Date: July 10, 2007
To: T10 Technical Committee
From: Alvin Cox (alvin.cox@seagate.com)
Subject: SAS-2 6Gbps PHY Electrical Specification

Abstract: The attached information defines the electrical requirements for 6 Gbps transmitter devices and receiver device. In addition, updates may include reference transmitter and receiver device definitions to provide a means of determining if a channel is compliant and a cable specification section with requirements for 6Gbps usage. Editor notes are included as reminders for specification development. Revisions will not include redlines.

Revision History:
r0: Initial posting that is very preliminary and nowhere near complete, provided as a starting point and a basis to leverage the final PHY proposal from rather than a PowerPoint format.
r1: Updated emphasis measurement, changed SCD22 to SCD11 and corrected receiver common mode impedance value.
r2: Updated emphasis measurement, changed SCD11 back to SCD22 and updated the figure for SCD22.
r3: Updated emphasis measurement, included reference receiver definition.
r4: Updated emphasis measurement and information from 07-001 and 07-071, added items per the interim meeting in Houston.
r5: Included updates to 5.3.3, Table 52, and Table 60.
r6: Updates to transmitter and receiver definitions plus various corrections.
r7: Added transmitter common mode requirements and updated physical receiver test description.
r8: Added additional text and entries to the transmitter device requirements.
r9: Added JTF definition and several updates plus changes to Annex B.

Reference proposals:

07-037 SAS-2 Common Mode Generation Specification [Witt, Bari]
07-007 Proposed 6G SAS Phy Specs for EMI Reduction [Jenkins]
07-001 Proposal for 6G SAS Phy Specification [Jenkins]
06-419 SAS-2 Reference Transmitter and Receiver Specification Proposal [Witt]
06-206 SAS-2 Data Eyes vs. De-Emphasis [Witt]
06-053 Roadmap to SAS-2 Physical Layer Specification [Witt]
06-052 Enhanced SFF-8470, SFF-8086 and SATA Cable at 6Gbps [Witt]
06-049 Comparison of Equalization Schemes for 6Gbps SAS Channels [Caroselli]
05-204 Towards a SAS-2 Physical Layer Specification [Witt]
05-426 SAS-2 Cable Reach Objective and Crosstalk [Witt]
05-425 SAS-2 Channel Model Simulations [Witt]
05-342 SAS-2 Adaptive Equalizer Physical Layer Feasibility [Witt]
05-341 Updated Test and Simulation Results in Support of SAS-2 [Witt]
05-203 SAS-2 6Gbps Test Results [Witt]
06-496 SAS-2 Electrical Specification Proposal [Witt]
07-071 Return loss measurement methodology discussion [Bari]
07-120 SAS-2 Transmitter De-Emphasis Measurement [Johnson, Bari]
07-135 StatEye Tap Defined [Newman]
07-236 SAS2-Statistical Confidence Levels of Test Results
07-205 SAS-2: Improving a Jitter Definition [Hill]

New definitions:

Decibel (dB): One tenth of the common logarithm of the ratio of relative powers. The ratio of powers P1 and P2 in dB is 10 log10 (P1/P2). If P1 = V1^2/R1, P2 = V2^2/R2, and R1=R2, this is equivalent to 20 log10 (V1/V2).

Reference channel: A set of s-parameters defining the electrical characteristics of a TxRx connection used as the basis for transmitter device and receiver device performance evaluation through mathematical modeling.

Reference receiver device: A set of parameters defining electrical performance characteristics to provide a set of minimum electrical performance requirements for a receiver device and that are also used in mathematical modeling to determine compliance of the TxRx connection or transmitter device.

Reference transmitter device: A set of parameters defining electrical performance characteristics of a transmitter device to be used in mathematical modeling to determine compliance of the TxRx connection.

5.3.3 General electrical characteristics

For 1,5 and 3,0 Gbps applications, each TxRx connection shall support a bit error ratio (BER) that is less than 10^{-12} (i.e., fewer than one bit error per 10^{12} bits). The parameters specified in this standard support meeting this requirement under all conditions including the minimum input and output amplitude levels.

Each TxRx connection shall be designed such that its loss characteristics are less than:

a) the loss of the TCTF test load plus ISI at 3 Gbps (see figure 108 in 5.3.2.3) over the frequency range of 50 MHz to 3 000 MHz; or
b) the loss of the low-loss TCTF test load plus ISI at 3 Gbps (see figure 110 in 5.3.2.4) over the frequency range of 50 MHz to 3 000 MHz, if the system supports SATA devices using Gen2i levels (see SATA-2) but the receiver device does not support SATA Gen2i levels through the TCTF test load.

Each TxRx connection shall meet the delivered signal specifications in table 58 (see 5.3.7.2).

> NOTE 17 - A TxRx connection is constructed from multiple components. It is possible that a TxRx connection does not meet the delivered signal requirements of table 58 (see 5.3.7.2) when the combined losses and noise introduced by those components is considered, even if each individual component is compliant with the requirements of this standard. Such a TxRx connection is not compliant with this standard.

For external cable assemblies, these electrical requirements are consistent with using good quality passive cable assemblies constructed with shielded twinaxial cable with 24 gauge solid wire up to 6 meters in length.

For 6 Gbps applications, the TxRx connection shall support a bit error ratio (BER) that is less than 10^{-15} (i.e., fewer than one bit error per 10^{15} bits) based on the results using StatEye (www.edotronik.de/stateye, www.stateye.org in the future) or an equivalent simulation, with data input from s-parameter measurements of the TxRx connection, the specified reference transmitter device, and the specified reference receiver device. The specific simulation program used is beyond the scope of this specification. For good quality external Mini SAS 4x cable assemblies, these electrical requirements are consistent with lengths up to 10 meters.

