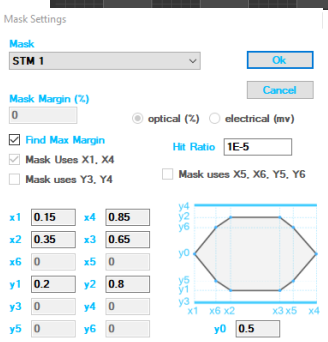
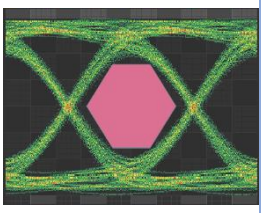
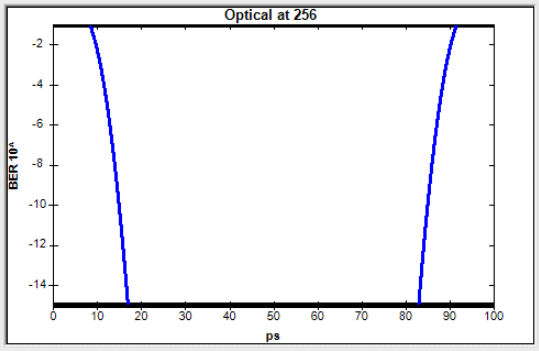
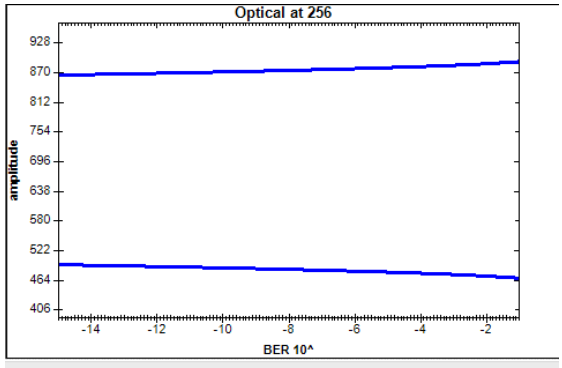
Figure 9: DSO Markers

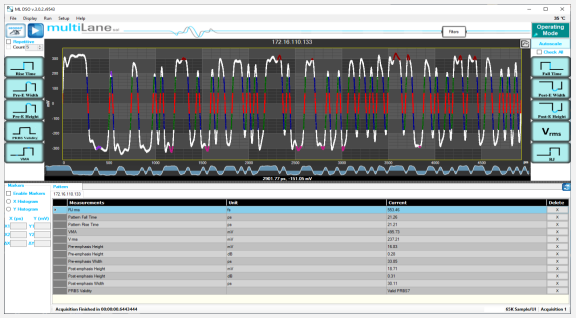
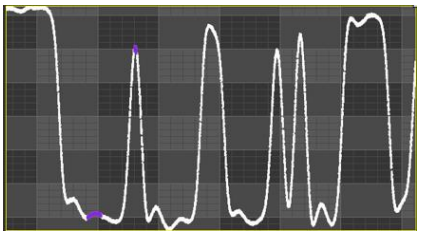
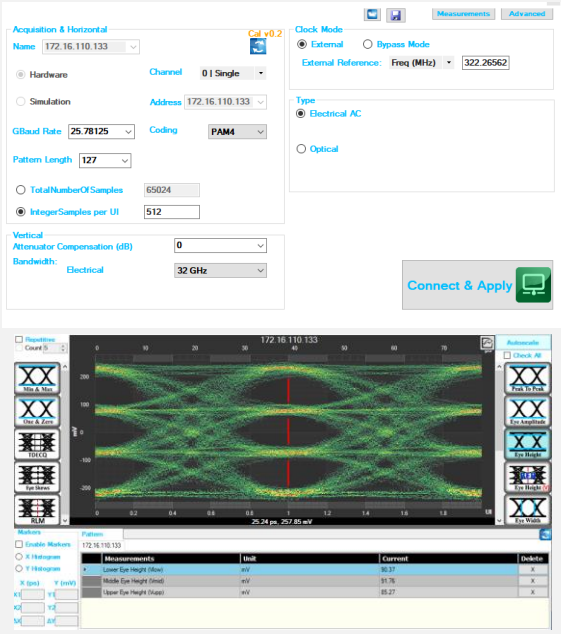
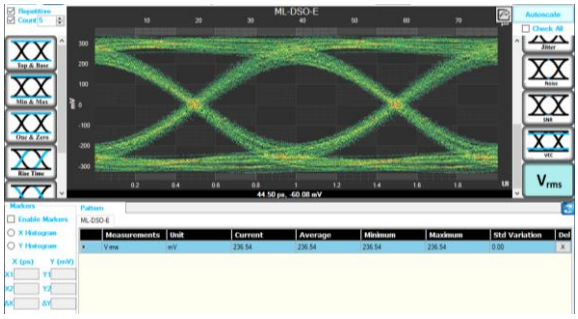
- First select the marker to be moved; it should be highlighted in yellow
- Drag the markers to the required location
- The marker values displayed in the textboxes bottom left can be used to manually specify the marker positions
- Markers help verify horizontal and vertical measurements, such as jitter, eye width, eye height, and mask margins. They can be dragged manually to view the delta or difference between 2 markers.

