



GRL Platform Solutions

**GRL-SAS4-RXA 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 Anritsu High Performance BERT and Real-Time
Oscilloscope with
GRL-SAS4-RXA Automation Software**

Published on 29 April 2026

DISCLAIMER

This document is provided "as is" with no warranties whatsoever, including any warranty of merchantability, no infringement, fitness for any particular purpose, or any warranty otherwise arising out of any proposal, specification, or sample. The GRL Platform Solutions disclaims all liability for infringement of proprietary rights, relating to use of information in this specification. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted herein.

All product names are trademarks, registered trademarks, or service marks of their respective owners.



Copyright © 2026 GRL Platform Solutions. All rights reserved.

TABLE OF CONTENTS

1	INTRODUCTION	8
2	REFERENCE DOCUMENTS	8
3	RESOURCE REQUIREMENTS	9
3.1	EQUIPMENT REQUIREMENTS	9
4	GENERAL OVERVIEW OF SAS RX ELECTRICAL REQUIREMENTS	11
5	SETTING UP GRL-SAS4-RXA AUTOMATION SOFTWARE	14
5.1	DOWNLOAD GRL-SAS4-RXA SOFTWARE.....	14
5.2	LAUNCH AND SET UP GRL-SAS4-RXA SOFTWARE	14
5.3	PRE-CONFIGURE GRL-SAS4-RXA SOFTWARE BEFORE CALIBRATION/TESTING.....	17
5.3.1	Enter Test Session Information.....	17
5.3.2	Set Measurement Conditions.....	17
6	CALIBRATING USING GRL-SAS4-RXA SOFTWARE	19
6.1	SET UP SAS-4 RX CALIBRATION WITH AUTOMATION	19
6.1.1	Connect Equipment for Signal Amplitude and Jitter Calibration	19
6.1.2	Connect Equipment for Insertion Loss Calibration	21
7	COMPLIANCE TESTING USING GRL-SAS4-RXA SOFTWARE	22
7.1	OVERVIEW OF SAS-4 RX DUT COMPLIANCE TEST	23
7.2	SET UP SAS-4 RX DUT TEST WITH AUTOMATION	23
7.2.1	Connect Equipment for Jitter Tolerance Compliance Test	23
8	CONFIGURING AND SELECTING CALIBRATION AND COMPLIANCE TESTS USING GRL-SAS4-RXA SOFTWARE	25
8.1	SET UP CALIBRATION/COMPLIANCE TEST REQUIREMENTS	25
8.1.1	ISI Generator Tab	25
8.1.2	Presets Tab.....	25
8.1.3	Custom SJ Frequencies Tab	26
8.1.4	BER Automation Tab.....	26
8.1.5	Error Detector Settings Tab	27
8.1.6	Compliance Test Tab.....	27
8.1.7	Margin Test Tab	28
8.2	SELECT CALIBRATION AND COMPLIANCE TESTS	28
8.2.1	Select Calibration.....	28
8.2.1	Select DUT Compliance Tests	29
8.2.1	Select Margin Search Tests.....	30
8.3	CALIBRATION/COMPLIANCE TEST PARAMETERS CONFIGURATION PAGE	30
8.4	CONFIGURE CALIBRATION TARGET VALUES.....	31

9	RUNNING AUTOMATION CALIBRATION AND TESTS USING GRL-SAS4-RXA SOFTWARE	32
10	INTERPRETING GRL-SAS4-RXA TEST REPORT	33
10.1	UNDERSTAND TEST REPORT INFORMATION.....	33
10.1.1	Test Session Information.....	33
10.1.2	Test Summary Table.....	34
10.1.3	Test Results	34
10.2	DELETE TEST RESULTS.....	36
11	SAVING AND LOADING GRL-SAS4-RXA TEST SESSIONS	37
12	APPENDIX A: METHOD OF IMPLEMENTATION (MOI) FOR MANUAL SAS-4 RECEIVER MEASUREMENTS	38
12.1	SAS-4 RECEIVER CALIBRATION/TEST SETUP OVERVIEW	38
12.1.1	Test Points.....	39
12.2	RECOMMENDED SAS-4 RX CALIBRATION FLOW	40
12.3	SAS-4 RX CALIBRATION SETUP AND PROCEDURE.....	46
12.3.1	Physical Setups	46
12.3.2	Calibration Steps.....	48
12.4	SAS-4 RX COMPLIANCE TEST SETUP AND PROCEDURE.....	57
12.4.1	Physical Setup	57
12.4.2	Test for Rx Jitter Tolerance BER Compliance	58
13	APPENDIX B: CONNECTING KEYSIGHT OSCILLOSCOPE TO PC	59
14	APPENDIX C: CONNECTING TEKTRONIX OSCILLOSCOPE TO PC	61
15	APPENDIX D: CONNECTING TELEDYNE LECROY OSCILLOSCOPE TO PC	63
16	APPENDIX E: ARTEK CLE1000 SERIES INSTALLATION	64
16.1	ISI GENERATOR DRIVER INSTALLATION	64
16.2	CLE1000 USER INTERFACE (UI) INSTALLATION	66
17	APPENDIX F: SPL-4 TEST PATTERN REQUIREMENTS	67

List of Figures

Figure 1. Select and Launch GRL Platform Solutions Framework	14
Figure 2. Start SAS-4 Rx Test Application	15
Figure 3. See License Details.....	15
Figure 4. Check License for Installed Applications	15
Figure 5. Connect Instruments with GRL Platform Solutions Software.....	16
Figure 6. Session Info Page	17
Figure 7. Select SSC Conditions.....	18
Figure 8. Select SJ Frequencies.....	18
Figure 9. Signal Amplitude and Jitter Calibration Setup.....	20
Figure 10. Insertion Loss and Crosstalk Calibration Setup	21
Figure 11. Rx DUT Signal Tolerance Interconnection Example (From SAS-4 Draft Standard)	22
Figure 12. Compliance Test Setup for Receiver DUT Jitter Tolerance	23
Figure 13. Select ISI Source.....	25
Figure 14. Configure Reference Presets	26
Figure 15. Configure Custom SJ Frequencies	26
Figure 16. Configure BER Automation Test	26
Figure 17. Configure Error Detector CTLE.....	27
Figure 18. Configure BER Compliance	27
Figure 19. Configure Margin Test Parameters	28
Figure 20. Rx Calibration Selection	28
Figure 21. Rx Compliance Test Selection.....	29
Figure 22. Rx Margin Search Test Selection.....	30
Figure 23. Calibration/Compliance Test Parameters Configuration	30
Figure 24. Calibration Target Overwrite.....	31
Figure 25. Run Tests Page	32
Figure 26. Connection Diagram Pop-Up Window Example	32
Figure 27. Test Report Page	33
Figure 28. Test Session Information Example	33
Figure 29. Test Summary Table Example.....	34
Figure 30. Test Results Example.....	35
Figure 31. Test Report Deleted	36
Figure 32. Save/Load/Create Test Sessions	37
Figure 33. Stressed Rx Jitter Tolerance Test/Calibration Setup Block Diagram (From SAS- 4 Draft Standard)	38
Figure 34. SAS Compliance Test Point Specifications (From SAS-4 Draft Standard)	39
Figure 35. SAS-4 TxRx connection at 22.5 Gbit/s Compliance Test Points (From SAS-4 Draft Standard).....	39
Figure 36. Preset Calibration Specs (From SAS-4 Draft Standard).....	40

Figure 37. Rx Stressed Signal Calibration Specs (From SAS-4 Draft Standard).....	41
Figure 38. SJ Calibration Specs Without SSC (From SAS-4 Draft Standard).....	43
Figure 39. SJ Calibration Specs With SSC (From SAS-4 Draft Standard).....	44
Figure 40. ISI Calibration Specs (From SAS-4 Draft Standard)	45
Figure 41. Calibration Connection Setup at Test Point A	46
Figure 42. Calibration Connection Setup at Test Point A-IR/CR.....	47
Figure 43. Jitter Calibration Specs (From SAS-4 Draft Standard)	51
Figure 44. Compliance Test Setup for Receiver DUT Jitter Tolerance	58
Figure 45. Keysight Connection Expert.....	59
Figure 46. Oscilloscope's VISA Address.....	59
Figure 47. OpenChoice Instrument Manager In Start Menu.....	61
Figure 48. OpenChoice Instrument Manager Menu	62
Figure 49. Utilities Setup Menu.....	63
Figure 50. Oscilloscope's IP Address.....	63
Figure 51. Device Manager Window.....	64
Figure 52. Update Driver Window	65
Figure 53. Windows Security Window And Confirmation Window	65
Figure 54. Device Manager Window After Installation	65
Figure 55. CLE1000 UI	66

List of Tables

Table 1. Equipment Requirements – Systems.....	9
Table 2. Equipment Requirements – Accessories.....	10
Table 3. SAS-4 Draft Standard Requirements – Transmitted Signal for SAS-4 Rx DUT Testing.....	13
Table 4. Calibration Description.....	29
Table 5. Test Description.....	30
Table 6. Test Description	30
Table 7. Calibration/Compliance Test Parameters Description	31

1 Introduction

This MOI & User Guide provides information on using the GRL-SAS4-RXA 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-RXA software provides automation control for performing SAS-4 based 22.5 Gbit/s signalling 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-RXA software to calibrate and test the 22.5 Gbit/s based DUT for receiver jitter tolerance compliance. The GRL Platform Solutions software is run from the computer or oscilloscope to automate both the Anritsu BERT and real-time oscilloscope to calibrate the stressed signal and test receiver conformance. The BERT and appropriate equipment are used to generate the necessary test patterns with jitter and ISI components. The real-time oscilloscope is required for signal calibration while the BERT analyzer/error detector is used for error checking via loopback mode. To enable loopback mode for Bit Error Ratio (BER) compliance testing, the DUT will go into a forced loopback state, where the loopback test pattern of the DUT will be measured and should achieve a specified BER with a 95% confidence level.

The GRL-SAS4-RXA software performs test automation to the T10/BSR Specification using high performance real-time oscilloscopes and the Anritsu BERT, along with a compliant ISI generator as main test equipment.

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 Standard (sas4r10b, T10/BSR INCITS 534 Revision 10b)
- SPL-4 Standard (spl4r13, T10/BSR INCITS 538 Revision 13)

3 Resource Requirements

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

3.1 Equipment Requirements

TABLE 1. EQUIPMENT REQUIREMENTS – SYSTEMS

System	Qty.	Description/Key Specification Requirement
GRL-SAS4-RXA	1	GRL Platform Solutions SAS-4 (22.5 Gb/s) Receiver Compliance Calibration & Test Automation Software – www.grlps.com – with Node Locked License to single Oscilloscope/PC OS
High Performance Real-Time Oscilloscope ^[a]	1	≥ 33 GHz bandwidth with Windows 7+ OS (for 22.5 Gb/s) ^[b]
Anritsu MP1900A BERT ^[c]	1	MP1900A Signal Quality Analyzer, with following modules: • MU181000A/B 12.5 GHz Synthesizer • MU181500B Jitter Modulation Source • MU195020A 21G/32G bit/s SI Pulse Pattern Generator • MU195040A 21G/32G bit/s SI Error Detector • MU195050A Noise Generator
ISI Source Generator	1	Compliant ISI channel source for variable or fixed ISI output (Anritsu J1758A ISI Board recommended if using internal variable ISI function of MP1900A BERT)
Common Mode (CM) Signal Generator <Optional>	1	Anritsu MG36221A RF/Microwave Signal Generator (9 kHz to 70 GHz)
VISA (Virtual Instrument Software Architecture) API Software	1	VISA Software is required to be installed on the host PC running GRL-SAS4-RXA software. GRL Platform Solutions' software framework has been tested to work with all three versions of VISA available on the Market: 1. NI-VISA: http://www.ni.com/download/ni-visa-17.0/6646/en/ 2. Keysight IO Libraries: www.keysight.com (Search on IO Libraries) 3. Tektronix TekVISA: www.tek.com (Downloads > Software > TekVisa)
Computer	1	Laptop or desktop PC running Windows 7+ OS for automation control

^[a] Oscilloscope with scope software requirements as specified in vendor specific MOI's. For example, the Keysight Scope requires scope software such as Keysight InfiniiSim / EZ-JIT / Serial Data Analysis / Serial Data Equalization to be used for testing and signal processing which must be pre-installed on the Scope. Similarly, the Tektronix Scope shall be used with DPOJET (Jitter and Eye Analysis Tools) software and the Teledyne LeCroy Scope with SDAIII analysis tool for making measurements.

^[b] Oscilloscope with scope bandwidth as specified in vendor specific MOI's.

^[c] BERT SAS-4 patterns are distributed with GRL-SAS4-RXA software and are installed during installation process.

TABLE 2. EQUIPMENT REQUIREMENTS – ACCESSORIES

Accessory	Qty.	Description	Key Specification Requirement
SAS Receptacle Test Adapter	1	– 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
Connection Cables		– DUT connector type and test configuration dependent	
DC Block	2 pairs	Anritsu K261 Precision DC Block	Optional (if required in setup only) 10kHz to 40GHz bandwidth
Power Splitter	1	Anritsu K241C Precision Power Splitter	Optional (if using an external CM signal generator) 6dB, DC to 40 GHz

4 General Overview of SAS Rx Electrical Requirements

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

Below shows the Applied SJ requirements with both SSC and without SSC support.

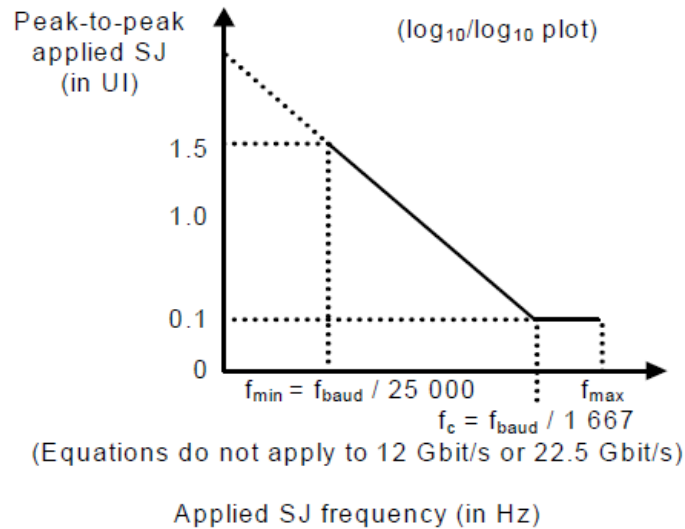


Figure 181 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s without SSC support

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

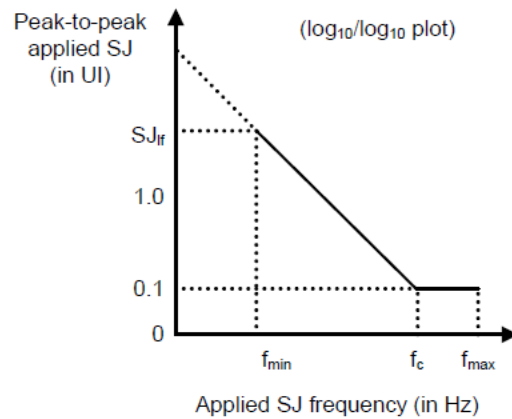


Figure 182 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

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

Table 84 — $f_{\min}$, f_c , $f_{\max}$, and SJ_{if} 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_{if}
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.

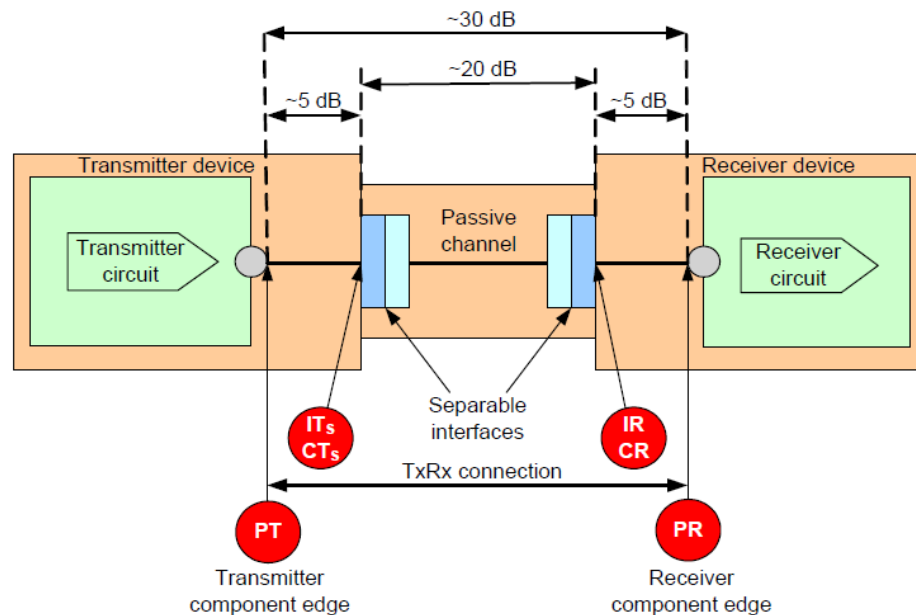


Figure 123 — Example TxRx connection for trained 22.5 Gbit/s

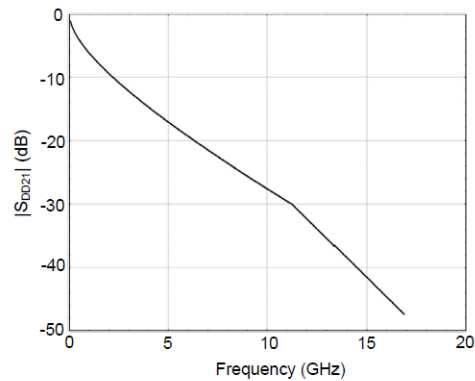


Figure 124 — Passive TxRx connection differential insertion loss for trained 22.5 Gbit/s

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 3. 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 characteristic	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 Gaussian 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 5.3.4) and the maximum value applies at IT (see 5.3.4) or CT (see 5.3.4). 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 13.3 ps at 22.5 Gbit/s.
^h 0.41 UI is 18.2 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 5.9 ps at 22.5 Gbit/s.
ⁿ 0.15 UI is 6.6 ps at 22.5 Gbit/s.
^o 0.165 UI is 7.3 ps at 22.5 Gbit/s.
^p 0.085 UI is 3.7 ps at 22.5 Gbit/s.
^q 0.10 UI is 4.4 ps at 22.5 Gbit/s.
^r 0.115 UI is 5.1 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 1.5 ps at 22.5 Gbit/s.
^u 0.28 UI is 12.4 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 contact GRL Platform Solutions for related user manuals.]

5 Setting Up GRL-SAS4-RXA Automation Software

This section provides the procedures to start up and pre-configure the GRL-SAS4-RXA automation software before running tests. It also helps users familiarize themselves with the basic operation of the software.

Note: The GRL-SAS4-RXA software installer will automatically create shortcuts in the Desktop and Start Menu when installing the software.

To start using the GRL-SAS4-RXA, follow the procedures in the following sections.