Table 52 — General electrical characteristics

Characteristic	Units	1,5 Gbps	3,0 Gbps	6,0 Gbps
Physical link rate (nominal)	MBps	150	300	600
Bit rate (nominal)	Mbaud	1 500	3 000	6 000
Unit interval (UI)(nominal)	ps	666,667	333,333	166,667
Differential TxRx connection impedance (nominal)	ohm	100		
Maximum A.C. coupling capacitor [a]	pF	12		
Maximum noise during OOB idle time [b]	mV(P-P)	120		

a. The coupling capacitor value for A.C. coupled transmit and receive pairs. A.C. coupling requirements for transmitter devices are described in 5.3.6.1. A.C. coupling requirements for receiver devices are described in 5.3.7.1.

b. With a measurement bandwidth of 1,5 times the highest supported baud rate (e.g., 9,0 GHz for 6 Gbps), no signal level during the idle time shall exceed the specified maximum differential amplitude.

(New section included in the eye mask section) Jitter transfer function (JTF)

With the inclusion of Spread Spectrum Clocking (SSC) in SAS 2.0, the differentiation between what is allowable timing variation and what is considered jitter becomes very critical. The application of a single pole high-pass frequency-weighting function that progressively attenuates jitter at 20 dB/decade below a frequency of ((bit rate) / 1 667) does not allow separation of the SSC component from the actual jitter and thus overstates the jitter value. The application of a single pole high-pass frequency-weighting function shall continue to be used for transceivers tested for compliance to specification revisions prior to SAS 2.0.

To improve the method of defining this boundary between jitter and allowable timing variations, the following frequency-weighting function shall be applied to the signal at the compliance point when determining the eye mask for transceivers compliant with SAS 2.0 and above. Additionally this method allows for verifying the characteristics of the Jitter Measuring Devices (JMDs) that are used to test this compliance.

The reference clock characteristics are controlled by the resulting JTF (jitter transfer function) characteristics obtained by taking the time difference between the PLL output (the reference clock) and the data stream sourced to the PLL. The PLL CLTF -3 dB corner frequency, and other adjustable CLTF parameters such a peaking, are determined by the value required to meet the requirements of the JTF.

The JTF shall have the following characteristics for an encoded D24.3 pattern (1100110011 0011001100). This is a test pattern that has clock-like characteristics and a transition density of 0.5.

1) The -3 dB corner frequency of the JTF shall be 2.6 MHz +/- 0.5 MHz.
2) The magnitude peaking of the JTF shall be 3.5 dB maximum.
3) The attenuation at 30 KHz +/-1% shall be 72 dB to 75 dB.

The JTF -3dB corner frequency and the magnitude peaking requirements shall be measured with sinusoidal PJ applied, with a peak-to-peak amplitude of 0.3 UI +/-10%. The relative attenuation at 30 KHz shall be measured with sinusoidal phase (time) modulation applied, with a peak-to-peak amplitude of 20.8 ns +/-10%.

New section after 5.3.6.4 for 6Gbps:

5.3.6.5 Transmitter device signal output characteristics for 6,0 Gbps applications

5.3.6.5.1 Transmitter device signal output characteristics as measured with the zero-length test load

Unless otherwise specified, Table AA specifies the signal output characteristics for the transmitter device as measured with the zero-length test load (see 5.3.2.2) attached at a transmitter device compliance point (i.e., IT or CT). All specifications are based on differential measurements.

Table AA -- Transmitter device signal output characteristics for 6,0 Gbps applications at IT and CT (unless otherwise noted)

Signal characteristic	Min	Nominal	Max	Units
Differential Voltage Swing V_{pk-pk} [a]	800		1200	mV(p-p)
Transmitter device off voltage [b]			50	mV(p-p)
Minimum rise/fall time [c]	0,25 (41,667)			UI (ps)
OOB offset delta [d]			±25	mV
OOB common mode delta [e]			±50	mV
Reference Diff Impedance		100		Ohm
Reference Common Mode Impedance		25		Ohm
Common mode voltage limit (rms) [f]			26	dBmV [g]
Random Jitter (0101b pattern, zero-length test load) [h]			0,18 (30)	UI (ps)
Total Jitter (thru ref channel, ref receiver, CJTPAT) [i]			0,60 (100)	UI (ps)
Differential eye opening (pk-pk) V_{pk-pk} (thru ref channel, ref receiver, CJTPAT) [i]	tbd			mV

a See 5.xxx for 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 Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 0101b pattern (see table 214 in 10.2.9.1) on the physical link.

d The maximum difference in the average differential voltage (D.C. offset) component between the burst times and the idle times of an OOB signal.

e The maximum difference in the average of the common-mode voltage between the burst times and the idle times of an OOB signal.

f Maximum value at the Nyquist frequency (3 GHz). See figure aa.

g For dBmV, the reference level of 0 dBmV is 1 mV. Hence, 0 dBm is one mW which is 158 mV across 25 ohms (the reference impedance for common mode voltage) which is 20log10(158) = +44 dBmV. +26 dBmV is, therefore, -18 dBm.

h RJ = 14 times the random jitter 1 sigma value, based on a BER of 10^{-12}.

i This value is obtained by simulation and represents the signal output within the reference receiver after equalization has been applied.

