multiLane

ML4039E

Technical Reference and user manual

400G Bit Error Ratio Tester

Innovation for the next generation

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1. General Description

The ML4039E is a fully featured 400G BERT that can be configured as a 4x53.125 GBaud BERT. At high rates (53 Gbaud) and low rates (25 Gbaud) both NRZ and PAM4 modes are supported. It is used in Production testing of transceivers as for Functional and SI testing.
The ML4039E is designed for 400G applications. This instrument is a fully integrated, ultra-compact, USB/Fast Ethernet controlled instrument that combines all the functions and features of a signal generator, bit error-ratio tester and data analysis system with Post-Emphasis and Pre-Emphasis, 7 taps FIR capabilities.

2. Ordering information

The instrument can be ordered with the following part number.

ML4039E	4 channels BERT
ML4039EN	4 channels BERT with Noise injection feature

Table 1: Hardware ordering information

For more details please refer to the below link:
For ML4039E: https://multilaneinc.com/product/ML4039e/
For ML4039EN: https://multilaneinc.com/product/ml4039en/

3. Operating conditions

A 110/220V adapter is used to power-up the board.
If the temperature of the board inside the box has surpassed the 70˚C value, in order to prevent overheating, this temperature is considered as the cutoff value.
The instrument will resume normal functionality again once the temperature is within the optimal range.

4. Block Diagram

The ML4039E block diagram is illustrated in figure 1. Signals are transmitted from the TX side through four independent channels, and the received signals are routed from the RX side of the error detector. These signals can be monitored and controlled channel by channel.

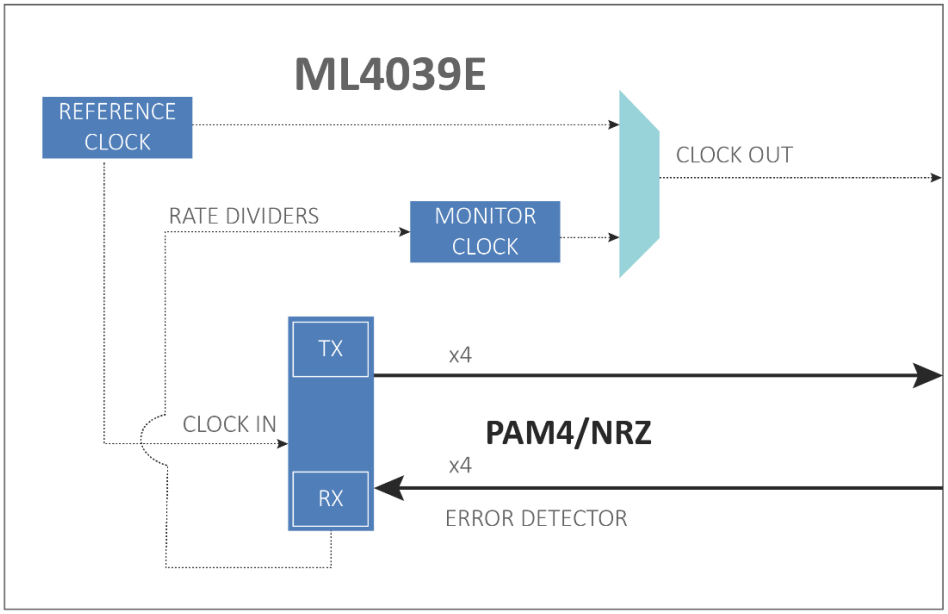

Figure 1: Block Diagram of the ML4039E

5. Hardware design overview

Figure 2 shows a general view of the ML4039E.

Figure 2: ML4039E mechanical drawing

Figure 3: ML4039E front view with dimensions

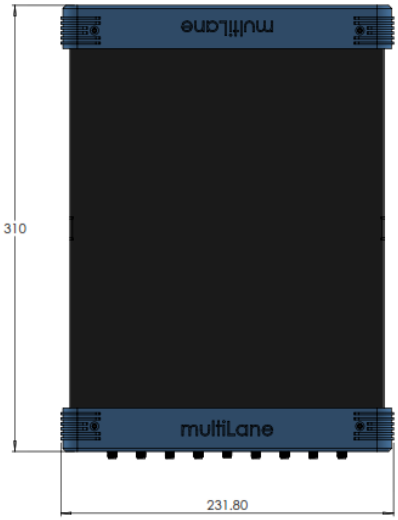

Figure 4: ML4039E top view with dimensions

The instrument dimensions in mm are shown in figures 3 and 4.

With an overall weight of two kilograms.
The back plate includes an ON-OFF switch button, Ethernet and USB ports. A 110/220V power adapter can be connected to supply the board with the required power.
The faceplate shows an SMA connector for clock out.
Also the faceplate shows sixteen connectors type K (2.92mm connectors) that are used to connect to the four differential TX and RX channels. Once powered up, and the switch button turned on, the board should be able to perform all the required measurements.

6. Clock Configuration

The ML4039E supports output clock. The user can switch between two options the reference clock and monitor clock. The monitor clock supports the following rate dividers: 4, 8, 16, 32, 64, and 128. Rate divider 4 is currently only supported at low rates.
The reference clock has an optimal value of 156.25 MHz.
In the current hardware revision, external clock option is not supported.

7. Transmitter side characteristics

As described above the TX signals are transmitted through four independent channels.
The Low voltage settings or high voltage settings for each channel, generated during the calibration process, at scaling 80% (for low voltage) or 100% (for high voltage), is being applied at high and low rates, and in both eye modes: NRZ and PAM4.
These settings once applied and saved, during calibration, ensure that the ML4039E performs all the required measurements in optimal mode.
These settings can be controlled by the user in advanced mode, in this way the user can control all the TX settings including: TX pattern, amplitude, Pre-emphasis, Main Tap, Post-Emphasis or the 7 FIR taps…

The ML4039E operates in PAM4 and NRZ modes, on numerous bitrates.
The BERT locks on all the supported rates, amplitudes and patterns. The parameters are mentioned in table 2.
The TX Equalization is a digital combination of FFE and DFE. PAM4 gray coding is also supported.
Test pattern generator per lane includes error injection.
The patterns, error insertion and emphasis taps can be checked and controlled per lane.
The user could turn off and disable the TX side channel by channel.

Kindly refer to the user manual paragraph 11 for more details on how to operate the ML4039E.

Table 2 shows the TX Output Characteristics of the ML4039E.

Parameter			Typical	Maximum	Unit
Line Rate	NRZ		22.75 – 29.25 45.5 – 56	up to 29.25 (low rate) up to 56 (high rate)	Gbps
	PAM4		22.75 – 29.25 45.5 – 55.5	up to 29.25 (low rate) up to 55.5 (high rate)	Gbaud
Clock-out Amplitude			TBD		mV
Clock-out Frequency	Monitor		Rate dividers: 4, 8, 16, 32, 64, 128	Up to Rate/4 (at low rates)	MHz
	Reference		156.25	133.82 -165	
Output Amplitude	Low Rate (NRZ& PAM4)	Advanced Mode	Up to 670		mV
		80% Calibrated	Up to 365		
	High Rate (NRZ & PAM4)	Advanced Mode	Up to 550		
		80% Calibrated	Up to 240		
Patterns			PRBS 7/9/11/13/15/23/31/58/9_4 SQ16, SQ32, LIN, CJT, SSPRQ, User Defined		
Transition time (20%-80%)	Low Rate		~14		ps
Transition time (20-80%)	High Rate		~12		
Jitter	Low Rate		TBD		ps
	High Rate		TBD		
Emphasis Resolution			± 1000		Steps

Table 2: TX output specifications

8. Receiver side characteristics

The receiver side characteristics are described in this section.
The BERT locks on different patterns, with the polarity inversion option. Real-Time BER can be measured. Histograms and SNR shared across all four channels. Independent CDR in each lane, being able to recover the supported rates.

