OPTICAL INTERNETWORKING FORUM

IA Title: Common Electrical I/O (CEI) - Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O

IA # OIF-CEI-03.0

1st September 2011

Implementation Agreement created and approved

by the Optical Internetworking Forum

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Implementation Agreement: OIF-CEI-03.0

Working Group: Physical and Link Layer

Title: Common Electrical I/O (CEI) - Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O

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ABSTRACT:

This document is the CEI implementation agreement, which specifies the transmitter, receiver and interconnect channel associated with 6G+ bps, 11G+ bps and 25G+ bps interfaces for application in high speed backplanes, chip to chip interconnect and optical modules. Also included is the Jitter definition and measurement methodologies associated with CEI interfaces. This version includes the CEI-28G-SR and CEI-25G-LR interfaces.

0 Document Structure and Contents

0.1 Revision History

The OIF document 2003.104 was the working document used for the development of the CEI-6G-SR, CEI-6G-LR, CEI-11G-SR interfaces and the jitter methodology. The history of this document is detailed in the table below:

Revision	Date	Description
OIF 2003.104.00	28th March 2003,	Draft 1.0. Compiled from baseline documents oif2002.605.03 (clause 0, 1), OIF2002.536.06 (clause 2), oif2002.520.02 (clauses 4, 5), OIF2002.506.02 (clause 6)
OIF 2003.104.01	3rd May 2003	Draft 2.0. Contains changes as result from comments received from Draft 1.0. Section added in Clause 6 relating to transparent application, derived from XFP specification. Parameters added re DC coupling option, derived from OIF2003.129
OIF 2003.104.02	24th May 2003	Draft 3.0. Updated to include approved changes from the OIF Plenary meeting in Scottsdale, 6-8 May 2003
OIF 2003.104.03	2nd October 2003	Draft 4.0. Updated to include changes as results of comment resolution from CEI Straw ballot (ballot#41), approved at the Ottawa meeting July 2003
OIF 2003.104.04	17th November 2003	Draft 4.1. As draft 4.0 but including changes approved at the Berlin interim/ plenary meetings 13 - 16 October 2003. These changes are summarized in OIF2003.326.03.
OIF2003.104.05	10th February 2004	Draft 5.0. Updated to include changes as results of comment resolution from the second CEI Straw ballot (ballot#49), approved at the San Diego meeting January 2004
OIF2003.104.06	5th May 2004	Draft 6.0. Updated to include changes as result of comment resolution from 3rd Straw ballot (ballot no 52), as approved at the Orlando Interim meeting March 15th 2004.
OIF2003.104.07	14th July 2004	Draft 7.0. As Draft 6.0, but updated to include changes approved at the Budapest Plenary meeting. Clause 2 reconstructed and SXI-5 and TFI-5 interfaces described as new clauses 4 and 5. Previous clauses 4,5,6 are renumbered as clauses 6,7,8
OIF2003.104.08	26th August 2004	Clause 8 modified to include changes agreed at the Hawaii Plenary meeting, to address discrepancies between CEI and XFP specifications.
OIF2003.104.09	20th October 2004	Draft 9.0. Updated to include changes as result of comment resolution from 4th Straw ballot (ballot no 55),
OIF2003.104.10	8th November 2004	Draft 10.0. As draft 9.0 with specific reference to version no of State Eye scripts in section 2.C.5 removed.

This revision was published as OIF-CEI-01.00 in December 2004.

The OIF document 2003.253 was the working document used for the development of the CEI-11G-MR and CEI-11G-LR interfaces. The history of this document is detailed in the table below:

Revision	Date	Description
OIF 2003.253.00	20th July 2003,	Draft 1.0. Compiled from baseline document oif2002.127.0 with changes and modifications from Scottsdale motions
OIF 2003.253.01	5th October 2003	Draft 1.1. adding changes and modifications from the July 2003 meeting in Ottawa. - New entries for table 1-1 moved to OIF2003.104. - Removed figure 1-1, table 1-2 and sections 1.8 and 3.2.10. - Moved appendix 3B to OIF2003.104 - Changed 7.2.8, 8 Taps down to 4 Taps - Changed 7.1 to required BER of 1e-15
OIF 2003.253.02	9th November 2003	Draft 2.0. adding changes and modifications from the October 2003 meeting in Berlin.
OIF2003.253.03	2nd February 2004	Draft 2.1 resolving comments from Straw ballot #50, motions and resolutions as agreed in the San Diego 2004 meeting. Corrections include: - DC coupling introduced with VTT = 1.2V - Channel compliance, section 7.2.7 - with introduction of reference transmitter and -receiver. - Changes in transmit amplitude to 1200mVppd max Comment resolution spread sheet, OIF2004.054.03 Clause 7 Editors report, OIF2004.053.01 PLL Meeting motions: OIF2004.076.00
OIF2003.253.04	3rd May 2004	Draft 2.2 resolving comments from straw ballot 53 and orlando interim meeting, March 15th. Corrections include - DC coupling editorials - Tap weight clarification - T_Y1 = 400 mVpp, T_Y2 = 600mVpp - driver and receiver absolute min and max voltages - Return loss alignment to 6G-LR
OIF2003.252.05	6 September 2004	Draft 2.3 including motions from Budapest and Hawaii meetings: - Changed clause no from 7 to 9 - Changed values in Table 9-1 and 9-8d - Changed reference receiver B definitions - Added appendix B, the StatEye.org template.
OIF2003.253.06	6 December 2004	Draft 3.0 including the motions from the Alexandria meeting, October 26-28 - Added CEI-11G-MR - Further specification of Reference Receiver B - StatEye templates for -LR Ref Receiver A and B and for -MR
OIF2003.253.06	25 January 2005	Draft 3.1 includes corrections to table 9.11 following discussions and motion from the Dallas meeting, 18-20 January 2005. Source documents uploaded as OIF2005.090.00

This revision was published as OIF-CEI-02.00 in February 2005.

The OIF document 2011.004 was the working document used for the development of maintenance updates to OIF-CEI-02.00. The comment resolution for this update is contained in 2011.121. These updates were published as part of OIF-CEI-03.00 in August 2011.

The OIF document 2008.029 was the working document used for the development of the CEI-28G-SR interface defined in clause 10. The history of this document is detailed in the table below:

Revision	Date	Description
OIF 2008.029.03	28th July 2008,	Document taken over from Beth Donnay
OIF 2008.029.04	23rd April 2009	Inserted text for all tbd locations according to work session results of Q2/09 meeting in Boston
OIF 2008.029.05	23rd April 2009	Finalized text proposal after continued discussion in Q2/09 meeting in Boston. Text proposal sent to Straw Ballot in Boston
OIF 2008.029.06	23rd July 2009	oif2009.129.02: Comment resolution according CEI-28-SR/25-LR Editors Report Finalized text proposal after continued discussion in Q3/09 meeting in Vancouver. Text proposal sent to Straw Ballot in Vancouver
OIF 2008.029.07	15th October 2009	oif2009.280.03: Comment Resolution Worksheet for CEI-28-SR Finalized text proposal after continued discussion in Q4/09 meeting in Lannion. Text proposal sent to Straw Ballot in Lannion and sent as liaison to IEEE 802.3ba for comments
OIF 2008.029.08	21st May 2010	oif2009.408.01: Comment Resolution Worksheet for CEI-28-SR Finalized text proposal after continued discussion in Q2/10 meeting in Hong Kong. Text proposal sent to Straw Ballot in electronic motion after Hong Kong meeting.
OIF 2008.029.09	25th August 2010	oif2010.239.01: Comment Resolution Worksheet for CEI-28-SR Finalized text proposal after continued discussion in Q3/10 meeting in Baltimore. Text proposal sent to Straw Ballot in electronic motion after Baltimore meeting.
OIF 2008.029.10	16th November 2010	oif2010.337.02: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q4/10 meeting in Nuremberg. Text proposal sent to Straw Ballot in electronic motion after Nuremberg meeting
OIF 2008.029.11	14th February 2011	oif2010.452.01: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q1/11 meeting in Dallas. Text proposal sent to Straw Ballot in electronic motion after Dallas meeting
OIF 2008.029.12	7th April 2011	oif2011.129.04: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q2/11 meeting in Glasgow. Text proposal sent to Straw Ballot during Glasgow meeting with option for Principal.
OIF 2008.029.13	3rd June 2011	oif2011.198.01: Comment Resolution Worksheet for CEI-25/28 Resolution of LSI, Qlogic Straw Ballot comments. Text proposal sent to another Straw Ballot in electronic motion. oif2011.271.01: Comment Resolution Worksheet for CEI-25/28 Document sent to principal member ballot at Philadelphia meeting

The OIF document 2008.161 was the working document used for the development of the CEI-25G-LR interface defined in clause 11. The history of this document is detailed in the table below:

Revision	Date	Description
OIF 2008.161.03	28th July 2008,	Document taken over from Beth Donnay
OIF 2008.161.04	23rd April 2009	Inserted text for all tbd locations according to work session results of Q2/09 meeting in Boston
OIF 2008.161.05	23rd April 2009	Finalized text proposal after continued discussion in Q2/09 meeting in Boston. Text proposal sent to Straw Ballot in Boston
OIF 2008.161.06	23rd July 2009	oif2009.129.02: Comment resolution according CEI-28-SR/25-LR Editors Report Finalized text proposal after continued discussion in Q3/09 meeting in Vancouver. Text proposal sent to Straw Ballot in Vancouver
OIF 2008.161.07	15th October 2009	oif2009.281.02: Comment Resolution Worksheet for CEI-25-LR Finalized text proposal after continued discussion in Q4/09 meeting in Lannion. Text proposal sent to Straw Ballot in Lannion and sent as liaison to IEEE 802.3ba for comments
OIF 2008.161.08	21st May 2010	oif2009.409.01: Comment Resolution Worksheet for CEI-25-LR Finalized text proposal after continued discussion in Q2/10 meeting in Hong Kong. Text proposal sent to Straw Ballot in electronic motion after Hong Kong meeting.
OIF 2008.161.09	25th August 2010	oif2010.240.01: Comment Resolution Worksheet for CEI-25-LR Finalized text proposal after continued discussion in Q3/10 meeting in Baltimore. Text proposal sent to Straw Ballot in electronic motion after Baltimore meeting.
OIF 2008.161.10	16th November 2010	oif2010.337.02: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q4/10 meeting in Nuremberg. Text proposal sent to Straw Ballot in electronic motion after Nuremberg meeting
OIF 2008.161.11	14th February 2011	oif2010.452.01: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q1/11 meeting in Dallas. Text proposal sent to Straw Ballot in electronic motion after Dallas meeting
OIF 2008.161.12	7th April 2011	oif2011.129.04: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q2/11 meeting in Glasgow. Text proposal sent to Straw Ballot during Glasgow meeting with option for Principal.
OIF 2008.161.13	3rd June 2011	oif2011.198.01: Comment Resolution Worksheet for CEI-25/28 Resolution of LSI, Qlogic Straw Ballot comments. Text proposal sent to another Straw Ballot in electronic motion. oif2011.271.01: Comment Resolution Worksheet for CEI-25/28 Document sent to principal member ballot at Philadelphia meeting

The OIF document 2010.189 was the working document used for the development of the Test Methodologies for CEI-28G-SR and CEI-25G-LR defined in clause 12. The history of this document is detailed in the table below:

Revision	Date	Description
OIF 2010.189.00	12th May 2010	Separate Clause extracted for common ‘TX Jitter and Channel Compliance Methodologies for CEI-28G-SR and CEI-25G-LR’ in Q2/10 meeting in Hong Kong.
OIF 2010.189.01	12th May 2010	Modifications during Hong Kong meeting
OIF 2010.189.02	21st May 2010	Editorial changes of PLL chair, see change bars Text proposal sent to Straw Ballot in electronic motion after Hong Kong meeting.
OIF 2010.189.03	25th August 2010	oif2010.241.01: Comment Resolution Worksheet for Clause 12 Finalized text proposal after continued discussion in Q3/10 meeting in Baltimore. Text proposal sent to Straw Ballot in electronic motion after Baltimore meeting.
OIF 2010.189.04	16th November 2010	oif2010.337.02: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q4/10 meeting in Nuremberg. Text proposal sent to Straw Ballot in electronic motion after Nuremberg meeting
OIF 2010.189.05	14th February 2011	oif2010.452.01: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q1/11 meeting in Dallas. Text proposal sent to Straw Ballot in electronic motion after Dallas meeting
OIF 2010.189.06	7th April 2011	oif2011.129.04: Comment Resolution Worksheet for CEI-25/28 Finalized text proposal after continued discussion in Q2/11 meeting in Glasgow. Text proposal sent to Straw Ballot during Glasgow meeting with option for Principal.
OIF 2010.189.07	3rd June 2011	oif2011.198.01: Comment Resolution Worksheet for CEI-25/28 Resolution of LSI, Qlogic Straw Ballot comments. Text proposal sent to another Straw Ballot in electronic motion. oif2011.271.01: Comment Resolution Worksheet for CEI-25/28 Document sent to principal member ballot at Philadelphia meeting

The combined revision including changes of above documents was published as OIF-CEI-03.00 in September 2011.

0.2 Document Structure

The CEI document is created as a clause based document to allow for a successive completion of the document as clauses are added. This reflects the split project schedule where there are different schedules for completion different application specifications.

The first release of the document included all clauses common for the applications covered by the CEI project. These clauses were completed to cover the requirements of the included applications. Further common specifications may be included as new application clauses are added, resulting in an update of the common clauses. The process of creating the CEI document can be explained as follows:

1. Prepare and complete all clauses necessary for the first release of the document, make it the master for future documents and submit it for its approval process (balloting cycles).
2. Follow on documents include new clauses for new functions and corrections and additions to all affected clauses of the Master document. Unchanged clauses from prior documents are not included, only deltas are listed (additions and deletions).
3. Once the Master document and following documents are approved it is an editorial task to merge the documents.
4. All requirements and specifications in the application specific clauses shall be referenced to the common clauses when appropriate.
5. Annexes and Appendices providing explanatory and informative text for a specific application shall be included in the corresponding clause and covered by the clause revision history. Information included in Annexes is normative with respect to the particular clause. Information included in Appendices is informative only with respect to the particular clause.

Contents

List of Figures

List of Tables

0.3 List of companies belonging to the OIF when the document is approved

Acacia Communications

ADVA Optical Networking

Alcatel-Lucent

Altera

AMCC

Amphenol Corp.

Anritsu

AT&T

Avago Technologies Inc.

Broadcom

Brocade

Centellax, Inc.

China Telecom

Ciena Corporation

Cisco Systems

ClariPhy Communications

Cogo Optronics

Comcast

Cortina Systems

CyOptics

Department of Defense

Deutsche Telekom

ECI Telecom Ltd.

Emcore

Ericsson

ETRI

EXFO

FCI USA LLC

Fiberhome Technologies Group

Finisar Corporation

Force 10 Networks

France Telecom

Fujitsu

Furukawa Electric Japan

Gennum Corporation

GigOptix Inc.

Hewlett Packard

Hitachi

Hittite Microwave Corp

Huawei Technologies

IBM Corporation

Infinera

Inphi

IP Infusion

JDSU

Juniper Networks

KDDI R&D Laboratories

Lightwire

LSI Corporation

Luxtera

Macom Technology Solutions

Marben Products

Mayo Clinic

Metaswitch

Mitsubishi Electric Corporation

Molex

MoSys, Inc.

NEC

NeoPhotonics

Nokia Siemens Networks

NTT Corporation

Oclaro

Opnext

Optoplex

Picometrix

PMC Sierra

QLogic Corporation

Santur

Semtech

SHF Communication Technologies

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Sumitomo Osaka Cement

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Tellabs

TeraXion

Texas Instruments

Time Warner Cable

TriQuint Semiconductor

u2t Photonics AG

Verizon

Vitesse Semiconductor

Xilinx

Xtera Communications

Yamaichi Electronics Ltd.

ZTE Corporation

1 Common electrical I/O project - Introduction, definitions and formats.

1.1 Introduction

The development of a Next Generation Common Electrical I/O Project was proposed in the OIF 2002.571.01 and approved in the Orlando Plenary meeting November 14, 2002. The purpose of the project is outlined in the problem statement:

A faster electrical interface is required to provide higher density and/or lower cost interfaces for payloads of 10Gbps and higher, including SERDES to Framer Interface (SFI), System Packet Interface (SPI), TDM-Fabric to framer Interface (TFI).

1.2 Overview

This Common Electrical IO Implementation Agreement includes:

- Electrical and jitter methodologies for new high speed interfaces and including the following older OIF interfaces: SxI-5, SFI-4.2, SFI-5.1, SPI-5.1 and TFI-5.
- A CEI-6G-SR specification for:

  Data lane(s) that support bit rates from 4.976 to 6.375Gsym/s over Printed Circuit Boards.

  Physical reach from 0 to 200mm and up to 1 connector.
- A CEI-6G-LR specification for

  Data lane(s) that support bit rates from 4.976 to 6.375Gsym/s over Printed Circuit Boards.

  Physical reach from 0 to 1m and up to 2 connectors.
- A CEI-11G-SR specification for:

  Data lane(s) that support bit rates from 9.95 to 11.2Gsym/s over Printed Circuit Boards.
- A CEI-11G-LR specification for:

  Data lane(s) that support bit rates from 9.95 to 11.2Gsym/s over Printed Circuit Boards.

  Physical reach from 0 to 1m with up to two connectors

The Implementation Agreement defines applicable data characteristics (e.g. DC balance, transition density, maximum run length), channel models and compliance points/parameters supporting the physical reach and conditions. The Implementation Agreement specifically excludes any pinout, management interface, power-supply specification, connector or higher-level activity such as addressing or error control. It does not endorse or specify any particular data protocol.

1.3 Objectives and Requirements

The objectives and requirements for the CEI are given by the project definition as follows:

The data path shall:

- allow single and multi-lane applications
- support AC coupling
- support Hot Plug
- achieve Bit Error Ratio of lower than 10^{-15} per lane but the test requirement will be to verify 10^{-12} per lane.
- define a 11G+ short reach link that is capable of supporting SONET/SDH compliance at the optical carrier (OC) interface
- define a 6G+ long reach link that shall accommodate legacy IEEE 802.3 XAUI and TFI-5 compliant backplanes.

The short and long reach links should interoperate for signal path lengths up to 200mm.

The primary focus of the 11G LR CEI implementation agreement will be for non-legacy applications, optimized for overall cost-effective system performance including total power dissipation.

The CEI Electrical Implementation Agreement and the CEI Protocol Implementation Agreement are peer documents. Adherence to one does not force adherence to the other. For example, a 10G SONET framer may connect directly to an optical module using CEI electricals with SONET scrambled data. In this case, CEI Protocol would be absent. It is also possible to use CEI Protocol without CEI Electricals. An example would be to encapsulate TFI-5 frames with CEI Protocol to provide forward error correction capability.

1.4 References

1. XFP Rev 3.1 (10 gigabit Small form factor Pluggable Module) April 25th 2003.
2. ITU Recommendation O.172 (03/01) Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH).
3. ITU G.825 (03/00) The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH). G.825 Erratum 1 (08/01) Erratum to Recommendation ITU-T G.825 (03/00).
4. Optical Internetworking Forum "OIF-TFI5-0.1.0 TFI-5 TDM Fabric to Framer Interface Implementation Agreement", September 16 2003.
5. Telecordia, GR-253-CORE, Issue 3 Sept. 2000 - "Synchronous Optical Network (SONET) Transport System: Common Generic Criteria"

6. ITU-T, Recommendation G.707, Oct. 2000 - "Network Node Interface For The Synchronous Digital Hierarchy (SDH)"
7. ITU-T, Recommendation G.707, Amendment 2, 2002 - "Network Node Interface For The Synchronous Digital Hierarchy (SDH), Amendment 2"
8. ITU-T, Recommendation G.709, Feb. 2001 - "Network Node Interface for the Optical Transport Network (OTN)"
9. Fiber Channel - Methodology for Jitter and Signal Quality Specification - MJSQ, INCITs T11.2 project 1316-DT
10. Optical Internetworking Forum, OIF-SFI4-02.0 - Serdes Framer Interface Level 4 (SFI4) Phase 2: Implementation Agreement for 10Gb/s Interface for Physical layer devices.
11. Optical Internetworking Forum, OIF-SFI5-01.0 - Serdes Framer Interface Level 5 (SFI5): 40Gb/s Interface for Physical Layer devices.
12. Optical Internetworking Forum, OIF-SPI5-01.0 - System Packet Interface Level 5 (SPI5): OC-768 System Interface for Physical Layer devices.
13. Optical Internetworking Forum, OIF-SxI5-01.0 - System Interface Level 5 (SxI5): Common Electrical Characteristics for 2.488 - 3.125Gb/s Parallel Interfaces.
14. Infiniband Architecture Release 1.0.a, Volume 2 — Physical Specifications, Infiniband Trade Association, 2001
15. High Speed Digital Interconnection, Thomas J. Buck, Dynamic Details Inc.
16. Even Mode Impedance, An Introduction, App Note 157, Polar Instruments
17. Eric Bogatin, ‘Differential Impedance... finally made simple, Bogatin Enterprises, 2000
18. R.J.Weber, Introduction to Microwave Circuits, IEEE Press, 2001
19. IEEE, 802.3™-2008, "Information Technology - Local & Metropolitan Area Networks - Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications"
20. Low Voltage Differential Swing (LVDS), ANSI/TIA/EIA-644-A-2001
21. ITU-T Recommendation O.150 May 1996 and corrigendum May 2002. General requirements for instrumentation for performance measurements on digital transmission equipment.
22. ITU-T Recommendation G.957 July 1999 and ammendment Dec 2003. Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.
23. Fiber Channel - Physical Interfaces, INCITs T11.2 project 1235D
24. Optical Internetworking Forum, OIF 2002.507.01 - High Speed Backplane (HSB) Interface Electrical Specification for 5-6.375Gbps Baud Rates over Currently Existing Communications Backplanes.

1.5 Abbreviations

Table 1-1. Abbreviations

Abbreviation	Meaning
BER	Bit Error Ratio
BERT	Bit Error Ratio Test or Tester
BUJ	Bounded Uncorrelated Jitter
CBGJ	Correlated Bounded Gaussian Jitter
CBHPJ	Correlated Bounded High Probability Jitter
CEI	Common Electrical I/O
CDF	Cumulative Distribution Function
CDR	Clock Data Recovery
CID	Consecutive Identical Digits
CML	Current Mode Logic
Cn	Cursor number
DCD	Duty Cycle Distortion
dB	Decibel
DDJ	Data Dependent Jitter
DFE	Decision Feedback Equalizer
DJ	Deterministic Jitter
DUT	Device Under Test
EMI	Electro-Magnetic Interference
erf	error function
erfinv	inverse error function
ESD	Electro-Static Discharge
FEXT	Far End Cross Talk
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
Gbps	Giga bits per second
GJ	Gaussian Jitter
Gsym/s	Giga symbols per second
HF	High Frequency
HPF	High Pass Filter
HPJ	High Probability Jitter
IA	Implementation Agreement
ISI	Inter-Symbol Interference

Table 1-1. Abbreviations

Abbreviation	Meaning
LMS	Least Mean Square
LPF	Low Pass Filter
LVDS [20]	Low Voltage Differential Signal
LR	Long Reach
mA	milli-Amp
mV	milli-Volt
NEXT	Near End Cross Talk
NRZ	Non Return to Zero
PCB	Printed Circuit Board
PDF	Probability Distribution Function
PECL	Positive Emitter Coupled Logic
PJ	Periodic Jitter
pp	Peak to Peak
ppd	Peak to Peak Differential (as in 300mVppd)
PLL	Phase Locked Loop
ps	pico second
PRBS	Pseudo Random Bit Stream
Q	Inverse error function
RJ	Random Jitter
RV	Random Variable
RX	Receiver
S11 and S22	reflection coefficient
S21	transmission coefficient
SCC11 and SCC22	Common mode reflection coefficients
SCD11 and SCD22	Differential to common mode conversion coefficient
SDD11 and SDD22	Differential reflection coefficients
SDC11 and SDC22	Common mode to differential conversion coefficient
SFI	SERDES - Framer Interface
SJ	Sinusoidal Jitter
SPI	System Packet Interface
SR	Short Reach
sym/s	symbols/second
TJ	Total Jitter
TDM	Time Division Multiplexed data
TFI	TDM Fabric to Framer Interface

Table 1-1. Abbreviations

Abbreviation	Meaning
TX	Transmitter
UBHPJ	Uncorrelated Bounded High Probability Jitter
UI	Unit Interval = 1/(baud rate)
UUGJ	Uncorrelated Unbounded Gaussian Jitter
XAUI	10 Gigabit Attachment Unit Interface

1.6 Definitions

Table 1-2. General Definitions (with exception of Jitter and Wander) (Sheet 1 of 2)

Parameter	Description
Bit Error Ratio	A parameter that reflects the quality of the serial transmission and detection scheme. The Bit Error Ratio 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.
Baud rate	Number of symbols per second, where a symbol can consist of more than one bit.
Channel	In this specification Channel shall mean electrical differential channel. The channel is combination of electrical interconnects that together form the signal path from reference points T to R - see Figure 1-6. The channel will typically consist of PCB traces, via holes, component attachment pads and connectors. A characteristic of a signal channel is the complex characteristic impedance Z.
Common Mode Voltage	Average of the Vhigh and Vlow voltage levels - see Figure 1-1
Confidence level	The use of this definition shall be understood as being with reference to a Gaussian Distribution
Differential Termination Resistance mismatch	The difference in the DC termination resistance with respect to ground of any two signals forming a differential pair. Usually due to large process spread the absolute termination resistance is specified relatively loose, e.g. 20% where the relative difference of resistors of the same device will be much less, e.g 5%. This parameter is used to specify the relative difference tighter than the overall resistance for the purpose of minimizing differential signal mode conversion
Gaussian	A statistical distribution (also termed “normal”) characterized by populations that are not bound in value and have well defined “tails”. The term “random” in this document always refers to a Gaussian distribution.
Golden PLL	Refers to a defined clock extraction unit which phase tracks the inherent clock present in a data signal. The phase tracking bandwidth is usually defined in terms of a corner frequency and if not defined with a corner frequency of baud/1667, a roll off of 20dB/dec and <0.1dB peaking

Table 1-2. General Definitions (with exception of Jitter and Wander) (Sheet 2 of 2)

Parameter	Description
Stress Channel	An otherwise compliant channel that has been selected or altered to test receiver or transmitter compliance (see also *Stressed Signal (or) Stressed Eye*.)
Intersymbol Interference	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. Intersymbol Interference is expected whenever any bit sequence has frequency components that are propagated at different rates by the transmission media.
Lane	A single CEI Channel
Link	A functional connection between the Tx and Rx ports of 2 components, that can be multiple or parallel CEI Lanes defined as 1:N. The definition a Link does not imply duplex operation.
non-transparent applications	Defines an application where the high frequency transmit jitter of a device is defined independently to the high frequency jitter present at any data input of the same device
Skew	The constant portion of the difference in the arrival time between the data of any two in-band signals.
Stressed Signal (or) Stressed Eye	In order to test the tolerance of a receiver a stressed signal or eye is defined which when applied to the receiver must be received with the defined Bit Error Rate. The stressed signal or eye is defined in terms of its horizontal closure or jitter and amplitude normally in conjunction with an eye-mask.
Transparent applications	Defines an application where the high frequency transmit jitter of a device is dependent on the high frequency jitter present at one or more of the data inputs of the same device
Symbol	Unit of information conveyed by a single state transition in the medium
Symbol spaced	Describes a time difference equal to the nominal period of the data signal
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 Symbol.

Table 1-3. Jitter and Wander Definitions (Sheet 1 of 2)

Parameter		Description
Jitter		Jitter is deviation from the ideal timing of an event at the mean amplitude of the signal population. Low frequency deviations are tracked by the clock recovery circuit, and do not directly affect the timing allocations within a bit interval. Jitter that is not tracked by the clock recovery circuit directly affects the timing allocations in a bit interval. Jitter is 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	sum of all jitter components.
	Jitter Generation	Jitter generation is the process whereby jitter appears at the output port in the absence of applied input jitter at the input port.
	Jitter Transfer	The ratio of 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.
Previous Terminology		To enable enhancements in jitter methodology, more descriptive terminology has been adopted. To enable the reader to understand the mapping of previous descriptions the following terms are included for clarity.
	Data Dependent Jitter	Now referred to as Correlated Bounded High Probability Jitter
	Deterministic Jitter	Now referred to as High Probability Jitter
	Random Jitter	Now referred to as Gaussian Jitter
Gaussian Jitter		An overall term that defines a jitter distribution that at the BER of interest e.g. 1e-15 still shows a Gaussian distribution. Unless otherwise specified Gaussian Jitter is the RMS sum of CBGJ and UUGJ.
	Jitter, Unbounded Gaussian	Jitter distribution that shows a true Gaussian distribution where the observed peak to peak value has an expected value that grows as a function of the measurement time. This form of jitter is assumed to arise from phase noise random processes typically found in VCO structures or clock sources. It is usually quantified as either the Root Mean Square (RMS) or Sigma of the Gaussian distribution, or as the expected peak value for a given measurement population. (Formally defined as T_RJ)
	Correlated Bounded Gaussian Jitter	Jitter distribution where the value of the jitter shows a correlation to the signal level being transmitted. The distribution is quantified, using a Gaussian approximation, as the gradient of the bathtub linearization at the Bit Error Rate of interest. R_RJ = R_GJ

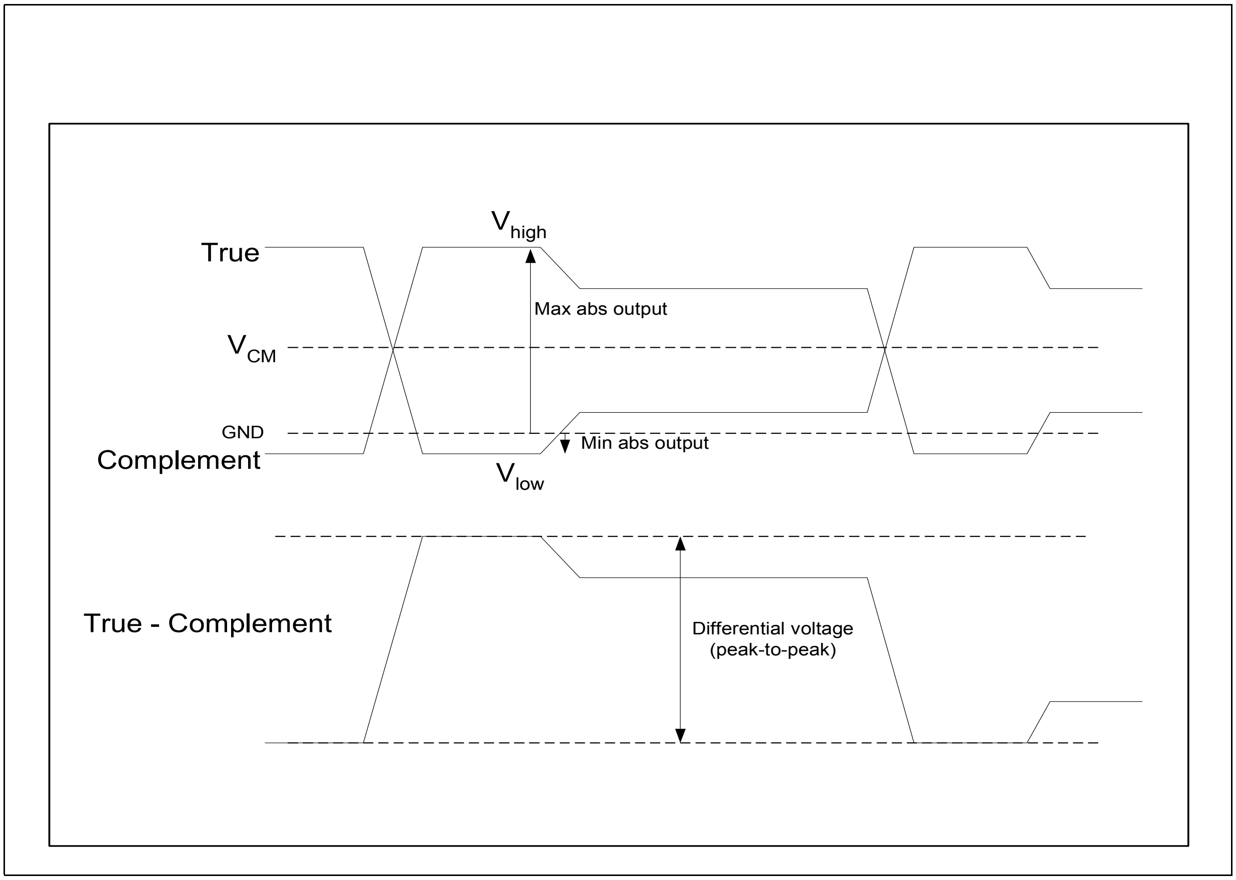
Table 1-3. Jitter and Wander Definitions (Sheet 2 of 2)

Parameter		Description
High probability Jitter		Jitter distribution that at the BER of interest is approximated by a dual dirac. Unless otherwise specified High Probability Jitter is the sum of UBHPJ, CBHPJ, PJ, SJ, DCD. The distribution is quantified, using a dual dirac approximation, as the offset of the bathtub linearization at the Bit Error Rate of interest.
	Uncorrelated Bounded High Probability Jitter.	Jitter distribution where the value of the jitter show no correlation to any signal level being transmitted. Formally defined as T_DJ.
	Correlated Bounded High Probability Jitter	Jitter distribution where the value of the jitter shows a strong correlation to the signal level being transmitted. This jitter may considered as being equalisable due to its correlation to the signal level.
	Periodic Jitter	A sub form of HPJ that defines a jitter which has a single fundamental harmonic plus possible multiple even and odd harmonics.
	Sinusoidal Jitter	A sub form of HPJ that defines a jitter which has a single frequency harmonic.
	Duty Cycle Distortion	The absolute value of the difference in the average width of a ’1’ symbol or a ’0’ symbol and the ideal periodic time in a clock-like repeating 0,1,0,1 sequence. Duty Cycle Distortion is part of the CBHPJ distribution and is measured at the time-averaged signal level.
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.
	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 (See Figure 1-2)
	Total wander	The sum of the correlated and uncorrelated wander. (See Figure 1-3)
	Uncorrelated wander	Components of wander that are not correlated across all applicable in band signals.
Unit		
	Peak-to-Peak Jitter	For any type of jitter, Peak to Peak Jitter is the full range of the jitter distribution that contributes within the specified BER.
	Jitter RMS	The root mean square value or standard deviation of jitter. See clause 2 for more information.
	Sigma	Refers to the standard deviation of a random variable modelled as a Gaussian Distribution. When used in reference to jitter, it refers to the standard deviation of the Gaussian Jitter component(s). When used in reference to confidence levels of a result refers to the probability that the result is correct given a Gaussian Mode, e.g. a measured result with 3 sigma confidence level would imply that 99.9% of the measurements are correct.

1.6.1 Definition of Amplitude and Swing

See Figure 1-1 for an illustration of absolute driver output voltage limits and definition of differential peak-to-peak amplitude.

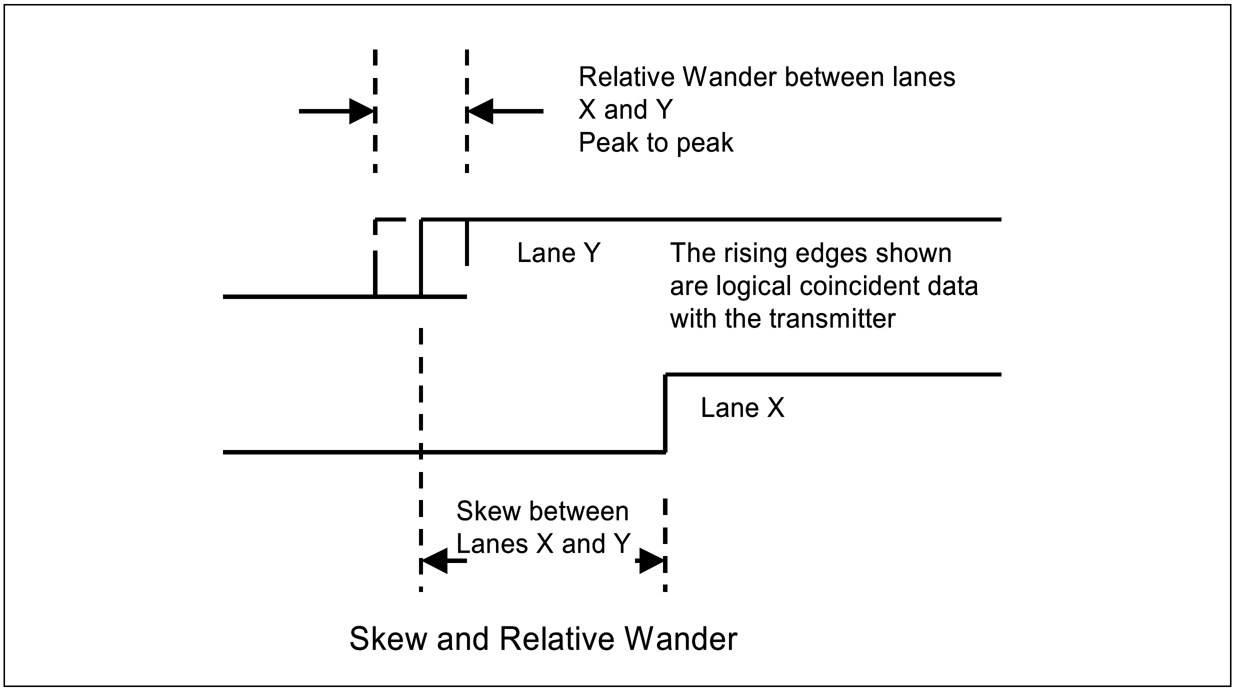
Figure 1-1.Definition of Driver Amplitude and Swing



1.6.2 Definition of Skew and Relative wander

See Figure 1-2 for an illustration of skew and relative wander.

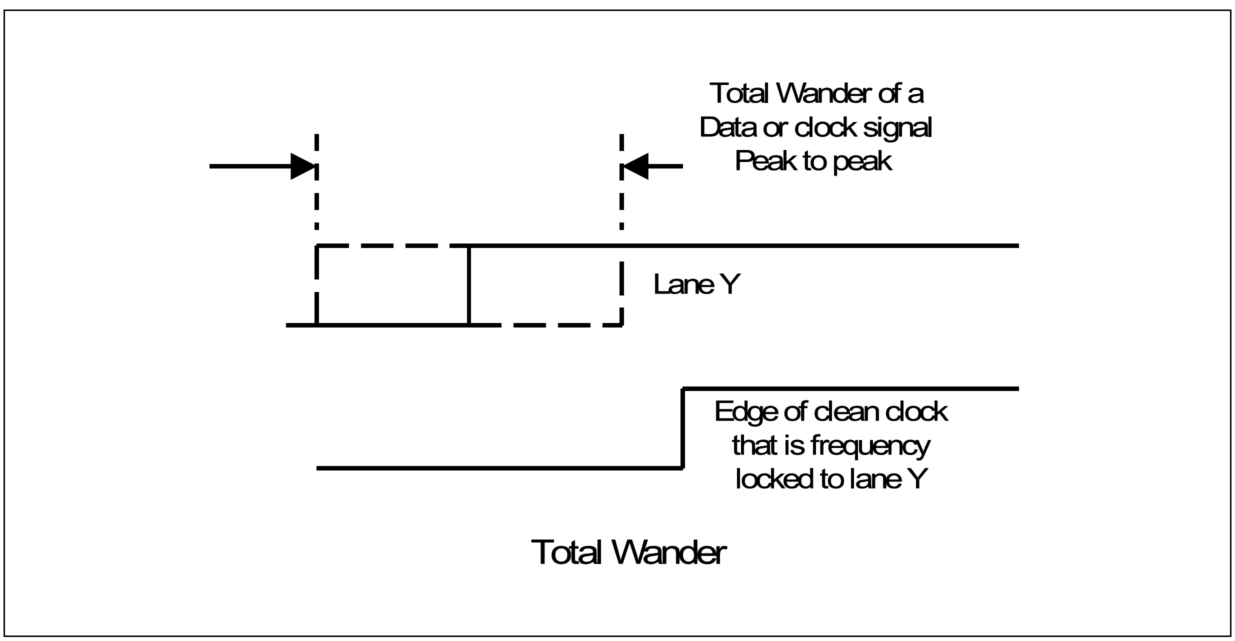
Figure 1-2.Skew and Relative Wander between in band Signals



1.6.3 Definition of Total wander

See Figure 1-3 for an illustration of total wander in a signal

Figure 1-3.Total Wander of a Signal



1.7 Table Entries and Specifications

The CEI IA shall use a common tabular definition of the parameters specified. The following section outlines examples of tables required for the definitions and the corresponding entries. All clauses must use this structure. Additional clause specific parameters are allowed.

1.7.1 Transmitter Electrical Output Specification

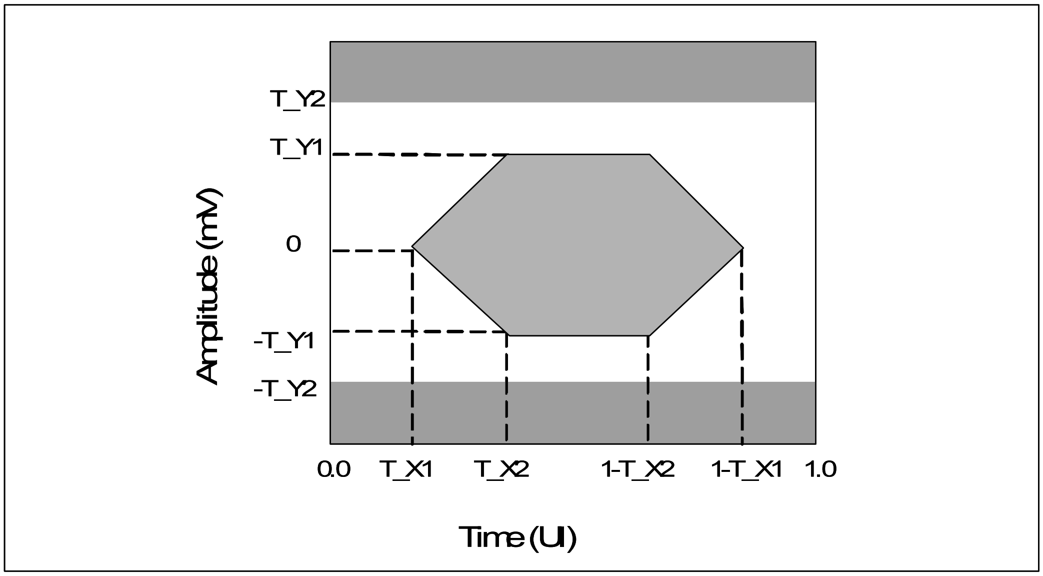
Table 1-4. Transmitter Electrical Output Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud					Gsym/s
Output Differential Voltage	T_Vdiff					mVppd
DC Common mode Voltage	T_Vcm					mV
Output AC Common Mode Voltage	T_VcmAC					mVrms
Differential Resistance	T_Rd					Ω
Differential Termination Resistance Mismatch	T_Rdm					%
Output Rise and Fall Time (20% to 80%)	T_tr, T_tf					ps
Differential Output Return Loss	T_SDD22					dB
Common Mode Output Return Loss	T_SCC22					dB
NOTES:						

Table 1-5. Transmitter Output Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Bounded High probability Jitter	T_UBHPJ					UIpp
Uncorrelated Unbounded Gaussian Jitter	T_UUGJ					UIpp
Duty cycle distortion	T_DCD					UIpp
Total Jitter	T_TJ					UIpp
Eye Mask	T_X1					UI
Eye Mask	T_X2					UI
Eye Mask	T_Y1					mV
Eye Mask	T_Y2					mV
NOTES: 1. Uncorrelated Unbounded Gaussian Jitter must be defined with respect to specified BER of 1e-15, Q=7.94						

Figure 1-4.Transmit Eye Mask



1.7.2 Receiver Electrical Input Specification

Table 1-6. Receiver Electrical Input Specification

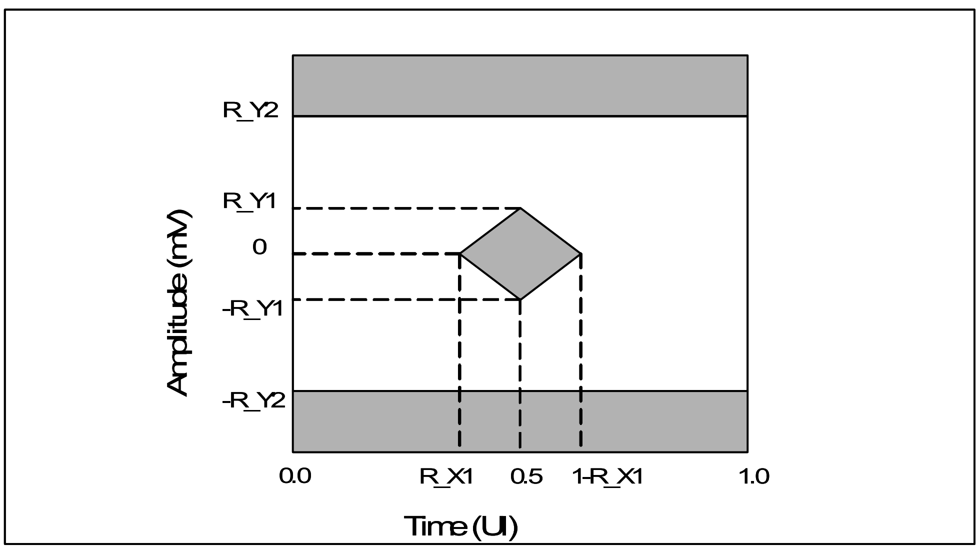
Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	R_Baud					Gsym/s
Input Differential Voltage	R_Vdiff					mVppd
DC Common mode voltage	R_Vrcm					mV
AC Common mode Voltage	R_VcmAC					mV
Differential Input Resistance	R_Rdin					Ω
Input Resistance Mismatch	R_Rm					%
Differential Input Return Loss	R_SDD11					dB
Common Mode Input Return Loss	R_SCC11					dB
Differential to Common Mode Input Conversion2	R_SCD11					dB
NOTES:						

1.7.3 Receiver input Jitter Specification

Table 1-7. Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Bounded High probability Jitter	R_UBHPJ					UIpp
Correlated Bounded High probability Jitter	R_CBHPJ					UIpp
Gaussian Jitter	R_GJ					UIpp
Sinusoidal Jitter	R_SJ					UIpp
Total Jitter	R_TJ					UIpp
Eye Mask	R_X1					UI
Eye Mask	R_Y1					mV
Eye Mask	R_Y2					mV
NOTES: 1. Gaussian Jitter must be defined with respect to specified BER of 1e-15, Q=7.94						

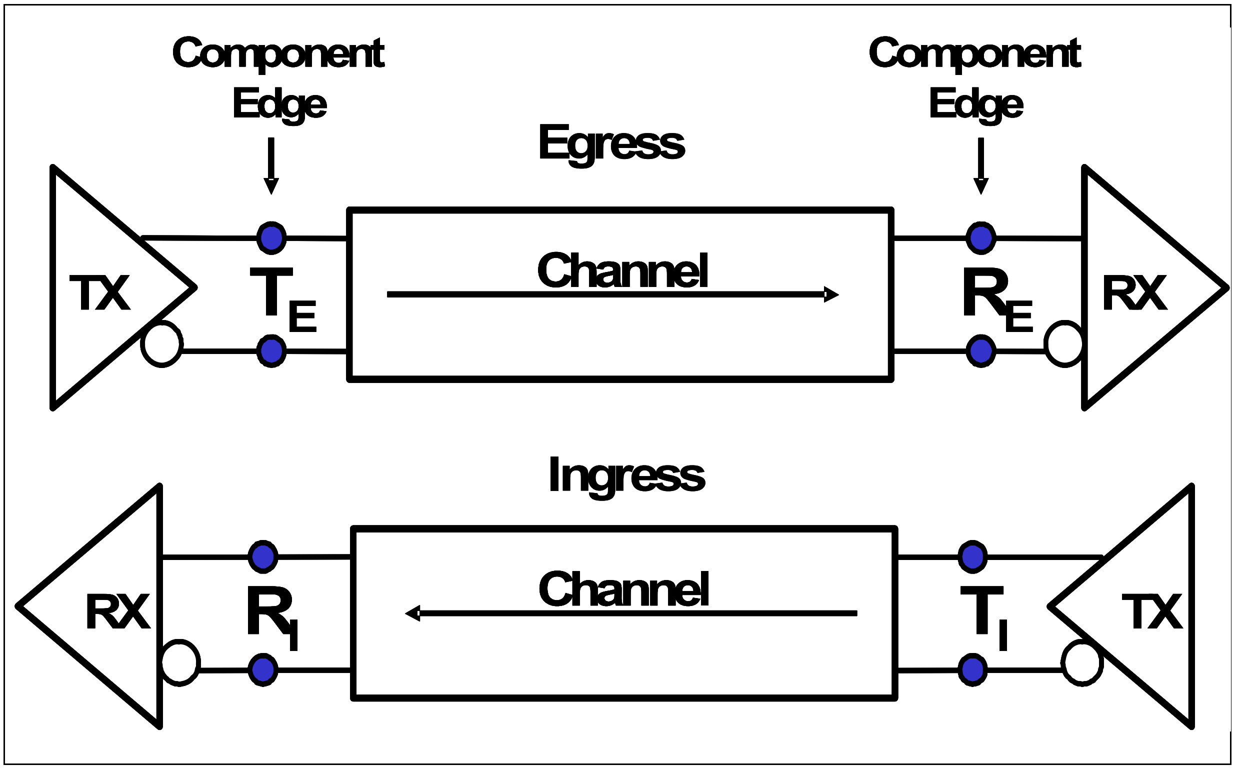
Figure 1-5.Receiver Input Mask



1.8 Reference Model

The CEI common reference model is defined in Figure 1-6. In cases where transmission direction matters the Ingress and Egress suffix is used, e.g. R_I for Receiver in the Ingress direction. In all other cases the R and T are used without a suffix. Note that the RX and TX blocks include all off-chip components associated with the respective function. Note also that a CEI Link does not imply a duplex connection, so the reference model shown in Figure 1-6 represents 2 CEI links.

Figure 1-6.Reference Model



1.A Appendix - Signal Definitions

Signals defined in this appendix are not referred to in this document, but relate to subsequent applications of CEI Links, e.g. SFI, SPI, TFI. Possible applications for CEI Links are described, but do not try to limit applications.

Whilst it is shown that CEI links can originate from a Serdes component, this is by no means essential. It is likely that CEI Links will be generated and received by TX and RX ports of an ASIC or FPGA component. In this case it will be necessary to have multiplexing and demultiplexing functions within the ASIC or FPGA. When a Serdes component is referred to, it can mean the Serializer/Deserializer is integrated within an ASIC or FPGA component, as well as being a separate component. In some applications, it will be necessary to also transmit control or status signals in parallel with the CEI Link. Some applications will also require clocks to be transmitted with the data.

The signal paths or CEI Lanes are unidirectional point-to-point connections. Each CEI Lane is made up of a balanced differential pair. A CEI Link can be comprised of a unidirectional single lane or parallel lanes in either the transmit or receive direction. A CEI Link does not imply duplex operation. See Figure 1-7 below for more information, which shows 2 CEI Links, in the receive and transmit directions..

Figure 1-7.Signal Diagram

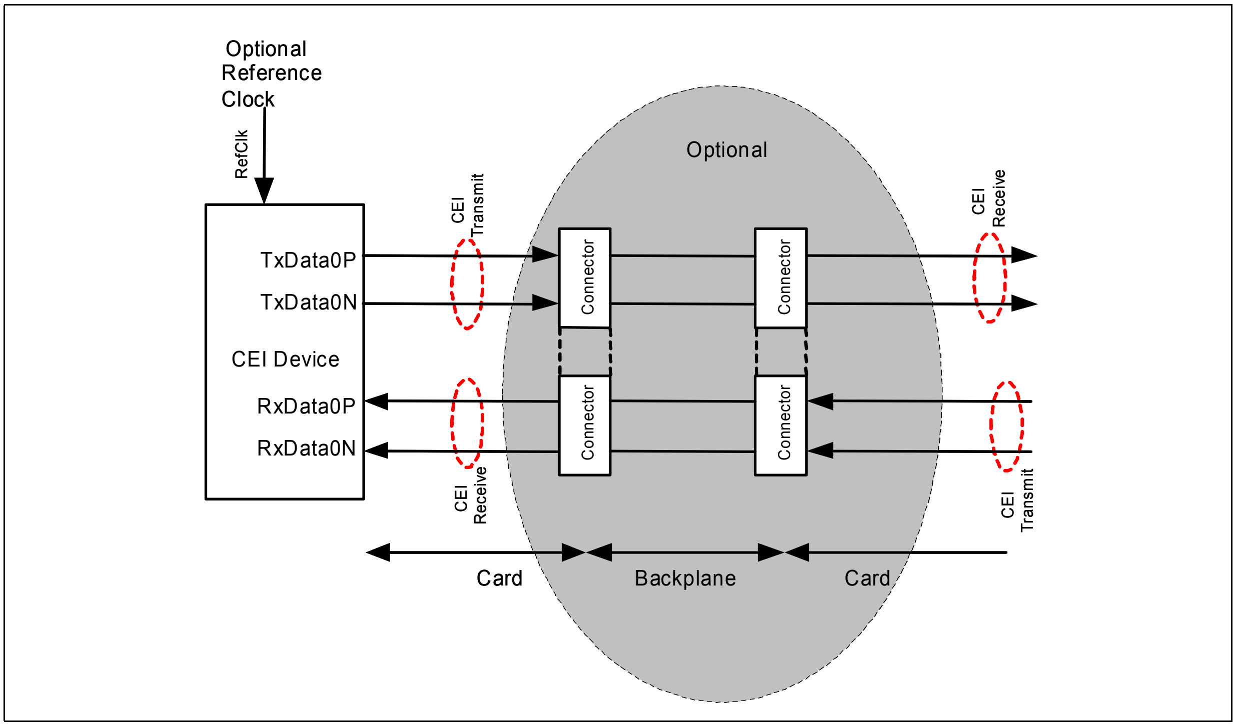


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Table 1-8. Receive Signal Summary

Signal Name	Direction	Function
RXDATA[n..0]P/N	Input to SERDES Component	The Receive Data (RXDATA[n]) signals are the inputs to the SERDES component.