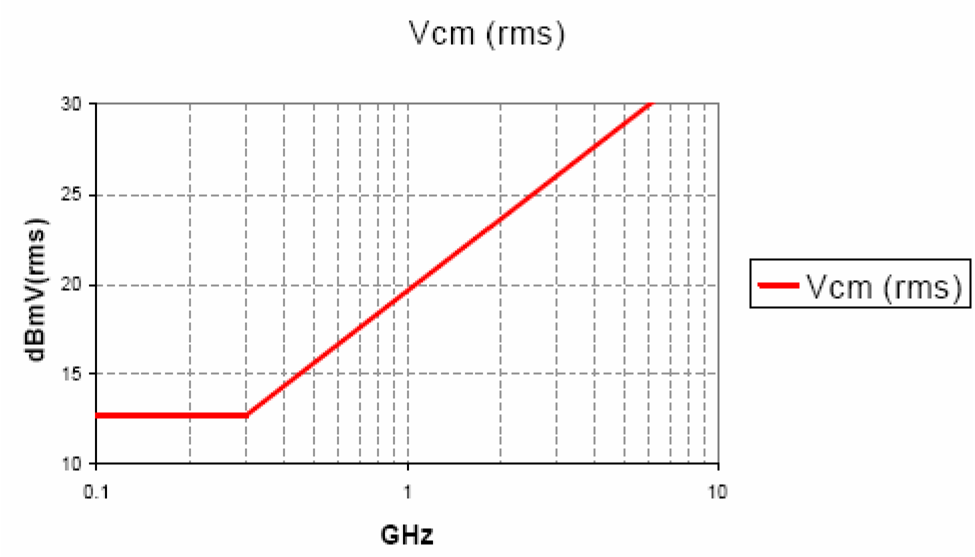


Figure aa Transmitter device common mode voltage limit

5.3.6.5.2 Transmitter device return loss

Return loss limits shall be calculated per the following formula. Variables are illustrated in Figure xxw and specified in Table 2.

$$\text{Measured Value} < \max [\ L, \min [\ H, N + 13.3 \log10(F/3\text{GHz})\ ]\ ]$$

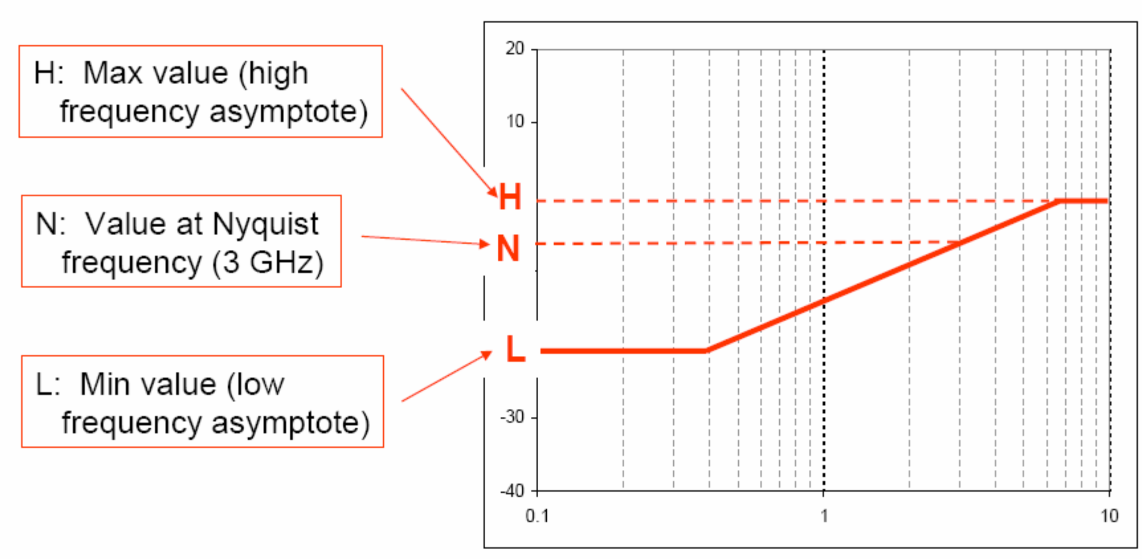


Figure xxw Return loss variables

	Figure	L(dB)	N(dB)	H(dB)	S(dB)	F_{Min}(MHz)	F_{Max}(GHz)
SCC22 common mode return loss	xxy	-6,0	-5,0	0	13,3	100	6,0
SDD22 differential return loss	xxy	-10	-7,9	0	13,3	100	6,0
SCD22 differential to common mode conversion	xxz	-26	-12,7	-10	13,3	100	6,0
Notes: 1. For return loss measurements, the transmitter under test shall transmit a continuous D24.3 pattern. The amplitude shall be -4,4 dBm (190mV zero to peak) maximum per port. See section B.9.3.							

Table 2 Return loss at the transmitter device compliance point (i.e., IT or CT)

