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

DATE:  1st September 2011

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.
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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:

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIF 2003.104.00</td>
<td>28th March 2003,</td>
<td>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)</td>
</tr>
<tr>
<td>OIF 2003.104.01</td>
<td>3rd May 2003</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2003.104.02</td>
<td>24th May 2003</td>
<td>Draft 3.0. Updated to include approved changes from the OIF Plenary meeting in Scottsdale, 6-8 May 2003</td>
</tr>
<tr>
<td>OIF 2003.104.03</td>
<td>2nd October 2003</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2003.104.04</td>
<td>17th November 2003</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2003.104.05</td>
<td>10th February 2004</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2003.104.06</td>
<td>5th May 2004</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2003.104.07</td>
<td>14th July 2004</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2003.104.08</td>
<td>26th August 2004</td>
<td>Clause 8 modified to include changes agreed at the Hawaii Plenary meeting, to address discrepancies between CEI and XFP specifications.</td>
</tr>
<tr>
<td>OIF 2003.104.09</td>
<td>20th October 2004</td>
<td>Draft 9.0. Updated to include changes as result of comment resolution from 4th Straw ballot (ballot no 55).</td>
</tr>
<tr>
<td>OIF 2003.104.10</td>
<td>8th November 2004</td>
<td>Draft 10.0. As draft 9.0 with specific reference to version no of State Eye scripts in section 2.C.5 removed.</td>
</tr>
</tbody>
</table>

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:

<table>
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<tr>
<th>Revision</th>
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<tr>
<td>OIF 2003.253.00</td>
<td>20th July 2003</td>
<td>Draft 1.0. Compiled from baseline document oif2002.127.0 with changes and modifications from Scottsdale motions</td>
</tr>
<tr>
<td>OIF 2003.253.01</td>
<td>5th October 2003</td>
<td>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</td>
</tr>
<tr>
<td>OIF2003.253.03</td>
<td>2nd February 2004</td>
<td>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</td>
</tr>
<tr>
<td>OIF2003.253.04</td>
<td>3rd May 2004</td>
<td>Draft 2.2 resolving comments from straw ballot 53 and orlando interim meeting, March 15th. Corrections include - DC coupling editorial - Tap weight clarification - T_Y1 = 400 mVpp, T_Y2 = 600mVpp - driver and receiver absolute min and max voltages - Return loss alignment to 6G-LR</td>
</tr>
<tr>
<td>OIF2003.252.05</td>
<td>6 September 2004</td>
<td>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.</td>
</tr>
</tbody>
</table>

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:

<table>
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<tr>
<th>Revision</th>
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<tr>
<td>OIF 2008.029.03</td>
<td>28th July 2008,</td>
<td>Document taken over from Beth Donnay</td>
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<tr>
<td>OIF 2008.029.04</td>
<td>23rd April 2009</td>
<td>Inserted text for all tbd locations according to work session results of Q2/09 meeting in Boston</td>
</tr>
<tr>
<td>OIF 2008.029.05</td>
<td>23rd April 2009</td>
<td>Finalized text proposal after continued discussion in Q2/09 meeting. Text proposal sent to Straw Ballot in Boston</td>
</tr>
<tr>
<td>OIF 2008.029.07</td>
<td>15th October 2009</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2008.029.08</td>
<td>21st May 2010</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2008.029.10</td>
<td>16th November 2010</td>
<td>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</td>
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<tr>
<td>OIF 2008.029.11</td>
<td>14th February 2011</td>
<td>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.</td>
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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:

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<td>OIF 2008.161.03</td>
<td>28th July 2008,</td>
<td>Document taken over from Beth Donnay</td>
</tr>
<tr>
<td>OIF 2008.161.04</td>
<td>23rd April 2009</td>
<td>Inserted text for all tbd locations according to work session results of Q2/09 meeting in Boston</td>
</tr>
<tr>
<td>OIF 2008.161.05</td>
<td>23rd April 2009</td>
<td>Finalized text proposal after continued discussion in Q2/09 meeting in Boston. Text proposal sent to Straw Ballot in Boston</td>
</tr>
<tr>
<td>OIF 2008.161.07</td>
<td>15th October 2009</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2008.161.08</td>
<td>21st May 2010</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2008.161.10</td>
<td>16th November 2010</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2008.161.11</td>
<td>14th February 2011</td>
<td>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</td>
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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:

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<th>Description</th>
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<tr>
<td>OIF 2010.189.00</td>
<td>12th May 2010</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2010.189.01</td>
<td>12th May 2010</td>
<td>Modifications during Hong Kong meeting</td>
</tr>
<tr>
<td>OIF 2010.189.02</td>
<td>21st May 2010</td>
<td>Editorial changes of PLL chair, see change bars Text proposal sent to Straw Ballot in electronic motion after Hong Kong meeting.</td>
</tr>
<tr>
<td>OIF 2010.189.04</td>
<td>16th November 2010</td>
<td>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.</td>
</tr>
<tr>
<td>OIF 2010.189.05</td>
<td>14th February 2011</td>
<td>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</td>
</tr>
<tr>
<td>OIF 2010.189.06</td>
<td>7th April 2011</td>
<td>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.</td>
</tr>
</tbody>
</table>

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.
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Acacia Communications
ADVA Optical Networking
Alcatel-Lucent
Altera
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Amphenol Corp.
Anritsu
AT&T
Avago Technologies Inc.
Broadcom
Brocade
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Comcast
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<td>Huawei Technologies</td>
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<td>KDDI R&amp;D Laboratories</td>
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<tr>
<td>Lightwire</td>
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<td>LSI Corporation</td>
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<td>Luxterna</td>
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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
Sumitomo Electric Industries
Sumitomo Osaka Cement
TE Connectivity
Telcordia Technologies
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

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).

7. ITU-T, Recommendation G.707, Amendment 2, 2002 - "Network Node Interface For The Synchronous Digital Hierarchy (SDH), Amendment 2"


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


23. Fiber Channel - Physical Interfaces, INCITs T11.2 project 1235D

1.5 Abbreviations

Table 1-1. Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER</td>
<td>Bit Error Ratio</td>
</tr>
<tr>
<td>BERT</td>
<td>Bit Error Ratio Test or Tester</td>
</tr>
<tr>
<td>BUJ</td>
<td>Bounded Uncorrelated Jitter</td>
</tr>
<tr>
<td>CBGJ</td>
<td>Correlated Bounded Gaussian Jitter</td>
</tr>
<tr>
<td>CBHPJ</td>
<td>Correlated Bounded High Probability Jitter</td>
</tr>
<tr>
<td>CEI</td>
<td>Common Electrical I/O</td>
</tr>
<tr>
<td>CDF</td>
<td>Cumulative Distribution Function</td>
</tr>
<tr>
<td>CDR</td>
<td>Clock Data Recovery</td>
</tr>
<tr>
<td>CID</td>
<td>Consecutive Identical Digits</td>
</tr>
<tr>
<td>CML</td>
<td>Current Mode Logic</td>
</tr>
<tr>
<td>Cn</td>
<td>Cursor number</td>
</tr>
<tr>
<td>DCD</td>
<td>Duty Cycle Distortion</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>DDJ</td>
<td>Data Dependent Jitter</td>
</tr>
<tr>
<td>DFE</td>
<td>Decision Feedback Equalizer</td>
</tr>
<tr>
<td>DJ</td>
<td>Deterministic Jitter</td>
</tr>
<tr>
<td>DUT</td>
<td>Device Under Test</td>
</tr>
<tr>
<td>EMI</td>
<td>Electro-Magnetic Interference</td>
</tr>
<tr>
<td>erf</td>
<td>error function</td>
</tr>
<tr>
<td>erfinv</td>
<td>inverse error function</td>
</tr>
<tr>
<td>ESD</td>
<td>Electro-Static Discharge</td>
</tr>
<tr>
<td>FEXT</td>
<td>Far End Cross Talk</td>
</tr>
<tr>
<td>FFT</td>
<td>Fast Fourier Transform</td>
</tr>
<tr>
<td>FIR</td>
<td>Finite Impulse Response</td>
</tr>
<tr>
<td>Gbps</td>
<td>Giga bits per second</td>
</tr>
<tr>
<td>GJ</td>
<td>Gaussian Jitter</td>
</tr>
<tr>
<td>Gsym/s</td>
<td>Giga symbols per second</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency</td>
</tr>
<tr>
<td>HPF</td>
<td>High Pass Filter</td>
</tr>
<tr>
<td>HPJ</td>
<td>High Probability Jitter</td>
</tr>
<tr>
<td>IA</td>
<td>Implementation Agreement</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter-Symbol Interference</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Meaning</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>LMS</td>
<td>Least Mean Square</td>
</tr>
<tr>
<td>LPF</td>
<td>Low Pass Filter</td>
</tr>
<tr>
<td>LVDS [20]</td>
<td>Low Voltage Differential Signal</td>
</tr>
<tr>
<td>LR</td>
<td>Long Reach</td>
</tr>
<tr>
<td>mA</td>
<td>milli-Amp</td>
</tr>
<tr>
<td>mV</td>
<td>milli-Volt</td>
</tr>
<tr>
<td>NEXT</td>
<td>Near End Cross Talk</td>
</tr>
<tr>
<td>NRZ</td>
<td>Non Return to Zero</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Distribution Function</td>
</tr>
<tr>
<td>PECL</td>
<td>Positive Emitter Coupled Logic</td>
</tr>
<tr>
<td>PJ</td>
<td>Periodic Jitter</td>
</tr>
<tr>
<td>pp</td>
<td>Peak to Peak</td>
</tr>
<tr>
<td>ppd</td>
<td>Peak to Peak Differential (as in 300mVppd)</td>
</tr>
<tr>
<td>PLL</td>
<td>Phase Locked Loop</td>
</tr>
<tr>
<td>ps</td>
<td>pico second</td>
</tr>
<tr>
<td>PRBS</td>
<td>Pseudo Random Bit Stream</td>
</tr>
<tr>
<td>Q</td>
<td>Inverse error function</td>
</tr>
<tr>
<td>RJ</td>
<td>Random Jitter</td>
</tr>
<tr>
<td>RV</td>
<td>Random Variable</td>
</tr>
<tr>
<td>RX</td>
<td>Receiver</td>
</tr>
<tr>
<td>S11 and S22</td>
<td>reflection coefficient</td>
</tr>
<tr>
<td>S21</td>
<td>transmission coefficient</td>
</tr>
<tr>
<td>SCC11 and SCC22</td>
<td>Common mode reflection coefficients</td>
</tr>
<tr>
<td>SCD11 and SCD22</td>
<td>Differential to common mode conversion coefficient</td>
</tr>
<tr>
<td>SDD11 and SDD22</td>
<td>Differential reflection coefficients</td>
</tr>
<tr>
<td>SDC11 and SDC22</td>
<td>Common mode to differential conversion coefficient</td>
</tr>
<tr>
<td>SFI</td>
<td>SERDES - Framer Interface</td>
</tr>
<tr>
<td>SJ</td>
<td>Sinusoidal Jitter</td>
</tr>
<tr>
<td>SPI</td>
<td>System Packet Interface</td>
</tr>
<tr>
<td>SR</td>
<td>Short Reach</td>
</tr>
<tr>
<td>sym/s</td>
<td>symbols/second</td>
</tr>
<tr>
<td>TJ</td>
<td>Total Jitter</td>
</tr>
<tr>
<td>TDM</td>
<td>Time Division Multiplexed data</td>
</tr>
<tr>
<td>TFI</td>
<td>TDM Fabric to Framer Interface</td>
</tr>
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</table>
1.6 Definitions