Table 1-9. Transmit Signal Summary

Signal Name	Direction	Function
TXDATA[n..0]P/N	Output of SERDES Component	The Transmit Data (TXDATA[n]) signals are the outputs of the SERDES component.

An example specification for the reference clock for a typical application is proposed in Table 1-10 below.

Table 1-10. Example specification of reference clock

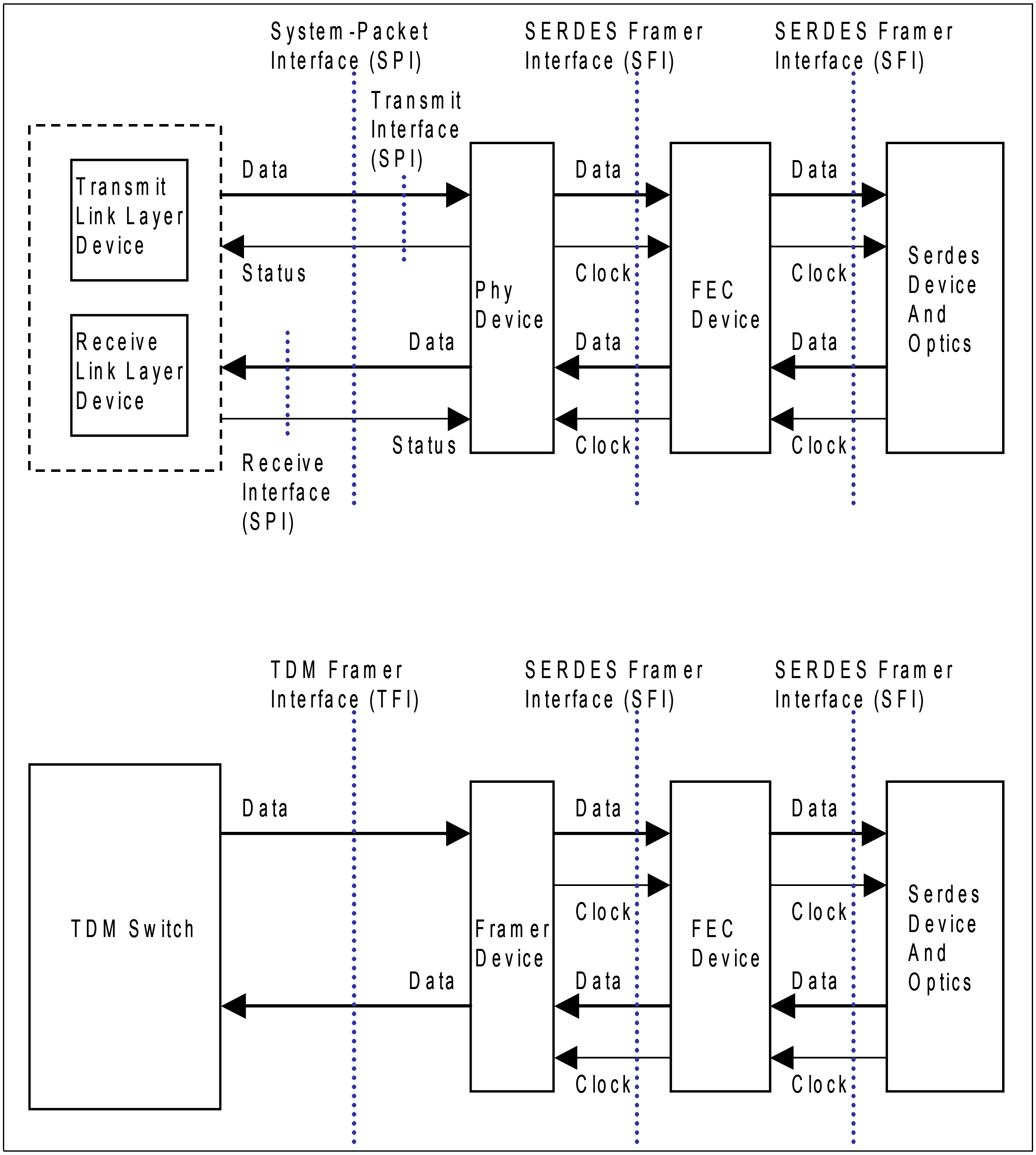
Characteristic	Description
Input Buffer	Internal Terminated LVDS
Frequency	Divide by 16 (e.g. 622MHz @9.95Gsym/s)
Rise/fall time (20/80%)	200ps
Duty cycle variation	<10%
Receiver Reference Clock frequency tolerance against data	+/-100ppm
Phase noise	-125dBc at 1MHz

It is expected that the reference clock input supports DC coupling, with AC coupling being optional (LVDS input having center tap or self biasing).

One reference clock input can support multiple Rx and Tx channels.

1.B Appendix - Examples of CEI links in Typical systems

Figure 1-8.Some typical systems



2 Jitter and Interoperability Methodology

This clause describes the requirements for interoperability testing of electrical interfaces as defined within this implementation agreement. The clause is organized into several methods of which the later Clauses will reference as the method for jitter or interoperability testing.

2.1 Method A

This sub-clause defines the interoperability methodology specifically for interfaces where neither transmit emphasis or receiver equalization are required for the receiver eye to be open to within the BER of interest.

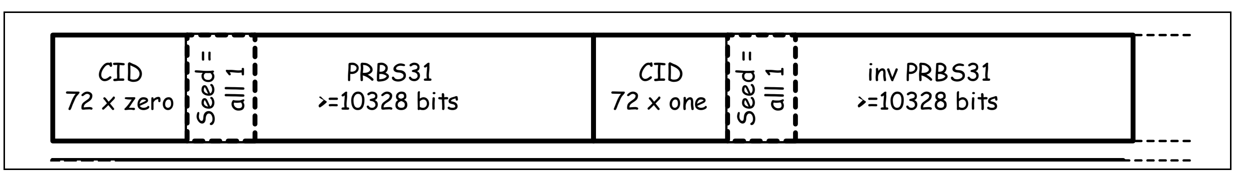
2.1.1 Defined Test Patterns[1]

The following patterns shall be used for the testing of jitter tolerance and output jitter compliance.

2.1.1.1 CID Jitter Tolerance Pattern

- The pattern is inverting to exercise possible weaknesses in rise and fall time symmetry
- 72 bits are defined for the Consecutive Identical Digits (CID) which aligns to [22.] recommendation
- The length of the PRBS31 is defined as greater than or equal to 10328
- The pattern is based on transition density comparisons between various PRBS patterns and a 3 sigma worst case analysis of a scrambled OC-768 frame.

Figure 2-1.CID Jitter Tolerance Pattern



2.1.1.2 Jitter Tolerance and General Test Patterns

- The pattern is a free running PRBS31 polynomial

2.1.2 Channel Compliance

The following steps shall be made to identify which channels are to be considered compliant.

1. All descriptions to PRBS31 imply the standard polynomial as described in [21.]

1. The forward channel and significant crosstalk channels shall be measured using a Network analyzer for the maximum baud rate that the channel is to operate at shall be used (see Appendix 2.E.6 for a suggested method)
2. An effective transmit filter as defined by the reference transmitter shall be used
3. An amplitude as defined by the reference transmitter shall be used
4. A transmitter jitter distribution (see Annex 2.C.4) as defined by the reference transmitter shall be used
5. A transmitter return loss as defined by the reference transmitter shall be used
6. A sampling point as defined by the reference receiver shall be used
7. A receiver return loss as defined by the reference receiver shall be used
8. The opening of the eye shall be calculated using Statistical Eye Analysis methods, as per Annex 2.C.5, and confirmed to be within the requirements at the required BER of the Implementation Agreement, usually,

   — Amplitude at the zero time offset sampling point

   — Time jitter measured at the zero amplitude sampling point

2.1.3 Transmitter Compliance

The following steps shall be made to identify which transmitters are to be considered compliant.

1. The high frequency transmit jitter shall be within that specified (see Appendix 2.E.1 for suggested methods)
2. The specified transmit eye mask shall not be violated (see Appendix 2.E.7 for a suggested method), after adjusting the horizontal time positions for the measured time with a confidence level of 3 sigma (see Appendix 2.F.3 for a suggested method of calculating Q given a measurement population)
3. The total wander shall be within that specified (see Appendix 2.E.2 for a suggested measurement method)
4. The relative wander shall be within that specified (see Appendix 2.E.3 for a suggested measurement method)

2.1.4 Receiver Compliance

The following step shall be made to identify which receivers are to be considered compliant.

1. The DUT shall be measured to have a BER[1] better than specified for a stressed signal (see Appendix 2.E.4.1 for a suggested method) with a confidence level of three sigma (see Appendix 2.F.2 for a suggested method), given:

1. if the defined measurement BER is different to system required BER, adjustments to applied stressed eye TJ are necessary

— The defined sinusoidal jitter mask for relative and total wander as per Annex 2.A.1 and Annex 2.A.2, with a high frequency total/relative wander of 0.1UI and a maximum total/relative wander as defined in the Implementation Agreement. Note that in some Implementation Agreements one needs to reduce the amount of High Probability Jitter by 0.1UI to account for this sinusoidal jitter.

2.2 Method B

This sub-clause defines the interoperability methodology specifically for interfaces where transmit emphasis may be used however receiver equalization is not required for the receiver eye to be open to within the BER of interest.

2.2.1 Defined Test Patterns[1]

The following pattern shall be used for the testing of jitter tolerance and output jitter compliance.

- A free running PRBS31 polynomial

2.2.2 Channel Compliance

The following steps shall be made to identify which channels are to be considered compliant.

1. The forward channel and significant crosstalk channels shall be measured using a Network analyzer for the maximum baud rate that the channel is to operate at shall be used (see Appendix 2.E.6 for a suggested method)
2. An n-tap emphasized transmitter as per Annex 2.B.3, where “n” is defined by the reference transmitter shall be used
3. An effective transmit filter as defined by the reference transmitter shall be used
4. An amplitude as defined by the reference transmitter shall be used
5. A transmitter jitter distribution (see Annex 2.C.4) as defined by the reference transmitter shall be used
6. A transmitter return loss as defined by the reference transmitter shall be used
7. A sampling point as defined by the reference receiver shall be used
8. A receiver return loss as defined by the reference receiver shall be used
9. The opening of the eye shall be calculated using Statistical Eye Analysis methods, as per Annex 2.C.5, and confirmed to be within the requirements at the required BER of the Implementation Agreement, usually:

   — Amplitude at the zero time offset sampling point

   — Time jitter measured at the zero amplitude sampling point

1. All descriptions to PRBS31 imply the standard polynomial as described in [21.]

2.2.3 Transmitter Compliance

The following step shall be made to identify which transmitters are to be considered compliant.

1. It shall be verified that the measured eye is equal or better than the calculated eye for the given measurement probability Q (see Appendix 2.F.3 for a suggested method of calculating Q given a measurement population), given:
   — A stress channel that is otherwise compliant as per 2.2.2, that requires at least half the maximum transmit emphasis as specified in the relevant clause or IA, with no receiver filtering or equalisation to produce an open eye.
   — Using this channel the transmitter shall be then optimally adjusted and the resulting eye measured (see Appendix 2.E.7 for a suggested method).
   — Using this channel the statistical eye shall then be calculated, as per Annex 2.C.5, using the maximum defined transmit jitter and the actual transmitter's amplitude and emphasis.

If the transmit jitter or transmit eye mask is additionally defined then the following steps shall also be made to identify which transmitters are to be considered compliant:

1. The high frequency transmit jitter shall be within that specified (see Appendix 2.E.1 for suggested methods)
2. The specified transmit eye mask shall not be not violated (see Appendix 2.E.7 for a suggested method), after adjusting the horizontal time positions for the measured time with a confidence level of 3 sigma (see Appendix 2.F.3 for a suggested method)

2.2.4 Receiver Compliance

The following step shall be made to identify which receivers are to be considered compliant.

1. The DUT shall be measured to have a BER[1] better than specified for a stressed signal (see Appendix 2.E.4.2 for a suggested method) with a confidence level of three sigma (see Appendix 2.F.2 for a suggested method), given:
   — The defined sinusoidal jitter mask for total and relative wander as per Annex 2.A.1 and Annex 2.A.2, with a high frequency total/relative wander and a maximum total/relative wander as defined in the Implementation Agreement
   — The specified amount of High Probability Jitter and Gaussian jitter.

1. if the defined measurement BER is different to system required BER, adjustments to applied stressed eye TJ are necessary

2.3 Method C

This sub-clause defines the interoperability methodology specifically for interfaces where transmit emphasis may be used and the receiver eye requires Linear Continuous Time equalization (from channel interoperability point of view) to be open to within the BER of interest.

2.3.1 Defined Test Patterns[1]

The following pattern shall be used for the testing of jitter tolerance and output jitter compliance.

- A free running PRBS31 polynomial

2.3.2 Channel Compliance

The following steps shall be made to identify which channels are to be considered compliant.

1. The forward channel and significant crosstalk channels shall be measured using a Network analyzer for the maximum baud rate that the channel is to operate at shall be used (see Appendix 2.E.6 for a suggested method)
2. An n-tap emphasized transmitter as per Annex 2.B.3, where “n” is defined by the reference transmitter shall be used
3. An effective transmit filter as defined by the reference transmitter shall be used
4. An amplitude as defined by the reference transmitter shall be used
5. A transmitter jitter distribution (see Annex 2.C.4) as defined by the reference transmitter shall be used
6. A transmitter return loss as defined by the reference transmitter shall be used
7. An ideal receiver filter of the form in Annex 2.B.7, using the restrictions as defined by the reference receiver shall be used
8. A sampling point as defined by the reference receiver shall be used
9. A receiver return loss as defined by the reference receiver shall be used
10. The opening of the eye shall be calculated using Statistical Eye Analysis methods, as per Annex 2.C.5, and confirmed to be within the requirements at the required BER of the Implementation Agreement, usually:
    - — Amplitude at the zero time offset sampling point
    - — Time jitter measured at the zero amplitude sampling point

1. All descriptions to PRBS31 imply the standard polynomial as described in [21.]

2.3.3 Transmitter Compliance

The following step shall be made to identify which transmitters are to be considered compliant.

1. It shall be verified that the measured eye is equal or better than the calculated eye for the given measurement probability Q (see Appendix 2.F.3 for a suggested method of calculating Q given a measurement population), given:
   - A stress channel that is otherwise compliant as per 2.3.2, that requires at least half the maximum transmit emphasis as specified in the relevant clause or IA, with no receiver filtering or equalisation to produce an open eye.
   - Using this channel the transmitter shall be then optimally adjusted and the resulting eye measured (see Appendix 2.E.7 for a suggested method).
   - Using this channel the statistical eye shall then be calculated, as per Annex 2.C.5, using the maximum defined transmit jitter and the actual transmitter's amplitude and emphasis.

If the transmit jitter or transmit eye mask is additionally defined then the following steps shall also be made to identify which transmitters are to be considered compliant:

1. The high frequency transmit jitter shall be within that specified (see Appendix 2.E.1 for suggested methods)
2. The specified transmit eye mask shall not be violated (see Appendix 2.E.7 for a suggested method), after adjusting the horizontal time positions for the measured time with a confidence level of 3 sigma (see Appendix 2.F.3 for a suggested method)

2.3.4 Receiver Compliance

The following step shall be made to identify which receivers are to be considered compliant.

1. The DUT shall be measured to have a BER[1] better than specified for a stressed signal (see Appendix 2.E.4.3 for a suggested method) with a confidence level of three sigma (see Appendix 2.F.2 for a suggested method), given:
   - The defined sinusoidal jitter mask for total and relative wander as per Annex 2.A.1 and Annex 2.A.2, with a high frequency total/relative wander and a maximum total/relative wander as defined in the Implementation Agreement
   - The specified amount of High Probability Jitter and Gaussian jitter.
   - A stress channel or filter as identified by the methods of 2.3.2. If the optional transmit filter of Appendix 2.E.4.3 is not included then no transmit emphasis shall be enabled in the reference transmitter. If the transmitter filter of Appendix 2.E.4.3 is present then the standard reference transmitter (as used in channel compliance) shall be used. The transmit filter characteristics (e.g. emphasis

1. if the defined measurement BER is different to system required BER, adjustments to applied stressed eye TJ are necessary

settings) shall be set in accordance with the optimised values resulting when the methods of 2.3.2 are applied.

— An additive crosstalk signal of amplitude such that the resulting statistical eye, given the channel, jitter and crosstalk, is as close as feasible in amplitude when compared to the defined minimum amplitude for channel compliance.

2.4 Method D

This sub-clause defines the interoperability methodology specifically for interfaces where transmit emphasis may be used and the receiver eye requires DFE equalization (from channel interoperability point of view) to be open to within the BER of interest.

2.4.1 Defined Test Patterns[1]

The following pattern shall be used for the testing of jitter tolerance and output jitter compliance.

- A free running PRBS31 polynomial

2.4.2 Channel Compliance

The following steps shall be made to identify which channels are to be considered compliant.

1. The forward channel and significant crosstalk channels shall be measured using a Network analyzer for the maximum baud rate that the channel is to operate at shall be used (see Appendix 2.E.6 for a suggested method)
2. An n-tap emphasized transmitter as per Annex 2.B.3, where “n” is defined by the reference transmitter shall be used
3. An effective transmit filter as defined by the reference transmitter shall be used
4. An amplitude as defined by the reference transmitter shall be used
5. A transmitter jitter distribution (see Annex 2.C.4) as defined by the reference transmitter shall be used
6. A transmitter return loss as defined by the reference transmitter shall be used
7. An ideal receiver filter of the form in Annex 2.B.6, using the restrictions as defined by the reference receiver shall be used
8. Any parameters that have degrees of freedom e.g. filter coefficients or sampling point, shall be optimised against the amplitude, at the zero phase offset, as generated by the Statistical Eye Output. e.g. by sweeping all degrees of freedom and selecting the parameters giving the maximum amplitude. A receiver return loss, as defined by the reference receiver, shall be used

1. All descriptions to PRBS31 imply the standard polynomial as described in [21.]

9. The opening of the eye shall be calculated using Statistical Eye Analysis methods, as per Annex 2.C.5, and confirmed to be within the requirements at the required BER of the Implementation Agreement, usually:
   — Amplitude at the zero time offset sampling point
   — Time jitter measured at the zero amplitude sampling point

2.4.3 Transmitter Compliance

The following step shall be made to identify which transmitters are to be considered compliant.

1. It shall be verified that the measured eye is equal or better than the calculated eye for the given measurement probability Q (see Appendix 2.F.3 for a suggested method of calculating Q given a measurement population), given:
   — A stress channel that is otherwise compliant as per 2.4.2, that requires at least half the maximum transmit emphasis as specified in the relevant clause or IA, with no receiver filtering or equalisation to produce an open eye.
   — Using this channel the transmitter shall be then optimally adjusted and the resulting eye measured (see Appendix 2.E.7 for a suggested method).
   — Using this channel the statistical eye shall then be calculated, as per Annex 2.C.5, using the maximum defined transmit jitter and the actual transmitter's amplitude and emphasis.

If the transmit jitter or transmit eye mask is additionally defined then the following steps shall also be made to identify which transmitters are to be considered compliant:

1. The high frequency transmit jitter shall be within that specified (see Appendix 2.E.1 for suggested methods)
2. The specified transmit eye mask shall not be violated (see Appendix 2.E.7 for a suggested method), after adjusting the horizontal time positions for the measured time with a confidence level of 3 sigma (see Appendix 2.F.3 for a suggested method)

2.4.4 Receiver Compliance

The following step shall be made to identify which receivers are to be considered compliant.

1. The DUT shall be measured to have a BER[1] better than specified for a stressed signal (see Appendix 2.E.4.3 for a suggested method) with a confidence level of three sigma (see Appendix 2.F.2 for a suggested method), given:
   — The defined sinusoidal jitter mask for total and relative wander as per Annex 2.A.1 and Annex 2.A.2, with a high frequency total/relative wander and a maximum total/relative wander as defined in the Implementation Agreement

1. if the defined measurement BER is different to system required BER, adjustments to applied stressed eye TJ are necessary

— The specified amount of High Probability Jitter and Gaussian jitter.

— A stress channel or filter as identified by the methods of 2.4.2. If the optional transmit filter of Appendix 2.E.4.3 is not included then no transmitter emphasis shall be enabled in the reference transmitter. If the transmitter filter of Appendix 2.E.4.3 is present then the standard reference transmitter (as used in channel compliance) shall be used. The transmit filter characteristics (e.g. emphasis settings) shall be set in accordance with the optimised values resulting when the methods of 2.4.2 are applied.

— An additive crosstalk signal of amplitude such that the resulting statistical eye, given the channel, jitter and crosstalk, is as close as feasible in amplitude when compared to the defined minimum amplitude for channel compliance

2.5 Method E

The following sub-clause defines the Interoperability methodology for interfaces where a simple receiver equalization may be used to improve the margin of the link and transparent applications may be used and the receiver eye is still open to within the BER of interest.

2.5.1 Defined Test Patterns

The following pattern shall be used for the testing jitter tolerance and output jitter compliance

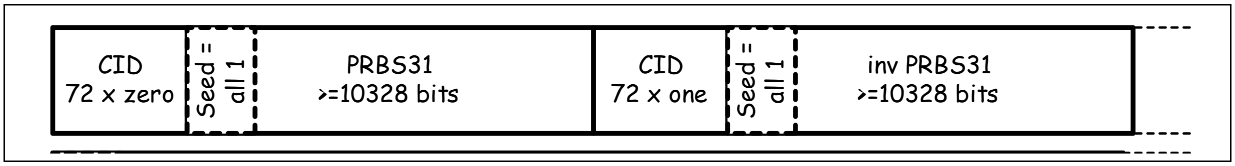
- A free running PRBS31 polynomial

when used in transparent applications the additional test pattern defined in 2.5.1.1 must be additionally tested.

2.5.1.1 CID Jitter Tolerance Pattern

- The pattern is inverting to exercise possible weaknesses in rise and fall time symmetry
- 72 bits are defined for the Consecutive Identical Digits (CID) which aligns to [22.] recommendation
- The length of the PRBS31 is defined as greater than or equal to 10328
- The pattern is based on transition density comparisons between various PRBS patterns and a 3 sigma worst case analysis of a scrambled OC-768 frame.

Figure 2-2.CID Jitter Tolerance Pattern



2.5.2 Channel Compliance

The following steps shall be made to identify which channels are to be considered compliant.

1. The forward channel and significant crosstalk channels shall be measured using a Network analyzer for the maximum baud rate that the channel is to operate at shall be used (see Appendix 2.E.6 for a suggested method)
2. An effective transmit filter as defined by the reference transmitter shall be used
3. An amplitude as defined by the reference transmitter shall be used
4. A transmitter jitter distribution (see Annex 2.C.4) as defined by the reference transmitter shall be used
5. A transmitter return loss as defined by the reference transmitter shall be used
6. All defined reference receivers
7. A sampling point as defined by the reference receiver shall be used
8. A receiver return loss as defined by the reference receiver shall be used
9. The opening of the eye shall be calculated using Statistical Eye Analysis methods, as per Annex 2.C.5, and confirmed to be within the requirements at the required BER of the Implementation Agreement for both receiver types, usually:

   — Amplitude at the zero time offset sampling point

   — Time jitter measured at the zero amplitude sampling point
10. Any parameters that have degrees of freedom e.g. filter coefficients, shall be optimised against the amplitude, at the zero phase offset, as generated by the Statistical Eye Output. e.g. by sweeping all degrees of freedom and selecting the parameters giving the maximum amplitude.

2.5.3 Transmitter Compliance

The following steps shall be made to identify whether a transmitter is considered compliant.

1. the high frequency transmit jitter shall be within that specified (see Appendix 2.E.1 for suggested methods)

- for jitter transparent applications the bandwidth of any defined Golden PLL should be adjusted according to the specific Implementation Agreement e.g. 8MHz for ITU

2. Specifically for “transparent ITU application egress transmitters” the transmit peak to peak jitter and optionally rms jitter with the defined bandwidth shall be less than that specified (see Appendix 2.E.1.2 for suggested methods)
3. Specifically for “transparent ingress transmitters” the defined jitter transfer mask shall be less than that specified (see Appendix 2.E.5 for suggested methods)

- an applied sinusoidal jitter conforming to the defined jitter tolerance mask for this line interface

4. the specified transmit eye mask is not violated (see Appendix 2.E.7 for a suggested method), after adjusting the horizontal time positions for the measured time and a confidence level of 3 sigma (see Appendix 2.F.3 for a suggested method of calculating Q given a measurement population)
5. the total wander is less than that specified (see Appendix 2.E.2 for a suggested method)

2.5.4 Receiver Compliance

The following steps shall be made to identify whether a receiver is considered compliant.

1. The DUT shall be measured to have a BER[1] better than specified for a stressed signal (see Appendix 2.E.4.2 for a suggested method) with a confidence level of three sigma (see Appendix 2.F.2. for a suggested method) given

- for non-transparent applications, the defined sinusoidal jitter mask for relative and total wander as per Annex 2.A.1 and Annex 2.A.2, with a high frequency total/relative wander and a maximum total/relative wander as defined in the Implementation Agreement
- for transparent application, the defined appropriate sinusoidal jitter mask for the specific optical standard
- the high frequency jitter should be calibrated by either
  - — applying the maximum specified amount of receiver High Probability Jitter and Gaussian jitter[2] including CBHPJ

or

  - — applying the maximum specified amount of receiver High Probability Jitter and Gaussian jitter[3] excluding CBHPJ
  - — cascading with a compliance channel or filter as identified by 2.5.2.
  - — applying an additive crosstalk signal of amplitude such that the resulting statistical eye, given the channel, jitter and crosstalk, is as close as feasible in amplitude when compared to the defined minimum amplitude for channel compliance

1. if the defined measurement BER is different to system required BER, adjustments to applied stressed eye TJ are necessary
2. for jitter “transparent application ingress receivers” the bandwidth of any defined Golden PLL for the calibration of the HPJ and GJ should be adjusted according to the specification Implementation Agreement e.g. 8MHz for ITU
3. for jitter “transparent application ingress receivers” the bandwidth of any defined Golden PLL for the calibration of the HPJ and GJ should be adjusted according to the specification Implementation Agreement e.g. 8MHz for ITU

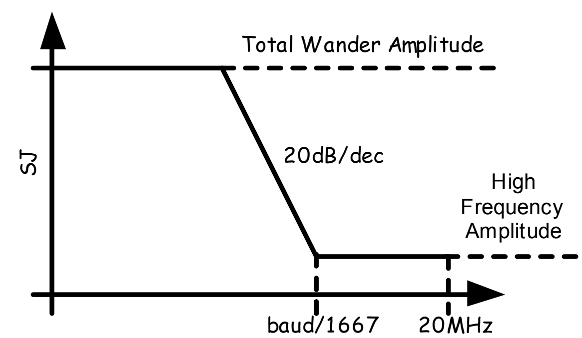
2.A Annex - Masks

2.A.1 Annex - Total Wander Mask

Total wander specifications should be considered as accumulated low frequency jitter. As modern CDRs are digitally based they show a corner tracking frequency plus slew limitation which has been guaranteed, therefore for jitter tolerance testing the total wander needs to be spectrally defined to ensure correct operation.

To this end, for jitter tolerance testing, the wander is considered a sinusoidal jitter source as shown below.

Figure 2-3.Total Wander Mask

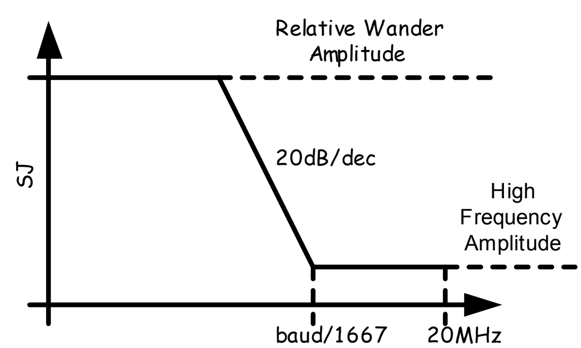


At higher frequency this jitter source is used to ensure margin in the high frequency jitter tolerance of the receiver. At lower frequencies the higher SJ should then be tracked by the CDR.

2.A.2 Annex - Relative Wander Mask

Specifically for interfaces defining relative wander, Figure 2-4 is also defined in terms of a sinusoidal jitter source as shown below.

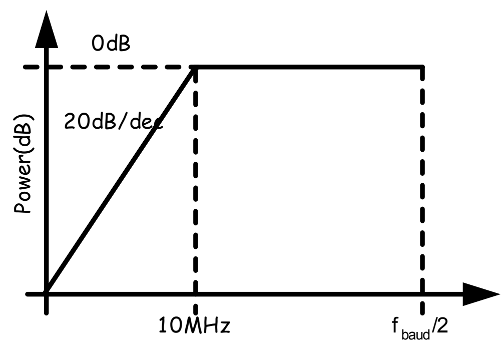
Figure 2-4.Relative Wander Mask



2.A.3 Annex - Random Jitter Mask

To ensure that the random jitter modulation of stressed signals is above the CDR bandwidth and therefore untracked, the following filter mask shall be applied where necessary.

Figure 2-5.Random Jitter Spectrum



2.B Annex - Pulse Response Channel Modelling

This annex shall describe the theoretical background for channel modelling

2.B.1 Annex - Generating a Pulse Response

Given the spectral transfer function as per Chapter 2.E.6 the pulse response of the channel can be calculated using tools such as Matlab.

The Pulse Response of the channel is the received pulse for an ideal square wave and is calculated by either

- convolving the pulse with the impulse response of the channel or
- multiplying the Fourier spectrum of the ideal transmitted square wave with the channel response and taking the inverse Fourier transform,

$$t_{step} = \frac{1}{f_{max}}$$

$$t = t_{step} \cdot n$$

$$n = [1, P]$$

$$tx(t) = H(0) \cdot H(t_{period} - t)$$

$$rx(\omega) = tx(\omega) \cdot Tr(\omega)$$

$$rx(t) = ifft(rx(\omega))$$

where

f_{max} is difference between the maximum positive and minimum negative frequency

P is the number of equally space points in the frequency array

$tx(t)$ is the transmit signal pulse

$tx(\omega)$ is the transmit signal pulse in the frequency domain

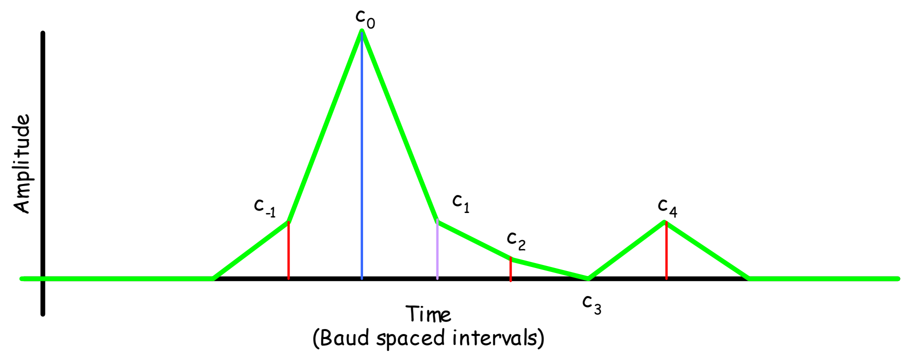
$Tr(\omega)$ is the transfer function of the channel

$rx(t)$ is the resulting pulse response of the channel

2.B.2 Annex - Basic Pulse Response Definitions

A receive pulse response as calculated above can be graphically represented, Figure 2-6.

Figure 2-6.Graphical Representation of Receiver Pulse



Cursors are defined as being the amplitude of the received pulse at symbol spaces from the maximum signal energy at c_0, and extend to infinity in both negative and positive time. The exact position of c_0 is arbitrary and is defined specifically by the various methodologies.

A precursor is defined as a cursor that occurs before the occurrence of the main signal c_0, i.e. c_n where n<0, usually convergences to zero within a small number of bits

A post cursor is defined as a cursor that occurs after the occurrence of the main signal c_0, i.e. c_n where n>0, and usually convergences to zero within twice the propagation time of the channel.

Given a deterministic data stream travelling across the channel, the superposition of the channel pulses give rise to Inter-Symbol Interference (ISI). This ISI has a maximum occurring for a worst case pattern, which for a channel response where all cursors are positive would be a single *1* or *0* in the middle of a long run of *0*s or *1*s respectively. This maximum is referred to Total Distortion

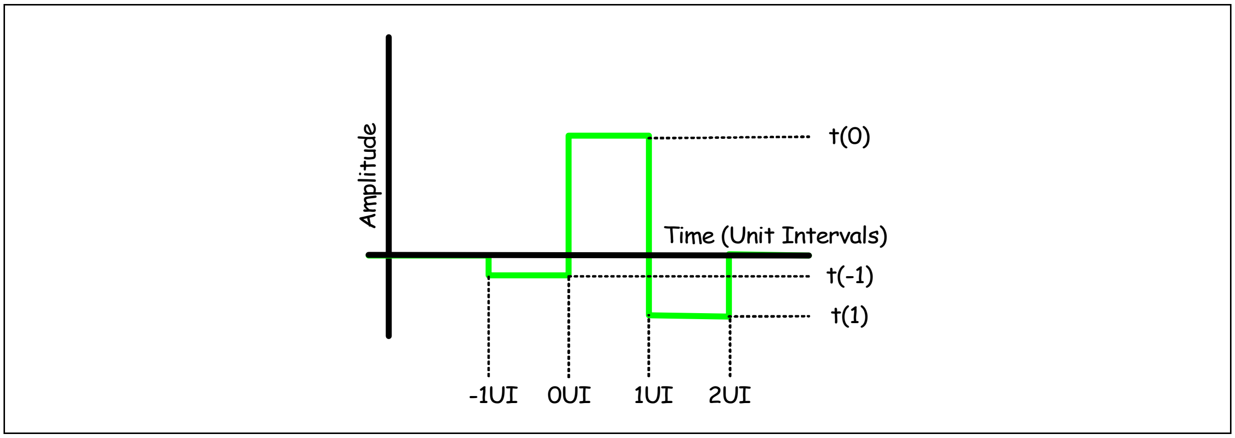
$$\Theta = \sum_{(n = -\infty), (n \neq 0)}^{n = \infty} |c_n|$$

Due to ISI an enclosure in the time domain also occurs which can be determined by either running exhaustive simulations or simulations with determined worst case patterns. For the case where the ISI is so large that the eye is closed, Inherent Channel Jitter has no meaning.

2.B.3 Annex - Transmitter Pulse Definition

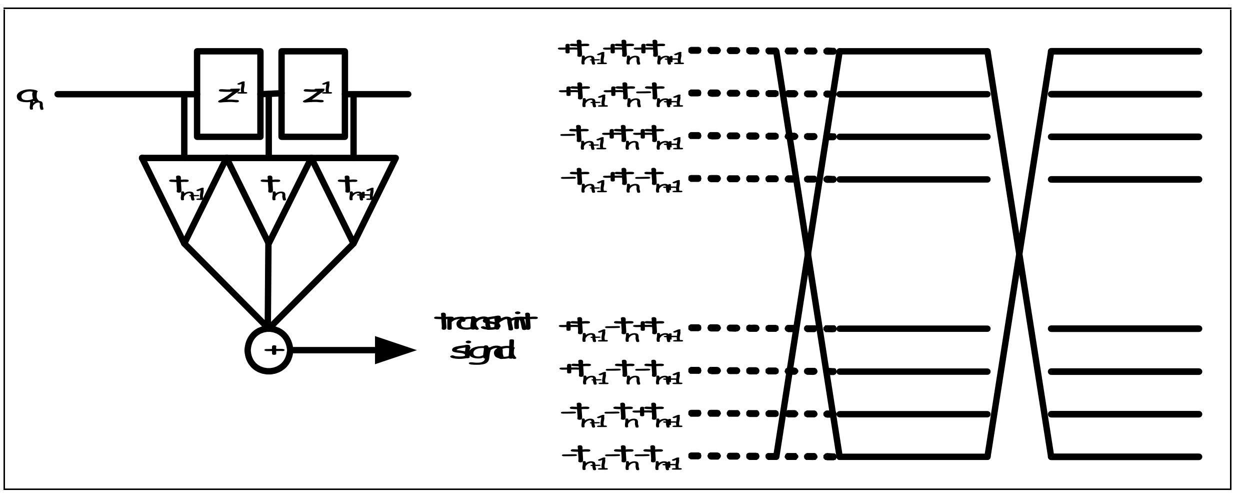
A transmitter is defined by its ability to generate a transmit pulse. A single *1* transmit symbol has different amplitudes at symbol space intervals, t_n, where post taps have n>0, and pre-taps have n<0.

Figure 2-7.Transmit Pulse



When a pulse train is transmitted the exact transmitted amplitude is therefore the superposition of the pulses from the previous and *to be* transmitted pulses, so as in a FIR filter.

Figure 2-8.Transmitter FIR Filter Function



This superposition can be understood by referring to the amplitudes depicted for various bit sequences in Figure 2-8.

The transmit emphasis can be defined to have certain limits of maximum transmit amplitude or ratios of emphasis as defined below

$$P_{post} = \frac{t_1}{t_0}$$

$$E = 20\log\frac{1 + P_{post}}{1 - P_{post}}$$

$$\sum |t_n| < T\_\text{Vdiff}$$

where

P_{post} is the first coefficient of the transmit FIR

E is the emphasis of the transmit emphasis

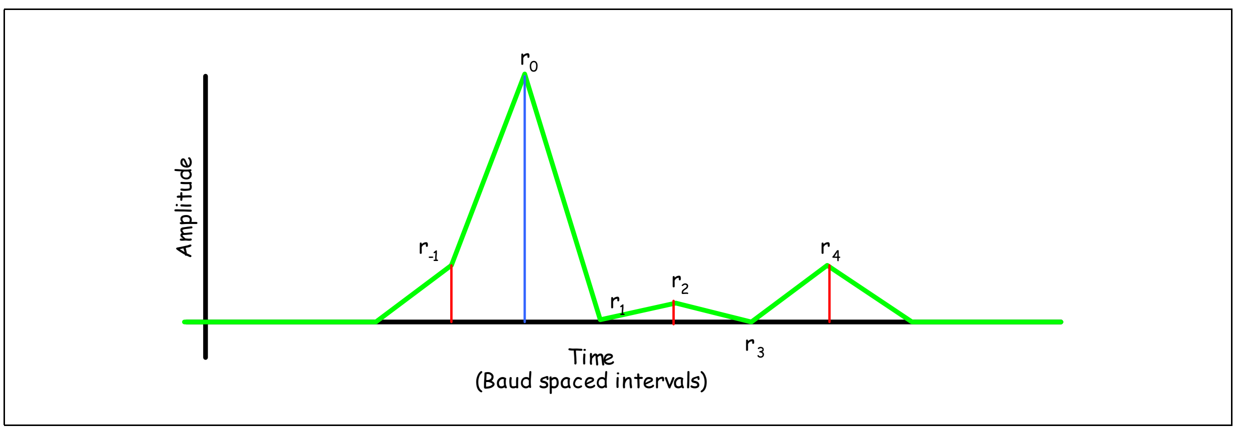
T_Vdiff is the maximum transmit amplitude

2.B.4 Annex - Receiver Pulse Response

Given an emphasized transmitter the pulse response of the receiver should be recalculated using the emphasized transmit pulse as opposed to a simple NRZ pulse.

the receiver pulse cursors are then defined as follows

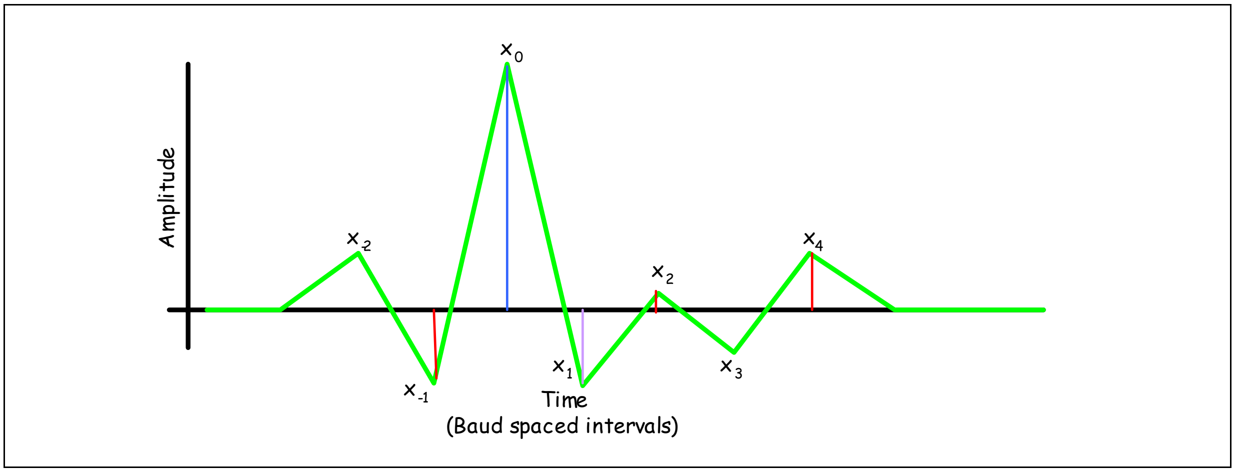
Figure 2-9.Receiver Pulse Definition



2.B.5 Annex - Crosstalk Pulse Response

The crosstalk pulse response is analogous to the receiver pulse response as defined in Annex 2.B.4 but using the crosstalk channel, i.e. NEXT or FEXT network analysis measurement.. The transmit signal as seen in the system should be used for the

Figure 2-10.Crosstalk Pulse Definition



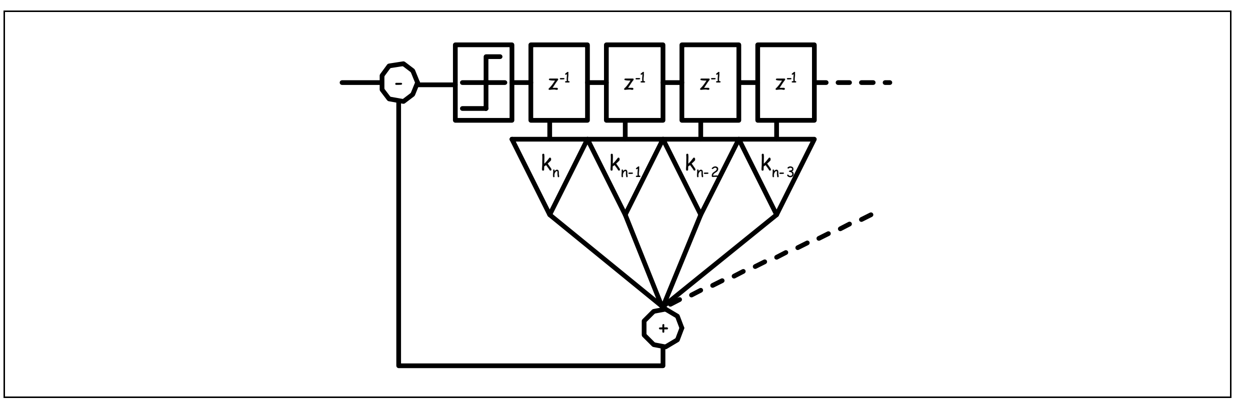
calculation of the resulting crosstalk pulse response, e.g.an emphasized transmitter from above, or XAUI transmit NRZ pulse.

The Crosstalk pulse response is then defined as above, as being a set of cursors x_n usually oscillatory in form. The position of x_0 is defined as being at the maximum amplitude of the pulse response.

2.B.6 Annex - Decision Feedback Equalizer

The following filter function can be used to verify the capability of the channel to be used in such an application.

Figure 2-11.Decision Feedback Equalizer



The value of the coefficients are calculated directly from the channel pulse response or the receiver pulse using an emphasized transmitter.

$k_n = c_n\Big|_{n=[1,m]}$ for unemphasized transmitters, or

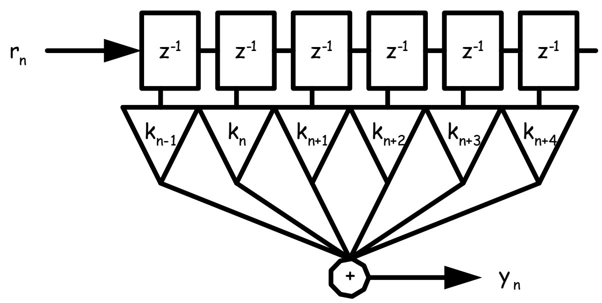
$k_n = r_n\Big|_{n=[1,m]}$ for emphasized transmitters

This equalizer is capable of equalizing a finite number of post cursors, whose individual values may be limited.

2.B.7 Annex - Time Continuous Transverse Filter

A.k.a. Feed forward Filter, Finite Input Response or Comb Structure, the Transverse Filter, Figure 2-12 consists of a finite number of coefficients, k. The sum of the continuous value of symbol spaced delayed samples multiplied by these coefficients then gives the resulting signal.

Figure 2-12.Feed Forward Filter



2.B.7.1 Annex - Time Continuous Zero-Pole Equalizer adaption

The pole-zero algorithm takes the SDD21 magnitude response for the through channel and inverts it to produce a desired CTE filter response curve. From a set of initial conditions for 3 poles and 3 zeros, the squared differences are minimized between the CTE response and the inverse channel response curve. The minimization is done using a simplex method, specifically the Nelder-Mead Multidimensional Unconstrained Non-Linear Minimization Method. The Nelder-Mead method provides a local minimization of the square of the difference between the two curves by descending along the gradient of the difference function. Once the optimization result is obtained, it is compared to a specified threshold. If the threshold exceeds the target tolerance, an incrementally offset seed point is generated from a 6-dimensional grid of seed points, and the process is iterated until the correct curve is obtained within the target tolerance.

2.B.8 Annex - Time Continuous Zero/Pole

The Zero/Pole Filter is defined, in the frequency domain by

$$H(f) = \frac{p}{z} \cdot \frac{(z + j2\pi f)}{(p + j2\pi f)}$$

and consists of a single zero, z, and single pole, p.

2.B.9 Annex - Degrees of Freedom

2.B.9.1 Annex - Receiver Sample Point

A receiver shall be allowed to either position the centre sampling point fully independently to the signal transitions or exactly in between the mean crossover of the receiver signal.

2.B.9.2 Annex - Transmit Emphasis

Transmit emphasis and receiver filter coefficients must be optimised with the defined resolution to give the best achievable results. Unless otherwise stated it shall be assumed that the coefficients are defined using floating point variables.

2.C Annex - Jitter Modelling

This annex describes the theoretical background of the methodology used for jitter budgeting and jitter measurement. To avoid fundamental issues with the addition of jitter using the dual dirac model through a bandlimited channel, a fundamental methodology call “stateye” is defined in Annex 2.C.5, which uses only convolution of the jitter distribution for the calculation of the jitter at the receiver.

2.C.1 Annex - High Frequency Jitter vs. Wander

Jitter is defined as the deviation of the signal transition from an origin, usually its mean. This deviation has an amplitude and an associated spectrum. High frequency jitter is defined by a 1st order high pass phase filter with a corner frequency equal to the ideal CDR bandwidth. The low frequency Jitter or Wander is defined by a 1st order low pass phase filter with a corner frequency equal to the bandwidth.

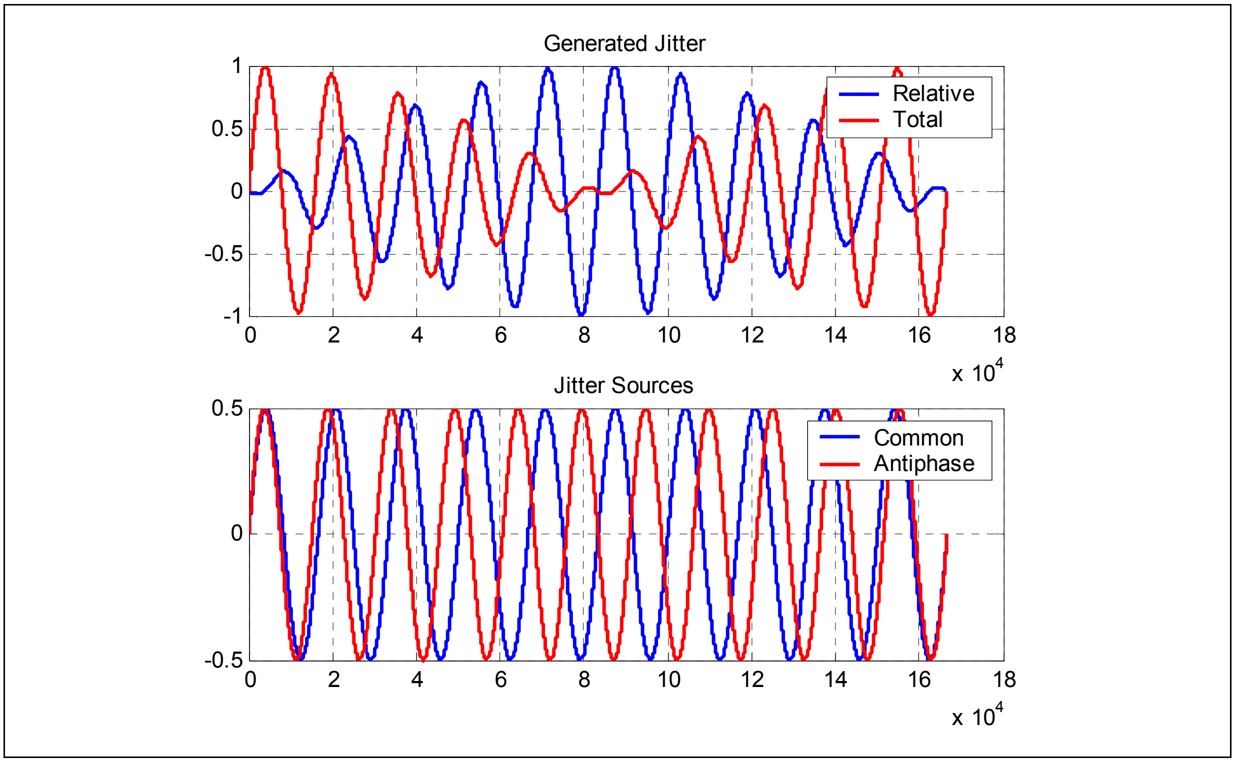
2.C.2 Annex - Total Wander vs. Relative Wander

Generation of Total and Relative Wander can be achieved using a “Common” and “AntiPhase” Sinusoidal Source, where the total and relative wander are then related as defined below.

$$A_{total} = A_{common} + A_{antiphase}$$
$$A_{relative} = 2A_{antiphase}$$

By adding sinusoidal frequencies of slightly differing frequencies the maximum total and relative wander is achieved at various phase relationships, Figure 2-13.

Figure 2-13.Generation of Total and Relative Wander



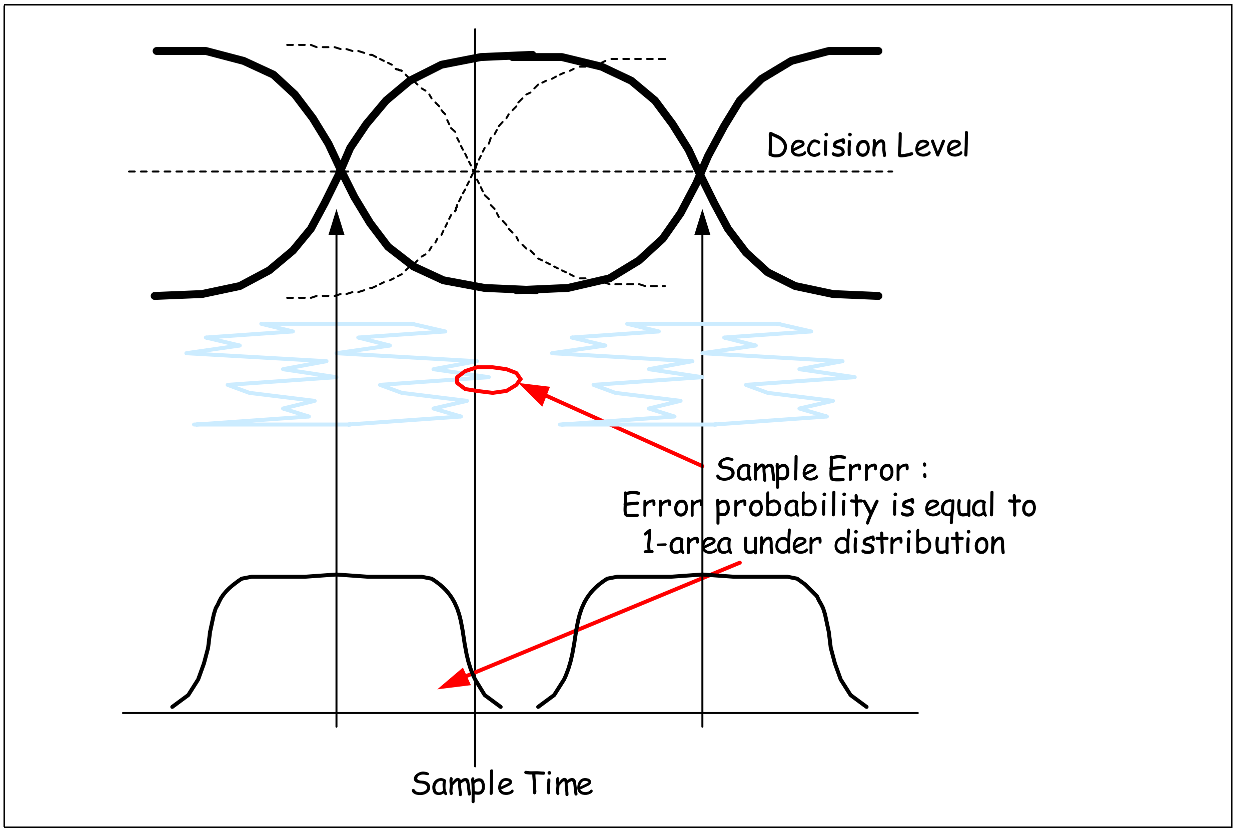
2.C.3 Annex - Correlated vs. Uncorrelated Jitter

If a correlation exists between the amplitude of the jitter and the current, past and future signal level of a data channel, this type of jitter is deemed correlated. Typically this is encountered when band limitation and inter-symbol interference occurs. Due to amplitude to phase conversion of the ISI, a jitter is observed which has a direct correlation to the data pattern being transmitted.