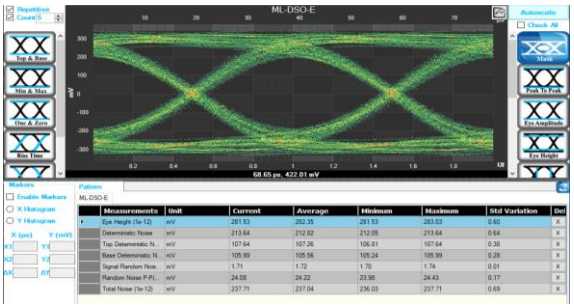
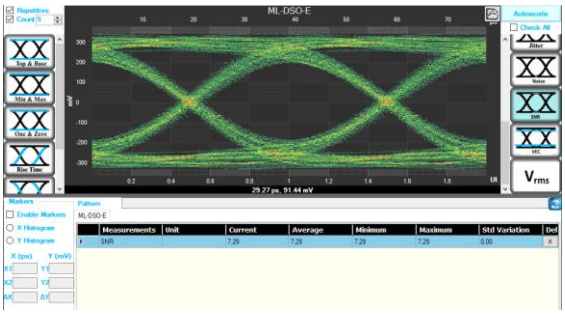
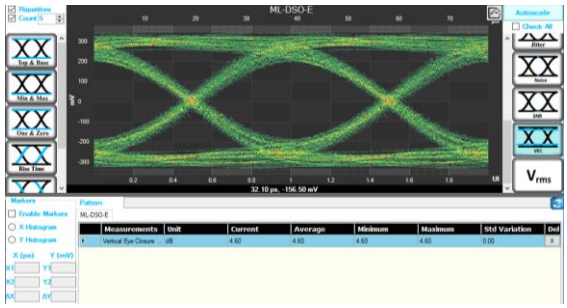
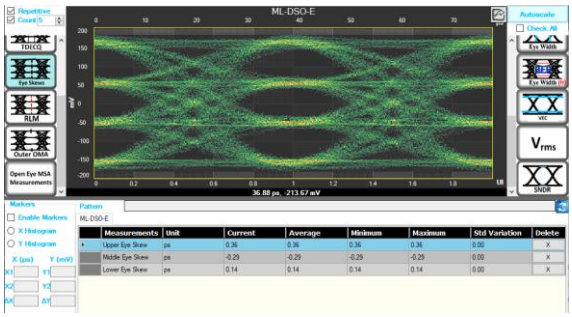
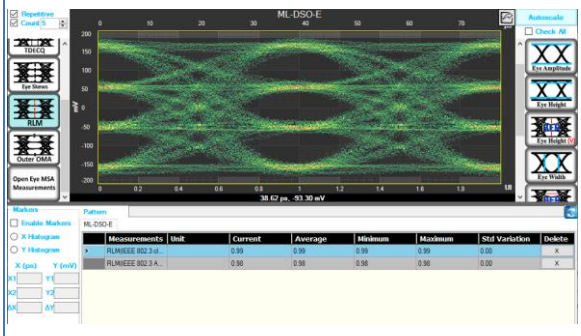
Measurement	Description	Screenshot
Histogram	The X and Y histograms show the density distribution of the samples along the x and y axes:	
Top	The average y-value of the high-to-high transitions.	
Base	The average y-value of the low-to-low transitions.	
One and Zero Levels	The average y-values at 20% around center of the eye	
Min	The minimum sample value.	

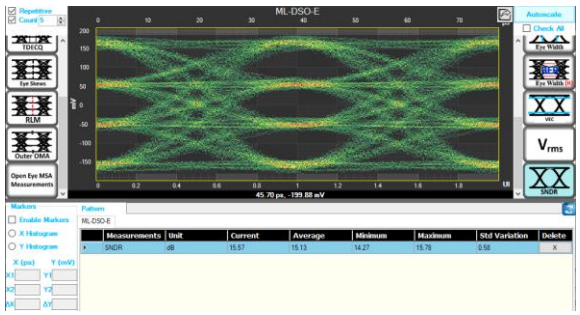
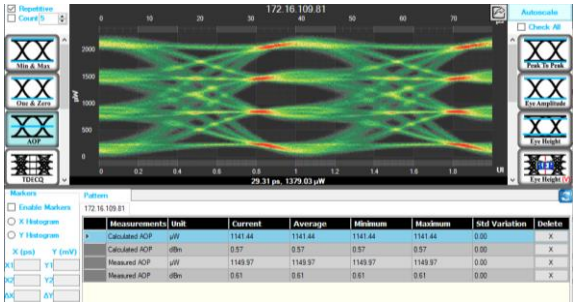
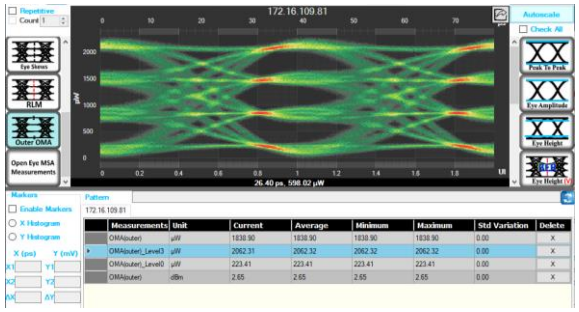
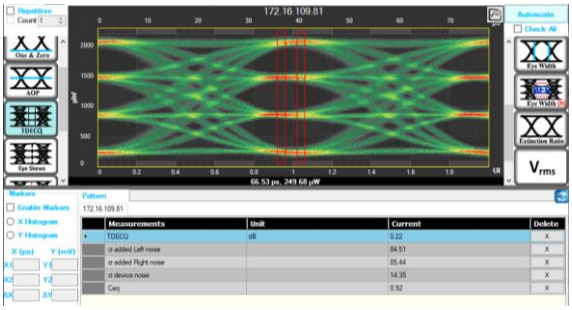
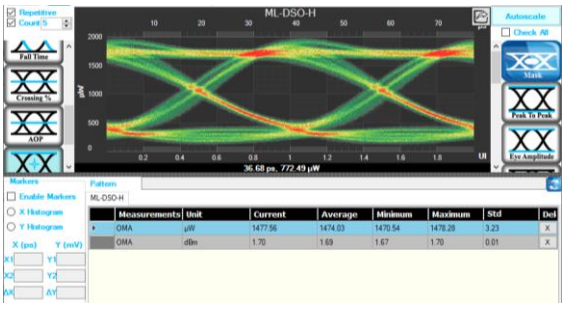
Max	The maximum sample value.	
Fall Time	The mean transition time of the data on the downward slope of an eye diagram between 2 defined thresholds e.g. 80% and 20%. Note that the percentage level of the rise and falling time can be changed by modifying the NRZ thresholds in the data configuration window.	
Rise Time	The mean transition time of the data on the upward slope of an eye diagram between 2 defined thresholds e.g. 20% and 80%.	
Peak to Peak	The difference between the max and the min eye sample values, here max is the value of the sample point with the highest amplitude and min is the value of the sample point with the lowest amplitude.	
Eye Amplitude	The difference between one level and zero level of an eye.	

