Tektronix PCI Express

PCI Express Receiver Test Suite Datasheet

Improve accuracy and precision of PCI Express Gen5 Receiver Stressed Eye Calibration, Receiver & Transmitter Link Equalization testing, and Receiver Jitter Tolerance with Tektronix automation software. Remove the complexity of receiver testing with a step-by-step user interface designed by industry leaders engaged in the standards bodies to drive the latest specifications to maturity. Industry engagement ensures our software will evolve in-step with the technology. Achieving the correct balance of simplicity and user control has been at the forefront of the design team to ensure your device can complete link training with the correct calibrated stress and be efficiently tested with optimized PHY settings.

Applications

- PCI Express Gen5 (32 GT/s)
- Base Specification (silicon validation) & CEM Specification (system verification & compliance)
- Root Complex & Non-Root Complex silicon
- Systems (motherboards & servers), Add-in Cards, Switches & Bridges, Extension Devices (retimers & redrivers)

Features and benefits

- Receiver automation software for Tektronix DPO70000SX Series Real Time Scopes & Anritsu MP1900A BERT
- Wizard based user interface for each step of calibration and test
- Pop-up user tips to simplify decision making
- Stressed Eye Calibration (32 GT/s)
  - Base & CEM
  - TP3 – Amplitude, AC/DC Balance, Tx Equalization, Sinusoidal Jitter tones, & Random Jitter
  - TP2 – DMI, CMI, Preset & CTLE Selection, Stressed Eye
- Automated loopback through Configuration & Recovery
- Insertions Loss computation powered by Seasim Statistical Simulation Tool
- Rx Link Equalization (32 GT/s)
- Tx Link Equalization (32 GT/s)
- Jitter Tolerance (32 GT/s)
- Latest industry tool support (SigTest & Seasim)
- Calibration and test reports

Stressed Eye Calibration

Calibration of the stressed eye signal, generated by the BERT's PPG, is important to ensure the receiver is tested in alignment with the PCI-SIG specifications with the proper amount of impairments. New challenged at 32 GT/s demand the fully automated approach taken by the Tektronix PCI Express Receiver Test Suite to avoid alternative tedious and error-prone approaches. Let the domain expertise and experience of the Tektronix engineers guide you through the steps of calibration starting with accurate TP3 measurements and ending with an end of channel eye diagram easily obtained within the tolerances required. Engineers will spend less time calibrating and more time collecting meaningful data on receiver performance and margin.

TP3 calibration

The TP3 (cable from BERT PPG to scope) is mandatory for all devices to ensure tolerances are met at the defined reference plane. Tek Tektronix PCI Express Receiver Test Suite wizard will guide the user through all the necessary steps to pre-channel signal is true to the specification requirements to ensure future calibration steps complete with ease.

1. AC-DC Balance – Small amounts of Tx EQ de-emphasis are enabled to balance low and high-frequency sections of the pattern at a common reference plane.
2. Amplitude – The differential voltage swing is required to be within 720 – 800 mV.
3. Tx Equalization Presets – Calibration of pre-shoot and de-emphasis is required to ensure true preset level are used for testing receivers
4. IL Measurement – Channel insertion loss is calculated using Seasim between TP3 and TP1 (loss before the TP3 reference is computed here for later removal)
5. RJ – Random Jitter (RJ) is calibrated to be 0.5 ps (RMS value) nominally
6. SJ – Sinusoidal Jitter (SJ) is calibrated over the required range of 1-5 ps (p-p) including the nominal SJ specification of 0.1 UI (or 3.125 ps) at 100 MHz frequency.

7. SJ@210 MHz – This calibration is required for JTOL measurements with some calibrations
8. Multi-tone SJ – For JTOL measurements where up to X frequencies are used, calibration for frequencies other than 100 MHz are required to be performed.

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PCIe5.0 CEM Receiver Calibration Report

TP1 Calibration Results

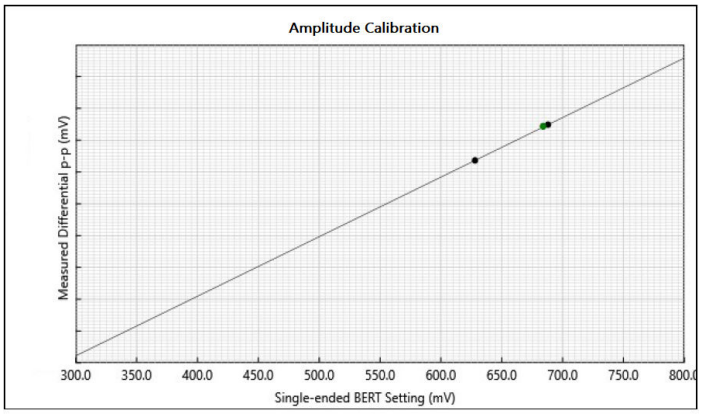
Test Details	
Unique ID	[Example_TP1_Calibration]
Date/Time	05 October 2020, 11:56 PM
Generated By	Tektronix