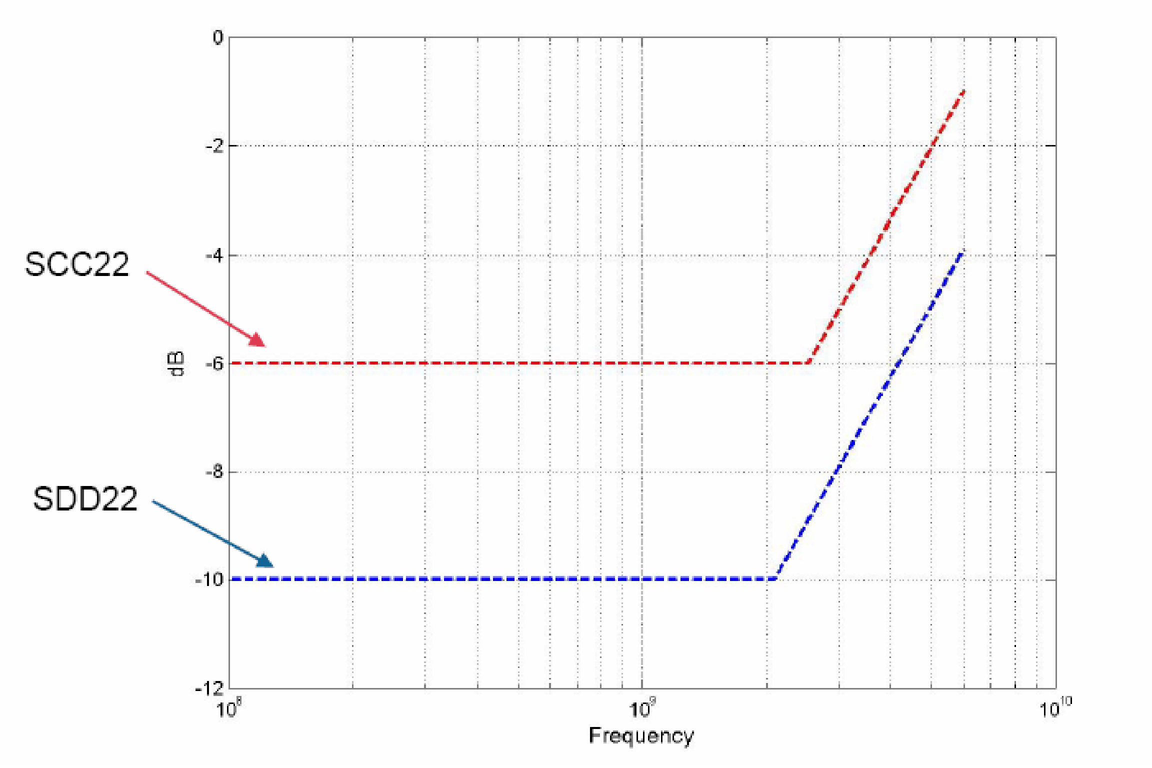


Figure xxy Transmitter Differential and Common Mode Return Loss

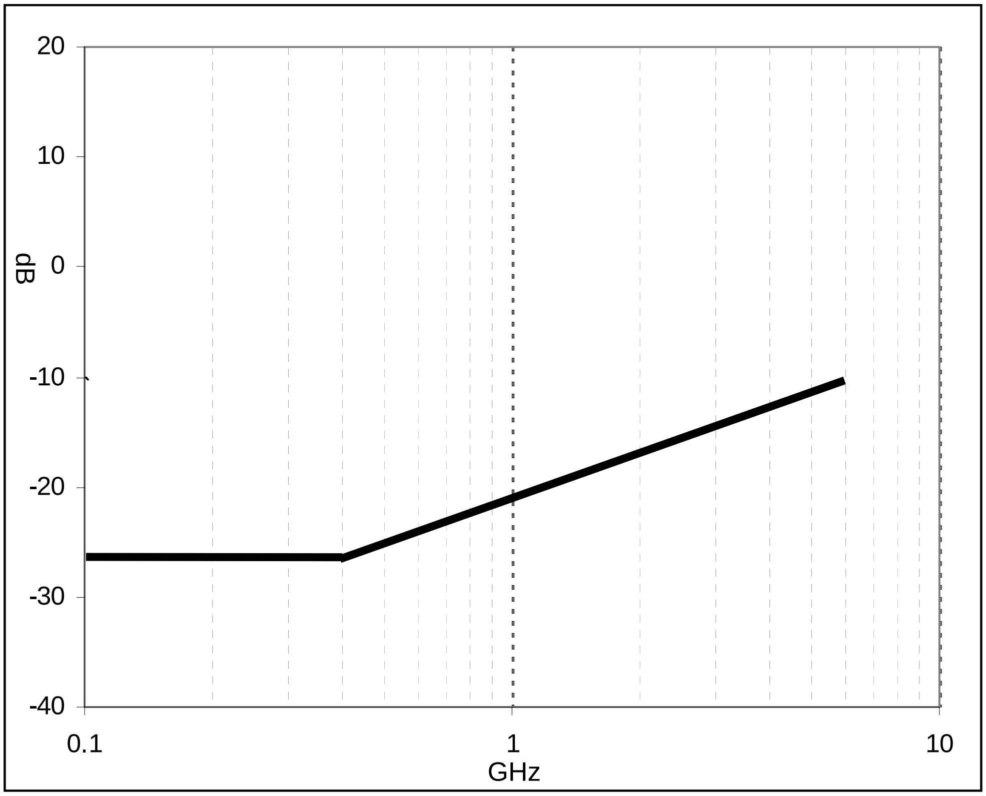


Figure xxz SCD22 Differential to Common Mode Conversion

5.3.6.5.3 Recommended transmitter device settings for interoperability.

The settings in Table y are recommended values for transmitter devices to provide interoperability with a broad range of applications utilizing compliant TxRx connections and compliant receiver devices. The values are based on the evaluation of simulations with a variety of characterized physical hardware. Use of the recommended values does not guarantee that an implementation is capable of achieving a specific BER.

Specific applications may obtain increased margin by deviating from the recommended values, however, such implementations are beyond the scope of this specification.

Table y Recommended transmitter device settings for interoperability

Transmitter device	Min	Nominal	Max	Units
Differential Voltage Swing (mode) V_{vma} [1]	600	707		mV
Tx Equalization [1]	2	3	4	dB
Notes: 1. See 5.xxx for measurement method.				

5.3.6.5.4 Reference transmitter device characteristics

The reference transmitter device is a set of parameters defining the electrical performance characteristics of a transmitter device to be used in mathematical modeling to determine compliance of the TxRx connection. The return loss characteristics of the reference transmitter device are represented by files that may be obtained under proposal number 07-267, 6G SAS Reference TX & RX Termination Networks. The physical implementation of a transmitter device shall provide electrical performance better than or equal to the reference transmitter device.