2.C.4 Annex - Jitter Distributions

High frequency is traditionally measured and described using probability density functions, Figure 2-14 (bottom) which describe the probability of the data signal crossing a decision threshold.

Figure 2-14.Jitter Probability Density Function



The low probability part of the jitter distribution can be described by two components, mathematically described below.

2.C.4.1 Annex - Unbounded and Bounded Gaussian Distribution

We define a Unbounded Gaussian distribution function in terms of sigma as below.

$$GJ(\tau, \sigma) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot e^{-\frac{\tau^2}{2\sigma^2}}$$

For every offset τ, there exists a finite and non-zero probability.

2.C.4.2 Annex - Bounded Gaussian Distribution

We define a Bounded Gaussian Distribution function[1] in terms of sigma and a maximum value as below.

$$GJ(\tau, \sigma) = \begin{bmatrix} \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot e^{\frac{\tau^2}{2\sigma^2}} \\ 0 \end{bmatrix} \text{if} \begin{matrix} \tau \le \tau_{max} \\ \tau > \tau_{max} \end{matrix}$$

For random processes consisting of a finite number of random variables there exists a finite non-zero probability only if $\tau \le \tau_{max}$. For example a bandlimited channel is bounded but shows a Gaussian Distribution below its maximum. See Annex 2.C.4.8 for an explanation concerning extrapolation.

2.C.4.3 Annex - High Probability Jitter

We define a dual dirac distribution function for a High Probability jitter (W) as below

$$HPJ(\tau, W) = \frac{\delta(\tau - \frac{W}{2})}{2} + \frac{\delta(\tau + \frac{W}{2})}{2}$$

2.C.4.4 Annex - Total Jitter

We define the convolution of the High Probability and Gaussian jitter as being the total jitter and define it as below.

$$TJ(\tau, W, \sigma) = \frac{1}{2\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot \left[e^{-\frac{\delta\left(\tau - \frac{W}{2}\right)^2}{2\sigma^2}} + e^{-\frac{\delta\left(\tau + \frac{W}{2}\right)^2}{2\sigma^2}} \right]$$

1. Due to its bounded nature the function does not comply with the requirement that the integral of the PDF from minus infinity to infinity is one. This small inaccuracy is recognized and accepted in this context.

2.C.4.5 Annex - Probability Distribution Function vs. Cumulative Distribution Function

An example of the convolution of GJ (magenta), HPJ (green) to give TJ (red) can be seen Figure 2-15. When integrating the probability distribution functions, same colours, we obtain the cumulative distribution function or half the bathtub, Figure 2-16.

Figure 2-15.Example of Total Jitter PDF

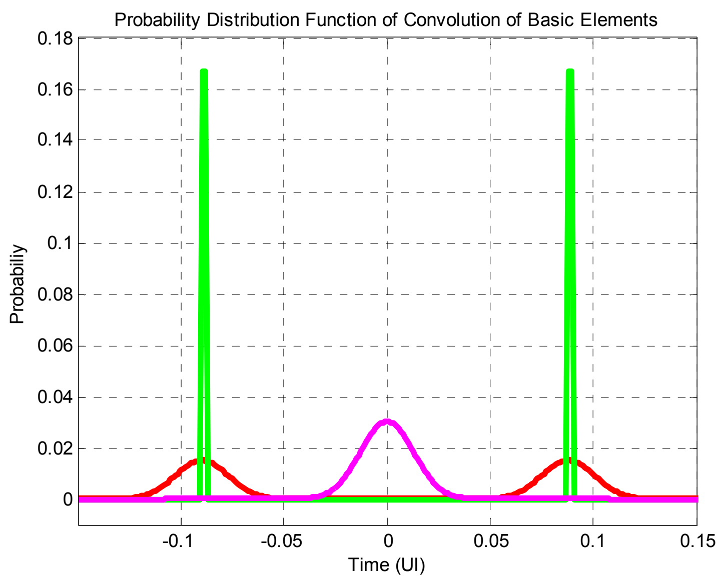
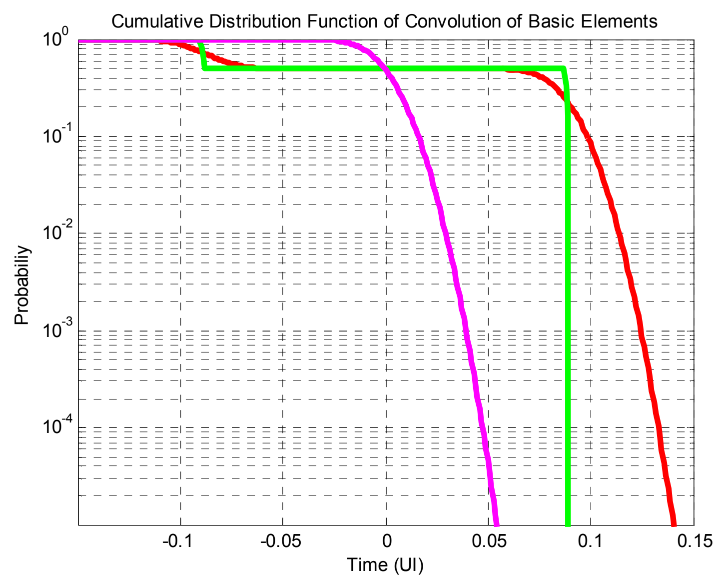


Figure 2-16.Example of Total Jitter CDF



2.C.4.6 Annex - BathTub

Given a measured bathtub curve consisting of measured BER for various sampling offsets, the defined Gaussian and High Probability Distributions can be used to describe the important features of the distribution.

Initially the BER axis should be converted to Q as defined below, e.g. a BER of 10^{-12} is a Q=7.04, and a BER of 10^{-15} a Q=7.94.[1]

$$Q = \sqrt{2} \cdot erf^{-1}(2 \cdot (1 - BER) - 1)$$

where

$erf^{-1}(x)$ is the inverse function of the error function $erf(x)$ and

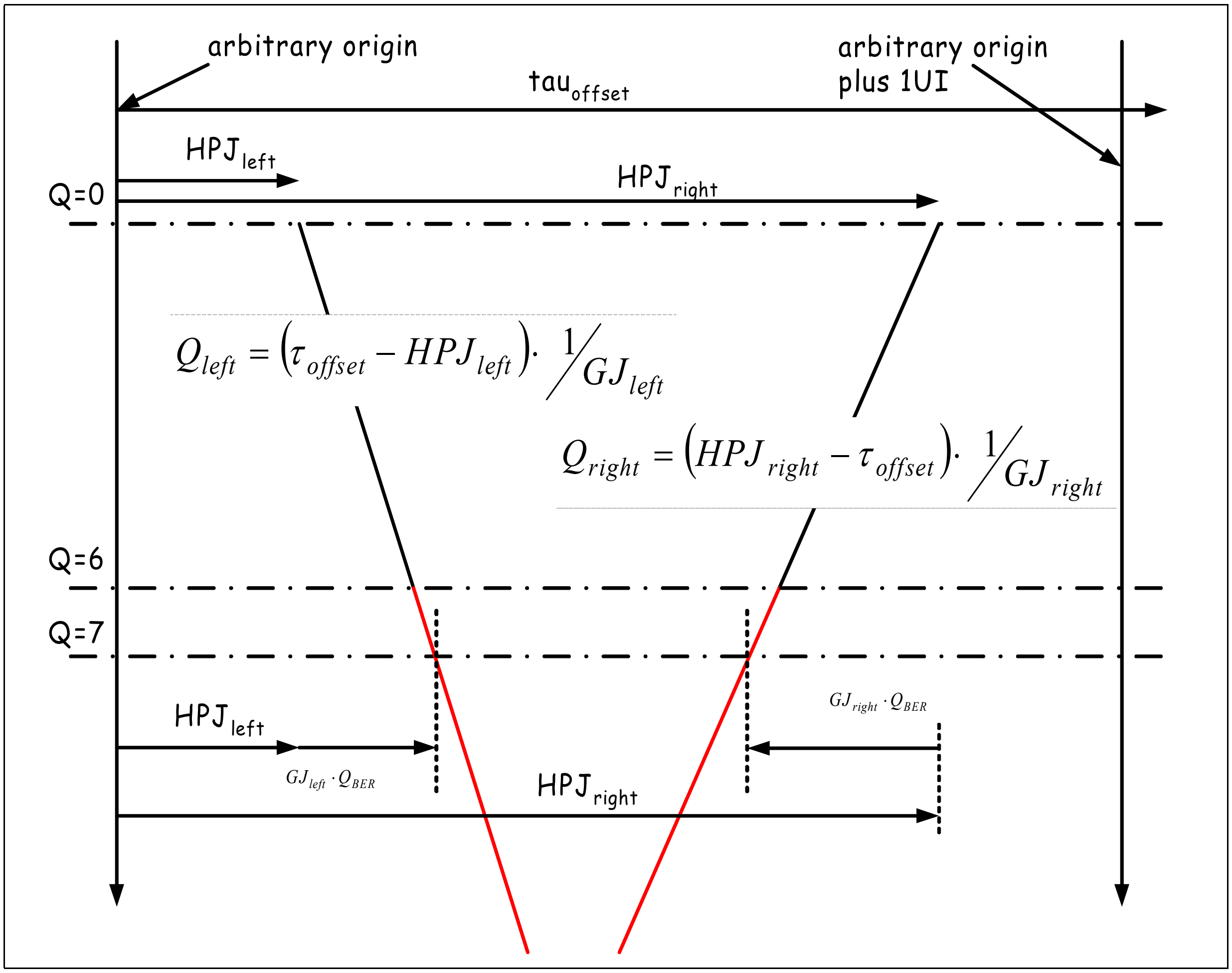
$$erf(z) = \frac{2}{\sqrt{\pi}} \cdot \int_0^z e^{-t^2} dt$$

Note: this conversion from BER to Q is only valid given a large time offset from the optimal sampling point. The use of the nomenclature BER in this reference should therefore be carefully used. Any accurate prediction of the BER towards the centre of the eye should be done using Marcum's Q function, and is outside the scope of this document.

1. It is assumed that when measuring the jitter bathtub that the left and right parts of the bathtub are independent to each other, e.g. the tail of the right hand part of the bathtub and negligible effect on the left hand side of the bathtub.

By linearising the bathtub, Figure 2-17, we can describe the function of the left and

Figure 2-17.Bathtub Definition



right hand linear parts of the bathtub in terms of an offset (HPJ) and gradient (1/GJ)

$$Q_{left}(\tau_{offset}) = (\tau_{offset} - HPJ_{left}) \cdot \frac{1}{GJ_{left}}$$

$$Q_{right}(\tau_{offset}) = (HPJ_{left} - \tau_{offset}) \cdot \frac{1}{GJ_{right}}$$

The conversion to a linearised bathtub from a measurement should be calculated using a polynomial fit algorithm for parts of the measurement made at low BERs or high Q.

2.C.4.7 Annex - Specification of GJ and HPJ

In Implementation Agreements the left and right hand terms are combined to give a single definition as below.

$$HPJ_{total} = 1-(HPJ_{right}-HPJ_{left})$$

$$GJ_{total} = GJ_{left}\cdot Q_{BER} + GJ_{right}\cdot Q_{BER} = 2Q_{BER}\cdot GJ_{rms}$$

$$GJ_{rms} = \frac{GJ_{left}+GJ_{right}}{2}$$

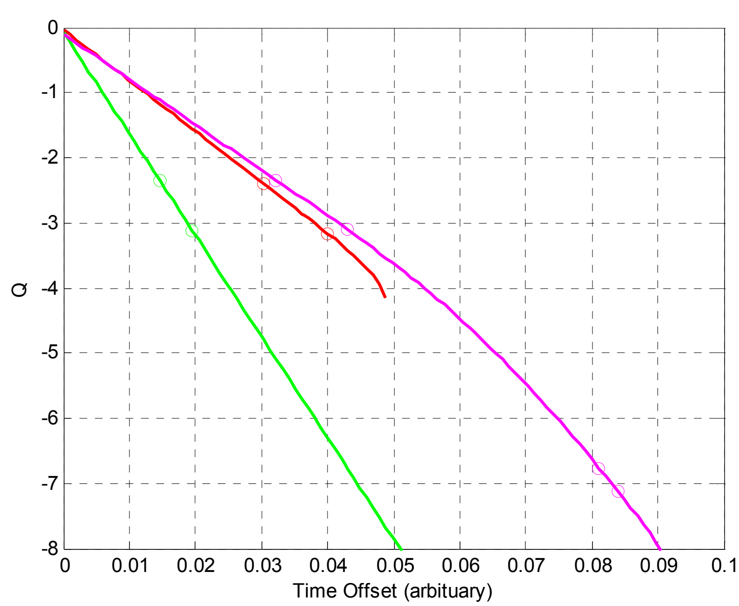
$$J_{total} = GJ_{total} + HPJ_{total}$$

where Q_{BER} is the Q for the BER of interest, e.g Q=7.04 for a $BER = 10^{-12}$

2.C.4.8 Annex - Example of Bounded Gaussian

Assuming that the Cumulative Distribution Function of the jitter could be measured to the probabilities shown, Figure 2-18 shows an example of when a jitter should be classified as Correlated High Probability or Correlated Bounded Gaussian..

Figure 2-18.Example of Bounded Gaussian



The convolution of a true Unbounded Gaussian Jitter (green) with a Bounded Gaussian Jitter (Red) can be seen (Magenta). It can be clearly seen and measured that at a Q of -3 the Bounded Jitter is still Gaussian and the resulting convolution can be calculated using RMS addition. Below a Q of -5 the Bounding effect can be seen, and if we linearize the Bathtub we measure a non-zero High Probability Jitter and Gaussian component.

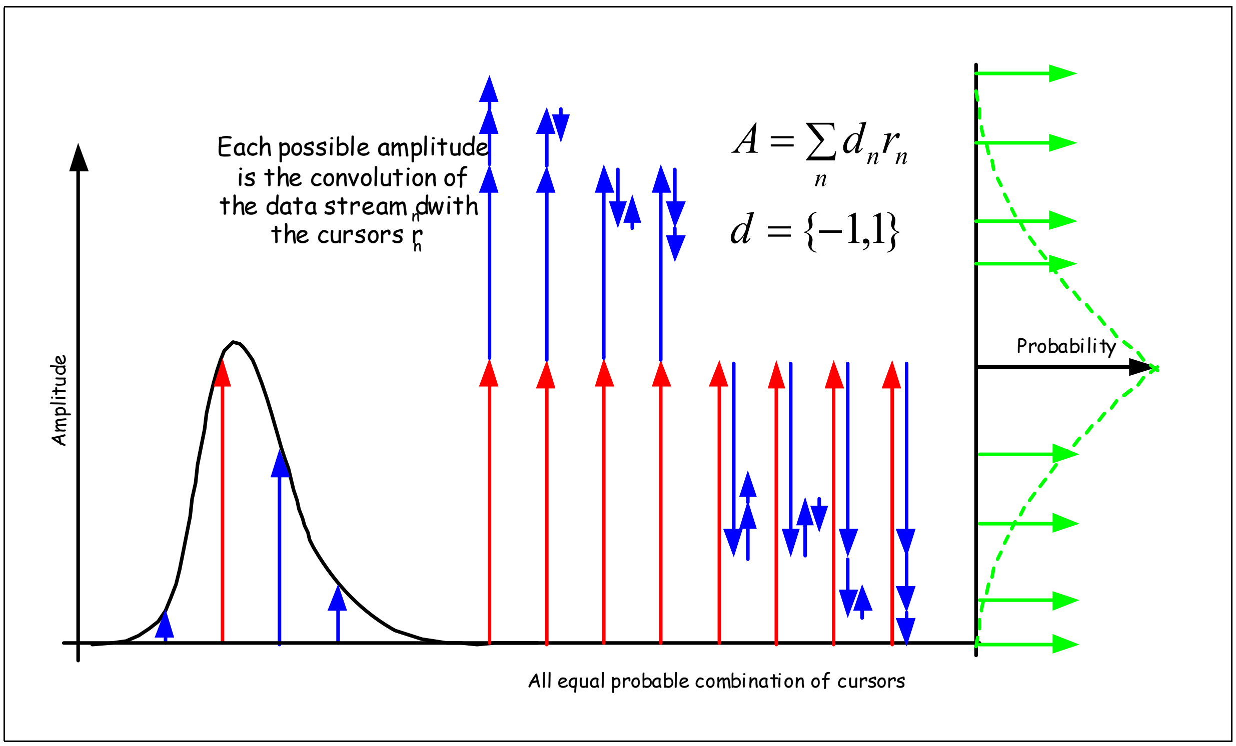
2.C.5 Annex - Statistical Eye Methodology

The following section describes the fundamental underlying the StatEye methodology. For a golden implementation please refer to the scripts on the OIF website, which are published separately, and to the appropriate appendix in this document for the compliance template.

2.C.5.1 Annex - Derivation of Cursors and Calculation of PDF

The Statistical Eye Methodology uses a channel pulse response and crosstalk pulse response in conjunction with a defined sampling jitter to generate an equivalent eye which represents the eye opening as seen by the receiver for a given probability of occurrence.

Figure 2-19.Statistics of Pulse Response Cursor

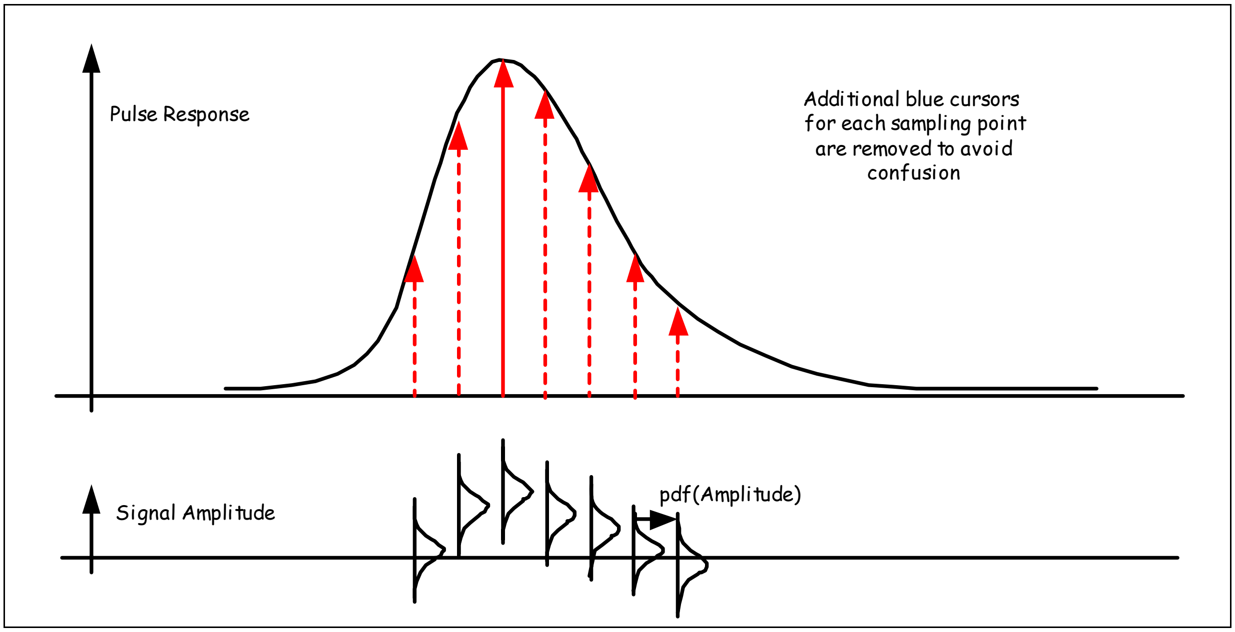


Given a pulse response (black left), Figure 2-19, we locate c_0 at an arbitrary point (red arrow), and measure the symbol space cursors (blue arrows)

Given a DFE the post cursors should be adjusted by negating the measured post cursors by the appropriate static coefficient of the DFE, up to the maximum number of cursors specified.

According to the exact data pattern these cursors superimpose to Inter-symbol Interference. Each possible combination of these cursors is calculated and from these combinations a histogram is generated to form the probability density function (PDF) (green).

Figure 2-20.Variation of the c0 sampling time



By varying the reference sampling point for c0, Figure 2-20, the previous function is repeated and family of conditional PDFs build up, which can be represented mathematically below.

Given,

$r_n(\tau)$ are the cursors of the pulse response at sampling τ

e_b is the ideal static equalization coefficients of the b tap DFE

$c(\tau)$ is the set of equalization cursors at sampling τ

$\delta(\tau) = \lim_{\varepsilon \to 0} \varepsilon|x|^{\varepsilon - 1}$ is the dirac or delta function

$d_{n,b}$ are all the possible combinations of the data stream and is either 1 or 0

$p(ISI, \tau)$ is the probability density function of the ISI for a given sample time

$$c(\tau) = \left[r_{-\frac{m}{2}}(\tau) \;\ldots\; r_{-1}(\tau) \;\; r_1(\tau) - e_1 \;\ldots\; r_b(\tau) - e_b \;\; r_{b+1}(\tau) \;\ldots\; r_{\frac{m}{2}}(\tau) \right]$$

$$d = \begin{bmatrix} d_{1,1} & d_{1,\ldots} & d_{1,m} \\ d_{\ldots,1} & d_{\ldots,\ldots} & d_{\ldots,m} \\ d_{2^m,1} & d_{2^m,\ldots} & d_{2^m,m} \end{bmatrix}$$

$$n = \sum_{b=[1,m]} d_{n,b} \cdot 2^{b-1} + 1$$

$$p(ISI, \tau) = \frac{1}{2^m} \sum_{n=[1,2^m]} \delta(c(\tau) \cdot (2d_n' - 1) - ISI)$$

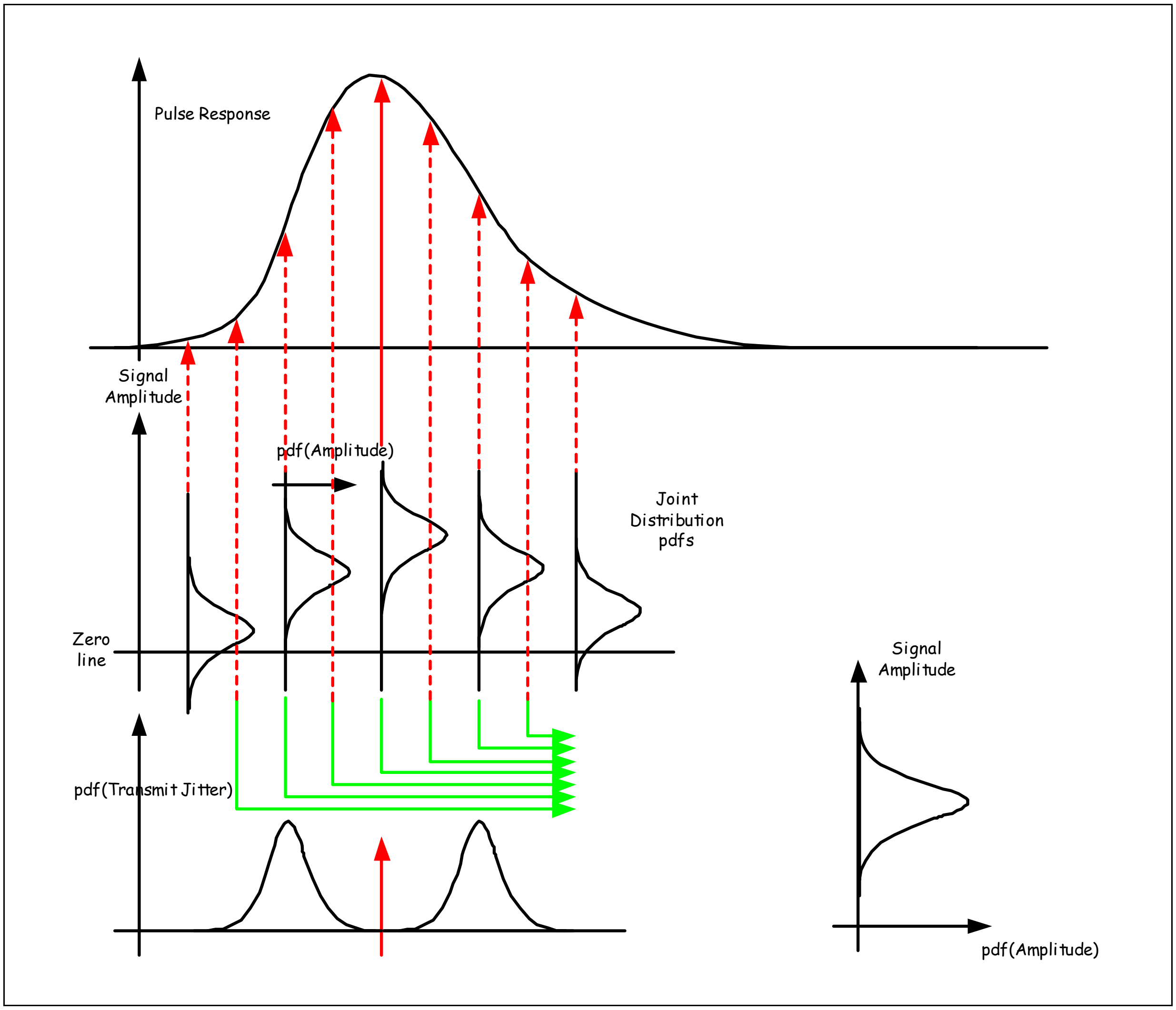
A similar family of PDFs are generated for the crosstalk pulse response and any other aggressors in the system using the cursor set below, noting that the entire pulse response is used

$$c(\tau) = \left[r_{-\frac{m}{2}}(\tau) \;\ldots\; r_{-1}(\tau) \;\; r_0(\tau) \;\; r_1(\tau) \;\ldots\; r_{\frac{m}{2}}(\tau) \right]$$

2.C.5.2 Annex - Inclusion of Sampling Jitter

In a real system the sampling point c0 is defined by the CDR and is jittered, for the sake of standardization, by the transmitter. This jitter has a probability density function which is centred at the receiver CDR sampling point and defines the probability of each of the previous conditional PDFs occurring[1].

Figure 2-21.Varying the Receiver Sampling Point



By multiplying each of the conditional PDFs by its associated sampling jitter probability and summing their results together, the joint probability density function at the given receiver CDR sample point can be calculated, Figure 2-21.

1. Currently DCD effects are not taken into account

Given,

$p_{jitter}(\tau, w, \sigma)$ is the dual dirac probability density function of the sampling jitter in the system, as defined in Annex 2.C.4.4

$p_{crosstalk}(ISI, \tau)$ is the probability density function of the crosstalk

$p_{forward}(ISI, \tau)$ is the probability density function of the ISI of the forward channel

$a \otimes b$ is the convolution operative

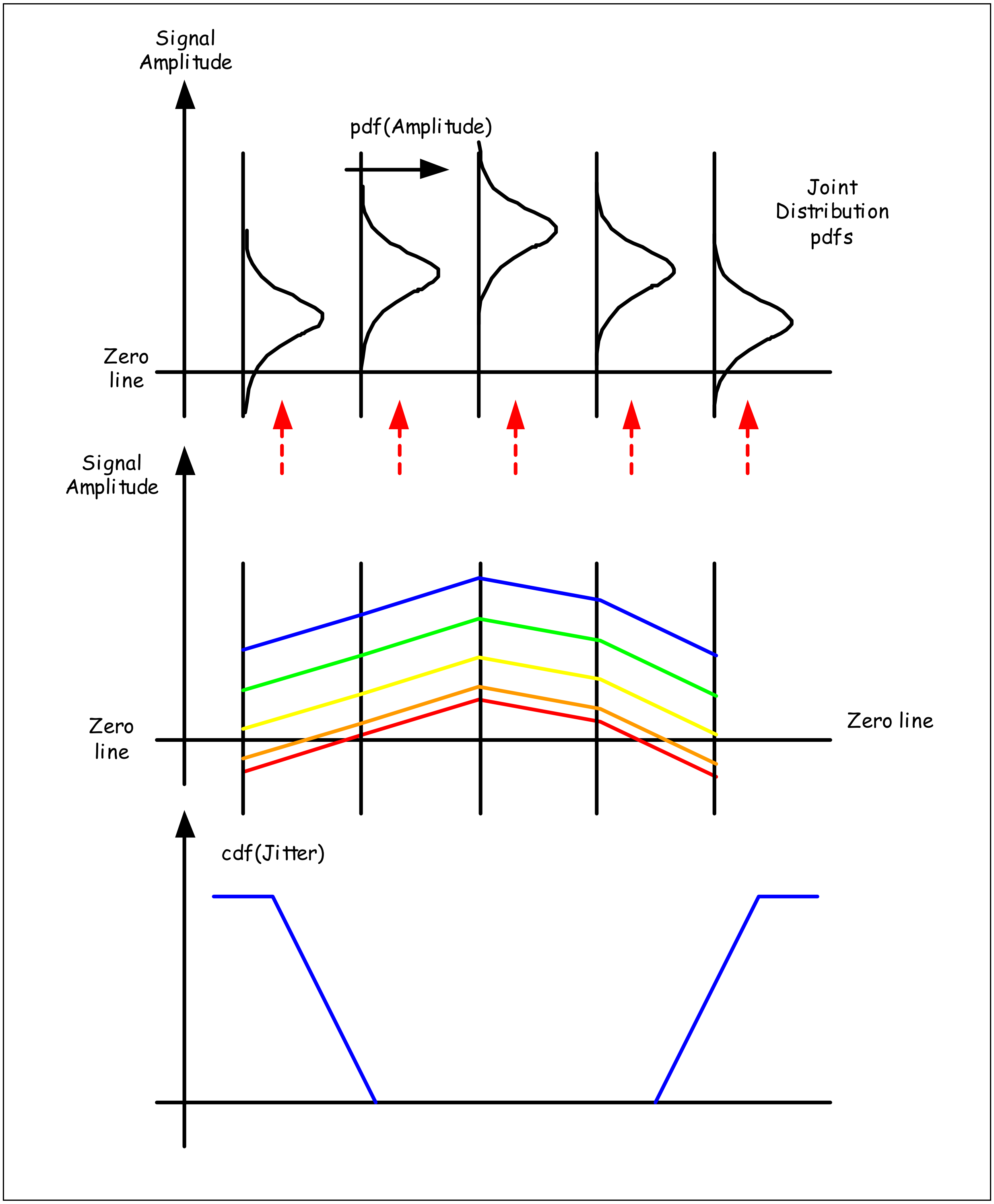
$$p_{average}(ISI, \tau) =$$

$$\int_{-\infty}^{\infty} \{[p_{crosstalk}(ISI, \tau + \upsilon + w) \otimes p_{forward}(ISI, \tau + \upsilon)] \cdot p_{jitter}(\upsilon, w, \sigma)\} d\upsilon$$

2.C.5.3 Annex - Generation of Statistical Eye

By varying the receiver CDR sampling point a new joint probability density function, Figure 2-21 can be generated.

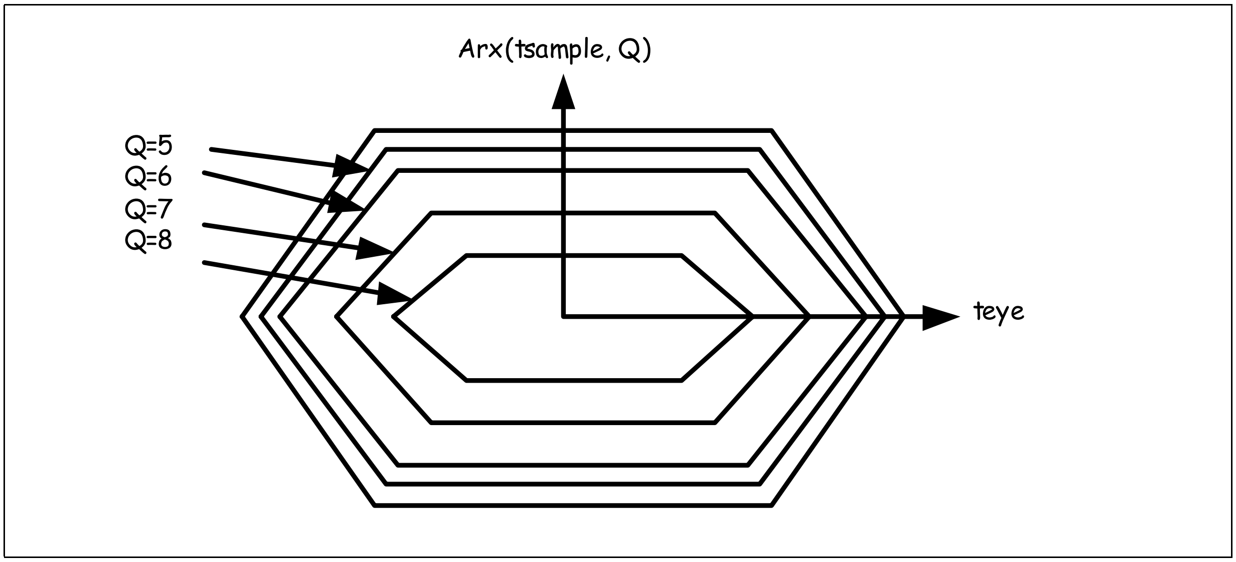
Figure 2-22.Generation of the Data Eye and Bathtub



By integrating the Joint Probability Density Function to give the Cumulative Distribution function, and creating a contour plot an equivalent of the receiver eye can be generated which shows the exact probability of obtaining a given amplitude, Figure 2-22, this equivalent eye is termed the statistical eye, Figure 2-23

By only plotting the probability against time by cutting the statistical Eye along the decision threshold axis, a bathtub of the jitter can be generated,Figure 2-22.

Figure 2-23.Statistical Eye



2.D Annex - Definition of CEI Test Patterns

2.D.1 Annex - PRBS31

The pattern is a free running PRBS31 polynomial in accorance with [21.]. The sequence is generated using taps 28 and 31.

2.D.2 Annex - Short Stress Pattern Random (SSPR)

The SSPR pattern was chosen to have baseline wander and timing content that are at least as stressful as 10,000 years of random binary.

- The baseline wander was assessed with a cut-off frequency of baudrate/10,000.
- The clock content was assessed with a corner frequency of baudrate/1667.
- The period of 10,000 years was chosen on the basis of random binary exceeding the baseline wander timing content limits of the short pattern once in 10 years in a network containing 1000 random streams.

The SSPR pattern is defined as:

Figure 2-24.Short Stress Pattern Random (SSPR)

PRBS28 Seed=0080080	CID 1, 72 x 0	PRBS28 Seed=FFFFFFF	PRBS28 Seed=0080080 Diff encoded	$\overline{\text{PRBS28}}$ Seed=0080080	$\overline{\text{CID}}$ 0, 72 x 1	$\overline{\text{PRBS28}}$ Seed=FFFFFFF	$\overline{\text{PRBS28}}$ Seed=0080080 Diff encoded
5437 bits	73 bits	5437 bits	5434 bits	5437 bits	73 bits	5437 bits	5434 bits

- Total length 32,762 bits
- All $2^{28}-1$ PRBS28 sequences are generated using taps 25 and 28
- Block 1 is 5437 bits of PRBS28 seed = 0x0080080 and begins with 8 x 0, 1, 11 x 0, 1, 12 x 0, 1 ...
- Block 2 is 1 followed by 72 x 0
- Block 3 is 5437 bits of PRBS28 seed = 0xFFFFFFF and begins with 28 x 1, 25 x 0, 3 x 1, 22 x 0 ...
- Block 4 takes the same sequence as block 1 (omitting the last 3 bits) and encodes it as follows:
  - — A zero causes a change of output
  - — A one causes no change of output
  - — The output before the first bit is assumed to have been zero
  - — This block begins 101010100101010101011010101010101011011010 ...
- Blocks 5 to 8 are the inverse of blocks 1 to 4 respectively.

Under some circumstances (e.g. to accommodate the restrictions of some pieces of test equipment) it may be desirable to modify this short pattern to have a total length of 32,768 bits (2^{15}) rather than 32,762 bits. To make use of this option, the differentially encoded blocks (blocks 4 and 8) should be extended by 3 bits making these blocks 5437 bits long.

2.D.3 Annex - Short Stress Pattern SDH 16 (SSPS-16)

The SSPS-16 pattern was chosen to have baseline wander and timing content that are at least as stressful as 10,000 years of STM-16 framed random binary.

- The baseline wander was assessed with a cut-off frequency of baud/10,000.
- The clock content was assessed with a corner frequency of baudrate/1667.
- The period of 10,000 years was chosen on the basis of STM-16 framed random binary exceeding the baseline wander and timing content limits of the short pattern once in 10 years in a network containing 1000 STM-16 framed streams.

The SSPS-16 pattern is defined as:

Figure 2-25.Short Stress Pattern SDH 16 (SSPS-16)

A1 F6	A2 28	NU AA	PRBS28 Seed 0080080 Diff. enc.	CID 1, 72 0's	PRBS28 Seed FFFFFFF	PRBS28 Seed 0080080	$\overline{\text{A1}}$ 09	$\overline{\text{A2}}$ D7	$\overline{\text{NU}}$ 55	$\overline{\text{PRBS28}}$ Seed 0080080 Diff. enc.	$\overline{\text{CID}}$ 0, 72 1's	$\overline{\text{PRBS28}}$ Seed FFFFFFF	$\overline{\text{PRBS28}}$ Seed 0080080
384 bits	384 bits	258 bits	5095 bits	73 bits	5095 bits	5092 bits	384 bits	384 bits	258 bits	5095 bits	73 bits	5095 bits	5092 bits

- Total length 32,762 bits
- All 2^{28}-1 PRBS28 sequences are generated using taps 25 and 28
- Block 1 is A1 (11110110) repeated 48 times to give 384 bits
- Block 2 is A2 (00101000) repeated 48 times to give 384 bits
- Block 3 is the National Use bits and consists of 1010 repeated for 258 bits
- Block 4 takes 5095 bits of PRBS28 seed = 0x0080080 and encodes it as follows:
  - — A zero causes a change of output
  - — A one causes no change of output
  - — The output before the first bit is assumed to have been zero
  - — This block begins 1010101001010101010110101010101011011010 ...
- Block 5 is 1 followed by 72 x 0
- Block 6 is 5095 bits of PRBS28 seed = 0xFFFFFFF and begins 28 x 1, 25 x 0, 3 x 1, 22 x 0 …
- Block 7 is 5092 bits of PRBS28 seed = 0x0080080 and begins with 8 x 0, 1, 11 x 0, 1, 12 x 0, 1 …

- Blocks 8 to 14 are the inverse of 1 to 7 respectively.

Under some circumstances (e.g. to accommodate the restrictions of some pieces of test equipment) it may be desirable to modify this short pattern to have a total length of 32,768 bits (2^{15}) rather than 32,762 bits. To make use of this option, the last block in each half (blocks 7 and 14) should be extended by 3 bits making these blocks 5095 bits long.

2.D.4 Annex - Short Stress Pattern SDH 64 (SSPS-64)

The SSPS-64 pattern was chosen to have baseline wander and timing content that are at least as stressful as 10,000 years of STM-64 framed random binary.

- The baseline wander was assessed with a cut-off frequency of baud/10,000.
- The clock content was assessed with a corner frequency of baudrate/1667.
- The period of 10,000 years was chosen on the basis of STM-64 framed random binary exceeding the baseline wander and timing content limits of the short pattern once in 10 years in a network containing 1000 STM-64 framed streams.

The SSPS-64 pattern is defined as:

Figure 2-26.Short Stress Pattern SDH 64 (SSPS-64)

A1 F6	A2 28	NU AA	PRBS28 Seed 0080080 Diff. enc.	CID 1, 72 0's	PRBS28 Seed FFFFFFF	PRBS28 Seed 0080080	$\overline{A1}$ 09	$\overline{A2}$ D7	$\overline{NU}$ 55	$\overline{PRBS28}$ Seed 0080080 Diff. enc.	$\overline{CID}$ 0, 72 1's	$\overline{PRBS28}$ Seed FFFFFFF	$\overline{PRBS28}$ Seed 0080080
1536 bits	1536 bits	1026 bits	4071 bits	73 bits	4071 bits	4068 bits	1536 bits	1536 bits	1026 bits	4071 bits	73 bits	4071 bits	4068 bits

- Total length 32,762 bits
- All 2^{28}-1 PRBS28 sequences are generated using taps 25 and 28
- Block 1 is A1 (11110110) repeated 192 times to give 1536 bits
- Block 2 is A2 (00101000) repeated 192 times to give 1536 bits
- Block 3 is the National Use bits and consists of 1010 repeated for 1026 bits
- Block 4 takes 4071 bits of PRBS28 seed = 0x0080080 and encodes it as follows:
  - — A zero causes a change of output
  - — A one causes no change of output
  - — The output before the first bit is assumed to have been zero
- This block begins 1010101001010101010110101010101011011010 ...
- Block 5 is 1 followed by 72 x 0
- Block 6 is 4071 bits of PRBS28 seed = 0xFFFFFFF and begins 28 x 1, 25 x 0, 3 x 1, 22 x 0 …

- Block 7 is 4068 bits of PRBS28 seed = 0x0080080 and begins with 8 x 0, 1, 11 x 0, 1, 12 x 0, 1 …
- Blocks 8 to 14 are the inverse of 1 to 7 respectively.

Under some circumstances (e.g. to accommodate the restrictions of some pieces of test equipment) it may be desirable to modify this short pattern to have a total length of 32,768 bits (2^{15}) rather than 32,762 bits. To make use of this option, the last block in each half (blocks 7 and 14) should be extended by 3 bits making these blocks 4071 bits long.

2.D.5 Annex - Use of CEI Test Patterns

The Test patterns required for the various electrical interfaces covered by CEI are specified in Table 2-1.

Table 2-1. Use of CEI Test Patterns

Electrical Requirement	"Method"	IA	Data	Test Patterns	
				Mandatory	Recommended
CEI Clause 4 (SxI-5)	A	SFI-4.2	Scrambled	PRBS31 or SSPR	
		Other	Scrambled	PRBS31 or SSPR	
		SPI-5	Scrambled	PRBS31 or SSPR	
		SFI-5.1	Partially scrambled	PRBS31 or SSPR	SSPR
		SFI-5.1s	Partially scrambled	PRBS31 or SSPR	SSPS-16
CEI Clause 5 (TFI-5)	B	TFI-5	Scrambled	PRBS31 or SSPR	
			Partially scrambled	PRBS31 or SSPR	SSPS-16
CEI Clause 6 (CEI-6G-SR)	B	TDM-P	Scrambled	PRBS31 or SSPR	
		CEI-P	Scrambled	PRBS31 or SSPR	
		Other	Scrambled	PRBS31 or SSPR	
		Other	Partially scrambled	PRBS31 or SSPR	SSPS-16
CEI Clause 7 (CEI-6G-LR)	D	TDM-P	Scrambled	PRBS31 or SSPR	
		CEI-P	Scrambled	PRBS31 or SSPR	
		Other	Scrambled	PRBS31 or SSPR	
		Other	Partially scrambled	PRBS31 or SSPR	SSPS-16
CEI Clause 8 (CEI-11G-SR)	E	TDM-P	Scrambled	PRBS31 or SSPR	
		CEI-P	Scrambled	PRBS31 or SSPR	
		SFI5.2	Scrambled	PRBS31 or SSPR	
		Other	Scrambled	PRBS31 or SSPR	
		Other	Partially scrambled	PRBS31 or SSPR	SSPS-64
CEI Clause 9 (CEI-11G-LR/MR)	see[a]	TDM-P	Scrambled	PRBS31 or SSPR	
		CEI-P	Scrambled	PRBS31 or SSPR	
		Other	Scrambled	PRBS31 or SSPR	
		Other	Partially scrambled	PRBS31 or SSPR	SSPS-64

a. Use method E for CEI-11G-MR and both methods C and D without any Tx emphasis for CEI-11G-LR.

2.D.6 Annex - Text Definitions of Patterns

Below are definitions of the patterns described in Annex 2.D.2, Annex 2.D.3 and Annex 2.D.4 as hexadecimal digits with the most significant bit of each digit transmitted first. Since these patterns are 32,762 bits long (which is not divisible by 4), the two least significant bits of the last digit shown are not included in the sequence.