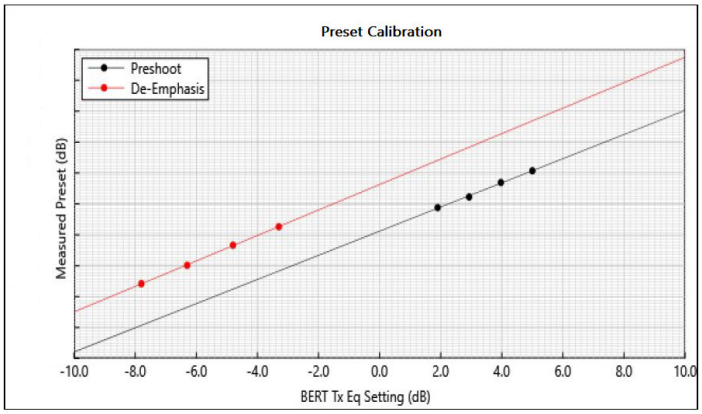
Additional Comments
No Comments

Test Equipment	
BERT	ANRITSU, MP1900A, 6261788378
Rx Test SW Version	6.0.1.28
RT Scope	TEKTRONIX, DPO77002SX, B321456
RT Scope FW Version	10.11.0 Build 30
TekRxService Version	2.8.0.8
DPOJET Version	10.2.0.17

Result Summary	
TP1 Calibration	Unique ID: [Example_TP1_Calibration]
	Balanced De-emphasis: -1.8 dB
	Differential Amplitude: 800.0 mV
	SJ Setting: 0.1 UI p-p @ 100 MHz (Nominal SJ 3.125 ps / 0.1 UI p-p)
	RJ Setting: 0.16 UI p-p (Nominal RJ 0.5 ps RMS / 0.016 UI p-p)
	SJ@210 MHz Regression Line Parameters: Slope = - / Intercept = -
	Multi-tone SJ Calibration performed for 7 frequencies

TP1 Calibration Details	
AC-DC Balance	Setting De-emphasis: -1.8 dB
	Pattern: 64ones_64zeros_128bit10
	Important RT Scope Settings: BW: 50.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 5000
Amplitude Calibration	Pattern: 64ones_64zeros_128bit10
Preset Calibration	Pattern: 64ones_64zeros_128bit10
	Important RT Scope Settings: BW: 50.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 5000



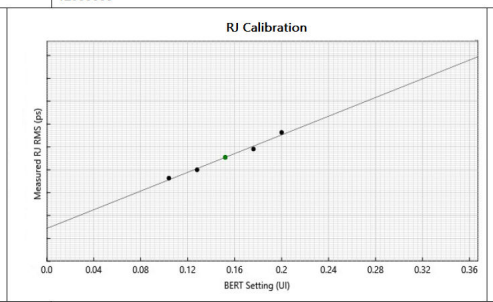


Preset	Preshoot (dB) Setting	De-emphasis (dB) Setting
P0	0	-6
P1	0	-3.5
P2	0	-4.4
P3	0	-2.5
P4	0	0
P5	1.9	0
P6	2.5	0
P7	3.5	-6
P8	3.5	-3.5
P9	3.5	0

Figure 1: TP1 calibration results

Automatic characterization and precise calibration of presets, RJ, and SJ along with the important parameters used for calibration like pattern type, scope, BERT settings, regression line slopes, and intercept for reference.

RJ Calibration	Setting: 0.5 ps (Nominal - 0.5 ps RMS)
	Pattern: Toggle_1bit
	Important RT Scope Settings: BW: 50.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 12500000



SJ Calibration	Setting: 3.125 ps (Nominal - 3.125 ps)
	Pattern: 128b130b_CP_L0_Gen5_P7
	Important RT Scope Settings: BW: 50.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 12500000