5.1 Download GRL-SAS4-RXA Software

Download and install the GRL-SAS4-RXA software on a PC or an oscilloscope (where GRL-SAS4-RXA is referred to as 'Controller PC' or 'Scope' respectively in this User Guide & MOI):

1. Install VISA (Virtual Instrument Software Architecture) on to the PC/Scope where GRL-SAS4-RXA is to be used (see Section 3.1).
2. Download the software ZIP file package from the GRL Platform Solutions support site.
3. The ZIP file contains:
 - **SAS4_AN_RxPatternFilesInstallation000000xxSetup.exe** – Run this on the Anritsu MP1900A BERT Signal Quality Analyzer to install the SAS-4 test pattern setup files.
 - **SAS4_AN_RxTestApplication000000xxSetup.exe** – Run this on the Controller PC or Scope to install the GRL-SAS4-RXA application.
 - **SAS4_AN_RxTestScopeSetupFilesInstallation000000xxSetup.exe** – Run this on the Scope to install the Scope setup files.

5.2 Launch and Set Up GRL-SAS4-RXA Software

1. Once the GRL-SAS4-RXA software is installed, open the **GRL** folder from the Windows Start menu. Click on **GRL – Automated Test Solutions** within the GRL folder to launch the GRL Platform Solutions software framework.

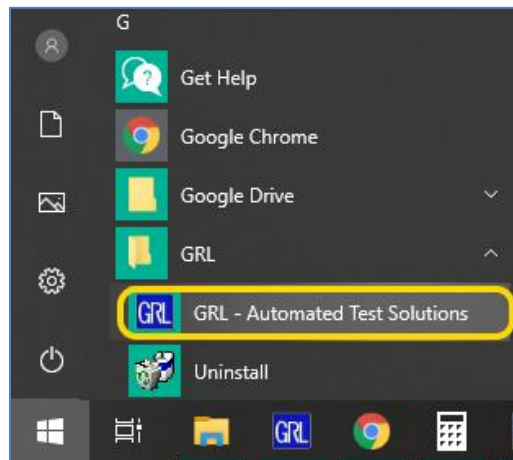


FIGURE 1. SELECT AND LAUNCH GRL PLATFORM SOLUTIONS FRAMEWORK

2. From the **Application → Rx Test Solution** drop-down menu, select **Anritsu 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.

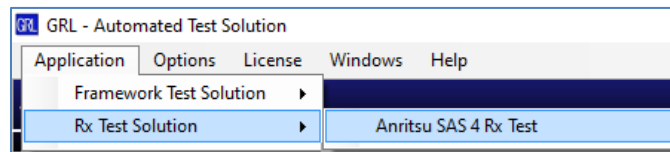


FIGURE 2. START SAS-4 RX TEST APPLICATION

3. To enable license, go to **License → License Info**.

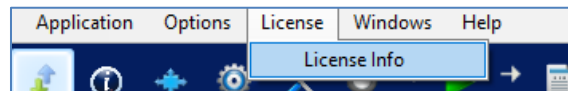


FIGURE 3. SEE LICENSE DETAILS

- a) Check the license status for the installed application.

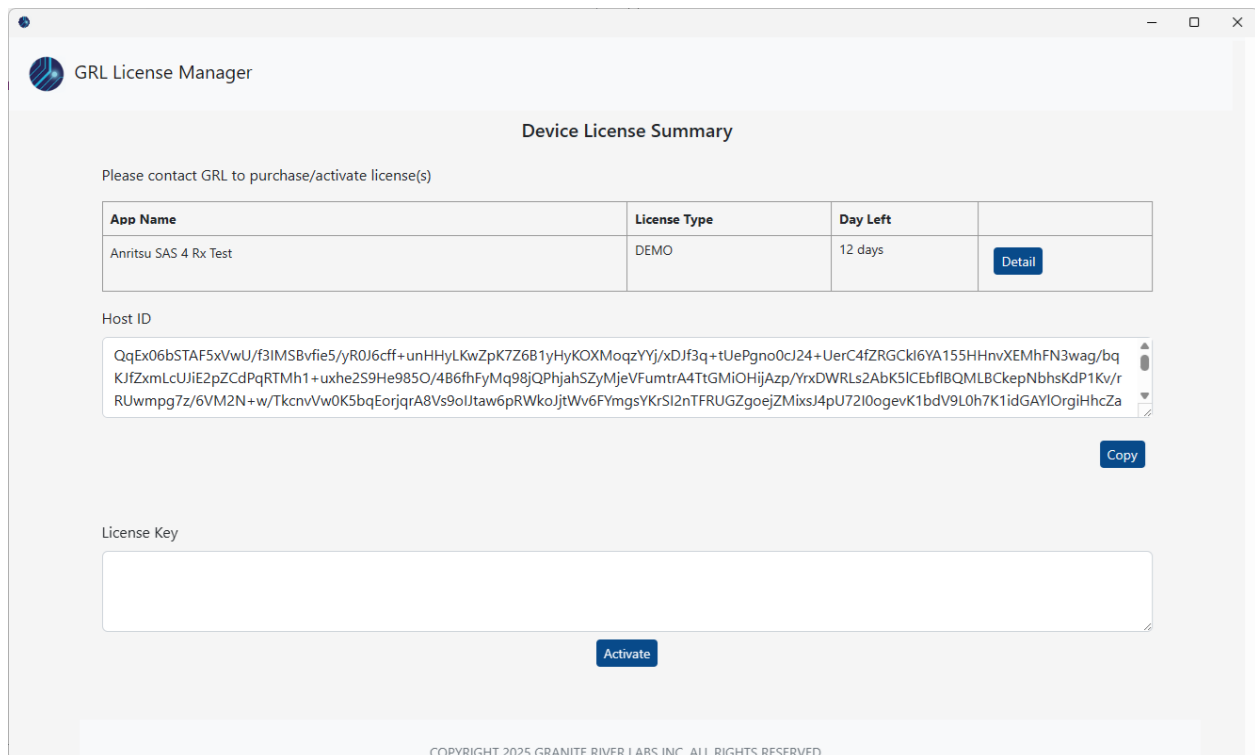


FIGURE 4. CHECK LICENSE FOR INSTALLED APPLICATIONS

- b) Activate a License:

- If you have an Activation Key, enter it in the **License Key** field provided and select **Activate**. The installed application is ready for use upon successful activation.
- If you do not have an Activation Key, close the above window to use a demo version of the application over a free 12-day trial period.

Note: Once the 12-day trial period ends, you will need to request an Activation Key to continue using the application on the same computer by contacting support@grlps.com.

4. Select the Equipment Setup icon  on the Anritsu SAS-4 Rx Test application menu.
 5. Connect the Anritsu MP1900A BERT via LAN to the GRL Platform Solutions automation control enabled Scope or PC. The BERT and MX183000A software can be connected using connection string formats similar to the following examples:
 - BERT: “TCPIP0::192.168.0.14::5001::SOCKET” or “192.168.0.14:5001”
 - MX183000A: “TCPIP0::192.168.0.14::5000::SOCKET” or “192.168.0.14:5000”
- Note the IP addresses listed above are only examples and should be changed according to the actual network connection being used.
6. If using an external ISI source (e.g., Artek CLE Series), connect the ISI source via USB to the GRL Platform Solutions automation control enabled Scope or PC. (Note: The USB driver software for the Artek ISI Generator must be installed on the Scope or PC. The driver is available from the ISI Generator manufacturer. Refer to Appendix of this MOI & User Guide for driver installation information.)
 7. If using an external Common Mode signal generator (e.g., Anritsu MG36221A), connect the signal generator via LAN to the GRL Platform Solutions automation control enabled Scope or PC.
 8. On the Scope or controller PC, obtain the network addresses for all the connected instruments from the device settings. Note these addresses as they will be used to connect the instruments to the GRL Platform Solutions automation software.
 9. On the Equipment Setup page of the Anritsu SAS-4 Rx Test application, type in the address of each connected instrument into the ‘Address’ field. (Note: If the GRL Platform Solutions software is installed on the **Tektronix Scope**, ensure the Scope is connected via GPIB and type in the GPIB network address, for example “GPIB8::1::INSTR”.) If the GRL Platform Solutions software is installed on the PC to control the Scope, type in the Scope IP address, for example “TCPIP0::192.168.0.110::inst0::INSTR”. Note to **omit** the Port number from the address.
 10. Select the “lightning” button  for each connected instrument.

The “lightning” button should turn green  once the GRL Platform Solutions software has successfully established connection with each instrument.

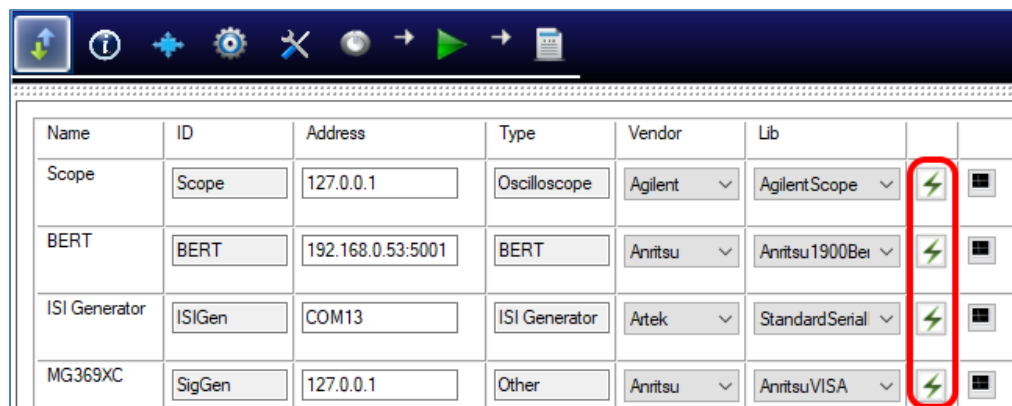


FIGURE 5. CONNECT INSTRUMENTS WITH GRL PLATFORM SOLUTIONS SOFTWARE

Note: Additional information for connecting supported vendor oscilloscopes (Keysight, Tektronix and Teledyne LeCroy) to the PC is provided in the Appendix of this document.

5.3 Pre-Configure GRL-SAS4-RXA 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-SAS4-RXA 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.

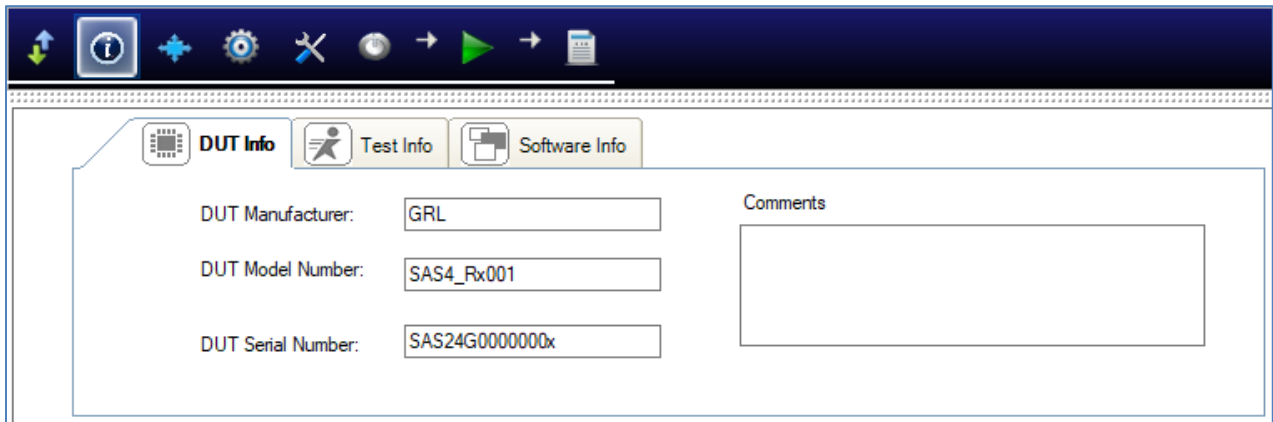


FIGURE 6. SESSION INFO PAGE

5.3.2 Set Measurement Conditions

Select  from the menu to access the **Conditions** page to set the conditions for calibration and compliance testing. The GRL-SAS4-RXA software will perform calibration and testing using selected Spread Spectrum Clock (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 SJ frequencies, then select the appropriate conditions for testing.
- a) **SSC** tab: Select to enable or disable SSC Capability as supported by the DUT for calibration or testing.

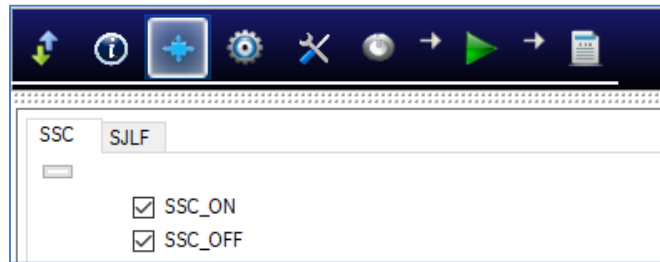


FIGURE 7. SELECT SSC CONDITIONS

- b) **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. These frequency values can be entered in the Setup Configuration  page under the *Custom SJ Frequencies* tab.

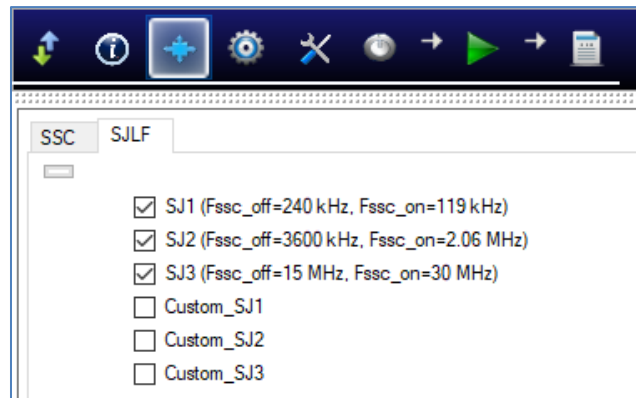


FIGURE 8. SELECT SJ FREQUENCIES

6 Calibrating Using GRL-SAS4-RXA Software

The GRL-SAS4-RXA test solution supports automated Rx calibration for SAS-4 Signal Amplitude, Jitter and Insertion Loss. To perform calibration, the GRL-SAS4-RXA 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 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. See Section 12.1 in Appendix for more details.

The Anritsu BERT and appropriate equipment are used in the setup to provide the necessary test patterns with jitter and ISI components during calibration. Optionally an external Common Mode signal generator can also be used for common mode noise measurements. A real-time high-performance Oscilloscope is required for signal calibration while a compliant ISI source is used to generate insertion loss.

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

The GRL-SAS4-RXA software provides a series of calibration that can be performed in the sequence as described in Section 12.2 in Appendix for the SAS-4 receiver. Also refer to Appendix for more details on SAS-4 calibration requirements.

When calibration is completed, the GRL-SAS4-RXA software will generate a test report detailing all results obtained from the calibration.

6.1 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.

6.1.1 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.

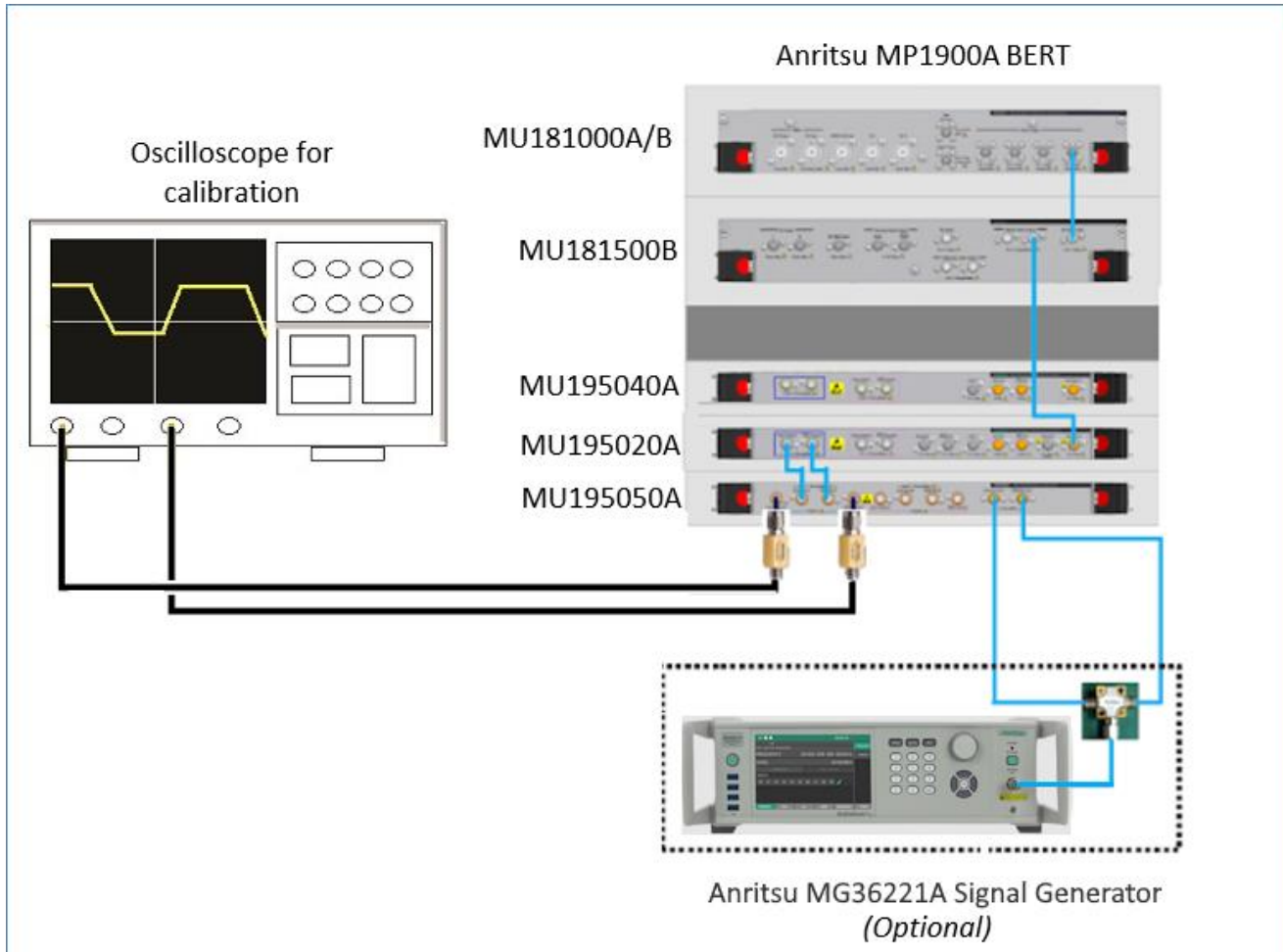


FIGURE 9. SIGNAL AMPLITUDE AND JITTER CALIBRATION SETUP

Connection Steps:

1. Connect the MU181000A/B clock output to the MU181500B Ext clock input.
2. Connect the MU181500B jittered clock output to the MU195020A Ext clock input.
3. Connect the MU195020A data outputs to the MU195050A data inputs.
4. Connect the MU195050A data outputs through DC blocks to Channels 1 and 3 on the oscilloscope.
5. Optionally if required, connect the MG36221A signal generator output to the power splitter tapped input port. Connect the power splitter output ports to the external auxiliary inputs of the MU195050A.