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Error Ratio</td>
<td>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.</td>
</tr>
<tr>
<td>Baud rate</td>
<td>Number of symbols per second, where a symbol can consist of more than one bit.</td>
</tr>
<tr>
<td>Channel</td>
<td>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.</td>
</tr>
<tr>
<td>Common Mode Voltage</td>
<td>Average of the Vhigh and Vlow voltage levels - see Figure 1-1</td>
</tr>
<tr>
<td>Confidence level</td>
<td>The use of this definition shall be understood as being with reference to a Gaussian Distribution</td>
</tr>
<tr>
<td>Differential Termination</td>
<td>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</td>
</tr>
<tr>
<td>Resistance mismatch</td>
<td></td>
</tr>
<tr>
<td>Gaussian</td>
<td>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.</td>
</tr>
<tr>
<td>Golden PLL</td>
<td>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 &lt;0.1dB peaking.</td>
</tr>
</tbody>
</table>
Table 1-2. General Definitions (with exception of Jitter and Wander) (Sheet 2 of 2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Channel</td>
<td>An otherwise compliant channel that has been selected or altered to test receiver or transmitter compliance (see also Stressed Signal (or) Stressed Eye.)</td>
</tr>
<tr>
<td>Intersymbol Interference</td>
<td>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, 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, 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.</td>
</tr>
<tr>
<td>Lane</td>
<td>A single CEI Channel</td>
</tr>
<tr>
<td>Link</td>
<td>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.</td>
</tr>
<tr>
<td>non-transparent applications</td>
<td>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</td>
</tr>
<tr>
<td>Skew</td>
<td>The constant portion of the difference in the arrival time between the data of any two in-band signals.</td>
</tr>
<tr>
<td>Stressed Signal (or) Stressed Eye</td>
<td>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.</td>
</tr>
<tr>
<td>Transparent applications</td>
<td>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</td>
</tr>
<tr>
<td>Symbol</td>
<td>Unit of information conveyed by a single state transition in the medium</td>
</tr>
<tr>
<td>Symbol spaced</td>
<td>Describes a time difference equal to the nominal period of the data signal</td>
</tr>
<tr>
<td>Unit Interval</td>
<td>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.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter</td>
<td>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.</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>sum of all jitter components.</td>
</tr>
<tr>
<td>Jitter Generation</td>
<td>Jitter generation is the process whereby jitter appears at the output port in the absence of applied input jitter at the input port.</td>
</tr>
<tr>
<td>Jitter Transfer</td>
<td>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.</td>
</tr>
<tr>
<td>Previous Terminology</td>
<td>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.</td>
</tr>
<tr>
<td>Data Dependent Jitter</td>
<td>Now referred to as Correlated Bounded High Probability Jitter</td>
</tr>
<tr>
<td>Deterministic Jitter</td>
<td>Now referred to as High Probability Jitter</td>
</tr>
<tr>
<td>Random Jitter</td>
<td>Now referred to as Gaussian Jitter</td>
</tr>
<tr>
<td>Gaussian Jitter</td>
<td>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.</td>
</tr>
<tr>
<td>Jitter, Unbounded Gaussian</td>
<td>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)</td>
</tr>
<tr>
<td>Correlated Bounded Gaussian Jitter</td>
<td>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</td>
</tr>
</tbody>
</table>
### Table 1-3. Jitter and Wander Definitions  (Sheet 2 of 2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High probability Jitter</td>
<td>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.</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>Jitter distribution where the value of the jitter show no correlation to any signal level being transmitted. Formally defined as $T_{DJ}$.</td>
</tr>
<tr>
<td>Correlated Bounded High Probability Jitter</td>
<td>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.</td>
</tr>
<tr>
<td>Periodic Jitter</td>
<td>A sub form of HPJ that defines a jitter which has a single fundamental harmonic plus possible multiple even and odd harmonics.</td>
</tr>
<tr>
<td>Sinusoidal Jitter</td>
<td>A sub form of HPJ that defines a jitter which has a single frequency harmonic.</td>
</tr>
<tr>
<td>Duty Cycle Distortion</td>
<td>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.</td>
</tr>
<tr>
<td>Wander</td>
<td>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.</td>
</tr>
<tr>
<td>Correlated wander</td>
<td>Components of wander that are common across all applicable in band signals.</td>
</tr>
<tr>
<td>Relative wander</td>
<td>Components of wander that are uncorrelated between any two in band signals (See Figure 1-2)</td>
</tr>
<tr>
<td>Total wander</td>
<td>The sum of the correlated and uncorrelated wander. (See Figure 1-3)</td>
</tr>
<tr>
<td>Uncorrelated wander</td>
<td>Components of wander that are not correlated across all applicable in band signals.</td>
</tr>
<tr>
<td>Unit</td>
<td></td>
</tr>
<tr>
<td>Peak-to-Peak Jitter</td>
<td>For any type of jitter, Peak to Peak Jitter is the full range of the jitter distribution that contributes within the specified BER.</td>
</tr>
<tr>
<td>Jitter RMS</td>
<td>The root mean square value or standard deviation of jitter. See clause 2 for more information.</td>
</tr>
<tr>
<td>Sigma</td>
<td>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.</td>
</tr>
</tbody>
</table>
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

![Diagram of driver amplitude and swing](image-url)
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**

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

**NOTES:**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Bounded High probability Jitter</td>
<td>T_UBHPJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulp</td>
</tr>
<tr>
<td>Uncorrelated Unbounded Gaussian Jitter</td>
<td>T_UUGJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulp</td>
</tr>
<tr>
<td>Duty cycle distortion</td>
<td>T_DCD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T_TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ulp</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Uncorrelated Unbounded Gaussian Jitter must be defined with respect to specified BER of 1e-15, Q=7.94
1.7.2 Receiver Electrical Input Specification

Table 1-6. Receiver Electrical Input Specification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>R_Baud</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mVppd</td>
</tr>
<tr>
<td>DC Common mode voltage</td>
<td>R_VrCM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>AC Common mode Voltage</td>
<td>R_VcmAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Differential Input Resistance</td>
<td>R_Rdin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Input Resistance Mismatch</td>
<td>R_Rm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Common Mode Input Return Loss</td>
<td>R_SCC11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Differential to Common Mode Input</td>
<td>R_SCD11</td>
<td>Conversion2</td>
<td></td>
<td></td>
<td></td>
<td>dB</td>
</tr>
</tbody>
</table>

NOTES:
1.7.3 Receiver input Jitter Specification

Table 1-7. Receiver Input Jitter Specification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Bounded High probability Jitter</td>
<td>R_UBHPJ</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Correlated Bounded High probability Jitter</td>
<td>R_CBHPJ</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Gaussian Jitter</td>
<td>R_GJ</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Sinusoidal Jitter</td>
<td>R_SJ</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Total Jitter</td>
<td>R_TJ</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R_X1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R_Y1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R_Y2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

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

- Component Edge
- Egress
- Channel
- Ingress
- Channel
- Component Edge

TX $T_E$ RX

RX $R_E$ TX

Ingress

Egress
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
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**

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

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

- Transmit Link Layer Device
- Receive Link Layer Device
- System-Packet Interface (SPI)
- Transmit Interface (SFI)
- Phy Device
- FEC Device
- SERDES Framer Interface (SFI)
- SERDES Device And Optics
- TDM Framer Interface (TFI)
- SERDES Framer Interface (SFI)
- SERDES Framer Interface (SFI)
- TDM Switch
- Frame Device
- FEC Device
- SERDES Device And Optics
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

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.

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

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

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

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\(^{\dagger}\) 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

\(^{\dagger}\) 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](image-url)
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](image)

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](image)
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,

\[
\begin{align*}
    t_{\text{step}} &= \frac{1}{f_{\text{max}}} \\
    t &= t_{\text{step}} \cdot n \\
    n &= [1, P] \\
    tx(t) &= H(0) \cdot H(t_{\text{period}} - t) \\
    rx(\omega) &= tx(\omega) \cdot Tr(\omega) \\
    rx(t) &= \text{ifft}(rx(\omega))
\end{align*}
\]

where

- \( f_{\text{max}} \) is difference between the maximum positive and minimum negative frequency
- \( P \) is the number of equally spaced 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**

![Graphical Representation of Receiver Pulse](image-url)

 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 0s or 1s respectively. This maximum is referred to Total Distortion

$$\Theta = \sum_{n=-\infty}^{n=\infty} |c_n|$$

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](image)

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](image)

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.
\[
P_{post} = \frac{t_1}{t_0}
\]
\[
E = 20 \log \frac{1 + P_{post}}{1 - P_{post}}
\]
\[
\sum |t_n| < T_{_Vdiff}
\]

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.

![Receiver Pulse Definition](image)
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 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.

The value of the coefficients are calculated directly from the channel pulse response or the receiver pulse using an emphasized transmitter.
\[ k_n = c_n \mid n = [1,m] \] for unemphasized transmitters, or
\[ k_n = r_n \mid n = [1,m] \] 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.

\[ y_n = \sum_{k=1}^{m} k_n z^{-k} \]

\[ H(f) = \frac{p}{z} \cdot \frac{(z + j2\pi f)}{(p + j2\pi f)} \]
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.

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.

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

For every offset \( \tau \), 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.

\[
GJ(\tau, \sigma) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot e^{-\frac{\tau^2}{2\sigma^2}} \begin{cases} 
\tau \leq \tau_{\text{max}} \\
0 & \text{if} \quad \tau > \tau_{\text{max}}
\end{cases}
\]

For random processes consisting of a finite number of random variables there exists a finite non-zero probability only if \(\tau \leq \tau_{\text{max}}\). 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.

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

---

\(^1\) 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.\(^1\)

\[
Q = \sqrt{2} \cdot \text{erf}^{-1}(2 \cdot (1 - BER) - 1)
\]

where

\[
\text{erf}^{-1}(x)\] is the inverse function of the error function \( \text{erf}(x) \) and

\[
\text{erf}(z) = \frac{2}{\sqrt{\pi}} \int_{0}^{z} e^{-t^2} dt
\]

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

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

\[
Q_{\text{right}}(\tau_{\text{offset}}) = (HPJ_{\text{right}} - \tau_{\text{offset}}) \cdot \frac{1}{GJ_{\text{right}}}
\]

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.

\[ A = \sum_{n} d_{n} r_{n} \]
\[ d = \{-1,1\} \]

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).

By varying the reference sampling point for $c_0$, 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 \( \tau \)

\[ e_b \] is the ideal static equalization coefficients of the b tap DFE

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

\[ \delta(\tau) = \lim_{\varepsilon \to 0} e^{\left[ x \right]} \] 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

\[ c(\tau) = \left[ \frac{r_m(\tau)}{2} \dot{r}_{-1}(\tau) \ldots - r_{-1}(\tau) \right. \]

\[ \ldots \left. (\tau) - e_1 r_0(\tau) - e_b r_{b+1}(\tau) \ldots r_m(\tau) \right] \]

\[ d = \begin{bmatrix} d_{1,1} & d_{1,2} & \ldots & d_{1,m} \\ d_{2,1} & d_{2,2} & \ldots & d_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m,1} & d_{m,2} & \ldots & d_{m,m} \end{bmatrix} \]

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

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

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

\[ c(\tau) = \left[ \frac{r_m(\tau)}{2} \dot{r}_{-1}(\tau) \ldots - r_{-1}(\tau) \right. \]

\[ \ldots \left. (\tau) - e_1 r_0(\tau) - e_b r_{b+1}(\tau) \ldots r_m(\tau) \right] \]
2.C.5.2 Annex - Inclusion of Sampling Jitter

In a real system the sampling point \( c_0 \) 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\(^1\).

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,

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

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

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

\( a \otimes b \) is the convolution operative

\[ p_{\text{average}}(\text{ISI}, \tau) = \int_{-\infty}^{\infty} \left\{ [p_{\text{crosstalk}}(\text{ISI}, \tau + \nu + w) \otimes p_{\text{forward}}(\text{ISI}, \tau + \nu)] \cdot p_{\text{jitter}}(\nu, w, \sigma) \right\} d\nu \]
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 accordance 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)**

- 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 = 0xFFFFFFFF 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 101010100101010101010101010101011011010 ...
- 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)**

- 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 = 0xFFFFFFFF 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:

- 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 1010101001010101010110101010101010110110101 ...
- 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>
<thead>
<tr>
<th>Electrical Requirement</th>
<th>&quot;Method&quot;</th>
<th>IA</th>
<th>Test Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEI Clause 4 (SxI-5)</td>
<td>A</td>
<td>SFI-4.2 Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPI-5 Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SFI-5.1 Partially scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SFI-5.1s Partially scrambled</td>
<td>SSPR</td>
</tr>
<tr>
<td>CEI Clause 5 (TFI-5)</td>
<td>B</td>
<td>TFI-5 Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially scrambled</td>
<td>SSPS-16</td>
</tr>
<tr>
<td>CEI Clause 6 (CEI-6G-SR)</td>
<td>B</td>
<td>TDM-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEI-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially scrambled</td>
<td>SSPS-16</td>
</tr>
<tr>
<td>CEI Clause 7 (CEI-6G-LR)</td>
<td>D</td>
<td>TDM-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEI-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
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<td></td>
<td></td>
<td>Partially scrambled</td>
<td>SSPS-16</td>
</tr>
<tr>
<td>CEI Clause 8 (CEI-11G-SR)</td>
<td>E</td>
<td>TDM-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
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<td></td>
<td>CEI-P Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
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<td>SF15.2 Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other Scrambled</td>
<td>PRBS31 or SSPR</td>
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<td></td>
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<td>Partially scrambled</td>
<td>SSPS-64</td>
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<tr>
<td>CEI Clause 9 (CEI-11G-LR/MR)</td>
<td>see\textsuperscript{a}</td>
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<td>PRBS31 or SSPR</td>
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<tr>
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<td>PRBS31 or SSPR</td>
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<td></td>
<td></td>
<td>Other Scrambled</td>
<td>PRBS31 or SSPR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partially scrambled</td>
<td>SSPS-64</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Use method E for CEI-11G-MR and both methods C and D without any Tx emphasis for CEI-11G-LR.
2.6 D - Annex - Text Definitions of Patterns