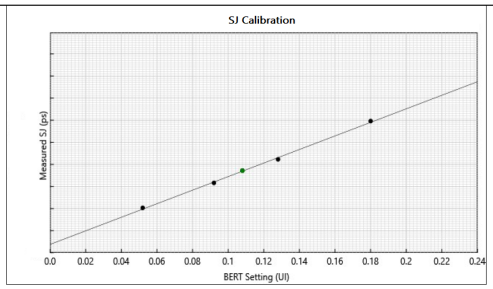


Figure 2: RJ/SJ calibration

TP2 calibration

The TP2 (end of the channel) calibration is a complex process requiring a deep understanding of the BERT, RT Oscilloscope, post-processing tools, and the PCIe specifications. The Tektronix PCI Express Receiver Test Suite will remove the complexity and ensure the desired results are achieved through user-friendly automation. Time to TP2 completion is critical, so efficient techniques have been Implemented to ensure an accurate stressed eye is achieved within a reasonable time scale. From calibration of DMI (differential mode interference modeling cross-talk) to the fine granularity adjustments to SJ and DMI necessary to find the stressed eye solutions space, our automation software will guide you through this otherwise daunting task.

1. DMI– The differential mode interference is required to be calibrated within 5-30 mV (p-p) by capturing the 2.1 GHz sinusoidal output for a duration of 40 ns.
2. CMI – The common-mode interference is required to be calibrated for a nominal voltage of 150 mV (p-p) by capturing the 120 MHz sinusoidal output for a duration of 62.5 us.
3. Channel insertion loss for DMI/ CMI channel and stressed eye channel is calculated using Seasim between TP3 and TP2 (loss before the TP3 reference is removed)
4. Channel Selection with Optimal CTLE/Preset – Selection of the highest loss channel within the specification defined range while finding the optimal behavioral CTLE and Tx Equalization (preset based) is key to reaching the stressed eye targets. Optimum CTLE / Preset selection – Tx Equalization Presets are used to find the optimal Eye Area with the optimal CTLE
5. Stressed-Eye calibration – Fine-tuning of the eye using amplitude, SJ, & DMI is utilized to place the stressed eye within allowed tolerances

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PCIe5.0 CEM Receiver Calibration Report

AIC TP2 Calibration Results

Test Details	
Unique ID	[Example_TP2_AIC_Calibration]
Date/Time	26 September 2020, 7:13 AM
Generated By	Tektronix

Additional Comments
No Comments

Test Equipment	
BERT	ANRITSU, MP1900A, 6261788378
Rx Test SW Version	6.0.1.18
RT Scope	TEKTRONIX, DPO77002SX, B321456
RT Scope FW Version	10.11.0 Build 30
TekRxService Version	2.8.0.8

Calibration Summary	
TP2 Calibration	Unique ID: [Example_TP2_AIC_Calibration]
	Full Channel Loss: 36 dB
	Selected Preset: P6
	Selected CTLE Index: 3.0
	Status: Converged
	Final Calibrated EW: 9.375 ps (8.875 ps ≤ Target EW ≤ 9.875 ps)
	Final Calibrated EH: 15.5 mV (13.5 mV ≤ Target EH ≤ 16.5 mV)
	Final SJ Stress Level: 3.125 ps (1 ps ≤ SJ Sweep ≤ 5 ps)
	Final DMI Stress Level: 10 mV (5 mV ≤ DMI Sweep ≤ 30 mV)
	Final Amplitude Level: 800 mV (Differential)
	SJ@210 MHz Setting during JTOL test: 0 UI p-p (Calibrated Value of SJ (ps) required to achieve the target stressed eye width minus 3.125 ps)
	Final CMI Stress Level: 150.0 mV

DMI	Pattern: Electrical_Idle
	Important RT Scope Settings: BW: 5.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 8000
CMI	Pattern: Electrical_Idle
	Important RT Scope Settings: BW: 5.0 GHz , Sample Rate: 200.0 GS/s , Record Length: 12500000