Transmitter device	Value	Units
Differential Voltage Swing (pk-pk) V_{pk-pk} [a]	800	mV
Tx Equalization [a]	2	dB
Maximum rise time [b]	0,41 (68,333)	UI (ps)
Random Jitter	0,18 (30)	UI (ps)
Deterministic Jitter	0,19 (31,667)	UI (ps)
a See 5.xxx for measurement method. b Rise/fall times are measured from 20 % to 80 % of the transition with a repeating 0101b pattern (see table 214 in 10.2.9.1) on the physical link.		

5.xxx Transmitter device equalization measurement

a The equalization measurement shall be based on a mode measurement for V_{vma} and a peak-to-peak measurement for $V_{pk\text{-}pk}$ using a TWO_DWORDS phy test pattern of D30.3 (see Table 215 in 10.2.9.1). If the phy test function is not supported, a vendor-specific method may be used to produce this pattern.

b The voltage measurements shall be made with the transmitter device terminated through the interoperability point into a Zero Length Test Load.

c The Vpk-pk and V_{vma} values shall be measured using the following or an equivalent procedure:

   a. An equivalent time sampling scope with a histogram function shall be used.
   b. The sampling scope shall be calibrated for measurement of a 3GHz signal.
   c. The V_{vma} mode value and $V_{pk\text{-}pk}$ peak value shall be determined as illustrated in Figure xxx. A sample size of 1000 minimum, 2000 maximum histogram hits for V_{vma} shall be used to determine the values. The histogram in the figure is a combination of two histograms, an upper histogram for TX+ and lower histogram for TX-.(The histograms on the left of the test pattern signal displayed on the right.) The V_{vma} mode value and $V_{pk\text{-}pk}$ peak value are determined by adding the values measured for TX+ and TX-.

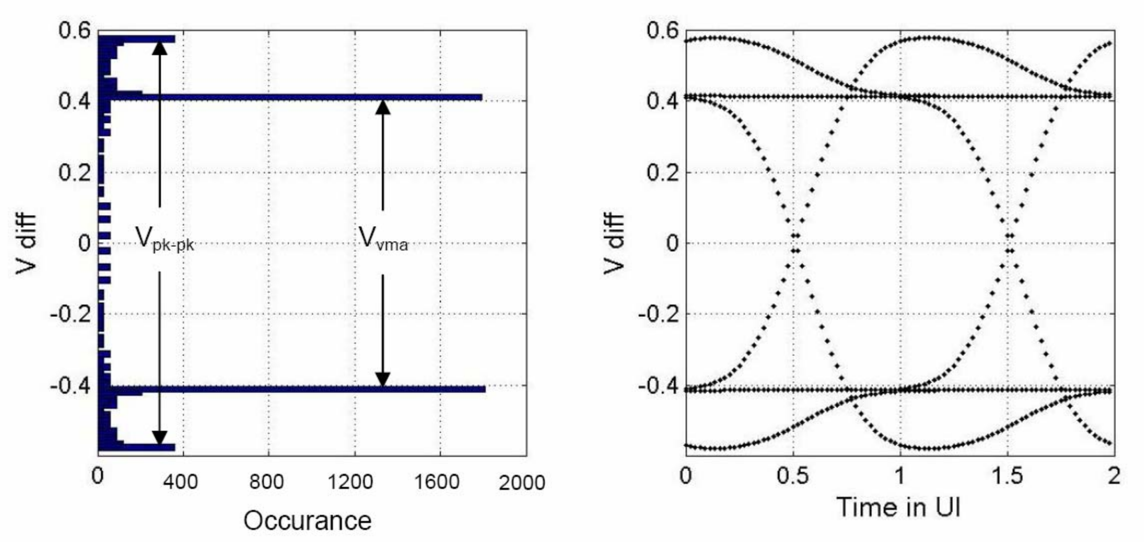


Figure xxx Transmitter equalization measurement

d The following formula shall be used to calculate the equalization value:

$$DE_{dB} = 20Log_{10}\left(\frac{V_{pk-pk}}{V_{vma}}\right)$$

Receiver:

Receiver device	Min	Nominal	Max	Units
SDD11 Differential Return Loss			See Figure xyx	dB
SCC11 Common Mode Return Loss			See Figure xyx	dB
Reference Diff Impedance		100		Ohm
Reference Common Mode Impedance		25		Ohm
Common Mode Tolerance (2-200MHz)	150			mV
Max Operational Differential Input Voltage (pk-pk) @ 6,0 Gbps	1200			mV
Max Operational Differential Input Voltage (pk-pk) @ 1,5 and 3,0 Gbps	1600			mV
Max Non-Operational Input Voltage(pk-pk)	2000			mV
Receiver amplitude: Reference receiver methodology could include				

Table 60 — Receiver device jitter tolerance at receiver device compliance points IR and CR
Mike Jenkins to update for 6Gbps

