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FIBRE CHANNEL

Physical Interface-4

(FC-PI-4)

REV 7.00

INCITS working draft proposed
American National Standard
for Information Technology

Sep. 20, 2007

Secretariat: Information Technology Industry Council

ABSTRACT: This standard describes the point-to-point physical interface portions of Fibre Channel serial electrical and optical link variants that support the higher level Fibre Channel protocols including FC-FS-2, HIPPI, IPI, SCSI and others. This standard is recommended for new implementations but does not obsolete the existing Fibre Channel standards.

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American National Standard for Information Technology

Fibre Channel — Physical Interface-4 (FC-PI-4)

Secretariat

Information Technology Industry Council

Approved (not yet approved)

American National Standards Institute, Inc.

Abstract

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Foreword (This Foreword is not part of American National Standard XX-00-200x.)

This standard was developed by Task Group T11.2 of Accredited Standards Committee INCITS during 2006 and 2007. The standards approval process started in 2006. This document includes annexes that are informative and are not considered part of the standard.

Requests for interpretation, suggestions for improvements or addenda, or defect reports are welcomed. They should be sent to the INCITS Secretariat, Information Technology Industry Council, 1250 Eye Street, NW, Suite 200, Washington, DC 20005-3922.

This standard was processed and approved for submittal to ANSI by the National Committee for Information Technology Standards (INCITS). Committee approval of the standard does not necessarily imply that all committee members voted for approval.

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Revision History

1) Revision 1.00 Initial draft.

2) Revision 6.01 draft for T11.2 ballot.

3) Revision 6.10 comments incorporated after T11.2 ballot.

4) Revision 7.00 draft for T11 ballot.

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1 Scope

This international standard describes the physical interface portions of high performance electrical and optical link variants that support the higher level Fibre Channel protocols including FC-FS-2, the higher Upper Level Protocols (ULPs) associated with HIPPI, SCSI, IP and others.

This document contains all the requirements specified in FC-PI, FC-PI-2 and SM-LL-V, plus additional requirements relating to 800 MB/s. FC-PI-4 also includes additional copper and optical connector options.

FC-PI-4 does not replace FC-PI-2 but is intended to carry forward the technical requirements specified in FC-PI-2 for the variants addressed in FC-PI-4.

2 References

2.1 Standards

The following standards contain provisions that, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. Standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the following list of standards. Members of IEC and ISO maintain registers of currently valid International Standards.

Copies of the following documents can be obtained from ANSI: Approved ANSI standards, approved and draft international and regional standards (ISO, IEC, CEN/CENELEC, ITU-T), and other approved standards (including BSI, JIS, and DIN). For further information, contact ANSI Customer Service Department at 212-642-4900 (phone), 212-302-1286 (fax) or via the World Wide Web at http://www.ansi.org.

2.2 Normative references

2.2.1 Approved references

[1] **ANSI INCITS 326-1999 Fibre Channel** - Low-Cost 10-km Optical 1063-MBaud Interface (100-SM-LC-L)

[2] **ANSI INCITS 364-2003 FC-10GFC -** Fibre Channel 10 Gigabit.

[3] **ANSI INCITS 364-2003 AM-1 FC-10GFC Amendment 1 -** Fibre Channel 10 Gigabit Amendment 1.

[4] **ANSI INCITS 1619D FC-FS-2** - Fibre Channel Framing and Signaling 2.

[5] **ANSI INCITS 1619D FC-FS-2 AM-1** - Fibre Channel Framing and Signaling 2 Amendment 1.

[6] **Code of Federal Regulations, Title 21, Volume 8** - Title 21- Food and Drugs, Chapter I - Food and Drug Administration, Department of Health and Human Services, Subchapter J - Radiological Health, Part 1040 - Performance Standards for Light-Emitting Products.

[7] **EIA-700-A0AF** - [SP-3652] Integral FC Device Connector

[8] **ISO/IEC 11801** - Information technology - Generic cabling for customer premises

[9] **IEC 60169-8** - R.F. Coaxial Connectors with Inner Diameter of Outer Conductor 6.5 mm (0.256 in) with Bayonet Lock (Type BNC)

[10] **IEC 60169-17** - R.F. Coaxial Connectors with Inner Diameter of Outer Conductor 6.5 mm (0.256 in) with Threaded Lock (Type TNC)

[11] **IEC 60793-1-43** - Optical fibres - Part 1-43: Measurement methods and test procedures - Numerical aperture

[12] **IEC 60793-2, Optical Fibres** - Part 2: Product Specifications, Fourth Edition, 1998-12

[13] **IEC 60793-2-10, Type A1b (OM1 fiber)** - Optical fibers - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibers

[14] **IEC 60793-2-10, Type A1a.1 (OM2 fiber)** - Optical fibers - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibers

[15] **IEC 60793-2-10, Type A1a.2 (OM3 fiber)** - Optical fibres - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibers

[16] **IEC 60793-2-50** - Optical fibers - Part 2-50: Product specifications - Sectional specification for class B single-mode fibers

[17] **IEC 60807-3** - Rectangular connectors for frequencies below 3 MHz (Type DB9)

[18] **IEC 60825-1**- Radiation safety of laser products - Equipment classification, requirements and user's guide, 1sr Ed. Nov. 1993, Amended Sep. 1997

[19] **IEC 60874-19-1 -** Connectors for optical fibers and cables - Part 19-1: Fibre optic patch cord connector type SC-PC

[20] **IEC 61076-3-103** - Detailed specification for rectangular connectors with non-removable ribbon-cable contacts on 1.25 mm pitch, single row, used with high-speed serial data connector (HSSDC)

[21] **IEC 61280-1-1** - Transmitter Output Power Coupled into Single-Mode Fiber Optical Cable

[22] **IEC 61280-1-3** - Fiber optic communication subsystem basic test procedures - Part 1-3: Test procedures for general communication subsystems - Central wavelength and spectral width measurement

[23] **IEC 61280-2-2** - Test Procedures for Digital Systems - Optical Eye Pattern, waveform, and Extinction Ratio

[24] **IEC 61300-2-5** - Fiber optic interconnecting devices and passive components - Basic test and measurement procedures - Part 2-5: Tests - Torsion/Twist

[25] **IEC 61754-4** - Fiber optic connector interfaces - Part 4: Type SC connector family

[26] **IEC 61754-6** - Fiber optic connector interfaces - Part 6: Type MU connector family

[27] **IEC 61754-18** - Fiber optic connector interfaces - Part 18: Type MT-RJ connector family**.**

[28] **IEC 61754-20** - Fiber optic connector interfaces - Part 20: Type LC connector family

[29] **IEEE 802.3-2005** - IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.

[30] **SFF-8451** - Specification for SCA-2 Unshielded Connections

[31] **SFF-8045** - 40-pin SCA-2 Connector with Parallel Selection

[32] **SFF-8410** - Testing and performance requirements for high speed serial and parallel - serial copper links

[33] **SFF-8480** - Specification for HSSDB9 (high speed serial DB9) connections

[34] **SFF-8420** - Specification for HSSDC-1 shielded connections

[35] **SFF-8421** - Specification for HSSDC-2 shielded connections

2.2.2 References under development

At the time of publication, the following referenced standards were still under development. For information on the current status of the documents, or regarding availability, contact the relevant standards body or other organization as indicated.

[36] **ANSI INCITS 1647D FC-PI-3 -** Fibre Channel Physical Interfaces 3.

[37] **SFF-8083** - Specification for 0.8mm SFP+ Compliant Card Edge Connector.

[38] **SFF-8431** - Specification for Enhanced 8.5 and 10 Gigabit Small Form Factor Pluggable Module "SFP+".

[39] **SFF-8432** - Specification for Improved Pluggable Formfactor.

2.3 Informative references

[40] **Gigabit Ethernet Networking** - DG Cunningham and WG Lane, Macmillan Technical Publication, ISBN 1-7870-062-0 Chapter 9, the gigabit Ethernet optical link model

[41] **INCITS-TR-34-2004** - Fibre Channel - Methodologies for Jitter and Signal Quality Specification-FC-MJSQ

NOTE – For more information on the current status of SFF documents, contact the SFF committee at 408-867-6630 (phone), or 408-867-2115 (fax). To obtain copies of these documents, contact the SFF committee at14426 Black Walnut Court, Saratoga, CA 95070 at 408-867-6630 (phone), from FaxAccess at 408-741-1600, or through http://www.sffcommittee.com.

3 Definitions and conventions

For the purposes of this Standard, the following definitions, conventions, abbreviations, acronyms, and symbols apply.

3.1 Definitions

3.1.1 **α_T, α_R:** Alpha T, Alpha R; reference points used for establishing signal budgets at the chip pins of the transmitter and receiver in an FC device or retiming element.

3.1.2 **β_T, β_R:** Beta T, Beta R; interoperability points used for establishing signal budget at the internal connector nearest the alpha point unless the point also satisfies the definition for delta or gamma when it is either a delta or a gamma point.

3.1.3 **δ_T, δ_R:** Delta T, Delta R; interoperability points used for establishing signal budget at the internal connector of a removable PMD element.

3.1.4 **ε_T, ε_R:** Epsilon T, Epsilon R; interoperability points used for establishing signal budget at the internal connector mainly in blade applications.

3.1.5 **γ_T, γ_R:** Gamma T, Gamma R; interoperability points used for establishing signal budgets at the external enclosure connector.

3.1.6 **Alpha T, Alpha R:** see α_T, α_R.

3.1.7 **attenuation:** The transmission medium power or amplitude loss expressed in units of dB.

3.1.8 **average power:** The optical power measured using an average-reading power meter when transmitting valid 8B/10B transmission characters.

3.1.9 **bandwidth:** In FC-PI-4 context, the corner frequency of a low-pass transmission characteristic, such as that of an optical receiver.

3.1.10 **baud:** a unit of signaling speed, expressed as the maximum number of times per second the signal may change the state of the transmission line or other medium. (Units of baud are symbols/sec) Note: With the Fibre Channel transmission scheme, a symbol represents a single transmission bit. [(Adapted from IEEE Std. 610.7-1995 [A16].12)].

3.1.11 **Beta T, Beta R:** see β_T, $\beta_{R.}$

3.1.12 **bit error ratio (BER):** the probability of a correct transmitted bit being erroneously received in a communication system. For purposes of this standard BER is the number of bits output from a receiver that differ from the correct transmitted bits, divided by the number of transmitted bits.

3.1.13 **bit synchronization:** The condition that a receiver is delivering retimed serial data at the required BER.

3.1.14 **byte:** An eight-bit entity prior to encoding, or after decoding, with its least significant bit denoted as bit 0 and most significant bit as bit 7. The most significant bit is shown on the left side in FC-FS-2, unless specifically indicated otherwise.

3.1.15 **bulkhead:** the boundary between the shielded system enclosure (where EMC compliance is maintained) and the external interconnect attachment

3.1.16 **cable plant:** all passive communications elements (e.g., optical fiber, twisted pair, coaxial cable, connectors, splices, etc.) between a transmitter and a receiver.

3.1.17 **center wavelength (laser):** The value of the central wavelength of the operating, modulated laser. This is the wavelength (see IEC 61280-1-3) where the effective optical power resides.

3.1.18 character: a defined set of n contiguous bits where n is determined by the encoding scheme. For FC that uses 8b10b encoding, n = 10.

3.1.19 coaxial cable: An unbalanced electrical transmission medium consisting of concentric conductors separated by a dielectric material with the spacings and material arranged to give a specified electrical impedance.

3.1.20 compliance point: an interoperability point where the interoperability specifications are met. Compliance points may include Beta, Gamma, and Delta points for transmitters and receivers.

3.1.21 component: entities that make up the link. Examples are connectors, cable assemblies, transceivers, port bypass circuits and hubs.

3.1.22 connector: electro-mechanical or opto-mechanical components consisting of a receptacle and a plug that provides a separable interface between two transmission media segments. Connectors may introduce physical disturbances to the transmission path due to impedance mismatch, crosstalk, etc. These disturbances may introduce jitter under certain conditions.

3.1.23 cumulative distribution function (CDF): the integral of the probability distribution function (PDF) from minus infinity to a specific time or from a specific time to plus infinity.

3.1.24 data dependent pulse width shrinkage (DDPWS): The difference between 1 UI and the minimum value of the zero-crossing-time differences (in UI) of all adjacent edges in an averaged waveform of a repeating data sequence.

3.1.25 Delta T, Delta R: see δ_T, δ_R.

3.1.26 deterministic jitter: See jitter, deterministic.

3.1.27 disparity: The difference between the number of ones and zeros in a Transmission Character. See FC-FS-2.

3.1.28 dispersion: (1) A term in this document used to denote pulse broadening and distortion from all causes. The two causes of dispersion in optical transmissions are modal dispersion, due to the difference in the propagation velocity of the propagation modes in a multimode fiber, and chromatic dispersion, due to the difference in propagation of the various spectral components of the optical source. Similar effects exist in electrical transmission lines. (2) Frequency dispersion caused by a dependence of propagation velocity on frequency, that leads to a pulse widening in a system with infinitely wide bandwidth. The term ‘dispersion’ when used without qualifiers is definition (1) in this document.

3.1.29 duty cycle distortion (DCD): (1) The absolute value of one half the difference in the average pulse width of a ’1’ pulse or a ’0’ pulse and the ideal bit time in a clock-like (repeating 0,1,0,1,...) bit sequence. (2) One-half of the difference of the average width of a one and the average width of a zero in a waveform eye pattern measurement. Definition (2) contains the sign of the difference and is useful in the presence of actual data. DCD from definition (2) may be used with arbitrary data and is approximately the same quantitatively as that observed with clock like patterns in definition (1). DCD is not a level 1 quantity. DCD is considered to be correlated to the data pattern because it is synchronous with the bit edges. Mechanisms that produce DCD are not expected to change significantly with different data patterns. The observation of DCD may change with changes in the data pattern. DCD is part of the DJ distribution and is measured at the average value of the waveform.

3.1.30 effective DJ: DJ used for level 1 compliance testing, and determined by curve fitting a measured CDF to a cumulative or integrated dual-Dirac function, where each Dirac impulse, located at +DJ/2 and -DJ/2, is convolved with separate half-magnitude Gaussian functions with standard deviations sigma1 and sigma2. Equivalent to level 1 DJ.

3.1.31 enclosure: the outermost electromagnetic boundary (that acts as an EMI barrier) containing one or more FC devices.

3.1.32 Epsilon T, Epsilon R: see ε_T, ε_R.

3.1.33 event: the measured deviation of a single signal edge time at a defined signal level of the signal from a reference time. The reference time is the jitter-timing-reference specified in 6.2.3 of FC-MJSQ. Events are also referred to as jitter events or signal events without changing the meaning. Examples include a sample in a sampling oscilloscope, a single TIA measurement, an error or non error reported by a BERT at a reference time and signal level.

3.1.34 external connector: a bulkhead connector, whose purpose is to carry the FC signals into and out of an enclosure, that exits the enclosure with only minor compromise to the shield effectiveness of the enclosure.

3.1.35 extinction ratio: The ratio of the high optical power to the low optical power. See annex A.1.1.5.

3.1.36 eye contour: the locus of points in signal level - time space where the CDF = 1E-12 in the actual signal population determines whether a jitter eye mask violation has occurred. Either time jitter or signal level jitter may be used to measure the eye contour.

3.1.37 fall time: The time interval for the falling edge of a signal to transit between specified percentages of the signal amplitude. In the context of FC-PI-4, the measurement points are the 80% and 20% voltage levels.

3.1.38 FC device: an entity that contains the FC protocol functions and that has one or more of the connectors defined in this document. Examples are: host bus adapters, disk drives, and switches. Devices may have internal connectors or bulkhead connectors.

3.1.39 FC device connector: A connector defined in this document that carries the FC serial data signals into and out of the FC device.

3.1.40 fiber: A general term used to cover all transmission media specified in FC-PI-4. See clause 5.

3.1.41 fiber optic cable: A jacketed optical fiber or fibers.

3.1.42 Fiber Optic Test Procedure (FOTP): Standards developed and published by the Electronic Industries Association (EIA) under the EIA-RS-455 series of standards.

3.1.43 Gamma T, Gamma R: see γ_T, γ_R.

3.1.44 Golden PLL: a function that conforms to the requirements in sub-clause 6.10.2 of FC-MJSQ that extracts the jitter timing reference from the data stream under test to be used as the timing reference for the instrument used for measuring the jitter in the signal under test.

3.1.45 insertion loss: The ratio (expressed in dB) of incident power at one port to transmitted power at a different port, when a component or assembly with defined ports is introduced into a link or system. May refer to optical power or to electrical power in a specified frequency range. Note the dB magnitude of S12 or S21 is the negative of insertion loss in dB.

3.1.46 interface connector: An optical or electrical connector that connects the media to the Fibre Channel transmitter or receiver. The connector set consists of a receptacle and a plug.

3.1.47 internal connector: A connector, whose purpose is to carry the FC signals within an enclosure (may be shielded or unshielded).

3.1.48 internal FC device: An FC device whose FC device connector is contained within an enclosure.

3.1.49 interoperability point: Points in a link or TxRx Connection that this standard defines signal requirements to enable interoperability. See β_T, β_R, δ_T, δ_R γ_T and γ_R.

3.1.50 intersymbol interference (ISI): reduction in the distinction of a pulse caused by overlapping energy from neighboring pulses. (Neighboring means close enough to have significant energy overlapping and does not imply or exclude adjacent pulses - many bit times may separate the pulses especially in the case of reflections). ISI may result in DDJ and vertical eye closure. Important mechanisms that produce ISI are dispersion, reflections, and circuits that lead to baseline wander.

3.1.51 jitter: the instantaneous deviations of a signal edge times at a defined signal level of the signal from the reference times for those events. The reference time is the jitter-timing-reference specified in 6.2.3 of FC-MJSQ that occurs under a specific set of conditions. In this document, jitter is defined at the average signal level.

3.1.52 jitter, data dependent (DDJ): jitter that is added when the transmission pattern is changed from a clock like to a non-clock like pattern. For example, data dependent deterministic jitter may be caused by the time differences required for the signal to arrive at the receiver threshold when starting from different places in bit sequences (symbols). DDJ is expected whenever any bit sequence has frequency components that are propagated at different rates. When different run lengths are mixed in the same transmission the different bit sequences (symbols) therefore interfere with each other. Data dependent jitter may also be caused by reflections, ground bounce, transfer functions of coupling circuits and other mechanisms.

3.1.53 jitter, deterministic (DJ): jitter with non-Gaussian probability density function. Deterministic jitter is always bounded in amplitude and has specific causes. Deterministic jitter comprises (1) correlated DJ (data dependent (DDJ) and duty cycle distortion (DCD)), and (2) DJ that is uncorrolated to the data and bounded in amplitude (BUJ). Level 1 DJ is defined by an assumed CDF form and may be used for compliance testing. See FC-MJSQ.

3.1.54 jitter distribution: a general term describing either PDF or CDF properties.

3.1.55 jitter eye opening (horizontal): the time interval, measured at the signal level for the measurement (commonly at the time-averaged signal level), between the 10^{-12} CDF level for the leading and trailing transitions associated with a unit interval.

3.1.56 jitter frequency: the frequency associated with the jitter waveform produced by plotting the jitter for each signal edge against bit time in a continuously running bit stream.

3.1.57 jitter, non-compensable data dependent, NC-DDJ: non-compensable data dependent jitter is a measure of any data dependent jitter that is present after processing by the reference receiver.

3.1.58 jitter, random, RJ: jitter that is characterized by a Gaussian distribution and is unbounded.

3.1.59 jitter, sinusoidal (SJ): single tone jitter applied during signal tolerance testing.

3.1.60 jitter timing reference: the signal used as the basis for calculating the jitter in the signal under test. The jitter timing reference has specific requirements on its ability to track and respond to changes in the signal under test. The jitter timing reference may be different from other timing references available in the system.

3.1.61 jitter tolerance for links: the ability of the link downstream from the receive interoperability point (γ_r, β_r, or δ_r) to recover transmitted bits in an incoming data stream in the presence of specified jitter in the signal. Jitter tolerance is measured by the amount of jitter required to produce a specified bit error ratio. The required jitter tolerance performance depends on the frequency content of the jitter. Since detection of bit errors is required to determine the jitter tolerance, receivers embedded in an FC Port require that the Port be capable of reporting bit errors. For receivers that are not embedded in an FC Port the bit error detection and reporting may be accomplished by instrumentation attached to the output of the receiver. Jitter tolerance is always measured using the minimum allowed signal amplitude unless otherwise specified. See also signal tolerance.

3.1.62 jitter tolerance for receivers: the ability of a receiver to recover transmitted bits in an incoming data stream in the presence of specified jitter in the signal. Jitter tolerance is measured by the amount of jitter required to produce a specified bit error ratio. The reference point for the jitter tolerance of the receiver is the α_R point. The required jitter tolerance performance depends on the frequency content of the jitter. Since detection of bit errors is required to determine the jitter tolerance, receivers embedded in an FC Port require that the Port be capable of reporting bit errors. For receivers that are not embedded in an FC Port the bit error detection and reporting may be accomplished by instrumentation attached to the output of the receiver. Jitter tolerance is always measured using the minimum allowed signal amplitude unless otherwise specified. See also signal tolerance.

3.1.63 jitter, total, TJ: total jitter is the difference in time between the two points on the jitter distribution with cumulative probability of 10^{-12}.

3.1.64 jitter, uncorrolated, UJ: uncorrolated jitter is a measure of any jitter that is not correlated to the data stream.

3.1.65 JSPAT: The JSPAT (scrambled jitter pattern) is a 500 bit pattern that has been developed for transmit jitter, DDPWS, WDP and RN testing, see annex F.

3.1.66 JTSPAT: The JTSPAT is a 1180 bit pattern intended to be used for receive jitter tolerance testing for scrambled systems see annex F.

3.1.67 level:
1. A document artifice, e.g. FC-0, used to group related architectural functions. No specific correspondence is intended between levels and actual implementations.
2. In FC-PI-4 context, a specific value of voltage or optical power (e.g., voltage level).
3. The type of measurement: level 1 is a measurement intended for compliance, level 2 is a measurement intended for characterization/diagnosis

3.1.68 level 1 DJ: term used in this document for the effective DJ value that is used for DJ compliance purposes.

3.1.69 limiting amplifier: an active non-linear circuit with amplitude gain that keeps the output levels within specified levels.

3.1.70 link:
1. Two unidirectional fibers transmitting in opposite directions and their associated transmitters and receivers.
2. A synonym for a duplex TxRx Connection.

3.1.71 MB/s: An abbreviation for megabytes (10^6) per second

3.1.72 media: (1) General term referring to all the elements comprising the interconnect. This includes fiber optic cables, optical converters, electrical cables, pc boards, connectors, hubs, and port bypass circuits. (2) May be used in a narrow sense to refer to the bulk cable material in cable assemblies that are not part of the connectors. Due to the multiplicity of meanings for this term its use is not encouraged.

3.1.73 mode partition noise: Noise in a laser based optical communication system caused by the changing distribution of laser energy partitioning itself among the laser modes (or lines) on successive pulses in the data stream. The effect is a different center wavelength for the successive pulses resulting in arrival time jitter attributable to chromatic dispersion in the fiber.

3.1.74 node: A collection of one or more N_Ports controlled by a level above FC-2.

3.1.75 numerical aperture: The sine of the radiation or acceptance half angle of an optical fiber, multiplied by the refractive index of the material in contact with the exit or entrance face. See IEC 60793-1-43.

3.1.76 OM1: 62.5/125 um multimode fiber with at minimum overfilled launch bandwidth of 200 MHz-km at 850 nm and 500 MHz-km at 1300 nm in accordance with IEC 60793-2-10 Type A1b fiber.

3.1.77 OM2: 50/125 um multimode fiber with a minimum overfilled launch bandwidth of 500 MHz-km at 850 nm and 500 MHz-km at 1300 nm in accordance with IEC 60793-2-10 Type A1a.1 fiber.

3.1.78 OM3: 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 1500 MHz-km at 850nm and 500 MHz-km at 1300 nm as well as an effective laser launch bandwidth of 2000 MHz-km at 850 nm in accordance with IEC 60793-2-10 Type A1a.2 fiber.

3.1.79 optical fiber: Any filament or fiber, made of dielectric material, that guides light.

3.1.80 optical modulation amplitude (OMA): the difference in optical power between the settled and averaged value of a long string of contiguous logic one bits and the settled and averaged value of a long string of contiguous logic zero bits. See annex A.1.1.1.

3.1.81 optical receiver overload: The condition of exceeding the maximum acceptable value of the received average optical power at point γ_R to achieve a BER < 10^{-12}.

3.1.82 optical receiver sensitivity: The minimum acceptable value of received signal at point Gamma R. to achieve a BER < 10^{-12}. See also the definitions for stressed receiver sensitivity and unstressed receiver sensitivity. See annex A.3.1.

3.1.83 optical path penalty: A link optical power penalty to account for signal degradation other than attenuation.

3.1.84 optical return loss (ORL): See return loss.

3.1.85 OS1: Dispersion unshifted single-mode fiber in accordance with IEC 60793-2-50 Type B1.1fiber.

3.1.86 OS2: Dispersion unshifted, low water peak, single-mode fiber in accordance with IEC 60793-2-50 Type B1.3 fiber.

3.1.87 plug: The cable half of the interface connector that terminates an optical or electrical signal transmission cable.

3.1.88 Port (or FC Port): a generic reference to a Fibre Channel Port. In this document, the components that together form or contain the following: the FC protocol function with elasticity buffers to re-time data to a local clock, the SERDES function, the transmit and receive network, and the ability to detect and report errors using the FC protocol.

3.1.89 receiver (Rx): an electronic component (Rx) that converts an analog serial input signal (optical or electrical) to an electrical (retimed or non-retimed) output signal.

3.1.90 receiver device: the device containing the circuitry accepting the signal from the link.

3.1.91 receive network: a receive network consists of all the elements between the interconnect connector inclusive of the connector and the deserializer or repeater chip input. This network may be as simple as a termination resistor and coupling capacitor or this network may be complex including components like photo diodes and transmittances amplifiers.

3.1.92 receptacle: The fixed or stationary half of the interface connector that is part of the transmitter or receiver.

3.1.93 reclocker: A type of repeater specifically designed to modify data edge timing such that the data edges have a defined timing relation with respect to a bit clock recovered from the (FC) data at its input.

3.1.94 reference points: Points in a TxRx Connection that may be described by informative specifications. These specifications establish the base values for the interoperability points. See α_T and α_R

3.1.95 reflections (optical): Power returned to the measurement point by discontinuities in the physical link.

3.1.96 repeater: An active circuit designed to modify the (FC) signals that pass through it by changing any or all of the following parameters of that signal: amplitude, slew rate, and edge to edge timing. Repeaters have jitter transfer characteristics. Types of repeaters include Retimers, Reclockers and amplifiers.

3.1.97 retimer (RT): a type of repeater specifically designed to modify data edge timing such that the output data edges have a defined timing relation with respect to a bit clock derived from a timing reference other than the (FC) data at its input. A retimer shall be capable of inserting and removing words from the (FC) data passing through it. In the context of jitter methodology, a retimer resets the accumulation of jitter such that the output of a retimer has the jitter budget of alpha T.

3.1.98 return loss: The ratio (expressed in dB) of incident power to reflected power from the same port, when a component or assembly with defined ports is introduced into a link or system. May refer to optical power or to electrical power in a specified frequency range. Note the dB magnitude of S11 or S22 is the negative of return loss in dB.

3.1.99 RIN_{12}(OMA): Relative Intensity Noise. Laser noise in dB/Hz with 12 dB optical return loss, with respect to the optical modulation amplitude.

3.1.100 rise time: The time interval for the rising edge of a signal to transit between specified percentages of the signal amplitude. In the context of FC-PI-4, the measurement points are the 80% and 20% voltage levels.

3.1.101 run length: number of consecutive identical bits in the transmitted signal e.g., the pattern 0011111010 has a run lengths of five (5), one (1), and indeterminate run lengths at either end.

3.1.102 running disparity: A binary parameter indicating the cumulative disparity (positive or negative) of all transmission characters since the most recent of (a) power on, (b) exiting diagnostic mode, or (c) start of frame. See FC-FS-2.

3.1.103 signal: the entire voltage or optical power waveforms within a data pattern during transmission

3.1.104 signal level: the instantaneous magnitude of the signal measured in the units appropriate for the type of transmission used at the point of the measurement. The most common signal level unit for electrical transmissions is voltage while for optical signals the signal level or magnitude is usually given in units of power: dBm and microwatts.

3.1.105 signal tolerance: the ability of the link downstream from the receive interoperability point (γ_r, β_r, or δ_r) to recover transmitted bits in an incoming data stream in the presence of a specified signal. Signal tolerance is measured by the amount of jitter required to produce a specified bit error ratio at a specified signal amplitude. The required signal tolerance performance depends on the frequency content of the jitter and on the amplitude of the signal. Since detection of bit errors is required to determine the signal tolerance, receivers embedded in an FC Port require that the Port be capable of reporting bit errors. For receivers that are not embedded in an FC Port the bit error detection and reporting may be accomplished by instrumentation attached to the output of the receiver. Signal tolerance is always measured using the minimum allowed signal amplitude and maximum allowed jitter unless otherwise specified. See also jitter tolerance.

3.1.106 special character: Any Transmission Character considered valid by the Transmission Code but not equated to a Valid Data Byte. Special Characters are provided by the Transmission Code for use in denoting special functions.

3.1.107 spectral width (RMS): The weighted root mean square width of the optical spectrum. See IEC 61280-1-3.

3.1.108 stressed receiver sensitivity: The normal amplitude of optical modulation in the stressed receiver test given in annex A.3.1.1.

3.1.109 stressed receiver vertical eye closure power penalty: The ratio of the power required to achieve normal optical modulation amplitude to the power required to achieve the vertical eye opening in the stressed receiver test (annex A.3.1).

3.1.110 synchronization: Bit synchronization, defined above, and/or Transmission-Word synchronization, defined in FC-FS-2. An FC-1 receiver enters the state “Synchronization-Acquired” when it has achieved both kinds of synchronization.

3.1.111 transceiver: A transmitter and receiver combined in one package

3.1.112 transmission bit: a symbol of duration one unit interval that represents one of two logical values, 0 or 1. For example, for 8b10b encoding, one tenth of a transmission character.

3.1.113 transmission character: any encoded character (valid or invalid) transmitted across a physical interface. Valid transmission characters are specified by the transmission code and include data and special characters.

3.1.114 transmission code: a means of encoding data to enhance its transmission characteristics. The transmission code specified by FC-FS-2 is byte-oriented, with both valid data bytes and special (control) codes encoded into 10-bit transmission characters.

3.1.115 transmission word: A string of four contiguous Transmission Characters occurring on boundaries that are zero modulo 4 from a previously received or transmitted Special Character.

3.1.116 transmit network: a transmit network consists of all the elements between a serializer or repeater output and the connector, inclusive of the connector. This network may be as simple as a pull-down resistor and ac capacitor or this network may include laser drivers and lasers.

3.1.117 transmitter (Tx): a circuit (Tx) that converts a logic signal to a signal suitable for the communications media (optical or electrical).

3.1.118 transmitter device: the device containing the circuitry on the upstream side of a TxRx connection.

3.1.119 transmitter and dispersion penalty (TDP): TDP is a measure of the penalty due to a transmitter and its specified worst-case medium, with a standardized reference receiver. See IEEE 802.3 sub-clause 52.9.10.

3.1.120 transmitter waveform and dispersion penalty (TWDP): TWDP is a measure of the deterministic penalty of the waveform from a particular transmitter and reference emulated multimode fibers or metallic media, with a reference equalizing receiver.

3.1.121 $t_{Rise/Fall}$: The adjusted 20% to 80% rise and fall time of the optical signal.

3.1.122 $t_{Rise/Fall\_FILTER}$: The measured 20% to 80% rise or fall time of a fourth order Bessel-Thomson filter with a step input.

3.1.123 **$t_{Rise/Fall\_MEAS}$:** The measured 20% to 80% rise or fall time of the optical signal.

3.1.124 **TxRx connection:** the complete signal path between a transmitter in one FC device and a receiver in another FC device.

3.1.125 **TxRx connection segment:** That portion of a TxRx connection delimited by separable connectors or changes in media.

3.1.126 **unit interval (UI):** the nominal duration of a single transmission bit.

3.1.127 **unstressed receiver sensitivity:** The normal amplitude of optical modulation in the unstressed sensitivity receiver test in annex A.3.1.2.

3.1.128 **voltage modulation amplitude (VMA):** VMA is the difference in electrical voltage between the stable one level and the stable zero level, see annex A.1.1.2.

3.1.129 **waveform distortion penalty (WDP):** WDP is a measure of the deterministic penalty of a waveform with a reference equalizing receiver.

3.1.130 **word:** in Fibre Channel protocol, a string of four contiguous bytes occurring on boundaries that are zero modulo 4 from a specified reference.

3.2 Editorial conventions

3.2.1 Conventions

In this Standard, a number of conditions, mechanisms, parameters, events, states, or similar terms are printed with the first letter of each word in upper-case and the rest lower-case (e.g. TxRx connection). Any lower case uses of these words have the normal technical English meanings.

Numbered items in this Standard do not represent any priority. Any priority is explicitly indicated.

In case of any conflict between figure, table, and text, the text takes precedence. Exceptions to this convention are indicated in the appropriate sections.

In all of the figures, tables, and text of this document, the most significant bit of a binary quantity is shown on the left side. Exceptions to this convention are indicated in the appropriate sections.

The ISO convention of numbering is used, i.e. the ten-thousands and higher multiples are separated by a space. A comma is used as the decimal point. A comparison of the American and ISO conventions are shown below:

Table 1 – ISO convention

ISO	American
2 048	2048
10 000	10,000
1 323 462.9	1,323,462.9

3.2.2 Keywords

3.2.2.1 **invalid:** Used to describe an illegal or unsupported bit, byte, word, field or code value. Receipt of an invalid bit, byte, word, field or code value shall be reported as error.

3.2.2.2 **ignored:** Used to describe a bit, byte, word, field or code value that shall not be examined by the receiving. port. The bit, byte, word, field or code value has no meaning in the specified context.

3.2.2.3 **mandatory:** A keyword indicating an item that is required to be implemented as defined in this standard.

3.2.2.4 may: A keyword that indicates flexibility of choice with no implied preference (equivalent to "may or may not").

3.2.2.5 may not: A keyword that indicates flexibility of choice with no implied preference (equivalent to "may or may not").

3.2.2.6 NA: A keyword indicating that this field is not applicable.

3.2.2.7 obsolete: A keyword indicating that an item was defined in a prior Fibre Channel standard but has been removed from this standard.

3.2.2.8 optional: Characteristics that are not required by FC-PI-4. However, if any optional characteristic is implemented, it shall be implemented as defined in FC-PI-4.

3.2.2.9 reserved: A keyword referring to bits, bytes, words, fields, pins and code values that are set aside for future standardization.

3.2.2.10 shall: A keyword indicating a mandatory requirement. Designers are required to implement all such mandatory requirements to ensure interoperability with other products that conform to this standard.

3.2.2.11 should: A keyword indicating flexibility of choice with a strongly preferred alternative; equivalent to the phrase "it is strongly recommended".

3.2.2.12 should not: A keyword indicating flexibility of choice with a strongly preferred alternative; equivalent to the phrase "it is strongly recommended not to".

3.2.2.13 vendor specific: Functions, code values, and bits not defined by this standard and set aside for private usage between parties using this standard.

3.2.3 Abbreviations, acronyms, and symbols

Abbreviations, acronyms and symbols applicable to this Standard are listed. Definitions of several of these items are included in clause 3.1

3.2.3.1 Signaling rate abbreviations

The exact signaling rates are used in the tables and the abbreviated forms are used in text.

Table 2 – Signaling rate abbreviations

Abbreviation	True signaling rate
1GFC	1 062.5 MBd
2GFC	2 125 MBd
4GFC	4 250 MBd
8GFC	8 500 MBd

– XX-00-200x Physical Interface-4 7.00

3.2.3.2 Acronyms and other abbreviations

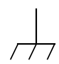
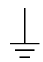
Table 3 – Acronyms and other abbreviations

Bd	baud
BER	bit error ratio
BNC	coaxial connector specified by reference 8
dB	decibel
dBm	decibel (relative to 1 mW)
DJ	deterministic jitter
DUT	device under test
ECL	Emitter Coupled Logic
EIA	Electronic Industries Association
EMC	electromagnetic compatibility
EMI	electromagnetic interference
FC	Fibre Channel
FOTP	fiber optic test procedure
GBd	gigabaud
hex	hexadecimal notation
IEEE	Institute of Electrical and Electronics Engineers
ITU-T	The International Telecommunication Union - Telecommunication Standardization (formerly CCITT)
LOS	loss of signal
LW	long wavelength
MB	megabyte = 10^6 bytes
MBd	megabaud
MM	multimode
NA	not applicable
NEXT	near-end crosstalk
N_Port	Node_Port
OMA	optical modulation amplitude
PMD	physical medium dependent
ppm	parts per million
RFI	radio frequency interference
RIN	relative intensity noise
RJ	random jitter
RMS	root mean square
Rx	receiver
SERDES	Serializer/Deserializer
SM	single-mode
S/N or SNR	signal-to-noise ratio
SW	short wavelength
TCTF	transmitter compliance transfer function
TDR	time domain reflectometry
TIA	Telecommunication Industries Association
TNC	coaxial connector specified by reference 10
Tx	transmitter
TxRx	a combination of transmitter and receiver
UI	unit interval = 1 bit period
ULP	Upper Level Protocol
VECP	vertical eye closure penalty

3.2.3.3 Symbols

Unless indicated otherwise, the following symbols have the listed meanings.

Table 4 – Symbols

α	alpha
β	beta
δ	delta
ε	epsilon
γ	gamma
Ω	ohm
μ	micro (e.g., μm = micrometer)
λ	wavelength
	chassis or earth ground
	signal reference ground

4 FC-PI-4 Structure and Concepts

4.1 Fibre Channel Structure

This clause provides an overview of the structure, concepts and mechanisms used in FC-PI-4 and is intended for informational purposes only.

The Fibre Channel (FC) is logically a bi-directional point-to-point serial data channel, structured for high performance information transport. Physically, Fibre Channel is an interconnection of one or more point-to-point links. Each link end terminates in a Port or Retimer. Ports are fully specified in FC-PI-4 and FC-FS-2. Fibre is a general term used to cover all physical media supported by Fibre Channel including optical fiber, twisted pair, and coaxial cable.

Fibre Channel is structured as a set of hierarchical functions as illustrated in figure 1. Fibre Channel consists of related functions FC-0 through FC-3. Each of these functions is described as a level. Fibre Channel does not restrict implementations to specific interfaces between these levels.

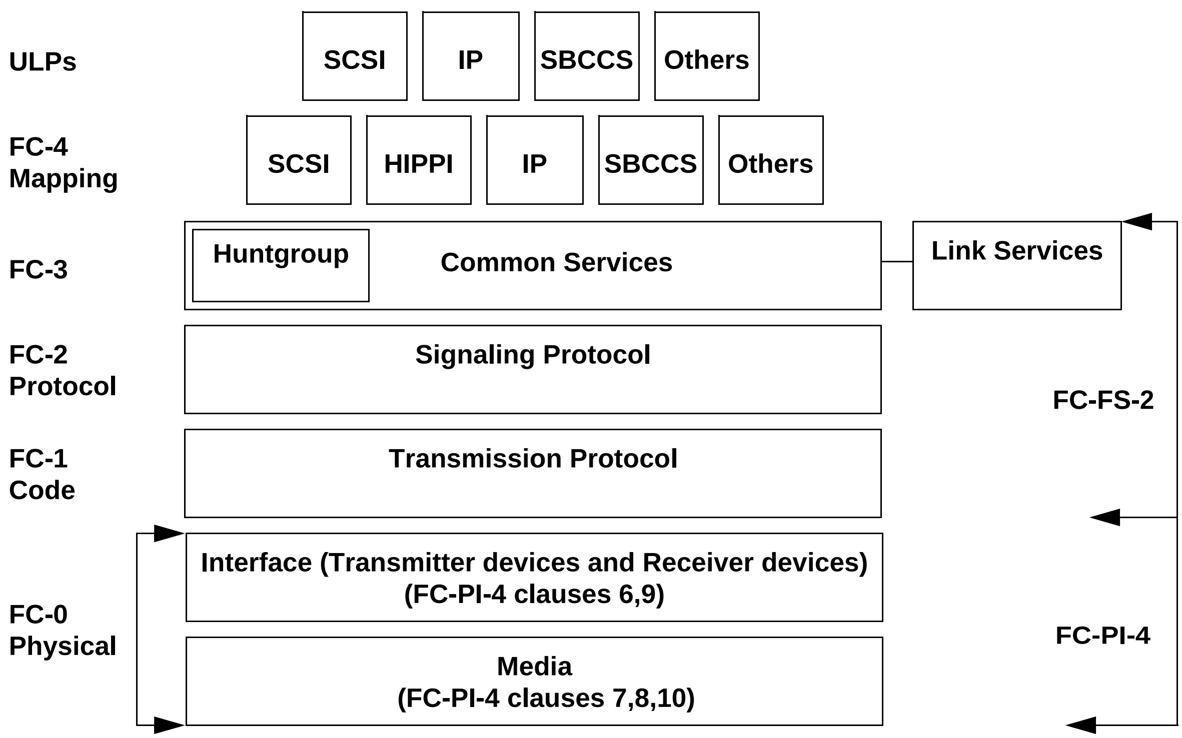


Figure 1 – Fibre channel structure

The Physical interface (FC-0), specified in FC-PI-4, consists of transmission media, transmitter devices, receiver devices and their interfaces. The Physical interface specifies a variety of media, and associated transmitter devices and receive devices capable of operating at various speeds.

The Transmission protocol (FC-1), Signaling protocol (FC-2) and Common Services (FC-3) are fully specified in FC-FS-2. Fibre Channel levels FC-1 through FC-3 specify the rules and provide mechanisms needed to transfer blocks of information end-to-end, traversing one or more links.

Scrambling is used at 8GFC. 1GFC, 2GFC, and 4GFC do not use scrambling. For information about scrambling refer to FC-FS-2 AM-1.

FC-PI-4 and FC-FS-2 define a suite of functions and facilities available for use by an Upper Level Protocols (ULP) Mapping protocol (FC-4). This suite of functions and facilities may exceed the requirements of any one FC-4. An FC-4 may choose only a subset of FC-PI-4 and FC-FS-2 functions and facilities. Fibre Channel provides a method for supporting a number of ULPs. The Link Services represent a mandatory function required by FC-PI-4 and FC-FS-2.

A Fibre Channel Node is functionally configured as illustrated in figure 2. A Node may support one or more N_Ports and one or more FC-4s. Each N_Port contains FC-0, FC-1 and FC-2 functions. FC-3 optionally provides the common services to multiple N_Ports and FC-4s.

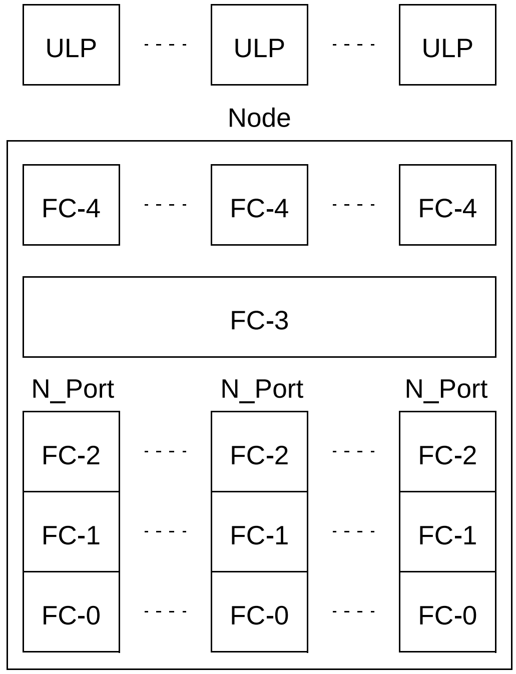


Figure 2 – Node functional configuration

4.2 FC-0 general description

The FC-0 level of FC-PI-4 describes the Fibre Channel link. The FC-0 level covers a variety of media and the associated transmitters and receivers capable of operating at a wide range of speeds. The FC-0 level is designed for maximum flexibility and allows the use of a large number of technologies to meet the widest range of system requirements.

Each fiber or copper cable is attached to a transmitter device at one link end and a receiver device at the other link end (see figure 3). When a Fabric is present in the configuration, multiple links may be utilized to attach more than one transmitter device to more than one receiver device (see figure 4). Patch panels or portions of the active Fabric may function as repeaters, concentrators or fiber converters. A path between two N_Ports may be made up of links of different technologies. For example, the path may have multimode fiber links or copper cables attached to end Ports but may have a single-mode link in between as illustrated in figure 5. In figure 6, a typical Fibre Channel building wiring configuration is shown.