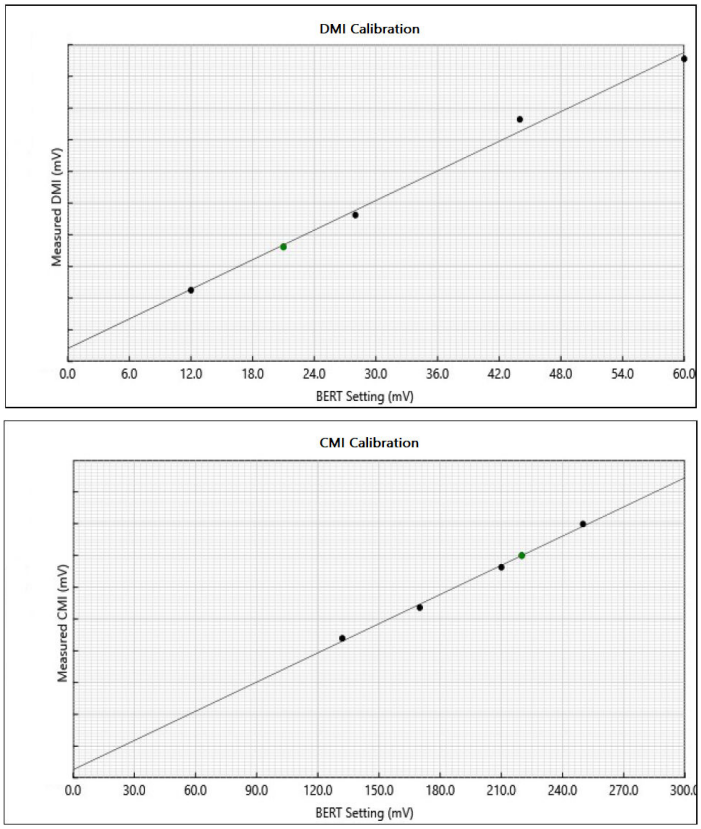

Figure 3: AIC TP2 calibration results

Stressed Eye Calibration	Final Amplitude Level: 800.0 mV
	Pattern: Toggle_512bits

Index	SJ (ps)	DMI (mV)	Amp (mV)	Eye Width (ps)	Eye Height (mV)
1	3.125	10	800	14.468	23.836
2	3.125	10	800	14.652	24.434
3	3.125	10	800	14.747	23.925
4	3.125	10	800	14.416	23.455
5	3.125	10	800	14.531	23.912
6	3.125	10	800	14.375	24.374
7	3.125	10	800	14.408	23.983
8	3.125	10	800	14.583	24.183
AVERAGE	3.125	10	800	14.522	24.013
⋮					
AVERAGE	3.125	27.5	800	10.26	16.183
73	3.375	27.5	800	9.882	15.575
74	3.375	27.5	800	10.049	16.18
75	3.375	27.5	800	10.096	15.675
76	3.375	27.5	800	9.801	15.192
77	3.375	27.5	800	9.912	15.655
78	3.375	27.5	800	9.943	16.09
79	3.375	27.5	800	9.824	15.717
80	3.375	27.5	800	10.07	15.882
AVERAGE	3.375	27.5	800	9.947	15.746
82	3.625	27.5	800	9.726	15.341
83	3.625	27.5	800	9.893	15.934
84	3.625	27.5	800	9.94	15.482
85	3.625	27.5	800	9.644	14.928
86	3.625	27.5	800	9.756	15.484
87	3.625	27.5	800	9.786	15.879
88	3.625	27.5	800	9.668	15.448
89	3.625	27.5	800	9.913	15.689
AVERAGE	3.625	27.5	800	9.791	15.523
SELECTED	3.625	27.5	800	9.791	15.523

Figure 4: Stressed eye calibration result

Automated TP2 calibration plots and stressed eye calibration details along with other important parameters like pattern type, scope and BERT settings and regression line slopes and intercept for reference.

Link training

Prior to receiver testing, the device-under-test (DUT) must be placed into loopback, where the data digitized at the Rx latch is retransmitted by the corresponding Tx giving visibility into a possible bit or burst errors. Entering the loopback test mode requires a complex dance through the Link Training Status State Machine (LTSSM) between the BERT and DUT. The Tektronix PCI Express Receiver Test Suite automates this sequence allowing loopback through configuration (short path) and loopback through recovery (full training of the link Tx & Rx) for different levels of receiver testing. Parameters are descriptively exposed to allow user control over this process without unnecessary complexity.

