OPTICAL INTERNETWORKING FORUM

System Interface Level 5 (SxI-5): Common Electrical Characteristics for 2.488 – 3.125Gbps Parallel Interfaces

OIF-SxI-5-01.0

October 2002

Implementation Agreement Created and Approved
by the Optical Internetworking Forum
www.oiforum.com

Implementation Agreement: OIF-SxI-5-01.0

Working Group: **Physical – Link Layer (PLL)**

TITLE: **System Interface Level 5 (SxI-5): Common Electrical Characteristics for 2.488 – 3.125Gbps Parallel Interfaces**

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DATE: **October 2002**

Document Status: Implementation Agreement: OIF-SxI-5-01.0
Project Name: SFI/SPI-5 common electrical
Project Number:

ABSTRACT:
This contribution is an Implementation Agreement for the electrical and jitter specifications between:
1)The Serdes and Framer devices within the Physical Layer (Serdes Framer Interface or SFI).
2) The System Packet Interface (SPI)
3) Future interfaces using 2.5-3.125Gbps parallel data paths
The initial application is for SFI-5 and SPI-5. These interfaces support OC-768 ATM and Packet over SONET/SDH (POS), as well as other protocols at the 40 Gb/s data rate.

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1 List of Figures

2 List of Tables

3 Document Revision History

Revision 1.1

- Update Vdiff from .7min/1.6max to .6min/1.0max.
- Moved Infiniband comparisons and jitter tutorial to appendices.
- Added TBD jitter bandwidth specs
- Added FEC device to system block diagram
- Changed Vtt from .5min/1.0max to 1.1min/1.3max
- Changed Vcm (output) from .5min/1.0max to .8min/1.1max
- Changed Vrcm (input) from .25min/1.25max to .75min/1.15max
- Modified Figure 1 to be compatible with SFI-5 document.

Revision 1.2

- Changed I_{DSHORT} from 1.6 V max. and –0.5 V min to 1.45 max and –0.25 V min
- All impedance values are specified as magnitude of the complex impedance value in Ohms
- Changed V_{RHP} from 1.45 –0.25 V and moved Hot Plug to Appendix
- Added Figure 1 Jitter Tolerance vs. Frequency
- Replaced Figure: Eye Opening at Receiver

Revision 1.3

- Added Jitter Reference Diagram
- Added R_{SE}, R_D, R_{MSE}, R_{HS}, RL_{DIFF} to Table SxI-5 Differential Output Characteristics
- Added Z_{INDIFF}, L_{DR} to Table SxI-5 Differential Input Characteristics
- Added Tables: Jitter Output, Jitter Tolerance
- Added Figure Jitter Bandwidth Table
- Removed V_{diff} lines and T_{DRF} max from Table SxI-5 Differential Output Characteristics.
- Changed T_{DRF} min from 75 psec to 50 psec in Table SxI-5 Differential Output Characteristics
- Removed Appendix 1
- Added Appendix 3, Table Detailed Jitter Allocation
- Added section 7.3 Jitter Reference Diagram
- Added section 7.3.1 Transmit Eye Mask, added Jitter Output Table
- Added section 7.3.2 Receive Eye Mask, added Jitter Tolerance Table
- Added section 7.3.3 Jitter Bandwidth Template, added Jitter Bandwidth Table
- Deleted J_D and J_T from Table SxI-5 Differential Output Characteristics
- Deleted T_{Reye} J_{DR} and J_{TR} from Table SxI-5 Differential Input Characteristics

Revision 1.4

- Added text in last paragraph in Appendix 1,
- Added Table Jitter Definitions and Table Jitter Specifications Summary to Appendix 1 (Jitter Components and Measurement Techniques)

Revision 1.5

- Added Table Jitter Summary
- Added Figure Jitter Templates
- Replaced Figure 4 with Figure Eye Mask and Jitter Reference Diagram
- Added Table Jitter Specifications in section 7
- Changed / deleted notes for Table Transmit Eye Mask Specifications

- Added Tables “Absolute Wander Budget” and “Relative Wander Budget” in Appendix 3
- Deleted Tables 5 and 6 in Appendix 1
- Deleted section 7.3.3.

Revision 1.6

- Added text about CML intent to Introduction
- Changed Table 4 for Jitter/wander
- Changed common mode voltages in Tables 2 and 3
- Changed comments for Zvtt and Vtt in Table 3
- Changed max input voltage in Table 3.
- Changed comments about Rhs and Rldiff in Table 3
- Removed Zd, Zse, Zmse, Rmse from Table 2
- Removed Notes 1,2 and 4 from Table 2.
- Removed Zmrterm and Notes 1 and 2 from Table 3
- Changed comments in Table 3 for Zrterm, Zindifff and Ldr.
- Added Appendix 4

Revision 1.7

- Removed change bars found in 1.6

Revision 1.8

- References to measured wander in Table 1 removed
- Note 1 removed, and note 4 removed.
- Figure 4 moved to section 6.3.
- In order for Figure 4 to make sense, changed note 1 to say: Values below fd/1667 are the limit when the signal is passed through a HPF and measured with respect to a reference. The HPF corner frequency is swept from fd/1667 down to DC. For each corner frequency, the maximum allowed jitter + wander out of the filter with respect to a reference is the value in the plot.
- Removed sentence: The differential output characteristics are specified so as to guarantee the specified eye opening at the receiver as shown in Figure 7.
- Table 2: changed unit interval max 402 ps and unit interval min 320ps
- Added note 1: “Magnitude of complex impedance”. Added reference to note 1 in comments for Zvtt.
- “Parameter is unspecified if DC blocking capacitors are present” removed from section 6.1
- Figure 4: Note 1 moved under Figure 6 in section 6.3.1. Note 1 changed to: “Transmitted eye mask at the transmitter pin is measured into a 100 ohm load having more than 20 dB return loss between DC and 1.6 * baud rate.
- Note 2 moved under Figure 7 in section 6.3.2. Note 2 changed to read: “Received eye mask at the receiver pin is measured with a signal from a 100 ohm source that has more than 20 dB return loss between DC and 1.6 * baud rate.
- Section 6.3 Changed first sentence to read: “The eye mask defines the horizontal(jitter) and vertical(signal amplitude) characteristics of the data and clock signals.”
- Section 6.3.1 First line of section changed to: The transmit eye mask specifies the jitter at reference points A and C as shown in Figure 5.

- Table 5: XT1(ui) for reference point C for data changed to .225 from .22
  XT1(ui) for reference point C for clock changed to .2 from .195
  In keeping more closely with the mask for point A, XT2(ui) for point C .445
- Note 3 for Table 5 removed
- Section 6.3.2 First line changed to read “the received eye mask specifies the jitter at reference points B and D as shown in Figure 5. The second line changed to read: “The horizontal limit specified in the eye mask shown in Table 6 represents the total jitter seen at the receiver input(both RJ and DJ).” The third sentence changed to read: “The jitter tolerance specifications are shown in Table 6(see also Appendix 3).
- Section 7 Removed the sentence “The values are chosen to be as close to the Infiniband specifications as possible so as to maximize availability and inter-operability.”
- Globally changed Gbps to Gb/s
- Font and formatting of Table 1 made consistent with the rest of the document.
- Table 1 Notes – the formatting of notes corrected to a standard format.
- Figure 4 Notes – the formatting of notes corrected to a standard format.
- Section 6.3.2 Receive Eye Mask – this section runs right into the notes from Table 5. Spaced these apart for readability.
- Removed blank page between Appendix 1 and Appendix 2
- Removed section 5.0 (“Technical Section”)
- Removed one occurrence of input sensitivity (Vrsense) in table 3.
- In Rhs and RLdiff comments columns of Table 2, the "0.004*baud rate-0.75*baud rate" changed to "From 0.004*baud rate to 0.75*baud rate"
- Section 4, bullet 10: changed "driver ad the" to "driver and the"
- Section 6, page 10. Table below figure 2. Problem with conversion to PDF. Increased space
- Section 6, page 11. Note (2), Changed "between and pair" to "between any pair".
- Section 6.2, page 14, table 3. Unit for Zvtt comes out as ? in PDF. Changed to Ohms.
- Section 6.3, page 16, last sentence before figure 5. Changed SFI-5 to SPI-5
- Appendix 1, page 23, last paragraph. Fixed "Error! Reference source not found."
- Section 6.3: Deleted last two sentences of first paragraph that define points A, B, C, D as they apply to SPI-5 and SFI-5.
- Duplicate entries for Revision 1.3 and Revision 1.6 in the change history. Changed to Revision 1.4 and Revision 1.7 respectively.
- Table 1 resized so the text fits within the boxes. Moved caption before the notes.
- Added the following note to Figure 3: "2. The frequency of the intersect point for Wander + LF Jitter measurements shall be >= fD/6668."
- Changed Table 4 Note 6 to: "6. Below the jitter corner frequency only the total jitter is specified."
- Replaced Table 4 Notes 8 and 9 with (and renumbered Note 10): "8. The wander corner frequency is (data bit rate)/6668."
- Reference [1] removed (and the remaining references renumbered).
- In Appendix 1 changed all occurrences of the acronym "MSJ-2" to "MJS-2". The reference to [4] after the first use of the acronym renumbered to [3]
- Replaced Appendix 1, last paragraph, first part of sentence 8 with: "Thus, although this model predicts that the jitter specifications would yield an expected BER ... "
- Added the following title to Appendix 3: "Pro Forma Timing Budgets"
- Added the following title to Appendix 4: "Differential and Common Mode Voltage model"
- Table 1; Two occurrences of "mecanical" changed to "mechanical"

