TEKTRONIX, INC

Technical Reference

DPOJET Option SAS3
SAS3 Measurements and Setup Library

Method of Implementation(MOI) for Verification, Debug and Characterization

Version 1.1

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Revision History				
Version	**Issue Date**	**Author**	**Pages**	**Nature of Change (include DDTs # if appropriate)**
0.1	05/08/12	Nitin Jhanwar	All	Initial draft release for internal review
0.2	20/09/12	Abhik Misra	All	Updated as per spec Working Draft Serial Attached SCSI - 3 (SAS-3) T10/2212-D Revision 02a
0.3	01/10/12	Abhik Misra	23, 24 &25	Common mode spectrum as per Spec 02a
0.4	29/04/13	Abhik Misra	All	Updated to include SAS1 and SAS2 measurements.
0.5	08/05/13	Abhik Misra	1	Introduction
0.6	09/07/13	Abhik Misra	1, 12 & 68	SSC mod type, added Live setup files
1.0	15/07/13	Abhik Misra	All	Updated as per spec Working Draft Serial Attached SCSI - 3 (SAS-3) Revision 05d
1.1	15/06/15	Nitin Jhanwar	All	Updated WDP and SAS Eye Opening measurement

Table of Contents

1 INTRODUCTION

The following table summarizes the electrical physical layer tests required on SAS Gen-3 Devices

Sl No	Test ID	Measurement Name	Applicable			Pattern Type	Unit	Limits			
			Applicable on Gen1	Applicable on Gen2	Applicable on Gen3			Gen1 Limits (1.5G)	Gen1 Limits(3G)	Gen2 Limits(6G)	Gen3 Limits(12G)
Group 1 – Tx OOB Signaling											
1	5.1.1	Tx Maximum Noise During OOB Idle	Yes	Yes	Yes	OOB	mV	<=120	<=120	<=120	<=120
2	5.1.2	Tx OOB Burst Amplitude	Yes	Yes	Yes	OOB	mV	>=240 & <=1600	>=240 & <=1600	>=240 & <=1600	>=240 & <=1600
3	5.1.3	Tx OOB Offset Delta	Yes	Yes	Yes	OOB	mV	>= -25 & <=25	>= -25 & <=25	>= -25 & <=25	>= -25 & <=25
4	5.1.4	Tx OOB Common Mode Delta	Yes	Yes	Yes	OOB	mV	>= -50 & <=50	>= -50 & <=50	>= -50 & <=50	>= -50 & <=50
Group 2 – Tx Spread Spectrum Clocking (SSC) Requirements											
5	5.2.1	Tx SSC Modulation Type	Yes	Yes	Yes	D10.2		NA	NA	NA	NA
6	5.2.2	Tx SSC Modulation Frequency	Yes	Yes	Yes	D10.2	KHz	>=30 & <=33	>=30 & <=33	>=30 & <=33	>=30 & <=33
7	5.2.3	Tx SSC Modulation Deviation	Yes	Yes	Yes	D10.2	ppm	+/- 2300 center spread, 0 no spread & +0/-2300 down spread	+/- 2300 center spread, 0 no spread & +0/-2300 down spread	+/- 2300 center spread, 0 no spread & +0/-2300 down spread	+/- 1000 center spread, 0 no spread & +0/-1000 down spread
8	5.2.4	Tx SSC Modulation Balance	Yes	Yes	Yes	D10.2	ppm	<288	<288	<288	<288
9	5.2.5	Tx SSC DFDT	Yes	Yes	Yes	D10.2	ppm/us	>= -850 & <=850	>= -850 & <=850	>= -850 & <=850	>= -850 & <=850
Group 3 – Tx NRZ Data Signaling Requirements											
10	5.3.1	Tx Physical Link Rate Long Term Stability	Yes	Yes	Yes	D10.2	ppm	>= -100 & <=100	>= -100 & <=100	>= -100 & <=100	>= -100 & <=100
11	5.3.2	Tx Common Mode RMS Voltage	Yes	Yes	Yes	CJTPAT	mV	<30	<30	<30	<30
12	5.3.3	Tx Common Mode Spectrum	Yes	Yes	Yes	CJTPAT		Below freq mask	Below freq mask	Below freq mask	Below freq mask
13	5.3.4	Tx Peak-to-Peak Voltage	Yes	Yes	Yes	D30.3	mV	>=850 & <=1200	>=850 & <=1200	>=850 & <=1200	>=850 & <=1200
14	5.3.5	Tx VMA (Voltage Modulation Amplitude)	Yes	Yes	Yes	K28.5	mV	>=600	>=600	>=600	>=80
15	5.3.6	Tx Equalization	Yes	Yes	No	K28.5	dB	>=2 & <=4	>=2 & <=4	>=2 & <=4	NA
16	5.3.7	Tx Rise Time	Yes	Yes	Yes	D10.2	ps	>166.67	>83.33	>41.67	>20.83
17	5.3.8	Tx Fall Time	Yes	Yes	Yes	D10.2	ps	>166.67	>83.34	>41.68	>20.84
18	5.3.9	Tx Random Jitter (RJ)	Yes	Yes	Yes	D24.3	ps	<=7.143	<=3.571	<=1.786	<=0.893
19	5.3.10	Tx Total Jitter (TJ)	Yes	Yes	Yes	D24.3	ps	<166.67	<83.33	<41.67	<20.83
20	5.3.11	Tx Waveform Distortion Penalty (WDP)	Yes	Yes	No	Scrambled 0	dB	<=4.5	<=7	<=13	NA
21	5.3.12	Tx SAS3_EYEOPENING	No	No	Yes	Scrambled 0	%	NA	NA	NA	>= 45
22	5.3.13	Tx Pre Cursor Equalization Ratio	No	No	Yes	K28.5	V/V	NA	NA	NA	>=1 & <=1.67
23	5.3.14	Tx Post Cursor Equalization Ratio	No	No	Yes	K28.5	V/V	NA	NA	NA	>=1 & <=3.33
24	5.3.15	Tx Vhl (transition bit voltage pk-pk)	No	No	Yes	K28.5	mV	NA	NA	NA	>=850 & <=1200
25	5.3.16	Tx Unit Interval	Yes	Yes	Yes	D10.2	ps	>=666.43 & <=670.23	>=333.22 & <=335.12	>=167.12 & <= 166.61	>=83.30 & <=83.77

This MOI contains the procedure for testing electrical transmitter testing for SAS specification. The tests covered in this document are limited to the Transmitter tests made with the DSA70000 C/D Series Real Time Oscilloscopes.

This document provides the details on
1. Equipment required for testing
2. Setting up the test equipment to make measurements consistent with the SCSI Specification.
3. Report Generation for Compliance Reporting.

In this MOI, the Transmitter tests are grouped by oscilloscope test setup that is dictated by the test pattern required and Scope Settings for each measurement. The test setup uses only two channel of the Oscilloscope. This grouping was done to provide 100 Ghz Sampling rate as 100 Ghz sampling is only available for either odd channels (Ch1,Ch3) or even channels(Ch2,Ch4) on the C and D series scopes of Tektronix.

1.1 Required Equipment

The Following Equipment is required for Transmitter Testing
1. Tektronix DSA/MSO/DPO70000 C/D Series Oscilloscope (12.5 GHz and above for 1.5 , 3 and 6Gbps data rate of SAS and 20 Ghz and above for 12Gbps data rate of SAS)
2. Tektronix Option DJA (DPOJET - Jitter and Eye Test) and SAS3 (SAS3 12 Gb/s TX Test Software).
3. Wilder fixture
4. Pair of matched low loss, high bandwidth SMA Cables

1.2 Oscilloscope

This document is developed using Tektronix digital storage oscilloscopes, Model# MSO72004C 20 GHz Model. Any DSA, MSO, or DPO (C or D series) oscilloscope from Tektronix with above criteria can be used for the testing documented as long as DPOJET is installed.

1.3 Oscilloscope Setup Files

A library of setup files have been developed for the Tektronix 70000 Series scopes that provide the Setups and Limits files to be used along with DPOJET for Transmitter measurements. Once installed, the hierarchy for these files on the Scope System is as follows:

Location of Setup files:

C:\Users\Public\Tektronix\TekApplications\SAS3\Setups\1.5G
C:\Users\Public\Tektronix\TekApplications\SAS3\Setups\3G
C:\Users\Public\Tektronix\TekApplications\SAS3\Setups\6G
C:\Users\Public\Tektronix\TekApplications\SAS3\Setups\12G

Location of Limit files
C:\Users\Public\Tektronix\TekApplications\SAS3\Limits

Please refer to Section 5 for more details on how to use setup files.

2 TX SPREAD SPECTRUM CLOCKING (SSC) REQUIREMENTS

2.1 Overview

This group of tests verifies the Spread Spectrum Clocking (SSC) requirements for SAS data signaling, as defined in the SAS-3 Standard.

2.2 Test Overview

2.2.1 Tx SSC Modulation Frequency

Purpose: To verify that the SSC modulation frequency of the DUT's transmitted signaling is within the conformance limits. *(Note this test only applies to DUT's that have SSC enabled on their output signaling.)*

Discussion:

Spread spectrum clocking (SSC) is the technique of modulating the operating frequency of a transmitted signal to reduce the measured peak amplitude of radiated emissions. .The SAS Standard defines the electrical interface requirements for 12.0Gbps, 6 Gbps, 3 Gbps, 1.5 Gbps SAS devices. This includes a requirement for the modulation frequency of a device's Spread Spectrum Clocking (SSC) behavior. The peak to peak voltage of differential signal of waveform must be more than 50mv.

In this test, the SSC modulation frequency of the DUT's transmitted output signaling will be measured while the DUT is transmitting SSC. A sample of the DUT's data signaling will be captured using a real-time DSO, and will be post-processed to recover the transmitter's SSC modulation profile. The frequency of the modulation will be observed by measuring the average period over a minimum of 10 SSC cycles, and the inverse of this result will be computed to produce the modulation frequency result.

The Specs says that:

> If the SSC modulation type is not no-spreading, then the phy shall transmit within the specified maximum SSC frequency deviation with an SSC modulation frequency that is a minimum of 30 kHz and a maximum of 33 kHz.

This spec requires the DUT to send a D10.2 pattern for this measurement. D10.2 is a clock like pattern and hence there is no special requirement to manage multi UI between transitions. SSC adds phase jitter to the input waveform. From the input pattern instantaneous UI is calculated. If the DUT is able to transmit data without period jitter then removing the nominal UI from instantaneous UI will give you the SSC profile. Since all DUT transmits data with a certain amount of period jitter hence it is important to remove the non SSC related jitter component from the function which tracks the variations of the instantaneous UI from the nominal UI.

It may be noted that the measurement can potentially be performed while the DUT is transmitting any arbitrary data pattern, provided the post-processing implementation is designed to handle non-clock data patterns, which requires that any multi-UI edge-to-edge time intervals (caused by consecutive runs of multiple 1's or 0's) be divided into separate single-UI values. If the post-processing implementation does not support this ability, the measurement must be performed on a repeating 1010 data pattern.

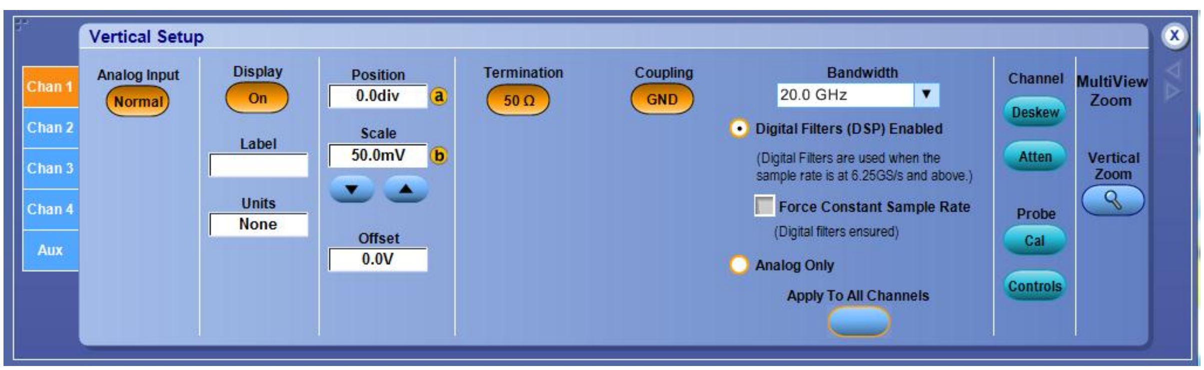
It may be noted that at 12 Gb/s one cycle of clock is 83.33 ps but one cycle of the SSC modulation is 1/30kHz=33 microsecond. Hence it takes roughly 1.8 Million reference clock cycles to complete 1 cycle of the SSC modulation. Hence the total phase change is governed by the short term phase variation that naturally occurs on a cycle by cycle basis, making SSC very difficult to observe. Hence the phase modulation trend is passed through a low pass filter. The spec recommends that the period jitter of the transmitter device is passed through a single-pole low-pass filter with a cutoff frequency of 3.7 ± 0.2 MHz.

The purpose of the lower cutoff value is to remove as much of the high-frequency artifacts from the SSC profile as possible, so that the filter output produces as smooth of a signal as possible, from which to measure the period. Any residual high-frequency content that is present on the SSC profile when the period is measured can potentially cause errors, particularly if they result in multiple crossing points at the threshold level used to determine the start and end points of the SSC profile period. Note that the exact filter cutoff value used does not have a significant effect on the result, as this measurement is effectively looking to measure the fundamental frequency of the modulation, which should be approximately 30 to 33 kHz. A 3.7 ± 0.2 MHz filter cutoff limit is a robust practical value, as it allows enough harmonic to remain such that the resulting waveform still contains the characteristic triangular SSC profile shape, but without allowing excessive high-frequency content that can cause errors in the period measurement.

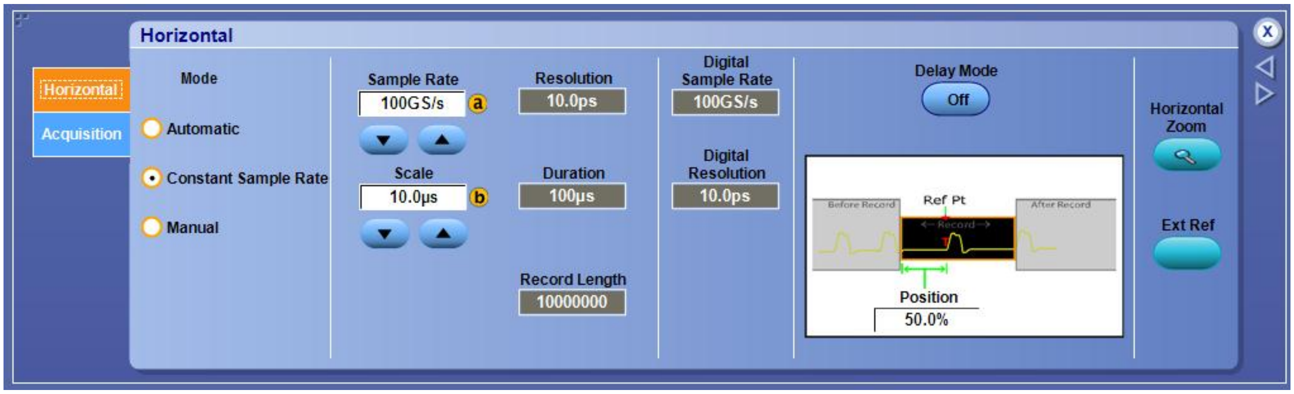
Test Procedure:

Following is the detailed setup of performing the tests:

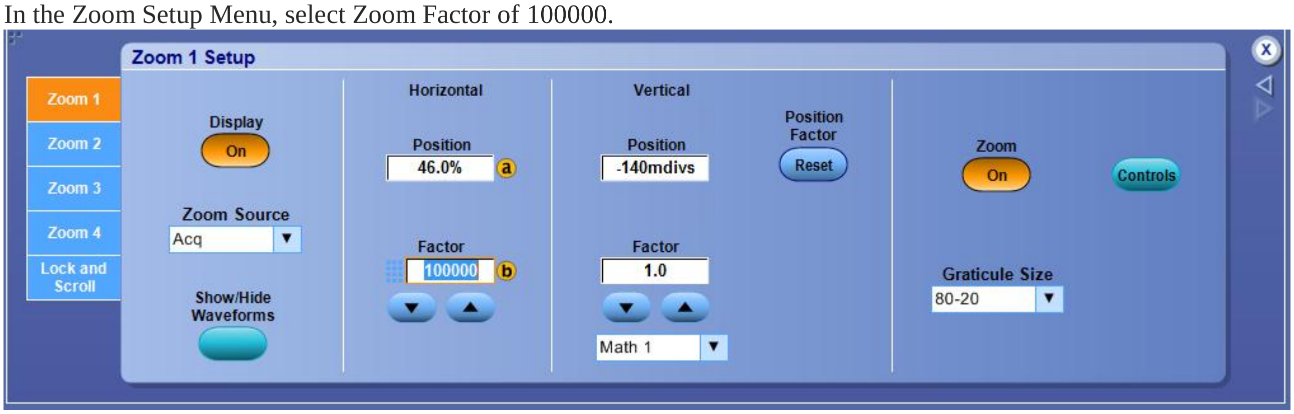
1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D



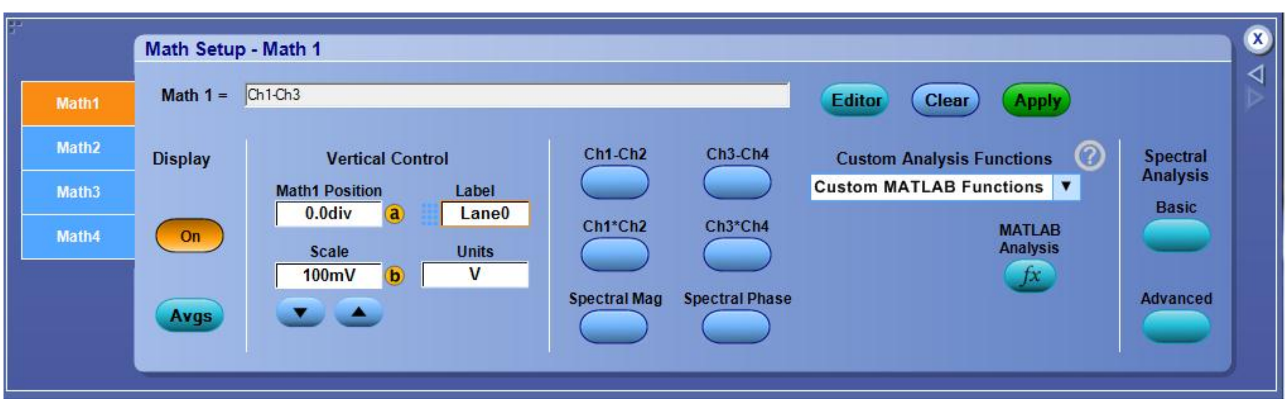
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).



10. In the Zoom Setup Menu, select Zoom Factor of 100000.

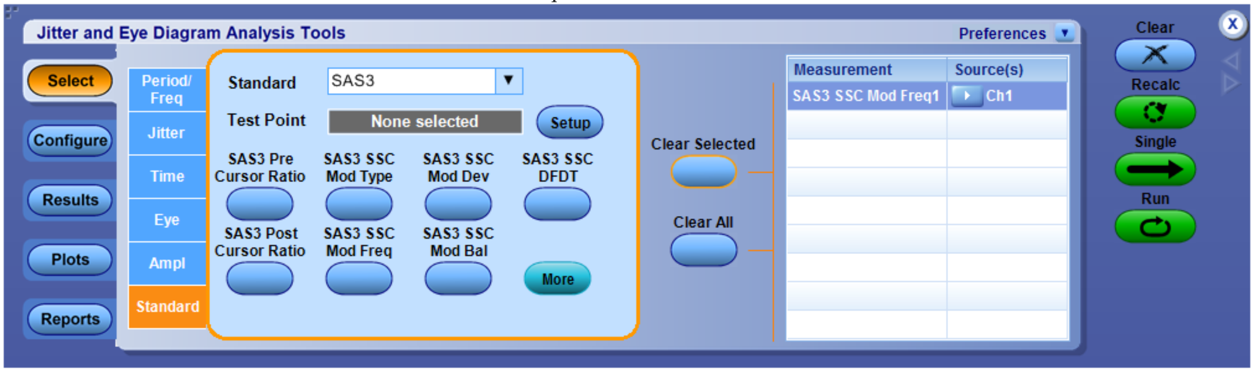


11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.



12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS3 to launch DPOJET.

13. From the Standard Tab Select SAS3 SSC Mod Freq.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits

    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The SSC modulation frequency shall be between 30 KHz and 33 KHz.

2.2.2 Tx SSC Modulation Type

Purpose: To verify the TX SSC modulation type(s) supported by the DUT.

Discussion:

The SAS Standard defines the electrical interface requirements for 12.0Gbps, 6 Gbps, 3 Gbps, 1.5 Gbps SAS devices. This includes requirements for the Spread Spectrum Clocking (SSC) modulation type, for which different requirements are defined, depending on whether the DUT is an Expander phy, or a SAS phy (i.e., non-Expander phy). The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the requirements is reproduced from the Standard in the figure below.

Table 64 — SAS phy transmitter SSC modulation types

Condition	SSC modulation type(s) [a]	
	Required	Optional
While attached to a phy that does not support SSC	No-spreading	
While attached to a phy that supports SSC	No-spreading	Down-spreading

[a] SAS phys compliant with versions of SAS standards previous to SAS-2 only transmitted with an SSC modulation type of no-spreading.

An expander phy transmits with the SSC modulation types defined in table 65.

Table 65 — Expander phy transmitter SSC modulation types

Condition	SSC modulation type(s) [a]	
	Required	Optional
While attached to a SAS phy or expander phy that does not support SSC	No-spreading	
While attached to a SAS phy or expander phy that supports SSC	No-spreading	Center-spreading
While attached to a SATA phy	No-spreading	Down-spreading

[a] Expander phys compliant with versions of SAS standards previous to SAS-2 only transmitted with an SSC modulation type of no-spreading.

As shown above, SAS devices are not normatively required to support SSC on their transmitted output signaling, and in fact are required to transmit without SSC when connected to a link partner phy that does not support reception of SSC. In other cases where the link partner supports reception of SSC, transmission of SSC is optional.

The purpose of this test is to determine the SSC capabilities of the DUT, and verify that these agree with the values claimed to be supported by the DUT manufacturer (as verification of the SSC type is critical in determining which of the additional SSC tests in this suite should be performed, and may also impact which conformance range(s) are used for certain SSC tests.

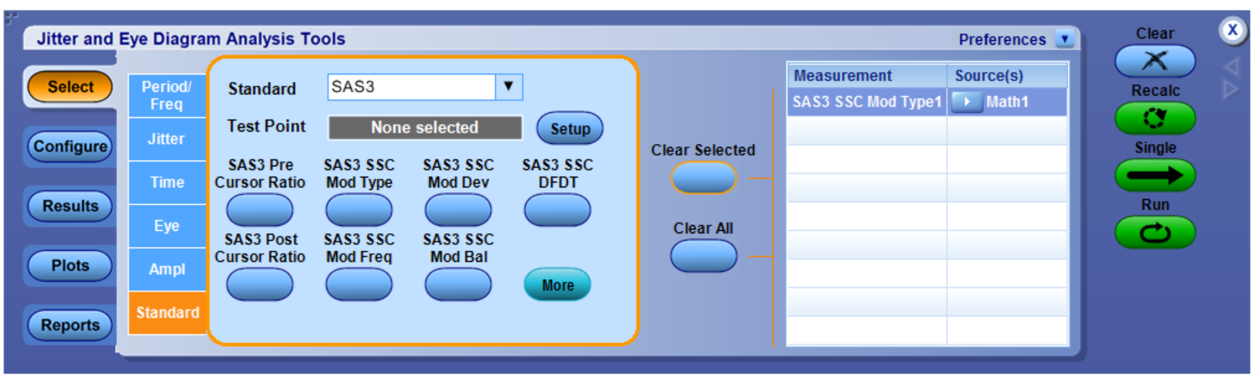
In this test, the DUT will be connected to other SAS devices that do and do not support SSC, and the established link will be inspected to determine if the proper SSC mode was established, according to the DUT's expected behavior (which must be specified by the DUT vendor upon submission of the product for testing). The DUT will be compared against the respective requirements for a SAS phy or an Expander phy, depending of the DUT type, and the exact method used to inspect the established link signaling is not explicitly specified for this test, as any method may be used that allows for verification of the presence or absence of SSC on the DUT's transmitted signal. (One method could involve using a high-impedance differential probe to sample the DUT's signaling, which can then be post-processed to determine whether or not SSC is present.)

The observed DUT behavior for connections established with all link partner types must agree with both the expected behavior as indicated by the DUT vendor, as well as the normative behavior defined by the spec in order to be considered conformant.

Test Procedure:

Following is the detailed setup of performing the tests:

1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
    i. Select 20GHz Bandwidth and press Apply to All Channels.
    ii. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select the measurement SAS3 SSC Mod Type button.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.

ii. Navigate to the folder with the file as per data rate as given below.
12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits

iii. Turn the Limits File to On.