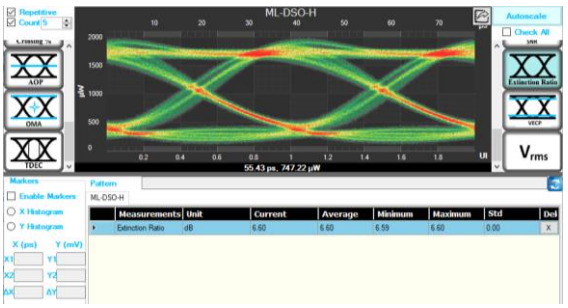
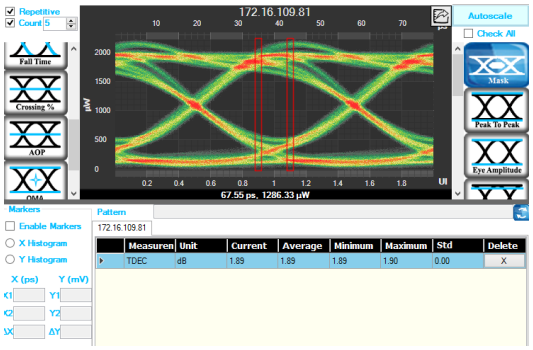
Voltage Amplitude	The difference between top and base of an eye.	
Eye Height	Eye Height is the vertical opening of the eye measured as the difference between the -3 sigma value of the high samples within the NRZ window and the +3 sigma values of the low samples within the NRZ window.	
Eye Width	The time between the latest possible occurrences of one eye crossing to the earliest possible occurrence of the next crossing.	
Total Peak-to-Peak Jitter	Jitter is defined as a measure of the short-term variations of the significant instances of a digital signal from its ideal position on the time axis. In other words, ideally, an edge should always land at the same position on the time axis. In the real world, the edge is sometimes a little early, sometimes a little late. This is jitter. In this revision the Jitter value is Peak to Peak.	
Crossing Percentage	The amplitude of the crossing level relative to the low and high levels. (The value of the crossing percentage is displayed in the bottom of the screen.)	
Jitter	The jitter measurement allows to calculate the total jitter, the jitter peak-to-peak and the jitter rms in ps.	

DJ & RJ	The Deterministic Jitter value is displayed in picoseconds and the Random Jitter value is displayed in fs.	
Mask Margin	The **Switch to Mask Mode** button, located between the Eye and Pattern buttons, is used to find the maximum mask margin that results in no more than a specified number or ratio of failing points. The figure below shows an example of where the user wants to determine the maximum mask margin available for the highest number of failing points, but no more than 25. The answer in this example is +13% for 8 points. Setting the margin below this level would result in less failing points in total. Setting the margin above this level would result in fewer failing points. The DSO has the following standard masks: 100Gbase-SR, LR, STM-1, STM-4, STM-16, Gb Ethernet, Fiber Channel (1x), Fiber Channel (2x, 4x), Fiber Channel (8x), Fiber Channel (10x), 10 Gb Ethernet, and user defined masks. New masks are continuously added. Recent additions are QDR & FDR.	  
Horizontal Bathtub	The Horizontal Bathtub curve is a depiction of Bit Error Rate as a function of unit interval (UI) position. As the measurement location is swept across a UI, the BER is captured, typically resulting in a figure that resembles a cross section of a bathtub, thus the name “bathtub curve”.	
Vertical Bathtub	The Vertical Bathtub curve is a depiction of total vertical noise in signal under test. Voltage points are plotted as a function of BER.	

Pattern Capture Mode	Pattern Capture mode enables the raw bit sequence captured by the DSO to be captured. In order to see the behavior of a specified sequence of bits, zoom in and out by scrolling the mouse wheel, or using the cursor to specify the region to be zoomed in upon. Pattern rise/fall times pre-emphasis, post-emphasis, PRBS validity and VMA (voltage modulation amplitude) can be measured in this mode. Note, Pattern Capture mode needs to be able to show the full pattern for certain features of the software to work, such as:	
VMA	The voltage modulation amplitude of a pattern displayed in mV.	
PAM4	Pulse-amplitude modulation (PAM4) is a form of signal modulation where the message information is encoded to one of 4 amplitude levels. Unlike NRZ which varies between 2 amplitude levels indicating zero and one, PAM 4 varies between 4 amplitude levels where one symbol corresponds to a value in the range zero to three. This leads to double the bit rate for the same baud rate as NRZ. To unlock the PAM4 measurement library, choose PAM4 as the signal type.	
Voltage RMS	The voltage RMS measurement can be captured without Pattern or Eye Lock, and can be used to determine noise floor, which is then entered in the Configuration/ Advanced Menu for De-Embedding the intrinsic noise from the setup. Some of the measurements (Min, Max, One, Zero, Peak to Peak, Eye Amplitude, Eye Height, Eye Width, Eye Height BER, Eye Width BER and VEC) are applicable in PAM4 mode.	

Noise	This library is a consolidation of all vertical noise measurements including rms and deterministic noise. For an optical DUT signal this will be depicted in Watts.	
SNR	The signal to noise is a ratio of the signal difference between one level and zero level relative to the noise present at both levels.	
VEC	VEC = Vertical Eye Closure in dB. Calculated in NRZ as: $20 \times \log\left(\frac{Eye\ Amplitude}{Eye\ Height}\right)$ Calculated in PAM 4 as: $20 \times \log\left[Max\left(\frac{AV_{upp}}{V_{upp}}\right),\left(\frac{AV_{mid}}{V_{mid}}\right),\left(\frac{AV_{low}}{V_{low}}\right)\right]$ Note: AV is the eye amplitude and V is the eye height in PAM4 mode.	
Eye Skews	Ratio Level Mismatch is a measure of linearity in a PAM4 signal. This measurement is defined by the IEEE as a metric to compare the consistency of the three eye openings of a PAM4 signal. Please refer to the 120D-6 IEEE annex for the relevant equation.	
R_{LM}	Ratio Level Mismatch is a measure of linearity in a PAM4 signal. This measurement is defined by the IEEE as a metric to compare the consistency of the three eye openings of a PAM4 signal. Please refer to the 120D-6 IEEE annex for the relevant equation.	

SNDR	Signal-to-Noise Distortion Ratio in dB. SNDR is defined by: $10 \times \log_{10}\left(\frac{P_{max^2}}{\sigma_{e^2}+\sigma_{n^2}}\right)$ where P_{max} is the maximum value of P(k) which is the linear fit pulse response, σ_e is the standard deviation of the error e(k) and σ_n is the RMS deviation from the mean voltage at a fixed point in a run of at least 8 consecutive identical levels.	
AOP	Average optical power of the input signal in dBm. Calculated average optical power is the average power level of all captured points in the eye diagram. Measured average optical power is derived from the optical-to-electrical converter within the scope.	
Outer OMA	The outer OMA (Optical Modulation Amplitude) depicts the difference between the power levels of the highest logic level (11 in PAM4) and the lowest logic level (00 in PAM4) in dBm. It is measured from consecutive identical bits of the two levels.	
TDECQ	Transmitter and Dispersion Eye Closure for Quaternary. TDECQ is, as defined by the IEEE, a measure of each optical transmitter's vertical eye closure when transmitted through a worst-case optical channel, as measured through an optical to electrical converter (O/E) and equalized with the reference equalizer.	
OMA	The standard OMA (Optical Modulation Amplitude) depicts the difference between the power levels of the ‘1’ and the ‘0’ logic level of an NRZ signal in dBm.	