Short Stress Pattern Random (SSPR)

```
008008004804802082081249248800000C8000068800032C8001A48800C80C8068868832CB2C
9A49248480000A080005A480028808016C8480A08A085A4DA4A882081EC9248E88000FAC8007
2C8803E48C81CC0E88FAC7ACF2CFACB64B2C904124812480088008O4C804822882O936C92408
0800448480260A081165A489A4880C480C86E0868B1E4B2D3EC1244C8C80628E88376FAC98C1
2C85EC848AA88A0DFECDA6208A09724DA42E020855E124AFAE801D2DA80F440E875647ABDE47
AF52C7AD5C4FAC7BE32CFA4FA4B283281269A68812492C8800048C80020E880127AC8081AC88
48CC8CA0EA8E9A7BEFA49A4928048006820803292481A60008C96004E826023A91613EE1A68C
9EC92E868805AB2C828F24896F600C214606D2B7630470C7B27F6FA218412B2DA48724080BE0
44854E260AF3F165D6C7A4B60FA810672E8935E5AC09AC8CC44C8EAE628FBDD76F2536C160C8
0CA668869952CB253C4920CDE0026A2E0113B5E098E1AE45FECDC6A08A3F3A4DBC6E8205F1A9
22A7CE03799BE18B544EDD1F63835E47F99AC78354CFB99F2B27566721DE55E2F2CFAF564B2D
5E41247AC4807ACE083ACBE49EC94C068832C32C9A4DA48482080A092485A4000A884005ECA4
02A898417EC5A4A88E881ECFAC8E8B2C8FAD248F2C400F64E407443C43D65DE5D64B2CB64124
904480012608008164804 8A40820D8449261A60016C9600A082605A491628801A76C80C9C088
687C4CB2B9E292776F601CC1460FACB7672C90C5E4816EAC08A1BCC4DAC5AE20CE8DF26BAE26
136DF1688027A2C811AB4889CF10CC7B796AFA0B23D2A523D478C3D77BEDD6CA483609809864
5845B469A681724928AE0006DDE003032E01B1A5E0C3C8AE6DD8DDD031E3351BEFA9DC492E73
E005DECE02B28BE1726D4EAE1073BDE93EE52A0C9CC7A687AFA92BAD2E076C45E3C400000000
000000003FFFFFFC000001C00000FC000071C0003FFC001C01C00FC0FC071C71C3FFFFFDC00
0013C00008DC0004E3C0023FDC013C13C08DC8DC4E38E3E3FFFFCFC0001B1C000C3FC006DC1C
0303CFC1B1DB1CC3F03FADC71C2C3FFFD4DC001723C00AE3DC05DFD3C2B214DD722B236E3723
81F8E3F8E3FFC3FFC01DC01C0F3C0FC76DC71FC03FFE1C1C00EFCFC0791B1C3B1C3FDE3FDC12
FC13C851C8D8ADF8E1DC23FEF3D3C096D4DC420723E523E3CCC3CFDAADDB10FC303971DB1F2F
F03E65071CD4D3FFA724C029E02C166E14CA51EB298DEB265E2B214AF722B1D4E373F73F8EC4
EC3F8E38DC3FFFE3DC000FD3C00714DC03FB23C1C223DCFD33D3B14AD4E3B1C73FE3FFEC0FC0
08C71C04EFFFC239001D3F100F4C790752FB13DC5238D3EC3FE4C8DC0C28E3C6D6FFDF061012
7369081E82148EA92B0FBE073724E3E8E03FCAFE1C19D0EFCD75791A6DEB1C902B3F81172C38
9AE4DFC4DC221E23D32EF3D4A596D7189206FDC023113C13B98DC8E75E38FDDAFFF130D0078B
6503BD04D1E55225ECFC30A8B1DB5ED3F01A84C70CEA2FF6BBB5043661D25856F409AE15444D
EBF6622B445737166EE8FA519AF28DD4D66E372651F8E14DE3FEB22FC0B2351C5239DFEC3F72
08DC4E24E3E3F03FCFC71C1B1FFFCC3E001ADCE00CC3BE06ADE4E33C2C3FADD4DC2C3723D4D8
E3D721FFD6E2E0161F5E0A6E5AE591C8DC91F8E381E3FFF8EFC003F91C01C31FC0FDBE1C7104
EFFF923900303F101B1C790C3FFB16DC023A03C13EA1DC8CBAF38E96D6FFA206102B23691723
821AE3F92CDFC304A21DB21B2F022C257134D0EF8925793C00EB0DC07B363C3A287DDEB6B932
B0370A7318F59EBDF596B5259231C0903BFC411E41E49EC4EC068E38C32FFFEDA5000808D004
84E5020A3CD125BDA5808508984AD4C5A1C72E8AFFE5ADD00C8C35068ED9D32F8174A538AD18
D54AAB555B55B552B52B56DB6DB4AAAAABB55555CB555513B555724B5544ABB55CB5CB513B13
B724924A4AAAAB2B55558DB55534AB5563B5B54D4B2B58DB8DB34AD4A83B6DB434AAABF3B555
EC4B55024BB57BABCB40C5F3BEC40C4E24EC495A924A924AAB4AAB55BB55B52CB52B6E3B6DAB
54AAA5B5B5522B2B569D8DB48DB4ABA4ABB5C2B5CB17DB13903A925BB44AA2CBCB51E3F3B745
6C4A7C4A4B334B2B803B8DD2B4D49EDB8DAC2AD4A67D6DB3F3CAA86C73541A5435E625F307DA
0C193A0C67A40C5F02EC40DBF24ECAECA9237234A92493B4AAAA4BB5552BCB556DF3B54A8C4B
5B444BB2BCCBC8DF03F248DB6CAA4AAA352B55136DB5722AAB449D55BCADD52F369D6FC28DCB
B7C493CA34AA7313B534124B63E2ABAD65D5C6CE1D15A145F1201C0D28A56CEC724A1254AB02
A5B59BD22B3EFE9D863A0DB1D40CA95DEC34918273AB73B445A44BCC22CBF079E3ED91C562BB
544DDCB5C8993B126FA492BB82AADCD3D5690E7D48BD73DA7FC47A32B4D010DB8FA3CAD58173
6D32042AE088FD74E65BC797E2F51825FF773A0AE6440F77ECEDE6221287D982C13BF3E624EC
67DA925F3A4AA0C42B50C4FDB7C49BAA34AEC513B724724A4AD4AB2B6DB58DAAAB34A55583B2
553348A5603A724CB434A83BF3B434EC4BF3924BEC5AABE24255E5AFA506278279DB13B1DA92
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495A4AAA922B554A9DB55B4DAB52B8A5B6DD722AA9C49D54D4ADD58DB69D34AA8DE3B544854B
5CA05BB13082C921E3E2A84565D40C4E1DEC4945824A9C33AB4D7045B8C58C2D44347EDCF3D2
291C7E9CB5520D3B568CE4B48416BBA0E09CC0D4ED06CD92F9A0BAF9E0FC79C4DB51D48AB75D
A75A71A372356124934C2AAA387D551513D571727D4504B3DC78B879517D119703F3785B6C21
02AA783BD53134FD61239BCC295EF07C903D932BB7BA0DCA0C0C930C6C2A1C5A7D07FBFFBFFD
BFDBFEFBEFBF6DB6DBBFFFFF9BFFFFCBBFFFE69BFFF2DBBFF9BF9BFCBBCBBE69A69B2DB6DBDB
FFFFAFBFFFD2DBFFEBBFBFF49BDBFAFBAFBD2D92DABBEFBF09B6DB8BBFFF829BFFC69BBFE0DB
9BF19F8BB829C29869829A4DA69B7DF6DBF6DBFFBBFFBFD9BFDBEEBBEFB649B6DFBFBFFDDBDB
FECFAFBF74D2DBB2DBBF9DBF9BC8FBCBA70DA69609F6DD9B9BFCEB8BBE44829B39F69BD09BDB
AABBAF900992CEFBAFB46D92DE8FEFBD50F6DA828BFF1692BF85DF8BC54DC2A10DC28569C295
1D829C20E6982D82DA6BE6BF6CB2CBBF6DB69BBFFFDB9BFFEF8BBFF6C29BFBF29BBDB99B9AF8
AB8B2C2082DB2DB6BFDBFFCBEFBFE6B6DBF2CFFFB9B4FFD8BECFEE2B74F608F2CB9B09B68BCB
BFD2A69BEB86DBB484FF9EF5CFC96A44E7DC79C26C0482EF3DF6A692DBC6DFBFA0FDDBD58ECF
A86074D149C2DA4F82BF7CC68BB650D29FB29B99DD9B8A8CEB82114486D649F4F9BF9ACCBBCB
3569A6D61DB6F990FFECAE8FF76250FB38F28DD00991CAFBAE062D921C8BEFD072B6EAC18FE4
3320F3A55D891704E3E50DC03329C3E559823306A6C54CC6F10D50E86982854DA6950DF6DC29
DBFC298FBE29A0DB09B59FCBBE69E69B2D92DBDBEFBFAFB6DBD2DFFFABBDFFD09ADFEABB3DF4
09D2DABB8BBF09829B8BA69B8296DB869DFF84D8DFC5DE1DE14D10D14DA69A4DF6DB7DDBFFF6
CFBFFBF4DBFDBADFBEF93DDB6CF2CFFF49B4FFAFBECFD2DB74EBBFF2C49BF9B1FBBCBC1D9A6A
30EB6C4484FF19F5CF829A44C69B79D0DBF48A9FBAF219D929D28EF98B906CA28ECF649074BB
FEC2E9BF72A5BBB187799C2434A82FA6E16AD6E15C39E144209149ADBE4FB3FB3CDD3DD25CB2
CBF46DB6BA8FFFC910FFE7E68FF272D0F9E1BA8C9139117E70E6572082B11DB68C60FFD1098F
EA6BA0F46C958A8F7C6210B608D6AF9B19C2CBC282B6A2968FC49DD0E1DFFFFFFFFFFFFFFFFF
E0000001FFFFFF1FFFFF81FFFFC71FFFE001FFF1FF1FF81F81FC71C71E0000011FFFFF61FFFF
B91FFFD8E1FFEE011FF61F61FB91B91D8E38E0E0000181FFFF271FFF9E01FFC91F1FE7E181F2
712719E07E0291C71E9E0001591FFF46E1FFA8E11FD10161EA6F59146EA6E48E46E3F038E038
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B93A9038F11EE0086161FB49591DEFC6E0D6E0E199E1812A9127781E7E34712706807E0CD7C7
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Short Stress Pattern SDH 16 (SSPS-16)

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Short Stress Pattern SDH 64 (SSPS-64)

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EDF7DFD7DB6DE96FFFD5DEFFE84D6FF55D9EFA04E96D5DC5DF84C14DC5D34DC14B6DC34EFFC2
6C6FE2EF0EF0A68868A6D34D26FB6DBEEDFFFB67DFFDFA6DFEDD6FDF7C8
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2.E Appendix - Lab Setups

All methodology described in this Appendix is only relevant for verification of low level CDR functionality, and does not cover any required tests for protocol compliance e.g. deskew. The methodology is based on the assumption that either an integrated BERT is present in the DUT or a loop or functionality for the attachment of external equipment.

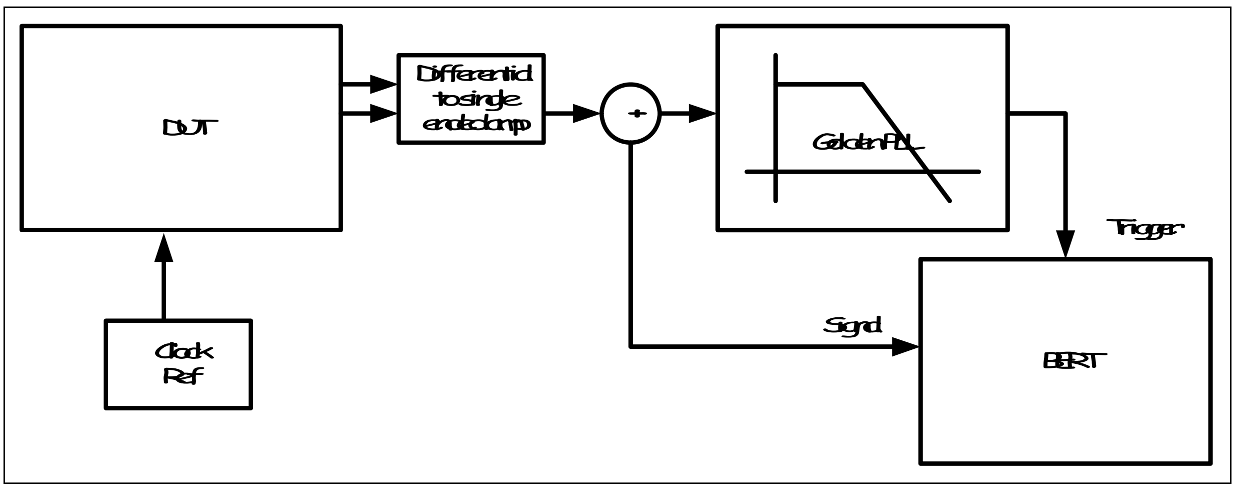
2.E.1 Appendix - High Frequency Transmit Jitter Measurement

The following sub-clause describes various methods for measuring high frequency jitter, which depending upon the baud rate can be applied for various levels of accuracy.

2.E.1.1 Appendix - BERT Implementation

Referring to Figure 2-27, this sub-clause describes test methodology based on bathtub extraction, which relies on equipment being available for the given baud rate.

Figure 2-27.BERT with Golden PLL



- This same methodology can be used by equalized transmitters, by initially turning the equalization off, or by performing the measurement at the output of a **Stress Channel**.
- The transmitter under test shall transmit the specified data pattern, while all other signals are active.
  - — The other channels can transmit the same pattern if they have at least a 16 bit offset with the channel under test.
  - — All links within a device under test to be active in both transmit and receive directions, and receive links are to use asynchronous clocks with respect to transmit links (to maximum allowed ppm. offset as specified in the protocol specifications).
- The data should be differentially analysed using an external differential amp or differential input BERT and Golden PLL.

  - — Use of single ended signals will give an inaccurate measurement and should not be used.
  - — The use of a balun will most likely degrade the signal integrity and is only recommended for 3Gsym/s signalling when the balun is linear with a return loss of better than -15dB until three times the baud rate.
- Inherent bandwidth of clock reference inputs of BERT should be verified e.g. in the case of parBERTs. Additional bandwidth limitation of the BERT will lead to inaccurate results.
- The use of a Golden PLL is required to eliminate inherent clock content (Wander) in transmitted data signals for long measurement periods.
  - — The Golden PLL should have at maximum a bandwidth of baud rate over 1667, with a maximum of 20dB/dec rolloff, until at least baud rate over 16.67, with no peaking around the corner frequency.
- The output jitter for the DUT is not defined as the contributed jitter from the DUT but as the total output jitter including the contributions from the reference clock. To this end, the reference clock of the DUT should be verified to have a performance similar to the real application.
- a confidence level of three sigma should be guaranteed in the measurement of BER for the Bathtub as per Appendix 2.F.2.[1]
- The High Probability and Gaussian Jitter components should be extracted from the bathtub measurement using the methodology defined in Annex 2.C.4.6.
- If not defined the maximum Gaussian jitter is equal to the maximum total jitter minus the actual High Probability jitter.

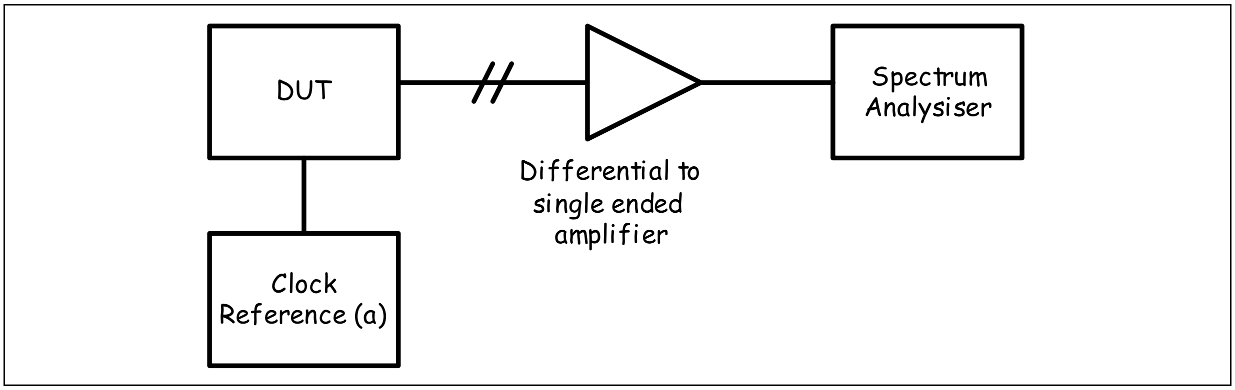
2.E.1.2 Appendix - Spectrum analyzer and Oscilloscope Methodology

Bandlimited[2] Unbounded Gaussian Noise

Referring to Figure 2-28, bandlimited or high frequency Gaussian noise can be measured at the transmitter of the DUT accurately using a high frequency 101010 pattern and measuring the spectral power[3].

1. It is assumed due to the magnitude of jitter present at the transmitter that the left and right hand parts of the bathtub are independent to each other
2. Normal CEI application will integrate from the defined ideal CDR bandwidth to infinity, while some CEI-11G-SR application will integrate over a specific band
3. The spectral power should be measured using averaging

Figure 2-28.Spectral Measurement Setup[a]



a.The clock reference is such that its power noise represents the typical power noise of the reference in the system

The spectral power is calculating by integrating over the frequency band of interest and converting into time jitter.

$$\tau_{rms} = \frac{1}{2\pi}\sqrt{2 \cdot \int_{f_1/100}^{100 f_2} \left| \frac{1/f_1 \cdot j \cdot f}{(1 + j \cdot f/f_1)(1 + j \cdot f/f_2)} \right| \cdot 10^{\frac{P(f)}{10}}}$$

where

τ_{rms} is the time jitter

$P(f)$ is the measured spectral power for 1Hz Bandwidth

It should be noted that the measured Gaussian noise for a driver can usually be considered equivalent to that derived from a full bathtub jitter distribution.

Bandlimited 60 second Total Jitter Measurements

In certain CEI-11G-SR applications total jitter measurements of 60 seconds are required. The Gaussian jitter, as measured above, should be multiplied by a Q of 6.96[1]. If spurs are present in the spectrum then these must be converted to time jitter separately using an inverse of the Bessel function as per Figure 2-29, which describes the power spectrum for a given phase modulated signal.

where

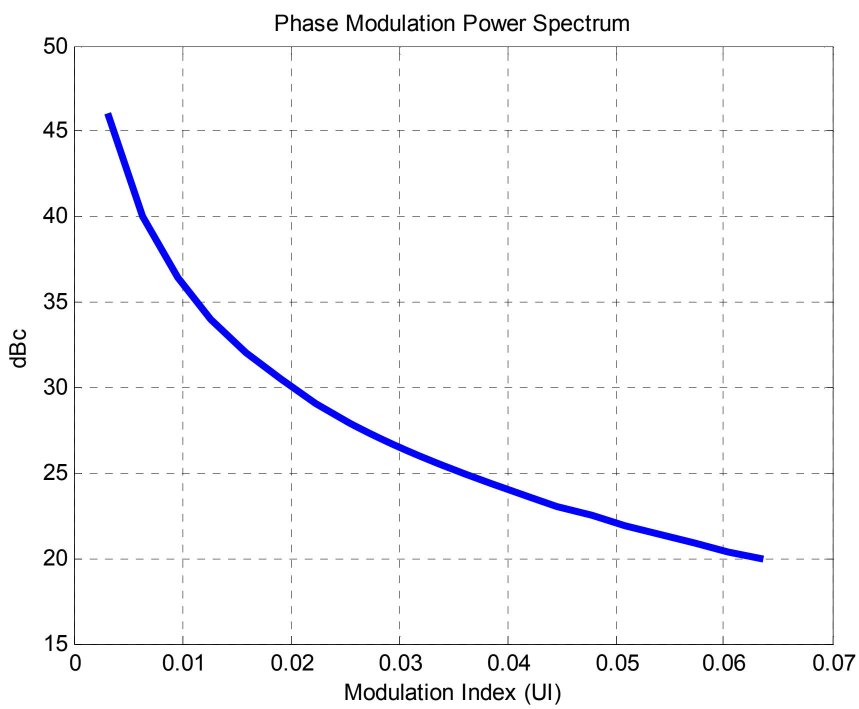
$F(P_n)$ is the inverse spectral SSB power to time modulation (below)

1. Traditional measurements are performed for 60 seconds using a demodulator and performing a real time peak to peak measurement of the jitter. Given this, the number of bits transmitter across the link in 60 seconds is calculated and the associated three sigma confidence level, peak to peak multiplication factor, Q, for the random jitter.

$$\tau_{pkpk} = 2Q\tau_{rms} + \sum_{n} F(P_n)$$

P_n is the relative SSB power of a spur

Figure 2-29.Single Side Band Relative Power Spectrum for Phase Modulated Signal



Uncorrelated High Probability Jitter

After measuring the Gaussian Jitter, as above, an oscilloscope measurement, as per Appendix 2.E.7, of the peak to peak jitter should be performed using a 101010 pattern.

The Uncorrelated High Probability Jitter is then calculated by removing the accumulated Unbounded Gaussian jitter.

$$\tau_{UBHJ} = \tau_{pkpk} - 2Q\tau_{rms}$$

using a Q calculated for a 3 sigma confidence level[1] as per Appendix 2.F.3.

1. It is recommended that enough samples on the oscilloscope should be made such that Q>4

Total High Probability Jitter

After measuring the Unbounded Gaussian Jitter, as above, an oscilloscope measurement, as per Appendix 2.E.7, of the peak to peak jitter should be performed using the standard pattern e.g. PRBS31.

The Total High Probability Jitter is then calculated by removing the accumulated Gaussian jitter.

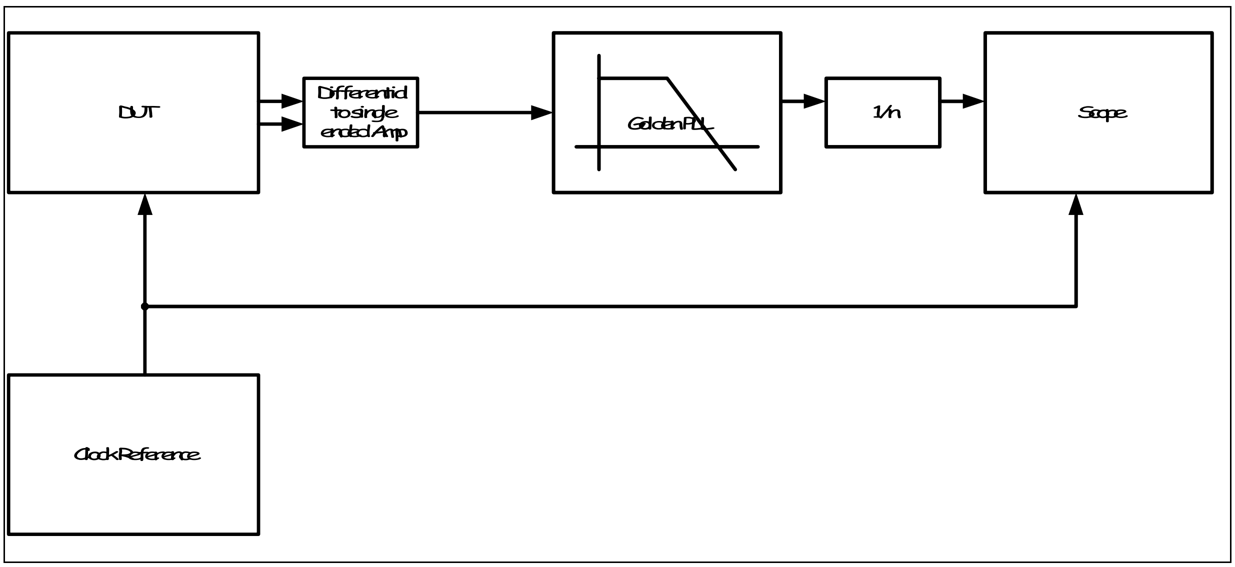
$$\tau_{HPJ} = \tau_{pkpk} - 2Q\tau_{rms}$$

using a Q calculated for a 3 sigma confidence level[1] as per Appendix 2.F.3.

2.E.2 Appendix - Total Transmit Wander Measurement

This sub-clause describes the total transmit wander of a simple non-equalized transmitter as depicted below

Figure 2-30.Transmit Wander Lab Setup



- The transmitter under test shall transmit the specified data pattern, while all other signals are active.
  - — The other channels can transmit the same pattern if they have at least a 16 bit offset with the channel under test.
  - — All lanes to be active in both transmit and receive directions, and opposite ends of the link, i.e. transmit to receiver, are to use asynchronous clocks (to maximum allowed ppm. offset as specified in the protocol specifications).
- The transmitter can be tested single ended as high frequency jitter components are filtered by the Golden PLL

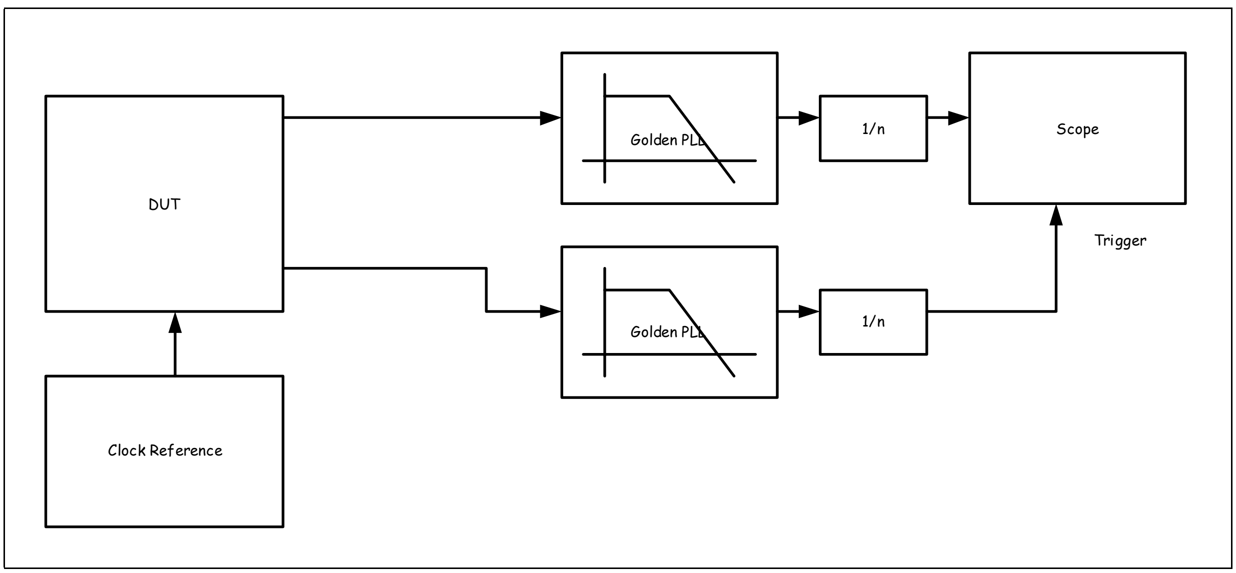
1. It is recommended that enough samples on the oscilloscope should be made such that Q>4

- Temperature and Supply Voltage should be cycled with a rate slower than baud rate over 166700Hz during test to exercise any delay components in the DUT.
- The inherent clock wander in signal shall be extracted using Golden PLL and divided, by the 1/n block, such as to limit the measured wander to 1UI at the divided frequency, and thus allowing it to be measured on an oscilloscope.
  — The Golden PLL should have at a minimum bandwidth of baud rate over 1667, with a maximum of 20dB/dec rolloff, until at least baud rate over 16.67, and is suggested to have no peaking around the corner frequency.
- The peak to peak total wander of the extracted clock should be measured using a scope trigger by the reference clock. The measured peak to peak wander should be verified to be bounded by repeating the measurement for ever increasing periods of time until the measurement is constant.

2.E.3 Appendix - Relative Transmit Wander Measurement

This sub-clause describes specifically for SxI-5 interfaces, where limitations are defined in terms of relative wander between data lane and clocks, whose relative wander can be measured as depicted below.

Figure 2-31.Relative Wander Lab Setup



- The transmitter under test shall transmit the specified data pattern, while all other signals are active.
  — The other channels can transmit the same pattern if they have at least a 16 bit offset with the channel under test.
  — All lanes to be active in both transmit and receive directions, and opposite ends of the link, i.e. transmit to receiver, are to use asynchronous clocks (to maximum allowed ppm. offset as specified in the protocol specifications).
- The transmitters can be tested single ended as high frequency jitter components are filtered by the Golden PLL

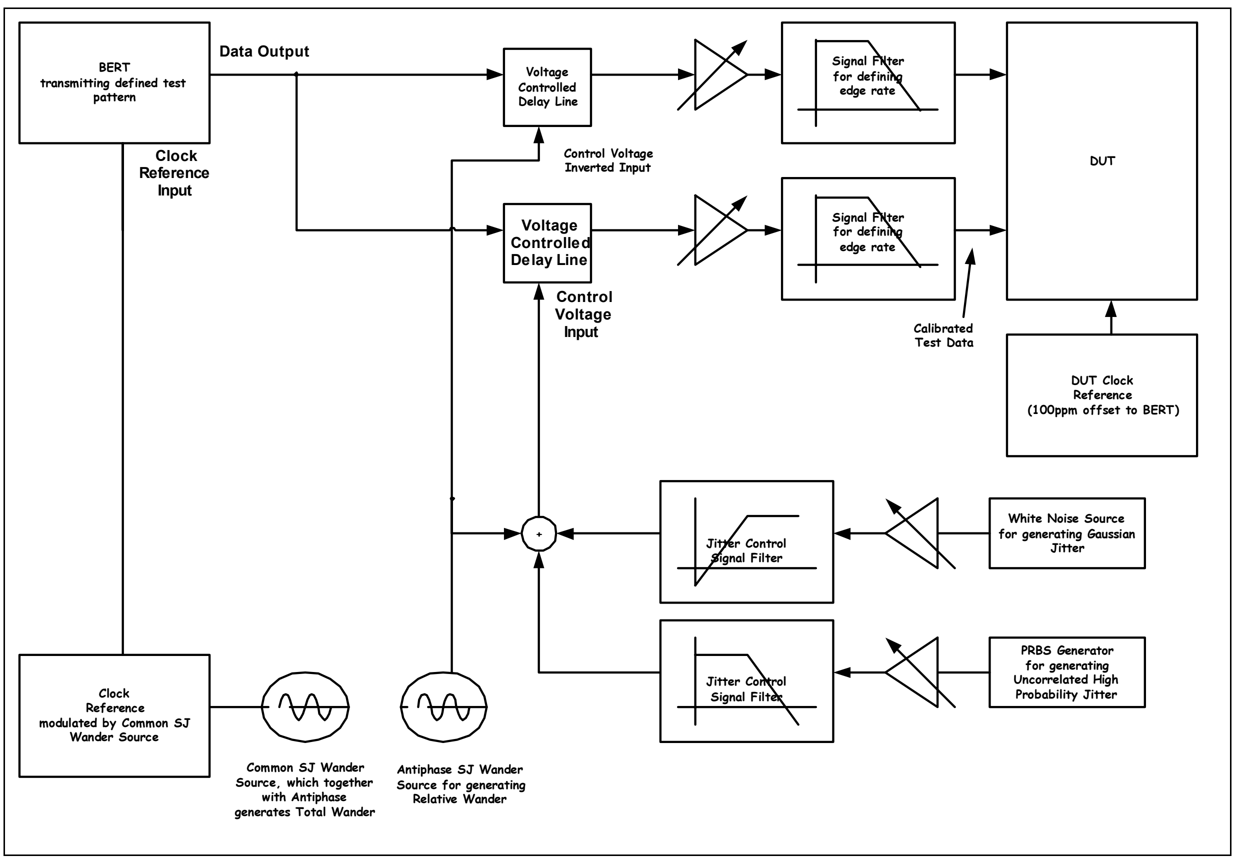
- Temperature and Supply Voltage should be cycled with a rate slower than baud rate over 166700Hz during test to exercise any delay components in the DUT.
- The inherent clock wander in each signal shall be extracted using Golden PLL and divided, by the 1/n block, such as to limit the measured wander to 1UI at the divided frequency, and thus allowing it to be measured on an oscilloscope.
  - — The Golden PLL should have at a minimum bandwidth of baud rate over 1667, with a maximum of 20dB/dec rolloff, until at least baud rate over 16.67, and is suggested to have no peaking around the corner frequency.
- The peak to peak relative wander between the extracted clocks should be measured using a scope trigger by one of the extracted clocks. The measured peak to peak wander should be verified to be bounded by repeating the measurement for ever increasing periods of time until the measurement is constant.

2.E.4 Appendix - Jitter Tolerance

2.E.4.1 Appendix - Jitter Tolerance with Relative Wander Lab Setup

The following sub-clause describes the required jitter tolerance methodology for devices where Relative Wander is applicable e.g. SxI.5 and where no receive equalization is implemented.

Figure 2-32.Jitter Tolerance with Relative Wander Lab Setup



General

- The transmitter under test shall transmit the specified data pattern, while all other signals are active.
  - — The other channels can transmit the same pattern if they have at least a 16 bit offset with the channel under test.
  - — All lanes to be active in both transmit and receive directions, and opposite ends of the link, i.e. transmit to receiver, are to use asynchronous clocks (to maximum allowed ppm. offset as specified in the protocol specifications).
- The Device Under Test (DUT) shall be tested using an internal BERT or loop to have the defined BER performance
- The confidence level of the BER measurement should be at least three sigma as per Appendix 2.F.2.

Synchronization

- All lanes are to be active in both transmit and receive direction.
- All reference clocks should have the maximum offset frequency, with respect to each other, as defined in the implementation agreement.

Jitter

- The applied calibrated test signal shall have applied a calibrated amount of HF GJ and HPJ
- The jitter control signal for generating High Probability Jitter should be filtered using at least a first order low pass filter with a corner frequency between 1/20 - 1/10 of the baud rate of the PRBS generator to ensure that high frequency components are removed. The distribution of the jitter after the filter must be reasonably even, symmetrical, and large spikes should be avoided. The order of the PRBS polynomial may be between 7 and 11, inclusive, to allow flexibility in meeting this objective. The rate of the PRBS generator should be between 1/10 - 1/3 of the data rate of the DUT being tested, and their rates must be not harmonically related. The upper -3 dB frequency of the filtered HPJ should be at least 1/100 of the data rate of the DUT being tested to represent transmitter jitter that is above the tracking frequencies of the DUT's CDR. Calibration of HPJ must be done with a golden PLL in place. Once these objectives are achieved, there is no need to vary these settings; any combination of settings that meets all the objectives is satisfactory.
- The jitter control signal for generating Unbounded Gaussian Jitter shall be filtered as per Figure 2-5 using the “Jitter Control Signal Filter”. However, the upper frequency of the Gaussian jitter spectrum will be, acceptably, limited by the bandwidth of the voltage controlled delay line. The crest factor of the White Noise generator should be better than 18dB.
- The calibrated test signal shall have a calibrated amount of Total Wander and Relative Wander as compared to the *used* clock by using the Common SJ Wander and Antiphase SJ Sources with 1% frequency offsets. (Note the use of the inverted input to the uppermost delay line), as per Annex 2.C.2

- The amplitude of the Total Wander and Relative Wander is defined by the sinusoidal masks defined in Annex 2.A.1 and Annex 2.A.2 with the specified amplitudes from the implementation agreement.
- Wander should be applied
  - — from a frequency equivalent to 1UI of Total Jitter up to 20MHz modulation frequency
  - — at a maximum of 2MHz frequency steps above the corner frequency
  - — at a maximum of 200kHz frequency steps below the corner frequency.

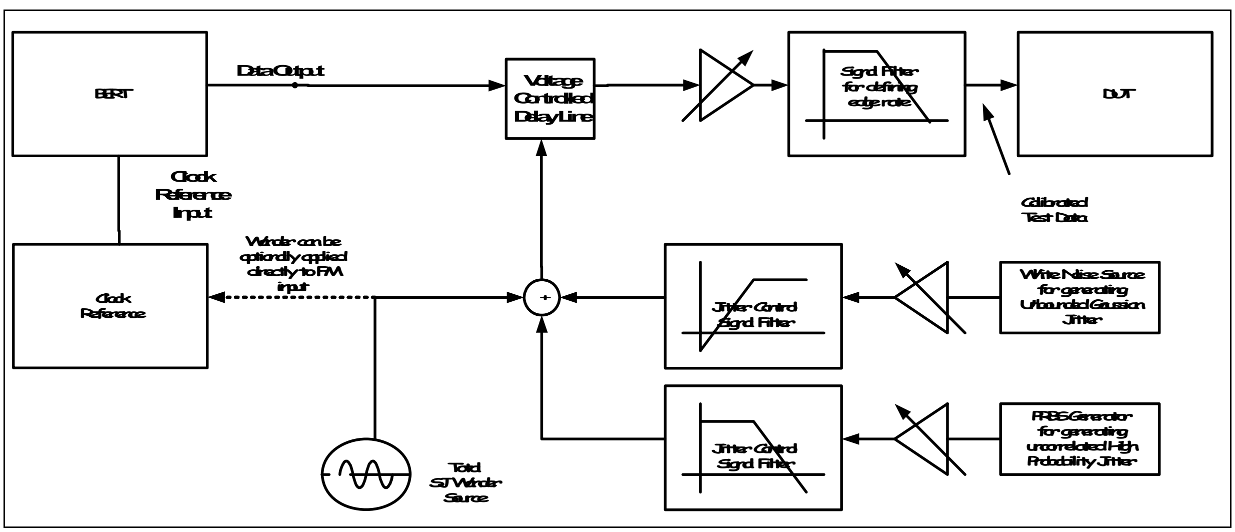
Amplitude

- The calibrated data signals should be filtered using a single pole low pass filter with a corner frequency of 0.7 times the baud rate, to define the edge rate.
- The amplitude of signal should be adjusted such that it *just passes* the defined receiver data eye sensitivity.
- For testing of DC coupled receivers either a pattern generator capable of generating differential signals and setting the common mode should be used or a combined AC coupled signal together with a biased-T. Using this setup the common mode should be varied between the defined maximum and minimum.

2.E.4.2 Appendix - Jitter Tolerance with no Relative Wander Lab Setup

The following sub-clause describes the required jitter tolerance methodology for devices where Relative Wander is not applicable and no receive equalization is implemented.

Figure 2-33.Jitter Tolerance with no Relative Wander

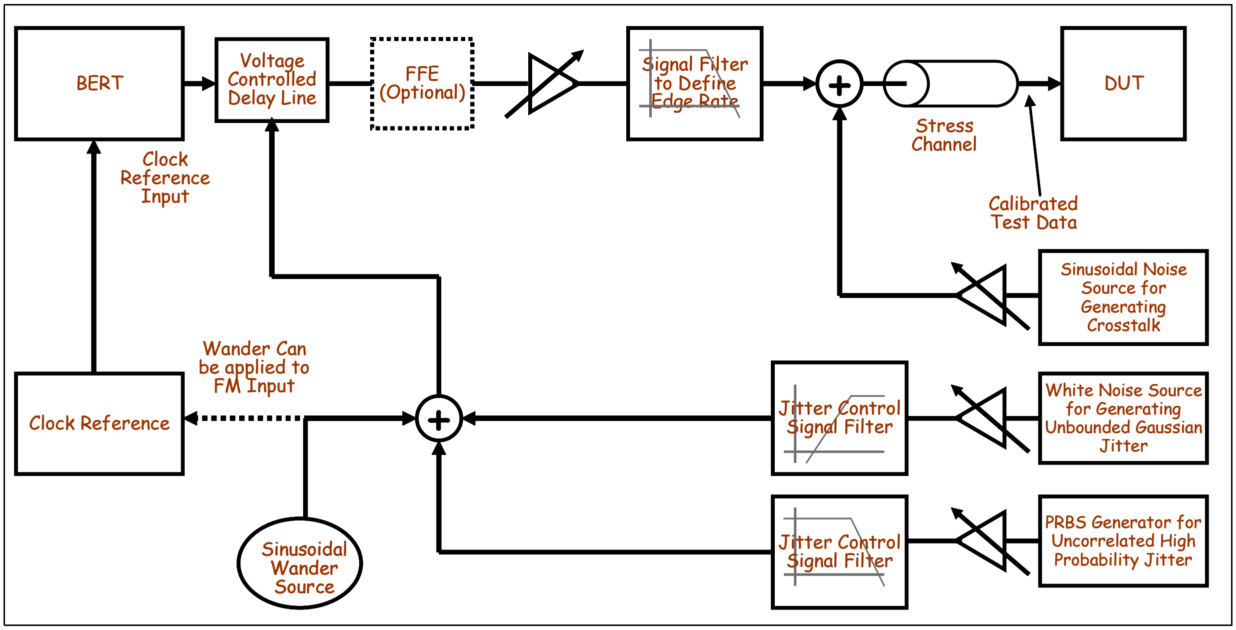


Referring to Figure 2-33, the DUT shall be tested as per the description in Appendix 2.E.4.1, omitting any requirements relating to relative wander and where only Total Wander is applied via the SJ Source shown.

2.E.4.3 Appendix - Jitter Tolerance with Defined ISI and no Relative Wander

The following sub-clause describes the required jitter tolerance methodology for devices where Relative Wander is not applicable e.g. SxI.5 and where receive equalization is implemented and the performance of the equalization must be verified.

Figure 2-34.Jitter Tolerance with Defined ISI



Referring to Figure 2-34, the DUT shall be tested as per the description in Appendix 2.E.4.1, omitting any requirements relating to relative wander, and additionally

- The transmit jitter and amplitude shall be initially calibrated as per Appendix 2.E.1 at the output of the delay line.
- The stress channel shall have the characteristics specified in the relevant test method.
- The use of a Transmit Equalizing Filter (FFE) is optional. If it is included then its characteristics should be adjusted in accordance with the relevant test method.
- The defined amount of uncorrelated additive noise shall be applied via a sinusoidal source differentially to the signal. The frequency used shall be between 100MHz and the lesser of 1/4 the data rate and 2GHz. There is no need to sweep the frequency.

2.E.5 Appendix - Jitter Transfer

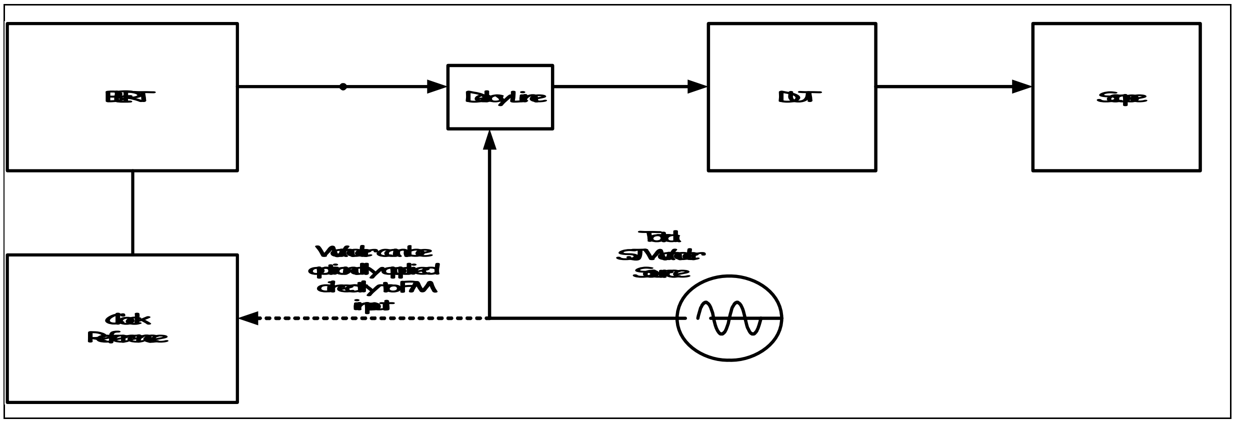
This section describes how jitter transfer relevant interfaces can be tested for compliance, e.g. CEI-11-SR-Transparent, SxI-5. Referring to Figure 2-35

- The BERT shall generate a data pattern as defined by the IA
- The jitter present before the delay line should be minimized as much as possible so as to maximize any transfer bandwidth function of the DUT

- A sinusoidal jitter should be applied following the same defined SJ mask as used for jitter tolerance, with the same resolution as described in Appendix 2.E.4.

The peak to peak jitter for a 60 second period measured on the scope should be compared before and after the application of the sinusoidal jitter. The ratio of the difference to the jitter applied is then defined as the jitter transfer function.

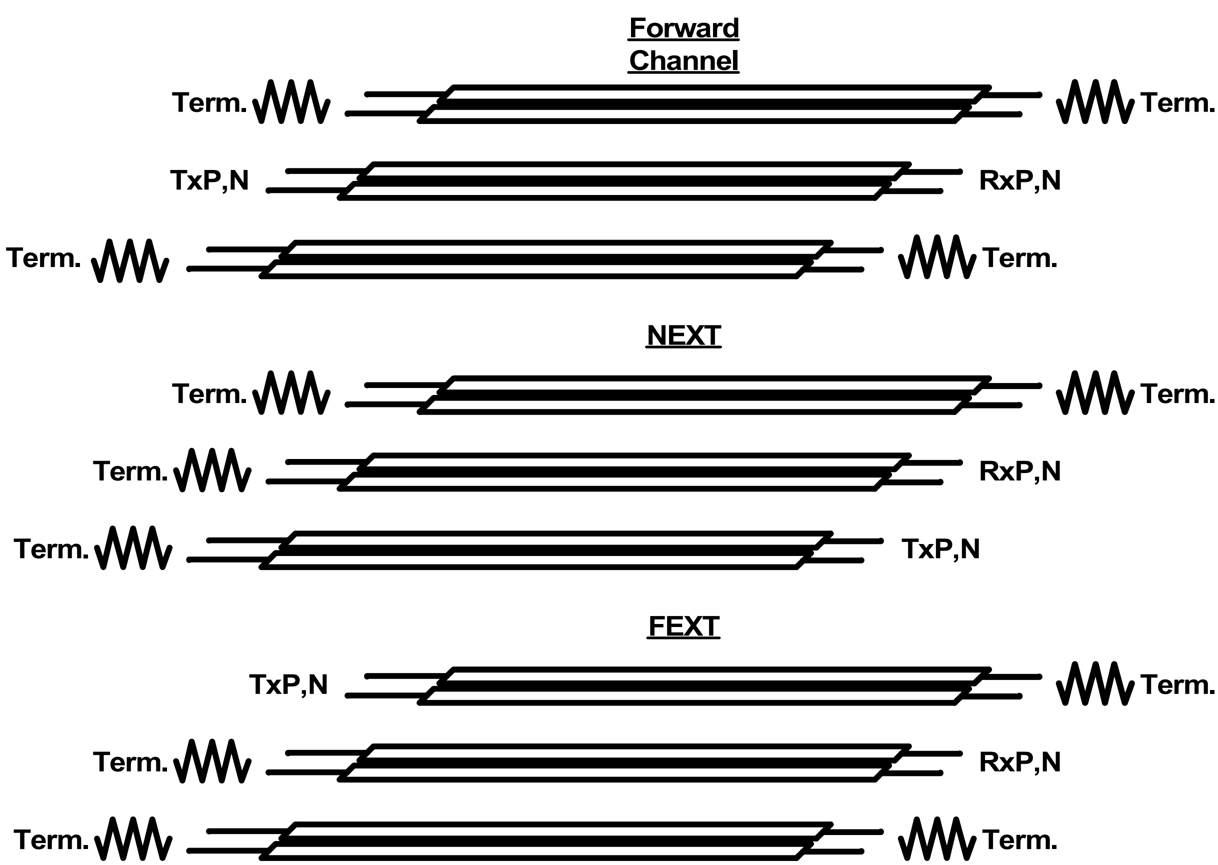
Figure 2-35.Jitter Transfer Lab Setup



2.E.6 Appendix - Network Analysis Measurement

To enable accurate analysis of a channel the following methodology should be followed for the measurement and calculation of the effective channel transfer function.

Figure 2-36.S-parameter Port definitions



- Figure 2-36 shows an overview of the termination and port definitions typically used when measuring the forward channel and NEXT/FEXT crosstalk aggressors
- The intermediate frequency (IF) bandwidth should be set to a maximum of 300 Hertz with 100 Hertz preferred. The launch power shall be specified to the highest available leveled output power not to exceed 0 dBm.[1]
- Either direct differential measurements of the channel S21 and S11 should be performed or multiple single ended measurements from which the differential modes should be calculated.[2]
- Linear frequency steps of the measurements shall be no larger than 12.5MHz.
- A frequency range from no higher than 100MHz to no lower than three times the fundamental frequency should be measured.

1. Please refer to Agilent PLTS data sheet #5989-0271EN, and Agilent TDR Users Guide #54753-97015, section 2.2
2. Special care must be taken when performing multiple single ended measurements if the system is tightly coupled

- Extrapolation towards DC should be performed linearly on magnitude part with the phase being extrapolated to zero at DC, i.e. only a real part is present at DC.
- The channel response of the channel should be calculated by cascading the complete 4 port s-parameter matrix with a worst case transmitter and receiver. The transmitter/receiver should be described as a parallel R and C, where R is the defined maximum allowed DC resistance of the interface and C is increased until the defined maximum Return Loss at the defined frequency is reached.
- Any defined effective transmit or receiver filters should also be cascaded with the channel response
- The time resolution should be increased by resampling the impulse response in the time domain
- If required interpolation of the frequency domain should be performed on the magnitude and unwrapped phase components of the channel response

$$Tr(\omega) = \begin{bmatrix} 1 & 1 \\ 1 & Tx_{22}(\omega) \end{bmatrix} \otimes \begin{bmatrix} S_{11}(\omega) & S_{21}(\omega) \\ S_{12}(\omega) & S_{22}(\omega) \end{bmatrix} \otimes \begin{bmatrix} Rx_{11}(\omega) & 1 \\ 1 & 1 \end{bmatrix}$$

where

$S_{m,n}$ is the measured 4 port differential data of the channel

Tx_{22} is the transmitter return loss

Rx_{11} is the receiver return loss

$Tr(\omega)$ is the receiver return loss

converting the original frequency range to time domain, we obtain

$$i(t_m) = ifft(Tr(\omega))$$

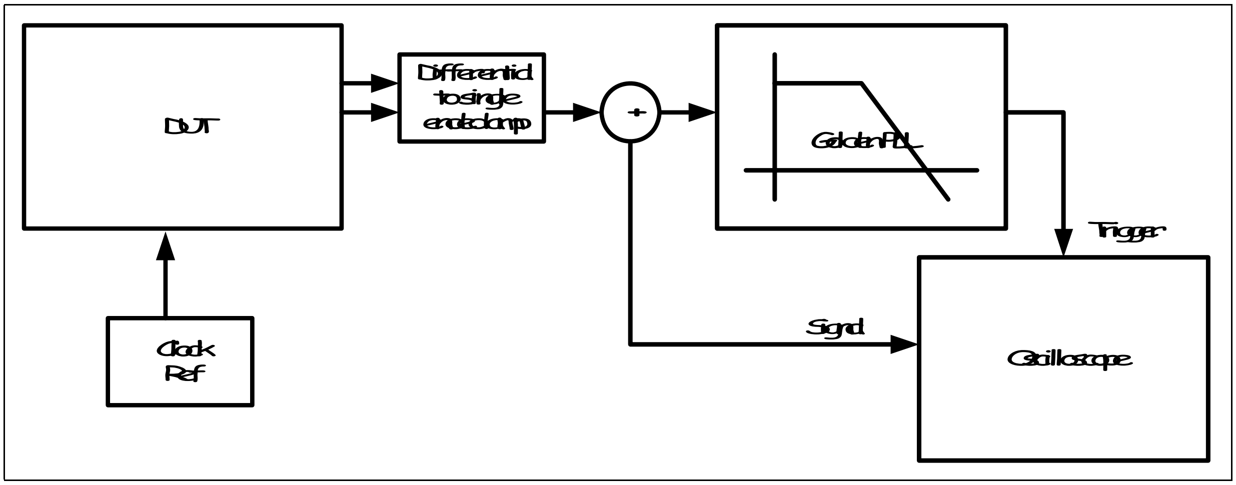
where

$$\omega = [-\frac{3}{4}f_{baud}, \frac{3}{4}f_{baud}]$$

2.E.7 Appendix - Eye Mask Measurement Setup

The measurement of an eye mask is defined by the various Implementation Agreements in terms of a polygon for the probability of the required Bit Error Rate. This polygon may have to be altered given that the sample population of the scope is limited and must be adjusted as per Appendix 2.F.3. For the measurement of the signal the laboratory setup shown in Figure 2-37 should be used, including the recommendations list in Appendix 2.E.1.

Figure 2-37.Eye Mask Measurement with Golden PLL



2.F Appendix - BER Adjustment Methodology

2.F.1 Appendix - Extrapolation of Correlated Bounded Gaussian Jitter to low BERs

For IAs with BER requirements of 1×10^{-15} or lower, measurements to that level are very time consuming (or rely on averaging multi-links), hence more practical to only take measurements to Qs around 7 (BER around 1×10^{-12}).

Bathtub Measurements

CBGJ can appear as either GJ or CBHPJ depending upon the Q at which it is linearised.

If HPJ and GJ are measured using a bathtub there is no knowledge as to if the GJ is UUGJ or CBGJ. For system budgeting it is recommended that the bathtub GJ should be assumed to be all UUGJ.

If combined spectral, oscilloscope methods are used then UUGJ, UBHPJ and CBHPJ can be estimated. It is not possible to estimate the CBGJ as it has already become bounded and appears as CBHPJ. For system budgeting it is recommended that this peak value is valid for the extrapolated Q of interest.

2.F.2 Appendix - Confidence Level of Errors Measurement

Assuming that a link, with a given BER, can be modelled as a Bernoulli random process, the following statistics can be assumed.

Given,

p is the probability of error

$q = (1 - p)$ is the probability of not erroring

n is the number of bits received and measured

then,

$m = np$ is the expected number of errors received

$\sigma = \sqrt{npq}$ is the sigma of the variation of the number of errors received

As an example process, for a 3 sigma confidential level

$$p = 10^{-12}$$

$$n = 100 \cdot 10^{12}$$

$$m = 100$$

$$\sigma = 10$$

$$m\Big|_{max}^{min} = [m + Q\sigma]\Big|_{Q=-3}^{Q=3}$$

$$m\Big|_{max}^{min} = \begin{matrix} 70 \\ 130 \end{matrix}$$

To assess the accuracy of such a measurement an equivalent process with a higher BER can be calculated that would show the same limit of error for the same confidence level and measured number of bits.

$$m|_{max} = E[m] - Q\sigma$$
$$m|_{max} = np - Q\sqrt{npq}$$
$$m|_{max} = np - Q\sqrt{np(1-p)}$$

Solving the quadrative equation for p

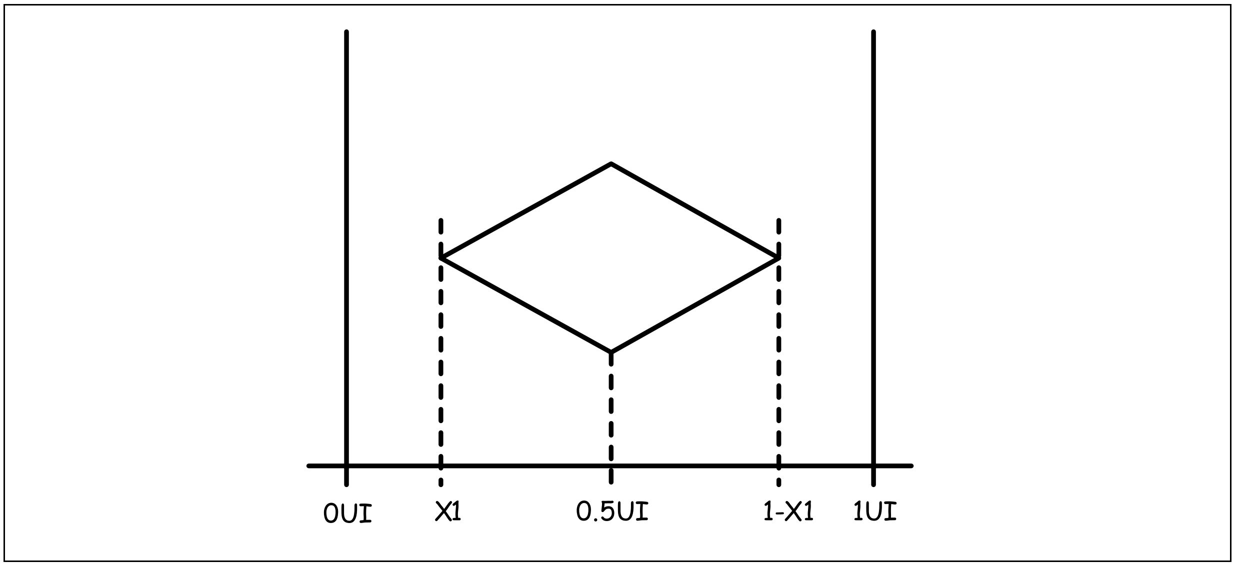
$$p = 1.69 \times 10^{-12}$$

2.F.3 Appendix - Eye Mask Adjustment for Sampling Oscilloscopes

In all Interoperability Agreement the data mask is defined for the bit error rate of the link. Given that this bit error rate is very small, typical oscilloscope measurement will not sample enough points to be able to verify compliance to these mask.

2.F.3.1 Appendix - Theory

Figure 2-38.Example Data Mask



Given an example eye mask, Figure 2-38, the extremes of the mask, X1 are defined as a linear addition of a Gaussian and High Probability jitter component.

$$X1 = \frac{HPJ}{2} + Q \cdot GJ_{rms}$$

where

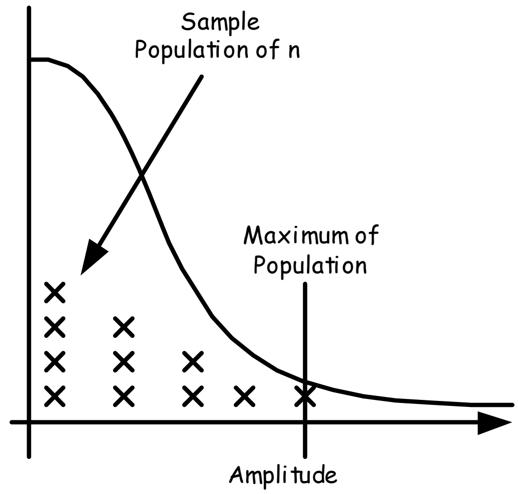
HPJ is the high probability jitter

GJ_{rms} is the gaussian distributed jitter

Q is the GJ multiplication factor

Given a low sample population and the requirements for mask verification to achieve a hit or no-hit result, X1 must be adjusted according to the sample population and the confidence level that a particular peak to peak is achieved., Given a random process

Figure 2-39.Example Data Mask



the probability of measuring a particular maximum amplitude on an oscilloscope, requires one sample to lie on the maximum and all other samples to lie below this value. Referring this all to a half Gaussian distribution and a population of n, there are n different ways this can occur,

$$P(x_m) = nQ(x_m)\left(\int_0^{x_m} Q(x)dx\right)^{n-1}$$

where

x_m is the random variable of the maximum amplitude measured

x is the random variable of the underlying random jitter process

$Q(x)$ is the Q function of the Normal probability density function

n is the sample population

$P(x_m)$ is a probability density function

The equation above is solved and the probability of attaining a given maximum (normalized to the sigma) for various populations plotted, Figure 2-40.

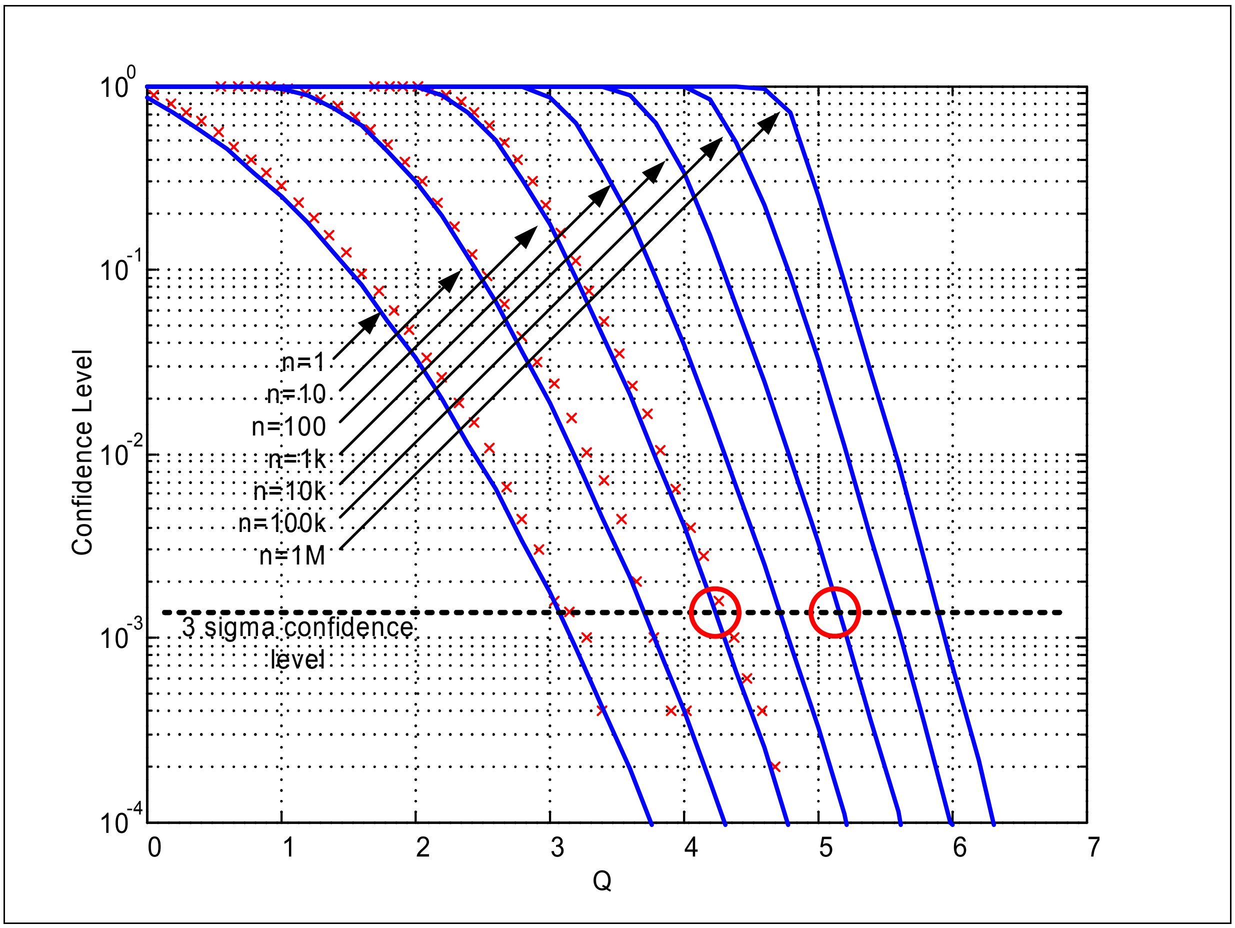
2.F.3.2 Appendix - Usage

Given a known sampling population, n, calculated from the measurement time, average transition density and sampling/collection frequency of the oscilloscope the three sigma confidence level (i.e. 1.3×10^{-3}) of the measured Gaussian jitter peak value can be read from Figure 2-40. This value should be multiplied by 2 to give the full peak to peak value of the random jitter.

The three sigma confidence level should be understood as ensuring that 99.96% of all good devices do not violate the eye mask. To limit the number of bad devices that also pass the eye mask it is strongly recommended that the sample population be chosen as to give a Q larger than 5.

e.g. refering to the red circled intersections Figure 2-40, if we calculate that the sample population for an oscilloscope was 100 i.e. n=100, then for a 3 sigma confidence this equals a Q of 4.2. As the recommended Q value is 5 we should increase the sample population to 10k to give a Q of 5.2.

Figure 2-40.Cumulative Distribution Function of Maximum Amplitude



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3 Common Electrical Specification

3.1 Introduction

This clause specifies electrical parameters and attributes common to all links defined in clause 1. In the event of a difference between an individual clause and these general requirements, the respective individual clause shall prevail.

3.2 General requirements

3.2.1 Data Patterns

This IA does not have any requirements for specific data patterns (i.e. 8B/10B, 64/66B, SONET scrambling, stream cipher, raw data, etc.), however the following requirements are necessary to insure proper operation. If all of these conditions are not met, then the link may not work to the full distance, or meet the BER, or in fact work at all.

- Average transition density needs to converge to 0.5 over a long period ($>10^9$ bits), but can in the extreme be between 0.45 and 0.55 over a 30,000 bit period with a probability of at least one minus the BER ratio ($1-10^{-15}$ with a test requirement to verify $1-10^{-12}$)
- Average DC balance needs to converge to 0.5 over a long period ($>10^9$ bits), but can in the extreme be between 0.45 and 0.55 over a 30,000 bit period with a probability of at least one minus the BER ratio ($1-10^{-15}$ with a test requirement to verify $1-10^{-12}$).
- Probability of run lengths over 10 to be proportional to 2^{-N} for N-like bits in a row ($N \geq 10$). Hence, a run length of 40 bits would occur with a max probability of 2^{-40}.
- If a fixed block coding scheme is used (e.g. 8B/10B, SONET), the raw data must be scrambled before coding or the coded data must be scrambled prior to transmission. This is to prevent the so called worst case patterns (e.g. CJPAT-like patterns).

SONET can be viewed as a coding scheme that can create worst case patterns (via the un-encoded overhead bytes). Two such cases would be the A1/A2 pattern and the Z0 byte that can be anything (each unscrambled byte is repeated N times in an OC-N stream [N = 3, 12, 48, 192]).

3.2.2 Signal Levels

The signal is a low swing differential interface. This implies that the receiver has a wide common mode range (within the max. absolute input voltages). All devices must support load type 0 defined in Table 3-1, SR devices can optionally support any/all of the other 3 load types while LR devices can optionally support load type 1.

Table 3-1. Definition of load types

Characteristic	Load Type 0	Load Type 1	Load Type 2	Load Type 3	Unit
R_Zvtt	>1k	<30	<30	<30	Ω
Nominal Vtt	undefined	1.2	1.0	0.8	V

This type of differential interface allows for interoperability between components operating from different supply voltages and different I/O types (CML, LVDS-like, PECL, etc.). Low swing differential signaling provides noise immunity and improved electromagnetic interference (EMI). Differential signal swings are defined in following sections and depend on several factors such as transmitter pre-equalization, receiver equalization and transmission line losses.

3.2.3 Bit Error Ratio

The link will operate with a Bit Error Ratio (BER) of 10^{-15} (with a test requirement to verify 10^{-12} - see Clause 2 for more information on the jitter model and how to measure BER)

3.2.4 Ground Differences

The maximum ground difference between the driver and the receiver shall be ±50mV for SR links and ±100mV for LR links. This will affect the absolute maximum voltages at compliance point 'R'. If driver and receiver are on the same PCB with no intervening connectors, then the ground difference is approximately 0 mV.

3.2.5 Cross Talk

Cross talk arises from coupling within the connectors, on the PCB, the package and the die. Cross talk can be categorized as either Near-End or Far-End Cross talk (NEXT and FEXT). In either of these categories, the amount of cross talk is dependent upon signal amplitudes, signal spectrum, and trace/cable length. There can be many aggressor channels onto one victim channel, however typically only a few are dominant.

Further consideration of Crosstalk can be found in Appendix 3.A.4.

3.2.6 Driver Test Load

All driver characteristics should be implemented and measured to a differential impedance of 100Ω±1% at DC with a return loss of better than 20dB from baud rate divided by 1667 to 1.5 times the baud rate, unless otherwise noted.

3.2.7 Driver Lane-to-Lane Skew

While the protocol layer will control some of the lane to lane skew, the electrical level is allowed up to 500ps of lane-to-lane skew caused by the driver circuitry and associated routing. Hence, the total output (i.e. measured) lane-to-lane skew is to be specified in the protocol standards with this 500ps taken into account. The driver lane-to-lane skew is only for the Serdes TX and does not include any effects of the channel.

3.2.8 Input Lane-to-Lane Skew

While the protocol layer will control the maximum amount of lane to lane skew that is allowed, it must allow for up to 1000ps of skew caused by the driver & receiver circuitry and associated routing (that is 500ps for the driver and 500ps for the Rx). The input lane-to-lane skew does not include any skew effects of the channel.

3.2.9 Driver Short Circuit Current

The max DC current into or out of the driver pins when either shorted to each other or to ground shall be ±100mA when the device is fully powered up. From a hot swap point of view, the ±100mA limit is only valid after 10 µs

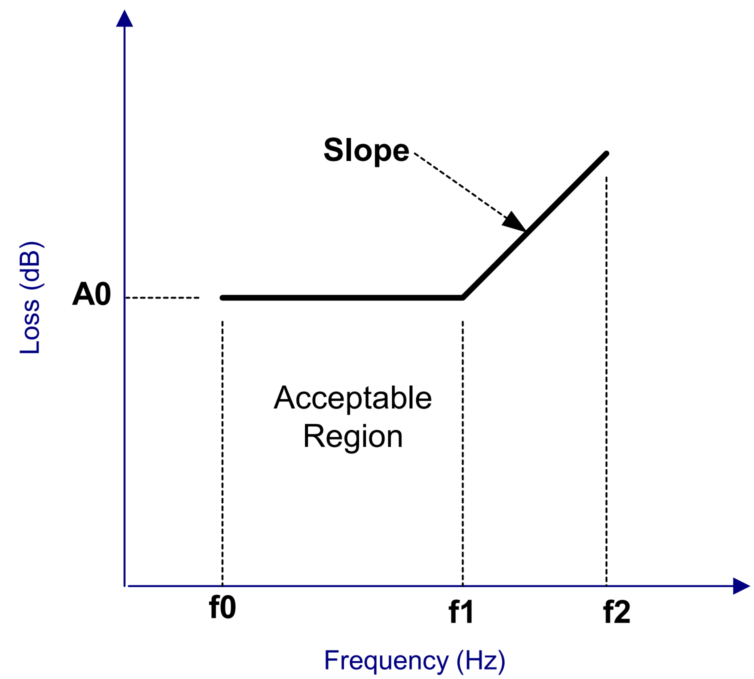
3.2.10 Differential Resistance and Return Loss, Driver and Receiver

The DC differential resistance shall be between 80 and 120Ω.

The differential return loss shall be better than A0 from f0 to f1 and better than A0 + Slope*log10(f/f1) where f is the frequency from f1 to f2. See Figure 3-1 for definitions. Differential return loss is measured at compliance points T and R. If AC coupling is used, then all components (internal or external) are to be included in this requirement. The reference impedance for the differential return loss measurements is 100Ω.

Common mode return loss measurement shall be better than -6dB between a minimum frequency of 100MHz and a maximum frequency of 0.75 times the baud rate. The reference impedance for the common mode return loss is 25Ω.

Figure 3-1.Driver and Input Differential Return Loss



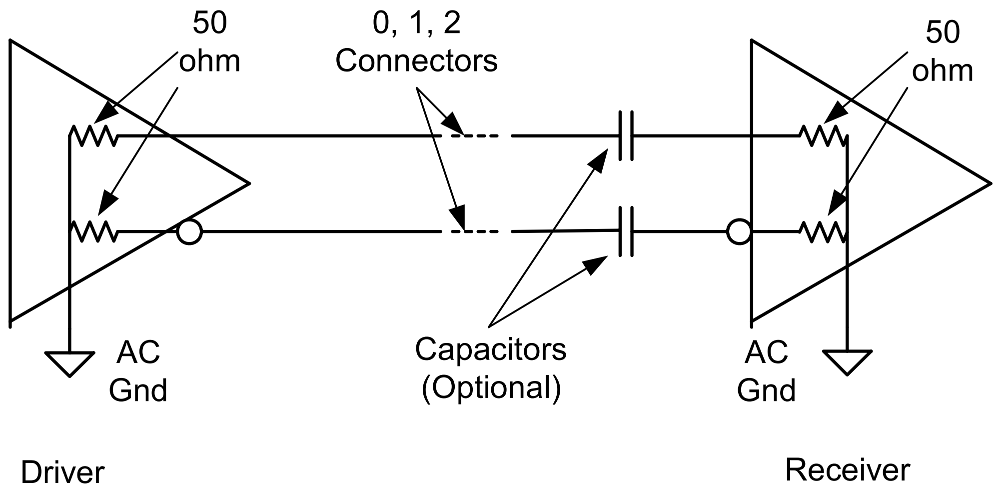
3.2.11 Baud Rate Tolerance

The range of operating Baud rates is defined specifically for each interface in the specific clauses. Each CEI interface is required to operate asynchronously with a tolerance of +/-100ppm from the nominal baud rate.

3.2.12 Termination and DC Blocking

Each link requires a nominal 100Ω differential source termination at the driver and a nominal 100Ω differential load termination at the receiver. The terminations shall provide both differential and common mode termination to effectively absorb differential or common mode noise and reflections. Receivers and transmitters shall support AC coupling and may also optionally support DC coupling. AC Coupled receivers require a differential termination >1kΩ at DC (by blocking capacitors in or near receivers as shown in Figure 3-2 or by circuit means within the receiver). DC Coupled Devices shall meet additional electrical parameters T_Vcm, R_Vrcm, R_Vtt, R_Zvtt. All termination components are included within the Rx and TX blocks as shown in the reference model as defined in Section 1.8.

Figure 3-2.Termination Example



3.A Appendix - Transmission Line Theory and Channel Information

3.A.1 Transmission Lines Theory

The performance of a high frequency transmission line is strongly affected by impedance matching, high frequency attenuation and noise immunity.

It is possible to design a high frequency transmission line using only a single conductor. Nevertheless most high frequency signals use differential transmission lines (i.e. a pair of coupled conductors carrying signals of opposite polarity). Although differential signaling appears wasteful of both pins and signal traces it results in much better noise immunity. Differential signals produce less conducted noise because the opposite power and ground current flows cancel each other both in the line driver and in the transmission line. Differential signals produce less radiated noise because over a modest distance the opposite fields induced by the opposite currents cancel each other. Differential signals are less susceptible to noise because most sources of noise (common mode noise) tend to affect both signal lines identically, producing a variation in common mode voltage but not in differential voltage.

3.A.1.1 Impedance Matching.

The AC impedance of a single conductor is determined by the trace geometry, distance to the nearest AC ground plane(s) and the dielectric constant of the material between the trace and the ground plane(s). If the distance between the signal trace and the nearest ground plane is significantly less than the distance to other signal traces the signal trace will behave as a single-ended transmission line. Its AC impedance does not vary with signal polarity although it may vary with frequency due to the properties of the dielectric material. This impedance is often called single ended impedance, Zse.

The AC impedance, Z of a differential transmission line is affected by the configuration of the pair of conductors and the relationship between their signal polarities, in addition to the trace geometry, distance to the nearest AC ground plane(s) and the dielectric constant of the material between the trace and the ground plane(s). If the paired conductors are close enough to interact (coupled), then the impedance for signals of opposite polarity (odd mode impedance, Zodd) will be lower than the impedance for signals of the same polarity (even mode impedance, Zeven).

If there is minimal coupling between the paired conductors then Zodd = Zeven = Zse. Coupled transmission lines always produce Zodd < Zse < Zeven. The following equations relate effective differential impedance, *zdiff* to common mode impedance, *Zcm* and single ended impedance, *Zse* to even and odd mode impedances:

$$Zdiff = 2Zodd \qquad Zcm = \frac{Zeven}{2} \qquad Zse = \frac{Zeven + Zodd}{2}$$

Most differential data signals are designed with *zdiff* = 100Ω and 25Ω < *Zcm* < 50Ω.

There is a trade-off in the choice of *Zcm*. With *Zcm* = 25Ω (no coupling) may reduce conducted noise for transmission lines with inadequate AC or DC grounding. *Zcm* = 50Ω (close coupling) may reduce radiated noise (crosstalk) which is more critical in backplanes. However close coupling requires careful ground construction to control common mode noise.

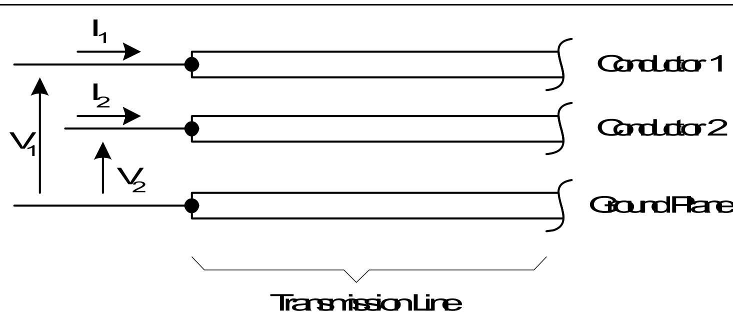
The reader may wonder why common mode impedance is meaningful in a differential transmission system. In a perfectly constructed system only odd mode (opposite polarity) signals propagate. However imperfections in the transmission system cause differential to common mode conversion. Once converted into common mode the energy may convert back to differential mode by the same imperfections. Thus, these imperfections convert some of the signal energy from opposite polarities to the same polarity and back.

The two main sources of mode conversion are impedance mismatches which cause part of the energy to be reflected, and differential skew which causes variations in forward signal propagation delay between the individual paths of the differential pair. Impedance mismatches typically occur at boundaries between transmission line segments, including wire bonds, solder joints, connectors, vias and trace-to-via transitions. Often ignored sources of impedance mismatches at these boundaries are discontinuities within the AC ground itself as well as asymmetric coupling between the individual traces and the AC ground. Differential skew can occur at these same boundaries and also due to mismatched trace lengths in device packages and in PCBs.

3.A.1.2 Impedance Definition Details

Differential transmission lines consist of two conductors and a ground plane. The voltage-current relationships at one end of this line can be formulated in terms of a two-port as in Figure 3-3.

Figure 3-3. Transmission Line as 2-port



The voltage current relationships are:

$$V_1 = Z_{11}I_1 + Z_{12}I_2 \qquad V_2 = Z_{21}I_1 + Z_{22}I_2$$

If the line is infinitely long or perfectly terminated, then these four impedance values are the characteristic impedance of the line. The characteristic impedance is a 2 x 2 matrix:

$$\hat{Z}_c = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

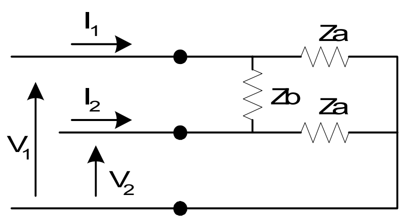
Generally, all four of the matrix entries are complex. But, at frequencies of interest, the inductance and capacitance per unit length dominate so that all four quantities are approximately real, positive numbers. For engineering purposes it is common to speak of the impedances as though they are resistances, with no imaginary part; keeping in mind that the imaginary part exists. Since the line is passive and symmetric, we have $Z_{11} = Z_{22}$ and $Z_{12} = Z_{21}$ so that the line is described by just two impedance values. If the line is to be perfectly terminated, then we must create a network that is equivalent to $\hat{Z}_c$. That is, we need a 3-terminal (2 nodes + ground) network that presents the same values of Z_{11} and Z_{12} as the line. A T or pi network could be used. The pi network is shown in Figure 3-4, along with the impedance values in terms of Z_{11} and Z_{12}.

.

Figure 3-4.PI Network Termination

$$Za = Z_{11} + Z_{12} \qquad Zb = \frac{Z_{11}^2 - Z_{12}^2}{Z_{12}}$$

$$Zodd = \frac{ZaZb}{2Za + Zb} = Z_{11} - Z_{12} \qquad Zeven = Za = Z_{11} + Z_{12}$$



The odd and even mode impedances, *Zodd* and *Zeven*, are other impedance definitions that are more descriptive referring to the polarity of the signal propagating the differential pair. In the case of opposite signal polarity in the two lines of the signal pair the odd mode impedance is used. In the case of same signal polarity the even mode is used. *Zodd* and *Zeven* are measured as shown in Figure 3-5.

Figure 3-5.Measurement of Zodd, Zeven

Zodd	*Zeven*
$V = V_1 = -V_2$	$V = V_1 = V_2$
$I = I_1 = -I_2$	$I = I_1 = I_2$
$Zodd = \frac{V}{I}$	$Zeven = \frac{V}{I}$

Odd mode impedance is the impedance measured when the two halves of the line are driven by equal voltage or current sources of opposite polarity. Even mode impedance is the impedance measured when the two halves of the line are driven by equal voltage or current sources of the same polarity. In this specification the differential mode impedance, *Zdiff* and the common mode impedance*, Zcm* are used. The relationship to even and odd mode impedances is given as:

$$Zdiff = 2Zodd \qquad Zcm = \frac{Zeven}{2} \qquad Zse = \frac{Zeven + Zodd}{2}$$

From the above equations we see that *Zeven* is always greater than *Zodd* by $2Z_{12}$, where Z_{12} is a measure of the amount of coupling between the lines. This means that *Zeven* is larger than *Zodd* for coupled transmission lines*.*

3.A.2 Density considerations

The preceding section showed that, for two idealized forms of termination, *Zodd* is correctly terminated but *Zeven* is not. The first illustrated case, using a 50 ohm resistor (or its equivalent) from either terminal to ground (or to AC ground), has become relatively standard. Because it has *ZoddT* = *ZevenT* = 50 ohm, it provides correct differential termination and is often close to providing correct common-mode termination.

By increasing the conductor spacing in the transmission line we can decrease Zeven (decrease Z_{12}) and bring it closer to 50 ohm. But dense backplanes require a large number of transmission lines per unit cross-sectional area of the printed circuit board. This means that the two printed circuit traces comprising the differential transmission line are forced close together, which increases Z_{12}. The backplane design is therefore, a compromise between the desire for high density of transmission lines and a desire for correct common-mode termination.

Transmission lines act as low-pass filters due to skin effect and dielectric absorption. As the density of transmission lines increases, both the series resistance per unit length and the parallel conductance per unit length increase. This, in turn, results in greater attenuation at a given frequency. Thus, high speed backplane design is not just a compromise between density and common-mode matching. There is also a compromise between density and attenuation.

3.A.3 Common-Mode Impedance and Return Loss

It is demonstrated above that increasing the density of transmission lines in a backplane results in higher common-mode impedance, which is known as interference and for high amplitudes the receiver is likely to be disrupted.

Common-mode interference arises from several sources. Among them are:

1. Imperfections in driver circuits.
2. A difference in length between the two conductors of the transmission line
3. Imperfections in impedance matching across board boundaries connectors and vias causing mode conversion, differential to Common mode
4. EMI.

The interference resulting from the driver probably has a spectrum that is the same as or similar to that of the signal. EMI arising from coupling into the printed circuit traces should be small, assuming that coupled stripline is used. However, connector pins may be exposed. EMI may have frequency components that are well below signal frequencies, which means that it won’t necessarily be attenuated to the extent that signals are. But, at the same time, the lower frequencies are probably poorly coupled into the backplane circuit.

Earlier, two ideal forms of termination were presented based on either one or two resistors. These ideal terminating devices are helpful in examining the relationship between the parameters of the transmission line versus those of the device. Real devices, however, are not simple resistances. They contain parasitic components and a non-ideal path from package pins to die. There may also be a need to AC-couple the terminations.

The most that we can do in this situation is to make the package and the die appear as close to ideal as possible over as much of the signal spectrum as possible. The extent of the deviation from ideal is specified and measured as a function of frequency. The preferred measures are S_{11} (single-ended return loss) or S_{DD11} (differential return loss) as functions of frequency. (Sometimes S_{22} or S_{DD22} are used to indicate an output.) Ideally these return losses are 0 (no reflection) over the frequency range of interest. In dB this is $-\infty$.

Note: Sometimes a return loss is specified as a positive number, it being understood that this still refers to the log of a reflection coefficient in the range of 0 to 1.

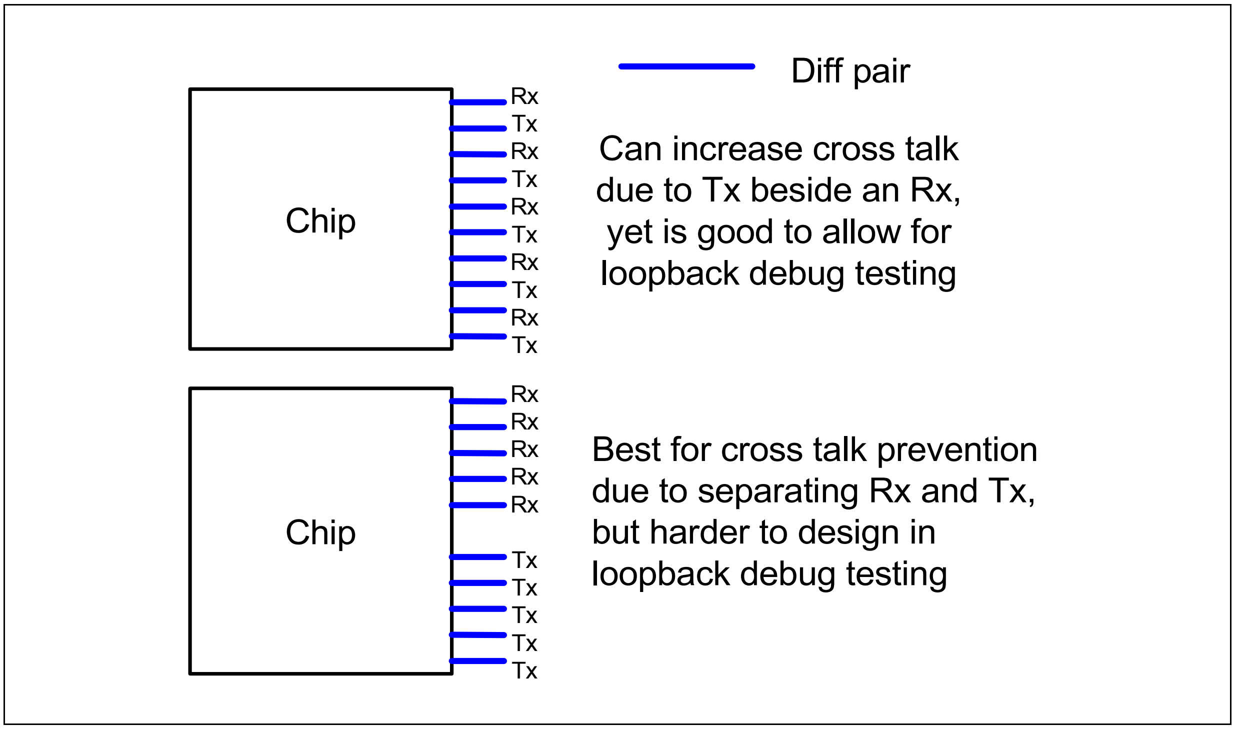
3.A.4 Crosstalk Considerations.

This IA assumes that the dominant cross talk can come from aggressors other than the transmitter associated with the receiver. Hence NEXT cancellation is not useful.

Crosstalk between CEI channels should be minimized by good design practices. This includes the pin-out arrangement to the driving/receiving IC’s, connectors and backplane tracking.

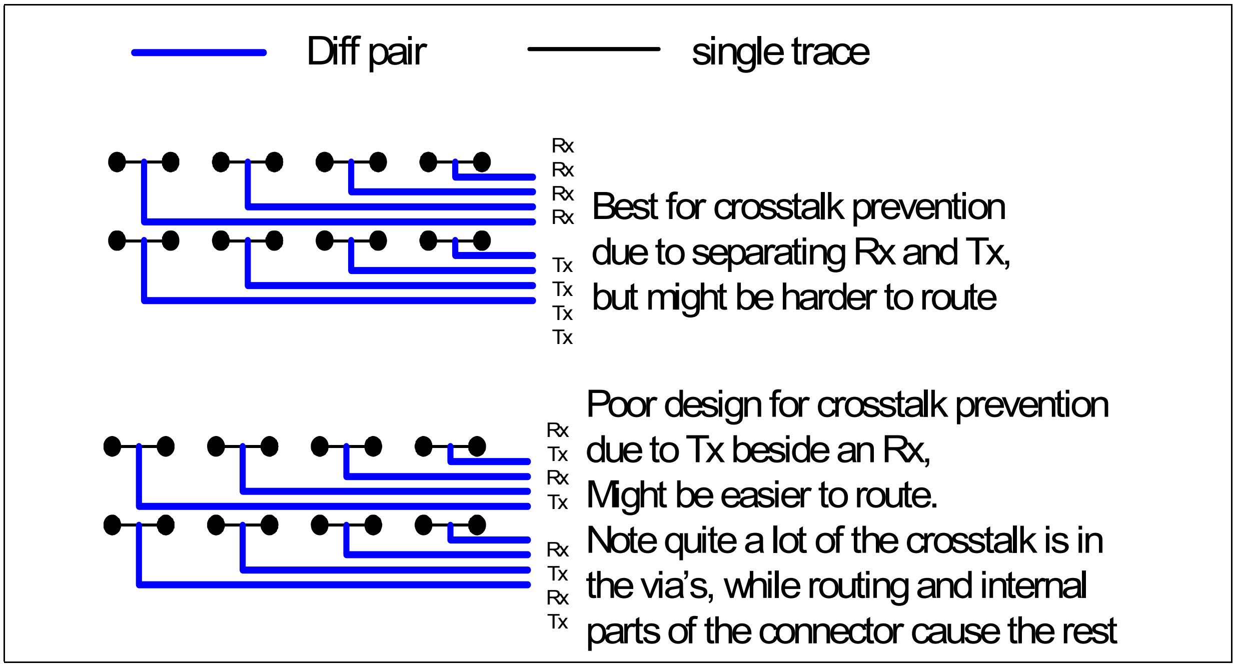
Optimum arrangement for minimising crosstalk between channels at IC pins is illustrated in Figure 3-6 below. Crosstalk between channels can be reduced by grouping TX and RX pins and avoiding close proximity between individual TX and Rx pins. This practice will minimize coupling of noise from TX drivers into RX inputs.

Figure 3-6.Minimisation of crosstalk at IC pins.



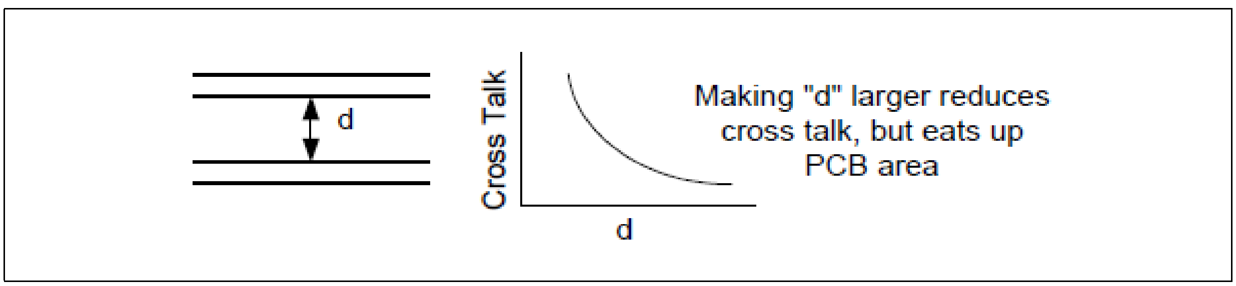
Crosstalk at connector pins can be minimized by careful optimisation of connections as shown in Figure 3-7 below.

Figure 3-7.Minimisation of crosstalk at connector pins



Crosstalk between channels over a backplane can be minimized by careful arrangement of tracking, avoiding coupling of noise into RX inputs and increasing spacing "d" between channels as far as possible as shown in Figure 3-8 below.

Figure 3-8.Minimisation of crosstalk over backplane



3.A.5 Equation based Channel Loss by curve fit.

This section describes a technique with specific limitations. It does not include any phase data for the SDD21, and includes no return loss information about SDD11 or SDD22, neither phase nor magnitude, information that is critical for the evaluation of a specific topology's performance. The above proposed statistical-eye characterization includes these effects by including the full 4-port s-parameter measurements. The following method is included for information only and is believed to be of relevance to the overall understanding of the channel transfer loss.

One way to specify the channel loss is to have an average or worst case “curve” fit to several real channels. This method includes effects of real vias and connectors. This method typically uses the equation below:

$$Att = -20\log(e)\left(a_1\sqrt{f} + a_2 f + a_3 f^2\right)$$

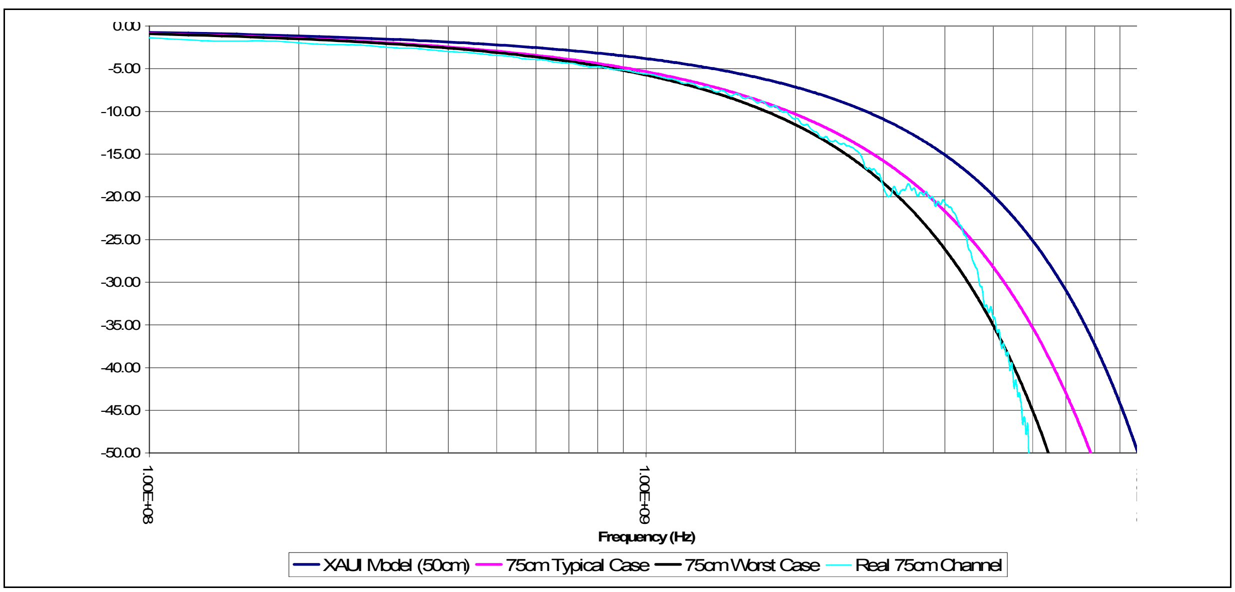
Where f is frequency in Hz, a_1, a_2, & a_3 are the curve fit coefficients and Att is in dB.

Table 3-2 gives some examples of these coefficients and Figure 3-9 plots them along with the PCB model and a real 75cm backplane (with 5cm paddle cards on both ends). These examples are representative for CEI-6G-LR applications but do not represent specifications that a CEI link are to comply with.

Table 3-2. Curve fit Coefficients

	a_1	a_2	a_3
XAUI [19] (50cm)	6.5e-6	2.0e-10	3.3e-20
75cm [24] “Worse”	6.5e-6	3.9e-10	6.5e-20
75cm [24] “Typical”	6.0e-6	3.9e-10	3.5e-20

Figure 3-9.Equation based Channel Loss curves



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4 SxI-5, SFI-4.2, SFI-5.1 & SPI-5.1 Interfaces

4.1 Introduction

This clause details the requirements for the SxI-5 electrical interface (which includes the following three OIF Implementation Agreements SFI-4.2, SFI-5.1 and SPI-5.1).

4.2 General Requirements

This clause uses "Method A" of the Jitter and Interoperability Methodology section.

4.2.1 Channel Compliance

As per 2.1.2, with the following reference transmitter and reference receiver (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the received eye mask as specified in [13], [10], [11] or [12] as required.

Also refer to Appendix 3.A for more information on the channel characteristics.

Reference Transmitter:

1. No emphasis
2. A concatenated first order low pass transmit filter with 0.75 times baud rate
3. An amplitude equal to the defined minimum transmit amplitude in the specific Implementation Agreement
4. A jitter distribution equal to the defined maximum allowed transmit jitter in the specific Implementation Agreement
5. Worst case transmitter return loss described as a parallel RC elements, see 2.E.6.

Reference Receiver:

1. No sampling jitter
2. No equalisation
3. A sampling point defined at the midpoint between the average zero crossings of the differential signal
4. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.
5. A BER as per [13].

4.3 Electrical Characteristics

Refer to [13] for detailed information on SxI-5, [10] for detailed infromation on SFI-4.2, [11] for detatiled information on SFI-5.1 and [12] for detailed information on SPI-5.1.

Note these implementation agreements require that one drop the high frequency jitter tolerance number by 0.1UI for the addition of the sinusoidal jitter.

4.A Appendix - StatEye.org Template

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution        = 0.010;
param.binsize               = 0.0005;
param.points                = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

%param.bps                  = 2.488e9; % lower rate SxI-5
param.bps                   = 3.125e9;
param.bitResolution         = 1/(4*param.bps);
param.txFilter              = 'singlepole';
param.txFilterParam         = [0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss            = 'on';
param.cpad                  = 2.25;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                 = [];
param.signal                = 1.0;
param.txpost                = [];
param.vstart                = [-0.3 -0.3];
param.vend                  = [+0.0 +0.0];
param.vstep                 = [0.1 0.05 0.025];
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];             % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;        % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;              % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                    = -0.1;

% no DFE
param.dfe                         = [];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                        = 0.17;
param.txrj                        = 0.18/(2*7.04);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user                        = [0.0];
param.useuser                     = 'no';
param.usesymbol                   = '';
param.xtAmp                       = 1.0;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.TransmitAmplitude = 0.500; % mVppdif
param.MinEye            = 0.175; % mVppdif

param.Q               = 2*704;
param.maxDJ           = 0.20;
param.maxTJ           = 0.56;
```