Parameter		Typical	Maximum	Unit
Line Rate	NRZ	22.75 – 29.25 45.5 – 56	up to 29.25 (low rate) up to 56 (high rate)	Gbps
	PAM4	22.75 – 29.25 45.5 – 55.5	up to 29.25 (low rate) up to 55.5 (high rate)	Gbaud
Sensitivity	Low Rate	90		mV
Sensitivity	High Rate	100		
Patterns		PRBS 7/9/11/13/15/23/31		
CTLE		Adaptive (not manually controlled)		Steps

Table 3: Receiver specifications

9. ML4039EN characteristics

The ML4039EN has the same features as the ML4039E but in addition to that it also has a noise injection feature where the user can set and control the noise rate, pattern and amplitude being injected channel by channel.

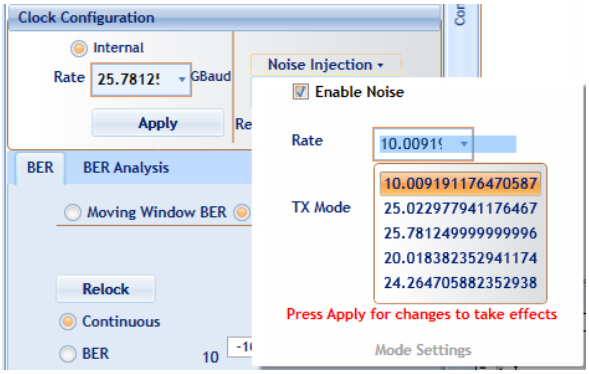

Figure 5 : Noise injection supported rates

10. Current revisions

The current revision of the ML4039E hardware is: ML4039E Rev C

All the listed features are tested using the following software and firmware:

- Software revision: MLBert_v.4.4.0.0
- Firmware revision:
  - ML4039E: ML4039E-Hyb_revC_FW_V3_0
  - ML4039EN: ML4039EN_V1_0

11. Future Features

The following features will be implemented in the future ML4039E versions:

- FEC implementation
- External clock option

12. User Manual

12.1 GUI General Description

This section describes how to operate the ML4039E and all the capabilities of this BERT.
The product software is available on the company's website on the below link:
https://multilaneinc.com/berts-gui/

12.2 Installation

This chapter covers the installation of the instrument, addressing the following topics:

- System Start-up
- How to connect to the instrument

Note: For windows vista, 7, 8 and 10 users should always run the GUI as administrator.

First Steps
When the customer receives the instrument, it has a pre-configured IP address from the factory. This IP address is printed on a label on the instrument's back plate. The user can choose to keep this IP or to change it. If changing the IP is needed, there are two ways to do it: either through the USB interface, or through the Ethernet interface. If changing through USB is selected, then the USB driver of this instrument should be installed from the company's website, and the user needs to choose the application ETH config.
If the LAN interface is used to change the IP, then the user has to download the application "IPChanger" from the company's website and temporarily change his PC's IP to be in the same domain as the instrument, i.e. 172.16.xx.xx. Once the instrument's IP is successfully changed, the user can change back his PC's IP.

- It would be good if the user prints a label with the newly assigned IP address and sticks it on the instrument. If for some reason the IP is lost, the user will need to use the USB interface together with the ETHconfig software to "read" the IP.

Connect through Ethernet:
In order to connect via Ethernet, the IP address of the board is required. While no drivers are required; the user should simply know the current board IP address, and need to enter it in the text box next to the **IP** label, then click on the **connect** button.
The user can make sure that he is connected, by pinging the device.
To change the IP address of the board, the user needs to install the USB drivers.
(Refer to paragraph 11.3).

After installing the setup, the user will be able to open the ML4039EGUI.

Figure 6: ML4039E GUI at start

12.3 Connecting Procedure

The user needs to connect using the board's IP, after that the board has been powered-up.

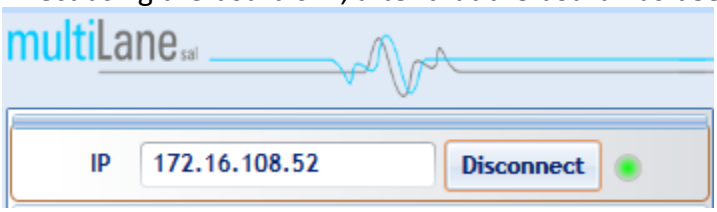

Figure 7: Connecting using the board IP

After clicking on Connect, all the Low voltage settings that have been saved during the calibration process are being applied. Also, the last used configuration is being applied.
Then the user can check the board's settings including the hardware ID and the firmware revision.

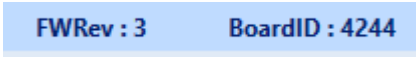

Figure 8: ML4039E Firmware revision and Board ID

The displayed information is updated whenever any of the fields is being updated.

12.4 BERT Tab

At the first glance, after connecting to the board, the user will be able to detect on the GUI the: IP, Serial number, monitoring temperature, channels TX and RX lock, selected bit rate and all the clock configurations...

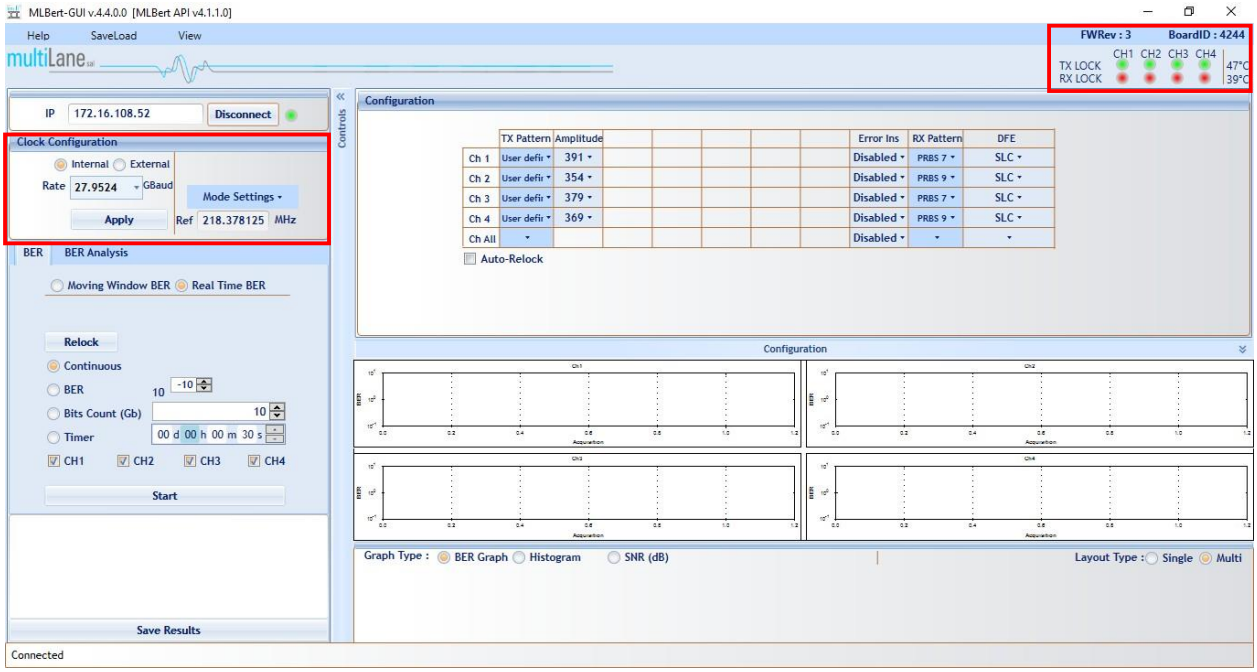

Figure 9: Main features detected after connecting

The user can select and control all the BERT settings.