Extinction Ratio	The Extinction Ration is defined as the ratio of the power levels of the '1' and the '0' logic levels of an NRZ signal. As it is a ratio of two powers, it is depicted in dB.	
TDEC	Transmitter and dispersion eye closure (TDEC) is a measure in dB of an NRZ optical transmitter's vertical eye closure as if observed at the end of a worst-case fiber. It is based upon vertical histogram data from an eye diagram measured through an optical to electrical converter (O/E) with a bandwidth equivalent to a combined Ref RX and worst-case optical channel.	

Multiple Measurements

The multiple measurements gives the user the ability to view the different measurements: Top, Base, Min, Max, Fall/ Rise time, Peak to Peak, Eye Amplitude, Eye Height, Eye Width, Jitter, and the crossing percentage for a number of measurements specified in the repetitive box or for an undetermined number. Use the **Check All** text box to display all the measurements.

Statistics

To enable repetitive data acquisition, and statistics measurements, the repetitive mode needs to be checked or the numbers of acquisition in the counter box needs to be increased, then the statistical measurements are shown and the following is displayed: Current value, average minimum, maximum and the standard deviation of each measurement.

Filters

The DSO GUI platform comes equipped with useful filters that offer a variety of signal processing techniques including cleaning the signal, de-embedding and discovering the optimal taps for improving an NRZ or PAM4 signal. The filtering GUI can be used to adaptively detect the minimum number of FFE or DFE taps required to reach a target Eye Height or SNR.

These filters can be applied to a DUT signal with or without introducing the **preserve noise** feature, which compensates for the filter side effect of reducing signal noise of adjacent measurement points. Please see **Appendix V** for more information regarding the preserve noise feature.

Click on the Filters button after a successful signal acquisition.

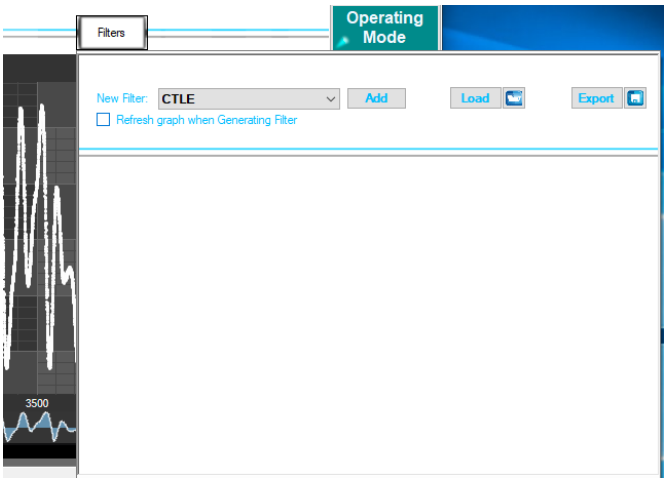


Figure 10: PAM4 pattern mode

Current List of Supported Filters:

1- Moving Average Filter for signal smoothing: User can specify window size.
2- 4th Order Bessel Thomson filter at frequency equal to 0.75 of the bit rate (order and cutoff are configurable).
3- CTLE filter: User can automatically or manually select the filter parameters. Adaptive CTLE can determine the CTLE for best Eye Height.
4- S2P/S4P De-Embedding: This filter simulates the inverse of a channel or DUT, where the channel's S2P or S4P file is loaded. Can also emulate channel insertion loss.
5- DFE: The Decision Feedback Equalizer (nonlinear adaptive equalizer) is based on the principle that once the decision circuit has determined the value of the current transmitted symbol, one can precisely remove the ISI contribution of that symbol to future received symbols. Optimal DFE parameters can be determined by the GUI, and it can also adaptively detect minimum taps required for a target Eye Height or SNR value.
6- FFE: With the Feed Forward Equalizer (linear equalizer), each value of the output sequence is a weighted sum of the most recent input values. Optimal FFE parameters can be determined by the software, and it can also adaptively detect minimum taps required for a target Eye Height or SNR value.
7- SIRC: Also referred to as SRC, stands for System Impulse Response Correction. It is the extracted time domain impulse response of a reference O/E which is converted into the frequency domain using an FFT. Two methods with which this file is generated are discussed in detail in Appendix IV. Either method will yield a 4th Order Bessel-Thompson roll-off as dictated by the IEEE 802.3bs/cd publication standards for both NRZ and PAM4 optical signals.

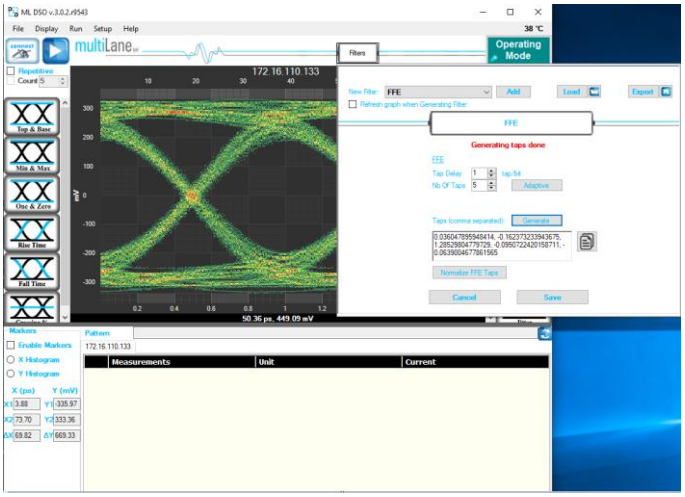
Filter Configuration Parameters follow:

FFE:

1. The tap delay is expressed as an integer fraction of the bit period.
2. Select the number of taps
3. Tap coefficients: enter the different tap coefficients separated by commas, from tap 0 to tap N.
4. Normalize: This would normalize the filter taps ensuring unity gain. Note that if taps were generated automatically, they would already be normalized (sum = 1).

DFE:

1. With DFE, tap delay is always fixed to 1 tap per bit.
2. Tap coefficients: Enter the different tap coefficients separated by commas, ranging from tap 0 to tap N.
3. Delay value, given in picoseconds, allows users to change the decision point of the DFE slicer. This value must range from the negative bit period/2 ($-T_b/2$) to the positive bit period/2 ($+T_b/2$) of the DFE Filter; this delay defines a shift magnitude from the center of the unit interval.



S Parameter Mode

The MultiLane DSO is now capable of measuring insertion loss S-parameters.
Depending on how the DSO is connected, the user should be able to measure either of S21 dd, S12 dd, S21, S12, S43, S34, etc.

The only difference between all the above is:

1. Single ended vs. differential connection.
2. The direction in which the DUT is connected for S-param capture.
3. The ports in use when connecting the DUT via a single ended connection.

