Granite River Labs

Pulse-Amplitude Modulation 4 (PAM4) Receiver Compliance Test Automation Solution

User Guide and Method of Implementation (MOI)

for Chip-to-Module 400Gb/s 8-Lane Attachment Unit Interface (CDAUI-8) for Hosts

Using

GRL-PAM4-RX Automation Test Software,

Anritsu 28Gb/s or 32Gb/s (MP1800A) BERT,

PAM4 6dB (MZ1854A) Combiner,

and

Tektronix MSO70000 (DPOJET) Series Oscilloscopes

Contact the GRL office to obtain the latest revision of this document.

Questions regarding this document in the GRL may be forwarded to:

Granite River Labs 3500 Thomas Road, Suite A, Santa Clara, CA 95054

Phone: 408-627-7608 Fax: 408-912-1810

E-mail: info@graniteriverlabs.com

http://www.graniteriverlabs.com

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Revision Record

Version	Revision Date	Description of Changes	Author(s)
1.0	11/2017	GRL-PAM4-RX User Guide/MOI Creation	Ong Gaik Pheng (GRL) gpong@graniteriverlabs.com

1 Introduction

This User Guide/Method of Implementation (MOI) provides information using the GRL-PAM4-RX test solution to deliver automation control for electrical device receiver (Rx) compliance.

The main body of this documentation describes how to set up the GRL-PAM4-RX software to perform stressed signal calibration and DUT compliance testing using existing PAM4 Host Compliance Boards (HCB's) and Module Compliance Boards (MCB's).

The test automation is carried out based on PAM4-approved MOI's with a high-performance Tektronix oscilloscope, Anritsu BERT, and PAM4 combiner as the main equipment. As technical reference, a manual test methodology that conforms to the PAM4 Compliance Test Specification (CTS) is also provided in the Appendix of this documentation.

The GRL-PAM4-RX solution consists of the GRL PAM4 receiver automation software which is run from the computer or oscilloscope to enable automation control to test the device under test (DUT) for Rx electrical compliance. The GRL automation control enabled PC or scope automates calibration and test sequencing and processing for signal tolerances of the DUT at selected parameters. The Rx path is tested with worst case eye to ensure a Bit Error Ratio (BER) of less than 1E-06 can be achieved. When combined with a satisfactory level of interoperability testing, these tests provide a reasonable level of confidence that the DUT's will function properly in most PAM4 environments.

The documentation covers the following major components for PAM4 Rx testing.

1. GRL-PAM4-RX automation software configuration and test setup.
2. Manual CTS calibration and test procedures for Chip-to-module 400Gb/s eight-lane Attachment Unit Interface (CDAUI-8) for host receivers.

The MOI reduces the CTS test description to practice using the specified test equipment and procedures in an effort to standardize testing across ATCs and equipment manufacturers who perform their own certification measurements.

2 Resource Requirements

Note: Equipment requirements may vary according to the lab setup and DUT. Below are the recommended lists of equipment for the typical test setup.

2.1 Equipment Requirements

TABLE 1. EQUIPMENT REQUIREMENTS – SYSTEMS

System	Qty.	Description/Key Spec Requirement
Tektronix High Performance Oscilloscope	1	MSO70000DX Series and above (recommended) ≥ 33GHz bandwidth DPOJET Software PAM4 Analysis Software
Anritsu BERT - Signal Quality Analyzer - Jitter Modulation Source	1	- MP1800A (28Gbit/s or 32Gbit/s Pulse Pattern Generator Output) - MU181500B
Anritsu PAM4 Combiner	1	MZ1854A (6dB)
Wilder Technologies PAM4 Module Compliance Board (MCB)	1	QSFP+ 100Gb (QSFP+ TPA100G-MCB-R Model)
Wilder Technologies PAM4 Host Compliance Board (HCB)	1	QSFP+ 100Gb (QSFP+ TPA100G-HCB-P Model)
Computer (laptop or desktop)	1	For automation control of the DUT

TABLE 2. EQUIPMENT REQUIREMENTS – ACCESSORIES

Accessory	Qty.	Description/Key Spec Requirement
Phase-matched SMA Cable	2	For BERT Data signals ≥ 33GHz bandwidth
SMA Cable	1	For BERT Sub-rate clock output
Attenuator (8dB)	2	For BERT Data signals to achieve eye height target of < 60mV ≥ 33GHz bandwidth

TABLE 3. SOFTWARE REQUIREMENTS

Software	Description/Source
GRL-PAM4-RX	Granite River Labs PAM4 Automated Receiver Compliance Test Solution – www.graniteriverlabs.com
BERT Software	Anritsu Mainframe MX180000A SQA Control Software (Version 8.00.04 or above)

3 Setting Up GRL-PAM4-RX Automation Software

This section provides the procedures to start up and pre-configure the GRL-PAM4-RX automation software before running tests. It also helps users familiarize themselves with the basic operation of the software.

Note: The GRL software installer will automatically create shortcuts in the Desktop and Start Menu when installing the software.

To start using the software, follow the procedures in the following sections.

3.1 Download Software

Download and install the software as follows:

1. Download the software ZIP file package from the Granite River Labs support site.
2. The zip file contains:
   a) **PAM4RxPatternFilesInstallation00xxxxxxSetup.exe** – Run this on the Anritsu BERT to install the pattern setup files.
   b) **PAM4RxTestApplication00xxxxxxSetup.exe** – Run this on the PC or the Tektronix Oscilloscope to install the application.
   c) **PAM4RxTestScopeSetupFilesInstallation00xxxxxxx.exe** – Run this on the Tektronix Oscilloscope to install the scope setup files.

3.2 Launch and Set Up Software

1. Once the software is installed, open the GRL folder from the Windows Start menu and select the GRL Framework. The GRL Framework will launch.

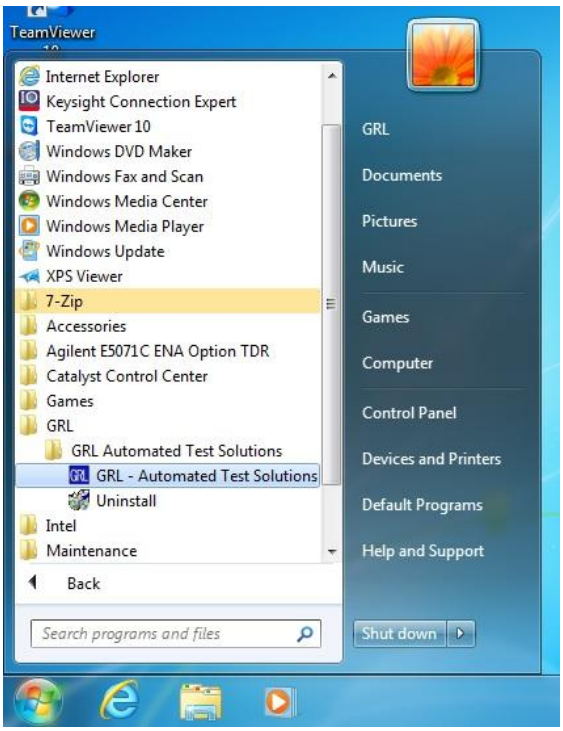


FIGURE 1. SELECT AND LAUNCH GRL FRAMEWORK

2. From the Application→Rx Test Solution drop-down menu, select "PAM4 Rx Test" to start the PAM4 Rx Test Application. If the selection is grayed out, it means that your license has expired.

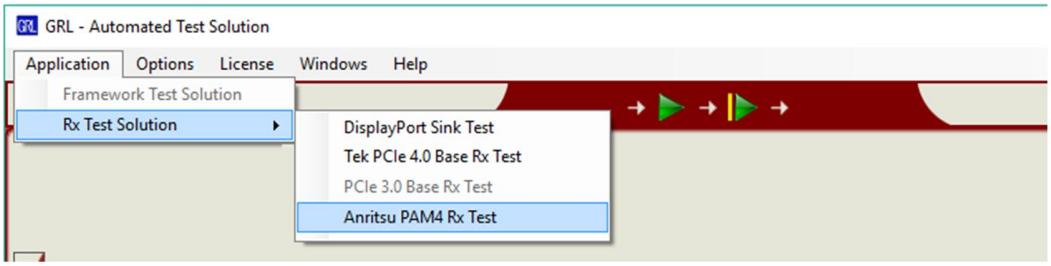


FIGURE 2. START PAM4 RX TEST APPLICATION

3. To enable license, go to License→License Details.

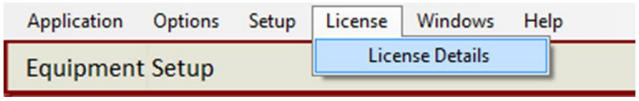


FIGURE 3. SEE LICENSE DETAILS

a) Check the license status for the installed application.

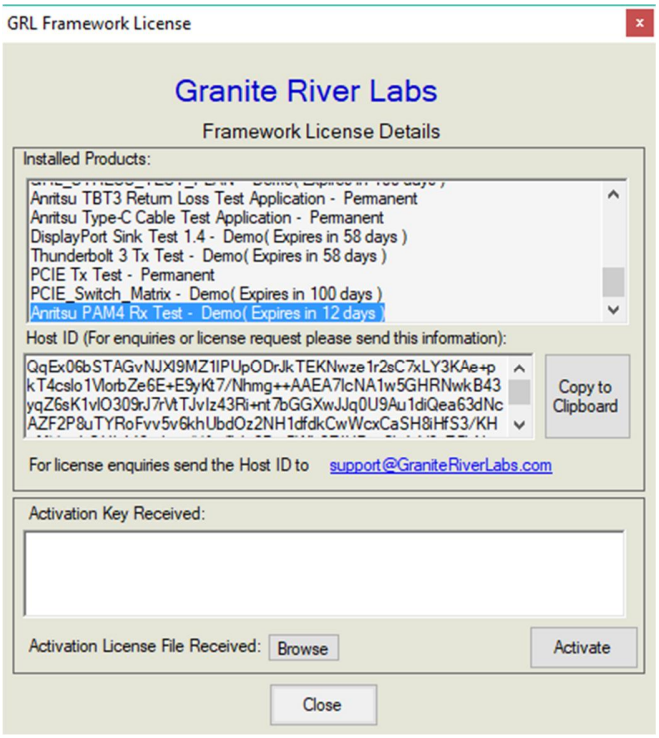


FIGURE 4. CHECK LICENSE FOR INSTALLED APPLICATIONS

b) Activate a License:

- If you have an Activation Key, enter it in the field provided and select "Activate".
- If you do not have an Activation Key, select "Close" to use a demo version of the software over a free 10-day trial period.

Note: *Once the 10-day trial period ends, you will need to request an Activation Key to continue using the software on the same computer or oscilloscope. The demo software is also limited in its capability, in that it will only calibrate the maximum frequency for each data rate. Thus, the demo version cannot be used to fully calibrate and test a device. For Demo and Beta Customer License Keys, please request an Activation Key by contacting support@graniteriverlabs.com.*

4. Select the Equipment Setup icon on the PAM4 Rx Test Application menu.
5. Connect the Anritsu BERT via LAN to the GRL automation control enabled Scope or PC.
6. On the Tektronix Oscilloscope or the PC, obtain the network addresses for all the connected instruments from the device settings. *(Note: The scope IP address can be obtained, if not known, by typing CMD → IPCONFIG on the scope and observe the IP address listed.)*

   For example, the addresses may look like the following when the BERT is connected to the scope:

   - 192.168.0.9 (Scope)
   - 192.168.0.47:5000 (BERT)

   Note these addresses as they will be used to connect the instruments to the GRL automation software.

7. On the Equipment Setup page of the GRL PAM4 Rx Test Application, type in the address of each connected instrument into the "Address" field.

   Then select the "lightning" button ( ) for each connected instrument.

   The "lightning" button should turn green ( ) once the application has successfully established connection with each instrument.

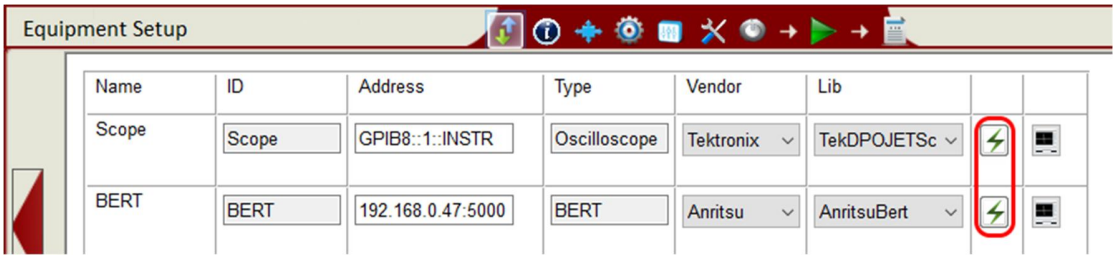


FIGURE 5. CONNECT INSTRUMENTS WITH GRL SOFTWARE

3.3 Pre-Configure Software before Testing

Once all equipment is successfully connected from the previous section, proceed to set up the preliminary settings before going to the advanced test setup.

3.3.1 Enter Test Session Information

Select  from the menu to access the **Session Info** page. Enter the information as required for the test session that is currently being run. The information provided will be included in the test report generated by the software once tests are completed.

- The fields under **DUT Info** and **Test Info** are defined by the user.
- The **Software Info** field is automatically populated by the software.

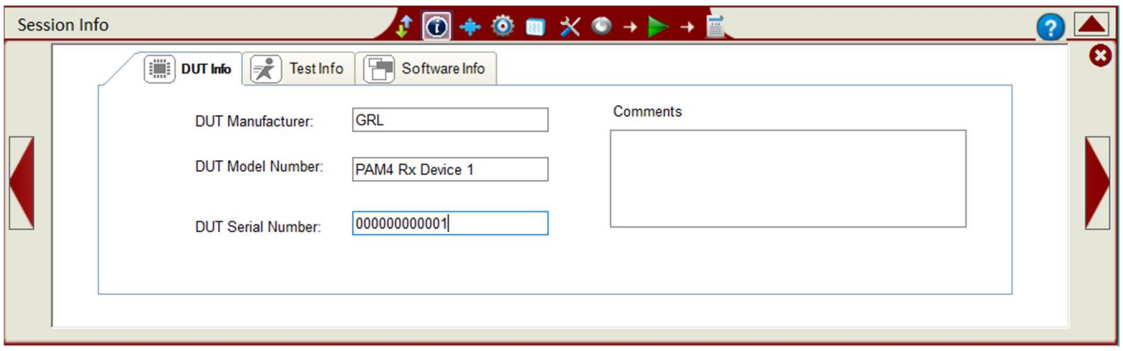


FIGURE 6. SESSION INFO PAGE

3.3.2 Set Test Conditions

Select  from the menu to access the **Conditions** page to set the conditions for testing. The software will run tests for the PAM4 data rate and SJ test frequencies that are selected.

a) **Data Rate** tab: PAM4 uses the standard 26.5625 GBd/s data rate which is pre-selected by default.

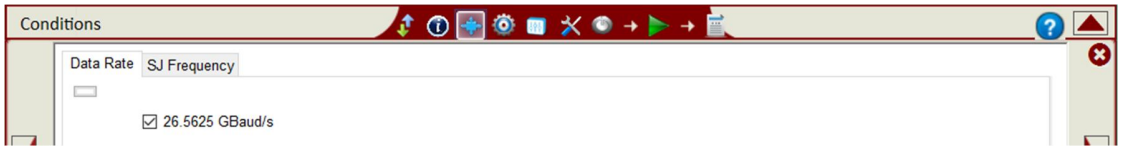


FIGURE 7. DATA RATE SETTING

b) **SJ Frequency**: Select the desired SJ frequencies for testing or calibration.

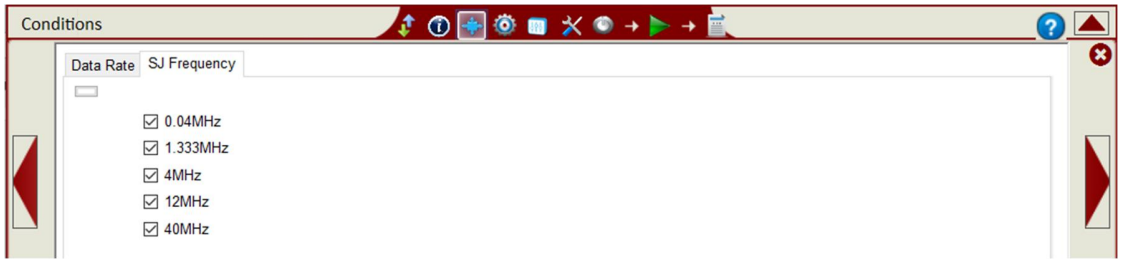


FIGURE 8. SELECT SJ FREQUENCIES

4 Calibrating Using GRL-PAM4-RX

The GRL-PAM4-RX test solution supports automated Rx calibration for stressed signals. The GRL automation software typically runs a calibration sequence from the PC/oscilloscope for stressed input followed by VEC, Eye Height, and Eye Width. The typical calibration setup requires pattern generators on the BERT to provide the necessary stress components as well as an oscilloscope, PAM4 combiner, and existing Host Compliance Board (HCB)/Module Compliance Board (MCB).