6.1.2 Connect Equipment for Insertion Loss Calibration

The connection diagram below shows the recommended equipment setup to calibrate for insertion loss (ISI) from TP-A to Test Point IR/CR. *Note the Anritsu J1758A ISI board is used in this setup.*

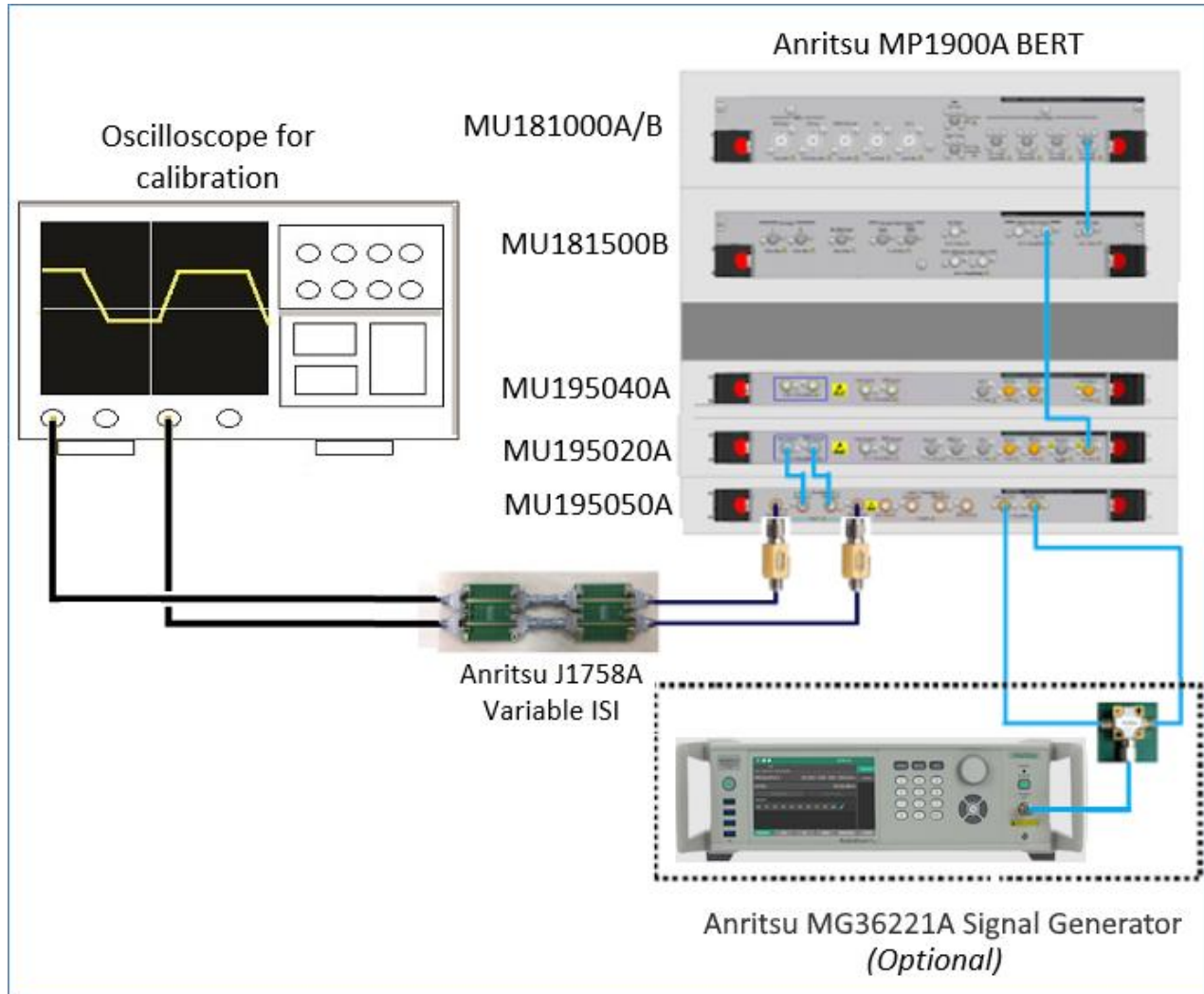


FIGURE 10. INSERTION LOSS AND CROSSTALK CALIBRATION SETUP

Connection Steps:

1. Using back the same BERT connections from the TP-A calibration, disconnect the MU195050A data outputs from the oscilloscope channels.
2. Connect the MU195050A data outputs to the J1758A ISI board.
3. Connect the J1758A ISI board to Channels 1 and 3 on the oscilloscope.
4. Optionally if required, connect the MG36221A signal generator output to the power splitter tapped input port. Connect the power splitter output ports to the external auxiliary inputs of the MU195050A.

7 Compliance Testing Using GRL-SAS4-RXA Software

The GRL-SAS4-RXA software supports automated Rx compliance testing with forced loopback mode for the receiver DUT.

Receiver compliance testing is performed for DUT jitter tolerance that requires using the BERT analyzer/error detector via loopback mode for error checking. The test will be run using the required components of mainly SSC control, minimum transmitter voltage amplitude, 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). To enable loopback mode for Bit Error Ratio (BER) compliance testing, the DUT will go into a forced loopback state, where the loopback test pattern of the DUT will be measured. During this process, the BERT will transmit PRBS31 signaling to the DUT and verify that the loopback pattern reports an allowable BER with a 95% confidence level (less than $1E-9$).

Refer to Figure 33 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.

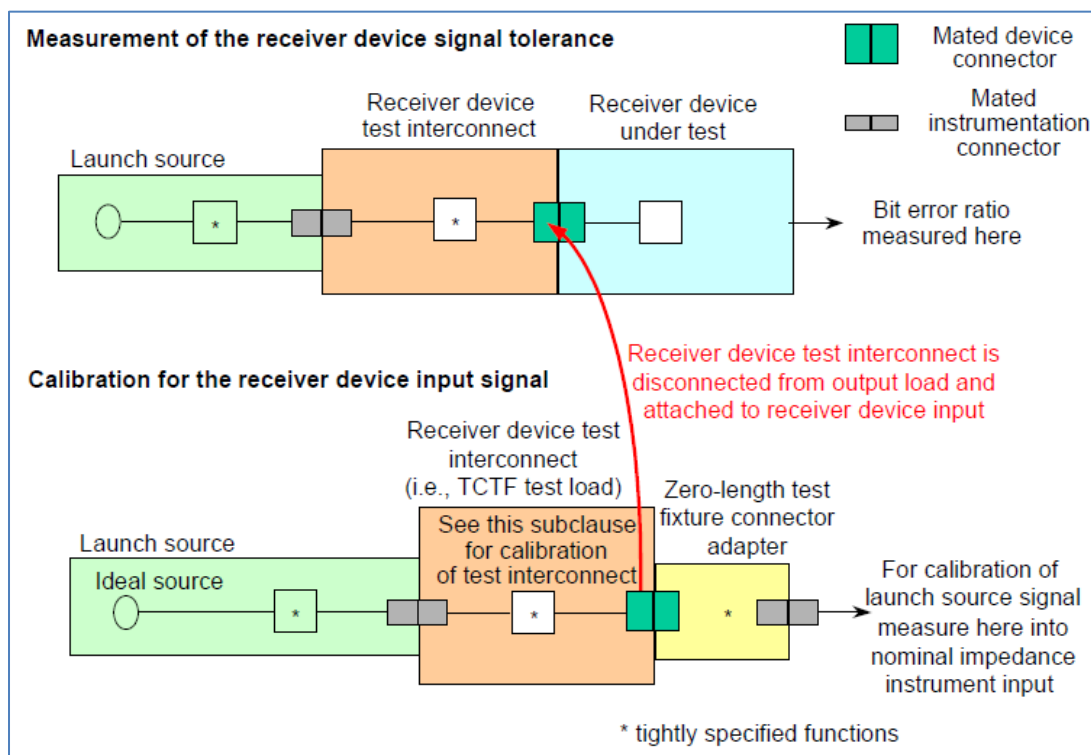


FIGURE 11. RX DUT SIGNAL TOLERANCE INTERCONNECTION EXAMPLE (FROM SAS-4 DRAFT STANDARD)

When testing is completed, the GRL-SAS4-RXA 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 BERT to transmit signal using the parameters in Table 3.
3. Set up the applied SJ (see Section 4).
4. Set up the BERT to transmit PRBS31 signaling to the Rx DUT and verify BER on the BERT 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 $1E-9$ 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.

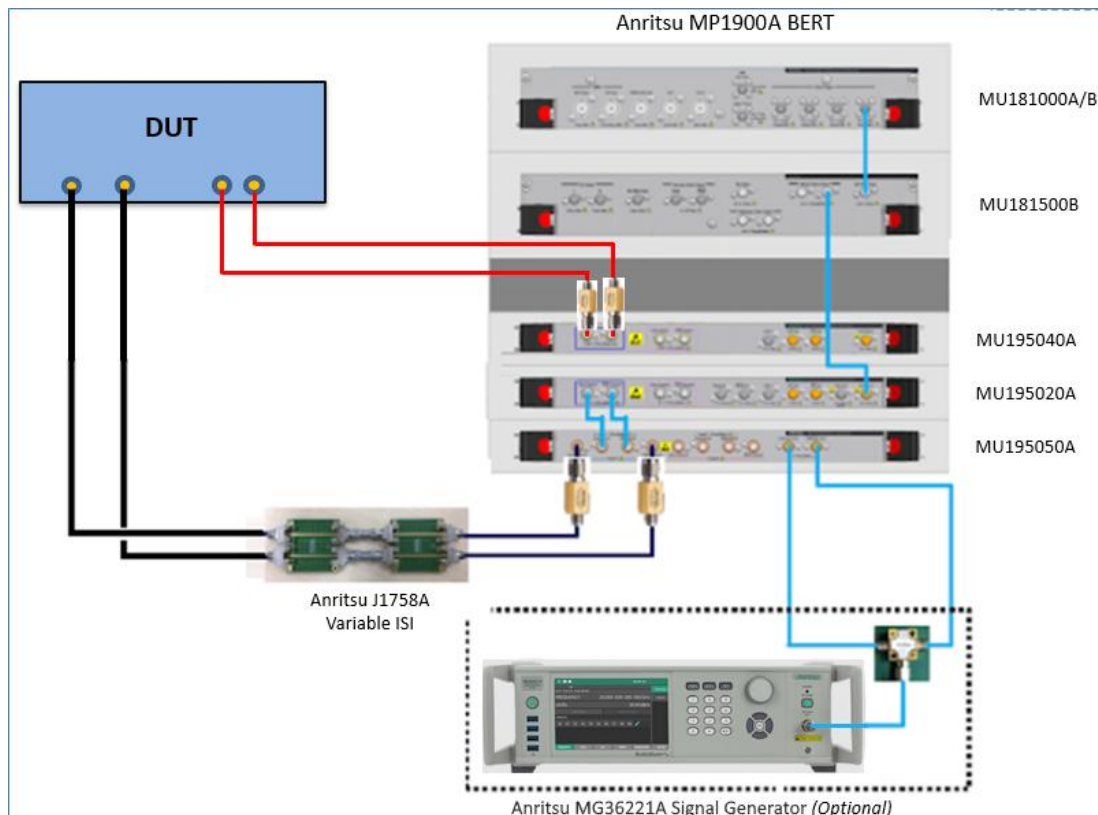


FIGURE 12. COMPLIANCE TEST SETUP FOR RECEIVER DUT JITTER TOLERANCE

Connection Steps:

1. Using back the same setup connections from the Insertion Loss calibration, disconnect the J1758A ISI board from the oscilloscope channels.
2. Connect the J1758A ISI board to the DUT data inputs.
3. Connect the DUT data outputs to the MU195040A data inputs through DC blocks for loopback error detection.

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

8.1 Set Up Calibration/Compliance Test Requirements

After setting up the physical equipment, select  from the Anritsu 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 the type of supported ISI generators to be used:

- “MP1900 ISI”: This is provided as an Option. The Anritsu BERT can be used in the setup for ISI automation if an external ISI channel is not available.
- “None”: This is the recommended method which is used to provide the required physical channel Insertion Loss for calibration and testing.
- “Artek”: This is provided as an Option. A compliant Artek CLE Model Series ISI channel can be used in the setup for ISI automation. *(Also see Appendix for more information on installing the Artek CLE Series.)*
- “ISI Board”: This is provided as an Option. A compliant ISI channel can be used in the setup for ISI automation.

The ISI source will be used for both calibration and compliance testing.

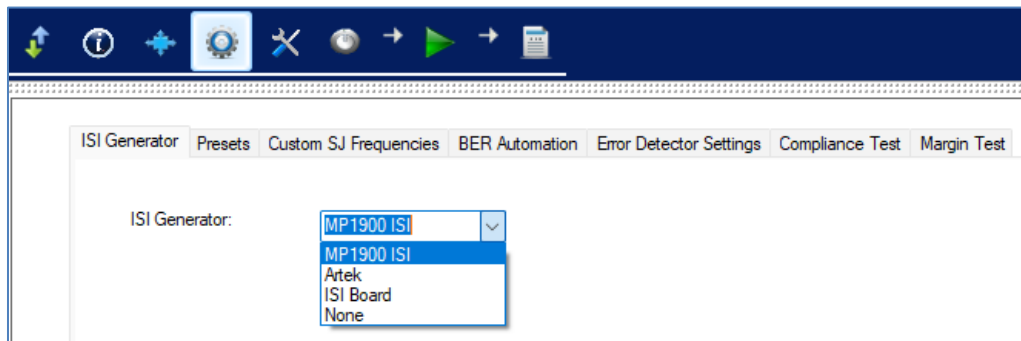


FIGURE 13. SELECT ISI SOURCE

8.1.2 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.

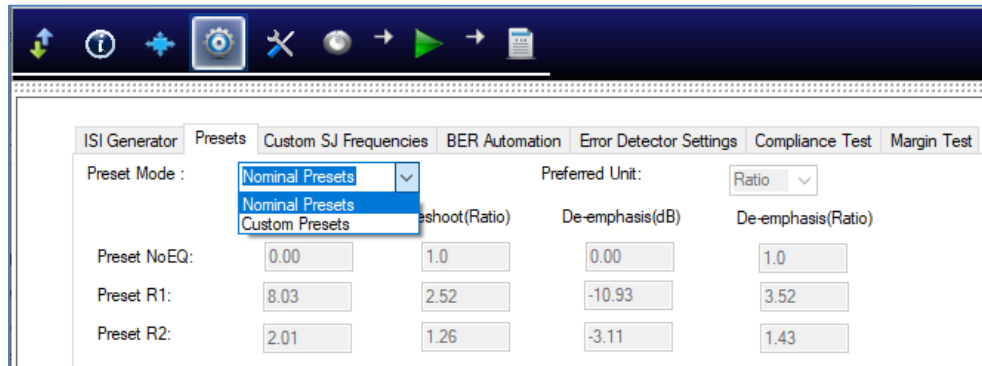


FIGURE 14. CONFIGURE REFERENCE PRESETS

8.1.3 Custom SJ Frequencies Tab

Enter the value for any Custom_SJ frequency selected from the Conditions  page. *This configuration will be used for SJ calibration and for testing.*

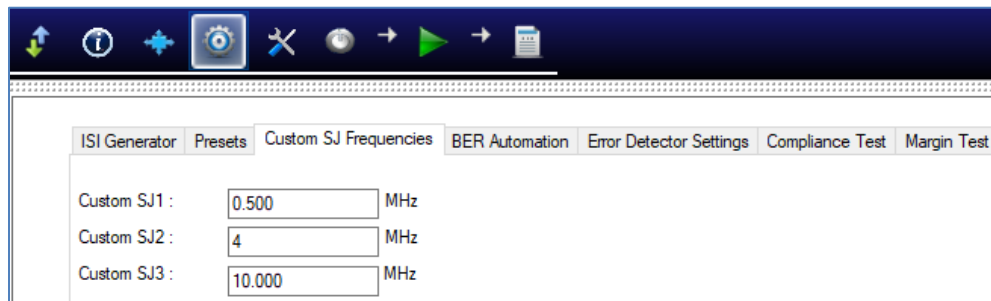


FIGURE 15. CONFIGURE CUSTOM SJ FREQUENCIES

8.1.4 BER Automation Tab

Select the test method to run the BER Rx automation tests for the DUT.

- **Forced Loopback** mode: This mode allows running BER Rx automation tests using software loopback method (if the DUT can be configured to loopback mode).
- **Manual** mode: This mode allows running BER Rx automation tests manually.

If “Forced Loopback” has been selected as the test method, then specify the test pattern type to be used for loopback in the **Loopback Pattern** field.

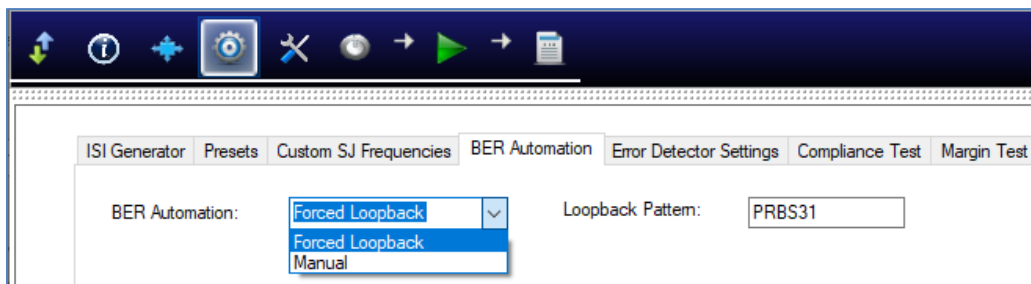


FIGURE 16. CONFIGURE BER AUTOMATION TEST

8.1.5 Error Detector Settings Tab

Select to enable (**ON**) or disable (**OFF**) the CTLE method to be used for error detection. If CTLE is enabled, select the appropriate gain setting index (**dB**) to be applied.

