Granite River Labs

GRL-SAS4-RX-BSX Serial Attached SCSI (SAS-4) 22.5 Gb/s Specification Receiver Calibration and Test Automation Software

Physical Layer User Guide/Method of Implementation (MOI)

Using

Tektronix High Performance BERTScope™, Real-Time Oscilloscope and Clock Recovery Unit

with

GRL-SAS4-RX-BSX Automation Software

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TABLE OF CONTENTS

List of Figures

List of Tables

Revision Record

Revision	Revision Date	Description of Changes	Author(s)
1.0	05/2018	GRL-SAS4-RX-BSX MOI & User Guide New document	Ong Gaik Pheng (GRL) gpong@graniteriverlabs.com

1 Introduction

This MOI & User Guide provides information on using the GRL-SAS4-RX-BSX automation software to set up and test an electrical receiver (Rx) device for Serial Attached SCSI (SAS-4) standard certification for the 22.5 Gb/s data rate.

The GRL-SAS4-RX-BSX software provides automation control for performing SAS-4 based 22.5 Gbit/s signaling calibration and tests using OIF-CEI test methods to evaluate the SAS-4 physical layer functionality for receiver (Rx) device electrical compliance. These calibration and tests are designed to determine if a receiver device-under-test (DUT) meets the requirements in the SAS-4 Rx Specifications Standard. The software also supports compatibility for previous SAS physical layer Rx versions. When combined with a satisfactory level of interoperability testing, these tests provide a reasonable level of confidence that the DUT will function properly in most SAS environments.

The main body of this MOI & User Guide describes how to configure the GRL-SAS4-RX-BSX software to calibrate and test the 22.5 Gbit/s based DUT for receiver jitter tolerance compliance. The GRL software is run from the computer or oscilloscope to automate both the Tektronix BERTScope and real-time oscilloscope to calibrate the stressed signal and test receiver conformance. The BERTScope and appropriate equipment are used to generate the necessary test patterns with jitter, ISI, and crosstalk. The real-time Oscilloscope is required for signal calibration while the BERTScope analyzer/error detector is used for error checking via a clock recovery unit. To enable loopback mode for Bit Error Ratio (BER) compliance testing, the DUT will undergo a Tx/Rx link training sequence to enter loopback state. The loopback test pattern of the DUT will be measured and should achieve a specified BER with a 95% confidence level.

The GRL-SAS4-RX-BSX software performs test automation to the T10/BSR Specification using the Tektronix high performance BERTScope, oscilloscope and clock recovery unit, along with a compliant ISI generator as main test equipment.

GRL-SAS4-RX-BSX can be further customized by the user or GRL Engineering using GRL's full KayaQ™ automation framework license. Contact GRL at support@graniteriverlabs.com or through your Tektronix Account Manager for further details.

Note: For manual test methodology, refer to Appendix of this documentation or approved vendor-specific MOI's as technical reference.

2 Reference Documents

- SAS-4 Working Draft Standard (sas4r09)
- SPL-4 Working Draft Standard (spl4r13)
- SAS-4 Specification (T10/BSR INCITS 534, Revision 10b, 28 March 2018, Information Technology – Serial Attached SCSI – 4 (SAS-4))

3 Resource Requirements

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

3.1 Equipment Requirements

TABLE 1. EQUIPMENT REQUIREMENTS – SYSTEMS

System	Qty.	Description	Key Specification Requirement
GRL-SAS4-RX-BSX[a]	1	Granite River Labs SAS-4 (22.5 Gb/s & 12 Gb/s) Receiver Compliance Calibration & Test Automation Software – www.graniteriverlabs.com – *with Node Locked License to single Oscilloscope/PC OS*	
BERTScope (with Clock Recovery Unit)	1	Tektronix BSX Generator set (for 22.5Gb/s) – BSX240/CR286A (minimum)	• Option STR for stress generation • Proper test patterns[b]
Real-Time Oscilloscope	1	Tektronix DPO/MSO70000DX or 70000SX Series Oscilloscope with DPOJET (Jitter and Eye Analysis) software	• ≥ 25 GHz bandwidth with Windows 7+ OS (for 22.5 Gb/s) • Option 5XL or higher memory depth • DPOJET setup files[c] • DPOJET SAS Tx Compliance Test Application[d] • DPOJET SAS Gen4 Compliance and Debug Solution[d]
ISI Generator	1	Compliant ISI channel source	For variable or fixed ISI generation[e]
Computer	1	Laptop or desktop PC	For external automation control

[a] If the GRL-SAS4-RX-BSX test solution is purchased, the user will need to install both the 22.5 Gb/s and 12 Gb/s solutions included in the package to perform testing for SAS-4 Rx at 22.5 Gb/s and 12 Gb/s data rates.

[b] BERTScope SAS-4 patterns are distributed with GRL-SAS4-RX-BSX software and are installed during installation process.

[c] DPOJET setup files are distributed with the GRL-SAS4-RX-BSX software and are installed during installation process.

[d] DPOJET SAS software is required to run SAS-4 Physical Layer Specification measurements. Works with the SAS Gen4 compliance and debug solution on the DPOJET. Downloadable from www.tek.com/oscilloscope/dpo71254c-software/dpojet-sas-tx-compliance-test-application-dpo-dsa-mso-70000cddxsx-0.

[e] The Artek CLE1000 Series Variable ISI Generator can be used as an option for variable ISI output. Refer to Appendix of this document for the Artek CLE1000 Series driver installation procedure.

TABLE 2. EQUIPMENT REQUIREMENTS – ACCESSORIES

Accessory	Qty.	Description	Key Specification Requirement
SAS Receptacle Test Adapter	1	TF-SAS-TPA-R – *DUT connector type dependent*	>15dB return loss from 50MHz to 6GHz, and insertion loss that meets the Zero-Length Test Load requirements of the SAS-4 Draft Standard
miniSASHD 24G SAS Receptacle	1	TF-SASHD-TPA-R – *DUT connector type dependent*	>15dB return loss from 50MHz to 6GHz, and insertion loss that meets the Zero-Length Test Load requirements of the SAS-4 Draft Standard
Phase Matched Cable Set	1	PMCABLE1M or equivalent	
DC Block	1	Picosecond Pulse Labs 5501A or equivalent	Optional (if required in setup)
Pick-off Tee	2	Picosecond Pulse Lab Model 5370-104-14dB	

3.2 Extended Customization

GRL-SAS4-RX-BSX can be further customized by the user or GRL Engineering using GRL's full KayaQ™ automation framework license. Contact GRL at support@graniteriverlabs.com or through your Tektronix Account Manager for further details.

4 General Overview of SAS Rx Electrical Requirements

This section extracts the general Rx measurement specifications from the latest SAS-4 Draft Standard. Please refer to the Standard document for the full details.

TABLE 3. SAS-4 DRAFT STANDARD REQUIREMENTS – GENERAL RX MEASUREMENT

Table 67 — Receiver device general electrical characteristics

Characteristic	Units	1.5 Gbit/s	3 Gbit/s	6 Gbit/s	12 Gbit/s	22.5 Gbit/s
Physical link rate accuracy tolerance at IR if SATA is not supported [a]	ppm	± 100				
Physical link rate accuracy tolerance at IR if SATA is supported [a]	ppm	± 350				
Physical link rate SSC modulation tolerance at IR and CR	ppm	See table 89				
Maximum receiver device transients [b]	V	± 1.2				
Minimum receiver A.C. common mode voltage tolerance V_{CM} [c] [d]	mV(P-P)	150		See table 68		
Receiver A.C. common mode frequency tolerance range F_{CM} [c]	MHz	2 to 200		See table 68		

[a] Physical link rate accuracy shall be measured over a minimum of 1 x 10^6 UI and should be measured using a minimum resolution of 100 Hz.
[b] See 5.8.2 for transient test circuits and conditions.
[c] Receiver devices shall tolerate sinusoidal common mode noise components within the peak to peak amplitude (V_{CM}) and the frequency range (F_{CM}).
[d] The measurement shall be made with a channel equivalent to the channel used in the zero-length test load (see figure 133).

The common mode frequency tolerance range for 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s is extended to include the effects of duty cycle distortion. Measurement methods for testing the extended frequency ranges for A.C. common mode tolerance are not defined by this standard; therefore the common mode signal characteristics defined in table 68 are recommended design guidelines for receiver devices supporting 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s.

Table 68 — Recommended receiver device common mode tolerance for 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s

Characteristic	Units	6 Gbit/s	12 Gbit/s	22.5 Gbit/s
Minimum receiver A.C. common mode voltage tolerance V_{CM} [a] [b]	mV(P-P)	150		
Receiver A.C. common mode frequency tolerance range F_{CM} [b]	MHz	2 to 3 000	2 to 6 000	2 to 11 250

[a] Receiver devices should be designed to tolerate sinusoidal common mode noise components within the peak to peak amplitude (V_{CM}) and the frequency range (F_{CM}).
[b] The value represents the signal characteristic at IR or CR when the channel between the transmitter device and IR or CR is equivalent to the channel used in the zero-length test load (see figure 133).

Table 86 — SSC modulation types

SSC modulation type	Maximum SSC frequency deviation (SSC_{tol}) [a]				
	1.5 Gbit/s	3 Gbit/s	6 Gbit/s	12 Gbit/s	22.5 Gbit/s
Center-spreading	+2 300 / -2 300 ppm			+1 000 / -1 000 ppm	+500 / -500 ppm
No-spreading	+0 / -0 ppm			+0 / -0 ppm	+0 / -0 ppm
Down-spreading	+0 / -2 300 ppm			+0 / -1 000 ppm	+0 / -500 ppm
SATA down-spreading [b]	+0 / -5 000 ppm			N/A	N/A

[a] This is in addition to the physical link rate accuracy and tolerance defined in table 44 and table 67.
[b] This is only used as a receiver parameter.

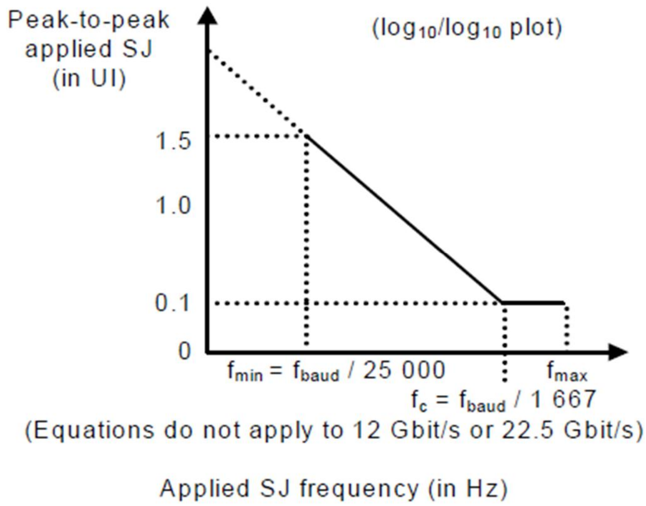


Figure 181 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s,and 22.5 Gbit/s without SSC support

Table 83 defines f_{min}, f_c, and f_{max} for figure 181. f_{baud} is defined in table 42 (see 5.8.1).

Table 83 — f_{min}, f_c, and f_{max} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s,and 22.5 Gbit/s without SSC support

Physical link rate	f_{min}	f_c	f_{max}
1.5 Gbit/s	60 kHz	900 kHz	5 MHz
3 Gbit/s	120 kHz	1 800 kHz	7.5 MHz
6 Gbit/s	240 kHz	3 600 kHz	15 MHz
12 Gbit/s	240 kHz	3 600 kHz	15 MHz
22.5 Gbit/s	240 kHz	3 600 kHz	15 MHz

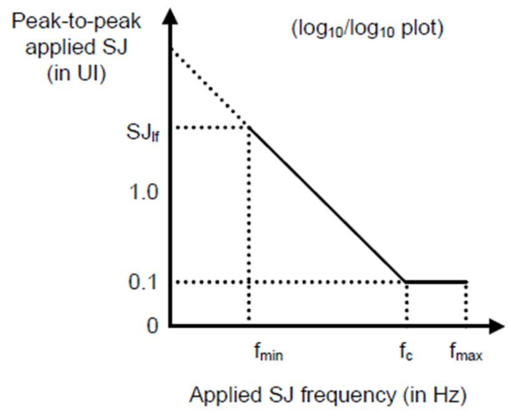


Figure 182 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

Table 84 defines f_{min}, f_c, f_{max}, and SJ_{lf} for figure 182.

Table 84 — f_{min}, f_c, f_{max}, and SJ_{lf} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

Physical link rate	f_{min}	f_c	f_{max}	SJ_{lf}
1.5 Gbit/s	97 kHz	1.03 MHz	5 MHz	11.3 UI
3 Gbit/s	97 kHz	1.46 MHz	7.5 MHz	22.6 UI
6 Gbit/s	97 kHz	2.06 MHz	15 MHz	45.3 UI
12 Gbit/s	111 kHz	2.06 MHz	15 MHz	34.6 UI
22.5 Gbit/s	119 kHz	2.06 MHz	30 MHz	30.1 UI

The diagram below displays an example of the maximum insertion loss of ~ 30 dB for the SAS-4 TxRx setup at 22.5 Gbit/s.

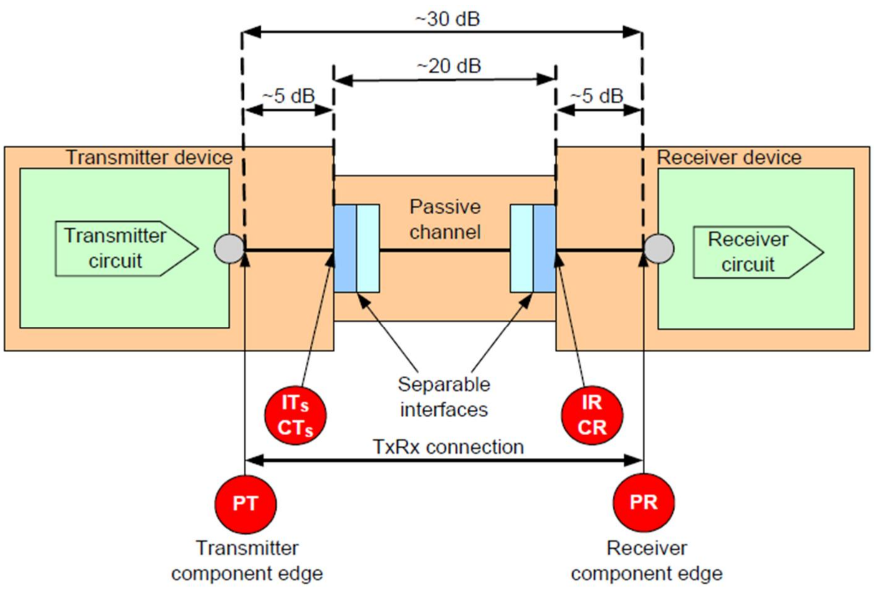


Figure 123 — Example TxRx connection for trained 22.5 Gbit/s

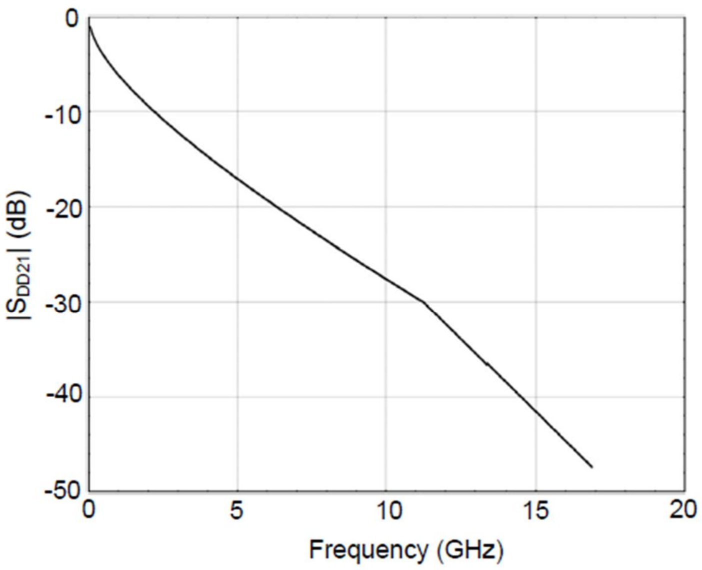


Figure 124 — Passive TxRx connection differential insertion loss for trained 22.5 Gbit/s

The following table shows the signal tolerance requirements of the Rx DUT at IR and CR compliance test points.

TABLE 4. SAS-4 DRAFT STANDARD REQUIREMENTS – RX IR/CR SIGNALING

Table 74 — Delivered signal characteristics for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s and 22.5 Gbit/s at IR and CR

Characteristic	Units	Minimum	Nominal	Maximum
Peak to peak voltage for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s [a] [b] [c] [d]	mV(P-P)			1 200
Non-operational input voltage	mV(P-P)			2 000
Reference differential impedance [e]	Ω		100	
Reference common mode impedance [e]	Ω		25	

[a] See 5.8.4.6.6 for the measurement method for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s.
[b] See table 53 for the measurement method for 12 Gbit/s.
[c] See table 61 for the measurement method for 22.5 Gbit/s.
[d] During OOB, SNW-1, SNW-2, and SNW-3 (see SPL-4), the untrained 1.5 Gbit/s and 3 Gbit/s specifications in 5.8.5.4 apply.
[e] For receiver device S-parameter characteristics, see 5.8.5.7.2.

Below are the requirements for signal to be transmitted by the pattern generator to test a SAS-4 based DUT for Rx compliance at 22.5 Gbit/s.

TABLE 5. SAS-4 DRAFT STANDARD REQUIREMENTS – TRANSMITTED SIGNAL FOR SAS-4 RX DUT TESTING

Table 82 — Test equipment transmitter device signal output characteristics for stressed receiver device testing for trained 22.5 Gbit/s at PT, IT, and CT

Signal characterisitic	Symbol	Units	Minimum	Nominal	Maximum
Peak to peak voltage (V_{P-P}) [a] [b]		mV(P-P)	850		1 000
Transmitter device off voltage at IT or CT [c] [d]		mV(P-P)			50
Reference differential impedance at IT or CT [e]		Ω		100	
Reference common mode impedance at IT or CT [e]		Ω		25	
Rise/fall time at IT or CT [f]		UI	0.30 [g]		0.41 [h]
Common mode noise [i]		mV rms			12
Uncorrelated unbounded Gausian jitter [j] [k] [l]	T_UUGJ	UI	0.135 [m]	0.15 [n]	0.165 [o]
Uncorrelated bounded high probability jitter [j] [k]	T_UBHPJ	UI	0.085 [p]	0.10 [q]	0.115 [r]
Duty cycle distortion [s]	T_DCD	UI			0.035 [t]
Total jitter [j] [k]	T_TJ	UI			0.28 [u]

[a] The V_{P-P} measurement shall be made with the transmitter device set to no equalization (see table 56) and amplitude set to maximum. The minimum value applies at PT.
(see 5.3.3) and the maximum value applies at IT (see 5.3.3) or CT (see 5.3.3). The measurement is made with a repeating 7Eh (i.e., D30.3) pattern (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4).
[b] The V_{P-P} amplitude should be set as close as possible to the minimum value.
[c] The transmitter device off voltage is the maximum A.C. voltage measured at compliance points IT and CT when the transmitter is unpowered or transmitting D.C. idle (e.g., during idle time of an OOB signal).
[d] If optical mode is enabled, then the transmitter device off voltage is not applicable.
[e] See 5.8.4.8.3 for transmitter device S-parameters characteristics.
[f] Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 01b pattern or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4).
[g] 0.30 UI is $13.\overline{3}$ ps at 22.5 Gbit/s.
[h] 0.41 UI is $18.\overline{2}$ ps at 22.5 Gbit/s.
[i] Common mode noise is measured using the PRBS15 (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4) (see ITU-T) on the physical link.
[j] For jitter measurements, see 5.8.4.8.4.
[k] The measurement shall include the effects of the JTF (see 5.8.3.2).
[l] The T_UUGJ nominal value of 0.15 UI corresponds to a value of 0.01 UI rms.
[m] 0.135 UI is $5.\overline{9}$ ps at 22.5 Gbit/s.
[n] 0.15 UI is $6.\overline{6}$ ps at 22.5 Gbit/s.
[o] 0.165 UI is $7.\overline{3}$ ps at 22.5 Gbit/s.
[p] 0.085 UI is $3.\overline{7}$ ps at 22.5 Gbit/s.
[q] 0.10 UI is $4.\overline{4}$ ps at 22.5 Gbit/s.
[r] 0.115 UI is $5.\overline{1}$ ps at 22.5 Gbit/s.
[s] T_DCD is measured with a repeating 01b pattern or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4) on the physical link. Duty cycle distortion is part of the CBHPJ (correlated bounded high probability jitter) distribution (see OIF-CEI) and is measured at the time-averaged signal level. T_DCD shall be measured with transmitter device equalization on and transmitter device equalization set to no_equalization (see table 56).
[t] 0.035 UI is $1.\overline{5}$ ps at 22.5 Gbit/s.
[u] 0.28 UI is $12.\overline{4}$ ps at 22.5 Gbit/s.