The approach used consists of the following steps:

1. Define Circuits:
    a. Main Circuit: Contains the DUT whose S-parameters are to be captured.
    b. Reference Circuit:
        i. Excludes the DUT whose S-parameters are to be captured.
        ii. Is as identical as possible to the Main Circuit, except for the DUT.
        iii. May require an additional component, such as a through, to be placed in the location of the DUT to close the circuit.

2. Set up the PPG:
    a. PRBS 7 or 9, PRBS9 is recommended.
    b. Maximum bit-rate possible (For maximum frequency range in the result)
    c. Cleanest possible Eye: This sometimes translates to maximum amplitude to maximize SNR. However, be careful not to exceed the maximum amplitude supported by the MultiLane DSO without using attenuators.

    Kindly note PPG settings and amplitudes should not be altered after this point.

3. Capture the reference signal: when having the optimal PPG settings as described above, and with the reference circuit connected, run the DSO S-Parameter Setup Wizard to capture reference data.

4. Without altering any of the PPG settings, connect the main circuit, simply connect the DUT where needed to switch from **Reference Circuit** to **Main Circuit**, and run in S-parameter mode, the S21 insertion loss result will be visible.

    For a constant PPG Source Signal, S21 Is calculated using the equation:
    Frequency Response of DUT = FFT (Main Circuit Signal) / FFT (Reference Circuit Signal)

5. Insertion loss can be saved in external .S21 or .DsoCirc files. These files contain both magnitude and phase information; however, phase information is not accurate in the

sense that there will always be a linear shift in phase. These files with their magnitude and phase information can later be used in the DSO Software for de- embedding or DUT emulation.

Components in Use

1. Two pairs of cables.
2. Two Module Compliance Boards that support the DAC connector. MCB S-parameters will be required. Often S-parameter information is supplied by the vendor.
3. One DAC cable.
4. Two through connectors that can mate the cable pairs together. These connectors will be considered to have negligible insertion loss.
5. MultiLane DSO
6. Any PPG, in this example the MultiLane BERT was used.

First, Connect Your Reference Circuit Hardware

Begin with connecting the circuit you will use as reference circuit as follows:
Connect PPG differentially to Cable Pair 1, to Throughs, to Cable Pair 2, then to the DSO PPG => Cables 1 => Through => Cables 2 => DSO.

Step 2, Configure your PPG for Cleanest Signal

1. Setup your PPG: Kindly refer to step 2 under "S Parameter Mode" found on page 30.

2. Observe the signal on the DSO after going through the 'Reference Circuit'. Tune the PPG settings, sometimes you need to alter emphasis settings, sometimes amplitudes, sometimes bit rates. The cleanest eye possible for the highest rate possible will yield the most accurate result.

3. Once PPG settings are finalized, note them down. Kindly note PPG settings should not be altered after this point

Step 3, Go Through the S-Parameter Wizard on the DSO

Connect to the DSO

This DSO should currently be reading the signal going through the reference circuit. Recommended settings include a packet size of 512 and SW-PTB enabled.

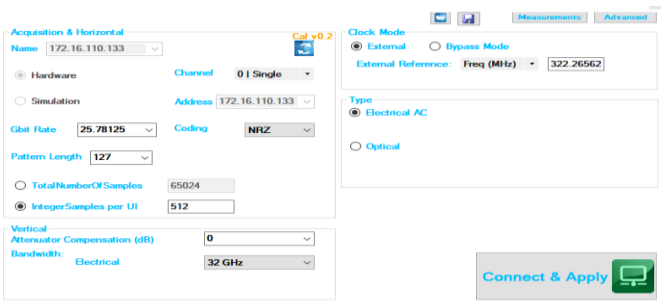


Figure 11: S-Param Configuration

Go to S-Parameter Setup

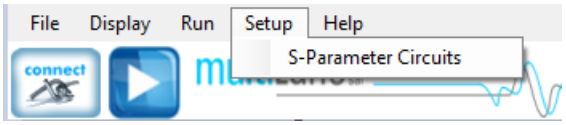


Figure 12: S-Param setup

Select the DSO Connected

After selecting the DSO click 'New Setup'.

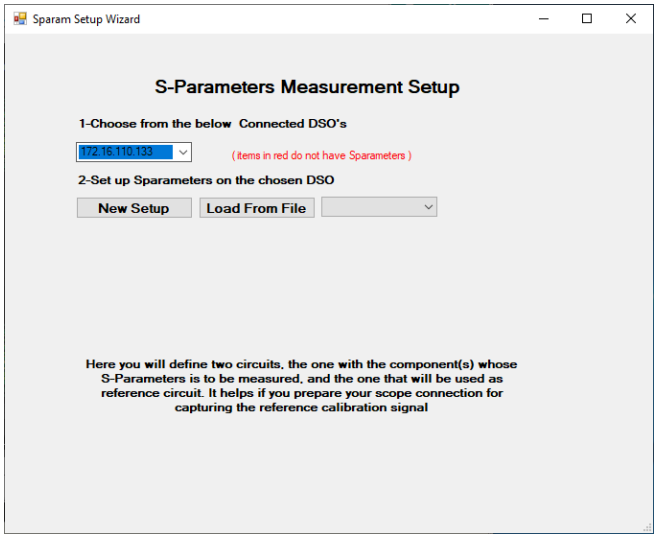


Figure 13: Setup

Create Your Main Circuit

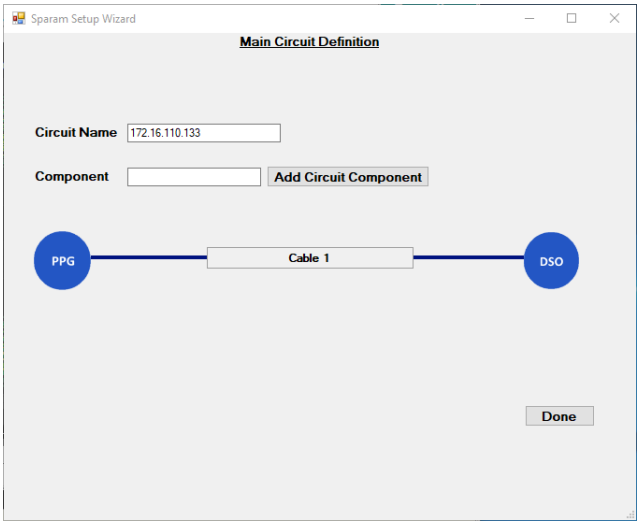


Figure 14: Main Circuit

Add the Main Circuit Components

Load the S-parameters of the MCBs. These will be used to calculate the S-parameters of the DAC DUT.