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5 TFI-5 Interface

5.1 Introduction

This clause details the requirements for the TFI-5 electrical interface.

5.2 General Requirements

This clause uses "Method B" of the "Jitter and Interoperability Methodology" section.

5.2.1 Channel Compliance

As per 2.2.2, with the following reference transmitter and reference receiver (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the received eye mask as specified in [4].

Also refer to Appendix 3.A for more information on the channel characteristics.

Reference Transmitter:

1. A single post tap transmitter, with ≤ 3dB of emphasis and infinite precision accuracy.
2. A maximum amplitude equal to the defined minimum transmit amplitude in the specific Implementation Agreement
3. A jitter distribution equal to the defined maximum allowed transmit jitter in the specific Implementation Agreement
4. At the maximum baud rate as defined by the specific Implementation Agreement
5. Worst case transmitter return loss described as a parallel RC elements, see 2.E.6.
6. A concatenated first order low pass transmit filter with 0.75 times baud rate.

Reference Receiver:

1. No sampling jitter
2. No equalisation
3. A sampling point defined at the midpoint between the average zero crossings of the differential signal
4. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.
5. A BER as per [4].

5.3 Electrical Characteristics

Refer to [4] for detailed information on TFI-5.

Note this implementation agreement requires that one drop the high frequency jitter tolerance number by 0.1UI for the addition of the sinusoidal jitter.

5.A Appendix - StatEye.org Template

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution        = 0.010;
param.binsize               = 0.0005;
param.points                = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles


%param.bps                  = 2.488e9; % lower rate TFI-5
param.bps                   = 3.11e9;
param.bitResolution         = 1/(4*param.bps);
param.txFilter              = 'singlepole';
param.txFilterParam         = [0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss            = 'on';
param.cpad                  = 2.25;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                 = [];
param.signal                = 1.0;
param.txpost                = [-0.1];
param.vstart                = [-0.3 -0.3];
param.vend                  = [+0.0 +0.0];
param.vstep                 = [0.1 0.05 0.025];
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];            % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;        % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;              % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                     = -0.1;

% no DFE
param.dfe                          = [];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                         = 0.175;
param.txrj                         = 0.175/(2*7.04);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user                         = [0.0];
param.useuser                      = 'no';
param.usesymbol                    = '';
param.xtAmp                        = 1.0;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.TransmitAmplitude = 0.350; % mVppdif
param.MinEye          = 0.175; % mVppdif

param.Q               = 2*7.04;
param.maxDJ           = 0.37;
param.maxTJ           = 0.65;
```

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6 CEI-6G-SR Short Reach Interface

6.1 Introduction

This clause details the requirements for the CEI-6G-SR short-reach high speed electrical interface between nominal baud rates of 4.976Gsym/s to 6.375Gsym/s using NRZ coding (hence 1 bit per symbol at the electrical level). A compliant device must meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100Ω. Connections are point-to-point balanced differential pair and signalling is unidirectional.

The electrical IA is based on loss & jitter budgets and defines the characteristics required to communicate between a CEI-6G-SR driver and a CEI-6G-SR receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100Ω differential. These characteristics are normative for the devices and informative for the channel. Rather than specifying materials, channel components, or configurations, the IA focuses on effective channel characteristics. Hence a short length of poorer material should be equivalent to a longer length of premium material. A ‘length’ is effectively defined in terms of its attenuation rather than physical length.

Short reach CEI-6G-SR devices from different manufacturers shall be inter-operable.

6.2 Requirements

1. Support serial baud rate from 4.976Gsym/s to 6.375Gsym/s.
2. Capable of low bit error rate (required BER of 10^{-15}).
3. Capable of driving 0 – 200mm of PCB and up to 1 connector.
4. Shall support AC coupled operation and optionally DC-coupled operation.
5. Shall allow multi-lanes (1:N).
6. Shall support hot plug.

6.3 General Requirements

This clause uses “Method B” of the Jitter and Interoperability Methodology section.

6.3.1 Data Patterns

Please refer to 3.2.1

6.3.2 Signal levels

Please refer to 3.2.2 and 6.4.1.

6.3.3 Signal Definitions

Please refer to 1.A

6.3.4 Bit Error Ratio

Please refer to 3.2.3

6.3.5 Ground Differences

Please refer to 3.2.4

6.3.6 Cross Talk

Please refer to 3.2.5

6.3.7 Channel Compliance

As per 2.2.2, with the following reference transmitter and reference receiver (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the received eye mask as specified in Figure 1-5 and Table 6-8.

Also refer to Appendix 3.A for more information on the channel characteristics.

Reference Transmitter:

1. A single post tap transmitter, with ≤ 3dB of emphasis and infinite precision accuracy.
2. A transmit amplitude of 400mVppd
3. Additional Uncorrelated Bounded High Probability Jitter of 0.15UIpp (emulating part of the Tx jitter)
4. Additional Uncorrelated Unbounded Gaussian Jitter of 0.15UIpp (emulating part of the Tx jitter)
5. A Tx edge rate filter: simple 20dB/dec low pass at 75% of baud rate, this is to emulate a Tx -3dB bandwidth at $^3/_4$ baud rate.
6. At the maximum baud rate that the channel is to operate at or 6.375Gsym/s which ever is the lowest.
7. Worst case transmitter return loss described as a parallel RC elements, see 2.E.6.

Reference Receiver:

1. No Rx equalization and the Rx bandwidth is assumed to be infinite.
2. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.
3. A BER as per 6.3.4.
4. A sampling point defined at the midpoint between the average zero crossings of the differential signal

6.4 Electrical Characteristics

The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100Ω. Connections are point-to-point balanced differential pair and signalling is unidirectional.

6.4.1 Driver Characteristics

The key driver characteristics are summarized in Table 6-1 and Table 6-2 while the following sub-clauses fully detail all the requirements.

Table 6-1. CEI-6G-SR Transmitter Output Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud	See 6.4.1.2	4.976		6.375	Gsym/s
Output Differential voltage (into floating load Rload=100Ω)	T_Vdiff	See 6.4.1.3	400		750	mVppd
Differential Resistance	T_Rd	See 6.4.1.5	80	100	120	Ω
Recommended output rise and fall times (20% to 80%)	T_tr, T_tf	See 6.4.1.4	30			ps
Differential Output Return Loss (100MHz to 0.75*T_Baud)	T_SDD22	See 6.4.1.5			-8	dB
Differential Output Return Loss (0.75*T_Baud to T_Baud)						
Common Mode Return Loss (100MHz to 0.75 *T_Baud)	T_SCC22	See 6.4.1.5			-6	dB
Transmitter Common Mode Noise	T_Ncm				5% of T_Vdiff	mVppd

NOTES:
1. For all Load Types: R_Rdin = 100Ω± 20Ω. For Vcm definition, see Figure 1-1
2. Load Type 0 with min T_Vdiff, AC-Coupling or floating load.
3. For Load Types 1 through 3: R_Zvtt ≤ 30Ω; Vtt is defined for each load type as follows: Load Type 1 R_Vtt = 1.2V +5%/-8%; Load Type 2 R_Vtt = 1.0V +5%/-8%; Load Type 3 R_Vtt = 0.8V +5%/-8%.
4. DC Coupling compliance is optional (Type 1 through 3). Only Transmitters that support DC coupling are required to meet this parameter. It is acceptable for a Transmitter to restrict the range of T_Vdiff in order to comply with the specified T_Vcm range. For a Transmitter which supports multiple T_Vdiff levels, it is acceptable for a Transmitter to claim DC Coupling Compliance if it meets the T_Vcm ranges for at least one of its T_Vdiff setting as long as those setting(s) that are compliant are indicated.
5. Simple CML Transmitters designed using Vdd ≥ 1.2V may still claim DC compliance if this parameter is not met.
6. Simple CML Transmitters designed using Vdd ≤ 0.8V may still claim DC compliance if this parameter is not met.

Table 6-1. CEI-6G-SR Transmitter Output Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Output Common Mode Voltage See Note 1, 3, 4 Also see 3.2.2	T_Vcm	Load Type 0 Note 2	0.0		1.8	V
		Load Type 1 Note 6	735		1135	mV
		Load Type 2	550		1060	mV
		Load Type 3 Note 5	490		850	mV

NOTES:
1. For all Load Types: R_Rdin = 100Ω± 20Ω. For Vcm definition, see Figure 1-1
2. Load Type 0 with min T_Vdiff, AC-Coupling or floating load.
3. For Load Types 1 through 3: R_Zvtt ≤ 30Ω; Vtt is defined for each load type as follows: Load Type 1 R_Vtt = 1.2V +5%/-8%; Load Type 2 R_Vtt = 1.0V +5%/-8%; Load Type 3 R_Vtt = 0.8V +5%/-8%.
4. DC Coupling compliance is optional (Type 1 through 3). Only Transmitters that support DC coupling are required to meet this parameter. It is acceptable for a Transmitter to restrict the range of T_Vdiff in order to comply with the specified T_Vcm range. For a Transmitter which supports multiple T_Vdiff levels, it is acceptable for a Transmitter to claim DC Coupling Compliance if it meets the T_Vcm ranges for at least one of its T_Vdiff setting as long as those setting(s) that are compliant are indicated.
5. Simple CML Transmitters designed using Vdd ≥ 1.2V may still claim DC compliance if this parameter is not met.
6. Simple CML Transmitters designed using Vdd ≤ 0.8V may still claim DC compliance if this parameter is not met.

Table 6-2. CEI-6G-SR Transmitter Output Jitter Specifications

Characteristic	**Symbol**	**Condition**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Uncorrelated High Probability Jitter	T_UHPJ	See 6.4.1.8			0.15	UIpp
Duty Cycle Distortion	T_DCD	See 6.4.1.8			0.05	UIpp
Total Jitter	T_TJ	See 6.4.1.8			0.30	UIpp
Eye Mask	T_X1	See 6.4.1.8			0.15	UI
Eye Mask	T_X2	See 6.4.1.8			0.40	UI
Eye Mask	T_Y1	See 6.4.1.8	200			mV
Eye Mask	T_Y2	See 6.4.1.8			375	mV

NOTES:

6.4.1.1 Driver Test Load

Please refer to 3.2.6

6.4.1.2 Driver Baud Rate

All devices shall work from 4.976Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

6.4.1.3 Driver Amplitude and Swing

Driver differential output amplitude shall be between 400 to 750mVppd either with or without any transmit emphasis. Absolute driver output voltage shall be between -0.1V and 1.9V with respect to local ground. See Figure 1-1 for an illustration of absolute driver output voltage limits and definition of differential peak-to-peak amplitude.

6.4.1.4 Driver Rise and Fall Times

The recommended minimum differential rise and fall times are 30ps as measured between the 20% and 80% of the maximum measured levels; the maximum differential rise and fall times are defined by the Tx eye diagram (Figure 1-4 and Table 6-4). Shorter rise and fall times may result in excessive high frequency components and increase EMI and cross talk.

6.4.1.5 Driver Resistance and Return Loss

As per 3.2.10, with the following parameters.

Table 6-3. CEI-6G-SR Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$T\_Baud \times \frac{3}{4}$	Hz
f2	T_Baud	Hz
Slope	16.6	dB/dec

6.4.1.6 Driver Lane-to-Lane Skew

Please refer to 3.2.7

6.4.1.7 Driver Short Circuit Current

Please refer to 3.2.9

6.4.1.8 Driver Template and Jitter

As per 2.2.3 for a BER as per 6.3.4, the driver shall satisfy both the near-end and far-end eye template and jitter requirements as given in Figure 1-4, Table 6-4, Figure 1-5 and Table 6-8 either with or without any transmit emphasis.

The maximum near-end duty cycle distortion (T_DCD) shall be less than 0.05UIpp.

It should be noted that it is assumed the Uncorrelated High Probability Jitter component of the driver jitter is not Inter-symbol Interference (ISI). This is only assumed from a receiver point of view and does not in any way put any restrictions on the real driver HPJ.

Table 6-4. CEI-6G-SR Near-End (Tx) Template Intervals

Characteristics	Symbol	Near-End Value	Units
Eye Mask	T_X1	0.15	UI
Eye Mask	T_X2	0.40	UI
Eye Mask	T_Y1	200	mV
Eye Mask	T_Y2	375	mV
Uncorrelated Bounded High Probability Jitter	T_UBHPJ	0.15	UIpp
Duty Cycle Distortion	T_DCD	0.05	UIpp
Total Jitter	T_TJ	0.30	UIpp

6.4.1.9 Driver Training Pattern

There is no requirement at the electrical level for a training pattern, however there may be a training pattern requirement(s) at the protocol level.

6.4.2 Receiver Characteristics

The key receiver characteristics are summarized in Table 6-5 and Table 6-6 while the following sub-clauses fully detail all the requirements.

Table 6-5. CEI-6G-SR Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Rx Baud Rate	R_Baud	See 6.4.2.1	4.976		6.375	Gsym/s
Input Differential voltage	R_Vdiff	See 6.4.2.3	125		750	mVppd
Differential Resistance	R_Rdin	See 6.4.2.7	80	100	120	Ω
Bias Voltage Source Impedance (load types 1 to 3)	R_Zvtt	See Note 1			30	Ω
Differential Input Return Loss (100MHz to 0.75*R_Baud)	R_SDD11	See 6.4.2.7			-8	dB
Differential Input Return Loss (0.75*R_Baud to R_Baud))						
Common mode Input Return Loss (100MHz to 0.75 *R_Baud)	R_SCC11	See 6.4.2.7			-6	dB

NOTES:
1. DC Coupling compliance is optional. For Vcm definition, see Figure 1-1
2. Receiver is required to implement at least one of specified nominal R_Vtt values, and typically implements only one of these values. Receiver is only required to meet R_Vrcm parameter values that correspond to R_Vtt values supported.
3. Input common mode voltage for AC-coupled or floating load input with min T_Vdiff,
4. For floating load, input resistance must be ≥ 1kΩ.

Table 6-5. CEI-6G-SR Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Termination Voltage Note 1, 2	R_Vtt	R_Vtt floating, Note 4	Not Specified			V
		R_Vtt = 1.2V Nominal	1.2 - 8%		1.2 + 5%	V
		R_Vtt = 1.0V Nominal	1.0 - 8%		1.0 + 5%	V
		R_Vtt = 0.8V Nominal	0.8 - 8%		0.8 + 5%	V
Input Common Mode Voltage Note 1, 2	R_Vrcm	R_Vtt floating, Note 3, 4	-0.05		1.85	V
		R_Vtt = 1.2V Nominal	720		R_Vtt - 10	mV
		R_Vtt = 1.0V Nominal	535		R_Vtt + 125	mV
		R_Vtt = 0.8V Nominal	475		R_Vtt + 105	mV
Wander divider (in Figure 2-30 & Figure 2-31)	n			10		

NOTES:
1. DC Coupling compliance is optional. For Vcm definition, see Figure 1-1
2. Receiver is required to implement at least one of specified nominal R_Vtt values, and typically implements only one of these values. Receiver is only required to meet R_Vrcm parameter values that correspond to R_Vtt values supported.
3. Input common mode voltage for AC-coupled or floating load input with min T_Vdiff,
4. For floating load, input resistance must be ≥ 1kΩ.

Table 6-6. CEI-6G-SR Receiver Input Jitter Tolerance Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Bounded High Probability Jitter	R_BHPJ	See 6.4.2.8			0.45	UIpp
Sinusoidal Jitter, maximum	R_SJ-max	See 6.4.2.8			5	UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See 6.4.2.8			0.05	UIpp
Total Jitter (Does not include Sinusoidal Jitter)	R_TJ	See 6.4.2.8			0.60	UIpp
Eye Mask	R_X1	See 6.4.2.8			0.30	UI
Eye Mask	R_Y1	See 6.4.2.8			62.5	mV
Eye Mask	R_Y2	See 6.4.2.8			375	mV

NOTES:

6.4.2.1 Input Baud Rate

All devices shall work from 4.976Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

6.4.2.2 Reference Input Signals

Reference input signals to the receiver have the characteristics determined by compliant driver. The reference input signal must satisfy the transmitter near-end template and jitter given in Figure 1-4 and Table 6-4, as well as the far-end eye template and jitter given in Figure 1-5 and Table 6-8, with the differential load impedance of 100Ω ±1% at DC with a return loss of better than 20dB from baud rate divided by 1667 to 1.5 times the baud rate. Note that the input signal might not meet either of these templates when the actual receiver replaces this load.

6.4.2.3 Input Signal Amplitude

The receiver shall accept differential input signal amplitudes produced by compliant transmitters connected without attenuation to the receiver. This may be larger than the 750mVppd maximum of the driver due to output/input impedances and reflections.

The minimum input amplitude is defined by the far-end driver template, the actual receiver input impedance and the loss of the actual PCB. Note that the far-end driver template is defined using a well controlled load impedance, however the real receiver is not, which can leave the receiver input signal smaller than the minimum 125mVppd.

6.4.2.4 Absolute Input Voltage

The absolute voltage levels with respect to the receiver ground at the input of the receiver are dependent on the driver implementation, the inter-ground difference, whether the receiver is AC or DC coupled, and (in the case of DC coupling load types 1 to 3) the nominal R_Vtt supported by the receiver. The voltage levels at the input of a DC coupled receiver shall be consistent with R_Vrcm and R_Vdiff values defined in Table 6-5.

The voltage levels at the input of an AC coupled receiver (if AC coupling is done within the receiver) or at the Tx side of the external AC coupling cap (if AC coupling is done externally) shall be between -0.15 to 1.95V with respect to local ground.

6.4.2.5 Input Common Mode Impedance

The input common mode impedance (R_Zvtt) at the input of the receiver is dependent on whether the receiver is AC or DC coupled. The value of R_Zvtt as measured at the input of an AC coupled receiver is undefined. The value of R_Zvtt as measured at the input of a DC coupled receiver is defined as per Table 6-5.

If AC coupling is used, it is to be considered part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that various methods for AC coupling are allowed (for example, internal to the chip or done externally). See also 3.2.12 for more information.

6.4.2.6 Input Lane-to-Lane Skew

Please refer to 3.2.8

6.4.2.7 Input Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 6-7. CEI-6G-SR Input Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$R\_Baud \times \frac{3}{4}$	Hz
f2	R_Baud	Hz
Slope	16.6	dB/dec

6.4.2.8 Input Jitter Tolerance

As per 2.2.4, the receiver shall tolerate at least the far-end eye template and jitter requirements as given in Figure 1-5 and Table 6-8 with an additional SJ with any frequency and amplitude defined by the mask of Figure 2-4 where the minimum & maximum total wander amplitude are 0.05UIpp & 5UIpp respectively. This additional SJ component is intended to ensure margin for wander, hence is over and above any high frequency jitter from Table 6-8.

Table 6-8. CEI-6G-SR Far-End (Rx) Template Intervals

Characteristics	Symbol	Far-End Value	Units
Eye Mask	R_X1	0.30	UI
Eye Mask	R_Y1	62.5	mV
Eye Mask	R_Y2	375	mV
Uncorrelated Bounded High Probability Jitter	R_UBHPJ	0.15	UIpp
Correlated Bounded High Probability Jitter	R_CBHPJ	0.30	UIpp
Total Jitter (Does not include Sinusoidal Jitter)	R_TJ	0.60	UIpp

6.A Appendix - Link and Jitter Budgets

The primary intended application is as a point-to-point interface of up to approximately 200mm (≈8”) and up to one connector between integrated circuits using controlled impedance traces on low-cost printed circuit boards (PCBs). Informative loss and jitter budgets are presented in Table 6-9 (see also Appendix 3.A for more information) to demonstrate the feasibility of legacy FR4 epoxy PCB’s. The jitter budget is given in Table 6-10. The performance of an actual transceiver interconnect is highly dependent on the implementation.

Table 6-9. CEI-6G-SR Informative Loss, Skew and Jitter Budget

	Loss (dB)	**Differential Skew (ps)**	Bounded High Probability **(UIpp)**	**TJ (UIpp)**
Driver	0	15	0.15	0.30
Interconnect (with Connector)	6.6	25	0.15	0.15
Other	3.5		0.15	0.15
Total	10.1	40	0.45	0.60

Table 6-10. CEI-6G-SR High Frequency Jitter Budget

CEI-6G-SR	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	High Probability	Bounded Gaussian	Bounded High Probability	Gaussian	Sinusoidal	Bounded High Probability	Total		
Abbreviation	**UUGJ**	**UHPJ**	**CBGJ**	**CBHPJ**	**GJ**	**SJ**	**HPJ**	**TJ**	**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmitter	**0.150**	**0.150**		**-0.200 See 1**	**0.150**		**-0.050**	**0.100**		**400.0**
Channel				0.500						
Receiver Input	**0.150**	**0.150**	**0.000**	**0.300**	**0.150**		**0.450**	**0.600**	**0.25**	**125**
Clock + Sampler	0.150	0.100		0.100						-50.0
Budget	**0.212**	**0.250**	**0.000**	**0.400**	**0.212**	**0.050**	**0.650**	**0.912**	**0.13**	**75.0**

NOTES:
1. Due to transmitter emphasis, it reduces the ISI as seen at the receiver. Thus this number is negative

6.B Appendix - StatEye.org Template

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution       = 0.01;
param.binsize              = 0.0005;
param.points               = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps                  = 6.375e9;
param.bitResolution        = 1/(4*param.bps);
param.txFilter             = 'singlepole';
param.txFilterParam        = [0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss           = 'on';
param.cpad                 = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                = [];
param.signal               = 1.0;
param.txpost               = [-0.1];
param.vstart               = [-0.3 -0.3];
param.vend                 = [+0.0 +0.0];
param.vstep                = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];            % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;        % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;             % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                    = -0.1;

% no DFE
param.dfe                         = [];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                        = 0.15;
param.txrj                        = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user                        = [0.0];
param.useuser                     = 'no';
param.usesymbol                   = '';
param.xtAmp                       = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
param.TransmitAmplitude = 0.400; % mVppdif
param.MinEye            = 0.125; % mVppdif

param.Q                 = 2*7.94;
param.maxDJ             = 0.30;
param.maxTJ             = 0.60;
```

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7 CEI-6G-LR Long Reach Interface

7.1 Introduction

This clause details the requirements for the CEI-6G-LR long-reach high speed electrical interface between nominal baud rates of 4.976Gsym/s to 6.375Gsym/s using NRZ coding (hence 1 bit per symbol at the electrical level). A compliant device must meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100Ω. Connections are point-to-point balanced differential pair and signalling is unidirectional.