Prior to running stress calibration, the software will first carry out skew alignments between two pattern generators to generate a PAM4 compliant test pattern. When completed, stress calibration will proceed without attaching a HCB/MCB mated pair. The stressed signal is applied at TP4a (output of the pattern generator) and calibrated for initial values of Random Jitter (RJ), Bounded Uncorrelated Jitter (BUJ), Total Jitter (TJ), and Sinusoidal Jitter (SJ).

After completing stress calibration, the stressed signal will additionally be calibrated at TP4 for final Eye Width, Eye Height, and VEC after attaching the HCB/MCB mated pair in the setup. This procedure will require obtaining an optimal CTLE which generates the largest Eye Height and Eye Width. Proper adjustments will then be carried out using this optimal CTLE to achieve the final Eye Height, Eye Width, and VEC.

Note: For more details on these calibration, refer to the manual CTS methodology under Appendix in Section 10 of this documentation.

4.1 Set Up PAM4 Rx Calibration with Automation

Once pre-configuration has been completed from Section 3.3, continue with the calibration setup. The following procedures show how to set up the physical connections to perform automated Rx calibration for stressed signals.

4.1.1 Connect Equipment for Signal Calibration Without Mated HCB/MCB Pair

The connection diagram below shows the recommended equipment setup to perform skew, RJ, TJ, and SJ calibration using a GRL automation control enabled scope, pattern generators, and PAM4 combiner. *(Note that this calibration is performed before including any mated HCB/MCB pair in the setup.)*

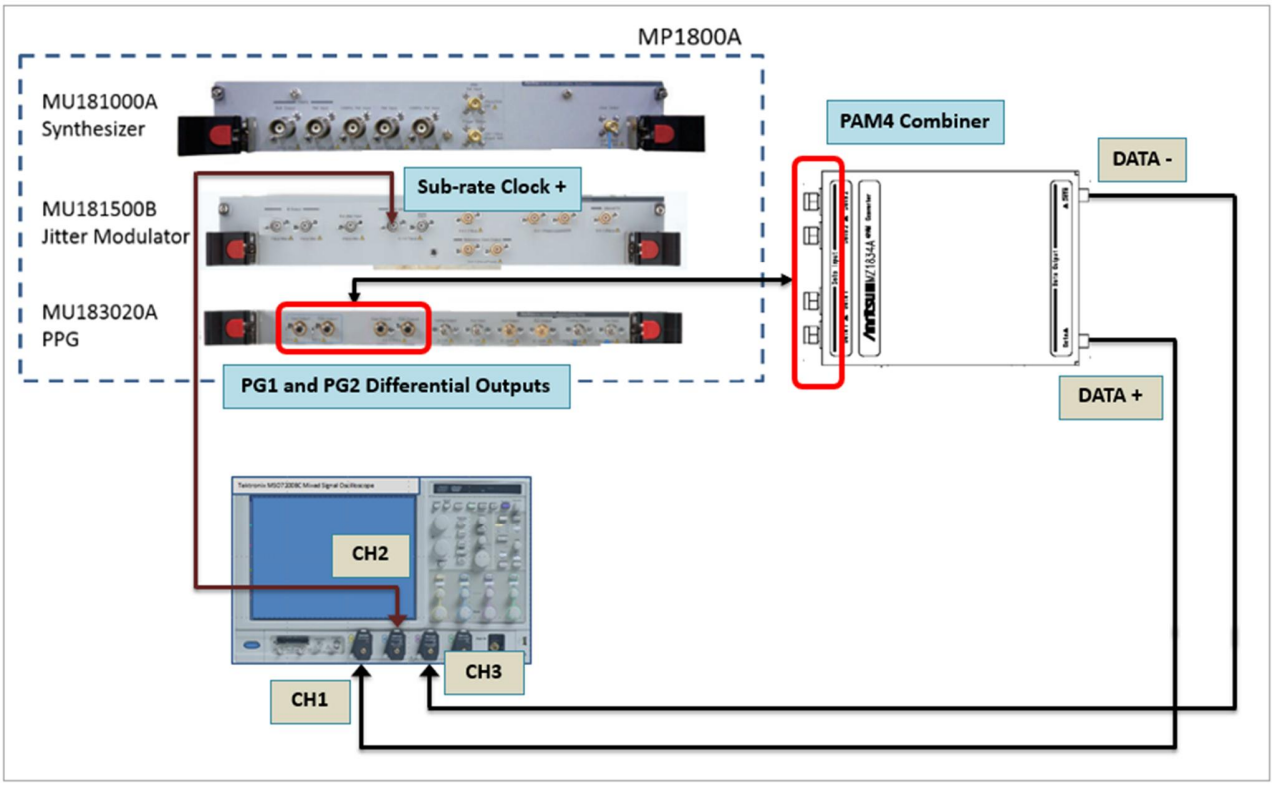


FIGURE 9. CONCEPTUAL PAM4 RX CALIBRATION SETUP DIAGRAM (WITHOUT MATED HCB/MCB PAIR)

1. Connect the Pattern Generator 1 (PG1) and Pattern Generator 2 (PG2) Outputs from the BERT to the PAM4 Combiner.
2. Connect the Data+ Output from the PAM4 Combiner to Channel 1 of the Scope.
3. Connect the Data- Output from the PAM4 Combiner to Channel 3 of the Scope.
4. Connect the Sub-rate Clock+ Output from the BERT to Channel 2 of the Scope.

4.1.2 Connect Equipment for Signal Calibration with Mated HCB/MCB Pair

The connection diagram below shows the recommended equipment setup to perform VEC, Eye Width, and Eye Height calibration using a GRL automation control enabled scope, pattern generators, PAM4 combiner, and mated 100G HCB/MCB pair.

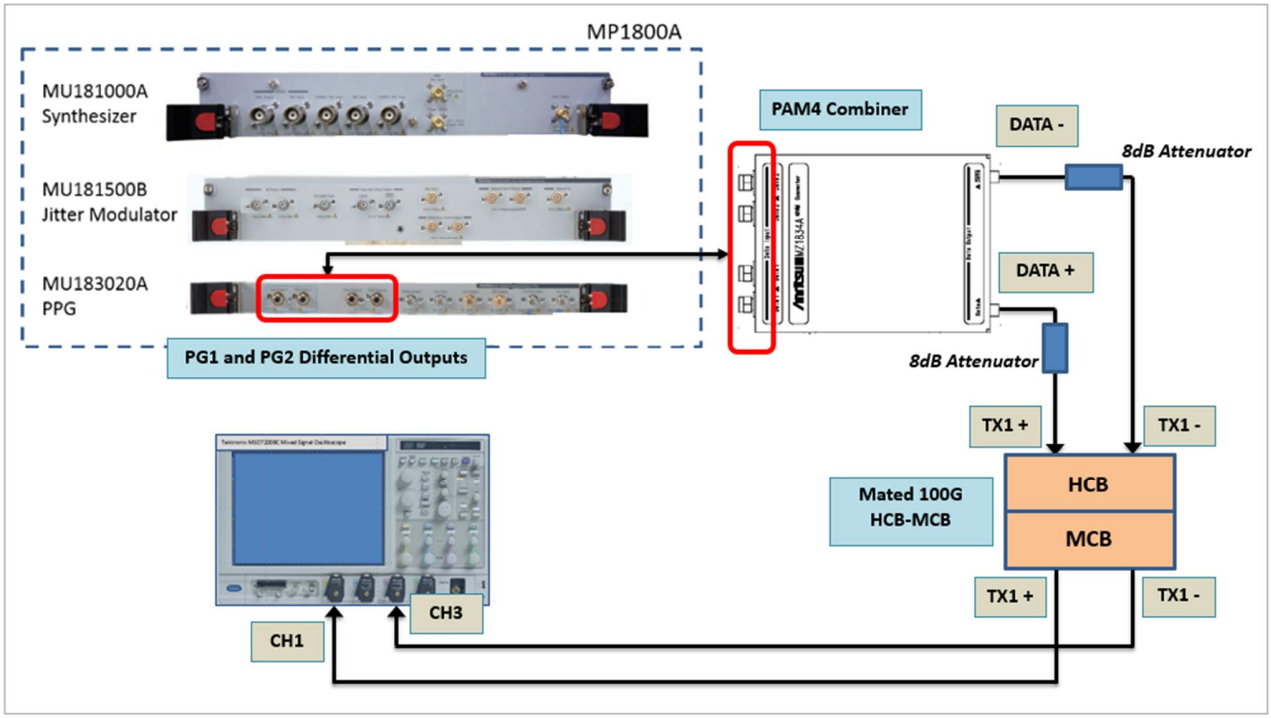


FIGURE 10. CONCEPTUAL PAM4 RX CALIBRATION SETUP DIAGRAM (WITH MATED HCB/MCB PAIR)

1. Connect the Pattern Generator 1 (PG1) and Pattern Generator 2 (PG2) Outputs from the BERT to the PAM4 Combiner.
2. Attach the 100G Host Compliance Board (HCB) to the 100G Module Compliance Board (MCB).
3. Connect the Data+ Output from the PAM4 Combiner to a 8dB attenuator to TX1+ on the HCB side of the mated 100G HCB/MCB pair.
4. Connect the Data- Output from the PAM4 Combiner to a 8dB attenuator to TX1- on the HCB side of the mated 100G HCB/MCB pair.
5. Connect the TX1+ Output on the MCB side of the mated 100G HCB/MCB pair to Channel 1 of the Scope.
6. Connect the TX1- Output on the MCB side of the mated 100G HCB/MCB pair to Channel 3 of the Scope.

5 Testing Using GRL-PAM4-RX

The GRL-PAM4-RX test solution supports automated Rx compliance testing for PAM4 Host DUT's. After completing calibration, the GRL automation software will perform testing for stressed input compliance of the Host DUT.

To create the typical test environment, the oscilloscope is first disconnected from the mated 100G HCB/MCB pair in the previous calibration setup. The MCB is then removed from the mated HCB/MCB pair to allow the DUT to be connected to the HCB. When setup is ready, testing will proceed and a detailed test report will be generated once test is completed.

5.1 Set Up PAM4 Rx Test with Automation for Host DUT

Once calibration has been completed from Section 4, continue with the following setup to perform Rx stressed input compliance testing for the Host DUT.

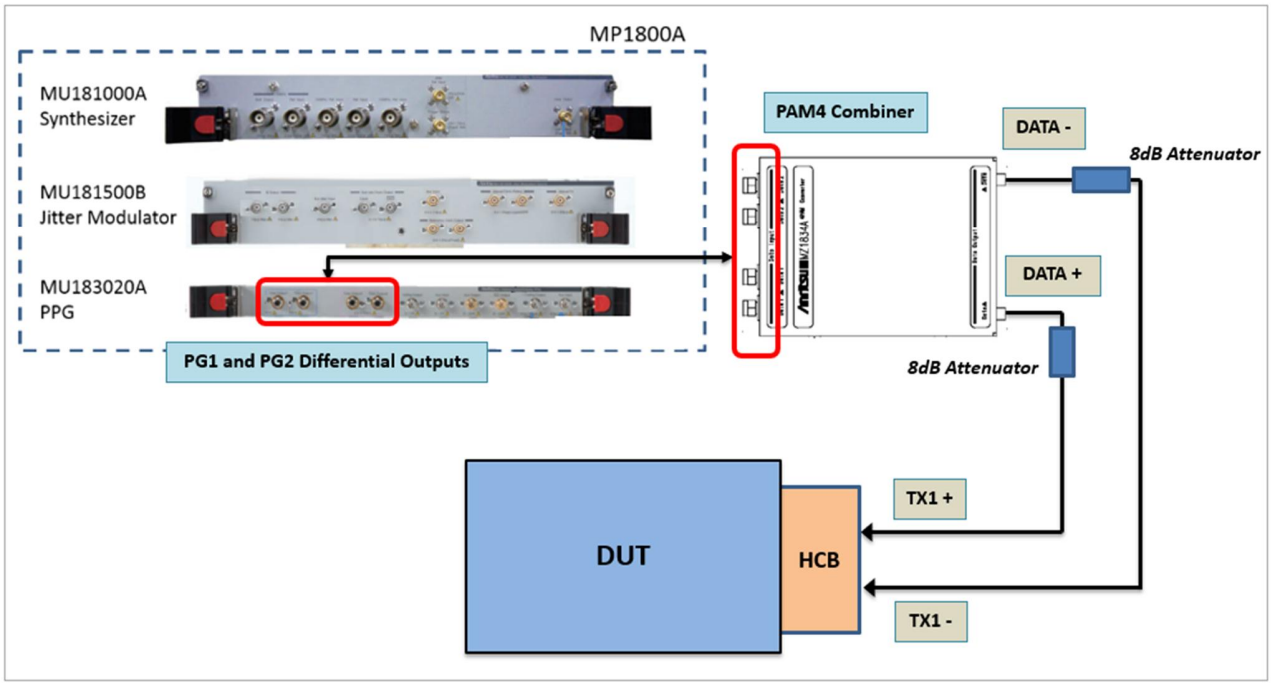


FIGURE 11. CONCEPTUAL PAM4 RX HOST DUT TEST SETUP DIAGRAM

1. From the previous calibration setup in Section 4.1.2, disconnect the oscilloscope from the mated 100G HCB/MCB pair.
2. Unplug the MCB from the mated 100G HCB/MCB pair.
3. Connect the HCB to the Host DUT.

6 Configuring and Selecting Calibration and Tests Using GRL-PAM4-RX

6.1 Set Up Calibration/Test Requirements

After setting up the physical equipment, select  from the GRL PAM4 Rx Test Application menu to access the Setup Configuration page.

Enter the target Eye Width and Eye Height values to be applied during final stage calibration.

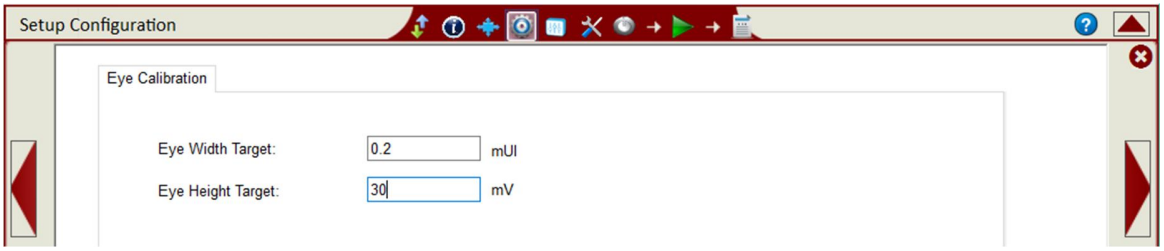


FIGURE 12. SET UP EYE PARAMETERS

6.2 Select Calibration and Tests

Select  from the menu to access the **Select Tests** page which displays all available Rx compliance calibration and tests. User must make sure to run and complete calibration first before proceeding with DUT testing. If calibration is not completed, running the DUT test will show an error message.

FIGURE 13. SELECT TESTS PAGE

6.2.1 Select Initial Stressed Signal Calibration

Under “Signal Calibration before Mated HCB/MCB Pair”, select to perform skew adjustments between dual pattern generators and stress calibration before applying the HCB/MCB mated pair. The stressed signal will be calibrated for initial values of Random Jitter (RJ), Total Jitter (TJ), and Sinusoidal Jitter (SJ).

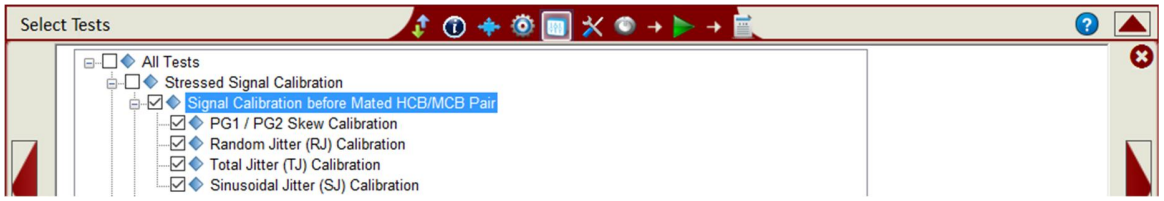


FIGURE 14. SELECT INITIAL STRESS CALIBRATION

6.2.2 Select Final Stressed Signal Calibration

Under "Signal Calibration after Mated HCB/MCB Pair", select to perform calibration for optimal CTLE and final Eye Height, Eye Width, and VEC using the optimal calibrated CTLE value after applying the HCB/MCB mated pair.

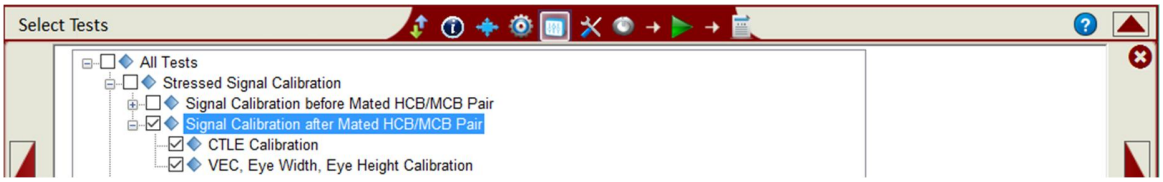


FIGURE 15. SELECT FINAL STRESS CALIBRATION

6.2.3 Select DUT Rx Compliance Test

After completing calibration, under "Receiver Tests", select to perform the Rx stressed input compliance test for the Host DUT.