16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

a. Output is 1 for up-spreading, 0 for center-spreading, -1 for down-spreading and -9 for no-spreading.
b. The DUT shall not transmit SSC when connected to a link partner that does not support reception of SSC.
c. When connected to SAS link partners that support SSC reception, the DUT shall transmit with the expected spreading type indicated by the DUT vendor, according to the specified requirements for the appropriate device type (i.e., Down-spreading for SAS phy DUT's, and Center-spreading for Expander phy DUT's.)
d. If the DUT is an Expander phy, it shall support the vendor-indicated behavior (Down-spreading or No-spreading) when connected to a SATA link partner.

2.2.3 Tx SSC Modulation Deviation

Purpose: To verify that the SSC modulation deviation of the DUT's transmitted signaling is within the conformance limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes requirements for the modulation deviation of a device's Spread Spectrum Clocking (SSC)[1], which is the range over which the DUT's instantaneous TX bitrate is allowed to deviate when SSC is enabled. The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the requirements is reproduced from the Standard in the figure below.

Table 61 — SSC modulation types

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

[a] This is in addition to the physical link rate long-term accuracy and tolerance defined in table 32 (see 5.8.4.3) and table 48 (see 5.8.5.3).
[b] This is only used as a receiver parameter.

In this test, the DUT SSC modulation profile is recovered in a similar way as defined in the SSC modulation frequency section. The deviation of the modulation will be determined by measuring maximum and minimum profile peak values per period, over at least 10 complete SSC cycles. From these values, the average maximum and average minimum peak values will be computed, and the results compared against the requirements listed above for the appropriate SSC modulation types.

Note that the post-processing procedure used to recover the SSC profile from the waveform data is identical to that described in Test 5.2.2, except that while Test 5.2.2 used a 200kHz filter cutoff value to isolate only the lowest harmonics of the SSC profile, this test will use the full 3.7+/-0.2MHz cutoff value in order to include the entire required range of harmonic content in the deviation measurement.

Note that in addition to specifying the deviation ranges for Center-spreading and Down-spreading modes, there is also one additional requirement defined for the Center-spreading case, which limits the maximum allowed asymmetry of the deviation around 288ppm. Refer below for the specification requirement:

The SSC modulation profile (e.g., triangular) is vendor specific, but should provide the maximum amount of electromagnetic interference (EMI) reduction. For center-spreading, the average amount of up-spreading (i.e., > 0 ppm) in the SSC modulation profile shall be the same as the average amount of down-spreading (i.e., < 0 ppm). The amount of asymmetry in the SSC modulation profile shall be less than 288 ppm.

As stated in the specification text in the figure above, the difference between the amount of up-spreading (i.e., averaged maximum peak level) and down spreading (averaged minimum peak level) must be no greater than

288ppm. The average peak levels are calculated over at least 10 SSC cycles. For the purposes of this test, this is formally calculated as:

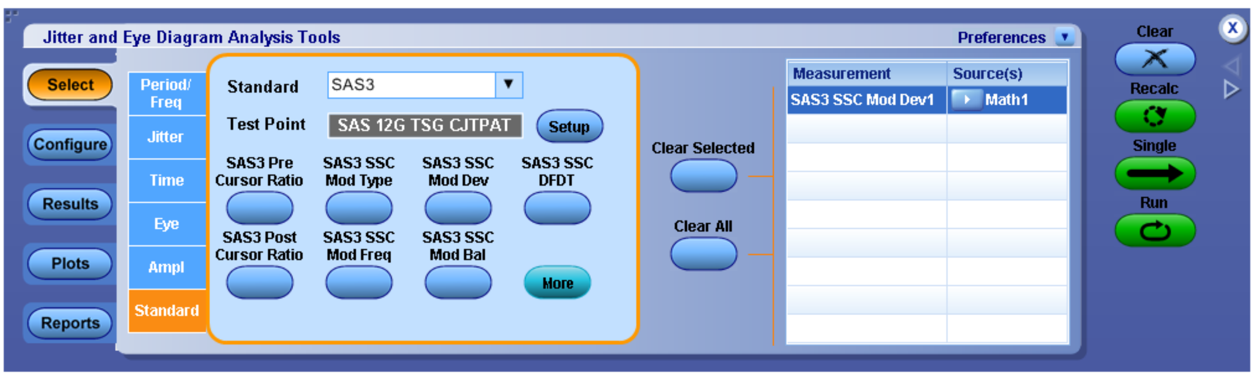
Deviation Asymmetry = abs (averaged max peak level + averaged minimum peak value).

(For example, if the averaged maximum peak value is measured to be +2100ppm, and the averaged lower peak level is -2200ppm, the Deviation Asymmetry would equal abs (2100 + -2200) = 100ppm.

Test Procedure:

Following is the detailed setup of performing the tests:

1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   i. Select 20GHz Bandwidth and press Apply to All Channels.
   ii. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    v. Select Math1 tab
    vi. Choose Ch1-Ch3
    vii. Set Scale to 100mv.
    viii. Label Math1 as Lane0.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select the measurement SAS3 SSC Mod Dev buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.

16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The Freq Deviation will be within +1000ppm and -1000 ppm from nominal frequency.

2.2.4 Tx SSC Modulation Balance

Purpose: To verify that the SSC modulation deviation of the DUT's transmitted signaling is within the conformance limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes requirements for the modulation deviation of a device's Spread Spectrum Clocking (SSC)[1], which is the range over which the DUT's instantaneous TX bitrate is allowed to deviate when SSC is enabled. The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the requirements is reproduced from the Standard in the figure below.

Table 61 — SSC modulation types

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

[a] This is in addition to the physical link rate long-term accuracy and tolerance defined in table 32 (see 5.8.4.3) and table 48 (see 5.8.5.3).
[b] This is only used as a receiver parameter.

In this test, the DUT SSC modulation profile is recovered in a similar way as defined in the SSC modulation frequency section. The deviation of the modulation will be determined by measuring maximum and minimum profile peak values per period, over at least 10 complete SSC cycles. From these values, the average maximum and average minimum peak values will be computed, and the results compared against the requirements listed above for the appropriate SSC modulation types.

Note that the post-processing procedure used to recover the SSC profile from the waveform data is identical to that described in Test 5.2.2, except that while Test 5.2.2 used a 200kHz filter cutoff value to isolate only the lowest harmonics of the SSC profile, this test will use the full 3.7+/-0.2MHz cutoff value in order to include the entire required range of harmonic content in the deviation measurement.

Note that in addition to specifying the deviation ranges for Center-spreading and Down-spreading modes, there is also one additional requirement defined for the Center-spreading case, which limits the maximum allowed asymmetry of the deviation around 288ppm. Refer below for the specification requirement:

The SSC modulation profile (e.g., triangular) is vendor specific, but should provide the maximum amount of electromagnetic interference (EMI) reduction. For center-spreading, the average amount of up-spreading (i.e., > 0 ppm) in the SSC modulation profile shall be the same as the average amount of down-spreading (i.e., < 0 ppm). The amount of asymmetry in the SSC modulation profile shall be less than 288 ppm.

As stated in the specification text in the figure above, the difference between the amounts of up-spreading (i.e., averaged maximum peak level) and down spreading (averaged minimum peak level) must be no greater than 288ppm. The average peak level is calculated over at least 10 SSC cycles. For the purposes of this test, this is formally calculated as:

Deviation Asymmetry = abs (averaged max peak level + averaged minimum peak value).

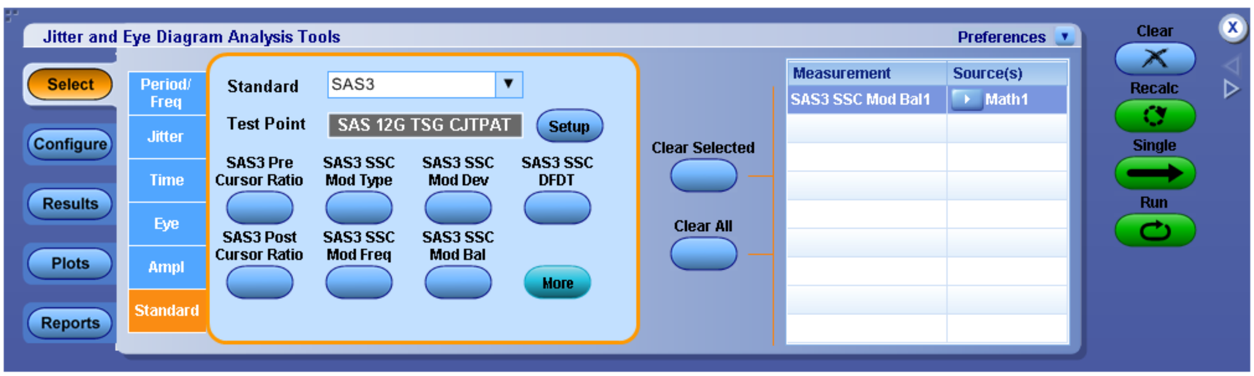
(For example, if the averaged maximum peak value is measured to be +2100ppm, and the averaged lower peak level is -2200ppm, the Deviation Asymmetry would equal abs (2100 + -2200) = 100ppm.)

Test Procedure:

Following is the detailed setup of performing the tests:

1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device

3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   iv. Select 20GHz Bandwidth and press Apply to All Channels.
   v. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    ix. Select Math1 tab
    x. Choose Ch1-Ch3
    xi. Set Scale to 100mv.
    xii. Label Math1 as Lane0.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select the measurement SAS3 SSC Mod Bal buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The Balance will be less than 288ppm.

2.2.5 Tx SSC DFDT

Purpose: To verify that the maximum short-term rate of change (slope) of the SSC modulation profile (also referred to as 'dF/dt') is less than the maximum recommended value.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes a specification for the slope of the modulation deviation of a device's SSC profile. (Note this parameter is also known by the name 'dF/dt', or simply DFDT, though the SAS-3 Standard does not use either of these terms.) The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the requirement is reproduced from the Standard in the figure below.

The slope of the frequency deviation should not exceed 850 ppm/µs when computed over any 0.27 ± 0.01 µs interval of the SSC modulation profile, after filtering of the transmitter device jitter output by a single-pole low-pass filter with a cutoff frequency of 3.7 ± 0.2 MHz. Alternatively, the transmitter device jitter may be filtered by the closed-loop transfer function of a measurement equipment's PLL that is compliant with the JTF.

The slope is computed from the difference equation:

slope = (f(t) - f(t - 0.27 µs)) / 0.27 µs

where:

f(t) is the SSC frequency deviation expressed in ppm.

A ± 2 300 ppm triangular SSC modulation profile has a slope of approximately 310 ppm/µs and meets the informative slope specification. Other SSC modulation profiles (e.g., exponential) may not meet the slope requirement. A modulation profile that has a slope of ± 850 ppm/µs over 0.27 µs creates a residual jitter of approximately 16.7 ps (i.e., 0.10 UI at 6 Gbps) after filtering by the JTF. This consumes the total BUJ budget of the transmitter device, which does not allow the transmitter device to contribute any other type of BUJ.

In this test, the slope of the SSC profile will be computed using post-processing techniques. The profile used will be the profile that was measured in the Modulation deviation and Balance test. An additional processing step will be performed on the profile, where a 'sliding window' will be moved across the profile values to compute the slope. This window will have a width of 0.27us, and the slope value for each horizontal point will be calculated using the equation defined above.

The DFDT result must be no greater than 850ppm/us in order to be considered conformant to the informative recommendation of the Standard.

The following are the steps needed in the algorithm:

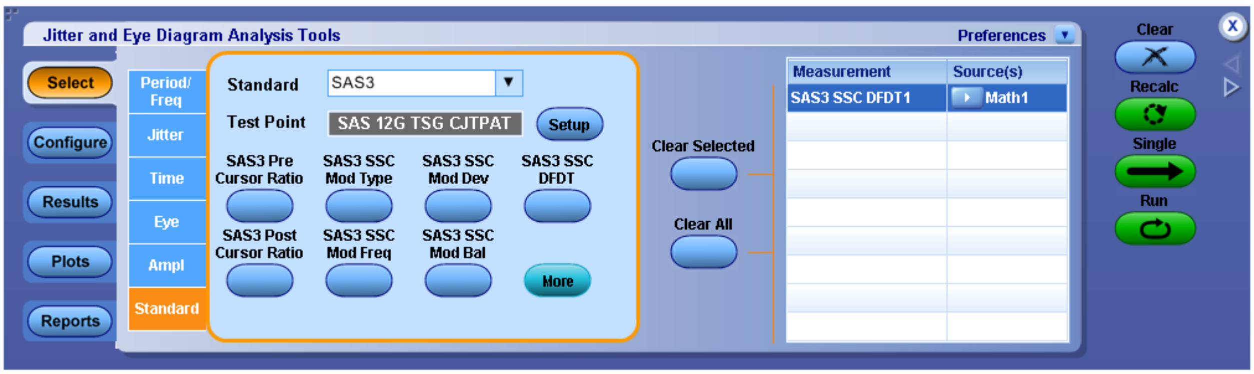
1. Obtain the SSC profile data similar to the way as discussed in Test 5.2.3
2. Post-process the profile data as described above, to create the DFDT profile.
3. Measure and record the peak DFDT value.

Test Procedure:

Following is the detailed setup of performing the tests:

1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.

8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select the measurement SAS3 SSC DFDT buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The peak DFDT shall not exceed +/-850ppm/us.

3 TX DATA SIGNALLING REQUIREMENT

3.1.1 TX Physical Link Rate Long Term Stability

Purpose: To verify that the long term stability of the DUT transmitter's physical link rate is within the conformance limits.

Discussion:

The SAS-2 Standard defines the electrical interface requirements for 6.0Gbps SAS devices. This includes a requirement for the physical link rate long-term stability [1], which is one metric for characterizing the quality and consistency of the transmitter's reference clock. The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the specification is reproduced in the figure below.

Table 32 — Transmitter device general electrical characteristics

Characteristic	Units	1.5 Gbps	3 Gbps	6 Gbps	12 Gbps
Physical link rate long-term accuracy [a] at IT and CT	ppm	± 100			
Physical link rate SSC modulation at IT and CT	ppm	See table 62 and table 63 in 5.8.6.2			
Maximum transmitter device transients [b]	V	± 1.2			

[a] Physical link rate long-term accuracy should be measured using a frequency counter with adequate resolution (e.g., 100 Hz).
[b] See 5.8.2 for transient test circuits and conditions.

Note that the specification defines conformance tolerances of +/- 100ppm for the physical link rate, however it is important to clarify specifically what this means, and also how it is measured, for the purposes of this test.

(Also note that this test is only applicable to DUT's when their TX SSC Type is configured for No Spreading.)

First, the use of ppm (Parts per Million) must be clarified, as ppm is by definition a tolerance with respect to a defined reference. For the purposes of this test, the reference is understood to be the nominal (i.e., 'ideal') bit rate specified for the given speed class (e.g., 1.5Gbps, 3.0 Gbps, 6.0Gbps or 12 Gbps exactly). The table below shows how the link rate tolerances in ppm translate to bit rate tolerances in Kbps for 1.5Gbps, 3.0Gbps, and 6.0Gbps devices.

Table 5. 3.1-1: Link Rate/Bit Rate Equivalent Tolerances

Link Rate Tolerance	Bit Rate Tolerance - 1.5Gbps	Bit Rate Tolerance - 3.0Gbps	Bit Rate Tolerance - 6.0Gbps	Bit Rate Tolerance - 12.0Gbps
+/- 100 ppm	+/- 150 Kbps	+/- 300 Kbps	+/- 600 Kbps	+/- 1200 Kbps

Second, the meaning of 'stability' must be clarified, as well as the methodology used to measure it. For the purposes of this test, stability is defined as the short-term accuracy of the transmitted bitrate of the device. In other words, the bitrate at any given point in time must be within the conformance limits.

However, in terms of measurement, even this definition is insufficient by itself, as how the instantaneous bitrate is measured can affect the numerical measurement result. Therefore, a more explicit definition and procedure must be specified for test purposes.

For the purpose of this test, the procedure used will consist of acquiring a sample of the DUT's transmitted differential signal using a real-time DSO, while the DUT is transmitting a repeating 1010 data pattern.

The differential waveform will then be post-processed to determine the TX Link Rate Long-Term Stability, using the following algorithm: First, the time points will be found where the differential signal crosses zero volts (i.e., zero crossings). A diff (difference) operation will be performed on this array of time values to produce an array of Unit Interval (UI) widths.

Note that because of the relatively low resolution of the sampled waveform (i.e., number of samples per UI), the computed UI values at this point will contain a certain amount of error. If the inverse of these UI values is computed, one could consider them to reflect the instantaneous bitrate of the transmitter. This is partially true, however the results would contain a high degree of high-frequency error, caused by the limited resolution of the sampling rate, and hence the UI accuracy. However, it is possible to remove this error by filtering the data using a low-pass filter, which will reveal the underlying lower-frequency stability of the link rate.

One important detail however, is that the cutoff frequency, as well as the exact implementation of the filter can have a significant impact on the result. The Standard actually specifies a cutoff frequency of 3.7 +/-0.2 MHz for the filter used for measurement of the slope of the frequency deviation (a.k.a., 'df/dt')[2], hence the same filter will be used here to compute the frequency deviation data. (For the df/dt measurement, see Test 5.2.4). Also, although the Standard does not explicitly specify the order of the filter used in this case, a 2nd-order Butterworth filter will be used.

The inverse of the UI values will be taken to produce an array of instantaneous frequency values. The test filter will then be applied to the inverse of the UI values. Note that in this case the 'sample rate' of the data is one value per UI, so the test filter must be designed accordingly in order to produce the desired 3.7 MHz cutoff.

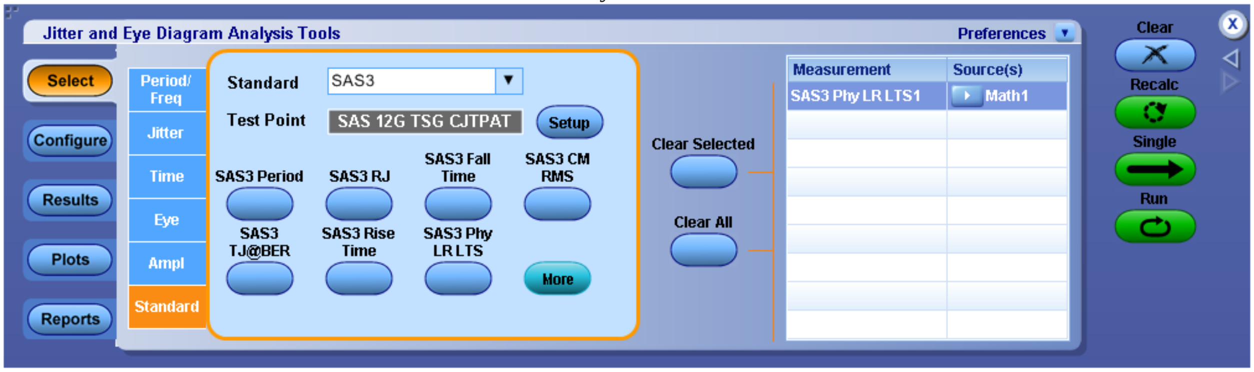
The resulting waveform that is produced at the output of the test filter will then be converted to ppm. This result will represent the instantaneous bitrate of the DUT. **All of the values must be between +100ppm and -100ppm of 12.0Gbps in order to be considered conformant.**

Test Procedure:
Following is the detailed setup of performing the tests:

1. Configure the DUT so that it is sourcing D10.2 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.

v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
vi. Label Math2 as Lane1.

12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select the measurement SAS3 Phy LR LTS buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The maximum and minimum TX bitrate values shall be within +/- 100ppm for all Gen of SAS3.

3.1.2 TX Common Mode RMS Voltage

Purpose: To verify that the common-mode RMS voltage of the DUT's transmitter device is less than the maximum allowed value.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0 Gbps SAS devices. This includes a requirement for the TX common-mode RMS voltage, which is a limit on the broadband RMS common-mode voltage. The peak to peak voltage of differential signal of waveform must be more than 50mv.A copy of the specification is reproduced in Appendix A.

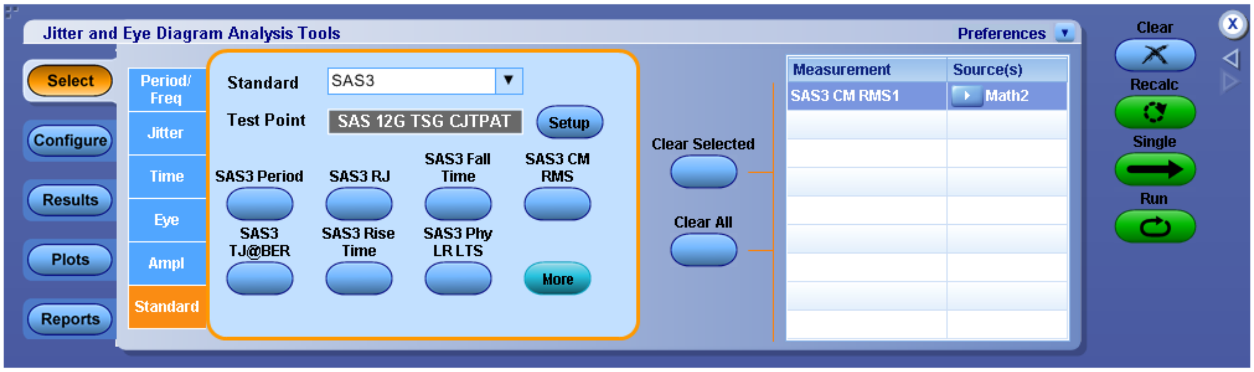
Whereas the differential signal is defined as the **difference** of the TXp(positive waveform) and TXn (negative) waveforms, a transmitter's common-mode signal is mathematically computed as the **average** of the TXp and TXn waveforms, i.e., Vcm =(TXp + TXn)/2. The characteristics of a device's common-mode signal are valuable to look at primarily because the common-mode signal provides a measure of how symmetric the positive and negative halves are of the differential signal. The common mode signal will also have high rms value if there is Skew between the positive and negative lanes.

Note: This measurement can only be performed on the Single ended input.

In an ideal transmitter, The TXn signal would be a perfectly inverted copy of the TXp signal. Thus, the average of the two signals would be exactly zero at all points of the waveform. In reality however, many characteristics of the driver can introduce asymmetry into the signals. Any difference in amplitude, rise/fall time, overshoot, and also timing skew between the two halves of the differential signal will result in a residual common- mode signal remaining when the average is taken. This is important, as one of the benefits of differential signaling is the decreased EMI that is introduced when the opposite fields from the positive and negative signaling halves serve to cancel each other out. If there is imbalance between the two signal halves, this cancellation is reduced, and radiated EMI is increased.

Test Procedure:

1. Configure the DUT so that it is sourcing CJTPAT signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output is connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Math1 = (Ch1+Ch3)/2
    iii. Set Scale to 40mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2+Ch4)/2 tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select SAS 3 Standard and within SAS 3 select SAS3 CM RMS button.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The RMS value of the common-mode signal must be less than or equal to 30mV in order to be considered conformant.

3.1.3 TX Common Mode Spectrum

Purpose: To verify that the common-mode spectral characteristics of the DUT transmitter device are below the maximum allowed limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes a requirement for the TX common-mode spectral limit, which places limits on the spectral content of the transmitted common-mode signal energy from the transmitter device. The peak to peak voltage of differential signal of waveform must be more than 50mv. A copy of the specification is reproduced from the Standard in the figure below.

Table 39 — Transmitter device common mode voltage limit characteristics

Characteristic	Reference	L [a] (dBmV) [b]	N [a] (dBmV) [b] [c]	S [a] (dBmV/decade) [b]	f_{min} [a] (MHz)	f_{max} [a] (GHz)
Spectral limit of common mode voltage [d]	Figure 126	12.7	26.0	13.3	100	6.0

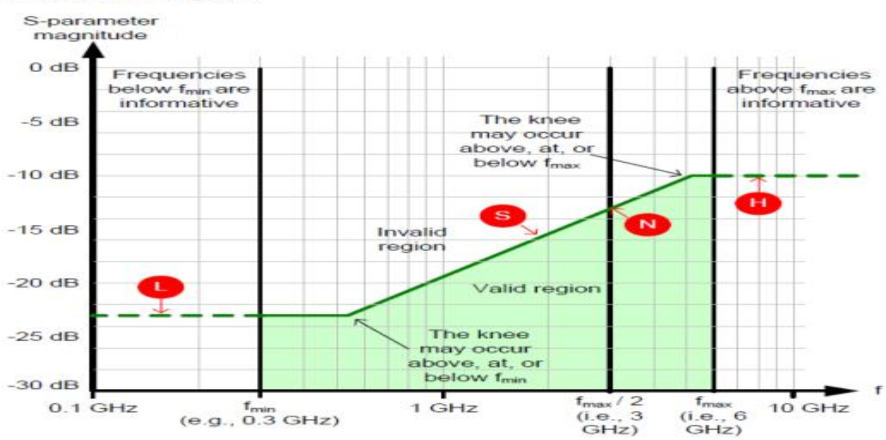
[a] See figure 4 in 5.2 for definitions of L, N, S, f_{min}, and f_{max}. For this parameter, units of dBmV is used in place of dB.
[b] For dBmV, the reference level of 0 dBmV is 1 mV (rms). Hence, 0 dBm is 1 mW which is 158 mV (rms) across 25 ohm (i.e., the reference impedance for common mode voltage) which is 20 × $\log_{10}(158)$ = +44 dBmV. +26 dBmV is therefore -18 dBm.
[c] Maximum value at the Nyquist frequency (i.e., 3 GHz) (see figure 126).
[d] The transmitter device common mode voltage shall be measured with a 1 MHz resolution bandwidth through the range of 100 MHz to 6 GHz with the transmitter device output of CJTPAT (see Annex A). The end points of the range shall be at the center of the measurement bandwidth.