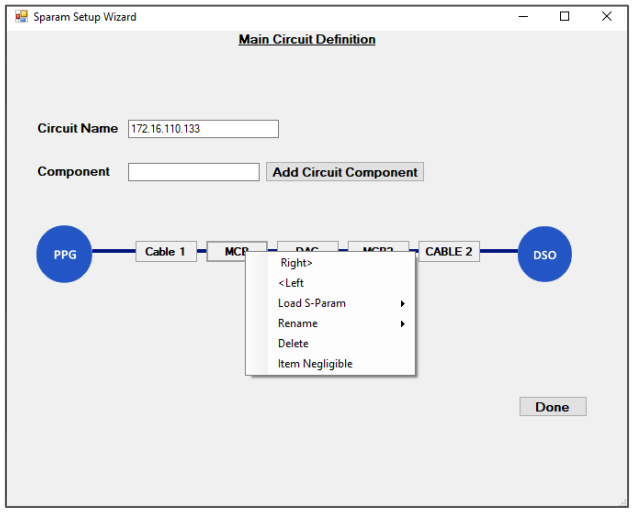


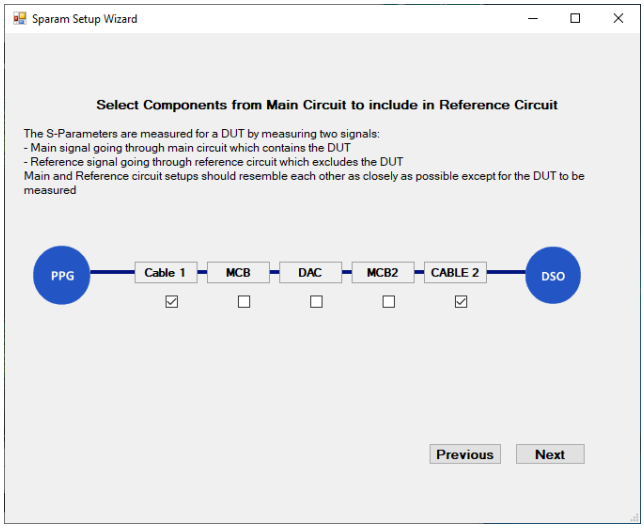
Figure 15: Main circuit component

Proceed by clicking 'Done'.

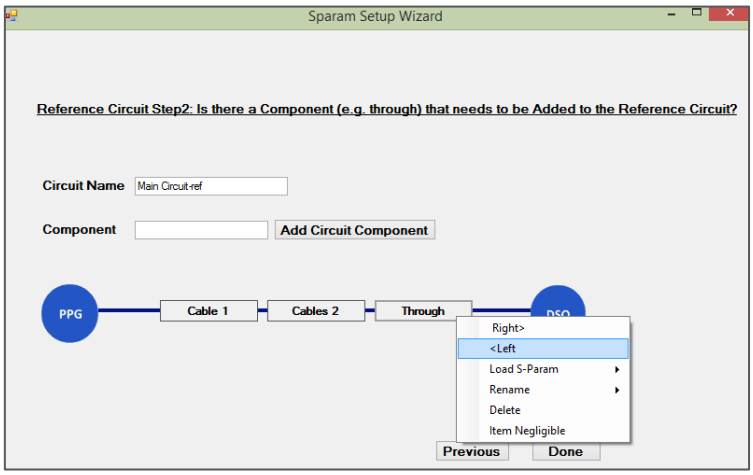
Select Components from Main Circuit Present in Reference Circuit

Select Cables 1 and 2 and click Next.

Add Through Connector in Reference Circuit Definition

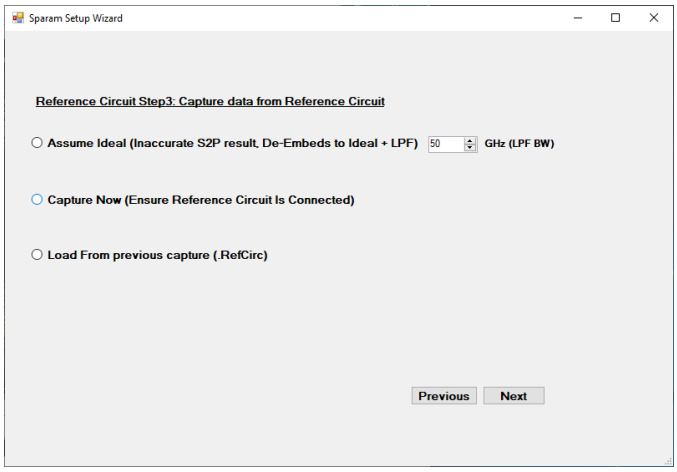


When done, click next.



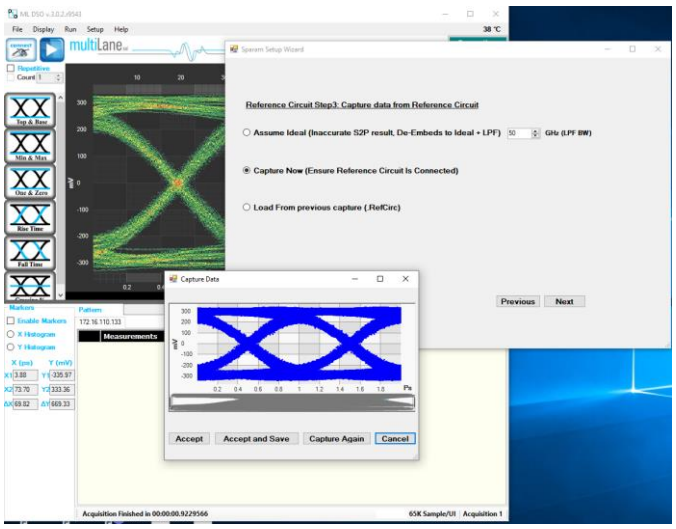
Capture Reference Data

Click 'Capture Now'



The captured eye is depicted, the user can accept it or recapture.

Alternatively, the user may 'Accept and Save' the reference eye data. This will save the captured reference data for future use, allowing the user to call on 'Load from. RefCirc' in the future when visiting this page, hence avoiding reconnecting the reference circuit.



Click ‘Next’

Frequency Domain Mode

Upon moving to frequency domain mode, the frequency response can be plotted, and the total harmonic distortions can be calculated.

Appendix I: USB Driver Installation

USB software drivers' names: **ML-DSO USB driver**.