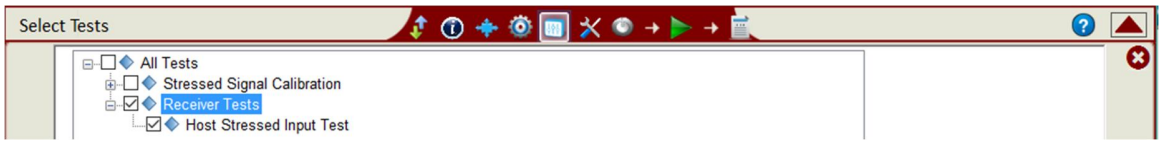


FIGURE 16. SELECT HOST DUT RX TEST

6.3 Configure Calibration and Test Parameters

After selecting the desired calibration/test, select  from the menu to access the Configurations page. Set the necessary parameters for calibration and testing as described below.

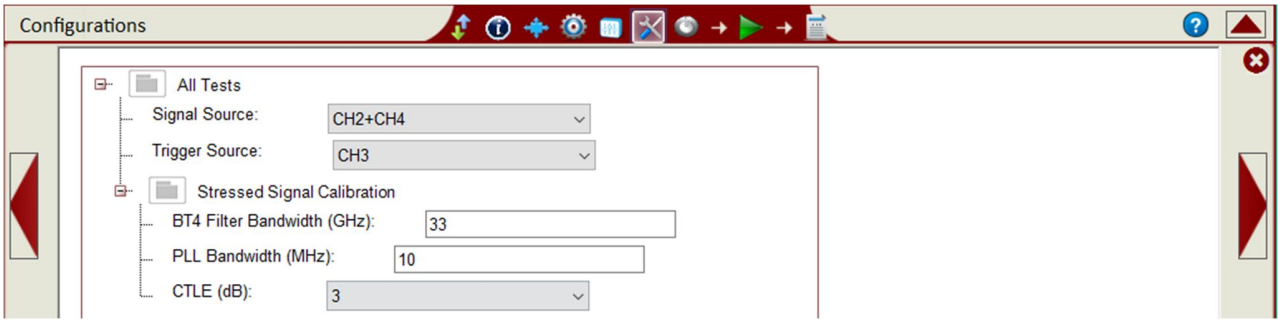


FIGURE 17. TEST PARAMETERS CONFIGURATION PAGE

TABLE 4. TEST PARAMETERS DESCRIPTION

Parameter	Description
Signal Source	Select the scope channels that are connected to the Data outputs of the PAM4 combiner.
Trigger Source	Select the scope channel that is connected to the Sub-rate Clock+ Output of the BERT.

BT4 Filter Bandwidth (GHz)	Set the frequency for the electrical bandwidth of the fourth-order Bessel-Thomson (BT4) filter used with the reference receiver. For PAM4 signals, the bandwidth is generally set to a frequency of 50% of the data rate.
PLL Bandwidth (MHz)	Set the frequency for the Phase Locked Loop (PLL) bandwidth of the reference receiver. The recovered clock will make use of the configured PLL bandwidth to reduce frequency effects in the stressed signal calibration.
CTLE (dB)	Select the CTLE of the reference receiver to obtain the optimal CTLE which generates the largest Eye Height and Eye Width.

6.4 Configure Calibration Target Values

For debugging purposes ONLY, the default calibration target values can be changed for the RJ or TJ calibration. To do this, select  from the menu to access the Calibration page.

By default, the calibration target values are those defined in the specification. To change the values, un-select the Use Default Value checkbox. In case the default values are required again, just select the checkbox to allow all existing values to be reset to default.

Note: The PID Control setting is used to adjust the step width for steps calculation if the target measurement cannot be met with the current step. To adjust, use a lower PID Control value to reduce the subsequent step or increase the control value to make the subsequent step bigger.

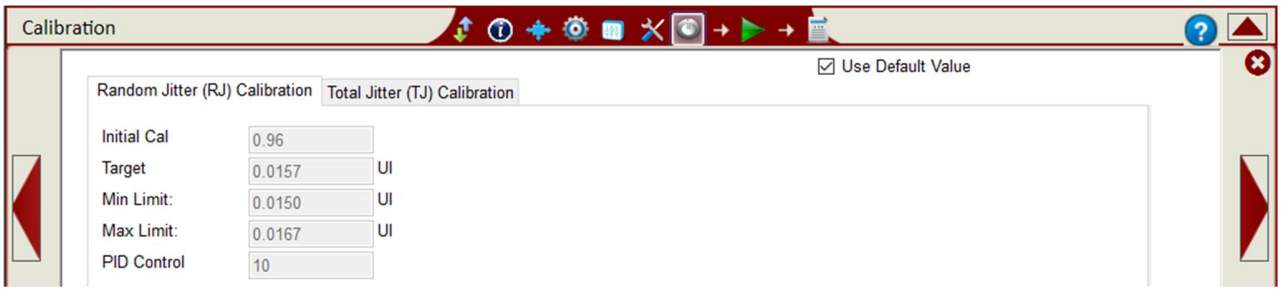


FIGURE 18. CALIBRATION TARGET OVERWRITE PAGE

7 Running Automation Calibration and Tests Using GRL-PAM4-RX

Once selected calibration and tests are ready to be run, select  from the GRL PAM4 Rx Test Application menu to access the Run Tests page.

Under "Run Option", select the option to either:

- **Skip Test if Result Exists** – If results from previous calibration/tests exist, the software will *skip* those calibration/tests, or
- **Replace if Result Exists** – If results from previous calibration/tests exist, the software will *replace* those calibration/tests with new results.

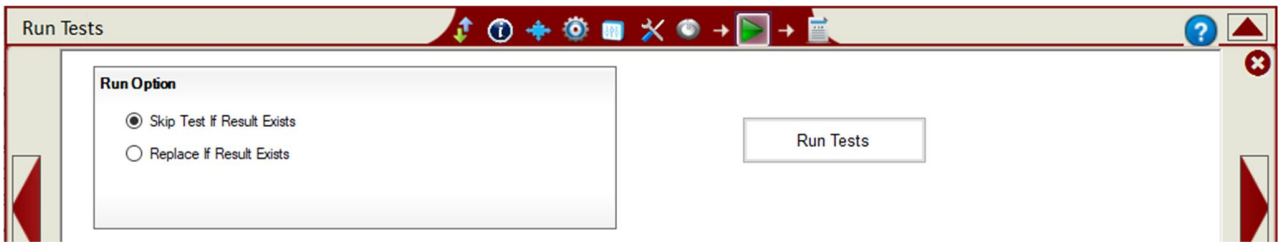


FIGURE 19. RUN TESTS PAGE

Select the **Run Tests** button to automatically start running the selected calibration and tests. At the start of a specific calibration/test, the corresponding connection diagram will initially appear to allow the user to verify with the recommended physical setup before continuing with the next step. Below shows an example of a connection diagram pop-up window.

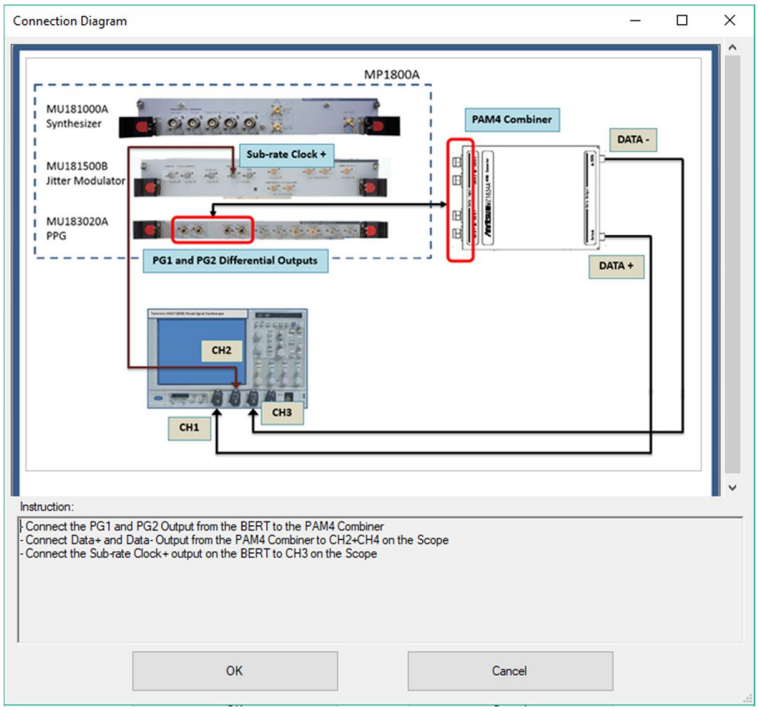


FIGURE 20. CONNECTION DIAGRAM POP-UP WINDOW EXAMPLE

8 Interpreting GRL-PAM4-RX Test Report

When all calibration and test runs have completed from the previous section, the GRL-PAM4-RX software will automatically display the results on the **Report** page.

Select  from the menu to access the Report page for a quick view of all results.

If some of the results are not desired, they can be individually deleted by selecting the **Delete** button.

For detailed test report, select the **Generate report** button to generate a PDF report. To have the calibration data plotted in the report, select the **Plot Calibration Data** checkbox.

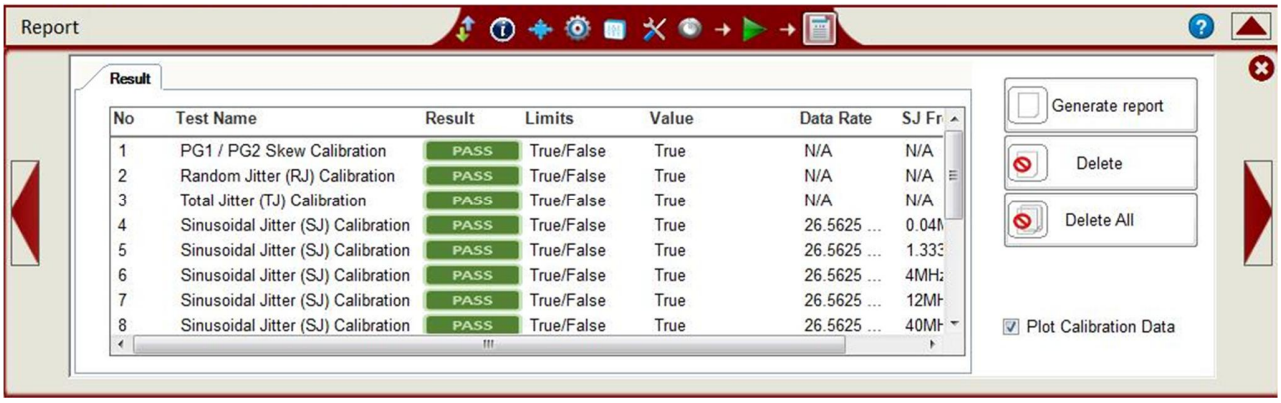


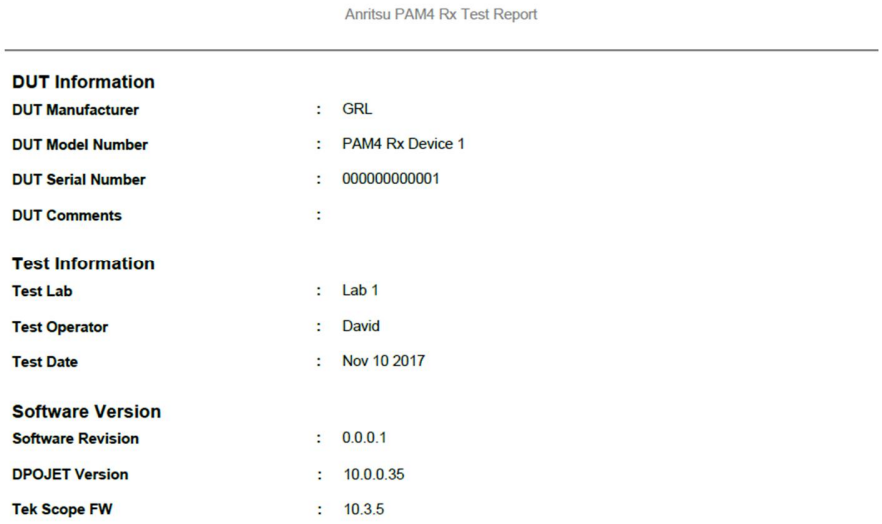
FIGURE 21. TEST REPORT PAGE

8.1 Understand Test Report Information

This section gives a general overview of the test report to help users familiarize themselves with the format. Select the **Generate report** button to generate the test report.

8.1.1 Test Session Information

This portion displays the information previously entered on the **Session Info** page.


Anritsu PAM4 Rx Test Report

DUT Information

DUT Manufacturer	:	GRL
DUT Model Number	:	PAM4 Rx Device 1
DUT Serial Number	:	000000000001
DUT Comments	:	

Test Information

Test Lab	:	Lab 1
Test Operator	:	David
Test Date	:	Nov 10 2017

Software Version

Software Revision	:	0.0.0.1
DPOJET Version	:	10.0.0.35
Tek Scope FW	:	10.3.5

FIGURE 22. TEST SESSION INFORMATION EXAMPLE

8.1.2 Test Summary Table

This table provides an overall view of all the calibration and tests performed along with their conditions and results.

No	TestName	Limits	Value	Results	Data Rate	SJ Frequency
1	PG1 / PG2 Skew Calibration	True/False	True	Pass		
2	Random Jitter (RJ) Calibration	True/False	True	Pass		
3	Total Jitter (TJ) Calibration	True/False	True	Pass		
4	Sinusoidal Jitter (SJ) Calibration	True/False	True	Pass	Rate_26G	SJ_0_04MHz
5	Sinusoidal Jitter (SJ) Calibration	True/False	True	Pass	Rate_26G	SJ_1_333MHz
6	Sinusoidal Jitter (SJ) Calibration	True/False	True	Pass	Rate_26G	SJ_4MHz
7	Sinusoidal Jitter (SJ) Calibration	True/False	True	Pass	Rate_26G	SJ_12MHz
8	Sinusoidal Jitter (SJ) Calibration	True/False	True	Pass	Rate_26G	SJ_40MHz
9	VEC, Eye Width, Eye Height Calibration	True/False	True	Pass	Rate_26G	SJ_1_333MHz
10	VEC, Eye Width, Eye Height Calibration	True/False	True	Pass	Rate_26G	SJ_4MHz
11	VEC, Eye Width, Eye Height Calibration	True/False	True	Pass	Rate_26G	SJ_12MHz
12	VEC, Eye Width, Eye Height Calibration	True/False	True	Pass	Rate_26G	SJ_40MHz
13	VEC, Eye Width, Eye Height Calibration	True/False	True	Pass	Rate_26G	SJ_0_04MHz
14	Host Stressed Input Test	N/A	True	InfoOnly	Rate_26G	SJ_40MHz

FIGURE 23. TEST SUMMARY TABLE EXAMPLE

8.1.3 Test Results

This portion displays the results in detail along with supporting data points and screenshots for each calibration/test run.