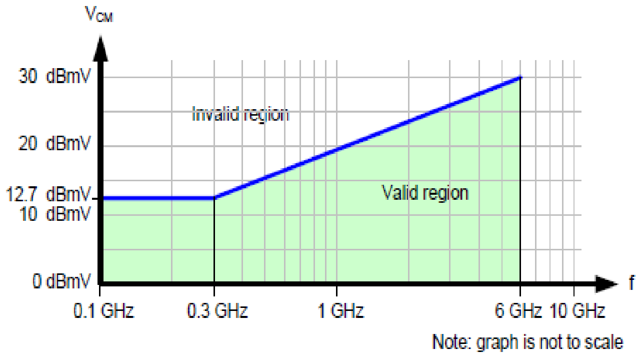
Table 44 — 12 Gbps transmitter device common mode voltage limit characteristics

Characteristic	Reference	L [a] (dBmV) [b]	N [a] (dBmV) [b] [c]	S [a] (dBmV/decade) [b]	H [a] (dBmV) [b]	f_{min} [a] (MHz)	f_{max} [a] (GHz)
Spectral limit of common mode voltage [d]	Figure 132	12.7	26.0	13.3	30.0	100	9.0

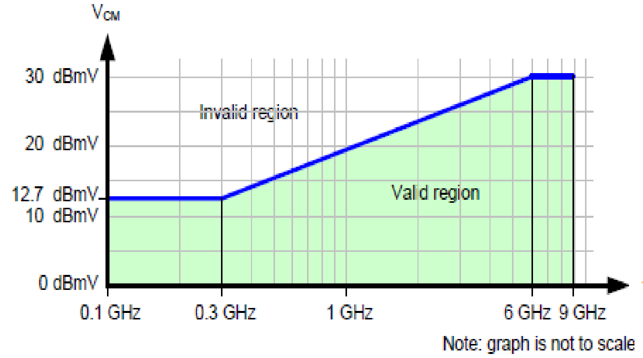
[a] See figure 4 in 5.2 for definitions of L, N, S, f_{min}, and f_{max}. For this parameter, units of dBmV is used in place of dB.
[b] For dBmV, the reference level of 0 dBmV is 1 mV (rms). Hence, 0 dBm is 1 mW which is 158 mV (rms) across 25 ohm (i.e., the reference impedance for common mode voltage) which is 20 × $\log_{10}(158)$ = +44 dBmV. +26 dBmV is therefore -18 dBm.
[c] Maximum value at 3 GHz (see figure 132).
[d] The transmitter device common mode voltage shall be measured with a 1 MHz resolution bandwidth through the range of 100 MHz to 6 GHz with the transmitter device output of CJTPAT (see Annex A). The end points of the range shall be at the center of the measurement bandwidth.

Figure 4 shows the values in a graph.





1.5 Gbps, 3 Gbps, and 6 Gbps Transmitter device common mode voltage limit



12 Gbps transmitter device common mode voltage limit

Figure: Transmitter device common mode voltage limit

Usually the Common Mode spectral content will show a peak at fundamental frequency and the second harmonics. Hence it will be sufficient to compare the Spectrum Amplitude at the first and second harmonics. Beyond the second harmonics the spectral content are not considered.

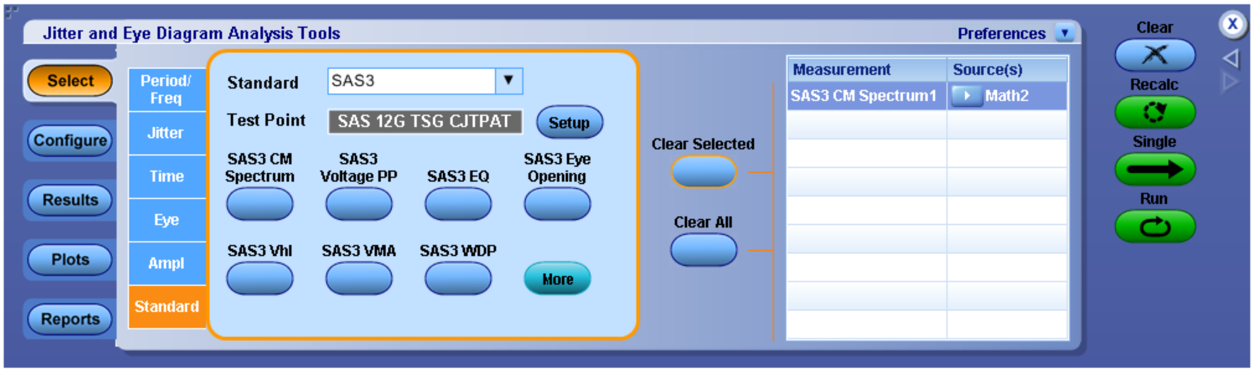
There are hence two measurements corresponding to this test. One measurement returns the Common Mode spectrum amplitude at the fundamental frequency and the other returns the spectrum amplitude at the second harmonic.

In this test, the frequency spectrum of the DUT's common-mode signal will be measured while the DUT is transmitting the CJTPAT pattern into the Zero-Length Test Load.

The spectrum the common-mode signal must be less than the specified limits in order to be considered conformant.

Test Procedure:

1. Configure the DUT so that it is sourcing CJTPAT signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
    i. Select 20GHz Bandwidth and press Apply to All Channels.
    ii. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Math1 = (Ch1+Ch3)/2
    iii. Set Scale to 40mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2+Ch4)/2 tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS3 to launch DPOJET.
13. From the Standard Tab Select SAS 3 Standard and within SAS3 select **SAS3 CM Spectrum** button.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
        12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
        6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
        3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
        1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The spectrum of the common mode signal should be less than Limit lines (red colored line). We are following the SAS3 spec to define this limit lines.

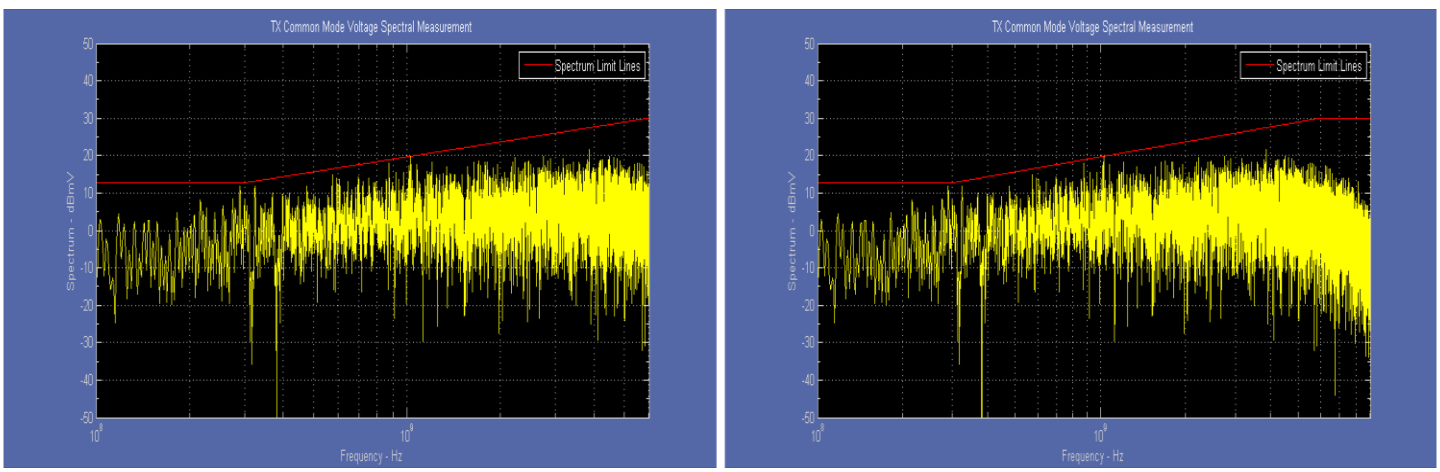


Figure: plots of common mode voltage spectrum test

3.1.4 TX Peak to Peak Voltage

Purpose: To verify that the peak-to-peak output voltage of the DUT's transmitter device is less than the maximum allowed value.

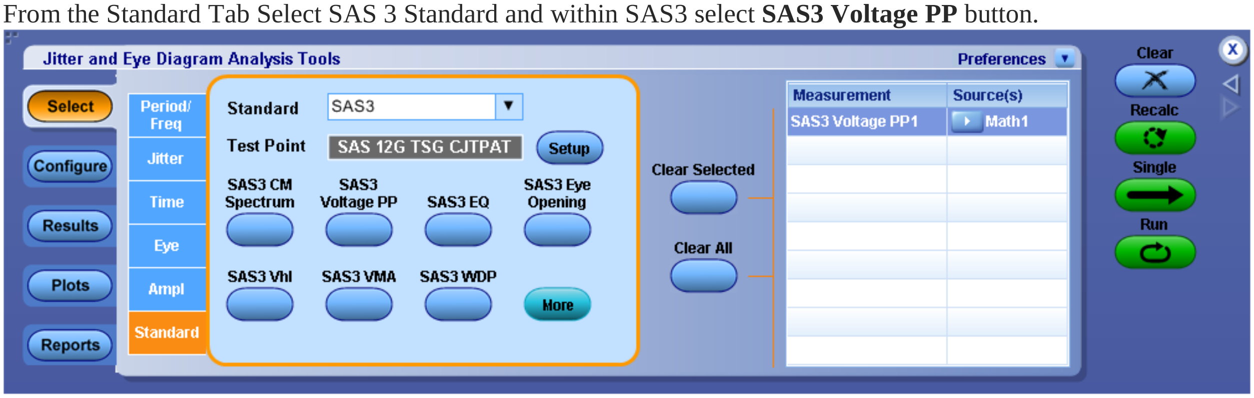
Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes requirements for the TX peak-to-peak voltage [1], as well as the procedure by which the parameter shall be measured. The peak to peak voltage of differential signal of waveform must be more than 50mv. Copies of these specifications can be found in Appendix A.

The V_{P-P} measurement is simply the absolute peak-to-peak voltage of the DUT's transmitted signaling. The Standard also specifies that this measurement be made while the DUT is transmitting a repeating D30.3 pattern into the Zero-Length Test Load. (Note that the binary value of D30.3 is either 0111100011 or 1000011100, depending on the running disparity, and since both forms invert running disparity, properly encoded stream of K28.5 code words.

Test Procedure:

1. Configure the DUT so that it is sourcing D30.3 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select SAS 3 Standard and within SAS3 select **SAS3 Voltage PP** button.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

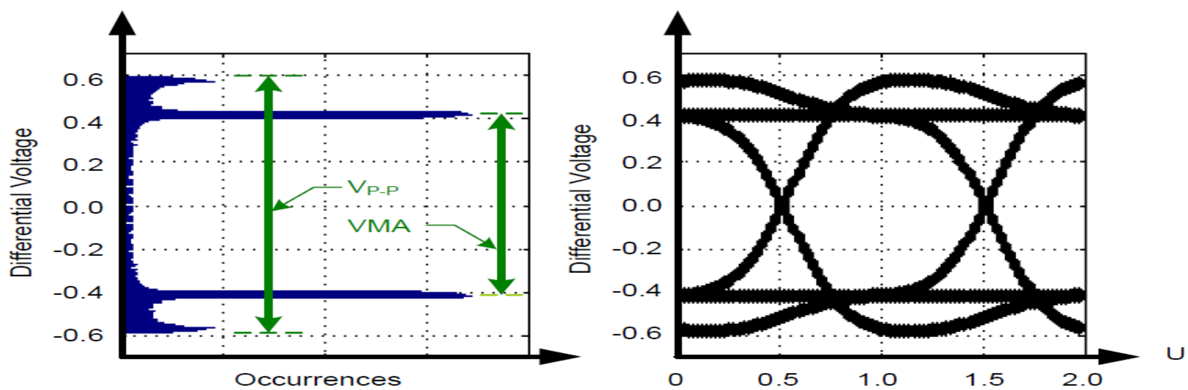
Observable Results:

The peak to peak voltage should be such that 850mv < peak to peak voltage < 1200mv

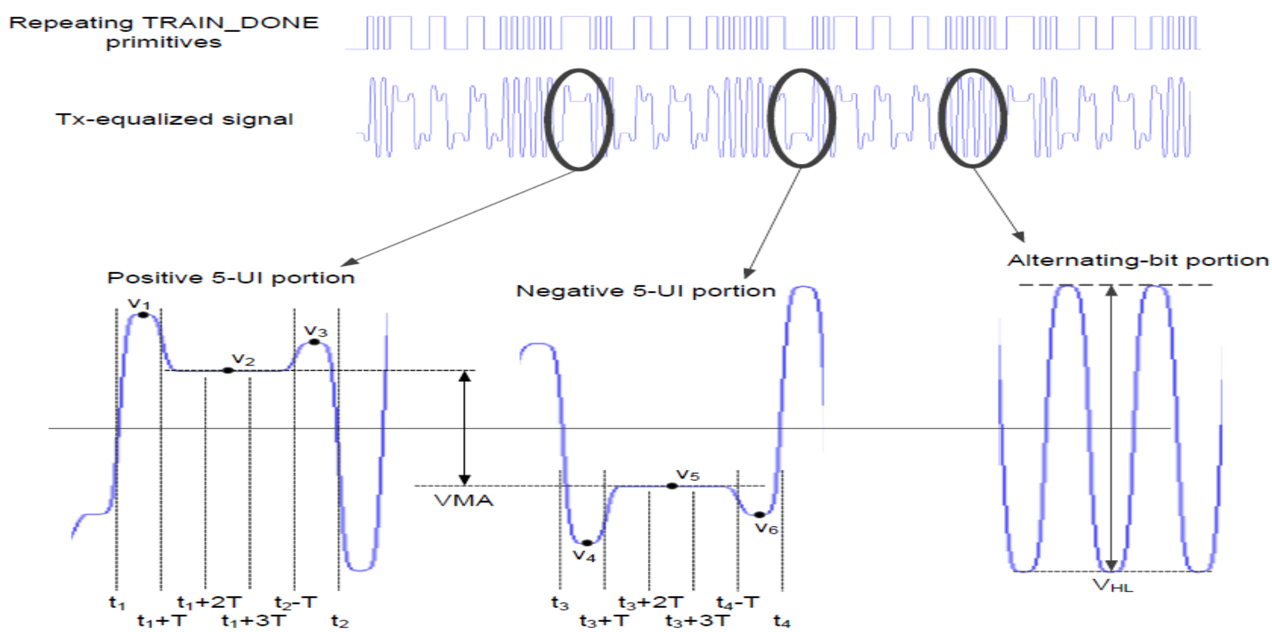
3.1.5 TX VMA

Purpose: To verify that VMA of the DUT transmitter device is within the allowed limit.

Discussion:
The SAS-12G specification includes conformance requirements for the transmitter output waveform related to coefficient status. VMA mean voltage modulation amplitude. VMA is the difference in electrical voltage of a signal between the stable one level and the stable zero level. The peak to peak voltage of differential signal of waveform must be more than 50mv.



In this test, the transmitter provides a K28.5 waveform. From the K28.5 waveform following variables are calculated:



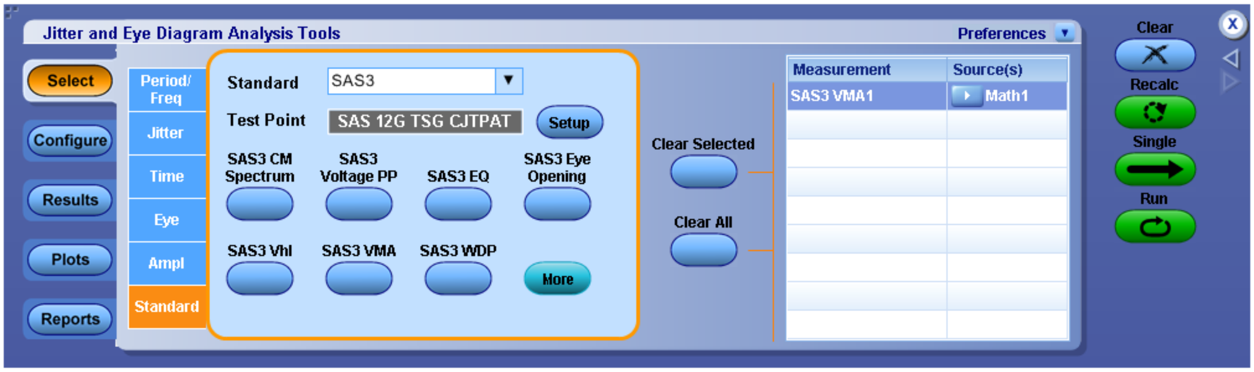
a. T is the symbol period;
b. t_1 is the zero-crossing point of the rising edge of the positive 5 UI CID;
c. t_2 is the zero-crossing point of the falling edge of the positive 5 UI CID;
d. t_3 is the zero-crossing point of the falling edge of the positive 5 UI CID;
e. t_4 is the zero-crossing point of the rising edge of the positive 5 UI CID;
f. v_1 is the maximum voltage measured in the interval t_1 to $t_1 + T$;

g. v_2 is the average voltage measured in the interval $t_1 + 2T$ to $t_1 + 3T$;
h. v_3 is the maximum voltage measured in the interval $t_2 - T$ to t_2;
i. v_4 is the minimum voltage measured in the interval t_3 to $t_3 + T$;
j. v_5 is the average voltage measured in the interval $t_3 + 2T$ to $t_3 + 3T$;
k. v_6 is the maximum voltage measured in the interval $t_4 - T$ to t_4;
l. VMA is $v_2 - v_5$;
m. V_{HL} is the peak-to-peak voltage measured in the interval t_1 to $t_1 + 80T$.

Equalization ratios are defined based on these voltages as follows:
VMA = V2-V5

Test procedure

1. Configure the DUT so that it is sourcing TRAIN_DONE primitive (see SPL-2) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    a. Select Math1 tab
    b. Choose Ch1-Ch3
    c. Set Scale to 100mv.
    d. Label Math1 as Lane0.
    e. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    f. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab select Sas3 and within SAS3 Standard select **SAS3 VMA** buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits

6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits

iii. Turn the Limits File to On.

16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

VMA > 600mv for SAS 12 GHz
VMA > 600mv for SAS 12 GHz
VMA > 80mv for SAS 12 GHz

3.1.6 Tx Equalization

Purpose: To verify that the Equalization Coefficients of the DUT transmitter device is within the allowed limit.

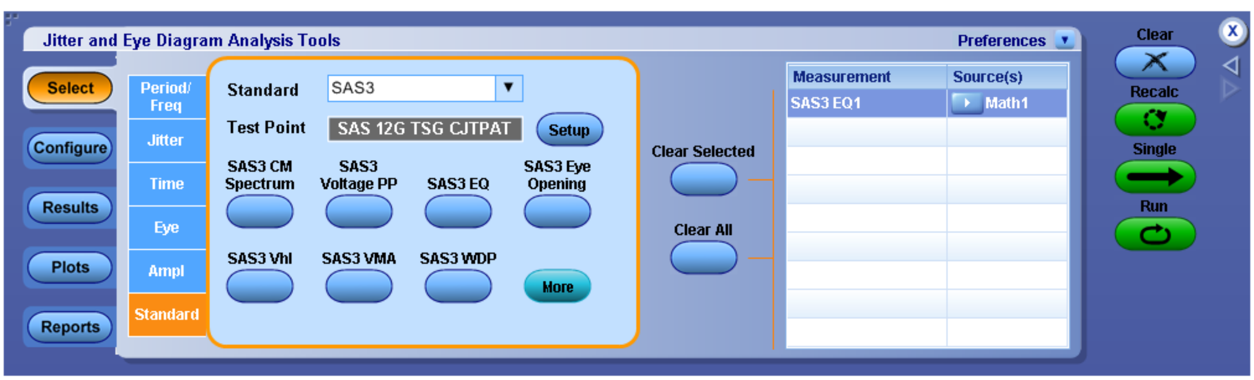
Discussion:
The SAS-12G specification includes conformance requirements for the transmitter output waveform related to coefficient status. The peak to peak voltage of differential signal of waveform must be more than 50mv.

The transmitter equalization measurement shall be based on the following values:
a) VMA: a mode (i.e., the most frequent value of a set of data) measurement; and
b) VP-P: a peak-to-peak measurement with a repeating 7Eh (i.e., D30.3) pattern (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2).
The VMA and VP-P measurements shall be made with the transmitter device terminated through the interoperability point into a zero length test load.

The VMA and VP-P measurements shall be made using an equivalent time sampling scope with a histogram function with the following or an equivalent procedure:
Determine VMA and VP-P as discussed in this section.
The following formula shall be used to calculate the transmitter equalization value:
Transmitter equalization = 20 × log10 (VP-P / VMA) dB

Test procedure

1. Configure the DUT so that it is sourcing TRAIN_DONE primitive (see SPL-2) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab select Sas3 and within SAS3 Standard select **SAS3 EQ** buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

TX EQ is >=2 & <=4

3.1.7 TX Rise time

Purpose: To verify that the rise time of the DUT’s transmitted SAS signaling are within the conformance limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 1.5, 3, 6and 12.0Gbps SAS devices. This includes requirements for the TX Rise time. Copies of these specifications can be found in Appendix A. The peak to peak voltage of differential signal of waveform must be more than 50mv.

The Standard specifies that the rise/fall time measurements be performed while the DUT is transmitting a repeating 1010 pattern. The measurement is defined as a 20/80% rise time, however the specification does not provide any additional detail about what amplitude reference is used to determine the 20/80% levels, or how this reference is measured.

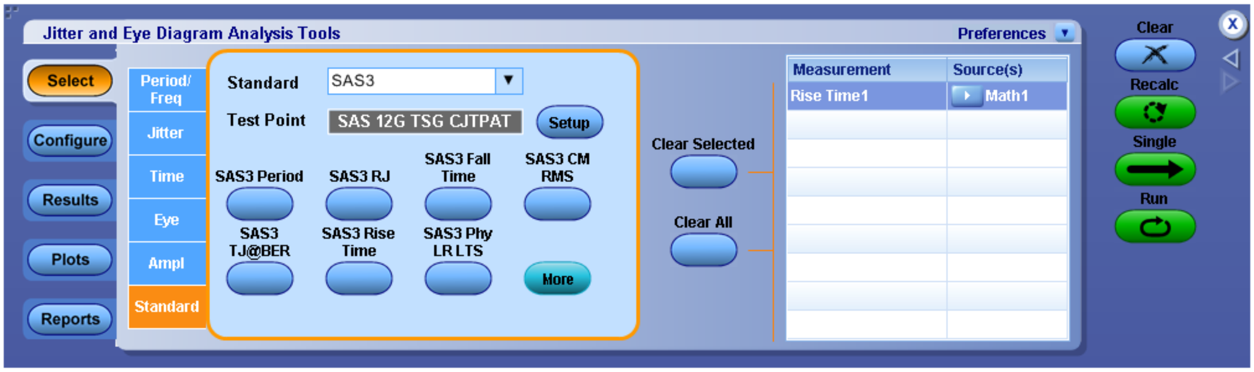
For the purposes of this test suite, an eye-diagram-based methodology will be used. This method determines the reference amplitude and subsequent rise/fall times using an accumulated eye diagram, constructed from the DUT's transmitted signaling. The reference amplitude (i.e., the 0/100% levels) will be defined as the mode values of the 0/1 symbol levels, measured at the center (i.e., 50% horizontal time point) of the Unit Interval. Based on the measured 0/100% levels, the corresponding 20/80% levels will be computed, and horizontal histograms will be computed based on where the rising and falling transitions of the eye diagram cross these levels. The **mean** values of these histograms will be used to determine the start and end times of the rise/fall measurements.

The primary benefit of the eye diagram approach is that the measured results are typically very stable and repeatable, due to the inherent averaging effect gained by using the eye diagram data as the basis for measurement. The method also provides direct visual feedback, which clearly shows how the measurement is computed based on the acquired data, which can help identify sources of measurement discrepancies when correlating results between different DUTs, test equipment, etc.