[Note that this MOI & User Guide focuses mainly on the SAS-4 based system for Rx calibration and testing. For SAS-3 and below, please refer to the GRL-SAS-12G-RX MOI & User Guide.]

5 Setting Up GRL-SAS4-RX-BSX Automation Software

This section provides the procedures to start up and pre-configure the GRL-SAS4-RX-BSX 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.

5.1 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:
    - **SAS4RxPatternFilesInstallationxxxxxxxxxSetup.exe** – Run this on the BERTScope to install the SAS-4 test pattern setup files.
    - **SAS24GRxTestApplicationxxxxxxxxxSetup.exe** – Run this on the controller PC or on the Scope to install the GRL-SAS4-RX-BSX application.
    - **SAS4RxTestScopeSetupFilesInstallationxxxxxxxxxx.exe** – Run this on the Scope to install the DPOJET setup files.

5.2 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.

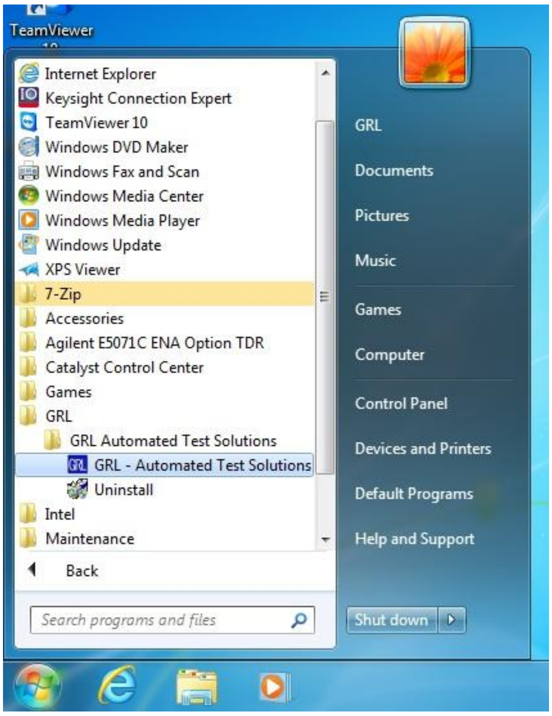


FIGURE 1. SELECT AND LAUNCH GRL FRAMEWORK

2. From the Application→Rx Test Solution drop-down menu, select 'SAS 4 Rx Test' to start the SAS-4 Rx Test Application. If the selection is grayed out, it means that your license has expired.

FIGURE 2. START SAS-4 RX TEST APPLICATION

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

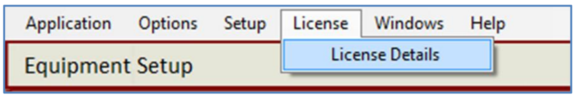


FIGURE 3. SEE LICENSE DETAILS

a) Check the license status for the installed application.

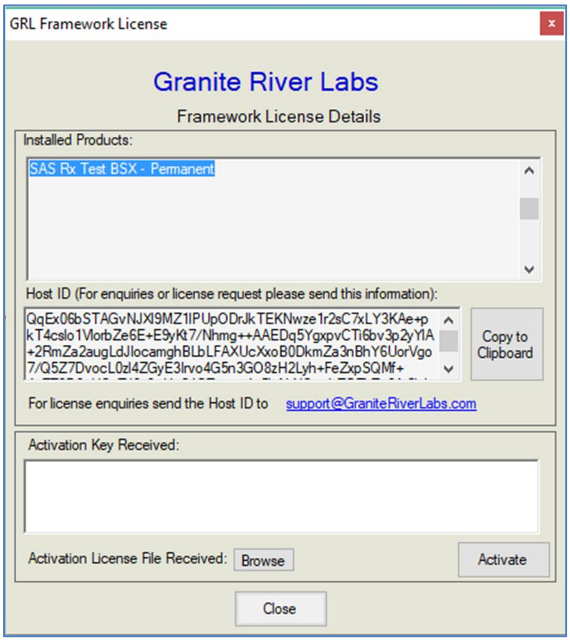


FIGURE 4. CHECK LICENSE FOR INSTALLED APPLICATIONS

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 SAS-4 Rx Test Application menu.
5. Enter the BERTScope IP address and Port number from the BERTScope *Remote Client* screen to connect the BERTScope to the GRL automation software.
6. Enter the oscilloscope IP address. If the GRL software is installed on the Scope, enter 'TCPIP0::localhost::inst0::INSTR'.

   (Note: The Scope IP address can be obtained, if not known, by typing CMD → IPCONFIG on the scope and observe the IP address listed.)

7. Connect a compliant ISI generator to the GRL automation control enabled Scope/PC and enter the network address of the ISI generator (e.g., if connected via USB, the Controller Serial (COM) should be entered).
8. Select the "lightning" button ( ) for each connected instrument.

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

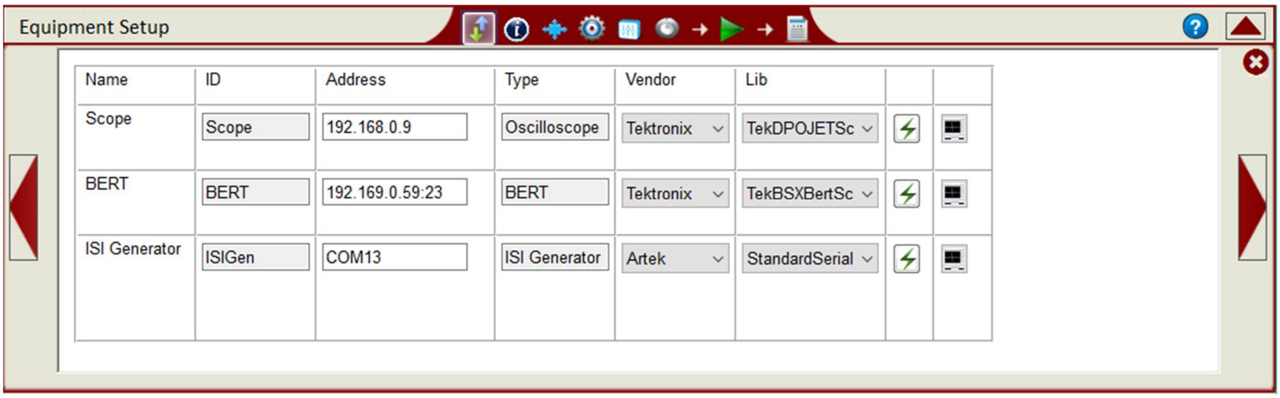


FIGURE 5. CONNECT INSTRUMENTS WITH GRL SOFTWARE

5.3 Pre-Configure Software Before Calibration/Testing

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

5.3.1 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 GRL 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.

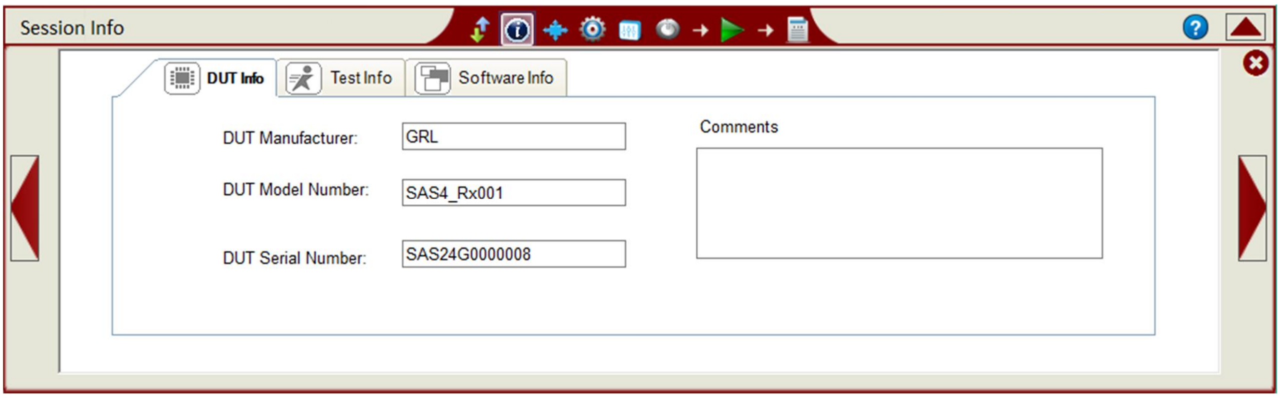


FIGURE 6. SESSION INFO PAGE

5.3.2 Set Measurement Conditions

Select from the menu to access the **Conditions** page to set the conditions for calibration and testing. The GRL software will perform calibration for selected Spread Spectrum Clock (SSC) Capabilities and SJ Test Frequencies. Selected Reference Presets will only be applied during testing. The software will perform testing using selected Reference Presets, SSC Capabilities, and SJ Test Frequencies.

Recommended procedure:

- *Step 1*: When calibrating, select all conditions that may be used for testing, and perform the calibration.
- *Step 2*: Once calibration is completed and ready for testing, re-select the necessary test conditions. For example, if required to test only one SSC Capability at two frequencies for Reference Preset 1, then select the appropriate conditions for testing.

a) **Preset** tab: Select Reference Presets as required for testing. For calibration, the software will produce a calibration curve based on a set of predefined Preset values.

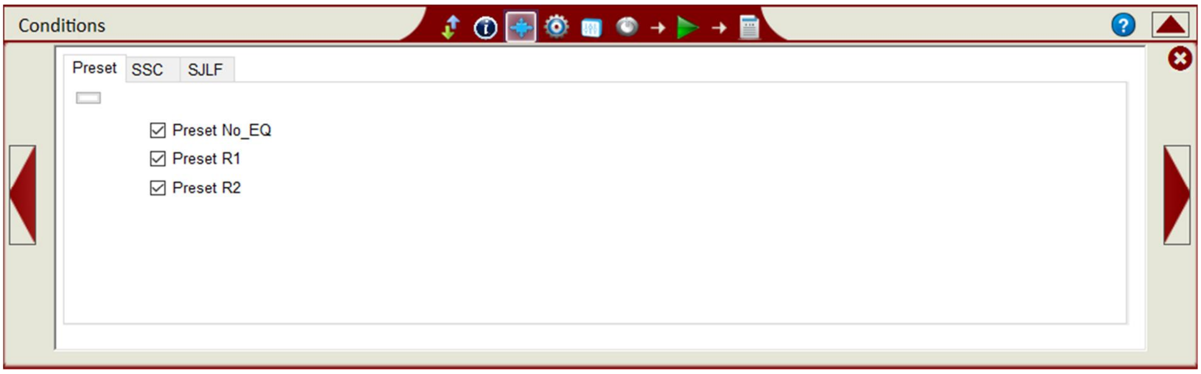


FIGURE 7. SELECT REFERENCE PRESETS

b) **SSC** tab: Select to enable or disable SSC Capability as supported by the DUT for calibration or testing.

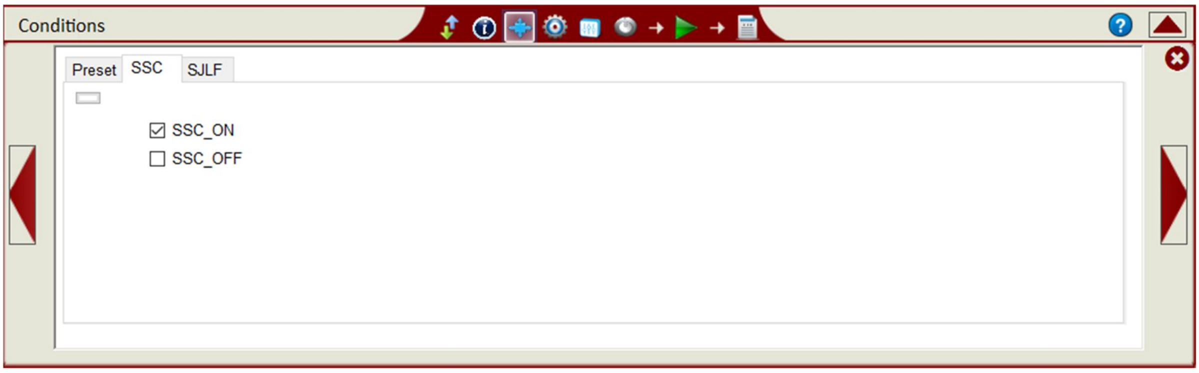


FIGURE 8. SELECT SSC CONDITIONS

c) **SJLF** tab: Select SJ Frequencies as required for calibration or testing.

Select the Custom_SJ frequencies to use additional SJ frequencies not defined by the Specification. The frequency values can be entered in the Setup Configuration ( ) page under the *Custom SJ Frequencies* tab (see Section 8.1).

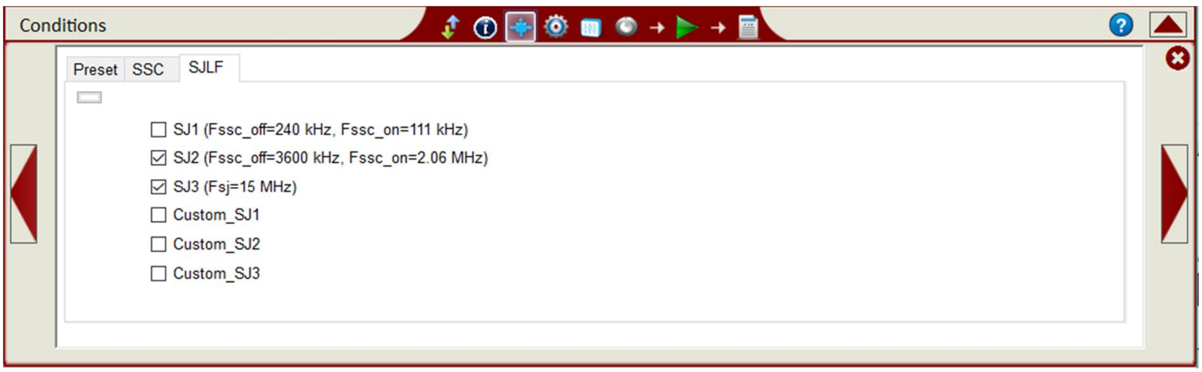


FIGURE 9. SELECT SJ FREQUENCIES

6 Calibrating Using GRL-SAS4-RX-BSX Software

The GRL-SAS4-RX-BSX test solution supports automated Rx calibration for SAS-4 Signal Amplitude and Jitter as well as Insertion Loss and Crosstalk. To perform calibration, the GRL software is run from the oscilloscope or an external controller PC to enable automation control for each step of calibration.

Calibration will basically be performed at Test Point A and Test Point IR/CR that generally apply for all SAS data rates. Test Point A (TP-A) is a physical test point for calibration while Test Point IR/CR is an electrical test point calculated by the *DPOJET SAS Gen4* software tool in the Scope test instrument for SAS-4 (22.5 Gbit/s) compliance. An additional Test Point PR will be measured at where S-parameters are tested and where the TxRx connection ends for 22.5 Gbit/s on the DUT.

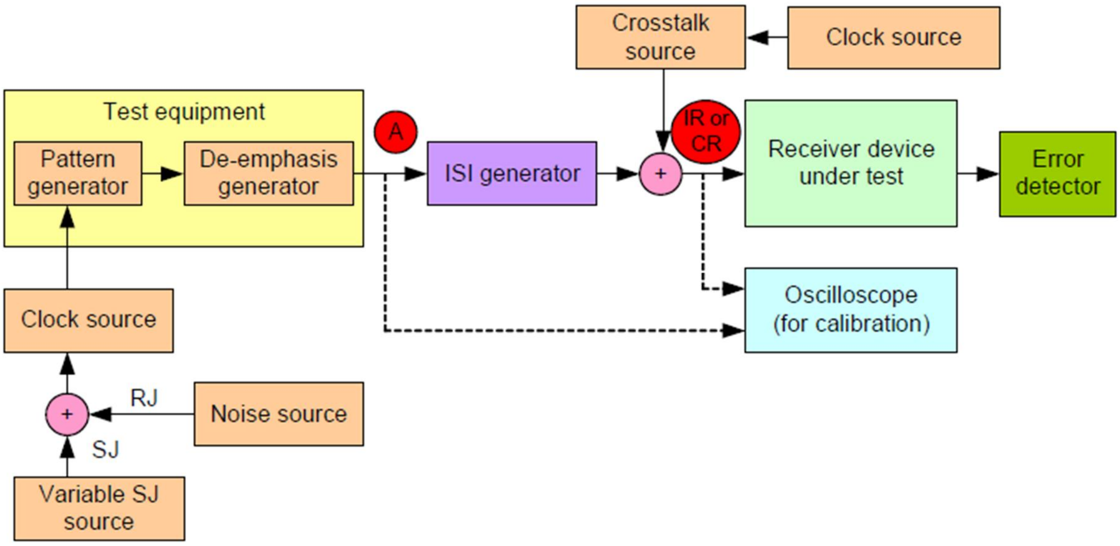


FIGURE 10. STRESSED RX CALIBRATION/JITTER TOLERANCE TEST SETUP BLOCK DIAGRAM (FROM SAS-4 DRAFT STANDARD)

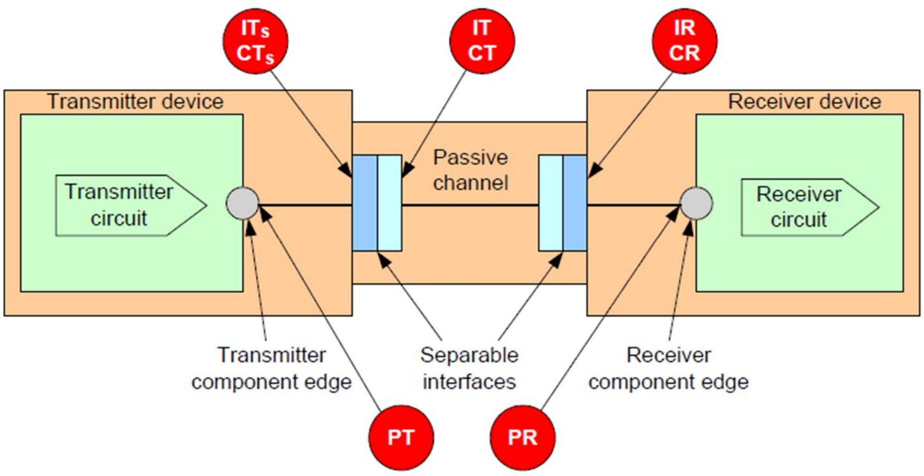


FIGURE 11. EXAMPLE SAS-4 TXRX CONNECTION AT COMPLIANCE TEST POINTS (FROM SAS-4 DRAFT STANDARD)

Below shows a series of SAS compliance test points as defined by the SAS-4 Draft Standard.