12. VEC, Eye Width, Eye Height Calibration [Rate_26G,SJ_40MHz]

Pass/Fail Stats	:	Pass
Test Limits	:	True/False
Result	:	True
Final Data1 Amplitude	:	1.1866 V
Final Data2 Amplitude	:	593.2977 mV
Final RJ setting	:	34.0000 mUI
Calibrated eye width	:	196.0047 mUI
Calibrated eye height	:	29.0500 mV
Test completed time	:	08 September 2017 5:29:42 AM

PAM4 eye

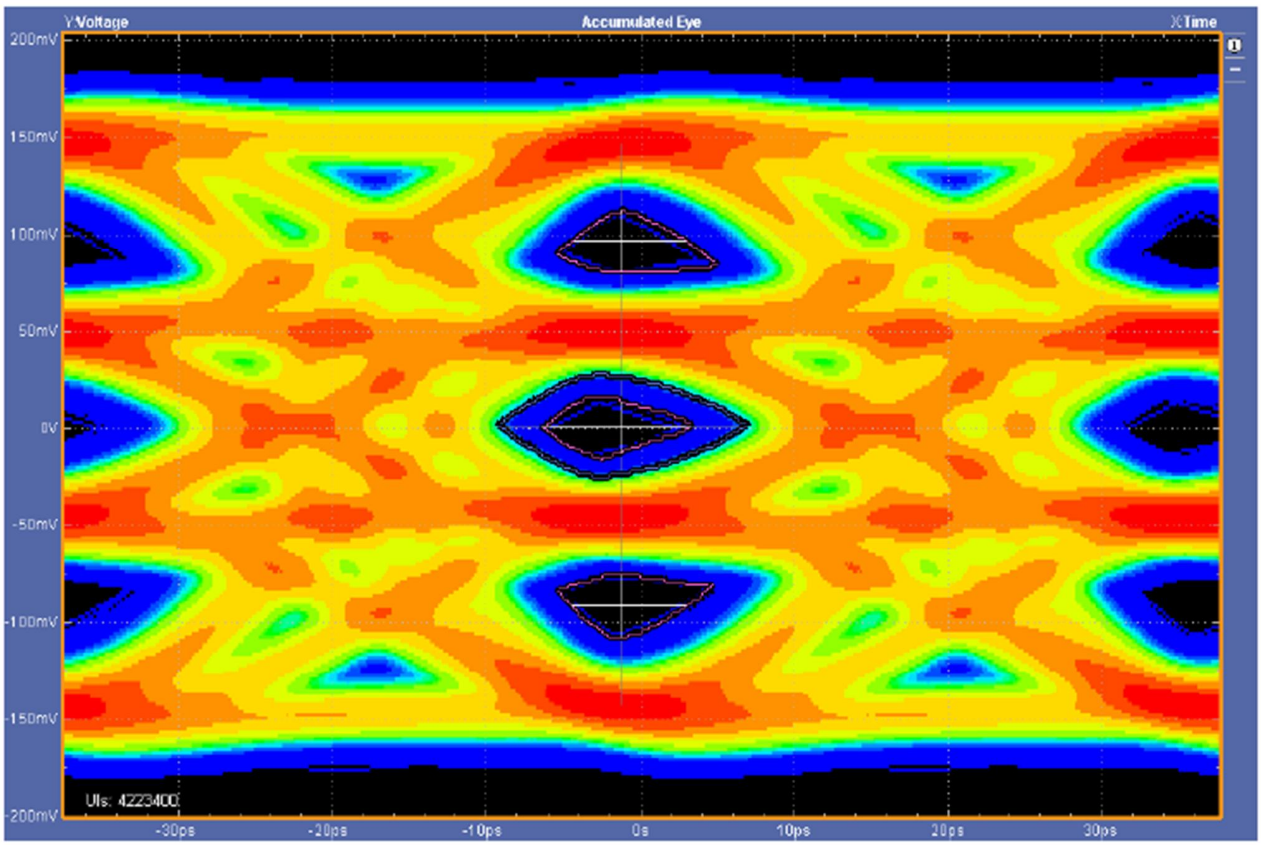


FIGURE 24. TEST RESULTS EXAMPLE

8.2 Delete Test Results

To individually delete any unwanted calibration/test results, select the corresponding result row and **Delete** button.

To entirely remove all existing calibration/test results, select the **Delete All** button.

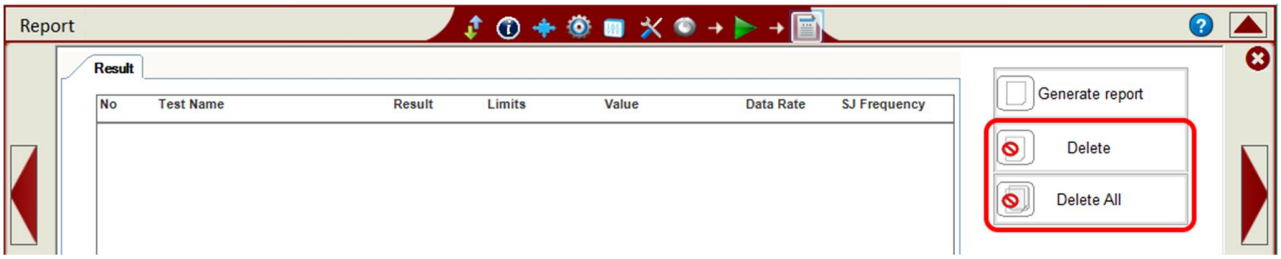


FIGURE 25. DELETE TEST RESULTS

9 Saving and Loading GRL-PAM4-RX Test Sessions

The usage model for the GRL-PAM4-TX software is that the test results are created and maintained as a 'Live Session' in the application. This allows the user to quit the application and return later to continue where the user left off.

Save and Load Sessions are used to save a test session that the user may want to recall later. The user can 'switch' between different sessions by saving and loading them when needed.

- To ***save a test session***, with all of the test parameter information, test results, and any waveforms, select the Options drop-down menu and then select "Save Session".
- To ***load a test session*** back into the application, including the saved test parameter settings, select Options → "Load Session".
- To ***create a new test session*** and return the application back to the default configuration, select Options → "New Session".

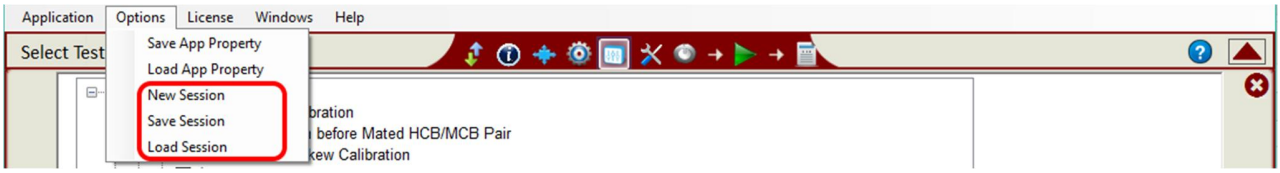


FIGURE 26. SAVE/LOAD/CREATE TEST SESSIONS

The test configuration and session results are saved in a file with the '.ses' extension, which is a compressed zip-style file, containing a variety of information.

10 Appendix A: Manual CTS Procedure for PAM4 Receiver Measurements

This section describes the methodology to perform PAM4 receiver measurements per the PAM4 PHY CTS requirements.

The following procedure gives a typical example on how to measure the stressed impairments for the PAM4 receiver.

i) Set up equipment without the Host Compliance Board (HCB)/Module Compliance Board (MCB).
ii) Perform skew alignments between the Pulse Pattern Generator 1 and 2 (hereafter referred to as PG1 and PG2). The electrical length of the dual pattern generators should be matched.
iii) Calibrate stresses before applying the HCB/MCB mated pair. At TP4a, the Pattern Generator will be calibrated for initial values of Random Jitter (RJ), Bounded Uncorrelated Jitter (BUJ), Total Jitter (TJ), and Sinusoidal Jitter (SJ).
iv) Insert the HCB/MCB mated pair.
v) Determine the optimal CTLE. Multiple CTLEs will be applied to the Reference Receiver to determine the optimal CTLE which generates the largest Eye Height and Eye Width.
vi) Adjust for final Eye Height, Eye Width, and VEC using the optimal CTLE.

10.1.1 Initial Equipment Setup

The following figure shows the initial setup without connecting the HCB/MCB mated pair (direct connection). *(Note that this setup is using the Anritsu BERT.)*

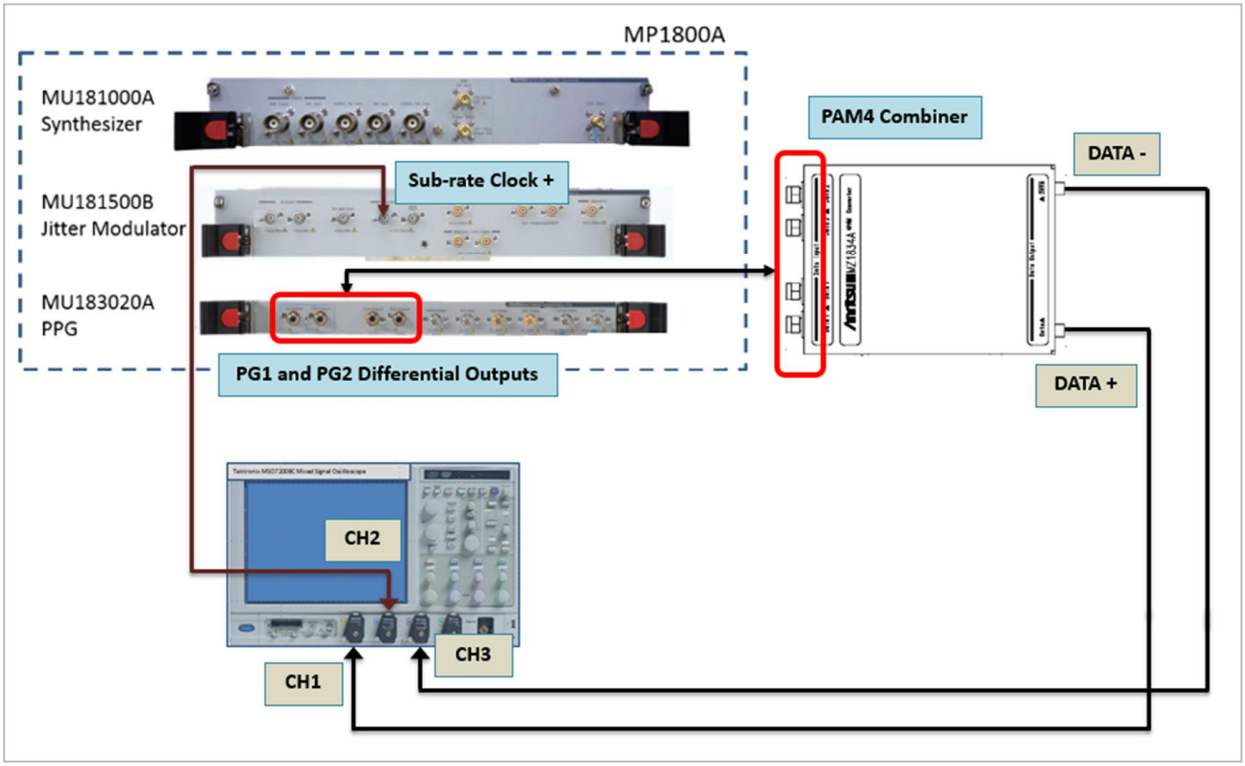


FIGURE 27. PHYSICAL SETUP BEFORE CONNECTING HCB/MCB

1. Connect the PAM4 Combiner directly to the PG1 and PG2 Differential Outputs of the BERT.
2. Connect the DATA+ Output of the PAM4 Combiner to CH1 of the Oscilloscope and the DATA- Output to CH3 (or CH2 and CH4 respectively, depending on the selected setup).
3. Connect the Sub-rate Clock+ of the BERT to the CH2 Clock Input (or the selected channel) of the Scope. *(Note: This will be used as the Trigger for PG1 and PG2 skew adjustment.)*
4. Enable the dual Pattern Generators of the BERT in Combination Mode. In Combination Mode, configure the PG1 and PG2 to generate the PAM4 signal:

   a) On the BERT's Pattern Generator page, select the "Misc2" tab.
   b) Select the "Setting…" button and select **Combination** under 'Operation'.

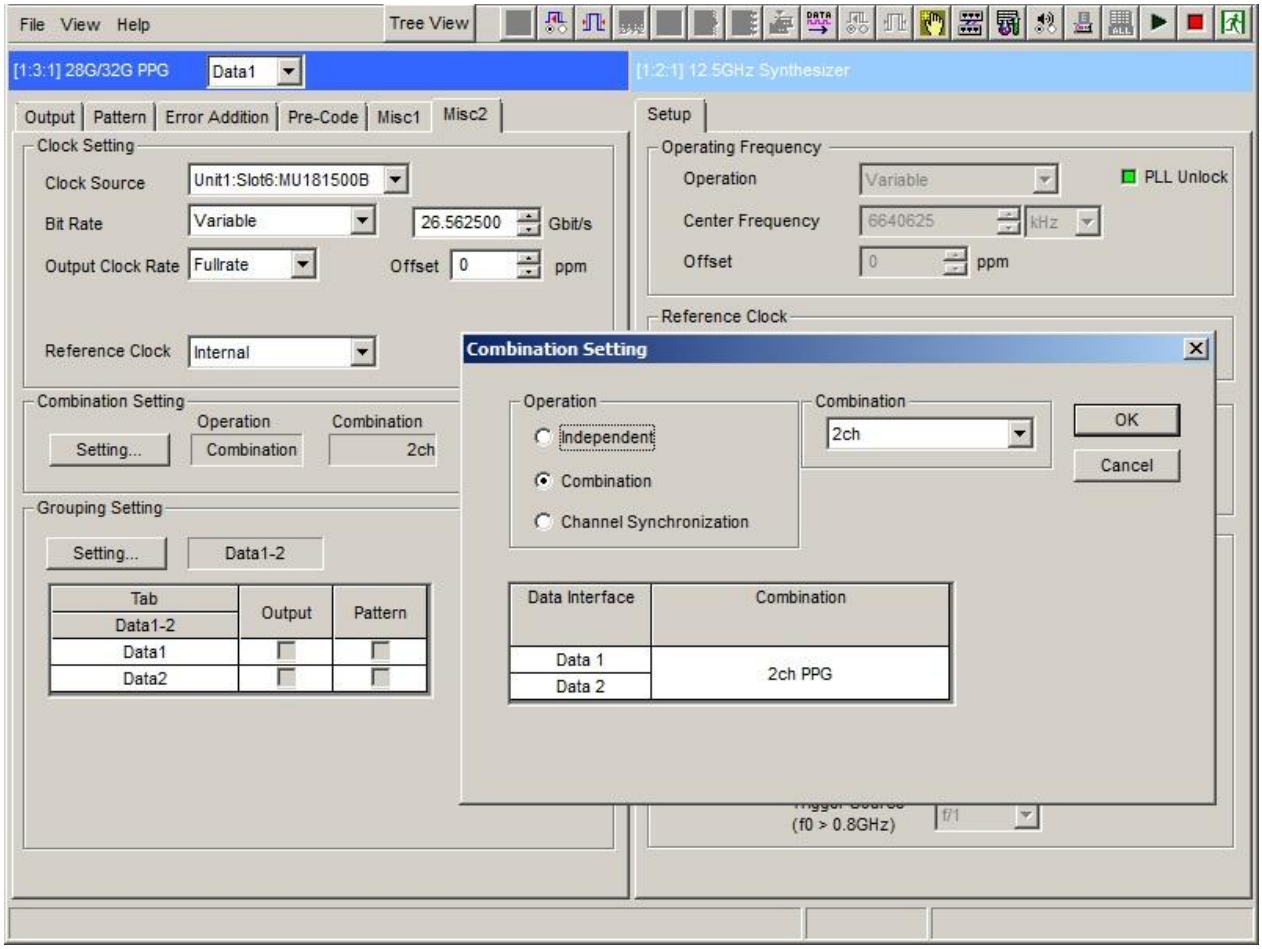


FIGURE 28. ENABLE BERT PATTERN GENERATOR IN COMBINATION MODE

10.1.2 PG1 and PG2 Skew Adjustment

To generate the PAM4 pattern, ensure that the electrical path lengths of PG1 and PG2 are as closely matched as possible, by performing delay line adjustments for both pattern generators. This will be done by measuring, adjusting, and matching Eye Diagram crossing locations for PG1 and PG2. The measurements on the Scope, in Equivalent Time Mode, will be referenced to the same clock which will be injected on CH2 of the scope.

1. On the BERT's Jitter Modulation Source page, turn ON all stresses (SJ, RJ, BUJ).
   a) Set 0% for all enabled stresses.
   b) Set the Sub-rate Clock to '1/80'.

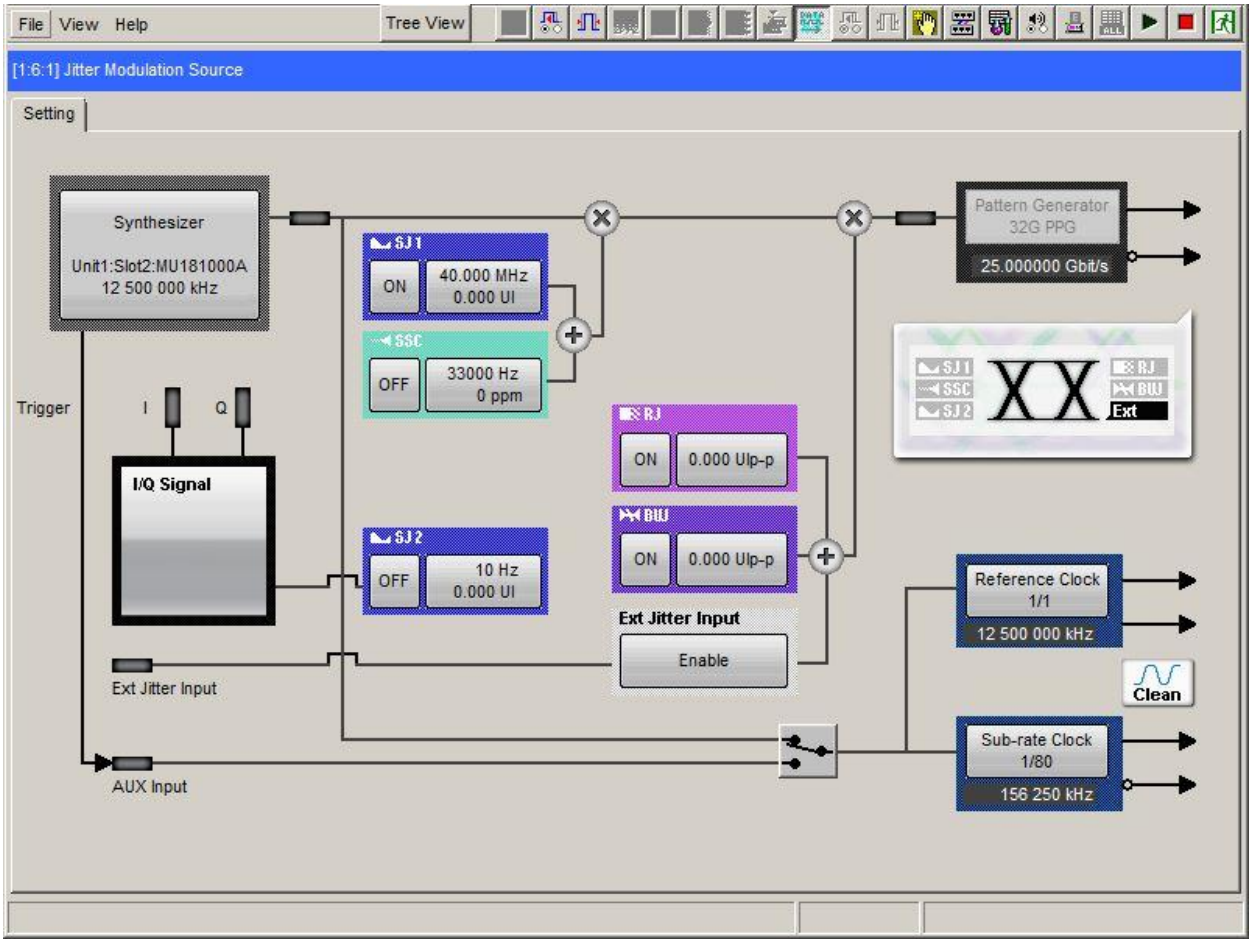


FIGURE 29. ENABLE ALL STRESSES

2. On the BERT's Pattern Generator page, select the "Output" tab and set the Data Rate to **26.5625Gbps**. Also set Amplitude to:
   a) **1.2Vpp** on Data1.
   b) **0.6Vpp** on Data2.