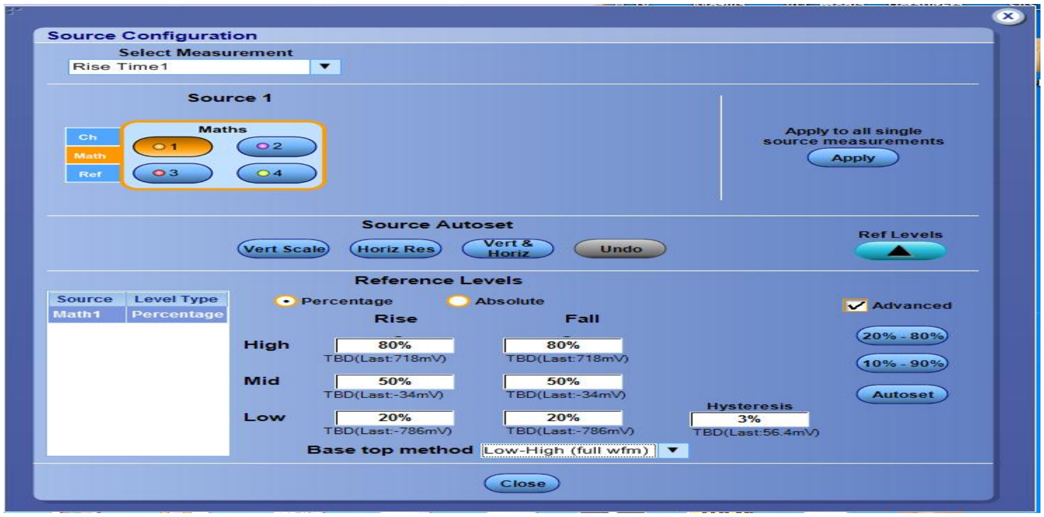
Test Procedure:

Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing 01b or 10b (D10.2 or D21.5) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select **SAS3 Rise Time** measurement button.



14. Set the Source for the measurement as Math1.
15. Set Reference level for lane0 and Lane1 from 20% to 80% as below



16. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
        12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
        6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
        3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
        1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
17. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

Rise Time > 166.66 ps for SAS 1.5 Gbps,
> 83.33 ps for SAS 3 Gbps,
> 41.68 ps for SAS 6 Gbps,
> 20.84 ps for SAS 12 Gbps

3.1.8 TX Fall time

Purpose: To verify that the fall time of the DUT's transmitted SAS signaling are within the conformance limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes requirements for the TX Fall time. Copies of these specifications can be found in Appendix A. The peak to peak voltage of differential signal of waveform must be more than 50mv.

The Standard specifies that the rise/fall time measurements be performed while the DUT is transmitting a repeating 1010 pattern. The measurement is defined as a 20/80% rise time, however the specification does not provide any additional detail about what amplitude reference is used to determine the 20/80% levels, or how this reference is measured.

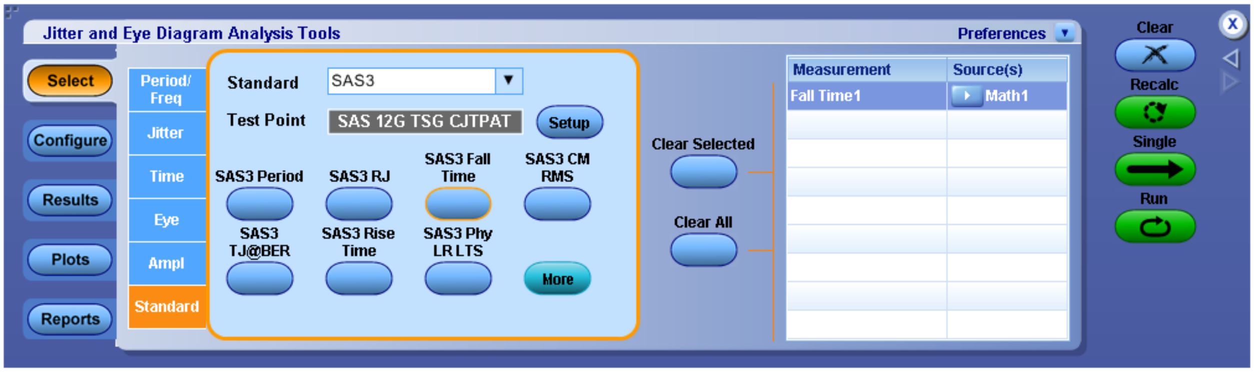
For the purposes of this test suite, an eye-diagram-based methodology will be used. This method determines the reference amplitude and subsequent rise/fall times using an accumulated eye diagram, constructed from the DUT's transmitted signaling. The reference amplitude (i.e., the 0/100% levels) will be defined as the mode values of the 0/1 symbol levels, measured at the center (i.e., 50% horizontal time point) of the Unit Interval. Based on the measured 0/100% levels, the corresponding 20/80% levels will be computed, and horizontal histograms will be computed based on where the rising and falling transitions of the eye diagram cross these levels. The **mean** values of these histograms will be used to determine the start and end times of the rise/fall measurements.

The primary benefit of the eye diagram approach is that the measured results are typically very stable and repeatable, due to the inherent averaging effect gained by using the eye diagram data as the basis for measurement. The method also provides direct visual feedback, which clearly shows how the measurement is computed based on the acquired data, which can help identify sources of measurement discrepancies when correlating results between different DUTs, test equipment, etc.

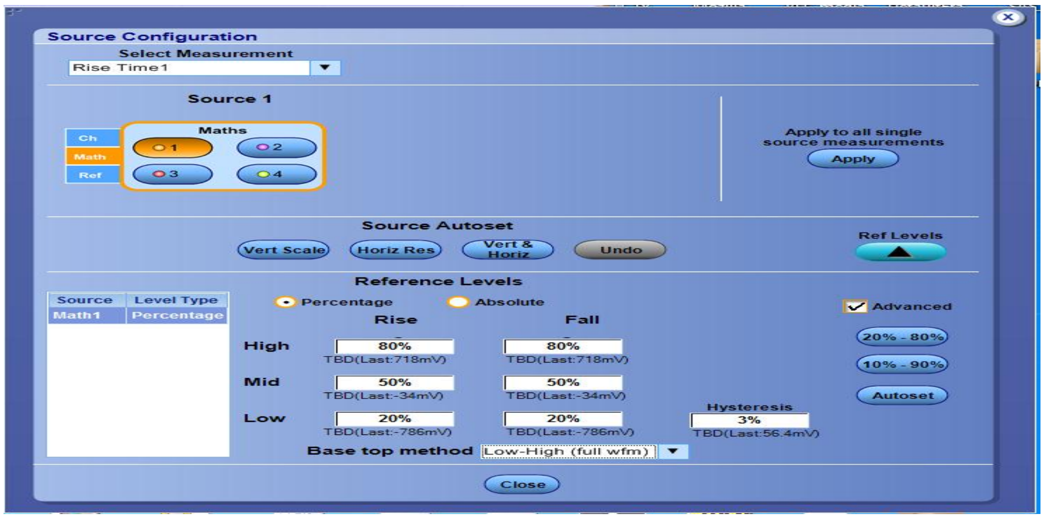
Test Procedure:

Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing 01b or 10b (D10.2 or D21.5) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select **SAS3 Fall Time** measurement button.



14. Set the Source for the measurement as Math1.
15. Set Reference level for lane0 and Lane1 from 20% to 80% as below



16. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
18. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

Fall Time > 166.66 ps for SAS 1.5 Gbps,
> 83.33 ps for SAS 3 Gbps,
> 41.68 ps for SAS 6 Gbps,
> 20.84 ps for SAS 12 Gbps

3.1.9 TX Random Jitter (RJ)

Purpose: To verify that the random jitter of the DUT transmitter device is less than the maximum allowed limit.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0 Gbps SAS devices. This includes requirements for the TX Random Jitter. Copies of these specifications can be found in Appendix A. The peak to peak voltage of differential signal of waveform must be more than 50mv.

This test will be performed while the DUT is transmitting MFTP pattern. Note the specification requires that the measurement shall include the effects of the JTF (Jitter Transfer Function), which is a Standard-defined weighting function that is intended to separate the low-frequency timing variations due to SSC from the actual jitter. The RJ measurement requires that the Jitter Measurement Device (JMD) be configured to use the proper JTF characteristics required by the Standard[2]. A copy of these requirements is reproduced from the Standard in the figure below.

Characteristic	Untrained		Trained without SSC support				Trained with SSC support			
	1.5 Gbps	3 Gbps	1.5 Gbps	3 Gbps	6 Gbps	12 Gbps	1.5 Gbps	3 Gbps	6 Gbps	12 Gbps
JTF -3 dB point (kHz) [a] [b]	900 ± 500	1 800 ± 500	900 ± 500	1 800 ± 500	3 600 ± 500	3 600 ± 500	1 300 ± 500	1 838 ± 500	2 600 ± 500	2 600 ± 500
JTF slope (dB/decade)	20	20	20	20	20	20	40	40	40	40
Attenuation at 30 kHz ± 1 % (dB) [c]	N/A	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
Maximum Peaking (dB)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

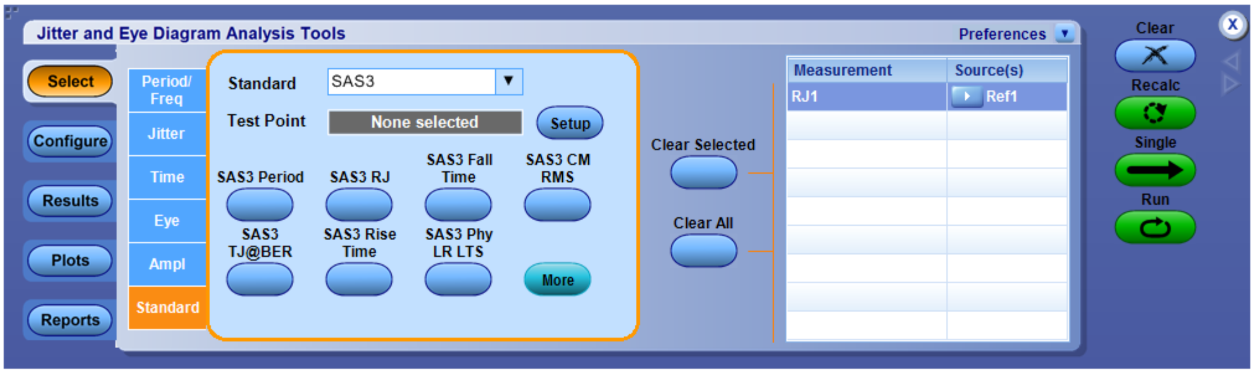
[a] For untrained or trained without SSC support this value equals f_{baud}/1 667 ± 500 kHz.
[b] For trained with SSC support this value equals $(f_{baud})^{0.5}$ x 33.566 x $Hz^{0.5}$ ± 500 kHz.
[c] For trained with SSC support this value equals 73.5 dB + [20 x log(f_{baud} / 6 x 10^9 Hz)] dB ± 1.5 dB.
[d] For the above equations, f_{baud} is expressed in Hz (i.e., 1.5 GHz for 1.5 Gbps, 3.0 GHz for 3 Gbps, 6.0 GHz for 6 Gbps, 12 GHz for 12Gbps).

Test Procedure:

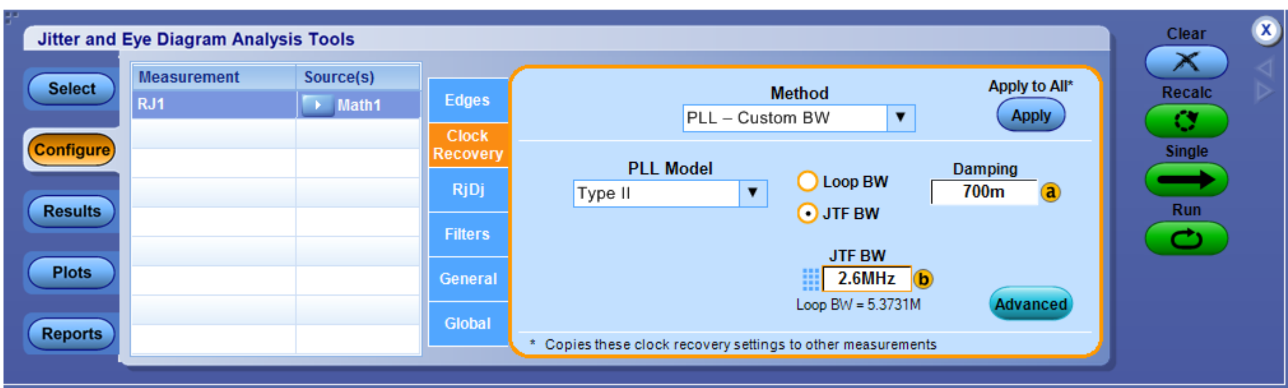
Following is the detailed test setup to run this measurement:

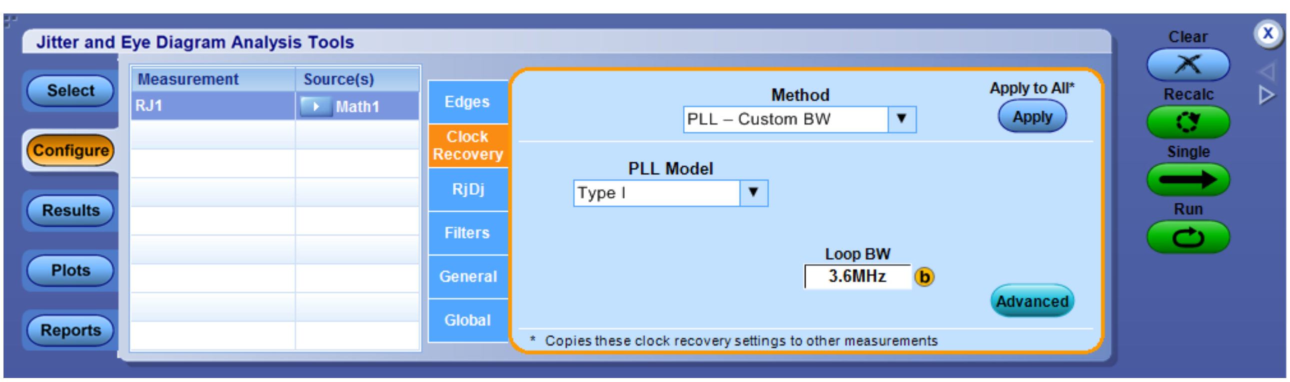
1. Configure the DUT so that it is sourcing 1100 or 0011 (D24.3 or MFTP) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.

11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select **SAS3 RJ** measurement button.

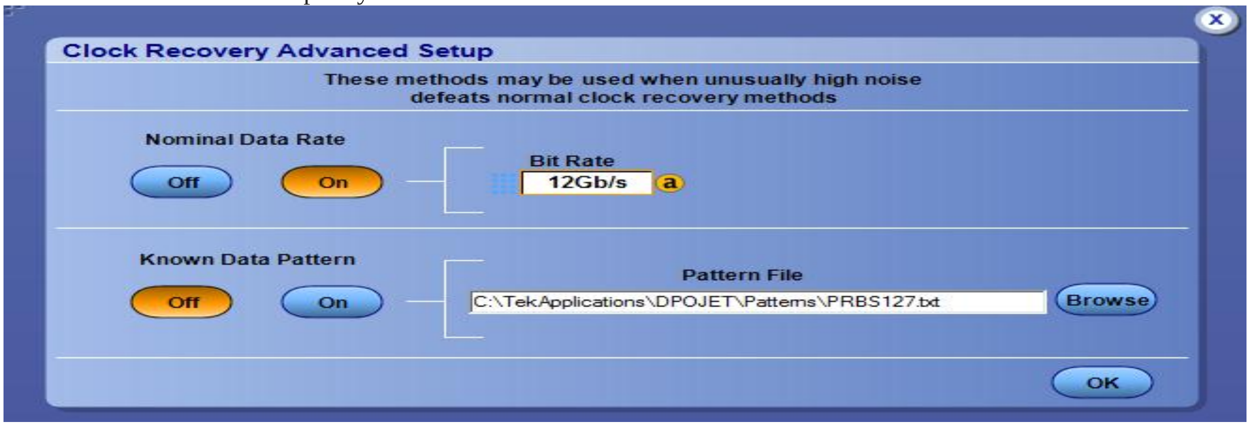


14. Set the Source for the measurement as Math1.
15. Go to Configure>Clock Recovery and set PLL settings as required for data with SSC and data without SSC.
    a. Data with SSC: Set Method to Custom BW, PLL Model to Type II and JTF BW to 2.6 MHz or Loop BW 5.373MHz and Damping factor of 0.7.
    b. Data without SSC: Set Method to Custom BW, PLL Model to Type I and JTF BW to 3.6 MHz or Loop BW 3.6 MHz. (Loop BW and JTF BW is same for Type I)

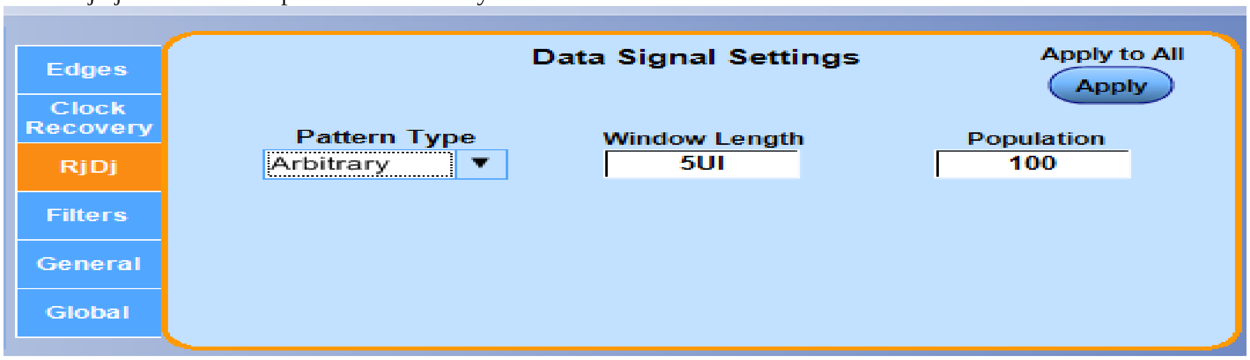




16. Click on advanced tab and specify the Data Rate as 12 Gb/s



17. Go to RjDj tab and select pattern as Arbitrary.



18. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
19. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

RJ (rms) < 0.0107 UI

Because, RJ < 0.15 UI (Pk-Pk) or 12.5 ps as per spec. (RJ is 14 times the RJ 1 sigma value, based on a BER of 10-12. So the limit value will be 0.15/14 UI or 12.5/14 ps, which is 0.0107 UI or 0.8929 ps)

3.1.10 TX Total Jitter (TJ)

Purpose: To verify that the Total Jitter of the DUT transmitter device is less than the maximum allowed limit.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This includes requirements for the TX Random Jitter. The peak to peak voltage of differential signal of waveform must be more than 50mv. Copies of these specifications can be found in Appendix A.

This test will be performed while the DUT is transmitting MFTP pattern. Note the specification requires that the measurement shall include the effects of the JTF (Jitter Transfer Function), which is a Standard-defined weighting function that is intended to separate the low-frequency timing variations due to SSC from the actual jitter. The RJ measurement requires that the Jitter Measurement Device (JMD) be configured to use the proper JTF characteristics required by the Standard[2]. Copies of these requirements are reproduced from the Standard in the figure below.

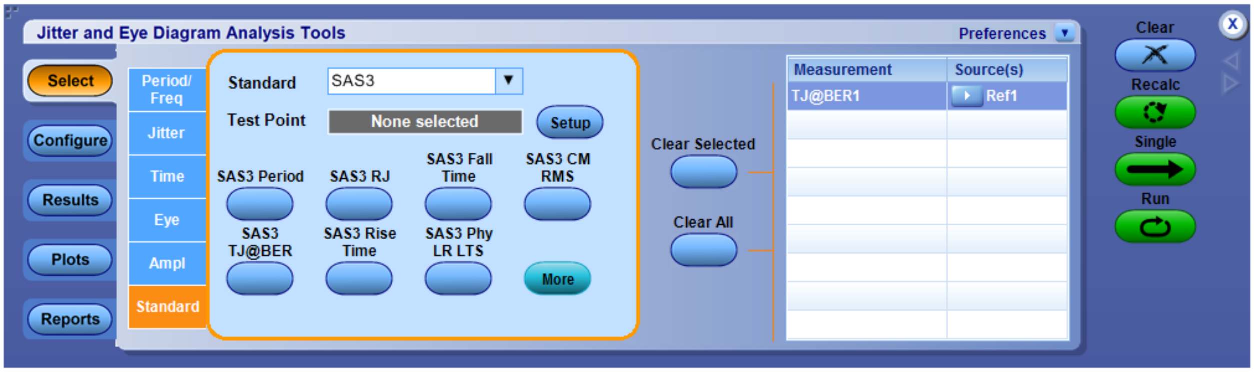
Characteristic	Untrained		Trained without SSC support				Trained with SSC support			
	1.5 Gbps	3 Gbps	1.5 Gbps	3 Gbps	6 Gbps	12 Gbps	1.5 Gbps	3 Gbps	6 Gbps	12 Gbps
JTF -3 dB point (kHz) [a] [b]	900 ± 500	1 800 ± 500	900 ± 500	1 800 ± 500	3 600 ± 500	3 600 ± 500	1 300 ± 500	1 838 ± 500	2 600 ± 500	2 600 ± 500
JTF slope (dB/decade)	20	20	20	20	20	20	40	40	40	40
Attenuation at 30 kHz ± 1 % (dB) [c]	N/A	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
Maximum Peaking (dB)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

[a] For untrained or trained without SSC support this value equals $f_{baud}/1\,667 \pm 500$ kHz.
[b] For trained with SSC support this value equals $(f_{baud})^{0.5} \times 33.566 \times Hz^{0.5} \pm 500$ kHz.
[c] For trained with SSC support this value equals 73.5 dB + [20 x log(f_{baud} / 6 x 10^9 Hz)] dB ± 1.5 dB.
[d] For the above equations, f_{baud} is expressed in Hz (i.e., 1.5 GHz for 1.5 Gbps, 3.0 GHz for 3 Gbps, 6.0 GHz for 6 Gbps, 12 GHz for 12Gbps).

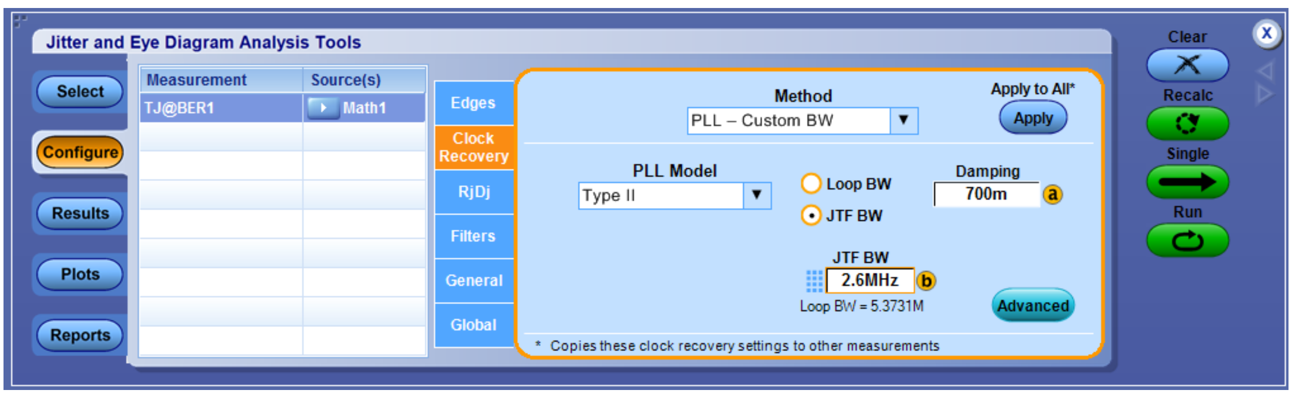
Test Procedure:

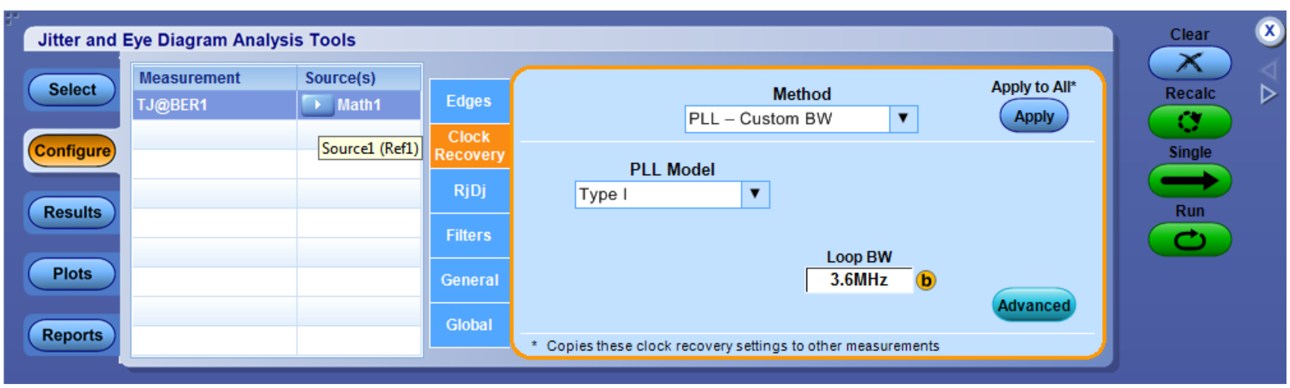
Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing 1100 or 0011 (D24.3 or MFTP) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select **SAS3 Tj@BER** measurement.