Table 3 — Compliance points

Compliance point	Type	Description
1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s compliance points		
IT	intra-enclosure (i.e., internal)	The signal from a transmitter device, as measured at probe points in a test load attached with an internal connector.
IT_S	intra-enclosure (i.e., internal)	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. This location is at the transmitter device side of the internal connector with a test load or a TxRx connection attached with an internal connector.
IR	intra-enclosure (i.e., internal)	The signal going to a receiver device, as measured at probe points in a test load attached with an internal connector.
CT	inter-enclosure (i.e., cabinet)	The signal from a transmitter device, as measured at probe points in a test load attached with an external connector.
CT_S	inter-enclosure (i.e., cabinet)	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. This location is at the transmitter device side of the external connector with a test load or a TxRx connection attached with an external connector.
CR	inter-enclosure (i.e., cabinet)	The signal going to a receiver device, as measured at probe points in a test load attached with an external connector.
12 Gbit/s only compliance points		
ET	transmitter circuit	The output signal from a transmitter circuit measured with the test load, TDCS, and TCCS de-embedded.
ER	receiver post equalization	A point defined at the output of the reference receiver device.
22.5 Gbit/s only compliance points		
PT	Transmitter device component edge	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 22.5 Gbit/s.
PR	Receiver device component edge	The location of a receiver device where S-parameters are measured and where the TxRx connection ends for 22.5 Gbit/s.

FIGURE 12. SAS COMPLIANCE TEST POINT SPECIFICATIONS (FROM SAS-4 DRAFT STANDARD)

The Tektronix BERTScope and appropriate equipment will be used to provide the necessary jitter, ISI, and crosstalk components during calibration. The BERTScope will also be used to add the required transmitter equalization, as requested during the link training stage while calibrating the test pattern. The signal will be measured using a real-time Oscilloscope.

When calibration is completed, the GRL software will generate a test report detailing all results obtained from the calibration.

Note: A Variable ISI Generator will be used as the ISI source in the calibration/test setup. Variable ISI enables calibration to be performed with minimum reconfiguration of the setup, which allows measurements to be more fully automated.

6.1 Overview of Rx Calibration Flow

The GRL-SAS4-RX-BSX software provides a series of calibration that can be performed in the following sequence for the SAS-4 receiver.

Note: Refer to Appendix for more details on SAS-4 calibration requirements.

a) Calibrate Reference Presets

Calibrate de-emphasis and pre-shoot using a pattern that contains both high-frequency and low-frequency components. This ensures proper equalization of initial high-frequency and low-frequency amplitudes for accurate calibrations.

b) Calibrate Insertion Loss (ISI)

Calibrate differential insertion loss of the passive TxRx connection by measuring the difference in frequency response magnitude to target specifications.

c) Calibrate Rx Signal Stresses

Calibrate stresses consisting of Launch Amplitude (peak-to-peak voltage), Uncorrelated Unbounded Gaussian Jitter, Uncorrelated Bounded High Probability Jitter, and Total Jitter to target specifications.

d) Calibrate SJ

Calibrate SJ (over 3 defined frequencies) for jitter tolerance with or/and without SSC support.

e) Calibrate Crosstalk

Calibrate the total peak-to-peak, differential crosstalk noise at 22.5 Gbit/s with SSC enabled (generated by the BERTScope) and using a specified cumulative probability.

6.2 Set Up SAS-4 Rx Calibration with Automation

After the software has been pre-configured from Section 5.3, continue with the calibration setup. The following procedures show how to set up the physical connections to perform automated Rx calibration for stressed signals.

6.2.1 Connect Equipment for Signal Amplitude and Jitter Calibration

The connection diagram below shows the recommended equipment setup to calibrate for signal amplitude and jitter at TP-A.

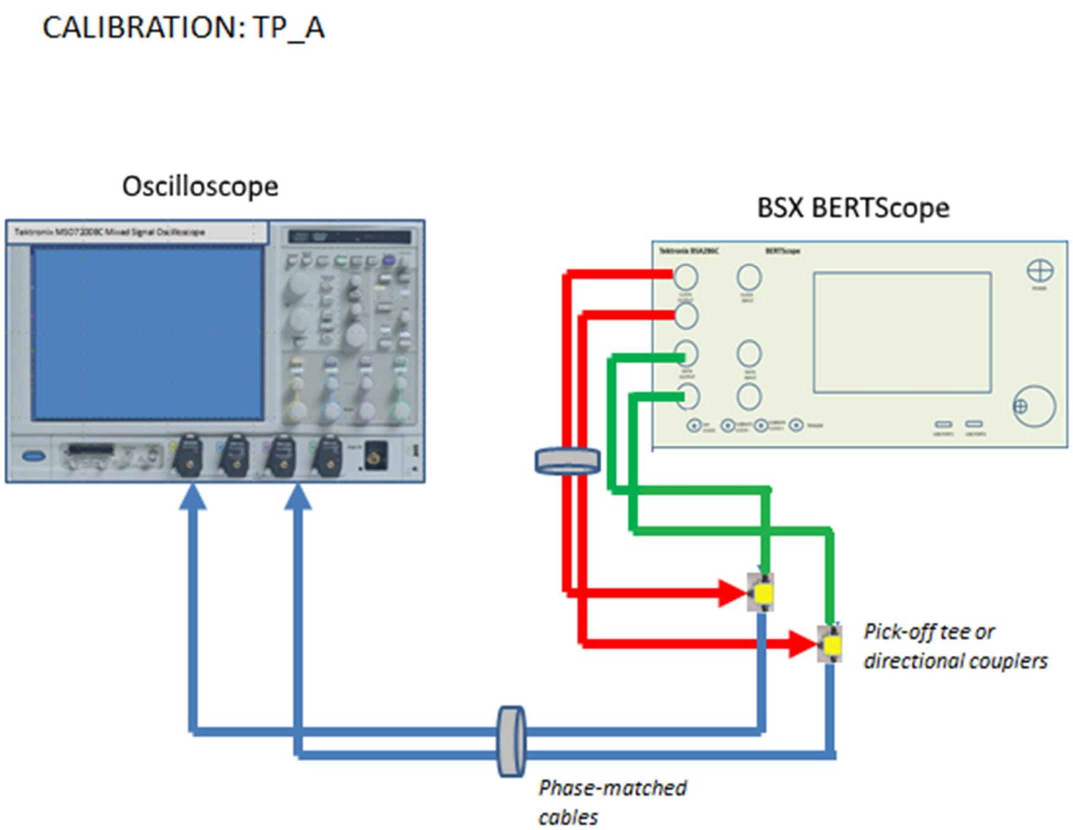


FIGURE 13. SIGNAL AMPLITUDE AND JITTER CALIBRATION SETUP

Connection Steps:

1. Connect DATA OUTPUT(+) of the BERTScope to an input port of pick-off tee 1/pick-off tee 2.
2. Connect DATA OUTPUT(–) of the BERTScope to the other input port of pick-off tee 1/pick-off tee 2.
3. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
4. Connect the output ports of pick-off tee 1 and pick-off tee 2 to Channel 1 and Channel 3 of the Oscilloscope.

6.2.2 Connect Equipment for Insertion Loss and Crosstalk Calibration

The connection diagram below shows the recommended equipment setup to calibrate for insertion loss (ISI) and crosstalk from TP-A to Test Point IR/CR. *Note a compliant variable ISI generator is used in this setup.*

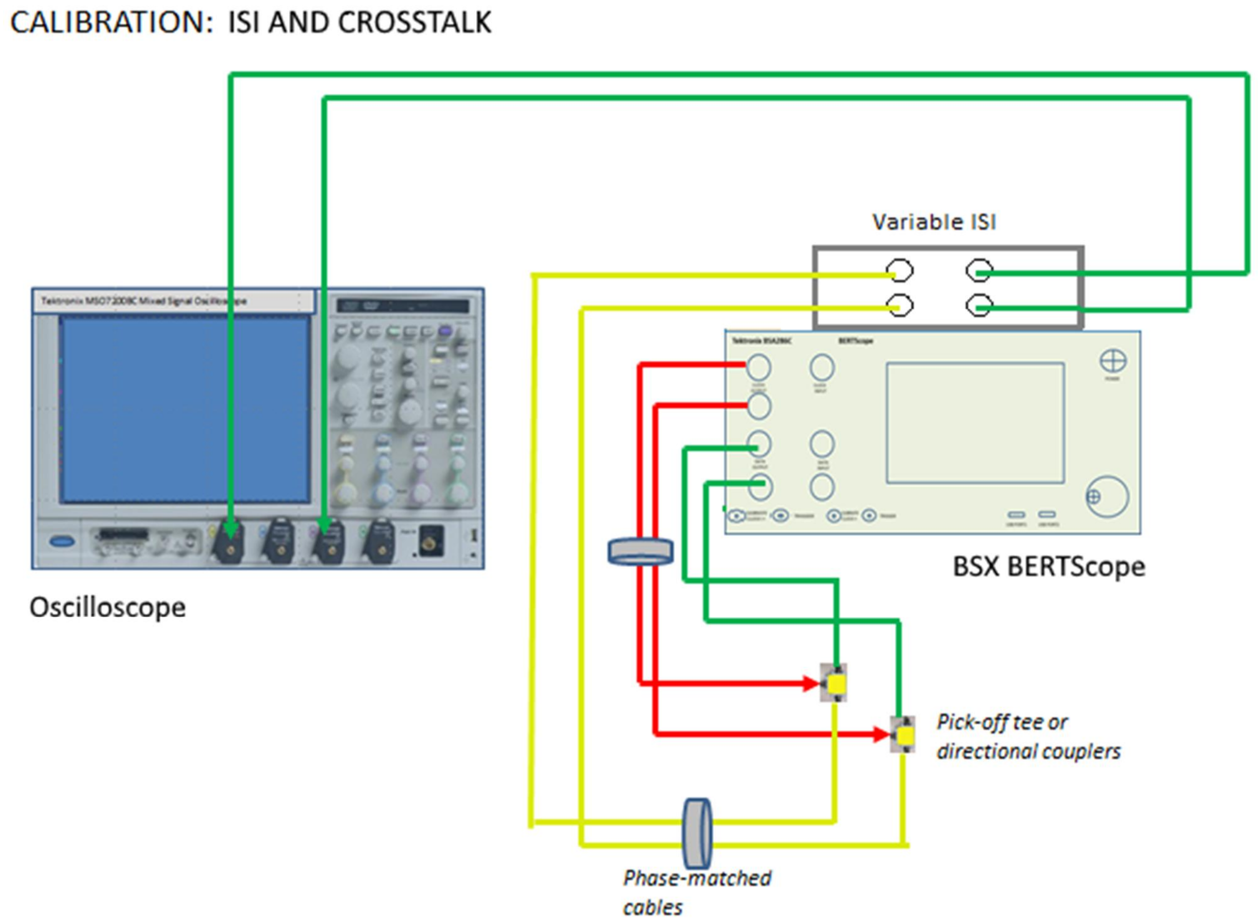


FIGURE 14. INSERTION LOSS AND CROSSTALK CALIBRATION SETUP

Connection Steps:

1. Connect DATA Outputs of the BERTScope to the pick-off tee 1 and tee 2 input ports.
2. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
3. Connect the pick-off tees output ports to the inputs of the Variable ISI Generator.
4. Connect the outputs of the Variable ISI Generator to Channels 1 and 3 of the Oscilloscope.

Note: To set up the equipment network connection, connect both the BERTScope and Scope with a LAN cable and then to a Network Switch, using the same network.

7 Compliance Testing Using GRL-SAS4-RX-BSX Software

The GRL-SAS4-RX-BSX software supports automated Rx compliance testing (with link optimization) as well as optional Rx margin search testing for the receiver DUT.

Receiver compliance testing is performed for DUT jitter tolerance that requires using the BERTScope analyzer/error detector via a clock recovery unit for loopback testing. The test will be run using the required components of mainly SSC control, minimum transmitter voltage amplitude, asynchronous crosstalk, PRBS31 test pattern, and jitter (which includes random and deterministic jitter of various types including a sinusoidal periodic jitter component that is swept across specific frequency intervals). The receiver DUT should be able to tolerate stress impairments which have been partially compensated or corrected through a Tx/Rx link training sequence.

When the DUT has transitioned to loopback state, it will undergo BER compliance testing to check for errors. During this process, the BERTScope will transmit PRBS31 signaling to the DUT and verify that the loopback pattern reports an allowable BER with a 95% confidence level (for SAS-4, a BER of less than 1E-12 must be achieved).

Refer to Figure 10 to view the block diagram for the general test setup.

Below is an example from the SAS-4 Draft Standard that shows the interconnectivity requirements for the Rx DUT to evaluate signal tolerance.

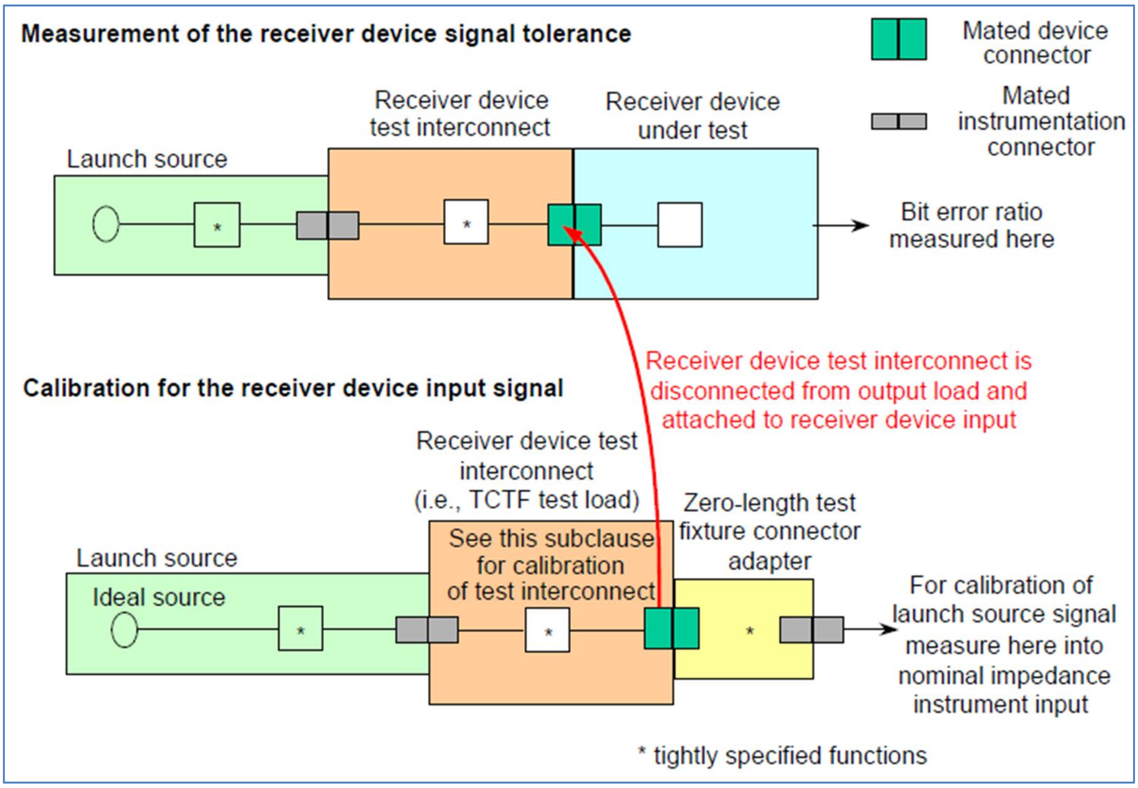


FIGURE 15. RX DUT SIGNAL TOLERANCE INTERCONNECTION EXAMPLE (FROM SAS-4 DRAFT STANDARD)

When testing is completed, the GRL software will generate a test report detailing all results obtained from the test runs.

7.1 Overview of SAS-4 Rx DUT Compliance Test

The SAS-4 based receiver DUT will be tested for compliance to jitter tolerance limits based on the following SAS-4 Draft Standard requirements at 22.5 Gbit/s.

Note: Refer to Appendix for more details on test requirements.

1. Set up and prepare the Rx DUT for loopback mode to transmit and receive stressed signals.
2. Set up the BERTScope pattern generator to transmit signal using the parameters in Table 5 before performing Tx/Rx training.
3. Perform Tx/Rx training on the signal with ISI and crosstalk sources enabled. *(Note: Channel specifications are defined in the SAS-4 Draft Standard under the 'Passive TxRx connection electrical characteristics for trained 22.5 Gbit/s' section.)*
    a. The BERTScope pattern generator will transmit a compliant Train_Tx-SNW pattern *(as defined in the SPL-4 Standard)*.
    b. The Rx DUT will complete link training for Train_Tx-SNW.
    c. The BERTScope will apply appropriate transmitter coefficients when requested by the Rx DUT *(as defined in the SPL-4 Standard)*.
    d. The BERTScope pattern generator will transmit a compliant Train_Rx-SNW pattern *(as defined in the SPL-4 Standard)*.
    e. The Rx DUT will complete link training for Train_Rx-SNW.
4. Set up the applied SJ (see Section 4).
5. Set up the BERTScope pattern generator to transmit PRBS31 signaling to the Rx DUT and verify BER on the BERTScope error detector over the loopback mode. Based on the maximum errors detected for the given number of bits received, verify that the DUT reports a BER of less than 1E-12 with a 95% confidence level, to ensure compliance.

7.2 Set Up SAS-4 Rx DUT Test with Automation

The following procedures show how to set up the physical connections to perform automated Rx stressed input compliance testing for the DUT.

7.2.1 Connect Equipment for Jitter Tolerance Compliance Test

The connection diagram below shows the recommended equipment setup to test the DUT for SAS-4 Rx jitter tolerance.

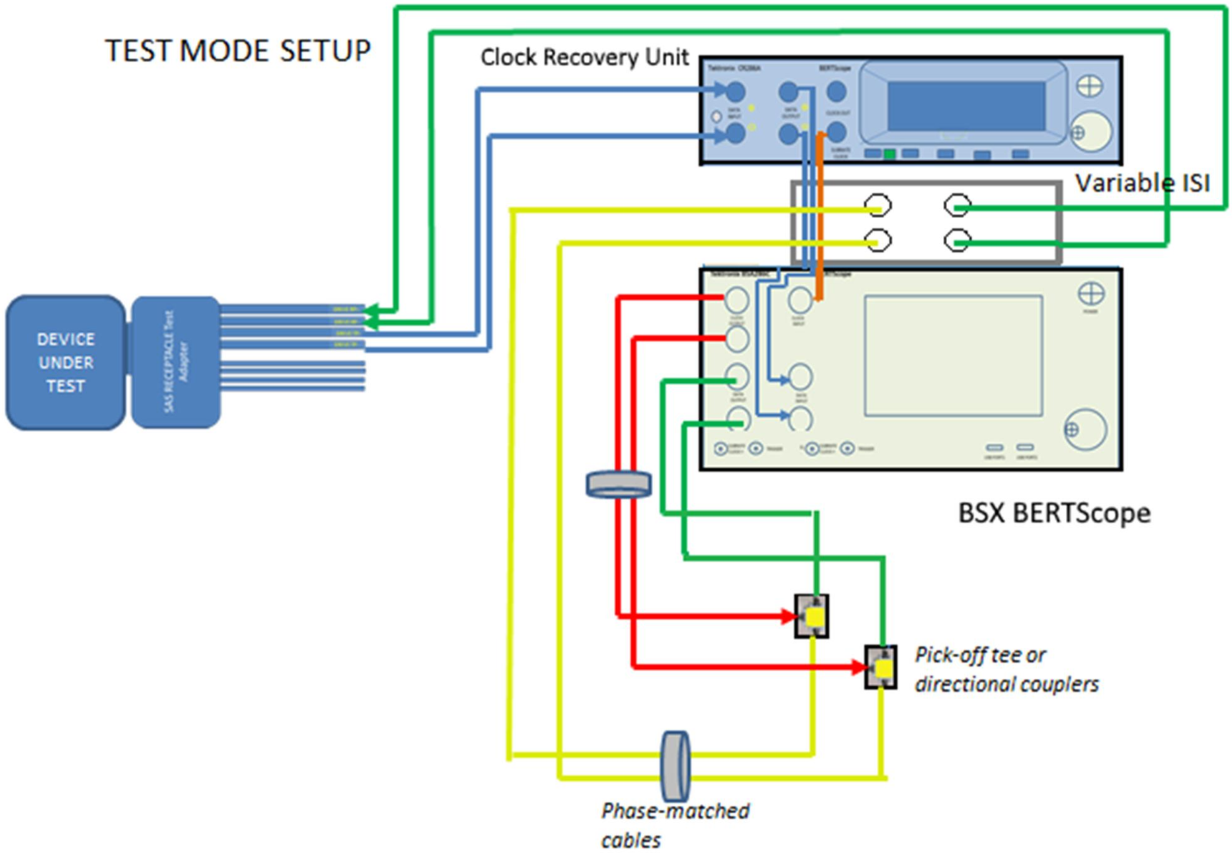


FIGURE 16. COMPLIANCE TEST SETUP FOR RECEIVER DUT JITTER TOLERANCE

Connection Steps:

1. Connect DATA Outputs of the BERTScope to the pick-off tee 1 and tee 2 input ports.
2. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
3. Connect the pick-off tees output ports to the inputs of the Variable ISI Generator.
4. Connect the outputs of the Variable ISI Generator to RX+/- of the DUT.
5. Connect TX+/- of the DUT to Data Input+/- of the Clock Recovery Unit.
6. Connect Data Output+/- of the Clock Recovery Unit to Data Input+/- of the BERTScope Error Detector.
7. Connect the Sub-rate Clock Output of the Clock Recovery Unit to the Clock Input of the BERTScope Error Detector.