The electrical IA is based on loss & jitter budgets and defines the characteristics required to communicate between a CEI-6G-LR driver and a CEI-6G-LR receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100Ω differential. These characteristics are normative for the devices and informative for the channel. Rather than specifying materials, channel components, or configurations, the IA focuses on effective channel characteristics. Hence a short length of poorer material should be equivalent to a longer length of premium material. A 'length' is effectively defined in terms of its attenuation rather than physical length.

Long reach CEI-6G-LR devices from different manufacturers shall be inter-operable.

7.2 Requirements

1. Support serial baud rate from 4.976Gsym/s to 6.375Gsym/s.
2. Capable of low bit error rate (required BER of 10^{-15}).
3. Capable of driving 0 – 1m of PCB (such as IEEE 802.3 XAUI/TFI-5 compliant backplane) and up to 2 connector.
4. Shall support AC coupled operation and optionally DC-coupled operation.
5. Shall allow multi-lanes (1:N).
6. Shall support hot plug.

7.3 General Requirements

This clause uses "Method D" of the Jitter and Interoperability Methodology section.

7.3.1 Data Patterns

Please refer to 3.2.1

7.3.2 Signal levels

Please refer to 3.2.2 and 7.4.1.

7.3.3 Signal Definitions

Please refer to 1.A

7.3.4 Bit Error Ratio

Please refer to 3.2.3

7.3.5 Ground Differences

Please refer to 3.2.4

7.3.6 Cross Talk

Please refer to 3.2.5

7.3.7 Channel Compliance

As per 2.4.2, with the following reference transmitter and reference receiver (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the equalized eye mask as specified in Figure 1-5 and Table 7-1. However for the case of a short reach Tx talking to a long reach Rx, the Rx needs to meet all requirements as given in 6.3.7 and 6.4.2.

Also refer to Appendix 3.A for more information on the channel characteristics.

Reference Transmitter:

1. Either a single pre or post tap transmitter, with ≤ 6dB of emphasis, with infinite precision accuracy.
2. A transmit amplitude of 800mVppd.
3. Additional Uncorrelated Bounded High Probability Jitter of 0.15UIpp (emulating part of the Tx jitter)
4. Additional Uncorrelated Unbounded Gaussian Jitter of 0.15UIpp (emulating part of the Tx jitter)
5. A Tx edge rate filter: simple 40dB/dec low pass at 75% of baud rate, this is to emulate both Rx and Tx -3dB bandwidths at $^3/_4$ baud rate.
6. At the maximum baud rate that the channel is to operate at or 6.375Gsym/s which ever is lowest
7. Worst case transmitter return loss described as a parallel RC elements, see 2.E.6.

Reference Receiver:

1. Rx equalization: 5 tap DFE, with infinite precision accuracy and having the following restriction on the coefficient values:

   Let W[N] be sum of DFE tap coefficient weights from taps N through M where

   N = 1 is previous decision (i.e. first tap)
   M = oldest decision (i.e. last tap)
   R_Y2 = T_Y2 = 400mV
   Y = min(R_X1, (R_Y2 - R_Y1) / R_Y2) = 0.30
   Z = $^{2}/_{3}$ = 0.66667

   Then W[N] $\leq$ Y * $Z^{(N - 1)}$

   For the channel compliance model the number of DFE taps (M) = 5. This gives the following maximum coefficient weights for the taps:

   W[1] ≤ 0.3000 (sum of taps 1 to 5)
   W[2] ≤ 0.2000 (sum of taps 2 to 5)
   W[3] ≤ 0.1333 (sum of taps 3 to 5)
   W[4] ≤ 0.0889 (sum of taps 4 and 5)
   W[5] ≤ 0.0593 (tap 5)

   Notes:
   - These coefficient weights are absolute assuming a T_Vdiff of 1Vppd
   - For a real receiver the restrictions on tap coefficients would apply for the actual number of DFE taps implemented (M)

2. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.

3. A BER as per 3.2.3.

Table 7-1. CEI-6G-LR Receiver Equalization Output Eye Mask

Parameter	Symbol	Max	Units
Eye mask	R_X1	0.3	UI
Eye mask	R_Y1	50	mV
Bounded High Probability Jitter	R_BHPJ	0.325	UI

7.4 Electrical Characteristics

The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100Ω. Connections are point-to-point balanced differential pair and signalling is unidirectional.

7.4.1 Driver Characteristics

The key driver characteristics are summarized in Table 7-2 and Table 7-3 while the following sub-clauses fully detail all the requirements.

Table 7-2. CEI-6G-LR Transmitter Output Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud	See 7.4.1.2	4.976		6.375	Gsym/s
Output Differential voltage (into floating load Rload=100Ω)	T_Vdiff	See 7.4.1.3 & Note 1	800		1200	mVppd
Differential Resistance	T_Rd	See 7.4.1.5	80	100	120	Ω
Recommended output rise and fall times (20% to 80%)	T_tr, T_tf	See 7.4.1.4	30			ps
Differential Output Return Loss (100MHz to 0.75*T_Baud)	T_SDD22	See 7.4.1.5			-8	dB
Differential Output Return Loss (0.75*T_Baud to T_Baud)						
Common Mode Return Loss (100MHz to 0.75 *T_Baud)	T_S11	See 7.4.1.5			-6	dB
Transmitter Common Mode Noise	T_Ncm				5% of T_Vdiff	mVppd
Output Common Mode Voltage See Notes 2, 3 & 4 See also 3.2.2	T_Vcm	Load Type 0 See Note 2	100		1700	mV
		Load Type 1 See Note 3 & 4	630		1100	mV

NOTES:
1. The Transmitter must be capable of producing a minimum T_Vdiff greater than or equal to 800 mVppd. In applications where the channel is better than the worst case allowed, a Transmitter device may be provisioned to produce T_Vdiff less than this minimum value, but greater than or equal to 400 mVppd, and is still compliant with this specification.
2. Load Type 0 with min T_Vdiff, AC-Coupling or floating load.
3. For Load Type 1: R_Zvtt ≤ 30Ω; T_Vtt & R_Vtt = 1.2V +5%/-8%
4. DC Coupling compliance is optional (Load Type 1). Only Transmitters that support DC coupling are required to meet this parameter.

Table 7-3. CEI-6G-LR Transmitter Output Jitter Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated High Probability Jitter	T_UHPJ	See 7.4.1.8			0.15	UIpp
Duty Cycle Distortion	T_DCD	See 7.4.1.8			0.05	UIpp
Total Jitter	T_TJ	See 7.4.1.8			0.30	UIpp
Eye Mask	T_X1	See 7.4.1.8			0.15	UI
Eye Mask	T_X2	See 7.4.1.8			0.50	UI
Eye Mask	T_Y1	See 7.4.1.8	400			mV
Eye Mask	T_Y2	See 7.4.1.8			600	mV

NOTES:

7.4.1.1 Driver Test Load

Please refer to 3.2.6

7.4.1.2 Driver Baud Rate

All devices shall work from 4.976Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

7.4.1.3 Driver Amplitude and Swing

Driver differential output amplitude shall be able to drive between 800 to 1200mVppd either with or without any transmit emphasis. However, for the case of this transmitter talking to a short reach receiver, the differential output amplitude shall be between 400 to 750mVppd either with or without any transmit emphasis. DC referenced logic levels are not defined since the receiver must have high common mode impedance at DC. However, absolute driver output voltage shall be between -0.1 V and 1.9 V with respect to local ground. See Figure 1-1 for an illustration of absolute driver output voltage limits and definition of differential peak-to-peak amplitude.

7.4.1.4 Driver Rise and Fall Times

The recommended minimum differential rise and fall time is 30ps as measured between the 20% and 80% of the maximum measured levels; the maximum differential rise and fall times are defined by the Tx eye diagram (Figure 1-4 and Table 7-5). Shorter rise and falls may result in excessive high frequency components and increase EMI and cross talk.

7.4.1.5 Output Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 7-4. CEI-6G-LR Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$T\_Baud \times \frac{3}{4}$	Hz
f2	R_Baud	Hz
Slope	16.6	dB/dec

7.4.1.6 Driver Lane-to-Lane Skew

Please refer to 3.2.7

7.4.1.7 Driver Short Circuit Current

Please refer to 3.2.9

7.4.1.8 Driver Template and Jitter

As per 2.4.3 for a BER as per 7.3.4, the driver shall satisfy both the near-end eye template & jitter requirements as given in Figure 1-4, Table 7-5 either with or without any transmit emphasis.

The maximum near-end duty cycle distortion (T_DCD) shall be less than 0.05UIpp.

It should be noted that it is assumed the Uncorrelated High Probability Jitter component of the driver jitter is not Inter-symbol Interference (ISI). This is only assumed from a receiver point of view so that a receiver can't equalize it and does not in any way put any restrictions on the real driver HPJ.

Table 7-5. CEI-6G-LR Near-End Template Intervals

Characteristics	Symbol	Near-End Value	Units	Comments
Eye Mask	T_X1	0.15	UI	
Eye Mask	T_X2	0.50	UI	
Eye Mask	T_Y1	400	mV	For connection to short reach Rx
		400		For connection to long reach Rx
Eye Mask	T_Y2	375	mV	For connection to short reach Rx
		600		For connection to long reach Rx
Uncorrelated Bounded High Probability Jitter	T_UBHPJ	0.15	UIpp	
Duty Cycle Distortion	T_DCD	0.05	UIpp	
Total Jitter	T_TJ	0.30	UIpp	

7.4.1.9 Driver Training Pattern

The driver is required to repeatedly transmit a "training pattern". This pattern may be needed by the receiver to aid in its power up adaptive process. The pattern is at least 384 bits long and is explained in Table 7-6. However it should be noted that other data (i.e. framing bits) may be present between the repeated groups of 384 bits.

Table 7-6. CEI-6G-LR Training Pattern

Pattern (in Hex)	Purpose
00 FF 00 FF 00 FF	48 bits - f/16 square wave
00 80 00	24 bits - positive impulse with 12 leading and trailing zeros
55 55 55 55 55 55	48 bits - f/2 square wave
FF EF FF	24 bits - negative impulse with 12 leading and trailing ones
00 FF 00 FF 00 FF	48 bits - f/16 square wave
At least 192 random or pseudo-random bits	Approximation of normal randomized data patterns (see 3.2.1)

The means to indicate to the driver when it has to send or stop the training pattern is beyond the scope of this IA.

Note there may well be other training pattern(s) requirements at the protocol level.

7.4.2 Receiver Characteristics

The key receiver characteristics are summarized in Table 7-7 while the following sub-clauses fully detail all the requirements.

Table 7-7. CEI-6G-LR Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Rx Baud Rate	R_Baud	See 7.4.2.1	4.976		6.375	Gsym/s
Input Differential voltage	R_Vdiff	See 7.4.2.3			1200	mVppd
Differential Resistance	R_Rdin	See 7.4.2.7	80	100	120	Ω
Bias Voltage Source Impedance (load type 1)	R_Zvtt	See Note 1			30	Ω
Differential Input Return Loss (100MHz to 0.75*R_Baud)	R_SDD11	See 7.4.2.7			-8	dB
Differential Input Return Loss (0.75*R_Baud to R_Baud))						
Common Mode Input Return Loss (100MHz to 0.75 *R_Baud)	R_SCC11	See 7.4.2.7			-6	dB
Input Common Mode Voltage See Notes: 1, 2 & 3	R_Vfcm	Load Type 0 See Note 2	0		1800	mV
		Load Type 1 Notes: 1 & 3	595		R_Vtt - 60	mV
Wander divider (in Figure 2-30 & Figure 2-31)	n			10		

NOTES:
1. DC Coupling compliance is optional (Load Type 1). Only receivers that support DC coupling are required to meet this parameter.
2. Load Type 0 with min T_Vdiff, AC-Coupling or floating load. For floating load, input resistance must be ≥ 1kΩ
3. For Load Type 1: T_Vtt & R_Vtt = 1.2V +5%/-8%.

7.4.2.1 Baud Rate

All devices shall work from 4.976Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

7.4.2.2 Reference Input Signals

Reference input signals to the receiver have the characteristics determined by compliant driver. The reference input signal must satisfy the transmitter near-end template and jitter given in Figure 1-4 and Table 7-5, as well as the far-end eye jitter given in Table 7-10, with the differential load impedance of 100Ω ±1% at DC with a return loss of better than 20dB from baud rate divided by 1667 to 1.5 times the baud rate. Note that the input signal might not meet either of these requirements when the actual receiver replaces this load.

7.4.2.3 Input Signal Amplitude

The receiver shall accept differential input signal amplitudes produced by compliant transmitters connected without attenuation to the receiver. This may be larger than the 1200mVppd maximum of the driver due to output/input impedances and reflections.

The minimum input amplitude is defined by the far-end driver template, the actual receiver input impedance and the loss of the actual PCB. Note that the far-end driver template is defined using a well controlled load impedance, however the real receiver is not, which can leave the receiver input signal smaller than expected.

7.4.2.4 Absolute Input Voltage

The absolute voltage levels with respect to the receiver ground at the input of the receiver are dependent on the driver implementation and the inter-ground difference.

The voltage levels at the input of an AC coupled receiver (if the effective AC coupling is done within the receiver) or at the Tx side of the external AC coupling cap (if AC coupling is done externally) shall be between -0.2 to 2.0V with respect to local ground.

7.4.2.5 Input Common Mode Impedance

The input common mode impedance (R_Zvtt) at the input of the receiver is dependent on whether the receiver is AC or DC coupled. The value of R_Zvtt as measured at the input of an AC coupled receiver is undefined. The value of R_Zvtt as measured at the input of a DC coupled receiver is defined as per Table 7-7.

If AC coupling is used, it is to be considered part of the receiver for the purposes of this specification unless explicitly stated otherwise. It should be noted that various methods for AC coupling are allowed (for example, internal to the chip or done externally). See also 3.2.12 for more information.

7.4.2.6 Input Lane-to-Lane Skew

Please refer to 3.2.8

7.4.2.7 Input Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 7-8. CEI-6G-LR Input Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$R\_Baud \times \frac{3}{4}$	Hz
f2	R_Baud	Hz
Slope	16.6	dB/dec

7.4.2.8 Jitter Tolerance

As per 2.4.4, the receiver shall tolerate at least the far-end jitter requirements as given in Table 7-1 in combination with any compliant channel, as per 7.3.7, with an additional SJ with any frequency and amplitude defined by the mask of Figure 2-4 where the minimum & maximum total wander amplitude are 0.05UIpp & 5UIpp respectively. This additional SJ component is intended to ensure margin for wander, hence is over and above any high frequency jitter from Table 7-1.

7.A Appendix - Link and Jitter Budgets

The primarily intended application is as a point-to-point interface of up to approximately 1m (≈40”) and up to two connector between integrated circuits using controlled impedance traces on low-cost printed circuit boards (PCBs). Informative loss and jitter budgets are presented in Table 7-9 (see also Appendix 3.A for more information) to demonstrate the feasibility of legacy FR4 epoxy PCB’s. The jitter budget is given in Table 7-10. The performance of an actual transceiver interconnect is highly dependent on the implementation.

Table 7-9. CEI-6G-LR Informative Loss, Skew and Jitter Budget

	Loss (dB)	**Differential Skew (ps)**	Bounded High Probability **(UIpp)**	**TJ (UIpp)**
Driver	0	15	0.15	0.30
Interconnect (with Connector)	15.9	25	0.35	0.513
Other	4.5		0.10	0.262
Total	20.4	40	0.60	0.875

Table 7-10. CEI-6G-LR High Frequency Jitter Budget

CEI-6G-LR	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	High Probability	Bounded Gaussian	Bounded High Probability	Gaussian	Sinusoidal	Bounded High Probability	Total		
Abbreviation	**UUGJ**	**UHPJ**	**CBGJ**	**CBHPJ**	**GJ**	**SJ**	**HPJ**	**TJ**	**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmitter	**0.150**	**0.150**			**0.150**		**0.150**	**0.300**		**800.0**
Channel			0.230	0.525						
Receiver Input	**0.150**	**0.150**	**0.230**	**0.525**	**0.275**		**0.675**	**0.950**	**0.00**	**0.0 See 2**
Equalizer				-0.350 See 1						
Post Equalization	**0.150**	**0.150**	**0.230**	**0.175**	**0.275**		**0.325**	**0.60**	**0.20**	**100.0**
DFE Penalties				0.100					-0.08	-45.0
Clock + Sampler	0.150	0.100		0.100						-45.0
Budget	**0.212**	**0.250**	**0.230**	**0.375**	**0.313**	**0.050**	**0.625**	**0.988**	**0.06**	**10.0**

NOTES:
1. Due to receiver equalization, it reduces the ISI as seen inside the receiver. Thus this number is negative.
2. It is assumed that the eye is closed at the receiver, hence receiver equalization is required as indicated below.

7.B Appendix - StatEye.org Template

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equalizer
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution = 0.01;
param.binsize = 0.0005;
param.points = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps = 6.375e9;
param.bitResolution = 1/(4*param.bps);
param.txFilter = 'twopole';
param.txFilterParam = [0.75 0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss = 'on';
param.cpad = 1.00;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre = [-0.1];
param.signal = 1.0;
param.txpost = [];
param.vstart = [-0.3 -0.3];
param.vend = [+0.0 +0.0];
param.vstep = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];            % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;        % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;             % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                    = -0.1;

param.dfe                         = [0.3 0.1 0.1 0.1 0.1];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                        = 0.15;
param.txrj                        = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user                        = [0.0];
param.useuser                     = 'no';
param.usesymbol                   = '';
param.xtAmp                       = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
param.TransmitAmplitude = 0.800; % mVppdif
param.MinEye            = 0.100; % mVppdif

param.Q               = 2*7.94;
param.maxDJ           = 0.325;
param.maxTJ           = 0.60;
```

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8 CEI-11G-SR Short Reach Interface

This clause details the requirements for the CEI-11G-SR short-reach high speed electrical interface between nominal baud rates of 9.95 Gsym/s to 11.2 Gsym/s using NRZ coding. A compliant device must meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100 Ω. Connections are point-to-point balanced differential pair and signaling is unidirectional.

The electrical IA is based on loss & jitter budgets and defines the characteristics required to communicate between a CEI-11G-SR driver and a CEI-11G-SR receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100 Ω differential. These characteristics are normative for the devices and informative for the channel. Rather than specifying materials, channel components, or configurations, the IA focuses on effective channel characteristics. Hence a short length of poorer material should be equivalent to a longer length of premium material. A ‘length’ is effectively defined in terms of its attenuation rather than physical length.

Short reach CEI-11G-SR devices from different manufacturers shall be inter-operable.

8.1 Requirements

1. Support serial data rate from 9.95 Gsym/s to 11.2 Gsym/s.
2. Capable of low bit error rate (required BER[1] of 10^{-15}).
3. Capable of driving 0 – 200 mm of PCB and up to 1 connector.
4. Shall support AC-coupled and optionally DC-coupled operation.
5. Shall allow multi-lanes (1 to n).
6. Shall support hot plug.

8.2 General Requirements

This clause uses “Method E” of the Jitter and Interoperability Methodology section.

8.2.1 Data Patterns

Please refer to 3.2.1

1. If optical components are included, i.e XFP modules, the BER is constrained by the optical specification.

8.2.2 Signal levels

Please refer to 3.2.2

8.2.3 Signal Definitions

Please refer to 1.A

8.2.4 Bit Error Ratio

Please refer to 3.2.3[1]

8.2.5 Ground Differences

Please refer to 3.2.4

8.2.6 Cross Talk

Please refer to 3.2.5

8.2.7 Channel Compliance

As per 2.5.2, with the following reference transmitter and reference receivers (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the receive eye mask as specified in Figure 1-5 and Table 8-5 when:

a. Using reference receiver A and Electrical Characteristic R_X1 less R_SJ-hf in Table 8-5

b. Using reference receiver B and Electrical Characteristic R_X1LessCBHPJ in Table 8-5

Also refer to Appendix 3.A for more information on the channel characteristics.

Reference Transmitter:

1. A transmitter with no emphasis
2. A transmit amplitude of both 360 mVppd and 770 mVppd
3. Additional Uncorrelated Bounded High Probability Jitter of 0.15 UIpp (emulating part of the Tx jitter)
4. Additional Uncorrelated Unbounded Gaussian Jitter of 0.15UIpp (emulating part of the Tx jitter)
5. At the maximum baud rate that the channel is to operate at or 11.2Gsym/s which ever is the lowest.

1. If optical components are included, i.e XFP modules, the BER is constrained by the optical specification.

6. A Tx edge rate filter: simple 20dB/dec low pass at 75% of baud rate, this is to emulate a Tx -3dB bandwidth at $^{3}/_{4}$ baud rate.
7. Worst case transmitter return loss described as a parallel RC elements, see 2.E.6.

Reference Receiver A:

1. No Rx equalization and the Rx bandwidth is assumed to be infinite.
2. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.
3. A BER[1] as per 3.2.3.
4. A wander divider (n in Figure 2-30 & Figure 2-31) equal to 10
5. A sampling point defined at the midpoint between the average zero crossings of the differential signal

Reference Receiver B[2]:

1. A receiver with a single zero single pole filter (as per Annex 2.B.8) and the Rx bandwidth is assumed to be infinite.
2. Worst case receiver return loss described as a parallel RC elements, see 2.E.6.
3. A BER[1] as per 3.2.3.
4. A wander divider (n in Figure 2-30 & Figure 2-31) equal to 10
5. A sampling point defined at the midpoint between the average zero crossings of the differential signal

8.3 Electrical Characteristics

The electrical signaling is based on high speed low voltage logic with a nominal differential impedance of 100 Ω.

All devices shall work from 9.95Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

8.3.1 Driver Characteristics

The driver electrical specifications at compliance point T are given in tableTable 8-1. As per 2.4.3, the driver shall satisfy both the near-end and far-end eye template and jitter requirements as given in Figure 1-4, Table 8-2, Figure 1-5 and Table 8-5. It is assumed

1. If optical components are included, i.e XFP modules, the BER is constrained by the optical specification.
2. Reference receiver B allows compliance to XFP Rev. 3.1 (10 gigabit Small form factor Pluggable Module) April 25th 2003

that the UBHPJ component of the driver jitter is not Inter-symbol Interference (ISI), hence it cannot be equalized in the receiver. To attenuate noise and absorb even/odd mode reflections, the source must provide a common mode return path.

For termination and DC-blocking information, please refer to 3.2.12

Table 8-1. Transmitter Electrical Output Specification.

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud		9.95		11.2	Gsym/s
Output Differential Voltage	T_Vdiff		360		770	mVppd
Differential Resistance	T_Rd		80	100	120	Ω
Differential Termination Resistance Mismatch	T_Rdm				5	%
Output Rise and Fall Time (20% to 80%)	T_tr, T_tf		24			ps
Differential Output Return Loss	T_SDD22	See 8.3.1.3				dB
Common mode Output Return Loss	T_SCC22	See 8.3.1.3			-6	dB
Transmitter Common Mode Noise	T_Ncm				15	mVrms
Output Common Mode Voltage Note 1, 3, 4	T_Vcm	Load Type 0 Note 2	0.05		3.55	V
		Load Type 1 Note 6	735		1135	mV
		Load Type 2	550		1060	mV
		Load Type 3 Note 5	490		850	mV

NOTES:
1. For Load Types 1, 2 and 3: R_Rdin = 100 ohms ± 20 ohms, R_Zvtt ≤ 30 ohms. For Vcm definition, see Figure 1-1
2. Load Type 0, AC-Coupling or floating load, R_Rdin = 100 ohms ± 20 ohms.Number includes ground difference
3. For Load Types 1 through 3: Vtt is defined for each load type as follows: Load Type 1 R_Vtt = 1.2V +5% / -8%; Load Type 2 R_Vtt = 1.0V +5% / -8%; Load Type 3 R_Vtt = 0.8V +5% / -8%.
4. DC Coupling compliance is optional (Type 1 through 3). Only Transmitters that support DC coupling are required to meet this parameter. It is acceptable for a Transmitter to restrict the range of T_Vdiff in order to comply with the specified T_Vcm range. For a Transmitter which supports multiple T_Vdiff levels, it is acceptable for a Transmitter to claim DC Coupling Compliance if it meets the T_Vcm ranges for at least one of it's T_Vdiff setting as long as those setting(s) are that are compliant are indicated
5. Simple CML Transmitters designed using Vdd ≥ 1.2V may still claim DC compliance if this parameter is not met.
6. Simple CML Transmitters designed using Vdd ≤ 0.8V may still claim DC compliance if this parameter is not met.

Table 8-2. Transmitter Output Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Bounded High Probability Jitter	T_UBHPJ				0.15	UIpp
Uncorrelated Unbounded Gaussian Jitter	T_UUGJ	Note 1			0.15	UIpp
Total Jitter	T_TJ				0.30	UIpp
Eye Mask	T_X1				0.15	UI
Eye Mask	T_X2				0.4	UI
Eye Mask	T_Y1		180			mV
Eye Mask	T_Y2				385	mV

NOTES:
1. BER=10^{-15}, Q=7.94

8.3.1.1 Driver Baud Rate

All devices shall work from 9.95Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11.

8.3.1.2 Driver Test Load

Please refer to 3.2.6.

8.3.1.3 Driver Resistance and Return Loss

Please refer to 3.2.10 with the following parameters..

Table 8-3. Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$T\_\mathrm{Baud} \times \frac{3}{4}$	Hz
f2	$T\_\mathrm{Baud} \times \frac{3}{2}$	Hz
Slope	16.6	dB/dec

8.3.1.4 Driver Lane-to-Lane Skew

Please refer to 3.2.7

8.3.1.5 Driver Short Circuit Current

Please refer to 3.2.9

8.3.2 Receiver Characteristics

Receiver electrical specifications are given in Table 8-4 and measured at compliance point R. To dampen noise sources and absorption of both even and odd mode reflections, the source in addition to improve differential termination must provide a common mode return path. Jitter specifications at reference R are listed in Table 8-5 and the compliance mask is shown in Figure 1-5.

As per 2.2.4, the receiver shall tolerate at least the far-end eye template and jitter requirements as given in Figure 1-5 and Table 8-5 with an additional SJ with any frequency and amplitude defined by the mask of Figure 2-4 where the maximum total wander amplitude is 5UIpp. This additional SJ component is intended to ensure margin for wander.

For termination and DC-blocking information, please refer to 3.2.12.

Table 8-4. Receiver Electrical Input Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	R_Baud		9.95		11.2	Gsym/s
Input Differential Voltage	R_Vdiff		110		1050	mVppd
Differential Input Resistance	R_Rdin		80	100	120	Ω
Receiver Common Mode Noise	R_Ncm				25	mVrms
Input Resistance Mismatch	R_Rm				5	%
Differential Input Return Loss	R_SDD11	See 8.3.2.3				dB
Common mode Return Loss	R_SCC11	See 8.3.2.3			-6	dB
Differential to Common mode input conversion	R_SCD11	See 8.3.2.3			-12	dB
Termination Voltage Note 1, 2	R_Vtt	R_Vtt floating, Note 3	Not Specified			V
		R_Vtt = 1.2V Nominal	1.2 - 8%		1.2 + 5%	V
		R_Vtt = 1.0V Nominal	1.0 - 8%		1.0 + 5%	V
		R_Vtt = 0.8V Nominal	0.8 - 8%		0.8 + 5%	V
Input Common Mode Voltage Note 1, 2	R_Vrcm	R_Vtt floating, Note 3	0		3.60	V
		R_Vtt = 1.2V Nominal	720		R_Vtt -10	mV
		R_Vtt = 1.0V Nominal	535		R_Vtt +125	mV
		R_Vtt = 0.8V Nominal	475		R_Vtt +105	mV

NOTES:
1. DC Coupling compliance is optional. Only Receivers which support DC coupling are required to meet this parameter. For Vcm definition, see Figure 1-1
2. Receiver is required to implement at least one of specified nominal R_Vtt values, and typically implements only one of these values. Receiver is only required to meet R_Vrcm parameter values that correspond to R_Vtt values supported.
3. Input common mode voltage for AC-coupled or floating load input.

Table 8-5. Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Bounded High Probability Jitter	R_UBHPJ				0.25	UIpp
Correlated Bounded High probability Jitter	R_CBHPJ				0.20	UIpp
Gaussian Jitter (UUGJ + CBGJ)	R_GJ	Note 2			0.20	UIpp
Sinusoidal Jitter, Maximum	R_SJ-max	See 2.2.4			5	UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See 2.2.4			0.05	UIpp

NOTES:
1. TJ includes high frequency sinusoidal jitter. The receiver must tolerate the total deterministic and random jitter with addition of the sinusoidal jitter. For transparent applications the specified jitter tolerance mask replace R_SJ.
2. BER=10^{-15}, Q=7.94

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Total Jitter, including R_SJ-hf	R_TJ	Note 1			0.70	UIpp
Total Jitter excl. Correlated High Probability Jitter	R_TJLess CHPJ				0.50	UIpp
Eye Mask incl. Correlated High Probability. Jitter	R_X1				0.35	UI
Eye mask excl. Correlated High Probability Jitter	R_X1Less CHPJ				0.25	
Eye Mask	R_Y1		55			mV
Eye Mask	R_Y2				525	mV

NOTES:
1. TJ includes high frequency sinusoidal jitter. The receiver must tolerate the total deterministic and random jitter with addition of the sinusoidal jitter. For transparent applications the specified jitter tolerance mask replace R_SJ.
2. BER=10^{-15}, Q=7.94

.

8.3.2.1 Input Baud Rate

All devices shall work from 9.95Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11.

8.3.2.2 Reference Input Signals

Reference input signals to the receiver shall have the characteristics determined by a compliant driver. The reference input signal must satisfy the transmitter near-end template and jitter given in Figure 1-4 and Table 8-2, as well as the far-end eye template and jitter given in Figure 1-5 and Table 8-5, with the differential load impedance of $100\Omega \pm 1\%$ at DC and a return loss of better than 20dB from baud rate over 1667 to 1.5 times the baud rate. Note that the input signal might not meet either of these templates when the actual receiver replaces this load.

8.3.2.3 Input Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 8-6. Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$R\_Baud \times \frac{3}{4}$	Hz
f2	$R\_Baud \times \frac{3}{2}$	Hz
Slope	16.6	dB/dec

SCD11 relates to the conversion of Differential to Common mode and the associated generation of EMI. The common mode reference impedance is 25Ω, measurement range is f0 to f1 of Table 8-6.

8.3.2.4 Input Lane-to-Lane Skew

Please refer to *3.2.8*

8.4 Specifications for Jitter-transparent applications

The CEI interface for short reach may be used for applications where connected elements are transparent to other clock domains with requirements to jitter performance that in some implementations may interfere with the CEI jitter requirements. Consider a situation using the CEI reference model, Figure 1-6, where the Ingress Transmitter T_I does not filter the jitter from the adjacent clock domain with a low frequency low pass filter and the Egress Receiver R_E likewise pass the CEI channel jitter unfiltered to the adjacent clock domain. In this case the requirements to handle the combined jitter of the CEI interface and the adjacent clock domain is evident. In the Ingress direction the unfiltered Jitter from the input to the Ingress Transmitter will be superimposed to the jitter of the Transmitter, link and Receiver. In the Egress direction the jitter of the Transmitter, Link and Receiver will be passed beyond the Egress Receiver R_E into the adjacent clock domain. The following sections specify the requirements to devices intended for use in transparent applications. The requirements have an effect on the previously defined channel, transmitter, and receiver compliance testing and must be carefully understood, please refer to 2.5 for further details.

8.4.1 Jitter Requirements for Transparent Applications in Telecom systems

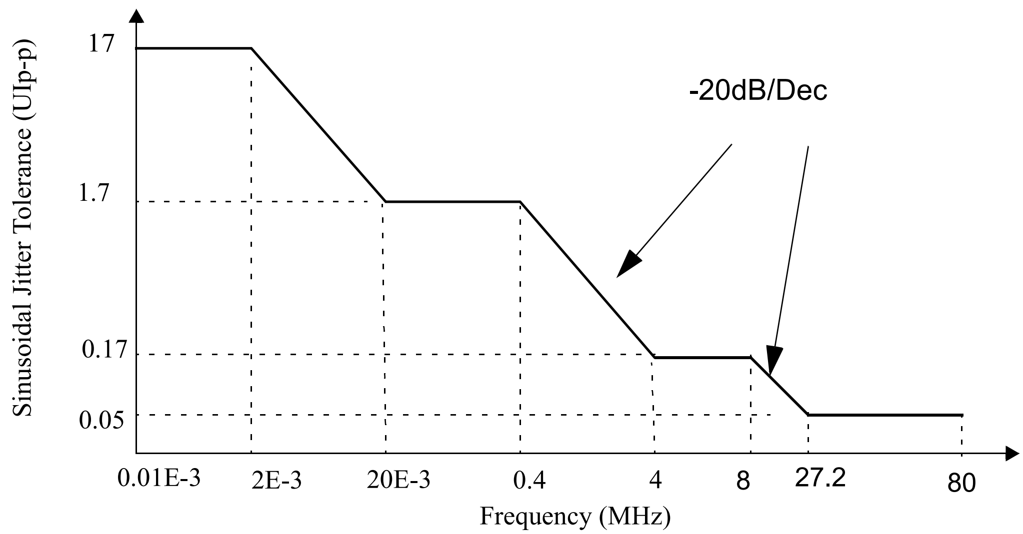
Telecom systems are Sonet as defined by ANSI: T1.105.03-2003 and Telcordia: GR-253, SDH systems as defined by ITU-T: G.783, G.812, G.813, G.825 and OTN systems as defined by ITU-T: G.8251 (for OTN jitter).

Currently there are discrepancies between Telcordia GR-253 and ITU-T G.783. This IA is compliant to both with respect to jitter transfer and aligned with ITU-T G.783 with respect to jitter generation

8.4.1.1 Sinusoidal Jitter tolerance mask for Ingress direction, CEI receiver at reference point R_I

.

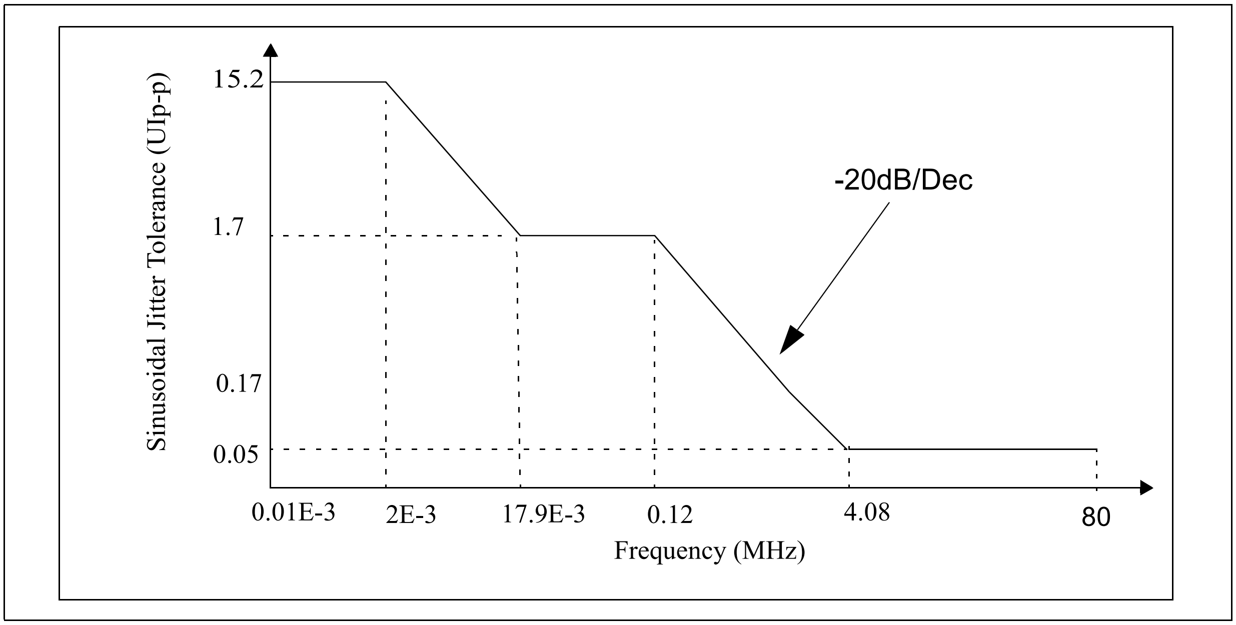
Figure 8-1.Jitter Ingress Receiver Input Telecom Sinusoidal Jitter



The Sinusoidal Jitter mask is aligned with the Telecom requirements for the Input Jitter Tolerance at the Signal Conditioner input and a required maximum loop BW of 8MHz in the case of a simple PLL based Signal Conditioner. Margins are added to the jitter amplitude to allow for added jitter by the signal conditioner and the CEI interconnect. This margin is not intended to alter in any way the telecom network limits as specified by ANSI/ITU-A but is required to assure the limits to be met by an Ingress CEI receiver that needs to tolerate the combined telecom network maximum jitter and CEI channel maximum jitter.

8.4.1.2 Sinusoidal Jitter tolerance mask for Egress direction, CEI receiver at reference point R_E.

Figure 8-2.Jitter Egress Receiver Input Telecom Sinusoidal Jitter



The Sinusoidal Jitter mask is aligned with the Telecom requirements for the Input Jitter of an Ingress Signal Conditioner with additional margin for the signal transfer to the Egress path in accordance with 8.4.1.3. This implies a required minimum loop BW of 4MHz in the case of a simple PLL based Signal Conditioner. The low frequency amplitude is required for tolerance testing only and does not reflect a valid condition during operation.

8.4.1.3 Telecom Jitter transfer

Jitter transfer specifications are necessary to constrain the Peaking and Bandwidth transfer function of the elements in a telecom system due to the synchronous timing of network elements. Measurements as per Annex 2.E.5. The following specifications assume an overall transfer -3dB bandwidth (20db/dec) limited to 120kHz by circuits outside the scope of this IA.

Table 8-7. Telecom Signal Conditioner, Egress direction

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Jitter Transfer Bandwidth	BW	Data see 1			8	MHz
Jitter Peaking		Frequency <120kHz			0.03	dB
		Frequency >120kHz			1	dB
NOTES: 1. PRBS 2^{31}-1, OC-192/SDH-64 Sinusoidal Jitter Tolerance Mask						

Table 8-8. Telecom Signal Conditioner, Ingress Direction

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Jitter Transfer Bandwidth	BW	Data, see 1			8	MHz
Jitter Peaking		Frequency <120kHz			0.03	dB
		Frequency >120kHz			1	dB
NOTES: 1. PRBS 2^{31}-1, OC-192/SDH-64 Sinusoidal Jitter Tolerance Mask						

8.4.1.4 Telecom Jitter Generation for Egress Direction

The Jitter generation measured at the Egress output of the Jitter Transparent Element is the sum of the jitter at the Egress Driver Output (reference point T_E in Figure 1-6), the CEI channel and the Jitter Transparent Element in which the CEI receiver R_E (Figure 1-6) resides. The maximum allowed Jitter Generation at the output of the Jitter Transparent Element is allocated in Table 8-9.

Table 8-9. Telecom Egress Jitter Generation budget

	Measurement range		Budget allocation
	Lower Frequency	Upper Frequency	
Egress driver	TE Egress output lower measurement limit	Signal conditioner max transfer bandwidth	42.5%
Egress channel	TE Egress output lower measurement limit	Signal conditioner max transfer bandwidth	7.5%
Egress TE, signal conditioner and path to Egress output	TE Egress output lower measurement limit	TE Egress output upper measurement limit	50%

Informative values for the Egress Driver is given in Table 8-10 based on current telecom recommendations...

Table 8-10. Telecom Egress Driver Jitter Generation

	TE Output Specified Range	Measurement Range	Method	Value	Unit
Telcordia GR-253	50kHz - 80MHz	50kHz - 8MHz	not specified, note 1	6.5	mUIrms
	50kHz - 80MHz	50kHz - 8MHz	not specified, note 1	43	mUIpp
ITU-T G.783	20kHz - 80MHz	20kHz - 8MHz	60 sec	129	mUIpp
	4MHz - 80MHz	4MHz - 8MHz	60 sec	43	mUIpp
NOTES: 1. The ITU-T specifications are applicable, Telcordia plans to align GR-253 those specifications when/if GR-253 is reissued					

The measurement range corresponds to the transfer bandwidth as stated in Table 8-7.

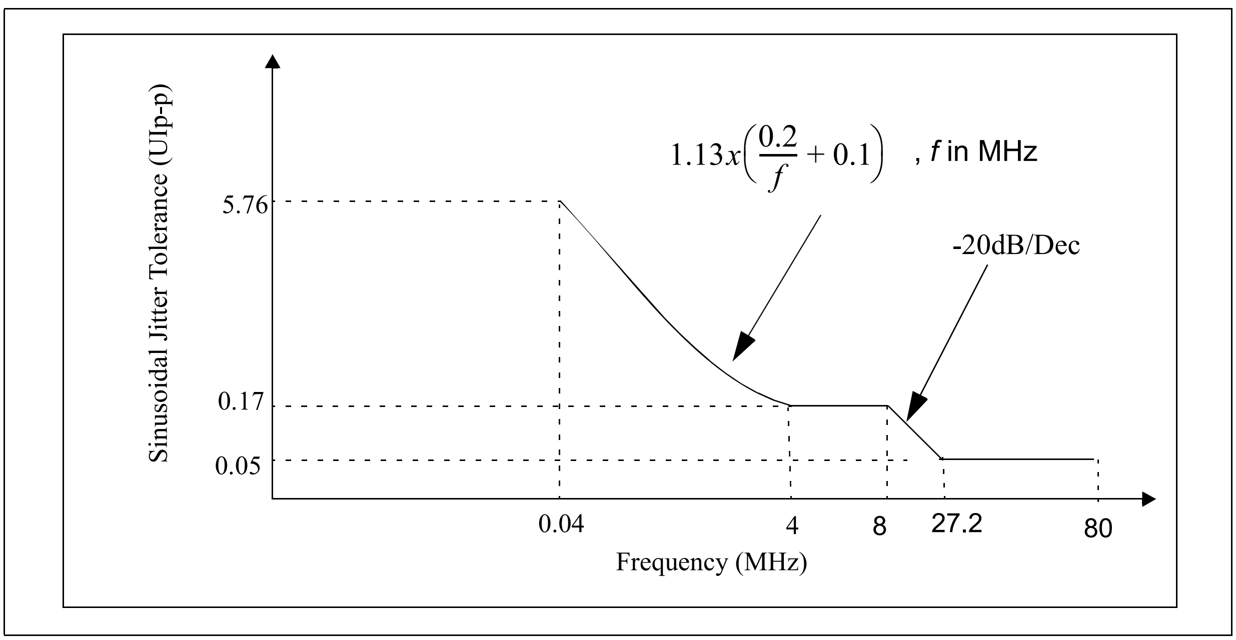
8.4.2 Jitter Requirements for Transparent Applications in Datacom systems

Datacom systems are 10GE as defined by IEEE 802.3ae-2002and the 10GFC as defined by INCITS, T11.2.

8.4.2.1 Sinusoidal Jitter tolerance mask for Ingress direction, CEI Receiver at reference point D

.

Figure 8-3.Jitter Ingress Receiver Input Datacom Sinusoidal Jitter



The Sinusoidal Jitter mask is aligned with the Datacom requirements for the Input Jitter Tolerance at the Signal Conditioner input and a required maximum loop BW of 8MHz in the case of a simple PLL based Signal Conditioner. Margins are added to the jitter amplitude to allow for added jitter by the signal conditioner and the CEI interconnect.

8.4.2.2 Datacom Jitter transfer

The jitter transparent Signal Conditioner of the Ingress and Egress directions need to be specified to constrain the overall signal jitter transferred to the receive end of the CEI channel and for the Egress direction further onto the transmit side of the signal conditioner.

Table 8-11. Datacom Signal Conditioner Egress direction

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Jitter Transfer Bandwidth	BW	Data see 1			8	MHz
Jitter Peaking		Frequency >50kHz			1	dB
NOTES: 1. Based on IEEE 802.3ae-2002 Clause 52 Sinusoidal Jitter Tolerance Mask, figure 52-4						

Table 8-12. Datacom Signal Conditioner Ingress Direction

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Jitter Transfer Bandwidth	BW	Data, see 1			8	MHz
Jitter Peaking		Frequency >50kHz			1	dB
NOTES: 1. Based on IEEE 802.3ae-2002 Clause 52 Sinusoidal Jitter Tolerance Mask, figure 52-4						

8.4.3 Jitter Transparency compliance nomenclature

For compliance to Jitter-transparent applications transmitters and receivers shall be identified as shown in table

Table 8-13. Datacom Signal Conditioner Ingress Direction

Characteristic	Symbol
Telecom Receiver, Ingress	**CEI 11GSR - TR(I)**
Telecom Transmitter, Ingress	**CEI 11GSR - TT(I)**
Telecom Receiver, Egress	**CEI 11GSR - TR(E)**
Telecom Transmitter, Egress	**CEI 11GSR - TT(E)**
Datacom Receiver, Ingress	**CEI 11GSR - DR(I)**
NOTES:	

Table 8-13. Datacom Signal Conditioner Ingress Direction

Characteristic	Symbol
Datacom Transmitter, Ingress	**CEI 11GSR - DT(I)**
Datacom Receiver, Egress	**CEI 11GSR - DR(E)**
Datacom Transmitter, Egress	**CEI 11GSR - DT(E)**
NOTES:	

8.A Appendix - Informative Jitter Budget

The Jitter Budget is presented in Table 8-14. Contributors in the 'Source' column should not exceed the value of the 'Value' column.

Table 8-14. Informative Jitter Budget

Source	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	Bounded High Prob.	Bounded Gaussian	Bounded High Prob.	Gaussian	Sinusoidal	High Prob.	Total		
Abbreviation	**UUGJ**	**UBHPJ**	**CBGJ**	**CBHPJ**					**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmitter	**0.150**	**0.150**			**0.150**		**0.150**	**0.300**		**360**
Channel		0,100	0,132	0.200		0,050				
Receiver Input	**0.150**	**0.250**	**0,132**	**0.200**	**0.200**	**0,050**	**0.450**	**0.650**	**0.31**	**110**
Equalizer				-0.200						
Post Equalizer	**0.150**	**0.250**	**0,132**	**0.000**	**0.200**	**0,050**	**0.250**	**0.450**	**0.31**	**110**
Clock & Sampler	0.150	0.100		0.100						-50
Budget with Equalizer	**0.212**	**0.350**	**0,132**	**0.100**	**0.250**	**0.050**	**0.450**	**0.750**		**60**
Budget without equalizer	**0.212**	**0.350**	**0,132**	**0.300**	**0.250**	**0.050**	**0650**	**0.950**		**60**
Note: Values in yellow are specified values from Table 8-2 and Table 8-5										

8.B Appendix - StatEye.org Template[1]

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution = 0.01;
param.binsize = 0.0005;
param.points = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps = 11.1e9;
param.bitResolution = 1/(3*param.bps);
param.txFilter = 'singlepole';
param.txFilterParam = [0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

% param.returnLoss = 'off';
param.returnLoss = 'on';
param.cpad = 0.60;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre = [];
param.signal = 1.0;
param.txpost = [];
param.vstart = [-0.3];
param.vend = [+0.0];
```

1. for Reference receiver B in 8.2.7, pls refer to XFP Rev. 3.1 (10 gigabit Small form factor Pluggable Module) April 25th 2003

```
param.vstep = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of 4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1]; % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1; % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2; % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample = -0.1;

param.dfe = [];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj = 0.15;
param.txrj = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user = [0.0];
param.useuser = 'no';
param.usesymbol = '';
param.xtAmp = 1.0;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

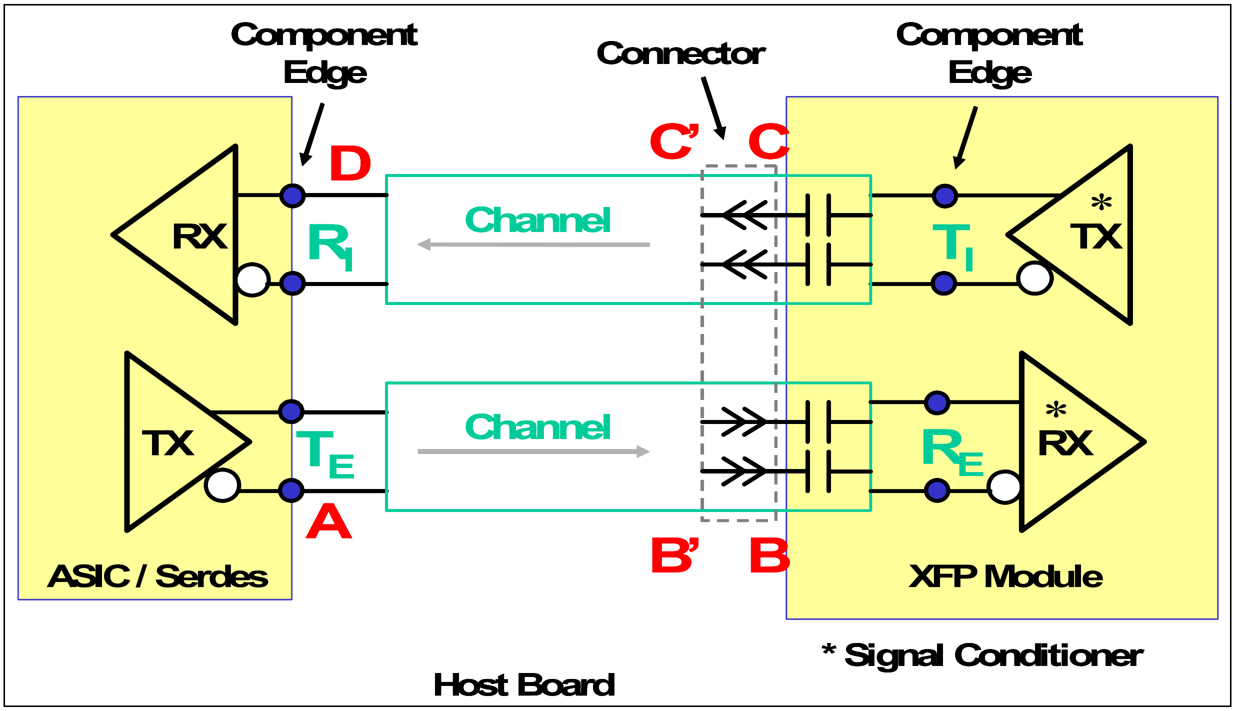
param.TransmitAmplitude = 0.360; % mVppdif
param.MinEye = 0.110; % mVppdif

param.Q = 2*7.94;
param.maxDJ = 0.45;
param.maxTJ = 0.65;
```

8.C Appendix - XFP reference points

The specification of the CEI-11G-SR is compatible with the XFI interface specified for the XFP (10 gigabit Small form factor Pluggable Module). However the definition of reference points diverts somewhat. Where the CEI is defining the active component interfaces to a generic compliant channel the XFP specifies the normative reference points at the edges of the XFP connector that forms the interface between an XFP module and its host board. The XFP reference points A and D at the component edge are informative only for XFP but identical to the CEI R_I and T_E respectively. Figure 8-4 shows the reference points of the XFP in comparison to the CEI. Note that the XFP specification does not define test points for the component edge of the components in the XFP module, the signal conditioners. Also note that CEI does not define the XFP reference points B, B', C and C' for the connector as this is considered part of the channel.