The following instructions are applicable for a manual USB driver installation using Windows XP, Windows 7 and 8. If the system is running windows 8, **driver signature must be disabled.**

- Power up the instrument
- Plug the USB cable into the PC and connect it to the ML-DSO
- Ignore the messages *new hardware found* or *driver software not successfully installed* by pressing **cancel** or **close**
- Go to the device manager via a right click on **My Computer:**
  - Click on **Manage**
  - Click on **Device Manager**
- Right click on the top-level tab (MultiLane-PC) and select "**Scan for hardware changes**"

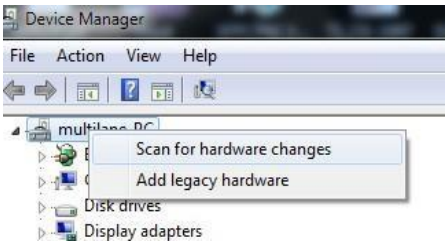


Figure 16: Scan for Hardware

- A message appears stating: "**Scanning Plug and Play compliant hardware**"

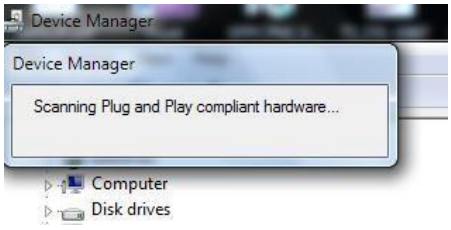


Figure 17: Scanning for plug and play compliant hardware

- In the **Other Devices** tab, right-click on the **ML-DSO USB Device** and select "**Update Driver Software**"
- A dialog box appears asking for the method to search for the driver software; select "**Browse my computer for driver software**"
- A dialog box appears asking for the Driver software path; enter the path and click "**Next**"

- A security dialog box appears, select "**Install this driver software anyway**"
- The PC commences driver software installation
- A Windows message appears (after some time) saying that the driver software is successfully updated
- In the Device Manager, a new tab appears named **MultiLane SAL Devices**; expanding it reveals "**MultiLane SAL ML-DSO USB Device**"
- USB connectivity is now possible

Appendix II: How to connect this instrument

The **ML-DSO** has 2 connection ports: USB (for configuring Ethernet IP) and fast Ethernet.

USB Cable Connection

The USB port is only used to configure the IP address of the device, not to perform measurements in real application mode.

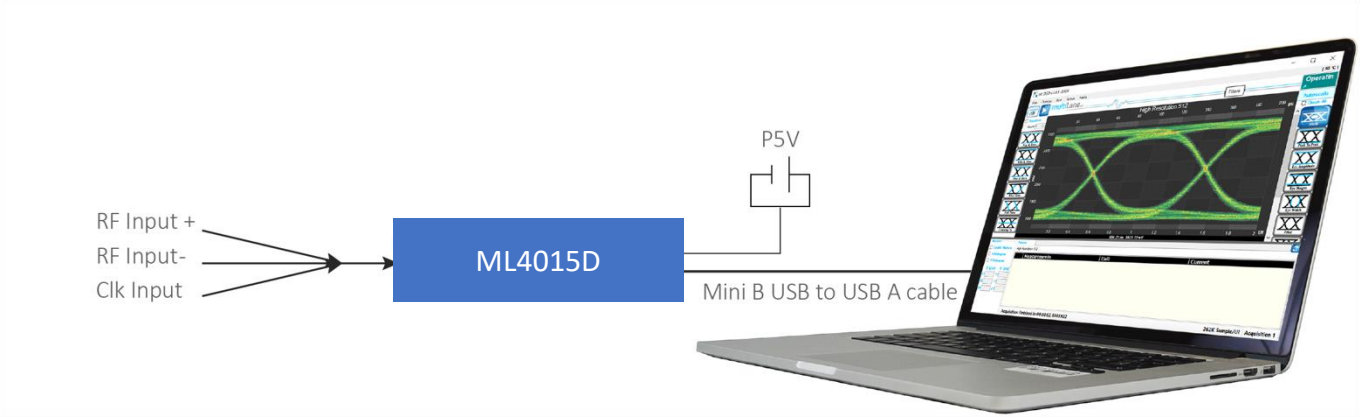


Figure 18: Connection via USB

Connection through an Ethernet cable

Connect an Ethernet crossover cable between the ML-DSO and the PC or instead a standard Ethernet cable between the ML-DSO and a router or switch. The device can be pinged to verify that a connection has been established.

Appendix III: Ethernet Configuration

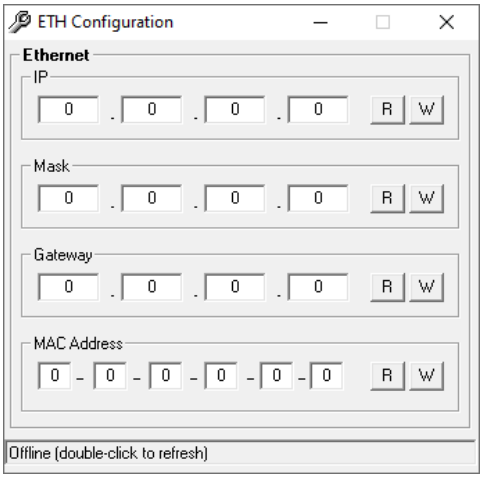


Figure 19: Ethernet Configuration

After connecting the ML-DSO to the PC through the USB cable, run the **DSO Conf** software. Read the current IP address by pressing the "R" button. Note that the device has a default IP address: 172.16.115.155; it can be changed to fit the network.
Press "W" to save the new address. The mask and gateway configurations can be changed in order to fit the network.
Double click inside the bottom white box in order re-establish the connection.

Appendix IV: SIRC Calibration Methods

A correctly implemented SIRC filter yields a 4th-Order Bessel Thompson roll-off response as outlined by the IEEE802.3bs/cd publications. ORR, the Optical Reference Receiver filter, is specified by selecting a certain frequency cutoff percentage of the bitrate, see the following examples:

- 75% of 25 Gbaud for legacy NRZ signals
- 50% of 26 Gbaud and 53 Gbaud for PAM TDECQ measurements of single-mode signals
- 75% of 26 Gbaud and 53 Gbaud for OMA measurements of single-mode signals
- 42% of 26 Gbaud for measurements of multi-mode signals

Method 1: Factory Calibration

SIRC Calibration is conducted at an ML premises with a femtosecond pulse laser. Using a 100 MHz rep rate, a pulse is sent from a high-end laser to each of our O/E's. We capture the electrical time domain pulse data from the O/E at different gain levels that are relevant to the application; following this the pulse is processed into the frequency domain. A filter file for each gain level is then generated, and these files are shipped to the end user along with the DSO platform.

Method 2: Field Calibration

This method can be carried out in an end-user lab environment and relies on the use of a third-party optical sampling scope as a reference. Due to its higher energy density, a PRBS signal can also be used to extract an accurate frequency response via a calibrated reference instrument. It is recommended to capture the reference signal at the highest Baud rate supported by the ML DSO in order to maximize frequency reach:

1. Using a ML MATLAB program, figure below, the end user can capture and save a .csv waveform using the reference instrument with **SIRC enabled**.