8 Configuring and Selecting Calibration and Compliance Tests Using GRL-SAS4-RX-BSX Software

8.1 Set Up Calibration/Compliance Test Requirements

After setting up the physical equipment, select from the GRL SAS-4 Rx Test Application menu to access the Setup Configuration page.

Use this page to configure the necessary measurement-related settings prior to running calibration and tests.

8.1.1 ISI Generator Tab

Select a compliant variable ISI generator to be used or 'None' if using a fixed ISI channel. *The ISI source will be used for both calibration and compliance testing.*

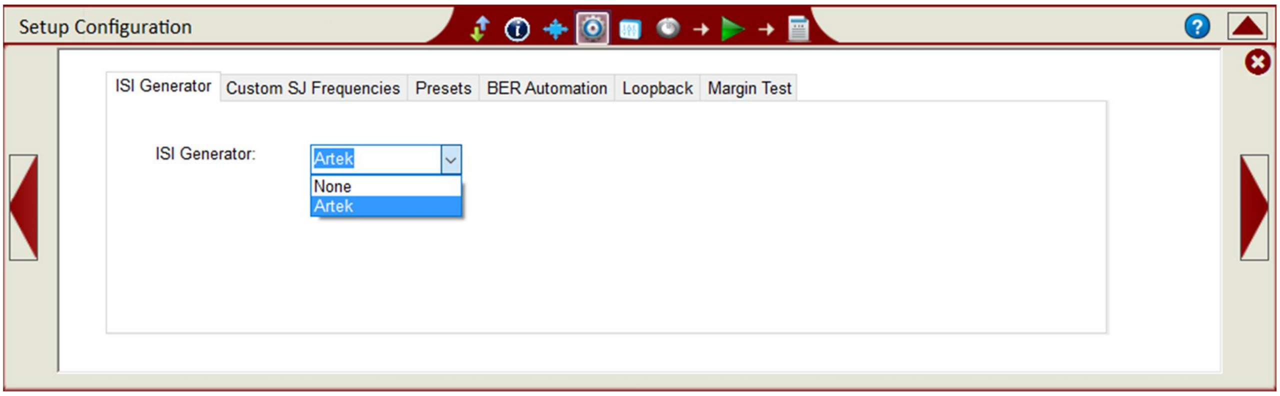


FIGURE 17. SELECT ISI SOURCE

8.1.2 Custom SJ Frequencies Tab

Enter the value for each Custom_SJ frequency that has been selected from the Conditions page. *This configuration will be used for SJ calibration and for compliance testing.*

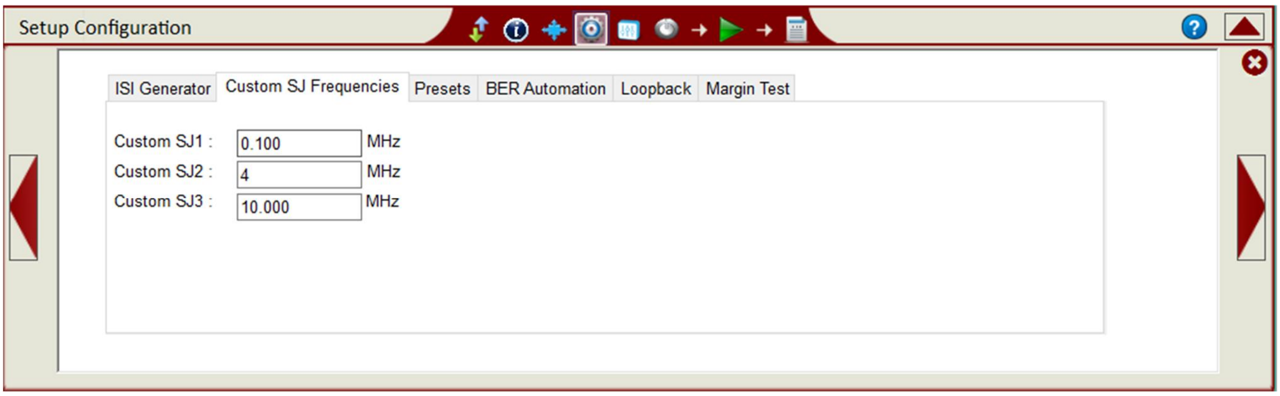


FIGURE 18. DEFINE CUSTOM SJ FREQUENCIES

8.1.3 Presets Tab

Set up Reference Presets for the selected Preset Mode.

- **Nominal Presets** mode: The settings in this mode are defined by the Specification, which disables any user configuration and displays the specified nominal values.
- **Custom Presets** mode: This mode allows user configuration for the presets.

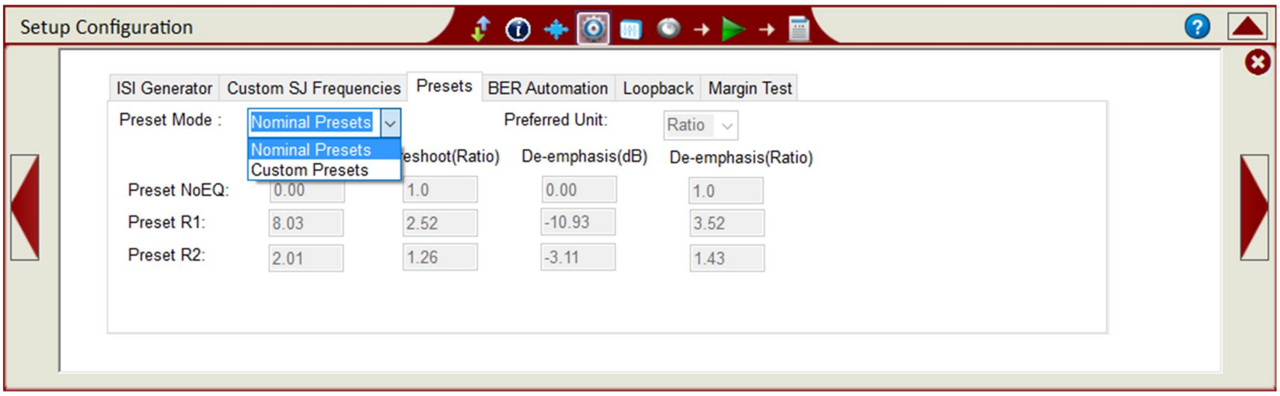


FIGURE 19. CONFIGURE REFERENCE PRESETS

8.1.4 BER Automation Tab

Select the method to enable BER Automation testing:

- **Forced Loopback** method: Select this method if using a proprietary software tool to control the DUT. For this, an appropriate loopback method must be selected under the 'Loopback' tab. The BERTScope will then apply the required stress and run BER tests using its built-in error detector. This method requires very little user input.
- **Manual** method: Select this method if the DUT does not support any loopback mode but has a built-in error detector to measure BER. The application will prompt the user to run BER tests manually and report the errors detected which will be saved in the results.
- **Local Script** method: Select this method if using an external *.exe script to force the DUT in the loopback mode and perform BER testing. This requires the user to specify the path for the script file which the application will call when it is ready to test the loopback BER.
- **Remote Script** method: This method is similar to Local Script where it also uses an external *.exe script to control the DUT loopback and BER measurement. Unlike the Local script, this Remote script resides on a remote (separate) PC, and thus requires the user to specify the IP address and port number for the script to be called by the application.

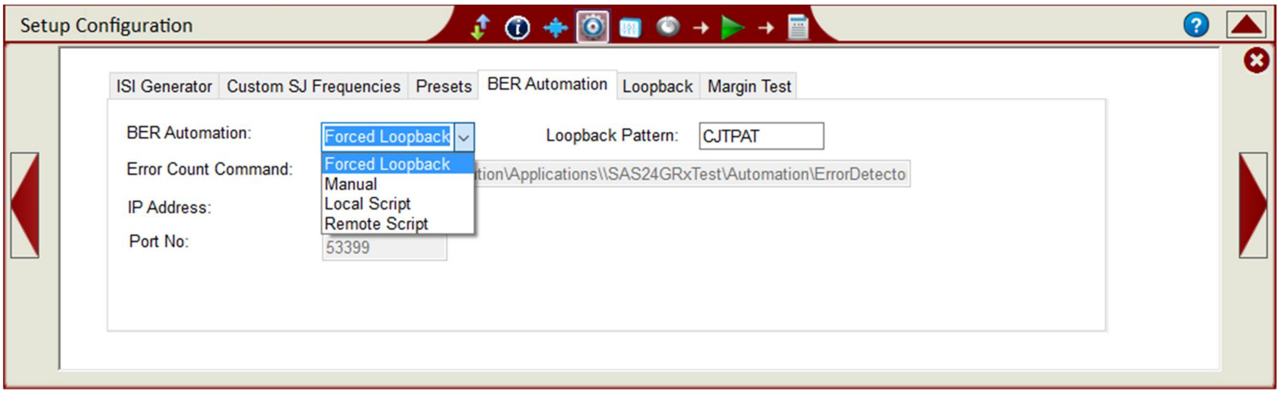


FIGURE 20. CONFIGURE BER AUTOMATION METHOD

8.1.5 Loopback Tab

Select the method to enable DUT loopback if the 'Forced Loopback' method is selected under the 'BER Automation' tab.

- **None** method: Select this method to place the DUT in the continuous loopback mode. The software will assume that the DUT is in loopback and will continue to test BER without any prompts.
- **Prompt User** method: Select this method to manually enable DUT loopback at every single time. This is recommended if the loopback method for the DUT is not known or there is a physical method that cannot be automated.
- **Local Script** method: This method is similar to Local Script for the BER Automation, but here the script will be called to force the DUT into loopback instead of testing BER.
- **Remote Script** method: Similar to Local Script, this method will also use an external script to force the DUT into loopback, except that the script is located on a remote terminal.

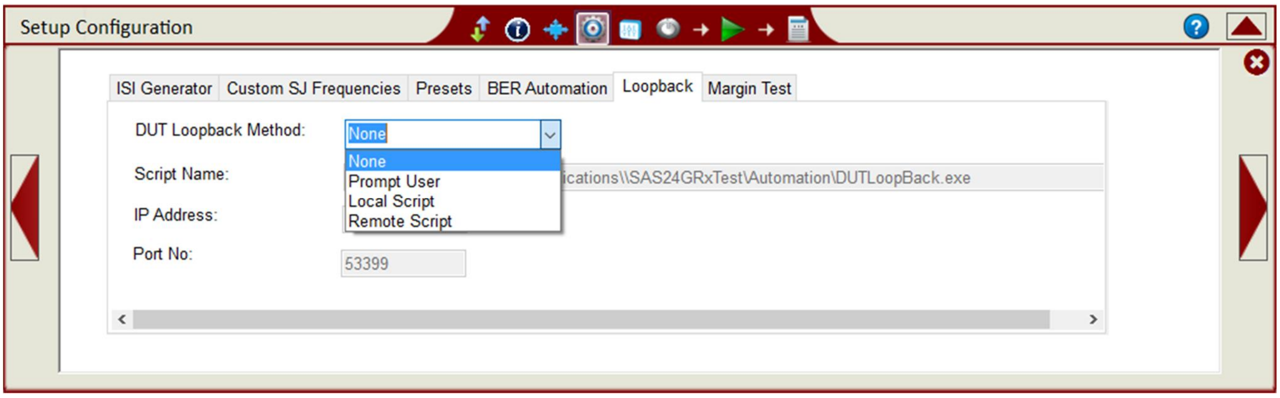


FIGURE 21. CONFIGURE DUT LOOPBACK METHOD

8.1.6 Margin Test Tab

Define the target BER and Confidence level to achieve when testing for compliance. If running the optional 'Rx Compliance + Margin' and 'Rx Margin Search' tests (see Section 8.2), specify the Step Size and Maximum Steps for stepping through margins.

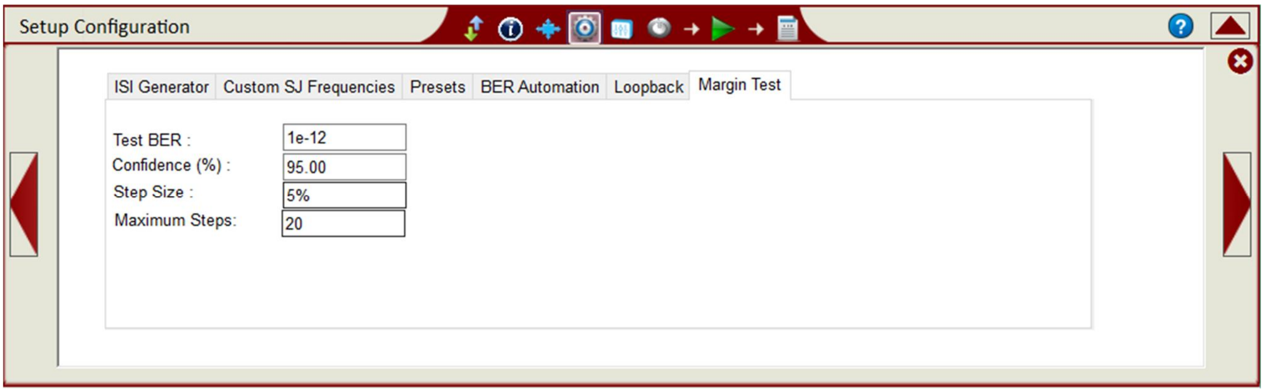


FIGURE 22. CONFIGURE TEST TARGETS AND PARAMETERS

8.2 Select Calibration and Tests

After setting up calibration/test requirements, select from the menu to access the **Select Tests** page which displays all available Rx calibration and DUT compliance tests. Select the check boxes of the respective calibration and tests to be performed.

Note: When running tests for the first time or changing anything in the setup, it is suggested to perform calibration first. If calibration is not completed, attempting to run the Rx tests will throw errors.

Note: For calibration/testing, it is recommended to use a variable ISI channel as it allows the channel to be more easily adjusted to meet the required specification.

8.2.1 Select Calibration

FIGURE 23. RX CALIBRATION SELECTION

TABLE 6. CALIBRATION DESCRIPTION

Calibration	Description
Launch Amplitude	Calibrate the launch amplitude (peak-to-peak voltage) using a repeating 7Eh pattern. This pattern includes high and low frequency components to determine if the initial signal generated by the BERTScope has equalized amplitudes for both high-frequency and low-frequency components.
De-emphasis	Calibrate de-emphasis using the 64ones_64zeros_64ones_zeros pattern to ensure the value is accurately measured.
Pre-shoot	Calibrate pre-shoot using the same pattern as de-emphasis calibration.
Rise/Fall Time *(Informative)*	Calibrate rise/fall time (20-80%) using a repeating 01b or 10b pattern. *This is performed for information purpose only.*
Common Mode Noise *(Informative)*	Calibrate common mode noise using a PRBS15 pattern. *This is performed for information purpose only.*
Duty Cycle Distortion *(Informative)*	Calibrate duty cycle distortion using a repeating 01b or 10b pattern with Tx device equalization enabled and set to 'no_equalization'. *This is performed for information purpose only.*
Uncorrelated bounded high probability jitter (BUJ)	Calibrate uncorrelated bounded high probability jitter using the PRBS15 pattern and measured using deterministic jitter function.
Uncorrelated unbounded Gaussian jitter (RJ)	Calibrate uncorrelated unbounded Gaussian jitter using the same pattern as uncorrelated bounded high probability jitter calibration, but measured using random jitter function.
SJ	Calibrate sinusoidal jitter over 3 defined frequencies for jitter tolerance.
TJ	Calibrate total jitter using the PRBS15 pattern and by adjusting both measured random and deterministic jitters.
Insertion Loss	Calibrate insertion loss (ISI) by measuring the difference in magnitude of the frequency response.
Crosstalk	Calibrate crosstalk using an All Zeroes pattern that measures only the crosstalk being injected.

8.2.1 Select DUT Compliance Tests

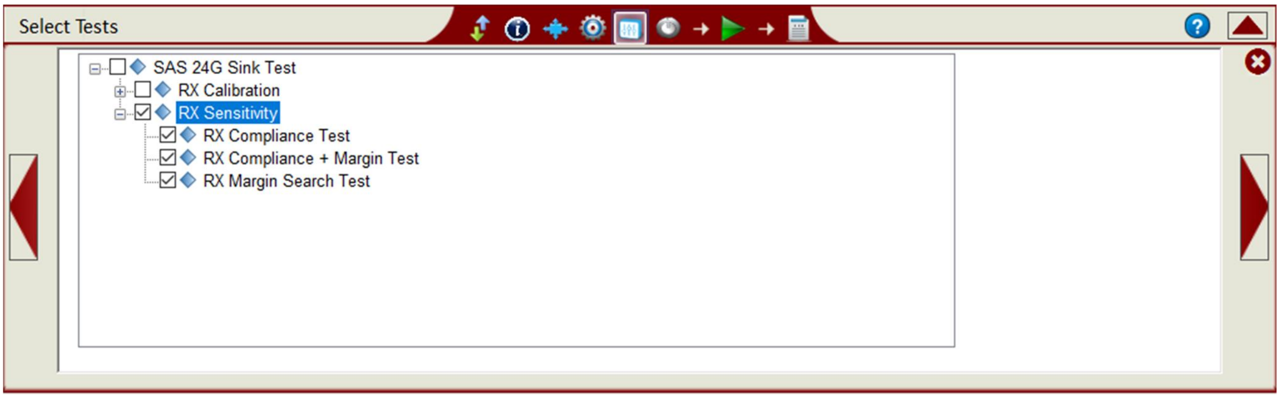


FIGURE 24. RX COMPLIANCE TEST SELECTION

TABLE 7. TEST DESCRIPTION

Test	Description
Rx Compliance	This is a compliance test for receiver jitter tolerance which measures jitter response at the calibrated levels mentioned in the Specification.
Rx Compliance + Margin	This test is similar to the Rx Compliance test but measures the jitter tolerance of the DUT at one step above the calibrated levels mentioned in the specification. The step value comes from the step size specified in the Setup Configuration page. The margin is the percentage value of the calibrated value.
Rx Margin Search	This is a jitter search test which measures the maximum SJ value that the DUT can handle at the chosen BER. The step size is the percentage value of the currently applied SJ.

8.3 Configure Calibration Target Values

For debugging purposes ONLY, the default calibration target values can be changed for any of the 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.