Note: A 2:1 ratio should be maintained to obtain appropriate PAM4 amplitudes.

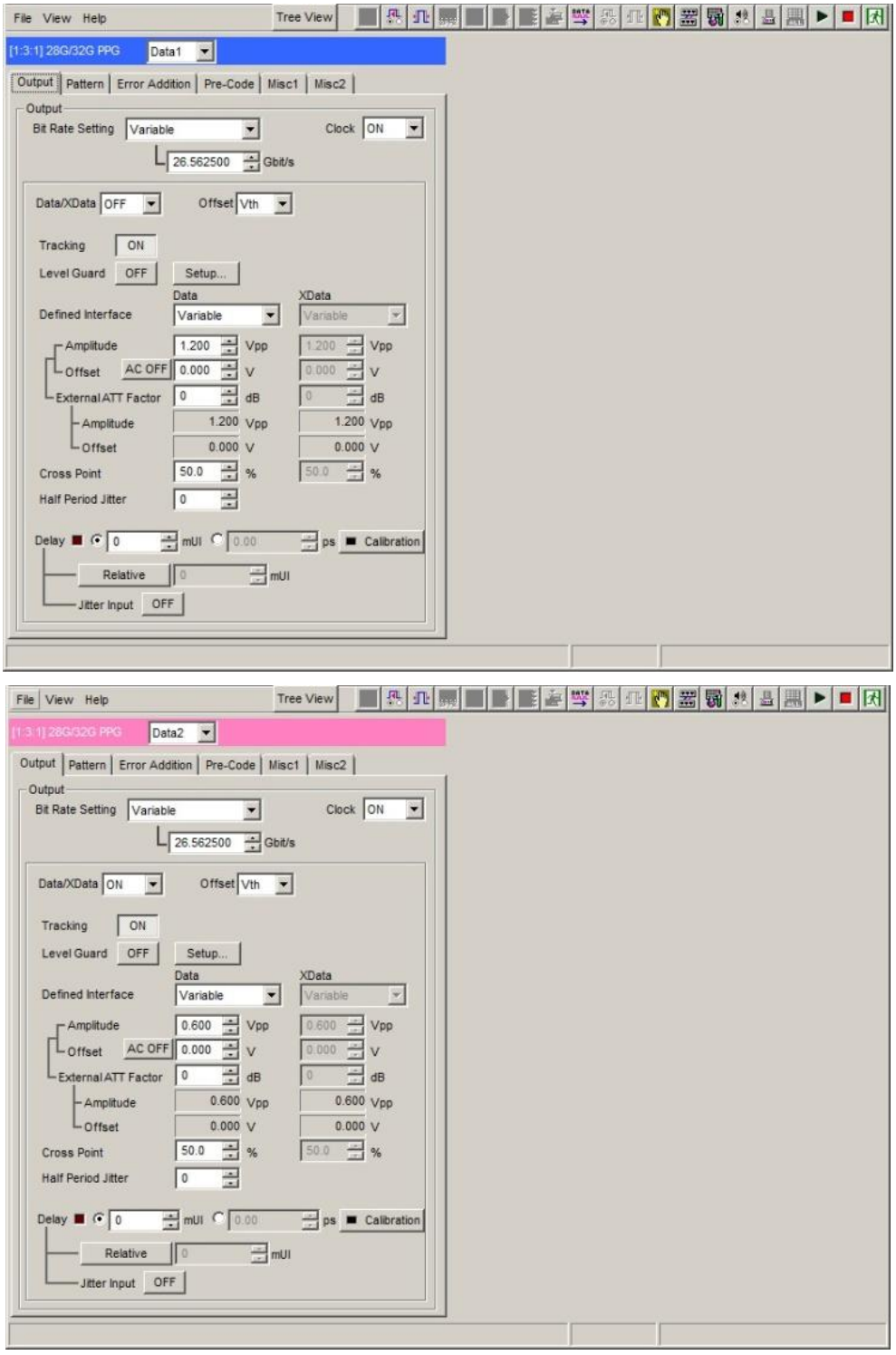


FIGURE 30. SET DATA RATE AND DATA1 AND 2 AMPLITUDES

3. **Turn OFF Data1** by setting "Data/XData" to OFF.

4. On the Scope:

a) Set Trigger Source *[Trig > A Event (Main) trigger setup > Ch2]*: **CH2**

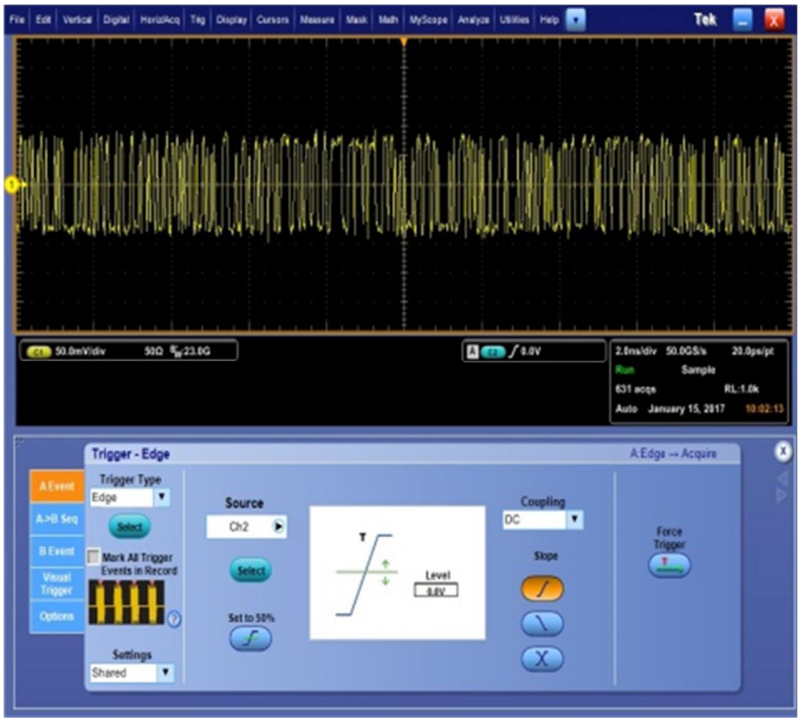


FIGURE 31. SET TRIGGER SOURCE

b) Set Math *[Math > Select Ch1-Ch3]*:

- Math1 Position: **0div**
- Scale: **100mV**

FIGURE 32. SET MATH

c) Set Sampling Mode *[Horiz/Acq tab > Sampling Modes > Equivalent Time]*: **Equivalent**

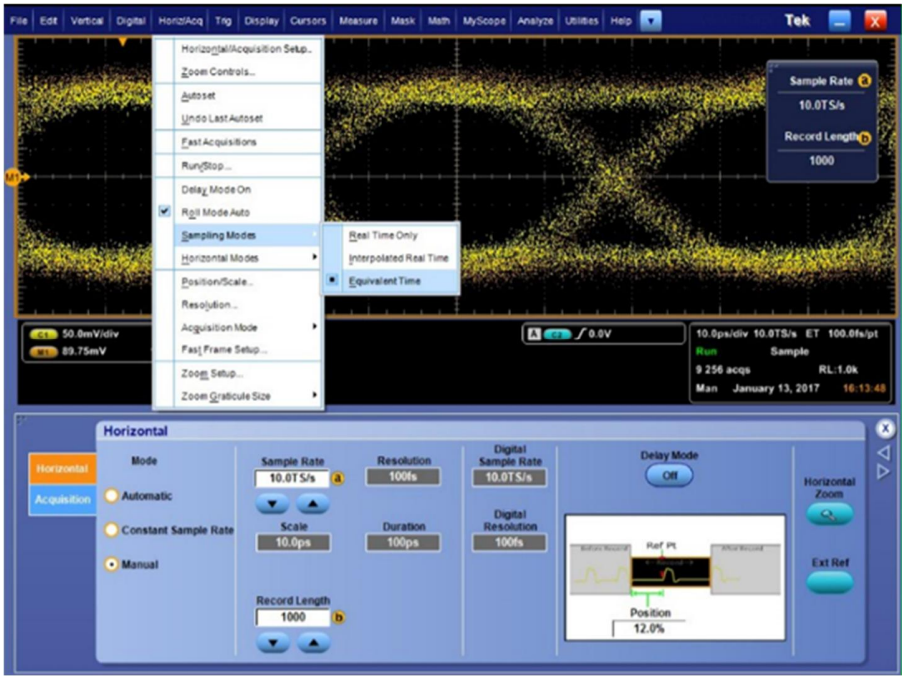


FIGURE 33. SET SAMPLING MODE

d) Set Variable Display Persistence *[Display tab > Display Persistence > Persistence Controls]*:

- Select "**Variable**"
- Persist Time: **100s**

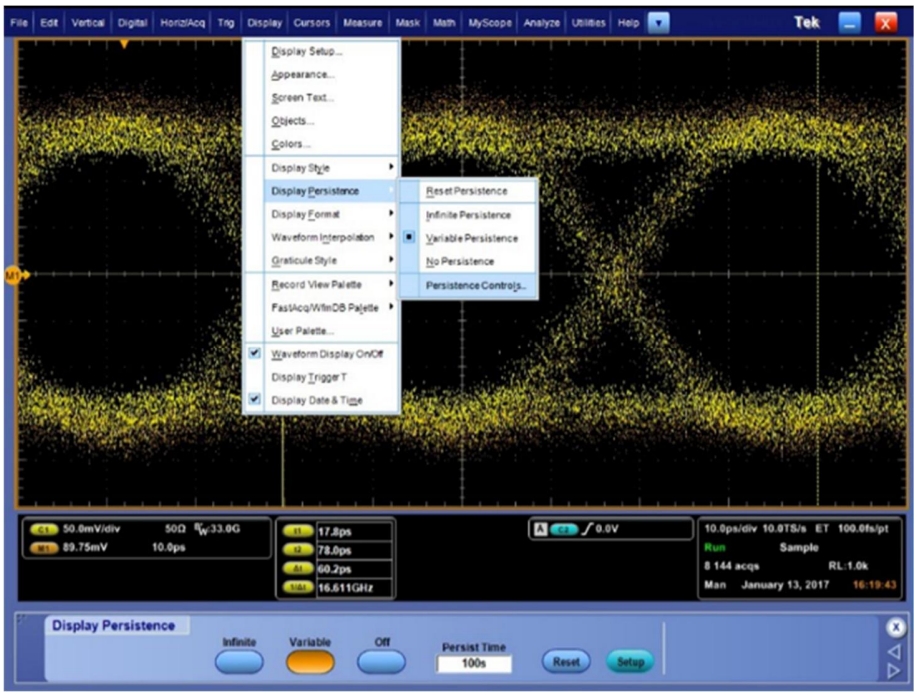


FIGURE 34. SET VARIABLE DISPLAY PERSISTENCE

e) Set Horizontal Acquisition *[Horiz/Acq tab > Horizontal Acquisition Setup]*:

- Sample Rate: **10T/s**
- Mode: **Manual**
- Record Length: **1000**

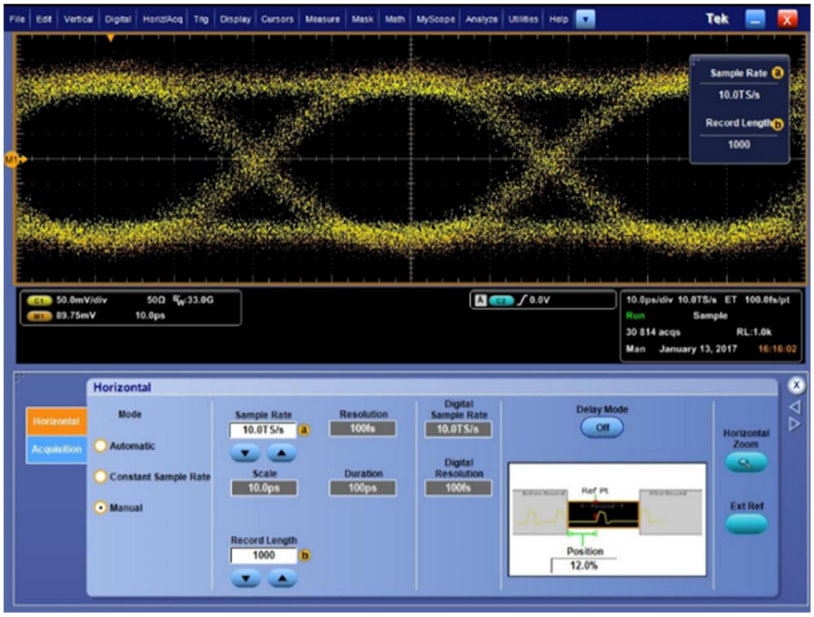


FIGURE 35. SET HORIZONTAL ACQUISITION

5. Apply Cursors *[Cursors tab]*:

- Check "**Cursors On**"
- Cursor Type: **V Bars**

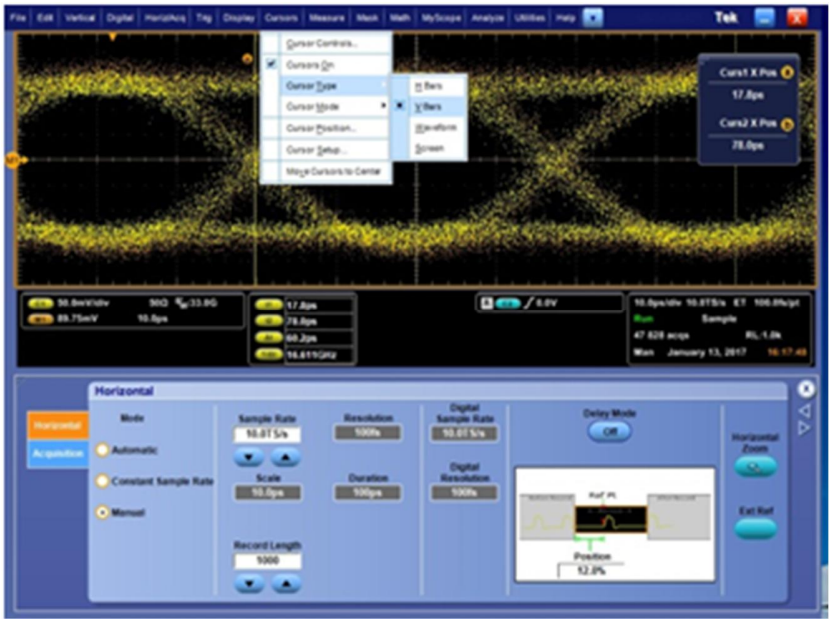


FIGURE 36. ENABLE CURSORS

6. Drag Cursor “a” to the center crossing on the DATA2 Eye Diagram.

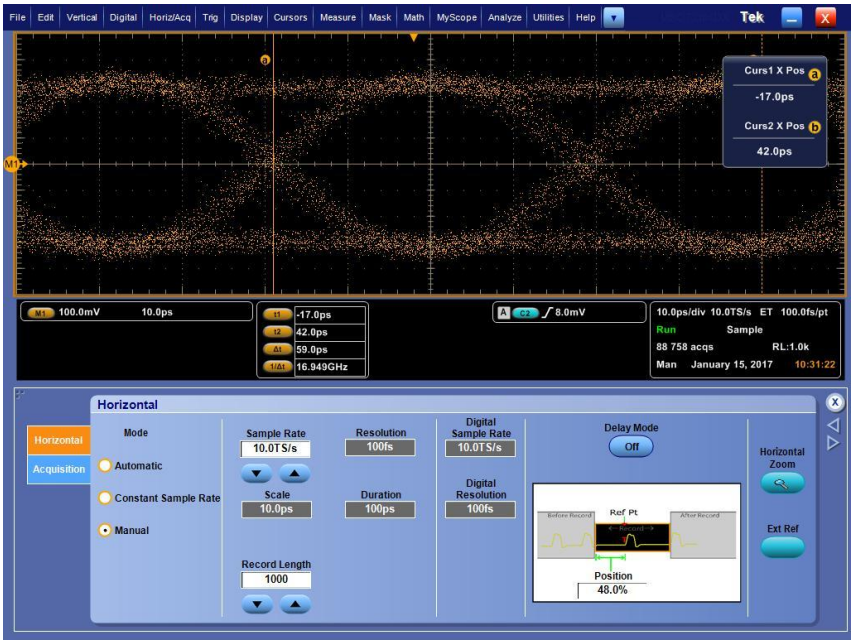


FIGURE 37. ADJUST CURSOR

7. **Turn ON DATA1** and **turn OFF DATA2**.
8. Using the Delay function on DATA2, adjust the delay until the DATA2 crossing matches the Marker location for the DATA1 crossing.