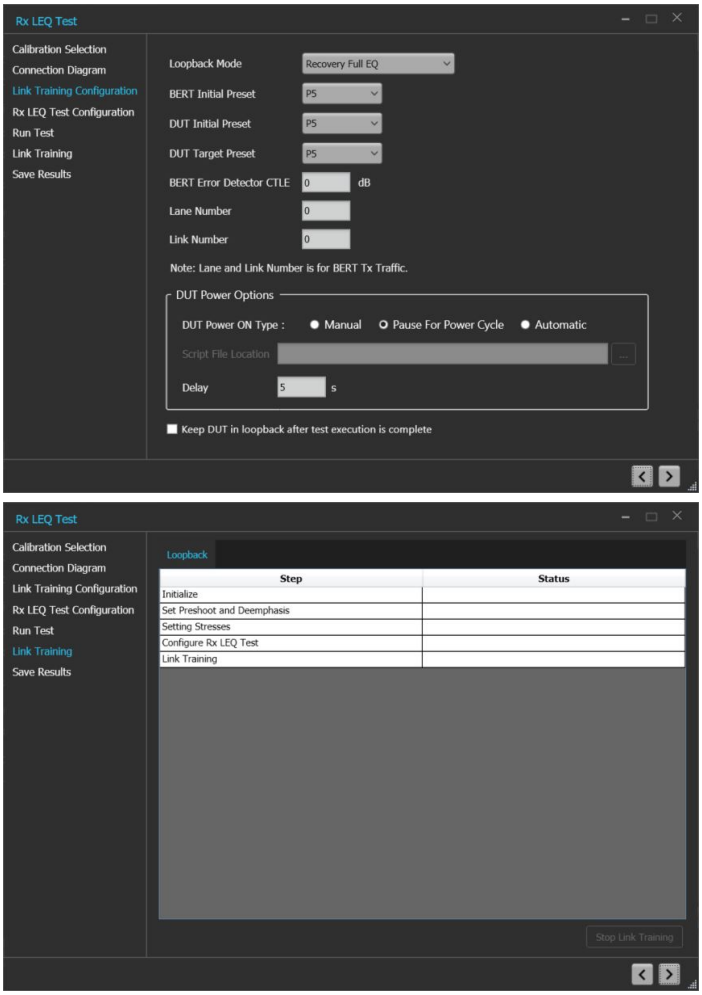

Figure 5: Flexible link training and loopback control

Figure 6: Tx-LEQ and Rx-LEQ test configuration

Receiver and transmitter link equalization testing

PCI Express compliance at 32 GT/s requires performing a Receiver Link Equalization test (checking analog Rx performance with a stressed signal after full link training) and a Transmitter Link Equalization test (ensuring key digital timing limits are achieved when an Rx makes Tx change requests to its link partner) both at 32GT/s. The Tektronix PCI Express Receiver Test Suite controls the BERT and RT Oscilloscope during these required tests to provide efficient test results with minimal overhead and control only where needed.

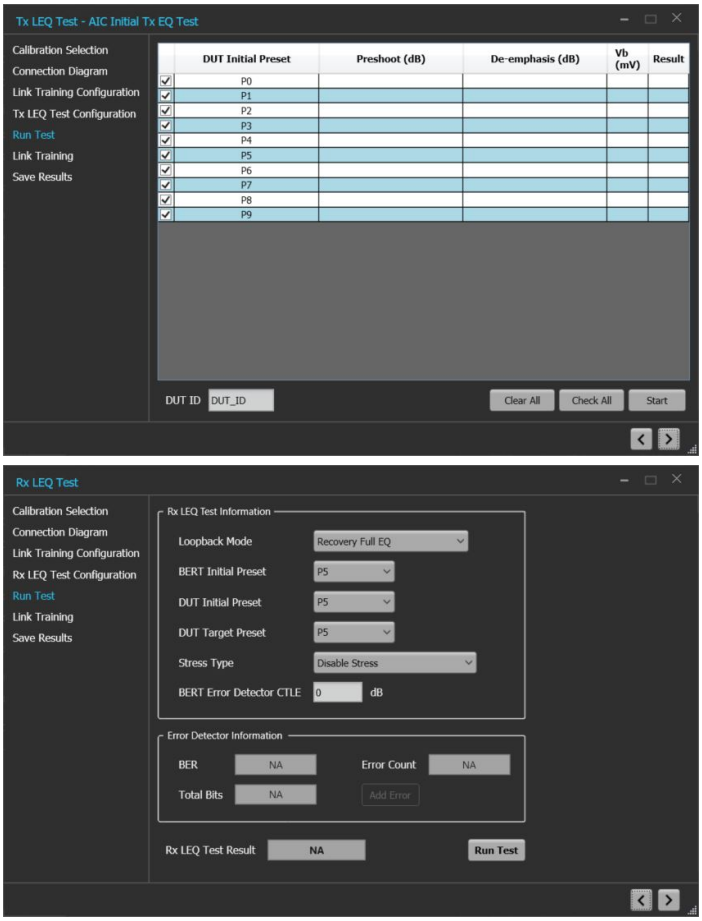

Figure 7: Tx-LEQ and Rx-LEQ execution page

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CEM Receiver Compliance Test Report

AIC LEQ Response Time Test Results

Test Details	
Unique ID	TxLEQResponse_Run2
Date/Time	11 December 2020, 1:06 PM
Generated By	SQE