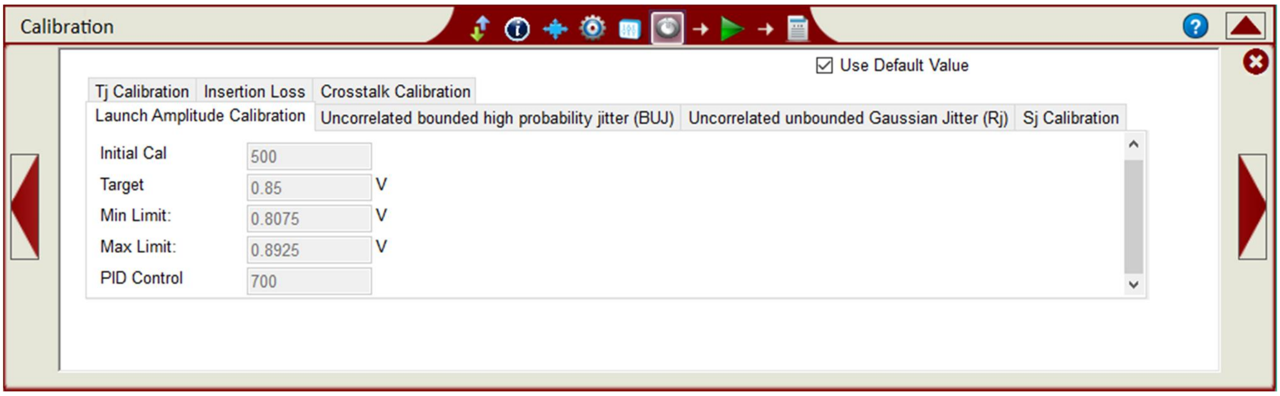


FIGURE 25. CALIBRATION TARGET OVERWRITE PAGE

9 Running Automation Calibration and Tests Using GRL-SAS4-RX-BSX Software

Once calibration and tests have been selected and set up from the previous sections, they are now ready to be run.

Select from the menu to access the Run Tests page. The GRL software automatically runs the selected calibration and tests when initiated.

Before running the tests, select the option to:

- **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.

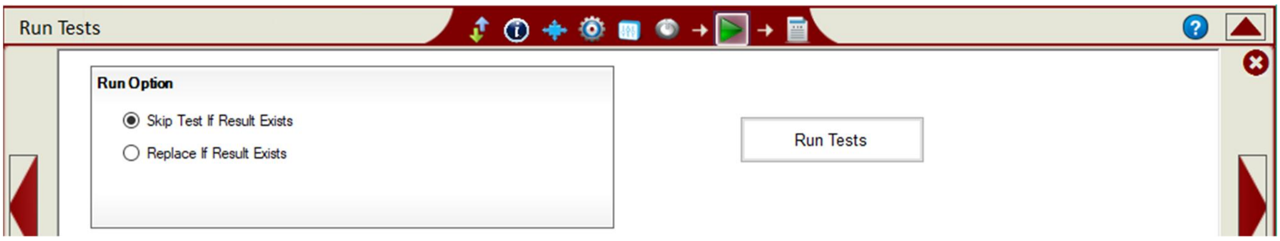


FIGURE 26. RUN TESTS PAGE

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.

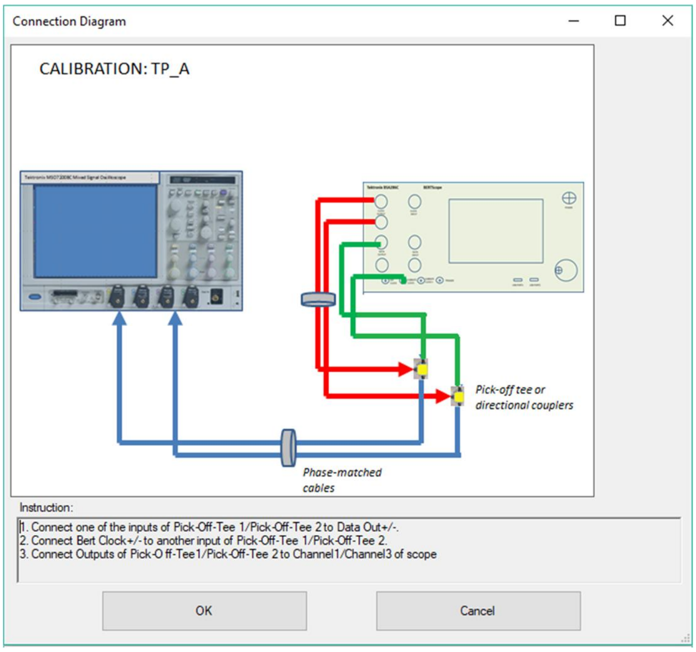


FIGURE 27. CONNECTION DIAGRAM POP-UP WINDOW EXAMPLE

10 Interpreting GRL-SAS4-RX-BSX Test Report

When all calibration and test runs have completed from the previous section, the GRL 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.

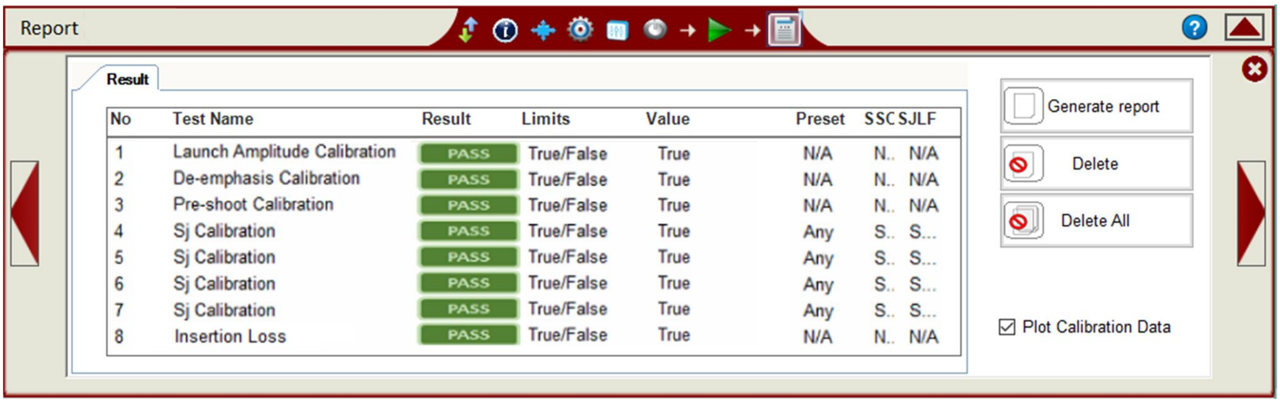


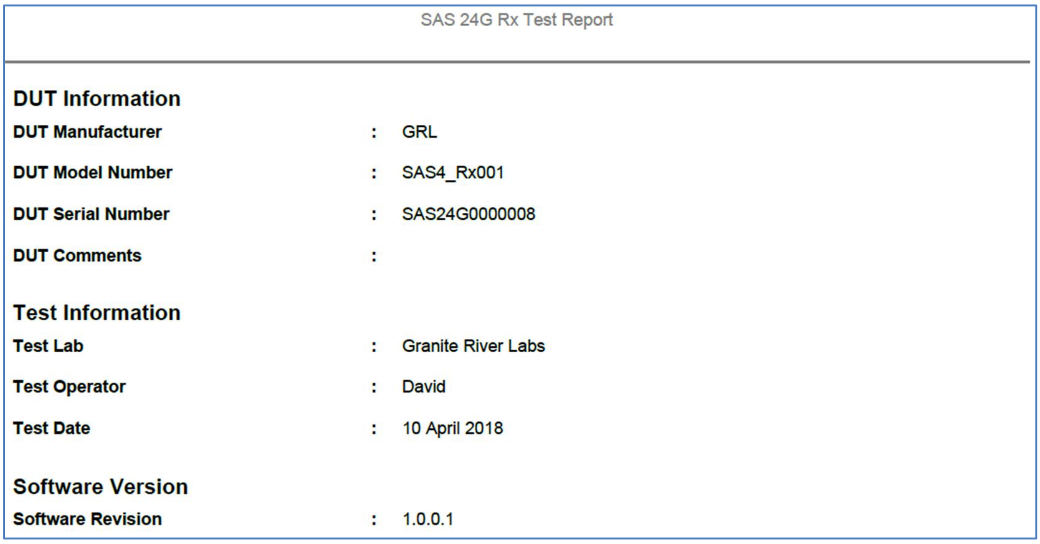
FIGURE 28. TEST REPORT PAGE

10.1 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.

10.1.1 Test Session Information

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


SAS 24G Rx Test Report

DUT Information

DUT Manufacturer	:	GRL
DUT Model Number	:	SAS4_Rx001
DUT Serial Number	:	SAS24G0000008
DUT Comments	:	

Test Information

Test Lab	:	Granite River Labs
Test Operator	:	David
Test Date	:	10 April 2018

Software Version

Software Revision	:	1.0.0.1

FIGURE 29. TEST SESSION INFORMATION EXAMPLE

10.1.2 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	Preset	SSC	SJLF
1	Launch Amplitude Calibration	True/False	True	Pass			
2	De-emphasis Calibration	True/False	True	Pass			
3	Pre-shoot Calibration	True/False	True	Pass			
4	Buj Calibration	True/False	True	Pass	N/A	SSC_ON	N/A
5	Buj Calibration	True/False	True	Pass	N/A	SSC_OFF	N/A
6	Rj Calibration	True/False	True	Pass	N/A	SSC_ON	N/A
7	Rj Calibration	True/False	True	Pass	N/A	SSC_OFF	N/A
8	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	SJ1
9	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	SJ2
10	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	SJ3
11	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	Custom_SJ1
12	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	Custom_SJ2
13	Sj Calibration	True/False	True	Pass	N/A	SSC_ON	Custom_SJ3
14	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	SJ1
15	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	SJ2
16	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	SJ3
17	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	Custom_SJ1
18	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	Custom_SJ2
19	Sj Calibration	True/False	True	Pass	N/A	SSC_OFF	Custom_SJ3
20	Tj Calibration	True/False	True	Pass	N/A	SSC_ON	N/A
21	Tj Calibration	True/False	True	Pass	N/A	SSC_OFF	N/A
22	Insertion Loss	True/False	True	Pass			
23	Crosstalk Calibration	True/False	True	Pass			
24	RX Compliance Test	True/False	True	Pass	Preset_No_EQ	SSC_ON	SJ1
25	RX Compliance + Margin Test	True/False	True	Pass	Preset_No_EQ	SSC_ON	SJ1
26	RX Margin Search Test	True/False	True	Pass	Preset_No_EQ	SSC_ON	SJ1

FIGURE 30. TEST SUMMARY TABLE EXAMPLE

10.1.3 Test Results

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

22. Insertion Loss

Pass/Fail Stats	:	Pass
Test Limits	:	True/False
Result	:	True
Cal Parameter	:	InsertionLoss_
InsertionLossCal Settings	:	20.0000
Measured Value	:	23.2540 dB
Test completed time	:	05 April 2018 20:08:00 PM

Screen shots 1

InsertionLossCal Plot

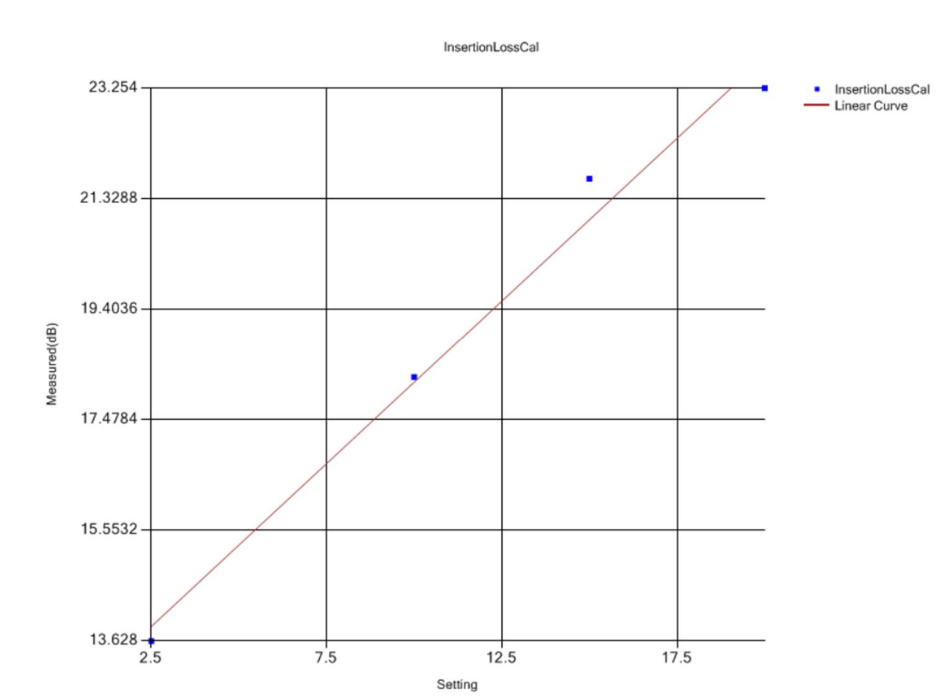


FIGURE 31. TEST RESULTS EXAMPLE

10.2 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.

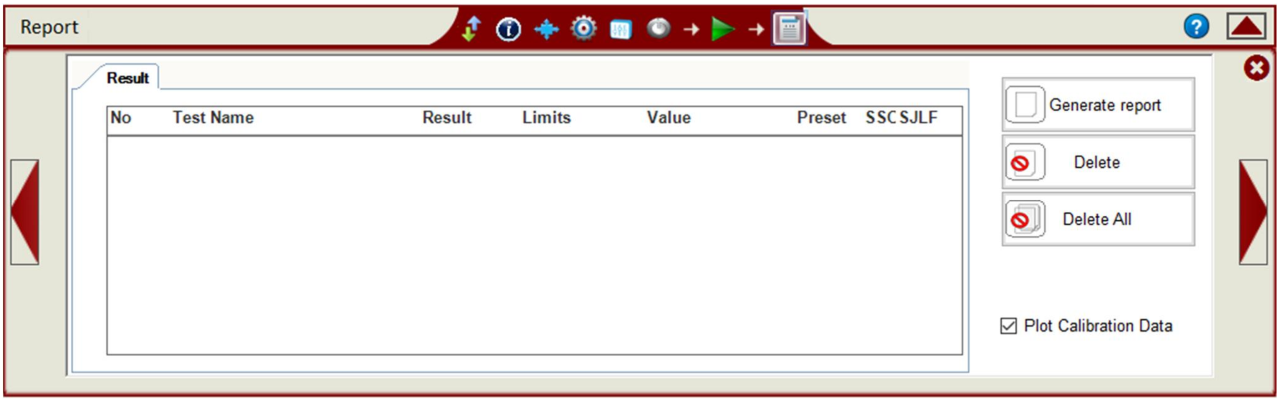


FIGURE 32. TEST REPORT DELETED

11 Saving and Loading GRL-SAS4-RX-BSX Test Sessions

The usage model for the GRL software is that the test results are created and maintained as a 'Live Session' in the software. This allows the user to quit the software 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 software, including the saved test parameter settings, select Options → 'Load Session'.
- To ***create a new test session*** and return the software back to the default configuration, select Options → 'New Session'.

FIGURE 33. 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.

12 Appendix A: Method of Implementation (MOI) for Manual SAS-4 Receiver Measurements

This section provides the manual SAS-4 24G Rx calibration and compliance test methodology based on the SAS-4 Draft Standard.

12.1 SAS-4 Receiver Calibration/Test Setup Overview

This MOI describes how to measure preset, ISI, stress, and SJ and test the SAS-4 Rx device for receiver compliance using a signal that contains the maximum allowable jitter, noise, and signal loss.

The BERTScope and appropriate equipment are used in the setup to provide the necessary test patterns with jitter, ISI, and crosstalk. The BERTScope is also used to add the required transmitter equalization, as requested during the link training stage while calibrating the test pattern. A real-time Oscilloscope is required for signal calibration while a variable ISI source is used to generate insertion loss. The analyzer/error detector on the BERTScope will be used for error checking via a clock recovery unit.

The calibration/test will be run using the required components of mainly SSC control, minimum transmitter voltage amplitude, asynchronous crosstalk, PRBS15 test pattern and jitter (which includes random and deterministic jitter of various types including a sinusoidal periodic jitter component that is swept across specific frequency intervals). The Rx DUT should be able to tolerate stress impairments which have been partially compensated or corrected through a Tx/Rx link training sequence.

For BER compliance testing, the BERTScope will transmit CJTPAT signaling to the Rx DUT and verify that the loopback pattern reports a BER that is less than 1E-12 with a 95% confidence level.

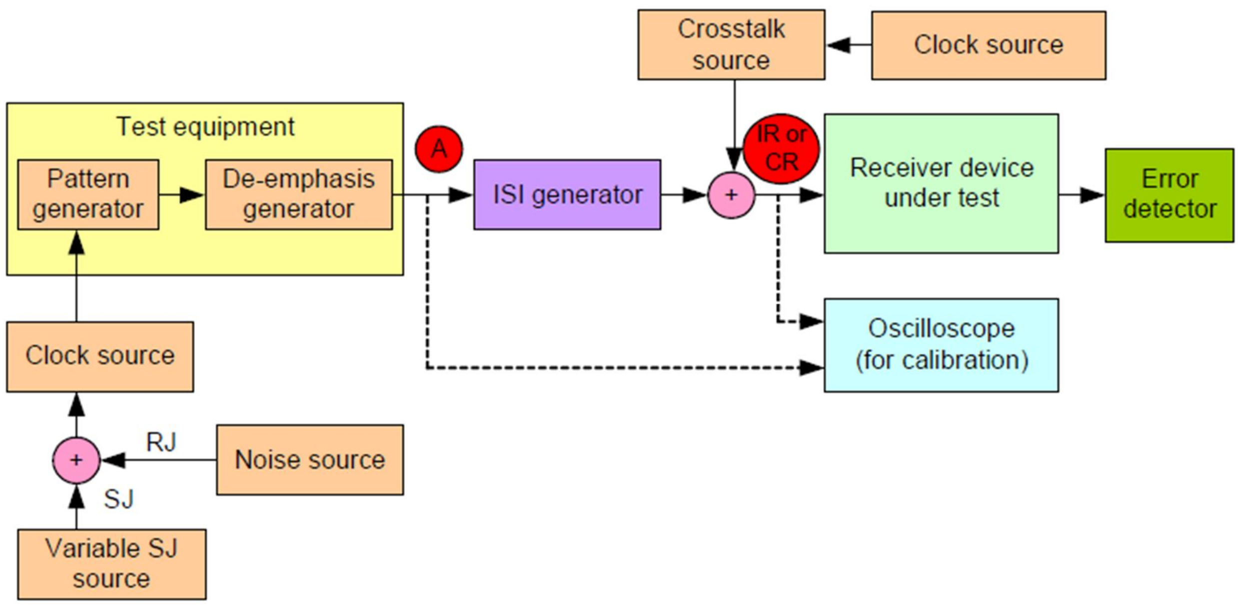


FIGURE 34. STRESSED RX JITTER TOLERANCE TEST/CALIBRATION SETUP BLOCK DIAGRAM (FROM SAS-4 DRAFT STANDARD)

12.1.1 Test Points

Below shows a series of SAS compliance test points as defined by the SAS-4 Draft Standard.

Table 3 — Compliance points

Compliance point	Type	Description
1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s compliance points		
IT	intra-enclosure (i.e., internal)	The signal from a transmitter device, as measured at probe points in a test load attached with an internal connector.
IT_S	intra-enclosure (i.e., internal)	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. This location is at the transmitter device side of the internal connector with a test load or a TxRx connection attached with an internal connector.
IR	intra-enclosure (i.e., internal)	The signal going to a receiver device, as measured at probe points in a test load attached with an internal connector.
CT	inter-enclosure (i.e., cabinet)	The signal from a transmitter device, as measured at probe points in a test load attached with an external connector.
CT_S	inter-enclosure (i.e., cabinet)	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. This location is at the transmitter device side of the external connector with a test load or a TxRx connection attached with an external connector.
CR	inter-enclosure (i.e., cabinet)	The signal going to a receiver device, as measured at probe points in a test load attached with an external connector.
12 Gbit/s only compliance points		
ET	transmitter circuit	The output signal from a transmitter circuit measured with the test load, TDCS, and TCCS de-embedded.
ER	receiver post equalization	A point defined at the output of the reference receiver device.
22.5 Gbit/s only compliance points		
PT	Transmitter device component edge	The location of a transmitter device where S-parameters are measured and where the TxRx connection begins for 22.5 Gbit/s.
PR	Receiver device component edge	The location of a receiver device where S-parameters are measured and where the TxRx connection ends for 22.5 Gbit/s.