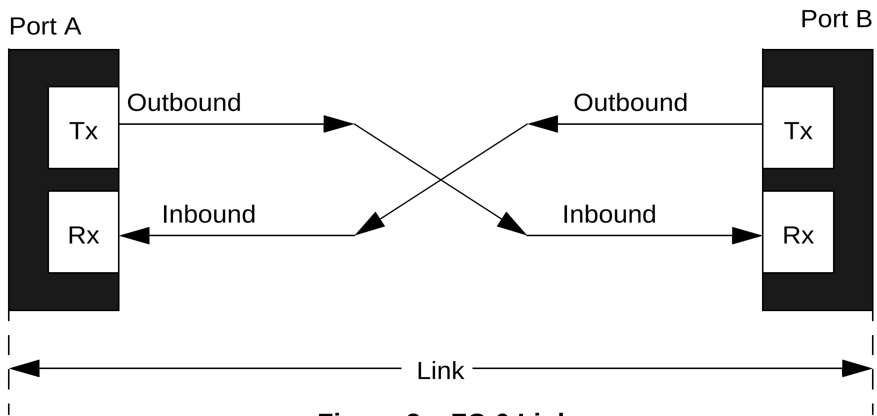


Figure 3 – FC-0 Link

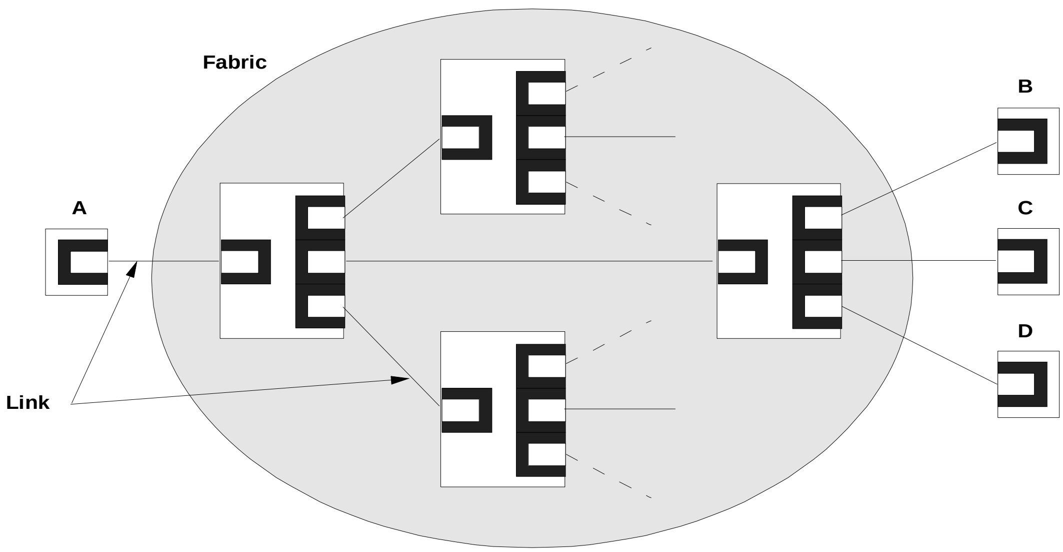


Figure 4 – Fabric

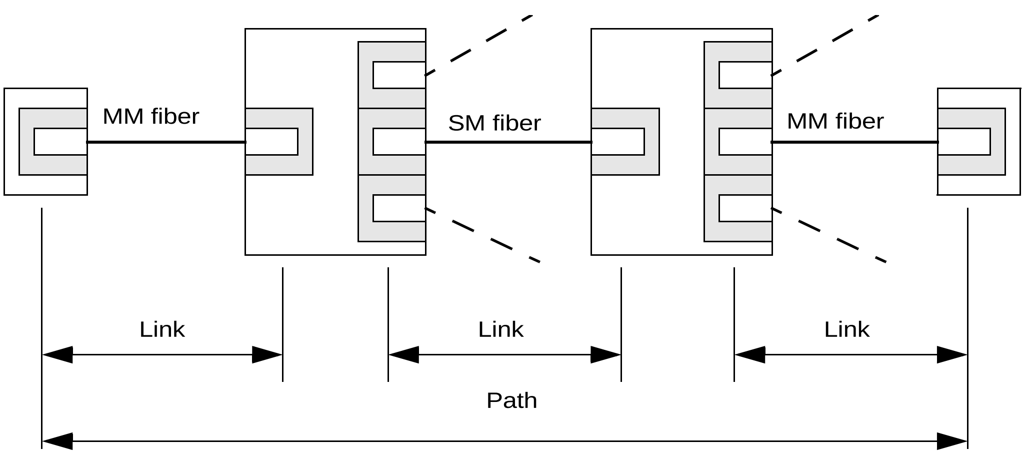


Figure 5 – FC-0 Path

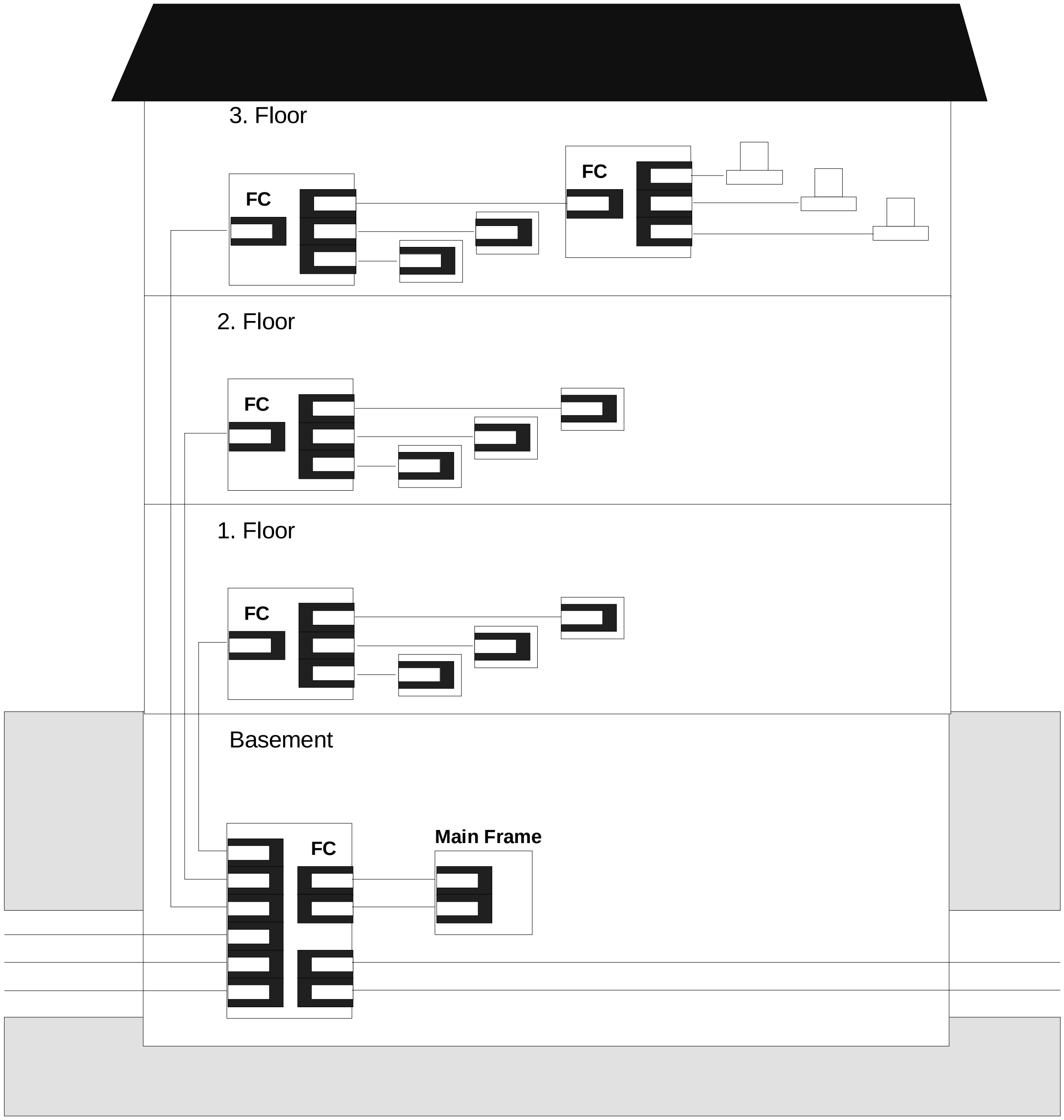


Figure 6 – Fibre channel building wiring

4.3 FC-0 interface overview

The interoperability points are shown in figures 8, 9, 10 and 11. The "α" points are for reference only.

The nomenclature used by FC-PI-4 to reference various combinations of components is defined in clause 5.

The link distance capabilities specified in FC-PI-4 are based on ensuring interoperability across multiple vendors supplying the technologies (both transceivers and cable plants) under the tolerance limits specified in FC-PI-4. Greater link distances may be obtained by specifically engineering a link based on knowledge of the technology characteristics and the conditions under which the link is installed and operated. However, such link distance extensions are outside the scope of FC-PI-4.

5 FC-PI-4 functional characteristics

5.1 General characteristics

FC-PI-4 describes the physical link, the lowest level, in the Fibre Channel system. It is designed for flexibility and allows the use of several physical interconnect technologies to meet a wide variety of system application requirements.

The FC-FS-2 protocol is defined to operate across connections having a bit error ratio (BER) detected at the receiving port of less than 10^{-12}. It is the combined responsibility of the component suppliers and the system integrator to ensure that this level of service is provided at every port in a given Fibre Channel installation.

FC-PI-4 has the following general characteristics.

In the physical media signals a logical “1” shall be represented by the following properties:

1) Optical - the state with the higher optical power

2) Balanced copper - the state where the conductor identified as “+” is more positive than the conductor identified as “-”

Serial data streams are supported at signaling rates of 1GFC, 2GFC, 4GFC, and 8GFC. All data rates have transmitter and receiver clock tolerances of ±100 ppm. A TxRx Connection bit error rate (BER) of $\leq 10^{-12}$ as measured at its receiver is supported. The basis for the BER is the encoded serial data stream on the transmission medium during system operation.

FC-PI-4 defines eight different specific physical locations in the FC system that include six interoperability points and two reference points. No interoperability points are required for closed or integrated links and FC-PI-4 is not required for such applications. For closed or integrated links the system designer shall ensure that the a BER of better than 10^{-12} as required by FC-FS-2 is delivered.

The requirements specified in FC-PI-4 shall be satisfied at separable connectors where interoperability and component level interchangeability within the link are expected. A compliance point is a physical position where the specification requirements are met. For purposes of this document the terms “compliance point” and “interoperability point” are equivalent. The specified interoperability points are defined at separable connectors as these are the points where different components can easily be added, changed, or removed. The reference points are the alpha points. There is no maximum number of interoperability points between the initiating FC device and the addressed FC device as long as (1) the requirements at the interoperability points are satisfied for the respective type of interoperability point and (2) the end to end signal properties are maintained under the most extreme allowed conditions in the system. The description and physical location of the specified interoperability points and reference points are detailed in sub-clause 5.11. All specifications are at the interoperability points in a fully assembled system as if measured with a non-invasive probe.

It is the combined responsibility of the component (the separable hardware containing the connector portion associated with an interoperability point) supplier and the system integrator to ensure that intended interoperability points are identified to the users of the components and system. This is required because not all connectors in a link are interoperability points and similar connectors and connector positions in different applications may not satisfy the FC-PI-4 requirements.

The signal and return loss requirements in this document apply under specified test conditions that simulate some parts of the conditions existing in service. This simulation includes, for example, duplex traffic on all Ports and under all applicable environmental conditions. Effects caused by other features existing in service such as non ideal return loss in parts of the link that are not present when measuring signals in the specified test conditions are included in the specifications themselves. This methodology is required to give each side of the interoperability point requirements that do not depend on knowing the properties of the other side. In addition, it allows measurements to be performed under conditions that are accessible with practical instruments and that are transportable between measurement sites.

Measuring signals in an actual functioning system at an interoperability point does not verify compliance for the components on either side of the interoperability point although it does verify that the specific combination of components in the system at the time of the measurement produces compliant signals. Interaction between components on either side of the interoperability point may allow the signal measured to be compliant but this compliance may have resulted because one component is out of specification while the other is better than required.

It is recommended that additional margin be allowed when performing compliance measurements to account for conditions existing in service that may not have been accounted for in the specified measurements and specifications.

The interface to FC-FS-2 occurs at the logical encoded data interfaces. As these are logical data constructs, no physical implementation is implied by FC-FS-2. FC-PI-4 is written assuming that the same single serial data stream exists throughout the link as viewed from the interoperability points. Other possible schemes for transmitting data, for example using parallel paths, are not defined in FC-PI-4 but could occur at intermediate places between interoperability points.

Physical links have the following general requirements:

a) Physical point-to-point data links; no multidrop attachments along the serial path.

b) Signal requirements shall be met under the most extreme specified conditions of system noise and with the minimum compliant quality signal launched at upstream interoperability points.

c) All users are cautioned that detailed specifications shall take into account end-of-life worst case values (e.g., manufacturing, temperature, power supply).

The interface between FC-PI-4 and FC-FS-2 is intentionally structured to be technology and implementation independent. That is, the same set of commands and services may be used for all signal sources and communication schemes applicable to the technology of a particular implementation. As a result of this, all safety or other operational considerations that may be required for a specific communications technology are to be handled by the FC-PI-4 clauses associated with that technology. An example of this would be ensuring that optical power levels associated with eye safety are maintained.

5.2 FC-0 States

5.2.1 Transmitter FC-0 states

The transmitter device is controlled by the FC-1 level. Its function is to convert the serial data received from the FC-1 level into the proper signal types associated with the transmission media.

The transmitter has the following states:

a) **Transmitter Not-Enabled State**: A not-enabled state is defined as optical output off for optical transmitters. Electrical transmitters in the not-enabled state shall not launch dynamic voltages exceeding the limits specified as Transmitter off voltage in table 23. A transmitter shall be in the not-enabled state at the completion of its power on sequence unless the transmitter is specifically directed otherwise by the FC-1 level.

b) **Transmitter Enabled State**: The transmitter is in an enabled state when the transmitter is capable of operation within its specifications while sending valid bit sequences.

c) **Transmitter Failure State**: Some types of transmitters are capable of monitoring themselves for internal failures. Examples are laser transmitters where the monitor diode current may be compared against a reference to determine a proper operating point. Other transmitters, such as Light Emitting Diodes and electrical transmitters do not typically have this capability. If the transmitter is capable of performing this monitoring function then detection of a failure shall cause entry into the transmitter failure state.

d) **Transition between Transmitter Not-Enabled and Transmitter Enabled States**: This transition is not specified in this document. However, see annex F for implementation examples.

5.2.2 Receiver States

The function of the receiver device is to convert the incoming data from the form required by the communications media employed, retime the data, and present the data and an associated clock to the FC-1 level. The receiver has no states.

5.3 Response to input data phase jumps

Some link_control_facilities may detect phase discontinuities in the incoming serial data stream. This may occur for example from the operation of an asynchronous serial switch at the transmitter. In the event of a phase discontinuity, the recovery characteristics of the receiver shall be as follows:

a) Phase jump - Uniform distribution between ±180°.

b) Link - Worst case

c) Degree of recovery - Within BER objective (10^{-12})

d) Probability of recovery - 95%

e) Recovery time - 2500 bit intervals from last phase jump

f) **Additional wait time before next phase jump** None

The FC-0 level shall require no intervention from higher levels to perform this recovery. If, at the end of the specified time, the higher levels determine that bit synchronization is not present these levels may assume a fault has occurred and take appropriate action.

5.4 Limitations on invalid code

FC-0 does not detect transmit code violations, invalid ordered sets, or any other alterations of the encoded bit stream. However, it is recognized that individual implementations may wish to transmit such invalid bit streams to provide diagnostic capability at the higher levels. Any transmission violation, such as invalid ordered sets, that follow valid character encoding rules shall be transparent to FC-0. Invalid character encoding could possibly cause a degradation in receiver sensitivity and increased jitter resulting in increased BER or loss of bit synchronization.

5.5 Receiver initialization time

The time interval required by the receiver from the initial receipt of a valid input to the time that the receiver is synchronized to the bit stream and delivering valid retimed data within the BER requirement, shall not exceed 1 ms. Should the retiming function be implemented in a manner that requires direction from a higher level to start the initialization process, the time interval shall start at the receipt of the initialization request.

5.6 Loss of signal (Rx_LOS) function

The FC-0 may optionally have a loss of signal function. If implemented, this function shall indicate when a signal is absent at the input to the receiver. The activation level shall lie in a range whose upper bound is the minimum specified sensitivity of the receiver and whose lower bound is defined by a complete removal of the input connector. While there is no defined hysteresis for this function there shall be a single transition between output logic states for any monotonic increase or decrease in the input signal power occurring within the reaction time of the signal detect circuitry. The reaction time to the input signal is defined in annex E.

5.7 Speed agile Ports that support Speed Negotiation

This clause specifies the requirements on speed agile Ports that support speed negotiation.

a) Ports shall not attain Transmission_Word synchronization unless the incoming signal is within ±10% of the receive rate set by the Port implementing the algorithm.

b) The Port transmitter shall be capable of switching from compliant operation at one speed to compliant operation at a new speed within 1 ms from the time the Speed Negotiation algorithm asks for a speed change.

c) The Port receiver shall attain Transmission_Word synchronization within 1ms when presented with a valid input stream as specified in sub-clause 5.5 if the input stream is at the receive rate set by the Port implementing the Speed Negotiation algorithm - the receiver shall also be capable of attaining Transmission_Word synchronization when presented with a valid input stream within 1 ms from the time the algorithm asks for a receiver speed change if the input stream is at the new receive rate set by the Port implementing the algorithm.

d) The Port transmitter and Port receiver shall be capable of operating at different speeds at the same time during Speed Negotiation.

5.8 Frame scrambling and emission lowering protocol

8GFC shall use the frame scrambling and emission lowering protocol as stated in FC-FS-2 AM1 (reference [5]). 1GFC, 2GFC, and 4GFC do not use scrambling.

5.9 Test patterns

8GFC shall use the test patterns stated in annex F. 1GFC, 2GFC, and 4GFC shall use the test patterns in FC-MJSQ.

5.10 FC-PI-4 nomenclature

The nomenclature for the Fibre Channel variants is illustrated in figure 7.

100-SM-LC-L

SPEED
1 200 -- 1 200 MB/s
800 -- 800 MB/s
400 -- 400 MB/s
200 -- 200 MB/s
100 -- 100 MB/s

TRANSMISSION MEDIA
SM -- single-mode optics connecting to a gamma point (OS1, OS2)
M5 -- multimode 50 µm optics connecting to a gamma point (OM2)
M5E -- multimode 50 µm optics connecting to a gamma point (OM3)
M6 -- multimode 62.5 µm optics connecting to a gamma points (OM1)
SE -- unbalanced copper connecting to any interoperability point
DF -- balanced copper connecting to any interoperability point

INTEROPERABILITY POINT TYPE (formerly transceiver)
LC -- gamma point for long wave LASER cost reduced (1310 nm) with limiting optical receiver
SN -- gamma point short wave LASER (850 nm) with limiting optical receiver
EL -- any electrical point except an EA delta point (includes SN PMD delta points) that assumes a non-equalizing reference receiver (with or without a compliance interconnect)
EA -- any electrical point that assumes a specified equalizing reference receiver for measurement
LL -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a limiting optical receiver
SA -- gamma point short wave LASER (850 nm) assuming a linear optical receiver
LA -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a linear optical receiver
Receiver type and fiber type indicates assumptions used for developing link budgets and does not indicate a requirement on receiver or fiber implementations

DISTANCE
V -- very long distance (up to 50 km)
L -- long distance (up to 10 km)
M -- medium distance (up to 4 km)
I -- intermediate distance (up to 2 km)
S -- short distance (up to 70 m)

NOTE -- The acronym "LC" when used with the "LC" connector and when used to describe the "LC" optical transmission variant are not related.

Figure 7 – Fibre Channel variant nomenclature

5.11 Interoperability points (informative)

This clause contains examples of interoperability points in various configurations. These examples are useful to illustrate how the definitions of the interoperability and reference points may appear in practical systems. This clause also shows an illustration of the two different signal specification environments defined in FC-PI-4, intra enclosure and inter enclosure, with all the different configurations of interoperability points that are possible within the same link.

Interoperability at the points defined requires satisfying both the specified physical location and the specified signal requirements. If either are missing then the interface becomes a non-interoperable interface for that point in the link only -- the link could still satisfy the requirements for end to end operation even if intermediate points do not meet the interoperability requirements. Durable identification is required for all points in the link that are expected to be interoperability points (in user documentation for example).

Figure 8 shows details of an implementation involving FC devices contained within an enclosure and shows how active components not specified in FC-PI-4 may be required to complete the link between the intra enclosure and inter enclosure environments.

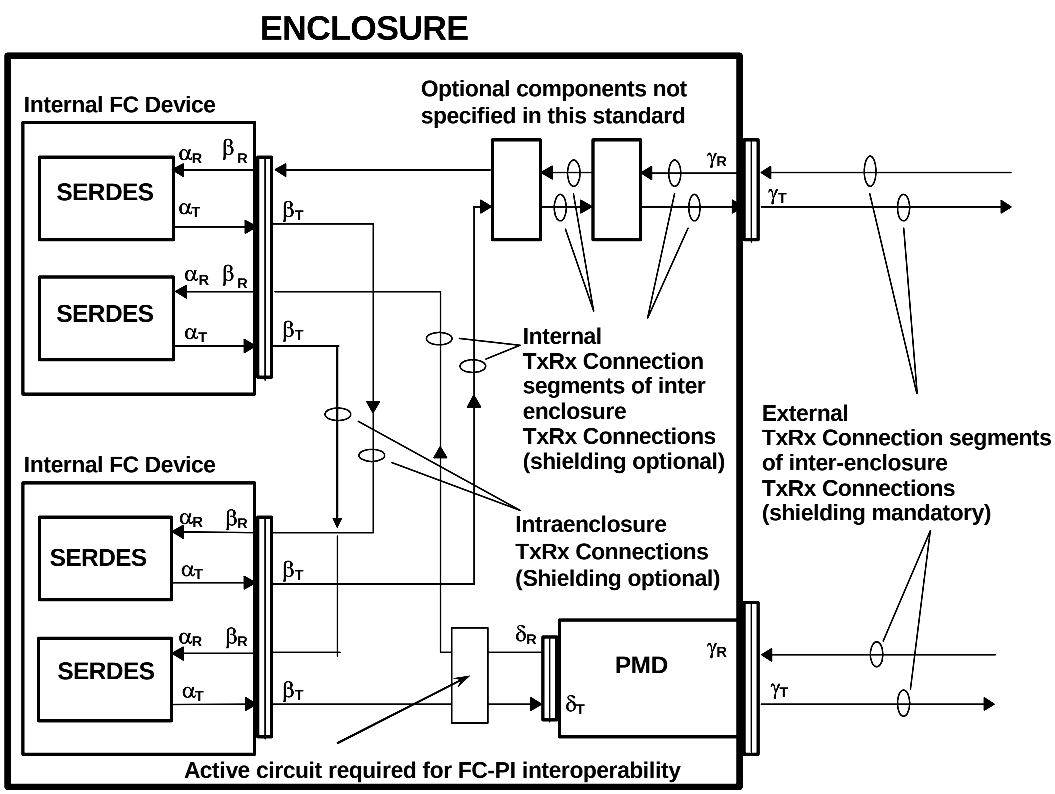
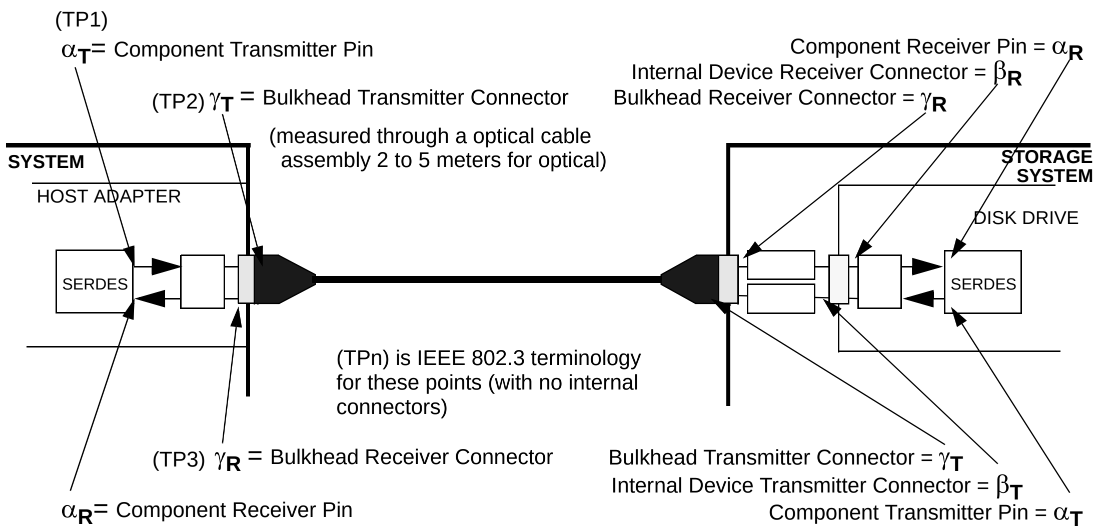
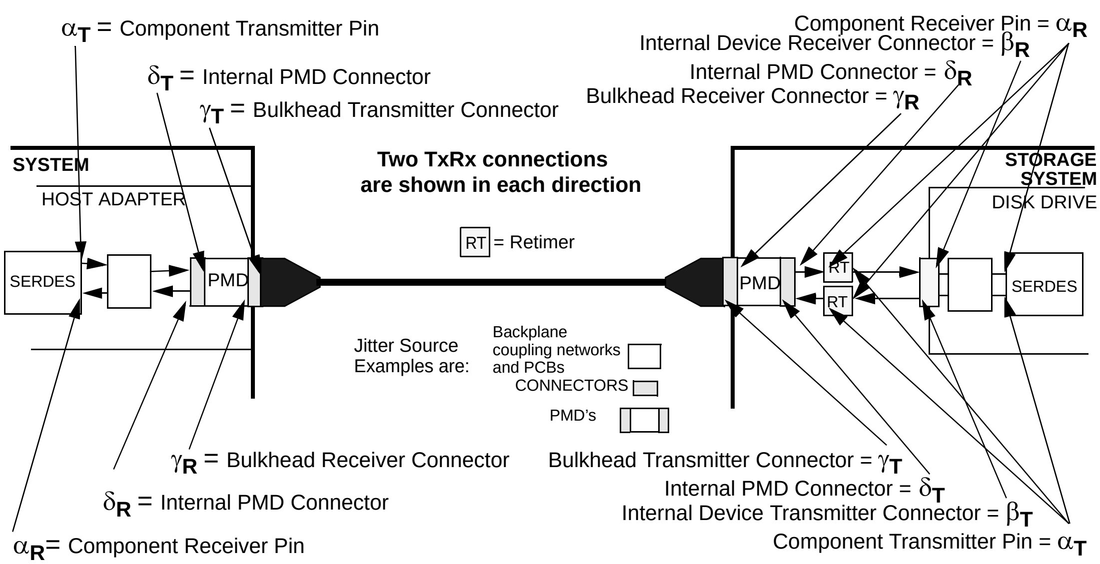


Figure 8 – Example of physical location of reference and interoperability points

Figure 9 shows another example of a complete duplex link between a host system adapter and a disk drive both with and without Delta points.



Without use of Internal δ Connectors

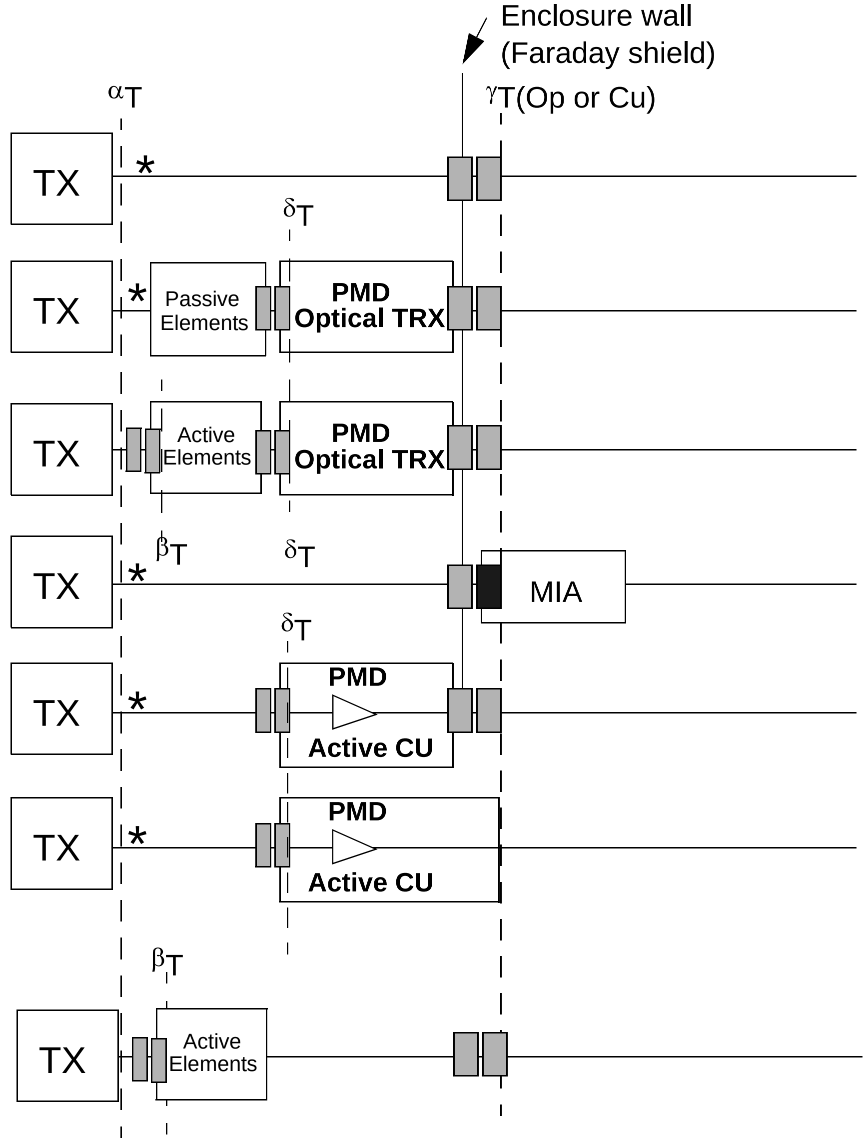


With use of internal δ connectors and retimers

(α is a reference point, not an interoperability point)

Figure 9 – Interoperability points examples at connectors

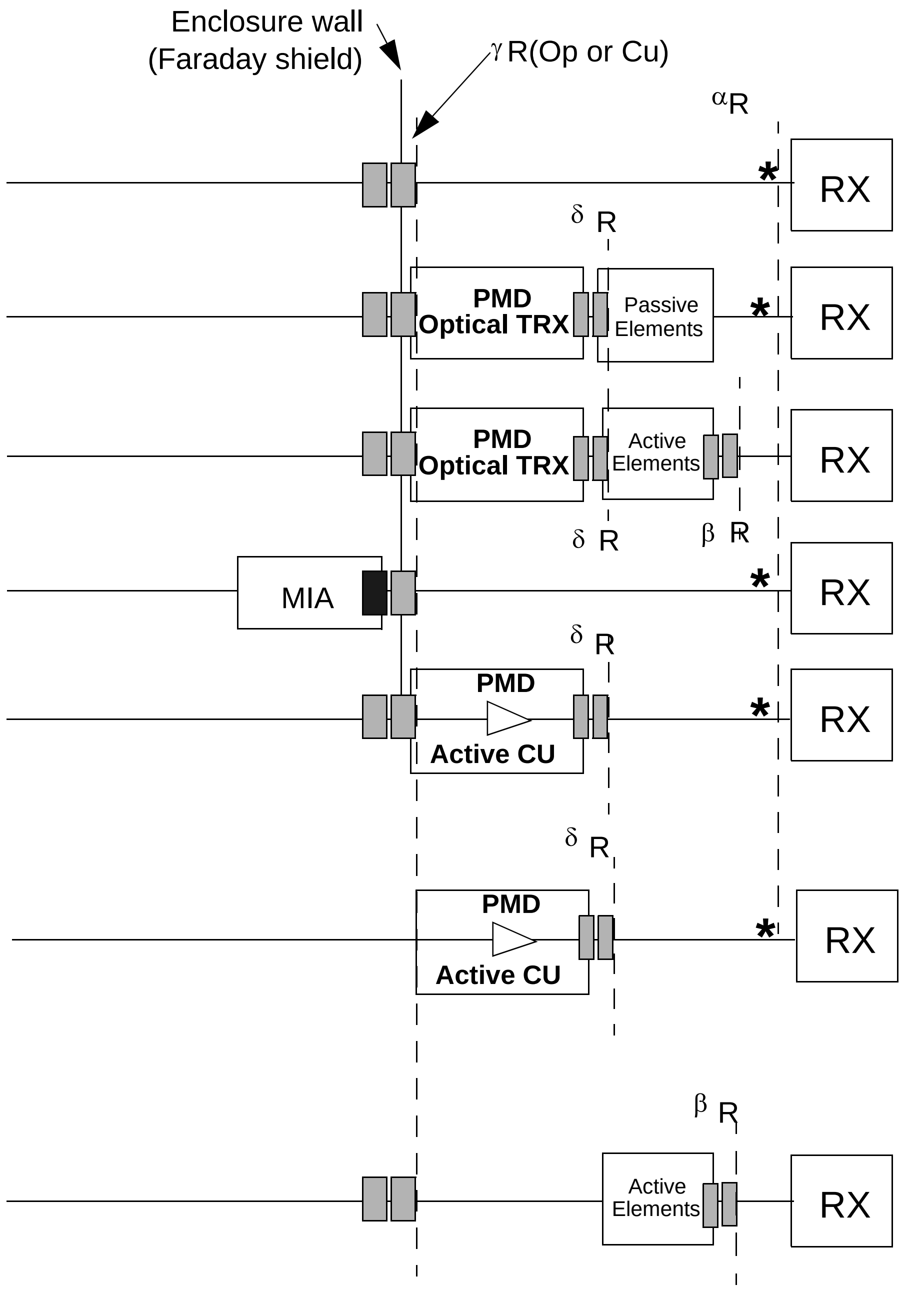
Figures 10 and 11 show more detailed examples of the Tx and Rx ends of simplex links with pointers to the physical location of the interoperability and reference points.



*** Inter enclosure configurations with beta points require active circuits for FC-PI-4 interoperability between beta and delta or, if no delta point exists, between beta and gamma. In this figure TX indicates a SERDES and associated transmitter.**

Figure 10 – Tx interoperability points (examples)

Figure 12 shows an example of a loop configuration that includes an external Retiming hub. Similar configurations that do not have Retiming elements in the hub will not have Gamma points associated with the hub external connectors.



*** Inter enclosure configurations with beta points require active circuits for FC-PI-4 interoperability between beta and delta or, if no delta point exists, between beta and gamma. In this figure RX indicates a SERDES and associated receiver.**

Figure 11 – Rx interoperability points (examples)

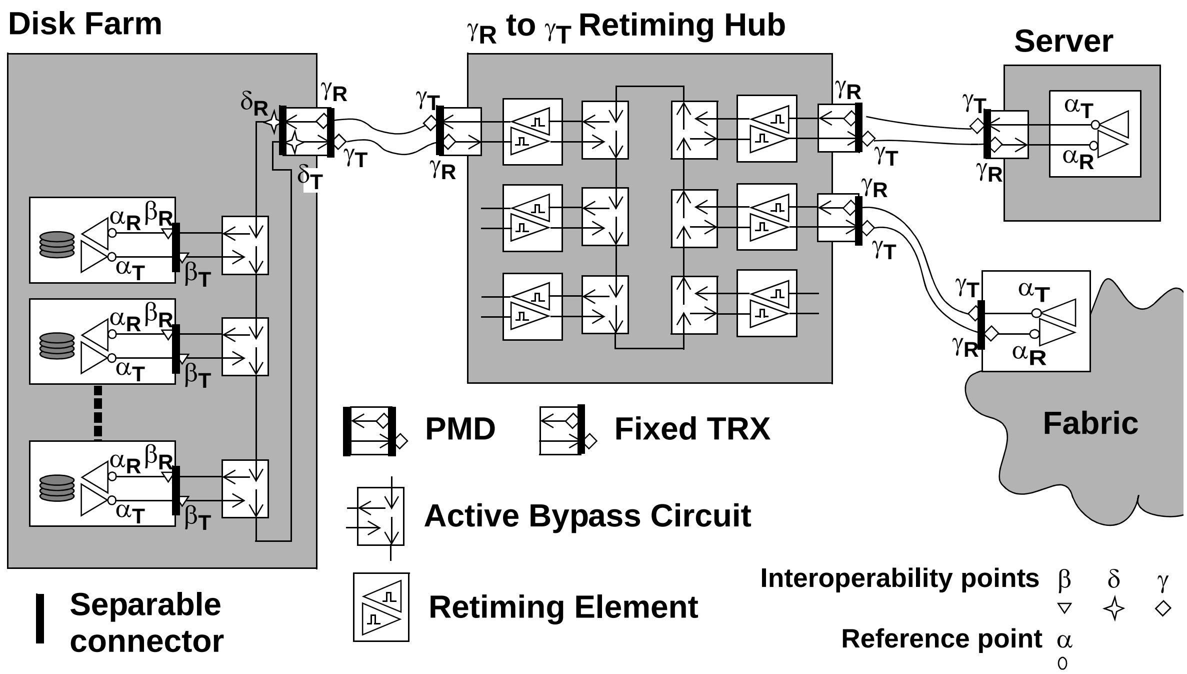


Figure 12 – Hub interoperability points (example)

Figure 13 shows examples of fabric and point to point configurations. For clarity, only simplex connections are illustrated.

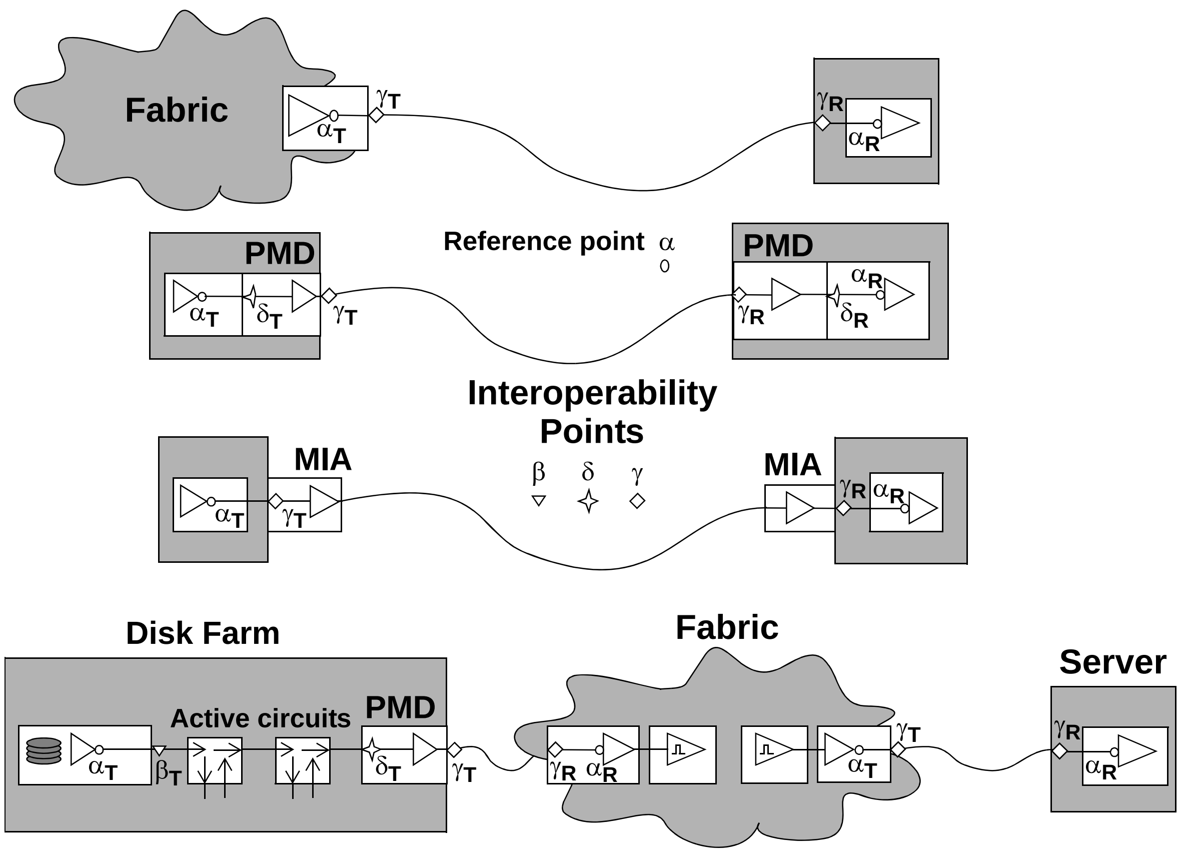
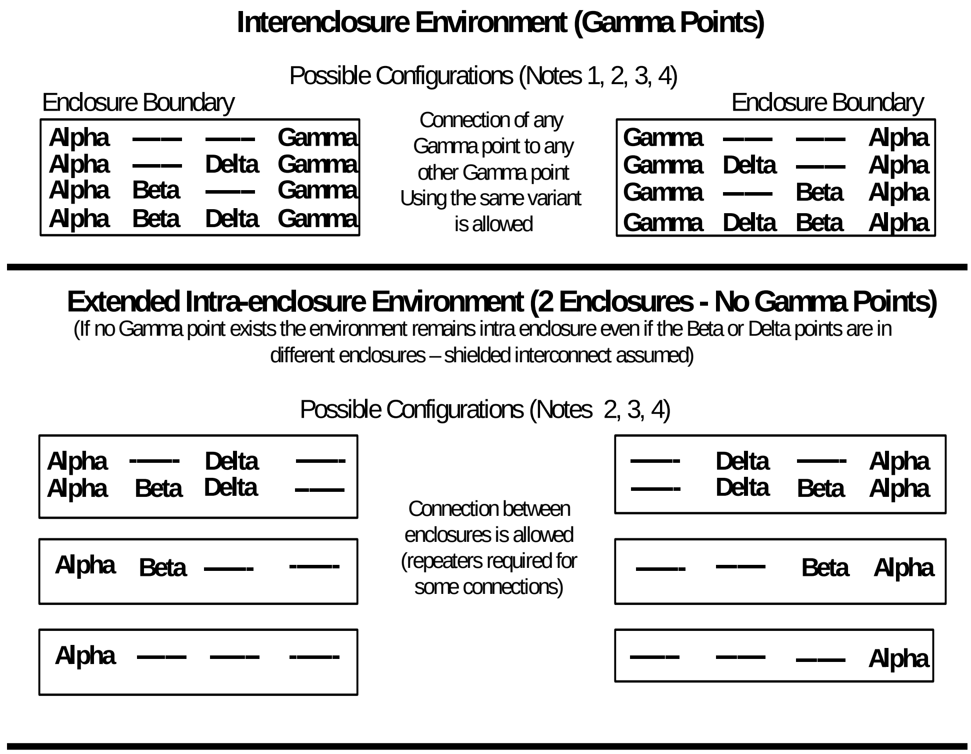


Figure 13 – Examples of interoperability points

The alpha points are at the pads of the package containing the SERDES. The beta points are at the downstream side of the separable connectors nearest the SERDES of the internal FC device. The delta points are at the downstream side of the separable connector inside the enclosure nearest the gamma points. The gamma points are at the downstream side of the external connector on the enclosure. The enclosure is the EMC shielded boundary (Faraday shield) for the components.

The signal requirements at each interoperability point are specified in the sections of this document that define the requirements for the variant.

Figure 14 shows an overview of the signal specification architecture used in FC-PI-4. The two largely independent environments, the requirement for active circuit isolation, and the possible combinations of interoperability points in a link are related in the ways shown in this figure.



Note 1:
Repeaters are required in the enclosure when the enclosure includes both Beta and Gamma points in the same link. Repeaters preserve independent amplitude budgets for both intra and inter environments. If retimers are used to provide this function, independent jitter budgets are also preserved.

Note 2:
Signal requirements for Alpha points associated with Beta points or intra-enclosure Alpha to Alpha configurations may be different from the signal requirements for Alpha points associated with Delta or Gamma points. No specifications are given for Alpha points in FC-PI-4. Alpha points only exist within enclosures.

Note 3:
As required by the application, a retimer may be inserted at any interoperability point in a configuration for purposes of compliance conversion to any other interoperability point.

Note 4:
The configuration on the left is independent of that on the right and vice versa. However, the compatibility between appropriate connecting points have been assumed.

Figure 14 – Overview of the signal specification architecture

5.12 Electrical TxRx connections

5.12.1 TxRx general overview

TxRx Connections may be divided into TxRx Connection Segments. (See figure 8.) Figure 15 shows the Beta compliance point in detail. Figure 16 shows the details of the Epsilon compliance point. In a single TxRx Connection individual TxRx Connection Segments may be formed from differing materials, including traces on printed circuit boards and optical fibers. This clause applies only to TxRx Connection Segments that are formed from electrical conductors.

The Electrical TxRx connection, or physical link, consists of three component parts: the transmitter device, the interconnect, and the receiver device. These three components may or may not be connected by two separable interconnects as shown in figure 15. In many cases one of the transmitter or receiver devices is embedded on the same board as the interconnect as shown in the example in figure 17. Because of these partially separable interconnect cases, where there may be only one interoperability point, all compliance point specifications in this clause assume that there is a compliant transmitter or receiver device terminating the other end of the interconnect.

Each electrical TxRx Connection Segment shall comply with the impedance requirements of table 36 for the media of which they are formed of.

TxRx Connections that are composed entirely of electrically conducting media shall be applied only to homogenous ground applications such as between devices within an enclosure or rack, or between enclosures interconnected by a common ground return or ground plane. This restriction minimizes safety and interference concerns caused by any voltage differences that could otherwise exist between equipment grounds.