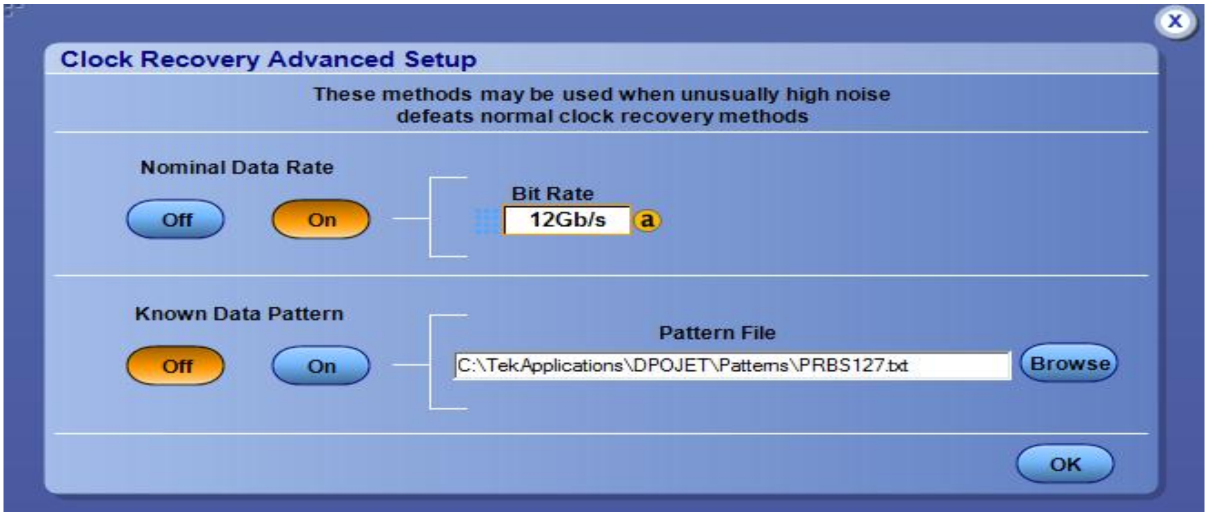


14. Set the Source for the measurement as Math1.
15. Go to Configure>Clock Recovery and set PLL settings as required for data with SSC and data without SSC.
    a. Data with SSC: Set Method to Custom BW, PLL Model to Type II and JTF BW to 2.6 MHz or Loop BW 5.373MHz and Damping factor of 0.7.
    b. Data without SSC: Set Method to Custom BW, PLL Model to Type I and JTF BW to 3.6 MHz or Loop BW 3.6 MHz without Damping factor. (Loop BW and JTF BW is same for Type I)

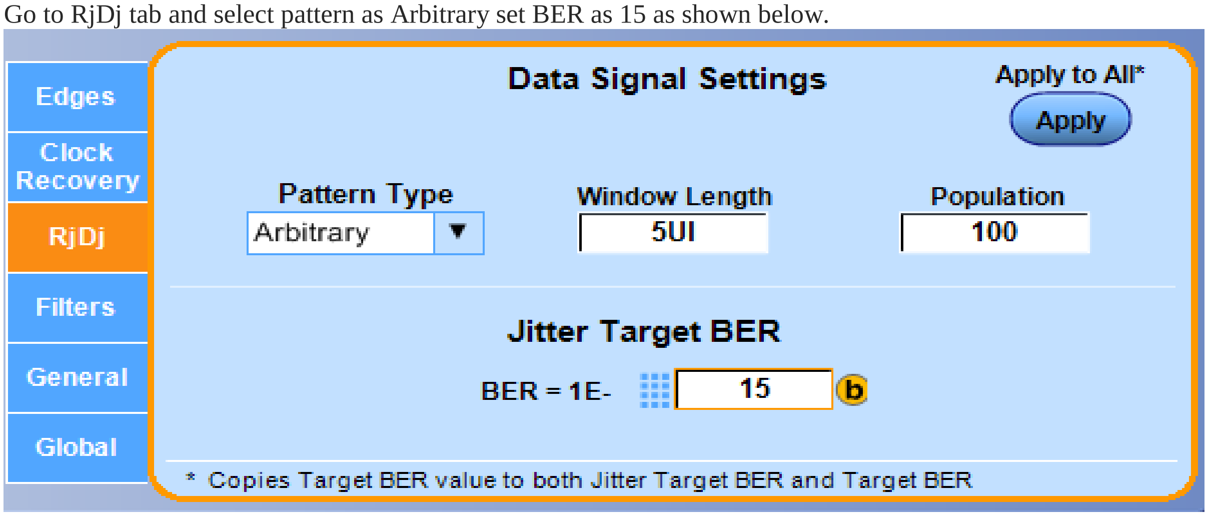




16. Click on advanced tab and specify the Data Rate as 12 Gb/s



17. Go to RjDj tab and select pattern as Arbitrary set BER as 15 as shown below.



18. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
        12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
        6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
        3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
        1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
20. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

TJ < 0.25 UI

3.1.11 Tx Waveform Distortion Penalty (WDP)

Purpose: To verify that the WDP of the DUT transmitter device is within the conformation limits.

Discussion:

The Standard defines WDP as, **"A simulated measure of the deterministic penalty of the signal waveform from a particular transmitter device transmitting a particular pattern and a particular test load with a reference receiver device"**. It also describes it as, **"A characterization of the signal output within the reference receiver device after equalization"**. The latter description is perhaps somewhat easier to understand from a conceptual perspective, as the WDP measurement is an example of what the DUT's transmitted signaling would 'look like' to a receiver device, after passing through an interconnect (i.e., channel, backplane, cable, etc.), and being received and processed by an equalizer circuit inside the receiver device. Because it is not typically possible to observe the signal at this point (as it is conceptually located inside the actual receiver IC, post-equalization) it is not possible to practically measure this signal, however it can be mathematically computed, based on a reference model of a SAS interconnect, and a reference receive equalizer. This mathematical modeling is performed by a set of MATLAB code that is included as part of the Standard. See Appendix D for reference. The peak to peak voltage of differential signal of waveform must be more than 50mv.

WDP will work in two modes i. TWDP, which is a TX measurement and ii. LDP which is basically a Rx measurement. To run the RX testing for WDP run measurement SAS3 WDPRX and to run the TX measurement use measurement button SAS3 WDP.

The WDP measurement scans through the waveform and finds the point where longest sequence of 1's happens. It looks for a transition of 101 after the longest sequence of ones to do measurement. This is because:

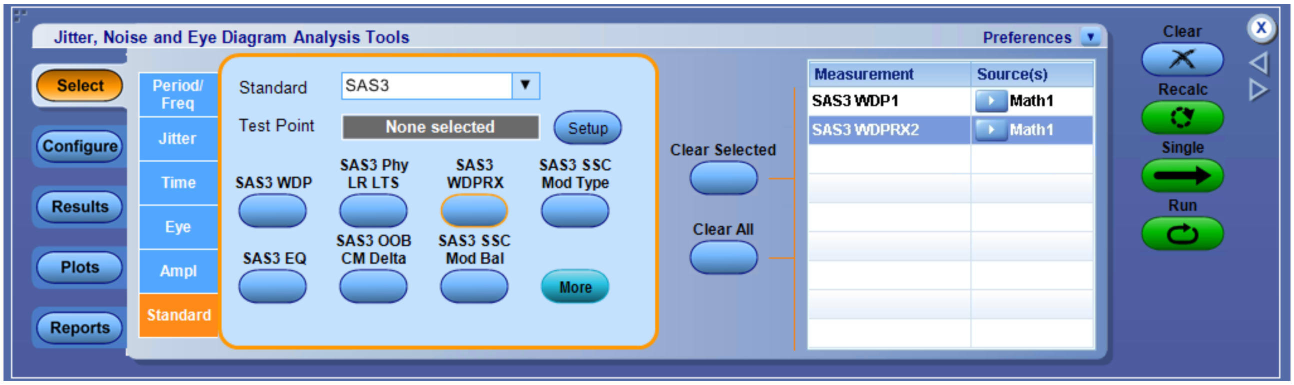
1. WDP measurement is very sensitive to the location in the waveform where measurement is done. The results can be very different if measurement is run on different parts of waveform from same DUT. The given methodology ensures that the measurement is done always from the same location of the repeating waveform.
2. WDP measurement should ideally be done at location where there are lot of transition initially. Hence we choose a location where there are consecutive 101 for the purpose.

Test Procedure:

Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing Scrambled 0 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).

10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS3 to launch DPOJET.
13. From the Standard Tab Select the SAS3 measurement you wish to run. For RX select **SAS3 WDPRX** and for TX run **SAS3 WDP** measurement.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Result:

WDP < 4.5 dB ps for SAS 1.5 Gbps,
< 4.5 dB for SAS 3 Gbps,
< 7 dB for SAS 6 Gbps,
< 13 dB for SAS 12 Gbps

3.1.12 TX SAS EYE OPENING

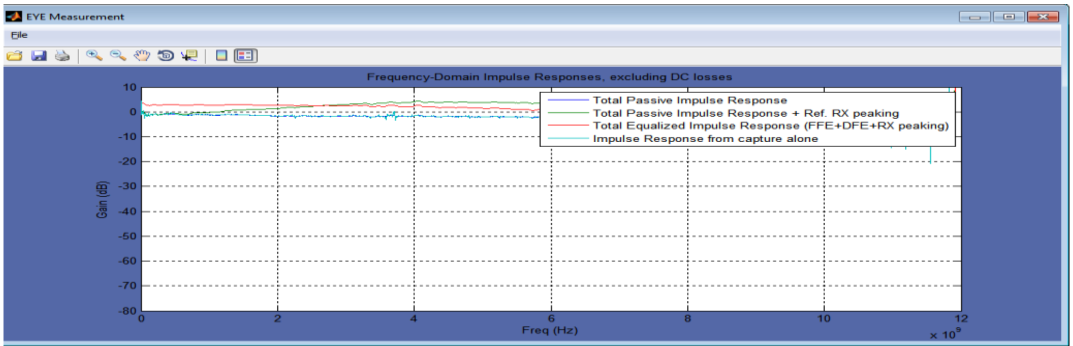
Purpose: To verify that the Eye Opening of the DUT transmitter device is within the conformation limits.

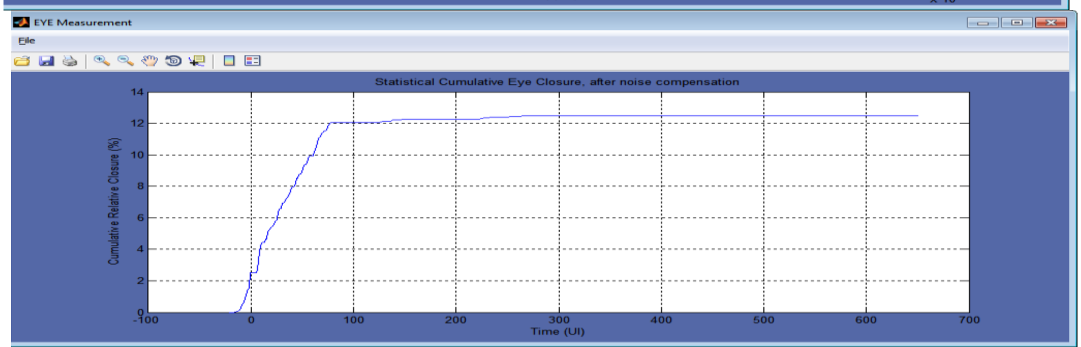
Discussion:

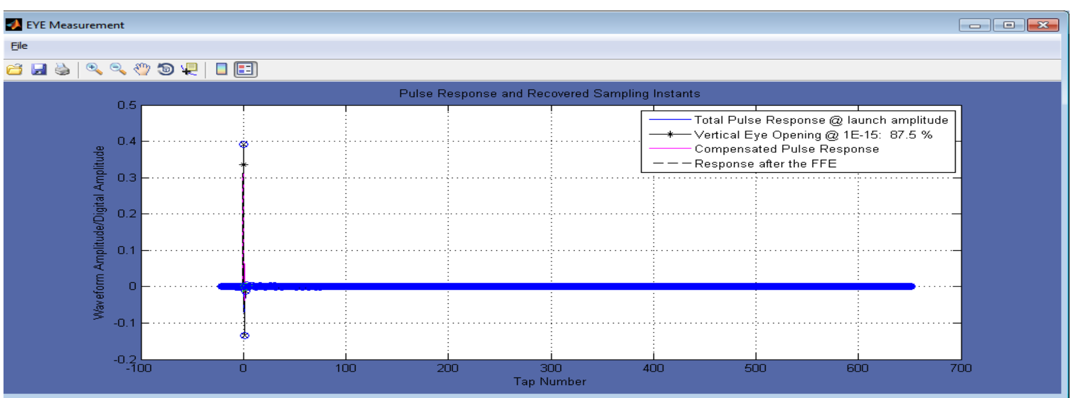
SAS is currently considering using a 5 tap DFE. The signal which contains a large amount of crosstalk/ISI and an almost close eye is passed through a DFE filter to recover all of its amplitude. The algorithm should contain

a. Method for calculating the optimized DFE parameter based on the data.
b. Pass the signal through the DFE filter and calculate the eye opening.

The following figures are giving description about eye opening plot and how signal is impacted by crosstalk because of aggressor.







Currently specs do not define what should be the methodology to calculate the DFE coefficients. Currently we find the equalization settings that will result in the least square error of the equalized signal. This can be understood simply by looking at the points sampled in the middle of the eye. You know that these points should be either a digital 1 or a digital 0. This means that their analog amplitude should optimally only take two values: either +T or –T, for a digital 1 or a digital 0, respectively. In reality, you will get +T+ error or –T+ error – where “error” is what your equalizer cannot correct. The algorithm is trying to reduce the sum of the error^2 terms over a very long sequence of bits. See Appendix C for reference. The peak to peak voltage of differential signal of waveform must be more than 50mv.

There are four modes in which one can run SAS Eye opening. Corresponding to each mode there is a button. The modes are:

a. Drive TX : Measurement Button: SAS3EOTXDH
b. Drive Rx : Measurement Button: SAS3EORXDH

c. Host TX : Measurement Button: SAS3EOTXHD
d. Host Rx : Measurement Button: SAS3EORXHD

You choose the button based on device and measurement you run.

The user has the option to convert one compliance point to another by providing s4p files corresponding to the path. For each of these measurement upto 2 s4p files can be provided. The s4p is supposed to be kept in the folder C:\Users\Public\tektronix\TekApplications\SAS3\TSG\

The s4p filename is hardcoded and following s4p files are used for each measurement:

1. SAS3EOTXDH
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveD2HTX.s4p
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveD2HTX1.s4p

2. SAS3EOTXHD
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveH2DTX.s4p
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveH2DTX1.s4p

3. SAS3EORXDH

   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveD2HRX.s4p
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveD2HRX1.s4p

4. SAS3EORXHD

   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveH2DRX.s4p
   C:\Users\Public\tektronix\TekApplications\SAS3\TSG\LongPassiveH2DRX1.s4p

Please note that:

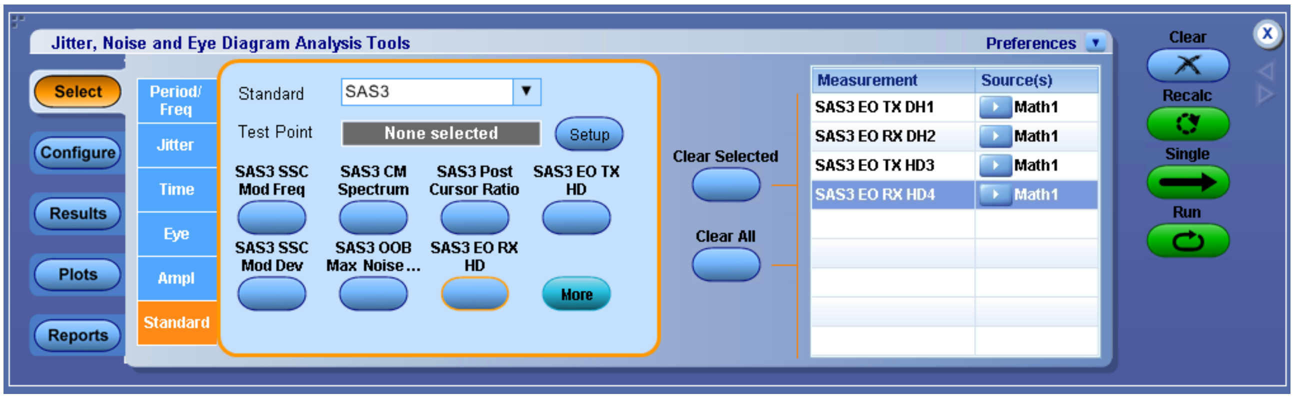
a. All s4p are embedding the channel. Essentially if you use the same s4p files for different measurement you will get the same results.
b. Only if an s4p file is present the measurement will embed the channel. If the hardcoded s4p file is not present in the folder then that s4p file is neglected and not used.

Test Procedure:

Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing Scrambled 0 signaling.
2. Connect the Zero-Length test load to the DUT transmitter device
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).

10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select corresponding **SAS3 Eye Opening** measurement that you wish to run.
14. Copy the appropriate s4p files corresponding to filters in C:\Users\Public\tektronix\TekApplications\SAS3\TSG\



15. Set the Source for the measurement as Math1.
16. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
       12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
       6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
       3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
       1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
17. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Result:

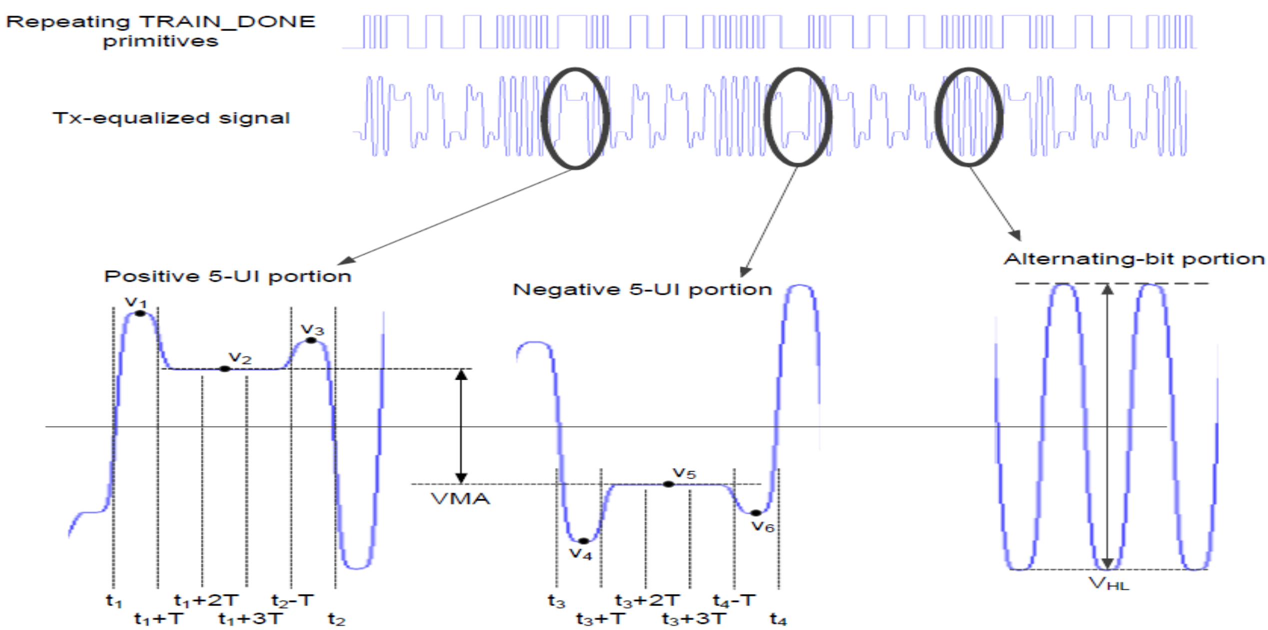
Eye opening should be greater than 45% for SAS 12 Gbps.

3.1.13 TX Pre-Cursor Equalization

Purpose: To verify that Pre-Cursor Equalization of the DUT transmitter device is within the allowed limit.

Discussion:
The SAS-12G specification includes conformance requirements for the transmitter output waveform related to coefficient status.

In this test, the transmitter provides a K28.5 waveform. The peak to peak voltage of differential signal of waveform must be more than 50mv. From the K28.5 waveform following variables are calculated:



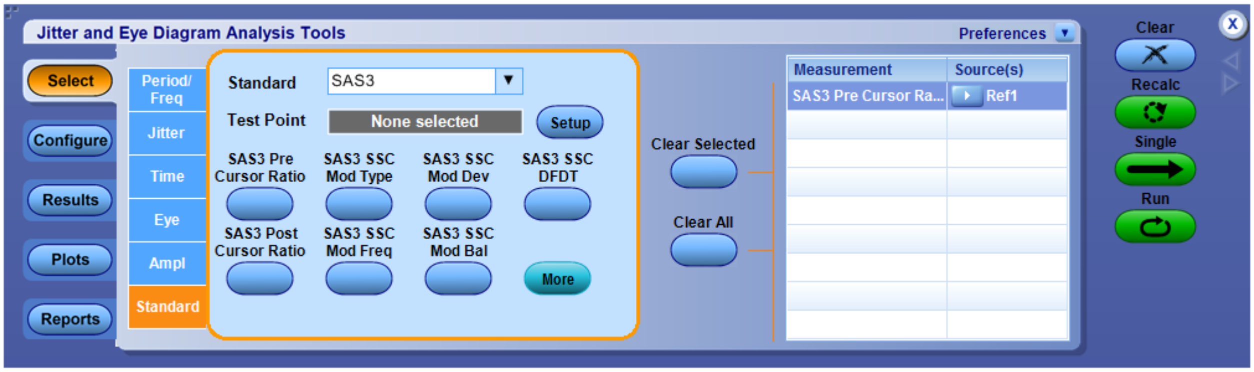
a. T is the symbol period;
b. t_1 is the zero-crossing point of the rising edge of the positive 5 UI CID;
c. t_2 is the zero-crossing point of the falling edge of the positive 5 UI CID;
d. t_3 is the zero-crossing point of the falling edge of the positive 5 UI CID;
e. t_4 is the zero-crossing point of the rising edge of the positive 5 UI CID;
f. v_1 is the maximum voltage measured in the interval t_1 to $t_1 + T$;
g. v_2 is the average voltage measured in the interval $t_1 + 2T$ to $t_1 + 3T$;
h. v_3 is the maximum voltage measured in the interval $t_2 - T$ to t_2;
i. v_4 is the minimum voltage measured in the interval t_3 to $t_3 + T$;
j. v_5 is the average voltage measured in the interval $t_3 + 2T$ to $t_3 + 3T$;
k. v_6 is the maximum voltage measured in the interval $t_4 - T$ to t_4;

l. VMA is v2 - v5;
m. VHL is the peak-to-peak voltage measured in the interval t1 to t1 + 80T.

Equalization ratios are defined based on these voltages as follows:

Test procedure

1. Configure the DUT so that it is sourcing TRAIN_DONE primitive (see SPL-2) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab select Sas3 and within SAS3 Standard select **SAS3 Pre Cursor Ratio** buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

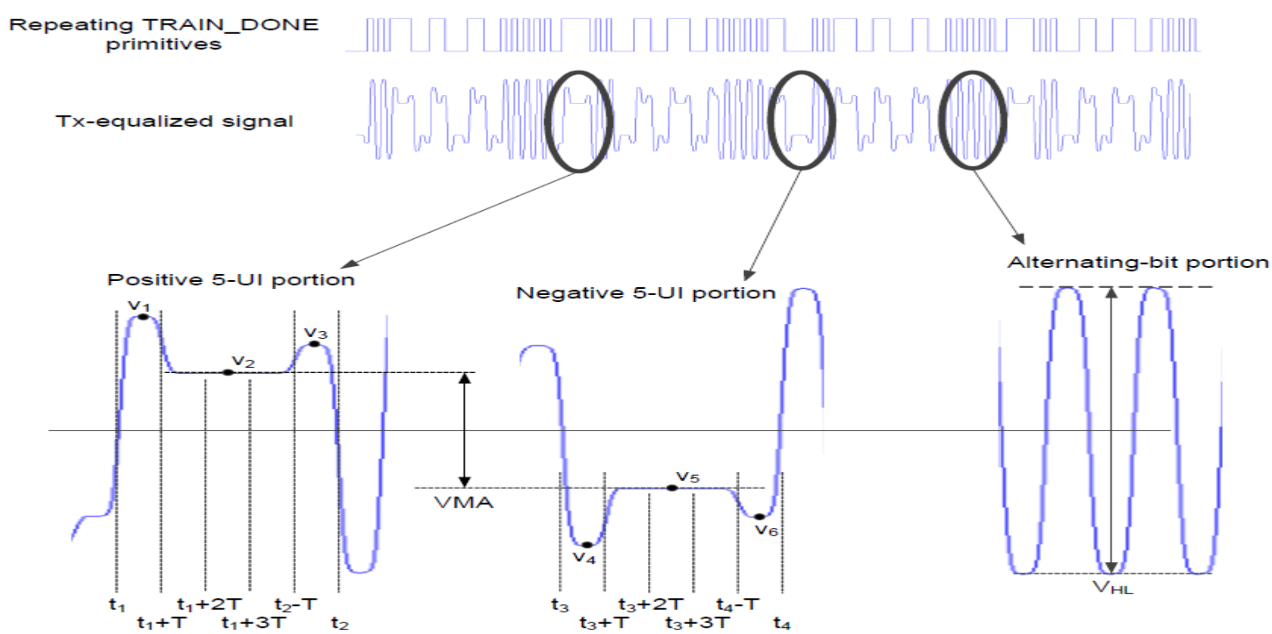
1.00 <Rpre <1.67 (SAS 12 Gbps).