- Table 2; Combined Vcm into a single row entry with max=1.23V and min-0.72V. Changed the note to say "1.05V<Vtt<1.35".
- Table 2; Vcm comments contain a reference to Fig 3. Changed to correct reference Figure 4.
- Beginning of section 4: Removed three full stops in first sentence
- Corrected typo in the last item in the final list in section 4: “ad” to “and”.
- Table 2 has two headers. Fixed display error
- First sentence of section 6.3 “The eye mask defines the horizontal (jitter) and vertical (signal amplitude) characteristics data and clock signals” changed to “The eye mask defines the horizontal (jitter) and vertical (signal amplitude) characteristics of data and clock signals”.
- At the start of section 6.3.1 “The Transmit eye mask specifies the jitter as” changed to “The Transmit eye mask specifies the jitter at”
- At the start of section 6.3.2 “The Receive eye mask specifies the jitter as” changed to “The Receive eye mask specifies the jitter at”
- Table 4 formatted appropriately to follow the rest of the document.
- Removed change bars in all of the table and figure references through the document
- Changed Working Group Chair to “Mike Lerer”
- Moved Table 1 after Figure 6
- Moved Figure 3 and 4 after Table 4
- Changed comments in Table 2 (replaced “Vtt=1.35 V” with “1.05V<Vtt<1.35”)
- Changed reference in Table 2 (replaced Figure 3 with Figure 5)
- Removed “UI” from Table 2
- Table 3: Changed Vtt to Max from 1.3 to 1.35 and Min from 1.1 to 1.05; Vrsense from 175mV to .175 V, deleted Peak-Peak Voltage from Comments; Changed Vrmax to Vp-p and added “see Figure 5” to Comments
- Added to Section 5.3: “Note that reference points C and D reference only the return status path for SPI-5. The eye mask defined for reference point A and B refers to both directions of data flow for the SFI-5 interface.”
- Reformatted and added “Units” to Table 4
- Section 6.1. deleted “”and notes”
- Added Note 3.”XT1 = Jtot/2” to Table 5
- Moved Figure 8 after Table 6
- Deleted Section 6 “Summary”
- Removed reference to Table 4 in last paragraph of Appendix 1
- Added “infinity” and “sigma” to second last paragraph of Appendix 1
- Added section “Definition of Terms”

Revision 1.9

- Changed OIF revision number from oif2001.149.8 to oif2001.149.9

Revision 1.10

- Table 1 moved to section 6.3
- Figure 4 moved to section 6.3
- Comments for Zindiff changed: Added ‘If AC coupled, parameter applies at .0035*fD only’
- Units for Zvtt changed to ohms. Added Note 1: Magnitude of complex impedance with real part >0.

- Table 3, Input Characteristics, VRmax Parameter. Comment changed to refer to fig. 7 (Receive eye mask)
- Table 5, Note 3. JTOT is indicated to be defined in Figure 7. Changed note to XT1 = Jtot/2 to be consistent with table 6
- Section 7 Summary: Removed the entire section
- Deleted reference in appendix 1
- fD is the baud rate (data rate in Hz): Added the term to the glossary.
- Jitter moved to section 5.3
- Changed table 3 Vtt from 1.3 to 1.35 and from 1.1 to 1.05. (To be consistent with carrying specs to 2 decimal places)
- Rise/Fall time in Table 2: Removed UI from Units column
- Note 3 modified to say: XT1 = Jtot/2.
- Added units column in table 4
- Changed note 3, Fig. 4 from: ‘Common Wander is measured with respect to a reference’ to ‘Common Wander is measured relative to an external reference’
- Section 6.1: Removed “All SxI-5 output drivers shall meet all the parameters and notes of Table 2”. Table 2 has no associated notes
- The common-mode output voltage in Table 2 specified within one row of the Table.
- In Table 2, the output rise/fall time has two sets of units (UI and ps): Eliminated UI
- Immediately prior to Table3 in section 6.2: “All SxI-5 input receivers shall meet all the parameters and notes of Table 3”. Eliminated “and notes of Table 3”.
- In Table 3, the note accompanying VRmax reworded
- Added glossary to define jitter terms, rearranged/deleted tables
- In the notes accompanying Table 5 for the definition of JTot: the relevant value for Jtot for Table 5 is 2*XT1: changed the reference
- Added the note “If AC coupled, parameter applies at 0.0035*fD only” to the ZINDIFF entry in table 2 of the SxI-5 document.
- Changed the table 5 entry for XT2 at point A for both clock and data from 0.4 to 0.45 (Tr/Tf should be the same for both point A and C drivers). Fixed the typo on the entries for point C (from 0.445 to 0.50)
- Added a note to the VCM entry in the output characteristics table of the SxI-5 document that says “The Vtt values take into account the assumption of up to ±50 mV of ground shift between transmitter and receiver.”
- Added the following values to the jitter specification table in the SxI-5 document for common/absolute clock and data wander; A: 5.10, B: 5.65, C: 10.10, and D: 10.65.
- Change the reference diagram figure to the figure shown below. A note will be added to state a reference point C output is timing derived from a reference point B input (to distinguish point A from point C).
- Made the following changes in the SxI-5 document:
  - Deleted jitter and wander summary table
  - Deleted footnote 5,6,8 on jitter specification table
  - Changed footnote 9 text from “wander corner frequency” to “frequency equal to (jitter corner frequency/CommonWander amplitude)*0.1”
  - Deleted relative wander template figure and common wander and jitter template figure and accompanying notes
  - Removed “low frequency jitter clock and data” row from jitter specification table
- Made the following changes in the SxI-5 document:
  - Deleted jitter and wander summary table
  - Removed “low frequency jitter clock and data” row from jitter specification table
  - Deleted footnote 5,6,8 on jitter specification table

- Changed footnote 9 text on jitter specification table from “wander corner frequency” to “frequency equal to jitter_corner_frequency/wander_amplitude)*0.1”
- Deleted relative wander template figure and common wander and jitter template figure and accompanying notes
- Jitter corner frequency definition (fd/1667) included in normative text portion of document. Wander corner frequency defined as (jitter_corner_frequency/wander_amplitude)*0.1” added in normative text portion of document.
- Deleted reference to hot plug in section 6.
- Added note 7 defining wander corner frequency
- Added note 4 and note 7 references in Table 3
- Deleted text ‘Parameter is unspecified if DC blocking capacitors are present because it conflicted with new text ‘If AC coupled, parameter applies at 0.0035*fD only’