Below are the definitions of patterns described in Annex 2.2.2, Annex 2.2.3 and Annex 2.4 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)

0800080048040820820824294284800008C00006880003C00801A48800C8008688632C2C
9A44294840000A008005A48002880016CB480A080A54DA4A8820816C9248E88000FAC9077
2C88034C81BC0E88FA7C02FCA6B42B9C0414821248080008004C804822820936C92408
8004484820608024484948848848686E81B4ED2B1EC124C8C80628E88736FA9C72C
2C8559C48AA8A0D9E5DCA6208A9G724DA42020855E124AFA8012DA80F4A48087546A7BDE47
AF52C7AD54CAFC7E8A4FA24B382328126A96812492880048C800280887127AC8019CA88
4C8CA0A8E8897BEFA4A9A49F840848682003022481A60008C96004E802230A91613EE1A68C
9EC928E88805A2C828F2489F66F0C2146626D730470C7B27F6FA218412D28A47824080B0
45845E260AFC3F1656C7A46B0FA810672E8935E5AC09CA8CC4C4CAEA682FBD7F6F2536C16DC8
0CA668689952CB253C4920CD0026A2E0113B5E98E1AE45FECDC6A08A3FA34DCCBE82051F9A9
227ACE07399BE185B54ED1F63835E4799CA7C8354CF9F2B7526765216B56E2F2CFA5645BD
5B41247AC4807ACE083ACBE49EC94C68832C3C29A4AD48A2800A9245A400A084080ECA4
02A889147ECC5A4A888818E1FCFAC8EB8CB282D482FC040E467443C4D56D65E642B46124
90448001260808164804A0820D849261A60016960A80265A49162801A76C809C0C88
687C4C2B929776F0101C146C0587751481E078A18C1CC4D4CA5SB802CB6DFD2BAE62
136DF168027A2C811AB4889CF10C77B796AFA0B23D2A523D7483C7D77BED6CA4E863908964
58A4B649A817249282B00600DDB03032E01B1A5E0C3CAE66DD031E351BEF94D9273
E005DEC02B2B6E1726DAE1703BDB93E52A09C776A7FA922BAD2E076C5483C040000000
000000003FF0FF0C00001C000C00FFC001001C00FFC00171C003FF0FCF0001C00FC0F071C7C3F3FFPFC0D0
013C003C00D0C0004E0C02FC0D13C13C08D8C4E3B0E3BFFFC0001B1C00CFC00FC0D1C003FC0B1CD3C3FAD7C123CFFD4D0C001723C00A3CD50DFD3C2B214D0722B363723
81FBE3F3FF3FC0FCD100C1DF03FC0FC76DC17FC03FFEE1C00C0FECFC07918BC13CB3F3E3FD1F2
FC13C851C8D8AF8E1D2C3F28ECD39C6D4C402723E523E3C3CCC3CDADADB1F003C30971DB1F2F
F30E65071CD4DFDA7F42C092E0C16E14E1A51EB29DB2652E214AF72B21D4E373F738EC4
EC3F838E3CD3F3000F3D300714D03CFB23C123CD3D3B14DE3B173FEC0F0C00
08C71C04EFFFC02CFCC73C3F3E3C001ADCEC03CBE06AD4E3C3CF3C3AD3D4D4C2C73D2D48
E3D721FFDFD3E01161F5E0A5E5A9E5F19F3E31E3PFF8EC03F910C13C1FC0FDE1C1704
EPF9F23190303F101B1C790C3FFB16D203A31C31E1D8C9CB9E896F6F2A026102B3691723
821A9F329FCDFC0102A2D125713D4DEP95279300C00B00CD7B363C3A2B7DDB69B32
B0370A7311F59EBDF5965295231C0933FC4114E14EC4EC68E383C32FFPEDA500500800D4
84E5201C5D215080580898443C5097C37B4E8F5ADD0C0C8350689D32F8174A5318AD18
D45A5B5B55B5B525B56BD6BDA4AAA2E4B55555CB555513B55724B554ABB55BC5B13B13
B724924A44AAAAB55555B5D5554A5B5B55B54DB2B58DB8D43A4D83B6DB434AAABF3B555
EC4B55024BBB75ABC4BCC0E4C3B0E4B24E52A4B5B58B52CB52B6E36DB6
4AA5AB5B5B522B569DD84DB4AA4BA8DCA2CB5217DB13903A25B5B44AA2BCCB51E3F3B745
6C4A7C4A4B334B2442C024D0D4B24EAAECA927324A924934B4AA4B5552B56DF3B5A84C4
B54448B2BCC8B6F0324B14A9A35B255136D572BA449DS5BCADD5F2369DF6C82DCB
B7C493CD3AA4713B354124B63E2B3AD65D5C6CE1D51A154F12D2A56C6EC24A21524AB02
AS5B529D23B3F9D63A0DB1D4CA95DE34918237AB3454A4BCC2CB2F0793E9D1C562B2
544DCB5C9391321B24C83D6569078D7BDB3D7ADF7C47A32B4D10D8BA3FCD58173
6D32042A8088FD746E5BC797EF2518255FF773A0A6440F777BCEDE6221287D982C13BF3B624EC
67DA925F3A4A0C425B0C4FDB7C94BA34AEBC513B724724A4D4AB26DB58DAAB3A455583B2
55354A560A3724CB43A83BF3B434EC4BF3924BEC5AAB32455E5AFA50627827D9BD1319A29
Short Stress Pattern SDH 64 (SSPS-64)


Implementation Agreement OIF-CEI-03.0
Common Electrical I/O (CEI)

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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

Bandlimited² 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 power³.

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

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

where

\( \tau_{rms} \) 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.
\[ \tau_{pkp} = 2Q\tau_{rms} + \sum F(P_n) \]

\( P_n \) 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.

\[ \tau_{UBHJ} = \tau_{pkp} - 2Q\tau_{rms} \]

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.

\[ \text{Figure 2-30. Transmit Wander Lab Setup} \]

- 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**

- BERT transmitting defined test pattern
- Clock Reference Input
- Voltage Controlled Delay Line
- Voltage Controlled Delay Line
- Voltage Control Input
- Control Voltage Inverted Input
- Common SJ Wander Source, which together with Antiphase generates Total Wander
- Clock Reference modulated by Common SJ Wander Source
- White Noise Source for generating Gaussian Jitter
- PRBS Generator for generating Uncorrelated High Probability Jitter
- Jitter Control for defining edge rate
- Jitter Control Signal Filter
- Jitter Control Signal Filter
- DUT Clock Reference (100ppm offset to BERT)
- Data Output

Optical Internetworking Forum - Clause 2: Jitter and Interoperability Methodology
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.

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 12.5 MHz.

- A frequency range from no higher than 100 MHz 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

\[
i(t_m) = \text{ifft}(Tr(\omega))
\]

where

\[
\omega = \left[-\frac{3}{4}f_{\text{baud}}, \frac{3}{4}f_{\text{baud}}\right]
\]

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

![Diagram of Eye Mask Measurement with Golden PLL](image-url)
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 $1 \times 10^{-15}$ 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 $1 \times 10^{-12}$).

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

\[ p = 10^{-12} \]
\[ n = 100 \cdot 10^{12} \]
\[ m = 100 \]
\[ \sigma = 10 \]
\[ m_{\text{max}}^{\text{min}} = [m + Q\sigma]_{Q = -3}^Q = 3 \]
\[ m_{\text{max}}^{\text{min}} = \frac{70}{130} \]

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.

\[ m_{\text{max}} = E[m] - Q\sigma \]
\[ m_{\text{max}} = np - Q\sqrt{npq} \]
\[ m_{\text{max}} = np - Q\sqrt{np(1-p)} \]

Solving the quadratic 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, $X_1$ must be adjusted according to the sample population and the confidence level that a particular peak to peak is achieved. Given a random process, 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. \(1.3 \times 10^{-3}\)) 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. referring 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≥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>
<thead>
<tr>
<th>Characteristic</th>
<th>Load Type 0</th>
<th>Load Type 1</th>
<th>Load Type 2</th>
<th>Load Type 3</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_Zvtt</td>
<td>&gt;1k</td>
<td>&lt;30</td>
<td>&lt;30</td>
<td>&lt;30</td>
<td>Ω</td>
</tr>
<tr>
<td>Nominal Vtt</td>
<td>undefined</td>
<td>1.2</td>
<td>1.0</td>
<td>0.8</td>
<td>V</td>
</tr>
</tbody>
</table>

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 $\pm 50\text{mV}$ for SR links and $\pm 100\text{mV}$ 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 $100\Omega \pm 1\%$ 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 10μs

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.
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

Driver

Receiver

50 ohm

0, 1, 2 Connectors

Capacitors (Optional)
### 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, $Z_{se}$.

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, $Z_{odd}$) will be lower than the impedance for signals of the same polarity (even mode impedance, $Z_{even}$).

If there is minimal coupling between the paired conductors then $Z_{odd} = Z_{even} = Z_{se}$. Coupled transmission lines always produce $Z_{odd} < Z_{se} < Z_{even}$. The following equations relate effective differential impedance, $Z_{diff}$ to common mode impedance, $Z_{cm}$ and single ended impedance, $Z_{se}$ to even and odd mode impedances:

$$Z_{diff} = 2Z_{odd} \quad Z_{cm} = \frac{Z_{even}}{2} \quad Z_{se} = \frac{Z_{even} + Z_{odd}}{2}$$
Most differential data signals are designed with $z_{diff} = 100\Omega$ and $25\Omega < Z_{cm} < 50\Omega$.

There is a trade-off in the choice of $Z_{cm}$. With $Z_{cm} = 25\Omega$ (no coupling) may reduce conducted noise for transmission lines with inadequate AC or DC grounding. $Z_{cm} = 50\Omega$ (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**

![Figure 3-3. Transmission Line as 2-port](image)

The voltage current relationships are:

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

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 $2 \times 2$ matrix:
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 $Z_c$. 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 $Z_{12}$.

The odd and even mode impedances, $Z_{odd}$ and $Z_{even}$, 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. $Z_{odd}$ and $Z_{even}$ are measured as shown in Figure 3-5.
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, $Z_{\text{diff}}$ and the common mode impedance, $Z_{\text{cm}}$ are used. The relationship to even and odd mode impedances is given as:

$$Z_{\text{diff}} = 2Z_{\text{odd}} \quad \text{and} \quad Z_{\text{cm}} = \frac{Z_{\text{even}}}{2}$$

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

### 3.A.2 Density considerations

The preceding section showed that, for two idealized forms of termination, $Z_{\text{odd}}$ is correctly terminated but $Z_{\text{even}}$ 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 $Z_{\text{oddT}} = Z_{\text{evenT}} = 50 \text{ ohm}$, 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 $Z_{\text{even}}$ (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.
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.