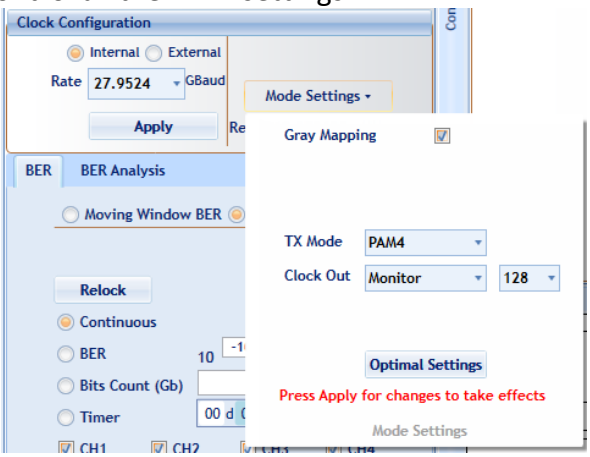

Figure 10: Rate and clock configurations

The ML4039E supports in low and high rates both eye modes: NRZ and PAM4.

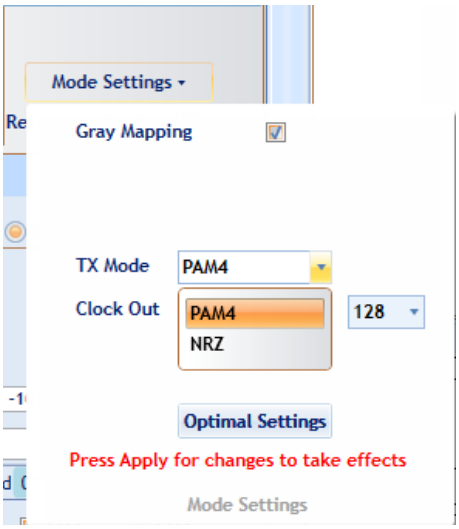

Figure 11: Supported eye modes

To switch between NRZ and PAM4 coding, use the TX Mode setting, then click Apply.
The option Gray Mapping is only available in PAM4 mode. Gray Mapping enables use of PRBSxxQ defined in IEEE802.3bs. When Gray mapping is enabled, the PRBS13 and PRBS31 under the pattern select menu turn into PRBS13Q and PRBS31Q respectively.

For the clock configuration first select internal as the option (external clock-in option will be added in future ML4039E versions).The user now can select from mode settings between reference clock and monitor clock. For optimal results the Ref Clk should be selected.

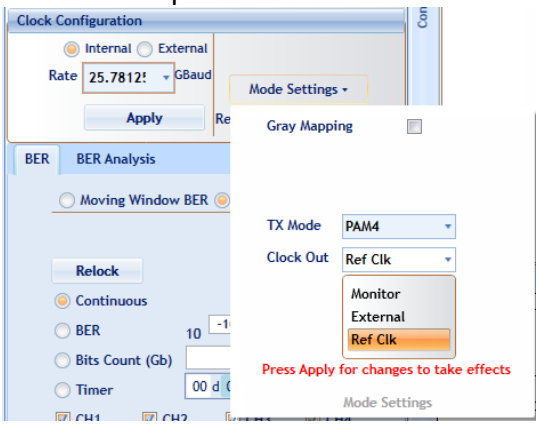

Figure 12: Internal Clock Selection

For the monitor clock the output can be controlled based on the selected clock divider.

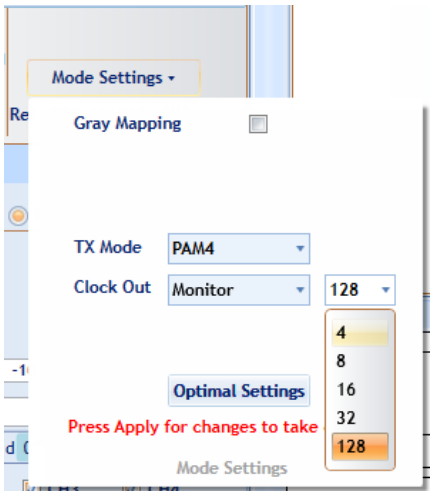

Figure 13: Monitor Clock-out options and dividers

For the line rate, the user can select any of the listed rates or enter any custom rate, but this rate should be in the supported range as described in table 2.
The user can control all the BERT configurations, channel by channel.
The test can be run in Low/High voltage settings mode or in advanced mode.

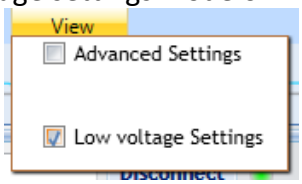

Figure 14: Selecting Advanced or Calibrated Settings mode

When operating in Low voltage settings mode, the Low voltage settings saved during the calibration process are being applied. And the user will be only able to control and change the amplitude. Based on the selected amplitude the software will automatically calculate the optimal settings.

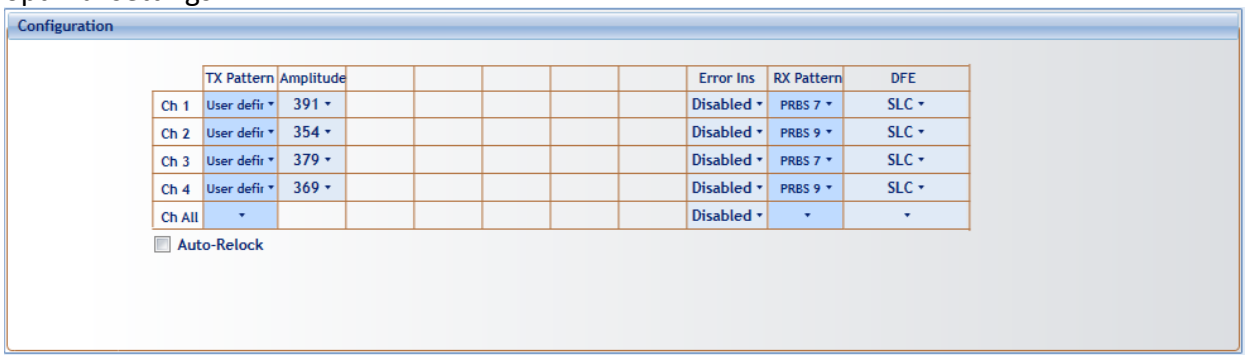

Figure 15: BERT side in Low Voltage settings mode

The ML4039E can output a wide range of pre-defined patterns. In addition to the PRBS patterns, there are linearity and jitter test patterns. Also, on top of the pre-defined patterns the user has the possibility of defining his own pattern.

Note: error detection only works on the PRBS patterns existing in the RX pattern drop down list. It is not possible to do error detection on custom defined patterns.

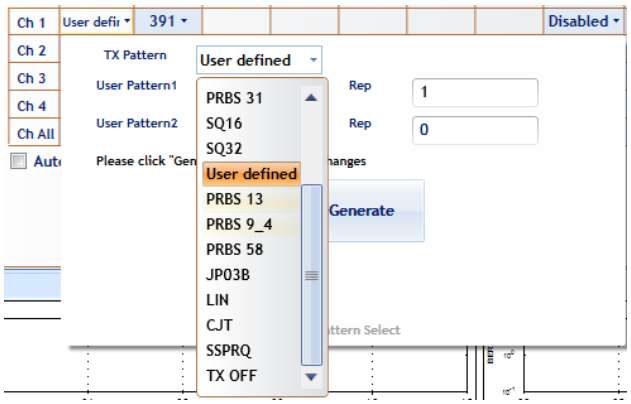

Figure 16: Pattern selection

In NRZ mode, for each level the corresponding eye amplitude is detected on the scope.