Revision 1.11

- Changed in chapter 6.1 “PC” to “printed circuit”
- Deleted in chapter 6.1 “The effects of high frequency attenuation can be reduced by pre-emphasis of the signal at the driver or by adaptive equalization at the receiver. This specification is accommodative to both techniques.”
- Added text to chapter 6.1 A Transmit Eye Mask (Figure 7) is used to specify amplitude timing and jitter requirements for the SXI-5 output drivers. This allows maximum design flexibility while still guaranteeing interoperability.
- Added note to Table 1: “For Amplitude and Maximum Rise/Fall time requirements see Figure 7 and Table 4”
- Deleted lines Vrsense, Trise/fall and Vrmax from Table 2
- Added note to Table 2: “For amplitude and rise/fall time requirements see Figure 8 and Table 5”
- Changed text in chapter 6.3: “Reference points C and D reference the return status path for SPI-5 and the transmit/egress data path for SFI-5. The eye mask defined for reference point A and B refers to both directions of data flow for the SPI-5 interface and the receive/ingress data path for SFI-5”
- Changed text in Appendix 4: “The information in Figure 10 and Figure 11 is the basis of the common mode voltages, which are specified in Table 1 and Table 2.”
- Deleted Appendix 2: Hot Plug Voltage
- Added text in chapter 6.3. In order to adequately specify the jitter for the SXI-5 interface, Table 3 includes both relative and common/absolute jitter requirements. The need to align multiple lanes of data necessitates the addition of skew and wander specifications to guarantee interoperability.
- Chaned definition for wander to: “The peak to peak variation in the phase of a signal(clock or data) after filtering the phase with a single pole low pass filter with the –3db point at the wander corner frequency. Wander does not include skew.”
- Added definition for Total Wander: The sum of the correlated and uncorrelated wander.
- Added definition for correlated wander Components of wander that are common across all applicable in band signals.
- Added definition for uncorrelated wander: Components of wander that are not correlated across all applicable in band signals.

- Changed definition for relative wander to: Components of wander that are uncorrelated between any two in band signals
- Removed definition for common wander
- Changed definition for jitter to: Phase variations in a signal(clock or data) after filtering the phase with a single pole high pass filter with the –3 dB point at the jitter corner frequency. Total Jitter is composed of both deterministic and random content.
- Added definition for skew: The constant portion of the difference in the arrival time between the data of any two in band signals.
- Added definition for in band signal: Data or clock between the system reference points as shown in Figure 4.
- Added Figure 1: Skew and Relative Wander between in band signals
- Added Figure 2: Total wander of a signal
- Changed 3 Skew, wander and jitter
- Removed OIF numbers and dates from chapter 7 References 1 and 2
- Changed equation 3 in Figure 9
- Deleted Table 8 and 9 in Appendix 3

Revision 1.12

- Added page breaks for improved readability
- Changed from Gbps from 2.5 to 2.488 in header and title "Electrical Characteristics for 2.488 – 3.125Gbps parallel interfaces"

Revision 1.13

- Table 5, Note 4 changed to "Receive eye mask is measured into a 100 ohm load with more than 20 dB return loss between DC and 1.6 * baud rate"
- Table 1, Idshort changed to 50max and –50min
- Section 4, definitions of random jitter and rms jitter – added reference to mjs-2

4 Definition of Terms

Baud	A unit of signaling speed, expressed as the maximum number of times per second the signal can change the state of the transmission line or other medium. (Units of Baud are Sec^{-1})
Bit Error Rate (BER)	A parameter that reflects the quality of the serial transmission and detection scheme. The BER is calculated by counting the number of erroneous bits output by a receiver and dividing by the total number of transmitted bits over a specified transmission period. For example, a BER of 10^{-12} is one bit error received in 10^{12} bits transmitted. For a 1,0625 Gbaud datastream, 10^{-12} bit error rate translates into an average of one bit error every 941 secs or one bit error every 16 minutes if the errors are occurring as isolated single events. For cases where the errors occur in bursts the temporal distribution must also be considered.
Common Mode Voltage	Average of the V(high) and V(low) voltage levels
Fd	Baudrate (Data Rate in Hz)
Gaussian	A statistical distribution (also termed “normal”) characterized by populations that are not bound in value and have well defined “tails”. Analog amplifiers are the most important source of Gaussian noise in serial data transmissions. The term “random” in this document always refers to jitter that has a Gaussian distribution.
In Band Signal	Data or clock between the system reference points as shown in Figure 6
Intersymbol Interference (ISI)	Data dependent deterministic jitter caused by the time differences required for the signal to arrive at the receiver threshold when starting from different places in bit sequences (symbols). For example when using media that attenuates the peak amplitude of the bit sequence consisting of alternating 0, 1, 0, 1…more than peak amplitude of the bit sequence consisting of 0, 0, 0, 0, 1, 1, 1, 1…the time required to reach the receiver threshold with the 0, 1, 0, 1…is less than required from the 0, 0, 0, 0, 1, 1, 1, 1…. The run length of 4 produces a higher amplitude which takes more time to overcome when changing bit values and therefore produces a time difference compared to the run length of 1 bit sequence. When different run lengths are mixed in the same transmission the different bit sequences (symbols) therefore interfere with each other. ISI is expected whenever any bit sequence has frequency components that are propagated at different rates by the transmission media.
Jitter	Phase variations in a signal(clock or data) after filtering the phase with a single pole high pass filter with the –3 dB point at the jitter corner frequency. Total Jitter is composed of both deterministic and random content.
Jitter Generation	The quantity of jitter added to an incoming signal by a

	component device, system, or media. This term is not used in this document.
Jitter Transfer	The ratio between the jitter output and jitter input for a component, device, or system often expressed in dB. A negative dB jitter transfer indicates the element removed jitter. A positive dB jitter transfer indicates the element added jitter. A zero dB jitter transfer indicates the element had no effect on jitter. The ratio should be applied separately to deterministic components and Gaussian (random) jitter components.
Jitter, Data Dependent	The jitter which is added when the transmission pattern is changed from a clock like to a non-clock like pattern. Includes ISI.
Jitter, Deterministic	Jitter with non-Gaussian probability density function. Deterministic jitter is always bounded in amplitude and has specific causes. Four kinds of deterministic jitter are identified: duty cycle distortion, data dependent, sinusoidal, and uncorrelated (to the data) bounded. DJ is characterized by its bounded peak-to-peak value.
Jitter, Peak-to-Peak	For any type of jitter, the minimum, full range of the jitter values that excludes (includes all but) 10^{-12} of the total jitter population.
Jitter, Random	Jitter that is characterized by a Gaussian distribution. Random jitter is defined to be the peak-to-peak value which is given to be 14 times the standard deviation of the Gaussian distribution for a BER of 10^{-12} based on the jitter model by MJS-2 [3].
Jitter, RMS	The root mean square value or standard deviation of jitter. For a Gaussian distribution, the RMS value is 1/14 of the peak-to-peak value for BER 10^{-12} based on the jitter model by MJS-2 [3].
SFI	SERDES - Framer Interface
Skew	The constant portion of the difference in the arrival time between the data of any two in band signals.
SPI	System Packet Interface
Unit Interval	One nominal bit period for a given signaling speed. It is equivalent to the shortest nominal time between signal transitions. UI is the reciprocal of Baud (Unit of UI are seconds)

WANDER

Correlated Wander	Components of wander that are common across all applicable in band signals.
Relative Wander	Components of wander that are uncorrelated between any

	two in band signals (Figure 1)
Total Wander	The sum of the correlated and uncorrelated wander. (See Figure 2)
Uncorrelated Wander	Components of wander that are not correlated across all applicable in band signals.
Wander	The peak to peak variation in the phase of a signal(clock or data) after filtering the phase with a single pole low pass filter with the –3db point at the wander corner frequency. **Wander does not include skew.**

