Date: April 25, 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.

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]

New definitions:

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 6Gbps applications, the TxRx connection should support an error rate based on the results using StatEye (www.stateye.org) 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. It is suggested that the 6Gbps simulation results support a bit error ratio (BER) that is less than 10^{-15} (i.e., fewer than one bit error per 10^{15} bits). For good quality external Mini SAS 4x cable assemblies, these electrical requirements should support up to 10 meters in length.

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., 4,5 GHz for 3 Gbps), no signal level during the idle time shall exceed the specified maximum differential amplitude.

Table in new section for 6Gbps:

General transmitter device requirements.

Transmitter device	Min	Nominal	Max	Units
Differential Voltage Swing (pk-pk) $V_{pk\text{-}pk}$ [1]	800		1200	mV
?Transition Time (20%-80%) [2]	0,25 (41,667)			UI (ps)
Reference Diff Impedance		100		ohm
Reference Common Mode Impedance		25		ohm
Random Jitter (1010 pattern, zero-length test load) [3]			0,18 (30) ?	UI (ps)
Total Jitter (thru ref channel, ref receiver, CJTPAT)			0,63 (105) ?	UI (ps)

1. See 5.xxx for measurement method.
2. No maximum transition time is included since this is limited by the pk-pk voltage requirement.
3. This is not a 1 sigma number.

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.

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

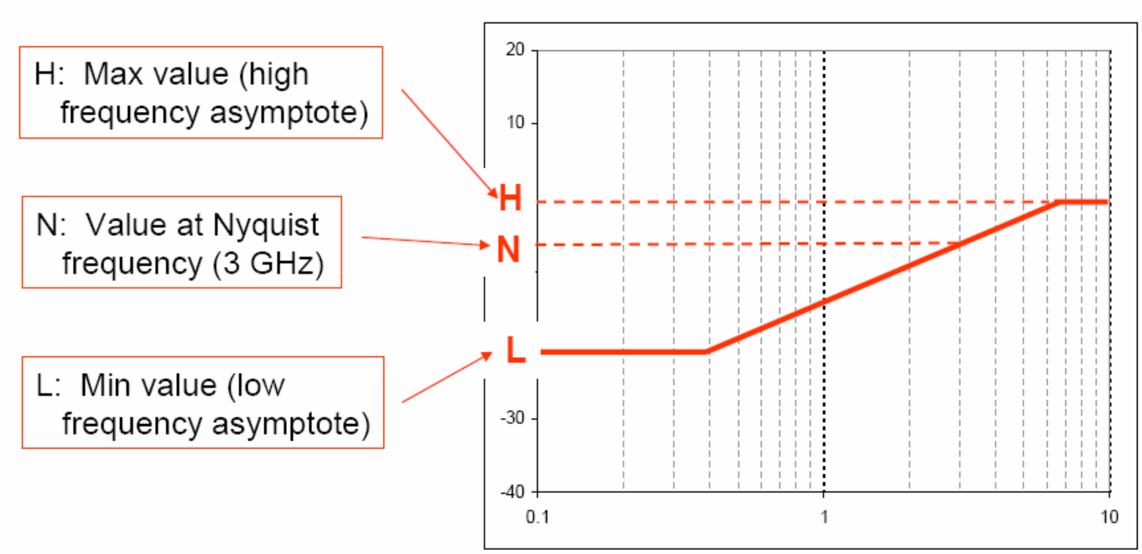


Figure xxw Return loss variables

	Figure	L(dB)	N(dB)	H(dB)	S(dB)	F_{Min}(MHz)	F_{Max}(GHz)
SDD22 Differential Return Loss	xxy	-6,0	-5,0	0	13,3	100	6,0
SCC22 Common Mode 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