Signal Characteristic	Units	IR			CR		
		1,5 Gbps	3,0 Gbps	6,0 Gbps	1,5 Gbps	3,0 Gbps	6,0 Gbps
Applied sinusoidal jitter (SJ) [b]	UI	0,10 [c]	0,10 [d]	0,10 [i]	0,10 [c]	0,10 [d]	0,10 [i]
Deterministic jitter (DJ) [a, h]	UI	0,35 [f]	0,35 [g]	0,35 [j]	0,35 [f]	0,35 [g]	0,35 [j]
Total jitter (TJ) [a, e, h, k]	UI	0,65					

a All DJ and TJ values are level 1 (see MJSQ).
b The jitter values given are normative for a combination of applied SJ, DJ, and TJ that receiver devices shall be able to tolerate without exceeding the required BER (see 5.3.3). Receiver devices shall tolerate applied SJ of progressively greater amplitude at lower frequencies, according to figure 116 (see 5.3.5.4), with the same DJ and RJ levels as were used in the high frequency sweep.
c Applied sinusoidal swept frequency: 900 kHz to the minimum of 5 MHz and (3,75 x 2(generation - 1) MHz) (e.g., 5 MHz for 1,5 Gbps and 7,5 MHz for 3 Gbps).
d Applied sinusoidal swept frequency: 1 800 kHz to the minimum of 5 MHz and (3,75 x 2(generation - 1) MHz) (e.g., 5 MHz for 1,5 Gbps and 7,5 MHz for 3 Gbps).
e No value is given for RJ. For compliance with this standard, the actual RJ amplitude shall be the value that brings TJ to the stated value at a probability of 10^{-12}. The additional 0,1 UI of applied SJ is added to ensure the receiver device has sufficient operating margin in the presence of external interference.
f The measurement bandwidth shall be 900 kHz to 750 MHz.
g The measurement bandwidth shall be 1 800 kHz to 1 500 MHz.
h The DJ and TJ values in this table apply to jitter measured as described in 5.3.5.3. Values for DJ and TJ shall be calculated from the CDF for the jitter population using the calculation of level 1 jitter compliance levels method in MJSQ.
i Applied sinusoidal swept frequency: 3 600 kHz to 15 MHz.
j The measurement bandwidth shall be 3 600 kHz to 3 000 MHz.
k TJ for 6 Gbps is after equalization and not at the compliance point.

Performance of the receiver device shall be equal to or better than the reference receiver.
OOB detection shall be as specified for 1,5 and 3,0 Gbps devices.
For jitter tolerance, see Table 60.

Reference Receiver

The receiver's return loss is illustrated in Figure xyx. (Need pointer to reference termination file.) The reference receiver has a 2 tap DFE with infinite precision taps and unit interval tap spacing. The reference coefficient adaptation algorithm is the Least Mean Squared (LMS). The DFE equalizer can be modeled at the center of the eye as:

$$y_k = x_k - \sum_{i=1}^{2} d_i x_{k-i}$$

The reference receiver assumes the coefficients (d_i) are positive and their magnitudes are less than ½.

The simulated steady-state equalizer inter-eye opening for a complaint link shall be 100mV vertical and 0.6 UI horizontal at a BER of 1e-15 with the appropriate noise, jitter and crosstalk sources.

Additional reference information may be found in: Lee, Edward A., Messerschmitt, David G., “Digital Communication,” Boston, Kluwer Academic Publishers, 1994

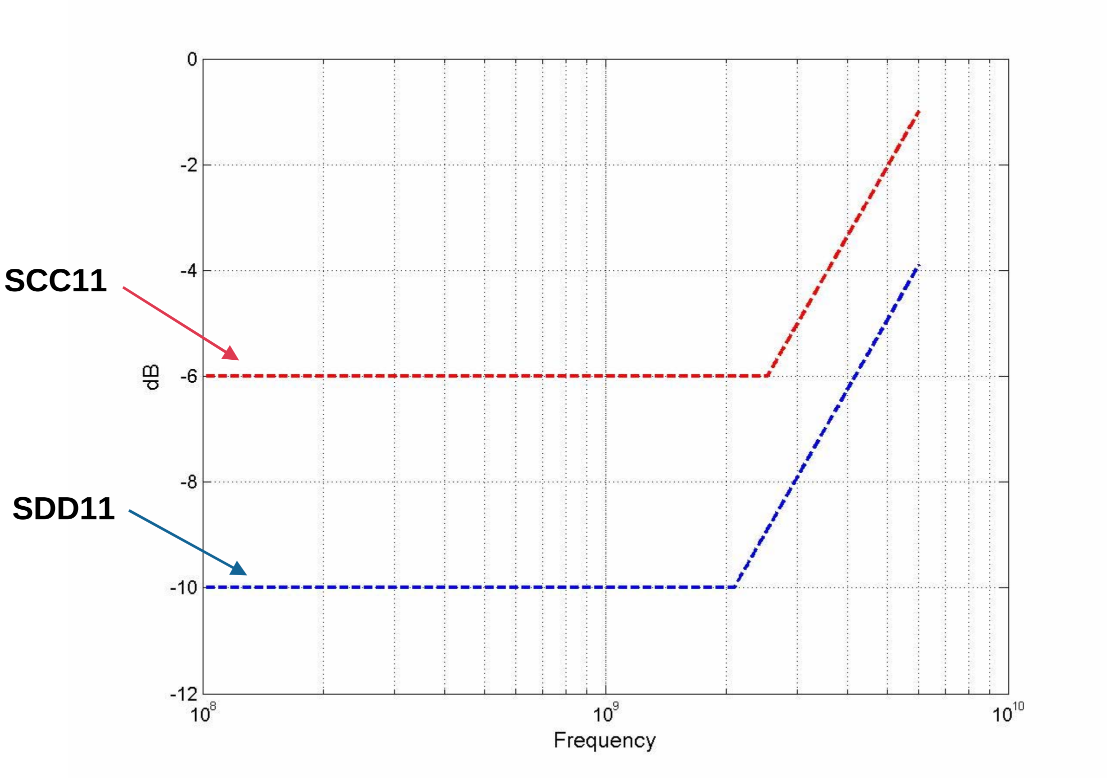


Figure xyx Receiver Differential and Common Mode Return Loss

Return loss limits shall be calculated per the following formula. Variables are illustrated in Figure xxw and specified in Table 5.