Figure 8-4.Reference Model



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9 CEI-11G-LR/MR Long/Medium Reach Interface

This clause details the requirements for the CEI-11G-LR and CEI-11G-MR high speed electrical interface between nominal baud rates of 9.95 Gsym/s to 11.2 Gsym/s using NRZ coding. A compliant device must meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic with nominal differential impedance of 100 Ω. Connections are point-to-point balanced differential pair and signaling is unidirectional.

The electrical IA is based on loss and jitter budgets and defines the characteristics required to communicate between a CEI-11G-LR driver and a CEI-11G-LR receiver and between a CEI-11G-MR driver and a CEI-11G-MR receiver, using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100 Ω differential. Rather than specifying materials, channel components or configurations, the IA focuses on effective channel characteristics. Hence a short length of poorer material should be equivalent to a longer length of premium material. A length is effectively defined in terms of its attenuation and phase response rather than its physical length.

CEI-11G-LR as well as CEI-11G-MR devices from different manufacturers shall be inter-operable.The CEI-11GLR/MR channel is tested to insure compliance using the statEye scripts. The transmitter is specified in terms of its ability to pre-equalize the transmit signal and the receiver must work to the given BER using a compliant driver and channel.

The primary focus of the CEI-11G-LR implementation agreement will be for non-legacy applications, optimized for overall cost-effective system performance including total power dissipation. Future clauses may address schemes otherwise optimized.

This clause also provides for a CEI-11G-MR low power option. The CEI-11G-MR option is based upon the following:

- A channel compliance specification is defined in this clause for CEI-11G-MR which is more stringent than that of CEI-11G-LR.
- CEI-11G-MR uses the same Transmitter device as is specified for CEI-11G-LR, making use of certain features otherwise defined as optional.
- CEI-11G-MR uses a Receiver device that is similar to the device specified for CEI-11G-SR in Clause 8, but with extended T_Vdiff range. Relevant specifications for this receiver device are incorporated by reference to Clause 8.

9.1 Requirements

1. Support NRZ coded serial data rate from 9.95 Gsym/s to 11.2 Gsym/s.
2. Capable of low bit error rate (required BER < 10^{-15}).
3. Capable of driving 0 — 1 meter (39 inches) of PCB and up to 2 connectors.
4. Capable of driving 0 — 600 mm of PCB and up to 2 connectors for low-power applications.
5. Shall support AC-coupled and optionally DC-coupled operation.
6. Shall allow multi-lanes (1 to n).
7. Shall support hot plug.

9.2 General Requirements

9.2.1 Data Patterns

See 3.2.1

9.2.2 Signal Levels

See 3.2.2

9.2.3 Signal Definitions

See 1.A

9.2.4 Bit Error Ratio

See 3.2.3

9.2.5 Ground Differences

See 3.2.4

9.2.6 Cross Talk

See 3.2.5

9.2.7 Channel Compliance

9.2.7.1 CEI-11G-LR Channel Compliance

A forward channel and associated dominant crosstalk channels are deemed compliant if for the specified reference transmitter and both the specified reference receivers, the signal conforms to the defined eye mask and does not exceed the defined jitter using the “Statistical Eye” methodology defined in 2.C

Reference Transmitter:

1. Maximum Transmit Pulse, as per 2.E.7, of T_Vdiff min. of Table 9-1
2. A TX edge rate filter simple 40dB/dec low pass at 75% of Baud Rate
3. Effective Driver UUGJ, UBHPJ and DCD as in Table 9-3
4. Equalizing Filter with 2 tap baud spaced emphasis no greater than a total of 6dB with finite resolution no better than 1.5dB.
5. Worst case Transmitter return loss described as a parallel RC element, see 2.E.6
6. Maximum baud rate that the channel is to operate at or 11.2 Gsym/sec whichever is the lowest, see 9.3.1.1

Reference Receiver A:

1. 4-tap baud spaced Non-Linear Discrete Inverse Channel Filter (DFE), with infinite precision accuracy and having the following restrictions:

   Let W[N] be sum of DFE tap coefficient weights from taps N through M where

   N = 1 is previous decision (i.e. first tap)
   M = 4
   R_Y2 = T_Y2 = 400mV
   Y = min(R_X1, (R_Y2 - R_Y1) / R_Y2) = 0.2625
   $Z = {}^{2}/_{3} = 0.66667$

   Then $W[N] \leq Y * Z^{(N-1)}$

   For the channel compliance model the number of DFE taps (M) = 4. This gives the following maximum coefficient weights for the taps:

   W[1] ≤ 0.2625 (sum of absolute value of taps 1 and2)
   W[2] ≤ 0.1750 (sum of absolute value of taps 2, 3 and 4)
   W[3] ≤ 0.1167 (sum of absolute value of taps 3 and 4)
   W[4] ≤ 0.0778 (sum of absolute value of tap 4)

   Notes:
   - Coefficient weights are absolute, assuming a T_Vdiff of 1Vppd

- For a real receiver the restrictions on tap coefficients would apply for the actual number of DFE taps implemented (M)
- LMS, Least Mean Squared Adaptation Algorithm.

2. Worst case Receiver return loss described as a parallel RC, see 2.E.6

Resulting Eye Mask of either receiver:

Table 9-1. CEI-11G-LR Receiver Equalization Output Eye Mask

Parameter	Symbol	Max	Units
Eye mask	R_X1	0.2625	UI
Eye mask	R_Y1	50	mV
Correlated Bounded High Probability Jitter, pre-equalizer	R_CBHPJ	0.40	UIpp
Correlated Bounded High Probability Jitter, post-equalizer	R_CBHPJ	0.10	UIpp
Uncorrelated Bounded High Probability Jitter	R_UBHPJ	0.15	UIpp
Uncorrelated Unbounded Gaussian Jitter	R_UUGJ	0.15	UIpp
Quality of signal (SNR in real number)	Q	7.94	

9.2.7.2 CEI-11G-MR Channel Compliance

As per 2.5.2, with the following reference transmitter and reference receiver (note these conditions do not specify any required implementation but rather indicate a methodology for testing channel compliance), and shall meet the receive eye mask as specified in Figure 1-5 and Table 9-9 when using electrical characteristic R_X1 less R_SJ-hf in Table 9-9.

Reference Transmitter as defined in “Reference Transmitter” in section 9.2.7.1.

Reference Receiver as defined in “Reference Receiver A” in Section 8.2.7.

9.3 Electrical Characteristics, CEI-11G-LR and CEI-11G-MR

The electrical signaling is based on high speed low voltage logic with a nominal differential impedance of 100 Ω.

9.3.1 Driver Characteristics

For termination and DC-blocking information, please refer to 8.2.7

Table 9-2. Transmitter Output Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud		9.95		11.2	Gsym/s
Output Differential Voltage	T_Vdiff	Pre-emphasis off or Tx Filter Applied, see note 1	800		1200	mVppd
Differential Output Impedance	T_Rd		80	100	120	Ω
Differential Termination Impedance Mismatch	T_Rm				10	%
Output Rise and Fall Time (20% to 80%)	T_tr, T_tf		24			ps
Differential Output Return Loss	T_SDD22	See 9.3.1.3				
Common Mode Return Loss	T_SCC22	See 9.3.1.3			-6	dB
Transmitter Common Mode Noise	T_Ncm				5% of T_Vdiff	mVppd
Output Common Mode Voltage See Notes 2, 3 & 4	T_Vcm	Load Type 0 See Note 2	100		1700	mV
		Load Type 1 See Note 3 & 4	630		1100	mV

NOTES:
1. In applications where the channel is better than the worst case allowed, a transmitter device may be provisioned to produce T_Vdiff less than this minimum value but ≥360mVppd and be compliant with this specification.
2. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load.
3. For Load Type 1: R_Zvtt ≤ 30Ω; T_Vtt & R_Vtt = 1.2V +5%/-8%
4. DC Coupling compliance is optional (Load Type). Only Transmitters that support DC coupling are required to meet this parameter.

Table 9-3. Transmitter Output Jitter Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Unbounded Gausian Jitter	T_UUGJ	See 9.3.1.6, Note 1			0.15	UI_{PP}
Uncorrelated Bounded High Probability Jitter	T_UBHPJ	See 9.3.1.6, Note 1			0.15	UI_{PP}
Duty Cycle Distortion (component of UBHPJ)	T_DCD	See 9.3.1.6			0.05	UI_{PP}
Total Jitter	T_TJ	See 9.3.1.6			0.30	UI_{PP}
Eye Mask	T_X1	See 9.3.1.6			0.15	UI
Eye Mask	T_X2	See 9.3.1.6			0.50	UI
Eye Mask	T_Y1	See 9.3.1.6 Note 3	400			mV
Eye Mask	T_Y2	See 9.3.1.6			600	mV

NOTES:
1. UBHPJ is composed of DCD, inter-symbol-interference (ISI), and Sinusoidal Jitter.
2. Except for amplitude, the CEI-11G+ long-reach driver electrical specifications of Table 9-3 are intended to be the same as for CEI-11G+ short-reach
3. The minimum value for channel compliance is 300mV and not 180mV. The 180mV is to allow lower power for channels that are better than the worst case channels allowed

9.3.1.1 Driver Baud Rate

All devices shall work from 9.95Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.12. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

9.3.1.2 Driver Amplitude and Swing

Driver differential output amplitude shall be able to drive between 800 to 1200mVppd either with or without any transmit emphasis. However, for the case of this transmitter talking to a short reach receiver, the differential output amplitude shall be between 380 to 770mVppd either with or without any transmit emphasis. DC referenced logic levels are not defined since the receiver must have high common mode impedance at DC. However, absolute driver output voltage shall be between -0.1 V and 1.9 V with respect to local ground. See Figure 1-1 for an illustration of absolute driver output voltage limits and definition of differential peak-to-peak amplitude.

9.3.1.3 Driver Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 9-4. Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$T\_\text{Baud} \times \frac{3}{4}$	Hz
f2	T_Baud	Hz
Slope	16.6	dB/dec

9.3.1.4 Driver Lane-to-Lane Skew

Please refer to 3.2.7

9.3.1.5 Driver Short Circuit Current

Please refer to 3.2.9

9.3.1.6 Driver Template and Jitter

As per 2.2.3 for a BER as per 9.2.4, the driver shall satisfy the eye template and jitter requirements as given in Figure 1-4.

9.3.2 CEI-11G-LR Receiver Characteristics

This section defines receiver characteristics for CEI-11G-LR receivers. Receiver characteristics for CEI-11G-MR receivers are defined in 9.3.3.

Receiver electrical specifications are given in Table 9-5 and measured at compliance point R. For termination and DC-blocking information, please refer to 3.2.12

Table 9-5. CEI-11G-LR Receiver Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud rate	R_Baud		9.95		11.2	GSym/s
Input Differential Voltage	R_Vdiff	Note 1			1200	mVppd
Differential Input Impedance	R_Rdin		80	100	120	Ω
Input Impedance Mismatch	R_Rm				10	%
Differential Input Return Loss	R_SDD11	See 9.3.2.3				
Common Mode Input Return Loss	R_SCC11	Below 10 GHz			-6	dB
Input Common Mode Voltage See Notes: 2, 3 & 4	R_Vcm	Load Type 0 See Note 3	0		1800	mV
		Load Type 1 See Notes 2, 4	595		R_Vtt - 60	mV
Wander Divider	n	See Note 5		10		

NOTES:
1. The long-reach receiver shall have a differential input voltage range sufficient to accept a signal produced at point R by the combined transmitter and channel. The channel response shall include the worst case effects of the return losses at the transmitter and receiver.
2. DC Coupling compliance is optional (Load Type 1). Only receivers that support DC coupling are required to meet this parameter.
3. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load. For floating load, input resistance must be ≥ 1kΩ
4. For Load Type 1: T_Vtt & R_Vtt = 1.2V +5%/-8%.
5. Used in Statistical Eye script, must be set to 10

Table 9-6. CEI-11G-LR Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Sinusoidal Jitter, Maximum	R_SJ-max	See 2.5.4, note 1, 2			5	UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See 2.5.4, note 1, 2			0.05	UIpp

NOTES:
1. The Receiver shall tolerate the sum of these jitter contributions: Total Driver jitter from Table 9-2;Sinusoidal jitter as defined in Table 9-6;The effects of a channel compliant to the Channel Characteristics (9.2.7).
2. The receiver must tolerate the total deterministic and random jitter with addition of the sinusoidal jitter.

9.3.2.1 Input Baud Rate

All devices shall work from 9.95Gsym/s to the maximum baud rate specified for the device, with the baud rate tolerance as per 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

9.3.2.2 Absolute Input Voltage

The absolute voltage levels with respect to the receiver ground at the input of the receiver are dependent on the driver implementation and the inter-ground difference.

The voltage levels at the input of an AC coupled receiver (if the effective AC coupling is done within the receiver) or at the Tx side of the external AC coupling cap (if AC coupling is done externally) shall be between -0.2 to 2.0V with respect to local ground.

9.3.2.3 Input Resistance and Return Loss

Please refer to 3.2.10 with the following parameters.

Table 9-7. Driver Return Loss Parameters

Parameter	Value	Units
A0	-8	dB
f0	100	MHz
f1	$R\_\mathrm{Baud} \times \frac{3}{4}$	Hz
f2	R_Baud	Hz
Slope	16.6	dB/dec

9.3.2.4 Input Signal Amplitude

The receiver shall accept differential input signal amplitudes produced by compliant transmitters connected without attenuation to the receiver. This may be larger than the 1200mVppd maximum of the driver due to output/input impedances and reflections.

The minimum input amplitude is defined by the far-end driver template, the actual receiver input impedance and the loss of the actual PCB. Note that the far-end driver template is defined using a well controlled load impedance, however the real receiver is not, which can leave the receiver input signal smaller than expected.

9.3.2.5 Input Lane-to-Lane Skew

Please refer to 3.2.8

9.3.3 CEI-11G-MR Receiver Characteristics

This section defines receiver characteristics for CEI-11G-MR receivers. Receiver characteristics for CEI-11G-LR receivers are defined in 9.3.2.

Receiver electrical specifications are given in Table 9-8 and measured at compliance point R. Jitter specifications at reference R are listed in Table 9-9 and the compliance mask is shown in Figure 1-5.

For termination and DC-blocking information, please refer to 3.2.12.

Table 9-8. CEI-11G-MR Receiver Electrical Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud rate	R_Baud		9.95		11.2	GSym/s
Input Differential Voltage	R_Vdiff	Note 1	110		1200	mVppd
Differential Input Impedance	R_Rdin		See R_Rdin in Table 8-4			Ω
Input Impedance Mismatch	R_Rm		See R_Rm in Table 8-4			%
Differential Input Return Loss	R_SDD11	See 9.3.2.3	See R_SDD11 in Table 8-4			
Common Mode Input Return Loss	R_SCC11	Below 10 GHz	See R_SCC11 in Table 8-4			dB
Input Common Mode Voltage	R_Vcm	Note 2	See R_Vcm in Table 9-5			mV
Wander Divider	n	See Note 5	See n in Table 9-5			

NOTES:
1. The medium-reach receiver shall have a differential input voltage range sufficient to accept a signal produced at point R by the combined transmitter and channel. The channel response shall include the worst case effects of the return losses at the transmitter and receiver.
2. DC Coupling compliance is optional (Load Type 1). Only receivers that support DC coupling are required to meet this parameter.

Table 9-9. CEI-11G-MR Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Bounded High Probability Jitter	R_UBHPJ		see R_UBHPJ in Table 8-5			UIpp
Correlated Bounded High probability Jitter	R_CBHPJ		see R_CBHPJ in Table 8-5			UIpp
Gaussian Jitter (UUGJ + CBGJ)	R_GJ	Note 2	see R_GJ in Table 8-5			UIpp
Sinusoidal Jitter, Maximum	R_SJ-max	See 2.2.4	see R_SJmax in Table 8-5			UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See 2.2.4	see R_SJ-hf in Table 8-5			UIpp
Total Jitter, including R_SJ-hf	R_TJ	Note 1	see R_TJ in Table 8-5			UIpp
Eye Mask incl. Correlated High Probability. Jitter	R_X1		see R_X1 in Table 8-5			UI
Eye Mask	R_Y1		see R_GJ in Table 8-5			mV
Eye Mask	R_Y2				600	mV

NOTES:
1. TJ includes high frequency sinusoidal jitter. The receiver must tolerate the total deterministic and random jitter with addition of the sinusoidal jitter. For transparent applications the specified jitter tolerance mask replace R_SJ.
2. BER=10^{-15}, Q=7.94

.

9.3.3.1 Input Baud Rate

Refer to 8.3.2.

9.3.3.2 Reference Input Signals

Reference input signals to the receiver shall have the characteristics determined by a compliant driver. The reference input signal must satisfy the transmitter near-end template and jitter given in Figure 1-4 and Table 9-3, as well as the far-end eye template and jitter given in Figure 1-5 and Table 9-9, with the differential loadimpedence of 100 ohms +/- 1% at DC and a return loss of better than 20dB from baud rate over 1667 to 1.5 times the baud rate. Note that the input signal might not meet either of these templates when the actual receiver replaces this load.

9.3.3.3 Input Resistance and Return Loss

Please refer to with the parameters shown in Table 8-6.

9.3.3.4 Input Lane-to-Lane Skew

Please refer to 3.2.8

9.A Appendix - Informative Jitter Budgets

9.A.1 Informative Jitter Budget for Long Reach

The following table is an informative jitter budget for long reach. It includes the specified transmit jitter and an estimate of receiver jitter. A receiver may trade its ability to equalize against its own internal jitter; possibly leading to different numbers than are shown here. The receiver must tolerate sinusoidal jitter in addition to jitter contained in this table.

Although only total jitter (TJ) and Uncorrelated Bounded High Probability Jitter (UBHPJ) are normative to the specification, a realistic jitter budget must account for Uncorrelated Unbounded Gaussian Jitter (UUGJ) of both the Receiver and Transmitter as well as Correlated Bounded Gaussian Jitter of the Channel. A budget based entirely on Uncorrelated bounded high Probability Jitter would be overly pessimistic or would unfairly burden the equalization.

Table 9-10. CEI-11G-LR Informative Jitter Budget

Source	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	Bounded High Prob.	Bounded Gaussian	Bounded High Prob.	Gaussian	Sinusoidal	High Prob.	Total		
Abbreviation	**UUGJ**	**UBHPJ**	**CBGJ**	**CBHPJ**					**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmitter	**0.150**	**0.150**			**0.150**		**0.150**	**0.300**		**800**
Channel			0.230	0.400						
Receiver Input	**0.150**	**0.150**	**0.230**	**0.400**	**0.275**		**0.550**	**0.825**	**0**	**0** See 2
Equalizer				-0.300 See 1						
Post Equalizer	**0.150**	**0.150**	**0.230**	**0.100**	**0.275**		**0.250**	**0.525**	**0.25**	**100**
DFE Penalties				0.100						-45
Clock & Sampler	0.150	0.100		0.100						-45
Budget	**0.212**	**0.250**	**0.230**	**0.300**	**0.313**	**0.050**	**0.550**	**0.913**	**0.13**	**10**

Note:
1. Due to receiver equalization, it reduces the ISI as seen inside the receiver. Thus this number is negative.
2. It is assumed that the eye is closed at the receiver, hence receiver equalization is required.
3. Values in yellow are specified values fromTable 9-5and Table 9-6

9.A.2 Informative Jitter Budget for Medium Reach

The following table is an informative jitter budget for medium reach. It includes the specified transmit jitter and an estimate of receiver jitter. A receiver may trade its ability to equalize against its own internal jitter; possibly leading to different numbers than are shown here. The receiver must tolerate sinusoidal jitter in addition to jitter contained in this table.

Although only total jitter (TJ) and Uncorrelated Bounded High Probability Jitter (UBHPJ) are normative to the specification, a realistic jitter budget must account for Uncorrelated Unbounded Gaussian Jitter (UUGJ) of both the Receiver and Transmitter as well as Correlated Bounded Gaussian Jitter of the Channel. A budget based entirely on Uncorrelated bounded high Probability Jitter would be overly pessimistic or would unfairly burden the equalization.

Table 9-11. CEI-11G-MR Informative Jitter Budget

Source	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	Bounded High Prob.	Bounded Gaussian	Bounded High Prob.	Gaussian	Sinusoidal	High Prob.	Total		
Abbreviation	**UUGJ**	**UBHPJ**	**CBGJ**	**CBHPJ**					**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmit equalizer				-0.200						
Transmitter	**0.150**	**0.150**		**-0.200**	**0.150**		**-0.050**	**0.100**		**800**
Channel		0.100	0.132	0.400		0.0				
Receiver Input	**0.150**	**0.250**	**0.132**	**0.200**	**0.200**	**0.050**	**0.450**	**0.700**	**0**	**110**
Clock & Sampler	0.150	0.100		0.100						-45
Budget	**0.212**	**0.350**	**0.132**	**0.300**	**0.250**	**0.050**	**0.650**	**0.950**	**0.13**	**10**

Note:
1. Due to receiver equalization, it reduces the ISI as seen inside the receiver. Thus this number is negative.
2. Values in yellow are specified values from Table 9-8 and Table 9-9

9.B Appendix - StatEye.org templates

9.B.1 StatEye.org templates for CEI-11G-LR, reference receiver A

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution          = 0.01;
param.binsize                 = 0.0005;
param.points                  = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps                     = 11.1e9;
param.bitResolution           = 1/(3*param.bps);
param.txFilter                = 'twopole';
param.txFilterParam           = [0.75 0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss              = 'on';
param.cpad                    = 0.60;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                   = [-0.1];
param.signal                  = 1.0;
param.txpost                  = [-0.1];
param.vstart                  = [-0.3 -0.3];
param.vend                    = [+0.0 +0.0];
```

```
param.vstep                    = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];          % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;       % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;             % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                 = -0.1;

param.dfe                      = [0.3 0.1 0.1 0.1];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% The CTE shall be controlled.

param.cte = 0; % CTE setting “0” = off; “1” = on;
param.ctethresh = 0; % max gain;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                     = 0.15;
param.txrj                     = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% the following options are not yet implemented and should
% not be changed

param.user                 = [0.0];
param.useuser              = 'no';
param.usesymbol            = '';
param.xtAmp                = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.TransmitAmplitude = 0.800; % mVppdif
param.MinEye         = 0.100; % mVppdif

param.Q              = 2*7.94;
param.maxDJ          = 0.275;
param.maxTJ          = 0.525;
```

9.B.2 StatEye.org Templates for CEI-11G-LR, reference receiver B

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version '_v1.0'];

% these are internal variables and should not be changed

param.scanResolution       = 0.01;
param.binsize              = 0.0005;
param.points               = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps                  = 11.1e9;
param.bitResolution        = 1/(3*param.bps);
param.txFilter             = 'twopole';
param.txFilterParam        = [0.75 0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
```

```
% using the appropriate option

param.returnLoss                = 'on';
param.cpad                      = 0.60;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                     = [-0.1];
param.signal                    = 1.0;
param.txpost                    = [-0.1];
param.vstart                    = [-0.3 -0.3];
param.vend                      = [+0.0 +0.0];
param.vstep                     = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];         % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;       % the coding is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set PAM amplitude and rate

param.PAM = 2;          % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                  = -0.1;

param.dfe                       = [];
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% The CTE shall be controlled.

param.cte = 1; % CTE setting “0” = off; “1” = on;
param.ctethresh = 3; % max gain;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj              = 0.15;
param.txrj              = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user              = [0.0];
param.useuser           = ’no’;
param.usesymbol         = ’’;
param.xtAmp             = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.TransmitAmplitude = 0.800; % mVppdif
param.MinEye        = 0.100; % mVppdif

param.Q         = 2*7.94;
param.maxDJ         = 0.275;
param.maxTJ         = 0.525;
```

9.B.3 StatEye.org templates for CEI-11G-MR reach

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% example template for setting up a standard, i.e. equaliser
% jitter and return loss

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.version = [param.version ’_v1.0’];

% these are internal variables and should not be changed
```

```
param.scanResolution              = 0.01;
param.binsize                    = 0.0005;
param.points                     = 2^13;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter and baud rate. The tx filter has two
% parameters defined for the corner frequency of the poles

param.bps                        = 11.1e9;
param.bitResolution              = 1/(3*param.bps);
param.txFilter                   = 'twopole';
param.txFilterParam              = [0.75 0.75];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the return loss up. The return loss can be turned off
% using the appropriate option

param.returnLoss                 = 'on';
param.cpad                       = 0.60;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the transmitter emphasis up. Some example setting are
% included which can be uncommented

% single tap emphasis
param.txpre                      = [-0.1];
param.signal                     = 1.0;
param.txpost                     = [-0.1];
param.vstart                     = [-0.3 -0.3];
param.vend                       = [+0.0 +0.0];
param.vstep                      = [0.1 0.05 0.025];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the de-emphasis of  4-point transmit pulse
% the de-emphasis run if param.txpre = [] and param.txpost = []

param.txdeemphasis = [1 1 1 1];          % de-emphasis is off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% set the data coding changing the transmit pulse spectrum
% the coding run if param.txpre = [] and param.txpost = []

param.datacoding = 1;       % the coding is off
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% set PAM amplitude and rate

param.PAM = 2;              % PAM is swithed off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the rxsample point does not need to be changed as it is
% automatically adjusted by the optimisation scripts.
% The number of DFE taps should be set, however, the initial
% conditions are irrelevant.

param.rxsample                    = -0.1;

param.dfe                         = [];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% The CTE shall be controlled.

param.cte = 0; % CTE setting "0" = off; "1" = on;
param.ctethresh = 0; % max gain;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% sampling jitter in HPJpp and GJrms is defined here

param.txdj                        = 0.15;
param.txrj                        = 0.15/(2*7.94);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% the following options are not yet implemented and should
% not be changed

param.user                        = [0.0];
param.useuser                     = 'no';
param.usesymbol                   = '';
param.xtAmp                       = 1.0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

param.TransmitAmplitude = 0.800; % mVppdif
param.MinEye            = 0.100; % mVppdif