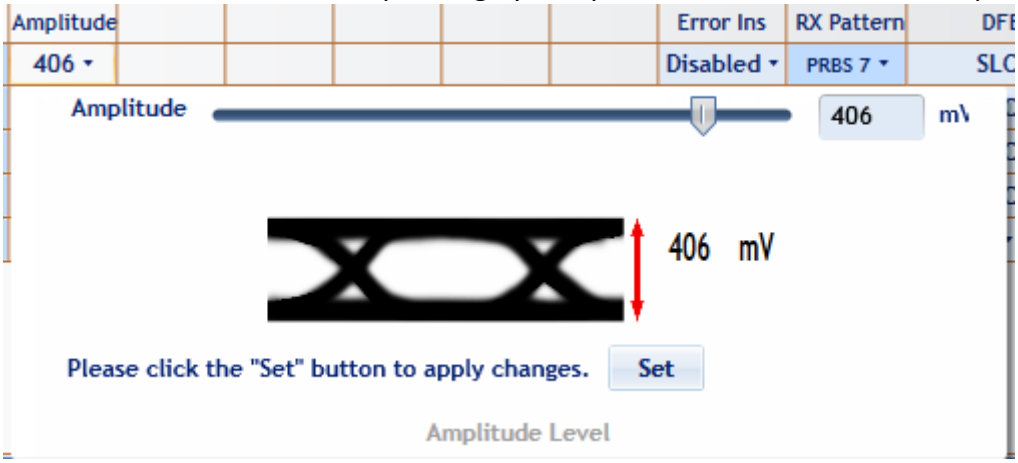

Figure 17: Amplitude control in NRZ mode and with the Low Voltage settings applied

In PAM4 mode, for each level the corresponding total eye amplitude is detected on the scope, this value is equal to the sum of the inner eye amplitude and two outer eye amplitudes. As shown in figure 17.

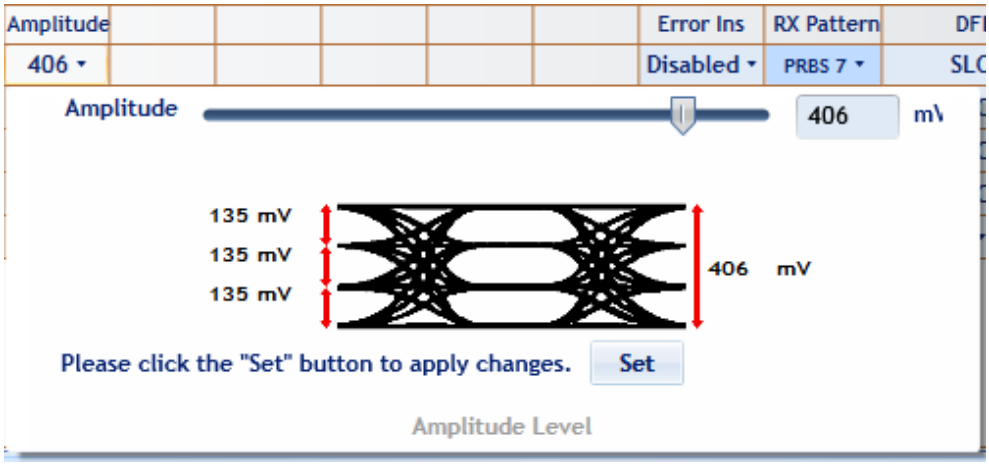

Figure 18: Amplitude control in PAM4 mode and with the Low Voltage settings applied

If the customer desires to control all the parameters, then he needs to go the advanced mode. While switching between advanced settings and calibrated settings modes the user will be modified that the optimal settings are being applied.

Figure 19: Settings being applied

If advanced settings mode is selected, after clicking "OK" on the pop-up window shown in figure 18, the BERT configuration window will be displayed as follows and the user will have access to control the amplitude and the FFE taps:

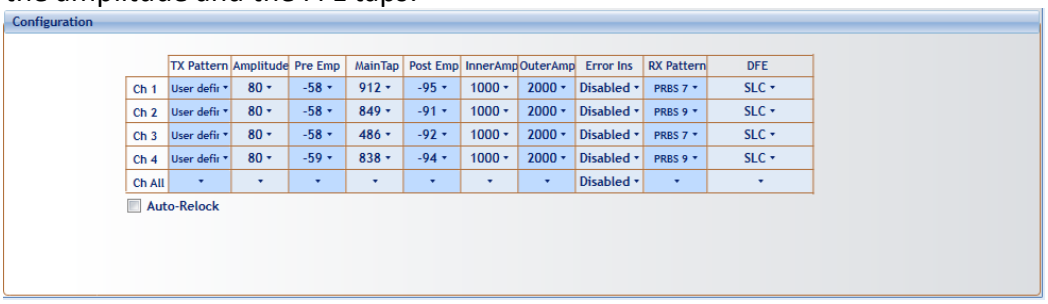

Figure 20: BERT Configurations in PAM4 and Advanced Mode with 3 taps option

Main-Tap, Pre and Post Emphasis level varies between ±1000. The amplitude slider does not show anymore the values that have been saved during the calibration. The user can go up to 120% and the corresponding amplitude is detected on a scope.

To access the 7 taps FIR the user should select the advanced settings then go to the mode settings tab and enable the 7 taps option, and press apply.

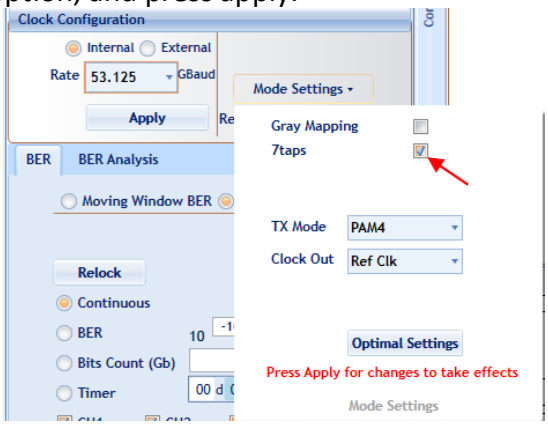

Figure 21: Enabling the 7 taps FIR option

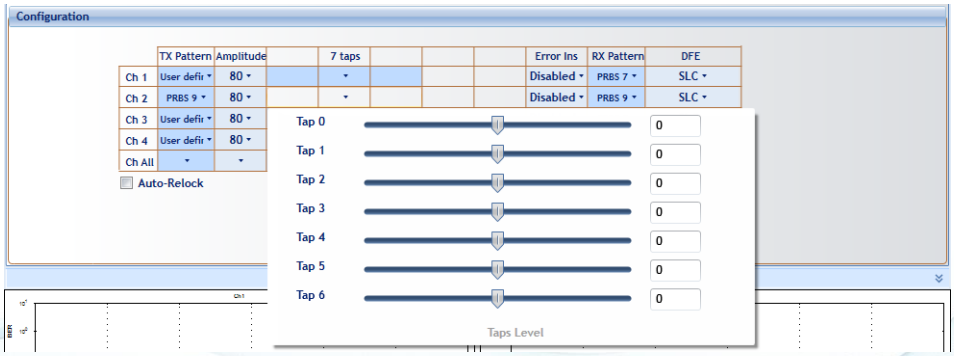

Figure 22: Configurations Tab in PAM4 and Advanced Mode with 7 taps option

The user can test the BER, histogram and SNR, on the selected channels.
Error insertion can be controlled channel by channel.
All these measurements can be performed on all the rates, patterns and in NRZ and PAM4 modes.
Below are shown some screenshots showing the eye in PAM4 and NRZ modes. These screenshots are captured, with the 80% calibrated settings being applied.