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:

\[ \text{Att} = -20 \log(e) \left( a_1 f + a_2 f^2 + a_3 f^3 \right) \]

Where \( f \) is frequency in Hz, \( a_1, a_2, \) & \( a_3 \) are the curve fit coefficients and \( \text{Att} \) 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

<table>
<thead>
<tr>
<th></th>
<th>( a_1 )</th>
<th>( a_2 )</th>
<th>( a_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>XAUI [19] (50cm)</td>
<td>6.5e-6</td>
<td>2.0e-10</td>
<td>3.3e-20</td>
</tr>
<tr>
<td>75cm [24] &quot;Worse&quot;</td>
<td>6.5e-6</td>
<td>3.9e-10</td>
<td>6.5e-20</td>
</tr>
<tr>
<td>75cm [24] &quot;Typical&quot;</td>
<td>6.0e-6</td>
<td>3.9e-10</td>
<td>3.5e-20</td>
</tr>
</tbody>
</table>

Figure 3-9. Equation based Channel Loss curves
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
5. A BER as per [13].
4.3 Electrical Characteristics


Note these implementation agreements require that one drop the high frequency jitter tolerance number by 0.1UI for the addition of the sinusoidal jitter.
% 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]; % 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 switched 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;
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 $\leq 3$dB 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
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 switched 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;
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

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_Vdif | 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.
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       | \(T_{\text{Baud}} \times \frac{3}{4}\) | Hz    |
| f2       | \(T_{\text{Baud}}\)            | 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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Near-End Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Mask</td>
<td>T_X1</td>
<td>0.15</td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X2</td>
<td>0.40</td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y1</td>
<td>200</td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y2</td>
<td>375</td>
<td>mV</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>T UBHPJ</td>
<td>0.15</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Duty Cycle Distortion</td>
<td>T_DCD</td>
<td>0.05</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T_TJ</td>
<td>0.30</td>
<td>Ulpp</td>
</tr>
</tbody>
</table>

#### 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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx Baud Rate</td>
<td>R_Baud</td>
<td>See 6.4.2.1</td>
<td>4.976</td>
<td>6.375</td>
<td>Gsym/s</td>
<td></td>
</tr>
<tr>
<td>Input Differential voltage</td>
<td>R_Vdiff</td>
<td>See 6.4.2.3</td>
<td>125</td>
<td>750</td>
<td>mVppd</td>
<td></td>
</tr>
<tr>
<td>Differential Resistance</td>
<td>R_Rdin</td>
<td>See 6.4.2.7</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Bias Voltage Source Impedance</td>
<td>R_Zvtt</td>
<td>See Note 1</td>
<td>30</td>
<td></td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td>See 6.4.2.7</td>
<td></td>
<td></td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SCD11</td>
<td>See 6.4.2.7</td>
<td></td>
<td></td>
<td>-6</td>
<td>dB</td>
</tr>
<tr>
<td>Common mode Input Return Loss</td>
<td>R_SCC11</td>
<td>See 6.4.2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.
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 $100\,\Omega \pm 1\%$ 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>R_Baud × 3/4</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>R_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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 0.05Ulpp & 5Ulpp 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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Far-End Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Mask</td>
<td>R_X1</td>
<td>0.30</td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R_Y1</td>
<td>62.5</td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R_Y2</td>
<td>375</td>
<td>mV</td>
</tr>
<tr>
<td>Un correlated bounded high probability jitter</td>
<td>R_UBHPJ</td>
<td>0.15</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Correlated bounded high probability jitter</td>
<td>R_CBHPJ</td>
<td>0.30</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Total Jitter (Does not include Sinusoidal Jitter)</td>
<td>R_TJ</td>
<td>0.60</td>
<td>Ulpp</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>Loss (dB)</th>
<th>Differential Skew (ps)</th>
<th>Bounded High Probability (ULpp)</th>
<th>TJ (ULpp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>0</td>
<td>15</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>Interconnect (with Connector)</td>
<td>6.6</td>
<td>25</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Other</td>
<td>3.5</td>
<td></td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Total</td>
<td>10.1</td>
<td>40</td>
<td>0.45</td>
<td>0.60</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CEI-6G-SR</th>
<th>Uncorrelated Jitter</th>
<th>Correlated Jitter</th>
<th>Total Jitter</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation</td>
<td>UUGJ</td>
<td>UHPJ</td>
<td>CBGJ</td>
<td>CBHPJ</td>
</tr>
<tr>
<td>Unit</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Transmitter</td>
<td>0.150</td>
<td>0.150</td>
<td>-0.200</td>
<td>0.15</td>
</tr>
<tr>
<td>Receiver Input</td>
<td>0.150</td>
<td>0.150</td>
<td>0.000</td>
<td>0.300</td>
</tr>
<tr>
<td>Clock + Sampler</td>
<td>0.150</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>Budget</td>
<td>0.212</td>
<td>0.250</td>
<td>0.000</td>
<td>0.400</td>
</tr>
</tbody>
</table>

**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 switched 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 = 'no';
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;
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

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 \( \leq 6 \text{dB} \) of emphasis, with infinite precision accuracy.

2. A transmit amplitude of 800mVppd.

3. Additional Uncorrelated Bounded High Probability Jitter of 0.15Ulpp (emulating part of the Tx jitter)

4. Additional Uncorrelated Unbounded Gaussian Jitter of 0.15Ulpp (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 \( \frac{3}{4} \) 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)
   $R_{Y2} = T_{Y2} = 400mV$
   $Y = \min(R_{X1}, (R_{Y2} - R_{Y1}) / R_{Y2}) = 0.30$
   $Z = \frac{2}{3} = 0.66667$

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

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

   $W[1] \leq 0.3000$ (sum of taps 1 to 5)
   $W[2] \leq 0.2000$ (sum of taps 2 to 5)
   $W[3] \leq 0.1333$ (sum of taps 3 to 5)
   $W[4] \leq 0.0889$ (sum of taps 4 and 5)
   $W[5] \leq 0.0593$ (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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye mask</td>
<td>$R_{X1}$</td>
<td>0.3</td>
<td>UI</td>
</tr>
<tr>
<td>Eye mask</td>
<td>$R_{Y1}$</td>
<td>50</td>
<td>mV</td>
</tr>
<tr>
<td>Bounded High Probability Jitter</td>
<td>$R_{BHPJ}$</td>
<td>0.325</td>
<td>UI</td>
</tr>
</tbody>
</table>

**7.4 Electrical Characteristics**

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 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

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

**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: $R_{Zvtt} \leq 30 \, \Omega$; $T_{Vtt} \& R_{Vtt} = 1.2V \pm 5%/-8%$
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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated High Probability Jitter</td>
<td>T_UHPJ</td>
<td>See 7.4.1.8</td>
<td>0.15</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Duty Cycle Distortion</td>
<td>T_DCD</td>
<td>See 7.4.1.8</td>
<td>0.05</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T_TJ</td>
<td>See 7.4.1.8</td>
<td>0.30</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X1</td>
<td>See 7.4.1.8</td>
<td>0.15</td>
<td></td>
<td></td>
<td>Ul</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X2</td>
<td>See 7.4.1.8</td>
<td>0.50</td>
<td></td>
<td></td>
<td>Ul</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y1</td>
<td>See 7.4.1.8</td>
<td>400</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y2</td>
<td>See 7.4.1.8</td>
<td>600</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>$T_{Baud} \times \frac{3}{4}$</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>$R_{Baud}$</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>Near-End Value</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Mask</td>
<td>T_X1</td>
<td>0.15</td>
<td>UI</td>
<td></td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X2</td>
<td>0.50</td>
<td>UI</td>
<td></td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y1</td>
<td>400</td>
<td>mV</td>
<td>For connection to short reach Rx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400</td>
<td></td>
<td>For connection to long reach Rx</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y2</td>
<td>375</td>
<td>mV</td>
<td>For connection to short reach Rx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600</td>
<td></td>
<td>For connection to long reach Rx</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>T UBHPJ</td>
<td>0.15</td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Duty Cycle Distortion</td>
<td>T DCD</td>
<td>0.05</td>
<td>Ulpp</td>
<td></td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T TJ</td>
<td>0.30</td>
<td>Ulpp</td>
<td></td>
</tr>
</tbody>
</table>

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

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

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

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

**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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>$R_{Baud} \times \frac{3}{4}$</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>$R_{Baud}$</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>$16.6$</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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.
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

<table>
<thead>
<tr>
<th></th>
<th>Loss (dB)</th>
<th>Differential Skew (ps)</th>
<th>Bounded High Probability (Ulpp)</th>
<th>TJ (Ulpp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>0</td>
<td>15</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>Interconnect (with Connector)</td>
<td>15.9</td>
<td>25</td>
<td>0.35</td>
<td>0.513</td>
</tr>
<tr>
<td>Other</td>
<td>4.5</td>
<td></td>
<td>0.10</td>
<td>0.262</td>
</tr>
<tr>
<td>Total</td>
<td>20.4</td>
<td>40</td>
<td>0.60</td>
<td>0.875</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CEI-6G-LR</th>
<th>Uncorrelated Jitter</th>
<th>Correlated Jitter</th>
<th>Total Jitter</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation</td>
<td>UUGJ</td>
<td>UHPJ</td>
<td>CBGJ</td>
<td>CBHPJ</td>
</tr>
<tr>
<td>Unit</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Transmitter</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
</tr>
<tr>
<td>Channel</td>
<td>0.230</td>
<td>0.525</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiver Input</td>
<td>0.150</td>
<td>0.150</td>
<td>0.230</td>
<td>0.525</td>
</tr>
<tr>
<td>Equalizer</td>
<td></td>
<td></td>
<td>-0.350</td>
<td>See 1</td>
</tr>
<tr>
<td>Post Equalization</td>
<td>0.150</td>
<td>0.150</td>
<td>0.230</td>
<td>0.175</td>
</tr>
<tr>
<td>DFE Penalties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clock + Sampler</td>
<td>0.150</td>
<td>0.100</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>Budget</td>
<td>0.212</td>
<td>0.250</td>
<td>0.230</td>
<td>0.375</td>
</tr>
</tbody>
</table>

**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 switched 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 = 'n';
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;
(This page intentionally left blank)
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 \( \Omega \). 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 \( \Omega \) 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 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

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 Ulpp (emulating part of the Tx jitter)
4. Additional Uncorrelated Unbounded Gaussian Jitter of 0.15Ulpp (emulating part of the Tx jitter)
5. At the maximum baud rate that the channel is to operate at or 11.2Gsymb/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 $\frac{3}{4}$ 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 table Table 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.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>T_Baud</td>
<td></td>
<td>9.95</td>
<td>11.2</td>
<td>Gsym/s</td>
<td></td>
</tr>
<tr>
<td>Output Differential Voltage</td>
<td>T_Vdif</td>
<td></td>
<td>360</td>
<td>770</td>
<td>mVppd</td>
<td></td>
</tr>
<tr>
<td>Differential Resistance</td>
<td>T_Rd</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Differential Termination Resistance Mismatch</td>
<td>T_Rdm</td>
<td></td>
<td>5</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Output Rise and Fall Time (20% to 80%)</td>
<td>T_tr, T_tf</td>
<td></td>
<td>24</td>
<td></td>
<td>ps</td>
<td></td>
</tr>
<tr>
<td>Differential Output Return Loss</td>
<td>T_SDD22</td>
<td>See 8.3.1.3</td>
<td></td>
<td></td>
<td>-6</td>
<td>dB</td>
</tr>
<tr>
<td>Common mode Output Return Loss</td>
<td>T_SCC22</td>
<td>See 8.3.1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Common Mode Loss</td>
<td>T_Ncm</td>
<td></td>
<td>0.05</td>
<td>3.55</td>
<td></td>
<td>V</td>
</tr>
</tbody>
</table>

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. For 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(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 8-2. Transmitter Output Jitter Specification.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>T UBHPJ</td>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Uncorrelated Unbounded Gaussian Jitter</td>
<td>T UUGJ</td>
<td>Note 1</td>
<td>0.15</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T TJ</td>
<td></td>
<td>0.30</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T X1</td>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T X2</td>
<td></td>
<td>0.4</td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T Y1</td>
<td></td>
<td>180</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T Y2</td>
<td></td>
<td>385</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>$T_{\text{Baud}} \times \frac{3}{4}$</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>$T_{\text{Baud}} \times \frac{3}{2}$</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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 \(5\text{UI}pp\). 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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>R_Baud</td>
<td></td>
<td>9.95</td>
<td>11.2</td>
<td>Gsym/s</td>
<td></td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td></td>
<td>110</td>
<td>1050</td>
<td>mVppd</td>
<td></td>
</tr>
<tr>
<td>Differential Input Resistance</td>
<td>R_Rdin</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Receiver Common Mode Noise</td>
<td>R_Ncm</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
<td>mVrms</td>
</tr>
<tr>
<td>Input Resistance Mismatch</td>
<td>R_Rm</td>
<td></td>
<td>5</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td>See 8.3.2.3</td>
<td></td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common mode Return Loss</td>
<td>R_SCC11</td>
<td>See 8.3.2.3</td>
<td>-6</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential to Common mode input conversion</td>
<td>R_SCD11</td>
<td>See 8.3.2.3</td>
<td>-12</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Termination Voltage Note 1, 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_Vtt floating, Note 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>R_Vtt = 1.2V Nominal</td>
<td></td>
<td>1.2 - 8%</td>
<td>1.2 + 5%</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_Vtt = 1.0V Nominal</td>
<td></td>
<td>1.0 - 8%</td>
<td>1.0 + 5%</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_Vtt = 0.8V Nominal</td>
<td></td>
<td>0.8 - 8%</td>
<td>0.8 + 5%</td>
<td>V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Input Common Mode Voltage Note 1, 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_Vtt floating, Note 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>R_Vtt = 1.2V Nominal</td>
<td></td>
<td>0</td>
<td>3.60</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_Vtt = 1.0V Nominal</td>
<td></td>
<td>720</td>
<td>R_Vtt -10</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_Vtt = 0.8V Nominal</td>
<td></td>
<td>535</td>
<td>R_Vtt +125</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_Vtt = 0.8V Nominal</td>
<td></td>
<td>475</td>
<td>R_Vtt +105</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>R_UBHPJ</td>
<td></td>
<td>0.25</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Correlated Bounded High probability Jitter</td>
<td>R_CBHPJ</td>
<td></td>
<td>0.20</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Gaussian Jitter (UUGJ + CBGJ)</td>
<td>R_GJ</td>
<td>Note 2</td>
<td>0.20</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Sinusoidal Jitter, Maximum</td>
<td>R_SJ-max</td>
<td>See 2.2.4</td>
<td>5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Sinusoidal Jitter, High Frequency</td>
<td>R_SJ-hf</td>
<td>See 2.2.4</td>
<td>0.05</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
</tbody>
</table>