3.1.14 TX Post-Cursor Equalization

Purpose: To verify that Post-Cursor Equalization of the DUT transmitter device is within the allowed limit.

Discussion:
The SAS-12G specification includes conformance requirements for the transmitter output waveform related to coefficient status.

In this test, the transmitter provides a K28.5 waveform. The peak to peak voltage of differential signal of waveform must be more than 50mv. From the K28.5 waveform following variables are calculated:

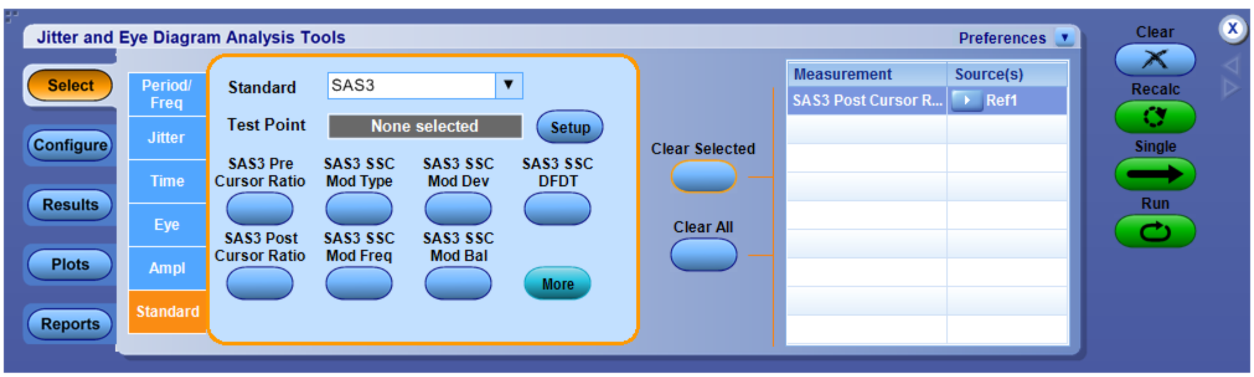


a. T is the symbol period;
b. t_1 is the zero-crossing point of the rising edge of the positive 5 UI CID;
c. t_2 is the zero-crossing point of the falling edge of the positive 5 UI CID;
d. t_3 is the zero-crossing point of the falling edge of the positive 5 UI CID;
e. t_4 is the zero-crossing point of the rising edge of the positive 5 UI CID;
f. v_1 is the maximum voltage measured in the interval t_1 to t_1 + T;
g. v_2 is the average voltage measured in the interval t_1 + 2T to t_1 + 3T;
h. v_3 is the maximum voltage measured in the interval t_2 - T to t_2;
i. v_4 is the minimum voltage measured in the interval t_3 to t_3 + T;
j. v_5 is the average voltage measured in the interval t_3 + 2T to t_3 + 3T;
k. v_6 is the maximum voltage measured in the interval t_4 - T to t_4;
l. VMA is v_2 - v_5;
m. V_{HL} is the peak-to-peak voltage measured in the interval t_1 to t_1 + 80T.

Equalization ratios are defined based on these voltages as follows:

Test procedure

1. Configure the DUT so that it is sourcing TRAIN_DONE primitive (see SPL-2) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    vii. Select Math1 tab
    viii. Choose Ch1-Ch3
    ix. Set Scale to 100mv.
    x. Label Math1 as Lane0.
    xi. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    xii. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab select Sas3 and within SAS3 Standard select **SAS3 Post Cursor Ratio** buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

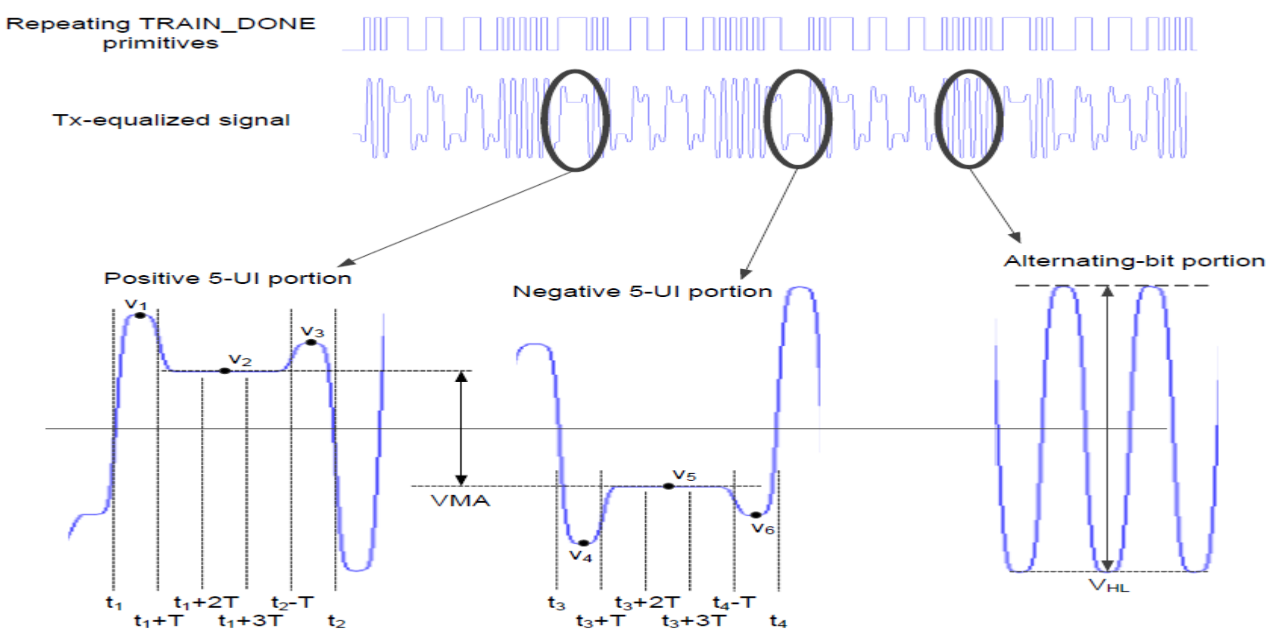
1.0 <Rpost <3.33. (SAS 12 Gbps)

3.1.15 Tx Transition bit voltage Pk-Pk (Vhl)

Purpose: To verify that transition bit voltage Pk-Pk of the DUT transmitter device is within the allowed limit.

Discussion:
The SAS-12G specification includes conformance requirements for the transmitter output waveform related to coefficient status.

In this test, the transmitter provides a K28.5 waveform. The peak to peak voltage of differential signal of waveform must be more than 50mv. From the K28.5 waveform following variables are calculated:

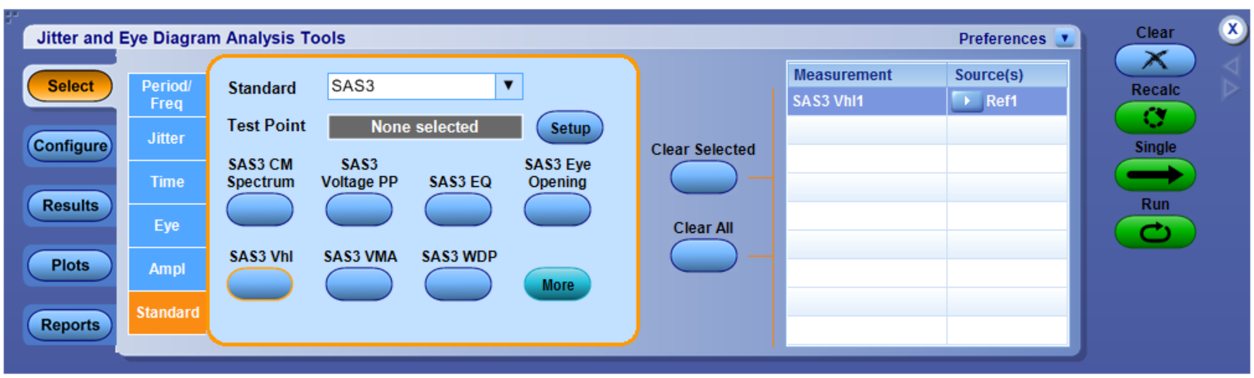


a. T is the symbol period;
b. t_1 is the zero-crossing point of the rising edge of the positive 5 UI CID;
c. t_2 is the zero-crossing point of the falling edge of the positive 5 UI CID;
d. t_3 is the zero-crossing point of the falling edge of the positive 5 UI CID;
e. t_4 is the zero-crossing point of the rising edge of the positive 5 UI CID;
f. v_1 is the maximum voltage measured in the interval t_1 to $t_1 + T$;
g. v_2 is the average voltage measured in the interval $t_1 + 2T$ to $t_1 + 3T$;
h. v_3 is the maximum voltage measured in the interval $t_2 - T$ to t_2;
i. v_4 is the minimum voltage measured in the interval t_3 to $t_3 + T$;
j. v_5 is the average voltage measured in the interval $t_3 + 2T$ to $t_3 + 3T$;
k. v_6 is the maximum voltage measured in the interval $t_4 - T$ to t_4;
l. VMA is $v_2 - v_5$;
m. V_{HL} is the peak-to-peak voltage measured in the interval t_1 to $t_1 + 80T$.

Equalization ratios are defined based on these voltages as follows:

Test procedure
1. Configure the DUT so that it is sourcing TRAIN_DONE primitive (see SPL-2) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.

4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    xiii. Select Math1 tab
    xiv. Choose Ch1-Ch3
    xv. Set Scale to 100mv.
    xvi. Label Math1 as Lane0.
    xvii. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    xviii. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab select Sas3 and within SAS3 Standard select **SAS3 Vhl** buttons.



14. Set the Source for the measurement as Math1.
15. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
16. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

1200mV>=Vhl>=850mV

3.1.16 TX Period

Purpose: To verify that the Period of the DUT's transmitted SAS signaling are within the conformance limits.

Discussion:

The SAS-3 Standard defines the electrical interface requirements for 1.5, 3, 6and 12.0Gbps SAS devices. This includes requirements for the Period measurement. The peak to peak voltage of differential signal of waveform must be more than 50mv. Copies of these specifications can be found in Appendix A.

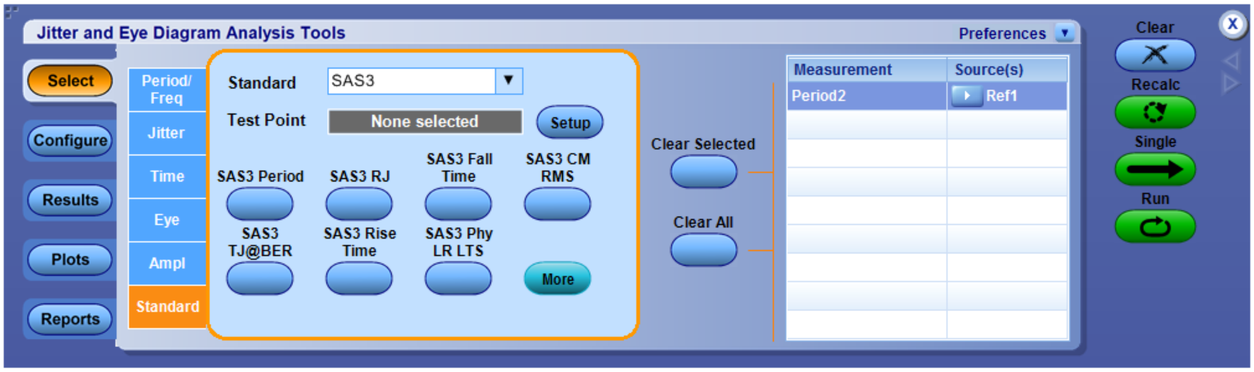
The Standard specifies that the rise/fall time measurements be performed while the DUT is transmitting a repeating 1010 pattern. The measurement is defined as a 20/80% rise time, however the specification does not provide any additional detail about what amplitude reference is used to determine the 20/80% levels, or how this reference is measured.
The following steps are used to perform this test:

a. Single ended waveforms of both polarities (+ve and –ve) of one lane are captured simultaneously.
b. Given a waveform find the zero crossing points. These zero crossing points are edges.
c. Calculate the time difference between adjacent edges.
d. Calculate number of bits within the edge by dividing time difference with nominal UI (expected bit rate) and generate actually UI.

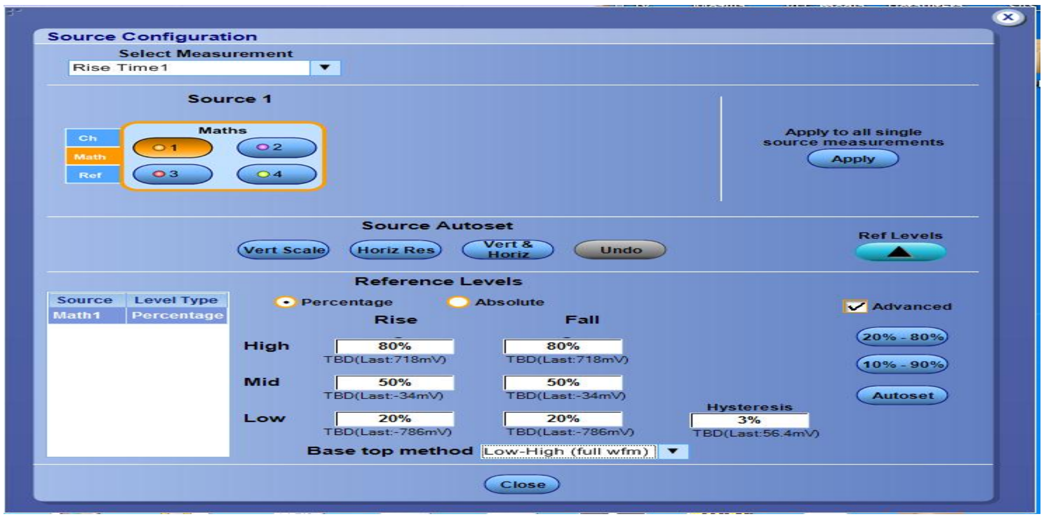
Test Procedure:

Following is the detailed test setup to run this measurement:

1. Configure the DUT so that it is sourcing 01b or 10b (D10.2 or D21.5) signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Outputs are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT outputs are connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
   a. Select 20GHz Bandwidth and press Apply to All Channels.
   b. Set Vertical Scale on all channels to 50mV/div for best A/D
9. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
10. In the Zoom Setup Menu, select Zoom Factor of 100000.
11. In the Math > Setup menu:
    i. Select Math1 tab
    ii. Choose Ch1-Ch3
    iii. Set Scale to 100mv.
    iv. Label Math1 as Lane0.
    v. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    vi. Label Math2 as Lane1.
12. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
13. From the Standard Tab Select **SAS3 Period** measurement button.



14. Set the Source for the measurement as Math1.
15. Set Reference level for lane0 and Lane1 from 20% to 80% as below



16. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits
    6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits
    3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
17. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

The Value will as following

i. >=666.43 & <=670.23 (1.5 Gbps SAS)
ii. >=333.22 & <=335.12 (3.0 Gbps SAS)
iii. >=167.12 & <= 166.61 (6.0 Gbps SAS)
iv. >=83.30 & <=83.77 (12.0 Gbps SAS)

4 TX OOB SIGNALLING REQUIREMENTS

4.1.1 TX Maximum Noise during OOB Idle

Purpose: To verify that the peak noise during OOB Idle of the DUT's transmitter is less than the maximum allowed value.

Discussion:
The SAS-3 Standard defines the electrical interface requirements for 12 Gbps SAS devices. This specification includes conformance limits for the maximum noise permitted by the transmitter during OOB Idle times [1]. The specification is reproduced in the figure below.

Table 31 — General electrical characteristics

Characteristic	Units	1.5 Gbps (i.e., G1)	3 Gbps (i.e., G2)	6 Gbps (i.e., G3)	12 Gbps (i.e., G4)
Physical link rate (nominal)	MBps	150	300	600	1 200
Unit interval (UI) (nominal) [a]	ps	$666.\overline{6}$	$333.\overline{3}$	$166.\overline{6}$	$83.\overline{3}$
Baud rate (f_{baud}) (nominal)	Gigasymbols/s	1.5	3	6	12
Maximum A.C. coupling capacitor [b]	nF	12			
Maximum noise during OOB idle time [c] [d]	mV(P-P)	120			

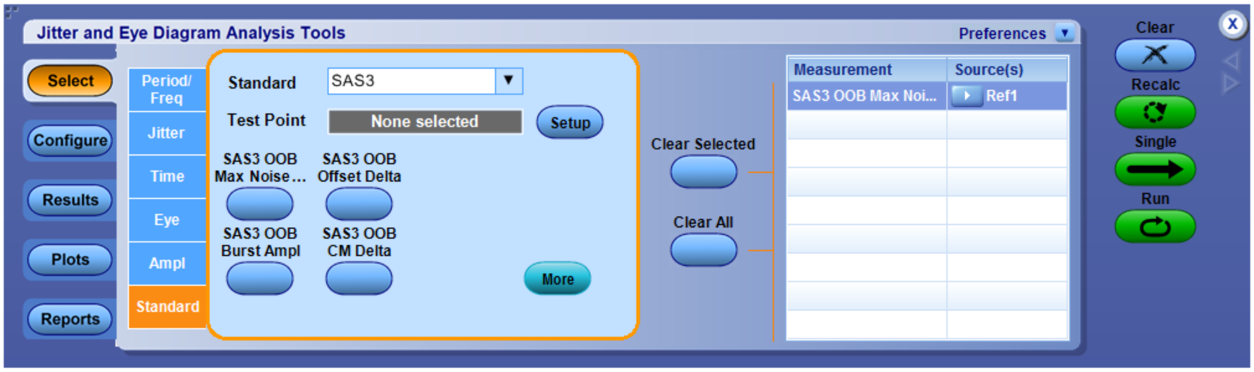
[a] $666.\overline{6}$ equals 2 000 / 3. $333.\overline{3}$ equals 1 000 / 3. $166.\overline{6}$ equals 500 / 3. $83.\overline{3}$ equals 250 / 3.
[b] The coupling capacitor value for A.C. coupled transmit and receive pairs. See 5.8.4.2 for A.C. coupling requirements for transmitter devices. See 5.8.5.2 for A.C. coupling requirements for receiver devices. The equivalent series resistance at 3 GHz should be less than 1 ohm.
[c] With a measurement bandwidth of $1.5 \times f_{baud}$ (e.g., 9 GHz for 6 Gbps), no signal level during the idle time shall exceed the specified maximum differential amplitude.
[d] This is not applicable when optical mode is enabled.

Figure: Maximum Noise During OOB Idle Specification

In this test, the maximum noise during OOB idle will be measured at the transmitter device output while the DUT is connected to the Zero-Length Test Load and transmitting OOB signaling. The peak to peak voltage of single ended signal of OOB must be more than 200mv so that we can trigger it at -100mv using edge trigger method. The maximum differential noise shall be observed during the Idle periods. The maximum peak-peak noise value must be less than 120mVppd in order to be considered conformant.

Test Procedure:
1. Configure the DUT so that it is sourcing OOB signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output is connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
9. a. Select 20GHz Bandwidth and press Apply to All Channels.
10. b. Set Vertical Scale on all channels to 50mV/div for best A/D
11. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).

12. In the Zoom Setup Menu, select Zoom Factor of 100000.
13. In the Math > Setup menu:
    a. Select Math1 tab
    b. Choose Ch1-Ch3 to perform differential mode operations.
    c. Set Scale to 100mv.
    d. Label Math1 as Lane0.
    e. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    f. Label Math2 as Lane1.
14. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
15. From the Standard Tab Select SAS 3 Standard and within SAS 3 select **SAS3 OOB Max Noise @ Idle** button.



16. Set the Source for the measurement as Math1.
17. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
18. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:
a. The maximum peak-to-peak OOB idle noise shall be less than 120mVppd.

4.1.2 TX OOB Burst Amplitude

Purpose: To verify that the amplitude of the DUT's transmitted OOB bursts is within the conformance limits.

Discussion:
The SAS-3 Standard defines the electrical interface requirements for 12.0 Gbps SAS devices. This includes requirements for the minimum and maximum amplitude of a device's transmitted OOB burst signaling [1]. The specifications are reproduced in the figure below.

Table 49 — Transmitter device signal output characteristics for OOB signals

Characteristic	Units	IT	CT
Maximum peak to peak voltage (i.e., 2 × Z2 in figure 112) [a]	mV(P-P)	1 600	
OOB offset delta [b] [c]	mV	± 25	
OOB common mode delta [c] [d]	mV	± 50	
Minimum OOB burst amplitude [e], if SATA is not supported	mV(P-P)	240 [f]	
Minimum OOB burst amplitude [e], if SATA is supported	mV(P-P)	240 [f] [g]	N/A

[a] The recommended maximum peak to peak voltage is 1 200 mV(P-P).
[b] The maximum difference in the average differential voltage (D.C. offset) component between the burst times and the idle times of an OOB signal.
[c] This is not applicable when optical mode is enabled or in low phy power conditions.
[d] The maximum difference in the average of the common-mode voltage between the burst times and the idle times of an OOB signal.
[e] With a measurement bandwidth of 4.5 GHz, each signal level during the OOB burst shall exceed the specified minimum differential amplitude before transitioning to the opposite bit value or before termination of the OOB burst as measured with each test load at IT and CT.
[f] The OOB burst contains either 1.5 Gbps repeating 0011b or 1100b pattern (e.g., D24.3), 1.5 Gbps ALIGN (0) primitives, or 3 Gbps ALIGN (0) primitives (see SPL-2 and SATA).
[g] Amplitude measurement methodologies of SATA and this standard differ. Under conditions of maximum rise/fall time and jitter, eye diagram methodologies used in this standard may indicate less signal amplitude than the technique specified by SATA. Implementers of designs supporting SATA are required to ensure interoperability and should perform additional system characterization with an eye diagram methodology using SATA devices.

Figure: TX OOB Amplitude Requirements

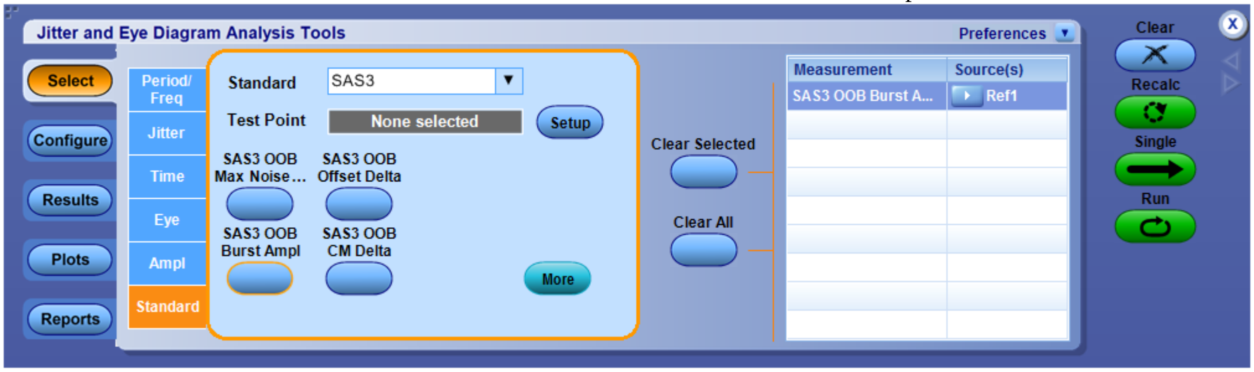
In this test, the DUT's transmitted OOB burst signaling will be captured with a real-time DSO. The peak to peak voltage of single ended signal of OOB must be more than 200mv so that we can trigger it at -100mv using edge trigger method. The minimum amplitude will be measured according to the definition specified in note (d) shown above, whereby the minimum amplitude will correspond to the lowest amplitude bit in the burst. The maximum amplitude will be measured as the maximum peak-to-peak differential amplitude across the entire burst. The minimum OOB amplitude must be greater than or equal to 240mVppd in order to be considered conformant, and the maximum OOB amplitude must be less than or equal to 1600mVppd in order to be considered conformant

Test Procedure:

1. Configure the DUT so that it is sourcing OOB signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
9. a. Select 20GHz Bandwidth and press Apply to All Channels.
10. b. Set Vertical Scale on all channels to 50mV/div for best A/D
11. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
12. In the Zoom Setup Menu, select Zoom Factor of 100000.
13. In the Math > Setup menu:
    a. Select Math1 tab
    b. Choose Ch1-Ch3 to perform differential mode functionalities.

c. Set Scale to 100mv.
d. Label Math1 as Lane0.
e. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
f. Label Math2 as Lane1.

14. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
15. From the Standard Tab select Sas3 and within SAS3 Standard select OOB Burst Ampl button.



16. Set the Source for the measurement as Math1.
17. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
18. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:
a. The minimum OOB burst amplitude shall be greater than 240mVppd for both test load cases.
b. The maximum OOB burst amplitude shall be less than 1600mVppd for both test load cases.

4.1.3 TX OOB Offset Delta

Purpose: To verify that the OOB offset delta of the DUT's transmitter device is within the conformance limits

Discussion:
The SAS-3 Standard defines the electrical interface requirements for 12.0Gbps SAS devices. This specification includes a requirement for the OOB offset delta, as well as the conditions under which this measurement shall be made [1]. A copy of the specification is reproduced in the figure below.