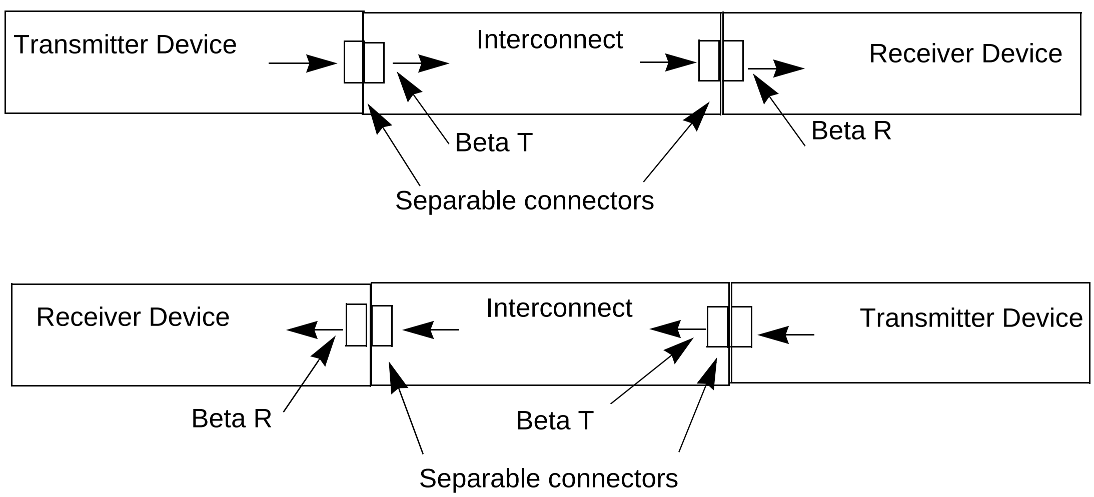


Figure 15 – Duplex Beta TxRx connections example

5.12.2 Partially separable links

There are many situations in which only one point in a link has an interoperability point. This happens, for example, if one device is imbedded (integrated) on the same board with the interconnect or when one end of the link is deemed by the system designer to not require interoperability (for example, a loop switch card in a JBOD system could be treated as part of the integrated system design where only the HDD’s are required to be interoperable).

Two cases of partially separable links are shown below in figure 17, both cases typically exist for duplex links - note that one may use the internal virtual connector (shown dotted) for system design.

– XX-00-200x Physical Interface-4 7.00

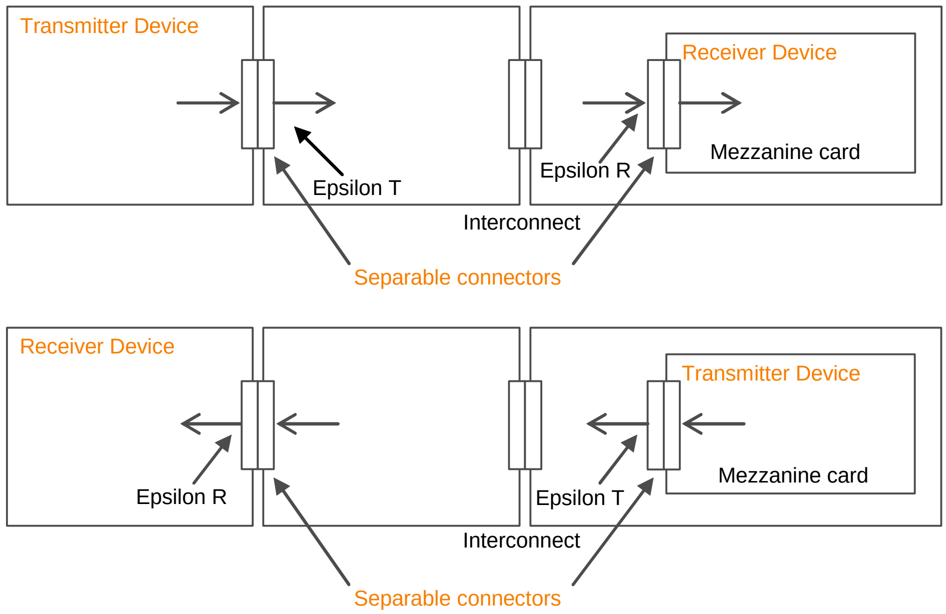


Figure 16 – Epsilon TxRx connection examples

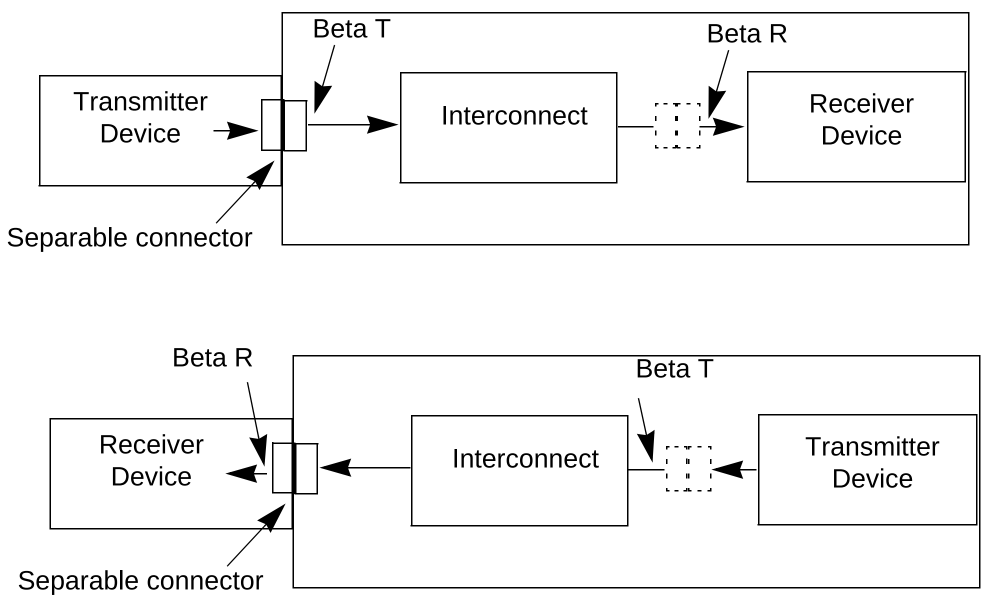


Figure 17 – Partially Separable links examples

5.13 FC-PI-4 variants

Table 5 lists variants by FC-PI-4 nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize the variant. The nomenclature is illustrated in figure 7. In addition other variants for longer distances are described in clause 11

Table 5 – FC-PI-4 variants

	100	200	400	800	1 200
SM OS1, OS2	**100-SM-LC-L** clause 6.3 SM 1 300 nm 2 m-10 km	**200-SM-LC-L** clause 6.3 SM 1 300 nm 2 m-10 km	**400-SM-LC-L** clause 6.3 SM 1 300 nm 2 m-10 km	**800-SM-LC-L** clause 6.3 SM 1 300 nm 2 m-10 km	note 1
	100-SM-LL-V clause 11 SM 1 550 nm 2 m-50 km	**200-SM-LL-V** clause 11 SM 1 550 nm 2 m-50 km			
			400-SM-LC-M clause 6.3 SM 1 300 nm 2 m-4 km	**800-SM-LC-I** clause 6.33 SM 1 300 nm 2 m-1.4 km	
MM 50 OM2	**100-M5-SN-I** clause 6.4 MM 850 nm 0.5 m-500 m	**200-M5-SN-I** clause 6.4 MM 850 nm 0.5 m-300 m	**400-M5-SN-I** clause 6.4 MM 850 nm 0.5 m-150 m	**800-M5-SN-S** clause 6.4 MM 850 nm 0.5 m-50 m	note 1
				800-M5-SA-I clause 6.4 MM 850 nm 0.5 m-100 m	
MM 50 OM3	**100-M5E-SN-I** clause 6.4 MM 780/850 nm 0.5 m-860 m	**200-M5E-SN-I** clause 6.4 MM 850 nm 0.5 m-500 m	**400-M5E-SN-I** clause 6.4 MM 850 nm 0.5 m-380 m	**800-M5E-SN-I** clause 6.4 MM 850 nm 0.5 m-150 m	note 1
				800-M5E-SA-I clause 6.4 MM 850 nm 0.5 m-300 m	
MM 62.5 OM1	**100-M6-SN-I** clause 6.4 MM 780/850 nm 0.5 m-300 m	**200-M6-SN-I** clause 6.4 MM 850 nm 0.5 m-150 m	**400-M6-SN-I** clause 6.4 MM 850 nm 0.5 m-70 m	**800-M6-SN-S** clause 6.4 MM 850 nm 0.5 m-21 m	note 1
				800-M6-SA-S clause 6.4 MM 850 nm 0.5 m-40 m	

Table 5 – FC-PI-4 variants

	100	200	400	800	1 200
EL Unbalanced (note 2)	**100-SE-EL-S** clause 9 Length depends on medium	**200-SE-EL-S** clause 9 Length depends on medium			note 1
EL Balanced	**100-DF-EL-S** clause 9 Length depends on medium	**200-DF-EL-S** clause 9 Length depends on medium	**400-DF-EL-S** clause 9 Length depends on medium	**800-DF-EL-S** clause 9 Length depends on medium	note 1

Notes:

1 For these variants refer to 10GFC and FC-PI-3.

2 This is obsoleted technology. For information refer to FC-PI-2.

The lengths specified in table 5 are the minimum lengths supported with transmitters, media, and receivers all simultaneously operating under the most degraded conditions allowed. Longer lengths may be achieved by restricting parameters in the transmitter, media, or receiver. If such restrictions are used on the link components then interoperability at interoperability points within the link and component level interchangeability within the link is no longer supported by this standard.

6 Optical interface specification

6.1 TxRx connections

Clause 6 defines the optical signal characteristics at the interface connector. Each conforming optical FC attachment shall comply with the requirements specified in clause 6 and other applicable clauses. Fibre Channel links shall not exceed the BER objective (10^{-12}) under any compliant conditions. The parameters specified in this clause support meeting that requirement under any compliant conditions. The corresponding cable plant specifications are described in clause 8.

A link, or TxRx connection, may be divided into TxRx connection segments (see figure 8). In a single TxRx connection individual TxRx connection segments may be formed from differing media and materials, including traces on printed wiring boards and optical fibers. This clause applies only to TxRx connection segments that are formed from optical fibre.

If electrically conducting TxRx connection segments are required to implement these optical variants, they shall meet the specifications of the appropriate electrical variants defined in clause 9 and clause 10.

6.2 Laser safety issues

a) The optical output shall not exceed the Class 1 maximum permissible exposure limits under any conditions of operation, (including open transmitter bore, open fiber and reasonable single fault conditions) per EN 60825-2 and CDRH 1040.10 regulations 21CFR chapter I sub chapter J.

b) Laser safety standards and regulations require that the manufacturer of a laser product provide information about a product's laser, safety features, labeling, use, maintenance and service.

6.3 SM data links

6.3.1 SM general information

Table 6 gives the variant names, a general link description, and the gamma compliance point specifications for 10 km single-mode optical fiber links running at 1GFC, 2GFC, 4GFC, and 8GFC, a 4 km single-mode fiber link running at 4GFC, and a 1.4 km single-mode fiber link running at 8GFC.

Table 6 – Single-mode link classes[1] (OS1, OS2)

FC-0	Unit	100-SM-LC-L	200-SM-LC-L	400-SM-LC-L	400-SM-LC-M	800-SM-LC-L	800-SM-LC-I	Note
Data rate	MB/s	100	200	400		800		
Nominal signaling rate	MBd	1 062.5	2 125	4 250		8 500		
Rate tolerance	ppm	±100						10
Operating distance	m	2 -10 000	2 -10 000	2 -10 000	2 - 4 000	2 -10 000	2 -1 400	
Transmitter (gamma-T)								
Type		Laser						
Center wavelength, max.	nm	figure 21	figure 22	figure 23	figure 24	1360	figure 25	2
Center wavelength, min.	nm					1260		
RMS spectral width, max.	nm					NA		
Optical modulation amplitude, min.	mW (dBm)					0.29 (-5.4)		2,5,13
Side-mode suppression	dB	NA				30	NA	
-20 dB spectral width	nm					1		
Average launched power, max.	dBm							3
Average launched power, min.	dBm	-9.5	-11.7	-8.4	-11.2	-8.4	-10.6	4
Rise/Fall time (20% - 80%), max.	ps	320	160	90	90	NA		6,12
RIN_{12} (OMA), max.	dB/Hz	-116	-117	-118	-120	-128	-128	7
Extinction Ratio, min	dB					3.5		
Transmitter and dispersion penalty, max	dB	NA				3.2	note 14	14
Receiver (gamma- R)								
Average received power, max.	dBm	-3	-3	-1	-1	+0.5	+0.5	
Rx jitter tolerance test, OMA	mW (dBm)	0.029 (-15.4)	0.022 (-16.6)	0.048 (-13.2)	0.048 (-13.2)	0.066 (-11.8)	0.066 (-11.8)	
Rx jitter tracking test, frequency and pk-pk amplitude	(kHz,UI)	NA				(510, 1) (100, 5)	(510, 1) (100, 5)	15
Unstressed receiver sensitivity, OMA	mW (dBm)	0.015 (-18.2)	0.015 (-18.2)	0.029 (-15.4)	0.029 (-15.4)	0.042 (-13.8)	0.042 (-13.8)	5,9,11
Return loss of receiver, min.	dB	12	12	12	12	12	12	
Receiver electrical 3 dB upper cutoff frequency, max	GHz	1.5	2.5	5.0	5.0	12	12	8

Table 6 – Single-mode link classes[1] (OS1, OS2)

Notes:

1 See: IEC 607932-2-50, Type B1.1 and IEC 607932-2-50, Type B1.3 Optical Fibres - Part 2: Product Specifications Fourth Edition, 1998-12

2 Trade-offs are available between center wavelength, RMS spectral width, and minimum optical modulation amplitude for transmitters other than 800-SM-LC-L. See figure 21 to figure 25.

3 Lesser of Class 1 laser safety limits (CDRH and EN 60825-2) or receiver power, max.

4 The value for 100-SM-LC-L is calculated using a 9 dB extinction ratio, consistent with 100-SM-LC-L of ANSI NCITS project 326-1999. The values for all other variants are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.

5 See annex A.1.1.1

6 Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in FC-PI-4 figure 18 for 1GFC, 2GFC, and 4GFC, and figure 19 for 8GFC. Transmitter eye diagram mask. If a filter is needed to conform to the mask the filter response effect is removed from the measured rise and fall times using the equation:

$T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 - (T_{RISE/FALL\_FILTER})^2]^{1/2}$

The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter. See annex A.1.1.4.

7 See annex A.1.3.2.

8 The receiver electrical upper cut off frequency values are informative and may be dependent upon the application and or the design approach of the receiver. See annex A.3.7.

9 See annex A.3.1.

10 The signaling rate shall not exceed ±100 ppm from the nominal data rate over all periods equal to 200 000 transmitted bits (~10 max length frames).

11 Whereas receiver sensitivity testing for the single-mode variants is allowed to be done with fast rise and fall time test signals, in application, some combinations of transmitters and cable plants may develop slowed rise and fall times and vertical eye closure due to the low pass filtering effects of chromatic dispersion. It is advised that optical receivers have sufficiently broad bandwidths in anticipation of this possibility.

12 Rise and fall time is controlled by transmitter and dispersion penalty (TDP) for 800 MB/s.

13 Optical modulation amplitude in dBm shall also exceed -7.0+TDP for 800-SM-LC-L. Note 2 does not apply to 800-SM-LC-L.

14 Transmitter and dispersion penalty (TDP) controls the contribution of RIN, the rise/fall times, and chromatic dispersion. TDP is defined by IEEE 802.3-2005 clause 52 using a fiber with dispersion at the worst case for the specified length. For 800-SM-LC-I the max values of TDP paired with the minimum values of OMA is given in figure 25.

15 Receiver jitter tracking is defined in annex A.3.5.

6.3.2 SM optical output interface

The optical transmit signal is defined at the output end of a patch cord between two and five meters in length, of a type specified in clause 8.1.2.

The mask of the eye diagram is intended to define the limits of overshoot, undershoot, and ringing of the transmitted optical signal. Conformance with the mask diagram is not to be used for determining compliance with the specifications for rise / fall time and jitter.

Optical modulation amplitude is defined as the difference in optical power between a logic-1 and a logic-0, as defined in annex A.1.1.1

The optical power is defined by the methods of IEC 61280-1-1, with the port transmitting an idle sequence or other valid Fibre Channel traffic.

The general laser transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see clause 5.11). These characteristics include rise time, fall time, pulse overshoot, pulse undershoot, and ringing. The parameters specifying the mask of the transmitter eye diagram are shown in figure 18 and figure 19. See annex A.1.1.3.

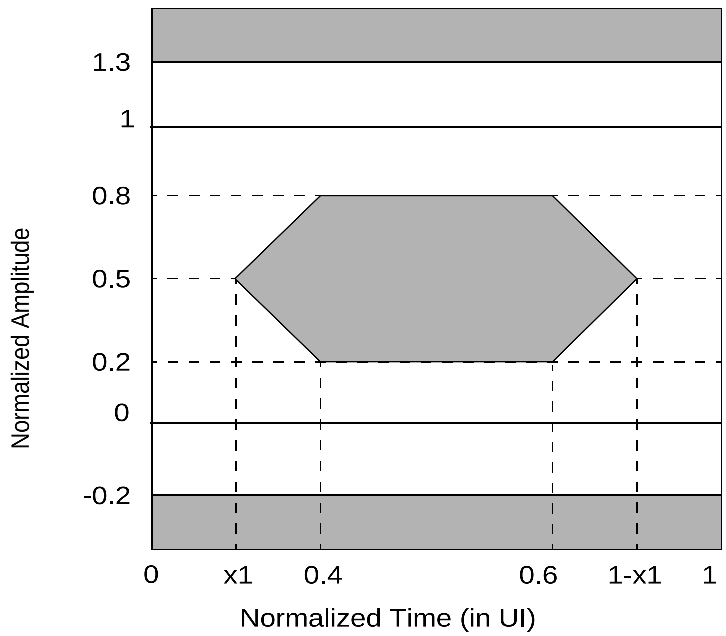


Figure 18 – SM transmitter eye diagram mask for 100, 200, and 400 variants

In figure 18, X1 shall be half the value given for total jitter at the gamma T point given in table 8. The test or analysis shall include the effects of a single pole high-pass frequency-weighting function, that progressively attenuates jitter at 20 dB/decade below a frequency of signaling rate/1 667. The value for X1 applies at a total jitter probability of 10^{-12}. At this level of probability direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements.

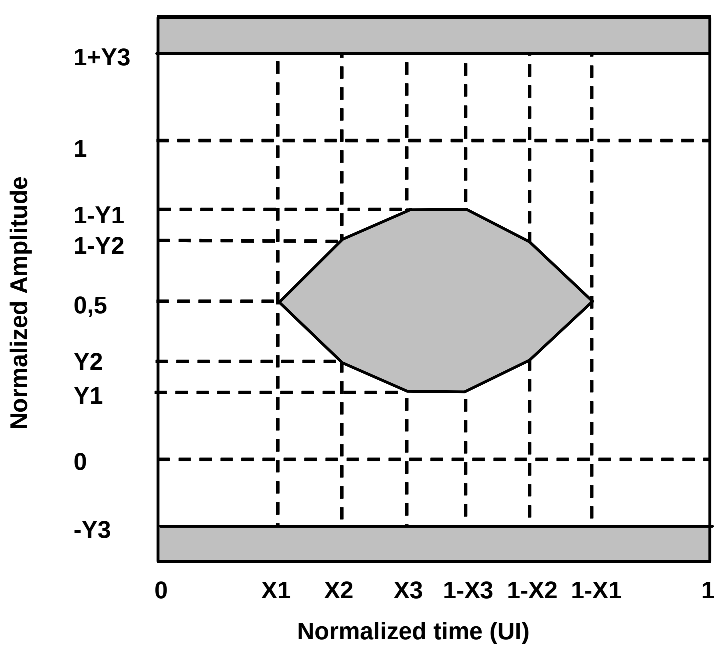


Figure 19 – SM transmitter eye mask for 800 MB/s variants

Table 7 shows the mask parameters of figure 19. The test or analysis shall include the effects of a single pole high-pass frequency-weighting function, that progressively attenuates jitter at 20 dB/decade below a frequency of signaling rate/1 667. The mask applies at a probability of 10^{-3}.

Table 7 – SM transmitter eye mask parameters for 800 MB/s variants

	Value	Unit
X1	0.25	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.32	
Y2	0.35	
Y3	0.40	

6.3.3 SM optical input interface

The receiver shall operate within the BER objective (10^{-12}) when the input power falls in the range given in table 6 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 18 and figure 19. See ISO/IEC 11801.

6.3.4 SM jitter budget

This sub-clause defines, for every interoperability point, the allowable jitter (see table 8, jitter output) and the jitter that shall be tolerated (see table 9). See FC-MJSQ clause 11.2.

Receiver TJ and DJ shall comply to the listed values in table 8, over all allowable optical power input ranges and extinction ratios, as listed in table 6.

Table 8 – SM jitter output, pk-pk, max

	Unit	β_T	δ_T	γ_T	γ_R	δ_R	β_R
100-SM-LC-L (note 4)							
Deterministic (DJ)[3]	UI	0.11	0.12	0.21	0.23	0.36	0.37
Total (TJ)[1,2,3]	UI	0.23	0.25	0.43	0.47	0.61	0.63
200-SM-LC-L (note 4)							
Deterministic (DJ)[3]	UI	NA	0.14	0.26	0.28	0.39	NA
Total (TJ)[1,2,3]			0.26	0.44	0.48	0.64	
400-SM-LC-M and 400-SM-LC-L (note 4)							
Deterministic (DJ)[3]	UI	NA	0.14	0.26	0.28	0.39	NA
Total (TJ)[1,2,3]			0.26	0.44	0.48	0.64	
800-SM-LC-I (note 4, 6)							
Deterministic (DJ)[3]	UI	NA	0.17	note 5		0.42	NA
Pulse Width Shrinkage (DDPWS)			0.11			0.36	
Total (TJ)[1,2,3]			0.31			0.71	
800-SM-LC-L (note 4, 6)							
Deterministic (DJ)[3]	UI	NA	0.17	note 5		0.42	NA
Pulse Width Shrinkage (DDPWS)			0.11			0.36	
Total (TJ)[1,2,3]			0.31			0.71	

Notes:

1 Total jitter is the sum of deterministic jitter and random jitter. If the actual deterministic jitter is less than the maximum specified, then the random jitter may increase as long as the total jitter does not exceed the specified maximum total jitter.

2 Total jitter is specified at the 10^{-12} probability.

3 The signal shall be measured using a jitter timing reference, e.g. Golden PLL.

4 Values at the α points are determined by the application.

5 Jitter at gamma T and gamma R are limited by TDP and receiver sensitivity as a composite measurement that replaces jitter values.

6 The values listed in this table are to be interpreted as at the appropriate compliance points which for delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for the higher signaling rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

Table 9 – SM jitter tolerance, pk-pk, min.

	Unit	β_T	δ_T	γ_T	γ_R	δ_R	β_R
100-SM-LC-L (note 4)							
Sinusoidal swept freq.(SJ)[3] **637 kHz to > 5 MHz**	UI	0.10					
Deterministic (DJ) 637 kHz-531 MHz	UI	0.11	0.12	0.21	0.23	0.36	0.37
Total (TJ)[1,2]	UI	0.28	0.30	0.48	0.52	0.66	0.68
200-SM-LC-L (note 4)							
Sinusoidal swept freq.(SJ)[3] **1 275 kHz to > 5 MHz**	UI	NA	0.10				NA
Deterministic (DJ) 1 275 kHz-1 062 MHz	UI	NA	0.14	0.26	0.28	0.39	NA
Total (TJ)[1,2]	UI	NA	0.31	0.49	0.53	0.69	NA
400-SM-LC-L and 400-SM-LC-M (note 4)							
Sinusoidal swept freq.(SJ)[3] **2 550 kHz to > 5 MHz**	UI	NA	0.10				NA
Deterministic (DJ) 2 550 kHz-2 125 MHz	UI	NA	0.14	0.26	0.28	0.39	NA
Total (TJ)[1,2]	UI	NA	0.31	0.49	0.53	0.69	NA
800-SM-LC-L and 800-SM-LC-I (note 4, 8)							
Sinusoidal swept freq.(SJ)[3] **5 098 kHz to > 20 MHz**	UI	NA	note 5		note 6	note 7	NA
Pulse Width Shrinkage (DDPWS)	UI	NA	note 5		note 6	0.36	NA
Deterministic (DJ) 5 098 kHz-4 250 MHz	UI	NA	note 5		note 6	0.42	NA
Total (TJ)[1,2]	UI	NA	note 5		note 6	0.71	NA

Notes:

1. The jitter values given are normative for a combination of DJ, RJ, and SJ that receivers shall be able to tolerate without exceeding a BER of 10^{-12}.
2. No value is given for random jitter (RJ). For compliance with this spec, the actual random jitter amplitude shall be the value that brings total jitter to the stated value at a probability of 10^{-12}.
3. Receivers shall tolerate sinusoidal jitter of progressively greater amplitude at lower frequencies, according to the mask in figure 20, combined with the same DJ and RJ levels as were used in the high frequency sweep
4. Values at the α points are determined by the application.
5. These values are not specified
6. Jitter at gamma R is limited by receiver sensitivity.
7. Receiver jitter tracking is measured using the procedure described in annex A.3.5. Receiver jitter tolerance is measured with SJ set to zero.
8. The values listed in this table are at the appropriate compliance points which for delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for the higher signaling rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

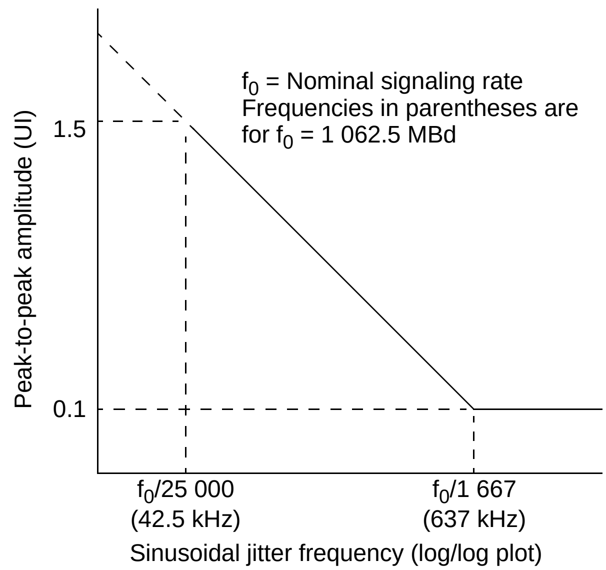


Figure 20 – Sinusoidal jitter mask

6.3.5 SM trade-offs

In order to meet the link power budget the transmitter's OMA, spectral width and center wavelength shall comply with figures 21 to 25. For any center wavelength and spectral width combination the minimum OMA required is equal to the value specified for the line which has the next largest spectral width.

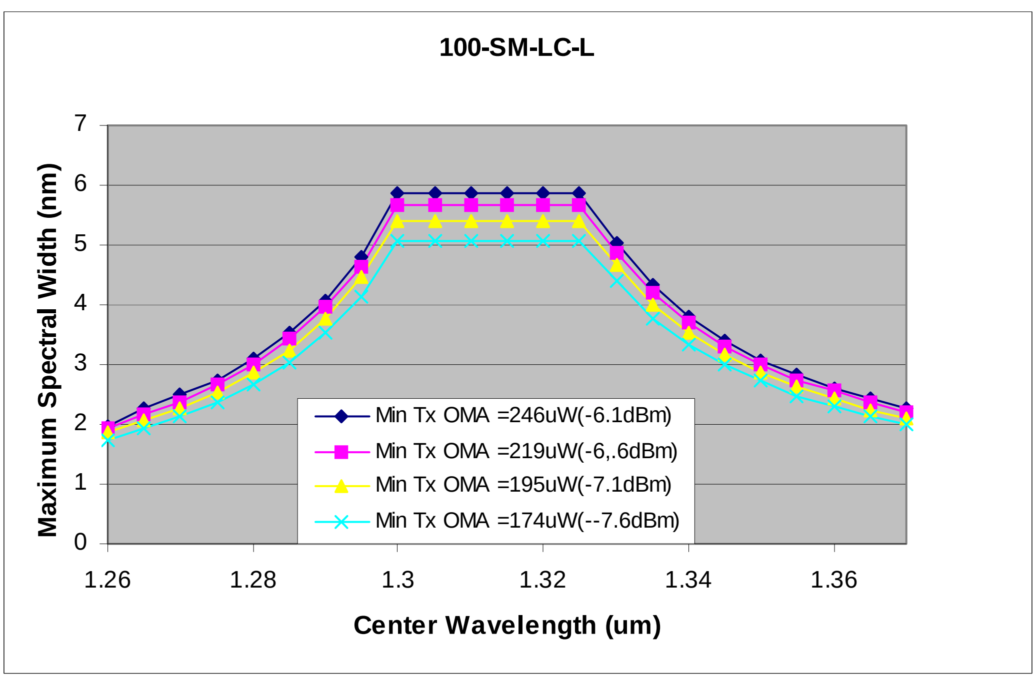


Figure 21 – 1GFC SM 10 km link

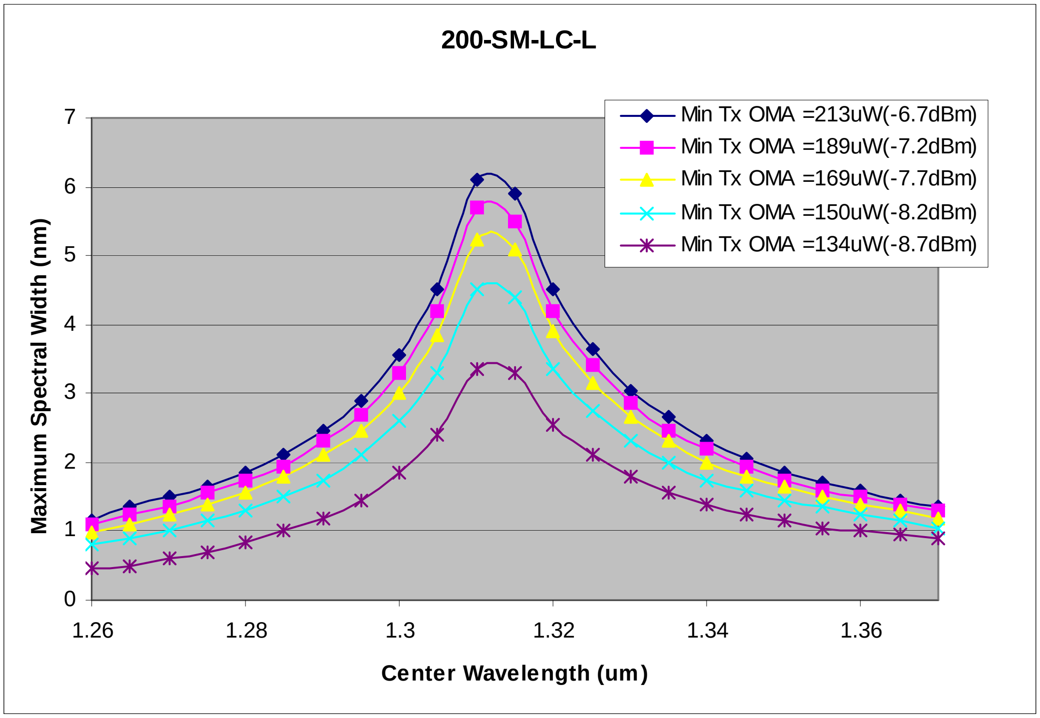


Figure 22 – 2GFC SM 10 km link

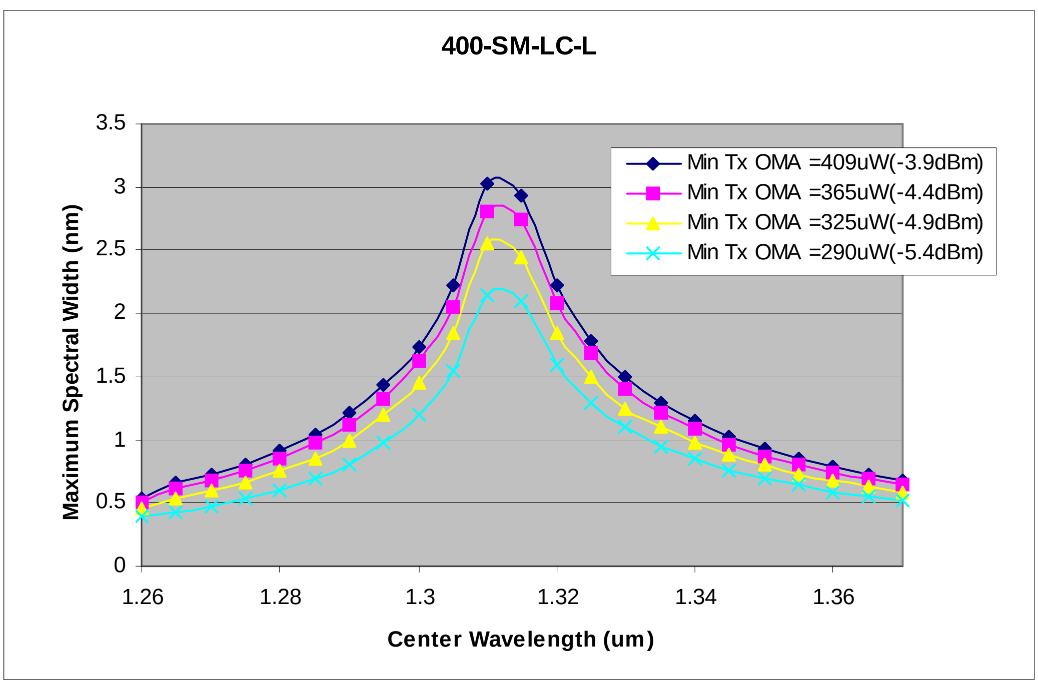


Figure 23 – 4GFC SM 10 km link

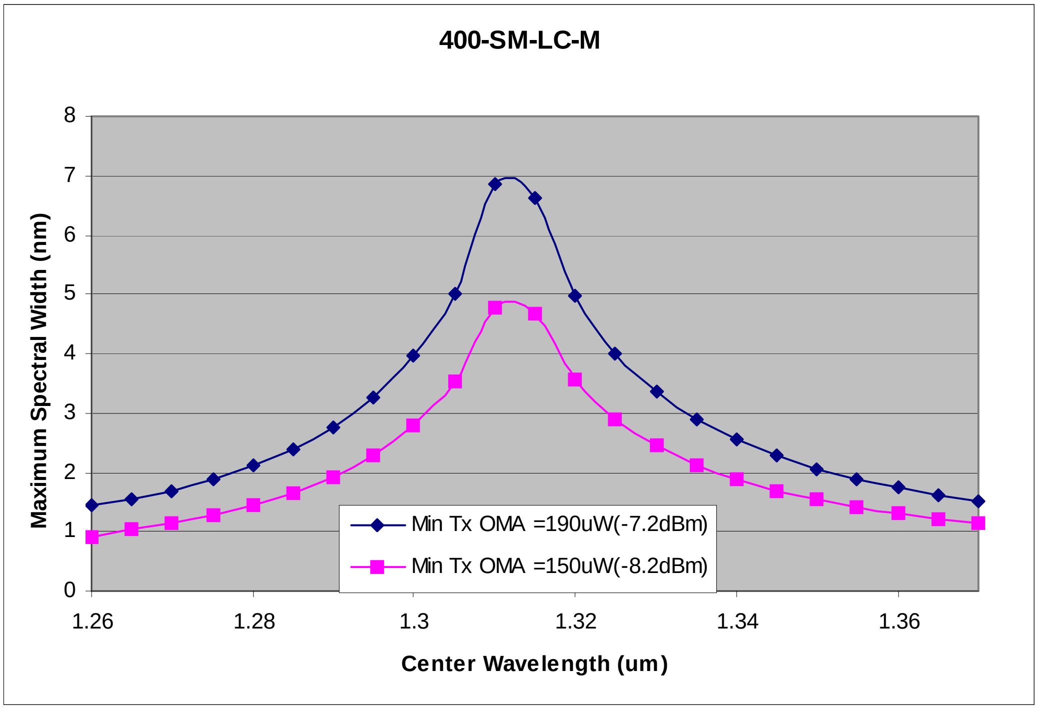


Figure 24 – 4GFC SM 4 km link

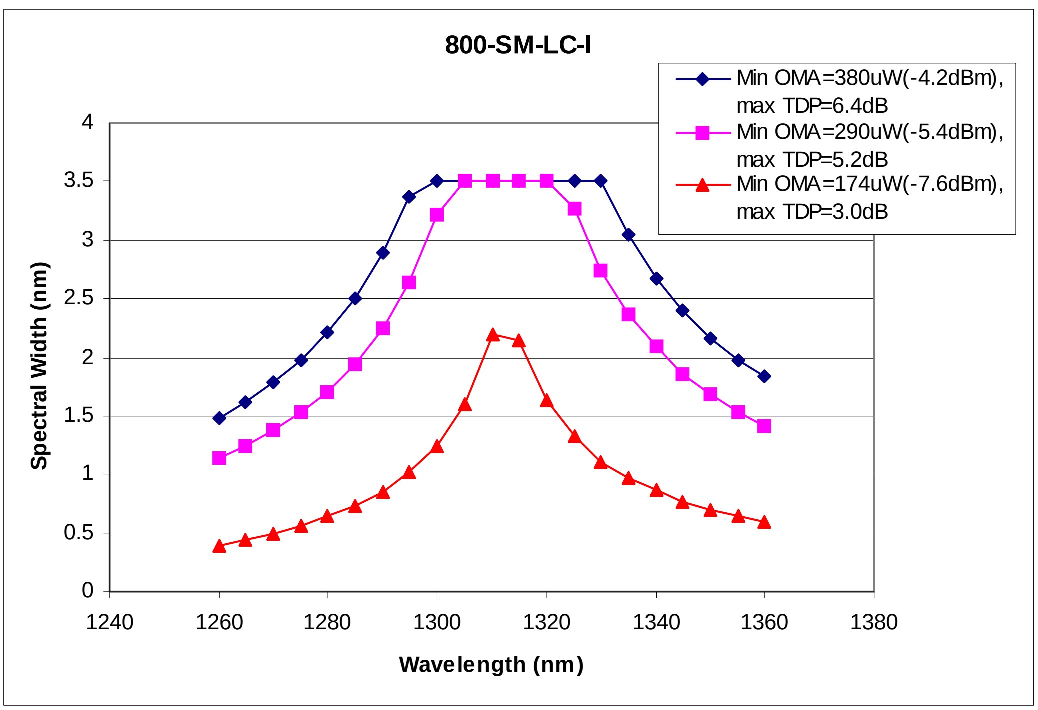


Figure 25 – 8GFC SM 1.4 km link

6.4 MM data links

6.4.1 MM general information

Tables 10 to 12 gives the variant names, a general link description, and the gamma compliance point specifications for multi-mode optical fiber links running at 1GFC, 2GFC, 4GFC, and 8GFC. The specifications in the tables are intended to allow compliance to Class 1 laser safety.

Table 10 – Multimode 50 μm link classes M5 (OM2)

FC-0	Unit	100-M5-SN-I	200-M5-SN-I	400-M5-SN-I	800-M5-SN-S	800-M5-SA-I	Note
Sub clause				6.4			
Data rate	MB/s	100	200	400	800	800	
Nominal signaling rate	MBd	1 062.5	2 125	4 250	8 500	8 500	
Rate tolerance	ppm			±100			note 10
Operating distance	m	0.5 - 500	0.5 - 300	0.5 - 150	0.5 - 50	0.5 - 100	note 1
Fiber core diameter	μm			50			note 2
Transmitter (gamma-T)							
Type				Laser			
Center wavelength, min.	nm	770	830	830	840	840	note 16
Center wavelength, max.	nm	860	860	860	860	860	note 16
RMS spectral width, max.	nm	1.0	0.85	0.85	0.65	note 20	note 16
Average launched power, max.	dBm						note 3
Average launched power, min.	dBm	-10	-10	-9	-8.2	-8	note 4
Optical modulation amplitude, min.	mW (dBm)	0.156 (-8.1)	0.196 (-7.1)	0.247 (-6.1)	0.302 (-5.2)	note 20	note 5
Rise/Fall time (20% - 80%), max.	ps	300	150	90	note 18		note 6
Transmitter waveform distortion penalty (TWDP), max	dB		NA		4.2	4.87	note 19
RIN_{12} (OMA), max.	dB/Hz	-116	-117	-118	-128	-128	note 7, 16
Receiver (gamma- R)							
Average received power, max.	dBm			0			
Unstressed receiver sensitivity, OMA	mW (dBm)	0.031 (-15.1)	0.049 (-13.1)	0.061 (-12.1)	0.076 (-11.2)	0.076 (-11.2)	note 5,9
Return loss of receiver, min.	dB			12			
Rx jitter tolerance test, OMA	mW (dBm)	0.064 (-11.9)	0.107 (-9.7)	0.154 (-8.1)	0.200 (-7.0)	NA	
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)		NA		(510, 1) (100, 5)	(510, 1) (100, 5)	note 17
Stressed test source for SA variants							
Relative noise RN (rms)				NA		0.0357	
OMA sensitivity	mW (dBm)					0.206 (-6.9)	note 14
WDP	dB					4.37	12,14,15
DDPWS	UI					0.21	note 14

Table 10 – Multimode 50 μm link classes M5 (OM2)

Stressed test source for SN variants							
Receiver sensitivity, OMA	mW (dBm)	0.055 (-12.6)	0.096 (-10.2)	0.138 (-8.6)	0.151 (-8.2)	NA	5,9,11,13
Receiver vertical eye closure penalty	dB	0.96	1.26	1.67	3.45		note 9,13
Receiver DCD component of DJ (at TX)	ps	80	40	20	NA		
Receiver DDPWS component of DJ	ps	NA			28		
Receiver DJ	ps				37.9		
Receiver electrical 3 dB upper cutoff frequency, max	GHz	1.5	2.5	5.0	12	12	note 8
Receiver electrical 10 dB upper cutoff frequency, max	GHz	3	6	12	NA	NA	note 8

Notes:

1. The operating ranges and loss budgets shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.
2. For details see sub-clause 8.2
3. Lesser of Class 1 laser safety limits (CDRH and EN 60825) or receiver power, max.
4. The value for 100-M5-SN-I is calculated using a 9 dB extinction ratio. The values for all other variants are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.
5. See annex A.1.1.1.
6. Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in figure 26 or figure 27. If a filter is needed to conform to the mask the filter response effect is removed from the measured rise and fall times using the equation:
   $T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 - (T_{RISE/FALL\_FILTER})^2]^{1/2}$
   The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter. See annex A.1.1.4
7. See annex A.1.3.2.
8. The receiver electrical upper cut off frequency values are informative and may be dependant upon the application and or the design approach of the receiver. See annex A.3.7.
9. The unstressed receiver sensitivity is informative only. See annex A.3.1.
10. The signaling rate shall not exceed ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames).
11. The stressed receiver sensitivity values in the table are for system level BER measurements that include the effects of actual CDR circuits. It is recommended that at least 0.5 dB additional margin be allocated if component / module level measurements are made with laboratory BERT instrumentation that samples in the center of the eye. 0.5dB is a typical value determined by observing the effects on margin when the receiver sampling window is reduced in the link model spreadsheets. Instead of adding margin, another possibility is to set the BERT to sample the receiver output eye at ±0.15 UI from the center.
12. Defined with DFE EQ reference receiver with 1 main and 2 feedback taps (see annex A.5)
13. The values for 800 MB/s links are calibrated with a forth order Bessel-Thomson filter at 0.75 x signal rate. The lower speed VECP calibration is with a wide band receiver.
14. OMA, RN, and DDPWS are defined through a 6.375 GHz fourth order Bessel-Thomson filter. The ISI filter that represents the fiber is disabled when these values are calibrated for receiver device testing. See annex A.5.
15. WDP is defined through a 6.375 GHz fourth order Bessel-Thomson filter. For receiver device testing WDP is defined with DDPWS already calibrated.
16. The Tx specifications for 400-M5E-SN-I are tighter than for 400-M5-SN-I and 400-M6-SN-I. The Tx Specifications for 100-M5E-SN-I are also tighter than for 100-M5-SN-I and 100-M6-SN-I.
17. Receiver jitter tracking is defined in annex A.3.5.
18. Transmitter deterministic performance is controlled by TWDP.
19. TWDP for the 800-M5-SN-S is calculated with a 1.0 equalizer and a 6.860 MHz Gaussian filter for the fiber simulation. TWDP for the 800-M5-SA-I option is calculated with a 1,2 equalizer and a 3.420 MHz Gaussian filter for the fiber simulation.
20. Trade offs are available between RMS spectral width and minimum optical modulation amplitude for 800-M5-SA-I variant. See figure 28.

Table 11 – Multimode 50 µm link classes M5E (OM3)

FC-0	Unit	100-M5E-SN-I	200-M5E-SN-I	400-M5E-SN-I (Note 16)	800-M5E-SN-I	800-M5E-SA-I	Note
Sub clause		6.4					
Data rate	MB/s	100	200	400	800	800	
Nominal signaling rate	MBd	1 062.5	2 125	4 250	8 500	8 500	
Rate tolerance	ppm	±100					note 10
Operating distance	m	0.5 - 860	0.5 - 500	0.5 - 380	0.5 - 150	0.5 - 300	note 1
Fiber core diameter	µm	50					note 2
Transmitter (gamma-T)							
Type		Laser					
Center wavelength, min.	nm	840	830	840	840	840	note 16
Center wavelength, max.	nm	860	860	860	860	860	note 16
RMS spectral width, max.	nm	0.85	0.85	0.65	0.65	note 21	note 16
Average launched power, max.	dBm						note 3
Average launched power, min.	dBm	-10	-10	-9	-8.2	-8	note 4
Optical modulation amplitude, min.	mW (dBm)	0.156 (-8.1)	0.196 (-7.1)	0.247 (-6.1)	0.302 (-5.2)	note 21	note 5
Rise/Fall time (20% - 80%), max.	ps	300	150	90	note 19		note 6
Transmitter waveform distortion penalty (TWDP), max	dB	NA			4.2	4.87	note 20
RIN_{12} (OMA), max.	dB/Hz	-116	-117	-120	-128	-128	note 7,note 16
Encircled flux		NA		note 18			
Receiver (gamma- R)							
Average received power, max.	dBm	0					
Unstressed receiver sensitivity, OMA	mW (dBm)	0.031 (-15.1)	0.049 (-13.1)	0.061 (-12.1)	0.076 (-11.2)	0.076 (-11.2)	note 5,9
Return loss of receiver, min.	dB	12					
Rx jitter tolerance test, OMA	mW (dBm)	0.064 (-11.9)	0.107 (-9.7)	0.154 (-8.1)	0.200 (-7.0)	NA	
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)	NA			(510, 1) (100, 5)	(510, 1) (100, 5)	note 17
Stressed test source for SA variants							
Relative noise RN (rms)	NA	NA				0.0501	
OMA sensitivity	mW (dBm)					0.214 (-6.7)	note 14
WDP	dB					4.07	12,14,15
DDPWS	UI					0.21	note 14
Stressed test source for SN variants							
Receiver sensitivity, OMA	mW (dBm)	0.047 (-13.3)	0.083 (-10.8)	0.126 (-9.0)	0.148 (-8.3)	NA	5,9,11,13
Receiver vertical eye closure penalty	dB	0.24	0.33	0.75	2.94		note 9,13
Receiver DCD component of DJ (at TX)	ps	80	40	20	NA		
Receiver DDPWS component of DJ	ps	NA			28		
Receiver DJ	ps				37.9		

Table 11 – Multimode 50 μm link classes M5E (OM3)

Receiver electrical 3 dB upper cutoff frequency, max	GHz	1.5	2.5	5.0	12	12	note 8
Receiver electrical 10 dB upper cutoff frequency, max	GHz	3	6	12	NA	NA	note 8

Notes:

1 The operating ranges and loss budgets shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.

2 For details see sub-clause 8.2

3 Lesser of Class 1 laser safety limits (CDRH and EN 60825) or receiver power, max.

4 The value for 100-M5E-SN-I is calculated using a 9 dB extinction ratio. The values for all other variants are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.