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 100Ω ±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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>$R_{Baud} \times \frac{3}{4}$</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>$R_{Baud} \times \frac{3}{2}$</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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
SCD11 relates to the conversion of Differential to Common mode and the associated
generation of EMI. The common mode reference impedance is $25\,\Omega$, measurement
range is $f_0$ to $f_1$ 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 \( R_i \)

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.
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 8-8. Telecom Signal Conditioner, Ingress Direction

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter Transfer Bandwidth</td>
<td>BW</td>
<td>Data, see 1</td>
<td>8</td>
<td>MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jitter Peaking</td>
<td></td>
<td>Frequency &lt;120kHz</td>
<td>0.03</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency &gt;120kHz</td>
<td>1</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
1. PRBS $2^{31}-1$, OC-192/SDH-64 Sinusoidal Jitter Tolerance Mask

### Table 8-9. Telecom Egress Jitter Generation budget

<table>
<thead>
<tr>
<th>Measurement range</th>
<th>Budget allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Frequency</td>
<td>Upper Frequency</td>
</tr>
<tr>
<td>Egress driver</td>
<td>Signal conditioner max transfer bandwidth</td>
</tr>
<tr>
<td>Egress channel</td>
<td>Signal conditioner max transfer bandwidth</td>
</tr>
<tr>
<td>Egress TE, signal conditioner and path to Egress output</td>
<td>TE Egress output upper measurement limit</td>
</tr>
</tbody>
</table>

NOTES:
1. PRBS $2^{31}-1$, OC-192/SDH-64 Sinusoidal Jitter Tolerance Mask
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

<table>
<thead>
<tr>
<th>TE Output Specified Range</th>
<th>Measurement Range</th>
<th>Method</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telcordia GR-253</td>
<td>50kHz - 80MHz</td>
<td>50kHz - 8MHz</td>
<td>not specified, note 1</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>50kHz - 80MHz</td>
<td>50kHz - 8MHz</td>
<td>not specified, note 1</td>
<td>43</td>
</tr>
<tr>
<td>ITU-T G.783</td>
<td>20kHz - 80MHz</td>
<td>20kHz - 8MHz</td>
<td>60 sec</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>4MHz - 80MHz</td>
<td>4MHz - 8MHz</td>
<td>60 sec</td>
<td>43</td>
</tr>
</tbody>
</table>

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-2002 and 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

\[ 1.13 \times \left( \frac{0.2}{f} + 0.1 \right), f \text{ in MHz} \]

-20dB/Dec
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>
<thead>
<tr>
<th>Table 8-11. Datacom Signal Conditioner Egress direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td>Jitter Transfer Bandwidth</td>
</tr>
<tr>
<td>Jitter Peaking</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Based on IEEE 802.3ae-2002 Clause 52 Sinusoidal Jitter Tolerance Mask, figure 52-4

<table>
<thead>
<tr>
<th>Table 8-12. Datacom Signal Conditioner Ingress Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td>Jitter Transfer Bandwidth</td>
</tr>
<tr>
<td>Jitter Peaking</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>Table 8-13. Datacom Signal Conditioner Ingress Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td>Telecom Receiver, Ingress</td>
</tr>
<tr>
<td>Telecom Transmitter, Ingress</td>
</tr>
<tr>
<td>Telecom Receiver, Egress</td>
</tr>
<tr>
<td>Telecom Transmitter, Egress</td>
</tr>
<tr>
<td>Datacom Receiver, Ingress</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>Source</th>
<th>Uncorrelated Jitter</th>
<th>Correlated Jitter</th>
<th>Total Jitter</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unbounded Gaussian</td>
<td>Bounded High Prob.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
</tr>
<tr>
<td>Receiver Input</td>
<td>0.150</td>
<td>0.250</td>
<td>0.200</td>
<td>0.200</td>
</tr>
<tr>
<td>Channel</td>
<td>0.100</td>
<td>0.132</td>
<td>0.200</td>
<td>0.100</td>
</tr>
<tr>
<td>Post Equalizer</td>
<td>0.150</td>
<td>0.250</td>
<td>0.132</td>
<td>0.000</td>
</tr>
<tr>
<td>Equalizer</td>
<td>-0.200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clock &amp; Sampler</td>
<td>0.150</td>
<td>0.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Budget with Equalizer</td>
<td>0.212</td>
<td>0.350</td>
<td>0.132</td>
<td>0.100</td>
</tr>
<tr>
<td>Budget without Equalizer</td>
<td>0.212</td>
<td>0.350</td>
<td>0.132</td>
<td>0.300</td>
</tr>
</tbody>
</table>

Note: Values in yellow are specified values from Table 8-2 and Table 8-5
8.B Appendix - StatEye.org Template¹

% 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 switched 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](image-url)
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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

   \[
   N = 1 \text{ is previous decision (i.e. first tap)} \\
   M = 4 \\
   R_{Y2} = T_{Y2} = 400mV \\
   Y = \min(R_{X1}, (R_{Y2} - R_{Y1}) / R_{Y2}) = 0.2625 \\
   Z = \frac{2}{3} = 0.66667
   \]

   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:

   \[
   W[1] \leq 0.2625 \text{ (sum of absolute value of taps 1 and 2)} \\
   W[2] \leq 0.1750 \text{ (sum of absolute value of taps 2, 3 and 4)} \\
   W[3] \leq 0.1167 \text{ (sum of absolute value of taps 3 and 4)} \\
   W[4] \leq 0.0778 \text{ (sum of absolute value of tap 4)}
   \]

   Notes:
   - Coefficient weights are absolute, assuming a T_Vdiff of 1Vppd
1. 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>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye mask</td>
<td>R_X1</td>
<td>0.2625</td>
<td>UI</td>
</tr>
<tr>
<td>Eye mask</td>
<td>R_Y1</td>
<td>50</td>
<td>mV</td>
</tr>
<tr>
<td>Correlated Bounded High Probability Jitter, pre-equalizer</td>
<td>R_CBHPJ</td>
<td>0.40</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Correlated Bounded High Probability Jitter, post-equalizer</td>
<td>R_CBHPJ</td>
<td>0.10</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>R_UHBPJ</td>
<td>0.15</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Uncorrelated Unbounded Gaussian Jitter</td>
<td>R_UUGJ</td>
<td>0.15</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Quality of signal (SNR in real number)</td>
<td>Q</td>
<td>7.94</td>
<td></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>T_Baud</td>
<td></td>
<td>9.95</td>
<td>11.2</td>
<td></td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Output Differential Voltage</td>
<td>T_Vdiff</td>
<td>Pre-emphasis off or Tx Filter Applied, see note 1</td>
<td>800</td>
<td>1200</td>
<td></td>
<td>mVppd</td>
</tr>
<tr>
<td>Differential Output Impedance</td>
<td>T_Rd</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Differential Termination Impedance Mismatch</td>
<td>T_Rm</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Output Rise and Fall Time (20% to 80%)</td>
<td>T_tr, T_tf</td>
<td></td>
<td>24</td>
<td></td>
<td></td>
<td>ps</td>
</tr>
<tr>
<td>Differential Output Return Loss</td>
<td>T_SDD22</td>
<td>See 9.3.1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Mode Return Loss</td>
<td>T_SCC22</td>
<td>See 9.3.1.3</td>
<td>-6</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Transmitter Common Mode Noise</td>
<td>T_Ncm</td>
<td>5% of T_Vdiff</td>
<td></td>
<td></td>
<td></td>
<td>mVppd</td>
</tr>
<tr>
<td>Output Common Mode Voltage</td>
<td>T_Vcm</td>
<td>Load Type 0 See Note 2</td>
<td>100</td>
<td></td>
<td>1700</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Load Type 1 See Note 3 &amp; 4</td>
<td>630</td>
<td></td>
<td>1100</td>
<td>mV</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Unbounded Gaussian Jitter</td>
<td>T_UUGJ</td>
<td>See 9.3.1.6, Note 1</td>
<td>0.15</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>T_USBHPJ</td>
<td>See 9.3.1.6, Note 1</td>
<td>0.15</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Duty Cycle Distortion (component of UBHPJ)</td>
<td>T_DCD</td>
<td>See 9.3.1.6</td>
<td>0.05</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T_TJ</td>
<td>See 9.3.1.6</td>
<td>0.30</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X1</td>
<td>See 9.3.1.6</td>
<td>0.15</td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_X2</td>
<td>See 9.3.1.6</td>
<td>0.50</td>
<td></td>
<td></td>
<td>UI</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y1</td>
<td>See 9.3.1.6, Note 3</td>
<td>400</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>T_Y2</td>
<td>See 9.3.1.6</td>
<td>600</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>( T_{\text{Baud}} \times \frac{3}{4} )</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>( T_{\text{Baud}} )</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>R_Baud</td>
<td>9.95</td>
<td>11.2</td>
<td>GSym/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td>Note 1</td>
<td>1200</td>
<td>mVppd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Impedance</td>
<td>R_Rdin</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Input Impedance Mismatch</td>
<td>R_Rm</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td>See 9.3.2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Mode Input Return Loss</td>
<td>R_SCC11</td>
<td>Below 10 GHz</td>
<td>-6</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Load Type 0</td>
<td>R_Vcm</td>
<td>Load Type 0</td>
<td>0</td>
<td>1800</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Load Type 1</td>
<td></td>
<td>See Notes 2, 3 &amp; 4</td>
<td>595</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Load Type 1</td>
<td></td>
<td>See Note 2, 3 &amp; 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wander Divider</td>
<td>n</td>
<td>See Note 5</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Jitter, Maximum</td>
<td>R_SJ-max</td>
<td>See 2.5.4, note 1, 2</td>
<td>5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Sinusoidal Jitter, High Frequency</td>
<td>R_SJ-hf</td>
<td>See 2.5.4, note 1, 2</td>
<td>0.05</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-8</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>100</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>$R_{\text{Baud}} \times \frac{3}{4}$</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>$R_{\text{Baud}}$</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>16.6</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>R_Baud</td>
<td></td>
<td>9.95</td>
<td>11.2</td>
<td></td>
<td>GSym/s</td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td>Note 1</td>
<td>110</td>
<td></td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Input Impedance Mismatch</td>
<td>R_Rm</td>
<td>See R_Rm in Table 8-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Input Return Loss</td>
<td>R_SDD11</td>
<td>See 9.3.2.3</td>
<td>See R_SDD11 in Table 8-4</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Common Mode Input Return Loss</td>
<td>R_SCC11</td>
<td>Below 10 GHz</td>
<td>See R_SCC11 in Table 8-4</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Input Common Mode Voltage</td>
<td>R_Vcm</td>
<td>Note 2</td>
<td>See R_Vcm in Table 9-5</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Wander Divider</td>
<td>n</td>
<td>See Note 5</td>
<td>See n in Table 9-5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>R UBHPJ</td>
<td>see R UBHPJ in Table 8-5</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Correlated Bounded High probability Jitter</td>
<td>R CBHPJ</td>
<td>see R CBHPJ in Table 8-5</td>
<td></td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Gaussian Jitter (UUGJ + CBGJ)</td>
<td>R GJ</td>
<td>Note 2</td>
<td>See R GJ in Table 8-5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Sinusoidal Jitter, Maximum</td>
<td>R SJ-max</td>
<td>See 2.2.4</td>
<td>see R SJ-max in Table 8-5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Sinusoidal Jitter, High Frequency</td>
<td>R SJ-hf</td>
<td>See 2.2.4</td>
<td>see R SJ-hf in Table 8-5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Total Jitter, including R SJ-hf</td>
<td>R T_j</td>
<td>Note 1</td>
<td>see R T_j in Table 8-5</td>
<td></td>
<td></td>
<td>Ulpp</td>
</tr>
<tr>
<td>Eye Mask incl. Correlated High Probability Jitter</td>
<td>R X1</td>
<td>See R X1 in Table 8-5</td>
<td></td>
<td></td>
<td></td>
<td>Ul</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R Y1</td>
<td>See R GJ in Table 8-5</td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Eye Mask</td>
<td>R Y2</td>
<td></td>
<td></td>
<td>600</td>
<td></td>
<td>mV</td>
</tr>
</tbody>
</table>