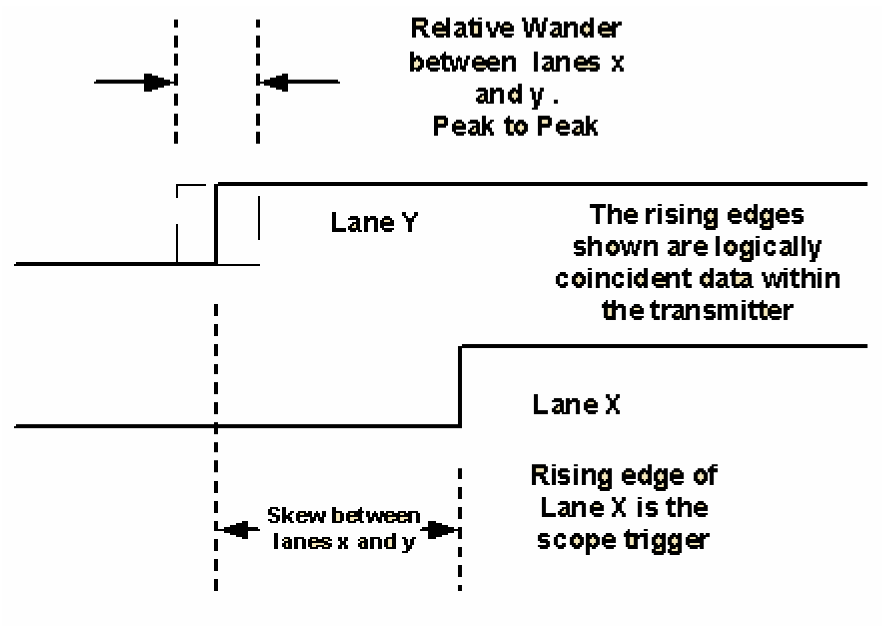

Figure 1: Skew and Relative Wander between in Band Signals

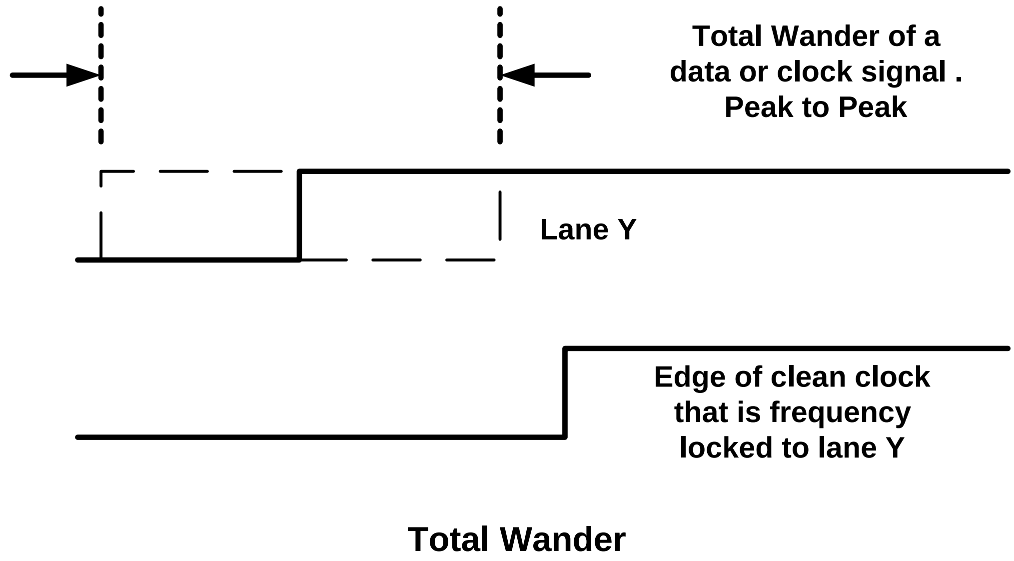

Figure 2: Total Wander of a Signal

5 Introduction

This document defines the electrical I/O characteristics for the SPI-5 and SFI-5 interfaces. This specification is based on 1.2 volts CML for the reasons below:

1. Easier for non-CMOS technologies to implement
2. Wider industry experience with signal integrity performance.
3. Greater compatibility with future lower voltage technologies.

A typical system with a 40 Gb/s bandwidth is shown in Figure 3 below. The optical module is connected to the SONET/SDH framer via an SFI-5 bus. Packet or cell data is transferred between the frame and the link layer device over the SPI-5 bus. These components may reside on separate PC cards.

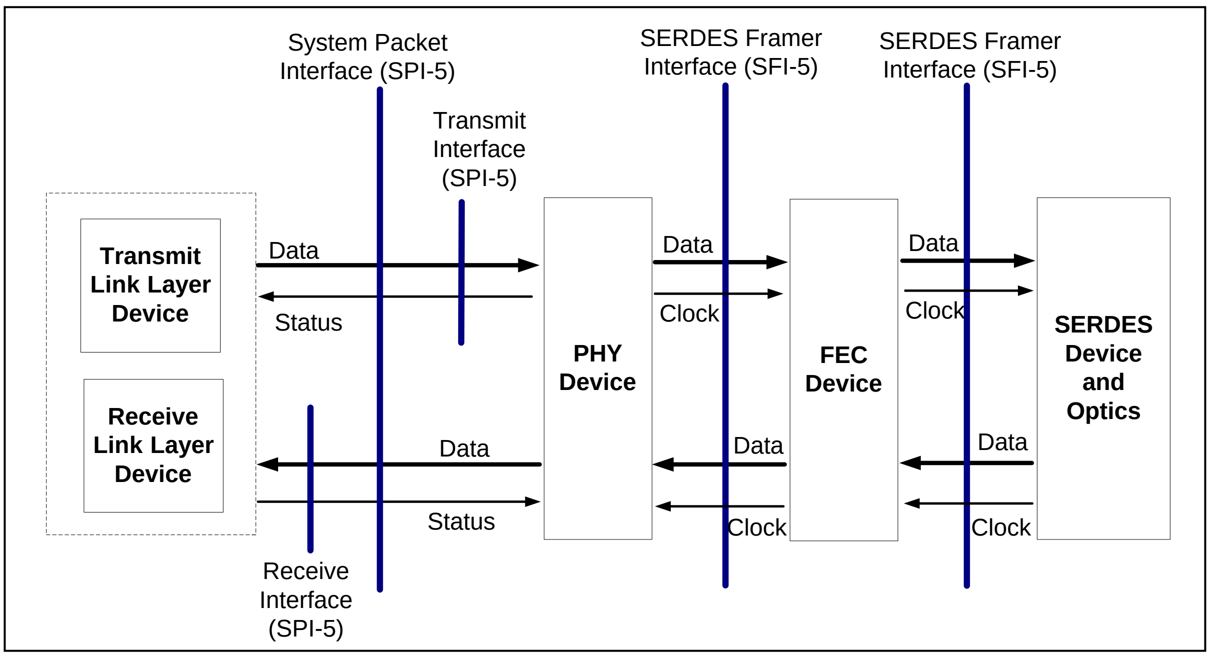

Figure 3: Typical 40 Gb/s System

The requirements of SxI-5 are:

1. Support serial data rate from 2.488 Gb/s to 3.125 Gb/s.
2. Provide well defined voltage levels and timing budgets.
3. Capable of low bit error rate.
4. Provide a clear forward migration path to future fabrication processes.
5. Capable of driving at least 8 inches of FR4 with 1 or 2 connectors.
6. Compatible with other high-speed I/O families.
7. Wide availability of components and intellectual property.
8. For full compliance, both the driver and receiver MUST support both AC and DC coupling.
9. For AC compliance, both the driver and receiver MUST support AC coupling.
10. For DC compliance, both the driver and the receiver MUST support DC coupling.

6 Interface Definition

This section describes the signaling that allows for SxI-5 link operation at 2.488 Gb/s to 3.125 Gb/s. Unless specifically excluded, the specifications apply to all high-speed signals on the SFI-5 and SPI-5 buses. The specification defines the characteristics required to communicate between an SxI-5 driver and an SxI-5 receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100 ohms differential. Connections are point-to-point and signaling is unidirectional. SxI-5 devices from different manufacturers shall be inter-operable.

Differential signaling conventions are shown Figure 4 below. The differential amplitude represents the value of the voltage between the true and complement signals. Peak-Peak voltage is defined as $2*(V_{high} – V_{low})$. The common mode voltage is the average of V_{high} and V_{low}.