5 See annex A.1.1.1.

6 Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in figure 26 or figure 27. If a filter is needed to conform to the mask the filter response effect is removed from the measured rise and fall times using the equation:

$T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 - (T_{RISE/FALL\_FILTER})^2]^{1/2}$

The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter. See annex A.1.1.4

7 See annex A.1.3.2.

8 The receiver electrical upper cut off frequency values are informative and may be dependant upon the application and or the design approach of the receiver. See annex A.3.7.

9 The unstressed receiver sensitivity is informative only. See annex A.3.1.

10 The signaling rate shall not exceed ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames).

11 The stressed receiver sensitivity values in the table are for system level BER measurements that include the effects of actual CDR circuits. It is recommended that at least 0.5 dB additional margin be allocated if component / module level measurements are made with laboratory BERT instrumentation that samples in the center of the eye. 0.5dB is a typical value determined by observing the effects on margin when the receiver sampling window is reduced in the link model spreadsheets. Instead of adding margin, another possibility is to set the BERT to sample the receiver output eye at ±0.15 UI from the center.

12 Defined with DFE EQ reference receiver with 1 main and 2 feedback taps (see annex A.5)

13 The values for 800 MB/s links are calibrated with a forth order Bessel-Thomson filter at 0.75 x signal rate. The lower speed VECP calibration is with a wide band receiver.

14 OMA, RN, and DDPWS are defined through a 6.375 GHz fourth order Bessel-Thomson filter. The ISI filter that represents the fiber is disabled when these values are calibrated for receiver device testing.

15 WDP is defined through a 6.375 GHz fourth order Bessel-Thomson filter. For receiver device testing WDP is defined with DDPWS already calibrated.

16 The Tx specifications for 400-M5E-SN-I are tighter than for 400-M5-SN-I and 400-M6-SN-I. The Tx Specifications for 100-M5E-SN-I are also tighter than for 100-M5-SN-I and 100-M6-SN-I.

17 Receiver jitter tracking is defined in annex A.3.5.

18 Encircled flux specifications in accordance with TIA-492AAAC-A and IEC 60793-2-10 or IEEE 802.3 clause 52.

19 Transmitter deterministic performance is controlled by TWDP.

20 TWDP for the 800-M5E-SN-I is calculated with a 1.0 equalizer and a 6.860 MHz Gaussian filter for the fiber simulation. TWDP for the 800-M5E-SA-I option is calculated with a 1,2 equalizer and a 3.420 MHz Gaussian filter for the fiber simulation.

21 Trade offs are available between RMS spectral width and minimum optical modulation amplitude for 800-M5E-SA-I variant. See figure 28.

Table 12 – Multimode 62.5 μm link classes (OM1)

FC-0	Unit	100-M6-SN-I	200-M6-SN-I	400-M6-SN-I	800-M6-SN-S	800-M6-SA-S	Note
Subclass		6.4					
Data rate	MB/s	100	200	400	800	800	
Nominal signaling rate	MBd	1 062.5	2 125	4 250	8 500	8 500	
Rate tolerance	ppm	±100					note 10
Operating distance	m	0.5 - 300	0.5 - 150	0.5 - 70	0.5 - 21	0.5 - 40	note 1
Fiber core diameter	μm	62.5					note 2
Transmitter (gamma-T)							
Type		Laser					
Center wavelength, min.	nm	770	830	830	840	840	note 16
Center wavelength, max.	nm	860	860	860	860	860	note 16
RMS spectral width, max.	nm	1.0	0.85	0.85	0.65	note 20	note 16
Average launched power, max.	dBm						note 3
Average launched power, min.	dBm	-10	-10	-9	-8.2	-8	note 4
Optical modulation amplitude, min.	mW (dBm)	0.156 (-8.1)	0.196 (-7.1)	0.247 (-6.1)	0.302 (-5.2)	note 20	note 5
Rise/Fall time (20% - 80%), max.	ps	300	150	90	note 18		note 6
Transmitter waveform distortion penalty (TWDP), max	dB	NA			4.2	4.87	note 19
RIN_{12} (OMA), max.	dB/Hz	-116	-117	-118	-128	-128	note 7,16
Receiver (gamma- R)							
Average received power, max.	dBm	0					
Unstressed receiver sensitivity, OMA	mW (dBm)	0.031 (-15.1)	0.049 (-13.1)	0.061 (-12.1)	0.076 (-11.2)	0.076 (-11.2)	note 5,9
Return loss of receiver, min.	dB	12					
Rx jitter tolerance test, OMA	mW (dBm)	0.078 (-11.1)	0.121 (-9.2)	0.164 (-7.9)	0.2 (-7.0)	NA	
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)	NA			(510, 1) (100, 5)	(510, 1) (100, 5)	note 17
Stressed test source for SA variants							
Relative noise, RN (rms)		NA				0.0357	
Receiver OMA sensitivity	mW (dBm)					0.217 (-6.6)	note 14
WDP	dB					4.36	12,14,15
DDPWS	UI					0.21	note 14
Stressed test source for SN variants							
Receiver sensitivity, OMA	mW (dBm)	0.067 (-11.7)	0.109 (-9.6)	0.148 (-8.3)	0.155 (-8.1)	NA	5,9,11,13
Receiver vertical eye closure penalty	dB	2.18	2.03	2.14	3.52		note 9,13
Receiver DCD component of DJ (at TX)	ps	80	40	20	NA		
Receiver DDPWS component of DJ	ps	NA			28		
Receiver DJ	ps				37.9		
Receiver electrical 3 dB upper cutoff frequency, max	GHz	1.5	2.5	5.0	12	12	note 8

Table 12 – Multimode 62.5 μm link classes (OM1)

Receiver electrical 10 dB upper cutoff frequency, max	GHz	3	6	12	NA	NA	note 8

Notes:

1 The operating ranges and loss budgets shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.

2 For details see sub-clause 8.2

3 Lesser of Class 1 laser safety limits (CDRH and EN 60825) or receiver power, max.

4 The value for 100-M6-SN-I is calculated using a 9 dB extinction ratio. The values for all other variants are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.

5 See sub-clause A.1.1.1.

6 Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in figure 26 or figure 27. If a filter is needed to conform to the mask the filter response effect is removed from the measured rise and fall times using the equation:

$T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 – (T_{RISE/FALL\_FILTER})^2]^{1/2}$

The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter. See annex A.1.1.4

7 See annex A.1.3.2.

8 The receiver electrical upper cut off frequency values are informative and may be dependant upon the application and or the design approach of the receiver. See annex A.3.7.

9 The unstressed receiver sensitivity is informative only. See annex A.3.1.

10 The signaling rate shall not exceed ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames).

11 The stressed receiver sensitivity values in the table are for system level BER measurements that include the effects of actual CDR circuits. It is recommended that at least 0.5 dB additional margin be allocated if component / module level measurements are made with laboratory BERT instrumentation that samples in the center of the eye. 0.5dB is a typical value determined by observing the effects on margin when the receiver sampling window is reduced in the link model spreadsheets.Instead of adding margin, another possibility is to set the BERT to sample the receiver output eye at ±0.15 UI from the center.

12 Defined with DFE EQ reference receiver with 1 main and 2 feedback taps (see annex A.5)

13 The values for 800 MB/s links are calibrated with a forth order Bessel-Thomson filter at 0.75 x signal rate. The lower speed VECP calibration is with a wide band receiver.

14 OMA, RN, and DDPWS are defined through a 6.375 GHz fourth order Bessel-Thomson filter. The ISI filter that represents the fiber is disabled when these values are calibrated for receiver device testing.

15 WDP is defined through a 6.375 GHz fourth order Bessel-Thomson filter. For receiver device testing WDP is defined with DDPWS already calibrated.

16 The Tx specifications for 400-M5E-SN-I are tighter than for 400-M5-SN-I and 400-M6-SN-I. The Tx Specifications for 100-M5E-SN-I are also tighter than for 100-M5-SN-I and 100-M6-SN-I.

17 Receiver jitter tracking is defined in annex A.3.5.

18 Transmitter deterministic performance is controlled by TWDP.

19 TWDP for the 800-M6-SN-S is calculated with a 1.0 equalizer and a 6.860 MHz Gaussian filter for the fiber simulation. TWDP for the 800-M6-SA-S option is calculated with a 1,2 equalizer and a 3.420 MHz Gaussian filter for the fiber simulation.

20 Trade offs are available between RMS spectral width and minimum optical modulation amplitude for 800-M6-SA-S variant. See figure 28.

6.4.2 MM optical output interface

The optical transmit signal shall comply with all requirements at the output end of any patch cord between one-half and five meters in length, of the relevant type specified in sub-clause 8.2.2.

The general laser driver pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see sub-clause 5.11). These characteristics include rise time, fall time, pulse overshoot, pulse undershoot, and ringing, all of these parameters shall be controlled to prevent excessive degradation of the receiver sensitivity. The parameters specifying the mask of the transmitter eye diagram are shown in figure 26 and figure 27.

n figure 26, X1 shall be half the value given for total jitter at the gamma T point given in table 13. The test or analysis shall include the effects of a single pole high-pass frequency-weighting function, that progressively attenuates jitter at 20 dB/decade below a frequency of signaling rate/1 667. The value for X1 applies at a total jitter probability of 10^{-12}. At this level of probability direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements.I

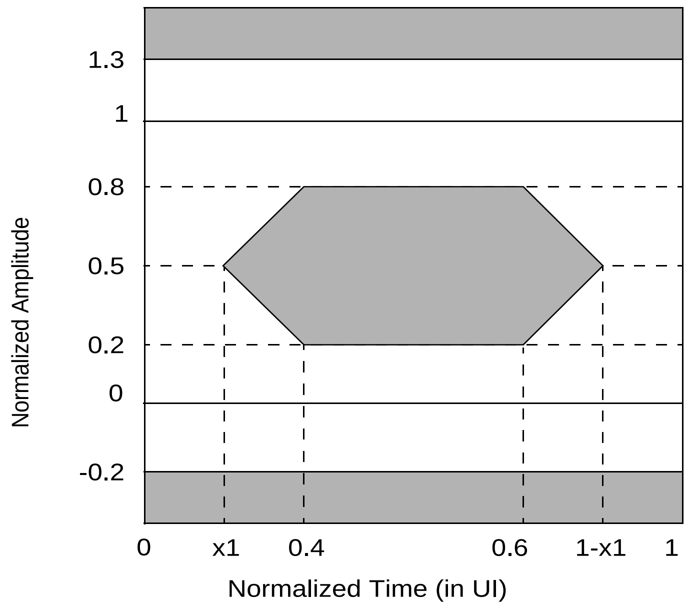
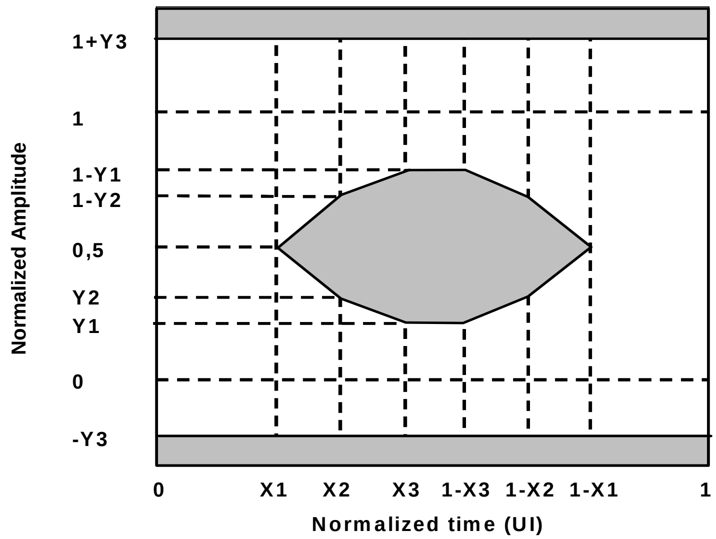


Figure 26 – MM transmitter eye diagram mask (except 8GFC)

Reflection effects on the transmitter are assumed to be small but need to be bounded. A specification of maximum Relative Intensity Noise (RIN) under worst case reflection conditions is included to ensure that reflections do not impact system performance.



	Value	Unit
X1	0.25	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.32	
Y2	0.35	
Y3	0.40	

Figure 27 – MM transmitter eye diagram mask for 8GFC

The test or analysis shall include the effects of a single pole high-pass frequency-weighting function, that progressively attenuates jitter at 20 dB/decade below a frequency of signaling rate/1 667. The mask applies at a probability of 10^{-3}.

6.4.3 MM optical input interface

The receiver shall operate shall operate with a maximum BER of 10^{-12} when the input power falls within the range given in table 10, table 11, or table 12 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 26 and figure 27. See IEC 61280-2-2 - Test Procedures for Digital Systems - Optical Eye Pattern, waveform, and Extinction Ratio.

6.4.4 MM jitter budget

This sub-clause defines, for every optical compliance point, the allowable jitter (see table 13) and the jitter that shall be tolerated (see table 14). See FC-MJSQ clause 11.2.

Receiver TJ and DJ shall comply to the listed values in table 13, over all allowable optical power input ranges and extinction ratios, as listed in table 10, table 11, or table 12.

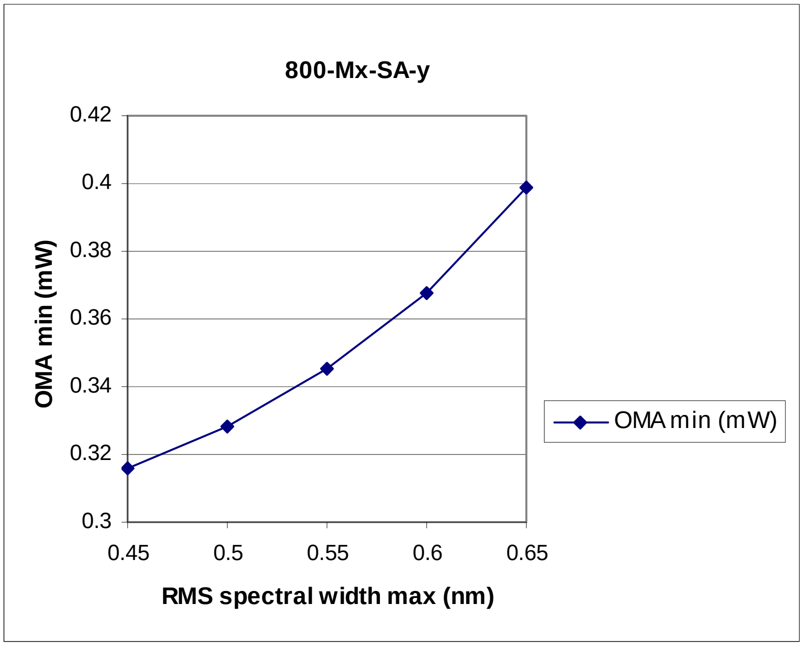


Figure 28 – RMS spectral width and OMA trade offs

Table 13 – MM jitter output, pk-pk, max

	Units	β_T	δ_T	γ_T	γ_R	δ_R	β_R
100-Mx-SN-I (note 4)							
Deterministic (DJ)[3]	UI	0.11	0.12	0.21	0.24	0.36	0.37
Total (TJ)[1,2,3]		0.23	0.25	0.43	0.47	0.61	0.63
200-Mx-SN-I (note 4)							
Deterministic (DJ)[3]	UI	NA	0.14	0.26	0.29	0.39	NA
Total (TJ)[1,2,3]			0.26	0.44	0.48	0.64	
400-Mx-SN-I (note 4)							
Deterministic (DJ)[3]	UI	NA	0.14	0.26	0.29	0.39	NA
Total (TJ)[1,2,3]			0.26	0.44	0.48	0.64	
800-Mx-SN-y (note 4, 6)							

Table 13 – MM jitter output, pk-pk, max

Deterministic (DJ)[3]			0.17	NA		0.42	
Pulse width shrinkage (DDPWS)[5]	UI	NA	0.11		NA	0.36	NA
Uncorrelated Jitter[7,8]			NA	0.2		NA	
Total (TJ)[1,2,3]			0.31	NA		0.71	
800-Mx-SA-y (note 4, 6)							
Deterministic (DJ)[3]			0.17	NA			
Pulse width shrinkage (DDPWS)[5]	UI	NA	0.11		NA		
Uncorrelated Jitter[7,8]			NA	0.2			
Total (TJ)[1,2,3]			0.31	NA			

Notes:

1 Total jitter is the sum of deterministic jitter and random jitter. If the actual deterministic jitter is less than the maximum specified, then the random jitter may increase as long as the total jitter does not exceed the specified maximum total jitter.

2 Total jitter is specified at the 10^{-12} probability.

3 The signal shall be measured using a jitter timing reference, e.g. Golden PLL.

4 Values at the α points are determined by the application.

5 DDPWS is a component of DJ. See annex A.1.2.2.

6 The values listed in this table are at the appropriate compliance points which for delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

7 Uncorrelated jitter is measured using the test methodology of IEEE 802.3 Clause 68.6.8.

8 Jitter values at γ_T and γ_R are controlled by TWDP and stress receiver sensitivity.

Table 14 – MM jitter tolerance, pk-pk, min.

	Unit	β_T	δ_T	γ_T	γ_R	δ_R	β_R
100-Mx-SN-I (note 4)							
Sinusoidal swept freq.(SJ) 637 kHz to > 5 MHz[3]	UI	0.10					
Deterministic (DJ) 637 kHz-531 MHz		0.11	0.12	0.21	0.24	0.36	0.37
Total (TJ)[1,2]		0.28	0.30	0.48	0.52	0.66	0.68
200-Mx-SN-I (note 4)							
Sinusoidal swept freq.(SJ) 1 275 kHz to > 5 MHz[3]	UI	NA	0.10				NA
Deterministic (DJ) 1 275 kHz-1 063 MHz			0.14	0.26	0.29	0.39	
Total (TJ)[1,2]			0.31	0.49	0.53	0.69	
400-Mx-SN-I (note 4)							
Sinusoidal swept freq.(SJ) 2 550 kHz to > 5 MHz[3]	UI	NA	0.10				NA
Deterministic (DJ) 2 550 kHz-2 125 MHz			0.14	0.26	0.29	0.39	
Total (TJ)[1,2]			0.31	0.49	0.53	0.69	
800-Mx-SN-y (note 4, 9)							
Sinusoidal swept freq.(SJ) 5 098 kHz to > 20MHz[3]	UI	NA	note 6		note 8	note 8	NA
Deterministic (DJ) 5 098 kHz-4 250 MHz					0.32	0.42	
Pulse width shrinkage (DDPWS)[5]					NA	0.36	
Total (TJ)[1,2]					0.55	0.71	
800-Mx-SA-y (note 4, 9)							
Sinusoidal swept freq.(SJ) 5 098 kHz to > 20 MHz[3]	UI	NA	note 6		note 7		NA
Deterministic (DJ) 5 098 kHz-4 250 MHz							
Pulse width shrinkage (DDPWS)[5]							
Total (TJ)[1,2]							

Notes:

1. The jitter values given are normative for a combination of DJ, RJ, and SJ that receivers shall be able to tolerate without exceeding a BER of 10^{-12}.
2. No value is given for random jitter (RJ). For compliance with this spec, the actual random jitter amplitude shall be the value that brings total jitter to the stated value at a probability of 10^{-12}.
3. Receivers shall tolerate sinusoidal jitter of progressively greater amplitude at lower frequencies, according to the mask in figure 20, combined with the same DJ and RJ levels as were used in the high frequency sweep
4. Values at the α points are determined by the application.
5. DDPWS is a required component of DJ. See annex A.1.2.2.
6. Not specified.
7. Receiver jitter performance for the linear system with an equalizing receiver is not applicable. The receiver performance is measured using the linear stress receiver test in annex A.5.
8. Receiver jitter tracking is defined in annex A.3.5.
9. The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

7 Optical interfaces

7.1 Optical interface general information

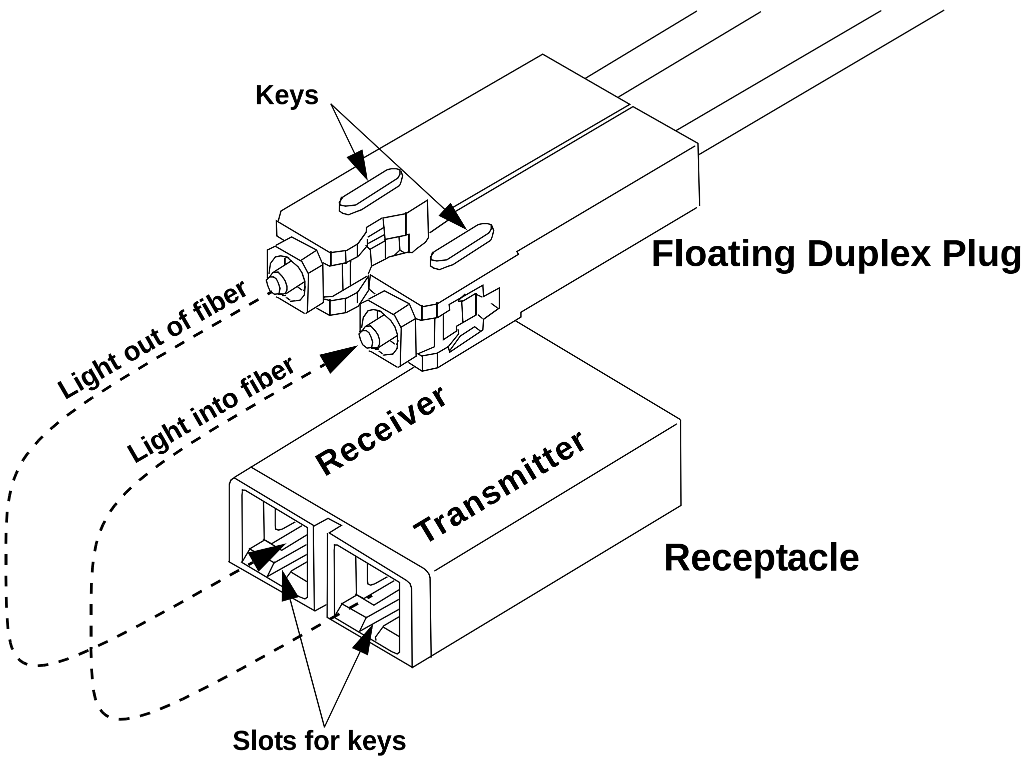
The primary function of the optical interface connector is to align the optical transmission fiber mechanically to an optical port on a component such as a receiver or a transmitter. The fiber optical interfaces are shown here for reference only. The fiber optical interfaces shall meet the optical, mechanical and environmental requirements of ISO/ IEC 11801 - Information technology - Generic cabling for customer premises.

7.2 SC optical interface

7.2.1 SC performance information

Mechanical, optical performance and intermatability for the SC connector system are specified in IEC 61754-4 Fibre optic connector interfaces - Part 4: Type SC connector family.

Figure 29 shows the SC optical interface plug and receptacle.



Connector keys are used for transmit/receive polarity only. The connector keys do not differentiate between single-mode and multimode connectors.

Figure 29 – Duplex SC optical interface

7.2.2 SC optical plug

Only the Floating Duplex style Connector Plug shall be used. Rigid SC Duplex connector shall not be used. Floating Duplex SC Connectors essentially take two simplex connectors and mechanically couple them together so each of the two SC Simplex Connectors are retained but free to 'float' within the constraints of the coupling assembly. Rigid Duplex SC connectors embody a single rigid housing to retain the simplex connectors and are not supported.

7.2.3 SC Duplex optical receptacle

The active SC Duplex Receptacle Interface shall conform to the requirements of IEC 61754-4 Duplex PC Interface with the following exception. The distance between the centre line of the active optical bores (ref DB) shall be increased from 12.65/12.75mm to 12.60/12.80mm. This is to facilitate the use of Floating Duplex SC Plug Connectors (example IEC 60874-19-1) and avoids the use of restrictive manufacturing tolerances associated with the transceiver. Increasing this tolerance precludes the use of Rigid Duplex SC connectors.

7.3 LC optical interface

Mechanical, optical performance and intermatability for the LC connector system are specified in IEC 61754-20 Fibre optic connector interfaces - Part 20: Type LC connector family. The acronym “LC” when used with the “LC” connector and when used to describe the “LC” optical transmission variant are not related.

Figure 30. outlines the LC interface.

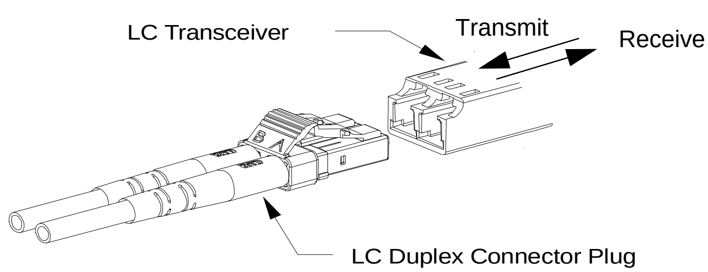


Figure 30 – Duplex LC interface

7.4 MT-RJ optical interface

7.4.1 MT-RJ performance information

Mechanical, optical performance and intermatability for the MT-RJ connector system are specified in IEC 61754-18 Fibre optic connector interfaces - Part 18: Type MT-RJ connector family.

Figure 31 outlines the MT-RJ interface.

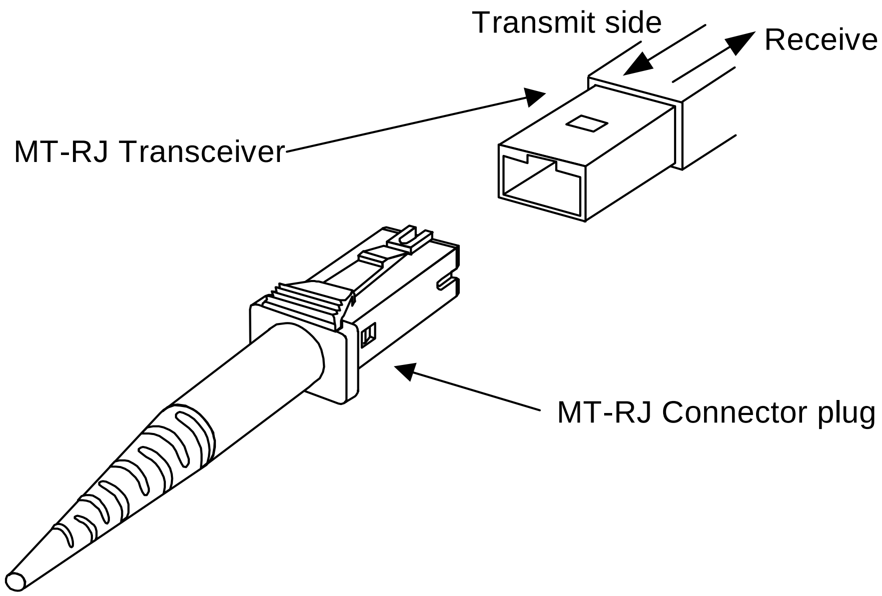


Figure 31 – MT connector interface

7.5 MU Connector

Mechanical, optical performance and intermatability for the MU connector system are specified in IEC 61754-6 Fibre optic connector interfaces - Part 6: Type MU connector family.

Figure 32 outlines the MU interface.

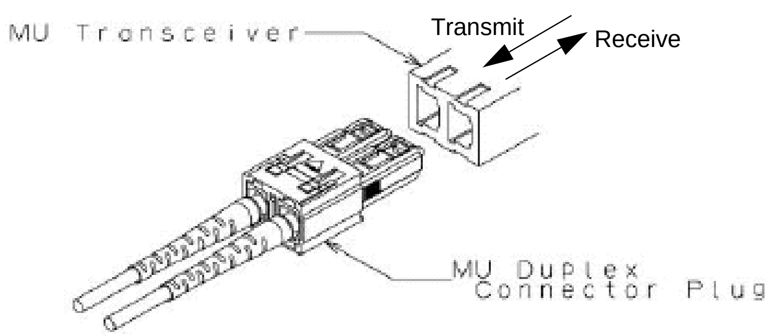


Figure 32 – MU connector interface

8 Optical fiber cable plant specification

8.1 SM cable plant specification

8.1.1 SM cable plant overview

This sub-clause specifies a single-mode cable plant for the Fibre Channel data rates of 1GFC, 2GFC, 4GFC, and 8GFC at their rated distance of 10 km and a single-mode cable plant for two other variants: one with the Fibre Channel data rate of 4GFC at its rated distance of 4km, and another with the Fibre Channel data rate of 8GFC at its rated distance of 1.4km.

The cable plant is generally insensitive to data rate and therefore any installed portions of the cable plant may be used at any data rate (see table 15).

The insertion loss is specified for a connection, that consists of a mated pair of optical connectors.

The maximum link distances for single-mode fiber are calculated based on an allocation of 2.0 dB total connection and splice loss. For example, this allocation supports four connections with typical insertion loss equal to 0.5 dB (or less) per connection. Different loss characteristics may be used provided the loss budget requirements of table 15 are met.

Table 15 – Single-mode cable plant

FC-0	100-SM-LC-L	200-SM-LC-L	400-SM-LC-M	400-SM-LC-L	800-SM-LC-L	800-SM-LC-I
Sub clause	6.3					
Operating Range (m)	2 -10 000	2 -10 000	2 -4 000	2 -10 000	2 -10 000	2 -1 400
Loss Budget (dB)	7.8	7.8	4.8	7.8	6.4 note 1	2.6 note 1
Notes: 1 Lower loss fiber is assumed for 8GFC than other speeds.						

8.1.2 SM optical fiber type

The optical fiber shall conform to IEC 60793-2-50, Type B1.1 (OS1) or IEC 60793-2-50, Type B1.3 (OS2) Optical Fibres - Part 2: Product Specifications. Both OS1 and OS2 are single-mode fibers having a nominal zero-dispersion wavelength in the 1310 nm transmission window. These fibers are commonly referred to as dispersion-unshifted fibers. OS2 is commonly referred to as "low water peak" single-mode fiber and is characterized by having a low attenuation coefficient in the vicinity of 1383 nm, traditionally referred to as the "water peak".

8.1.3 SM cable plant loss budget

The loss budget for single-mode cable plant shall be no greater than specified in table 15. These limits were arrived at by taking the difference between the minimum transmitter output power and the receiver sensitivity and subtracting link penalties.

8.1.4 SM optical return loss

The cable plant optical return loss, with the compliant receiver connected, shall be greater than or equal to 12 dB. This is required to keep the reflection penalty under control.

Connectors and splices shall each have a return loss greater than 26 dB as measured by the methods of IEC 61300-2-6.

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8.2 MM cable plant specification

8.2.1 MM cable plant overview

There are three commonly used MM cable plants used today, the 62.5 µm (OM1) and two 50 µm (OM2 and OM3) cables. For short wavelength lasers a 50 µm cable plant will have better performance than a 62.5 µm cable plant because of its fiber properties

The maximum link distances for multimode fiber are calculated based on an allocation of 1.5 dB total connection and splice loss. For example, this allocation supports three connections with typical insertion loss equal to 0.5 dB (or less) per connection, or two connections with insertion loss of 0.75 dB. Different loss characteristics may be used provided the loss budget requirements of table 16, 17, 18, 19 as appropriate are met. See annex D for examples.

Table 16 – Multimode cable plant for OM1 limiting variants

FC-0	**100-M6-SN-I**	**200-M6-SN-I**	**400-M6-SN-I**	**800-M6-SN-S**
Sub clause	6.4			
Date rate (MB/s)	100	200	400	800
Operating range (m)	0.5-300	0.5-150	0.5-70	0.5-21
Loss Budget (dB)	3.00	2.10	1.78	1.58
NOTE – The operating ranges shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.				

Table 17 – Multimode cable plant for OM2 limiting variants

FC-0	**100-M5-SN-I**	**200-M5-SN-I**	**400-M5-SN-I**	**800-M5-SN-S**
Sub clause	6.4			
Date rate (MB/s)	100	200	400	800
Operating range (m)	0.5 -500	0.5 -300	0.5 -150	0.5-50
Loss Budget (dB)	3.85	2.62	2.06	1.68
NOTE – The operating ranges shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.				

Table 18 – Multimode cable plant for OM3 limiting variants

FC-0	**100-M5E-SN-I**	**200-M5E-SN-I**	**400-M5E-SN-I**	**800-M5E-SN-I**
Sub clause	6.4			
Date rate (MB/s)	100	200	400	800
Operating range (m)	0.5-860	0.5-500	0.5-380	0.5-150
Loss Budget (dB)	4.62	3.31	2.88	2.04
NOTE – The operating ranges shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.				

Table 19 – Multimode cable plant for linear variants

FC-0	800-M6-SA-S	800-M5-SA-I	800-M5E-SA-I
Sub clause	6.4		
Date rate (MB/s)	800	800	800
Operating range (m)	0.5-40	0.5-100	0.5-300
Loss Budget (dB)	1.64	1.85	2.59
NOTE – The operating ranges shown here are based on MM fiber bandwidth given in table 21. For link budget calculations and other MM fiber bandwidths see annex C.			

8.2.2 MM optical fiber types

The fiber optic cable shall conform to IEC 60793-2-10 Type A1a or Type A1b fibers

.

Table 20 – Multimode fiber types

Nominal Core Diameter	Cladding Diameter	Nominal Numerical Aperture	IEC 60793-2-10
62.5 *µm*	125 *µm*	0.275	Type A1b (OM1)
50 *µm*	125 *µm*	0.20	Type A1a.1 (OM2)
50 *µm*	125 *µm*	0.20	Type A1a.2 (OM3)

8.2.3 MM modal bandwidth

The following normalized bandwidth values are based on a nominal source wavelength of 850 nm and 1 300 nm as described in table 21.

Table 21 – Multimode fiber

Optical fiber cable type note 1	**Fiber reference**	**Wavelength** (nm) note 4	**Overfilled modal bandwidth-length product (MHz*km)** note 2	**Effective modal bandwidth-length product (MHz*km)** note 3
62.5/125 *µm* multimode (OM1)	TIA-492AAAA-A IEC 60793-2-10 Type A1b	850 1 300	200 500	Not Required Not Required
50/125 *µm* Multimode (OM2)	TIA-492AAAB IEC 60793-2-10 Type A1a.1	850 1 300	500 500	Not Required Not Required
850 nm laser-optimized 50/125 *µm* (OM3)	TIA-492AAAC-A IEC 60793-2-10 Type A1a.2	850 1 300	1 500 500	2000 Not Required

Notes:

1. The fiber types listed in the table correspond to the referenced fiber designations in ISO 11801 2nd Ed (OM1, OM2, OM3).
2. Some users may install higher modal bandwidth fiber to facilitate future use of the cable plant for higher bandwidth applications. For shorter distances, a lower bandwidth fiber may be substituted provided that the performance requirements are met. See annex C.
3. A minimum effective modal bandwidth-length product of 2000 MHz*km is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA-492AAAC-A and IEC 60793-2-10, with a 50 µm fiber meeting either the DMD specifications or the EMBc specifications in TIA-492AAAC-A and IEC 60793-2-10.
4. 1310 nm MM operation is not part of this standard.

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8.2.4 MM cable plant loss budget

The loss budget for the multimode fiber cable plant at the maximum stated link distances shall be no greater than specified in table 16, table 17, table 18, or table 19. These limits were arrived at by taking the difference between the minimum transmitter optical modulation amplitude and the receiver optical modulation minimum, and subtracting the link power penalties. The limits include the losses of the fiber and other components in the link such as splices and connectors. The connectors at the ends of the links are included in the transmitter and receiver specifications and not in the cable plant limit.

Conformance to the loss budget requirements is defined by IEC 60793-1-4.

For informative loss budgets for shorter distances see annex D.

8.2.5 MM optical return loss

The cable plant optical return loss, with the receiver connected, shall be greater than or equal to 12dB. This is required to keep the reflection penalty under control. The receiver shall have a return loss greater than or equal to one glass-air interface.

Connectors and splices shall each have a return loss greater than 20 dB.

8.3 Connectors and splices

Connectors and splices of any nature are allowed inside the cable plant as long as the resulting loss conforms to the optical budget of this standard. The number and quality of connectors and splices represent a design trade-off. See annex D.

9 Electrical interface specification -- single lane variants

9.1 General electrical characteristics

This clause defines the electrical requirements at the interoperability points Beta, Epsilon, Delta and Gamma in a TxRx Connection. The existence of a Beta, Epsilon, Delta or Gamma point is determined by the existence of a connector at that point in a TxRx connection.

Each conforming electrical FC device shall be compatible with this serial electrical interface to allow interoperability within an FC environment. All Fibre Channel TxRx Connections described in this clause shall operate within the BER objective (10^{-12}). The parameters specified in this clause support meeting that requirement under all conditions including the minimum input and output amplitude levels. The corresponding cable plant specifications are described in sub-clause 10.

These specifications are based on ensuring interoperability across multiple vendors supplying the technologies (both transceivers and cable plants) under the tolerance limits specified in the document. TxRx connections operating at these maximum distances may require some form of equalization to enable the signal requirements to be met. Greater distances may be obtained by specifically engineering a TxRx connection based on knowledge of the technology characteristics and the conditions under that the TxRx Connection is installed and operated. However, such distance extensions are outside the scope of this standard. The general electrical characteristics are described in table 22.

Table 22 – General electrical characteristic

<table>
<tr><th></th><th>Units</th><th>100-DF-EL-S
note- 1</th><th>200-DF-EL-S
note- 1</th><th>400-DF-EL-S
note- 1,3</th><th>800-DF-EL-S
note- 1,3</th><th>800-DF-EA-S
note- 1,3</th></tr>
<tr><td>Data Rate note- 2</td><td>MB/s</td><td>100</td><td>200</td><td>400</td><td colspan="2">800</td></tr>
<tr><td>Nominal Bit Rate</td><td>MBd</td><td>1 062.5</td><td>2 125</td><td>4 250</td><td colspan="2">8 500</td></tr>
<tr><td>Tolerance</td><td>ppm</td><td colspan="5">±100</td></tr>
<tr><td colspan="7">Gamma bulk cable</td></tr>
<tr><td>Impedance</td><td>Ω (nom)</td><td>150</td><td>150</td><td>150</td><td colspan="2">NA</td></tr>
<tr><td colspan="7">Delta PCB</td></tr>
<tr><td>Impedance</td><td>Ω (nom)</td><td>150</td><td colspan="4">100</td></tr>
<tr><td colspan="7">Epsilon PCB</td></tr>
<tr><td>Impedance</td><td>Ω (nom)</td><td colspan="4">NA</td><td>100</td></tr>
<tr><td colspan="7">Beta PCB</td></tr>
<tr><td>Impedance</td><td>Ω (nom)</td><td>150</td><td>100</td><td>100</td><td>NA</td><td>100</td></tr>
<tr><td colspan="7">Notes:
1 The impedances shown for nnn-DF-EL-S and 800-DF-EA-S are differential impedances.
2 The data rate may be verified by determining the time to transmit at least 200 000 transmission bits (10 max length FC frames).
3 This is a reference impedance only.</td></tr>
</table>

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9.2 Transmitted signal characteristics

9.2.1 General

This clause defines the interoperability requirements of the transmitted signal at the driver end of a TxRx connection. Test loads for gamma and delta points are defined in corresponding figures of sub-clause 9.11. The 4GFC and 8GFC differential inter enclosure and intra enclosure signaling rates shall also meet the requirements of a compliance interconnect specified in sub-clause 9.11. Details for the measurement process are specified in Annex A.

Table 23 – Signal output and return loss requirements at β_T, ε_T, δ_T and γ_T

<table>
<tr><th></th><th></th><th>Units</th><th>100-DF-EL-S note- 8</th><th>200-DF-EL-S note- 8</th><th>400-DF-EL-S note- 8</th><th>800-DF-EL-S note- 8</th><th>800-DF-EA-S note- 12</th></tr>
<tr><td colspan="8">Beta T point</td></tr>
<tr><td rowspan="4">Eye mask Figure 46 note- 1</td><td>B note- 2</td><td>mV</td><td colspan="2">1 000</td><td rowspan="4">See sub-clause 9.2.2</td><td rowspan="9">NA</td><td rowspan="4">See sub-clause 9.5</td></tr>
<tr><td>A note- 3</td><td>mV</td><td colspan="2">300</td></tr>
<tr><td>X1</td><td>UI</td><td colspan="2">note- 4</td></tr>
<tr><td>X2</td><td>UI</td><td colspan="2">X1+0.19</td></tr>
<tr><td>Skew, note- 7</td><td>Max</td><td>ps</td><td>25</td><td>15</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="2">Rise / Fall Time 20--80% note- 6,9</td><td>Max</td><td>ps</td><td>385</td><td>192</td><td>NA</td><td>NA</td></tr>
<tr><td>Min</td><td>ps</td><td>100</td><td>75</td><td>60 note- 10</td><td>40 note- 10</td></tr>
<tr><td>Return Loss</td><td></td><td>dB</td><td colspan="2">NA</td><td>See sub-clause 9.2.4</td><td>See sub-clause 9.2.4</td></tr>
<tr><td>Common Mode Voltage,RMS</td><td>Max</td><td>mV</td><td></td><td></td><td>30</td><td>30 note- 16</td></tr>
<tr><td colspan="8">Epsilon T point</td></tr>
<tr><td rowspan="4">Eye mask Figure 46 note- 1</td><td>B note- 2</td><td>mV</td><td colspan="4" rowspan="9">NA</td><td rowspan="4">See sub-clause 9.5</td></tr>
<tr><td>A note- 3</td><td>mV</td></tr>
<tr><td>X1</td><td>UI</td></tr>
<tr><td>X2</td><td>UI</td></tr>
<tr><td>Skew, note- 7</td><td>Max</td><td>ps</td><td>NA</td></tr>
<tr><td rowspan="2">Rise / Fall Time 20--80% note- 6,9</td><td>Max</td><td>ps</td><td>NA</td></tr>
<tr><td>Min</td><td>ps</td><td>40 note- 10</td></tr>
<tr><td>Return Loss</td><td></td><td>dB</td><td>See sub-clause 9.2.4</td></tr>
<tr><td>Common Mode Voltage,RMS</td><td>Max</td><td>mV</td><td>30 note- 16</td></tr>
<tr><td colspan="8">Delta T Point (note- 15)</td></tr>
<tr><td rowspan="4">Eye Mask Figure 46 note- 1,14</td><td>B note- 2</td><td>mV</td><td colspan="2">1 000</td><td>800</td><td colspan="2">350</td></tr>
<tr><td>A note- 3</td><td>mV</td><td colspan="3">325</td><td colspan="2">90</td></tr>
<tr><td>X1</td><td>UI</td><td colspan="5">note- 4</td></tr>
<tr><td>X2</td><td>UI</td><td colspan="3">X1+0.19</td><td colspan="2">0.5</td></tr>
</table>

Table 23 – Signal output and return loss requirements at β_T, ε_T, δ_T and γ_T

		Units	100-DF-EL-S note- 8	200-DF-EL-S note- 8	400-DF-EL-S note- 8	800-DF-EL-S note- 8	800-DF-EA-S note- 12
Skew note- 7	Max	ps	20	NA			
Rise / Fall Time 20--80% note- 6,9	Max	ps	385				
	Min	ps	100				
Return Loss		dB	NA		See sub-clause 9.2.4		
Common Mode Voltage, RMS	Max	mV	NA		30	30 note- 16	
Gamma T Point							
Eye mask Figure 46 note- 1	B note- 2	mV	1 000		See sub-clause 9.2.2	NA	
	A note- 3	mV	550				
	X1	UI	note- 4				
	X2	UI	X1+0.19				
Skew note- 7	Max	ps	25	15	NA		
Rise / Fall Time 20--80% note- 6,9	Max	ps	385	192	NA		
	Min	ps	100	75	60 note- 10		
Return loss		dB	NA		See sub-clause 9.2.4		
Transmitter off voltage (Tx_off) note- 5	Max	mV (p-p)	70				
Common Mode Voltage, RMS	Max	mV	NA		30		
Eye mask normalized amplitudes, at all points (note- 1)							
Y1			0.2		0.2 note- 11		
Y2			0.1				

Table 23 – Signal output and return loss requirements at β_T, ε_T, δ_T and γ_T

Notes:

1 transmitters shall meet both the absolute and normalized amplitude requirements.

2 The B amplitude specification identifies the maximum signal peak (including overshoots) that will be delivered into a resistive load matching those shown in figure 56 and figure 57.

3 The minimum allowed p-p eye amplitude opening that shall be delivered into a resistive load matching those shown in figure 56 and figure 57 is twice the 'A' amplitude shown above.

4 The value of X1 shall be half the value for total jitter given table 30. The signal shall be measured using a jitter timing reference, e.g. Golden PLL. The value for X1 applies at a total jitter probability of 10^{-12}. At this level of probability direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements, see sub-clause 9.6.