**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 load impedance 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncorrelated Jitter</th>
<th>Correlated Jitter</th>
<th>Total Jitter</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation</td>
<td>UUGJ</td>
<td>UBHPJ</td>
<td>CBGJ</td>
<td>CBHPJ</td>
</tr>
<tr>
<td>Unit</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Transmitter</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
<td>0.150</td>
</tr>
<tr>
<td>Channel</td>
<td></td>
<td></td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td>Receiver Input</td>
<td>0.150</td>
<td>0.150</td>
<td>0.230</td>
<td>0.400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equalizer</td>
<td></td>
<td></td>
<td>-0.300</td>
<td></td>
</tr>
<tr>
<td>Post Equalizer</td>
<td>0.150</td>
<td>0.150</td>
<td>0.230</td>
<td>0.100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DFE Penalties</td>
<td></td>
<td></td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>Clock &amp; Sampler</td>
<td>0.150</td>
<td>0.100</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>Budget</td>
<td>0.212</td>
<td>0.250</td>
<td>0.230</td>
<td>0.300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 from Table 9-5 and 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncorrelated Jitter</th>
<th>Correlated Jitter</th>
<th>Total Jitter</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unbounded Gaussian</td>
<td>Bounded High Prob.</td>
<td>Bounded Gaussian</td>
<td>Bounded Gaussian</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>UUGJ</td>
<td>UBHPJ</td>
<td>CBGJ</td>
<td>CBHPJ</td>
</tr>
<tr>
<td>Unit</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
<td>Ulpp</td>
</tr>
<tr>
<td>Transmit equalizer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td>0.150</td>
<td>0.150</td>
<td>-0.200</td>
<td>0.150</td>
</tr>
<tr>
<td>Channel</td>
<td>0.100</td>
<td>0.132</td>
<td>0.400</td>
<td>0.0</td>
</tr>
<tr>
<td>Receiver Input</td>
<td>0.150</td>
<td>0.250</td>
<td>0.132</td>
<td>0.200</td>
</tr>
<tr>
<td>Clock &amp; Sampler</td>
<td>0.150</td>
<td>0.100</td>
<td>0.100</td>
<td>0.0</td>
</tr>
<tr>
<td>Budget</td>
<td>0.212</td>
<td>0.350</td>
<td>0.132</td>
<td>0.300</td>
</tr>
</tbody>
</table>

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]; % 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 switched 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;


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

% 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 switched 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;


% 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
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;
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 $\Omega$ 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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL(f)</td>
<td>Differential insertion loss, -SDD21 magnitude (dB)</td>
</tr>
<tr>
<td>RL1(f)</td>
<td>Differential input return loss, -SDD11 magnitude (dB)</td>
</tr>
<tr>
<td>RL2(f)</td>
<td>Differential output return loss, -SDD22 magnitude (dB)</td>
</tr>
<tr>
<td>NEXTm(f)</td>
<td>Differential near-end crosstalk loss (m\textsuperscript{th} aggressor), -SDD21 magnitude (dB)</td>
</tr>
<tr>
<td>FEXTn(f)</td>
<td>Differential far-end crosstalk loss (n\textsuperscript{th} aggressor), -SDD21 magnitude (dB)</td>
</tr>
</tbody>
</table>

### Table 10-2. Calculated Channel Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL\textsubscript{fitted}(f)</td>
<td>Fitted insertion loss (dB)</td>
</tr>
<tr>
<td>ILD(f)</td>
<td>Insertion loss deviation (dB)</td>
</tr>
<tr>
<td>ICN(f)</td>
<td>Integrated crosstalk noise (mV, RMS)</td>
</tr>
<tr>
<td>ILD(rms)</td>
<td>RMS value of the insertion loss Deviation (dB)</td>
</tr>
</tbody>
</table>

### 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 ≤ \( f_b \) ≤ 28.05 Gsym/s).

### Table 10-3. Channel Insertion Loss Frequency Range

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>f\textsubscript{min}</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>f\textsubscript{max}</td>
<td>28.05</td>
<td>GHz</td>
</tr>
</tbody>
</table>

\[
IL\textsubscript{max} = \begin{cases} 
  0.1188 + 1.54 \left( \frac{f \times 28.05}{f_b} \right) + 0.68 \frac{f \times 28.05}{f_b} , & f\textsubscript{min} \leq f < \frac{f_b}{2} \\
  -15.43 + 2.2 \frac{f \times 28.05}{f_b} , & \frac{f_b}{2} \leq f \leq f_b
\end{cases} \tag{10-1}
\]
IL_{min} = \begin{cases} 
0, & f_{min} \leq f \leq 1\,GHz \\
\frac{1}{3}(f - 1), & 1\,GHz < f \leq 17.5\,GHz \\
5.5, & 17.5\,GHz < f \leq f_b 
\end{cases} \quad (10-2)

Note: f in (10-1) and (10-2) is in GHz.
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           |
| 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              | 1.5             |
| Fitted insertion loss, $a_1$     | dB              | 0               |
| Fitted insertion loss, $a_2$     | dB              | 30.855          |
| Fitted insertion loss, $a_4$     | dB              | 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).

$$ILD = IL - IL_{fitted}$$ \hspace{1cm} (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.

$$ILD \geq ILD_{min} = \begin{cases} 
-1.0 - 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\
-4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax}
\end{cases} \hspace{1cm} (10-4)$$

$$ILD \leq ILD_{max} = \begin{cases} 
1.0 + 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\
4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax}
\end{cases} \hspace{1cm} (10-5)$$

$ILD_{rms}$ 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.

$$W(f) = \sin^2 \left( \frac{f}{f_b} \right) \left[ \frac{1}{1 + (f/f_c)^4} \right] \left[ \frac{1}{1 + (f/f_c)^8} \right] \hspace{1cm} (10-6)$$
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. $T_{tr} \times f_t = 0.2365$), 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.

\[
ILD_{rms} = \sqrt{\frac{\sum W(f) \times ILD(f)^2}{N}}
\]  

(10-7)

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:

- $RL(f) \geq 12 \text{ dB}$ for $f_{min} < f \leq f_b/4$  
- $RL(f) \geq 12 \text{ dB} - 15 \log_{10}(4f/f_b)$ for $f_b/4 < f < f_b$  

(10-8)

(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>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>$f_b$</td>
<td>max. Baud Rate sup. by Channel</td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Near-end aggressor peak to peak differential output amplitude</td>
<td>$A_{nt}$</td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Far-end aggressor peak to peak differential output amplitude</td>
<td>$A_R$</td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Near-end aggressor 20 to 80% rise and fall times</td>
<td>$T_{nt}$</td>
<td>8</td>
<td>ps</td>
</tr>
<tr>
<td>Far-end aggressor 20 to 80% rise and fall times</td>
<td>$T_{ft}$</td>
<td>8</td>
<td>ps</td>
</tr>
</tbody>
</table>

\[
\sigma_x \leq \sigma_{x, max} = 10 \ (mV, RMS) \quad \text{for} \quad 3 \text{ dB} < IL \leq 5.3 \text{ dB}
\]

\[
= 12.4 \ - \ 0.45 \ IL \ (mV, RMS) \quad \text{for} \quad 5.3 \text{ dB} < IL \leq 15.42 \text{ dB}
\]

(10-10)

In Equation (10-10), the $IL$ denotes the value of the channel insertion loss in dB at 1/2 baud rate (NRZ).

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Figure 10-3. Illustration integrated crosstalk noise limits

- **Integrated crosstalk noise (mV, RMS)**
  - 12
  - 10
  - 8
  - 6
  - 4
  - 2
  - 0

- **Insertion loss at Nyquist (dB)**
  - 3
  - 5
  - 7
  - 9
  - 11
  - 13
  - 15
  - 17
  - 19
10.3 Electrical Characteristics

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

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 viewpoint, 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.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>T_Baud</td>
<td></td>
<td>19.90</td>
<td></td>
<td>28.05</td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Output Differential Voltage</td>
<td>T_Vdiff</td>
<td>Emphasis off.</td>
<td>800</td>
<td></td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Differential Resistance</td>
<td>T_Rd</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>$\Omega$</td>
</tr>
<tr>
<td>Differential Termination Resistance Mismatch (see Table 1-2)</td>
<td>T_Rdm</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Output Rise and Fall Time (20% to 80%)</td>
<td>T_tr, T_tf</td>
<td>Emphasis off.</td>
<td>8</td>
<td></td>
<td></td>
<td>ps</td>
</tr>
<tr>
<td>Common Mode Noise</td>
<td>T_Ncm</td>
<td>Note 3</td>
<td></td>
<td></td>
<td>12</td>
<td>mVrms</td>
</tr>
<tr>
<td>Differential Output Return Loss</td>
<td>T_SDD22</td>
<td>See Section 10.3.1.3</td>
<td></td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Common Mode Output Return Loss</td>
<td>T_SCC22</td>
<td>Below 10 GHz</td>
<td></td>
<td>-6</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 GHz to baud rate</td>
<td></td>
<td>-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Common Mode Voltage</td>
<td>T_Vcm</td>
<td>Load Type 0</td>
<td></td>
<td>-100</td>
<td>1700</td>
<td>mV</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated Unbounded Gaussian Jitter</td>
<td>T_UUGJ</td>
<td></td>
<td>0.15</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Uncorrelated Bounded High Probability Jitter</td>
<td>T_UBHPJ</td>
<td>Note 2</td>
<td></td>
<td></td>
<td>0.15</td>
<td>UIpp</td>
</tr>
<tr>
<td>Duty Cycle Distortion (component of UBHPJ)</td>
<td>T_DCD</td>
<td>Note 3</td>
<td>0.035</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>T_TJ</td>
<td>Note 1</td>
<td>0.28</td>
<td></td>
<td></td>
<td>UIpp</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-12</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>0.1714 x T_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>T_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>12.0</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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:

\[ H(z) = C_{-1} + C_0 z^{-1} + C_1 z^{-2} \]  (10-11)

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>
<thead>
<tr>
<th>Coefficient</th>
<th>Normalized Amplitude</th>
<th>Normalized Step Size (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min (%)</td>
<td>Max (%)</td>
</tr>
<tr>
<td>C_{-1}</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>C_1</td>
<td>-25</td>
<td>0</td>
</tr>
<tr>
<td>C_0</td>
<td>40</td>
<td>100</td>
</tr>
</tbody>
</table>

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 (\( C_{0_{\text{max}}} \)) 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>
<thead>
<tr>
<th>Parameter</th>
<th>Value (UI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear fit pulse length $T_{N_p}$</td>
<td>8</td>
</tr>
<tr>
<td>Linear fit pulse delay $T_{D_p}$</td>
<td>2</td>
</tr>
<tr>
<td>Equalizer length $T_{N_w}$</td>
<td>8</td>
</tr>
<tr>
<td>Equalizer delay $T_{D_w}$</td>
<td>2</td>
</tr>
</tbody>
</table>

The differential zero to peak output voltage at T in the steady state, $v_f$, is estimated by equation (10-12).

$$v_f = \frac{1}{M} \cdot \sum_{k=1}^{M} p(k)$$  \hspace{1cm} (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, $p_{\text{max}}$, shall satisfy the requirements of Table 10-11. The RMS value of the error between the linear fit and measured waveform from step 3, $\sigma_e$, shall satisfy the requirements of Table 10-11.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady state output voltage, $2 \times v_f$</td>
<td>max</td>
<td>mVppd</td>
</tr>
<tr>
<td>Steady state output voltage, $2 \times v_f$</td>
<td>min</td>
<td>mVppd</td>
</tr>
<tr>
<td>Linear fit pulse peak, $p_{\text{max}}$</td>
<td>min</td>
<td>-</td>
</tr>
<tr>
<td>RMS error, $\sigma_e$</td>
<td>max</td>
<td>-</td>
</tr>
</tbody>
</table>
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, \( \sigma_e \), 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).
Rotate the symbols vector \( x \) by the specified pulse delay \( D_p \) to yield \( x_r \).

\[
x_r = \begin{bmatrix} x(T - D_p + 1) & x(T - D_p + 2) & \cdots & x(N) & x(1) & \cdots & x(T - D_p) \end{bmatrix}
\]  

(10-14)

Define the matrix \( X \) to be an \( N \)-by-\( N \) matrix derived from \( x_r \) as shown in (10-15).

\[
X = \begin{bmatrix} x_r(1) & x_r(2) & \cdots & x_r(N) \\ x_r(N) & x_r(1) & \cdots & x_r(N-1) \\ \vdots & \vdots & \ddots & \vdots \\ x_r(2) & x_r(3) & \cdots & x_r(1) \end{bmatrix}
\]  

(10-15)

Define the matrix \( X_1 \) to be the first \( T_N - D_p \) rows of \( X \) concatenated with a row vector of 1’s of length \( N \). The \( M \)-by-\( (T_N - D_p + 1) \) coefficient matrix, \( P \), corresponding to the linear fit is then defined by (10-16).