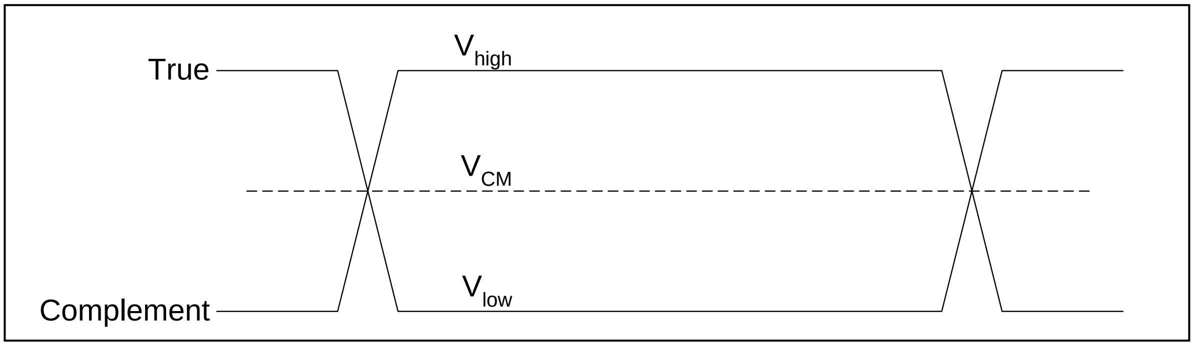

Figure 4: General Signal Definition

6.1 Differential Output Characteristics

Output parameters that can be derived from other specified parameters may not be explicitly specified. The use of DC blocking capacitors is optional. Any loss or jitter caused by these capacitors must be accounted for as part of the allocation for the printed circuit board on which the capacitors reside.

The frequency dependent attenuation of the inter-connection media degrades the signal and thus produces inter-symbol interference or data dependent jitter.

All SxI-5 output drivers shall meet all the parameters of Table 1, Table 4 and Figure 7. A Transmit Eye Mask (Figure 7) is used to specify amplitude timing and jitter requirements for the SXI-5 output drivers. This allows maximum design flexibility while still guaranteeing interoperability.

Symbol	Parameter	Max	Min	Units	Comments
V_{CM}	Output Common Mode Voltage	1.23	0.72	V	(V_{high} + V_{low}) / 2. When using a load of Figure 5 with 1.05V<V_{tt}<1.35, 37.5<rterm<62.5 ohms, 0<Zvtt<30 ohms. Ground in Figure 5 is to be the same potential as the driver ground. (see note 1) Parameter is unspecified if DC blocking capacitors are present.
T_{DRF}	Driver Rise/Fall Time		50	ps	At 20% - 80% into 100 ohm load
I_{DSHORT}	Short Circuit Current	50	-50	mA	To any voltage between 1.45 and –0.25 V, power on or off
UI_{D}	Unit Interval	402	320	ps	2.488 Gb/s to 3.125 Gb/s, ±100 ppm
R_{SE}	Single-ended output impedance	65	35	Ohm	at DC
R_{D}	Differential Impedance	125	75	Ohm	at DC
R_{HS}	Single-ended return loss		7.5	dB	From 0.004*baud rate to 0.75*baud rate
RL_{DIFF}	Differential return loss		7.5	dB	From 0.004*baud rate to 0.75*baud rate

Table 1: SxI-5 Differential Output Characteristics

Notes

1. *The Vtt values take into account the assumption of up to +/-50mv ground shift between transmit and receiver*
2. *For Amplitude and maximum Rise/Fall time requirements see Figure 7 and Table 4*

6.2 Differential Input Characteristics

All SxI-5 input receivers shall meet all the parameters of Table 2.

Symbol	Parameter	Max	Min	Units	Comments
V_{tt}	Termination Voltage	1.30	1.10	V	Parameter unspecified if DC blocking capacitors are present
Z_{Vtt}	Bias Voltage Source Impedance	30		Ohm	From DC to .75*baud rate if DC blocking capacitors are not present. From 500Mhz to .75*baud rate if DC blocking capacitors are present. (see note 1)
V_{RCM}	Input Common Mode Voltage	Vtt	0.7	V	$(V_{high} + V_{low}) / 2$ Parameter unspecified if DC blocking capacitors are present
Z_{INDIFF}	Differential input impedance	125	75	Ohm	At DC. If AC coupled, parameter applies at 0.0035*Fd only
L_{DR}	Differential return loss		10	dB	From 0.004*baud rate to 0.75*baud rate relative to 100 ohms

Table 2: SxI-5 Differential Input Characteristics

Notes

1. *Magnitude of complex impedance with real part >0*
2. *For amplitude and rise/fall time requirements see Figure 8 and Table 5*

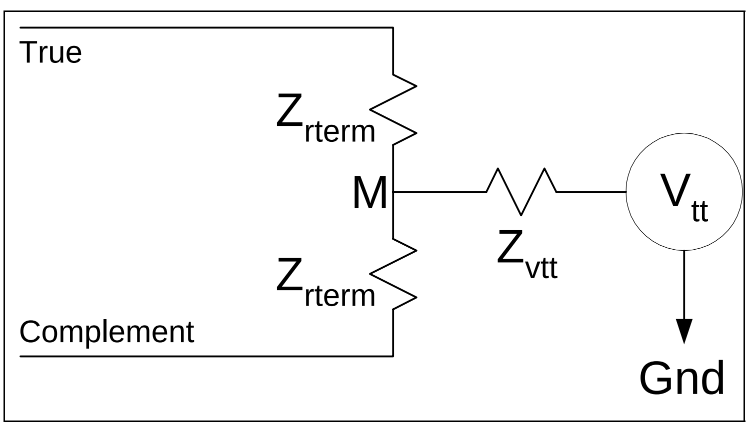

Figure 5: Termination and Signaling

6.3 Jitter Requirements

The eye mask defines the horizontal (jitter) and vertical (signal amplitude) characteristics of the data and clock signals. The eye masks are defined for transmitter outputs (reference points A and C) and the receiver inputs (reference points B and D) as shown in Figure 6. Reference points C and D reference the return status path for SPI-5 and the transmit/egress data path for SFI-5. The eye mask defined for reference point A and B refers to both directions of data flow for the SPI-5 interface and the receive/ingress data path for SFI-5. See SFI-5 and SPI-5 agreements for details on reference point definitions. In the event of conflict between SxI-5 and SFI-5/SPI-5 reference point definitions the SFI-5/SPI-5 documents would take precedence.

In order to adequately specify the jitter for the SXI-5 interface, Table 3 includes skew, relative, correlated and uncorrelated wander requirements. The need to align multiple lanes of data necessitates the addition of skew and wander specifications to guarantee interoperability.

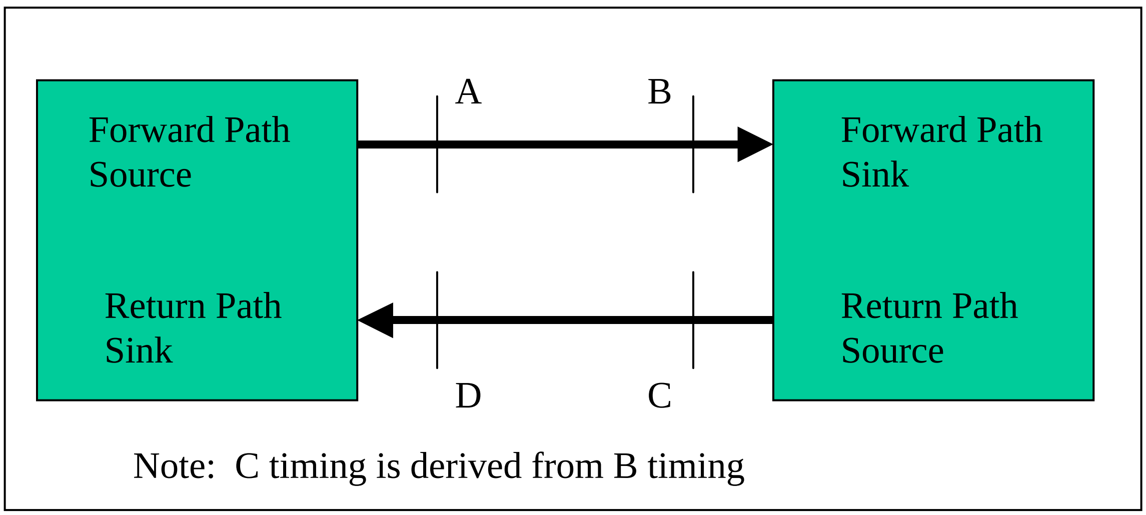

Figure 6: Eye Mask and Jitter Reference Diagram

PARAMETER	SIGNAL TYPE	SYSTEM POINTS A	B	C	D	UNITS
Skew	Data	2.0	5.0	2.0	5.0	UI peak
Correlated Wander	All	4.5	5.0	9.5	10.0	UI peak to peak
Uncorrelated Wander	All	.60	.65	.6	.65	UI peak to peak
Total Wander	All	5.1	5.65	10.1	10.65	UI peak to peak
Relative Wander	All	1.2	1.3	1.2	1.3	UI peak to peak
Skew + (Relative Wander)/2	Data	2.6	5.65	2.6	5.65	UI peak
Deterministic Jitter(DJ)	Clock	.12	.21	.15	.24	UI peak to peak
	Data	.17	.32	.2	.35	UI peak to peak
Total Jitter(TJ)	Clock	.3	.45	.4	.54	UI peak to peak
	Data	.35	.56	.45	.65	UI peak to peak