5 The 'transmitter off voltage' is the maximum voltage measured at point g_T (across a resistive load matching those shown in figure 56 and figure 57) when the transmitter is logically turned off or is un-powered.

6 Rise/fall time measurements to be made using an oscilloscope with a bandwidth including probes of at least 1.8 times the signaling rate. See annex A.1.1.4

7 Skew measurements are to be made using an oscilloscope with a bandwidth including probes of at least 1.8 times the signaling rate. See annex A.1.3.4.

8 All specifications for 100-DF-EL-S, 200-DF-EL-S, 400-DF-EL-S, and 800-DF-Ex-S are based on differential measurements unless specifically listed otherwise.

9 Shall be measured with a D21.5 pattern (clock pattern) to eliminate the effects of pre-compensation.

10 Informative only.

11 Relative (Y1 and Y2) values do not apply to measurements at the output of a TCTF. See table 21 for applicable absolute values

12 800-DF-EA-S uses the same Beta T, Gamma T and Delta T specifications as 800-DF-EL-.S.

13 Relative eye mask is not required for Delta-T for 800-DF-Ex-S.

14 DC blocking shall be provided on the receive side of the delta-T point connection.

15 The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

16 From 50 MHz to 8.5 GHz, each spectral component of the TX common mode voltage shall be less than 20 mV (rms) when measured with a 1 MHz measurement bandwidth.

9.2.2 400-DF-EL-S transmitted signal requirements

The transmitted signal requirements for the 400-DF-EL-S β_T, and γ_T compliance points are measured over two idealized load conditions shown in figure 33. One shown in the top half of figure 33, is the zero length interconnect case and the other, shown in the bottom half of figure 33 is measured through a transmitter compliance transfer function. The signal requirements shall meet the output voltage and timing requirements listed in table 24 and table 30 measured through the transmitter compliance function as described in sub-clause 9.11.

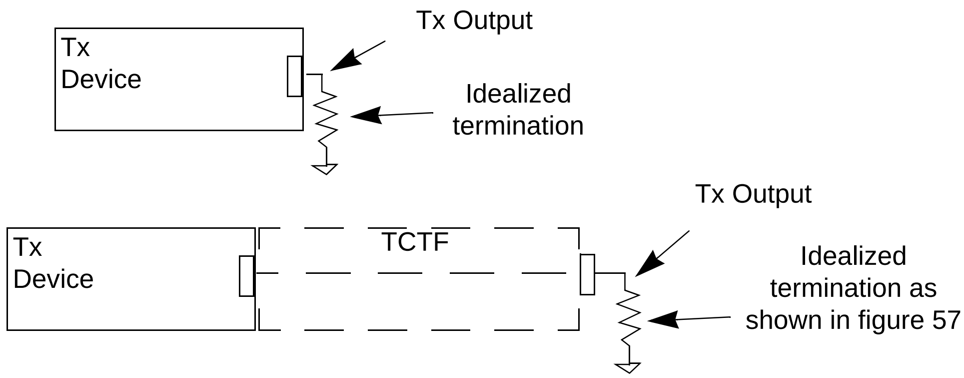

Figure 33 – Transmit device output, two idealized load conditions, Zero length and through TCTF

Table 24 – Transmitted signal mask requirements for 400-DF variant

			400-DF-EL-S	
		Units	β_T	γ_T
Eye Mask figure 46	**A**	mV	155	155
	B	mV	800	800
	X1	UI	note- 1	
	X2	UI	0.5	0.5

Notes:
1 The value for X1 shall be half the value given for total jitter in table 30. The signal shall be measured using a jitter timing reference, e.g. Golden PLL.

9.2.3 400-DF-EL-S amplitude and jitter requirements at transmit interoperability points

The system tolerance is a BER output test that is used to measure downstream signal tolerance and is a measure of the systems ability to tolerate a compliant transmitter output. The signal source is calibrated into an idealized load before applying it to the interconnect as shown in figure 34. The signal amplitude shall be adjusted to the minimum allowed at the interoperability point in table 25. The signal amplitude also shall not exceed the value of B stated in table 23 at any point in time. The BER shall be better then 10^{-12}. The values for the system input tolerance signal are listed in table 25.

Table 25 – 400-DF-EL-S amplitude and jitter requirements at transmit interoperability points

			400-DF-EL-S		
		Units	β_T	δ_T	γ_T
Eye Mask figure 46	**A**	mV	138	300 note- 2	138
	X1	UI	note- 1		
	X2	UI	0.5		0.5

Notes:
1 The value for X1 shall be half the value given for total jitter in table 30. The signal shall be measured using a jitter timing reference, e.g. Golden PLL.
2 Delta points are not calibrated through a TCTF.

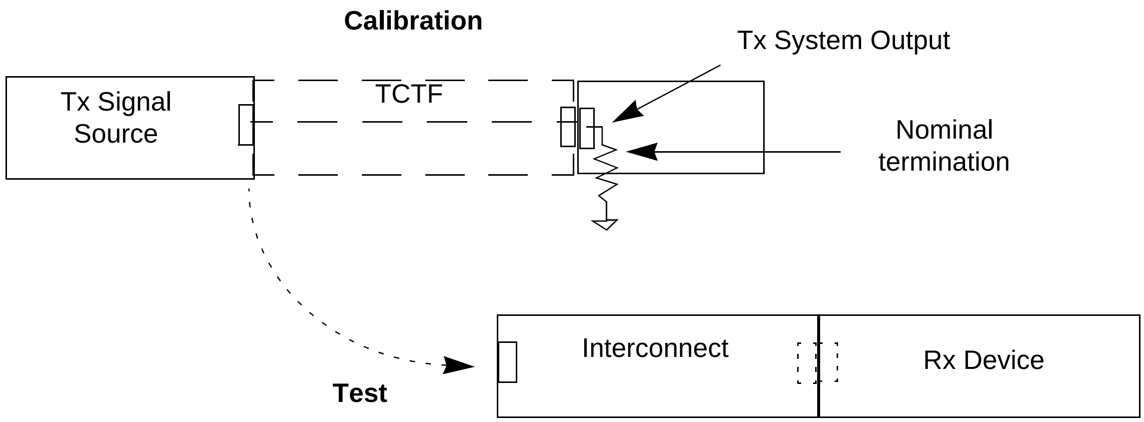

Figure 34 – Transmit, system (interconnect + receiver device) input tolerance test

9.2.4 Return loss at the transmitter compliance points

There are two differential return loss requirements at any transmit device connector. One is of the transmit device itself, (SDD22) and the other is of the down stream system, (SDD11), as shown in figures 37 and 38. The down stream system includes the interconnect and the receiver device. The return loss requirements are listed in table 26.

Table 26 – Return loss at the Transmit Compliance Points

Compliance point	**Figure**	**L (dB)**	**N (dB)**	**H (dB)**	**S (dB/dec)**	**Fmin (MHz)**	**Fmax (MHz)**
400-DF-EL-S (note- 1,2)							
β_T SDD22	37	-12	-5.0				
β_T SDD11	37	-12	-5.0				
δ_T SDD22	38	-12	-5.0				
δ_T SDD11	38	-12	-5.0				
γ_T SDD22	37	-12	-5.0	0	11.3	50	3 200
γ_T SDD11	37	-12	-5.0				
β_T SCC22	37	-6	-3.0				
δ_T SCC22	38	-6	-4.0				
γ_T SCC22	37	-6	-3.0				
800-DF-Ex-S (note- 1,2)							

Table 26 – Return loss at the Transmit Compliance Points

<table>
<tr><th>Compliance point</th><th>Figure</th><th>L (dB)</th><th>N (dB)</th><th>H (dB)</th><th>S (dB/dec)</th><th>Fmin (MHz)</th><th>Fmax (MHz)</th></tr>
<tr><td>β_T SDD22</td><td>37</td><td>-10</td><td>-5.9</td><td>0</td><td>13.33</td><td rowspan="15">50</td><td rowspan="15">8 500</td></tr>
<tr><td>β_T SDD11</td><td>37</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td></tr>
<tr><td>β_T SCC22</td><td>37</td><td>-6</td><td>-3.0</td><td>0</td><td>13.33</td></tr>
<tr><td>β_T SCD11</td><td>37</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>β_T SCD22</td><td>37</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>ε_T SDD22</td><td>37</td><td>-10</td><td>-5.9</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_T SDD11</td><td>37</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_T SCC22</td><td>37</td><td>-6</td><td>-3.0</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_T SCD11</td><td>37</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>ε_T SCD22</td><td>37</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>δ_T SDD22</td><td>38</td><td>-10</td><td>-5.9</td><td>0</td><td>13.33</td></tr>
<tr><td>δ_T SDD11</td><td>38</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td></tr>
<tr><td>δ_T SCC22</td><td>38</td><td>-6</td><td>-3.0</td><td>0</td><td>13.33</td></tr>
<tr><td>δ_T SCD11</td><td>38</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>δ_T SCD22</td><td>38</td><td>-10</td><td>-10.0</td><td>-10</td><td>NA</td></tr>
<tr><td>γ_T SDD22</td><td colspan="7" rowspan="3">NA</td></tr>
<tr><td>γ_T SDD11</td></tr>
<tr><td>γ_T SCC22</td></tr>
</table>

Notes:

1. The return loss requirements are given by Sxxnn in the equation below with parameters listed in table 26. Y(f)=N+S*log(freq/0.5*symbol rate.
2. The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

$$\left|S_{xxnn}(f)\right| \text{in dB} = \begin{cases} L & \text{while} \quad y(f) \le L \\ y(f) & \text{while} \quad L < y(f) < H \\ H & \text{while} \quad H \le y(f) \end{cases}$$

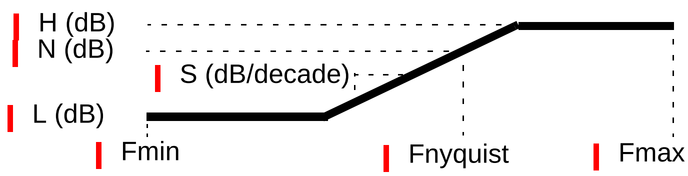

Figure 35 – Sxxnn graphical representation

For example SDD11 for δ_T 400-DF-EL-S is plotted in figure 36:

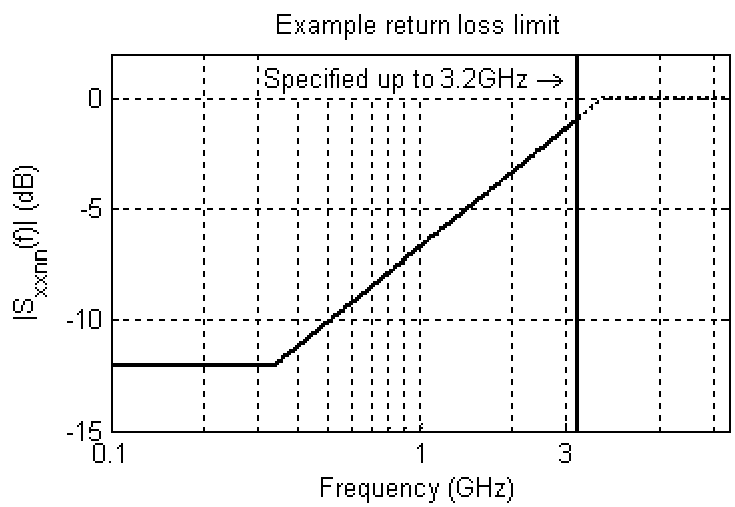

Figure 36 – Example of SDD11 for δ_T 400-DF-EL-S

Fibre Channel 400-DF-EL-S and 800-DF-Ex-S transmitter devices shall meet the SCC22 common mode return loss as specified in table 26.The reference impedance for the common mode return loss measurement is 25 Ohms.

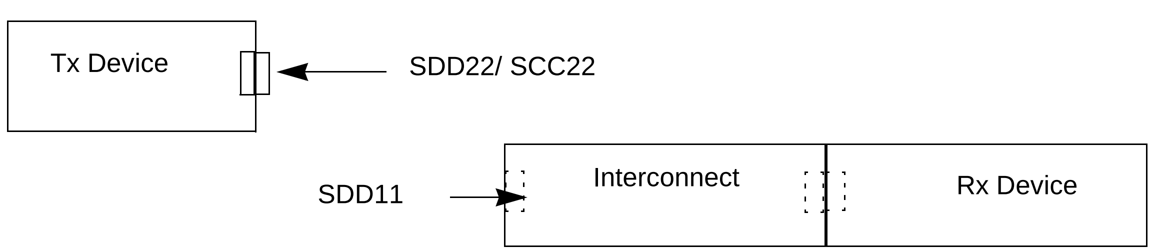

Figure 37 – Sxx at Beta T, Epsilon T, and Gamma T

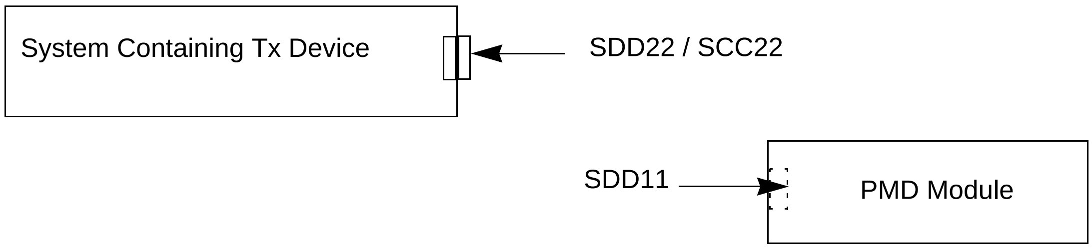

Figure 38 – Sxx at Delta T

9.3 Receive device signal characteristics

9.3.1 General

This clause defines the interoperability requirements of the delivered signal at the receive device end of a TxRx Connection. The 1GFC, 2GFC, 4GFC and 8GFC Gamma R differential inter enclosure signaling rates shall be measured using a test load as specified in figure 56. The 1GFC differential intra enclosure signaling rates shall be measured using a test load as specified in figure 56. The 2GFC, 4GFC and 8GFC Beta R and Delta R differential intra enclosure signaling rates shall be measured using a test load as specified in figure 57.

Table 27 – Signal output and return loss requirements at β_R, ε_R, δ_R and γ_R

		Units	100-SE-EL-S	100-DF-EL-S note- 4	200-SE-EL-S	200-DF-EL-S note- 4	400-DF-EL-S note- 4	800-DF-EL-S note- 4	800-DF-EA-S note- 4
Gamma R point									
Eye mask (note- 1) figure 47	A	mV	200				138	NA	
	B	mV	1000				800 note- 5		
	X1	UI	note- 1						
	X2	UI	0.5						
Return Loss		dB	NA				See sub-clause 9.3.3		
Skew (note- 3)	Max	ps	NA	200	NA	100	NA		
Common Mode Voltage, RMS	Max.	mV	NA				40		
Delta R point (note- 7)									
Eye mask (note- 2,6) figure 47	A	mV	185					170	See sub-clause 9.5
	B	mV	1000				800 note- 5	425	
	X1	UI	note- 1						
	X2	UI	0.5						
Return Loss		dB	NA				See sub-clause 9.3.3		
Skew (note- 3)	Max	ps	NA	205	NA	105	NA		
Common Mode Voltage, RMS	Max.	mV	NA				30	30 note- 8	
Epsilon R point									
Eye mask (note- 2) figure 47	A	mV	NA						See sub-clause 9.5
	B	mV							
	X1	UI							
	X2	UI							
Return Loss		dB							See sub-clause 9.3.3
Skew (note- 3)	Max	ps							NA
Common Mode Voltage, RMS	Max	mV							30 note- 8
Beta R point									
Eye mask (note- 2) figure 47	A	mV	200				138	NA	See sub-clause 9.5
	B	mV	1000				800 note- 5		
	X1	UI	note- 1						
	X2	UI	0.5						
Return Loss		dB	NA				See sub-clause 9.3.3		See sub-clause 9.3.3
Skew (note- 3)	Max	ps max.	NA	200	NA	100	NA		NA
Common Mode Voltage, RMS	Max	mV	NA				40		30 note- 8

Table 27 – Signal output and return loss requirements at β_R, ε_R, δ_R and γ_R

Notes:

1. The value for X1 shall be half the value given for total jitter in table 30. The signal shall be measured using a jitter timing reference, e.g. Golden PLL.
2. The value for X1 applies at a total jitter probability of 10^{-12}. At this level of probability direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements, see sub-clause 9.6.
3. Skew measurements are to be made using an oscilloscope with a bandwidth including probes of at least 1.8 times the signaling rate. The figure given assumes a combined maximum transmitter and maximum interconnect skew. See annex A.1.3.4.
4. All specifications for 100-DF-EL-S, 200-DF-EL-S, 400-DF-EL-S, and 800-DF-EL-S are based on differential measurements unless specifically listed otherwise.
5. 400-DF-EL-S and 800-DF-EL-S receiver devices shall tolerate up to 1000 mV in service without damage (such as required to survive connection with 1GFC or 2GFC devices during speed negotiation). These values assume that the receiver presents a perfect reference load at the measurement point.
6. DC blocking shall be provided by the transmitter prior to the delta-R point.
7. The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.
8. From 50 MHz to 8.5 GHz, each spectral component of the TX common mode voltage shall be less than 20 mV (rms) when measured with a 1 MHz measurement bandwidth.

9.3.2 400 and 800 -DF-EL-S Signal tolerance amplitude and jitter requirements at receiver device interoperability points

The receiver device tolerance is a BER output test that is used to measure the receiver device's ability to accept a signal when delivered from an interconnect system that is not perfectly matched to the receiver's impedance. The signal source and TCTF interconnect are calibrated into an idealized load before applying to a receiver β_R or γ_R compliance point as shown in figure 39. The BER shall be better than 10^{-12}. For the δ_R compliance point the signal source and interconnect are calibrated into an idealized load as shown in Figures 39 and 40. Signal tolerance amplitude and jitter requirements at receive interoperability points are listed in table 28.

Table 28 – 400-DF-EL-S and 800-DF-EL-S signal tolerance amplitude and jitter requirements at receive interoperability points

		Units	400-DF-EL-S			800-DF-EL-S
			β_R	δ_R	γ_R	δ_R
Eye Mask figure 40	**A**	mV	138	170	138	170
	B	mV	800			425
	X1	UI	Note- 1			
	X2	UI	0.5			0.5
Rx jitter tracking test, VMA (note- 2)	Max	mV	NA			340
Rx jitter tracking test, jitter frequency and pk-pk amplitude (note- 2)		(kHz,UI)	NA			(510, 1) (100, 5)

Notes:

1. The value for X1 shall be half the value given for total jitter in table 31. The signal shall be measured using a jitter timing reference, e.g. Golden PLL.
2. Receiver jitter tracking is measured using the procedure described in annex A.3.5.

Test setup

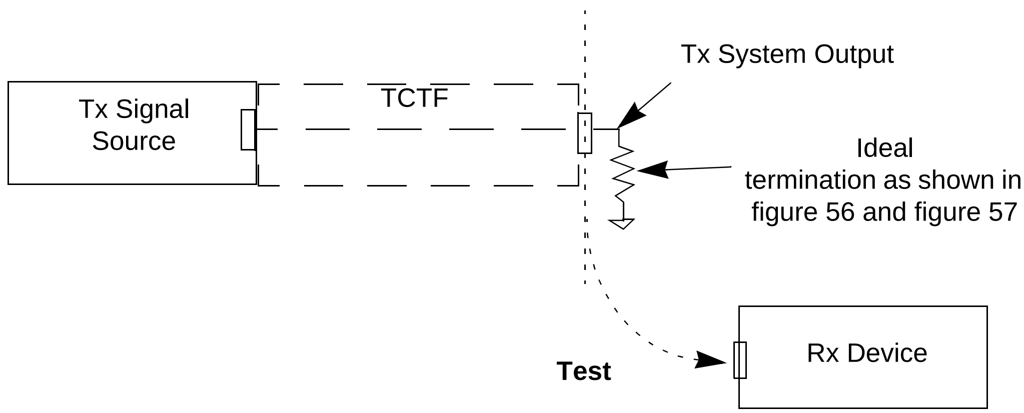

Figure 39 – Signal tolerance test set up for Rx device at Beta R and Gamma R

Test setup

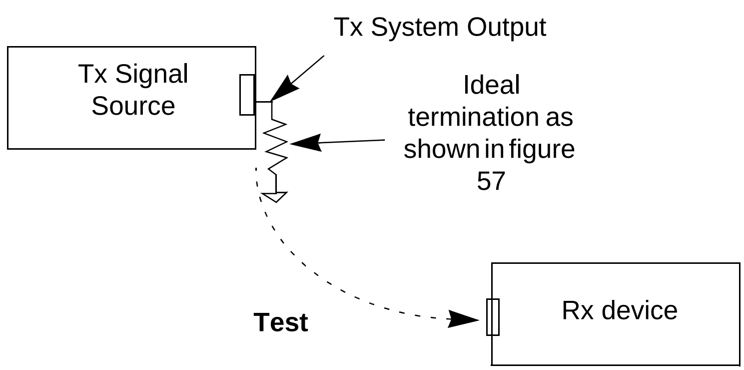

Figure 40 – Signal tolerance test set up for Rx device at Delta R

9.3.3 Return loss at the receive device compliance points

There are two differential return loss requirements at any receive device connector, one is for the receiver device itself, (SDD11) and one for the up stream system, (SDD22) as shown in figure 44. The up stream system includes the interconnect and the transmitter device. Refer to Annex A.5 for the test methodology and measurements.

Table 29 – Return loss at the receive device compliance points

Compliance point	Figure	L (dB)	N (dB)	H (dB)	S (dB/dec)	Fmin (MHz)	Fmax (MHz)
400-DF-EL-S note- 1,2							
β_R SDD22	43	-12	-5.0	0	11.3	50	3 200
β_R SDD11		-12	-5.0				
δ_R SDD22		-12	-9.0.0				
δ_R SDD11		-12	-6.0				
γ_R SDD22		-12	-5.0				
γ_R SDD11		-12	-5.0				
β_R SCC22		-6	-3.0				
δ_R SCC22		-6	-7.0				
γ_R SCC22		-6	-3.0				
800-DF-Ex-S note- 1,2							
β_R SDD22	43	-10	-8.0	0	13.33	50	8 500
β_R SDD11		-10	-5.9	0	13.33		
β_R SCC22		-6	-3.0	0	13.33		
β_R SCD11		-10	-10.0	-10	NA		
β_R SCD22		-10	-10.0	-10			
ε_R SDD22		-10	-8.0	0	13.33		
ε_R SDD11		-10	-5.9	0	13.33		
ε_R SCC22		-6	-3.0	0	13.33		
ε_R SCD11		-10	-10.0	-10	NA		
ε_R SCD22		-10	-10.0	-10			
δ_R SDD22		-10	-8.0	0	13.33		
δ_R SDD11		-10	-5.9	0	13.33		
δ_R SCC22		-6	-3.0	0	13.33		
δ_R SCD11		-10	-10.0	-10	NA		
δ_R SCD22		-10	-10.0	-10			
γ_R SDD22	NA						
γ_R SDD11							
γ_R SCC22							

Notes:

1 The return loss requirements are given by Sxxnn in the equation below with parameters listed in table 26. Y(f)=N+S*log(freq/0.5*symbol rate.

2 The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

$$
\left|S_{xxnn}(f)\right| \text{in dB} = \begin{cases} L & \text{while} \quad y(f) \le L \\ y(f) & \text{while} \quad L < y(f) < H \\ H & \text{while} \quad H \le y(f) \end{cases}
$$

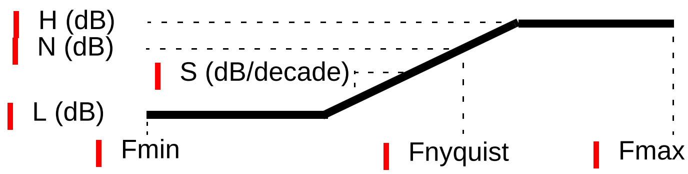

Figure 41 – Sxxnn graphical representation

For example SDD11 for 400-DF-EL-S γ_R is plotted below:

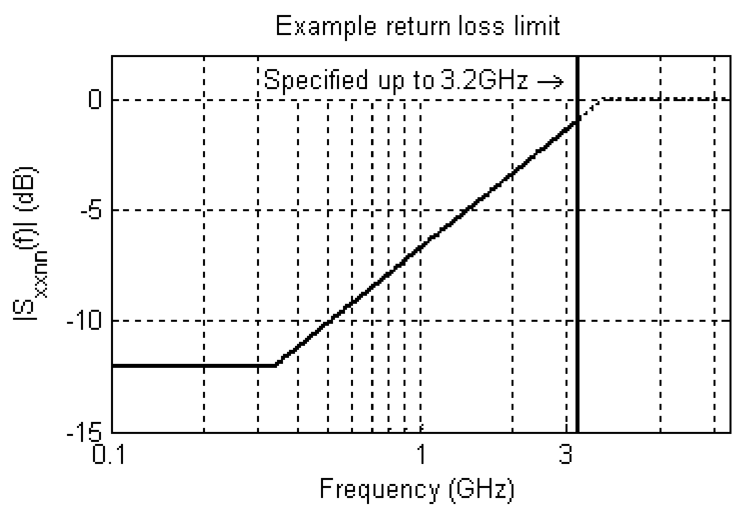

Figure 42 – Example of SDD11 for γ_R 400-DF-EL-S

Fibre Channel 4GFC and 8GFC receiver devices shall meet the SCC22 common mode return loss from 50 MHZ to 3.2 GHz for 400-DF-EL-S and 50 MHz to signaling rate for 800-DF-EL-S as specified in table 29. The reference impedance for the common mode return loss measurement is 25 Ohms.

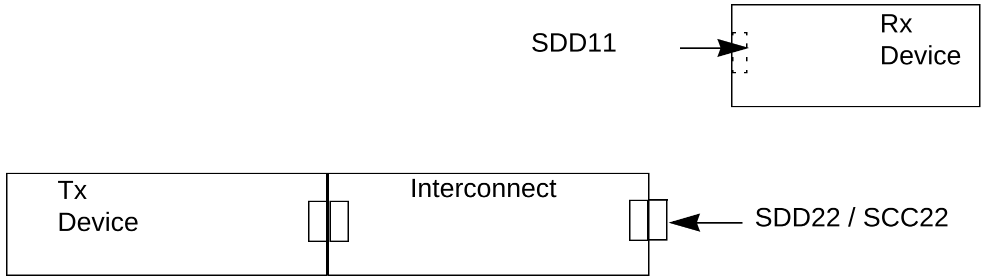

Figure 43 – Sxx at the Beta R, Epsilon R, and Gamma R

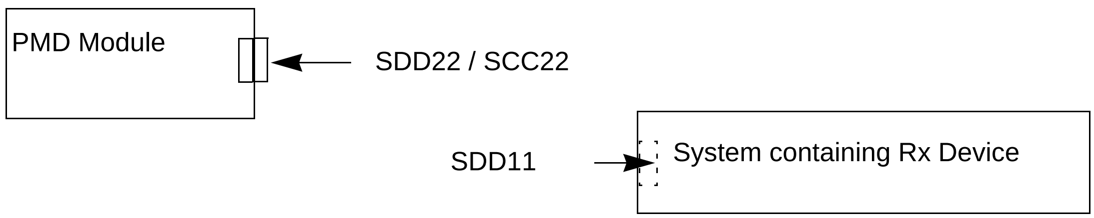

Figure 44 – Sxx at Delta R

9.4 Jitter characteristics

This clause defines, at every electrical compliance point, the allowable jitter output, specified in table 30, and the jitter that shall be tolerated, specified in table 31. Both tables contain entries for inter-enclosure TxRx Connections and for intra-enclosure TxRx connections.

The values for jitter in this clause are measured at the average signal level. The methods described in clause 11 of FC-MJSQ may be used for all of the jitter measurements used for table 31 except Pulse Width Shrinkage that has been defined in annex A-7. The deterministic and total values in this table apply to jitter when measured using a jitter timing reference, e.g. Golden PLL.

The values specified for gamma interoperability points and delta R Tj output apply only to electrical variants. See table 8 and table 13 for the values of the optical variants.

Table 30 – Max jitter output

<table>
<tr><th>Units: UI pk-pk</th><th>β_T</th><th>ε_T</th><th>δ_T</th><th>γ_T</th><th>γ_R</th><th>δ_R</th><th>ε_R</th><th>β_R</th></tr>
<tr><td colspan="9">100-SE-EL-S and 100-DF-EL-S Inter-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="2">NA</td><td>0.12</td><td>0.13</td><td>0.35</td><td>0.36</td><td colspan="2" rowspan="2">NA</td></tr>
<tr><td>Total (note- 1)</td><td>0.25</td><td>0.27</td><td>0.54</td><td>0.56</td></tr>
<tr><td colspan="9">100-SE-EL-S and 100-DF-EL-S Intra-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td>0.11</td><td colspan="6" rowspan="2">NA</td><td>0.37</td></tr>
<tr><td>Total (note- 1)</td><td>0.23</td><td>0.58</td></tr>
<tr><td colspan="9">200-SE-EL-S and 200-DF-EL-S Inter-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="2">NA</td><td>0.14</td><td>0.16</td><td>0.37</td><td>0.39</td><td colspan="2" rowspan="2">NA</td></tr>
<tr><td>Total (note- 1)</td><td>0.26</td><td>0.30</td><td>0.57</td><td>0.59</td></tr>
<tr><td colspan="9">200-SE-EL-S and 200-DF-EL-S Intra-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td>0.20</td><td colspan="6" rowspan="2">NA</td><td>0.33</td></tr>
<tr><td>Total (note- 1)</td><td>0.33</td><td>0.52</td></tr>
<tr><td colspan="9">400-DF-EL-S Inter-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="2">NA</td><td>0.14</td><td>0.37
note- 5</td><td>0.37</td><td>0.39</td><td colspan="2" rowspan="2">NA</td></tr>
<tr><td>Total (note- 1)</td><td>0.26</td><td>0.57
note- 5</td><td>0.57
note- 8</td><td>0.59</td></tr>
<tr><td colspan="9">400-DF-EL-S Intra-enclosure (note- 3)</td></tr>
<tr><td>Deterministic</td><td>0.33
note- 4</td><td colspan="6" rowspan="2">NA</td><td>0.33</td></tr>
<tr><td>Total (note- 1)</td><td>0.52
note- 4</td><td>0.52
note- 7</td></tr>
<tr><td colspan="9">800-DF-EL-S Inter-enclosure (note- 3,11)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="3">NA</td><td>0.17</td><td colspan="2" rowspan="3">NA</td><td>0.42</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Pulse width shrinkage (DDPWS) (note- 9)</td><td>0.11</td><td>0.36</td></tr>
<tr><td>Total (note- 1)</td><td>0.31</td><td>0.71</td></tr>
<tr><td colspan="9">800-DF-EA-S Intra-enclosure (note- 3,11)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="2">See sub-clause 9.5.2</td><td colspan="4" rowspan="2">NA</td><td colspan="2" rowspan="2">See sub-clause 9.5.2</td></tr>
<tr><td>Total (note- 1)</td></tr>
<tr><td colspan="9">800-DF-EA-S Inter-enclosure (note- 3,10,11)</td></tr>
<tr><td>Deterministic</td><td colspan="2" rowspan="3">See sub-clause 9.5.2</td><td>0.17</td><td colspan="3" rowspan="3">NA</td><td colspan="2" rowspan="3">See sub-clause 9.5.2</td></tr>
<tr><td>Pulse width shrinkage (DDPWS) (note- 9)</td><td>0.11</td></tr>
<tr><td>Total (note- 1)</td><td>0.31</td></tr>
</table>

Table 30 – Max jitter output

Notes:

1 Total jitter is specified at a probability of 10^{-12}.
2 The deterministic and total values in this table apply to jitter when measured using a jitter timing reference, e.g. Golden PLL.
3 α points are determined by the application.
4 Shall meet the β_R jitter specification for both: a) measured through the β_T compliance interconnect specified in sub-clause 9.11 and (b) measured through a zero length interconnect.
5 Shall meet Gamma jitter specification (a) measured through the Gamma T compliance interconnect specified in sub-clause 9.11 and (b) measured through a zero length interconnect.
6 These alpha points are informative. The small jitter budget between the alpha to delta points and the alpha to beta points may cause design constraints.
7 Pre-compensation at the transmitter may be used to cancel DDJ at BetaR however, the remaining total jitter budget cannot be assigned entirely to RJ. In order to allow compensation in the receiver the opportunity to compensate ISI, broadband non-DDJ components of TJ should not exceed 0.33 UI.
8 Pre-compensation at the transmitter may be used to cancel DDJ at gamma R however, the remaining total jitter budget cannot be assigned entirely to RJ. In order to allow compensation in the receiver the opportunity to compensate ISI, broadband non-DDJ components of TJ should not exceed 0.39 UI
9 DDPWS is measured according to annex A.1.2.2
10 This variant is delta to delta connection and, therefore, media agnostic.
11 The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

Table 31 – Min Jitter tolerance

<table>
<tr><th>Units: UI pk-pk</th><th>β_T</th><th>ε_T</th><th>δ_T</th><th>γ_T</th><th>γ_R</th><th>δ_R</th><th>ε_R</th><th>β_R</th></tr>
<tr><td colspan="9">100-SE-EL-S and 100-DF-EL-S Inter-enclosure (note- 1, 5)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ) note- 4
637 kHz to > 5 MHz</td><td colspan="2" rowspan="3">NA</td><td colspan="4">0.10</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Deterministic (DJ)
637 kHz-531 MHz</td><td>0.12</td><td>0.13</td><td>0.35</td><td>0.36</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.35</td><td>0.37</td><td>0.64</td><td>0.66</td></tr>
<tr><td colspan="9">100-SE-EL-S and 100-DF-EL-S Intra-enclosure (note- 1, 5)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ) note- 4
637 kHz to > 5 MHz</td><td>0.10</td><td colspan="6" rowspan="3">NA</td><td>0.10</td></tr>
<tr><td>Deterministic (DJ)
637 kHz-531 MHz</td><td>0.11</td><td>0.37</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.33</td><td>0.68</td></tr>
<tr><td colspan="9">200-SE-EL-S and 200-DF-EL-S Inter-enclosure (note- 1, 5)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ) note- 4
1274 kHz to > 5 MHz</td><td colspan="2" rowspan="3">NA</td><td colspan="4">0.10</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Deterministic (DJ)
1274 kHz-1062 MHz.</td><td>0.14</td><td>0.16</td><td>0.37</td><td>0.39</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.36</td><td>0.40</td><td>0.67</td><td>0.69</td></tr>
<tr><td colspan="9">200-SE-EL-S and 200-DF-EL-S Intra-enclosure (note- 1, 5)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ) note- 4
1274 kHz to > 5 MHz.</td><td>0.10</td><td colspan="6" rowspan="3">NA</td><td>0.10</td></tr>
<tr><td>Deterministic (DJ)
1274 kHz-1062 MHz.</td><td>0.20</td><td>0.33</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.43</td><td>0.62</td></tr>
<tr><td colspan="9">400-DF-EL-S Inter-enclosure (note- 1, 5, 10)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ) note- 4,8
2550 kHz to > 5 MHz.</td><td colspan="2" rowspan="3">NA</td><td>0.10</td><td>0.10
note- 7</td><td>0.10</td><td>0.10</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Deterministic (DJ)
2550 kHz - 2125 MHz.
note- 9</td><td>0.14</td><td>0.39
note- 7</td><td>0.37</td><td>0.39</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.36</td><td>0.69
note- 7</td><td>0.67</td><td>0.69</td></tr>
<tr><td colspan="9">400-DF-EL-S Intra-enclosure (note- 1, 5, 10)</td></tr>
<tr><td>Applied Sinusoidal swept freq. (SJ)
2550 kHz to > 5 MHz.
note- 4,8</td><td>0.10
note- 6</td><td colspan="6" rowspan="3">NA</td><td>0.10</td></tr>
<tr><td>Deterministic (DJ)
2550 kHz to 2125 MHz
note- 9</td><td>0.33
note- 6</td><td>0.33</td></tr>
<tr><td>Total (note- 2,3)</td><td>0.62
note- 6</td><td>0.62</td></tr>
</table>

Table 31 – Min Jitter tolerance

800-DF-EL-S Inter-enclosure (note- 1, 5, 10, 14)					
Applied Sinusoidal swept freq. (SJ) 5098 kHz to > 20 MHz. note- 4,8	NA	note- 11	NA	note- 13	NA
Deterministic (DJ) 5098 KHz to 4250 MHz note- 9				0.47	
Pulse width shrinkage (DDPWS UI)				0.36	
Total (note- 2,3)				0.71	
800-DF-EA-S Intra-enclosure (note- 1, 5, 10, 14)					
Applied Sinusoidal swept freq. (SJ) 5098 kHz to > 20 MHz. note- 4,8	See sub-clause 9.5.2	note- 11	NA		See sub-clause 9.5.2
Deterministic (DJ) 5098 KHz to 4250 MHz note- 9					
Total (note- 2,3)					

Notes:

1. The jitter values given are normative for the jitter content of the signals that apply at the interoperability point defined. See also the definition of other signal requirements in sub-clause 9.3.2
2. No value is given for random jitter (RJ). For compliance with this spec, the actual random jitter amplitude shall be the value that brings total jitter to the stated value at a probability of 10^{-12}.
3. The applied SJ shall be swept between the upper and lower frequencies defined in figure 50 and shall be equal to or greater than the mask value over the entire range defined in this table. The number of frequency points used to verify compliance with this requirement is not specified in this document.
4. The additional 0.1 UI of sinusoidal jitter is added to ensure the receiver has sufficient operating margin in the presence of external interference.
5. Values at the α points are determined by the application.
6. Shall meet β_R jitter specification calibrated through the β_T compliance interconnect. See Annex B for further information.
7. Shall meet γ_R jitter tolerance specification calibrated through the γ_T compliance interconnect. See Annex B for further information.
8. A higher frequency sweep of 2.55 MHz to 20 or 21.25 MHz as described by FC-MJSQ is recommended.The upper frequency should exceed the upper loop response of the CDR.
9. This is the minimum pass band frequency of the instrument used to calibrate the signal tolerance.
10. The signal amplitude shall be adjusted to the minimum allowed at the interoperability point in table 25 or table 28
11. Delta T and gamma T tolerances are not specified for 800 MB/s variants
12. For the equalizing receiver the jitter tolerance specification is replaced by the stress receiver sensitivity specification. See sub-clause 9.5 and SFF-8431 appendix D.8.
13. Receiver jitter tracking is defined in annex A.3.5.
14. The values listed in this table are at the appropriate compliance points which or delta points are on the printed circuit board immediately after the mated connector. Probing at these points is generally not feasible particularly for higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 800 MB/s delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in annex G.

9.5 Signal characteristics for 800-DF-EA-S variants

This sub-clause describes performance requirements at beta T, epsilon T, beta R, epsilon R, and delta R for the linear variants.

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9.5.1 800-DF-EA-S at delta R compliance point

The δ_R output shall meet the parameters in Table 32.

Table 32 – signal output requirements for 800-DF-EA-S delta R

800-DF-EA-S, Inter-enclosure	δ_R
Relative noise, RN (dimensionless)	note- 2
VMA (mV), min	225
Max voltage PK-PK (mV)	850
WDP (dB) (note- 1)	note- 2
DDPWS (UI)	0.21

Notes:
1 WDP is defined here with 1,2 equalizer. See annex A.5.
2 Trade-offs exist between the maximum RN and maximum WDP given in figure 45

Maximum WDP is 5.0 dB.

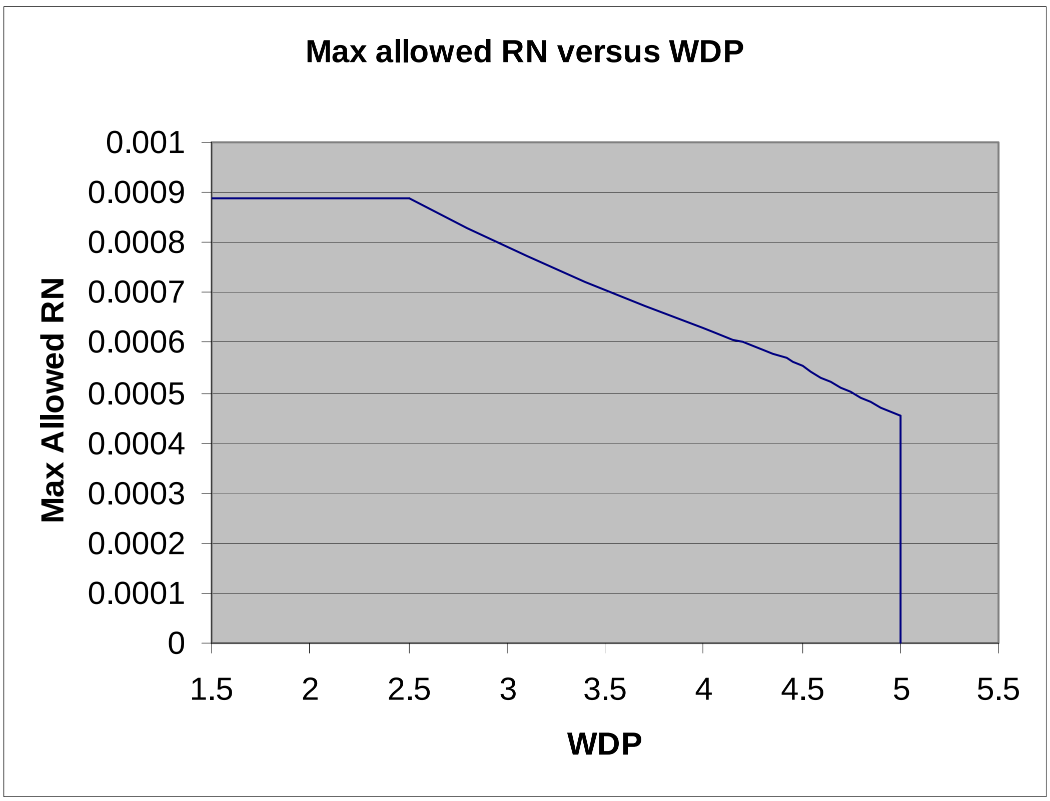


Figure 45 – Trade-off between RN and WDP for 800-DF-EA-S delta R

For WDP less than or equal to 2.5 dB, maximum RN is 0.0887.
For WDP in the range of 2.5 dB and 4.2 dB maximum RN is $0.057*10^{(WDP-4.2)/10}$.
For WDP in the range of 4.2 dB and 5.0 dB maximum RN is $0.057*10^{(WDP-4.2)/5.8}$.

The system shall tolerate both case1 and case 2 input signals defined in Table 33 at all VMA levels between the minimum and maximum values. These conditions represent the maximum value of RN and maximum value of WDP.table 33.

Table 33 – signal tolerance requirements for 800-DF-EA-S delta R

800-DF-EA-S, Inter-enclosure	Case 1 δ_R	Case 2 δ_R
Relative noise, RN (dimensionless)	0.0453	0.0887
VMA (mV), min	225	
Max voltage PK-PK (mV)	850	
WDP (dB) (note- 1, 2)	5.0	2.5
DDPWS (UI)	0.21	
Rx jitter tracking test, VMA (note- 3) max (mV)	225	
Rx jitter tracking test, jitter frequency and pk-pk amplitude (note- 3) (kHz,UI)	(510, 1) (100, 5)	

Notes:
1 For receiver testing WDP is defined with DDPWS already calibrated.
2 WDP is defined here with 1,2 equalizer. See annex A.5.
3 Receiver jitter tracking is defined in annex A.3.5.

9.5.2 800-DF-EA-S at Beta and epsilon compliance points

The signal requirements for 800-DF-EA-S at beta T and epsilon T is shown in table 34.

Table 34 – Signal requirements for 800-DF-EA-S at beta T and epsilon T

TCTF index		Units	Beta T Point		Epsilon T Point		
			1	2	1	2	3
Peak-to-peak differential output voltage	Max	mV	1200		1200		
VMA (note- 1)	Max	mV	1000		1000		
	Min	mV	665		665	665	535
U_J, RMS (note- 2)	Max	UI	0.020		0.020		
P_{ALLOC} (note- 3)		dBe	18.6		18.6	18.6	20.7
TWDP (note- 3)	Max	dBe	7.1	10.5	7.1	10.5	15.4
NC-DDJ (note- 3)	Max	UI	0.110	0.150	0.110	0.150	0.330

Notes:
1 Voltage modulation amplitude is measured using the procedure described in annex A.1.1.2.
2 Uncorrelated jitter is measured using the procedure described in annex A.5.
3 TWDP and NC-DDJ are measured using the procedure described in annex A.5 and defined using a reference receiver with 1 feed-forward and 3 feedback taps.

The signal requirements for 800-DF-EA-S at beta R and epsilon R is given in table 35. For beta and epsilon compliance points, the receiver device shall accept differential input amplitudes produced by compliant transmitter device connected without attenuation to the receiver device, and operate at a BER no greater than 10^{-12}. The peak-to-peak amplitude present at beta R or epsilon R may be larger than the maximum stated in table 34. This is the result of the possible mismatch of the termination impedance at the receiver and the transmitter. In addition, receiver device shall tolerate a peak-to- peak differential input amplitude of 2000 mV applied at beta R without suffering permanent damage.

Table 35 – Signal requirements for 800-DF-EA-S epsilon R and beta R

Test index	Units	Beta R Point		Epsilon R Point		
		1	2	1	2	3
VMA (note- 1)	mV	540	470	540	470	300
BUJ (note- 2)	UI	0.035		0.035		
R_J, peak-to-peak (note- 2)	UI	0.140		0.140		
RI, peak-to-peak (note- 3)	mV	187	109	187	109	50
P_{ALLOC} (note- 4)	dBe	16.8	15.7	16.8	15.7	15.7
WDP (note- 4)	dBe	7.1	10.5	7.1	10.5	15.4
NC-DDJ (note- 4)	UI	0.110	0.150	0.110	0.150	0.330
Rx jitter tracking test, VMA, max (note- 5)	mV	300				
Rx jitter tracking test, jitter frequency and pk-pk amplitude (note- 5)	(kHz,UI)	(510,1) (100.5)				

Notes:

1 Voltage modulation amplitude is measured at the input to the receiver device under test using the procedure defined in annex A.1.1.2.
2 Bound uncorrelated jitter (BUJ) and random jitter (R_J) are measured at the input to the ISI filter per the procedure defined in annex A.5. Peak-to-peak R_J includes all but 10^{-12} of the amplitude population.
3 Random interference (RI) is applied at the receiver device input per the signal tolerance procedure defined in annex A.3.6. Peak-to-peak RI includes all but 10^{-12} of the amplitude population.
4 WDP and NC-DDJ are measured using the procedure described in annex A.5 and defined using a reference receiver with 1 feed-forward and 3 feedback taps.
5 Receiver jitter tracking is defined in annex A.3.5.