Measured Value < max [L, min [H, N + 13.3 log10(F/3GHz)]]

	Figure	L(dB)	N(dB)	H(dB)	S(dB)	F_{Min}(MHz)	F_{Max}(GHz)
SCC11 common mode return loss	xyx	-6,0	-5,0	0	13,3	100	6,0
SDD11 differential return loss	xyx	-10	-7,9	0	13,3	100	6,0
SCD11 differential to common mode conversion	xyy	-26	-12,7	-10	13,3	100	6,0
Notes: 1. For return loss measurements, the transmitter shall transmit a continuous D24.3 pattern. The amplitude shall be -4,4 dBm (190mV zero to peak) maximum per port. See section B.9.3.							

Table 5 Return loss at the receiver device compliance point

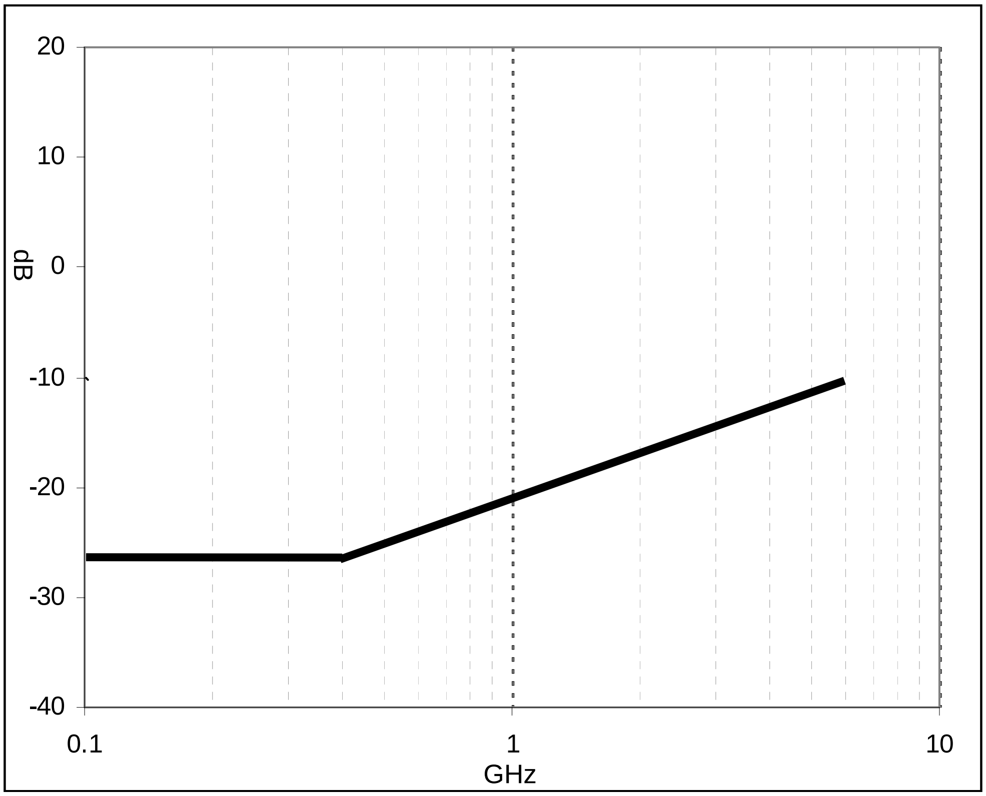


Figure xxz SCD11 Differential to Common Mode Conversion

A SAS-2 receiver device has the electrical characteristics illustrated in Table xx

Informative receiver physical test:

The TxRx connection should consist of 10-meter Mini SAS 4x cable with s-parameter characteristics similar to those of the reference channel (07-193).
Apply an 800mV pk-pk signal from a compliant transmitter.
Jitter should be applied at the transmitter end.
SSC should be enabled. The SSC profile should be the same as that applied to the receiver device during normal operation. Multiple tests may be required depending on if the receiver device supports connection to SATA, center-spreading transmitter devices, or downspreading transmitter devices.
NEXT should be actively applied at the receiver end.
The receiver should perform data recovery at 10e-12 with 95% confidence level (assuming Poisson distribution). The table below indicates the minimum number of bits required to be received versus the number of bit errors detected to achieve a 95% confidence level of 10^{-12} BER performance.

	95% confidence level of 10^{-12} BER					
Number of errors	0	1	2	3	4	5
Number of bits	3.00×10^{12}	4.74×10^{12}	6.30×10^{12}	7.75×10^{12}	9.15×10^{12}	1.05×10^{13}

B.1 Signal performance measurements overview

This annex specifies the configuration requirements for making electrical performance measurements. These measurements consist of signal output, signal tolerance, and return loss. Standard loads are used in all cases so that independent specification of connection components and transportability of the measurement results are possible.

~~NOTE 106 - The methodology for making return loss measurements are specified in this annex although this standard does not define any return loss values. Statements in this annex that imply return loss values are specified should be ignored.~~

B.2.3 Definition of receiver sensitivity and receiver device sensitivity

For Previous versions of this specification, receiver device sensitivity is defined as the minimum vertical inner eye opening measured at the signal output point for the input to the receiver device at which the receiver chip (i.e., the receiver circuit in the chip package on the board containing the receiver device interoperability point as shown in figure B.3) delivers the required BER (see 5.3.3) with:

~~h~~a) the minimum horizontal eye opening;
~~a~~b) all activity expected in the application for the receiver circuit present (i.e., not quiesced as for the receiver sensitivity definition); and
~~b~~c) the CJTPAT pattern being received (see Annex A).