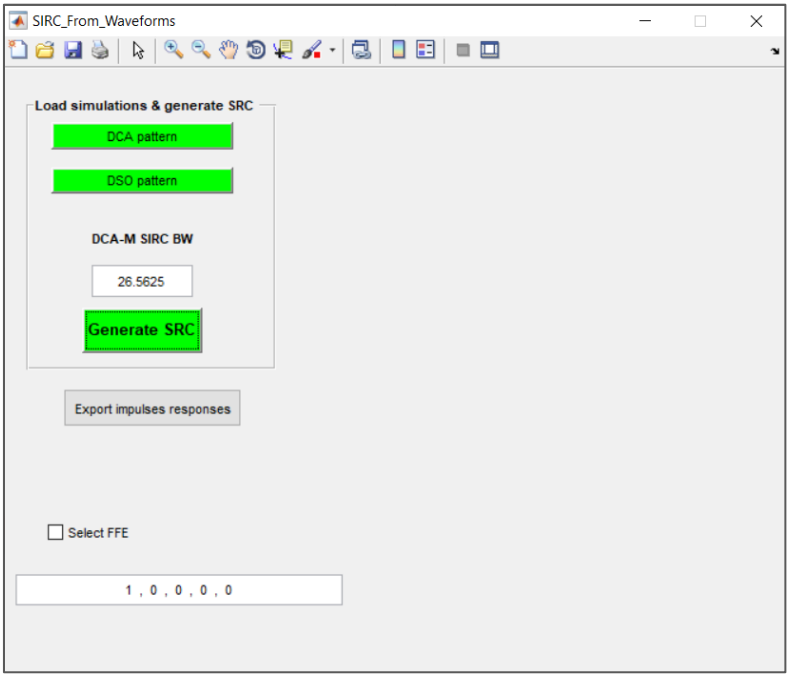


Figure 20: MATLAB SIRC Calibration Script

2. Using the same setup, the end user should capture and save an offline raw data capture from the MultiLane optical DSO at different gain levels.
3. These two waveforms must then be loaded into the MATLAB software. An overlay will be drawn as depicted below and following this a filter file will be extracted.

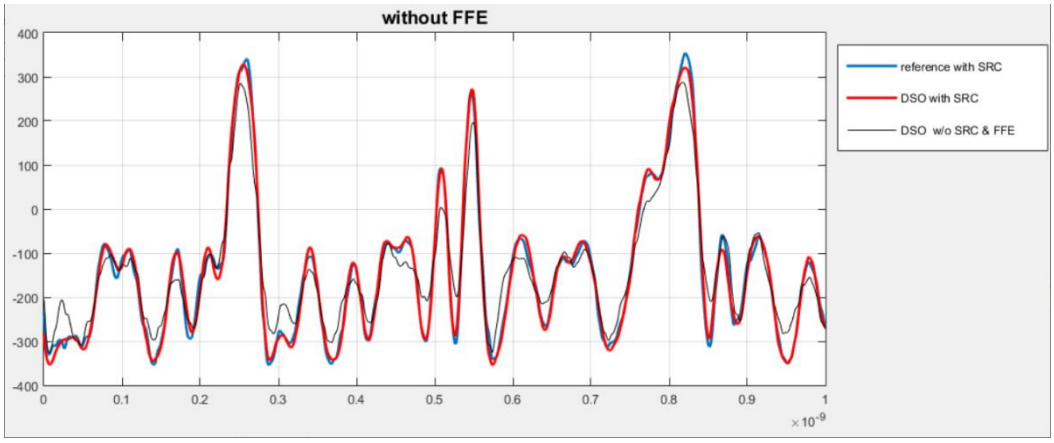


Figure 21: Graphed response with and without filters

Appendix V: Preserve Noise Feature

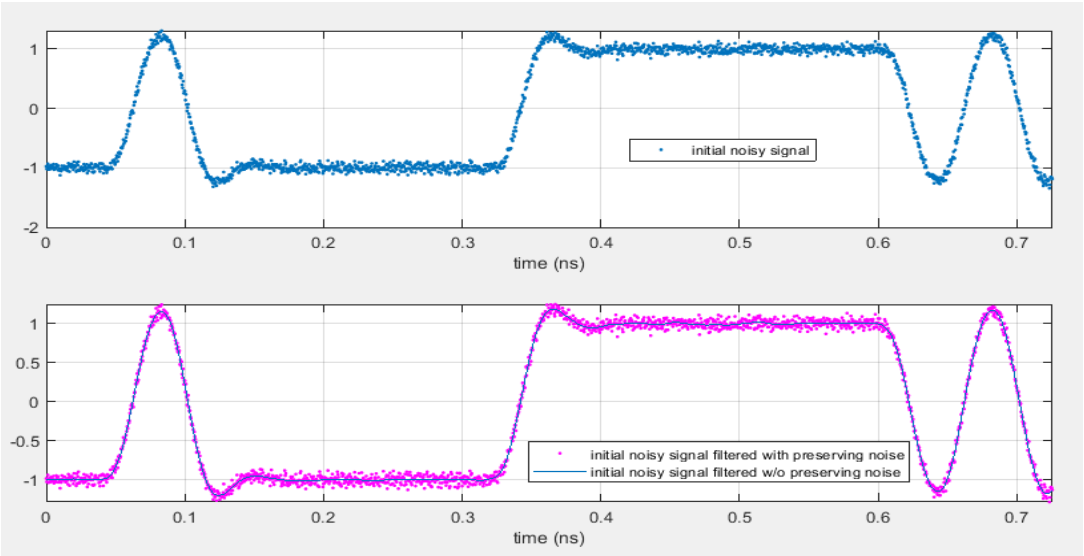


Figure 22: Effect of "Preserve Noise" feature

In order to accurately represent noise in a DUT waveform, a sufficient number of samples must be acquired per symbol. In this case, when higher resolution is attained, noise can be more accurately re-injected into the DUT waveform. Thus, the preserve noise feature in the Low-Pass filter in the ML DSO compensates for the filter function's side effect of noise reduction for adjacent measurement points. Note that an incorrect implementation of this feature can negatively affect measurement accuracy. Some examples will follow:

- This feature is advantageous during mask testing, as the mask hits could be too low (optimistic result) without noise preservation
- The accuracy of TDEC and TDECQ measurements is directly related to the existent random jitter and noise in the DUT waveform. If noise is changed or compensated due to the usage of a low-pass filter like Bessel-Thompson, then the measurement will naturally be inaccurate.
- Setting "preserve noise" to 0% yields a purely deterministic signal, while 100% yields the unfiltered signal with the complete noise profile.