param.Q                 = 2*7.94;
param.maxDJ             = 0.275;
param.maxTJ             = 0.525;
```

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10 CEI-28G-SR Short Reach Interface

This clause details the requirements for the CEI-28G-SR short reach high speed electrical interface between nominal baud rates of 19.90 Gsym/s and 28.05 Gsym/s using NRZ coding. A compliant device shall meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic. Connections are point-to-point balanced differential pairs and signaling is unidirectional.

The electrical IA is based on loss and jitter budgets and defines the characteristics required to communicate between a CEI-28G-SR transmitter and a CEI-28G-SR receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100 Ω differential. A ‘length’ is effectively defined in terms of its attenuation and phase response rather than its physical length. Refer to Section 10.2.6 for channel requirements.

Short reach CEI-28G-SR devices from different manufacturers shall be interoperable.

10.1 Requirements

1. Support serial baud rates within the range from 19.90 Gsym/s to 28.05 Gsym/s.
2. Capable of low bit error ratio (10^{-15}, with a test requirement to verify 10^{-12}).
3. Capable of driving up to 300 mm of PCB and up to 1 connector.
4. Shall support AC-coupled operation
5. Shall allow multi-lanes (1 to n).
6. Shall support hot plug.

10.2 General Requirements

10.2.1 Data Patterns

Please refer to Section 3.2.1

10.2.2 Signal levels

Please refer to Section 3.2.2. All transmitter and receiver devices shall support “Load Type 0”. Other load types are not supported by this clause.

10.2.3 Signal Definitions

Please refer to Section 1.A

10.2.4 Bit Error Ratio

Please refer to Section 3.2.3

10.2.5 Ground Differences

Please refer to Section 3.2.4

10.2.6 Channel Compliance

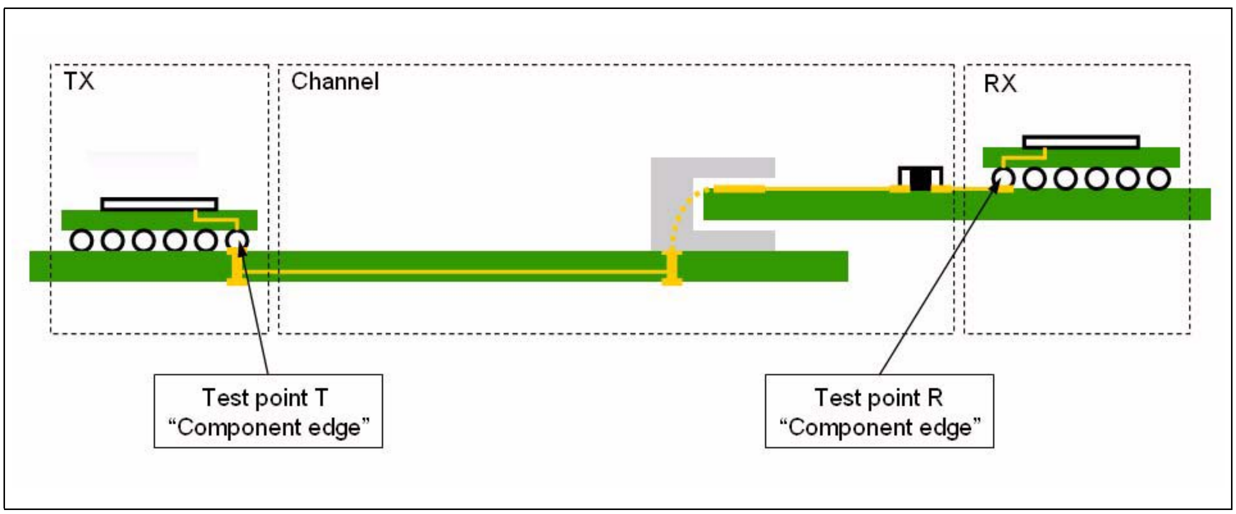
A forward channel and associated dominant crosstalk channels are deemed compliant if the channel characteristics conform to the requirements in this section.

10.2.6.1 Reference Model

The channel consists of PCB traces, vias, and 0 or 1 connector. The reference PCB trace differential impedance is 100Ω.

Figure 10-1 shows a diagram of test points on an example board.

Figure 10-1.CEI-28G-SR Reference Model



Note: Test points differ from definitions in Section 1.8, as DC blocking capacitors, if physically located outside of the package, are part of the channel.

Measured at these test points, several channel characteristics are parametrized. Port definitions noted in Figure 2-33 allow proper measurement of the parameters in Table 10-1 used for calculation of the channel parameters found in Table 10-2.

Table 10-1. Measured Channel Parameters

Symbol	Description
$IL(f)$	Differential insertion loss, -SDD21 magnitude (dB)
$RL_1(f)$	Differential input return loss, -SDD11 magnitude (dB)
$RL_2(f)$	Differential output return loss, -SDD22 magnitude (dB)
$NEXT_m(f)$	Differential near-end crosstalk loss (m^{th} aggressor), -SDD21 magnitude (dB)
$FEXT_n(f)$	Differential far-end crosstalk loss (n^{th} aggressor), -SDD21 magnitude (dB)

Table 10-2. Calculated Channel Parameters

Symbol	Description
$IL_{fitted}(f)$	Fitted insertion loss (dB)
$ILD(f)$	Insertion loss deviation (dB)
$ICN(f)$	Integrated crosstalk noise (mV, RMS)
$ILD(rms)$	RMS value of the insertion loss Deviation (dB)

10.2.6.2 Insertion Loss

Channel insertion losses, including PCB traces and connectors, shall comply with the limits specified by equations (10-1), (10-2) and plotted in Figure 10-2. Note that the variable f_b is the maximum baud rate to be supported by the channel under test (19.90 Gsym/s $\le f_b \le$ 28.05 Gsym/s).

Table 10-3. Channel Insertion Loss Frequency Range

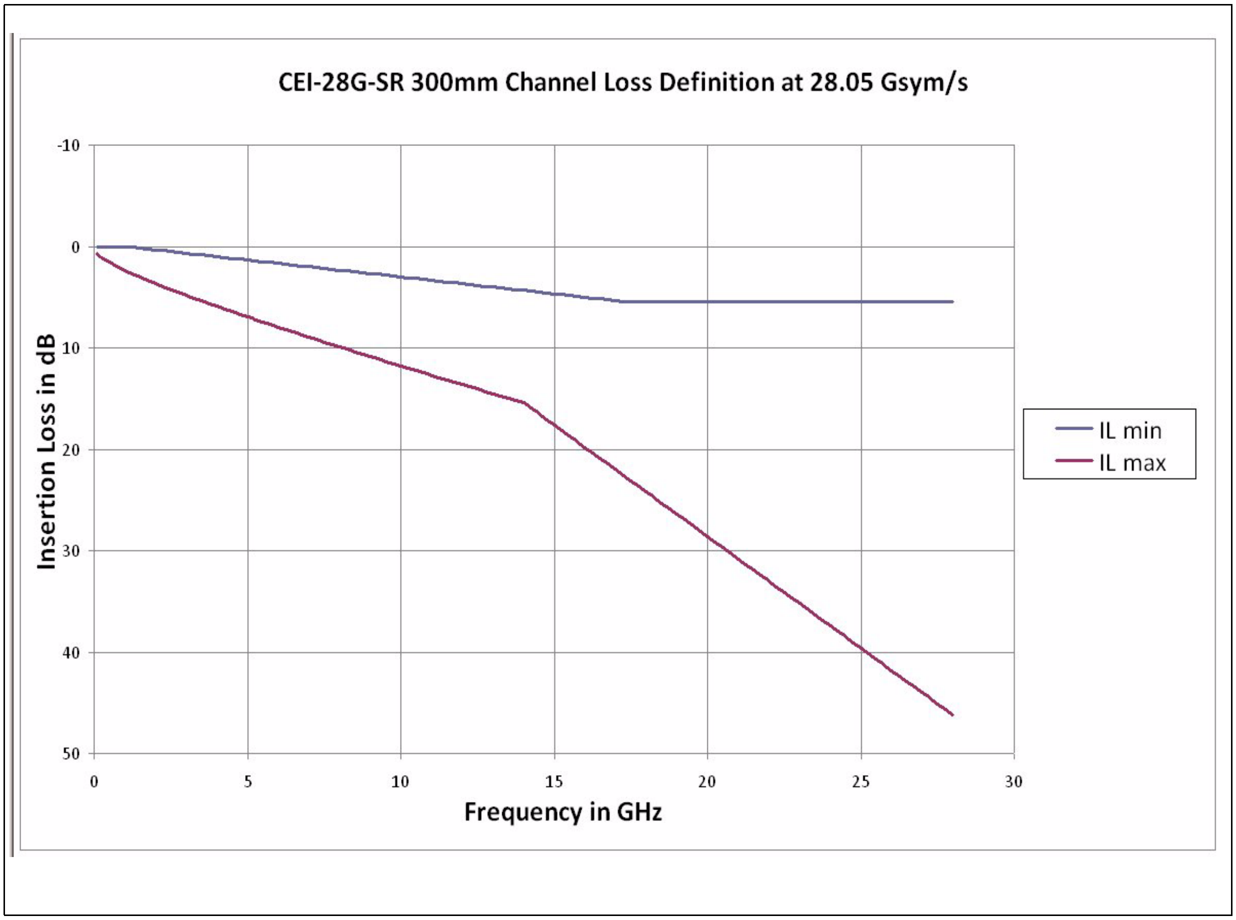
Parameter	Value	Units
fmin	50	MHz
fmax	28.05	GHz

$$IL_{max} = \begin{cases} 0.1188 + 1.54\sqrt{\dfrac{f\times 28.05}{f_b}} + 0.68\dfrac{f\times 28.05}{f_b}, & f_{min} \le f < \dfrac{f_b}{2} \\ -15.43 + 2.2\dfrac{f\times 28.05}{f_b}, & \dfrac{f_b}{2} \le f \le f_b \end{cases} \quad (10\text{-}1)$$

$$IL_{min} = \begin{pmatrix} 0\,, & f_{min} \le f \le 1GHz \\ \frac{1}{3}(f-1)\,, & 1GHz < f \le 17.5GHz \\ 5.5\,, & 17.5GHz < f \le f_b \end{pmatrix} \qquad (10\text{-}2)$$

Note: f in (10-1) and (10-2) is in GHz.

Figure 10-2.CEI-28G-SR Normative Channel Insertion Loss at 28.05 Gsym/s



10.2.6.3 Fitted insertion loss

For fitted insertion loss definitions, please refer to section 12.2.1.1

The channel shall meet the insertion loss requirements defined in Table 10-4. Note that the variable f_b is the maximum baud rate to be supported by the channel under test.

Table 10-4. Channel fitted insertion loss characteristics

Parameter	Units	Value	
		Min.	Max.
Minimum frequency, f_{ILmin}	GHz	0.05	-
Maximum frequency, f_{ILmax}	GHz	-	f_b
Fitted Insertion loss at Nyquist	dB	-	15.42
Fitted insertion loss, a_0	dB	-1	1.5
Fitted insertion loss, a_1	dB	0	9.533
Fitted insertion loss, a_2	dB	0	30.855
Fitted insertion loss, a_4	dB	0	14.162

10.2.6.4 Insertion loss deviation (ILD)

The insertion loss deviation *ILD* is the difference between the measured insertion *IL* and the fitted insertion loss IL_{fitted} as defined in (10-3).

$$ILD = IL - IL_{fitted} \tag{10-3}$$

The insertion loss deviation ILD shall be within the region defined by (10-4) and (10-5) where f_b is the maximum baud rate to be supported by the channel under test and f_{ILmin} and f_{ILmax} are given in Table 10-4.

$$ILD \geq ILD_{min} = \begin{Bmatrix} -1.0 - 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ -4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{Bmatrix} \tag{10-4}$$

$$ILD \leq ILD_{max} = \begin{Bmatrix} 1.0 + 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ 4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{Bmatrix} \tag{10-5}$$

ILD_{rms} is the RMS value of the ILD curve, and is calculated as indicated below.

Define the weight at each frequency *f* using equation (10-6) below.

$$W(f) = \operatorname{sinc}^2(f/f_b)\left[\frac{1}{1+(f/f_t)^4}\right]\left[\frac{1}{1+(f/f_r)^8}\right] \tag{10-6}$$

Note that -3 dB transmit filter bandwidth f_t is inversely proportional to the minimum 20 to 80% rise and fall times *T_tr and T_tf*. The constant of proportionality is 0.2365 (e.g. T_tr x f_t = 0.2365), where T_tr is in nano seconds and f_t is in GHz. In addition, f_r is the -3 dB reference receiver bandwidth, which should be set at (3/4)f_b, where f_b is the maximum baud rate to be supported by the channel.

$$ILD_{rms} = \sqrt{\frac{\sum W(f) \times ILD\langle f\rangle^2}{N}} \quad (10\text{-}7)$$

where N is the number of frequency points, the summation is done over the frequency range of ILD and ILD_{rms} shall be less than 0.3dBrms for valid channels.

10.2.6.5 Channel differential return loss

Channel differential return loss shall be bounded by:

- RL(f) >= 12 dB for $f_{min} < f \le f_b/4$ (10-8)
- RL(f) >= 12 dB - 15 $Log_{10}(4f/f_b)$ for $f_b/4 < f < f_b$ (10-9)

Note: f_{min} is as defined in Table 10-3

10.2.6.6 Channel integrated crosstalk noise

Using the Integrated crosstalk noise method of 12.2.1.2 and the parameters of Table 10-5, the total integrated crosstalk noise for the channel shall be less than the value specified by Equation (10-10) and illustrated in Figure 10-3.

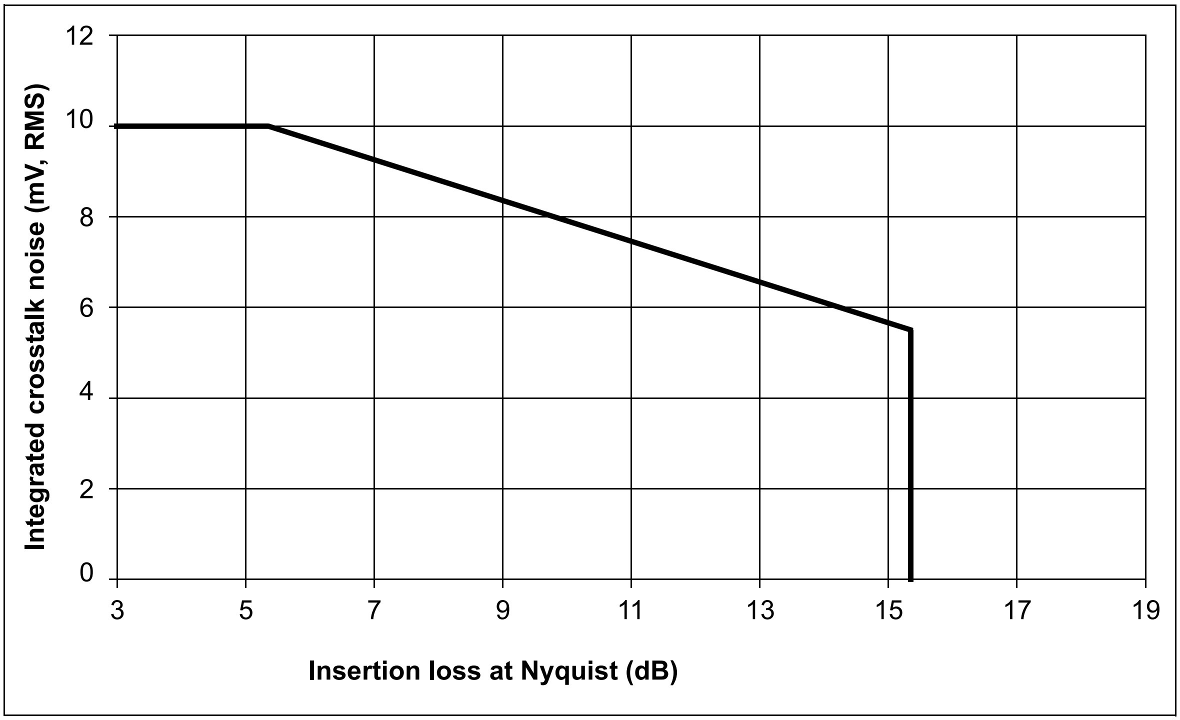
Table 10-5. Channel integrated crosstalk aggressor parameters

Parameter	Symbol	Value	Units
Baud rate	f_b	max. Baud Rate sup. by Channel	Gsym/s
Near-end aggressor peak to peak differential output amplitude	A_{nt}	1200	mVppd
Far-end aggressor peak to peak differential output amplitude	A_{ft}	1200	mVppd
Near-end aggressor 20 to 80% rise and fall times	T_{nt}	8	ps
Far-end aggressor 20 to 80% rise and fall times	T_{ft}	8	ps

$$\sigma_x \le \sigma_{x,\,max} = 10\ (mV, RMS) \quad for \quad 3\,dB < IL \le 5.3\,dB \quad (10\text{-}10)$$
$$= 12.4 - 0.45\,IL\ (mV, RMS) \quad for \quad 5.3\,dB < IL \le 15.42\,dB$$

In Equation (10-10), the *IL* denotes the value of the channel insertion loss in dB at 1/2 · baud rate (NRZ).

Figure 10-3. Illustration integrated crosstalk noise limits



10.3 Electrical Characteristics

The electrical signaling is based on high speed low voltage logic with a nominal differential impedance of 100 Ω.

All devices shall work within the range from 19.90 Gsym/s to 28.05 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

10.3.1 Transmitter Characteristics

The transmitter electrical specifications at compliance point T are given in Table 10-6. The transmitter shall satisfy jitter requirements specified in Table 10-7. Jitter is measured as specified in Section 2.2.3, for a BER as specified in Section 10.2.4. It is assumed that the UBHPJ component of the transmitter jitter is not data-dependent jitter (DDJ) from the receiver view point, hence it cannot be equalized in the receiver. To attenuate noise and absorb even/odd mode reflections, the transmitter shall satisfy the Common Mode Output Return Loss requirement of Table 10-6.

Link budgets in this document assume adaptive TX FIR equalization that is part of the system management function. The specific implementation is outside the scope of this document.

Table 10-6. Transmitter Electrical Output Specification.

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud		19.90		28.05	Gsym/s
Output Differential Voltage	T_Vdiff	Emphasis off. See Note 4	800		1200	mVppd
Differential Resistance	T_Rd		80	100	120	Ω
Differential Termination Resistance Mismatch (see Table 1-2)	T_Rdm				10	%
Output Rise and Fall Time (20% to 80%)	T_tr, T_tf	Emphasis off. See Note 2	8			ps
Common Mode Noise	T_Ncm	Note 3			12	mVrms
Differential Output Return Loss	T_SDD22	See Section 10.3.1.3				dB
Common Mode Output Return Loss	T_SCC22	Below 10 GHz			-6	dB
		10 GHz to baud rate			-4	
Output Common Mode Voltage	T_Vcm	Load Type 0 See Note 1	-100		1700	mV

NOTES:
1. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load.
2. The transmitter under test is preset such that C0 is its maximum value (C0_max) and all other coefficients are zero. The 20% and 80% values are of the steady state one and zero. The max value is limited by the linear fit pulse peak value in Table 10-11.
3. Measurement procedure is defined in Section 12.3.
4. T_Vdiff is two times the steady-state value V_f as defined in Section 10.3.1.6.2. The value is given as differential p-p voltage.

Table 10-7. Transmitter Output Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Unbounded Gaussian Jitter	T_UUGJ				0.15	UI_{PP}
Uncorrelated Bounded High Probability Jitter	T_UBHPJ	Note 2			0.15	UI_{PP}
Duty Cycle Distortion (component of UBHPJ)	T_DCD	Note 3			0.035	UI_{PP}
Total Jitter	T_TJ	Note 1			0.28	UI_{PP}

NOTES:
1. T_TJ includes all of the jitter components measured without any transmit equalization.
2. Measured with all possible values of transmitter equalization, excluding DDJ as defined in 12.1.1.
3. included in T_UBHPJ

10.3.1.1 Transmitter Baud Rate

All devices shall work within the range from 19.90 Gsym/s to 28.05 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

10.3.1.2 Transmitter Amplitude and Swing

Transmitter differential output amplitude shall be able to drive between 800 to 1200 mVppd with transmit emphasis disabled. The absolute transmitter output voltage shall be between -0.3V and 1.9 V with respect to local ground. Transmitter differential output amplitude shall additionally adhere to the requirements in Section 10.3.1.6.

10.3.1.3 Transmitter Resistance and Return Loss

Please refer to Section 3.2.10 with the following parameters.

Table 10-8. Transmitter Differential Return Loss Parameters

Parameter	Value	Units
A0	-12	dB
f0	50	MHz
f1	0.1714 x T_Baud	Hz
f2	T_Baud	Hz
Slope	12.0	dB/dec

10.3.1.4 Transmitter Lane-to-Lane Skew

Please refer to Section 3.2.7

10.3.1.5 Transmitter Short Circuit Current

Please refer to Section 3.2.9

10.3.1.6 Transmitter output waveform requirements

The transmitter shall include an equalizer defined as:

$$H(Z) = C_{-1} + C_0 z^{-1} + C_1 z^{-2} \quad (10\text{-}11)$$

10.3.1.6.1 Summary of requirements

The normalized amplitudes of the coefficients of the transmitter equalizer (computed per 10.3.1.6.2) shall meet the requirements in Table 10-9.

Table 10-9. Coefficient range and step size

Coefficient	Normalized Amplitude		Normalized Step Size (%)
	Min (%)	Max (%)	
C_{-1}	-10	0	1.25 to 5
C_1	-25	0	1.25 to 5
C_0	40	100	1.25 to 5

The amplitude of a coefficient can be computed by multiplying its normalized amplitude by v_f, which is defined in equation (10-12). "min" is defined as the minimum normalized amplitude of the coefficient that must be supplied by the transmitter to be compliant. "max" is defined as the maximum normalized amplitude of the coefficient that must be supplied by the transmitter to be compliant.

In addition:

a) $|C_{-1}|+|C_0|+|C_1|$, the peak output voltage shall not exceed 1200 mVppd.

b) $C_{-1} + C_0 + C_1$, the steady-state output voltage shall be greater than or equal to 140 mVppd.

10.3.1.6.2 Process to compute coefficients

The coefficients of the transmitter equalizer shall be determined from the measured waveform during TX compliance test using the process described below.

1. The transmitter under test is preset such that C_0 is its maximum value (C_{0_max}) and all other coefficients are zero.

2. Capture at least one complete cycle of the test pattern PRBS9 at T [T is defined as the test point at the output of transmitter package] per 10.3.1.6.3.

3. Compute the linear fit to the captured waveform per 10.3.1.6.4.

4. Define t_x to be the time where the rising edge of the linear fit pulse, p, from step 3 crosses 50% of its peak amplitude.

5. Sample the linear fit pulse, p, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.

6. Use p_i to compute the vector of coefficients, w, of a T_N_w-tap symbol-spaced transversal filter that equalizes for the transfer function from the transmit function to T per 10.3.1.6.5.

The parameters of the pulse fit and the equalizing filter are given in Table 10-10.

Table 10-10. Linear fit pulse and equalizing filter parameters

Parameter	Value (UI)
Linear fit pulse length T_N_p	8
Linear fit pulse delay T_D_p	2
Equalizer length T_N_w	8
Equalizer delay T_D_w	2

The differential zero to peak output voltage at T in the steady state, v_f, is estimated by equation (10-12).

$$v_f = \frac{1}{M} \cdot \sum_{k=1}^{M \cdot T\_Np} p(k) \tag{10-12}$$

In (10-12), p is the linear fit pulse from step 3 and M is the number of samples per symbol as defined in 10.3.1.6.3. The peak value of the linear fit pulse from step 3, p_{max}, shall satisfy the requirements of Table 10-11.The RMS value of the error between the linear fit and measured waveform from step 3, σ_e, shall satisfy the requirements of Table 10-11.

Table 10-11. Transmitter output waveform requirements

Parameter	Condition	Units	
Steady state output voltage, 2 x v_f	max	mVppd	1200
Steady state output voltage, 2 x v_f	min	mVppd	800
Linear fit pulse peak, p_{max}	min	-	0.80 x v_f
RMS error, σ_e	max	-	0.027 x v_f

For each configuration of the transmit equalizer:

7. Configure the transmitter under test as required.

8. Capture at least one complete cycle of the test pattern PRBS9 at T.

9. Compute the linear fit to the captured waveform per 10.3.1.6.4.

10. Define t_x to be the time where the rising edge of the linear fit pulse, *p*, from step 3 crosses 50% of its peak amplitude.

11. Sample the linear fit pulse, *p*, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.

12. Equalize the sampled pulse, p_i, using the coefficient vector, *w*, computed in step 6 per 10.3.1.6.5 to yield the equalized pulse q_i.

The RMS value of the error between the linear fit and measured waveform from step 9, σ_e, shall satisfy the requirements of Table 10-11.

The normalized amplitude of coefficient C_{-1} is the value of q_i at time $t_0 + (T\_D_w - 1)$ UI. The normalized amplitude of coefficient C_0 is the value of q_i at time $t_0 + T\_D_w$ UI. The normalized amplitude of coefficient C_1 is the value of q_i at time $t_0 + (T\_D_w + 1)$ UI.

10.3.1.6.3 Waveform acquisition

The transmitter under test repetitively transmits the specified test pattern. The waveform shall be captured with an effective sample rate that is *M* times the signaling rate of the transmitter under test. The value of *M* shall be an integer not less than 7. Averaging multiple waveform captures is recommended.

The captured waveform shall represent an integer number of repetitions of the test pattern totaling *N* bits. Hence the length of the captured waveform should be $M \cdot N$ samples. The waveform should be aligned such that the first *M* samples of waveform correspond to the first bit of the test pattern, the second *M* samples to the second bit, and so on.

10.3.1.6.4 Linear fit to the waveform measured at T

Given the captured waveform *y(k)* and corresponding aligned symbols *x(n)* derived from the procedure defined in 10.3.1.6.2, define the *M*-by-*N* waveform matrix *Y* as shown in (10-13).

$$Y = \begin{bmatrix} y(1) & y(M+1) & \cdots & y(M(N-1)+1) \\ y(2) & y(M+2) & \cdots & y(M(N-1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ y(M) & y(2M) & \cdots & y(MN) \end{bmatrix} \quad (10\text{-}13)$$

Rotate the symbols vector *x* by the specified pulse delay D_p to yield x_r.

$$x_r = \begin{bmatrix} x(T\_D_p+1) & x(T\_D_p+2) & \cdots & x(N) & x(1) & \cdots & x(T\_D_p) \end{bmatrix} \quad (10\text{-}14)$$

Define the matrix *X* to be an *N*-by-*N* matrix derived from x_r as shown in (10-15).

$$X = \begin{bmatrix} x_r(1) & x_r(2) & \cdots & x_r(N) \\ x_r(N) & x_r(1) & \cdots & x_r(N-1) \\ \vdots & \vdots & \cdots & \vdots \\ x_r(2) & x_r(3) & \cdots & x_r(1) \end{bmatrix} \quad (10\text{-}15)$$

Define the matrix X_1 to be the first T_N_p rows of *X* concatenated with a row vector of 1's of length *N*. The *M*-by-(T_N_p + 1) coefficient matrix, *P*, corresponding to the linear fit is then defined by (10-16).

$$P = YX_1^{\mathrm{T}}(X_1X_1^{\mathrm{T}})^{-1} \quad (10\text{-}16)$$

In (10-16) the superscript "T" denotes the matrix transpose operator.

$$E = PX_1 - Y = \begin{bmatrix} e(1) & e(M+1) & \cdots & e(M(N-1)+1) \\ e(2) & e(M+2) & \cdots & e(M(N-1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ e(M) & e(2M) & \cdots & e(MN) \end{bmatrix} \quad (10\text{-}17)$$

The error waveform, *e(k)*, is then read column-wise from the elements of *E*.

Define P_1 to be a matrix consisting of the first T_N_p columns of the matrix P as shown in (10-18).

$$P_1 = \begin{bmatrix} p(1) & p(M+1) & \cdots & p(M(T\_N_p-1)+1) \\ p(2) & p(M+2) & \cdots & p(M(T\_N_p-1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ p(M) & p(2M) & \cdots & p(MT\_N_p) \end{bmatrix} \quad (10\text{-}18)$$

The linear fit pulse response, *p(k)*, is then read column-wise from the elements of P_1.

10.3.1.6.5 Removal of the transfer function between the transmit function and T

Rotate sampled pulse response p_i by the specified equalizer delay T_D_w to yield p_r as shown in (10-19).

$$p_r = \left[p_i(T\_D_w+1) \quad p_i(T\_D_w+2) \quad \cdots \quad p_i(T\_N_p) \quad p_i(1) \quad \cdots \quad p_i(T\_D_w) \right] \quad (10\text{-}19)$$

Define the matrix P_2 to be a T_N_p-by-T_N_p matrix derived from pr as shown in (10-20).

$$P_2 = \begin{bmatrix} p_r(1) & p_r(T\_N_p) & \cdots & p_r(2) \\ p_r(2) & p_r(1) & \cdots & p_r(3) \\ \vdots & \vdots & \cdots & \vdots \\ p_r(T\_N_p) & p_r(T\_N_p-1) & \cdots & p_r(1) \end{bmatrix} \quad (10\text{-}20)$$

Define the matrix P_3 to be the first T_N_w rows of P_2. Define a unit pulse column vector x_p of length T_N_p. The value of element $x_p(T\_D_p + 1)$ is 1 and all other elements have a value of 0. The vector of filter coefficients *w* that equalizes p_i is then defined by (10-21).

$$w = (P_3^{\mathrm{T}} P_3)^{-1} P_3^{\mathrm{T}} x_p \quad (10\text{-}21)$$

Given the column vector of equalizer coefficients, *w*, the equalized pulse response q_i is determined by (10-22).

$$q_i = P_3 w \quad (10\text{-}22)$$

10.3.2 Receiver Characteristics

A compliant receiver shall operate at the specified BER with the worst case combination of a compliant transmitter and a compliant channel.

Receiver electrical specifications are given in Table 10-12 and measured at compliance point R. To dampen noise sources and absorption of both even and odd mode reflections, the receiver shall satisfy the Common Mode Input Return Loss requirement of Table 10-12. Jitter specifications at reference R are listed in Table 10-13.

Table 10-12. Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud rate	R_Baud		19.90		28.05	GSym/s
Input Differential Voltage	R_Vdiff	Note 1			1200	mVppd
Differential Input Impedance	R_Rdin		80	100	120	Ω
Input Impedance Mismatch	R_Rm				10	%
Differential Input Return Loss	R_SDD11	See 10.3.2.3				
Common Mode Input Return Loss	R_SCC11	Below 10 GHz			-6	dB
		10GHz to baud rate			-4	
Input Common Mode Voltage	R_Vcm	Load Type 0 See Note 2	-200		1800	mV

NOTES:
1. The receiver shall have a differential input voltage range sufficient to accept a signal produced at point R by the combined transmitter and channel. The channel response shall include the worst case effects of the return losses at the transmitter and receiver.
2. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load. For floating load, input resistance shall be ≥ 1kΩ

Table 10-13. Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Sinusoidal Jitter, Maximum	R_SJ-max	See Section 2.5.4, note 1			5	UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See Section 2.5.4, note 1			0.05	UIpp

NOTES:
1. The Receiver shall tolerate the sum of these jitter contributions: Total transmitter jitter from Table 10-7;Sinusoidal jitter as defined in Table 10-13;The effects of a channel compliant to the Channel Characteristics (Section 10.2.6).

10.3.2.1 Input Baud Rate

All devices shall work within the range from 19.90 Gsym/s to 28.05 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11.

10.3.2.2 Reference Input Signals

The receiver shall accept differential input signal amplitudes produced by a compliant transmitter connected with the minimum attenuation specified in Figure 10-2 to the receiver. This may be larger than the 1200 mVppd maximum of the transmitter due to output/input impedances and reflections.

The minimum input amplitude is defined by the minimum transmitter amplitude, the actual receiver input impedance and the loss of the actual PCB. Note that the minimum transmitter amplitude is defined using a well controlled load impedance, however the real receiver is not, which can leave the receiver input signal smaller than expected. Additionally it will be determined by the environmental noise inside and outside the receiver.

10.3.2.3 Input Resistance and Return Loss

Please refer to Section 3.2.10 with the following parameters.

Table 10-14. Receiver Differential Return Loss Parameters

Parameter	Value	Units
A0	-12	dB
f0	50	MHz
f1	0.1714 x R_Baud	Hz
f2	R_Baud	Hz
Slope	12.0	dB/dec

10.3.2.4 Input Lane-to-Lane Skew

Please refer to Section 3.2.8.

10.3.2.5 Absolute Input Voltage

The absolute voltage levels with respect to the receiver ground at the input of the receiver are dependent on the transmitter implementation and the inter-ground difference. The voltage levels at the input of an AC coupled receiver (if the effective AC coupling is done within the receiver) or at the TX side of the external AC coupling cap (if AC coupling is done externally) shall be between -0.3 to 2.0V with respect to local ground.

11 CEI-25G-LR Long Reach Interface

This clause details the requirements for the CEI-25G-LR long reach high speed electrical interface between nominal baud rates of 19.90 Gsym/s and 25.80 Gsym/s using NRZ coding. A compliant device shall meet all of the requirements listed below. The electrical interface is based on high speed, low voltage logic. Connections are point-to-point balanced differential pairs and signaling is unidirectional.

The electrical IA is based on loss and jitter budgets and defines the characteristics required to communicate between a CEI-25G-LR transmitter and a CEI-25G-LR receiver using copper signal traces on a printed circuit board. The characteristic impedance of the signal traces is nominally 100 Ω differential. A 'length' is effectively defined in terms of its attenuation and phase response rather than its physical length. Refer to Section 11.2.6 for transmission line guidelines to meet the channel requirements.

Long reach CEI-25G-LR devices from different manufacturers shall be interoperable.

11.1 Requirements

1. Support serial baud rates within the range from 19.90 Gsym/s to 25.80 Gsym/s.
2. Capable of low bit error ratio (10^{-15}, with a test requirement to verify 10^{-12}).
3. Capable of driving up to 686 mm of PCB and up to 2 connectors.
4. Shall support AC-coupled operation.
5. Shall allow multi-lanes (1 to n).
6. Shall support hot plug.

11.2 General Requirements

11.2.1 Data Patterns

Please refer to Section 3.2.1

11.2.2 Signal levels

Please refer to Section 3.2.2. All transmitter and receiver devices shall support "Load Type 0". Other load types are not supported by this clause.

11.2.3 Signal Definitions

Please refer to Section 1.A

11.2.4 Bit Error Ratio

Please refer to Section 3.2.3

11.2.5 Ground Differences

Please refer to Section 3.2.4

11.2.6 Channel Compliance

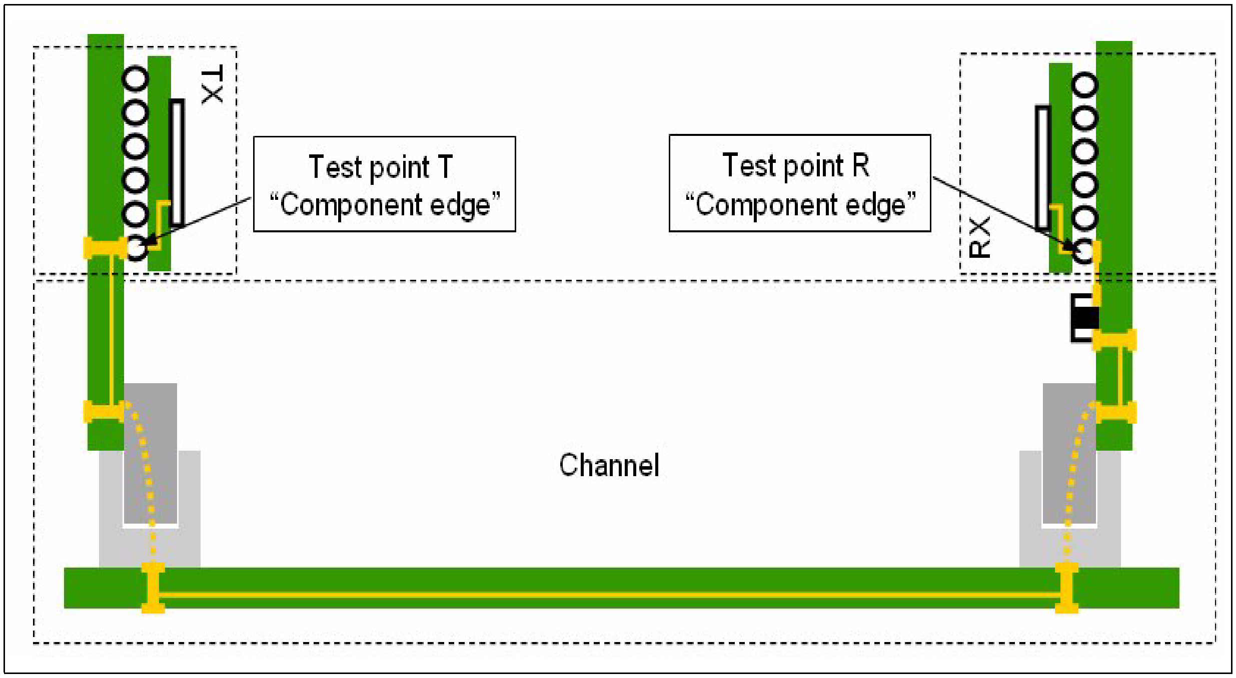
A forward channel and associated dominant crosstalk channels are deemed compliant if the channel characteristics conform to the requirements in this section.

11.2.6.1 Reference Model

The channel consists of PCB traces, vias, and up to 2 connectors. The reference PCB trace differential impedance is 100Ω.

Figure 11-1 shows a diagram of test points on an example board.

Figure 11-1.CEI-25G-LR Reference Model



Note: Test points differ from definitions in Section 1.8, as DC blocking capacitor, if physically located outside of the package, is part of the channel.

Measured at these test points, several channel characteristics are parametrized. Port definitions as noted in Figure 2-33 allow proper measurement of the parameters in Table 11-1 used for calculation of the channel parameters found in Table 11-2.

Table 11-1. Measured Channel Parameters

Symbol	Description
$IL(f)$	Differential insertion loss, -SDD21 magnitude (dB)
$RL_1(f)$	Differential input return loss, -SDD11 magnitude (dB)
$RL_2(f)$	Differential output return loss, -SDD22 magnitude (dB)
$NEXT_m(f)$	Differential near-end crosstalk loss (m^{th} aggressor), -SDD21 magnitude (dB)
$FEXT_n(f)$	Differential far-end crosstalk loss (n^{th} aggressor), -SDD21 magnitude (dB)

Table 11-2. Calculated Channel Parameters

Symbol	Description
$IL_{fitted}(f)$	Fitted insertion loss (dB)
$ILD(f)$	Insertion loss deviation (dB)
$ICN(f)$	Integrated crosstalk noise (mV, RMS)
$ILD(rms)$	RMS value of the insertion loss Deviation (dB)

11.2.6.2 Insertion Loss

Channel insertion losses, including PCB traces and connectors, shall comply with the limits specified by equations (11-1), (11-2) and plotted in Figure 11-2. Note that the variable f_b is the maximum baud rate to be supported by the channel under test (19.90 Gsym/s $\leq f_b \leq$ 25.80 Gsym/s).

Table 11-3. Channel Insertion Loss Frequency Range

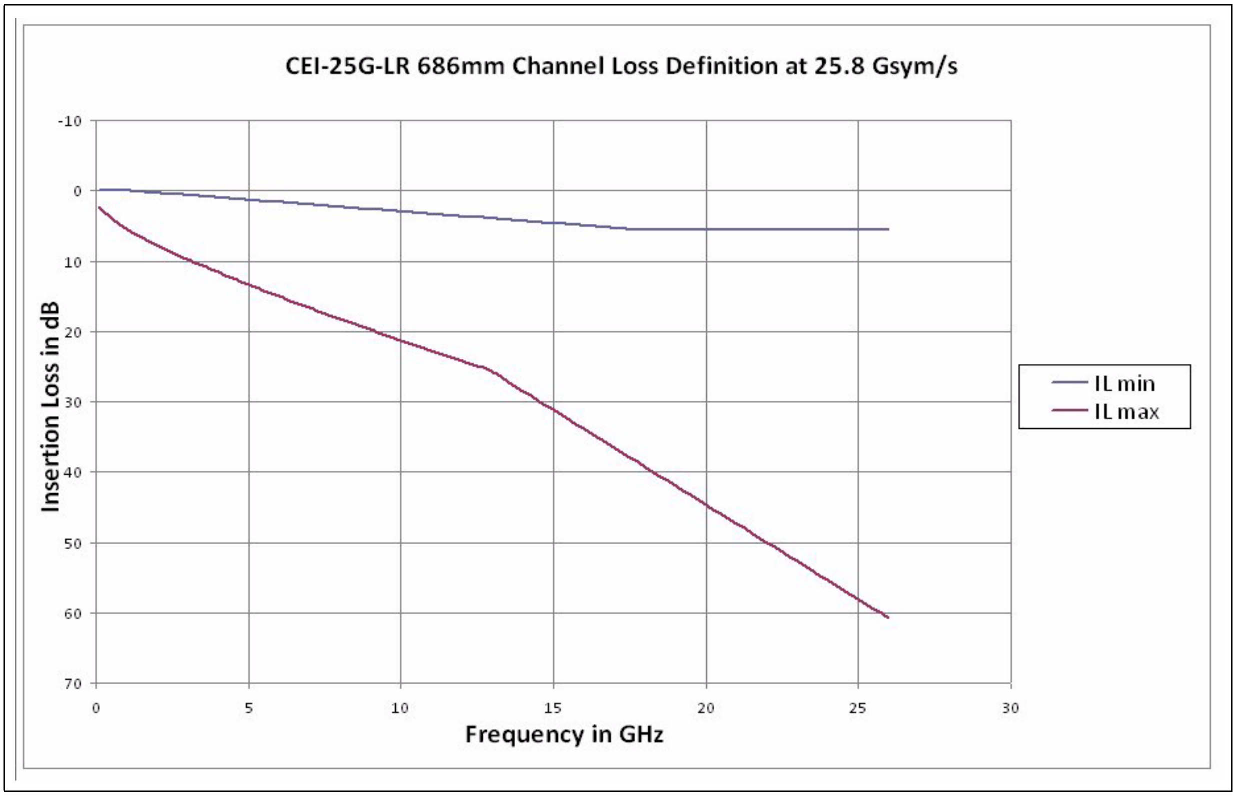
Parameter	Value	Units
fmin	50	MHz
fmax	25.8	GHz

$$IL_{max} = \begin{cases} 1.083 + 3.35\sqrt{\dfrac{f \times 25.8}{f_b}} + 0.96\dfrac{f \times 25.8}{f_b}, & f_{min} \leq f < \dfrac{f_b}{2} \\ -9.25 + 2.694\dfrac{f \times 25.8}{f_b}, & \dfrac{f_b}{2} \leq f \leq f_b \end{cases} \quad (11\text{-}1)$$

$$IL_{min} = \begin{pmatrix} 0\,, & f_{min} \le f \le 1\,GHz \\ \frac{1}{3}(f-1), & 1\,GHz < f \le 17.5\,GHz \\ 5.5\,, & 17.5\,GHz < f \le f_b \end{pmatrix} \quad (11\text{-}2)$$

Note: f in (11-1) and (11-2) is in GHz.

Figure 11-2. CEI-25G-LR Normative Channel Insertion Loss at 25.80 Gsym/s.



11.2.6.3 Fitted insertion loss

For fitted insertion loss definitions, please refer to section 12.2.1.1

The channel shall meet the insertion loss requirements defined in Table 11-4. Note that the variable f_b is the maximum baud rate to be supported by the channel under test.

Table 11-4. Channel fitted insertion loss characteristics

Parameter	Units	Value	
		Min.	Max.
Minimum frequency, f_{ILmin}	GHz	0.05	-
Maximum frequency, f_{ILmax}	GHz	-	f_b
Fitted Insertion loss at Nyquist	dB	-	25.5
Fitted insertion loss, a_0	dB	-1	2.0
Fitted insertion loss, a_1	dB	0	20.317
Fitted insertion loss, a_2	dB	0	51.6
Fitted insertion loss, a_4	dB	0	25.294

11.2.6.4 Insertion loss deviation (ILD)

The insertion loss deviation *ILD* is the difference between the measured insertion *IL* and the fitted insertion loss IL_{fitted} as defined in (11-3).

$$ILD = IL - IL_{fitted} \tag{11-3}$$

The insertion loss deviation ILD shall be within the region defined by (11-4) and (11-5) where f_b is the maximum baud rate to be supported by the channel under test and f_{ILmin} and f_{ILmax} are given in Table 11-4.

$$ILD \geq ILD_{min} = \begin{Bmatrix} -1.0 - 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ -4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{Bmatrix} \tag{11-4}$$

$$ILD \leq ILD_{max} = \begin{Bmatrix} 1.0 + 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ 4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{Bmatrix} \tag{11-5}$$

ILD_{rms} is the RMS value of the ILD curve, and is calculated as indicated below.

Define the weight at each frequency *f* using equation (11-6) below.

$$W(f) = \mathrm{sinc}^2(f/f_b)\left[\frac{1}{1+(f/f_t)^4}\right]\left[\frac{1}{1+(f/f_r)^8}\right] \tag{11-6}$$

Note that -3 dB transmit filter bandwidth f_t is inversely proportional to the minimum 20 to 80% rise and fall times *T_tr and T_tf*. The constant of proportionality is 0.2365 (e.g. T_tr x f_t = 0.2365), where T_tr is in nano seconds and f_t is in GHz. In addition, f_r is the -3 dB reference receiver bandwidth, which should be set at (3/4)f_b, where f_b is the maximum baud rate to be supported by the channel.

$$ILD_{rms} = \sqrt{\frac{\sum W(f) \times ILD\langle f\rangle^2}{N}} \quad (11\text{-}7)$$

where N is the number of frequency points, the summation is done over the frequency range of ILD and ILD_{rms} shall be less than 0.3dBrms for valid channels.

11.2.6.5 Channel Return Loss

Channel Return Loss shall be bounded by:

- RL(f) >= 12 dB for $f_{min} < f \le f_b/4$ (11-8)
- RL(f) >= 12 dB - 15 $Log_{10}(4f/f_b)$ for $f_b/4 < f < f_b$ (11-9)

Note: f_{min} is as defined in Table 11-3

11.2.6.6 Channel integrated crosstalk noise

Using the Integrated crosstalk noise method of 12.2.1.2 and the parameters of Table 11-5, the total integrated crosstalk noise for the channel shall be less than the value specified by Equation (11-10) and illustrated in Figure 11-3.

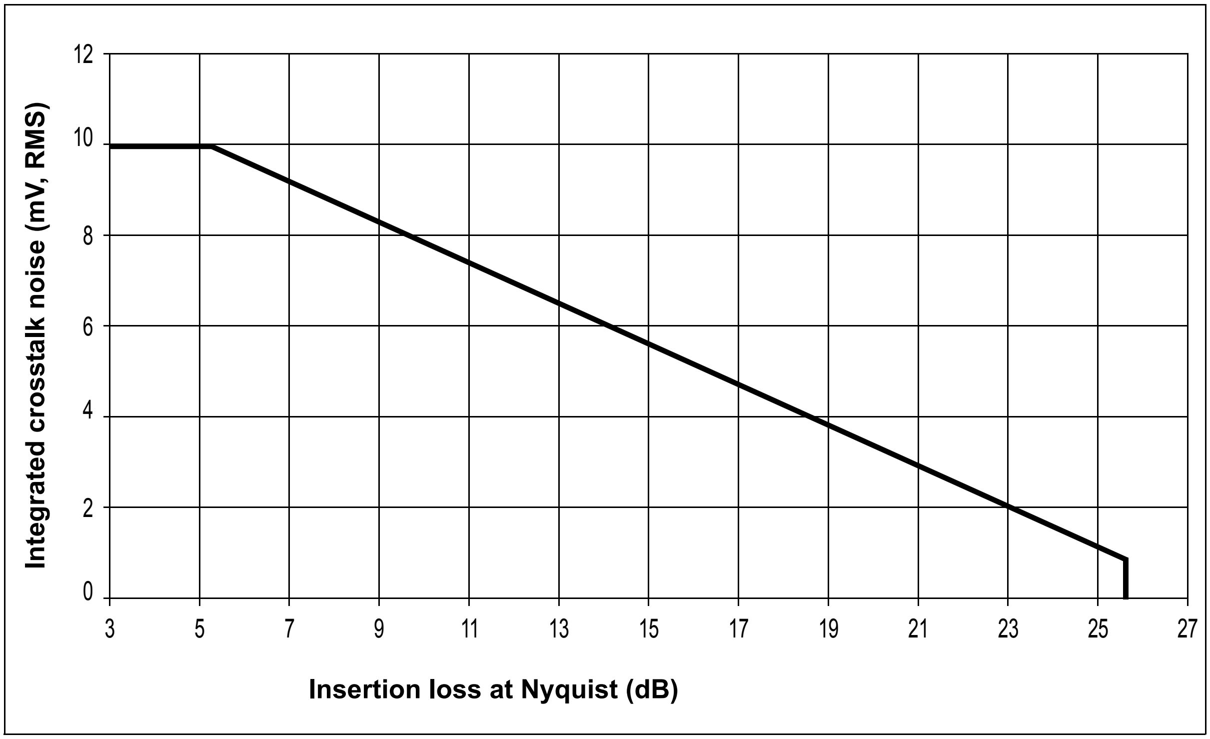
Table 11-5. Channel integrated crosstalk aggressor parameters

Parameter	Symbol	Value	Units
Baud rate	f_b	max. Baud Rate sup. by Channel	Gsym/s
Near-end aggressor peak to peak differential output amplitude	A_{nt}	1200	mVppd
Far-end aggressor peak to peak differential output amplitude	A_{ft}	1200	mVppd
Near-end aggressor 20 to 80% rise and fall times	T_{nt}	8	ps
Far-end aggressor 20 to 80% rise and fall times	T_{ft}	8	ps

$$\begin{aligned} \sigma_x \le \sigma_{x,\,max} &= 10\ (mV, RMS) \quad for \quad 3\,dB < IL \le 5.3\,dB \\ &= 12.4 - 0.45\,IL\ (mV, RMS) \quad for \quad 5.3\,dB < IL \le 25.5\,dB \end{aligned} \quad (11\text{-}10)$$

In Equation (11-10), the *IL* denotes the value of the channel insertion loss in dB at 1/2 · baud rate (NRZ).

Figure 11-3.Illustration integrated crosstalk noise limits



11.3 Electrical Characteristics

The electrical signaling is based on high speed low voltage logic with a nominal differential impedance of 100 Ω.

All devices shall work within the range from 19.90 Gsym/s to 25.80 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

11.3.1 Transmitter Characteristics

The transmitter electrical specifications at compliance point T are given in Table 11-6. The transmitter shall satisfy jitter requirements specified in Table 11-7. Jitter is measured as specified in Section 2.2.3, for a BER as specified in Section 11.2.4. It is assumed that the UBHPJ component of the transmitter jitter is not data-dependent jitter (DDJ) from the receiver view point, hence it cannot be equalized in the receiver. To attenuate noise and absorb even/odd mode reflections, the transmitter shall satisfy the Common Mode Output Return Loss requirement of Table 11-6.

Link budgets in this document assume adaptive TX FIR equalization that is part of the system management function. The specific implementation is outside the scope of this document.

Table 11-6. Transmitter Electrical Output Specification.

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud Rate	T_Baud		19.90		25.80	Gsym/s
Output Differential Voltage	T_Vdiff	Emphasis off. See Note 4.	800		1200	mVppd
Differential Resistance	T_Rd		80	100	120	Ω
Differential Termination Resistance Mismatch (see Table 1-2)	T_Rdm				10	%
Output Rise and Fall Time (20% to 80%)	T_tr, T_tf	Emphasis off. See Note 2.	8			ps
Common Mode Noise	T_Ncm	See Note 3.			12	mVrms
Differential Output Return Loss	T_SDD22	See Section 11.3.1.3				dB
Common Mode Output Return Loss	T_SCC22	Below 10 GHz			-6	dB
		10 GHz to baud rate			-4	
Output Common Mode Voltage	T_Vcm	Load Type 0 See Note 1	-100		1700	mV

NOTES:
1. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load.
2. The transmitter under test is preset such that C0 is its maximum value (C0_max) and all other coefficients are zero. The 20% and 80% values are of the steady state one and zero. The max value is limited by the linear fit pulse peak value in Table 11-11.
3. Measurement procedure is defined in Section 12.3.
4. T_Vdiff is two times the steady-state value V_f as defined in Section 11.3.1.6.2. The value is given as differential p-p voltage.

Table 11-7. Transmitter Output Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Uncorrelated Unbounded Gaussian Jitter	T_UUGJ				0.15	UI_{PP}
Uncorrelated Bounded High Probability Jitter	T_UBHPJ	Note 2			0.15	UI_{PP}
Duty Cycle Distortion (component of UBHPJ)	T_DCD	Note 3			0.035	UI_{PP}
Total Jitter	T_TJ	Note 1			0.28	UI_{PP}

NOTES:
1. T_TJ includes all of the jitter components measured without any transmit equalization.
2. Measured with all possible values of transmitter equalization, excluding DDJ as defined in 12.1.1.
3. included in T_UBHPJ

11.3.1.1 Transmitter Baud Rate

All devices shall work within the range from 19.90 Gsym/s to 25.80 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11. Note that implementation of specific protocols will define the operating baud rate without affecting CEI compliance.

11.3.1.2 Transmitter Amplitude and Swing

Transmitter differential output amplitude shall be able to drive between 800 to 1200 mVppd with transmit emphasis disabled. The absolute transmitter output voltage shall be between -0.3V and 1.9 V with respect to local ground. Transmitter differential output amplitude shall additionally adhere to the requirements in Section 11.3.1.6.

11.3.1.3 Transmitter Resistance and Return Loss

Please refer to Section 3.2.10 with the following parameters.

Table 11-8. Transmitter Differential Return Loss Parameters

Parameter	Value	Units
A0	-12	dB
f0	50	MHz
f1	0.1714 x T_Baud	Hz
f2	T_Baud	Hz
Slope	12.0	dB/dec

11.3.1.4 Transmitter Lane-to-Lane Skew

Please refer to Section 3.2.7

11.3.1.5 Transmitter Short Circuit Current

Please refer to Section 3.2.9

11.3.1.6 Transmitter output waveform requirements

The transmitter shall include an equalizer defined as:

$$H(Z) = C_{-1} + C_0 z^{-1} + C_1 z^{-2} \quad (11\text{-}11)$$

11.3.1.6.1 Summary of requirements

The normalized amplitudes of the coefficients of the transmitter equalizer (computed per 11.3.1.6.2) shall meet the requirements in Table 11-9.

Table 11-9. Coefficient range and step size

Coefficient	Normalized Amplitude		Normalized Step Size (%)
	Min (%)	Max (%)	
C_{-1}	-25	0	1.25 to 5
C_1	-25	0	1.25 to 5
C_0	40	100	1.25 to 5

The amplitude of a coefficient can be computed by multiplying its normalized amplitude by v_f, which is defined in equation (11-12). "min" is defined as the minimum normalized amplitude of the coefficient that must be supplied by the transmitter to be compliant. "max" is defined as the maximum normalized amplitude of the coefficient that must be supplied by the transmitter to be compliant.

In addition:

a) $|C_{-1}|+|C_0|+|C_1|$, the peak output voltage shall not exceed 1200 mVppd.

b) $C_{-1} + C_0 + C_1$, the steady-state output voltage shall be greater than or equal to 80 mVppd.

11.3.1.6.2 Process to compute coefficients

The coefficients of the transmitter equalizer shall be determined from the measured waveform during TX compliance test using the process described below.

1. The transmitter under test is preset such that C_0 is its maximum value (C_{0_max}) and all other coefficients are zero.

2. Capture at least one complete cycle of the test pattern PRBS9 at T [T is defined as the test point at the output of transmitter package] per 11.3.1.6.3.

3. Compute the linear fit to the captured waveform per 11.3.1.6.4.

4. Define t_x to be the time where the rising edge of the linear fit pulse, p, from step 3 crosses 50% of its peak amplitude.

5. Sample the linear fit pulse, p, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.

6. Use p_i to compute the vector of coefficients, w, of a T_N_w-tap symbol-spaced transversal filter that equalizes for the transfer function from the transmit function to T per 11.3.1.6.5.

The parameters of the pulse fit and the equalizing filter are given in Table 11-10.

Table 11-10. Linear fit pulse and equalizing filter parameters

Parameter	Value (UI)
Linear fit pulse length T_N_p	8
Linear fit pulse delay T_D_p	2
Equalizer length T_N_w	8
Equalizer delay T_D_w	2

The differential zero to peak output voltage at T in the steady state, v_f, is estimated by equation (11-12).

$$v_f = \frac{1}{M} \cdot \sum_{k=1}^{M \cdot T\_Np} p(k) \tag{11-12}$$

In (11-12), p is the linear fit pulse from step 3 and M is the number of samples per symbol as defined in 11.3.1.6.3. The peak value of the linear fit pulse from step 3, p_{max}, shall satisfy the requirements of Table 11-11.The RMS value of the error between the linear fit and measured waveform from step 3, σ_e, shall satisfy the requirements of Table 11-11.

Table 11-11. Transmitter output waveform requirements

Parameter	Condition	Units	
Steady state output voltage, 2 x v_f	max	mVppd	1200
Steady state output voltage, 2 x v_f	min	mVppd	800
Linear fit pulse peak, p_{max}	min	-	0.80 x v_f
RMS error, σ_e	max	-	0.027 x v_f

For each configuration of the transmit equalizer:

7. Configure the transmitter under test as required.

8. Capture at least one complete cycle of the test pattern PRBS9 at T.

9. Compute the linear fit to the captured waveform per 11.3.1.6.4.

10. Define t_x to be the time where the rising edge of the linear fit pulse, *p*, from step 3 crosses 50% of its peak amplitude.

11. Sample the linear fit pulse, *p*, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.

12. Equalize the sampled pulse, p_i, using the coefficient vector, *w*, computed in step 6 per 11.3.1.6.5 to yield the equalized pulse q_i.

The RMS value of the error between the linear fit and measured waveform from step 9, σ_e, shall satisfy the requirements of Table 11-11.

The normalized amplitude of coefficient C_{-1} is the value of q_i at time $t_0 + (T\_D_w - 1)$ UI. The normalized amplitude of coefficient C_0 is the value of q_i at time $t_0 + T\_D_w$ UI. The normalized amplitude of coefficient C_1 is the value of q_i at time $t_0 + (T\_D_w +1)$ UI.

11.3.1.6.3 Waveform acquisition

The transmitter under test repetitively transmits the specified test pattern. The waveform shall be captured with an effective sample rate that is *M* times the signaling rate of the transmitter under test. The value of *M* shall be an integer not less than 7. Averaging multiple waveform captures is recommended.

The captured waveform shall represent an integer number of repetitions of the test pattern totaling *N* bits. Hence the length of the captured waveform should be $M \cdot N$ samples. The waveform should be aligned such that the first *M* samples of waveform correspond to the first bit of the test pattern, the second *M* samples to the second bit, and so on.

11.3.1.6.4 Linear fit to the waveform measured at T

Given the captured waveform *y(k)* and corresponding aligned symbols *x(n)* derived from the procedure defined in 11.3.1.6.2, define the *M*-by-*N* waveform matrix *Y* as shown in (11-13).

$$Y = \begin{bmatrix} y(1) & y(M+1) & \cdots & y(M(N-1)+1) \\ y(2) & y(M+2) & \cdots & y(M(N-1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ y(M) & y(2M) & \cdots & y(MN) \end{bmatrix} \qquad (11\text{-}13)$$

Rotate the symbols vector x by the specified pulse delay D_p to yield x_r.

$$x_r = \left[x(T\_D_p + 1) \quad x(T\_D_p + 2) \quad \cdots \quad x(N) \quad x(1) \quad \cdots \quad x(T\_D_p) \right] \tag{11-14}$$

Define the matrix X to be an N-by-N matrix derived from x_r as shown in (11-15).

$$X = \begin{bmatrix} x_r(1) & x_r(2) & \cdots & x_r(N) \\ x_r(N) & x_r(1) & \cdots & x_r(N-1) \\ \vdots & \vdots & \cdots & \vdots \\ x_r(2) & x_r(3) & \cdots & x_r(1) \end{bmatrix} \tag{11-15}$$

Define the matrix X_1 to be the first T_N_p rows of X concatenated with a row vector of 1's of length N. The M-by-(T_N_p + 1) coefficient matrix, P, corresponding to the linear fit is then defined by (11-16).

$$P = YX_1^{\mathrm{T}}(X_1X_1^{\mathrm{T}})^{-1} \tag{11-16}$$

In (11-16) the superscript "T" denotes the matrix transpose operator.

$$E = PX_1 - Y = \begin{bmatrix} e(1) & e(M+1) & \cdots & e(M(N-1)+1) \\ e(2) & e(M+2) & \cdots & e(M(N-1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ e(M) & e(2M) & \cdots & e(MN) \end{bmatrix} \tag{11-17}$$

The error waveform, $e(k)$, is then read column-wise from the elements of E.

Define P_1 to be a matrix consisting of the first T_N_p columns of the matrix P as shown in (11-18).

$$P_1 = \begin{bmatrix} p(1) & p(M+1) & \cdots & p(M(T\_N_p - 1)+1) \\ p(2) & p(M+2) & \cdots & p(M(T\_N_p - 1)+2) \\ \vdots & \vdots & \cdots & \vdots \\ p(M) & p(2M) & \cdots & p(MT\_N_p) \end{bmatrix} \quad (11\text{-}18)$$

The linear fit pulse response, *p(k)*, is then read column-wise from the elements of P_1.

11.3.1.6.5 Removal of the transfer function between the transmit function and T

Rotate sampled pulse response p_i by the specified equalizer delay T_D_w to yield p_r as shown in (11-19).

$$p_r = \begin{bmatrix} p_i(T\_D_w+1) & p_i(T\_D_w+2) & \cdots & p_i(T\_N_p) & p_i(1) & \cdots & p_i(T\_D_w) \end{bmatrix} \quad (11\text{-}19)$$

Define the matrix P_2 to be a T_N_p-by-T_N_p matrix derived from pr as shown in (11-20).

$$P_2 = \begin{bmatrix} p_r(1) & p_r(T\_N_p) & \cdots & p_r(2) \\ p_r(2) & p_r(1) & \cdots & p_r(3) \\ \vdots & \vdots & \cdots & \vdots \\ p_r(T\_N_p) & p_r(T\_N_p - 1) & \cdots & p_r(1) \end{bmatrix} \quad (11\text{-}20)$$

Define the matrix P_3 to be the first T_N_w rows of P_2. Define a unit pulse column vector x_p of length T_N_p. The value of element $x_p(T\_D_p + 1)$ is 1 and all other elements have a value of 0. The vector of filter coefficients *w* that equalizes p_i is then defined by (11-21).

$$w = (P_3^{\mathrm{T}} P_3)^{-1} P_3^{\mathrm{T}} x_p \quad (11\text{-}21)$$

Given the column vector of equalizer coefficients, *w*, the equalized pulse response q_i is determined by (11-22).

$$q_i = P_3 w \quad (11\text{-}22)$$

11.3.2 Receiver Characteristics

A compliant receiver shall operate at the specified BER with the worst case combination of a compliant transmitter and a compliant channel.

Receiver electrical specifications are given in Table 11-12 and measured at compliance point R. To dampen noise sources and absorption of both even and odd mode reflections, the receiver shall satisfy the Common Mode Input Return Loss requirement of Table 11-12. Jitter specifications at reference R are listed in Table 11-13.

Table 11-12. Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud rate	R_Baud		19.90		25.80	GSym/s
Input Differential Voltage	R_Vdiff	Note 1			1200	mVppd
Differential Input Impedance	R_Rdin		80	100	120	Ω
Input Impedance Mismatch	R_Rm				10	%
Differential Input Return Loss	R_SDD11	See 11.3.2.3				
Common Mode Input Return Loss	R_SCC11	Below 10 GHz			-6	dB
		10GHz to baud rate			-4	
Input Common Mode Voltage	R_Vcm	Load Type 0 See Note 2	-200		1800	mV

NOTES:
1. The receiver shall have a differential input voltage range sufficient to accept a signal produced at point R by the combined transmitter and channel. The channel response shall include the worst case effects of the return losses at the transmitter and receiver.
2. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load. For floating load, input resistance shall be ≥ 1kΩ

Table 11-13. Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Sinusoidal Jitter, Maximum	R_SJ-max	See Section 2.5.4, note 1			5	UIpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See Section 2.5.4, note 1			0.05	UIpp

NOTES:
1. The Receiver shall tolerate the sum of these jitter contributions: Total transmitter jitter from Table 11-7;Sinusoidal jitter as defined in Table 11-13;The effects of a channel compliant to the Channel Characteristics (Section 11.2.6).

11.3.2.1 Input Baud Rate

All devices shall work within the range from 19.90 Gsym/s to 25.80 Gsym/s as specified for the device, with the baud rate tolerance as per Section 3.2.11.

11.3.2.2 Reference Input Signals

The receiver shall accept differential input signal amplitudes produced by a compliant transmitter connected with the minimum attenuation specified in Figure 11-2 to the receiver. This may be larger than the 1200 mVppd maximum of the transmitter due to output/input impedances and reflections.

The minimum input amplitude is defined by the minimum transmitter amplitude, the actual receiver input impedance and the loss of the actual PCB. Note that the minimum transmitter amplitude is defined using a well controlled load impedance, however the real receiver is not, which can leave the receiver input signal smaller than expected. Additionally it will be determined by the environmental noise inside and outside the receiver.

11.3.2.3 Input Resistance and Return Loss

Please refer to Section 3.2.10 with the following parameters.

Table 11-14. Receiver Differential Return Loss Parameters

Parameter	Value	Units
A0	-12	dB
f0	50	MHz
f1	0.1714 x R_Baud	Hz
f2	R_Baud	Hz
Slope	12.0	dB/dec

11.3.2.4 Input Lane-to-Lane Skew

Please refer to Section 3.2.8.

11.3.2.5 Absolute Input Voltage

The absolute voltage levels with respect to the receiver ground at the input of the receiver are dependent on the transmitter implementation and the inter-ground difference. The voltage levels at the input of an AC coupled receiver (if the effective AC coupling is done within the receiver) or at the TX side of the external AC coupling cap (if AC coupling is done externally) shall be between -0.3 to 2.0V with respect to local ground.

12 Test Methodologies for CEI-28G-SR and CEI-25G-LR

This clause defines the common requirements for the Test Methodologies for CEI-28G-SR and CEI-25G-LR.

12.1 TX jitter measurement methodology

- TX jitter measurements are performed using the Short Stress Pattern Random (SSPR) defined in Annex 2.D.2 of the "Implementation Guide for the Common Electrical Interface 2.0", except for DDJ, which is measured using PRBS9.
- Unless otherwise specified, TX jitter parameters defined in Table 10-7 and 11-7 are measured with TX FIR equalization turned-off and on.
- Jitter distributions are defined in 2.C.4, and are the basis for determining the jitter parameters
- Jitter distributions are measured with any jitter measurement capable instrument (e.g., scope, BERT) referenced to a golden PLL recovery clock timing with its corner frequency set at baud rate/1667.
- T_UUGJ, T_UBHPJ, and T_TJ are derived with the method defined in 2.C.4.6 from the BER CDF. T_UBHPJ is calculated as HPJ_{total} - DDJ.
- T_DCD is defined in Clause 1.6, Table 1-3
- The DDJ difference with TX FIR on and off is defined as:
  diff_DDJ = T_DDJ (FIR on) -T_DDJ (FIR off)
- T_UUGJ, T_UBHPJ, T_TJ, T_DCD, and T_DDJ need to be measured with TX FIR on and off
- diff_DDJ should be subtracted from the T_TJ measured when the FIR is on
- T_UUGJ, T_UBHPJ, T_TJ, and T_DCD measured with FIR on and off should be within the limits as defined in Table 10-7 and 11-7
- The measurement instrument bandwidth should be at least 40 GHz. If the measurement bandwidth affects the result, it can be corrected using post-processing

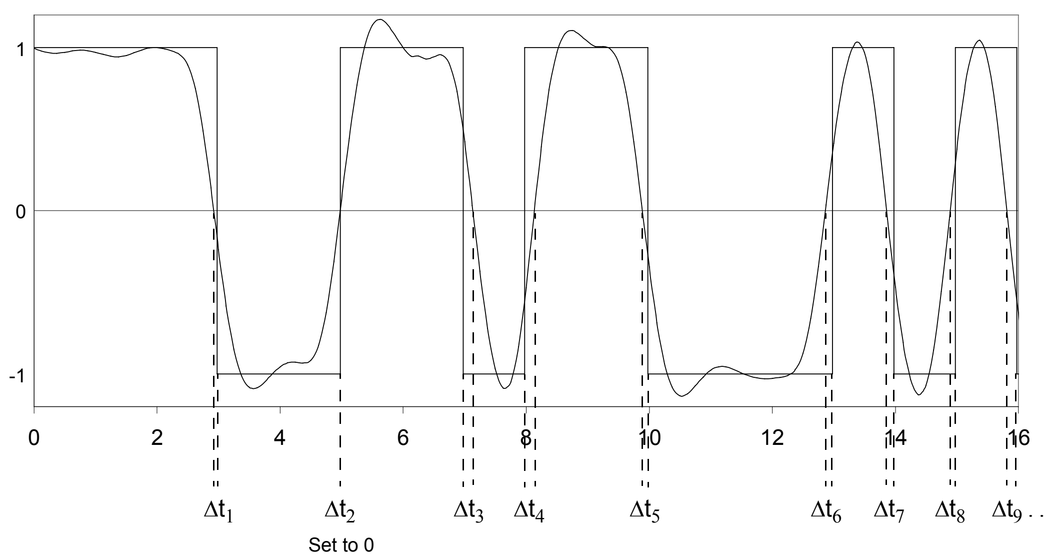
12.1.1 Data Dependent Jitter (DDJ) measurement

A high-resolution oscilloscope, time interval analyzer, or other instrument with equivalent capability may be used to measure DDJ. Establish a crossing level equal to the average value of the entire waveform being measured.

Synchronize the instrument to the pattern repetition frequency and average the waveforms or the crossing times sufficiently to remove the effects of random jitter and noise in the system. The mean time of each crossing is then compared to the expected time of the crossing, and a set of timing variations is determined. DDJ is the range (max-min) of the timing variations. Keep track of the signs (early/late) of the variations. Note, it may be convenient to align the expected time of one of the crossings with the measured mean crossing. All edges of the repeating pattern that have been averaged need to be included in the measurement.

The following Figure 12-1 illustrates the method. The vertical axis is in arbitrary units, and the horizontal axis is plotted in UI. The waveform is AC coupled to an average value of 0, therefore 0 is the appropriate crossing level. The rectangular waveform shows the expected crossing times, and the other is the waveform with jitter that is being measured. Only 16 UI are shown in this example. The waveforms have been arbitrarily aligned with ($\Delta t_2 = 0$) at 5 UI.

Figure 12-1.DDJ Measurement Method



$$DDJ = \max(\Delta t_1, \Delta t_2, \ldots \Delta t_n) - \min(\Delta t_1, \Delta t_2, \ldots \Delta t_n)$$

12.2 Channel compliance methodology

12.2.1 Channel Compliance

A forward channel and associated dominant crosstalk channels are deemed compliant if the channel characteristics conform to the requirements in the relevant clause, using the methodologies described in this section.

12.2.1.1 Fitted insertion loss

The weighted fitted insertion loss IL_{fitted} as a function of frequency f is defined by the equation below.

$$IL_{fitted}(f) = a_0 + a_1\sqrt{\frac{f}{f_b}} + a_2\frac{f}{f_b} + a_4\left(\frac{f}{f_b}\right)^2 \ (dB) \qquad (12\text{-}1)$$

Where f_b is the maximum symbol rate to be supported by the channel under test.

Given the channel insertion loss measurement at N uniformly-spaced frequencies f_n spanning f_{ILmin} to f_{ILmax} with a maximum frequency spacing of 10MHz. The coefficients of the fitted insertion loss are computed as follows.

Note: f_{ILmin}, f_{ILmax} are defined in Table 10-4/11-4.

Define the weighted frequency matrix F as shown below, where "*mag(IL$_f$)*" is the magnitude of the measured insertion loss at each frequency point [$mag(IL_{fx}) = 10$^(-IL_{fx}/10)]. Note: $mag(IL_f)$ is a real number between 0 and 1.

$$F = \begin{bmatrix} mag(IL_{f_1}) & mag(IL_{f_1})\times\sqrt{\frac{f_1}{f_b}} & mag(IL_{f_1})\times\frac{f_1}{f_b} & mag(IL_{f_1})\times\left(\frac{f_1}{f_b}\right)^2 \\ mag(IL_{f_2}) & mag(IL_{f_2})\times\sqrt{\frac{f_2}{f_b}} & mag(IL_{f_2})\times\frac{f_2}{f_b} & mag(IL_{f_2})\times\left(\frac{f_2}{f_b}\right)^2 \\ \cdots & \cdots & \cdots & \cdots \\ mag(IL_{f_N}) & mag(IL_{f_N})\times\sqrt{\frac{f_N}{f_b}} & mag(IL_{f_N})\times\frac{f_N}{f_b} & mag(IL_{f_N})\times\left(\frac{f_N}{f_b}\right)^2 \end{bmatrix} \qquad (12\text{-}2)$$

The polynomial coefficients a_0, a_1, a_2, and a_4 are determined using the Equation below.

$$\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_4 \end{bmatrix} = \langle F^T F \rangle^{-1} F^T \left[mag(IL_f) \times IL_f \right] \quad (12\text{-}3)$$

Where T denotes the matrix transpose operator and IL_f is a column vector of the measured insertion loss values, in dB, at each frequency point.

This polynomial fit process is expected to yield values for the coefficients a_0, a_1, a_2, and a_4 that are greater than the minimum and less than the maximum coefficients (as specified in the specific clauses). If any of the coefficients in the equation are below the minimum allowed value they are forced to the minimum value and the fitting process is iterated (see example below). Iteration is done by creating a newIL by subtracting all coefficients below the minimum allowed value from the original IL, removing those coefficients from F and recalculating the remaining coefficients. At the end of the iteration, limit all coefficients to the maximum allowed, followed by a final iteration on any coefficients not previously limited.

Example iteration: If a_2 needs to be set to zero, but all other coefficients are within the range, then calculate newIL and solve for a_0, a_1 & a_4 as indicated below.

$$newIL = IL - \left[a_{2_{fixed}} \times \frac{f}{f_b} \right] \quad (12\text{-}4)$$

Define the frequency matrix F as shown below

$$F = \begin{bmatrix} mag(IL_{f_1}) & mag(IL_{f_1}) \times \sqrt{\frac{f_1}{f_b}} & mag(IL_{f_1}) \times \left(\frac{f_1}{f_b}\right)^2 \\ mag(IL_{f_2}) & mag(IL_{f_2}) \times \sqrt{\frac{f_2}{f_b}} & mag(IL_{f_2}) \times \left(\frac{f_2}{f_b}\right)^2 \\ \ldots & \ldots & \ldots \\ mag(IL_{f_N}) & mag(IL_{f_N}) \times \sqrt{\frac{f_N}{f_b}} & mag(IL_{f_N}) \times \left(\frac{f_N}{f_b}\right)^2 \end{bmatrix} \quad (12\text{-}5)$$

The polynomial coefficient a_0, a_1 & a_4 are determined using the Equation below.

$$\begin{bmatrix} a_0 \\ a_1 \\ a_4 \end{bmatrix} = \langle F^T F \rangle^{-1} F^T \left[mag(IL_f) \times IL_f \right] \quad (12\text{-}6)$$

Where T denotes the matrix transpose operator and IL_f is a column vector of the measured insertion loss values, in dB, at each frequency point.

If after this iteration, a_1 is below minimum allowed value, then another newIL is calculated as indicated below.

$$newIL = IL - \left[a_{1_{fixed}} \times \sqrt{\frac{f}{f_b}} + a_{2_{fixed}} \times \frac{f}{f_b} \right] \quad (12\text{-}7)$$

Define the frequency matrix F as shown below

$$F = \begin{bmatrix} mag(IL_{f_1}) & mag(IL_{f_1}) \times \left(\frac{f_1}{f_b}\right)^2 \\ mag(IL_{f_2}) & mag(IL_{f_2}) \times \left(\frac{f_2}{f_b}\right)^2 \\ \dots & \dots \\ mag(IL_{f_N}) & mag(IL_{f_N}) \times \left(\frac{f_N}{f_b}\right)^2 \end{bmatrix} \quad (12\text{-}8)$$

The polynomial coefficient a_0 & a_4 are determined using the Equation below.

$$\begin{bmatrix} a_0 \\ a_4 \end{bmatrix} = \langle F^T F \rangle^{-1} F^T \left[mag(IL_f) \times IL_f \right] \quad (12\text{-}9)$$

Where T denotes the matrix transpose operator and IL_f is a column vector of the measured insertion loss values, in dB, at each frequency point.

If after this iteration all values are within range, the calculation is finished.

12.2.1.2 Integrated crosstalk noise

Given multi-disturber near-end crosstalk loss $MDNEXT_{loss}$ and multi-disturber far-end crosstalk loss $MDFEXT_{loss}$ measured over N frequencies f_x spanning 0.05 GHz to f_b (where f_b is the maximum baud rate supported by the channel), with uniform frequency step Δf, the RMS value of the integrated crosstalk noise σ_x shall be calculated as follows.

$MDNEXT_{loss}$ is determined from all individual pair-to-pair differential NEXT loss values using Equation (12-10).

$$MDNEXT_{loss}(f) = -10 \times \log_{10}\left(\sum_{i=0}^{all\ NEXTs} 10^{-(NLi(f))/10}\right)\ (dB) \qquad (12\text{-}10)$$

for 0.05 GHz ≤ f ≤ f_b

where

$MDNEXT_{loss}(f)$	is the MDNEXT loss at frequency *f,*
$NL_i(f)$	is the NEXT loss at frequency *f* of pair combination *i*, in dB,
f	is the frequency in GHz,
i	is all pair-to-pair combinations.

$MDFEXT_{loss}$ is determined from all individual pair-to-pair differential FEXT loss values using Equation (12-11).

$$MDFEXT_{loss}(f) = -10 \times \log_{10}\left(\sum_{i=0}^{all\ \ FEXTs} 10^{-(NLi(f))/10}\right)\ (dB) \qquad (12\text{-}11)$$

for 0.05 GHz ≤ f ≤ f_b

where

$MDFEXT_{loss}(f)$	is the MDFEXT loss at frequency *f,*
$NL_i(f)$	is the FEXT loss at frequency *f* of pair combination *i*, in dB,
f	is the frequency in GHz,
i	is all pair-to-pair combinations.

Define the weight at each frequency f_n using Equation (12-12) and Equation (12-13).

$$W_{nt}(f) = (A_{nt}^2/4f_b)\,\mathrm{sinc}^2(f/f_b)\left[\frac{1}{1+(f/f_{nt})^4}\right]\left[\frac{1}{1+(f/f_r)^8}\right] \qquad (12\text{-}12)$$

$$W_{ft}(f) = (A_{ft}^2/4f_b)\,\mathrm{sinc}^2(f/f_b)\left[\frac{1}{1+(f/f_{ft})^4}\right]\left[\frac{1}{1+(f/f_r)^8}\right] \qquad (12\text{-}13)$$

Note that -3 dB transmit filter bandwidths f_{nt} and f_{ft} are inversely proportional to the 20 to 80% rise and fall times T_{nt} and T_{ft} respectively. The constant of proportionality is 0.2365 (e.g. $T_{nt} f_{nt}$ = 0.2365), where T_{nt} is in nano seconds and f_{nt} is in GHz. In addition, f_r is the -3 dB reference receiver bandwidth, which should be set at 3/4 the maximum baud rate specified for the device.

The near-end integrated crosstalk noise σ_{nx} is calculated using Equation (12-14).

$$\sigma_{nx} = \left(2\Delta f \sum_n W_{nt}(f_n) 10^{-MDNEXT_{loss}(f_n)/10} \right)^{1/2} \quad (12\text{-}14)$$

The far-end integrated crosstalk noise σ_{fx} is calculated using Equation (12-15).

$$\sigma_{fx} = \left(2\Delta f \sum_n W_{ft}(f_n) 10^{-MDFEXT_{loss}(f_n)/10} \right)^{1/2} \quad (12\text{-}15)$$

The total integrated crosstalk noise σ_x is calculated using Equation (12-16).

$$\sigma_x = \sqrt{\sigma_{nx}^2 + \sigma_{fx}^2} \quad (12\text{-}16)$$

12.3 Common Mode Noise

Common mode noise specification is to be measured using the following test procedure.

The data pattern is normal traffic or a common test pattern. Connect both waveform polarities through a suitable test fixture to a 50 ohm communication analysis oscilloscope system. Waveforms are not triggered (free-run mode). Scope shall have a minimum bandwidth (including probes) of 1.8 times the signaling rate.

No filtering except AC coupling with a high-pass 3dB low frequency not greater than 10MHz.

The two inputs are summed for common mode analysis. Set the horizontal scale for full width to span one UI. Set up a vertical histogram with full display width. Measure the rms value of the histogram. Common mode rms value (*Ncm*) is half the rms value of the histogram.

Follow equation (12-17) below to account for instrumentation noise.

$$T\_Ncm(orR\_Ncm) = \sqrt{(measured\_Ncm)^2 - (instrumentation\_noise)^2} \tag{12-17}$$