Table 49 — Transmitter device signal output characteristics for OOB signals

Characteristic	Units	IT	CT
Maximum peak to peak voltage (i.e., 2 × Z2 in figure 112) [a]	mV(P-P)	1 600	
OOB offset delta [b c]	mV	± 25	
OOB common mode delta [c d]	mV	± 50	
Minimum OOB burst amplitude [e], if SATA is not supported	mV(P-P)	240 [f]	
Minimum OOB burst amplitude [e], if SATA is supported	mV(P-P)	240 [f g]	N/A

[a] The recommended maximum peak to peak voltage is 1 200 mV(P-P).
[b] The maximum difference in the average differential voltage (D.C. offset) component between the burst times and the idle times of an OOB signal.
[c] This is not applicable when optical mode is enabled or in low phy power conditions.
[d] The maximum difference in the average of the common-mode voltage between the burst times and the idle times of an OOB signal.
[e] With a measurement bandwidth of 4.5 GHz, each signal level during the OOB burst shall exceed the specified minimum differential amplitude before transitioning to the opposite bit value or before termination of the OOB burst as measured with each test load at IT and CT.
[f] The OOB burst contains either 1.5 Gbps repeating 0011b or 1100b pattern (e.g., D24.3), 1.5 Gbps ALIGN (0) primitives, or 3 Gbps ALIGN (0) primitives (see SPL-2 and SATA).
[g] Amplitude measurement methodologies of SATA and this standard differ. Under conditions of maximum rise/fall time and jitter, eye diagram methodologies used in this standard may indicate less signal amplitude than the technique specified by SATA. Implementers of designs supporting SATA are required to ensure interoperability and should perform additional system characterization with an eye diagram methodology using SATA devices.

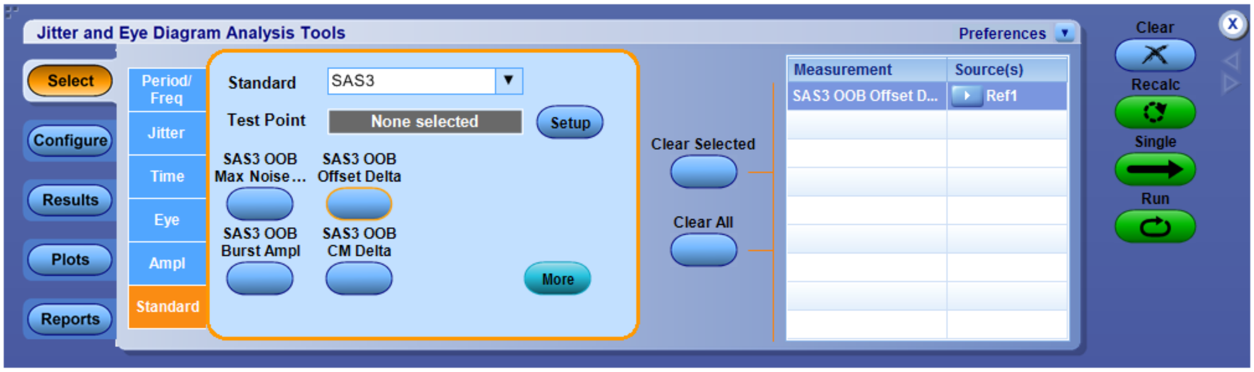
Figure: OOB Offset Delta Requirement

The specification defines the OOB offset delta as the maximum difference in the average differential voltage (DC offset) component between the burst times and the idle times of an OOB signal. The peak to peak voltage of single ended signal of OOB must be more than 200mv so that we can trigger it at -100mv using edge trigger method. In this test, the OOB offset delta will be measured at the transmitter device output using a real-time DSO while the DUT is connected to the Zero-Length test load. The edges of the burst will be computed at the time points where the differential signal crosses the +/-50mV thresholds. The differential waveform samples between these two points will be extracted and the mean value will be computed. (The average value of the differential signal during the idle times will not be directly measured, as it is understood to be zero volts due to the fact that the DUT will be connected to the DSO using DC blocking capacitors.) Thus, the mean value of the differential burst waveform samples will be computed as the OOB offset delta. The absolute value of the OOB offset delta must be less than or equal to 25mV in order to be considered conformant.

Test Procedure:

1. Configure the DUT so that it is sourcing OOB signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
9. a. Select 20GHz Bandwidth and press Apply to All Channels.
10. b. Set Vertical Scale on all channels to 50mV/div for best A/D
11. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).

12. In the Zoom Setup Menu, select Zoom Factor of 100000.
13. In the Math > Setup menu:
    a. Select Math1 tab
    b. Choose Ch1-Ch3 to perform differential mode functionalities.
    c. Set Scale to 100mv.
    d. Label Math1 as Lane0.
    e. Repeat Steps (a) through (c) in the Math2 (Ch2-Ch4) tab.
    f. Label Math2 as Lane1.
14. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
15. From the Standard Tab select Sas3 and within SAS3 Standard select.



17. Set the Source for the measurement as Math1.
18. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
19. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:
a. The OOB offset delta shall not exceed +/- 25mV.

4.1.4 TX OOB Common Mode Delta

Purpose: To verify that the OOB common mode delta of the DUT transmitter device is within the conformance limits.

Discussion:
The SAS-3 Standard defines the electrical interface requirements for 12.0 Gbps SAS devices. This includes a requirement for the OOB common mode delta, as well as the conditions under which this measurement shall be made [1]. A copy of the specification is reproduced in the figure below.

Table 49 — Transmitter device signal output characteristics for OOB signals

Characteristic	Units	IT	CT
Maximum peak to peak voltage (i.e., 2 × Z2 in figure 112) [a]	mV(P-P)	1 600	
OOB offset delta [b c]	mV	± 25	
OOB common mode delta [c d]	mV	± 50	
Minimum OOB burst amplitude [e], if SATA is not supported	mV(P-P)	240 [f]	
Minimum OOB burst amplitude [e], if SATA is supported	mV(P-P)	240 [f g]	N/A

[a] The recommended maximum peak to peak voltage is 1 200 mV(P-P).
[b] The maximum difference in the average differential voltage (D.C. offset) component between the burst times and the idle times of an OOB signal.
[c] This is not applicable when optical mode is enabled or in low phy power conditions.
[d] The maximum difference in the average of the common-mode voltage between the burst times and the idle times of an OOB signal.
[e] With a measurement bandwidth of 4.5 GHz, each signal level during the OOB burst shall exceed the specified minimum differential amplitude before transitioning to the opposite bit value or before termination of the OOB burst as measured with each test load at IT and CT.
[f] The OOB burst contains either 1.5 Gbps repeating 0011b or 1100b pattern (e.g., D24.3), 1.5 Gbps ALIGN (0) primitives, or 3 Gbps ALIGN (0) primitives (see SPL-2 and SATA).
[g] Amplitude measurement methodologies of SATA and this standard differ. Under conditions of maximum rise/fall time and jitter, eye diagram methodologies used in this standard may indicate less signal amplitude than the technique specified by SATA. Implementers of designs supporting SATA are required to ensure interoperability and should perform additional system characterization with an eye diagram methodology using SATA devices.

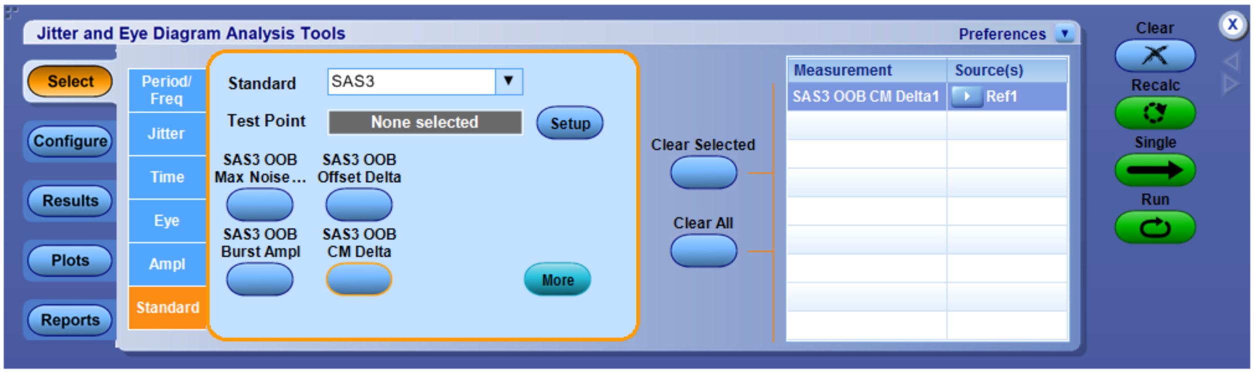
Figure: TX OOB Common-Mode Delta Requirement

The specification defines the OOB common mode delta as the maximum difference in the average common mode voltage between the burst times and the idle times of an OOB signal. The peak to peak voltage of single ended signal of OOB must be more than 200mv so that we can trigger it at -100mv using edge trigger method. In this test, the OOB common-mode delta will be measured at the transmitter device output using a real-time DSO while the DUT is connected to the Zero-Length test load. The common-mode signal will be computed as (TXp + TXn)/2, and the differential signal will be computed as (TXp - TXn) (where TXp and TXn are the positive and negative halves of the TX differential signal, respectively). The edges of the burst will be computed at the time points where the differential signal crosses the +/-50mV thresholds. The common-mode waveform samples between these two points will be extracted and the mean value will be computed. (The average value of the common-mode signal during the idle times will not be directly measured, as it is understood to be zero volts due to the fact that the DUT will be connected to the DSO using DC blocking capacitors.) Thus, the mean value of the common-mode burst samples will be computed as the OOB common-mode delta.

Test Procedure:

1. Configure the DUT so that it is sourcing OOB signaling.
2. Connect the Zero-Length test load to the DUT transmitter device.
3. Connect the Positive and Negative output of DUT to Ch1 and Ch3 or Ch2 and Ch4.
4. Perform Calibration procedure in Appendix B.
5. Perform De-Skew procedure on (Ch1-Ch3) and (Ch2-Ch4) by following the procedure outlined in Appendix B of this document.
6. Press Default Setup on the Oscilloscope front panel.
7. Turn on Ch1 and Ch3 if Output are connected to Ch1 and Ch3 or turn on Ch2 and Ch4 if DUT output is connected to Ch2 and Ch4. Ensure that only Ch1 and Ch3 or Ch2 and Ch4 are enabled.
8. In the Vertical > Setup menu:
9. a. Select 20GHz Bandwidth and press Apply to All Channels.
10. b. Set Vertical Scale on all channels to 50mV/div for best A/D
11. In the Horizontal > Setup menu, select Constant Sample Rate and adjust Sample rate to 100.0 GS/s and Horizontal Scale to 50.0us/div (50Meg RL).
12. In the Zoom Setup Menu, select Zoom Factor of 100000.

13. In the Math > Setup menu:
    a. Select Math1 tab
    b. Choose (Ch1+Ch3)/2 to perform common mode functionalities.
    c. Set Scale to 100mv.
    d. Label Math1 as Lane0.
    e. Repeat Steps (a) through (c) in the Math2 (Ch2+Ch4)/2 tab.
    f. Label Math2 as Lane1.
14. Go to Analysis > Jitter and Eye Analysis (DPOJET) > SAS 3 to launch DPOJET.
15. From the Standard Tab select Sas3 and within SAS3 Standard select.



16. Set the Source for the measurement as Math1.
17. To Load the Limits file
    i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.
    ii. Navigate to the folder with the file as per data rate as given below.
    1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits
    iii. Turn the Limits File to On.
18. To run the test, Press the Single button on the right hand side of the DPOJET menu. The results are logged in the Results panel along with the Pass/Fail indication.

Observable Results:

a. The OOB common mode delta shall not exceed +/- 50mV.

5 USING SETUP FILES FOR TESTING

The SAS measurements come with setup files. If you have the following setup files then measurements can be made much more easily using these setup files. The table below shows the various setup files, which comes with the installer.

Setup files based on Live Channel (Ch1 and Ch3):

Name	Description	Mesurements
SAS 1.5G OOB OOB Live.set	OOB setup file of SAS 1.5 Gbps	Tx Maximum Noise During OOB Idle Tx OOB Burst Amplitude Tx OOB Offset Delta Tx OOB Common Mode Delta
SAS 1.5G PHY D10.2 Live.set	PHY Setup file of SAS 1.5 Gbps	Tx SSC modulation type Tx SSC Modulation frequency Tx SSC modulation deviation Tx SSC modulation Balance Tx SSC DFDT
SAS 3G PHY D10.2 Live.set	PHY Setup file of SAS 3 Gbps	
SAS 6G PHY D10.2 Live.set	PHY Setup file of SAS 6 Gbps	
SAS 12G PHY D10.2 Live.set	PHY Setup file of SAS 12 Gbps	
SAS 1.5G TSG D10.2 Live.set	TSG Setup file of SAS 1.5 Gbps for D10.2 pattern	Tx Period Tx Rise Time Tx Fall Time Tx Physical link rate long term stability
SAS 3G TSG D10.2 Live.set	TSG Setup file of SAS 3 Gbps for D10.2 pattern	
SAS 6G TSG D10.2 Live.set	TSG Setup file of SAS 6 Gbps for D10.2 pattern	
SAS 12G TSG D10.2 Live.set	TSG Setup file of SAS 12 Gbps for D10.2 pattern	
SAS 1.5G TSG CJTPAT Live.set	TSG Setup file of SAS 1.5 Gbps for CJTPAT pattern	Tx Common Mode RMS Tx Common Mode Spectrum
SAS 3G TSG CJTPAT Live.set	TSG Setup file of SAS 3 Gbps for CJTPAT pattern	
SAS 6G TSG CJTPAT Live.set	TSG Setup file of SAS 6 Gbps for CJTPAT pattern	
SAS 12G TSG CJTPAT Live.set	TSG Setup file of SAS 12 Gbps for CJTPAT pattern	
SAS 1.5G TSG D24.3 Live.set	TSG Setup file of SAS 1.5 Gbps for D24.3 pattern	Tx Random Jitter Tx Total Jitter
SAS 3G TSG D24.3 Live.set	TSG Setup file of SAS 3 Gbps for D24.3 pattern	
SAS 6G TSG D24.3 Live.set	TSG Setup file of SAS 6 Gbps for D24.3 pattern	
SAS 12G TSG D24.3 Live.set	TSG Setup file of SAS 12 Gbps for D24.3 pattern	
SAS 1.5G TSG D24.3_SSC Live.set	TSG Setup file of SAS 1.5 Gbps for D24.3 pattern with SSC	Tx Random Jitter Tx Total Jitter (With SSC)
SAS 3G TSG D24.3_SSC Live.set	TSG Setup file of SAS 3 Gbps for D24.3 pattern with SSC	
SAS 6G TSG D24.3_SSC Live.set	TSG Setup file of SAS 6 Gbps for D24.3 pattern with SSC	
SAS 12G TSG D24.3_SSC Live.set	TSG Setup file of SAS 12 Gbps for D24.3 pattern with SSC	
SAS 1.5G TSG D30.3 Live.set	TSG Setup file of SAS 1.5 Gbps for D30.3 pattern	Tx Peak to Peak Voltage
SAS 3G TSG D30.3 Live.set	TSG Setup file of SAS 3 Gbps for D30.3 pattern	
SAS 6G TSG D30.3 Live.set	TSG Setup file of SAS 6 Gbps for D30.3 pattern	
SAS 12G TSG D30.3 Live.set	TSG Setup file of SAS 12 Gbps for D30.3 pattern	
SAS 1.5G TSG SCRMLD0 Live.set	TSG Setup file of SAS 1.5 Gbps for SCRMLD 0 pattern	Tx WDP
SAS 3G TSG SCRMLD0 Live.set	TSG Setup file of SAS 3 Gbps for SCRMLD 0 pattern	
SAS 6G TSG SCRMLD0 Live.set	TSG Setup file of SAS 6 Gbps for SCRMLD 0 pattern	
SAS 12G TSG SCRMLD0 Live.set	TSG Setup file of SAS 12 Gbps for SCRMLD 0 pattern	Tx Eye Opening
SAS 1.5G TSG K28.5 Live.set	TSG Setup file of SAS 1.5 Gbps for K28.5 pattern	Tx VMA TX Equalization
SAS 3G TSG K28.5 Live.set	TSG Setup file of SAS 3 Gbps for K28.5 pattern	
SAS 6G TSG K28.5 Live.set	TSG Setup file of SAS 6 Gbps for K28.5 pattern	
SAS 12G TSG K28.5 Live.set	TSG Setup file of SAS 12 Gbps for K28.5 pattern	Tx VMA Tx Pre Cursor Equalization Ratio Tx Post Cursor Equalization Ratio Tx Vhl

Setup files based on Ref Channel (Ref1 and Ref2):

Name	Description	Mesurements
SAS 1.5G OOB OOB Ref.set	OOB setup file of SAS 1.5 Gbps	Tx Maximum Noise During OOB Idle Tx OOB Burst Amplitude Tx OOB Offset Delta Tx OOB Common Mode Delta
SAS 1.5G PHY D10.2 Ref.set	PHY Setup file of SAS 1.5 Gbps	Tx SSC modulation type Tx SSC Modulation frequency Tx SSC modulation deviation Tx SSC modulation Balance Tx SSC DFDT
SAS 3G PHY D10.2 Ref.set	PHY Setup file of SAS 3 Gbps	
SAS 6G PHY D10.2 Ref.set	PHY Setup file of SAS 6 Gbps	
SAS 12G PHY D10.2 Ref.set	PHY Setup file of SAS 12 Gbps	
SAS 1.5G TSG D10.2 Ref.set	TSG Setup file of SAS 1.5 Gbps for D10.2 pattern	Tx Period Tx Rise Time Tx Fall Time Tx Physical link rate long term stability
SAS 3G TSG D10.2 Ref.set	TSG Setup file of SAS 3 Gbps for D10.2 pattern	
SAS 6G TSG D10.2 Ref.set	TSG Setup file of SAS 6 Gbps for D10.2 pattern	
SAS 12G TSG D10.2 Ref.set	TSG Setup file of SAS 12 Gbps for D10.2 pattern	
SAS 1.5G TSG CJTPAT Ref.set	TSG Setup file of SAS 1.5 Gbps for CJTPAT pattern	Tx Common Mode RMS Tx Common Mode Spectrum
SAS 3G TSG CJTPAT Ref.set	TSG Setup file of SAS 3 Gbps for CJTPAT pattern	
SAS 6G TSG CJTPAT Ref.set	TSG Setup file of SAS 6 Gbps for CJTPAT pattern	
SAS 12G TSG CJTPAT Ref.set	TSG Setup file of SAS 12 Gbps for CJTPAT pattern	
SAS 1.5G TSG D24.3 Ref.set	TSG Setup file of SAS 1.5 Gbps for D24.3 pattern	Tx Random Jitter Tx Total Jitter
SAS 3G TSG D24.3 Ref.set	TSG Setup file of SAS 3 Gbps for D24.3 pattern	
SAS 6G TSG D24.3 Ref.set	TSG Setup file of SAS 6 Gbps for D24.3 pattern	
SAS 12G TSG D24.3 Ref.set	TSG Setup file of SAS 12 Gbps for D24.3 pattern	
SAS 1.5G TSG D24.3_SSC Ref.set	TSG Setup file of SAS 1.5 Gbps for D24.3 pattern with SSC	Tx Random Jitter Tx Total Jitter (With SSC)
SAS 3G TSG D24.3_SSC Ref.set	TSG Setup file of SAS 3 Gbps for D24.3 pattern with SSC	
SAS 6G TSG D24.3_SSC Ref.set	TSG Setup file of SAS 6 Gbps for D24.3 pattern with SSC	
SAS 12G TSG D24.3_SSC Ref.set	TSG Setup file of SAS 12 Gbps for D24.3 pattern with SSC	
SAS 1.5G TSG D30.3 Ref.set	TSG Setup file of SAS 1.5 Gbps for D30.3 pattern	Tx Peak to Peak Voltage
SAS 3G TSG D30.3 Ref.set	TSG Setup file of SAS 3 Gbps for D30.3 pattern	
SAS 6G TSG D30.3 Ref.set	TSG Setup file of SAS 6 Gbps for D30.3 pattern	
SAS 12G TSG D30.3 Ref.set	TSG Setup file of SAS 12 Gbps for D30.3 pattern	
SAS 1.5G TSG SCRMLD0 Ref.set	TSG Setup file of SAS 1.5 Gbps for SCRMLD 0 pattern	Tx WDP
SAS 3G TSG SCRMLD0 Ref.set	TSG Setup file of SAS 3 Gbps for SCRMLD 0 pattern	
SAS 6G TSG SCRMLD0 Ref.set	TSG Setup file of SAS 6 Gbps for SCRMLD 0 pattern	
SAS 12G TSG SCRMLD0 Ref.set	TSG Setup file of SAS 12 Gbps for SCRMLD 0 pattern	Tx Eye Opening
SAS 1.5G TSG K28.5 Ref.set	TSG Setup file of SAS 1.5 Gbps for K28.5 pattern	Tx VMA TX Equalization
SAS 3G TSG K28.5 Ref.set	TSG Setup file of SAS 3 Gbps for K28.5 pattern	
SAS 6G TSG K28.5 Ref.set	TSG Setup file of SAS 6 Gbps for K28.5 pattern	
SAS 12G TSG K28.5 Ref.set	TSG Setup file of SAS 12 Gbps for K28.5 pattern	Tx VMA Tx Pre Cursor Equalization Ratio Tx Post Cursor Equalization Ratio Tx Vhl

The next section shows how to use the setup files for making the measurements.

5.1 How to evaluate measurements using setup file and its corresponding limit file

This is only an example for particular setup files, which work on 12G, but same procedure will be applicable for all speed.

Basically the current setup files based on pattern type as you can see above.

Setup file: SAS 12G TSG CJTPAT Live. Set (12G)

The setup in this section performs the following measurements:

a. Tx Common Mode RMS

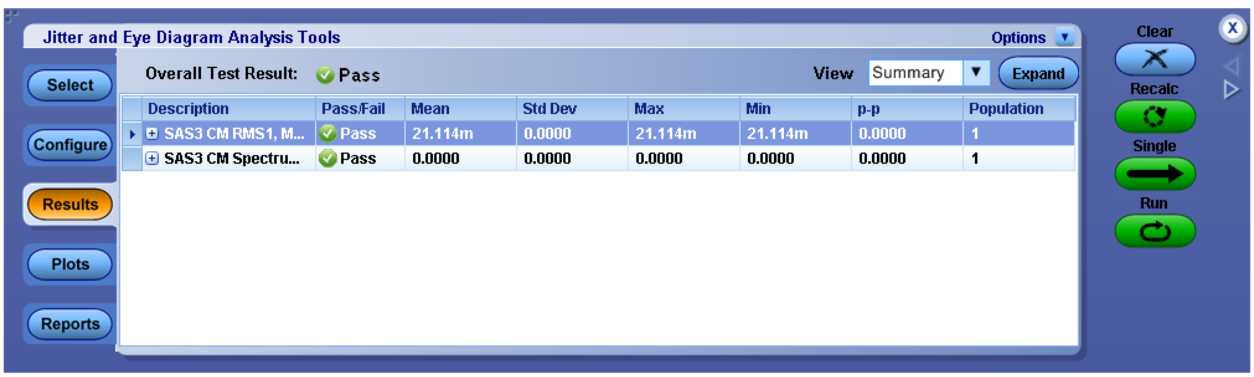
b. Tx Common Mode Spectrum

Measurements are made using positive and negative waveform from single ended probes from SAS link. For measurements, Math1 (Ch1-Ch3) are used to derive the differential signals to be analyzed. For differential skew, the skew between the Positive (Ch1, Ch2) and Negative legs (Ch3, Ch4) of each lane is measured.

(It also can be done by using Ref1 and Ref2 signal, for that +ve and –ve polarity signal will be connected to Ref1 a Ref2 respectively)

The following are the detailed steps for doing the Common Mode Voltage measurement:

1. Perform Calibration procedure in Appendix B.
2. Perform De-Skew procedure on (Ch1, Ch3) and (Ch2, Ch4) by following the procedure outlined in Appendix B of this document.
3. Connect the DUT TX to the Scope Ch1 and Ch3.
4. Press Default Setup on the Oscilloscope front panel.
5. Select File > Recall Setup from the TekScope main menu. Recall the following setup file for live data: C:\Users\Public\Tektronix\TekApplications\SAS3\Setups\12G**SAS 12G TSG CJTPAT Live. Set**
6. Initiate the pattern CJTPAT from the SAS DUT.
7. Press Clear Button and then the Single Button in DPOJET to make an acquisition.
8. Results will appear as in Figure below.
   (If you can't find Pass/Fail column please load the limit file as discussed below from following location *C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits*)
9. To Save a Report of the measurements, select the Report Tab and Press Save Result in the DPOJET menu.



N.B. How to load limit file:

i. Go to Applications > Jitter and Eye Analysis (DPOJET) >Limits.

ii. Navigate to the folder with the file as per data rate as given below.