9.6 Eye masks

9.6.1 Overview

The eye masks shown in this clause shall be interpreted as graphical representations of the voltage and time limits.The mask boundaries define the eye contour of the 10^{-12} population at all signal levels. Current equivalent time sampling oscilloscope technology is not practical for measuring compliance to this eye contour. See FC-MJSQ for some methods that are suitable for verifying compliance to these masks. The oscilloscope remains valid for determining rise / fall times, amplitude and under and overshoots.

9.6.2 Transmitter device eye mask at β_T, δ_T and γ_T.

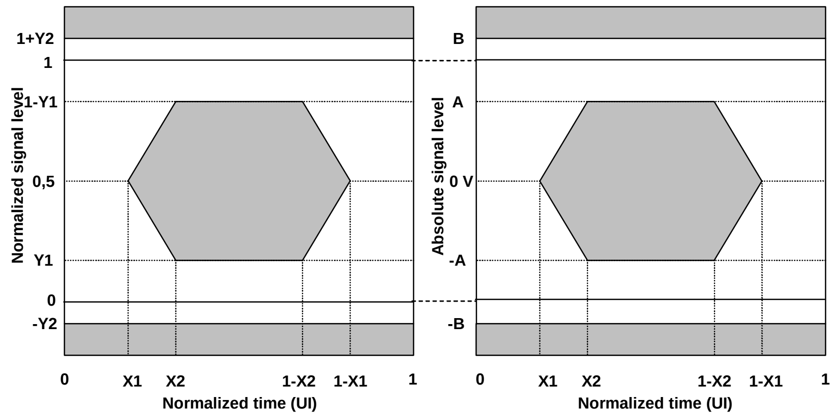


Figure 46 – Normalized (left) and absolute (right) eye diagram masks at β_T, δ_T and γ_T.

The Y1 and Y2 amplitudes allow signal overshoot of 10% and undershoot of 20%, relative to the amplitudes determined to be 1 and 0. There is no relative eye mask requirement for 800-DF-EL-S and 800-DF-EA-S at the delta T point.

To accurately determine the 1 and 0 amplitudes for use with the normalized mask use an oscilloscope having an internal histogram capability. Use the voltage histogram capability and set the time limits of the histogram to extend from 0.4 UI to 0.6 UI. Set the voltage limits of the histogram to include only the data associated with the 1 level. The 1 level to be used with the normalized mask shall be the mean of the histogram.   Repeat this procedure for the 0 level.

Signals seeking compliance with the eye diagram mask shall be measured with a jitter timing reference that conforms to FC-MJSQ.

9.6.3 Receiver device eye mask at β_R, δ_R and γ_R for EL variants

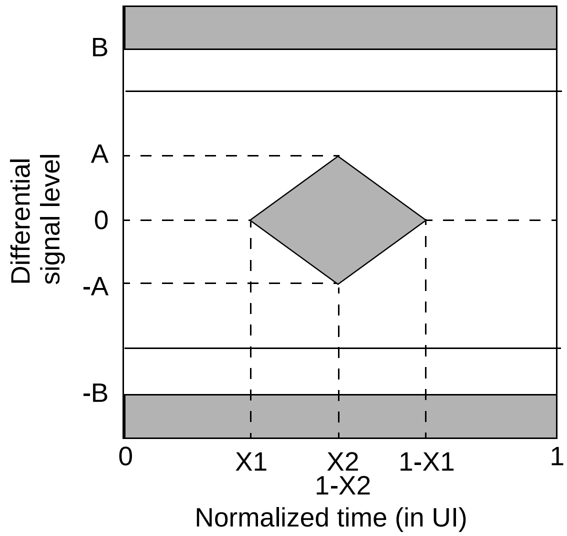


Figure 47 – Eye diagram mask at β_R, δ_R, and γ_R for EL variants

The received eye diagram mask applies to jitter when measured using a jitter timing reference, e.g. Golden PLL.

Verifying compliance with the limits represented by the received eye mask should be done with reverse channel traffic present in order that the effects of cross talk are taken into account. See subclause 5 for requirements on activity on ports not under test while the signal measurement is performed.

To accurately determine the 1 and 0 amplitudes for use with the normalized mask use an oscilloscope having an internal histogram capability. Use the voltage histogram capability and set the time limits of the histogram to extend from 0.4 UI to 0.6 UI. Set the voltage limits of the histogram to include only the data associated with the 1 level. The 1 level to be used with the normalized mask shall be the mean of the histogram. Repeat this procedure for the 0 level.

9.6.4 Jitter tolerance masks

Tolerance eye masks at β_T, δ_T and γ_T shall be based on figure 46 and shall be constructed using the X2, A and B values given in table 23 and the A value given in table 25 for the 400-DF-EL-S variant. X1 values shall be half the value for total jitter given in table 31 for jitter value frequencies above signaling rate/1 667.

Note that the x_T tolerance masks are identical to the output masks (per table 23) except that X1 and X2 values are each increased by half the amount of the sinusoidal jitter values given in table 31.

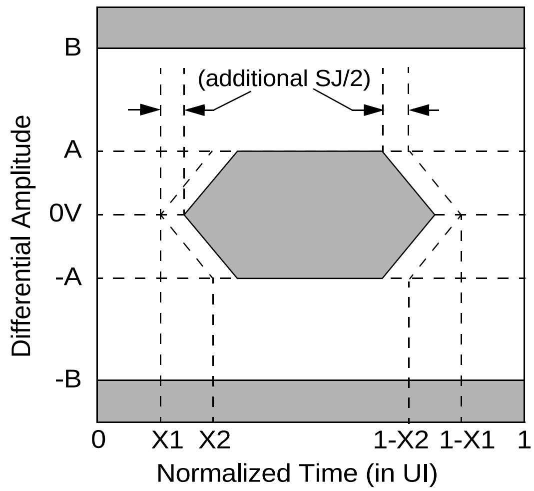


Figure 48 – Deriving the tolerance mask at the interoperability T points

Tolerance eye masks at β_R, δ_R and γ_R shall be based on figure 47 and shall be constructed using the X2 and B values given in table 27. X1 shall be half the value for total jitter given in table 31 for jitter frequencies above signaling rate/1 667. However, the leading and trailing edge slopes of figure 47 (with ALL values from table 23) shall be preserved. As a result the amplitude value of A will be less than that given in table 27 and shall therefore be calculated from those slopes as follows:

$A_{Tol} = A_{OP}(X2_{OP} - 0.5(\text{additional SJ UI}) - X1_{OP})/(X2_{OP} - X1_{OP})$

A_{Tol} = value for A to be used for the tolerance masks

A_{OP}, $X1_{OP}$ and $X2_{OP}$ are the values in table 27 for A, X1 and X2

Note that the X1 points in the x_R tolerance masks are greater than the X1 points in the output masks (per table 23), again due to the addition of sinusoidal jitter.

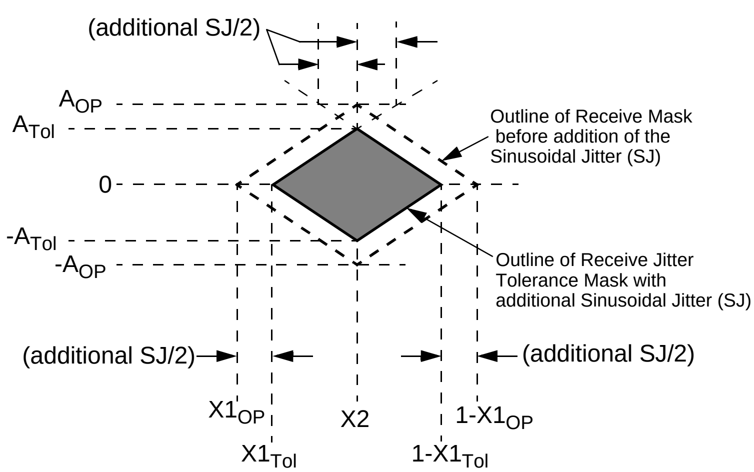


Figure 49 – Deriving the tolerance mask at the interoperability R points

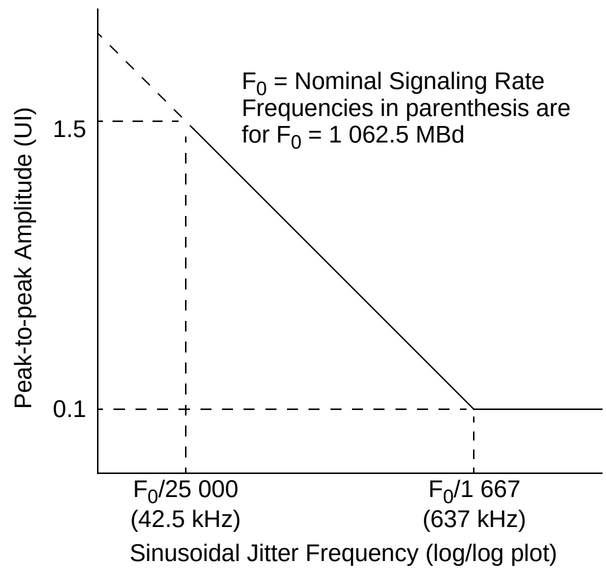


Figure 50 – Sinusoidal jitter mask

9.7 Grounding and shielding requirements at interoperability points

Figures 51 through 53 contain the grounding and shielding requirements at the interoperability points. Where there is a shield, the Faraday shield boundary is at the separable part of the connector that defines the interoperability point.

The interface specifications assume that all measurements are made after a mated connector pair, relative to the source or destination of the signal using a load equivalent to those of figure 56, or 57 as appropriate.

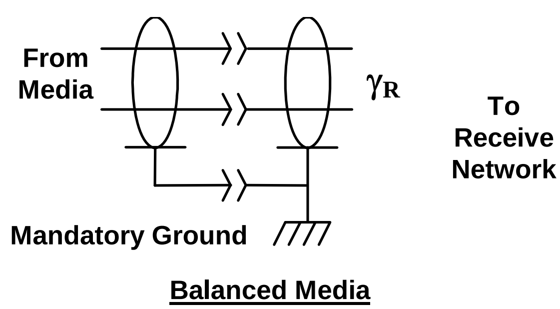


Figure 51 – Inter-enclosure receiver compliance point γ_R

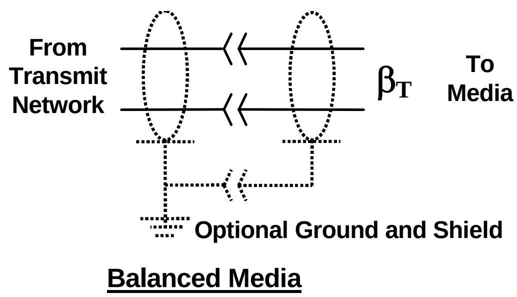


Figure 52 – Intra-enclosure transmitter compliance point β_T

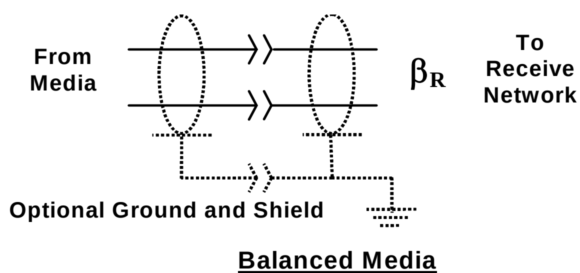


Figure 53 – Intra-enclosure receiver compliance point β_R

9.8 Transmitter device characteristics

For all inter-enclosure TxRx Connections, the transmit device shall be AC coupled to the cable through a transmission network.

For all intra-enclosure TxRx Connections the transmit device may be either AC or DC-coupled to the bulk cable.

The 100 and 200 DF-EL-S inter-enclosure transmit devices shall have output voltages and timing listed in table 23 and table 30 measured at the designated interoperability points. This measurement shall be made across a load equivalent to that shown in figure 56. The 200-DF-EL-S intra-enclosure transmit devices shall have output voltages and timing listed in table 23 and table 30 measured at the designated interoperability points. The 400-DF-EL-S intra-enclosure transmit device shall have output voltages and timing listed in table 24 and table 30 measured at the designated interoperability points. The measurement for the 200-DF-EL-S and the 400-DF-EL-S transmitters shall be made across a load equivalent to that shown in figure 57. The 400-DF-EL-S transmitters shall also use the appropriate TCTF described in sub-clause 9.11. The default point is γ_T for inter-cabinet TxRx connections and β_T for intra-cabinet TxRx connections.

9.9 Return loss and impedance requirements

Return loss and impedance requirements are necessary to limit reflected energy at interfaces. Impedance is the ratio of instantaneous voltage to instantaneous current at a point in time. Return loss (dB) is the negative of S11 or S22. S11 or S22, is the ratio of reflected signal to incident signal at a certain frequency and at a specified reference impedance level. FC-PI used the impedance specification methodology except for applications where magnetic coupling was used. FC-PI-4 uses the return loss methodology exclusively for the 400-xx-xx-x, and 800-xx-xx-x variants but retains the impedance methodology for the 100-xx-xx-x, and 200-xx-xx-x variants.

The Impedance can be derived from a TDR measurement using an incident signal with a known rise time. Where this waveform is flat a single number describes the impedance. If the waveform has structure then the entire waveform is needed to describe the impedance measurement. Having a flat waveform is equivalent to specifying the return loss under d.c. conditions.

In general it is expected that the impedance waveform will not be flat due to structural inhomogeneities in the signal path caused by connectors, conductor terminations, PC board pads, vias, ESD protection devices, chip packages, and other necessary elements. In order to allow for these necessary inhomogenieties in the simplest possible way a methodology was employed prior to FC-PI-2 that allowed certain ‘exception windows’ in the impedance vs. time waveform that deviated from the impedance in the uniform bulk cable portion of the interconnect assembly. Exception window methodology is a time domain approach somewhat analogous to using a spectral mask for a return loss specification.

FC-PI-4 preserves the impedance waveform with exception window methodology for the 100 and 200 speed variants but adopts exclusively the return loss spectral mask methodology for the 400 and 800 speed variants. Return loss specification methodology is now preferred because it is useful for all kinds of coupling circuits, including magnetics, and because S-parameters may be directly input into common simulation tools.

Table 36 uses both impedance and return loss methodologies with the understanding that return loss spectra and impedance waveforms are duals of each other and either may be produced from the other by using Fourier methods.

The impedance specifications for the interconnect are outlined in table 36.

Table 36 – Return loss and impedance requirements

<table>
<tr><th></th><th>Units</th><th>100-DF-EL-S</th><th>200-DF-EL-S</th><th>400-DF-EL-S
note- 11</th><th>800-DF-Ex-S
note- 11</th></tr>
<tr><td>TDR rise time
note- 1, 2</td><td>ps</td><td>100</td><td>75</td><td>60</td><td>35</td></tr>
<tr><td colspan="6">Inter-enclosure / Gamma Points</td></tr>
<tr><td>Media (bulk cable)
note- 2, 3, 4</td><td>Ω</td><td>150 ± 10</td><td>150 ± 10</td><td>150</td><td rowspan="7">NA</td></tr>
<tr><td>Through Connection
note- 1, 2, 5</td><td>Ω</td><td>150 ± 30</td><td>150 ± 30</td><td>100</td></tr>
<tr><td>Exception window (max)
note- 1, 2, 5, 6, 7</td><td>ps</td><td>800</td><td colspan="2" rowspan="2">NA</td></tr>
<tr><td>Exception window
note- 1, 2, 5, 6, 7</td><td>Ω</td><td>150 ± 50</td></tr>
<tr><td>Transmission line terminator, note- 2</td><td>Ω</td><td>150 ± 10</td><td>150 ± 10</td><td>150</td></tr>
<tr><td>Receiver termination impedance
note- 1, 2, 8, 9, 10</td><td>Ω</td><td>150 ± 30</td><td>150 ± 30</td><td>NA</td></tr>
<tr><td>Return Loss (min)
note- 2, 10</td><td>dB</td><td colspan="3">15</td></tr>
</table>

Table 36 – Return loss and impedance requirements

	Units	100-DF-EL-S	200-DF-EL-S	400-DF-EL-S note- 11	800-DF-Ex-S note- 11
Intra-enclosure / Beta & Delta points					
Media (PCB) note- 2, 3, 4	Ω	150 ± 15	100 ± 15	100	100
Through Connection note- 1, 2, 5	Ω	150 ± 30	100 ± 30	100	100
Exception window (max) note- 1, 2, 5, 6, 7	ps	800	NA		
Exception window note- 1, 2, 5, 6, 7	Ω	150 ± 50			
Transmission line terminator, note- 2	Ω	150 ± 10	100 ± 10	NA	
Receiver termination impedance note- 1, 2, 8, 9, 10	Ω	150 ± 30	100 ± 30		
Return Loss (min) note- 2, 10	dB	15			

Notes:

1 All times indicated for TDR measurements are recorded times. Recorded times are twice the transit time of the TDR signal.

2 All measurements are made through mated connector pairs.

3 The bulk cable impedance measurement identifies the impedance mismatches present in the bulk cable when terminated in its characteristic impedance. This measurement includes mated connectors at both ends of the bulk cable, where they exist, and any intermediate connectors or splices.

4 Where the bulk cable has an electrical length of > 4 ns the procedure detailed in SFF-8410, or an equivalent procedure, shall be used to determine the impedance.

5 The through connection tolerance and the exception window may be applied only at the interoperability points, and shall be wholly contained within 2 ns of that point.

6 The Exception Window begins at the point where the measured impedance first falls below the impedance tolerance limit for Through Connection. It ends at the point where the measured impedance subsequently remains within the limits for Through Connection impedance.

7 During the Exception Window, no single excursion shall exceed the Through Connection impedance tolerance for a period greater than twice the TDR rise time specified for the measurement.

8 The receiver termination impedance specification applies to each and every receiver in a TxRx connection and covers all time points between the connector nearest the receiver, the receiver, and the transmission line terminator. This measurement shall be made from that connector.

9 At the time point corresponding to the connection of the receiver to the transmission line the input capacitance of the receiver and, its connection to the transmission line, may cause the measured impedance to fall below the minimum impedances specified in this table. The area of the dip caused by this capacitance is directly proportional to the capacitance. An approximate value for the area is given by the product of the amplitude of the dip (in units of rho) and its width (in ps) measured at the half amplitude point. The product calculated by this method shall not be greater than 150 ps. The amplitude is defined as being the difference in rho between the rho at the nominal impedance and the rho at the minimum impedance point

10 All impedance measurements shall be TDR measurements except where the receiver termination being tested includes inductive components such as transformers. When inductive components exist in the receiver termination a swept frequency Return Loss or VSWR measurement may be more appropriate. The frequency sweep shall cover the range signaling rate/10 to signaling rate/2.

11 Impedances values for the 400-DF-EL-S and 800-DF-Ex-S are for reference only.

9.10 Receiver characteristics

The receiver shall be AC-coupled to the media through a receive network. The receive network shall terminate the TxRx Connection by an equivalent impedance as specified in table 36.

The receiver shall operate within the BER objective (10^{-12}) when an FC signal with valid voltage and timing characteristics is delivered to the interoperability point from a balanced 150 Ω (100,200-DF-EL-S) source. For the 400-DF-EL-S inter-cabinet the source shall be 150 Ω and the 400-DF-EL-S inter-cabinet shall be 100 Ω. The delivered FC signal shall be considered valid if it meets the voltage and timing limits specified in figure 47 and table 30 when measured across a load equivalent to those of figure 56, or 57 as appropriate. See table 36.

Additionally the receiver shall also operate within the BER objective when the signal at α_R has the additional sinusoidal jitter present that is specified in table 31. Jitter tolerance figures are given in table 31 for all interoperability points in a TxRx Connection. The figures given assume that any external interference occurs prior to the point that the test is applied. When testing the jitter tolerance capability of a receiver the additional 0.1 UI of sinusoidal jitter may be reduced by an amount proportional to the actual externally induced interference between the application point of the test and α_R. Note: The addition of additional jitter reduces the eye opening in both voltage and time; see sub-clause 9.6.4.

9.11 Transmitter Compliance Transfer Function

9.11.1 TCTF overview

For the 400-DF-EL-S a combination of a zero-length test load and the transmitter compliance transfer function (TCTF) test load methodology is used for the specification of the transmitter characteristics. The TCTF is the mathematical statement of the transfer function that the transmitter shall be capable of producing acceptable signals as defined by the receive mask. The transmitter compliance transfer function is used to specify the requirements on transmitters that may or may not incorporate pre-emphasis or other forms of compensation. A compliance interconnect is any physical interconnect with equal or greater loss at all frequencies then that required by the transmitter compliance function.

This methodology specifies the transmitter signal at the test points on the required test loads. The transmitter shall use the same settings (e.g., pre-emphasis, voltage swing, etc.) with both the zero-length test load and the TCTF test load. The receiver signal specifications shall be met under each of these loading conditions.

The TCTF is the mathematical statement of the transfer function that the transmitter shall be capable of producing acceptable signals as defined by the receive mask.

The TCTF is not a statement of the performance requirements for the interconnect.

9.11.2 400-DF-EL-S Intra cabinet Transmitter Compliance Transfer Function

The TCTF for the intra cabinet β_T test point has been chosen to represent a typical 100 Ω differential system specified with respect to transmission magnitude and intersymbol interference (ISI) loss. The compliance interconnect limits have been chosen to allow a realistic differential interconnect of about 50 cm length on FR4 epoxy PCB (Printed Circuit Board). The TCTF is the mathematical statement of the transfer function that the transmitter shall be capable of producing acceptable signals as defined by the receive mask. For the β_T test point the transmission magnitude response [S_{21}], of the TCTF in dB satisfies the following equation:

$$|S_{21}| \leq |S_{21}|_{limit} = - 20 \log(e) \times [a_1 \sqrt{f} + a_2 f + a_3 f^2]$$

where f is frequency in Hz, $a_1=6.5x10^{-6}$, $a_2=2.0x10^{-10}$ and $a_3=3.3x10^{-20}$. This limit applies from DC to 4.25 GHz. The magnitude response above 4.25 GHz does not exceed -16.25 dB. The ISI loss, defined as the difference in magnitude response between two frequencies, is greater than 4.0 dB between 425 MHz and 2.125 GHz. The magnitude response and ISI loss limits are illustrated in figure 54.

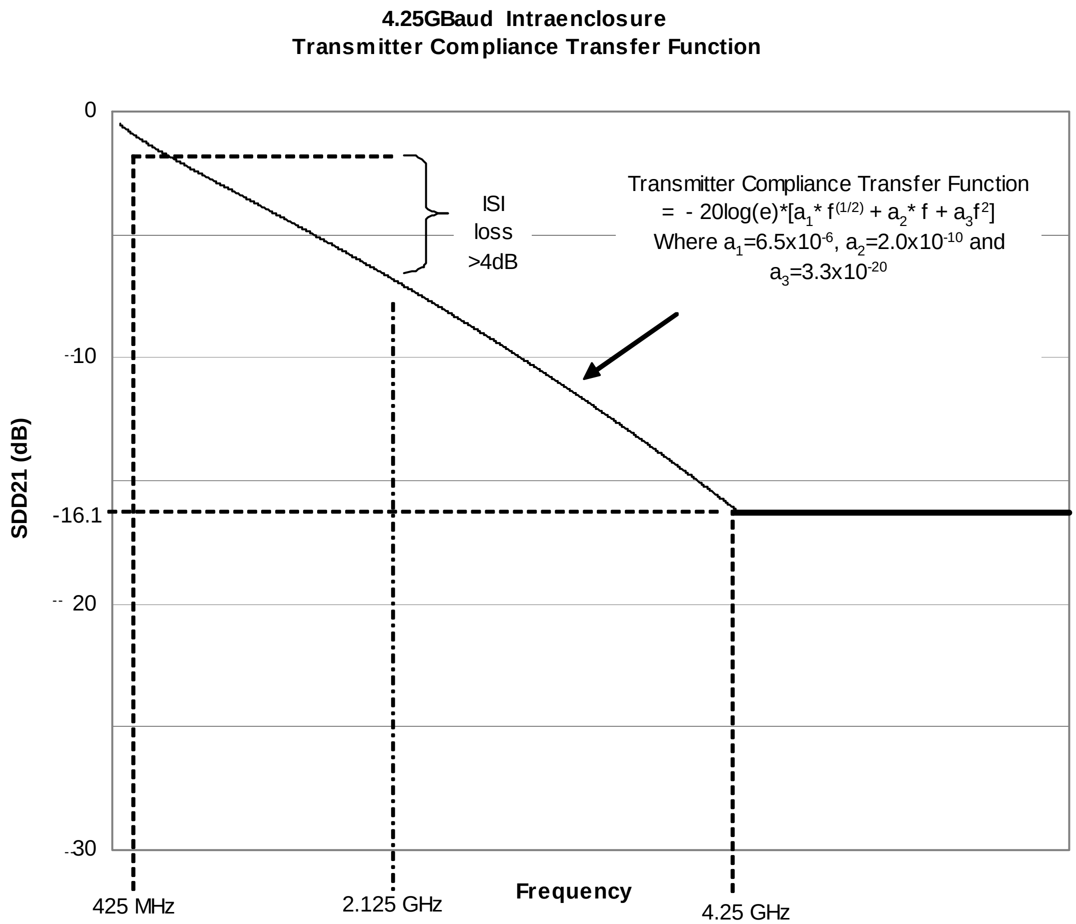


Figure 54 – 400-DF-EL-S Intra-enclosure Transmitter Compliance Transfer Function

9.11.3 400-DF-EL-S Inter cabinet Transmitter Compliance Transfer Function

The TCTF for the inter-enclosure γ_T test point has been chosen to represent a typical 150 Ω differential interconnect using 24 gauge wire, 7 meters in length, being driven with a 156 ps rise time. The TCTF is the mathematical statement of the transfer function that the transmitter shall be capable of producing acceptable signals as defined by the receive mask. For the γ_T test point the transmission magnitude response $[S_{21}]$, of the TCTF in dB satisfies the following equation

$$|S_{21}| \le |S_{21}|_{limit} = -20\log(e)*(a_1 \sqrt{f} + a_2 f)$$

where f is frequency in Hz, a_1= 8.0x10^{-6} and a_2= 1.55x10^{-10} for the case where the rise time is 156ps. This limit applies from DC to 4.25 GHz. The magnitude response above 4.25 GHz does not exceed -10.3 dB. The ISI loss, defined as the difference in magnitude response between two frequencies, is greater than 4.0 dB between 425 MHz and 2.125 GHz. The magnitude response and ISI loss limits are illustrated in figure 55 below.

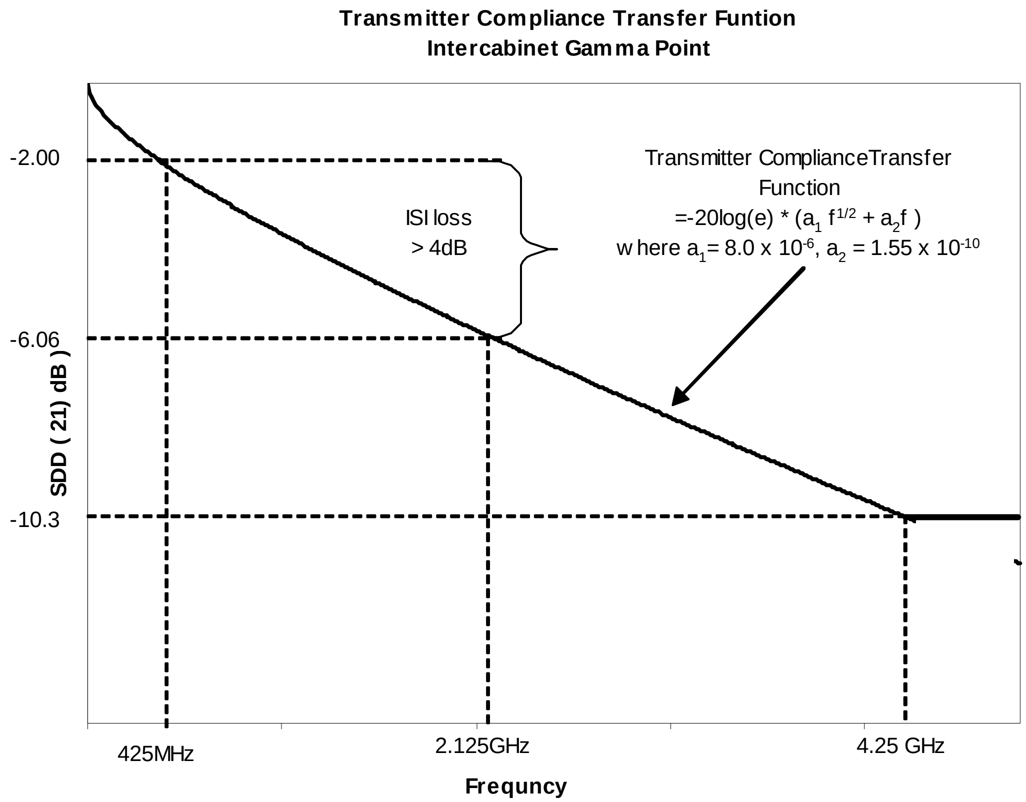
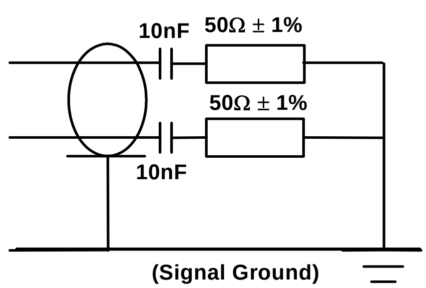


Figure 55 – 400-DF-EL-S Inter cabinet transmitter compliance transfer function

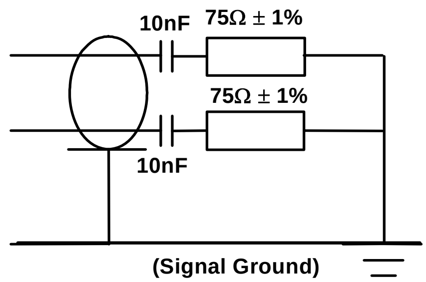
9.12 Test loads



Balanced Test load

NOTE: 10 nF capacitors are required if output under test is not DC isolated.

Figure 57 – 200, 400 and 800-DF-EL-S 100 Ohm test load



Balanced Test load

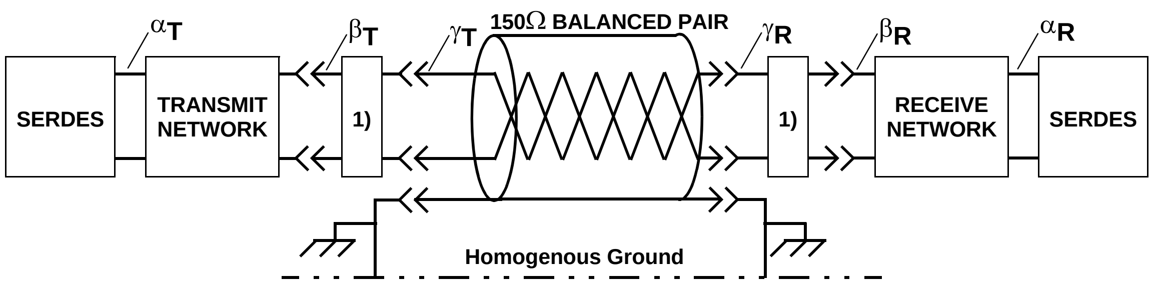
NOTE: 10 nF capacitors are required if output under test is not DC isolated.

Figure 56 – 100, 200, 400 and 800-DF-EL-S 150 Ohm test load

The mask of the transmitter eye diagram is given in figure 46**.** The normalized amplitudes, Y1 and Y2, allow signal overshoots of 10% and undershoots of 20%. The transmitter shall meet both the normalized and absolute values. The normalized amplitudes do not apply for compliance channel-based methods.

9.13 Example TxRx connections

Figure 58 is example of a typical differential TxRX connection showing all of the compliance points.



1). Active circuits and coupling networks maybe be required to ensure interoperability

Figure 58 – Example xxx-DF-EL-S inter-enclosure TxRx with 150Ω balanced cable

10 Electrical cable plant and connector specifications for single lane variants

10.1 Overview

This clause defines the TxRx connection requirements for a Fibre Channel electrical cable plant and its connectors.

It is the implementer's responsibility to ensure that the impedances, attenuation (loss), jitter, and shielding are within the operating limits of the TxRx connection type and data rate being implemented.

An optional equalizer network may exist and operate as part of the cable plant. It shall be used to correct for frequency selective attenuation loss of the transmitted signal, as well as timing variations due to the differences in propagation delay time between higher and lower frequency components. An equalizer should need no adjustment.

For those cables containing embedded equalization circuits, the operation of the cable may be both data rate and length specific. All cables containing such circuits shall be marked with information identifying the specific designed operational characteristics of the cable assembly.

10.2 Shielding

Cable assemblies shall have a transfer impedance through the shield(s) of less than 100 mΩ/m from DC through the (signaling rate)/2 equivalent frequency.

Cable shield(s) on inter-enclosure cables shall be earthed through the bulkhead connector shell(s) on both the transmitter and receiver ends as shown in sub-clause 9.7 and sub-clause 9.13.

10.3 Cable interoperability

All styles of balanced cables are interoperable; i.e., electrically compatible with minor impact on TxRx connection-length capability when intermixed. Interoperability implies that the transmitter and receiver signal level and timing specifications are preserved, with the trade-off being distance capability in an intermixed system. Any electrically compatible, interoperable cables may be used to achieve goals of longer distance, higher data rate, or lower cost as desired in the system implementation, if they are connector, impedance, and propagation mode compatible.

When cable types are mixed, it is the responsibility of the implementer to validate that the lengths of cable used do not distort the signal beyond the received signal specifications referenced in sub-clause 9.10.

At transmission rates of 1062.5 Mbaud or greater, particular attention must be given to the transition between cable segments. No more than four connection points should be present from the transmitter to the receiver.

10.4 Unbalanced cable connectors

This technology is obsolete. Refer to FC-PI-2 for information.

10.5 Balanced cable connectors

10.5.1 Balanced cable wiring

Balanced cables, when used in full duplex TxRx Connections, shall be wired in a crossover fashion as shown in figure 59, with each pair being attached to the transmit contacts at one end of the cable and the receive contacts at the other end.

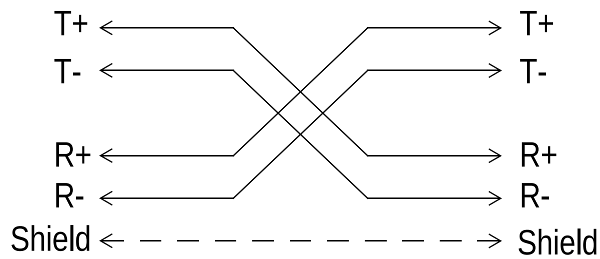


Figure 59 – Balanced cable wiring

10.5.2 Inter-enclosure connectors for balanced cable

10.5.2.1 Overview of balanced cable inter-enclosure connectors

Connections between enclosures require the use of shielded cable assemblies, terminated in polarized shielded connectors. All balanced cable types shall be connected using either style-1, style-2 or style-3 balanced cable connectors.

Standard cable assemblies shall have style-1 connectors at both ends of the cable, style-2 connectors at both ends of the cable or style-3 connectors at both ends of the cable. Cables may also be constructed with one of style-1, style-2 or style-3 connectors on each end for use in mixed connector installations or to adapt from one style to the other.

The cable connector shall be the plug or male connector while the bulkhead connector shall be the receptacle or female connector.

All three styles of inter-enclosure connectors may be populated with additional contacts to support additional functions. The presence of such contacts in the connector assemblies does not imply support for additional functions.

The suggested use for these additional contacts or contact locations is listed table 37.

Table 37 – Optional inter-enclosure contact uses

Contact Name	Pin Number		
	Style 1	**Style 2**	**Style 3**
Power supply, nominal + V dc	2	7	1
Module fault detect	3	4	7
Mechanical key	4		
Output disable	7	5	
Signal ground / + V dc return	8	2	4

– XX-00-200x Physical Interface-4 7.00

10.5.2.2 Style-1 balanced cable connector

The style-1 connector for balanced cable is the 9-pin shielded D-subminiature connector conforming to IEC 60807-3. The plug (male) half of the connector shall be mounted on the cable. One connector is required to connect both transmitting and receiving shielded pairs at one port. The connector pin assignments are shown in figure 60. Unused pin positions within the connector body are reserved. Electrical and mechanical details are also given in document SFF 8480.

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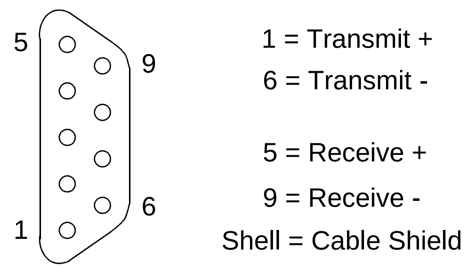


Figure 60 – Style-1 balanced connector plug contact locations

10.5.2.3 Style-2 balanced cable connector

10.5.2.3.1 Style-2 overview

The style-2 connector for balanced cables, shown in figure 61, shall conform to the mechanical and electrical characteristics of IEC 61076-3-103. The connector pin assignments are shown in figure 62. Electrical and mechanical details are also given in document SFF 8420.

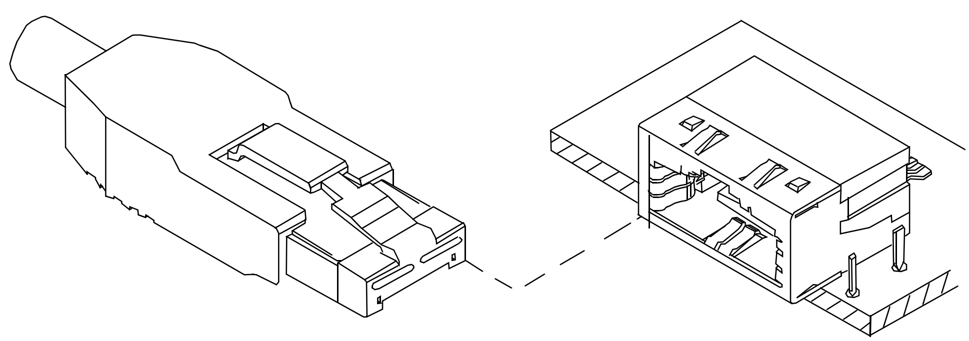


Figure 61 – Style-2 plug and receptacle

10.5.2.3.2 Style-2 plug

The plug (male) half of the connector shall be mounted on the cable. One connector is required to connect both the transmitting and the receiving shielded pairs at one port. The style-2 plug is shown in the left half of figure 61.

10.5.2.3.3 Style-2 receptacle

The style-2 receptacle is shown in the right half of figure 61. This connector mates with both transmit and receive balanced pairs. The connector contains eight pin locations plus an external shield. Pin locations 1, 3, 6, and 8 shall be populated in the connector body. Unused pin positions within the connector body are reserved. The connector pin assignments are shown in figure 62.

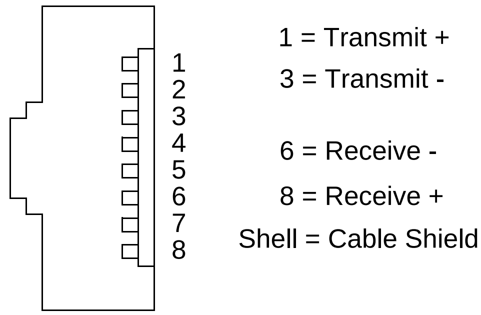


Figure 62 – Style-2 balanced connector receptacle contact locations

10.5.2.4 Style-3 Balanced Cable Connector

10.5.2.4.1 Style-3 Overview

The style-3 connector for balanced cables, shown in figure 63, shall conform to the mechanical and electrical characteristics of SFF-8421. Receptacle and connector pin assignments are shown in figure 64.

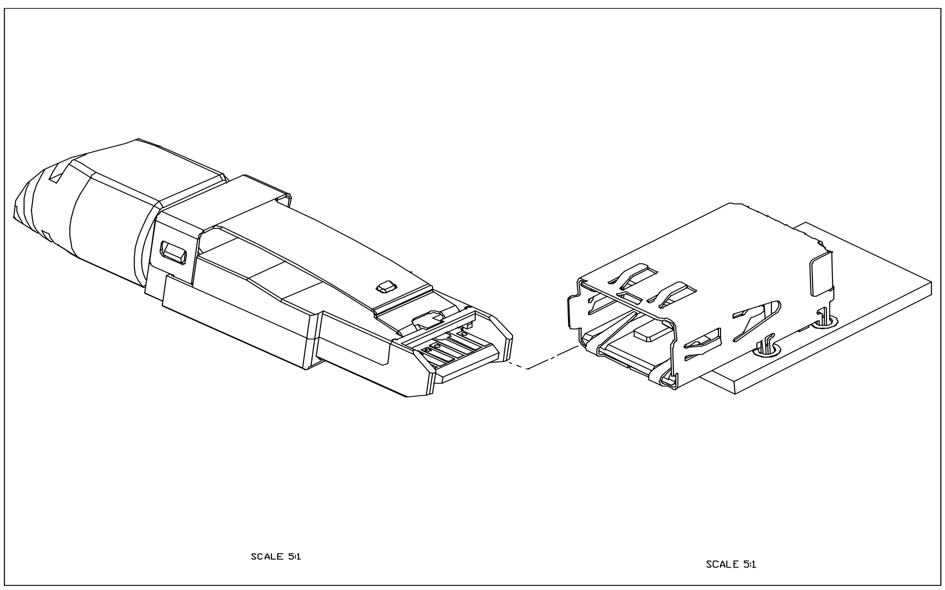


Figure 63 – Style-3 Plug and Receptacle

10.5.2.4.2 Style-3 Plug

The plug (male) half of the connector shall be mounted on the cable. One connector is required to contact both the transmitting and receiving shielded pairs at one port. The style-3 plug is the shown the left half of figure 63.

– XX-00-200x Physical Interface-4 7.00

10.5.2.4.3 Style-3 Receptacle

The receptacle (female) half of the connector shall be mounted on the printed circuit board. The style-3 receptacle is shown in the right side of figure 63. The pin assignments and location are shown in figure 64.

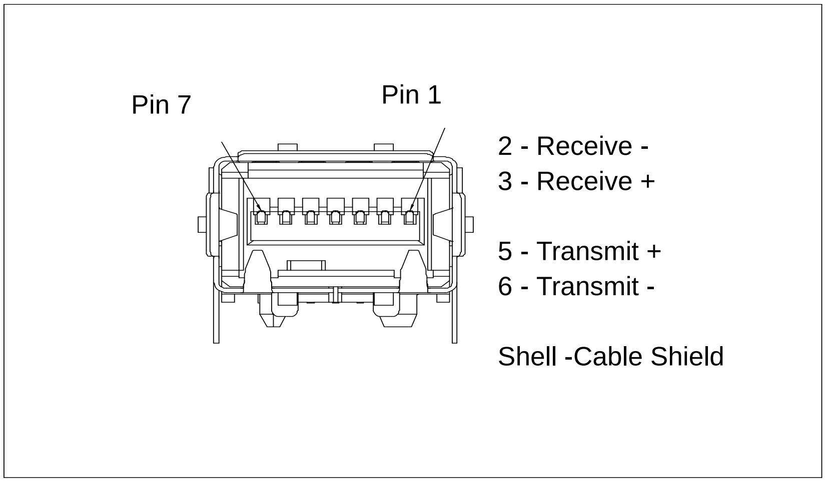


Figure 64 – Style-3 balanced connector receptacle contact locations

10.5.3 Intra-enclosure connectors for balanced cable

TxRx connections that remain entirely within an enclosure do not normally require the same level of shielding as connections external to an enclosure. These connections may be implemented with any number or mix of transmission line types. The target differential impedance for these connections are given in table 36.

Due to the shorter distances within an enclosure, and the uncontrolled impedance of the mating connectors, it is advised that source matching be used to limit the effect of signal reflections.

Any number of styles of connectors, including the balanced connectors documented in sub-clause 10.5.2, may be used to implement intra-enclosure TxRx connections. Connectors for these connections are specified by the desired functionality of the connectors. These connectors are not entirely shielded and leakage of RFI may occur.

A shielded enclosure (or other RF leakage control techniques such as ferrite beads or lossy tubing) is recommended for compliance with EMC standards, even when used with double-shielded balanced cables.

10.5.4 Integral FC device balanced connector

The integral intra-enclosure connector for FC devices supports multiple TxRx connections. It is documented to carry power for the FC device as well as numerous configuration and status options. Internal FC devices that require these capabilities shall use the 40-position SCA-2 connector specified in EIA-700 A0AF (SP-3652), and shall conform to the signaling requirements of SFF-8451 and SFF-8045.

This connector is shown in figure 65, and is primarily designed for backplane or rack mount applications. The contact locations are defined in figure 66.