\[
P = YX_1^T(X_1X_1^T)^{-1}
\]  

(10-16)

In (10-16) the superscript "T" denotes the matrix transpose operator.

\[
E = PX_1 - Y = \begin{bmatrix} e(1) & e(M+1) & \cdots & e(M(N-1)+1) \\ e(2) & e(M+2) & \cdots & e(M(N-1)+2) \\ \vdots & \vdots & \ddots & \vdots \\ e(M) & e(2M) & \cdots & e(MN) \end{bmatrix}
\]  

(10-17)

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 $T_Np$ columns of the matrix $P$ as shown in (10-18).

$$P_1 = \begin{bmatrix} p(1) & p(M + 1) & \cdots & p(M(T_Np - 1) + 1) \\ p(2) & p(M + 2) & \cdots & p(M(T_Np - 1) + 2) \\ \vdots & \vdots & \ddots & \vdots \\ p(M) & p(2M) & \cdots & p(MT_Np) \end{bmatrix} \tag{10-18}$$

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 $T_Dw$ to yield $p_r$ as shown in (10-19).

$$p_r = \begin{bmatrix} p_i(T_Dw + 1) & p_i(T_Dw + 2) & \cdots & p_i(T_Np) & p_i(1) & \cdots & p_i(T_Dw) \end{bmatrix} \tag{10-19}$$

Define the matrix $P_2$ to be a $T_Np$-by-$T_Np$ matrix derived from $p_r$ as shown in (10-20).

$$P_2 = \begin{bmatrix} p_r(1) & p_r(T_Np) & \cdots & p_r(2) \\ p_r(2) & p_r(1) & \cdots & p_r(3) \\ \vdots & \vdots & \ddots & \vdots \\ p_r(T_Np) & p_r(T_Np - 1) & \cdots & p_r(1) \end{bmatrix} \tag{10-20}$$

Define the matrix $P_3$ to be the first $T_Nw$ rows of $P_2$. Define a unit pulse column vector $x_p$ of length $T_Np$. The value of element $x_p(T_Dp + 1)$ 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).

$$w = (P_3^T P_3)^{-1} P_3^T x_p \tag{10-21}$$

Given the column vector of equalizer coefficients, $w$, the equalized pulse response $q_i$ is determined by (10-22).

$$q_i = P_3 w \tag{10-22}$$
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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>R_Baud</td>
<td>19.90</td>
<td>28.05</td>
<td>GSym/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td>Note 1</td>
<td>1200</td>
<td>mVppd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Impedance</td>
<td>R_Rdin</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>Input Impedance Mismatch</td>
<td>R_Rm</td>
<td>10</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td>See 10.3.2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Mode Input Return Loss</td>
<td>R_SCC11</td>
<td>Below 10 GHz</td>
<td>-6</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10GHz to baud rate</td>
<td>-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Common Mode Voltage</td>
<td>R_Vcm</td>
<td>Load Type 0 See Note 2</td>
<td>-200</td>
<td>1800</td>
<td>mV</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Jitter, Maximum</td>
<td>R_SJ-max</td>
<td>See Section 2.5.4, note 1</td>
<td>5</td>
<td>Ulpp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinusoidal Jitter, High Frequency</td>
<td>R_SJ-hf</td>
<td>See Section 2.5.4, note 1</td>
<td>0.05</td>
<td>Ulpp</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-12</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>0.1714 x R_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>R_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>12.0</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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 interface 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.

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(IL(f))</td>
<td>Differential insertion loss, -SDD21 magnitude (dB)</td>
</tr>
<tr>
<td>(RL_1(f))</td>
<td>Differential input return loss, -SDD11 magnitude (dB)</td>
</tr>
<tr>
<td>(RL_2(f))</td>
<td>Differential output return loss, -SDD22 magnitude (dB)</td>
</tr>
</tbody>
</table>
| \(NEXT_m(f)\) | 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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(IL_{fitted}(f))</td>
<td>Fitted insertion loss (dB)</td>
</tr>
<tr>
<td>(ILD(f))</td>
<td>Insertion loss deviation (dB)</td>
</tr>
<tr>
<td>(ICN(f))</td>
<td>Integrated crosstalk noise (mV, RMS)</td>
</tr>
<tr>
<td>(ILD(rms))</td>
<td>RMS value of the insertion loss deviation (dB)</td>
</tr>
</tbody>
</table>

### 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 ≤ \(f_b\) ≤ 25.80 Gsym/s).

### Table 11-3. Channel Insertion Loss Frequency Range

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_{min})</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>(f_{max})</td>
<td>25.8</td>
<td>GHz</td>
</tr>
</tbody>
</table>

\[
IL_{max} = \begin{cases} 
1.083 + 3.35 \left( \frac{f \times 25.8}{f_b} \right)^{0.96} \frac{f \times 25.8}{f_b}, & f_{min} \leq f < \frac{f_b}{2} \\
-9.25 + 2.694 \left( \frac{f \times 25.8}{f_b} \right), & \frac{f_b}{2} \leq f \leq f_b 
\end{cases} \quad (11-1)
\]
\[ IL_{\text{min}} = \begin{cases} 
0, & f_{\text{min}} \leq f \leq 1 \text{GHz} \\
\frac{1}{3}(f-1), & 1 \text{GHz} < f \leq 17.5 \text{GHz} \\
5.5, & 17.5 \text{GHz} < f \leq f_b 
\end{cases} \quad (11-2) \]

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>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum frequency, ( f_{ILmin} )</td>
<td>GHz</td>
<td>0.05</td>
</tr>
<tr>
<td>Maximum frequency, ( f_{ILmax} )</td>
<td>GHz</td>
<td>( f_b )</td>
</tr>
<tr>
<td>Fitted Insertion loss at Nyquist</td>
<td>dB</td>
<td>-25.5</td>
</tr>
<tr>
<td>Fitted insertion loss, ( a_0 )</td>
<td>dB</td>
<td>-1</td>
</tr>
<tr>
<td>Fitted insertion loss, ( a_1 )</td>
<td>dB</td>
<td>0</td>
</tr>
<tr>
<td>Fitted insertion loss, ( a_2 )</td>
<td>dB</td>
<td>51.6</td>
</tr>
<tr>
<td>Fitted insertion loss, ( a_4 )</td>
<td>dB</td>
<td>25.294</td>
</tr>
</tbody>
</table>

**Table 11-4. Channel fitted insertion loss characteristics**

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).

\[
ILD = IL - IL_{fitted}
\]  

(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.

\[
ILD_{min} \leq ILD_{min} = \begin{cases} 
-1.0 - 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\
-4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax}
\end{cases}
\]

(11-4)

\[
ILD_{max} \leq ILD_{max} = \begin{cases} 
1.0 + 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\
4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax}
\end{cases}
\]

(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.

\[
W(f) = \sin c^2 (f/f_b) \left[ \frac{1}{1 + (f/f_c)^4} \right] \left[ \frac{1}{1 + (f/f_c)^8} \right]
\]

(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. $T_{tr} \times f_t = 0.2365$), 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.

\[ ILD_{rms} = \sqrt{\frac{\sum W(f) \times ILD(f)^2}{N}} \]  
\[ (11-7) \]

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:

- $RL(f) \geq 12 \text{ dB}$ for $f_{\text{min}} < f \leq f_b/4$  
- $RL(f) \geq 12 \text{ dB} - 15 \log_{10}(4f/f_b)$ for $f_b/4 < f < f_b$  

\[ (11-8) \]
\[ (11-9) \]

Note: $f_{\text{min}}$ 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>$f_b$</td>
<td>max. Baud Rate sup. by Channel</td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Near-end aggressor peak to peak differential output amplitude</td>
<td>$A_{nt}$</td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Far-end aggressor peak to peak differential output amplitude</td>
<td>$A_{ft}$</td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Near-end aggressor 20 to 80% rise and fall times</td>
<td>$T_{nt}$</td>
<td>8</td>
<td>ps</td>
</tr>
<tr>
<td>Far-end aggressor 20 to 80% rise and fall times</td>
<td>$T_{ft}$</td>
<td>8</td>
<td>ps</td>
</tr>
</tbody>
</table>

\[ \sigma_x \leq \sigma_{x,\text{max}} = 10 \ (mV, RMS) \quad \text{for} \quad 3 \text{ dB} < IL \leq 5.3 \text{ dB} \]
\[ = 12.4 - 0.45 \ IL \ (mV, RMS) \quad \text{for} \quad 5.3 \text{ dB} < IL \leq 25.5 \text{ dB} \]  
\[ (11-10) \]

In Equation (11-10), the $IL$ denotes the value of the channel insertion loss in dB at $1/2 \cdot$ baud rate (NRZ).
Figure 11-3. Illustration integrated crosstalk noise limits

Integrated crosstalk noise (mV, RMS)

Insertion loss at Nyquist (dB)
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.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>T_Baud</td>
<td></td>
<td>19.90</td>
<td></td>
<td>25.80</td>
<td>Gsym/s</td>
</tr>
<tr>
<td>Output Differential Voltage</td>
<td>T_Vdiff</td>
<td>Emphasis off.</td>
<td></td>
<td>800</td>
<td>1200</td>
<td>mVppd</td>
</tr>
<tr>
<td>Differential Resistance</td>
<td>T_Rd</td>
<td></td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
</tr>
<tr>
<td>Differential Termination Resistance Mismatch (see Table 1-2)</td>
<td>T_Rdm</td>
<td></td>
<td>10</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Output Rise and Fall Time (20% to 80%)</td>
<td>T_tr, T_tf</td>
<td>Emphasis off. See Note 2.</td>
<td>8</td>
<td></td>
<td>ps</td>
<td></td>
</tr>
<tr>
<td>Common Mode Noise</td>
<td>T_Ncm</td>
<td>See Note 3.</td>
<td></td>
<td>12</td>
<td></td>
<td>mVRms</td>
</tr>
<tr>
<td>Differential Output Return Loss</td>
<td>T_SDD22</td>
<td>See Section 11.3.1.3</td>
<td></td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Common Mode Output Return Loss</td>
<td>T_SCC22</td>
<td>Below 10 GHz</td>
<td>-6</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 GHz to baud rate</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Common Mode Voltage</td>
<td>T_Vcm</td>
<td>Load Type 0</td>
<td>-100</td>
<td></td>
<td>1700</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>See Note 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Vf as defined in Section 11.3.1.6.2. The value is given as differential p-p voltage.
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-12</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>0.1714 x T_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>T_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>12.0</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

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:

\[ H(Z) = C_{-1} + C_0 z^{-1} + C_1 z^{-2} \]  \hspace{1cm} (11-11)

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>
<thead>
<tr>
<th>Coefficient</th>
<th>Normalized Amplitude</th>
<th>Normalized Step Size (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min (%)</td>
<td>Max (%)</td>
</tr>
<tr>
<td>C_{-1}</td>
<td>-25</td>
<td>0</td>
</tr>
<tr>
<td>C_1</td>
<td>-25</td>
<td>0</td>
</tr>
<tr>
<td>C_0</td>
<td>40</td>
<td>100</td>
</tr>
</tbody>
</table>

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 (\( C_{0_{\text{max}}} \)) and all other coefficients are zero.