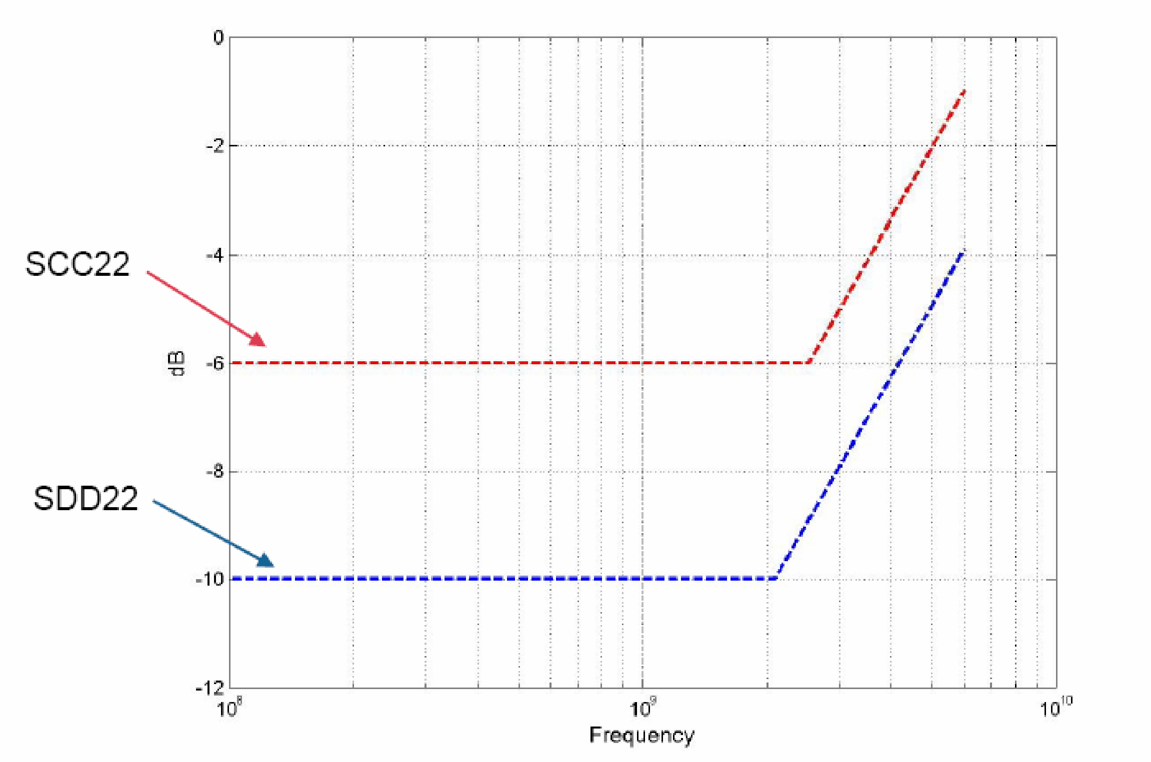


Figure xxy Transmitter Differential and Common Mode Return Loss

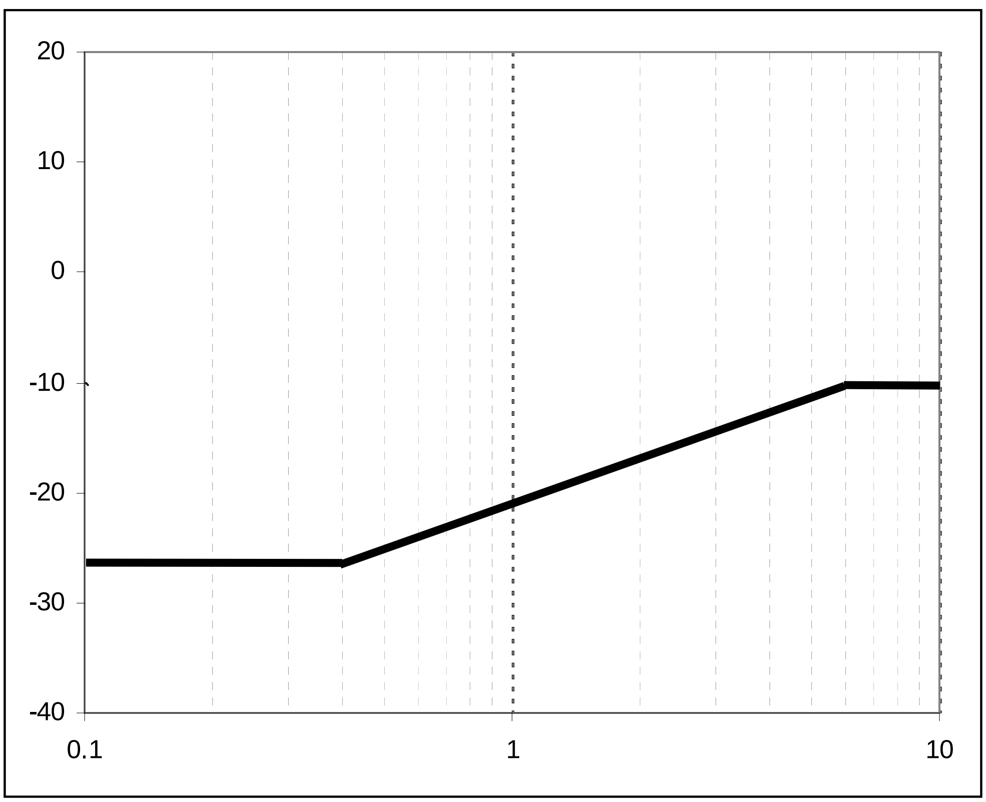


Figure xxz SCD22 Differential to Common Mode Conversion

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.				

Reference transmitter device characteristics

Transmitter device	Value			Units
Differential Voltage Swing (pk-pk) $V_{pk\text{-}pk}$ [2]	800			mV
Tx Equalization [2]	2			dB
Transition Time (20%-80%)	0,41 (68,333)			UI (ps)
Random Jitter	0,18 (30) ?			UI
Deterministic Jitter	0,63 (105) ?			UI
Notes: 1. Transmitter assumed to provide a Gaussian wave shape. 2. See 5.xxx for measurement method.				

Table z   Reference transmitter device definition for simulation models

	Figure	L(dB)	N(dB)	H(dB)	S(dB)	F_{Min}(MHz)	F_{Max}(GHz)
SDD22 Differential Return Loss	xxy	-6,0	-5,0	0	13,3	100	6,0
SCC22 Common Mode 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: 2. 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 reference transmitter device compliance point (Mike Jenkins to provide values)

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-.