Additional Comments
NA

Test Equipment	
BERT	ANRITSU, MP1900A, 6261788378
BERT FW Version	4.09.41
Rx Test SW Version	6.0.1.142
RT Scope	TEKTRONIX, DPO77002SX, B321456
RT Scope FW Version	10.12.0 Build 1

Test Results

DUT Initial Preset	Target Preset/Coeff		Preshoot (dB)	De-Emph (dB)	Vb (mV) (Informative)	Electrical Response Time (ns)	Protocol Response Time (ns) (informative)	DUT Reported Coefficients	Result
P4	P0	Preset	0.000	-5.95	206.4	55.49	166.6	(0,47,16)	Pass
P4		Coeff	0.000	-5.96	206.4	85.55	143.4	-	Pass
P4	P1	Preset	0.000	-3.54	272.7	97.94	155.2	(0,52,11)	Pass
P4		Coeff	0.000	-3.56	272.1	89.05	161.1	-	Pass
P4	P2	Preset	0.000	-4.37	247.7	62.48	165.4	(0,50,13)	Pass
P4		Coeff	0.000	-4.39	247.2	82.64	151.9	-	Pass
P7	P3	Preset	0.000	-2.38	311.6	119.0	161.6	(0,55,8)	Pass
P7		Coeff	0.000	-2.38	311.4	97.28	146.3	-	Pass
P7	P4	Preset	0.000	0.000	409.9	107.7	154.2	(0,63,0)	Pass
P7		Coeff	0.000	0.000	410.1	98.04	144.7	-	Pass
P7	P5	Preset	1.708	0.000	336.7	121.2	155.6	(6,57,0)	Pass
P7		Coeff	1.712	0.000	336.7	99.07	156.0	-	Pass
P7	P6	Preset	2.380	0.000	311.6	110.6	164.6	(8,55,0)	Pass
P7		Coeff	2.396	0.000	311.2	106.0	148.4	-	Pass
P4	P7	Preset	3.130	-5.79	172.7	95.89	166.6	(7,45,11)	Pass
P4		Coeff	3.094	-5.77	173.1	58.44	154.9	-	Pass
P4	P8	Preset	3.694	-3.69	203.6	96.18	162.6	(8,47,8)	Pass
P4		Coeff	3.725	-3.71	202.8	93.49	152.7	-	Pass
P7	P9	Preset	3.540	0.000	272.7	117.5	158.6	(11,52,0)	Pass
P7		Coeff	3.551	0.000	272.4	99.82	149.7	-	Pass

Figure 8: Tx-LEQ AIC Response time test results

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PCIe5.0 CEM Receiver Compliance Test Report

System Rx LEQ Test Results

Test Details	
Unique ID	RxLEQ_Pattern
Date/Time	19 October 2020, 3:10 AM
Generated By	SQE

Additional Comments
ClockPattern

Test Equipment	
BERT	ANRITSU,MP1900A,6261788378
BERT FW Version	4.03.13
Rx Test SW Version	6.0.1.62

Calibration Summary	
TP2 Calibration	Unique ID: [Example_TP2_AIC_Calibration]
	Full Channel Loss: 36 dB
	Status: Converged
	Final Calibrated EW: 9.375 ps (8.875 ps ≤ Target EW ≤ 9.875 ps)
	Final Calibrated EH: 15.5 mV (13.5 mV ≤ Target EH ≤ 16.5 mV)
	Final SJ Stress Level: 3.125 ps (1 ps ≤ SJ Sweep ≤ 5 ps)
	Final DMI Stress Level: 10 mV (5 mV ≤ DMI Sweep ≤ 30 mV)
	Final Amplitude Level: 800 mV (Differential)
	Final CMI Stress Level: 150.0 mV
TP1 Calibration	Unique ID: [Example_TP1_Calibration]
	Differential Amplitude: 800.0 mV
	SJ Setting: 0.1 UI p-p @ 100 MHz (Nominal SJ 3.125 ps / 0.1 UI p-p)
	RJ Setting: 0.16 UI p-p (Nominal RJ 0.5 ps RMS / 0.016 UI p-p)

Test Configuration	
Rx LEQ Test	Loopback Type: Recovery Full EQ
	Link Training Status: Successful
	BERT Initial Preset: P6
	DUT Initial Preset: P9
	DUT Target Preset: P9
	Link #: 0 , Lane #: 0
	CTLE @ ED: 0 dB
	BER Measurement Pattern: RxLEQ_Pattern
	Error Limit: 1
	Test Duration: 125 s
	Test Confidence: 26.42% at 0E+00 Bits
	Stress Configuration: Un-calibrated
	Stress Type: Apply Stress
	RJ: 0.03 UI
	SJ: 0.030 UI
	DMI: 2.00 mV
	CMI: 2.00 mV
	Amplitude: 800.0 mV

Rx LEQ Test Results	
Status	PASS
BER	0.0000E-11
Error Count	0
Initial BERT Preset	P6
Final BERT Preset	P5
Final BERT Coefficients	(2, 22, 0)

Figure 9: AIC Rx LEQ test results

Remote control protocol

The test software can be operated remotely through ASCII commands sent through TCP/IP, giving engineers further flexibility in designing “Beyond Compliance” tests.