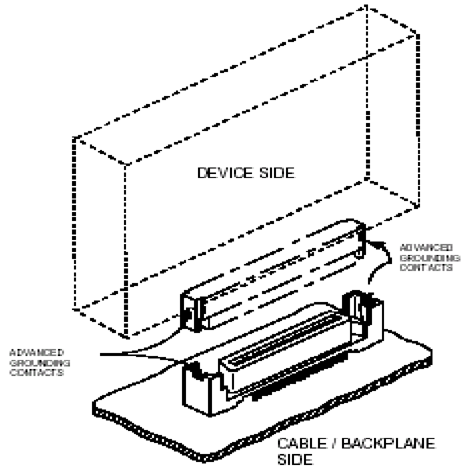
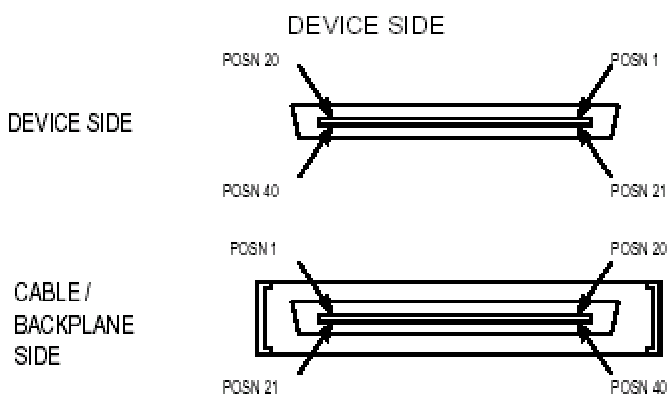


Figure 65 – Intra-enclosure integral FC device connector

DEVICE SIDE



CABLE/BACKPLANE SIDE

Figure 66 – Contact numbering for integral FC device connector

10.5.5 Non-device inter-enclosure connectors

Internal connectors that are not directly attached to the FC devices (non-device internal connectors) are not controlled by this standard. These connectors may be used within the enclosure as part of the

TxRx connection. Such connections are still required to meet the performance requirements of the transmit and receive signals at the compliance points.

11 Very Long Length Optical Interface (SM-LL-V)

11.1 Introduction

This clause (SM-LL-V) defines the very long length interface operating at data rates at or exceeding 1063 MBd using a long wavelength (1550 nm) laser on single-mode fiber. This clause defines the requirements, in addition to those in clause 6 and clause 8, needed to implement the very long length optical interface variants.

11.2 SM cable plant specification

Additional options to table 15 are listed in table 38.

Table 38 – Additional options to table 15

FC-0	Units	100-SM-LL-V	200-SM-LL-V
Subclause		8.1	8.1
Operating Range	m	2 to 50 000	2 to 50 000
Loss Budget	dB	18.5	18.5

11.3 Optical fiber interface specification

11.3.1 SM-LL-V data links

Additional options to table 6 are listed in table 39.

Table 39 – Additional physical links for single-mode classes

FC-0	Units	100-SM-LL-V	200-SM-LL-V	Notes
Subclause	6.3			
Signaling rate	MB/s	100	200	
Nominal signaling rate	MBd	1 062.5	2 125	
Tolerance	ppm	±100		note 10
Operating range	m	2 to >50 000		
Fiber core diameter (mode field diameter)	µm			note 9
Transmitter				
Type	laser			
λ (center wavelength), min	nm	1 480		
λ (center wavelength), max	nm	1 580		
Spectral width, max	nm	0.10	0.05	note 1
Side mode suppression ratio, min	dB	30		
Ave launched power, max	dBm	+2	+5	note 2
Optical modulation amplitude, min	mW (dBm)	0.8 (-1.0)	1.6 (+2.0)	note 2, 3
RIN_{12} (OMA),max	dB/Hz	-120		note 3

Table 39 – Additional physical links for single-mode classes

FC-0	Units	100-SM-LL-V	200-SM-LL-V	Notes
Rise and fall time (20%to80%), max	ps	320	160	note 4
Total jitter, max	%UI	note 6		note 5
Deterministic jitter, max	%UI			
Receiver				
Optical modulation amplitude, min	mW (dBm)	0.008 (-21.0)	0.016 (-18.0)	note 3, 7
Ave received power, max	dBm	+2	+5	
Optical path penalty, max	dB	note 8	note 8	
Return loss of receiver, min	dB	12	12	

Notes:

1. Applies under all operating conditions.
2. If the cable plant ensures that a minimum loss occurs between the transmitter and the receiver then the maximum average launched power and OMA may be increased by the amount of this minimum loss as long the eye safety limit is not exceeded - the launched power is limited to avoid overloading the receiver in a short link.
3. See annex A.
4. See sub-clause 6.3.2.
5. @ BER $\leq 10^{-12}$
6. See sub-clause 6.3.4.
7. Receiver optical modulation amplitude min is measured by sampling at the time center of the eye. Receiver test conditions should not incur the penalties that are already built into the link power budget.
8. See sub-clause 11.5.
9. See: IEC 607932, Type B1.1 and IEC 607932, Type B1.3 Optical Fibres - Part 2: Product Specifications Fourth Edition, 1998-12.
10. The signaling rate shall not exceed ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames).

11.3.2 SM optical response specifications

Optical response time specifications are based on the unfiltered waveforms. For the purposes of standardizing the measurement method, measured waveforms shall conform to the mask defined in figure 16 using the values for X1 derived from table 40. If a filter is used to measure the rise/fall time the filter response effect shall be removed from the measured rise and fall times using the equations:

$$t_R^2 = t_{R\_MEAS}^2 - t_{R\_FILTER}^2$$

$$t_F^2 = t_{F\_MEAS}^2 - t_{F\_FILTER}^2$$

where “R” indicates rise and “F” indicates fall.

The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson filter.

11.3.3 SM-LL-V jitter output specifications

The numbers in table 40 represent the high frequency jitter and do not include low frequency jitter or wander.

Table 40 – SM-LL-V jitter budget

	100-SM-LL-V		200-SM-LL-V	
Measurement point	**Total jitter** UI	**Deterministic jitter** UI	**Total jitter** UI	**Deterministic jitter** UI
γ_T	**0.43**	**0.21**	**0.44**	**0.26**
γ_R	**0.47**	**0.23**	**0.48**	**0.28**
NOTE – Interoperability points, γ_T and γ_R, shown in **bold** are defined as shown in figure 8 and figure 9 in clause 5.				

11.4 Optical fiber cable plant specification

Enhancement to clause 8 is specified.

This sub-clause specifies a single-mode cable plant (see sub-clause 8.1.2 for the definition) for the long length optical interface (SM-LL-V).

Table 41 – Single-mode cable plant

FC-0	Unit	100-SM-LL-V	200-SM-LL-V
Subclause		6.3	6.3
Operating range	m	2 to at least 50 000	2 to at least 50 000
Core diameter (mode field diameter) - nominal	µm	note 1	note 1
Zero dispersion Wavelength	nm	1300 to 1324	1300 to 1324
Zero dispersion slope (max)	ps/nm^2·km	0.093	0.093
Maximum optical path penalty	dB	1.5	1.5
Maximum passive loss budget	dB	18.5	18.5
Notes: 1 See: IEC 607932-2-50, Type B1.1 and IEC 607932-2-50, Type B1.3 Optical Fibres - Part 2: Product Specifications - Sectional Specification for Class B Single-mode Fibers			

11.5 Cable plant loss budget

The passive loss budget for the SM-LL-V shall be no greater than specified in table 41. This limit was arrived at by taking the difference between the minimum transmitter output optical modulation amplitude (table 39) and the receiver optical modulation amplitude, (min.) (table 39) and subtracting the maximum optical path penalty. Optical path penalties shown in table 41 are the sum of the maximum calculated penalties due to intersymbol interference, mode partition noise, reflection, and receiver eye opening requirements.

For lengths over 50 000 m different optical path penalties exist. For example, for a 75 km link operating at 1GFC the passive loss is decreased to 18.4 dB. For 2GFC operation over a 75 km path only 17.3 dB is allowed for passive loss.

Annex A (normative)
Test Methods

This annex defines terms, measurement techniques and conditions for testing jitter and wave shapes. This annex deals with issues specific to Fibre Channel and is not intended to supplant standard test procedures referenced in the specifications. See annex B.

This annex directly applies to verification of terminal equipment compliance to the Fibre Channel specification and the relevant optical and electrical interface specifications. In some instances these procedures may be applicable to measurement of a single component of the system.

The test block diagrams in this annex should be viewed as functional or logical diagrams, rather than the exact test hardware implementation or platform for the test. For a same logical or functional diagram, there can be several hardware implementations.

All measurements assume non-invasive perfect test equipment unless stated otherwise

A.1 Metrics derived from an eye diagram

A.1.1 Metrics of a signal

A.1.1.1 Optical modulation amplitude (OMA) test procedure

OMA is defined as the difference in optical power between the stable one level and the stable zero level.

The recommended technique for measuring optical modulation amplitude requires test equipment with the following minimum requirements:

a) An oscilloscope and optical to electrical converter with bandwidth at least equal to the signaling rate. The O/E converter shall be calibrated at the appropriate wavelength for the transmitter under test.

b) A 4th order Bessel Thomson filter with a 3 dB bandwidth of 0.75 signaling rate (optional).

While transmitting 1111100000 pattern, trigger the oscilloscope with clock divided by ten. Measure the stable one and stable zero levels and compute OMA.

The following measurement methods will give an approximation of the OMA, however they are likely to underestimate the OMA on dispersive channels. While transmitting with valid data such as CRPAT, use the following procedure to measure optical modulation amplitude.

a) Refer to figure A.2. With a valid waveform displayed on the oscilloscope, place the first cursor at the mean voltage level of the “topline” logic 1.

b) Refer to figure A.2. With a valid waveform displayed on the oscilloscope, place the first cursor at the mean voltage level of the “baseline” logic 0.

c) Measure and record the voltage difference between the two cursors.

d) Calculate the OMA by multiplying the voltage difference by the conversion gain of the O/E converter at the wavelength of the laser source.

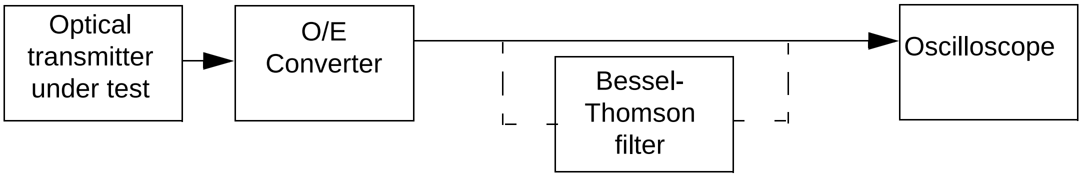


Figure A.1 – Optical modulation amplitude test equipment configuration

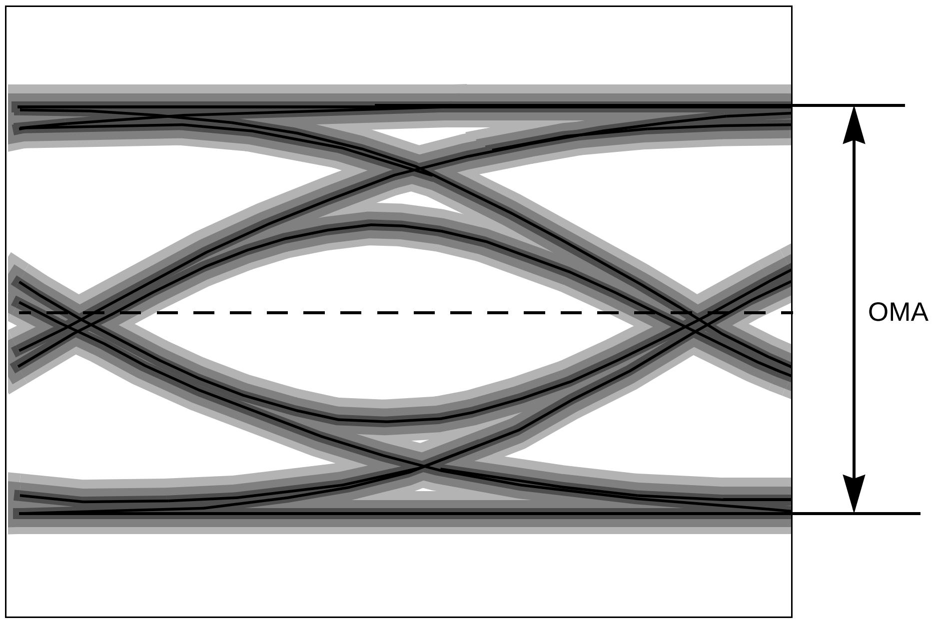


Figure A.2 – Alternate OMA measurement

OMA is estimated by the TWDP code in IEEE 802.3 Clause 68.

An alternative method to approximate the OMA is to measure the average optical power A (in mW) and the extinction ratio E (absolute ratio NOT dB) as described in IEC 61280-2-2.

The approximate OMA = 2A((E-1)/(E+1))

A.1.1.2 Voltage modulation amplitude (VMA) test procedure

VMA is defined as the difference in electrical voltage between the stable one level and the stable zero level.

The recommended technique for measuring VMA requires test equipment with the following minimum requirements:

a) An oscilloscope with bandwidth at least equal to the signaling rate.

b) A 4th order Bessel Thomson filter with a 3 dB bandwidth of 0.75 signaling rate (optional).

While transmitting 1111100000 pattern, trigger the oscilloscope with clock divided by ten. Measure the stable one and stable zero levels and compute VMA.

The following measurement methods will give an approximation of the VMA, however they are likely to underestimate the VMA. While transmitting with valid data such as CRPAT, use the following procedure to measure VMA.

a) Refer to figure A.4. With a valid waveform displayed on the oscilloscope, place the first cursor at the mean voltage level of the “topline” logic 1.

b) Refer to figure A.4. With a valid waveform displayed on the oscilloscope, place the first cursor at the mean voltage level of the “baseline” logic 0.

c) Measure and record the voltage difference between the two cursors. This is the approximate value of VMA.

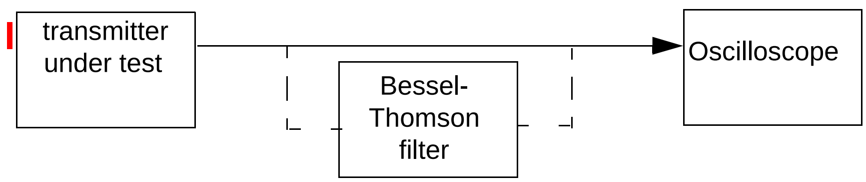


Figure A.3 – Voltage modulation amplitude test equipment configuration

VMA is estimated by the TWDP code in IEEE 802.3 clause 68.

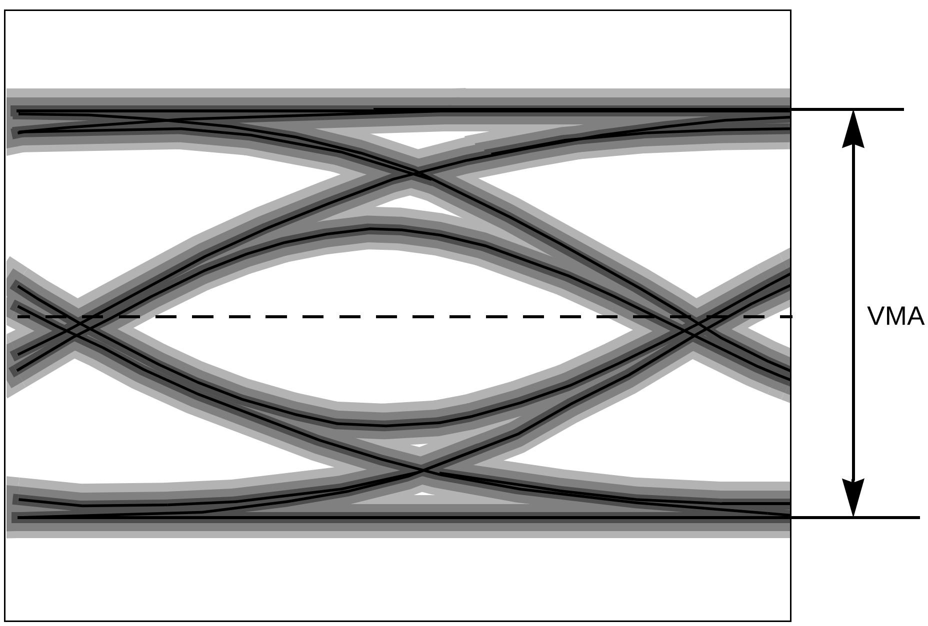


Figure A.4 – Alternate VMA measurement

A.1.1.3 Mask of the eye diagram

The mask of the eye diagram is covered in clause 6 and sub-clause 9.4. Measurements should be performed with traffic consisting of frames of data so that the receiving equipment may perform its normal synchronizing operations. Recommended frame contents are detailed in the FC-MJSQ technical report reference [41].

Eye mask testing should be performed with a bit-rate trigger. To accomplish the desired low-frequency jitter response, the trigger may be derived from the data stream being measured with a low noise Golden PLL as described in the FC-MJSQ technical report, (NCITS-TR-25:1999).

Eye mask testing (and several measurement in FC-PI-4) require determination of the average voltage or power amplitude level of the waveform, averaged over at least 1 000 bit times. Note that due to waveform distortions, this is frequently not the same as the mid-value halfway between logic 0 and logic 1. As defined in IEC 61280-2-2, the mid value is the average value in the center 20% of the bit period.

For measurements of electrical signals the bandwidth of the measuring system shall be wide enough that it does not affect the measurement. For measurements of signals the waveform may be measured and related to the mask by the method of IEC 61280-2-2 using a reference receiver-oscilloscope combination having a fourth-order Bessel-Thomson transfer function. The apparatus consists of an oscilloscope with reference receiver and a clock recovery unit, the "Golden PLL" as described in FC-MJSQ (reference [41]). This is illustrated in IEEE Std 802.3 Figure 52-9.

A.1.1.3.1 Bessel-Thomson filter

The fourth-order Bessel-Thomson transfer function is given by

:

$$H_p = \frac{105}{105 + 105y + 45y^2 + 10y^3 + y^4}$$

With

$$y = 2.114p \qquad p = \frac{j\omega}{\omega_r} \qquad \omega_r = 2\pi f_r \qquad f_r = 0,75xf_0$$

NOTE – This filter is not intended to represent the noise filter used within an optical receiver but it is intended to provide a uniform measurement condition.

The nominal attenuation at the reference frequency, f_r, is 3 dB. The corresponding attenuation and group delay distortion at various frequencies are given in table A.1. f_0 is the signalling rate expressed as a frequency.

.

Table A.1 – Bessel-Thomson frequency response

f/f_0	f/f_r	Attenuation (dB)	Distortion (UI)
0.15	0.2	0.1	0
0.3	0.4	0.4	0
0.45	0.6	1.0	0
0.6	0.8	1.9	0.002
0.75	1.0	3.0	0.008
0.9	1.2	4.5	0.025
1.0	1.33	5.7	0.044
1.05	1.4	6.4	0.055
1.2	1.6	8.5	0.10
1.35	1.8	10.9	0.14
1.5	2.0	13.4	0.19
2.0	2.67	21.5	0.30

The tolerance in attenuation (Delta_a) (positive or negative) allowed for the reference receiver-oscilloscope combination's frequency response is given by:

$$\text{Delta\_a (dB)} = \begin{cases} 0{,}5 & f/f_r \le 1 \\ \dfrac{2{,}5 \log_{10}(f/f_r)}{\log_{10} 2} & f/f_r > 1 \end{cases}$$

A.1.1.4 Pulse parameters and rise/fall times

Rise and fall times may be difficult to measure on terminal equipment. If jitter is less than rise and fall times, the following method is preferred.

a) Configure the device under test to transmit frame data such as CRPAT.

b) Connect the device to the measurement system and trigger the scope with a bit-rate trigger (see annex A.1.1.3).

c) Measure the 0% and 100% points as described by the appropriate relative mask test methods specified in clause 6 and clause 9.

d) Calculate the 20% and 80% levels. Setup horizontal histograms centered at these levels with minimal vertical openings and horizontal boundaries set to distinguish the rising and falling portions of the eye crossing. Measure the mean time of 4 positions:

rising edge left of the crossing (T_left,bottom)

rising edge right of the crossing (T_right,top)

falling edge left of the crossing (T_left,top)

falling edge right of the crossing (T_right,bottom)

e) T_rise = T_right,top - T_left,bottom; T_fall = T_right,bottom - T_left,top

If this method is not possible (for example, if jitter exceeds the rise or fall times), or testing is being done at a component level, it may be appropriate to transmit a low frequency square wave such as K28.7 (but do not use D21.5 or D10.2 for optical testing) and trigger the scope with a pattern trigger. If this method is used, measurements are performed in the normal manner using built-in scope algorithms, if they exist.

An optical measurement system may have a low pass fourth-order Bessel-Thomson transfer function (described in sub-clause 6.3.2 or equivalent. If a separate filter having a fourth order Bessel-Thomson transfer function is used, care should be taken with source and load impedances of the equipment connected to the filter. In filters constructed with common techniques the proper transfer function is obtained only when the source and load impedances are at a specified value over the frequency range of interest. Other impedance values may result in the introduction of significant waveform distortion.

A.1.1.5 Extinction ratio

Extinction ratio is defined as the ratio of the average one to the average zero in the central 20% of the eye, according to the methods of IEC 61280-2-2 [23]. It is measured with the same oscilloscope filter response as for the optical waveform (eye). The oscilloscope has low reflection; deliberate reflections are not used. The pattern being transmitted is JSPAT. Measurements with a scrambled 8B/10B signal or ARB(ff) (idle for 8GFC) are expected to give similar results.

Extinction ratio is usually expressed as a power ratio in decibels.

A.1.2 Metrics derived from an averaged waveform

A.1.2.1 Data Dependent Jitter (DDJ)

See SFF-8431.

A.1.2.2 Data dependent pulse width shrinkage (DDPWS)

The difference between 1 UI and the minimum value of the zero-crossing-time differences (in UI) of all adjacent edges in an averaged waveform of a repeating data sequence is called pulse width shrinkage.

The pulse width T_{PW} is defined by the figure A.5.

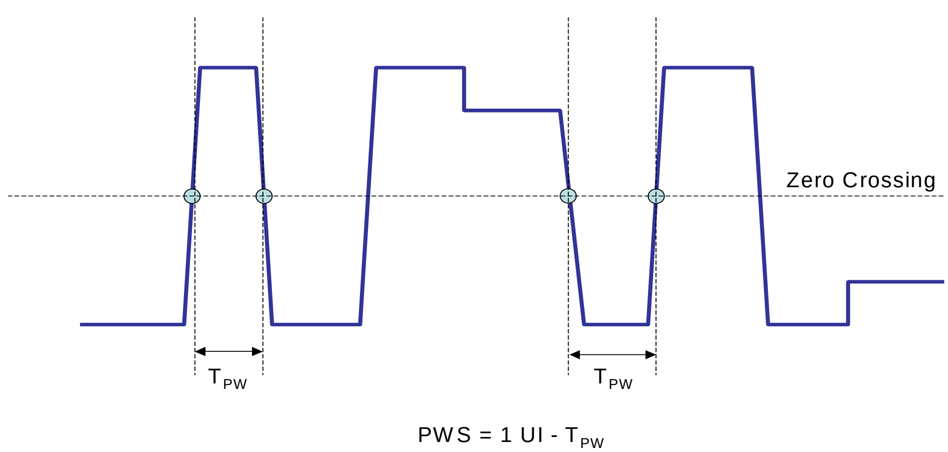


Figure A.5 – Pulse width and pulse width shrinkage

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The waveform displayed is an average one containing only the data dependent jitter. All uncorrelated jitters (i.e. P_J, R_J, and Bounded Uncorrelated jitter) are averaged out.

The DDPWS is the difference between 1 UI and the pulse width value defined by the zero crossing time difference (in UI) between two adjacent edges in an averaged waveform of a repeating data sequence.

The maximum DDPWS is determined from all the DDPWS within the pattern.

A.1.2.3 Waveform distortion penalty (WDP)

WDP is a wave shape metric for waveform filtering or other sources of data-dependent distortion. WDP used in this document is based on a similar procedure and code as defined by TWDP in IEEE 802.3 sub-clause 68.6.6. The following modifications were made:

- Addition of spectral line timing recovery and horizontal eye opening evaluation (NC-DDJ).
- Adjustment of P_{ALLOC} based on the calculated VMA.
- Anti-aliasing filter bandwidth scaled to 75% of the signaling speed in contrast to the static 7.5 GHz.
- For purposes of this document, the definitions and procedures generally apply to both optical and electrical signals. Optical terms (such as power) and units can be converted to corresponding electrical terms (such as voltage) and units, etc.
- JTSPAT is suitable as a test sequence for all applications unless specified otherwise.

A.1.2.4 Transmitter waveform and distortion penalty (TWDP)

The transmitter and waveform dispersion penalty (TWDP) is a measure of the deterministic dispersion penalty due to transmitter device under test with the reference transmitter compliance transfer functions and receiver. The test conditions (P_{ALLOC}) and the TWDP and non-compensable data dependent jitter (NC-DDJ) requirements are described in table 34.

The TWDP measured utilizes the procedure described in annex A.1.2.3 to capture and post-process the transmitter waveform at the output of the compliance test card. The post-processing algorithm is further augmented as described below.

- Introduce the electrical stressors described by the transmitter compliance transfer functions (refer to annex A.5.2).
- Assignment of an independent P_{ALLOC} value for each stressor.
- It is expected that transmitter emphasis (pre-cursor and post-cursor) will be necessary to satisfy the requirements. For each stressor, the corresponding TWDP limit shall be satisfied for at least one equalization setting of the transmitter device under test.

Since the noise environment is not a function of VMA_T, VMA_T in excess of the minimum results in a larger P_{ALLOC}. An increase in P_{ALLOC} implies an increase in the permissible TWDP.

Given the measured (estimated) VMA_T, P_{ALLOC} may be adjusted in the TWDP test script, and the TWDP result compared to a limit adjusted by the correction term, dTWDP, shown below.

A.1.3 Metrics derived from histograms

A.1.3.1 Relative noise (RN)

See SFF-8431.

A.1.3.2 Relative intensity noise (RIN) (OMA) measuring procedure

A.1.1.3.2 Test objective

When lasers that are subject to reflection induced noise effects are operated in a cable plant with a low optical return loss the lasers will produce an amount of noise that is a function of the magnitude and polarization state of the reflected light.

The magnitude of the reflected light tends to be relatively constant. However, the polarization state varies significantly as a function of many cable parameters, particularly cable placement. In a cable plant that is physically fixed in place the variation is slow. If the fibre is subject to motion, such as occurs in a jumper cable, the change may be sudden and extreme. The effect is unpredictable changes in the noise from the laser with the result that the communication link may exhibit sudden and unexplainable bursts of errors.

The solution to this is to assure that the lasers used do not generate excessive noises under conditions of the worst case combination of polarization and magnitude of reflected optical signal.

The noise generated is a function of the return loss of the cable plant. For the Fibre Channel the specified return loss is 12 dB resulting in the notation of $RIN_{[12]}$ for the relative intensity noise.

One of the measurements required to determine RIN specifies that the laser transmitter be powered to its DC level but not transmitting AC data. This may not be possible for some FC devices unless special test modes are available. If it is not possible to set the laser transmitter into this mode while in the FC device, then testing should be done at the component level. An alternative measurement procedure, which avoids this restriction and gives giving approximately the same results, is described in IEEE Std 802.3 sub-clause 68.6.7.

A.1.1.3.3 General test description

The test arrangement is shown in figure A.1. The test cable between the Device Under Test (DUT) and the detector forms an optical path having a single discrete reflection at the detector with the specified optical return loss. There shall be only one reflection in the system as the polarization rotator can only adjust the polarization state of one reflection at a time.

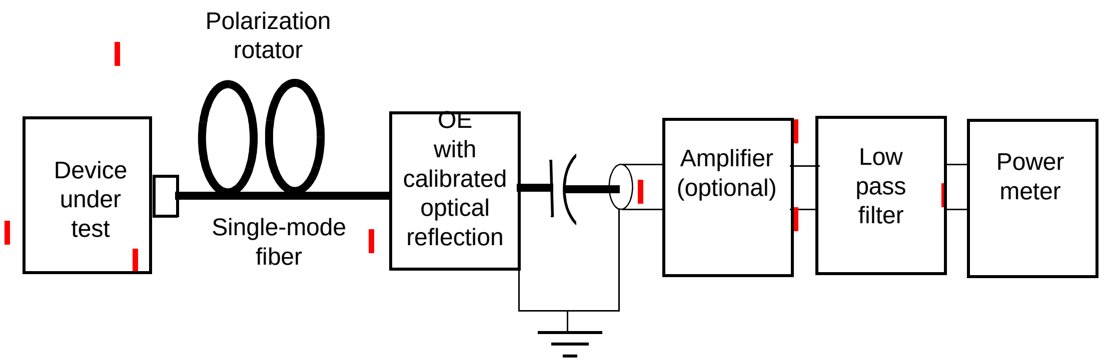

Figure A.1 – RIN (OMA) test setup

Both the OMA power and noise power are measured by AC coupling the O/E converter into the high frequency electrical power meter. If needed, an amplifier may be used to boost the signal to the power meter.

A low pass filter is used between the photodetector and the power meter to limit the noise measured to the passband appropriate to the data rate of interest.

In order to measure the noise the modulation to the DUT shall be turned off, unless the method of IEEE Std 802.3aq 68.6.7 is used.

A.1.1.3.4 Component descriptions

Test Cable: The test cable and detector combination shall be configured for a single dominant reflection with an optical return loss of 12 dB. (The Optical return loss may be determined by the method of FOTP-107) If multiple lengths of cable are required to complete the test setup they should be joined with splices or connectors having return losses in excess of 30 dB. The length of the test cable is not critical but should be in excess of 2 m.

Polarization Rotator: The polarization rotator shall be capable of transforming an arbitrary orientation elliptically polarized wave into a fixed orientation linearly polarized wave. A polarization rotator consisting of two quarter wave retarders has the necessary flexibility.

O/E converter (and amplifier): The O/E converter may be of any type that is sensitive to the wavelength range of interest. The frequency response of the O/E converter shall be higher than the cut-off frequency of the low pass filter.

If necessary, the noise may be amplified to a level consistent with accurate measurement by the power meter.

Filter: The low pass filter shall have a 3 dB bandwidth as specified in table A.1. The total filter bandwidth used in the RIN calculation shall take the low frequency cut-off of the d.c. blocking capacitor into consideration. The low frequency cutoff is recommended to be <1 MHz.

Table A.2 – Filter 3 dB point

Signaling rate	Filter 3dB point
1.0625 GBd	800 MHz
2.125 GBd	1 600 MHz
4.250 GBd	3 200 MHZ
8.500 GBd	6 375 MHZ

The filter should be placed in the circuit as the last component before the power meter so that any high frequency noise components generated by the detector/amplifier are eliminated. If the power meter used has a very wide bandwidth care should be taken in the filter selection to ensure that the filter does not lose its rejection at extremely high frequencies.

Power Meter: The power meter should be an RF type designed to be used in a 50 Ω coaxial system. The meter shall be capable of being zeroed in the absence of input optical power to remove any residual noise from the detector or its attendant amplifier, if used.

An oscilloscope with signal analysis capabilities may be used instead of an RF power meter. Be sure that only AC signals (not the optical DC value) are measured. Canceling of instrumentation noises may be done by subtracting the dark power (measured when no signals are present) from the measurement for P_N and P_M. If root-mean-square (rms) signals are measured, be sure they are squared before subtracting dark noise or applying them in equation below.

A.1.1.3.5 Test Procedure

a) Connect and turn on the test equipment. Allow the equipment to stabilize for the manufacturers recommended warm up time.

b) With the DUT disconnected zero the power meter to remove the contribution of any noise power from the detector and amplifier, if used.

c) Connect the DUT, turn on the laser, and ensure that the laser is not modulated. This may not be possible in some FC devices unless special test modes are available.

d) Operate the polarization rotator while observing the power meter output to maximize the noise read by the power meter. Note the maximum power, P_N.

e) Turn on the modulation to the laser and note the power measurement, P_M. The recommended data pattern is a repeating sequence of K28.7s with alternating disparity. If a different data pattern is used, a correction factor should be applied to the RIN value. For example, if a high transition density pattern is used, such as repeating IDLEs, then 2 dB should be subtracted from the result of equation 4. If a frame pattern such as CRPAT or other unknown sequence is used, then 1 dB should be subtracted from the result of equation 4. Both of these correction factors are approximate.

f) Calculate RIN from the observed detector current and electrical noise by use of the equation:

$$RIN_{12}\ (OMA) = 10 \log [P_N/(BW*P_M)]\ (dB/Hz)$$

Where:

RIN_{12} (OMA)	= Relative Intensity Noise referred to optical modulation amplitude
P_N	= Electrical noise power in watts with modulation off
P_M	= Electrical noise power in watts with modulation on
BW	=1.05*(3 dBBW) for the fourth order Bessel filter. It is up to the user to determine the multiplier if different filters are used.

For testing multimode components or systems, the polarization rotator shall be removed from the setup and the single mode fiber replaced with a multimode fiber. Step d) of the test procedure shall be eliminated.

A.1.3.3 Uncorrelated jitter (U_J)

U_J as defined by IEEE 802.3 clause 68 is a measure of any jitter that is uncorrelated to the data stream. The definition and test procedure for U_J are identical to those defined in IEEE 802.3 subclause 68.6.8 with the following considerations:

- The transmitter shall comply while the receiver is operating with asynchronous data and all other ports operating as in normal operation, including proper termination.
- For purposes of this document the procedures defined for optical testing also applies to electrical testing. Optical terms (such as power) and units, such as in figure 68-9 in IEEE 802.3, can be converted to corresponding electrical terms (such as voltage) and units, etc.
- The 4th-order Bessel-Thomson response is to be used only for optical measurements of U_J. U_J in the electrical domain is defined in a bandwidth of 12 GHz, unless specified by the application standard.
- JSPAT is suitable as a test sequence for all applications unless specified otherwise.

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- The bandwidth of the CRU is the signaling speed divided by 1667.

A.1.3.4 Skew measurement

A skew measurement is valid only for balanced transmitter configurations. The measurement is to be made at the sink side of mated connector pairs, and across a load equivalent to those shown in sub-clause 9.12. These are single-ended measurements and assume a.c. coupling between the oscilloscope and the transmitter. A valid pattern such as CRPAT or primitive sequence should be transmitted during this test.

For each signal (true and complement), measure the mean of the eye crossing using a horizontal histogram vertically centered at the average value of the waveform. The same stable trigger, coherent to the data stream, shall be used for both the true and complement signals. Skew is defined as the time difference between the two means.

A.1.3.5 Jitter measurements

The jitter output specifications apply in the context of a 10^{-12} bit error rate (BER). Jitter may be measured with methods as described in the FC-MJSQ technical report, reference [41]. The optical measurement system may have a low pass fourth-order Bessel-Thomson transfer function (described in sub-clause 6.3.2) or equivalent.

A.1.3.6 Common mode voltage measurement

The common mode voltage is also only valid for balanced transmitter configurations. The measurement is to be made on the sink side of mated connector pairs, and across the load equivalent to those shown in sub-clause 9.12.

The data pattern should be normal traffic or a common test pattern as within FC-MJSQ. Both waveform polarities are to be connected through a suitable test fixture to a 50 Ohm communication analysis oscilloscope system. The waveforms should not be triggered (free-run). No filtering is allowed except that AC coupling may be used. If AC coupling is used, the high-pass 3 dB low frequency corner shall not be greater than 10 MHz. The upper end of the measurement system bandwidth should be at least 10 GHz. Be sure all measurement elements are well-matched in delay and amplitude loss across the full frequency band (below 1 MHz to above 10 GHz). Mismatched properties of the test system may significantly mask or degrade results and compensate for rms instrumentation noise. The two input waveforms should be summed for common mode analysis. Set up a vertical histogram with full display width. Measure the rms value of the histogram. The common mode RMS value is half the RMS value of the histogram.

Note: This definition is different than the definition in FC-PI-2.

A.1.4 Non-temporal metrics

A.1.4.1 Optical spectrum measurement

The center wavelength and spectral width RMS value of the transmit interface is measured as appropriate using an optical spectrum analyzer per IEC 61280-1-3. The patch cable used to couple the light from the transmit interface to the spectrum analyzer should be short to minimize spectral filtering by the patch cable. The transmit signal during the measurement should be any valid 8B/10B code pattern. Note that the definition of RMS spectral width is the standard deviation of the spectrum, which is a half-width.

A.2 Transmit or receive interface

A.2.1 Return loss and reflections

See SFF-8431.

A.2.2 Termination mismatch

See SFF-8431.

A.3 Receive interface

The source of the receive interface test signal may be any source conforming to the worst case limits of the receive interface specifications of the media under test.

The test should be performed with traffic consisting of frames of data so that the receiving equipment may perform its normal synchronizing operations. Recommended frame contents are detailed in the FC-MJSQ technical report (reference [41]).

A compliant port should receive the test signal over the range of conditions specified with a BER $\leq 10^{-12}$. The requirements in clause 6 were written in terms of BER to facilitate the specification of components to be used in a particular implementation.

The characteristics of the test signal may be measured with the methods outlined in the FC-MJSQ technical report (reference [41]).

A.3.1 Optical receiver sensitivity test

A.3.1.1 Stress receiver sensitivity test

Testing BER of optical receivers for conformance to the stressed receiver power penalty requirement shall use a signal at γ_R (see figure A.2) conforming to the requirements described in figure A.2. The receiver stress-test pattern is recommended to be CRPAT as described in the FC-MJSQ technical report (reference [41]) and is conditioned by adding jitter as shown schematically in figure A.2. The horizontal eye closure as defined in figure A.2, shall be 0.085UI. The vertical eye closure penalty shall be the values specified in table 10 for SW 50 μm OM2, table 11 for SW 50 μm OM3, or table 12 for SW 62.5 μm. The DJ cannot be added with a simple phase modulation.

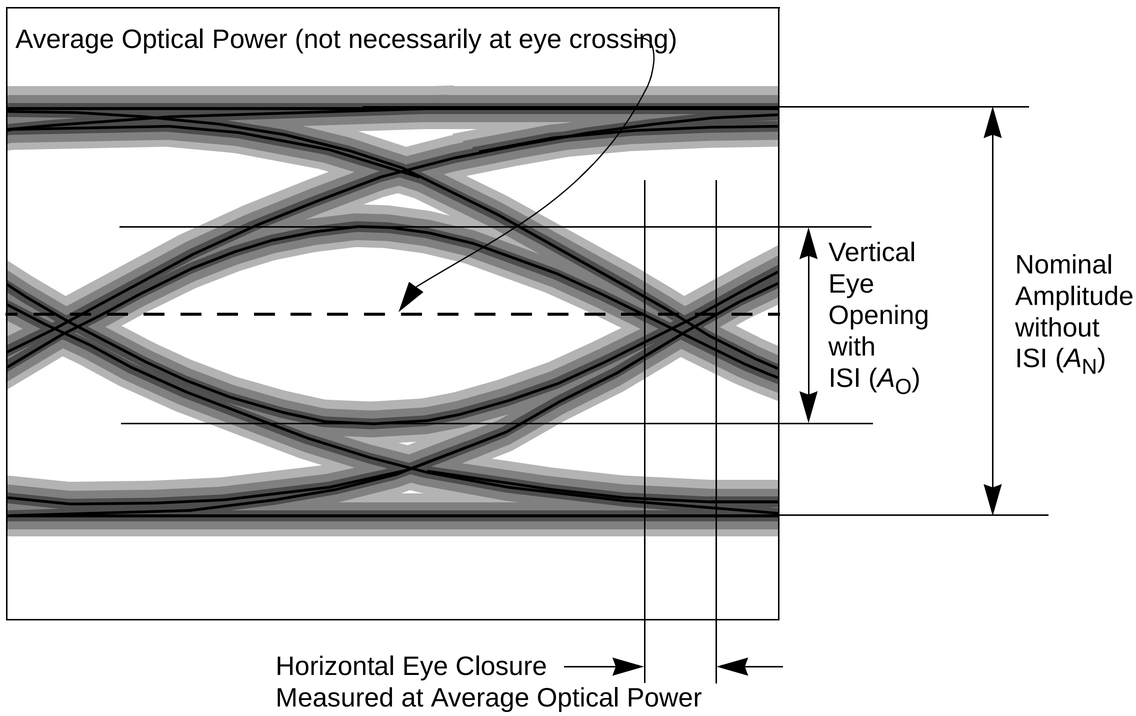


Figure A.2 – Required characteristics of the conformance test signal at γ_R

The vertical eye closure penalty is given by:

$$\text{Vertical eye closure penalty [dB]} = 10 \times \log\frac{A_O}{A_N}$$

where, A_O is the amplitude of the eye opening and A_N is the normal amplitude without ISI, as measured in figure A.2. The VECP for the multimode cable is shown in figure A.3. The figure assumes that the measurement system bandwidth is sufficiently high that the observed vertical eye closure is dominated by the response of the filter used to generate the closure.

Figure A.4 shows the recommended test set up for producing the stressed receive conformance test signal at γ_R. The coaxial cable is adjusted in length to produce the required additional jitter. Since the cable causes dispersion in addition to adding jitter, a limiting amplifier is used to restore fast rise and fall times. A Bessel Thomson filter is selected to produce the minimum eye closure as specified per table 10 for SW 50 μm OM2, table 11 for SW 50 μm OM3 or table 12 for SW 62.5 μm OM1. This conditioned signal is used to drive a high bandwidth linearly modulated laser source.

For the 100, 200, and 400 MB/s systems, the vertical and horizontal eye closures to be used for receiver conformance testing are verified using a fast photodetector and amplifier. The bandwidth of the photodetector shall be at least 2 x the nominal Baud in GHz and be coupled through a fourth-order Bessel Thomson filter at 1.5 x the nominal Baud to the oscilloscope input. For the 800 MB/s systems the verification should use a reference receiver with a combined response of the photodetector, amplifier, and filter to have a Bessel Thompson response with a bandwidth equal to 0.75 times the signaling rate. Special care should be taken to ensure that all the light from the fiber is collected by the fast photodetector and that there is negligible mode selective loss.

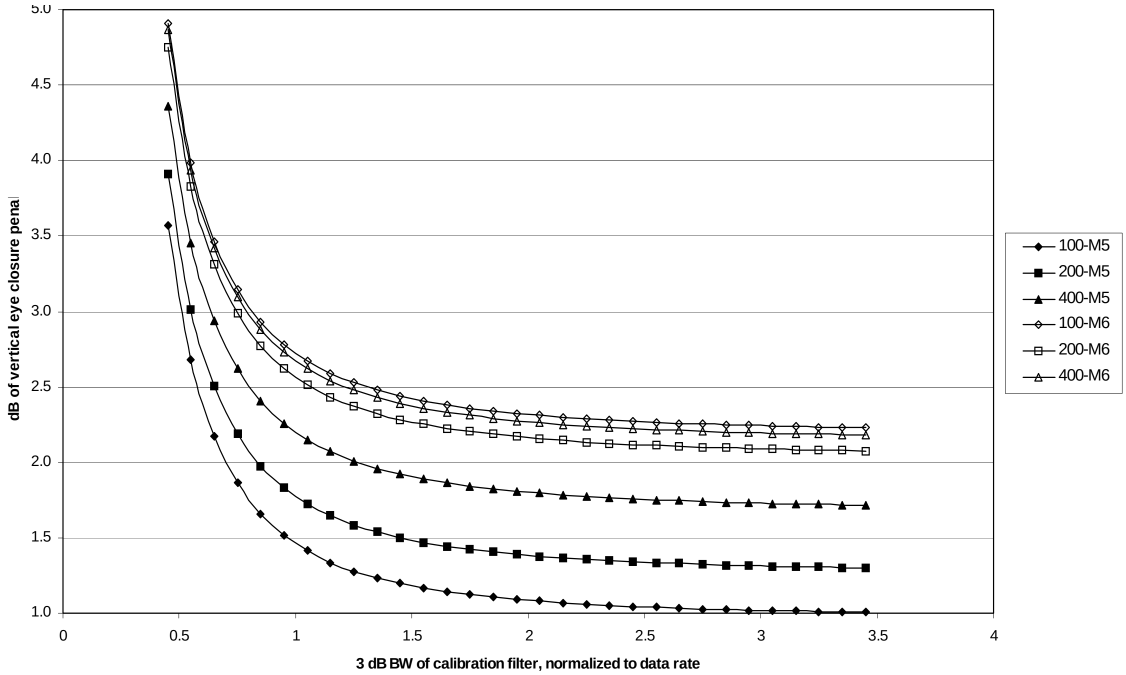


Figure A.3 – VECP for multimode cable

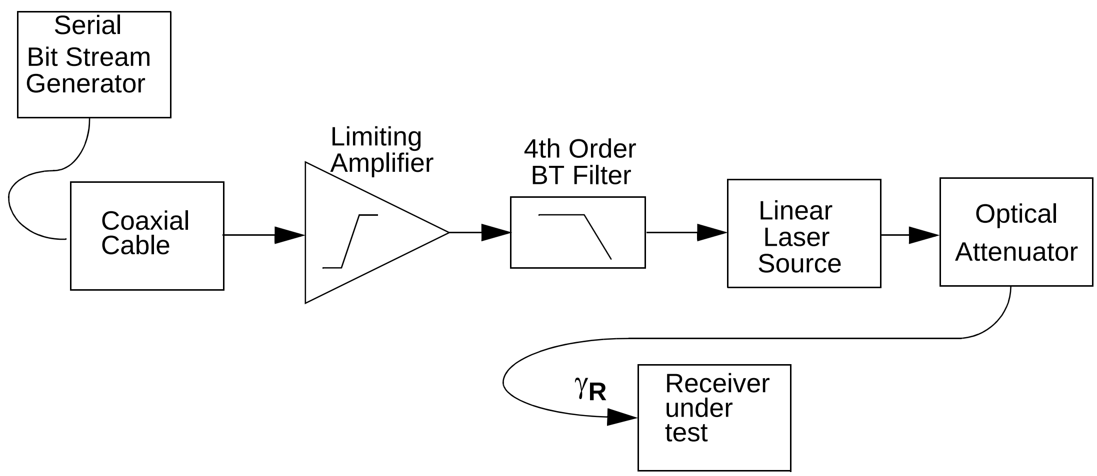


Figure A.4 – Apparatus for generating stressed receive conformance test signal at γ_R

A.3.1.2 Unstressed receiver sensitivity test

For unstressed receiver sensitivity testing, the methods given above apply, except for that the coaxial cable, limiting amp and filter should be removed from the test setup shown in figure A.4. The optical test signal for Unstressed sensitivity testing should have low jitter, low vertical closure and noise, and rise and fall times faster than 0.3 UI (20 - 80%). Only the optical attenuator is used to degrade the input test signal.