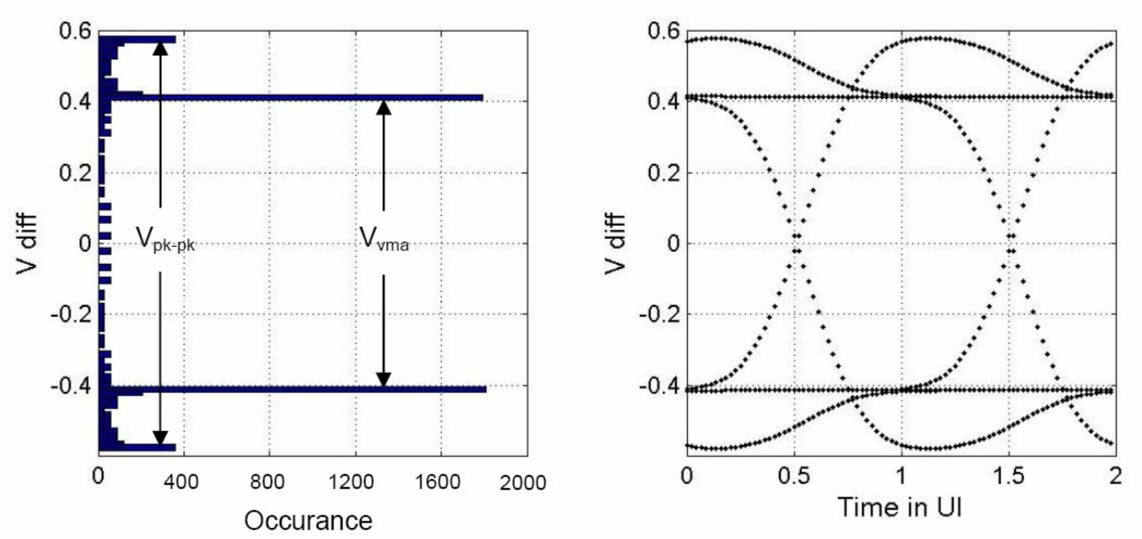


Figure xxx Transmitter equalization measurement

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:

Editor's note:
There are some factors at the far end that complicate the receiver specification. Since the receiver is expected to have an equalization function, a mathematical equalization equation is defined to process the received signal at the compliance point to determine if the resulting signal is proper for testing the receiver device. The mathematical equation may be programmed into several different measurement devices available on the market today.

Mahbubul to provide:
Informative physical test with an 800mV launch from a compliant transmitter into a 10-meter ipass cable with some amount of jitter applied at the transmitter end, with SSC enabled, NEXT actively applied. Receiver to perform data recovery at 10e-12 with 95% confidence level.

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

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	1,0 [c]	1,0 [d]	1,0 [i]	1,0 [c]	1,0 [d]	1,0 [i]
Deterministic jitter (DJ) [a, h]	UI	0,35 [f]	0,35 [g]	0,35 [j]	0,35 [f]	0,35 [f]	0,35 [j]
Total jitter (TJ) [a, e, h]	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 15 MHz.

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 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 receiver's return loss is illustrated in Figure xyx.
Equalized inner eye mask. (100mV vertical and .6 UI horizontal after equalization)
Bounds on tap weights (magnitude, time, sign)