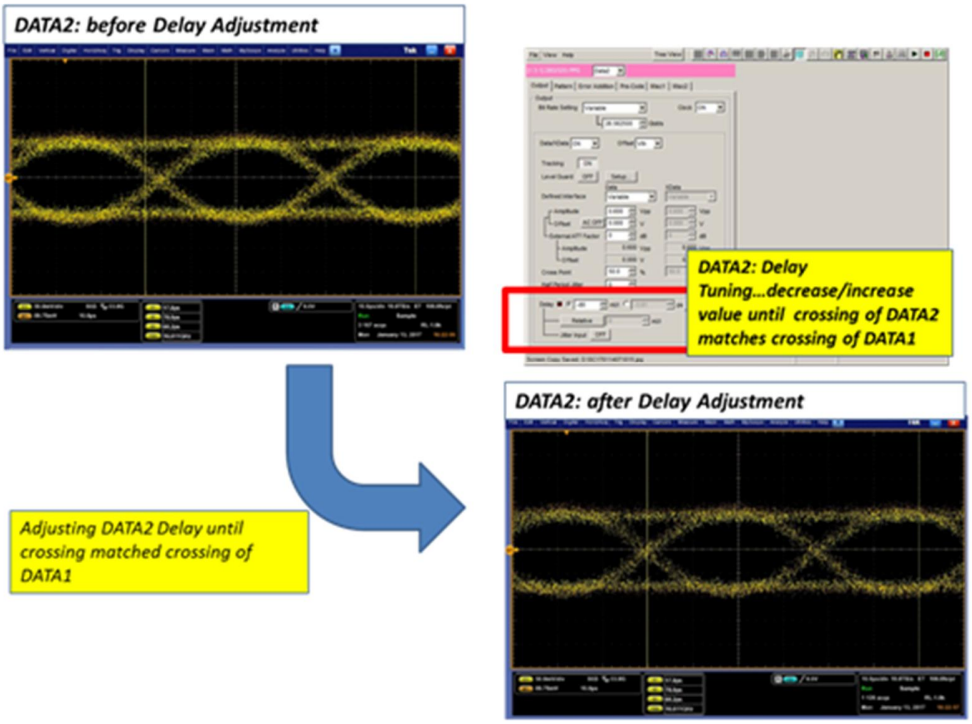


FIGURE 38. ADJUST DATA2 DELAY

9. Now **re-enable DATA1**. Both DATA Outputs should now be enabled.

10. Verify that the generated Eye is a PAM4 Eye Diagram.

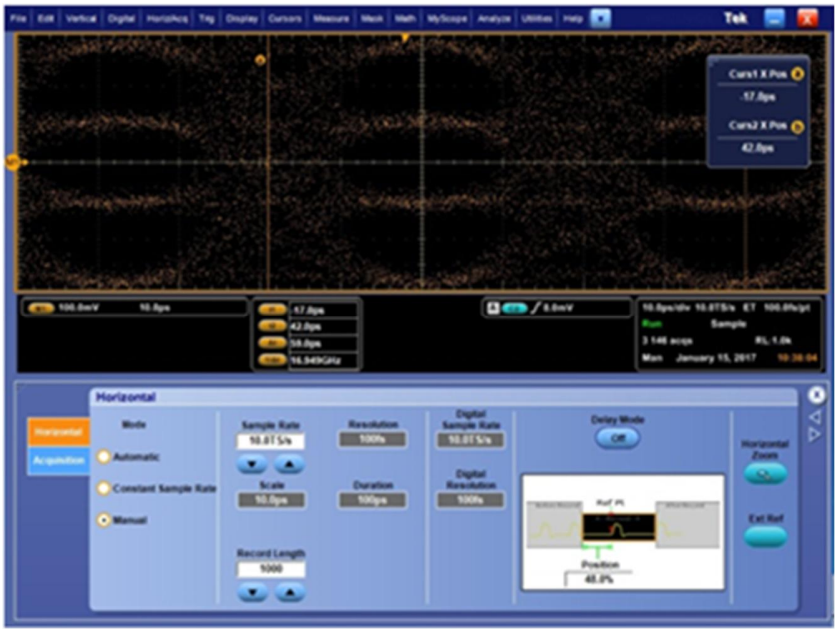


FIGURE 39. VERIFY EYE DIAGRAM

10.1.3 Stress Calibration Before Attaching HCB/MCB Mated Pair

The following diagram shows an example of the stressed input calibration/test setup for the host under test. The stressed signal is applied at TP4a (output of BERT) and will additionally be calibrated at TP4 (after attaching the HCB/MCB mated pair).

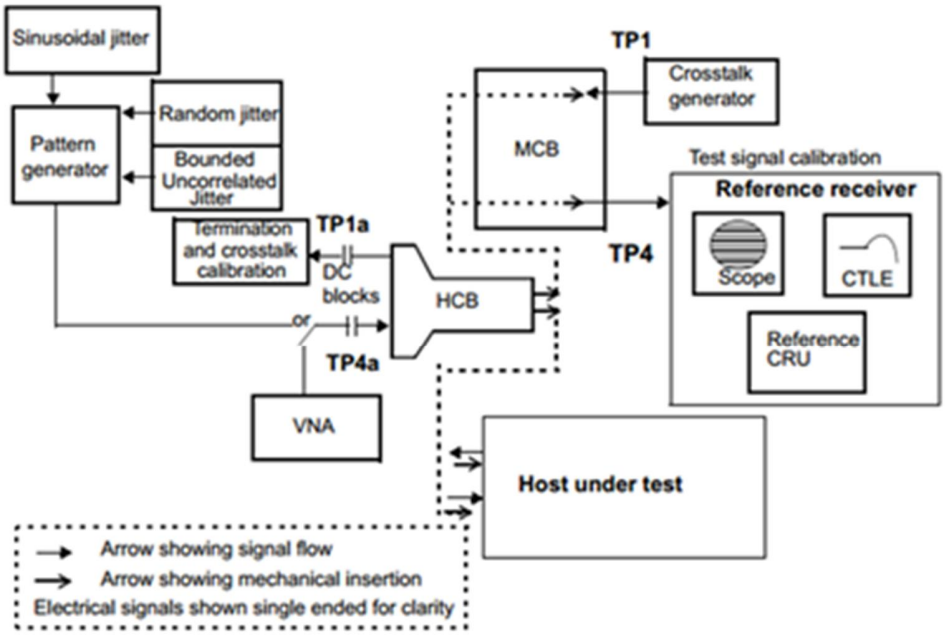


Figure 120E–10—Example host stressed input test

FIGURE 40. HOST STRESSED INPUT CONNECTION SETUP

This section describes the calibration for the Pattern Generator Jitter characteristics at the output of the pattern generator (TP4a).

1. Using the same physical setup from Figure 27, calibrate the pattern generator (BERT) output at TP4a.

   a) On the BERT, change the pattern to the PAM4 Clock Pattern JP03A.

   i) Select PPG > Pattern > Test Pattern > Data.
   ii) Select "Edit" to change DATA pattern.
   iii) Select File > Open > Pattern Files > PAM Pattern.
   iv) Under *Directories*, select "JP03A".
   v) Under *File List*, select "JPO3A.txt".

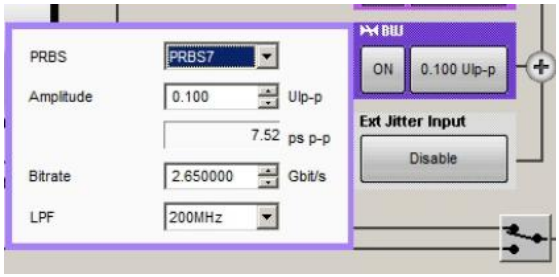


FIGURE 41. CHANGE PATTERN ON BERT

   b) On the Scope, set Jitter Measurements with Clock Pattern.

   i) Open DPOJET.
   ii) Select Analyze > Jitter and Eye Analysis(DPOJET) > Select:

- TJ@BER
- RJ-DD1
- DCD1

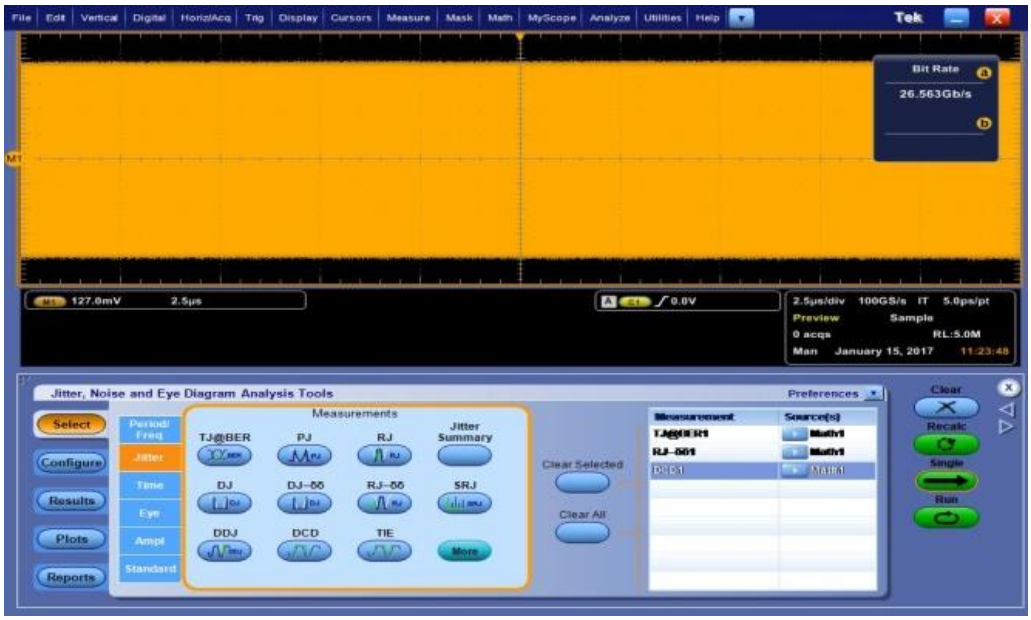


FIGURE 42. SELECT JITTER MEASUREMENTS ON SCOPE

iii) Select the "Configure" button followed by:

- Edges:
    - Make sure all Measurements use "Data" as the Signal Type.

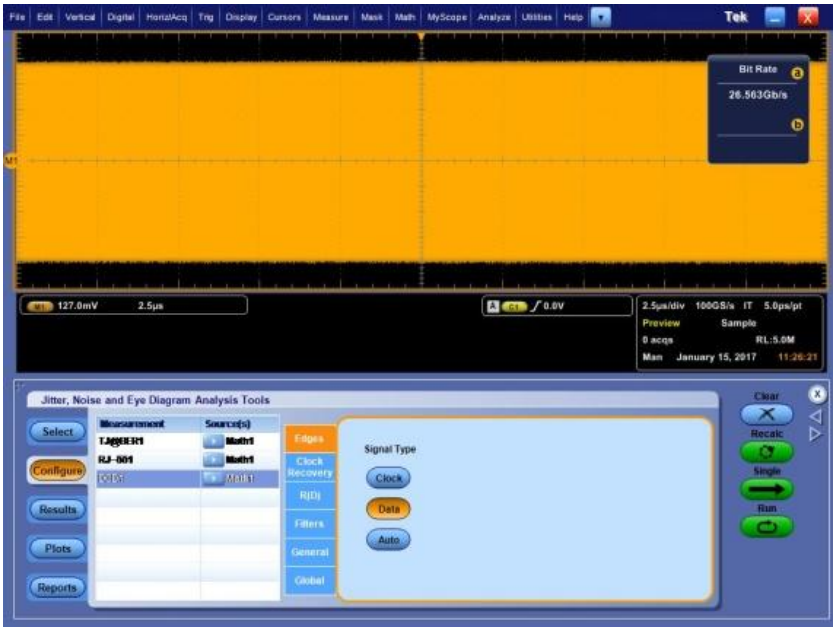


FIGURE 43. SELECT DATA SIGNAL TYPE ON SCOPE

- RjDj:
    - Set Target BER to "1E-06".
    - Click "Apply to All".

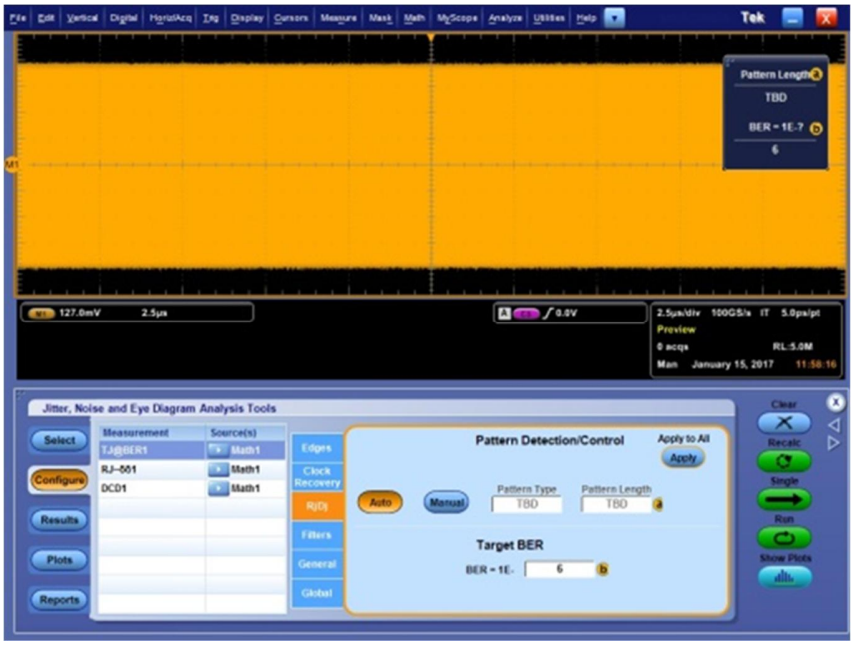


FIGURE 44. SET TARGET BER ON SCOPE

- Clock Recovery:
    - Set Method to “Constant Clock – Mean”.

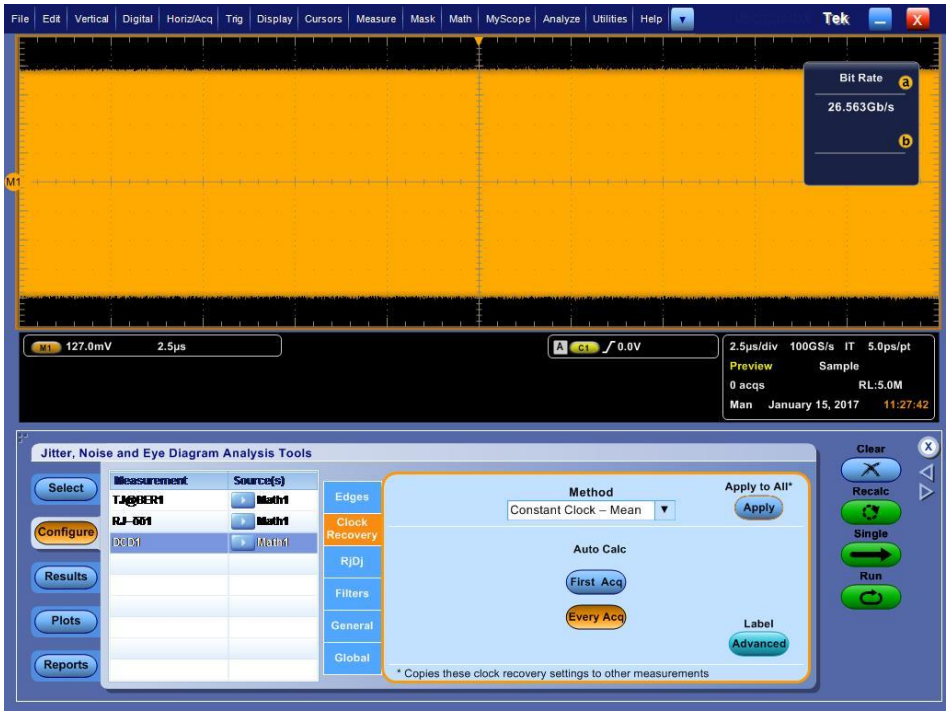


FIGURE 45. SET CLOCK RECOVERY METHOD ON SCOPE

iv) Select the “Plots” button and select the “Eye Diagram” plot.