Table 3: Skew, Wander and Jitter

Notes

1. *The unit interval is 1/(data bit rate)*
2. *The maximum random jitter is equal to the maximum total jitter minus the actual deterministic jitter*
3. *The peak-to-peak random jitter is equal to 14 standard deviations (14 Sigma) of the random jitter distribution*
4. *The jitter corner frequency is (data bit rate)/1667*
5. *The deterministic jitter and total jitter values apply after the application of a single pole high-pass frequency-weighting function which progressively attenuates jitter at 20 dB per decade below the jitter corner frequency*
6. *The specified wander values apply after the application of a single pole low -pass frequency-weighting function which progressively attenuates jitter at 20 dB per decade above the frequency equal to (jitter_corner_frequency/wander_amplitude)*0.1*
7. *Wander corner frequency is 0.1*(jitter corner frequency(Hz)/wander amplitude(UI))*

6.3.1 Transmit Eye Mask

The transmit eye mask specifies the jitter at reference points A and C as shown in Figure 6. The horizontal limit specified in the eye mask shown in Figure 7 represents the total jitter seen at the transmitter output (both RJ and DJ). The jitter output specifications are shown Table 4 (see also Appendix 2).

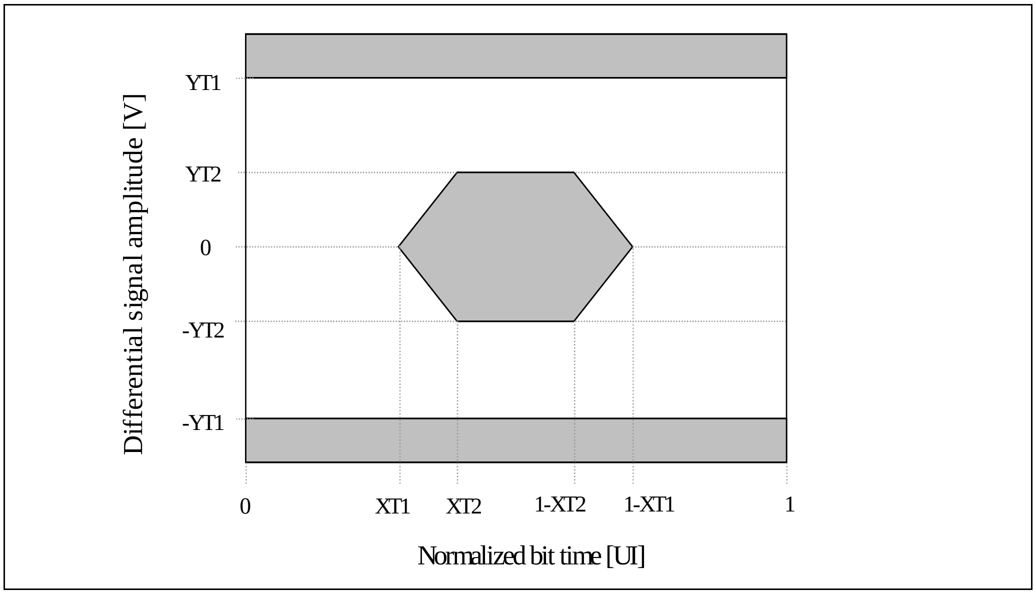

Figure 7: Transmit Eye Mask

Note

1. *Transmitted eye mask at the transmitter pin is measured into a 100 ohm load having more than 20 dB return loss between DC and 1.6 * baud rate.*

Reference Point	Data / Clock	XT1 (UI)	XT2 (UI)	YT1 (V)	YT2 (V)	DJ [pp UI]	Total Jitter J_{Tot}[pp UI]
A	Data	0.175	0.45	0.50	0.25	0.17	0.35
A	Clock	0.15	0.45	0.50	0.25	0.12	0.30
C	Data	0.225	0.50	0.50	0.25	0.20	0.45
C	Clock	0.20	0.50	0.50	0.25	0.15	0.40

Table 4: Transmit Eye Mask Specifications

Notes

1. *Reference points are defined in Figure 6*
2. *XT1, XT2, YT1 and YT2 are defined in Figure 7*
3. *XT1 = Jtot/2*

6.3.2 Receive Eye Mask

The receive eye mask specifies the jitter at reference points B and D as shown in Figure 6. The horizontal limit specified in the eye mask shown in Table 5 represents the total jitter seen at the receiver input (both RJ and DJ). The jitter tolerance specifications are shown in Table 5 (see also Appendix 2).

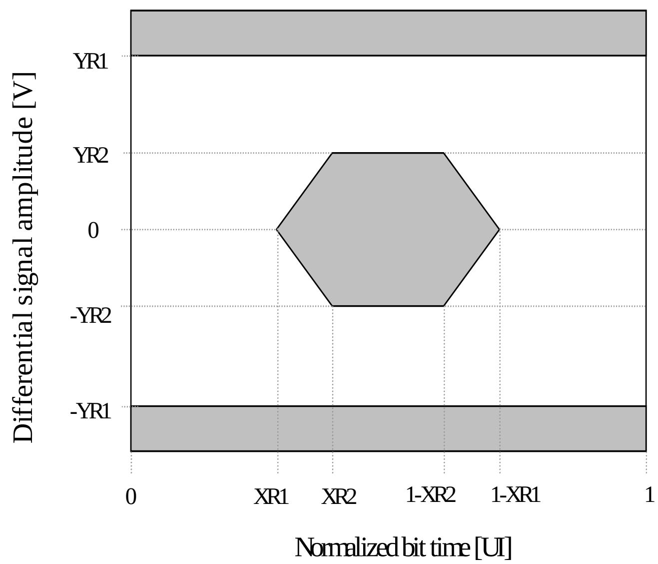

Figure 8: Eye Opening at Receiver

Reference Point	Data / Clock	XR1 (UI)	XR2 (UI)	YR1 (V)	YR2 (V)	DJ [pp UI]	Total Jitter [pp UI]
B	Data	0.28	0.39	0.5	0.0875	0.32	0.56
B	Clock	0.23	0.36	0.5	0.0875	0.21	0.45
D	Data	0.33	0.42	0.5	0.0875	0.35	0.65
D	Clock	0.27	0.39	0.5	0.0875	0.24	0.54

Table 5: Receive Eye Mask Specifications

Notes

1. *Reference points are defined in Figure 6*
2. *XT1, XT2, YT1 and YT2 are defined in Figure 7*
3. *XR1 =* $J_{tot}/2$
4. *Receive eye mask is measured into a 100 ohm load with more than 20 dB return loss between DC and 1.6 * baud rate.*

7 References

[1] Optical Internetworking Forum, SPI-5 (OC-768 System Packet Interface) OIF-SPI-5-01.0: System Packet Interface Level 5 (SPI-5): OC-768 System Interface for Physical and Link Layer Devices".

[2] Optical Internetworking Forum, "SFI-5: (OC-768 SERDES-Framer Interface) OIF-SFI-5-01.0:-,SERDES-Framer Interface Level 5.