FIGURE 35. SAS COMPLIANCE TEST POINT SPECIFICATIONS (FROM SAS-4 DRAFT STANDARD)

The following diagram shows a clearer view of the SAS-4 compliance test points.

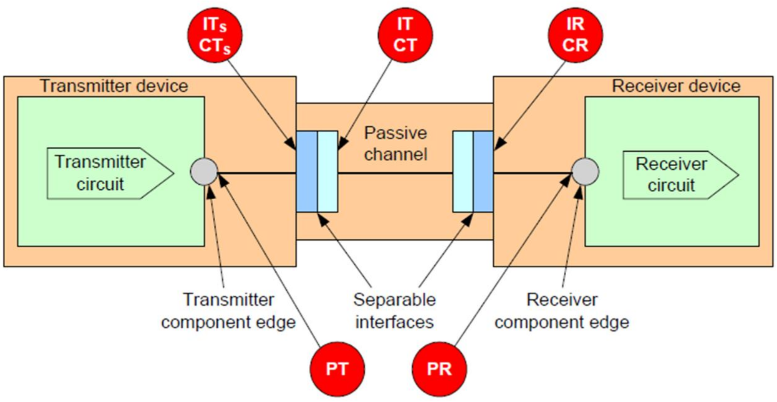


FIGURE 36. SAS-4 TXRX CONNECTION AT COMPLIANCE TEST POINTS (FROM SAS-4 DRAFT STANDARD)

12.2 Recommended SAS-4 Rx Calibration Flow

a) Calibrate Reference Presets

Calibrate de-emphasis and pre-shoot using a pattern that contains both high-frequency and low-frequency components. This ensures proper equalization of initial high-frequency and low-frequency amplitudes for accurate calibrations.

Calibrate nominal de-emphasis/pre-shoot settings for three reference presets (reference_1, reference_2 and no_equalization), as specified below.

Table 56 — Transmitter circuit coefficient presets at ET

Coefficient settings [a]	R_{pre} (V/V) [b]			R_{post} (V/V) [b]		
	Min	Nom	Max	Min	Nom	Max
normal [c]						
reference_1 [d] [e]	2.10	2.52	2.97	2.94	3.52	4.16
reference_2 [e] [f]	1.05	1.26	1.49	1.19	1.43	1.68
no_equalization [e] [g]	0.84	1.00	1.19	0.84	1.00	1.19

Key:

Max = Maximum
Min = Minimum
Nom = Nominal

[a] The coefficient setting field in the TTIU (see SPL-4).
[b] All measurements are performed with a repeating TRAIN_DONE primitive (see SPL-4 and figure 162). If a simulation tool (e.g., SAS3_EYEOPENING) is used, then this measurement may be performed with IDLE dwords (see SPL-4) as the test pattern.
[c] See SPL-4.
[d] Equivalent to the reference transmitter setting transmitter circuit coefficient 1 (i.e., C1) set to -0.15, coefficient 2 (i.e., C2) set to 0.6, and coefficient 3 (i.e., C3) set to -0.25 with a ± 1.5 dB tolerance on R_{pre} and R_{post}.
[e] The reference_1, reference_2, and no_equalization presets shall set the transmitter to its maximum peak to peak voltage (V_{P-P}).
[f] Equivalent to the reference transmitter setting transmitter circuit C1 set to -0.075, C2 set to 0.8, and C3 set to -0.125 with a ± 1.5 dB tolerance on R_{pre} and R_{post}.
[g] Equivalent to the reference transmitter setting transmitter circuit C1 set to zero, C2 set to one, and C3 set to zero with a ± 1.5 dB tolerance on R_{pre} and R_{post}.

FIGURE 37. PRESET CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

b) Calibrate Insertion Loss (ISI)

Calibrate differential insertion loss of the passive TxRx connection by measuring the difference in frequency response magnitude, as specified below.

5.5.7.2 Passive TxRx connection insertion loss for trained 22.5 Gbit/s

The differential insertion loss of the passive TxRx connection for trained 22.5 Gbit/s shall comply with the following equations:

$$IL(f) = -0.043 + 5.031\sqrt{f} + 1.171f \quad \text{for } 0.05\text{ GHz} \le f \le 11.25\text{ GHz; and}$$

$$IL(f) = -4.752 + 3.089f \quad \text{for } 11.25\text{ GHz} < f \le 16.875\text{ GHz (i.e., (3/4) } f_{baud}\text{)}$$

where:

$IL(f)$ is the differential insertion loss (i.e., $-|S_{DD21}|$); and

f is the signal frequency in Hz.

Figure 124 shows the differential insertion loss of the passive TxRx connection for trained 22.5 Gbit/s.

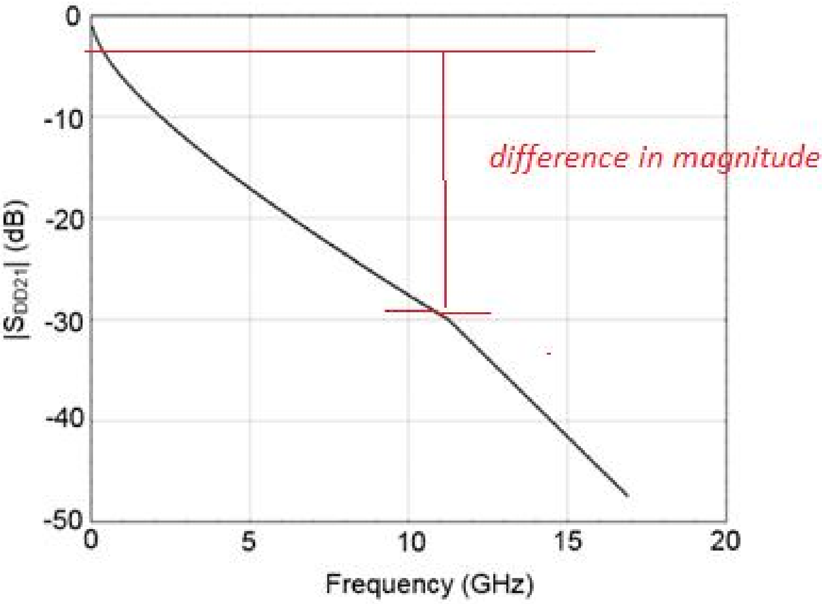


Figure 124 — Passive TxRx connection differential insertion loss for trained 22.5 Gbit/s

FIGURE 38. ISI CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

c) Calibrate Signal Stresses

Perform calibration for the stressed Rx signal to within below specifications.

Table 82 — Test equipment transmitter device signal output characteristics for stressed receiver device testing for trained 22.5 Gbit/s at PT, IT, and CT

Signal characterisitic	Symbol	Units	Minimum	Nominal	Maximum
Peak to peak voltage (V_{P-P}) [a] [b]		mV(P-P)	850		1 000
Transmitter device off voltage at IT or CT [c] [d]		mV(P-P)			50
Reference differential impedance at IT or CT [e]		Ω		100	
Reference common mode impedance at IT or CT [e]		Ω		25	
Rise/fall time at IT or CT [f]		UI	0.30 [g]		0.41 [h]
Common mode noise [i]		mV rms			12
Uncorrelated unbounded Gausian jitter [j] [k] [l]	T_UUGJ	UI	0.135 [m]	0.15 [n]	0.165 [o]
Uncorrelated bounded high probability jitter [j] [k]	T_UBHPJ	UI	0.085 [p]	0.10 [q]	0.115 [r]
Duty cycle distortion [s]	T_DCD	UI			0.035 [t]
Total jitter [j] [k]	T_TJ	UI			0.28 [u]

[a] The V_{P-P} measurement shall be made with the transmitter device set to no equalization (see table 56) and amplitude set to maximum. The minimum value applies at PT.
(see 5.3.3) and the maximum value applies at IT (see 5.3.3) or CT (see 5.3.3). The measurement is made with a repeating 7Eh (i.e., D30.3) pattern (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4).
[b] The V_{P-P} amplitude should be set as close as possible to the minimum value.
[c] The transmitter device off voltage is the maximum A.C. voltage measured at compliance points IT and CT when the transmitter is unpowered or transmitting D.C. idle (e.g., during idle time of an OOB signal).
[d] If optical mode is enabled, then the transmitter device off voltage is not applicable.
[e] See 5.8.4.8.3 for transmitter device S-parameters characteristics.
[f] Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 01b pattern or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4).
[g] 0.30 UI is $13.\overline{3}$ ps at 22.5 Gbit/s.
[h] 0.41 UI is $18.\overline{2}$ ps at 22.5 Gbit/s.
[i] Common mode noise is measured using the PRBS15 (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4) (see ITU-T) on the physical link.
[j] For jitter measurements, see 5.8.4.8.4.
[k] The measurement shall include the effects of the JTF (see 5.8.3.2).
[l] The T_UUGJ nominal value of 0.15 UI corresponds to a value of 0.01 UI rms.
[m] 0.135 UI is $5.\overline{9}$ ps at 22.5 Gbit/s.
[n] 0.15 UI is $6.\overline{6}$ ps at 22.5 Gbit/s.
[o] 0.165 UI is $7.\overline{3}$ ps at 22.5 Gbit/s.
[p] 0.085 UI is $3.\overline{7}$ ps at 22.5 Gbit/s.
[q] 0.10 UI is $4.\overline{4}$ ps at 22.5 Gbit/s.
[r] 0.115 UI is $5.\overline{1}$ ps at 22.5 Gbit/s.
[s] T_DCD is measured with a repeating 01b pattern or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol Specific diagnostic page in SPL-4) on the physical link. Duty cycle distortion is part of the CBHPJ (correlated bounded high probability jitter) distribution (see OIF-CEI) and is measured at the time-averaged signal level. T_DCD shall be measured with transmitter device equalization on and transmitter device equalization set to no_equalization (see table 56).
[t] 0.035 UI is $1.\overline{5}$ ps at 22.5 Gbit/s.
[u] 0.28 UI is $12.\overline{4}$ ps at 22.5 Gbit/s.

FIGURE 39. RX STRESSED SIGNAL CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

i) Calibrate Launch Amplitude

Calibrate launch amplitude (peak-to-peak voltage) using a repeating 7Eh pattern to the target minimum peak-to-peak amplitude of 850 mVpp or higher, as specified above.

ii) Measure Rise/Fall Time (*Informative*)

Measure 20-80% rise/fall time using a repeating 01b or 10b pattern to the target minimum value of 0.30 UI or higher, as specified above. This is performed for information purpose only.

iii) Measure Common Mode Noise (*Informative*)

Measure common mode noise using a PRBS15 pattern to the target maximum value of 12 mVrms or lower, as specified above. This is performed for information purpose only.

iv) Calibrate Uncorrelated Unbounded Gaussian Jitter (T_UUGJ)

Calibrate T_UUGJ using a PRBS15 pattern to the target nominal value of 0.15 UI, as specified above.

v) Calibrate Uncorrelated Bounded High Probability Jitter (T_UBHPJ)

Calibrate T_UBHPJ using a PRBS15 pattern to the target nominal value of 0.10 UI, as specified above.

vi) Calibrate Duty Cycle Distortion (T_DCD)

Calibrate T_DCD using a repeating 01b or 10b pattern with Tx device equalization enabled and set to 'no_equalization'. Measure to the target maximum value of 0.035 UI or lower, as specified above. This is performed for information purpose only.

vii) Calibrate Total Jitter (T_TJ)

Calibrate T_TJ using a PRBS15 pattern to the target maximum value of 0.28 UI or lower, as specified above.

d) Calibrate SJ

Calibrate SJ (over 3 frequencies) for jitter tolerance using the PRBS15 pattern, with or/and without SSC support, as defined below.

For the case without SSC support:

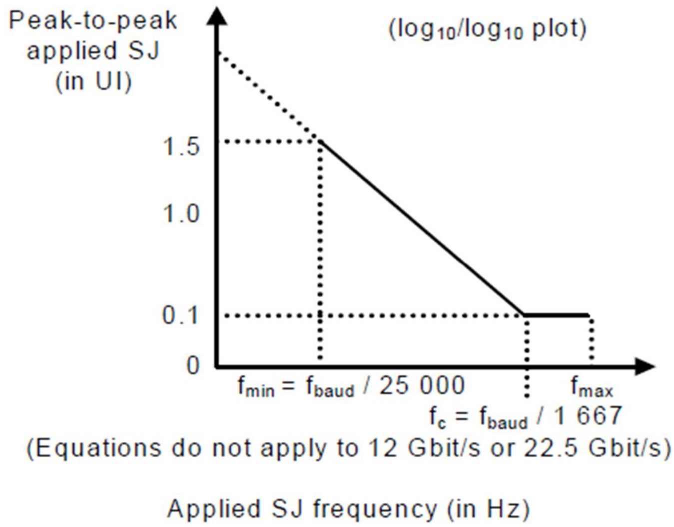


Figure 181 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s,and 22.5 Gbit/s without SSC support

Table 83 defines f_{min}, f_c, and f_{max} for figure 181. f_{baud} is defined in table 42 (see 5.8.1).

Table 83 — f_{min}, f_c, and f_{max} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s,and 22.5 Gbit/s without SSC support

Physical link rate	f_{min}	f_c	f_{max}
1.5 Gbit/s	60 kHz	900 kHz	5 MHz
3 Gbit/s	120 kHz	1 800 kHz	7.5 MHz
6 Gbit/s	240 kHz	3 600 kHz	15 MHz
12 Gbit/s	240 kHz	3 600 kHz	15 MHz
22.5 Gbit/s	240 kHz	3 600 kHz	15 MHz

FIGURE 40. SJ CALIBRATION SPECS WITHOUT SSC (FROM SAS-4 DRAFT STANDARD)

For the case with SSC support:

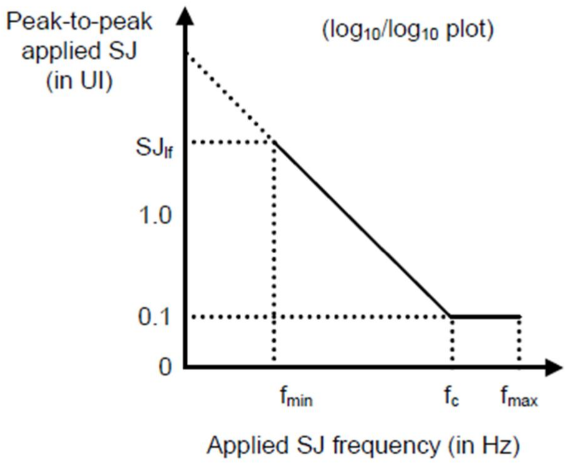


Figure 182 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

Table 84 defines f_{min}, f_c, f_{max}, and SJ_{lf} for figure 182.

Table 84 — f_{min}, f_c, f_{max}, and SJ_{lf} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

Physical link rate	f_{min}	f_c	f_{max}	SJ_{lf}
1.5 Gbit/s	97 kHz	1.03 MHz	5 MHz	11.3 UI
3 Gbit/s	97 kHz	1.46 MHz	7.5 MHz	22.6 UI
6 Gbit/s	97 kHz	2.06 MHz	15 MHz	45.3 UI
12 Gbit/s	111 kHz	2.06 MHz	15 MHz	34.6 UI
22.5 Gbit/s	119 kHz	2.06 MHz	30 MHz	30.1 UI

FIGURE 41. SJ CALIBRATION SPECS WITH SSC (FROM SAS-4 DRAFT STANDARD)

Note: The "with SSC support" jitter tolerance above increases the low-frequency SJ to 30.1 UI. This low SJ frequency would allow for testing of DUT CR rejection at near SSC frequencies.

e) Calibrate Crosstalk

Calibrate the total integrated crosstalk noise at 22.5 Gbit/s with SSC enabled (generated by the BERTScope) to within compliance limits as shown below. Calculation of crosstalk noise is based on variables defined in Table 38 of the SAS-4 Draft Standard.

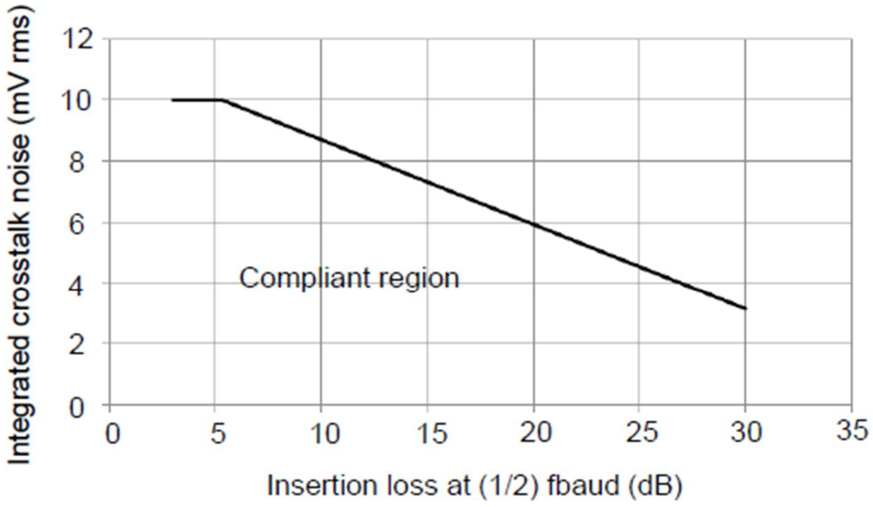


Figure 125 — Integrated crosstalk noise limit

12.3 SAS-4 Rx Calibration Setup and Procedure

Calibration for SAS-4 will be performed at two test points: Point A and Point IR/CR. Test Point A (TP-A) is a physical test point for calibration. Test Point IR/CR is an electrical test point calculated by the *DPOJET SAS Gen4* software tool in the Scope test instrument for SAS-4 (22.5 Gbit/s) compliance.

Refer to Figure 34 to view the block diagram for the general calibration setup.

12.3.1 Physical Setups

12.3.1.1 Connect Equipment at Test Point A (TP-A)

The connection diagram below shows the recommended equipment setup to calibrate for signal amplitude and jitter at TP-A.

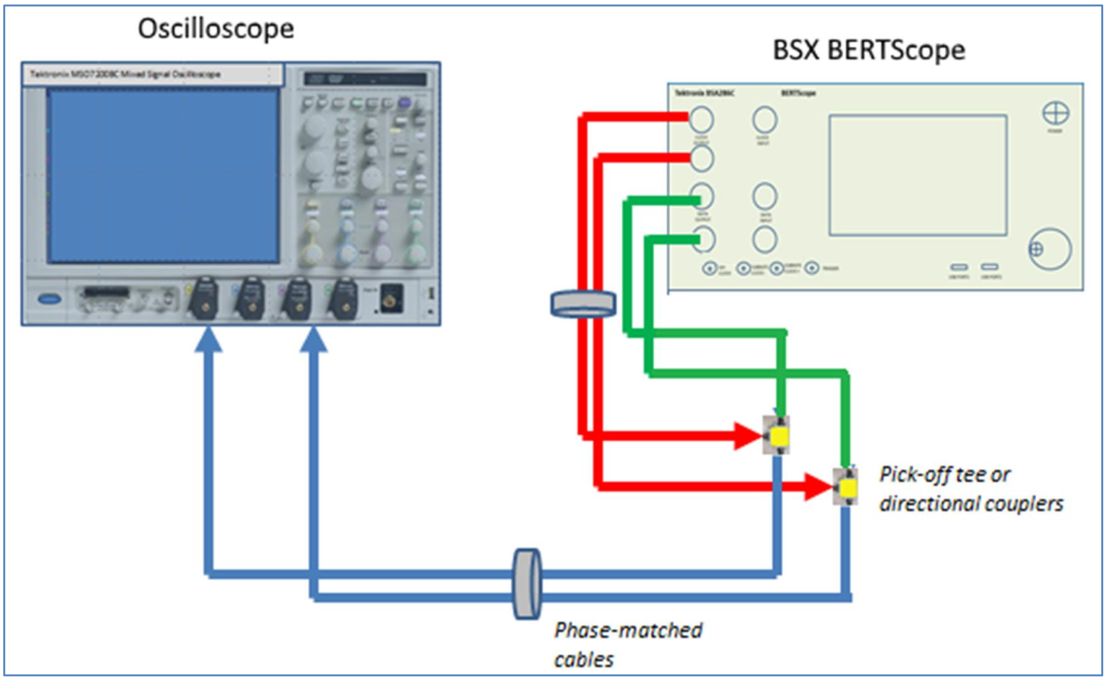


FIGURE 42. CALIBRATION CONNECTION SETUP AT TEST POINT A

Connection Steps:

1. Connect DATA OUTPUT(+) of the BERTScope to an input port of pick-off tee 1/pick-off tee 2.
2. Connect DATA OUTPUT(–) of the BERTScope to the other input port of pick-off tee 1/pick-off tee 2.
3. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
4. Connect the outputs of pick-off tee 1 and pick-off tee 2 to Channel 1 and Channel 3 of the Oscilloscope.