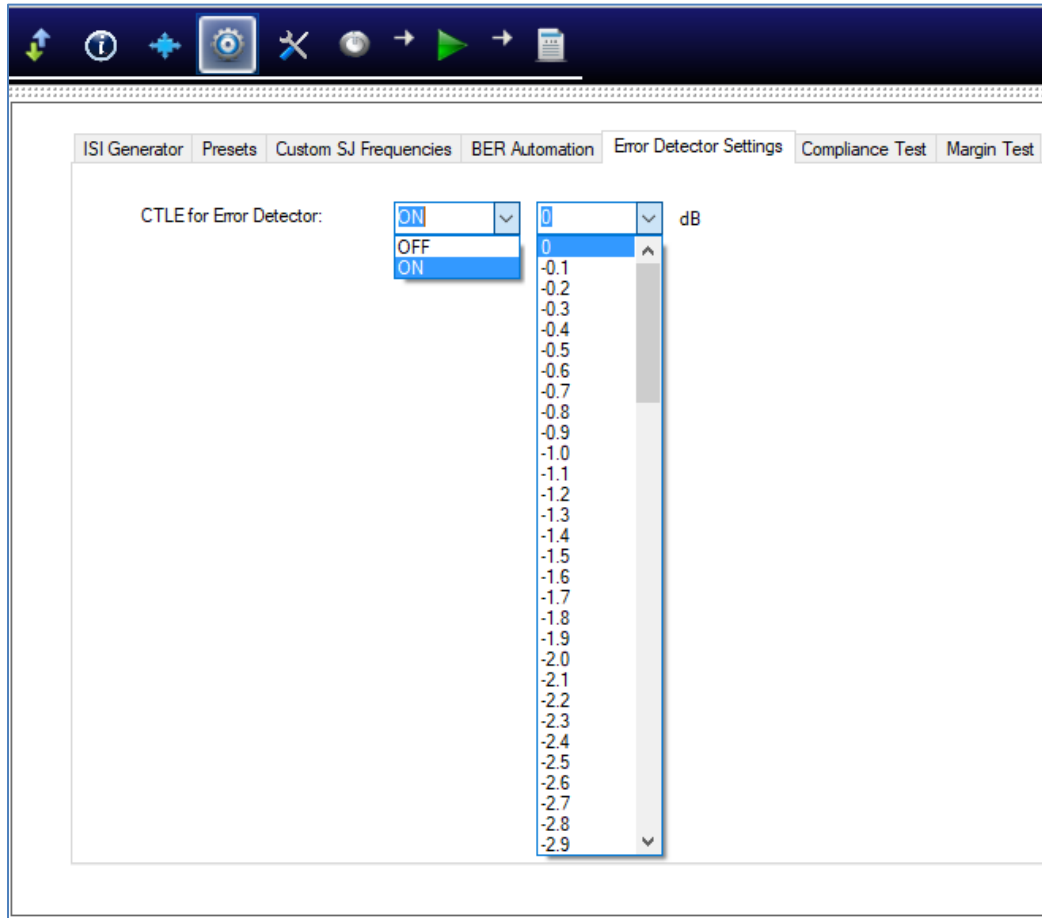


FIGURE 17. CONFIGURE ERROR DETECTOR CTLE

8.1.6 Compliance Test Tab

Specify the duration for the BER test run in the **Compliance Test Time** field and the maximum error limits in the **Maximum Error Count** field to be tested for compliance.

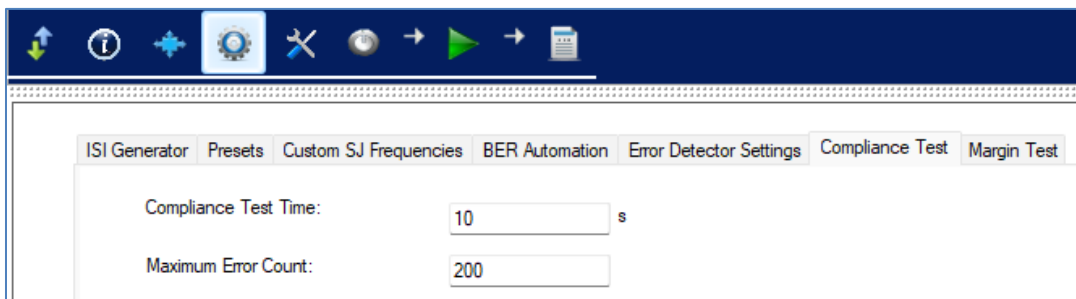


FIGURE 18. CONFIGURE BER COMPLIANCE

8.1.7 Margin Test Tab

Specify the test duration in the **Margin Test Time** field, maximum error limits in the **Maximum Error Count** field, **Step Size** and **Maximum Steps** to be applied during marginal testing.

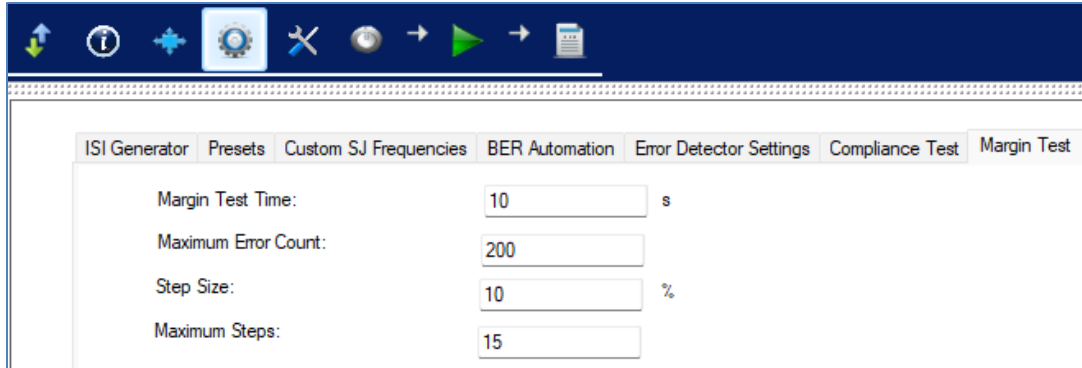


FIGURE 19. CONFIGURE MARGIN TEST PARAMETERS

8.2 Select Calibration and Compliance Tests

After setting up calibration/compliance test requirements, go to the test selection page which allows all available Rx calibration and DUT compliance tests to be selected. 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

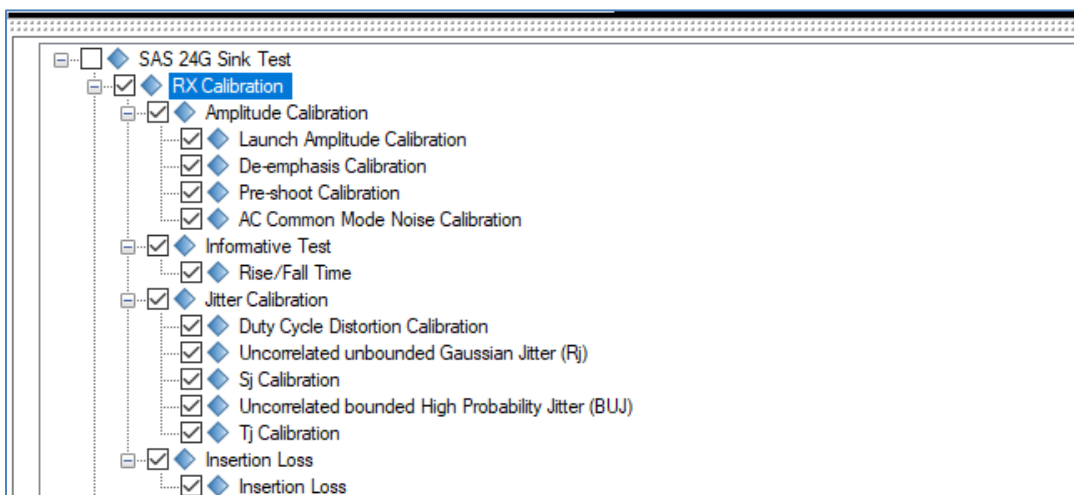


FIGURE 20. RX CALIBRATION SELECTION

TABLE 4. 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 BERT 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.
AC Common Mode Noise	Calibrate AC common mode (CM) noise using a PRBS15 pattern.
Rise/Fall Time (Informative)	Calibrate rise/fall time (20-80%) using a repeating 01b or 10b pattern. <i>This is performed for information purpose only.</i>
Duty Cycle Distortion	Calibrate duty cycle distortion using a repeating 01b or 10b pattern with Tx device equalization enabled and set to 'no_equalization'.
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.
Uncorrelated bounded high probability jitter (BUJ)	Calibrate uncorrelated bounded high probability jitter using the PRBS15 pattern and measured using deterministic jitter function.
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.

8.2.1 Select DUT Compliance Tests

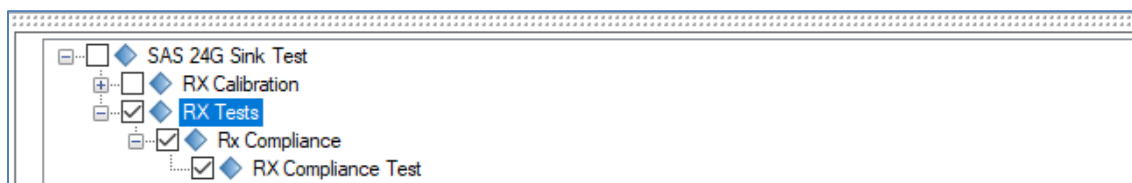


FIGURE 21. RX COMPLIANCE TEST SELECTION

TABLE 5. 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.

8.2.1 Select Margin Search Tests

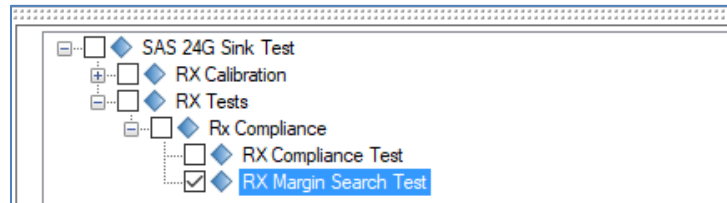


FIGURE 22. RX MARGIN SEARCH TEST SELECTION

TABLE 6. TEST DESCRIPTION

Test	Description
Rx Margin Search	This is an optional test for conducting a margin search for jitter tolerance.

8.3 Calibration/Compliance Test Parameters Configuration Page

Select  from the menu to access the Configurations page.

Set any of the available parameters required for measurement as described below. To return all parameters to their default values, select the 'Set Default' button.

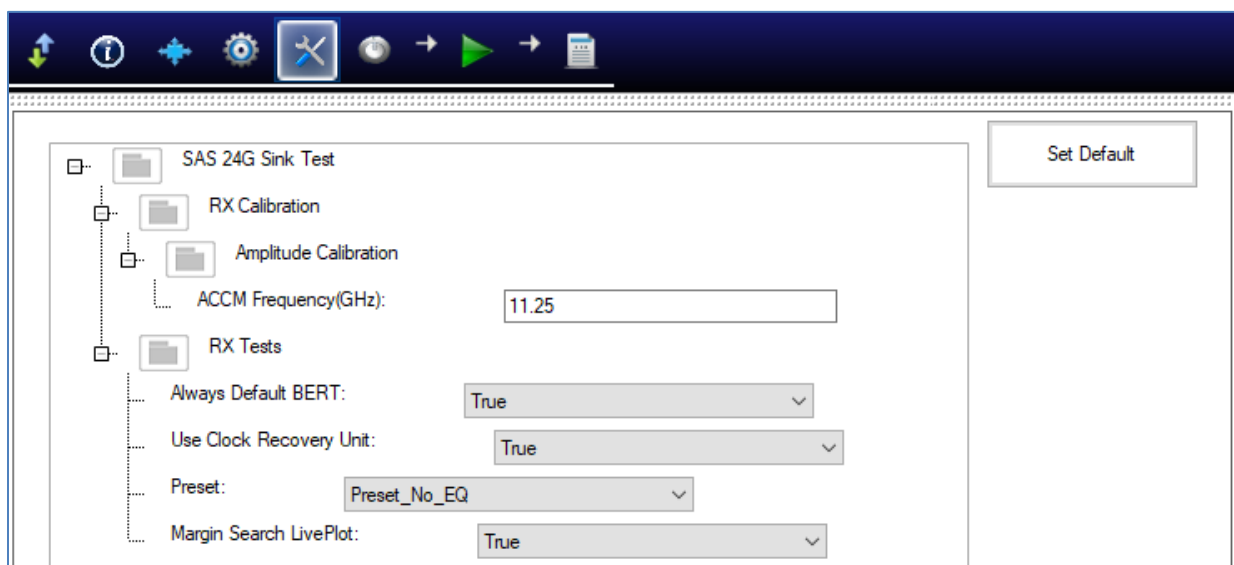


FIGURE 23. CALIBRATION/COMPLIANCE TEST PARAMETERS CONFIGURATION

TABLE 7. CALIBRATION/COMPLIANCE TEST PARAMETERS DESCRIPTION

Parameter	Description
ACCM Frequency	Set the ACCM frequency in GHz to be used for AC Common Mode Noise calibration.
Always Default BERT	Select 'True' to always enable or 'False' to always disable default configuration on the BERT during testing.
Use Clock Recovery Unit	If "Forced Loopback" has been selected from the BER Automation tab in the Setup Configuration page (refer Section 8.1.4), then select 'True' to enable the Clock Recovery method. To disable select 'False'.
Preset	Select the Reference Preset to be used for testing if 'Custom Presets' has been selected as the Preset Mode in the Setup Configuration page (refer Section 8.1.4).
Margin Search Live Plot	Select 'True' to enable a graphical margin plot that updates as the margin test is performed to indicate progress of the test results. To disable select 'False'.

8.4 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.

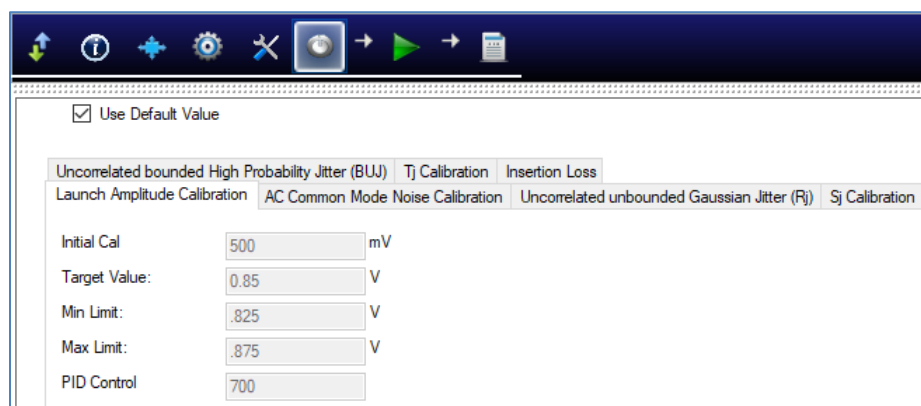


FIGURE 24. CALIBRATION TARGET OVERWRITE

9 Running Automation Calibration and Tests Using GRL-SAS4-RXA 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-SAS4-RXA 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.

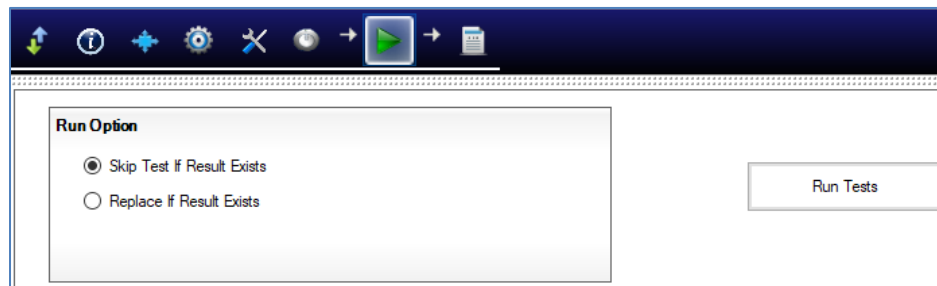


FIGURE 25. RUN TESTS PAGE

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.

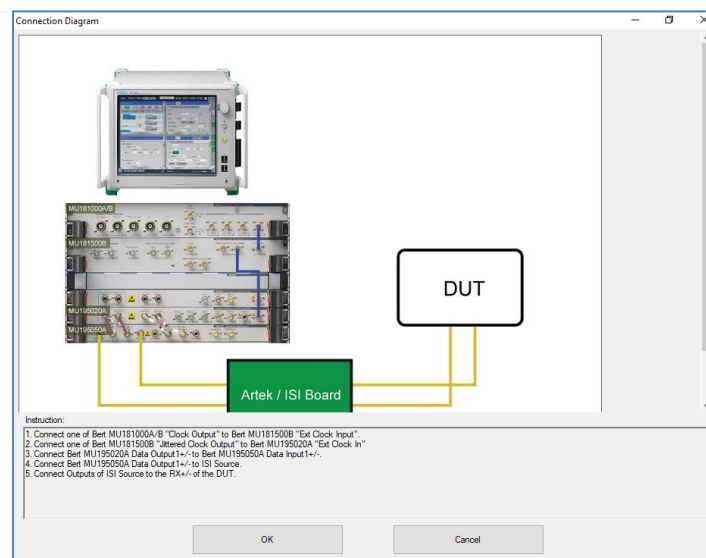


FIGURE 26. CONNECTION DIAGRAM POP-UP WINDOW EXAMPLE

10 Interpreting GRL-SAS4-RXA Test Report

When all calibration and test runs have completed from the previous section, the GRL-SAS4-RXA 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.

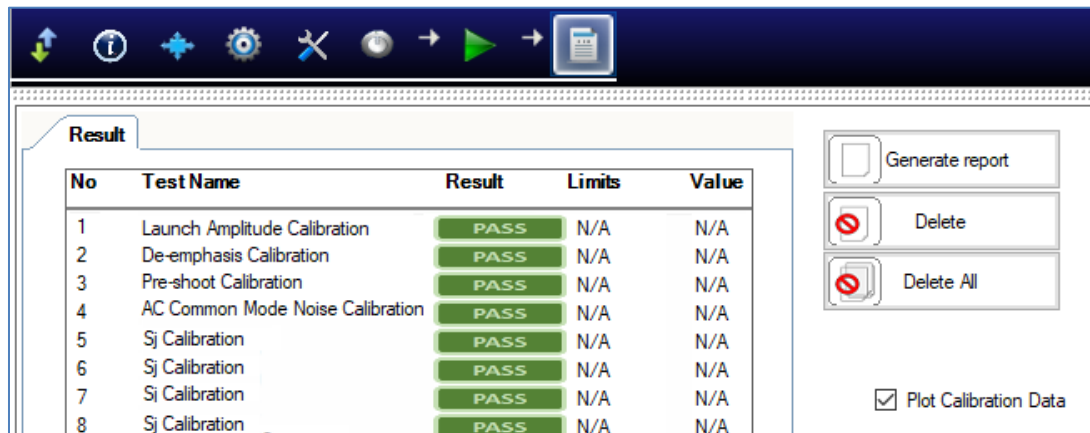


FIGURE 27. TEST REPORT PAGE

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.