Jitter Tolerance (JTOL) test

Jitter tolerance (JTOL) testing requires sweeping numerous calibrated SJ tones from low to high amplitude to see how the receiver-under-test’ CDR tracks the stress (typically in the presence of other noise & jitter sources). Custom JTOL pass/fail masks can be configured while testing with different search algorithms (upward linear, logarithmic, etc. …). The Tektronix PCI Express Receiver Test Suite allows engineers minimal setup with quick and descriptive test reports.

Figure 10: JTOL test configuration settings

Both the custom mask and the specification mask are provided in the JTOL test to have a better understanding of the DUT performance, especially at the design stage. The Receiver solution performs an automatic back channel equalization and sampling point optimization ensures to ensure the best conditions for the DUT transmitted data traffic to be accurately comprehended at the BERT receiver to ensure the correct determination of BER performance.

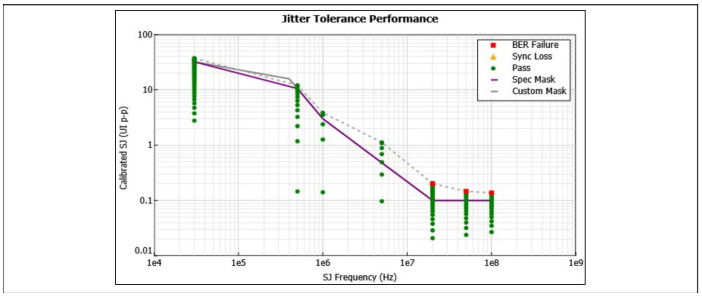

Figure 11: JTOL test result with specification

Figure 12: Error detector and stress settings for JTOL

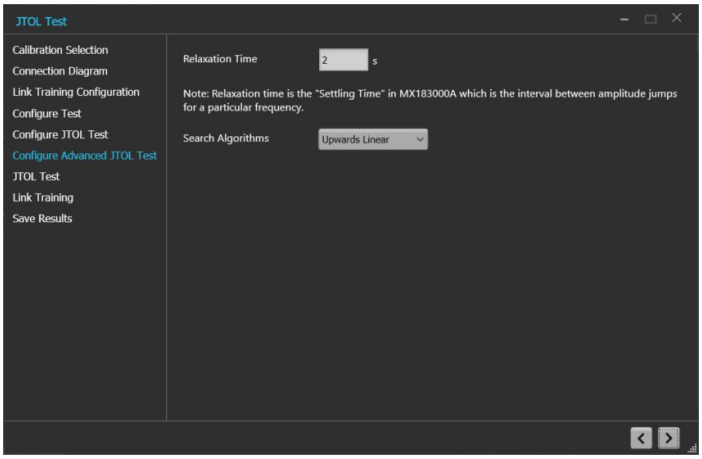

Figure 13: Different margin search algorithm settings for JTOL test

Ordering information

Table 1: PCIe Gen5 Base Rx

Item	Vendor	Type	R/O	Qty	Description	Notes
DPS75004SX	Tektronix	Equipment	Required	1	Dual-Stack 50 GHz Sx Scope	50 G or better[1]
DPO7RFK2	Tektronix	Tek accessory	Required	2	Attenuator kit	Attenuator kit + DC blocks
103047400	Tektronix	Tek accessory	Required	2	Connector savers (1.85 mm)	1.85 mm scope channel input connection
Anritsu MP1900A[5]	Anritsu	3rd party equipment	Required	1	Bit Error Rate Tester (BERT)[2]	Configuration provided by 3rd party
DJA	Tektronix	Equipment SW option	Required	1	DPOJET advanced option	DPOJET advanced option
SDLA64	Tektronix	Equipment SW option	Required	1	Serial Data Link Analysis (SDLA) Software	Serial Data Link Analysis (SDLA) Software
174-6659-01	Tektronix	Tek accessory	Required	1 pr	Cable; SMA - SMP cable pair	Refclk connection between DUT & BERT
PMCABLE1M	Swiftbridge	Tek accessory	Required	2 pr	Cable; 2.92-to-2.92 mm, Straight, 1.5 ps phase-matched, 40 GHz	Equipment connections to relica channel & DUT
Gen5 Base Test Fixture Set	PCI-SIG	Test fixtures	Required	1	Gen 5 Base Rev3 Test Fixtures[3]	Rev3 is Meg6 material with MMPX connectors[4]
RXSW-XXX-PCI5	Tektronix	SW option	Required	1	PCIe Gen5 Receiver Software	Select from Node locked Perpetual /1 year subscription