Note: It is recommended to use pick-off tees with low-loss thru channel to maximize the dynamic range of the BERTScope data outputs. Optionally, directional couplers can also be used in a similar manner.

12.3.1.2 Connect Equipment at Test Point A-IR/CR

The connection diagram below shows the recommended equipment setup to calibrate for insertion loss (ISI) and crosstalk from TP-A to Test Point IR/CR. *Note a compliant variable ISI generator is used in this setup.*

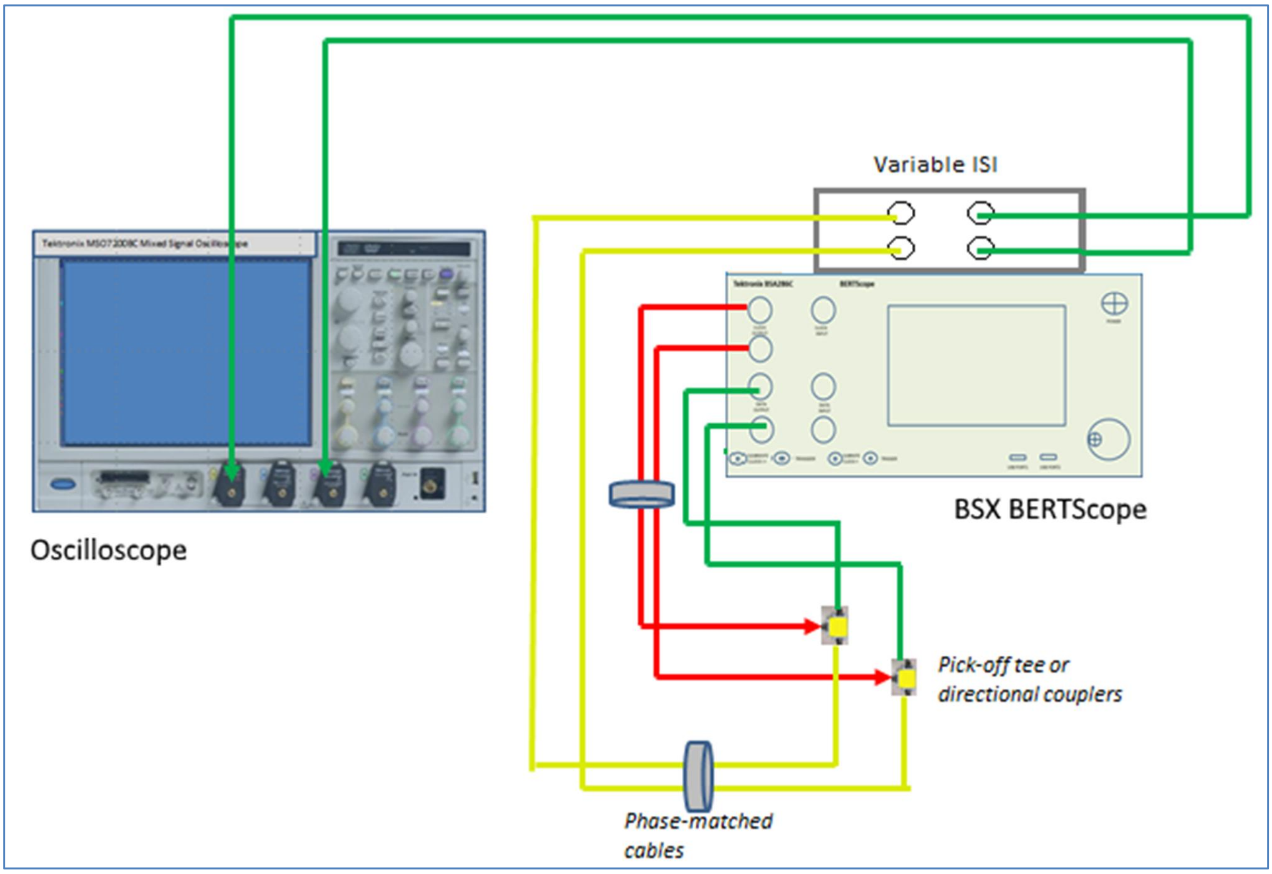


FIGURE 43. CALIBRATION CONNECTION SETUP AT TEST POINT A-IR/CR

Connection Steps:

1. Connect DATA Outputs of the BERTScope to the pick-off tee 1 and tee 2 input ports.
2. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
3. Connect the pick-off tees outputs to the inputs of the Variable ISI Generator.
4. Connect the outputs of the Variable ISI Generator to Channels 1 and 3 of the Oscilloscope.

12.3.2 Calibration Steps

12.3.2.1 Step 1: Calibrate and Save Reference Presets

This step verifies that the nominal settings for the reference preset (which uses de-emphasis and pre-shoot) meet the target values, and then saves the settings. A total of 3 reference presets, with nominal de-emphasis/pre-shoot settings for each preset, will be used in this measurement.

For this example, Reference Preset 1 will be calibrated using the 64X1_64x0_64x10.ram pattern to the following target values:

- Target De-emphasis: -10.9dB +/- 2dB
- Target Pre-shoot: 8dB +/- 2dB

The calibrated nominal settings will then be saved for future use.

1. Set De-emphasis and Pre-shoot on the BSX BERTScope to the above target values.
2. Measure the actual de-emphasis and pre-shoot on the Scope. Using cursors, measure the peak-to-peak transition amplitude.
3. Using cursors, measure the peak-to-peak non-transition amplitude.
4. For example, assuming the measured transition amplitude is 825mVpp and the measured non-transition amplitude is 254mV, calculate De-emphasis as follows:

   De-emphasis = 20log[Non-transition/Transition]
   = 20log[254mV/824mV]
   = 20log[0.31]
   =–10.2dB *(which conforms to the target of -10.9dB +/- 2dB)*

5. Now, measure the pre-shoot amplitude using cursors on the Scope.
6. For example, assuming the measured pre-shoot amplitude is 622mV, calculate Pre-shoot as follows:

   Pre-shoot = 20log[Pre-shoot/Non-transition]
   = 20log[622mV/254mV]
   = 20log[2.44]
   = 7.8dB *(which conforms to the target of 8dB +/- 2dB)*

Note: To obtain more precise measurements, adjust the pre-shoot/de-emphasis accordingly on the BERTScope.

7. Save the Reference Preset 1 settings to a file e.g., 'SAS24G_reference1' on the BERTScope.
8. Repeat the above calibration and saving procedure for Reference Presets 2 and 3.

12.3.2.2 Step 2: Calibrate Insertion Loss (ISI)

This step verifies that a trained 22.5Gbit/s signal of the passive TxRx connection meets the target differential ISI in Figure 38 of Section 12.2. This is performed by measuring the frequency response and ensure that the difference in magnitude is within the allowable range.

Note: A compliant variable ISI generator is used in this setup to output ISI components.

1. Perform triggering on the Unit Step function (long string of 0's, followed by an edge, and long string of 1's).
2. Calculate derivative of the signal from the previous step to obtain an impulse response of the signal.
3. Calculate FFT of the impulse response, which results in the frequency response.
4. Measure the difference in magnitude of the response between ~33MHz (minimum frequency, limited by sampling rate) and 11.25GHz.
5. Calculate the ideal magnitude difference using the equation given in Figure 38 of Section 12.2.
6. Adjust the variable ISI generator until the measured magnitude meets the calculated ideal magnitude difference.

12.3.2.3 Step 3: Calibrate Rx Signal Stresses

This step measures the stress tolerance of the received signal to verify that the stressed signal of the receiver complies to target specifications in Figure 39 of Section 12.2.

For measurements in this calibration step, set up the BERTScope as follows:

- Set Amplitude to 850mV.
- Turn on DATA + and DATA –.

12.3.2.3.1 Measure Peak-to-Peak Launch Amplitude (Vp-p)

This measurement verifies that the peak-to-peak voltage of the Launch Amplitude meets the target of 850mVp-p or above. If needed, the BERTScope DATA outputs are adjusted to reach the target value.

For this case, a repeating 7Eh pattern on the BERTScope is used.

1. Set up the Scope as follows:
   - Data channels: ON
   - Vertical scale: 60mV
   - Horizontal scale: 100ns.
   - Function 1: CH1-CH3 and ON
2. Measure the peak-to-peak voltage (Vp-p) using cursors, while adjusting the BERTScope amplitude to achieve the minimum target of 850mVp-p or above.

12.3.2.3.2 Measure Rise/Fall Time (Informative)

This measurement verifies that the rise/fall time of 20% to 80% transition meets the target of 0.30UI or above. This is performed for information purpose only.

For this case, a repeating 01b pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from previous calibration step.
2. Set Function 1 on the Scope to CH1-CH3 and turn ON.
3. Measure 20-80% rise/fall time of Function 1 to meet the minimum target of 0.30UI or above. Record the measured value.

12.3.2.3.3 Measure Common Mode Noise (Informative)

This measurement verifies that the common mode noise meets the target of 12mVrms or below. This is performed for information purpose only.

For this case, a PRBS15 pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from the Launch Amplitude calibration step.
2. Set up the Scope as follows:
    - Vertical scale: 10mV/div
    - Function 1: CH1-CH3 and ON
3. Measure Vrms of Function 1 to meet the maximum target of 12mVrms or below. Record the measured value.

12.3.2.3.4 Measure Uncorrelated Unbounded Gaussian Jitter (T_UUGJ)

This measurement verifies that the T_UUGJ meets the target of 0.15UI nominal.

For this case, a PRBS15 pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Random Jitter (RJ) to 0.15UIp-p.
2. Enable the DPOJET function on the Scope and configure RJ measurement as follows:
    - PLL Model: Type I (*assuming the DUT does not support SSC*)
    - Loop BW: 13.5MHz
3. Measure RJ on the DPOJET, while adjusting the BERTScope amplitude to achieve the nominal target of 0.15UI.

12.3.2.3.5 Measure Uncorrelated Bounded High Probability Jitter (T_UBHPJ)

This measurement verifies that the T_UBHPJ meets the target of 0.10UI nominal.

For this case, a PRBS15 pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Bounded Uncorrelated Jitter (BUJ) to 0.10UIp-p.
2. Enable the DPOJET function on the Scope and configure DJ/DDJ measurement as follows:
   - PLL Model: Type I (*assuming the DUT does not support SSC*)
   - Loop BW: 13.5MHz
3. Measure DJ and DDJ on the DPOJET, while adjusting the BERTScope amplitude to achieve the nominal target of 0.10UI.

   Calculate *T_UBHPJ = DJ – DDJ*

12.3.2.3.6 Measure Duty Cycle Distortion (T_DCD) (Informative)

This measurement verifies that the T_DCD meets the target of 0.035UI or below, which also requires Tx device equalization to be enabled and set to 'no_equalization'. This is performed for information purpose only.

For this case, a repeating 01b pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from the Launch Amplitude calibration step.
2. Enable the DPOJET function on the Scope and configure as follows:
   - PLL Model: Type I (*assuming the DUT does not support SSC*)
   - Loop BW: 13.5MHz
3. Measure T_DCD on the DPOJET to meet the maximum target of 0.035UI or below.

12.3.2.3.7 Measure Total Jitter (T_TJ)

This measurement verifies that the T_TJ meets the target of 0.28UI or below.

For this case, a PRBS15 pattern on the BERTScope is used.

1. Set the BERTScope amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set RJ and BUJ to the calibrated values from previous calibration steps.
2. Enable the DPOJET function on the Scope and configure as follows:
   - PLL Model: Type I (*assuming the DUT does not support SSC*)
   - Loop BW: 13.5MHz
   - BER: 1e-12
3. Measure T_TJ on the DPOJET. If the measurement exceeds the 0.28UI maximum limit, reduce RJ/BUJ until the value is measured to below 0.28UI.

12.3.2.4 Step 4: Calibrate SJ

This step verifies the jitter tolerance at 3 distinct SJ frequencies as defined in Figure 41 of Section 12.2, which is performed with SSC support for this case.

Note: Magnitude and SJ will vary depending on testing with or without SSC support.

For **trained 22.5Gbit/s with SSC support**, SJ will need to be calibrated to the following target values:

- SJ at 119kHz: 30.1UI
- SJ at 2.06MHz: 0.10UI (or 10%UI)
- SJ at 30MHz: 0.10UI (or 10%UI)

Note: Additional Jitter Tolerance points can be added if desired.

i) Calibrate SJ at 119kHz

1. In the Clock Recovery section of DPOJET, set the Method to 'Constant Clock – Mean'. This is to prevent filtering of the low frequency jitter modulation for verification.
2. On the BERTScope, turn on the Phase Modulator, and set the PM Frequency to 119kHz and PM Deviation to 30.1UI.
3. Measure PJ1 on the DPOJET.
4. Convert the measured PJ1 value to UI (where 1UI = 83ps) to meet the target of ~30.1UI.
5. Record the SJ value on the BERTScope needed to generate the required SJ at 119kHz, which is to be used for the Jitter Tolerance configuration later.

ii) Calibrate SJ at 2.06MHz

1. Set the Sine Jitter on the BERTScope to an initial 7%UI.
2. Measure SJ on the DPOJET.
3. Convert the measured SJ value to UI (where 1UI = 83ps) to meet the target of ~0.10UI.
4. Record the SJ value on the BERTScope needed to generate 10% SJ at reference point, which is to be used for the Jitter Tolerance configuration later.

Note: For SJ at 30MHz with 0.10UI (or 10%UI) target, follow the same calibration procedure as above.

12.3.2.5 Step 4a: Configure Jitter Tolerance Template

This step creates a Jitter Tolerance template to store the 3 calibrated SJ frequencies (for SSC support, as described above) to be used later.

1. On the BERTScope, select 'Template Builder' in the Jitter Tolerance function.
2. Key in the calibrated values for SJ as previously measured.
3. Save the template file as e.g., 'SAS_24G_JTOL' or any desired name.

12.3.2.6 Step 5: Calibrate Crosstalk

This step verifies that the crosstalk amplitude is within the maximum target of 15 to 20mVpp. For this case, a compliant variable ISI generator is applied, while the BERTScope Clock output is used to generate the crosstalk and can be adjusted to achieve the expected crosstalk value.

The SAS-4 Draft Standard specifies that S-parameter files and crosstalk amplitude per usage models (part 1 of 2) crosstalk amplitude should be between 15 to 20mV pk-pk. *Note: The crosstalk required is Far End Crosstalk (FEX) and should include ISI effects (the loss profile as previously calibrated for ISI generator) as well as being applied in differential mode.*

1. On the BERTScope, transmit the 'All Zeroes' pattern to ensure no signal is being transmitted during crosstalk calibration.
2. Enable the BERTScope Clock Output and set it to divide-by-2. The 6GHz Clock supplies a 1010 pattern at 24Gbps.
3. On the Scope, set Channel 2 and Channel 4 to the minimum scale of 10mV.
4. On the BERTScope, set the Clock +/- amplitudes to 250mV.
5. Set the Scope to measure the maximum Vpp on Channel 3 – Channel 4 over 5 seconds.
6. Adjust the Clock Amplitude until the amplitude measured is between the maximum 15 to 20mVpp as targeted.

12.4 SAS-4 Rx Compliance Test Setup and Procedure

Compliance testing for jitter tolerance of the receiver DUT will use the BERTScope analyzer/error detector via a clock recovery unit in the loopback mode. The BERTScope will typically transmit PRBS31 signaling (which includes ISI effects, jitter, and crosstalk) to the Rx DUT. During loopback, the clock recovery unit will extract clock data from the DUT's transmitted signal and send the data to the BERTScope error detector for error checking. The DUT will pass compliance if the target BER of less than 1E-12 with a 95% confidence level is met.

Refer to Figure 34 to view the block diagram for the general test setup.

12.4.1 Physical Setup

The connection diagram below shows the recommended equipment setup to test the DUT for SAS-4 Rx jitter tolerance.

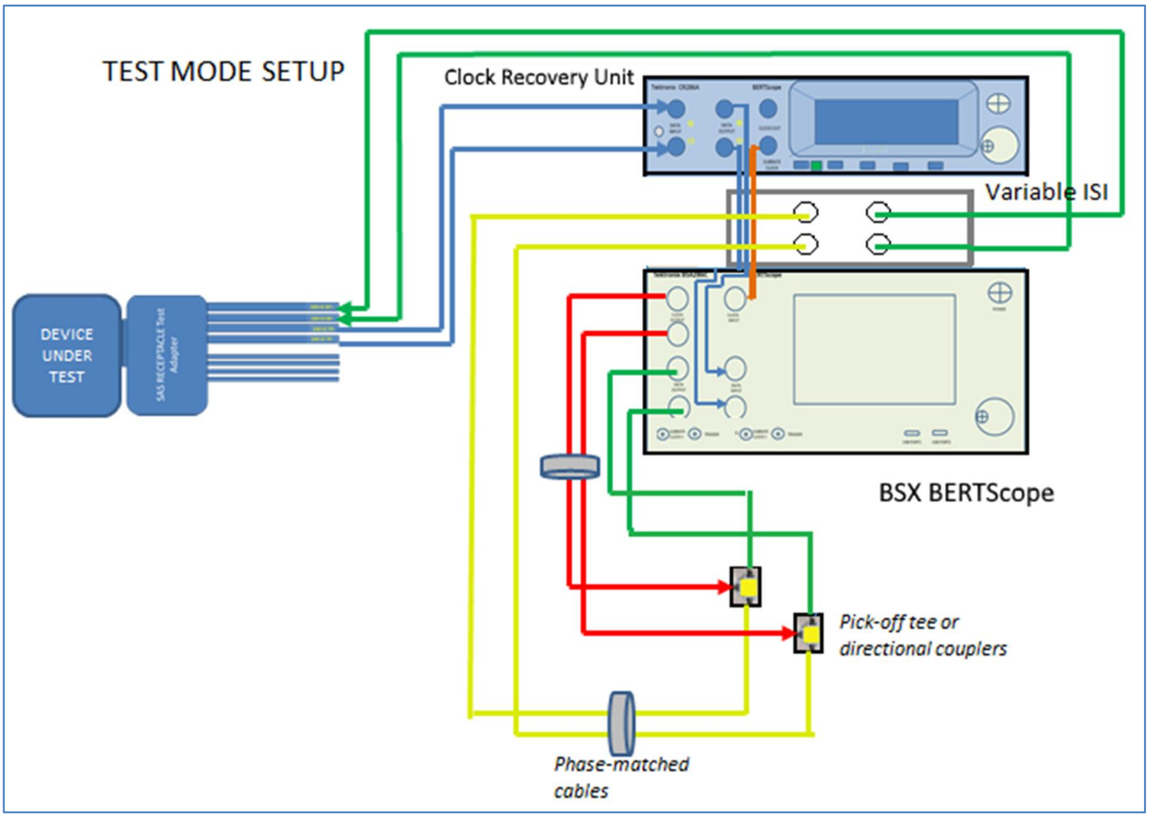


FIGURE 44. COMPLIANCE TEST SETUP FOR RECEIVER DUT JITTER TOLERANCE

Connection Steps:

1. Connect DATA Outputs of the BERTScope to the pick-off tee 1 and tee 2 input ports.
2. Connect Clock Outputs of the BERTScope to the pick-off tees tapped input ports (labeled as 14dB).
3. Connect the pick-off tees outputs to the inputs of the Variable ISI Generator.
4. Connect the outputs of the Variable ISI Generator to RX+/- of the DUT.
5. Connect TX+/- of the DUT to Data Input+/- of the Clock Recovery Unit.