Anritsu SAS 4 Rx Test Report	
DUT Information	
DUT Manufacturer	: GRL
DUT Model Number	: SAS4_Rx001
DUT Serial Number	: SAS24G0000000x
DUT Comments	:
Test Information	
Test Lab	: Granite River Labs
Test Operator	: David
Test Date	: 9 July 2020
Software Version	
Software Revision	: 0.0.65

FIGURE 28. 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	SSC	SJLF
1	Launch Amplitude Calibration	N/A	N/A	Pass		
2	De-emphasis Calibration	N/A	N/A	Pass		
3	Pre-shoot Calibration	N/A	N/A	Pass		
4	AC Common Mode Noise Calibration	N/A	N/A	Pass		
5	Rise/Fall Time	N/A	0.4129 UI	InfoOnly		
6	Duty Cycle Calibration	N/A	N/A	Pass		
7	Uncorrelated unbounded Gaussian Jitter (Rj)	N/A	N/A	Pass	SSC_ON	N/A
8	Uncorrelated unbounded Gaussian Jitter (Rj)	N/A	N/A	Pass	SSC_OFF	N/A
9	Sj Calibration	N/A	N/A	Pass	SSC_ON	SJ1
10	Sj Calibration	N/A	N/A	Pass	SSC_ON	SJ2
11	Sj Calibration	N/A	N/A	Pass	SSC_ON	SJ3
12	Sj Calibration	N/A	N/A	Pass	SSC_OFF	SJ1
13	Sj Calibration	N/A	N/A	Pass	SSC_OFF	SJ2
14	Sj Calibration	N/A	N/A	Pass	SSC_OFF	SJ3
15	Uncorrelated bounded high probability jitter (BUJ)	N/A	N/A	Pass	SSC_ON	SJ3
16	Uncorrelated bounded high probability jitter (BUJ)	N/A	N/A	Pass	SSC_OFF	SJ3
17	Tj Calibration	N/A	N/A	Pass	SSC_ON	SJ3
18	Tj Calibration	N/A	N/A	Pass	SSC_OFF	SJ3
19	Insertion Loss	N/A	N/A	Pass		
20	RX Compliance Test	N/A	N/A	Fail	SSC_ON	SJ1
21	RX Compliance Test	N/A	N/A	Pass	SSC_ON	SJ2
22	RX Compliance Test	N/A	N/A	Fail	SSC_ON	SJ3

FIGURE 29. 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.

19. Insertion Loss	
Pass/Fail Stats	: Pass
Cal Parameter	: InsertionLoss_
InsertionLossCal Settings	: 16.2500
Measured Value	: 17.8906 dB
Test completed time	: 04 April 2019 23:46:25 PM

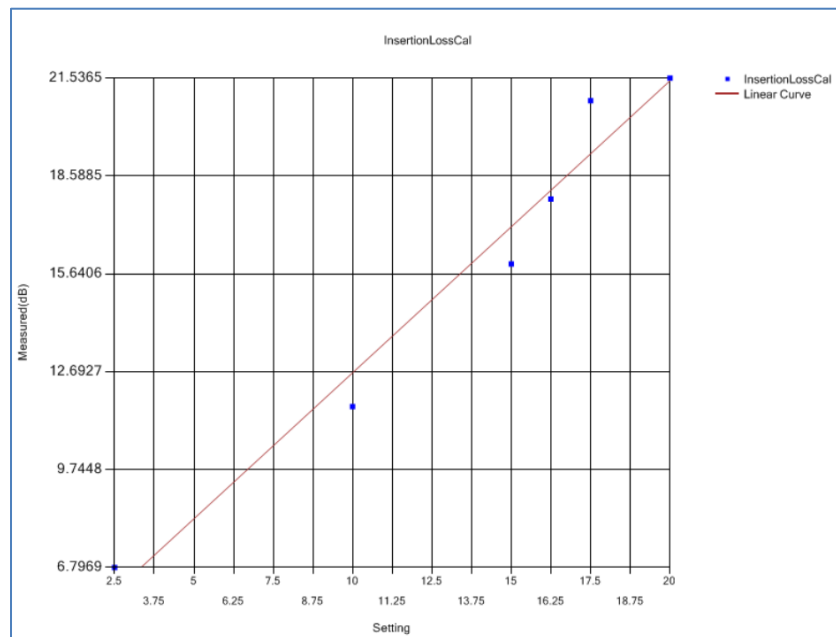


FIGURE 30. TEST RESULTS EXAMPLE

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.

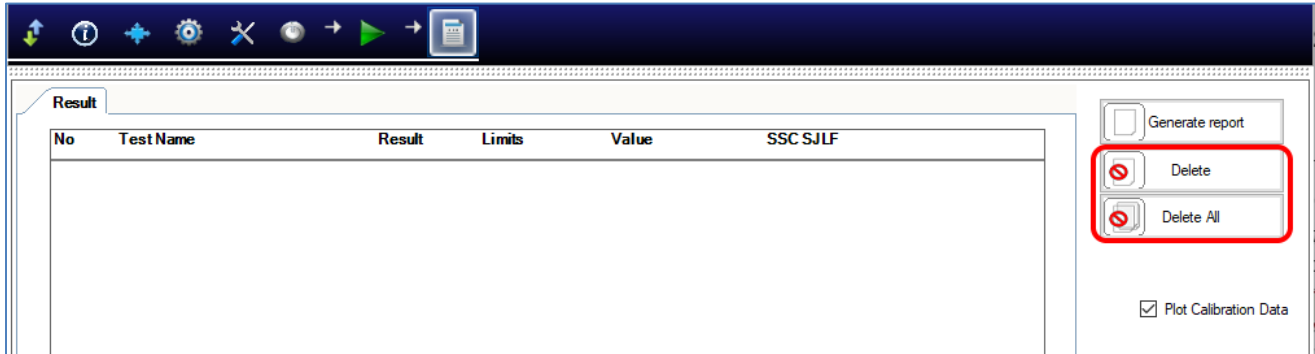


FIGURE 31. TEST REPORT DELETED

11 Saving and Loading GRL-SAS4-RXA Test Sessions

The usage model for the GRL-SAS4-RXA software is that the test results are created and maintained as a 'Live Session' in the application. This allows the user to quit the application and return later to continue where the user left off.

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

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

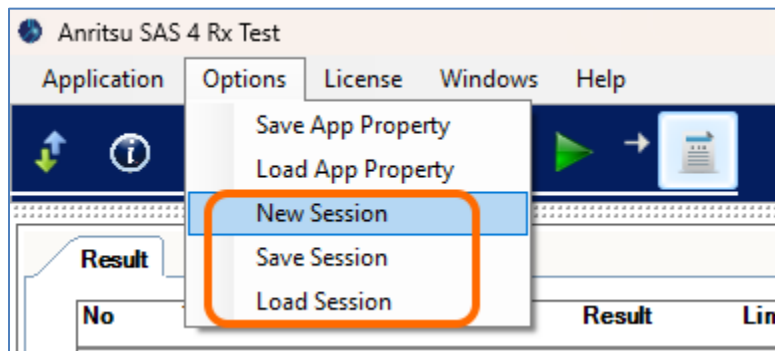


FIGURE 32. SAVE/LOAD/CREATE TEST SESSIONS

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 22.5G Rx calibration and compliance test methodology based on the SAS-4 Draft Standard. *Note the Keysight Scope will be used in the following MOI.*

12.1 SAS-4 Receiver Calibration/Test Setup Overview

This MOI describes how to measure presets, ISI, stresses 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 BERT and appropriate equipment are used in the setup to provide the necessary test patterns with jitter and ISI components. Optionally an external Common Mode signal generator can also be used for common mode noise measurements. A real-time Oscilloscope is required for signal calibration (in this case the Keysight Scope will be used) while a compliant variable ISI source is used to generate insertion loss. The analyzer/error detector on the BERT will be used for error checking via loopback mode.

The calibration will be run using the required components of mainly SSC control, minimum transmitter voltage amplitude, 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 when entering loopback state to determine BER compliance.

For BER compliance testing, the BERT will transmit PRBS31 signaling to the Rx DUT and verify that the loopback pattern reports a BER that is less than $1E-9$ (for 22.5 Gbit/s) with a 95% confidence level.

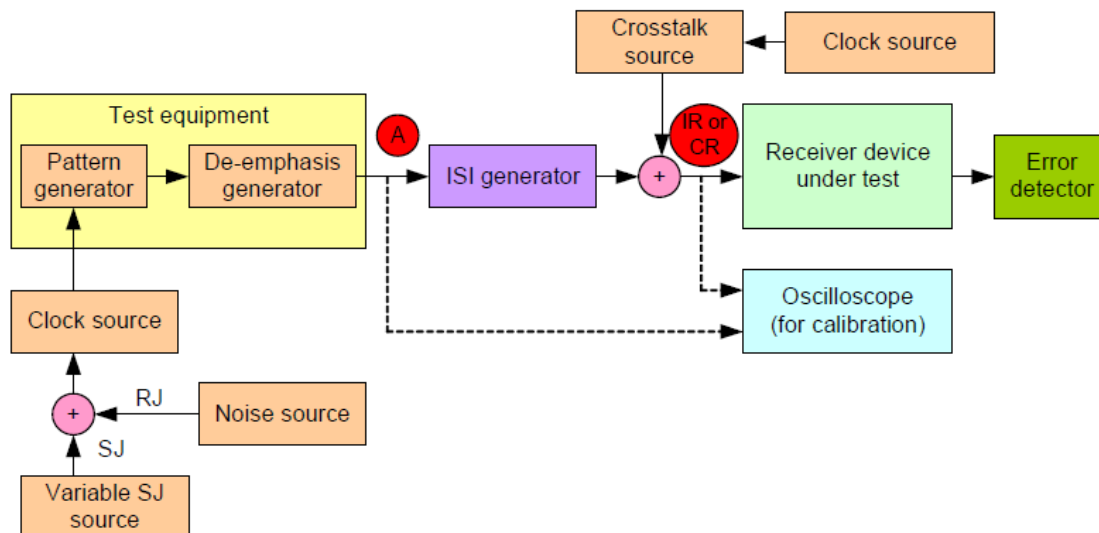


FIGURE 33. STRESSED RX JITTER TOLERANCE TEST/CALIBRATION SETUP BLOCK DIAGRAM (FROM SAS-4 DRAFT STANDARD)

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

Below shows a clearer view of the SAS-4 compliance test points for trained 22.5 Gbit/s.

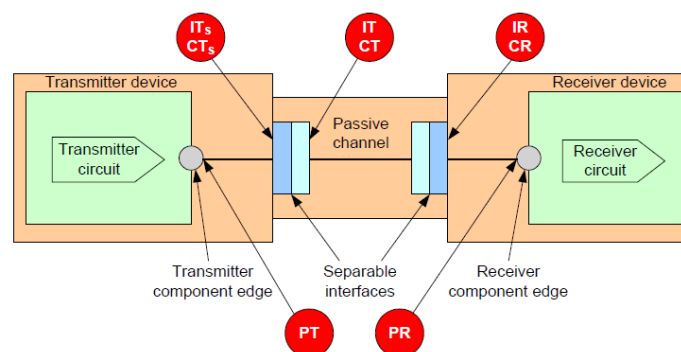


FIGURE 35. SAS-4 TxRx CONNECTION AT 22.5 GBIT/S COMPLIANCE TEST POINTS (FROM SAS-4 DRAFT STANDARD)

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

b) 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 characteristic	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 Gaussian 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 5.3.4) and the maximum value applies at IT (see 5.3.4) or CT (see 5.3.4). 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 13.3 ps at 22.5 Gbit/s.
^h 0.41 UI is 18.2 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 5.9 ps at 22.5 Gbit/s.
ⁿ 0.15 UI is 6.6 ps at 22.5 Gbit/s.
^o 0.165 UI is 7.3 ps at 22.5 Gbit/s.
^p 0.085 UI is 3.7 ps at 22.5 Gbit/s.
^q 0.10 UI is 4.4 ps at 22.5 Gbit/s.
^r 0.115 UI is 5.1 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 1.5 ps at 22.5 Gbit/s.
^u 0.28 UI is 12.4 ps at 22.5 Gbit/s.

FIGURE 37. RX STRESSED SIGNAL CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

Note: The PRBS15 pattern stated below applies for the main data signal.

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 Common Mode Noise

Measure common mode noise using a PRBS15 pattern to the target maximum value of 12 mVrms or lower, as specified above.

iii) 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.

iv) 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.

v) 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.

vi) 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.

c) Calibrate Applied SJ

Calibrate SJ (over 3 frequencies) for jitter tolerance using the 1100 pattern, with or/and without SSC support, as defined below.

For the case without SSC support:

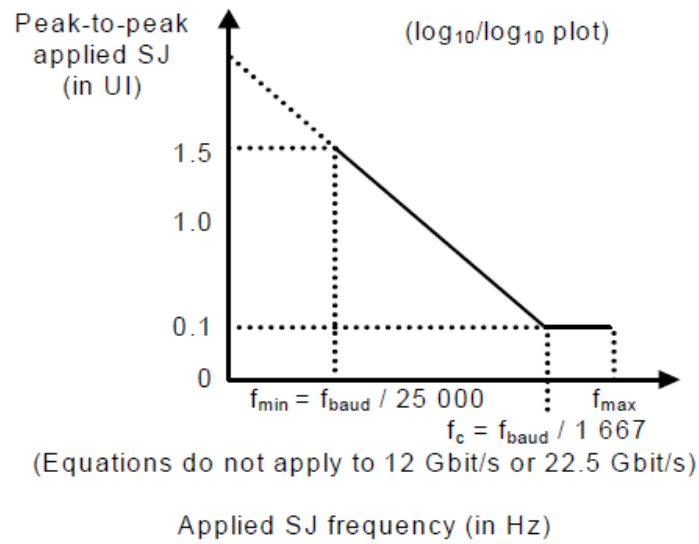


Figure 181 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s without SSC support

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

For the case with SSC support:

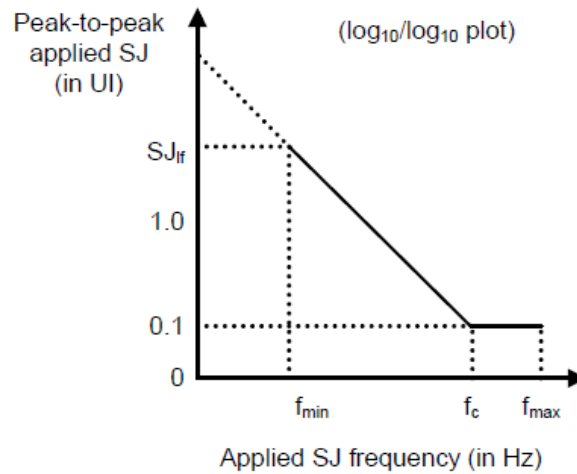


Figure 182 — Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, 12 Gbit/s, and 22.5 Gbit/s with SSC support

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 39. 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.

d) 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:

$$\begin{aligned} IL(f) &= -0.043 + 5.031\sqrt{f} + 1.171f && \text{for } 0.05 \text{ GHz} \leq f \leq 11.25 \text{ GHz; and} \\ IL(f) &= -4.752 + 3.089f && \text{for } 11.25 \text{ GHz} < f \leq 16.875 \text{ GHz (i.e., } (3/4) f_{\text{baud}}) \end{aligned}$$

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.

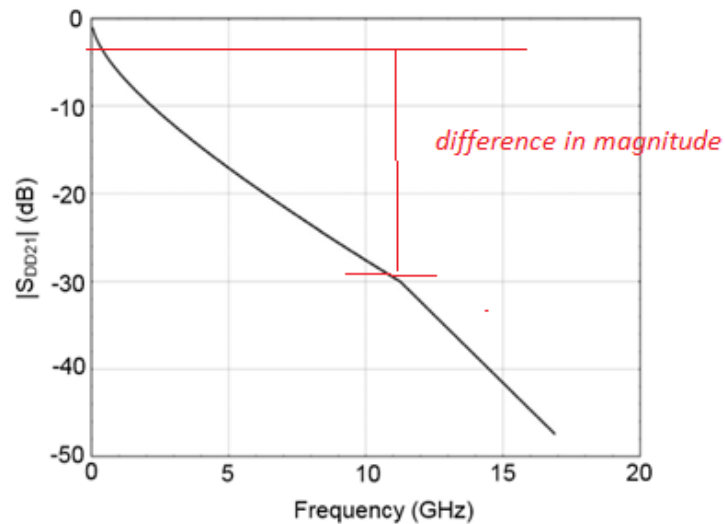


Figure 124 — Passive TxRx connection differential insertion loss for trained 22.5 Gbit/s

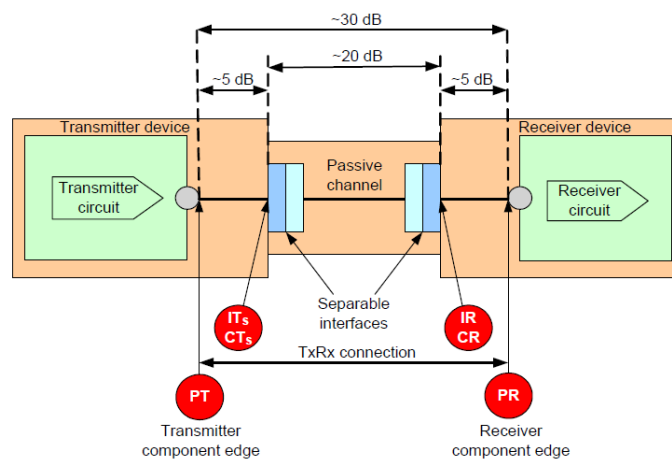


Figure 123 — Example TxRx connection for trained 22.5 Gbit/s

FIGURE 40. ISI CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

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 Scope test instrument for SAS-4 (22.5 Gbit/s) compliance.

Refer to Figure 33 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.