[3] Secretariat National Committee for Information Technology Standardization (NCITS), T11.2/Project 1316-DT/Rev 0.0, "Fibre Channel – Methodologies for Jitter Specification –2", April 11, 2000.

Appendix 1

Jitter Components and Measurement Techniques

Jitter is the mis-positioning of significant edges in a sequence of data bits from their ideal positions. Data errors result when the mis-positioning extends past the sampling point at the receiver. Jitter is discussed in great detail in MJS-2 [3]. A brief synopsis is given here.

Total jitter is the combination of two types of jitter processes; deterministic (systematic) and random (non-systematic). Deterministic jitter (DJ) is due to non-Gaussian processes and has a bounded amplitude and a specific cause. The four kinds of deterministic jitter are: duty cycle distortion (DCD), data dependent (e.g., inter-symbol interference-ISI), sinusoidal, and un-correlated (to the data) bounded. Deterministic jitter is measured as a peak-to-peak value and sums linearly.

Random jitter (RJ) is all jitter that is Gaussian in nature. It is often measured in RMS value, which equals the standard deviation (Sigma) in a Gaussian process. Due to the unbounded “tail” in a Gaussian distribution, a true peak-to-peak value cannot be ascertained. A practical peak-to-peak value can be obtained by defining a threshold that would include all but an insignificant fraction of the population. In MJS-2, the threshold is set at ±7 Sigma. At that level, approximately 5 x 10^{-13} of the population is excluded. Given this definition, the peak-to-peak value of random jitter is 14 * the RMS value.

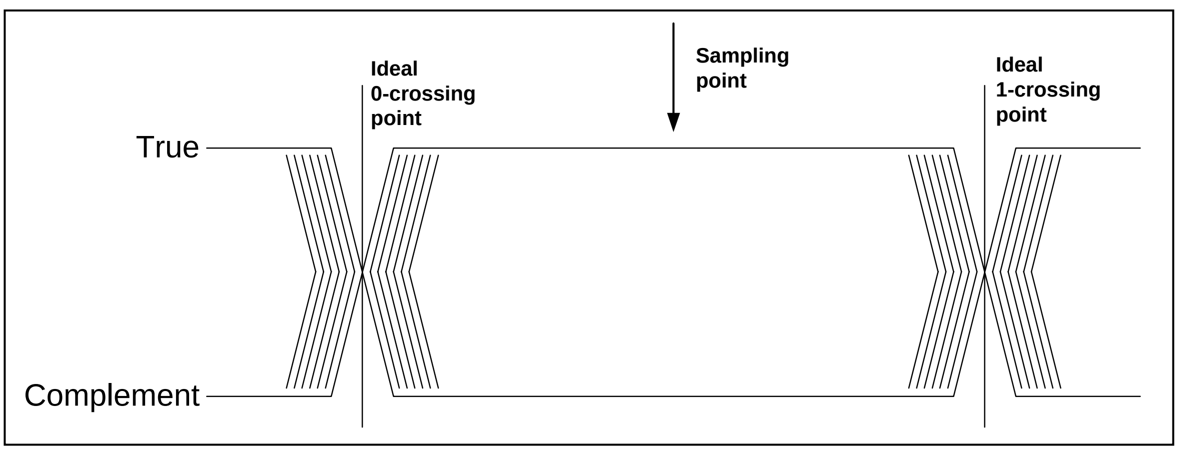

Figure 9: Jittered Bit Cell

Figure 9 shows the time domain effects of jitter. The ideal 0-crossing point and the ideal 1-crossing point are labeled. Jitter moves the crossing points away from the idea positions. The amount that the crossing points are mis-positioned is the combined effect of deterministic jitter and random jitter. A bit error is generated when jitter moves the crossing point to beyond the sampling point. From a mathematical point of view, the probability density function (pdf) of random jitter is a Gaussian distribution with zero mean and standard deviation equal to the RMS jitter value. In MJS-2, a worst-case scenario is chosen for the deterministic jitter. It is assumed to have a pdf that is represented by two Dirac delta functions of amplitude one-half, and located +/- the zero-to-peak jitter value. The pdf of the total jitter is the convolution of the Gaussian distribution with the two Dirac delta functions. The result is a pdf that is the sum of two Gaussian distributions that are separated by W, the peak-to-peak value of DJ.

One can determine the probability of a 0-crossing producing a bit error by integrating the pdf of the total jitter process from ½UI to infinity. The probability of a 1-crossing error is the integral from -infinity to -½UI. By the symmetry of the pdf, the two probabilities are equal. Since the two Gaussian distributions that make up the total jitter pdf are widely separated (by W/2), only the Gaussian closer to the sampling point contribute significantly to error probabilities. By choosing 7 sigma as the total peak-to-peak jitter from RJ, and representing the pdf of DJ by a Dirac delta function, a link operating at the limit would be able to tolerate all but $5x10^{-13}$ of the events at the left crossing and like amounts at the right crossing. This yields a predicted BER of $1x10^{-12}$.

It is important to note that the pdf assumptions are chosen for mathematical tractability. Actual systems do not necessarily behave as modeled. Gaussian distributions have an infinite tail. But, physical processes are invariably bounded. The choice of the Dirac delta function for DJ is a conservative approximation. It assumes that the deterministic jitter takes on the maximal value, with 50% probability, at every crossing point of the data line. This assumption implies that DJ is somehow correlated with the data. Sinusoidal jitter and un-correlated bounded jitter components of DJ do not have this property. Thus, although this model predicts that the jitter specifications would yield an expected BER of 10^{-12}, actual system performance would likely be far superior. History has shown that systems so specified have good performance. The BER from the model is best viewed as a figure of merit to compare systems and to study trends. It is not useful as a predictor of absolute system performance.

Appendix 2

Pro Forma Timing Budgets

Location	Description	UI (peak-to-peak)
Before reference point A	Deterministic jitter at reference point A	0.12
	Random jitter at reference point A (14 Sigma)	0.18
	Total jitter at reference point A	0.30
Between reference points A and B	Additional deterministic jitter	0.09
	Additional random jitter (14 Sigma)	0.16
	Deterministic jitter at reference point B	0.21
	Random jitter at reference point B (14 Sigma)	0.24
	Total jitter at reference point B	0.45
Between reference points B and C	Deterministic jitter attenuation	0.06
	Random jitter gain (14 Sigma)	0.07
	Deterministic jitter at reference point C	0.15
	Random jitter at reference point C (14 Sigma)	0.25
	Total jitter at reference point C	0.40
Between reference points C and D	Additional deterministic jitter	0.09
	Additional random jitter (14 Sigma)	0.16
	Deterministic jitter at reference point D	0.24
	Random jitter at reference point D (14 Sigma)	0.30
	Total jitter at reference point D	0.54

Table 6: Clock Jitter Budget

Location	Description	UI (peak-to-peak)
Before reference point A	Deterministic jitter at reference point A	0.17
	Random jitter at reference point A (14 Sigma)	0.18
	Total jitter at reference point A	0.35
Between reference points A and B	Additional deterministic jitter	0.15
	Additional random jitter (14 Sigma)	0.16
	Deterministic jitter at reference point B	0.32
	Random jitter at reference point B (14 Sigma)	0.24
	Total jitter at reference point B	0.56
Between reference points B and C	Deterministic jitter attenuation	0.12
	Random jitter gain (14 Sigma)	0.07
	Deterministic jitter at reference point C	0.20
	Random jitter at reference point C (14 Sigma)	0.25
	Total jitter at reference point C	0.45
Between reference points C and D	Additional deterministic jitter	0.15
	Additional random jitter (14 Sigma)	0.16
	Deterministic jitter at reference point D	0.35
	Random jitter at reference point D (14 Sigma)	0.30
	Total jitter at reference point D	0.65

Table 7: Data Jitter Budget

Component	Skew	Unit
Source BGA breakout	1.50	in
Source connector breakout	0.75	in
Connector	0.30	in
Sink connector breakout	0.75	in
Sink BGA breakout	1.50	in
Total Skew	4.80	in
(3.125 Gbps @ 160 ps / in)	2.40	UI
(3.125 Gbps @ 180 ps / in)	2.70	UI
(3.125 Gbps @ 200 ps / in)	3.00	UI

Table 8: Interconnect Skew Budget

Appendix 3

Differential and Common Mode Voltage Model

Figure 10 below is the model that is used to construct the set of equations in Figure 11. The information in Figure 10 and Figure 11 is the basis of the common mode voltages, which are specified in Table 1 and Table 2.