2. Capture at least one complete cycle of the test pattern PRBS9 at \( T \) \([ T \text{ is defined as the test point at the output of transmitter package} \) 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 $T_{Nw}$-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>
<thead>
<tr>
<th>Parameter</th>
<th>Value (UI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear fit pulse length $T_{Np}$</td>
<td>8</td>
</tr>
<tr>
<td>Linear fit pulse delay $T_{Dp}$</td>
<td>2</td>
</tr>
<tr>
<td>Equalizer length $T_{Nw}$</td>
<td>8</td>
</tr>
<tr>
<td>Equalizer delay $T_{Dw}$</td>
<td>2</td>
</tr>
</tbody>
</table>

The differential zero to peak output voltage at $T$ in the steady state, $v_f$, is estimated by equation (11-12).

$$v_f = \frac{1}{M} \sum_{k=1}^{M} p(k)$$

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, $p_{\text{max}}$, shall satisfy the requirements of Table 11-11. The RMS value of the error between the linear fit and measured waveform from step 3, $\sigma_e$, shall satisfy the requirements of Table 11-11.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady state output voltage, $2 \times v_f$</td>
<td>max</td>
<td>mVppd</td>
</tr>
<tr>
<td>Steady state output voltage, $2 \times v_f$</td>
<td>min</td>
<td>mVppd</td>
</tr>
<tr>
<td>Linear fit pulse peak, $p_{\text{max}}$</td>
<td>min</td>
<td>-</td>
</tr>
<tr>
<td>RMS error, $\sigma_e$</td>
<td>max</td>
<td>-</td>
</tr>
</tbody>
</table>
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, \( \sigma_e \), 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).

\[
Y = \begin{bmatrix}
    y(1) & y(M+1) & \cdots & y(M(N-1)+1) \\
    y(2) & y(M+2) & \cdots & y(M(N-1)+2) \\
    \vdots & \vdots & \ddots & \vdots \\
    y(M) & y(2M) & \cdots & y(MN)
\end{bmatrix}
\]  

(11-13)
Rotate the symbols vector $x$ by the specified pulse delay $D_p$ to yield $x_r$.

$$x_r = \begin{bmatrix} x(T - D_p + 1) & x(T - D_p + 2) & \cdots & x(N) & x(1) & \cdots & x(T - D_p) \end{bmatrix} \quad (11-14)$$

Define the matrix $X$ to be an $N$-by-$N$ matrix derived from $x_r$ as shown in $(11-15)$.

$$X = \begin{bmatrix} x_r(1) & x_r(2) & \cdots & x_r(N) \\ x_r(N) & x_r(1) & \cdots & x_r(N-1) \\ \vdots & \vdots & \ddots & \vdots \\ x_r(2) & x_r(3) & \cdots & x_r(1) \end{bmatrix} \quad (11-15)$$

Define the matrix $X_1$ to be the first $T_Np$ rows of $X$ concatenated with a row vector of 1's of length $N$. The $M$-by-$(T_Np + 1)$ coefficient matrix, $P$, corresponding to the linear fit is then defined by $(11-16)$.

$$P = YX_1^T(X_1X_1^T)^{-1} \quad (11-16)$$

In $(11-16)$ the superscript "T" denotes the matrix transpose operator.

$$E = PX_1 - Y = \begin{bmatrix} e(1) & e(M + 1) & \cdots & e(M(N-1) + 1) \\ e(2) & e(M + 2) & \cdots & e(M(N-1) + 2) \\ \vdots & \vdots & \ddots & \vdots \\ e(M) & e(2M) & \cdots & e(MN) \end{bmatrix} \quad (11-17)$$

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 $T_Np$ columns of the matrix $P$ as shown in $(11-18)$. 
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 \( T_D \) to yield \( p_r \) as shown in (11-19).

\[
p_r = [p_i(T - D_w + 1) \quad p_i(T - D_w + 2) \quad \ldots \quad p_i(T - N_p) \quad p_i(1) \quad \ldots \quad p_i(T - D_w)]
\]

(11-19)

Define the matrix \( P_2 \) to be a \( T_Np \)-by-\( T_Np \) matrix derived from \( p_r \) as shown in (11-20).

\[
P_2 = \begin{bmatrix}
p_r(1) & p_r(T - N_p) & \ldots & p_r(2) \\
p_r(2) & p_r(1) & \ldots & p_r(3) \\
\vdots & \vdots & \ddots & \vdots \\
p_r(T - N_p) & p_r(T - N_p - 1) & \ldots & p_r(1)
\end{bmatrix}
\]

(11-20)

Define the matrix \( P_3 \) to be the first \( T_Nw \) rows of \( P_2 \). Define a unit pulse column vector \( x_p \) of length \( T_Np \). 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).

\[
w = (P_3^T P_3)^{-1} P_3^T x_p
\]

(11-21)

Given the column vector of equalizer coefficients, \( w \), the equalized pulse response \( q_i \) is determined by (11-22).

\[
q_i = P_3 w
\]

(11-22)
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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
<td>R_Baud</td>
<td>19.90</td>
<td>25.80</td>
<td>GSym/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Differential Voltage</td>
<td>R_Vdiff</td>
<td>Note 1</td>
<td>1200</td>
<td>mVppd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Impedance</td>
<td>R_Rdin</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>Input Impedance Mismatch</td>
<td>R_Rm</td>
<td>10</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Return Loss</td>
<td>R_SDD11</td>
<td>See 11.3.2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Mode Input Return Loss</td>
<td>R_SCC11</td>
<td>Below 10 GHz</td>
<td>-6</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10GHz to baud rate</td>
<td>-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Common Mode Voltage</td>
<td>R_Vcm</td>
<td>Load Type 0 See Note 2</td>
<td>-200</td>
<td>1800</td>
<td>mV</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Condition</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Jitter, Maximum</td>
<td>R_SJ-max</td>
<td>See Section 2.5.4, note 1</td>
<td>5</td>
<td>Ulpp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinusoidal Jitter, High Frequency</td>
<td>R_SJ-hf</td>
<td>See Section 2.5.4, note 1</td>
<td>0.05</td>
<td>Ulpp</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>-12</td>
<td>dB</td>
</tr>
<tr>
<td>f0</td>
<td>50</td>
<td>MHz</td>
</tr>
<tr>
<td>f1</td>
<td>0.1714 x R_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>f2</td>
<td>R_Baud</td>
<td>Hz</td>
</tr>
<tr>
<td>Slope</td>
<td>12.0</td>
<td>dB/dec</td>
</tr>
</tbody>
</table>

Table 11-14. Receiver Differential Return Loss Parameters

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:
  $\text{diff\_DDJ} = T_{DDJ} \text{ (FIR on)} - T_{DDJ} \text{ (FIR off)}$

- $T_{UUGJ}$, $T_{UBHPJ}$, $T_{TJ}$, $T_{DCD}$, and $T_{DDJ}$ need to be measured with TX FIR on and off.

- $\text{diff\_DDJ}$ 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](image)

\[
\text{DDJ} = \max(\Delta t_1, \Delta t_2, \ldots, \Delta t_n) - \min(\Delta t_1, \Delta t_2, \ldots, \Delta t_n)
\]
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 \( IL_{\text{fitted}} \) as a function of frequency \( f \) is defined by the equation below.

\[
IL_{\text{fitted}}(f) = a_0 + a_1 \frac{f}{f_b} + a_2 \left( \frac{f}{f_b} \right)^2 (dB)
\]  

(12-1)

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 \( f_{IL_{\text{min}}} \) to \( f_{IL_{\text{max}}} \) with a maximum frequency spacing of 10MHz. The coefficients of the fitted insertion loss are computed as follows.

Note: \( f_{IL_{\text{min}}} \), \( f_{IL_{\text{max}}} \) are defined in Table 10-4/11-4.

Define the weighted frequency matrix \( F \) as shown below, where "\( \text{mag}(IL_f) \)" is the magnitude of the measured insertion loss at each frequency point \( [\text{mag}(IL_{f_x}) = 10^{\frac{-IL_{f_x}}{10}}] \). Note: \( \text{mag}(IL_f) \) is a real number between 0 and 1.

\[
F = \begin{bmatrix}
\text{mag}(IL_{f_1}) \times \frac{f_1}{f_b} & \text{mag}(IL_{f_1}) \times \frac{f_1}{f_b} & \text{mag}(IL_{f_1}) \times \left( \frac{f_1}{f_b} \right)^2 \\
\text{mag}(IL_{f_2}) \times \frac{f_2}{f_b} & \text{mag}(IL_{f_2}) \times \frac{f_2}{f_b} & \text{mag}(IL_{f_2}) \times \left( \frac{f_2}{f_b} \right)^2 \\
\vdots & \vdots & \vdots \\
\text{mag}(IL_{f_N}) \times \frac{f_N}{f_b} & \text{mag}(IL_{f_N}) \times \frac{f_N}{f_b} & \text{mag}(IL_{f_N}) \times \left( \frac{f_N}{f_b} \right)^2
\end{bmatrix}
\]  

(12-2)

The polynomial coefficients \( a_0, a_1, a_2, \) and \( a_4 \) are determined using the Equation below.
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 new $IL$ 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 new $IL$ and solve for $a_0$, $a_1$ & $a_4$ as indicated below.

\[
newIL = IL - [a_{2_{\text{fixed}}} \times \frac{f}{f_b}]
\]  

Define the frequency matrix $F$ as shown below

\[
F = \begin{bmatrix}
mag(IL_{f_1}) \times \frac{f_1}{f_b} & mag(IL_{f_2}) \times \left(\frac{f_1}{f_b}\right)^2 \\
mag(IL_{f_2}) \times \frac{f_2}{f_b} & mag(IL_{f_2}) \times \left(\frac{f_2}{f_b}\right)^2 \\
\vdots & \vdots & \vdots \\
mag(IL_{f_N}) \times \frac{f_N}{f_b} & mag(IL_{f_N}) \times \left(\frac{f_N}{f_b}\right)^2
\end{bmatrix}
\]  

The polynomial coefficient $a_0$, $a_1$ & $a_4$ are determined using the Equation below.

\[
\begin{bmatrix}
a_0 \\
a_1 \\
a_4
\end{bmatrix} = \langle F^T F \rangle^{-1} F^T \left[ mag(IL_f) \times IL_f \right]
\]
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 new $IL$ is calculated as indicated below.

$$newIL = IL - a_1 \frac{\sqrt{f_b}}{f_b} + a_2 \frac{\sqrt{f_b}}{f_b}$$

(12-7)

Define the frequency matrix $F$ as shown below

$$F = \begin{bmatrix}
    \text{mag}(IL_{f_1}) & \text{mag}(IL_{f_1}) \times \left(\frac{f_1}{f_b}\right)^2 \\
    \text{mag}(IL_{f_2}) & \text{mag}(IL_{f_2}) \times \left(\frac{f_2}{f_b}\right)^2 \\
    \vdots & \vdots \\
    \text{mag}(IL_{f_N}) & \text{mag}(IL_{f_N}) \times \left(\frac{f_N}{f_b}\right)^2
\end{bmatrix}$$

(12-8)

The polynomial coefficient $a_0$ & $a_4$ are determined using the Equation below.

$$\begin{bmatrix} a_0 \\ a_4 \end{bmatrix} = (F^T F)^{-1} F^T [\text{mag}(IL_f) \times IL_f]$$

(12-9)

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 $MDNEXT_{\text{loss}}$ and multi-disturber far-end crosstalk loss $MDFEXT_{\text{loss}}$ 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 $\Delta f$, the RMS value of the integrated crosstalk noise $\sigma_x$ shall be calculated as follows.

$MDNEXT_{\text{loss}}$ is determined from all individual pair-to-pair differential NEXT loss values using Equation (12-10).
\[ MDNEXT_{\text{loss}}(f) = -10 \times \log_{10} \left( \sum_{i=0}^{\text{all \ NEXTs}} 10^{- (NL_i(f))/10} \right) \text{ (dB)} \] 

(12-10)

for \( 0.05 \text{ GHz} \leq f \leq f_b \)

where

\( MDNEXT_{\text{loss}}(f) \) 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.

\( MDFEXT_{\text{loss}} \) is determined from all individual pair-to-pair differential FEXT loss values using Equation (12-11).

\[ MDFEXT_{\text{loss}}(f) = -10 \times \log_{10} \left( \sum_{i=0}^{\text{all \ FEXTs}} 10^{- (NL_i(f))/10} \right) \text{ (dB)} \] 

(12-11)

for \( 0.05 \text{ GHz} \leq f \leq f_b \)

where

\( MDFEXT_{\text{loss}}(f) \) 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).

\[ W_a(f) = \left( A_a / 4 f_a \right) \text{sinc}^2 \left( f / f_a \right) \left[ \frac{1}{1 + (f / f_a)^4} \right] \left[ \frac{1}{1 + (f / f_a)^8} \right] \] 

(12-12)

\[ W_b(f) = \left( A_b / 4 f_b \right) \text{sinc}^2 \left( f / f_b \right) \left[ \frac{1}{1 + (f / f_b)^4} \right] \left[ \frac{1}{1 + (f / f_b)^8} \right] \] 

(12-13)
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 \( \sigma_{nx} \) is calculated using Equation (12-14).

\[
\sigma_{nx} = \left( 2\Delta f \sum W_s (f_s) 10^{-MDNEXT_{ns}(f_{ns})/10} \right)^{1/2} \tag{12-14}
\]

The far-end integrated crosstalk noise \( \sigma_{fx} \) is calculated using Equation (12-15).

\[
\sigma_{fx} = \left( 2\Delta f \sum W_s (f_s) 10^{-MDNFEXT_{ns}(f_{ns})/10} \right)^{1/2} \tag{12-15}
\]

The total integrated crosstalk noise \( \sigma_x \) is calculated using Equation (12-16).

\[
\sigma_x = \sqrt{\sigma_{nx}^2 + \sigma_{fx}^2} \tag{12-16}
\]

### 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 ($N_{cm}$) is half the rms value of the histogram.

Follow equation (12-17) below to account for instrumentation noise.

$$T_{Ncm} = \sqrt{(\text{measured}_{Ncm})^2 - (\text{instrumentation}_{noise})^2}$$  \(12-17\)