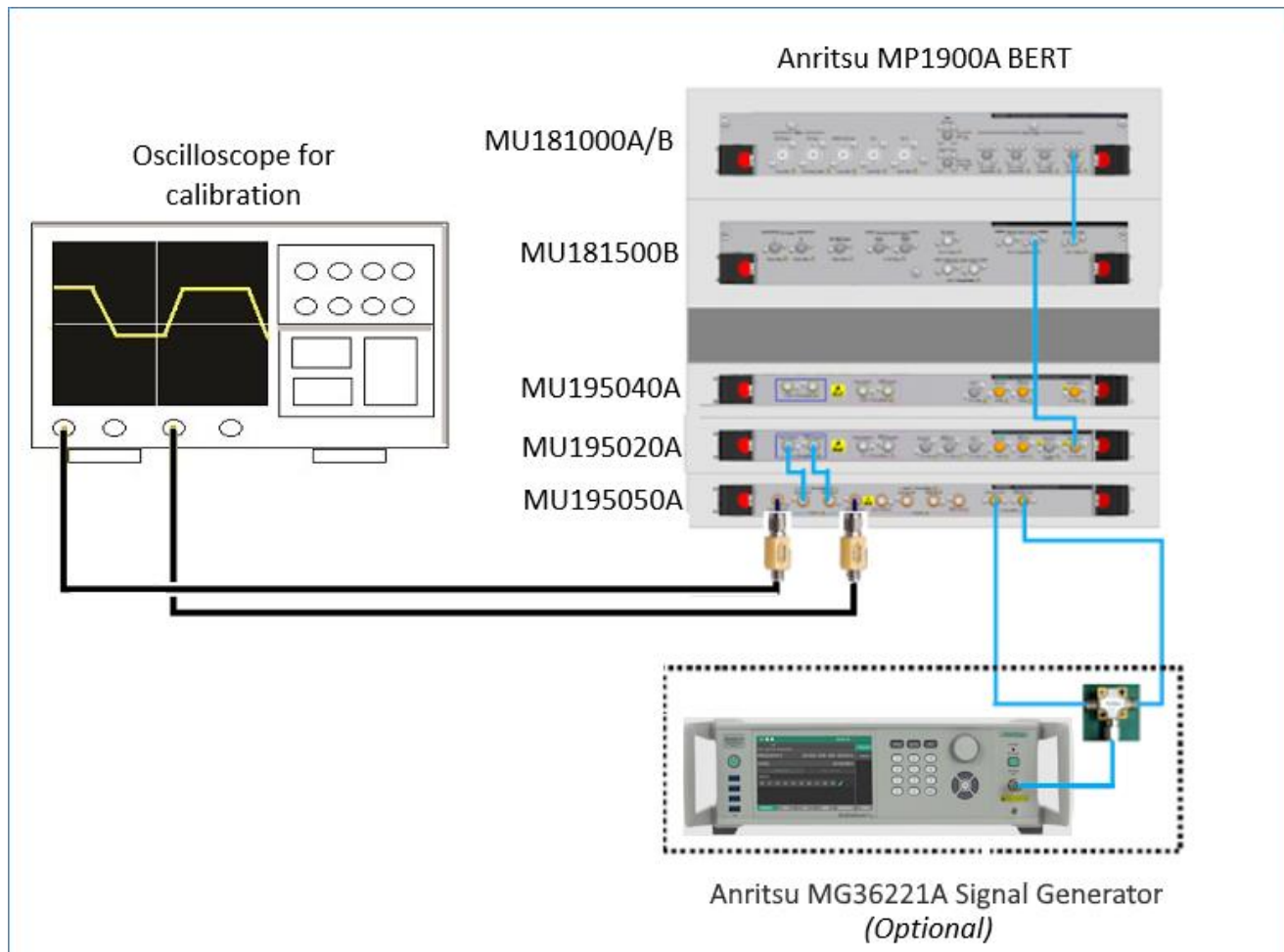


FIGURE 41. CALIBRATION CONNECTION SETUP AT TEST POINT A

Connection Steps:

1. Connect the MU181000A/B clock output to the MU181500B Ext clock input.
2. Connect the MU181500B jittered clock output to the MU195020A Ext clock input.
3. Connect the MU195020A data outputs to the MU195050A data inputs.
4. Connect the MU195050A data outputs through DC blocks to Channels 1 and 3 on the oscilloscope.

5. Optionally if required, connect the MG36221A signal generator output to the power splitter tapped input port. Connect the power splitter output ports to the external auxiliary inputs of the MU195050A.

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) from TP-A to Test Point IR/CR. *Note the Anritsu J1758A ISI board is used in this setup.*

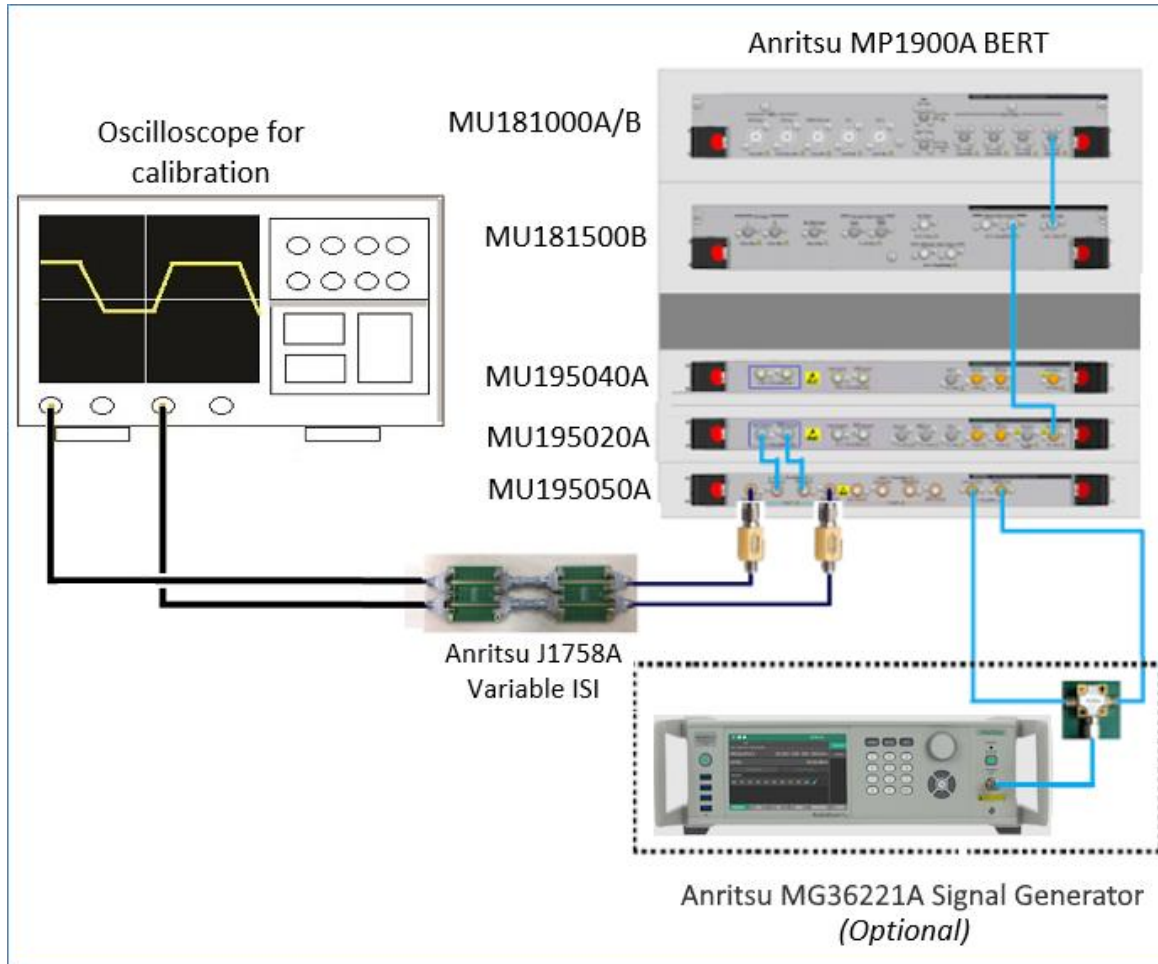


FIGURE 42. CALIBRATION CONNECTION SETUP AT TEST POINT A-IR/CR

Connection Steps:

1. Using back the same BERT connections from the TP-A calibration, disconnect the MU195050A data outputs from the oscilloscope channels.
2. Connect the MU195050A data outputs to the J1758A ISI board.
3. Connect the J1758A ISI board to Channels 1 and 3 on the oscilloscope.
4. Optionally if required, connect the MG36221A signal generator output to the power splitter tapped input port. Connect the power splitter output ports to the external auxiliary inputs of the MU195050A.

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 BERT 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:

$$\begin{aligned}\text{De-emphasis} &= 20\log[\text{Non-transition/Transition}] \\ &= 20\log[254\text{mV}/824\text{mV}] \\ &= 20\log[0.31] \\ &= -10.2\text{dB (which conforms to the target of -10.9dB +/- 2dB)}\end{aligned}$$

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:

$$\begin{aligned}\text{Pre-shoot} &= 20\log[\text{Pre-shoot/Non-transition}] \\ &= 20\log[622\text{mV}/254\text{mV}] \\ &= 20\log[2.44] \\ &= 7.8\text{dB (which conforms to the target of 8dB +/- 2dB)}\end{aligned}$$

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

7. Save the Reference Preset 1 settings to a file e.g., 'SAS4_reference1' on the BERT.
8. Repeat the above calibration and saving procedure for Reference Presets 2 and 3.

12.3.2.2 Step 2: 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 37 of Section 12.2.

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

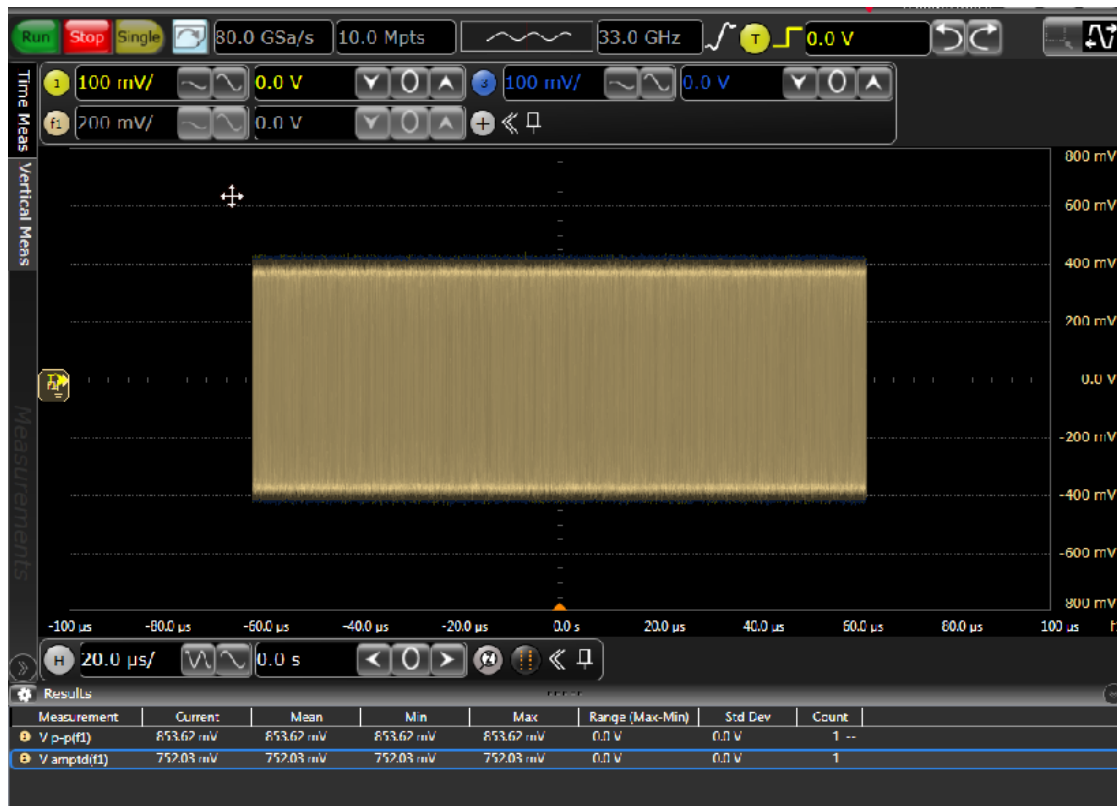
- Set Amplitude to 850mV.
- Turn ON data output.

12.3.2.2.1 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 BERT data outputs are adjusted to reach the target value.

For this case, a repeating 7Eh pattern on the BERT 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 BERT amplitude to achieve the minimum target of 850mVp-p or above.



12.3.2.2.2 Measure Common Mode Noise

This measurement verifies that the common mode noise meets the target of 12mVrms or below. The Anritsu MG36221A signal generator is used in this setup to output Common Mode (CM) components.

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

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step.
2. Set the MG36221A signal generator noise frequency to 11.25GHz.
3. Set up the Scope as follows:
 - Data channels: ON
 - Vertical scale: 10mV
 - Horizontal scale: 100ns
 - Function 1: CH1+CH3 and ON
4. Measure Vrms of Function 1, while adjusting the CM signal generator to achieve the maximum target of 12mVrms or below. Record the measured value.



Jitter Calibration Parameters (for SSC and non-SSC Support)

Table 43 — JTF parameters

Characteristic	Without SSC support					With SSC support				
	1.5 Gbit/s	3 Gbit/s	6 Gbit/s	12 Gbit/s	22.5 Gbit/s	1.5 Gbit/s	3 Gbit/s	6 Gbit/s	12 Gbit/s	22.5 Gbit/s
JTF -3 dB point (kHz) ^{a b}	900 ± 500	1 800 ± 500	3 600 ± 500	3 600 ± 500	3 600 ± 500	1 300 ± 500	1 838 ± 500	2 600 ± 500	2 600 ± 500	2 600 ± 500
JTF slope (dB/decade)	20	20	20	20	20	40	40	40	40	40
Attenuation at 30 kHz ± 1 % (dB) ^c	N/A	N/A	N/A	N/A	N/A	61.5 ± 1.5	67.5 ± 1.5	73.5 ± 1.5	73.5 ± 1.5	73.5 ± 1.5
Maximum Peaking (dB)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Key: N/A = not applicable f_{baud} = Units of Hz (i.e., 1.5 GHz for 1.5 Gbit/s, 3.0 GHz for 3 Gbit/s, and 6.0 GHz for 6 Gbit/s). 12 Gbit/s and 22.5 Gbit/s use the value for 6 Gbit/s. ^a For untrained or trained without SSC support this value equals f_{baud}/1 667 ± 500 kHz for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. 12 Gbit/s and 22.5 Gbit/s use the value for 6 Gbit/s. ^b For untrained or trained with SSC support this value equals (f_{baud})^{0.5} x 33.566 x Hz^{0.5} ± 500 kHz for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. 12 Gbit/s and 22.5 Gbit/s use the value for 6 Gbit/s. ^c For untrained or trained with SSC support this value equals 73.5 dB + [20 x log₁₀(f_{baud} / 6 x 10⁹ Hz)] dB ± 1.5 dB for 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s. 12 Gbit/s and 22.5 Gbit/s use the value for 6 Gbit/s.										

Uncorrelated unbounded Gaussian 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 5.3.4) and the maximum value applies at IT (see 5.3.4) or CT (see 5.3.4). 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 13.3 ps at 22.5 Gbit/s.
- ^h 0.41 UI is 18.2 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 5.9 ps at 22.5 Gbit/s.
- ⁿ 0.15 UI is 6.6 ps at 22.5 Gbit/s.
- ^o 0.165 UI is 7.3 ps at 22.5 Gbit/s.
- ^p 0.085 UI is 3.7 ps at 22.5 Gbit/s.
- ^q 0.10 UI is 4.4 ps at 22.5 Gbit/s.
- ^r 0.115 UI is 5.1 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 1.5 ps at 22.5 Gbit/s.
- ^u 0.28 UI is 12.4 ps at 22.5 Gbit/s.

FIGURE 43. JITTER CALIBRATION SPECS (FROM SAS-4 DRAFT STANDARD)

12.3.2.2.3 Measure Uncorrelated Unbounded Gaussian Jitter (T_{UUGJ})

This measurement verifies that the T_{UUGJ} meets the target of 10mUI rms @ BER-15 as referenced in Figure 43 for both SSC and non-SSC support on the DUT.

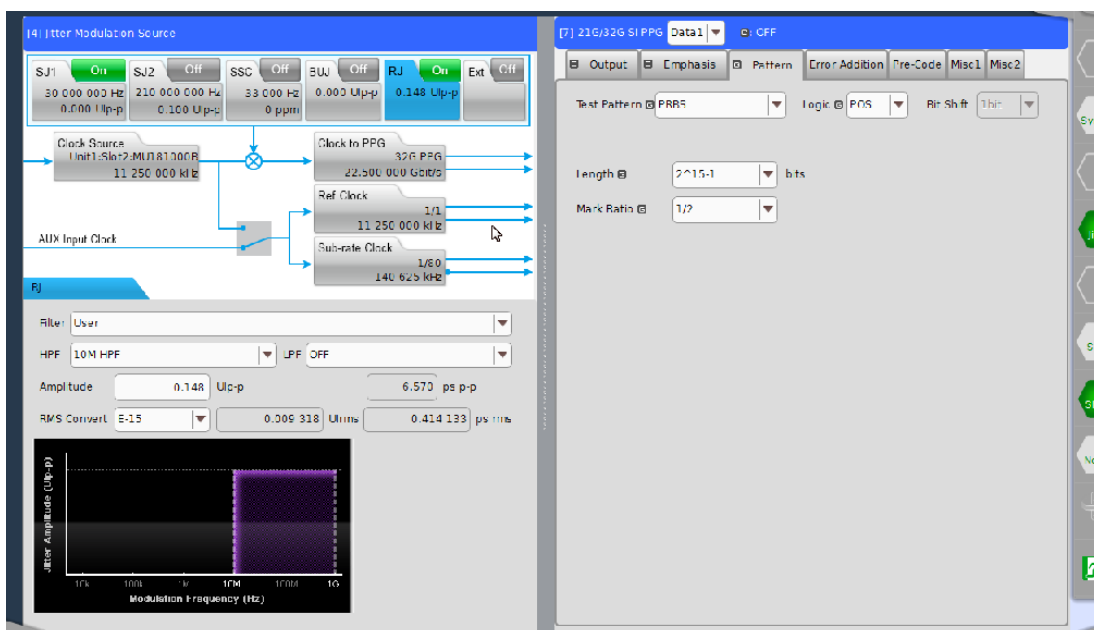
The PRBS15 pattern on the BERT is used for this measurement.

a) **If the DUT does not support SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Random Jitter (RJ) to 0.15UIp-p.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type I, Second Order, JTF Loop Bandwidth = 3.6MHz, Damping Factor = 50.0
3. Measure RJ (rms) on the Scope, while adjusting the BERT amplitude to achieve the specified target of 10mUI rms @ BER-15.
4. Perform additional measurements to plot the “RJ Setting vs Measured RJ” linear curve.

b) **If the DUT supports SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Random Jitter (RJ) to 0.15UIp-p.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type II, Second Order, JTF Loop Bandwidth = 2.6MHz, Damping Factor = 0.86
3. Measure RJ (rms) on the Scope, while adjusting the BERT amplitude to achieve the specified target of 10mUI rms @ BER-15.
4. Perform additional measurements to plot the “RJ Setting vs Measured RJ” linear curve.



12.3.2.2.4 Measure Uncorrelated Bounded High Probability Jitter (T_{UBHPJ})

This measurement verifies that the T_{UBHPJ} meets the target of 0.085 to 0.115 UI as referenced in Figure 43 for both SSC and non-SSC support on the DUT.

The PRBS15 pattern on the BERT is used for this measurement.

a) **If the DUT does not support SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set the SJ2 frequency to 100MHz and amplitude to 0.1UIp-p.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type I, Second Order, JTF Loop Bandwidth = 3.6MHz, Damping Factor = 50.0
3. Measure BUJ on the Scope.
4. Adjust the BERT SJ2 amplitude to achieve the specified target of 0.085 to 0.115 UI.

b) **If the DUT supports SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set the SJ2 frequency to 100MHz and amplitude to 0.1UIp-p.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type II, Second Order, JTF Loop Bandwidth = 2.6MHz, Damping Factor = 0.86
3. Measure BUJ on the Scope.
4. Adjust the BERT SJ2 amplitude to achieve the specified target of 0.085 to 0.115 UI.