12G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN3_12G_Limits.xml
6G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN2_6G_Limits.xml
3G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_3G_Limits.xml
1.5G: C:\Users\Public\tektronix\TekApplications\SAS3\Limits\SAS_GEN1_1.5G_Limits.xml

iii. Turn the Limits File to On.

6 APPENDIX

6.1 APPENDIX A: Transmitter device signal output characteristics

Table 41 — Transmitter device signal output characteristics for trained 12 Gbps at TC

Signal characteristic	Units	Minimum	Nominal	Maximum
Peak to peak voltage (V_{P-P}) [a] [b]	mV(P-P)	850	1 000	1 200
Transmitter device off voltage [c] [d]	mV(P-P)			50
Withstanding voltage (non-operational)	mV(P-P)	2 000		
Rise/fall time [e]	ps	20.8		
Reference differential impedance [f]	ohm		100	
Reference common mode impedance [f]	ohm		25	
Pre-cursor equalization ratio R_{pre} [g]	V/V	0.88		1.67
Post-cursor equalization ratio R_{post} [h]	V/V	0.88		2.5
VMA [i]	mV	40		
Common mode voltage limit (rms) [j]	mV			30
RJ [j] [k] [l]	UI			0.15 [m]
TJ [l] [n]	UI			0.25 [o]

[a] See 5.8.4.6.6 for the V_{P-P} measurement method.
[b] Maximum voltage compliance point is at RC.
[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] This is not applicable when optical mode is enabled.
[e] Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 01b or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2) on the physical link.
[f] See 5.8.4.7.2 for transmitter device S-parameters characteristics.
[g] Ratio measured with post-cursor equalization disabled. When both pre-cursor and post-cursor equalization are active the maximum observed R_{pre} may be as high as 3.8 at the VMA limit.
[h] Ratio measured with pre-cursor equalization disabled, When both pre-cursor and post-cursor equalization are active the maximum observed R_{post} may be as high as 5.5 at the VMA limit.
[i] Measured as the maximum of $100 \times (v_1 + v_4) / v_1$, $100 \times (v_2 + v_5) / 2$, or $100 \times (v_3 + v_6) / 3$ when $v_2 > 100$mV (see figure 120).
[j] This is a broadband limit. For additional limits on spectral content, see figure 113 and table 37.
[k] The RJ measurement shall be performed with a repeating 0011b or 1100b pattern (e.g., D24.3)(see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2) with SSC disabled. RJ is 14 times the RJ 1 sigma value, based on a BER of 10^{-12}. For simulations based on a BER of 10^{-15}, the RJ specified is 16 times the RJ 1 sigma value.
[l] The measurement shall include the effects of the JTF (see 5.8.3.2).
[m] 0.15 UI is 12.5 ps at 12 Gbps.
[n] The TJ measurement shall be performed with a repeating 0011b or 1100b pattern (e.g., D24.3) (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2). If the transmitter device supports SSC, then this test shall be performed with both SSC enabled and SSC disabled. TJ is equivalent to BUJ + RJ. ISI is minimized by the test pattern.
[o] 0.25 UI is 20.8 ps at 12 Gbps.

6.2 APPENDIX B: Scope/Probe/Cable Calibration

Before beginning any test or data acquisition, the oscilloscope must be warmed, calibrated, and cables de-skewed. This section includes the procedure for calibrating the scope and de-skewing the cables.
Calibration can be performed in the following order:

1. Signal Path Compensation compensates the signal pathways for gain and offset errors.
2. Cable de-skew compensates for timing differences between two cables. Once these calibrations are performed, they are not permanent. It's recommended the signal path compensation be performed once a week and whenever the ambient temperature of the oscilloscope has changed by more than 50 C, whereas the cable de-skews can be performed

Signal Path Compensation Procedure

This type of calibration can be done through the scope's utilities menu by selecting Utilities->Instrument calibration.

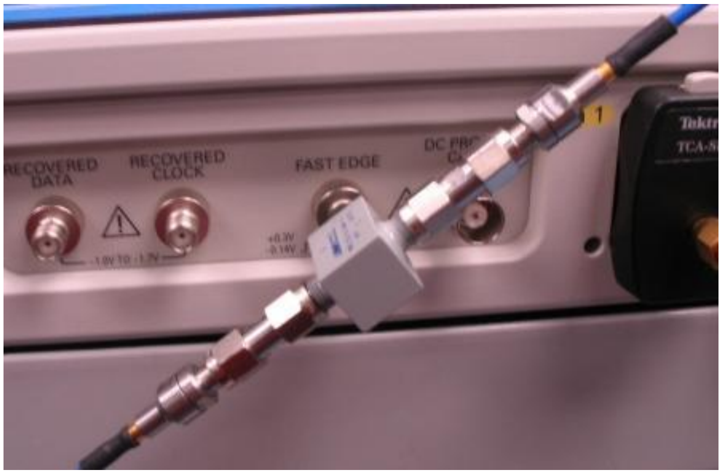
To perform this operation ensure that

a. All input cables to the scope channels must be disconnected.
b. Ensure the Tektronix TCA-SMA input adapters are installed in channels 1 and 3 and nothing is connected to the scope inputs. This prevents transient voltages from leaking into the input amplifiers and ADC's that could adversely affect the quality of the calibration routine. Click on the "Calibrate" button. It takes about 10 minutes to get the calibration result. Final status should be "Pass"

Cable Deskew Procedure

Use the following procedure to compensate for timing differences between SMA cables:
This procedure is performed on a pair of cables at a time.

1. Connect SMA TekConnects to channels 1 and 2of the scope.
2. Click ""Default Setup"
3. Connect the SMA end of the SMA cable pair to the channels Ch1 and Ch2 of the scope through SMA TekConnects. Use torque-wrench to tighten the connection.(7-10 in lbs.)
4. Select the two channels using Ch1 and Ch3 buttons on scope front panel.
5. Make sure that channels Ch2 and Ch4 are de-selected.
6. Connect the power splitter to the "Fast Edge" output of the scope. Refer Figure below
7. Connect two SMA (male)-SMA (Male) adapters to two outputs of the power splitter. Refer Figure above.
8. Connect SMA (Female)-SMA (Male) adapter to the two SMA adapters. Refer Figure.
9. Tighten all the connection joints using torque-wrench.(7-10 in lbs.)
10. Connect SMA ends of the cables from Ch1 and Ch3 to these adapters.
11. Click on scope "Autoset" button on front panel
12. Click "Ok" on the confirmation window.
13. Adjust the Vertical Scale (Increase it without any clipping) and Position controls for each channel so that the signals overlap and are centered on the display.



Cable de-skewconnections

14. Click Horiz/Acq->Horizontal/Acquisition Setup.
15. Click on “Acquisition” tab.
16. Select “Average” acquisition mode.
17. Keep the “# of Wfms” as default which is 16.

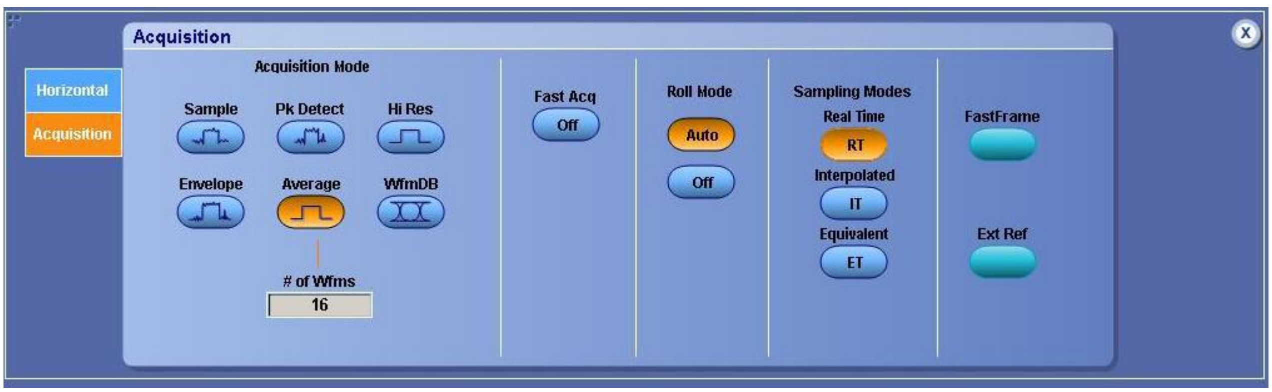


Figure 54: Setting Average

Visible Cable De-skew

18. Adjust the Horizontal Position so that a rising edge is triggered at the center of the display.
19. Adjust the horizontal Scale (Lower time/pt) so that the differences in the channel delays are clearly visible.
20. Adjust the horizontal Position again so that the first rising edge is exactly at the center of the display. The short length (Electrical length) cable is connected to this channel.
21. Select Vertical ->Deskew from the scope menu to open the Deskew control window.
22. Select one of the slower channels.
23. Adjust the de-skew time for the slower channel so that its signal aligns with that of the fastest channel. The de-skew adjustment range is ±75 ns.
24. Remove the SMA ends of cables attached to Ch1 and Ch2 from cable de-skew attachment. Keep the SMA end of cables attached to Ch1 and Ch2.
25. Repeat Steps (1) thru (24) to complete Deskew of Ch2 and Ch4.

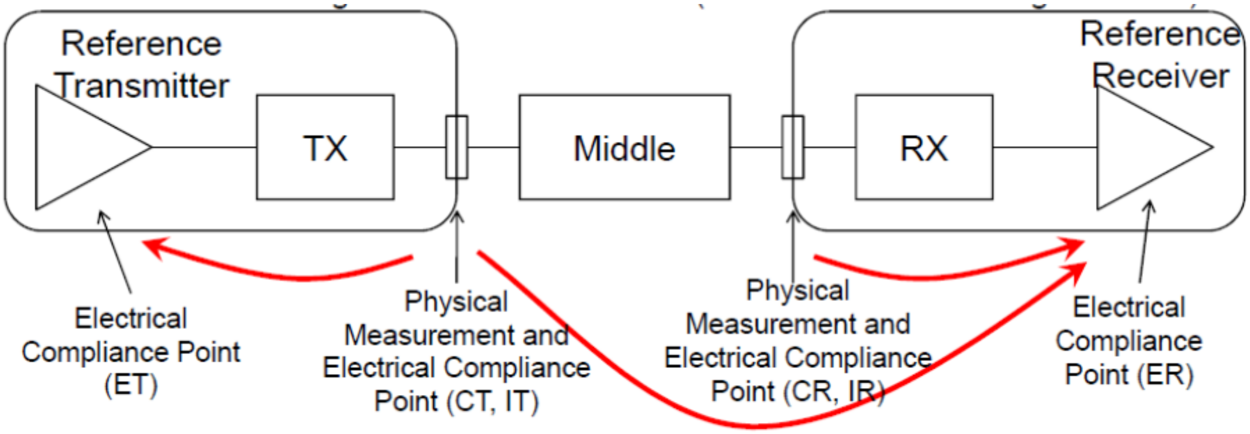
Cable Skew Adjusted

6.3 APPENDIX C: SAS EYE OPENING

The SAS3 Eye opening is used to transform the measurement from a Physical Compliance point into an Electrical Compliance Point e.g.

- CT/IT into ET for TX Equalization and Amplitude
- CT/IT into ER for TX ISIS and crosstalk
- CR/IR into ER for crosstalk

The below figure shows the reference points discussed above



The 12G design problem is a serious one. You start with 1000mV signal, and a Feed Forward Equalizer circuit (FFE), the signal then traverses out of the package, through the transition flip-chip structures, onto a circuit board transmission path. From this point of signal launch, the problems of escape bandwidth and crosstalk become evident in just the first 20 mm (.8") of the transmission path.

The most insidious problem emerges from the significant amounts of crosstalk generated by these close proximity (highly field coupled) transmission paths. The collective effects of multiple aggressor channels on victim channel can results in half the power from aggressors coupling into the victim.

Traditional methods of applying pre-emphasis makes the crosstalk problem even worse, as it's the high frequency content that most efficiently couples from aggressors to victims.

The signal has now significant frequency dependent losses which can be over 20dB at the first harmonic. These losses if it is pure ISI it's compensable with a Decision Feedback Equalizer (DFE) circuit at the receiver. The eye will be completely closed but by using a reference DFE, near full recovery of the signal is possible.

The SAS3 specs specify the following:

> The reference receiver device includes a multiple tap DFE with infinite precision taps and unit interval tap spacing. The reference coefficient adaptation algorithm is the LMS algorithm. The DFE may be modeled at the center of the eye as:
>
> $$y_k = x_k - \sum_{i=1}^{Ndfe} d_i \times \mathrm{sgn}(y_{k-i})$$
>
> where:
>
> | | |
> |---|---|
> | y | equalizer differential output voltage; |
> | x | equalizer differential input voltage; |
> | d | equalizer feedback coefficient; |
> | k | sample index in UI; and |
> | Ndfe | number of equalizer DFE taps. |
>
> Ndfe = 3 for the trained 1.5 Gbps, 3 Gbps, and 6Gbps reference receiver device. Ndfe = 5 for the 12 Gbps reference receiver device.

The DFE has to be applied for any simulation involving the reference receiver. That means it shall be applied for simulating compliance - of everything except an actual receiver, and even there, it can be used to calibrate the stress. The reference coefficient adaptation algorithm which is recommended by specs is the LMS algorithm.

The DFE does not bring previous samples to the current sample to be corrected, but rather previous decisions (i.e. sgn(y k-i) in the above equation). This means that previous ISI is not carried into the current decision. The optimal DFE coefficient #N is thus simply the value that will remove the effect of the bit sent N bits before into the current bit. This value can be read directly from the pulse response: the effect of the bit sent N bits before the current bit is equal to the pulse response's value N UIs after the main cursor (i.e. approx. the peak of the pulse response).

These algorithms are trying to find the equalization settings that will result in the least square error of the equalized signal. This can be understood simply by looking at the points sampled in the middle of the eye (or middle of the UI). You know that these points should be either a digital 1 or a digital 0. This means that their analog amplitude should optimally only take two values: either +T or –T, for a digital 1 or a digital 0, respectively. In reality, you will get +T+error or –T+error – where "error" is what your equalizer cannot correct. The algorithm is trying to reduce the sum of the error^2 terms over a very long sequence of bits.

6.4 APPENDIX D: SAS WDP

The SAS-3 Standard defines the electrical interface requirements for 6.0Gbps SAS devices. This includes a requirement for the transmitter device's waveform distortion penalty (WDP). A copy of the specification is reproduced in the figure below.

Table 38 — Transmitter device signal output characteristics for trained 1.5 Gbps, 3 Gbps, and 6 Gbps at IT and CT

Signal characteristic	Units	Minimum	Nominal	Maximum
Peak to peak voltage (V_{P-P}) [a]	mV(P-P)	850		1 200
Transmitter device off voltage [b] [c]	mV(P-P)			50
Withstanding voltage (non-operational)	mV(P-P)	2 000		
Rise/fall time [d]	ps	41.6		
Reference differential impedance [e]	ohm		100	
Reference common mode impedance [e]	ohm		25	
Common mode voltage limit (rms) [f]	mV			30
RJ [g] [h]	UI			0.15 [i]
TJ [h] [j]	UI			0.25 [k]
WDP at 6 Gbps [l]	dB			13
WDP at 3 Gbps [l]	dB			7
WDP at 1.5 Gbps [l]	dB			4.5

[a] See 5.9.4.6.6 for the V_{P-P} measurement method.

[b] 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).

[c] This is not applicable when optical mode is enabled.

[d] Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 01b or 10b pattern (e.g., D10.2 or D21.5) (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2) on the physical link.

[e] See 5.9.4.6.3 for transmitter device S-parameters characteristics.

[f] This is a broadband limit. For additional limits on spectral content, see figure 126 and table 39.

[g] The RJ measurement shall be performed with a repeating 0011b or 1100b pattern (e.g., D24.3)(see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2) with SSC disabled. RJ is 14 times the RJ 1 sigma value, based on a BER of 10^{-12}. For simulations based on a BER of 10^{-15}, the RJ specified is 16 times the RJ 1 sigma value.

[h] The measurement shall include the effects of the JTF (see 5.9.3.2).

[i] 0.15 UI is 25 ps at 6 Gbps, 50 ps at 3 Gbps, and 100 ps at 1.5 Gbps.

[j] The TJ measurement shall be performed with a repeating 0011b or 1100b pattern (e.g., D24.3) (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2). If the transmitter device supports SSC, then this test shall be performed with both SSC enabled and SSC disabled. TJ is equivalent to BUJ + RJ. ISI is minimized by the test pattern.

[k] 0.25 UI is 41.6 ps at 6 Gbps, 83.3 ps at 3 Gbps, and 166.6 ps at 1.5 Gbps.

[l] See 5.9.4.6.2 for the transmitter device test procedure.

The Standard defines WDP as, "***A simulated measure of the deterministic penalty of the signal waveform from a particular transmitter device transmitting a particular pattern and a particular test load with a reference receiver device.***"[2]. It also describes it as, "***a characterization of the signal output within the reference receiver device after equalization***"[3]. The latter description is perhaps somewhat easier to understand from a conceptual perspective, as the WDP measurement is an example of what the DUT's transmitted signaling would 'look like' to a receiver device, after passing through an interconnect (i.e., channel, backplane, cable, etc), and being received and processed by an equalizer circuit inside the receiver device.

Because it is not typically possible to observe the signal at this point (as it is conceptually located inside the actual receiver IC, post-equalization) it is not possible to practically measure this signal, however it can be mathematically computed, based on a reference model of a SAS interconnect, and a reference receive equalizer. This mathematical modeling is performed by a set of MATLAB code that is included as part of the standard [4].

The Standard specifies a test procedure for performing the WDP measurement, which is reproduced below.

5.9.4.6.2 Trained 1.5 Gbps, 3 Gbps, and 6 Gbps transmitter device test procedure

The transmitter device test procedure is as follows:

1) attach the transmitter device to a zero-length test load, where its signal output is captured by an oscilloscope;
2) configure the transmitter device to transmit the SCRAMBLED_0 pattern (see the phy test patterns in the Protocol-Specific diagnostic page in SPL-2);
3) configure the transmitter device to minimize DCD and BUJ;

NOTE 17 - WDP values computed by SASWDP are influenced by all sources of eye closure including DCD, BUJ, and ISI, and increased variability in results may occur due to increases in those sources other than ISI.

4) capture multiple sets of the first 58 data dwords (i.e., 2 320 bits on the physical link) of the SCRAMBLED_0 pattern. Use averaging to minimize RJ; and
5) input the captured pattern into SASWDP simulation (see Annex B) with the usage variable set to 'SAS2_TWDP'.

Note that the specified procedure requires that the measurement be performed using the SCRAMBLED_0 pattern, which is one of several reference patterns defined by the Standard. This pattern will typically be enabled via the Protocol-Specific diagnostic page mechanism (see [5] and [6]).

Note also that the MATLAB code for the SASWDP function assumes that the input waveform data contains 16 evenly spaced samples per UI (which is the format offered by some sampling scopes, which allow a selectable number of samples per UI when exporting waveform data). However, if a real-time DSO is used as the digitizing source, note that the sampling rate of the DSO is typically fixed at a constant rate that is not frequency or phase synchronous with the DUT's transmitted signal. In these cases, the captured waveform data will need to be resampled and interpolated to produce exactly 16 evenly spaced samples per UI. This can be accomplished relatively easily via post-processing in MATLAB prior to passing the data to the SASWDP function.

The SASWDP function produces as one of its outputs a plot showing the simulated eye opening as a statistical BER map. An example BER map is shown in the figure below.

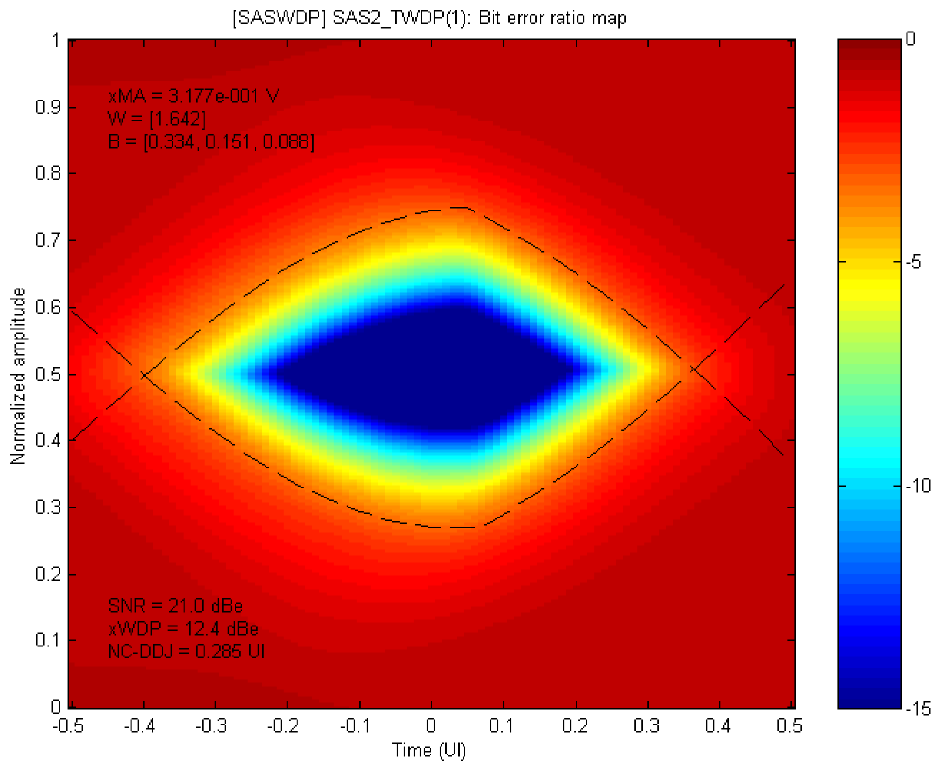


Figure: Example BER Map with WDP Results
(Output from SASWDP MATLAB Script)

The primary value of interest produced by the WDP script is the WDP result (marked 'xWDP' in the figure above).

6.5 APPENDIX E: SAS Patterns

Sl No	Patterns Types	Remarks	Measurements	Measurement Groups
	OOB	OOB pattern at 1.5 Gbps	Tx Maximum Noise During OOB Idle	OOB
	OOB	OOB pattern at 1.5 Gbps		
	OOB	OOB pattern at 1.5 Gbps	Tx OOB Burst Amplitude	
1	OOB	OOB pattern at 1.5 Gbps	Tx OOB Offset Delta	
	D10.2	D10.2 pattern with SSC at SAS 1.5 Gbps	Tx SSC modulation type	PHY
	D10.2	D10.2 pattern with SSC at SAS 3 Gbps	Tx SSC Modulation frequency	
	D10.2	D10.2 pattern with SSC at SAS 6 Gbps	Tx SSC modulation deviation	
2	D10.2	D10.2 pattern with SSC at SAS 12 Gbps	Tx SSC modulation Balance	
	CJTPAT	CJTPAT pattern at SAS 1.5 Gbps	Tx Common Mode RMS Tx Common Mode Spectrum	TSG
	CJTPAT	CJTPAT pattern at SAS 3 Gbps		
	CJTPAT	CJTPAT pattern at SAS 6 Gbps		
3	CJTPAT	CJTPAT pattern at SAS 12 Gbps		
	D10.2	D10.2 pattern at SAS 1.5 Gbps	Tx Period	
	D10.2	D10.2 pattern at SAS 3 Gbps	Tx Rise Time	
	D10.2	D10.2 pattern at SAS 6 Gbps	Tx Fall Time	
4	D10.2	D10.2 pattern at SAS 12 Gbps	Tx Physical link rate long term	
	D24.3	D24.3 pattern at SAS 1.5 Gbps	Tx Random Jitter Tx Total Jitter	
	D24.3	D24.3 pattern at SAS 3 Gbps		
	D24.3	D24.3 pattern at SAS 6 Gbps		
5	D24.3	D24.3 pattern at SAS 12 Gbps		
	D24.3	D24.3 pattern with SSC at SAS 1.5 Gbps	Tx Random Jitter	
	D24.4	D24.3 pattern with SSC at SAS 3 Gbps	Tx Total Jitter	
	D24.5	D24.3 pattern with SSC at SAS 6 Gbps	(With SSC)	
6	D24.6	D24.3 pattern with SSC at SAS 12 Gbps		
	D30.3	D30.3 pattern at SAS 1.5 Gbps	Tx Peak to Peak Voltage	
	D30.3	D30.3 pattern at SAS 3 Gbps		
	D30.3	D30.3 pattern at SAS 6 Gbps		
7	D30.3	D30.3 pattern at SAS 12 Gbps		
	Scrambled 0	Scrambled 0 pattern at SAS 1.5 Gbps	Tx WDP	
	Scrambled 0	Scrambled 0 pattern at SAS 3 Gbps		
	Scrambled 0	Scrambled 0 pattern at SAS 6 Gbps		
8	Scrambled 0	Scrambled 0 pattern at SAS 12 Gbps	Tx Eye Opening	
	K28.5	K28.5 pattern at SAS 1.5 Gbps	Tx VMA Tx Vhl TX Equalization	
	K28.5	K28.5 pattern at SAS 3 Gbps		
	K28.5	K28.5 pattern at SAS 6 Gbps		
9	K28.5	K28.5 pattern at SAS 12 Gbps	Tx VMA Tx Pre Cursor Equalization Ratio Tx Post Cursor Equalization Ratio Tx Vhl	