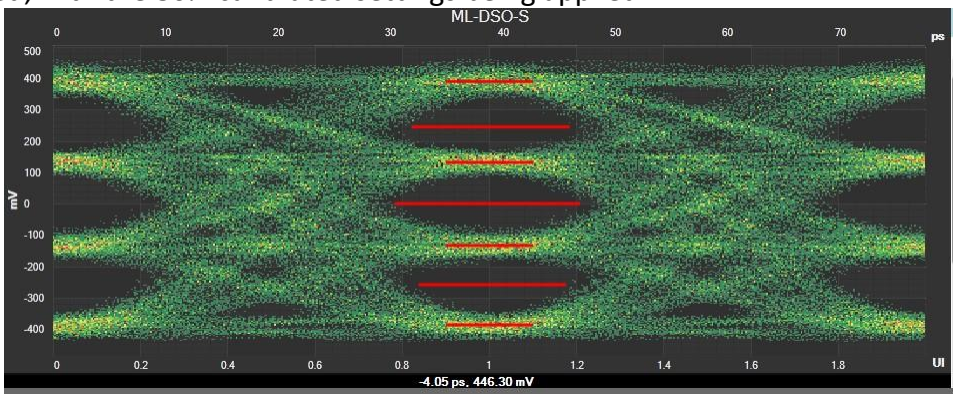

Figure 23: PAM4 mode, low rate

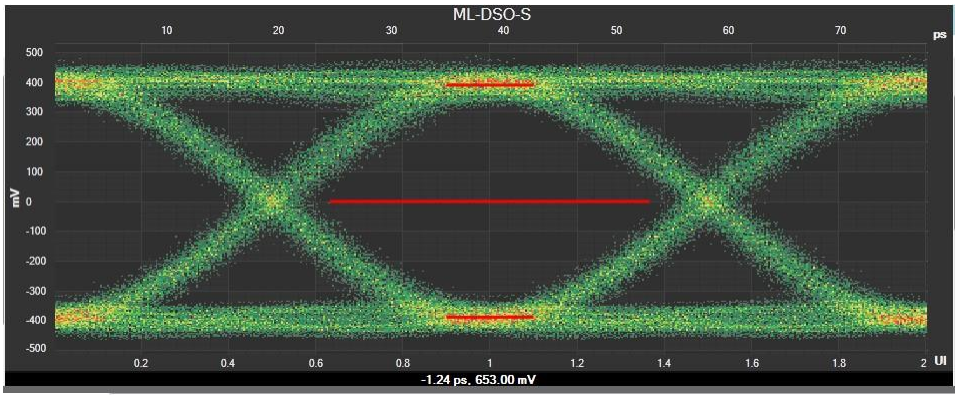

Figure 24: NRZ mode, low rate

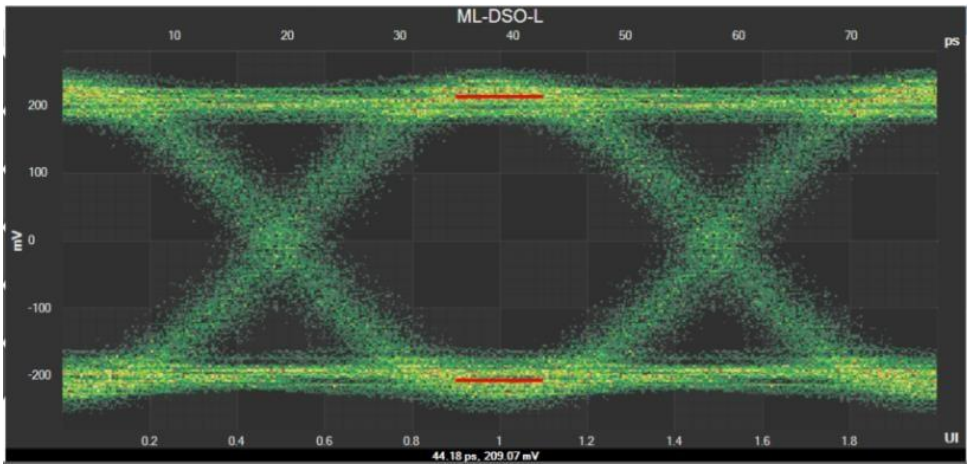

Figure 25: NRZ mode, high rate

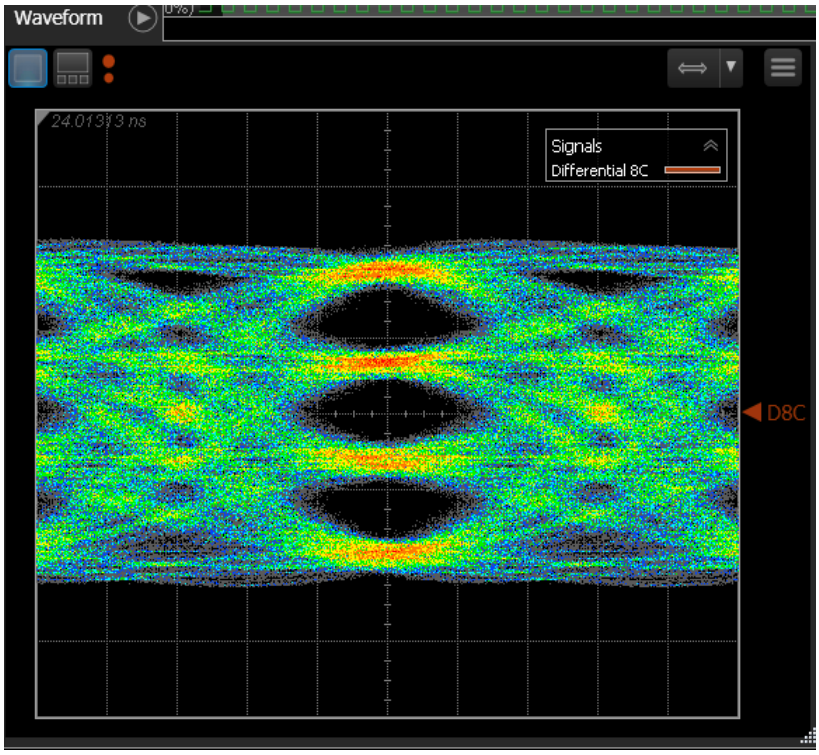

Figure 26: PAM4 mode, High rate with PTB

Figure 26 shows the 7 taps settings that are used to capture figure 27(NRZ eye) and 28 (PAM4 eye).