FIGURE 46. SELECT EYE DIAGRAM PLOT ON SCOPE

v) Configure Acquisition (*Horiz/Acq > Horizontal Acquisition Setup*).

- Set Mode to "Manual".
- Set Bandwidth to "33GHz".
- Set Sample Rate to "200GS/s".
- Set Record Length to "5M".

c) Enable and calibrate RJ.

i) On the BERT, go to the jitter Setting page and set the initial RJ to "0.096 UIp-p".

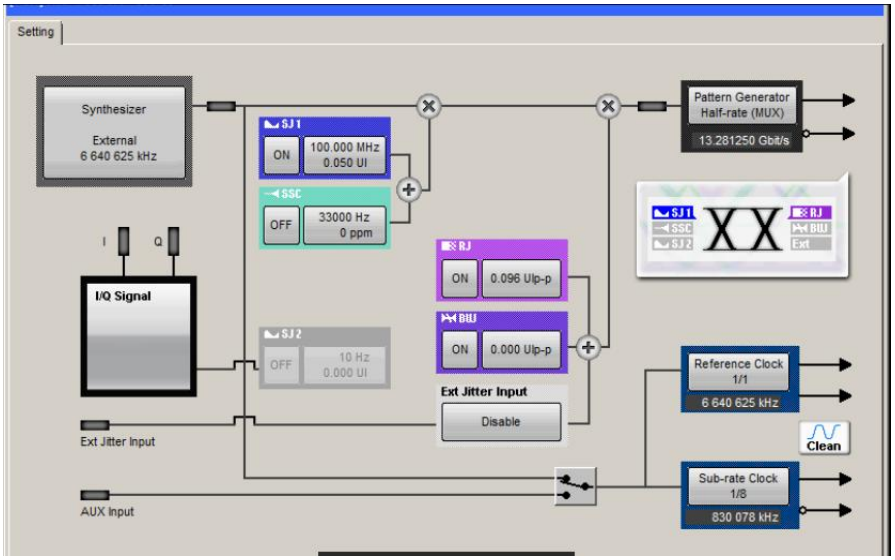


FIGURE 47. SET INITIAL RJ ON BERT

ii) On the Scope, measure RJ to the target value of 0.15UIp-p at BER 1E-06.

iii) On the BERT, adjust RJ until the target value is met.

d) Enable and calibrate TJ.

i) On the BERT, go to the jitter Setting page and enable BUJ with the following settings:

- PRBS: "PRBS7"
- Amplitude: "0.100UIp-p"
- Bitrate: "2.65Gbps"
- LPF: "200MHz"

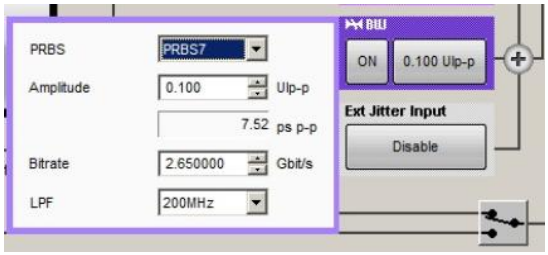


FIGURE 48. SET UP BUJ ON BERT

ii) On the Scope, measure TJ to the target value of 0.28UIp-p at BER 1E-06.
iii) On the BERT, adjust BUJ until the target TJ value is met.

e) Enable and calibrate SJ.

i) On the BERT, go to the jitter Setting page. Enable SJ and disable RJ and BUJ.
ii) For each case in the table below:

- Set the SJ frequency and amplitude to the values defined.
- Measure the SJ amplitude on the Scope to the target value.
- Adjust the SJ amplitude on the BERT until the target SJ value is met.

Parameter	Case A	Case B	Case C	Case D	Case E	Units
Jitter frequency	0.04	1.333	4	12	40	MHz
Jitter amplitude	5	0.15	0.05	0.05	0.05	UI

FIGURE 49. SET UP SJ ON BERT

10.1.4 VEC, Eye Height and Eye Width Calibration After Attaching HCB/MCB Mated Pair

The Eye Height and Eye Width will be measured to a probability of 10E-6 at TP4. This is performed by adjusting the RJ and Output Amplitude of the pattern generator (while making sure not to exceed 900mVpp at the output of the pattern generator) to meet the target Eye Height and Eye Width. This can be done by setting the CTLE of the Reference Receiver to obtain the optimal CTLE which generates the largest Eye Height and Eye Width. Using this optimal CTLE, proper adjustments will then be carried out to achieve the final Eye Height, Eye Width, and VEC.

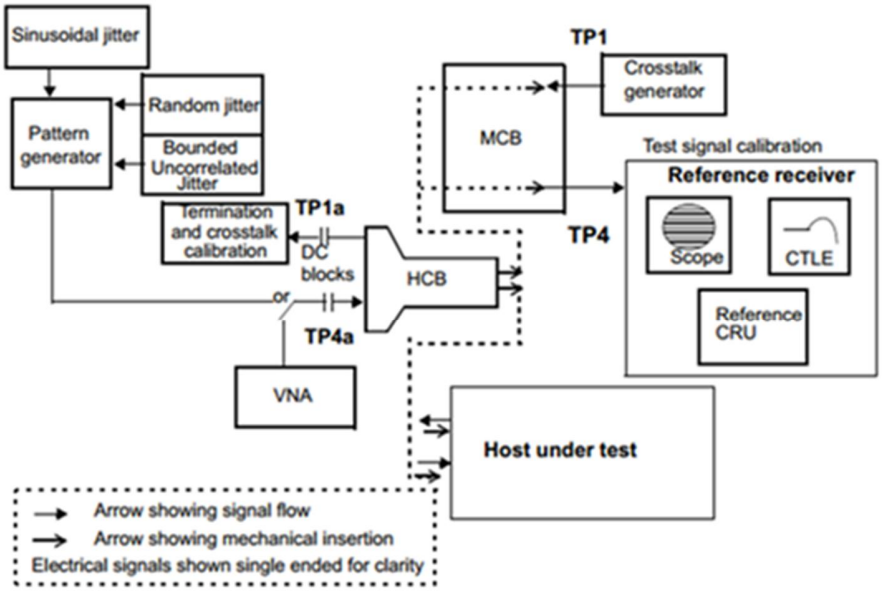


Figure 120E–10—Example host stressed input test

FIGURE 50. VEC, EYE HEIGHT AND EYE WIDTH CONNECTION SETUP

1. Set up the equipment as shown in the following diagram. Both the Host Compliance Board (HCB) and Module Compliance Board (MCB) are included in the setup to perform final Eye Width, Eye Height, and VEC measurements. *(Note: The current 100G test fixture has four differential TX ports and four differential RX ports. All paths should be the same, but TX1 is used as the default path in this setup.)*

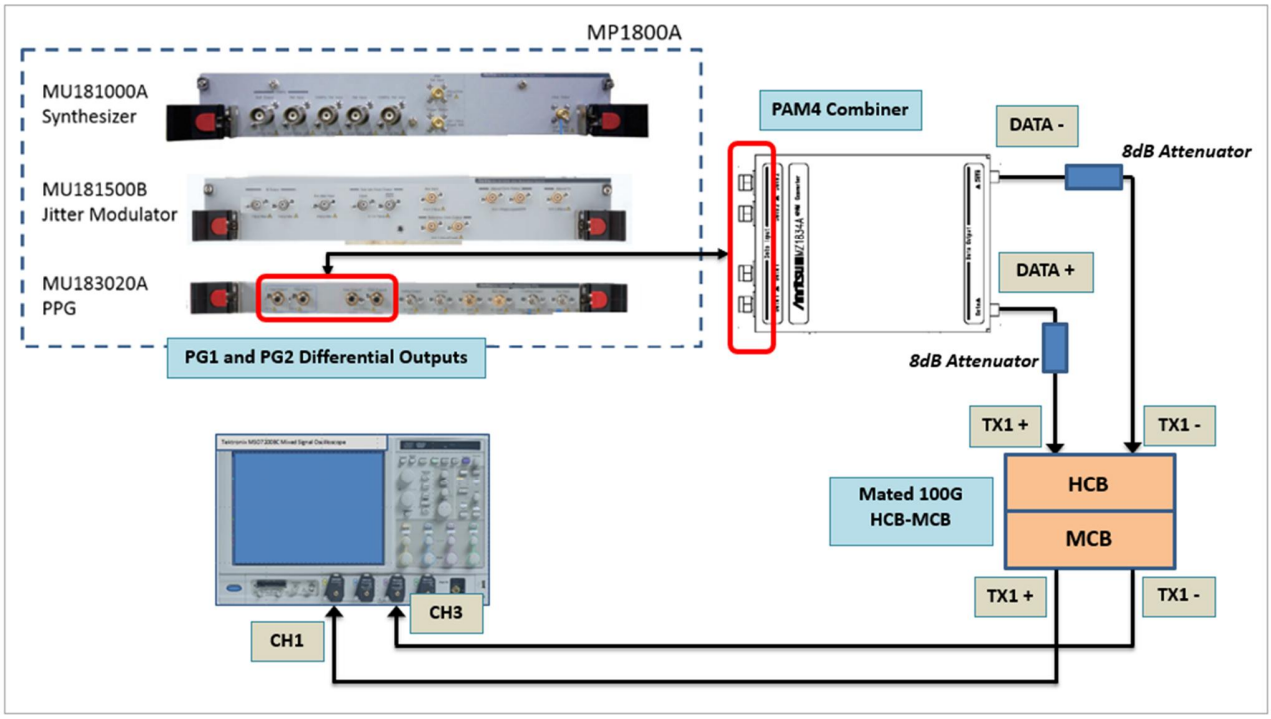


FIGURE 51. PHYSICAL SETUP WITH HCB/MCB ATTACHED

2. Connect the PAM4 Combiner directly to the PG1 and PG2 Differential Outputs of the BERT.
3. Connect the DATA+ and DATA- Outputs of the Combiner to 8dB attenuators to TX1+ and TX1- of the HCB side of the mated 100G HCB-MCB respectively. *(Note: Use the 8dB attenuators to enable the BERT Data signals to achieve eye height target of < 60mV.)*
4. Connect the TX1+ and TX1- Outputs of the MCB side of the mated 100G HCB-MCB to CH1 and CH3 or CH2 and CH4 of the Scope respectively.
5. Set up the Scope as follows:

a) Set Math to "Ch1-Ch3" *[Math > Math Setup]. (Note: Ch1 and Ch3 should be scaled appropriately.)*

FIGURE 52. SET MATH

b) Set Bandwidth to "33GHz" *[Vertical > Vertical Setup]*. This applies to All channels.

FIGURE 53. SET BANDWIDTH

c) Set Sample Rate *[Horiz/Acq > Horizontal/Acquisition Setup]* as follows:

- Mode: "Manual"
- Sample Rate: "200GS/s"
- Record Length: "20M"

FIGURE 54. SET SAMPLE RATE

6. Open and set up the Tektronix PAM4 Analysis Tool as follows:

a) Select Analyze > PAM4 Analysis.
b) Select the "Config" button and configure the following:

i) Under *Main Setup*:

- Symbol Rate: "26.5625GBd"
- Waveform Source: "Math 1"

ii) Under *Clock Recovery*:

Clock Recovery is set for First-Order, 20dB/decade roll-off with JTF BW at 10MHz.

- PLL Model: "Type 1"
- JTF BW (MHz): "10MHz"

iii) Under *CTLE*:

- Enable CTLE (select the CTLE check box)
- CTLE Presets: "OIF-CEI GEN I"

iv) Select *Bessel-Thomson (BT) Filter*:

- Enable BT Filter.
- Set to Manual Bandwidth Mode.
- Set BW: "33GHz"

c) Select the "Prefs" button and configure *Population Control*:

- Limit Method: "Number of Symbols"
- Number of Symbols: "4000000"

7. Determine the CTLE which maximizes product of Eye Height and Eye Width as follows:

a) Set CTLE to 1dB.
b) Select the "Run" function on the Tektronix PAM4 Analysis Tool.

(Note: Make sure to select the "Run" mode and not "Single", in order for the application to run continuously for several minutes to capture the required number of waveforms for 10E-06 analysis.)

c) Select the "Full Wfm" button and capture the following:

i) Eye Height EH6
ii) Eye Width EW6
iii) VEC

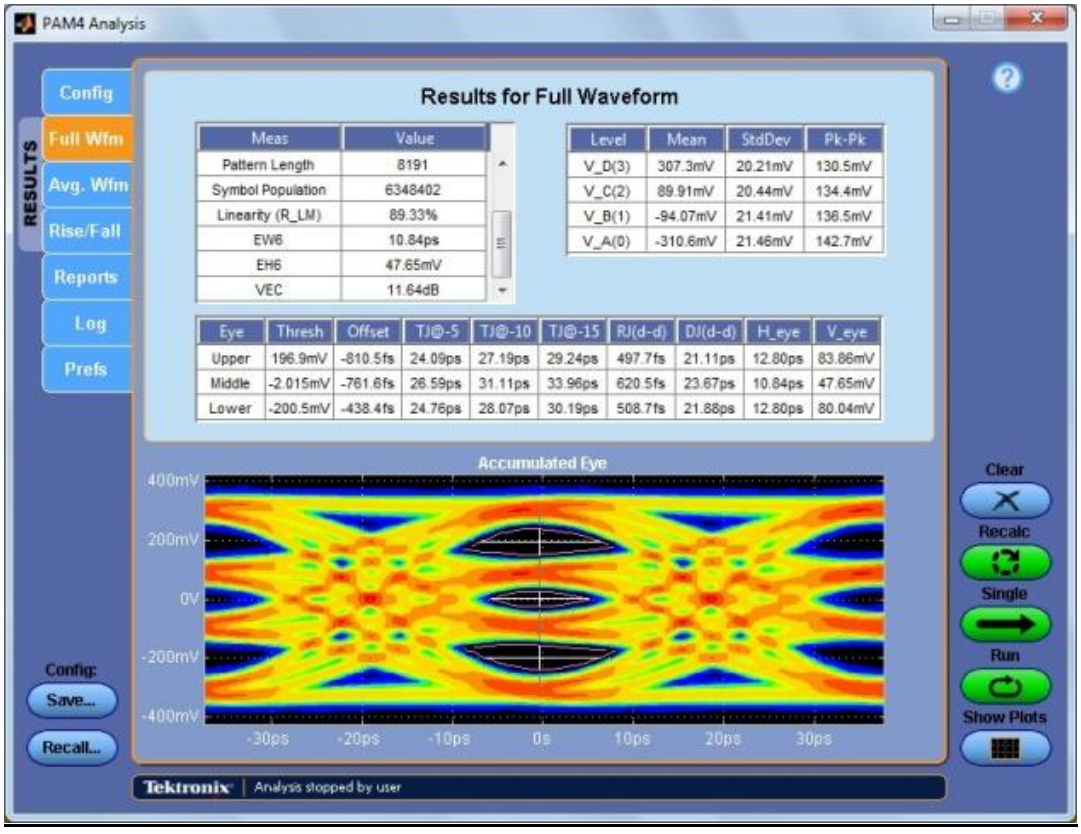


FIGURE 55. CAPTURE EYE MEASUREMENTS

d) Populate the EH6, EW6, and VEC measured values in the following table. Calculate the Area. *(Note: Typically 3 or 4 CTLE's will need to be measured to find the CTLE with the largest area.)*

CTLE	Target: 5.3 to 6.3dB VEC (dB)	Target: 0.20UI or 14.96ps EYE WIDTH (UI)	Target: 40mV EYE HEIGHT (mV)	AREA (EH6 x EW6)
1				0
2	6.262	0.21	29.48	6.1908
3				0
4				0
5				0
6				0
7				0
8				0
9				0

e) Repeat steps a to d with additional CTLE's (2 to 9dB) and enter the EH6, EW6, and VEC values in the table.

f) Determine the optimal CTLE that generates the largest area. This CTLE will be used for final measurement.

8. Perform final adjustments for the RJ and pattern generator Output Amplitude (without exceeding 900mVpp) with the largest area CTLE. These should be adjusted to reach the target EH6, EW6, and VEC values in the specifications using the reference receiver with the setup of the optimal CTLE that was determined in the previous step.