For SAS-2 receiver devices, the eye opening above is determined by simulation. The signal measured at the input to the receiver device is processed in a manner to simulate the additional interconnect losses (i.e., board traces, IC package, etc) and then the equalization function provided by the receiver circuit is applied to determine the resulting eye opening. Special test conditions are required to measure these sensitivities (see B.8). The terminology used in this standard is signal tolerance instead of receiver device sensitivity.

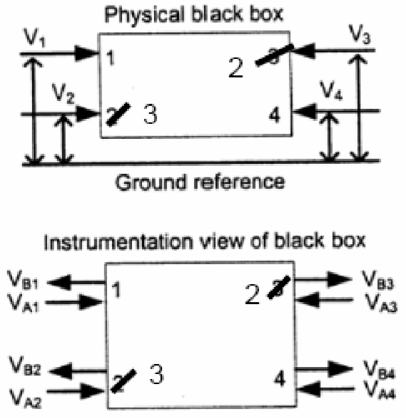
B.9.3 Use of single-ended instrumentation in differential applications

There are four categories of S-parameters for a differential system:
a) SDDij: differential stimulus, differential response;
b) SCDij: differential stimulus, common-mode response (i.e., mode conversion causing emissions);
c) SDCij: common-mode stimulus, differential response (i.e., mode conversion causing susceptibility); and
d) SCCij: common-mode stimulus, common-mode response.

~~All the measurements specified in this standard relate to differential signal pairs, and all specified S-parameters are of the SDDij form.~~

Figure B.13 shows the connections that are made to a four port VNA or TDNA for measuring S-parameters on a four single-ended port black box device.

VNA ports are all single-ended; the differential and common-mode properties for differential ports are calculated internal to the VNA or may mathematically derived. If using a TDNA, consult the details for the specific instrument. Four analyzer ports are required to measure the properties of two differential ports.

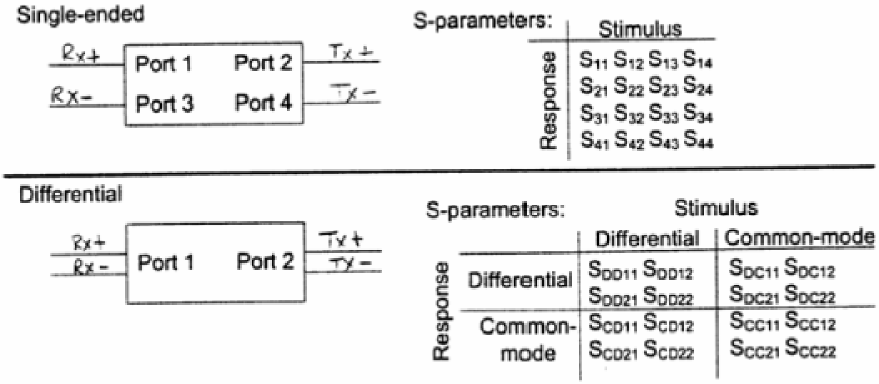


$V_1 = V_{A1} + V_{B1}$
$V_2 = V_{A2} + V_{B2}$
$V_3 = V_{A3} + V_{B3}$
$V_4 = V_{A4} + V_{B4}$

V_{A1}, V_{A2}, V_{A3}, and V_{A4} are incident signals
V_{B1}, V_{B2}, V_{B3}, and V_{B4} are reflected signals

Figure B.13 — Four single-ended port or two differential port element

Figure B.14 shows the set of S-parameters for a single-ended system and for a differential system.



S-parameters:

	Stimulus			
Response	S_{11}	S_{12}	S_{13}	S_{14}
	S_{21}	S_{22}	S_{23}	S_{24}
	S_{31}	S_{32}	S_{33}	S_{34}
	S_{41}	S_{42}	S_{43}	S_{44}

S-parameters:

		Stimulus	
		Differential	Common-mode
Response	Differential	S_{DD11} S_{DD12} S_{DD21} S_{DD22}	S_{DC11} S_{DC12} S_{DC21} S_{DC22}
	Common-mode	S_{CD11} S_{CD12} S_{CD21} S_{CD22}	S_{CC11} S_{CC12} S_{CC21} S_{CC22}

Figure B.14 — S-parameters for single-ended and differential systems

$$S_{mm} = \frac{1}{2}\begin{bmatrix} \overset{\textbf{SDD11}}{\boxed{S_{11} - S_{13} - S_{31} + S_{33}}} & S_{12} - S_{14} - S_{32} + S_{34} & \overset{\textbf{SDC11}}{\boxed{S_{11} + S_{13} - S_{31} - S_{33}}} & S_{12} + S_{14} - S_{32} - S_{34} \\ S_{21} - S_{23} - S_{41} + S_{43} & S_{22} - S_{24} - S_{42} + S_{44} & S_{21} + S_{23} - S_{41} - S_{43} & S_{22} + S_{24} - S_{42} - S_{44} \\ \underset{\textbf{SCD11}}{\boxed{S_{11} - S_{13} + S_{31} - S_{33}}} & S_{12} - S_{14} + S_{32} - S_{34} & \underset{\textbf{SCC11}}{\boxed{S_{11} + S_{13} + S_{31} + S_{33}}} & S_{12} + S_{14} + S_{32} + S_{34} \\ S_{21} - S_{23} + S_{41} - S_{43} & S_{22} - S_{24} + S_{42} - S_{44} & S_{21} + S_{23} + S_{41} + S_{43} & S_{22} + S_{24} + S_{42} + S_{44} \end{bmatrix}$$