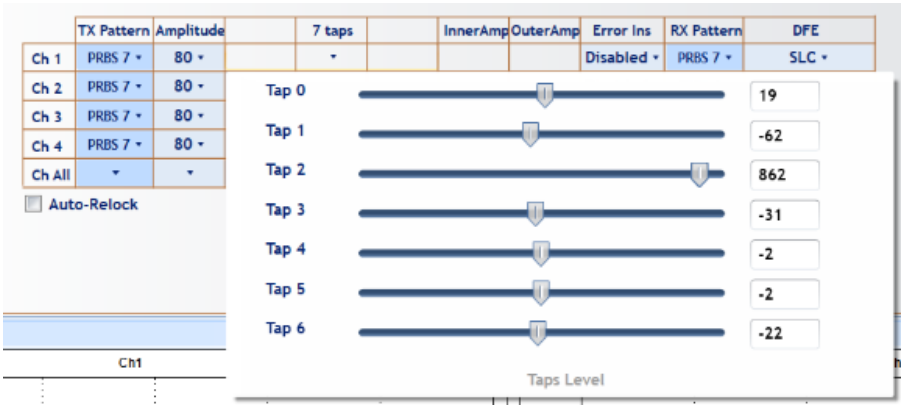

Figure 27: 7 taps values

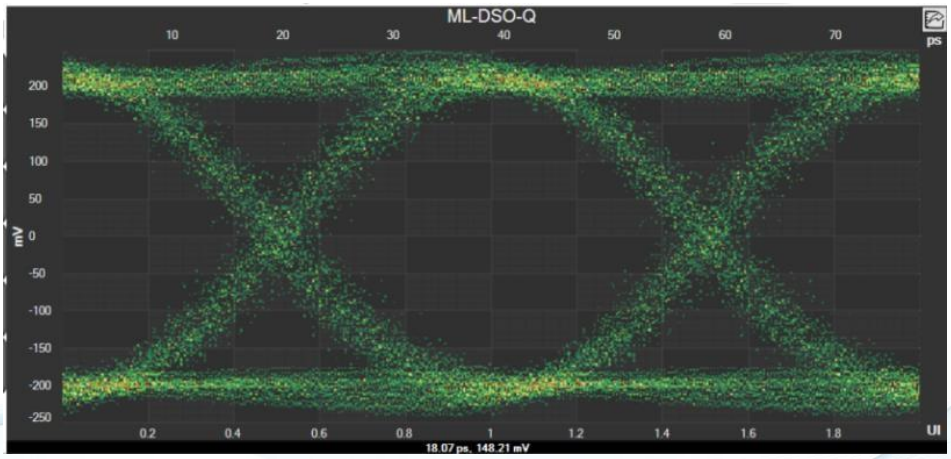

Figure 28: Captured eye in NRZ mode using 7 taps settings

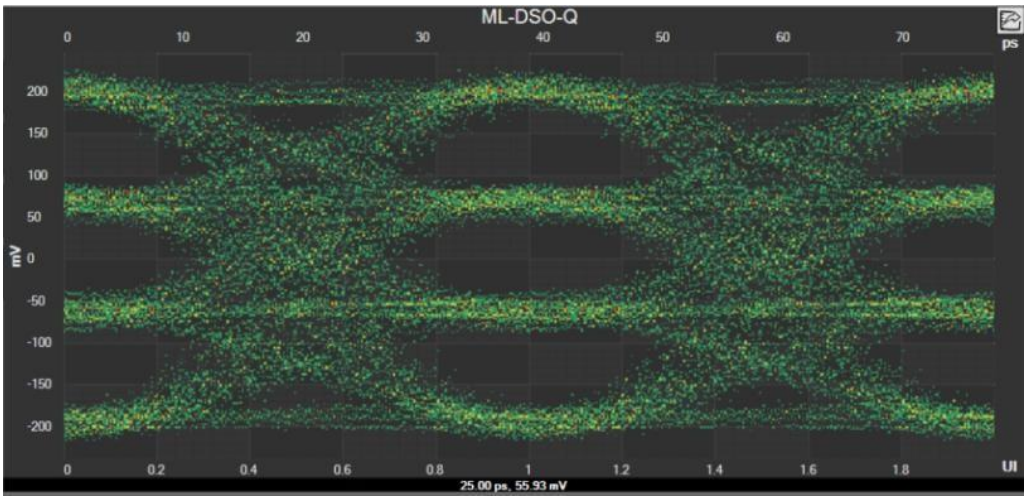

Figure 29: Captured eye in PAM4 mode using 7 taps settings

12.5 BERT measurements

To be able to start BER measurements, the instrument ports should be in loopback mode, which means the TX ports should be connected to the RX ports and the PPG and ED patterns should match. It is not necessarily to supply a PRBS from the same physical instrument – the source can be a different instrument and the error-detector of the ML4039E can derive its own clock from the received data (no need for a separate clock link). However, if Gray coding is used in the source, one should tell the receiver to expect Gray coding as well. There should be a match in pattern, polarity and coding to have lock.

The user can run the BER test on selected channels continuously or choose a target BER or set a timer.

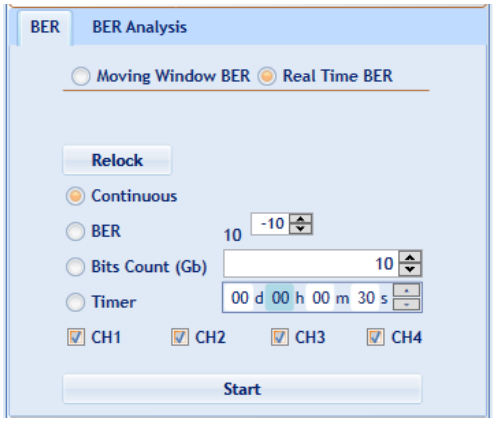

Figure 30: BER control panel

The BER values are displayed per channel and their corresponding BER graph. In PAM4 the value of the BER at MSB and LSB is shown. The graph shows the total BER value.

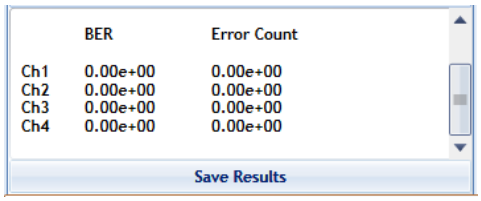

Figure 31: BER values in NRZ mode

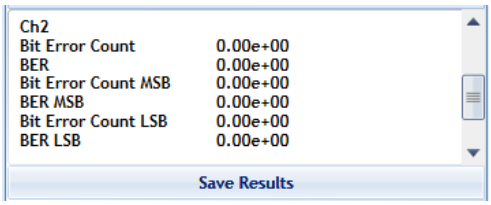

Figure 32: BER values in PAM4 mode

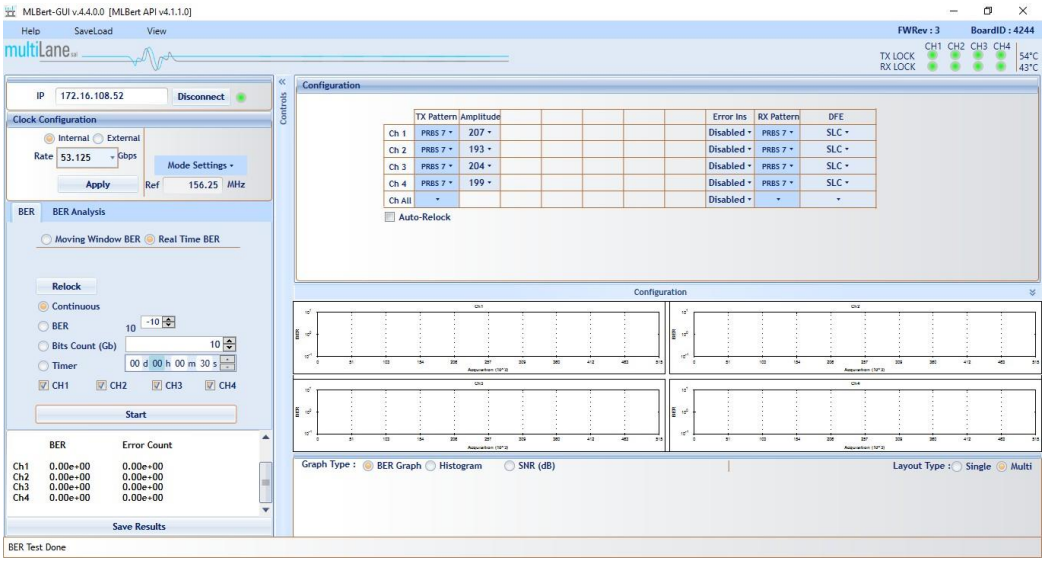

Figure 33: BER test on 4 channels

The user can test the BER, histogram and SNR, on the selected channel, in NRZ and PAM4 modes.