12.3.2.2.5 Measure Duty Cycle Distortion (T_{DCD})

This measurement verifies that the T_{DCD} meets the target of 0.035 UI as referenced in Figure 43 for both SSC and non-SSC support on the DUT. For this measurement, Tx device equalization needs to be enabled and set to 'no_equalization' while a repeating 10b pattern is used on the BERT.

a) **If the DUT does not support SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Half Period Jitter to 0.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type I, Second Order, JTF Loop Bandwidth = 3.6MHz, Damping Factor = 50.0
3. Measure T_{DCD} on the Scope (increment by 1 until reaches 10).
4. Adjust the BERT Half Period Jitter to achieve the specified target of 0.035 UI.
5. Plot a curve of Half Period Jitter Setting vs DCD Measured Value on the Scope.

b) **If the DUT supports SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set Half Period Jitter to 0.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure the PLL Model as follows:
 - Type II, Second Order, JTF Loop Bandwidth = 2.6MHz, Damping Factor = 0.86
3. Measure T_DCD on the Scope (increment by 1 until reaches 10).
4. Adjust the BERT Half Period Jitter to achieve the specified target of 0.035 UI.
5. Plot a curve of Half Period Jitter Setting vs DCD Measured Value on the Scope.

12.3.2.2.6 Measure Total Jitter (T_{TJ})

This measurement verifies that the T_{TJ} meets the target of 0.28-0.29 UI as referenced in Figure 43 for both SSC and non-SSC support on the DUT.

The PRBS15 pattern on the BERT is used for this measurement.

a) **If the DUT does not support SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set RJ and SJ2 (T_{UBHPJ}) to the calibrated values from previous calibration steps.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure as follows:
 - PLL Model: Type I, Second Order, JTF Loop Bandwidth = 3.6MHz, Damping Factor = 50.0
 - BER: 1e-15
3. Measure T_{TJ} on the Scope, while increasing T_{DCD} to achieve the specified target of 0.28-0.29 UI. If T_{TJ} is too high, reduce SJ2 (BUJ). If SJ2 is needed more than < 0.085 UI, then reduce RJ up to 0.135 UI.

b) **If the DUT supports SSC**, follow these steps:

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step. Set RJ and SJ2 (T_{UBHPJ}) to the calibrated values from previous calibration steps.
2. Enable the EZJIT Plus Jitter Analysis function on the Scope and configure as follows:
 - PLL Model: Type II, Second Order, JTF Loop Bandwidth = 2.6MHz, Damping Factor = 0.86
 - BER: 1e-15
3. Measure T_{TJ} on the Scope, while increasing T_{DCD} to achieve the specified target of 0.28-0.29 UI. If T_{TJ} is too high, reduce SJ2 (BUJ). If SJ2 is needed more than < 0.085 UI, then reduce RJ up to 0.135 UI.



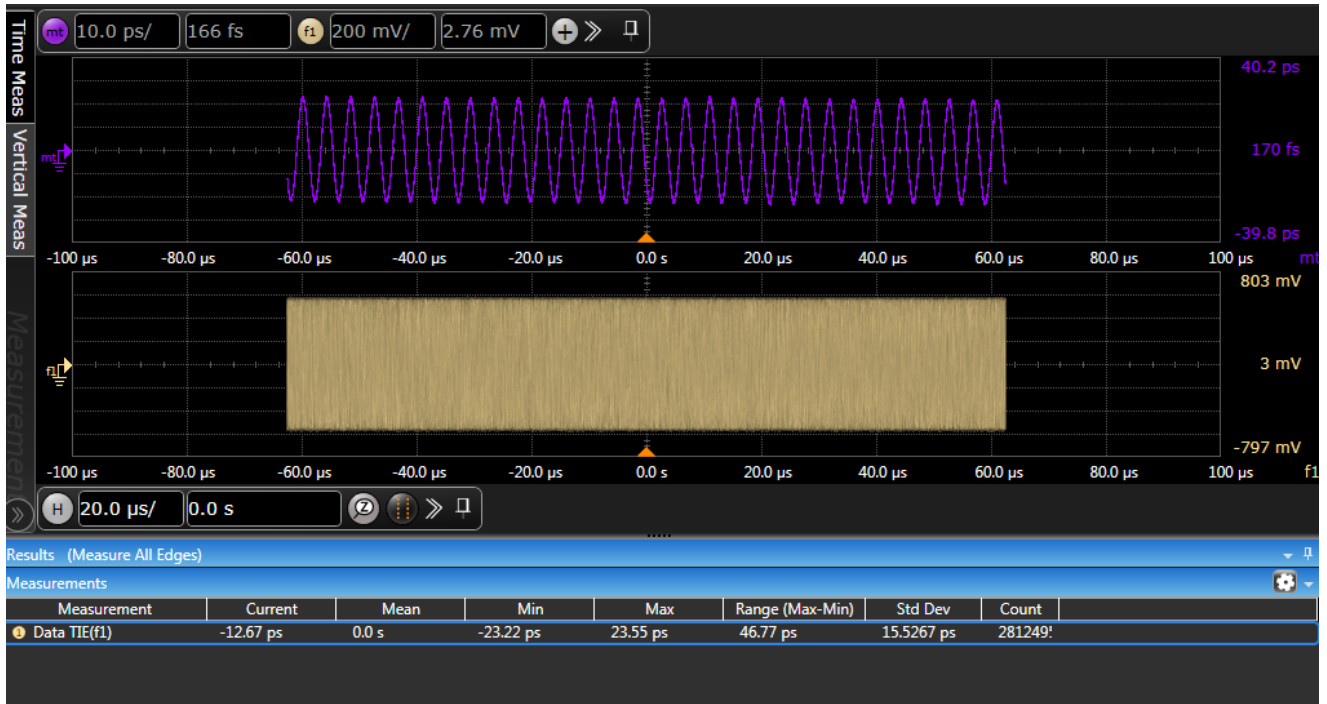
12.3.2.3 Step 3: Calibrate Applied SJ

This step verifies the jitter tolerance at 3 distinct SJ frequencies as defined under **Calibrate Applied SJ** of Section 12.2, which is performed with or without SSC support.

Note: Magnitude and SJ will vary depending on testing with or without SSC support. Additional Jitter Tolerance points can be added if desired.

The 1100 pattern on the BERT is used for this measurement.

1. Set the BERT amplitude to the calibrated voltage from the Launch Amplitude calibration step.
2. Set the BERT De-emphasis and Pre-shoot to 0dB.
3. Set the BERT SJ, RJ and SJ2 (BUJ) to 0.
4. Enable the TIE Measurement function on the Scope and configure the PLL setting to Constant Clock. Measure Intrinsic TIE.
5. Set SJ to 5% and calculate as follows:
 - $SJ = TIE(SJ) - TIE(Intrinsic)$
6. Adjust SJ accordingly to achieve the specified target value. Record the measured value.
7. Repeat steps 4 to 6 for all SJ frequencies and for both SSC and non-SSC test cases.
8. Save all the calibrated SJ frequency values to a file as e.g., 'SAS4_JTOL' or any desired name.



12.3.2.4 Step 4: Calibrate Insertion Loss (ISI)

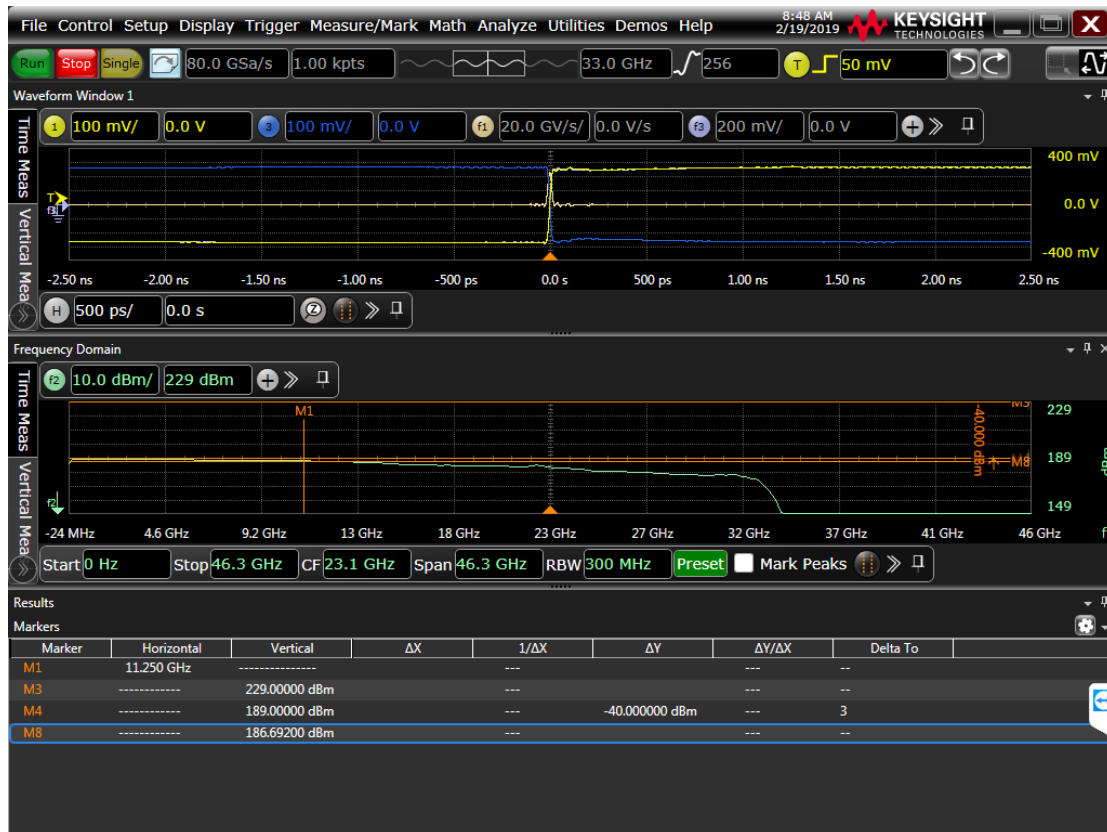
This step verifies that a trained 22.5Gbit/s signal of the passive TxRx connection meets the target differential ISI in Figure 40 of Section 12.2. This is performed by measuring the frequency response and ensure that the difference in magnitude is within the allowable range.

Note: The Anritsu J1758A ISI board 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 40 of Section 12.2.
6. Adjust the variable ISI source until the measured magnitude meets the calculated ideal magnitude difference of 18.86dB:

Target values:

- $IL(0.05e9) = 1.14dB$
- $IL(11.25e9) = 30.0dB$
- Target $(IL11.25G - 0.05G) = 30.0 - 5.0 - 5.0 - 1.14 = 18.86dB$



12.4 SAS-4 Rx Compliance Test Setup and Procedure

Compliance testing for jitter tolerance of the receiver DUT will use the BERT analyzer/error detector in loopback mode. The BERT will typically transmit PRBS31 signaling (which includes ISI effects and stressors) to the Rx DUT. During loopback, the DUT will transmit the test signal to the BERT error detector for error checking. The DUT will pass compliance if the target BER of less than $1E-9$ (for 22.5 Gbit/s) with a 95% confidence level is met.

Refer to Figure 33 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.

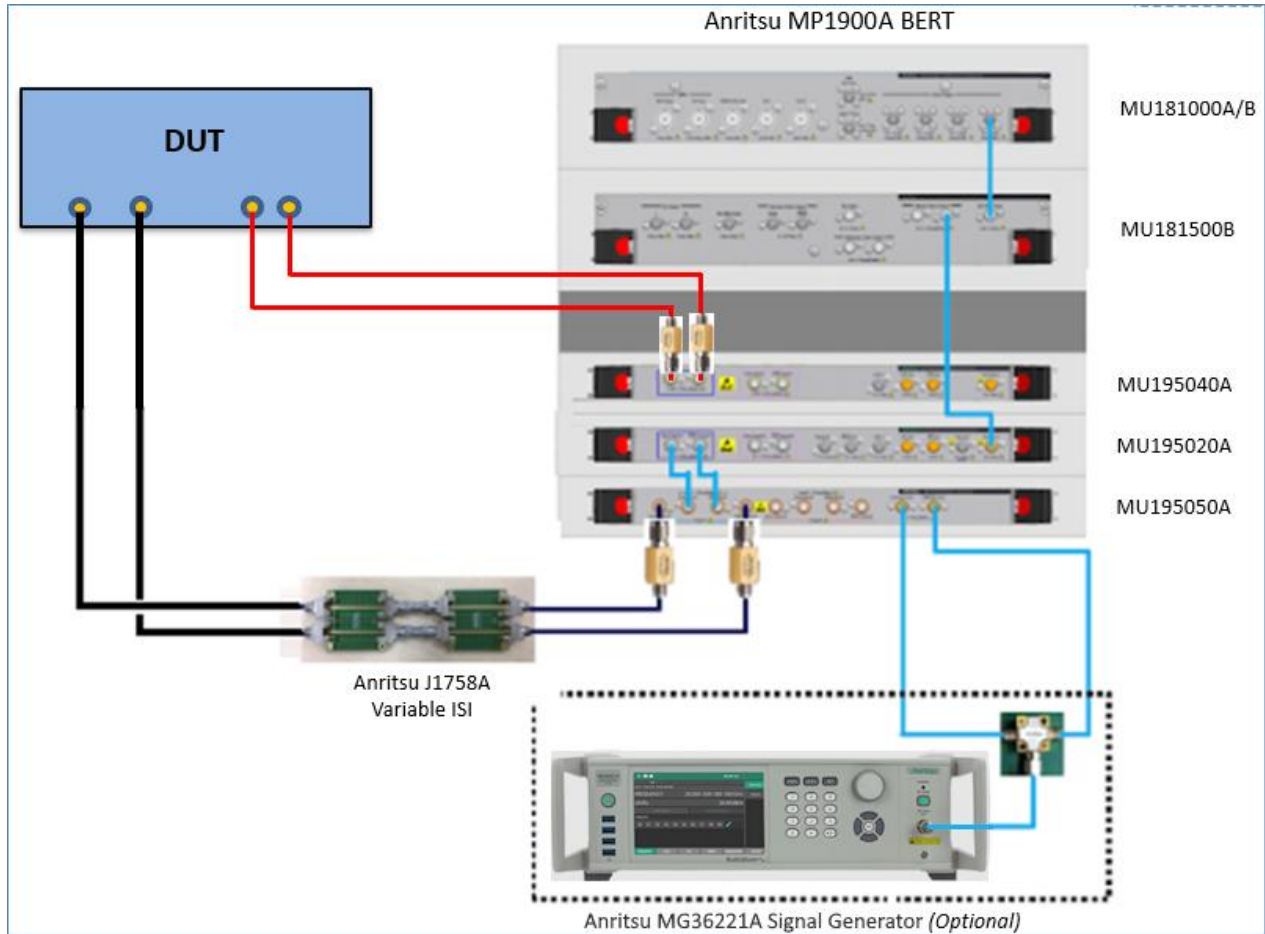


FIGURE 44. COMPLIANCE TEST SETUP FOR RECEIVER DUT JITTER TOLERANCE

Connection Steps:

1. Using back the same setup connections from the Insertion Loss calibration, disconnect the J1758A ISI board from the oscilloscope channels.
2. Connect the J1758A ISI board to the DUT data inputs.
3. Connect the DUT data outputs to the MU195040A data inputs through DC blocks for loopback error detection.

12.4.2 Test for Rx Jitter Tolerance BER Compliance

Transmit PRBS31 signaling to the Rx DUT and verify BER on the BERT 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 $1E-9$ (for 22.5 Gbit/s) with a 95% confidence level, in order to pass compliance.

13 Appendix B: Connecting Keysight Oscilloscope to PC

Refer to the following procedure on how to connect the Keysight oscilloscope to be used with a PC. The Keysight Scope can be connected to the PC through GPIB, USB, or LAN.

1. Download the latest version of the Keysight IO Libraries Suite software from the Keysight website and install on the PC.
2. When installed successfully, the IO icon () will appear in the taskbar notification area of the PC.
3. Select the IO icon to launch the **Keysight Connection Expert**.
4. Click Rescan.

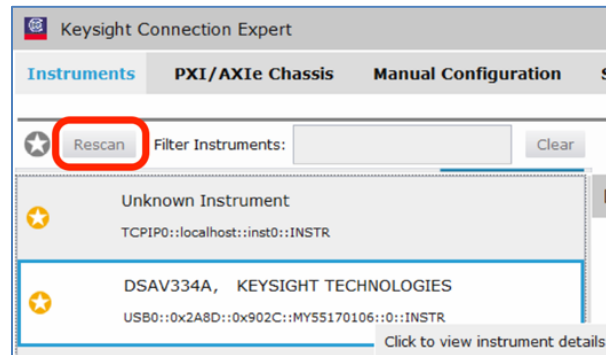


FIGURE 45. KEYSIGHT CONNECTION EXPERT

5. Refresh the system. The Keysight Scope is shown on the left pane and the VISA address is shown on the right pane.

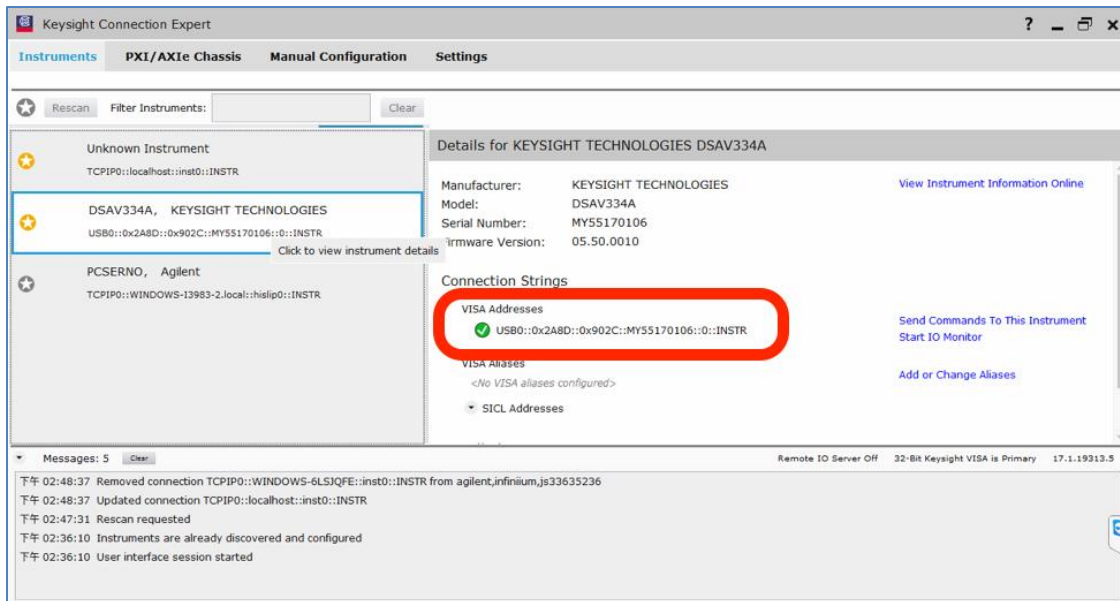


FIGURE 46. OSCILLOSCOPE'S VISA ADDRESS

6. When connecting the Keysight Scope to the PC through GPIB/USB, type in the VISA address into the 'Address' field on the Equipment Setup page of the Anritsu SAS-4 Rx

Test Application. If connected via LAN, type in the Scope IP address, for example “TCPIP0::192.168.0.110::inst0::INSTR”. Note to **omit** the Port number from the address.