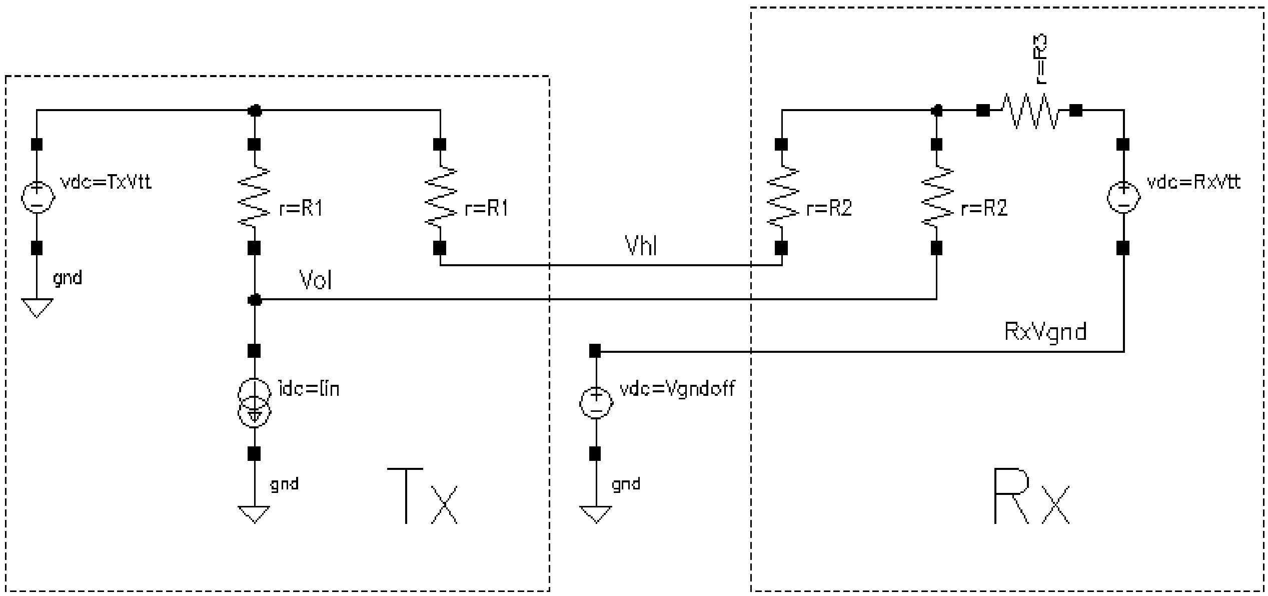

Figure 10: Schematic for Common Mode and Differential Voltage Calculations

$$Vol = \frac{-R1*\left(\frac{-(RxVtt+Vgndoff)*(R1+R2)-2.0*R3*TxVtt+R3*R1*Iin}{R1+R2+2.0*R3}\right)+R2*TxVtt-R1*R2*Iin}{R1+R2}$$

$$Vhl = \frac{TxVtt+R1*\left(-\left(\frac{-(RxVtt+Vgndoff)*(R1+R2)-2.0*R3*TxVtt+R3*R1*Iin}{R1+R2+2.0*R3}\right)-TxVtt\right)}{R1+R2}$$

$$Vcm = \frac{(Vhl - Vol)}{2} + Vol$$

$$Vdiff = 2.0*\frac{R1*R2*Iin}{R1+R2}$$

Figure 11: Common Mode and Differential Voltage Equations

Appendix 4

OIF Companies at Time of Ballot Period:

Accelerant Networks	Ciena Communications
Accelight Networks	Cisco Systems
Actel	Coherent Telecom
Acterna Eningen GmbH	Conexant
ADC Telecommunications	CoreOptics
Aeluros	Coriolis Networks
Agere Systems	Corrigent Systems
Agilent Technologies	Cortina Systems
Agility Communications	Corvis Corporation
Alcatel	Cypress Semiconductor
All Optical Networks, Inc.	Data Connection
Altamar Networks	Department of Defense
Altera	DeriveIt
Alvesta Corporation	E2O Communications
AMCC	ELEMATICS
America Online	Elisa Communications
Ample Communications	Emcore
Analog Devices	Equant Telecommunications SA
ANDO Corporation	Equipe Communications
Anritsu	Ericsson
Aralight	ETRI
ASTRI	Extreme Networks
AT&T	EZChip Technologies
Atrica Inc.	Fiberhome Telecommunications
Avici Systems	Fiberspace
Axiowave Networks	Finisar Corporation
Bandwidth9	Flextronics
Bay Microsystems	Force 10 Networks
Big Bear Networks	France Telecom
Bit Blitz Communications	Free Electron Technology
Blaze Network Products	Fujikura
Blue Sky Research	Fujitsu
Bookham Technology	Furukawa Electric Technologies
Booz-Allen & Hamilton	Galazar Networks
Broadcom	General Dynamics
Cable & Wireless	Glimmerglass Networks
Cadence Design Systems	Harris Corporation
Calient Networks	Harting Electro-Optics GmbH
Calix Networks	Helix AG
Caspian Networks	Hi/fn
Celion Networks	Hitachi
Centellax	Huawei Technologies
Centillium Communications	IBM Corporation
Ceyba	Ignis Optics
Chiaro Networks	Industrial Technology Research Institute
Chunghwa Telecom Labs	Infineon Technologies

Infinera	Optix Networks
Innovance Networks	Optobahn
Inphi	OptronX
Integrated Device Technology	PacketLight Networks
Intel	Parama Networks
Internet Machines	Paxonet Communications
Interoute	Peta Switch Solutions
Intune Technologies, Ltd.	PhotonEx
Iolon	Photuris, Inc.
Japan Telecom	Phyworks
JDS Uniphase	Picarro
Jennic	Pine Photonics Communications
Juniper Networks	PMC Sierra
KDDI R&D Laboratories	Polaris Networks, Inc.
Kirana Networks	Princeton Optronics
KT Corporation	Procket Networks
Larscom	Quake Technologies
Lattice Semiconductor	Qwest Communications
LSI Logic	RedClover Networks
Lucent	RF Micro Devices
Lumentis	RHK
LuxN	Sandia National Laboratories
LYNX - Photonic Networks	Santec Corporation
Mahi Networks	Santel Networks
Marconi Communications	Santur
MathStar	SBC
Maxim Integrated Products	Siemens
MergeOptics GmbH	Sierra Monolithics
Meriton	Silicon Access Networks
Metro-OptiX	Silicon Labs
Mintera	Silicon Logic Engineering
Mitsubishi Electric Corporation	Sky Optix
Multilink Technology Corporation	Solidum
Multiplex	Southampton Photonics
MultiWave Networks	Spirent Communications
Myrica Networks	StrataLight Communications
Mysticom	Stratos Lightwave
National Semiconductor	Sumitomo Electric Industries
Nayna Networks	Sun Microsystems
NEC	Sycamore Networks
NetTest	TDK Semiconductor
Network Elements	Tektronix
NIST	Telcordia Technologies
Nortel Networks	Telecom Italia Lab
NTT Corporation	Tellabs
NurLogic Design	Tellium
OpNext	Tenor Networks
Optical Datacom	TeraBurst Networks
Optillion	TeraConnect
Optium	Teradiant Networks, Inc.
Texas Instruments	

T-Networks, Inc.
Toshiba Corporation
Transpectrum
Transpera Networks
TriQuint Semiconductor
Tropic Networks Inc.
Tsunami Photonics
T-Systems Nova
Turin Networks
US Conec
Velio Communications
Velocium (TRW)
Verizon
Vitesse Semiconductor
VSK Photonics
W.L. Gore & Associates
Wavecrest Corporation
Wavium AB
West Bay Semiconductor
Xanoptix
Xelerated
Xignal Technologies
Xilinx
Xindium
Xlight Photonics
Zagros Networks
Zarlink Semiconductor