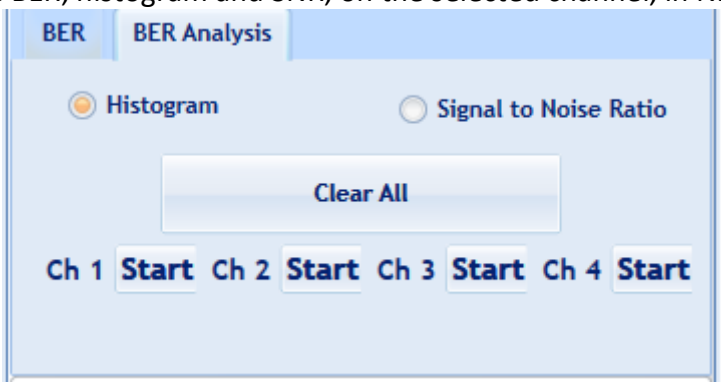

Figure 34: BER analysis tab

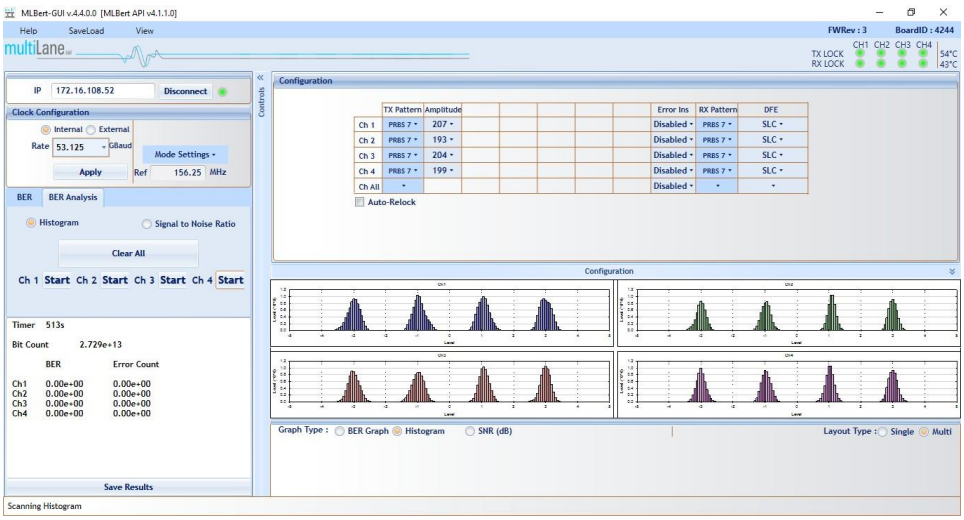

Figure 35: Histograms in PAM4 mode

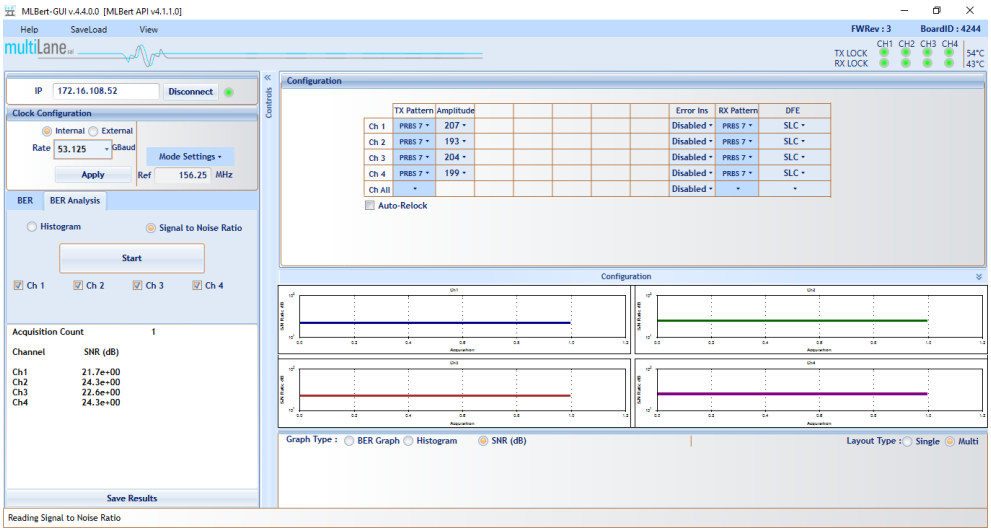

Figure 36: SNR in PAM4 mode

This BERT gives the user the possibility to insert errors by enabling the error insertion option.

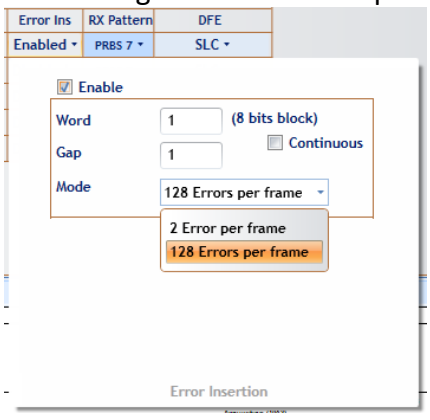

Figure 37: Error Insertion options in NRZ mode

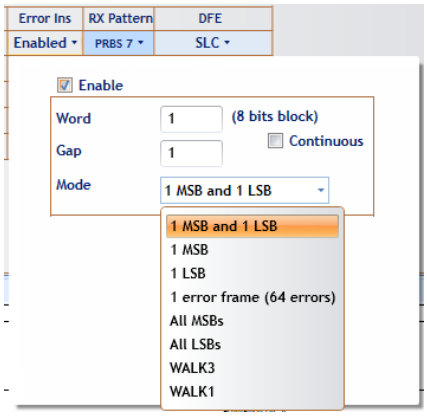

Figure 38: Error insertion options in PAM4 mode

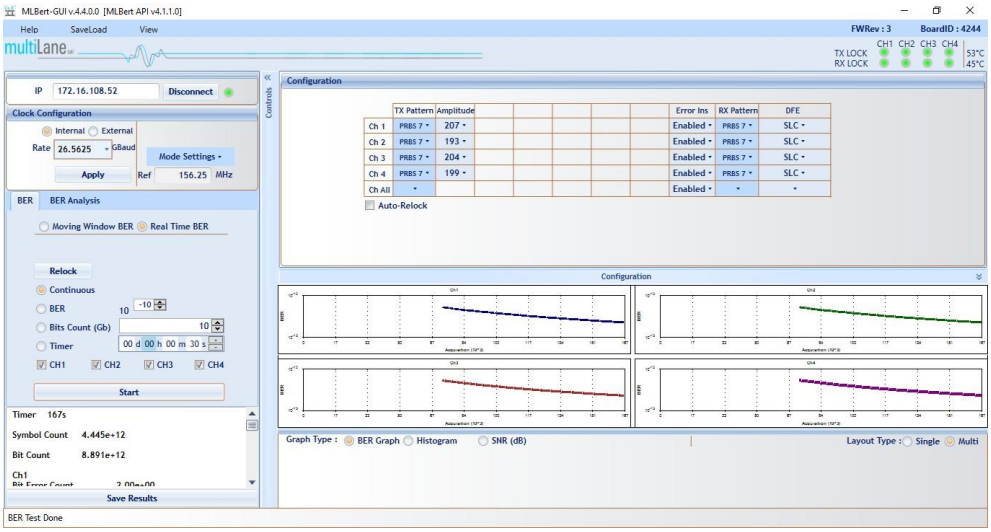

Figure 39: BER measurement with 1 error inserted at the MSB and 1 error at the LSB

The user can choose among two DSP modes: slicer for non-strenuous links and slicer with reflection canceller.

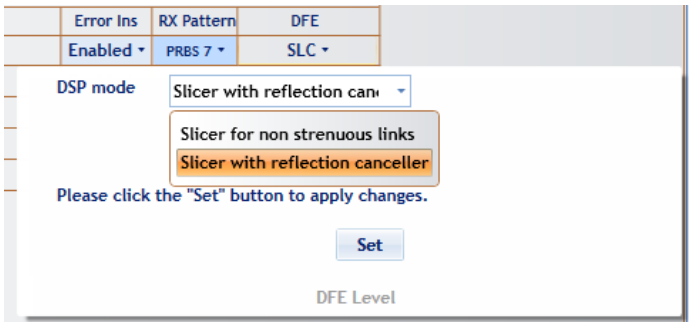

Figure 40: DSP mode options

12.6 ML4039EN Noise injection

The same is applicable for the ML4039EN with an additional noise injection feature. When connected to an ML4039EN and additional noise injection tab will show in clock configuration.

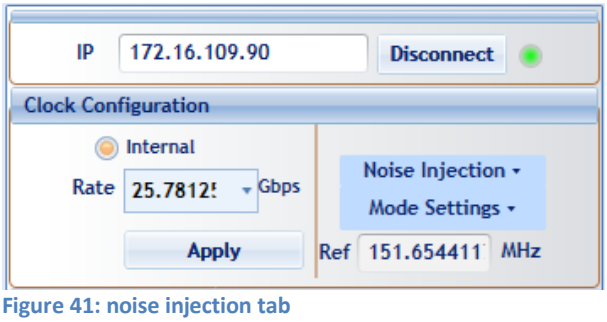

Figure 41: noise injection tab

To access noise injection settings the user should first enable noise injection and pick a rate from the drop down list also choose the preferred TX mode: PAM4 or NRZ (note that PAM4 is not available at rate 10.009191176470587) and press apply.