14 Appendix C: Connecting Tektronix Oscilloscope to PC

If using a Tektronix DPOJET Series oscilloscope, refer to the following procedure on how to connect the Scope to be used with a PC. The Tektronix Scope can be connected to the PC through GPIB, USB, or LAN.

1. Download the latest version of the Tektronix TekVISA software from the Tektronix website and install on the PC.
2. When installed successfully, open the OpenChoice Instrument Manager application.

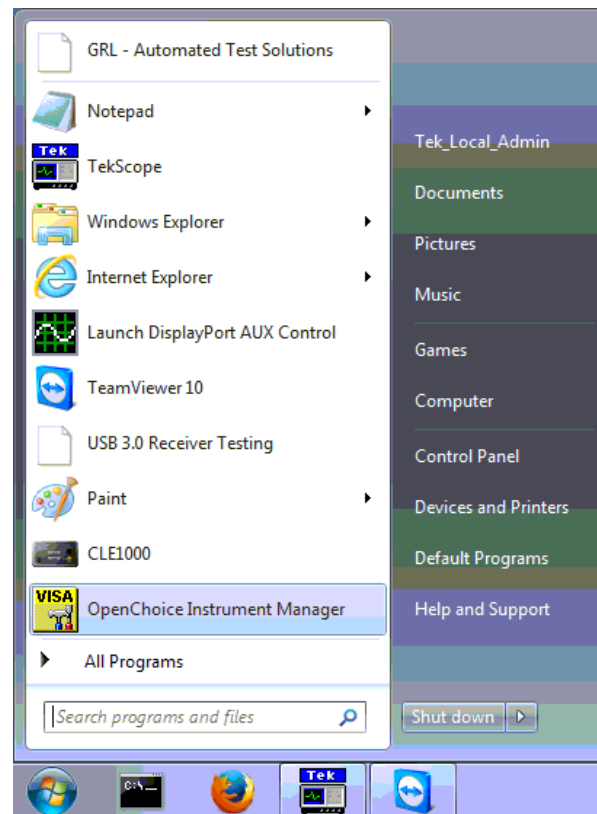


FIGURE 47. OPENCHOICE INSTRUMENT MANAGER IN START MENU

3. The left “Instruments” panel on the OpenChoice Instrument Manager will display all connected instruments. The functional buttons below the “Instruments” panel – “Instrument List Update”, “Search Criteria”, “Instrument Identify” and “Properties” can be used to detect the Scope in case it does not initially appear under “Instruments”.
 - a) “Instrument List Update”: Select to refresh the instrument list and locate new instruments connected to the PC.
 - b) “Search Criteria”: Select to configure the instrument search function.
 - c) “Instrument Identify”: Select to use a supported programming language to send a query to identify the selected instrument.
 - d) “Properties”: Select to display and view the selected instrument properties.

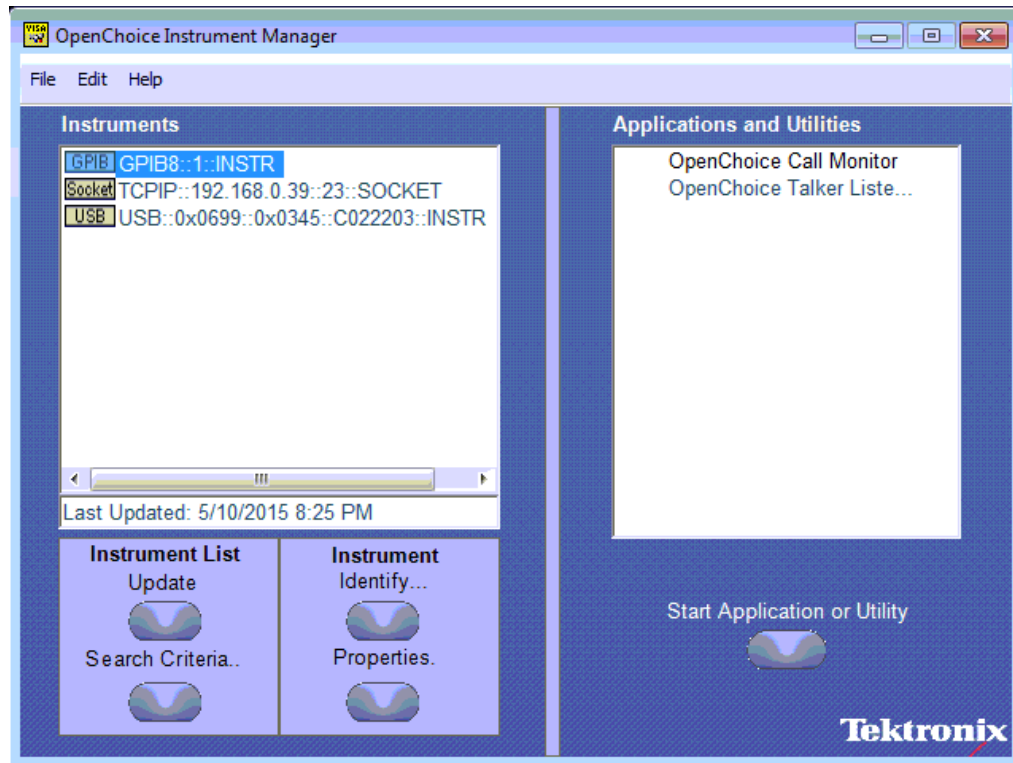


FIGURE 48. OPENCHOICE INSTRUMENT MANAGER MENU

4. If connecting the Tektronix Scope to the PC via USB, select the “Search Criteria” function to ensure that USB connection is enabled, and then select the “Instrument List Update” function. When the Scope appears on the “Instruments” panel, select it and then go to the “Instrument Identify” function. This will display the model and serial number of the Scope once detected. Select the “Properties” function to view the Scope address.
5. If connecting the Tektronix Scope to the PC via LAN, the Scope IP address must be pre-determined beforehand. Then select the “Search Criteria” function to ensure that LAN connection is enabled and type in the Scope IP address. When the Scope shows up in the list, select it followed by “Search”. The Scope should then appear on the “Instruments” panel. Select it and access the “Instrument Identify” function to view the Scope model and serial number as well as the “Properties” function to view the Scope address.
6. On the Equipment Setup page of the GRL-SAS4-RXA Application, type in the Scope address into the ‘Address’ field. If the GRL-SAS4-RXA Application is installed on the Tektronix Scope, ensure the Scope is connected via GPIB and type in the GPIB network address, for example “GPIB8::1::INSTR”. If GRL-SAS4-RXA is installed on the PC to control the Scope, type in the Scope IP address, for example “TCPIP0::192.168.0.110::inst0::INSTR”. Note to **omit** the Port number from the address.

15 Appendix D: Connecting Teledyne LeCroy Oscilloscope to PC

If using a Teledyne LeCroy oscilloscope, refer to the following procedure on how to connect the scope to be used with a PC. The Teledyne LeCroy scope can be connected to the PC through LAN.

1. From the oscilloscope main menu bar, select **Utilities → Utilities Setup....**

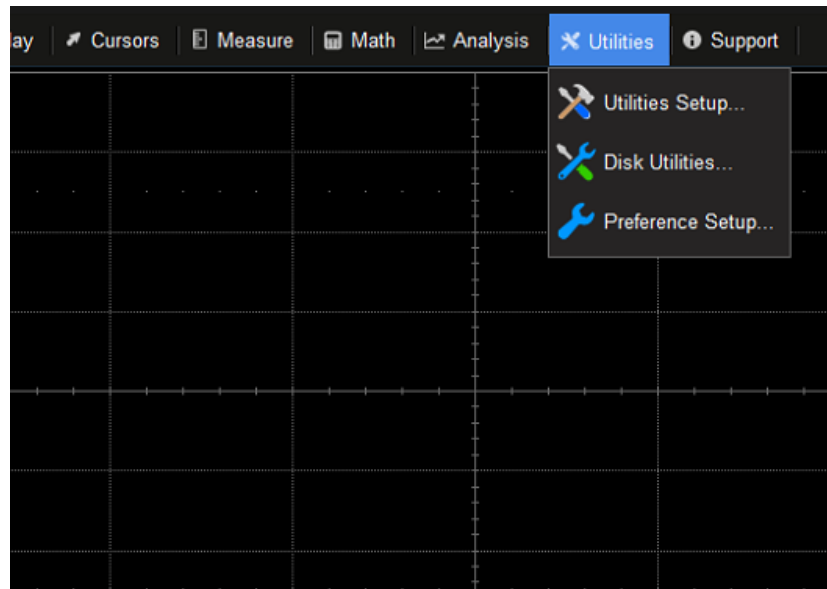


FIGURE 49. UTILITIES SETUP MENU

2. In the **Remote** tab, set the **Control from** settings to **LXI (VXI11)**. Note down the IP address of the scope.

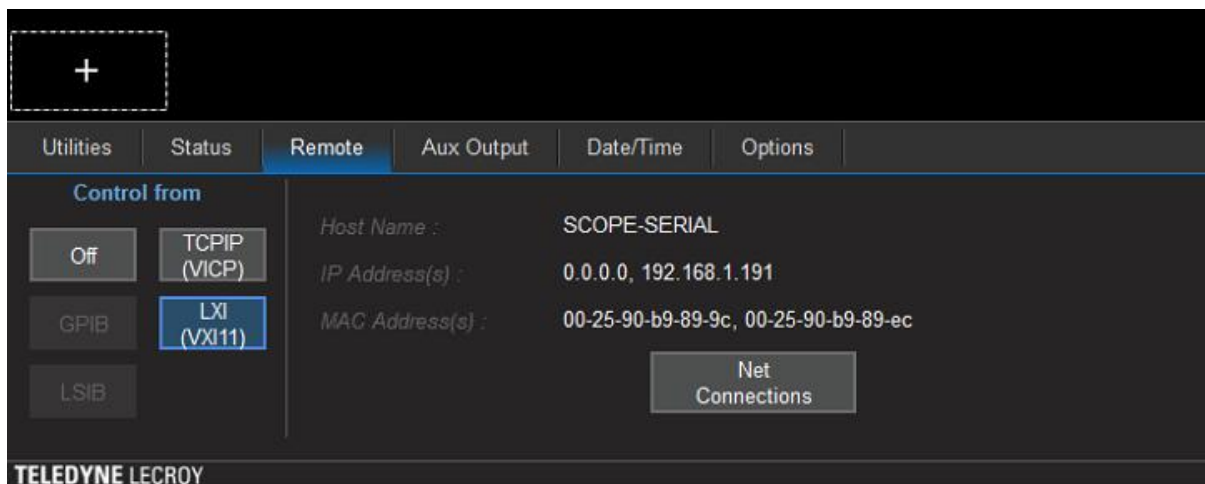


FIGURE 50. OSCILLOSCOPE'S IP ADDRESS

3. On the Equipment Setup page of the GRL-SAS4-RXA Application, type in the Scope IP address into the 'Address' field.

16 Appendix E: Artek CLE1000 Series Installation

16.1 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-SAS4-RXA 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.

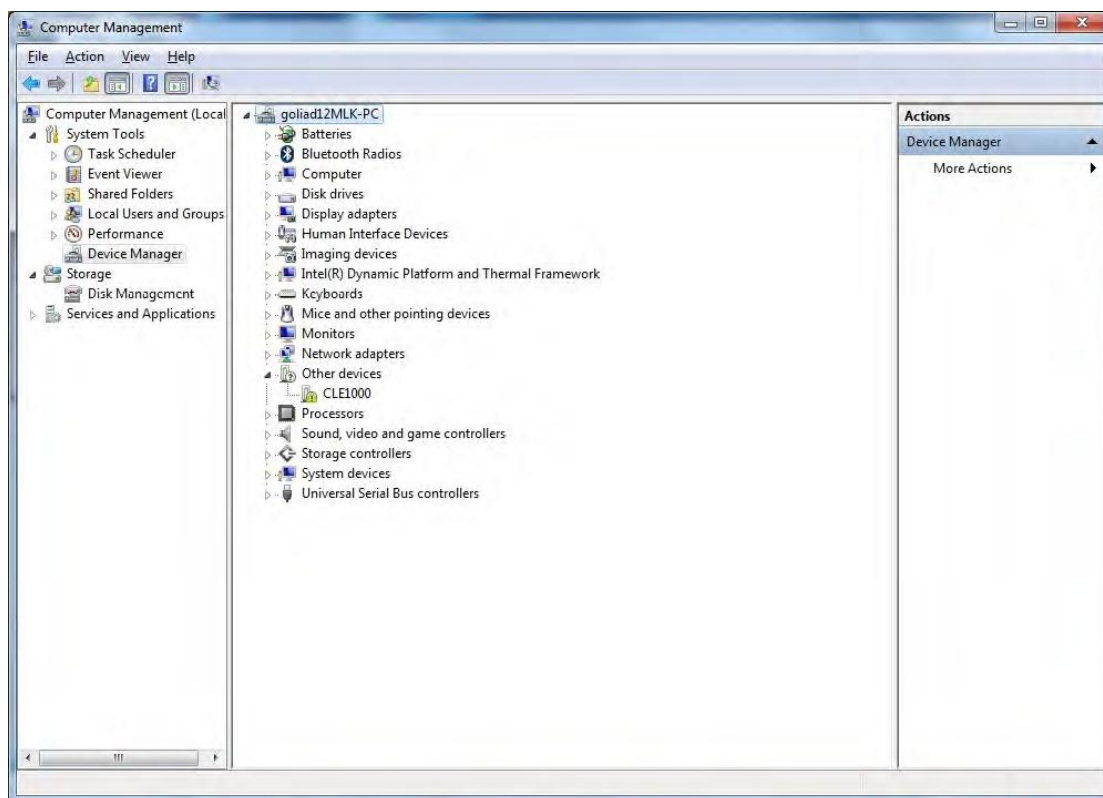


FIGURE 51. DEVICE MANAGER WINDOW

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 52).
 - 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 53).
6. Once installation has completed, the Device Manager window should look like the example in Figure 54.



FIGURE 52. UPDATE DRIVER WINDOW

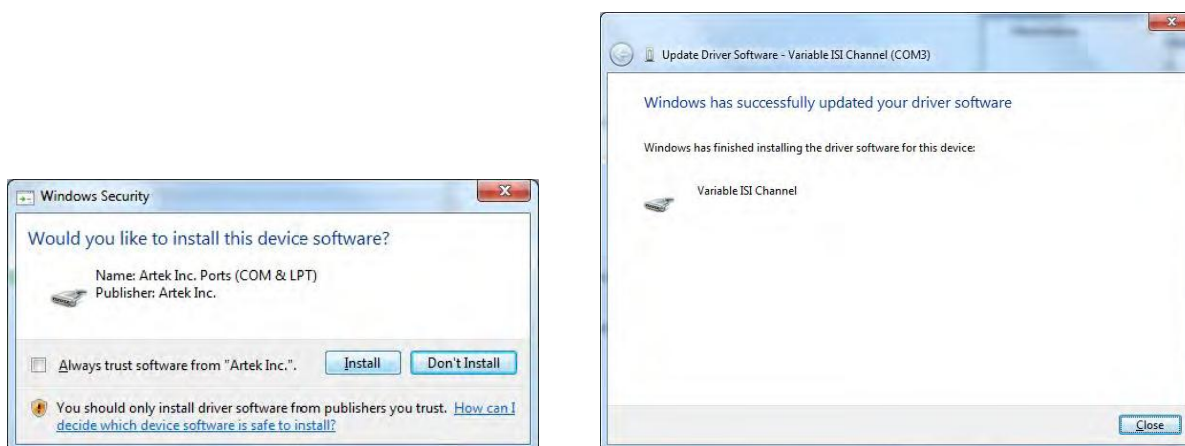


FIGURE 53. WINDOWS SECURITY WINDOW AND CONFIRMATION WINDOW

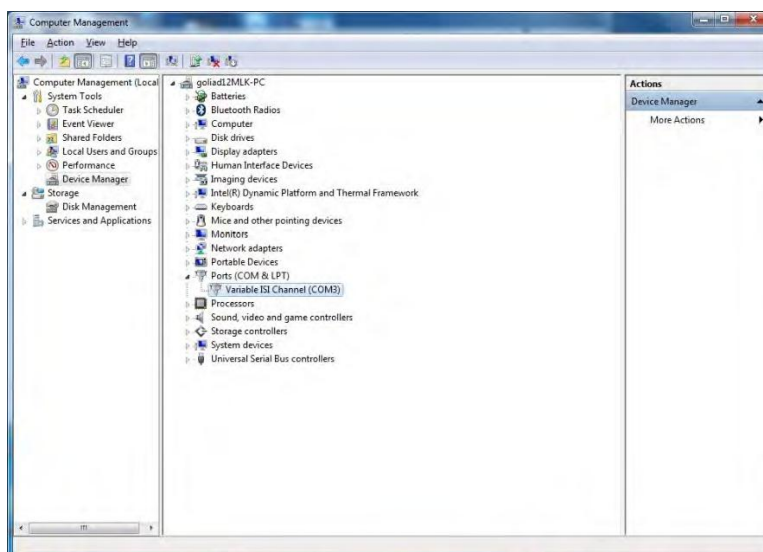


FIGURE 54. DEVICE MANAGER WINDOW AFTER INSTALLATION

The CLE1000 is now ready to be used remotely with the GRL-SAS4-RXA software.

16.2 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.

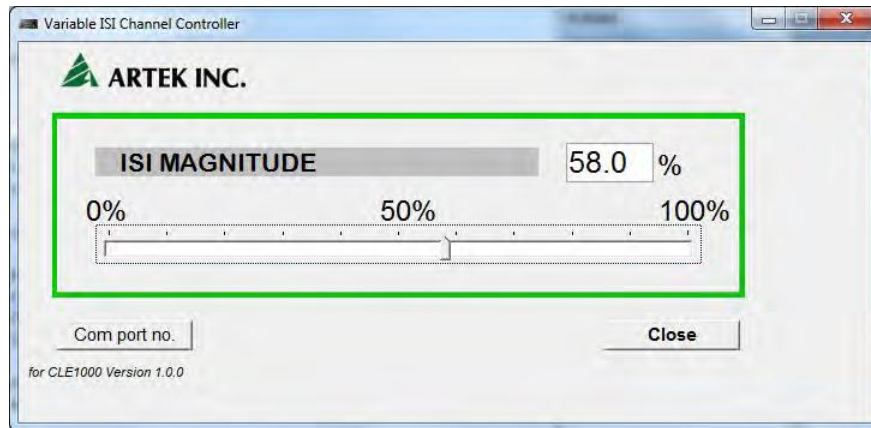


FIGURE 55. CLE1000 UI

17 Appendix F: 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).

END_OF_DOCUMENT