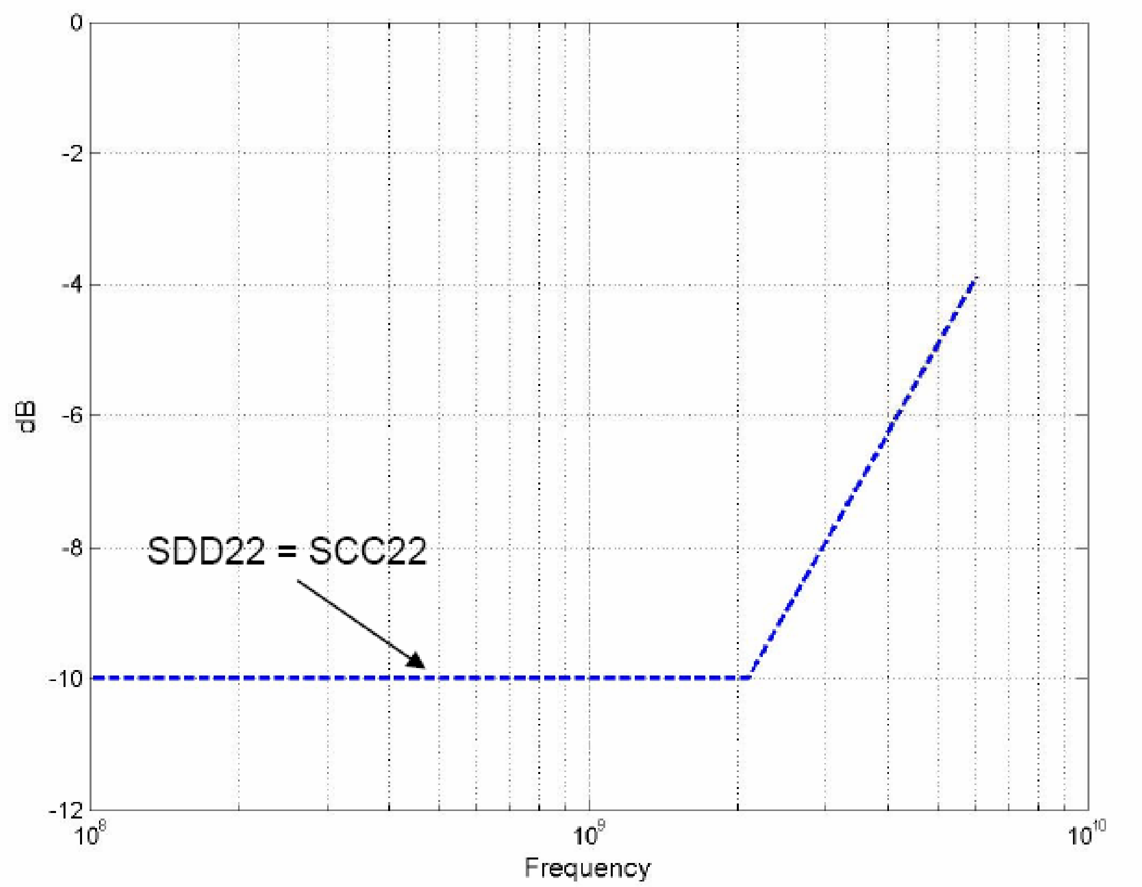


Figure xyx Receiver Differential and Common Mode Return Loss

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

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)
Differential Return Loss	xyx	-10	-7,9	0	13,3	100	6,0
SCC22 Common Mode Return Loss	xyx	-10	-7,9	0	13,3	100	6,0
Notes: 3. 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.							

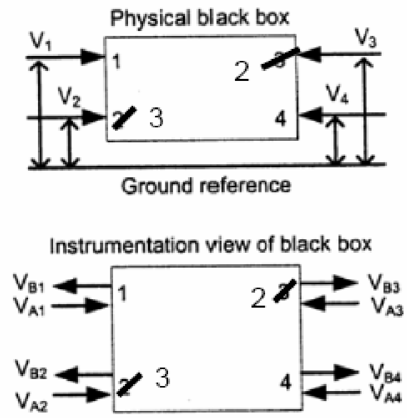
Table 5 Return loss at the receiver device compliance point

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

Reference channel shall be represented by the 10-meter ipass cable.

Section B.9 in Annex B describes S-parameter measurements. Clarification should be added to section B.9.3 on transmitter and receiver connection related to the S-parameter measurements.

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.

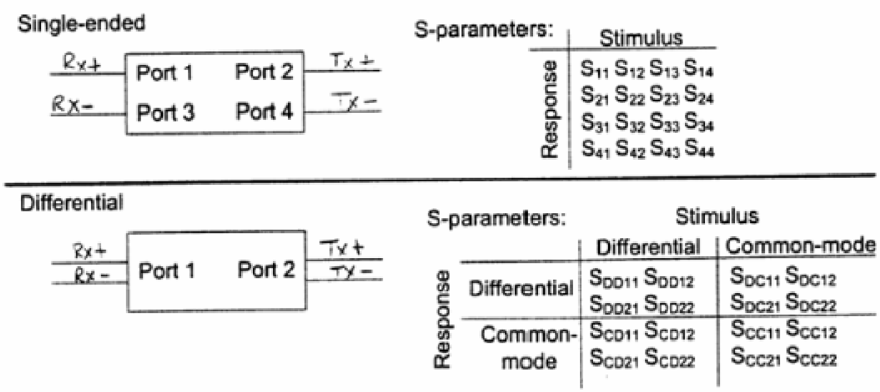


$V_1 = V_{A1} + V_{B1}$
$V_2 = V_{A2} + V_{B2}$
$V_3 = V_{A3} + V_{B3}$
$V_4 = V_{A4} + V_{B4}$

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.



Single-ended S-parameters:

Response \ Stimulus				
	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}

Differential S-parameters:

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

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

SDD11 SDC11

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

SCD11 SCC11