6. Connect Data Output+/- of the Clock Recovery Unit to Data Input+/- of the BERTScope Error Detector.
7. Connect the Sub-rate Clock Output of the Clock Recovery Unit to the Clock Input of the BERTScope Error Detector.

12.4.2 Configure BERTScope Jitter Tolerance

Set the following number of received bits per respective maximum number of errors allowable for the BERTScope jitter tolerance. The specified number of bits will be transmitted to the DUT and the number of observable errors will be recorded. This is done to ensure a confidence level of 95% for the target BER of less than 1E-12.

Number of Errors	Number of Bits
0	3×10^{12}
1	4.74×10^{12}
2	6.3×10^{12}
3	7.75×10^{12}
4	9.15×10^{12}
5	1.05×10^{13}

12.4.3 Set Up Clock Recovery Unit with/without SSC Support

Follow the same procedure from calibration to configure the clock recovery unit for SSC support (if supported by the DUT).

12.4.4 Set Up BERTScope Error Detector for Symbol Filtering

Perform Tx/Rx training on the signal with ISI and crosstalk sources enabled.

a) The BERTScope pattern generator will transmit the following Train_Tx-SNW pattern (Reference_SPL-4).

Table 90 – Transmitter training pattern

Transmitter training pattern	Mode	Description
Train_Tx pattern	SAS dword	Sequence of: 1) pattern marker (see 5.11.4.2.3.4.3); 2) TTIU (see 5.11.4.2.3.5); and 3) 58 data dwords set to 00000000h that are transmitted scrambled and 8b10b encoded.
	SAS packet	Sequence of: 1) pattern marker (see 5.11.4.2.3.4.3); 2) TTIU (see 5.11.4.2.3.5); 3) 59 SPL packet payloads containing scrambled idle segments; and 4) one END_TRAIN.

The scrambler is the same as that defined for the link layer (see 6.8) and shall be initialized at the end of RCDT. The scrambler shall not be reinitialized for the remainder of the Train_Tx-SNW.

The phy shall start transmitting Train_Tx patterns at the end of RCDT. The number of Train_Tx patterns transmitted is determined by the time required for the phys to complete transmitter training.

After RCDT, the local phy's receiver shall attempt to train the attached phy's transmitter as follows:

a) if the local phy and the attached phy complete transmitter training within MTTT, then the phy shall start Train_Rx-SNW (see 5.11.4.2.3.5). At the point the phy completes transmitter training the phy shall consider the Train_Tx-SNW to be valid; or
b) if the local phy and the attached phy do not complete transmitter training within MTTT, then the phy shall consider the Train_Tx-SNW to be invalid.

The phy shall not transmit primitives during Train_Tx-SNW.

During the Train_Tx-SNW the phy's transmitter shall transmit a pattern marker (see figure 76) at the start of each Train_Tx pattern as defined in table 90.

b) The Rx DUT will complete link training for the Train_Tx-SNW.
c) The BERTScope pattern generator will transmit the following Train_Rx-SNW pattern (Reference_SPL-4).

The Train_Rx-SNW contains receiver training patterns formed by TRAIN and TRAIN_DONE (see 6.2) as defined in table 91.

Table 91 – Receiver training patterns while in SAS dword mode

Receiver training pattern	Description
TRAIN pattern	Sequence of: 1) TRAIN primitive sequence; and 2) 58 data dwords set to 00000000h that are transmitted scrambled and 8b10b encoded.
TRAIN_DONE pattern	Sequence of: 1) TRAIN_DONE primitive sequence; and 2) 58 data dwords set to 00000000h that are transmitted scrambled and 8b10b encoded.

The scrambler is the same as that defined for the link layer (see 6.8). If there is no Train_Tx-SNW, then the scrambler shall be initialized at the end of RCDT. If there is a Train_Tx-SNW, then the scrambler shall be initialized at the end of Train_Tx-SNW. The scrambler shall not be reinitialized for the remainder of the Train_Rx-SNW.

If there is no Train_Tx-SNW, then the phy shall start transmitting TRAIN patterns at the end of RCDT. If a Train_Tx-SNW occurs, then the phy shall start transmitting TRAIN patterns at the end of the transmitter training (see 5.11.4.2.3.4.2). The first TRAIN pattern may have either starting disparity. The number of TRAIN patterns transmitted is determined by the time required for the phy's receiver to complete training and acquire dword synchronization. The phy shall transmit at least one TRAIN pattern and shall transmit a minimum of four TRAIN_DONE patterns:

a) if the phy achieves dword synchronization within the TLT, then, after completing transmission of the current TRAIN pattern, the phy shall change from transmitting TRAIN patterns to transmitting TRAIN_DONE patterns for the remainder of the Train_Rx-SNW window time (i.e., the remainder of the SNW time); or
b) if the phy does not achieve dword synchronization within the TLT, then the phy shall continue transmitting TRAIN patterns for the remainder of the MRTT (i.e., the remainder of the SNW time).

The phy shall not compare the received data characters to the expected transmitted data characters in the receiver training pattern.

If the phy:

a) transmits four or more TRAIN_DONE patterns; and
b) receives a minimum of one TRAIN_DONE primitive sequence before MRTT,

then the phy shall:

a) after completing transmission of the current TRAIN_DONE pattern, transmit at least one more TRAIN_DONE pattern, stop transmitting TRAIN_DONE patterns, and start transmitting dwords from the link layer; and
b) consider the Train_Rx-SNW to be valid.

If the phy does not receive a TRAIN_DONE primitive sequence before MRTT and transmits four or more TRAIN_DONE patterns, then it shall consider the Train_Rx-SNW to be invalid.

d) The Rx DUT will complete link training for the Train_Rx-SNW.

The formal back channel communication mechanism described in parts a) through d) above requires either access to state control registers that provide link training feedback or a separate protocol aware toolset (e.g., analyzer).

12.4.5 Test for Rx Jitter Tolerance BER Compliance

Transmit PRBS31 signaling to the Rx DUT and verify BER on the BERTScope error detector over the loopback mode. Based on the maximum errors detected for the given number of bits received, verify that the DUT reports a BER of less than 1E-12 with a 95% confidence level, in order to pass compliance.

13 Appendix B: Artek CLE1000 Series Installation

13.1 ISI Generator Driver Installation

If using a Artek CLE1000 Series model for variable ISI generation, follow these steps to install the ISI generator driver before selecting it as an ISI channel in the GRL automation software.

1. Connect the CLE1000 to the computer being used as the controller using a USB 2.0 cable.
2. Turn on the front panel power switch on the CLE1000.
3. Right-click on **My Computer > Manage > Device Manager**. If no software for the CLE1000 has been installed, you will see a 'bang' in the Device Manager window.

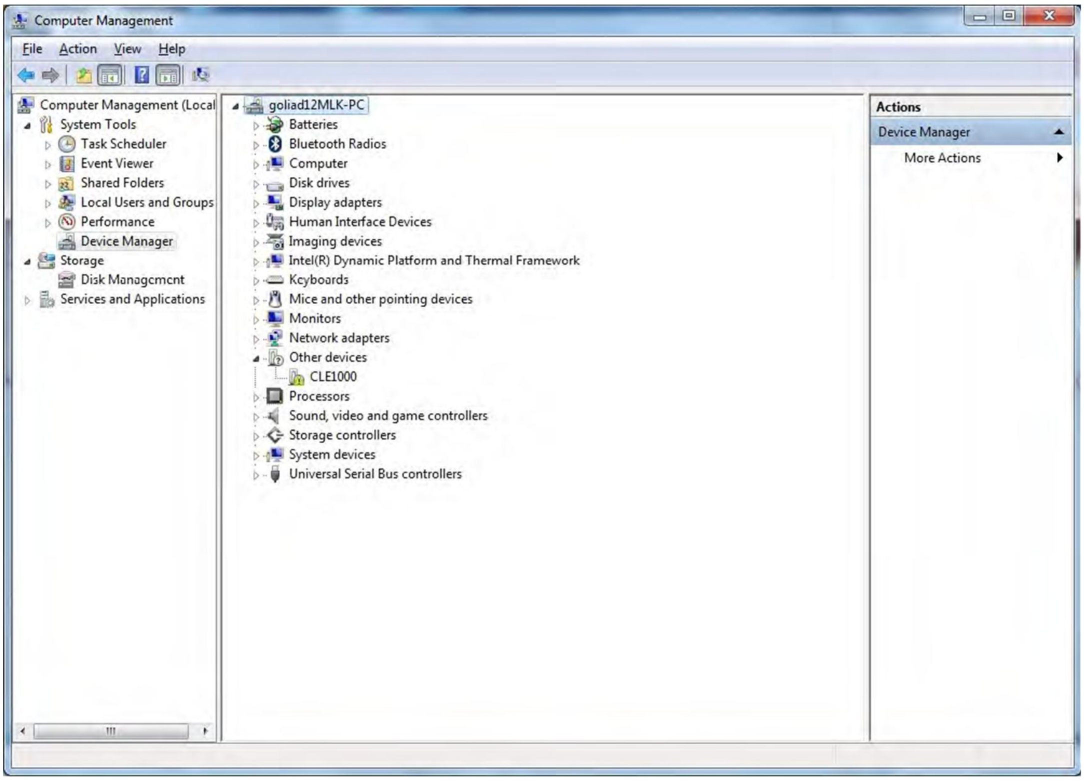


FIGURE 45. DEVICE MANAGER WINDOW

4. To install the CLE1000 driver, go to http://www.aceunitech.com/support.html and download the Control Software package for the CLE1000.
5. Unzip the CLE1000 Software folder and install the driver as follows:

   a) In Device Manager, right-click on **CLE1000** > **Update Driver**.
   b) Select **Browse My Computer for Driver** from Windows dialog (see Figure 46).
   c) Browse to the root directory of the unzipped CLE1000 Software folder.
   d) Click **Next** and then click **Install** to complete installation for the driver software (see Figure 47).

6. Once installation has completed, the Device Manager window should look like the example in Figure 48.

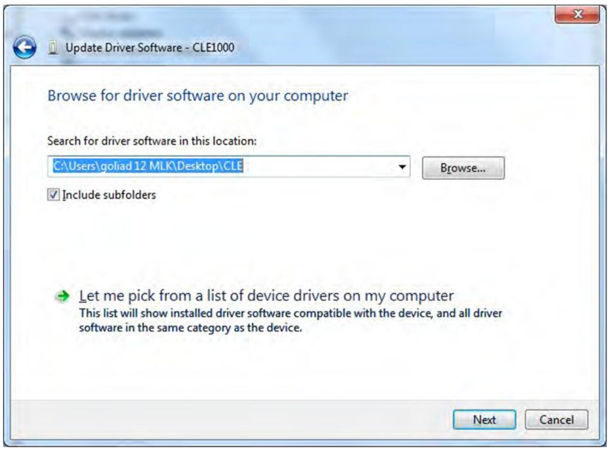


FIGURE 46. UPDATE DRIVER WINDOW

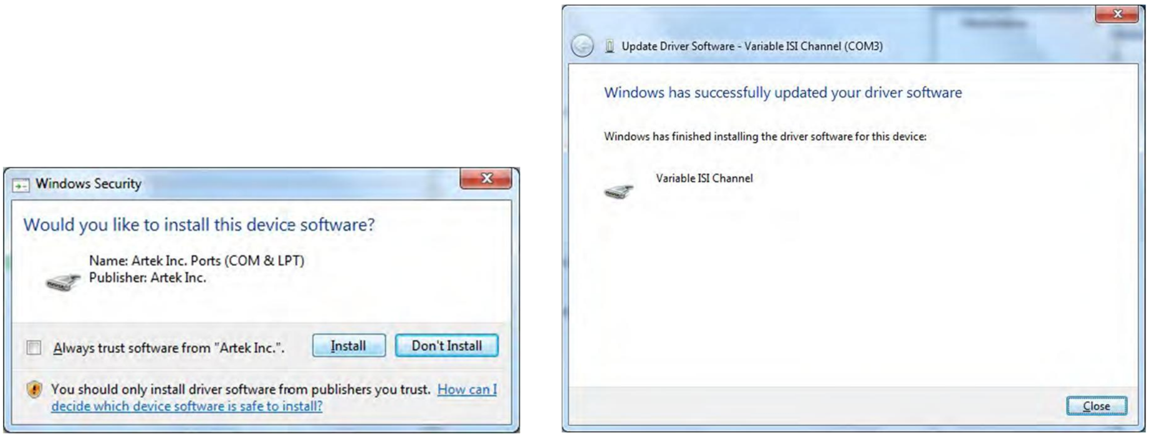


FIGURE 47. WINDOWS SECURITY WINDOW AND CONFIRMATION WINDOW

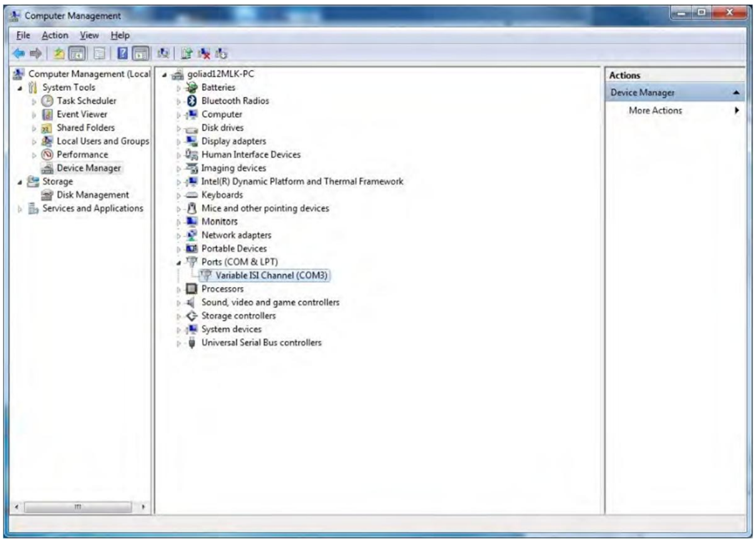


FIGURE 48. DEVICE MANAGER WINDOW AFTER INSTALLATION

The CLE1000 is now ready to be used remotely with the GRL automation software.

13.2 CLE1000 User Interface (UI) Installation

It may also be useful to install the CLE1000 UI, so that the ISI channel can also be controlled manually from the computer. To install the UI, follow these steps:

1. In the CLE1000 Software folder, select and install the Setup.exe file. Upon successful installation, the following UI window will appear.
2. Close this window if manual control is not required.

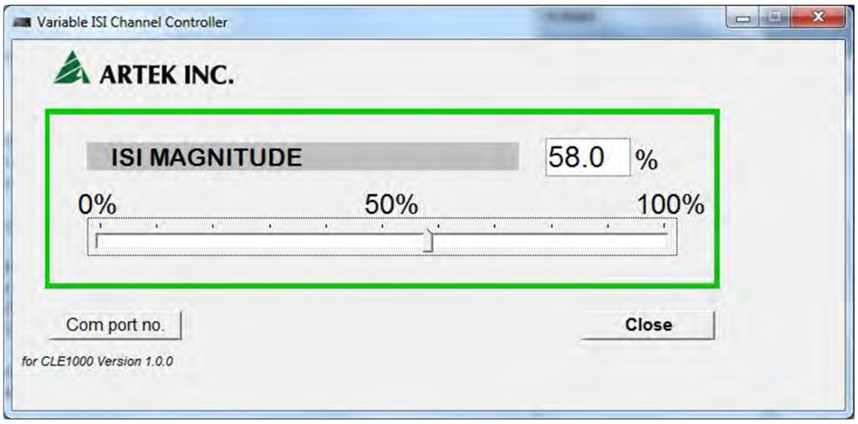


FIGURE 49. CLE1000 UI

14 Appendix C: SPL-4 Test Pattern Requirements

Table 276 – PHY TEST PATTERN field

Code	Name	Description
00h	Reserved	
01h	JTPAT	The selected phy shall repeatedly transmit JTPAT for RD+ and RD- (see A.1).
02h	CJTPAT	The selected phy shall repeatedly transmit CJTPAT (see A.2).
03h	PRBS9	The selected phy shall repeatedly transmit PRBS9 (see SAS-4)
04h	PRBS15	The selected phy shall repeatedly transmit PRBS15 (see SAS-4)
05h to 0Fh	Reserved	
10h	TRAIN	The selected phy shall repeatedly transmit the TRAIN pattern (see 5.11.4.2.3.5).
11h	TRAIN_DONE	The selected phy shall repeatedly transmit the TRAIN_DONE pattern (see 5.11.4.2.3.5).
12h	IDLE	The selected phy shall repeatedly transmit idle dwords (see 6.6).
13h	SCRAMBLED_0	The selected phy shall repeatedly transmit a repeating pattern of at least 58 dwords (i.e., 2 320 bits on the physical link) set to 00000000h that are transmitted scrambled and 8b10b encoded (see 6.6). The scrambler shall be reinitialized at the beginning of each pattern. See table F.2 in F.1.4.
14h to 3Fh	Reserved	
40h	TWO_DWORDS	The selected phy shall repeatedly transmit the dwords specified by the PHY TEST PATTERN DWORDS CONTROL field and the PHY TEST PATTERN DWORDS field without scrambling. This pattern is only for use for characterization of the transmitter device and the passive interconnect. Phys are not required to support all patterns that may be specified.
41h to EFh	Reserved	
F0h to FFh	Vendor specific	

Table 280 – TWO_DWORDS phy test pattern examples

PHY TEST PATTERN DWORDS CONTROL field	PHY TEST PATTERN DWORDS field	Description
00h	4A4A4A4A 4A4A4A4Ah	D10.2 characters (see table 49 in 5.3.6). This pattern contains 01b repeating and has the highest possible frequency. This pattern may be used for measuring intra-pair skew, rise time, fall time, and RJ (see SAS-4).
00h	B5B5B5B5 B5B5B5B5h	D21.5 characters (see table 49 in 5.3.6). This pattern contains 10b repeating and has the highest possible frequency. This pattern may be used for measuring intra-pair skew, rise time, fall time, and RJ (see SAS-4).
00h	78787878 78787878h	D24.3 characters (see table 49 in 5.3.6). This pattern contains 0011b or 1100b repeating (depending on starting disparity) and has half the highest possible frequency. This pattern may be used for calibrating the JTF, calibrating the reference transmitter test load, and measuring transmitter device S-parameters (see SAS-4).
00h	D926D926 D926D926h	Pairs of D25.6 and D6.1 characters (see table 49 in 5.3.6). This pattern contains 1001b repeating and has half the highest possible frequency.
00h	7E7E7E7E 7E7E7E7Eh	D30.3 characters (see table 49 in 5.3.6). This pattern contains four bits of one polarity, three bits of the other polarity, and three bits of the first polarity (e.g., 11 11000111b), followed by the inverse (e.g., 00 00111000b). This pattern may be used for measuring transmitter equalization and SSC-induced jitter (see SAS-4).
88h	BC4A4A7B BC4A4A7Bh	ALIGN (0) primitives (see table 125 in 6.2.3). This pattern may appear during OOB bursts (SAS-4), the SATA speed negotiation sequence (see 5.11.2.2), and the SAS speed negotiation sequence (see 5.11.4.2).
88h	BC070707 BC070707h	ALIGN (1) primitives (see table 125 in 6.2.3). This pattern may appear during the SAS speed negotiation sequences (see 5.11.4.2).
80h	BC4A4A7B 4A787E7Eh	Pairs of an ALIGN (0) (see table 125 in 6.2.3) and a dword containing D10.2, D24.3, D30.3, and D30.3 characters (see table 49 in 5.3.6).

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