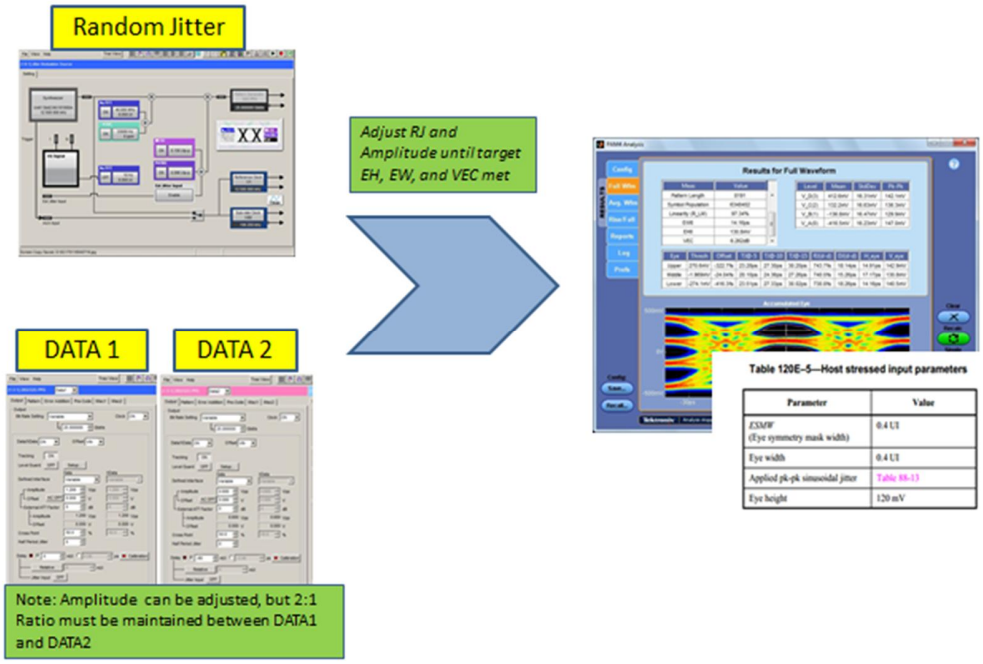


FIGURE 56. FINAL ADJUSTMENTS FOR RJ AND PG OUTPUT AMPLITUDE

Note: Ensure to maintain the 2:1 ratio between the DATA1 and DATA2 output amplitudes of the pattern generator for proper PAM4 signaling.

a) On the PAM4 Analysis Tool, set *CTLE Presets* to "OIF-CEI Type I" (Optimal CTLE).
b) On the BERT Jitter Modulation Source page, configure the following:

i) Turn on Sinusoidal Jitter (SJ) at 100 MHz.
ii) Set the SJ frequency to 0.04MHz as defined in the following table.

Parameter	Case A	Case B	Case C	Case D	Case E	Units
Jitter frequency	0.04	1.333	4	12	40	MHz
Jitter amplitude	5	0.15	0.05	0.05	0.05	UI

iii) Set the SJ amplitude to the previously calibrated value.

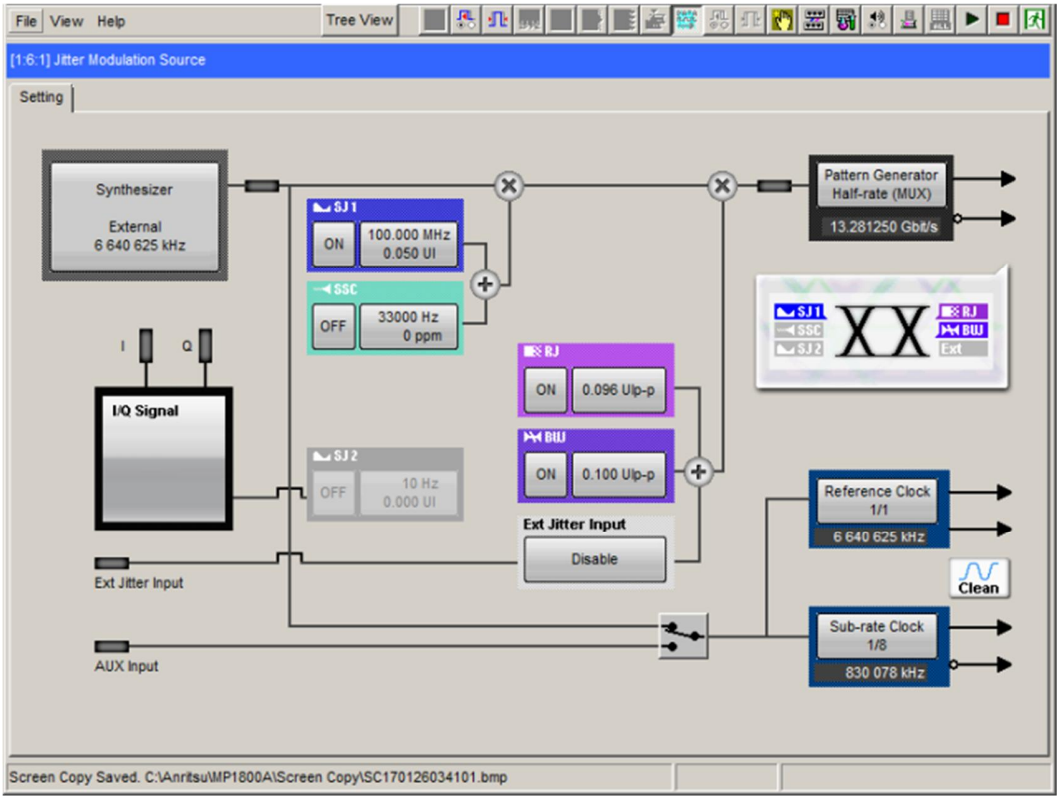


FIGURE 57. SET UP SJ ON BERT

iv) Adjust RJ by increasing or decreasing the RJ until the target values of Eye Height, Eye Width, and VEC are met.

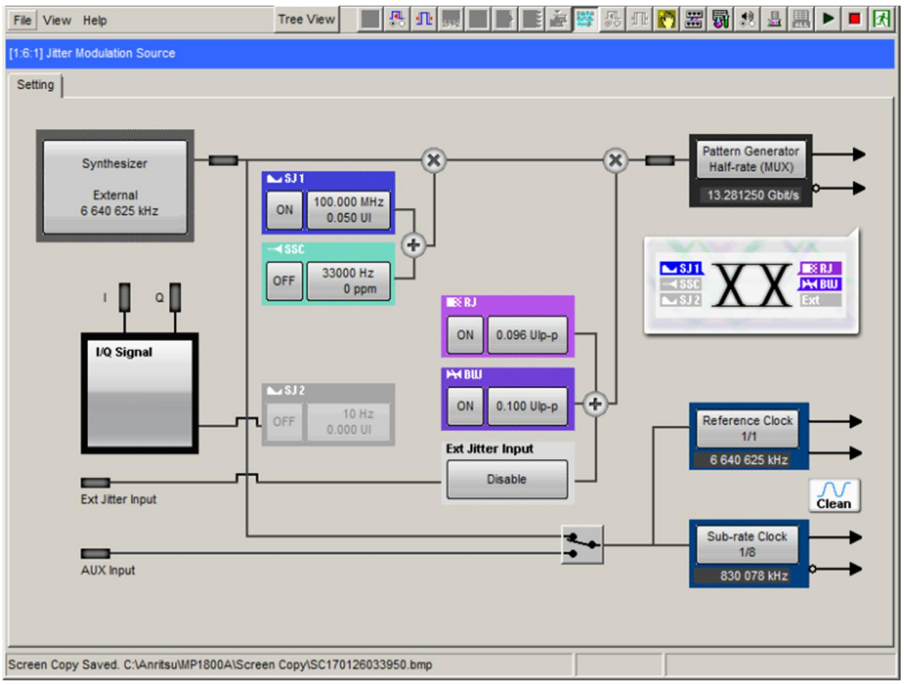


FIGURE 58. ADJUST RJ ON BERT

c) On the BERT PPG page, adjust the DATA1/DATA2 Amplitude.

Note: Ensure to maintain the 2:1 ratio between the DATA1 and DATA2 output amplitudes of the pattern generator for proper PAM4 signaling.

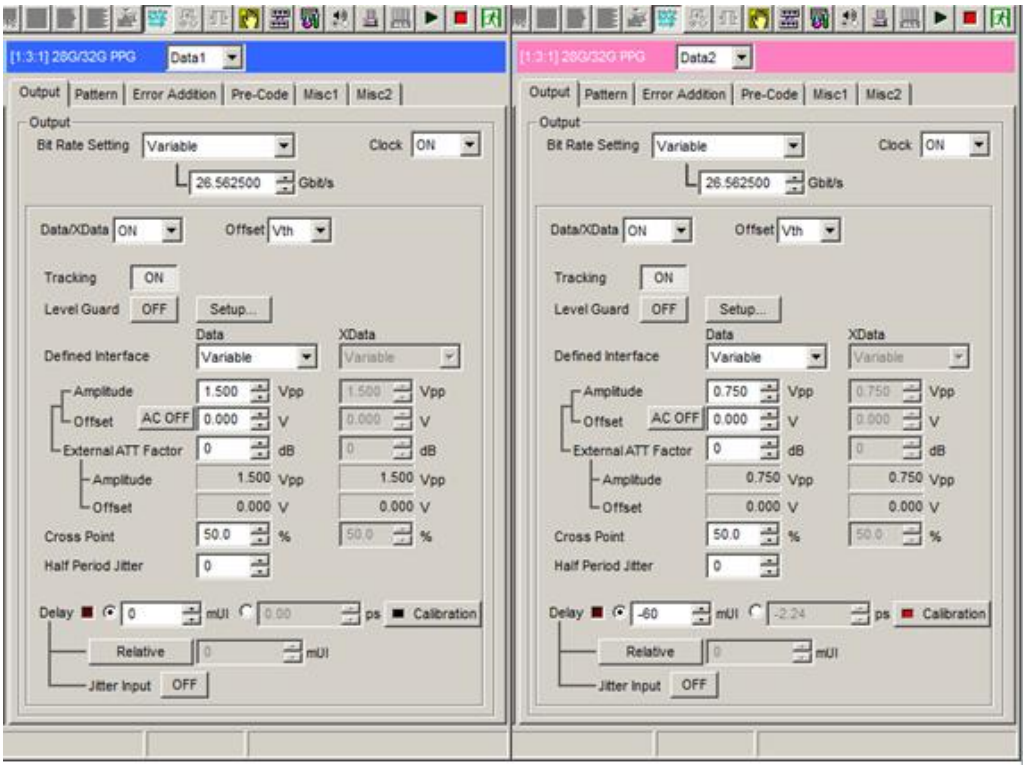


FIGURE 59. ADJUST DATA OUTPUT AMPLITUDE ON BERT

d) Measure EH6, EW6, and VEC and verify that their target values are met, as follows:

i) On the PAM4 Analysis Tool, select the "Run" function.

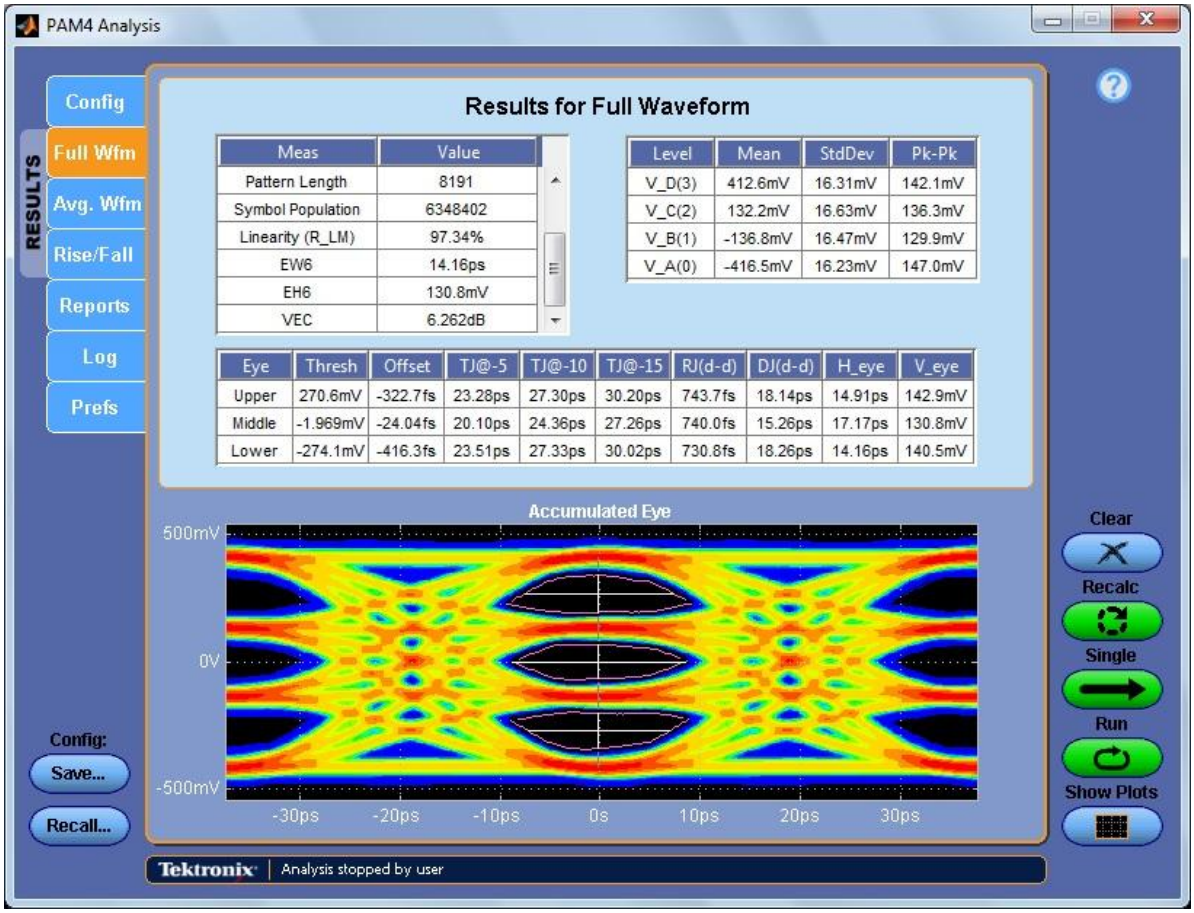


FIGURE 60. MEASURE EH6, EW6, AND VEC

ii) If the target values are met, the measurement is completed successfully. Otherwise repeat step b (iv) onwards to adjust the RJ and output amplitude.

10.1.5 Equipment Setup for DUT Testing

The following figure shows the typical connection setup for testing the Host DUT.

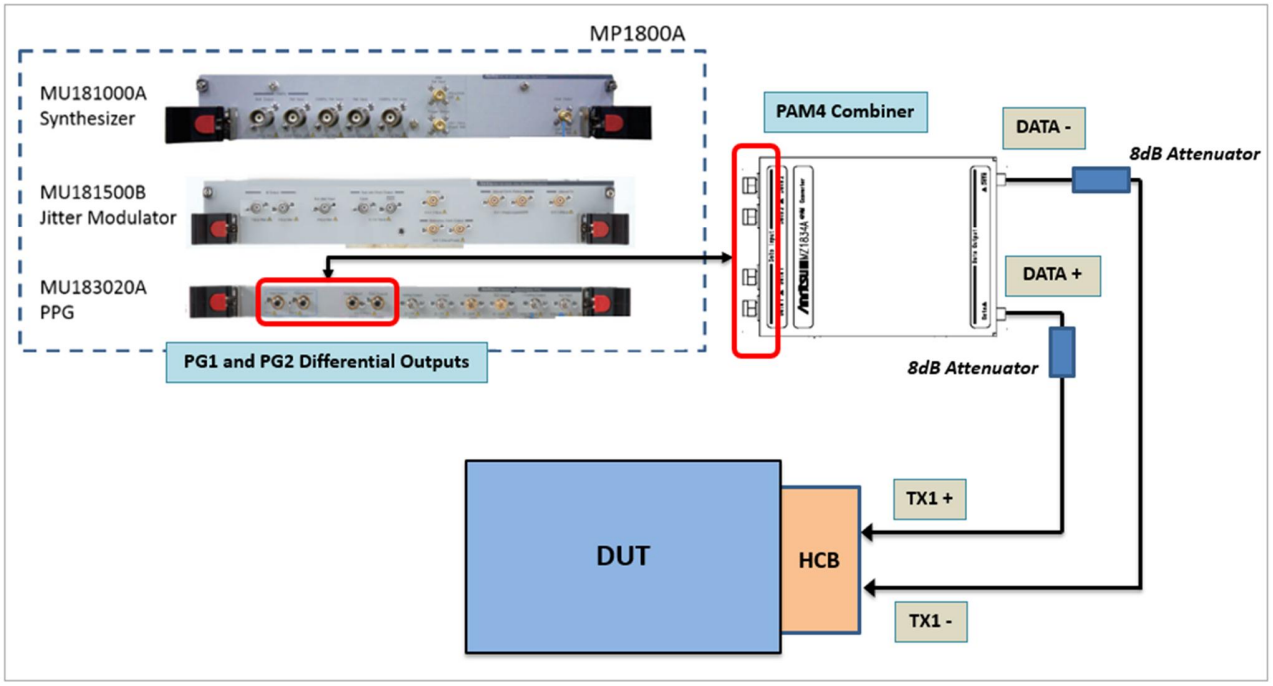


FIGURE 61. PHYSICAL TEST SETUP FOR HOST DUT

1. Connect the PAM4 Combiner directly to the PG1 and PG2 Differential Outputs of the BERT.
2. Connect the DATA+ and DATA- Outputs of the Combiner to 8dB attenuators to TX1+ and TX1- of the HCB respectively.
3. Connect the HCB to the Host DUT.

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