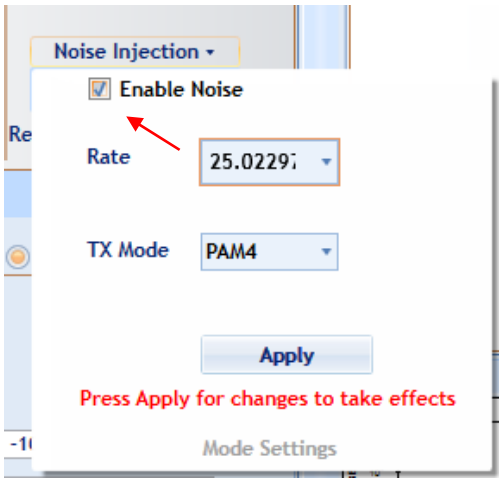

Figure 42: noise rate and TX mode for noise

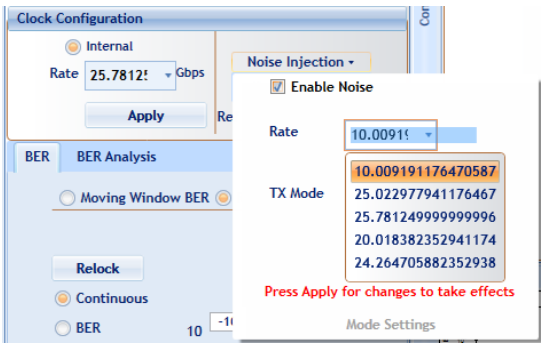

Figure 43: available noise rates

After pressing apply a new noise row will appear on the configuration table for each channel where the user will be able to control the noise pattern and amplitude.

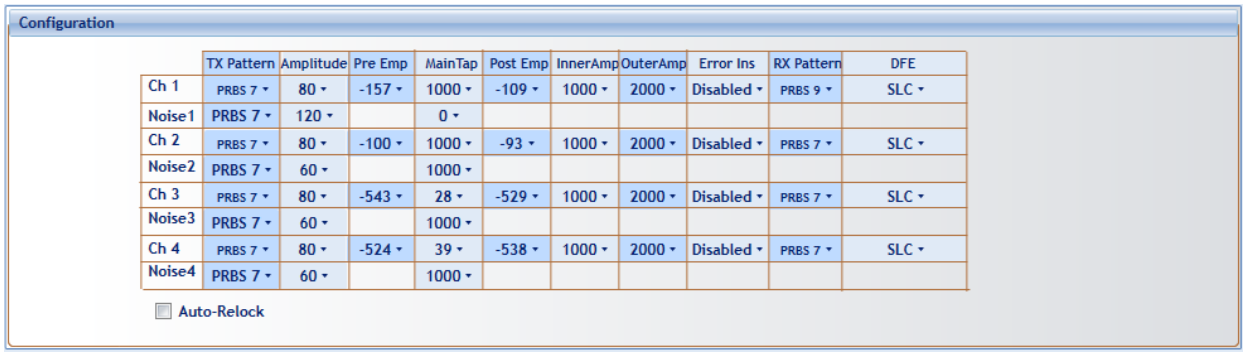

Figure 44: configuration table after enabling noise injection

Below are some screenshots showing the noise being injected at different rates to a 53.125 PAM4 signal.

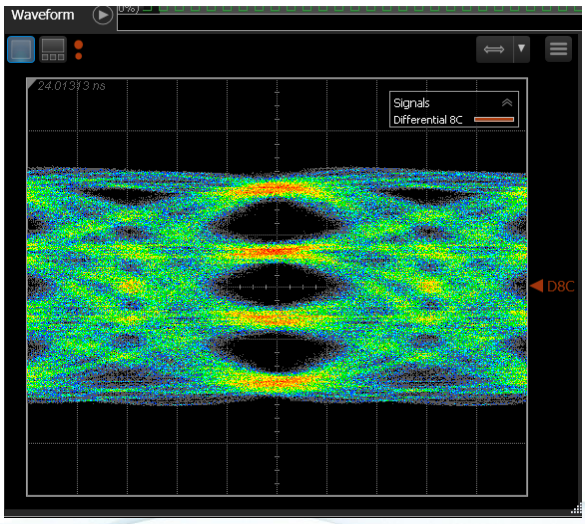

Figure 45: PAM4 clean eye

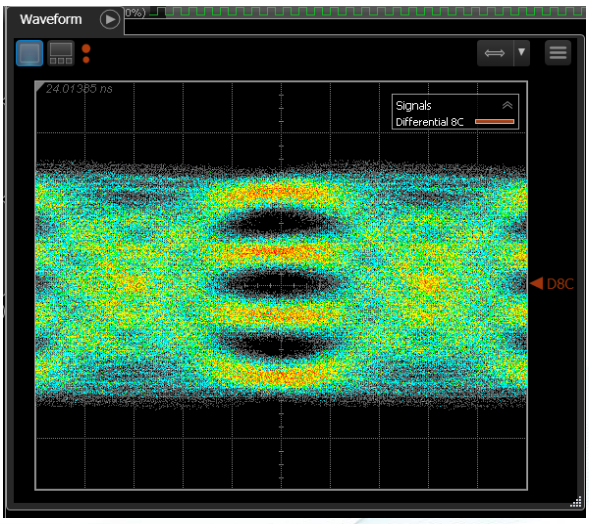

Figure 46: noise being injected at rate 10.3125 and main tap 1000

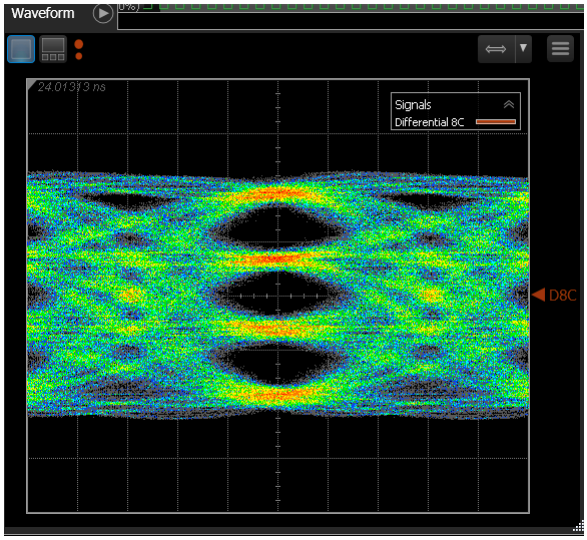

Figure 47: PAM4 clean eye

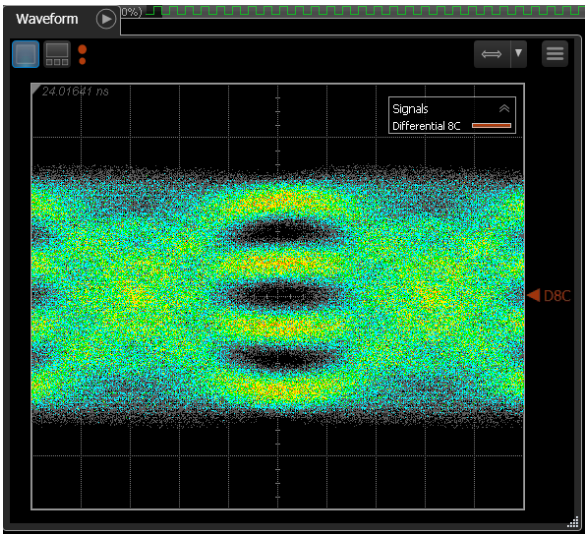

Figure 48: noise being injected at rate 25.78125 and main tap 1000

13. IP changer tool

If the user needs to change the IP of the board, the link represented below, has all needed tools (software and user guide).
https://multilaneinc.com/berts-gui/

Figure 49: IP changer GUI and User Guide

Figure50: Ethernet Configuration Software

14. Revision History

Revision number	Date	Description
1.0	11/14/2019	▪ Document created
1.1	11/18/2019	▪ Added ML4039EN characteristics and user manual

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