Table 2: PCIe Gen5 CEM LEQ

Item	Vendor	Type	R/O	Qty	Description	Notes
DPS75004SX	Tektronix	Equipment	Required	1	Dual Stack 50 GHz Sx scope	50 G or better[1]
DPO7RFK2	Tektronix	Tek accessory	Required	2	Attenuator kit	Attenuator kit + DC blocks
103047400	Tektronix	Tek accessory	Required	2	Connector savers (1.85 mm)	1.85 mm scope channel input connection
Anritsu MP1900A[5]	Anritsu	3rd party equipment	Required	1	Bit Error Rate Tester (BERT) [2]	Configuration provided by 3rd party
DJA	Tektronix	Equipment SW option	Required	1	DPOJET advanced option	DPOJET advanced option
SDLA64	Tektronix	Equipment SW option	Required	1	Serial Data Link Analysis (SDLA) software	Serial Data Link Analysis (SDLA) software
PMCABLE1M	Tektronix	Tek accessory	Required	2 pr	Cable; 2.92-to-2.92 mm, straight, 1.5 ps phase-matched, 40 GHz	Equipment connection to fixtures and DUT

Table continued…

1 If ATI channels will be used for refclk measurements they will need Option Key 4 (50 XL)

2 Cables required for connection between BERT modules shall be included for the 3rd party vendor

3 Gen5 BaseTest Fixtures are not backwards compatible for Gen3 & Gen4 Base Rx

4 It is assumed MMPX cables and MMPX to SMA adaptor cables for test fixture connections are included with the fixture kit

5 Configuration for BERT provided by 3rd party vendor

Item	Vendor	Type	R/O	Qty	Description	Notes
174-6663-01	Tektronix	Tek accessory	Required	1 pr	Cable; 2.92-to-2.92 mm, straight, 1.5 ps phase-matched, 500 mm, 40 GHz	Signal connection between scope and BERT for Tx LEQ
174-6666-01	Tektronix	Tek accessory	Required	2 pr	Cable; SMA-to-SMA, Right Angle-Right Angle, 500 mm	Signal connection between scope and BERT for Tx LEQ & Trigger
174-6659-01	Tektronix	Tek accessory	Required	1 pr	Cable; SMA - SMP cable pair	Refclk connection between DUT & BERT
MPR40M	Fairview Microwave	3rd party	Required	2	Power divider	Split signal from DUT Tx to the scope and Error Detector
C7035	CentricRF	3rd party	Optional	4	Right Angle Male-Female 2.92 mm adapter	Cable management
C7049	CentricRF	3rd party	Required	3	2.92 mm Male to 2.92 mm Male adaptor	Power divider output to scope input
Redriver	3rd party	3rd party equipment	Optional	1	Active Gen5 Redriver (back channel equalization)[6]	High loss back channels (DUT Tx to Error Detector) may need EQ
PowerUSB - Basic	PowerUSB	3rd party	Optional	1	Power USB Power Strip	Automate DUT power cycle
TF-PCIE5-CEM-X16	Tektronix or PCI-SIG	Test fixtures	Required	1	Gen 5 CEM Test fixtures[7]	Tektronix fixtures are not officially approved by PCI-SIG[4]
RXSW-XXX-PCI5	Tektronix	SW option	Required	1	PCIe Gen5 Receiver software	Select from Node locked Perpetual /1 year subscription

Host system software requirements Microsoft Windows 10

CE Marking Not Applicable.

Tektronix is registered to ISO 9001 and ISO 14001 by SRI Quality System Registrar.

6 Another matched pair of cables (e.g. 174-6663-xx) will be required if the Active redriver is used for Rx or Tx LEQ

7 Gen5 CEM Test Fixtures are not backwards compatible for Gen3 & Gen4 CEM Rx

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For Further Information. Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit *www.tek.com*.

25 Feb 2021 61W-73782-0
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