A.3.2 Electrical compliance signal at B" for the SFP transmitter

See SFF-8431.

A.3.3 Test method for host receiver with a limiting module

See SFF-8431.

A.3.4 Test method for host receiver with a linear module

See SFF-8431.

A.3.5 Receiver jitter tracking

This procedure measures the ability of a receiver to track low frequency jitter without the occurrence of errors.

Figure A.5 illustrates the measurement configuration for the receiver jitter tracking test. A pattern generator output is impaired by frequency modulation of the generating clock source. The pattern generator is connected to the receiver under test via a variable attenuator.

Two sets of jitter frequency and amplitude combinations are specified for each variant to which this procedure applies. These values are applied as the conditions of the two separate receiver jitter tracking tests. The variable attenuator is configured to set the amplitude at the receiver, in OMA for optical signals and VMA for electrical signals, to the jitter tolerance test amplitude specified for the variant. For each test, a BER of better than 10^{-12} shall be achieved.

Various implementations may be used, provided that the resulting jitter matches that specification. Phase or frequency modulation may be applied to induce the sinusoidal jitter, and the modulation may be applied to the clock source or to the data stream itself.

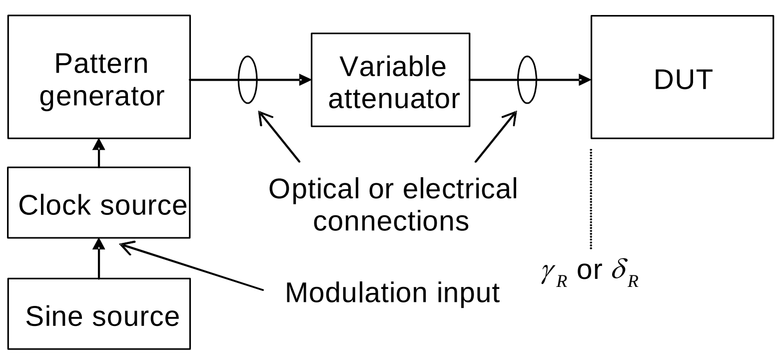


Figure A.5 – Measurement configuration for receiver jitter tracking test

A.3.6 Receiver jitter tolerance test for 800-DF-EL-S delta point variants

A.3.6.1 Overview

Table 33 places bounds on the expected jitter that needs to be tolerated at delta R. For limiting receiver applications this jitter is expected to be predominantly non-equalizable.

This section describes required test signal characteristics along with considerations and suggested approaches for test signal generation. The test signal is generated by the functions shown in figure A.6 or by equivalent means.

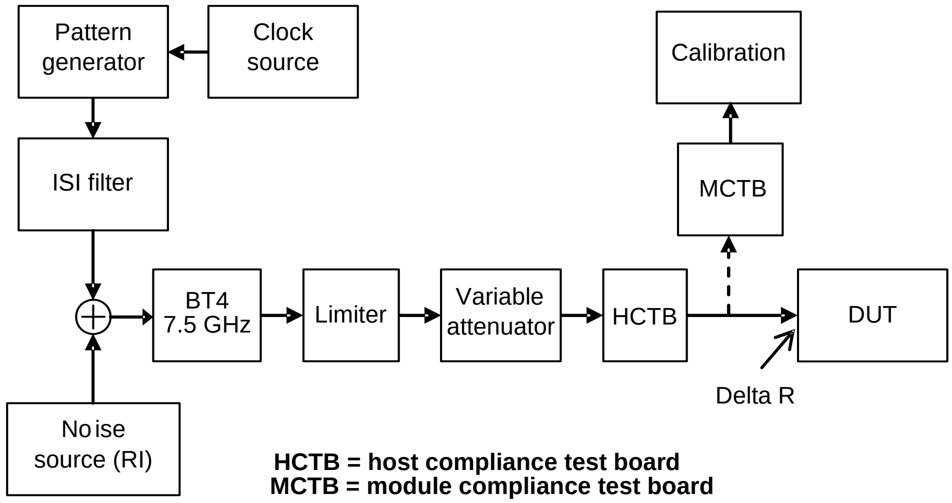


Figure A.6 – Sample jitter tolerance test configuration

JTSPAT, as defined in annex F.3, shall be the test sequence for jitter tolerance measurements.

The FC-MJSQ (reference [41]) provides further information on definitions, setups, and calibration methods for jitter tolerance testing.

Deterministic jitter (D_J) is comprised of inter-symbol interference (ISI) jitter passed through a limiting function. The signal at delta R shall have D_J and pulse width shrinkage (DDPWS) as defined in table 33.

ISI jitter creation may be achieved through the use of a low pass filter, length of board trace, length of coax cable or other equivalent method. It is required that this jitter be passed through a limiter function to ensure that the resulting jitter is not totally equalizable.

The variable gain function should have a minimum 3 dB bandwidth of 10 GHz. The attenuator is used to set the output amplitude to minimum and maximum values allowed by the eye mask of table 27.

A voltage stress before the limiter function is to be applied. This stress is comprised of a broadband noise source, or random interference (RI), with a minimum bandwidth of 6 GHz and minimum crest factor of 7. It is the intent that this combination of RI and limiting function introduce broadband random jitter.

A.3.6.2 Calibration

The test signal should be calibrated differentially into standard instrumentation loads. If complementary single-ended signals are used; they should be carefully matched in both amplitude and phase.

For improved visibility for calibration, it is imperative that all elements in the signal path (cables, DC blocks, etc.) have wide and flat frequency response as well as linear phase response throughout the spectrum of interest. Baseline wander and overshoot/undershoot should be minimized.

Jitter requirements are defined for a probability level of 10^{-12}. To calibrate the jitter, the methods given in FC-MJSQ are recommended.

The ISI filter should be tuned such that the specified amount of D_J (and DDPWS) has been created at delta R. Once the D_J and DDPWS have been set, the RI amplitude should be increased until the specified amount of total jitter (T_J) at delta R is achieved. The peak-to-peak T_J includes all but 10^{-12} of the jitter population.

The variable gain is then adjusted so that the inner vertical eye opening at delta R is the minimum allowed level (A) specified in table 27.

A.3.6.3 Test Procedure

The receiver device shall comply while the transmitter is operating with asynchronous data and all other ports operating as in normal operation, including proper termination. With the calibrated jitter tolerance test signal applied at Delta R, the receiver device under test shall operate at a BER no greater than 10^{-12}.

A.3.7 Measurement of the optical receiver upper cutoff frequency

The measurement of the 3 dB and 10 dB electrical cutoff frequencies of the optical receiver shall be performed using the test setup shown in figure A.7. An RF signal is added asynchronously to the data stream, consisting of the CRPAT character stream, that is used to modulate the laser. The laser and modulator frequency response shall be calibrated to assure that an accurate measurement is made. The measurements use the following steps.

a) With no applied RF modulation, connect the laser output to the receiver under test through an optical attenuator and set the optical power to a level between the stressed receiver sensitivity and the receiver OMA, min.

b) Turn on the RF modulation while maintaining the same average optical power.

c) At all tested frequencies, measure the necessary RF modulation amplitude (in dBm) required to achieve a constant BER (e.g. 10^{-6}).

d) The receiver upper cutoff frequency is calculated by normalizing the measured response from step c to the frequency response of the measurement system.

e) The receiver 3 dB electrical upper cutoff frequency is that frequency where the corrected RF modulation amplitude increases by 3 dB (electrical). The receiver 10 dB electrical upper cutoff frequency is that frequency where the corrected RF modulation amplitude increases by 10 dB (electrical). Care should be taken to convert to electrical dB and to correctly compensate for the frequency response of the measurement system.

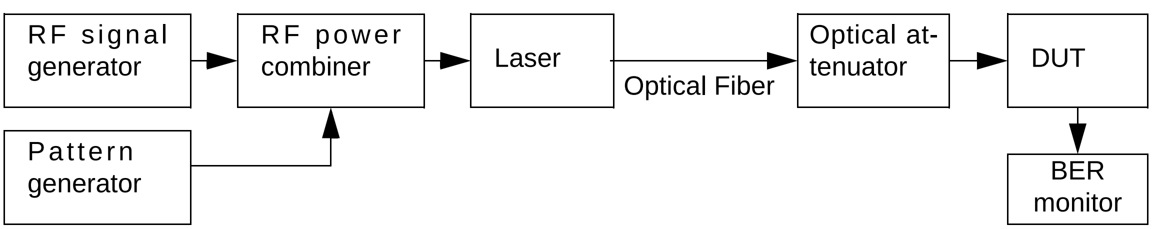


Figure A.7 – Test setup for receiver bandwidth measurement

A.3.8 AC common mode tolerance test

See SFF-8431.

A.4 Transfer metrics

A.4.1 Linear module receiver compliance tests

See SFF-8431.

A.4.1.1 Linear module receiver added noise compliance test

See SFF-8431.

A.4.1.2 Linear module receiver distortion penalty compliance test

See SFF-8431.

A.5 Test methodology and measurements

A.5.1 Beta and epsilon compliance test board definition

The beta and epsilon point compliance test board is used for collecting the transmit waveforms to be used in the TWDP algorithm and for measuring transmit jitter. The test board is also used to calibrate input signals for receiver signal tolerance test. The test board is connector agnostic given that there is not a specific widely used standardized connector.

A DC blocking capacitor on the test board should not be necessary as the devices under test are expected to incorporate the required DC blocking structures. Also termination is not needed on the test board as it will be in the test equipment and the receiver devices under test.

The S parameter requirements (including the mated connector) for the test board are in the table A.3.

Table A.3 – S parameter requirements of beta & epsilon

	Max (dB)
SDD11 (note 1)	-12
SDD21 (note 1)	-1.5
Notes: 1 The S parameter numbers are at 4.25 GHz.	

A.5.2 Beta and epsilon point transmitter compliance transfer function definition

The transmitter and waveform dispersion penalty measurement for beta T and epsilon T utilizes three measurement-based transmitter compliance transfer functions. These functions are intended to represent the loss that may be encountered in modular platform environments during compliant operation. The three cases model low, medium, and high loss interconnects and are defined in terms of the over-sampled impulse response. For beta T testing, only TCTF(1) and TCTF(2) are considered. For epsilon T testing, TCTF(3) is included.

Figure A.9 show the impulse response models for each transmitter compliance transfer function, and the numerical values are tabulated in table A.4, table A.5, and table A.6.

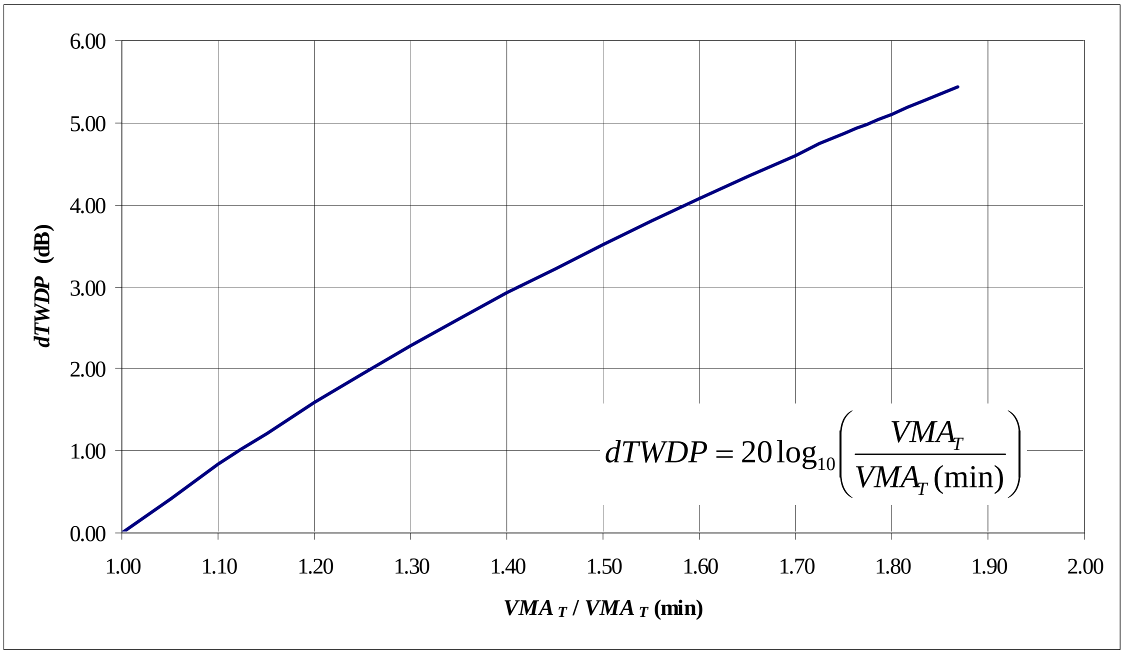


Figure A.8 – dTWDP for epsilon and beta compliance points

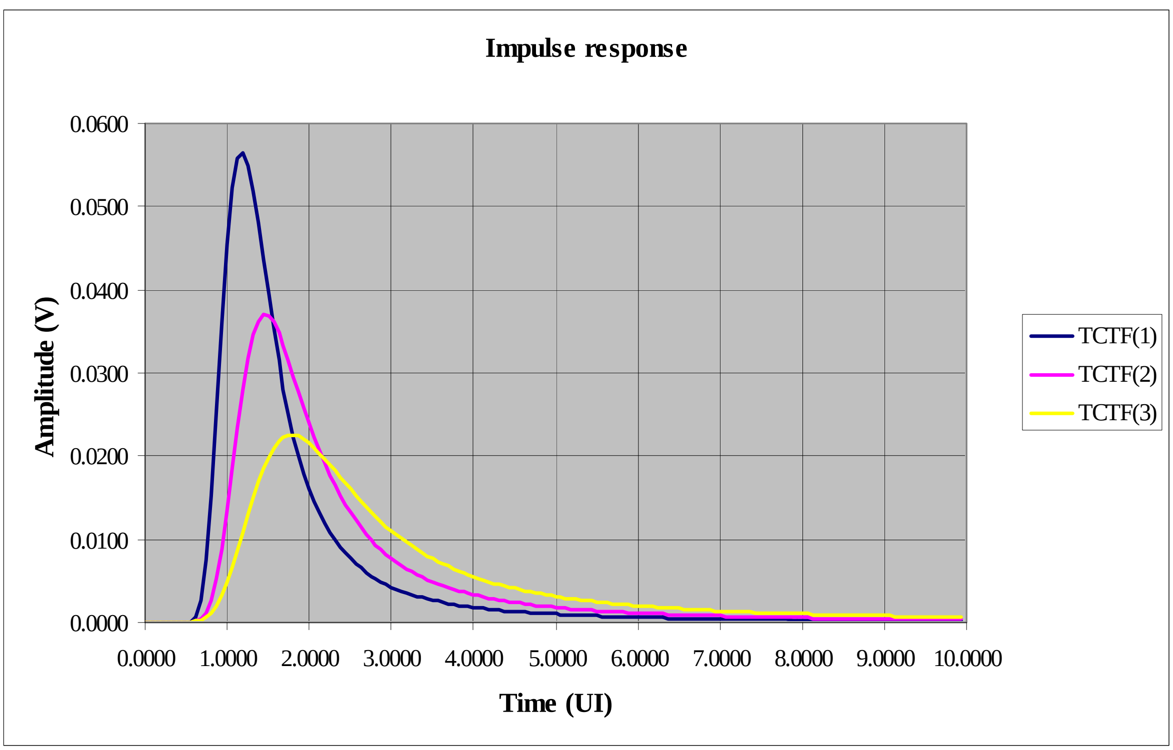


Figure A.9 – 800-DF-EA-S beta T and epsilon T TCTF impulse response models

Table A.4 – 800-DF-EA-S beta T and epsilon T TCTF(1) impulse response (low loss)

Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)
0.0000	0.0000	2.0000	0.0161	4.0000	0.0018	6.0000	0.0006	8.0000	0.0003
0.0625	0.0000	2.0625	0.0145	4.0625	0.0018	6.0625	0.0006	8.0625	0.0003
0.1250	0.0000	2.1250	0.0131	4.1250	0.0017	6.1250	0.0006	8.1250	0.0003
0.1875	0.0000	2.1875	0.0119	4.1875	0.0016	6.1875	0.0006	8.1875	0.0003
0.2500	0.0000	2.2500	0.0108	4.2500	0.0015	6.2500	0.0006	8.2500	0.0003
0.3125	0.0000	2.3125	0.0099	4.3125	0.0015	6.3125	0.0006	8.3125	0.0003
0.3750	0.0000	2.3750	0.0090	4.3750	0.0014	6.3750	0.0005	8.3750	0.0003
0.4375	0.0000	2.4375	0.0083	4.4375	0.0014	6.4375	0.0005	8.4375	0.0003
0.5000	0.0000	2.5000	0.0076	4.5000	0.0013	6.5000	0.0005	8.5000	0.0003
0.5625	0.0001	2.5625	0.0070	4.5625	0.0013	6.5625	0.0005	8.5625	0.0003
0.6250	0.0007	2.6250	0.0065	4.6250	0.0012	6.6250	0.0005	8.6250	0.0003
0.6875	0.0027	2.6875	0.0060	4.6875	0.0012	6.6875	0.0005	8.6875	0.0003
0.7500	0.0074	2.7500	0.0056	4.7500	0.0011	6.7500	0.0005	8.7500	0.0003
0.8125	0.0152	2.8125	0.0052	4.8125	0.0011	6.8125	0.0005	8.8125	0.0003
0.8750	0.0254	2.8750	0.0049	4.8750	0.0011	6.8750	0.0005	8.8750	0.0003
0.9375	0.0361	2.9375	0.0046	4.9375	0.0010	6.9375	0.0004	8.9375	0.0002
1.0000	0.0455	3.0000	0.0043	5.0000	0.0010	7.0000	0.0004	9.0000	0.0002
1.0625	0.0522	3.0625	0.0040	5.0625	0.0010	7.0625	0.0004	9.0625	0.0002
1.1250	0.0558	3.1250	0.0038	5.1250	0.0009	7.1250	0.0004	9.1250	0.0002
1.1875	0.0565	3.1875	0.0035	5.1875	0.0009	7.1875	0.0004	9.1875	0.0002
1.2500	0.0550	3.2500	0.0033	5.2500	0.0009	7.2500	0.0004	9.2500	0.0002
1.3125	0.0519	3.3125	0.0032	5.3125	0.0009	7.3125	0.0004	9.3125	0.0002
1.3750	0.0480	3.3750	0.0030	5.3750	0.0008	7.3750	0.0004	9.3750	0.0002
1.4375	0.0437	3.4375	0.0028	5.4375	0.0008	7.4375	0.0004	9.4375	0.0002
1.5000	0.0394	3.5000	0.0027	5.5000	0.0008	7.5000	0.0004	9.5000	0.0002
1.5625	0.0353	3.5625	0.0025	5.5625	0.0008	7.5625	0.0004	9.5625	0.0002
1.6250	0.0315	3.6250	0.0024	5.6250	0.0007	7.6250	0.0004	9.6250	0.0002
1.6875	0.0281	3.6875	0.0023	5.6875	0.0007	7.6875	0.0003	9.6875	0.0002
1.7500	0.0251	3.7500	0.0022	5.7500	0.0007	7.7500	0.0003	9.7500	0.0002
1.8125	0.0224	3.8125	0.0021	5.8125	0.0007	7.8125	0.0003	9.8125	0.0002
1.8750	0.0200	3.8750	0.0020	5.8750	0.0007	7.8750	0.0003	9.8750	0.0002
1.9375	0.0179	3.9375	0.0019	5.9375	0.0006	7.9375	0.0003	9.9375	0.0002

Table A.5 – 800-DF-EA-S beta T and epsilon T TCTF(2) impulse response (medium loss)

Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)
0.0000	0.0000	2.0000	0.0240	4.0000	0.0033	6.0000	0.0011	8.0000	0.0006
0.0625	0.0000	2.0625	0.0223	4.0625	0.0032	6.0625	0.0011	8.0625	0.0006
0.1250	0.0000	2.1250	0.0207	4.1250	0.0031	6.1250	0.0011	8.1250	0.0005
0.1875	0.0000	2.1875	0.0192	4.1875	0.0029	6.1875	0.0011	8.1875	0.0005
0.2500	0.0000	2.2500	0.0177	4.2500	0.0028	6.2500	0.0010	8.2500	0.0005
0.3125	0.0000	2.3125	0.0165	4.3125	0.0027	6.3125	0.0010	8.3125	0.0005
0.3750	0.0000	2.3750	0.0153	4.3750	0.0026	6.3750	0.0010	8.3750	0.0005
0.4375	0.0000	2.4375	0.0142	4.4375	0.0025	6.4375	0.0010	8.4375	0.0005
0.5000	0.0000	2.5000	0.0132	4.5000	0.0024	6.5000	0.0009	8.5000	0.0005
0.5625	0.0000	2.5625	0.0123	4.5625	0.0023	6.5625	0.0009	8.5625	0.0005
0.6250	0.0001	2.6250	0.0114	4.6250	0.0022	6.6250	0.0009	8.6250	0.0005
0.6875	0.0004	2.6875	0.0107	4.6875	0.0022	6.6875	0.0009	8.6875	0.0005
0.7500	0.0012	2.7500	0.0100	4.7500	0.0021	6.7500	0.0009	8.7500	0.0005
0.8125	0.0027	2.8125	0.0093	4.8125	0.0020	6.8125	0.0008	8.8125	0.0005
0.8750	0.0053	2.8750	0.0087	4.8750	0.0019	6.8750	0.0008	8.8750	0.0004
0.9375	0.0089	2.9375	0.0082	4.9375	0.0019	6.9375	0.0008	8.9375	0.0004
1.0000	0.0134	3.0000	0.0077	5.0000	0.0018	7.0000	0.0008	9.0000	0.0004
1.0625	0.0185	3.0625	0.0072	5.0625	0.0018	7.0625	0.0008	9.0625	0.0004
1.1250	0.0235	3.1250	0.0068	5.1250	0.0017	7.1250	0.0007	9.1250	0.0004
1.1875	0.0280	3.1875	0.0064	5.1875	0.0017	7.1875	0.0007	9.1875	0.0004
1.2500	0.0318	3.2500	0.0061	5.2500	0.0016	7.2500	0.0007	9.2500	0.0004
1.3125	0.0345	3.3125	0.0057	5.3125	0.0016	7.3125	0.0007	9.3125	0.0004
1.3750	0.0362	3.3750	0.0054	5.3750	0.0015	7.3750	0.0007	9.3750	0.0004
1.4375	0.0370	3.4375	0.0052	5.4375	0.0015	7.4375	0.0007	9.4375	0.0004
1.5000	0.0369	3.5000	0.0049	5.5000	0.0014	7.5000	0.0007	9.5000	0.0004
1.5625	0.0361	3.5625	0.0047	5.5625	0.0014	7.5625	0.0006	9.5625	0.0004
1.6250	0.0349	3.6250	0.0044	5.6250	0.0013	7.6250	0.0006	9.6250	0.0004
1.6875	0.0333	3.6875	0.0042	5.6875	0.0013	7.6875	0.0006	9.6875	0.0004
1.7500	0.0315	3.7500	0.0040	5.7500	0.0013	7.7500	0.0006	9.7500	0.0004
1.8125	0.0297	3.8125	0.0038	5.8125	0.0012	7.8125	0.0006	9.8125	0.0004
1.8750	0.0277	3.8750	0.0037	5.8750	0.0012	7.8750	0.0006	9.8750	0.0004
1.9375	0.0258	3.9375	0.0035	5.9375	0.0012	7.9375	0.0006	9.9375	0.0003

Table A.6 – 800-DF-EA-S beta T and epsilon T TCTF(3) impulse response (high loss)

Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)	Time (UI)	Amp (V)
0.0000	0.0000	2.0000	0.0216	4.0000	0.0055	6.0000	0.0020	8.0000	0.0010
0.0625	0.0000	2.0625	0.0210	4.0625	0.0053	6.0625	0.0020	8.0625	0.0010
0.1250	0.0000	2.1250	0.0204	4.1250	0.0051	6.1250	0.0019	8.1250	0.0010
0.1875	0.0000	2.1875	0.0197	4.1875	0.0049	6.1875	0.0019	8.1875	0.0010
0.2500	0.0000	2.2500	0.0190	4.2500	0.0047	6.2500	0.0018	8.2500	0.0010
0.3125	0.0000	2.3125	0.0182	4.3125	0.0046	6.3125	0.0018	8.3125	0.0009
0.3750	0.0000	2.3750	0.0175	4.3750	0.0044	6.3750	0.0017	8.3750	0.0009
0.4375	0.0000	2.4375	0.0168	4.4375	0.0043	6.4375	0.0017	8.4375	0.0009
0.5000	0.0000	2.5000	0.0160	4.5000	0.0041	6.5000	0.0017	8.5000	0.0009
0.5625	0.0000	2.5625	0.0153	4.5625	0.0040	6.5625	0.0016	8.5625	0.0009
0.6250	0.0001	2.6250	0.0146	4.6250	0.0038	6.6250	0.0016	8.6250	0.0009
0.6875	0.0003	2.6875	0.0140	4.6875	0.0037	6.6875	0.0016	8.6875	0.0008
0.7500	0.0006	2.7500	0.0133	4.7500	0.0036	6.7500	0.0015	8.7500	0.0008
0.8125	0.0012	2.8125	0.0127	4.8125	0.0035	6.8125	0.0015	8.8125	0.0008
0.8750	0.0020	2.8750	0.0121	4.8750	0.0034	6.8750	0.0015	8.8750	0.0008
0.9375	0.0032	2.9375	0.0116	4.9375	0.0033	6.9375	0.0014	8.9375	0.0008
1.0000	0.0048	3.0000	0.0110	5.0000	0.0032	7.0000	0.0014	9.0000	0.0008
1.0625	0.0066	3.0625	0.0105	5.0625	0.0031	7.0625	0.0014	9.0625	0.0008
1.1250	0.0086	3.1250	0.0100	5.1250	0.0030	7.1250	0.0013	9.1250	0.0008
1.1875	0.0108	3.1875	0.0096	5.1875	0.0029	7.1875	0.0013	9.1875	0.0007
1.2500	0.0130	3.2500	0.0092	5.2500	0.0028	7.2500	0.0013	9.2500	0.0007
1.3125	0.0150	3.3125	0.0088	5.3125	0.0027	7.3125	0.0013	9.3125	0.0007
1.3750	0.0169	3.3750	0.0084	5.3750	0.0026	7.3750	0.0012	9.3750	0.0007
1.4375	0.0186	3.4375	0.0080	5.4375	0.0026	7.4375	0.0012	9.4375	0.0007
1.5000	0.0200	3.5000	0.0077	5.5000	0.0025	7.5000	0.0012	9.5000	0.0007
1.5625	0.0210	3.5625	0.0074	5.5625	0.0024	7.5625	0.0012	9.5625	0.0007
1.6250	0.0218	3.6250	0.0070	5.6250	0.0024	7.6250	0.0011	9.6250	0.0007
1.6875	0.0223	3.6875	0.0068	5.6875	0.0023	7.6875	0.0011	9.6875	0.0007
1.7500	0.0226	3.7500	0.0065	5.7500	0.0022	7.7500	0.0011	9.7500	0.0007
1.8125	0.0226	3.8125	0.0062	5.8125	0.0022	7.8125	0.0011	9.8125	0.0006
1.8750	0.0224	3.8750	0.0060	5.8750	0.0021	7.8750	0.0011	9.8750	0.0006
1.9375	0.0221	3.9375	0.0057	5.9375	0.0021	7.9375	0.0010	9.9375	0.0006

A.5.3 Epsilon point signal tolerance test procedure

An example compliance method for epsilon R signal tolerance test is shown in figure A.10. The receiver input can be tested for BER compliance with test signals that represent the worst case waveshape and interference properties expected during compliant operation.

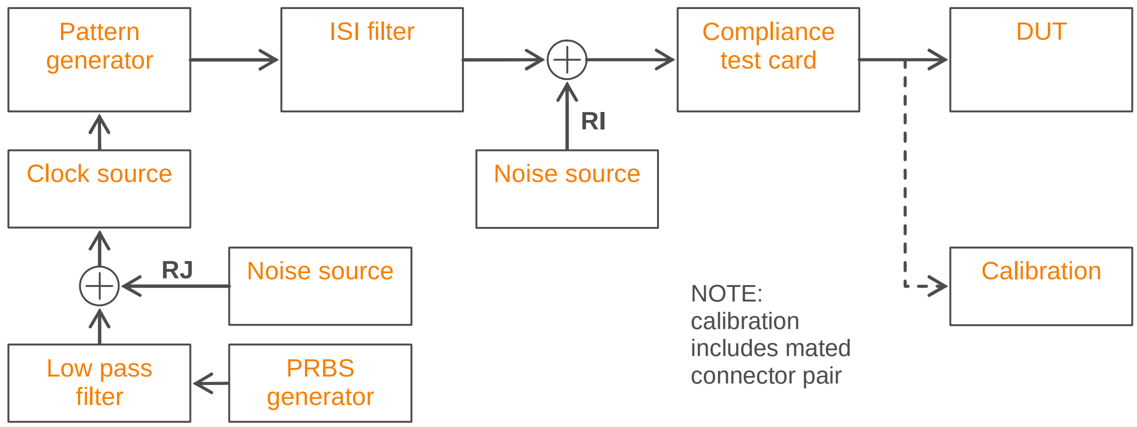


Figure A.10 – Example of epsilon R signal tolerance method

The test setup generates electrical signals with output VMA, distortion (WDP and NC-DDJ), and interference properties defined for the receiver input. The specifications given in table 35 are as measured during calibration through the compliance test board.

The ISI filter is intended to represent the waveform distortion that may be encountered during compliant operation. The ISI filter shall be constructed in such a way that it accurately represents the insertion loss and group delay characteristics of differential traces on a printed circuit board. The differential output amplitude of the pattern generator is adjusted so that the VMA applied to the receiver under test is the specified value. The test signal output should be AC coupled. The output of the tester is plugged through the compliance test board into laboratory equipment for calibration. After calibration, the tester is plugged into the receiver under test for compliance testing.

The interference generator is intended to represent the insertion loss deviation and crosstalk that may be encountered during compliant operation. The interference generator is a broadband noise source with adjustable amplitude. The power spectral density of the noise shall be flat to ±3 dB from 100 MHz to 4.25 GHz. The noise amplitude is specified in terms of the peak-to-peak voltage applied to receiver input of the device under test, as measured at the output of a filter with a 40 dB/decade roll-off and a -3 dB frequency of 4.25 GHz. The peak-to-peak amplitude includes all but 10^{-12} of the amplitude population

Any implementation of the measurement configuration may be used, provided that the resulting signal and interference match those defined in table 35. Under all specified test conditions, a BER of better than 10^{-12} shall be achieved.

Annex B (normative)
Signal performance measurements for 400-DF-EL-S and 800-DF-EL-S electrical variants

B.1 Introduction

This annex specifies the configuration requirements for making electrical performance measurements at the 4GFC and 8GFC interoperability points. These measurements consist of signal output, signal tolerance, and return loss. Standard loads are used in all cases so that independent specification of connection components and transportability of the measurement results are possible.

B.1.1 A simple connection

B.1.1.1 Overview

In the basic structure considered the physical link consists of three component parts: the transmitter device, the interconnect, and the receiver device each connected by a separable connector. If a duplex connection is used signals travel in opposite directions down the same nominal path.

Figure B.1 shows such a duplex link and the location of the connectors.

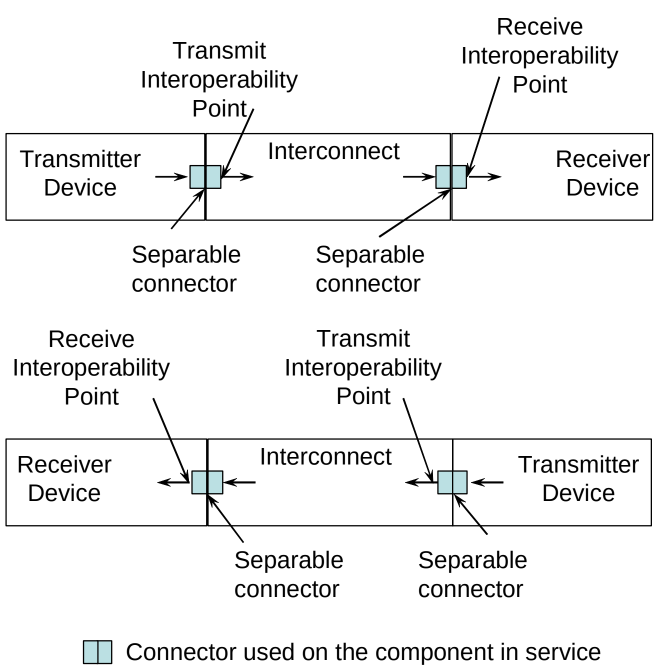


Figure B.1 – A simple duplex link physical connection

Since connectors are always used in the mated condition the only access to the signals is before the signal enters the mated connector (i.e. upstream) or after the signal exits the connector (i.e. downstream). Even if signals could be practically accessed at the point of mating within the connector such access would disturb the connector to the point that the measurement of the signal would be compromised. Attempting to access the un-mated connector with probes, for example, is also not acceptable because the connector is not the same when un-mated as when mated and the probe contact points will not be at the same location as the connector contact points. Using probes the contacts are not deflected and the shields are not connected in un-mated electrical connectors. For optical connectors the only practical access method to an unmated connector is by adding the mating half and that makes it a mated connector.

In this annex the signal outputs are always measured downstream of the mated connector (as shown in figure B.1) so that the contribution of the connector to the signal properties is included in the measurement. This approach assigns a portion of the connector losses to the upstream component but it also makes the signal measurement conservative. If the connectors on both ends of the interconnect are the same the additional loss at the downstream connector is balanced by the reduced loss at the upstream connector. For transmitter devices a slightly stronger transmitter is required to pass the signal through the downstream half of the connector that does not belong to the transmitter device. The signal coming into receiver devices is specified after the signal has passed through the connector.

Examination of the details of the measurement methods described later shows that the mated connector issue may not be as severe as it appears.

The TxRx connection has an assumed ‘reference impedance’ e.g. 100 ohms

B.1.2 Assumptions for the structure of the transmitter device and the receiver device

Figure B.2 shows the details of a transmitter device. Notice that there are at least three internal parts of this transmitter device that could be called a ‘transmitter’:

- the transmitter circuit in the chip
- the chip itself
- the chip and its associated chip package

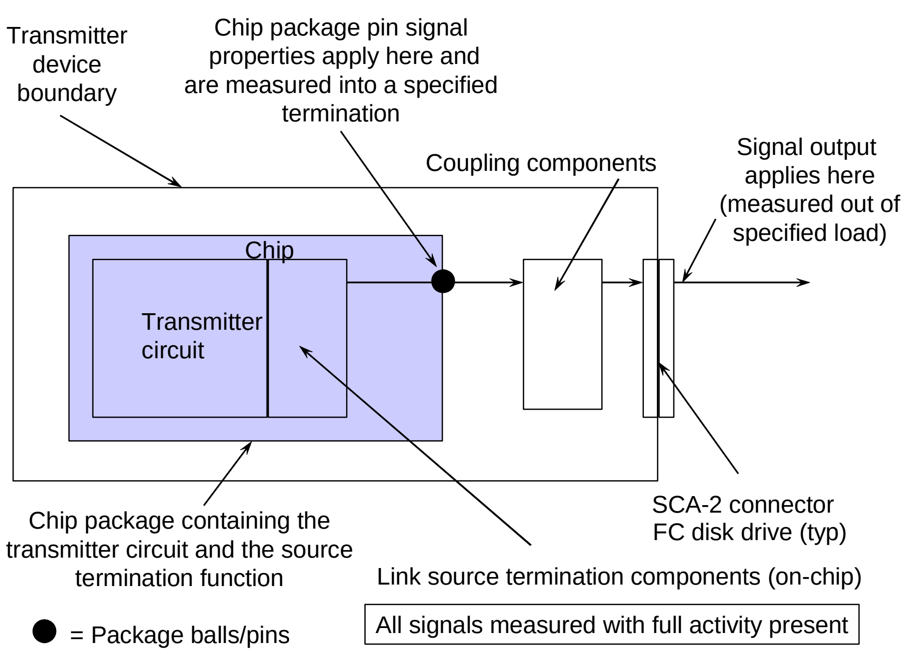


Figure B.2 – Transmitter device details for an HDD type interoperability point

The term ‘transmitter’ is therefore not well defined and is not used in the terminology without a modifier.

The transmitter device contains a connector (half a mated pair), optional coupling circuits, the source termination, the transmitter circuit, PCB traces and vias, the chip package, and possibly ESD devices. It is assumed that the source termination is contained within the chip package.

Interoperability points might be defined at the chip package pins in some network standards (e. g., Ethernet XAUI). FC standards do not define requirements at chip package pins.

Figure B.3 shows the details of a receiver device. It is similar to the transmitter device

.

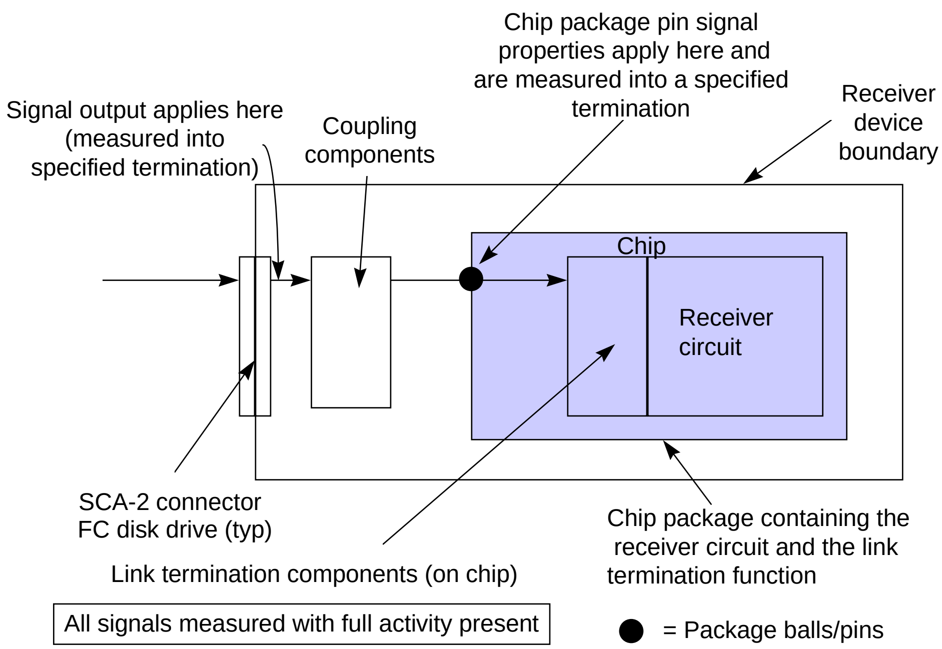


Figure B.3 – Receiver device details for an HDD type interoperability point

Notice that there are at least three internal parts of this receiver device that could be called a 'receiver':

- the receiver circuit in the chip
- the chip itself
- the chip and its associated chip package

The term 'receiver' is therefore not well defined and is not used in the terminology without a modifier.

The receiver device contains a connector (half a mated pair), optional coupling circuits, the link termination, the receiver circuit, PCB traces and vias, the chip package, and possibly ESD devices. It is assumed that the link termination is contained within the chip package.

B.1.3 Definition of receiver sensitivity and receiver device sensitivity

The term 'receiver sensitivity' is problematic in common usage. This term is not used for interoperability specifications but it has proven impossible to purge the term. A related term applicable to the receiver device input signal is the 'receiver device sensitivity'. While these two terms are related they are significantly different because of the noise environment assumed. The following description is used to uniquely define these terms with the understanding that this document discourages usage of either term.

Receiver sensitivity:

- The ‘receiver’ in the ‘receiver sensitivity’ refers to signal properties at the chip package pin for the chip package that contains the receiver circuit.
- Receiver sensitivity is defined as the minimum vertical inner eye opening at which the receiver chip delivers the required BER – the horizontal eye opening shall be minimum (maximum jitter present) and all activity is quiesced except for the receiver itself.
- Receiver sensitivity is not defined in the FC-PI-2 context because there are no chip pin specifications

Receiver device sensitivity:

The term ‘receiver device sensitivity’ is defined as the minimum vertical inner eye opening measured at the signal output point for the input to the receiver device at which the receiver chip (the chip in the chip package on the board containing the receiver device interoperability point) delivers the required BER with all activity expected in the application for the receiver circuit present (not quiesced as for the receiver sensitivity definition), with the CJTPAT (see FC-MJSQ), and the minimum horizontal eye opening in the signal at the receive device interoperability point.

Special test conditions are required to measure these sensitivities as described later. The terminology used is signal tolerance instead of receiver device sensitivity.

B.2 Measurement architecture requirements

B.2.1 General

Signal specifications are only meaningful if the signals can be measured with practical instrumentation. Another requirement is that different laboratories making measurements on the same signal get the same results within acceptable measurement error. In other words the measurements must be accessible, verifiable, and transportable. As of this writing there are no accepted standards for creating signals with traceable properties and with all the properties required for an effective signal specification architecture for high speed serial applications.

Some of the elements required for practical, verifiable, and transportable signal measurements are included in this document.

Having signal specifications at interoperability points that do not depend on the actual properties of the other link components not under test requires that specified known loads be used for the signal measurements. In service, the load presented to the interoperability point will be that of the actual component and environment existing in service.

Interfacing with practical instruments also requires that specified impedance environments be used. This forces a signal measurement architecture where the impedance environment is 50 or possibly 75 ohms single-ended (100 or 150 ohms differential). It also forces the requirement for instrumentation quality loads of the correct value.

Instrumentation quality loads are readily available for simple transmission line termination. For more complex loads the industry is still working on how to make these available. The properties of more complex loads include specified propagation time, insertion loss properties, crosstalk properties, and jitter creation properties. More discussion on the complex loads is given in clause 9.

For signal tolerance measurements the signal shall be calibrated before applying it to the interoperability point under test. This calibration is done by adjusting the properties of the signal measured across of a known load (just like the signal output case) and then removing the known load and applying the signal unchanged to the interoperability point under test. It is assumed that any changes to the signal from the calibration state to the measurement state are caused by the interoperability point under test and is therefore part of the performance sought by the measurement.

B.2.2 Relationship between signal compliance measurements at interoperability points and operation in systems

The signal and return loss measurements in this document apply under specified test conditions that simulate some parts of the conditions existing in service. This simulation includes, for example, duplex traffic on all Ports and under all applicable environmental conditions. Other features existing in service such as non ideal return loss in parts of the link that are not present when measuring signals in the specified test conditions are included in the specifications themselves. This methodology is required to give each side of the interoperability point signal performance requirements that do not depend on knowing the properties of the other side.

Measuring signals in an actual functioning system at an interoperability point does not verify compliance for the components on either side of the interoperability point although it does verify that the specific combination of components in the system at the time of the measurement produces compliant signals. Interaction between components on either side of the interoperability point may allow the signal measured to be compliant but this compliance may have resulted because one component is out of specification while the other is better than required.

It is recommended that additional margin be allowed when performing signal compliance measurements to account for conditions existing in service that may not have been accounted for in the specified measurements and specifications.

B.3 De-embedding connectors in test fixtures

Connectors are necessarily part of the test fixtures required for obtaining access to the interoperability points. This is intrinsic for most practical measurements because the connectors used on the service components are different from those used on the instrumentation.

The effects of the portions of the connector that is used on the test fixture need to be accounted for in order to not penalize the point under test by the performance of the test fixture connector. This accounting process is termed ‘de-embedding’ in this section.

Figure B.4 shows two cases that apply.

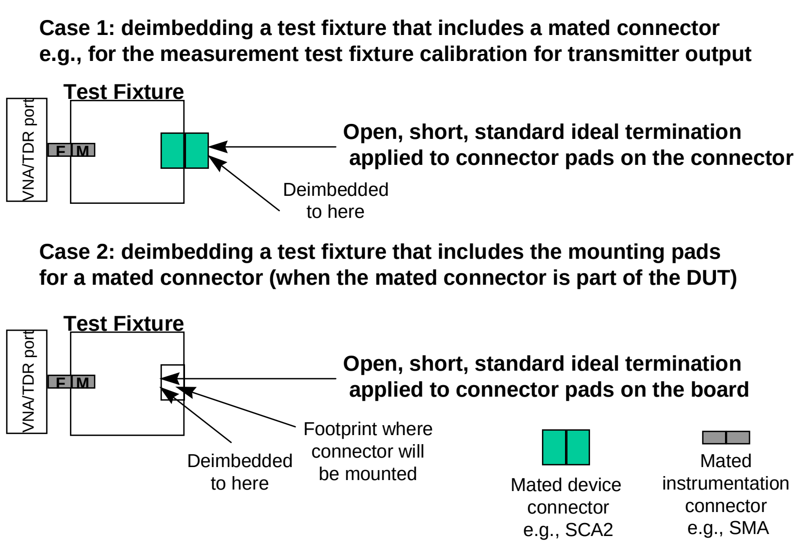


Figure B.4 – De-embedding of connectors in test fixtures

The de-embedding process assumes that the test fixture is linear and that S parameter methodologies are used. Fundamentally an S parameter model for the test fixture with or without the connector in place is the result. Knowing this model for the test fixture (with or without the connector in place) allows simulation of the impact of the test fixture on the signal measurement.

B.4 Measurement conditions for signal output (DSO) at the transmitter device

The measurement conditions required for a differential transmitter device signal output (DSO) are shown in figure B.5. Two required cases are described in this figure: one where the transmitter device is directly attached to the receiver device and the other where the transmitter device is attached to the receiver device through an interconnect assembly (cable assembly or PCB).

To simulate some of the properties of the interconnect assembly an instrumentation quality compliance interconnect is used. This compliance interconnect is assumed embedded in the compliance interconnect test fixture as shown in more detail in figure B.6.

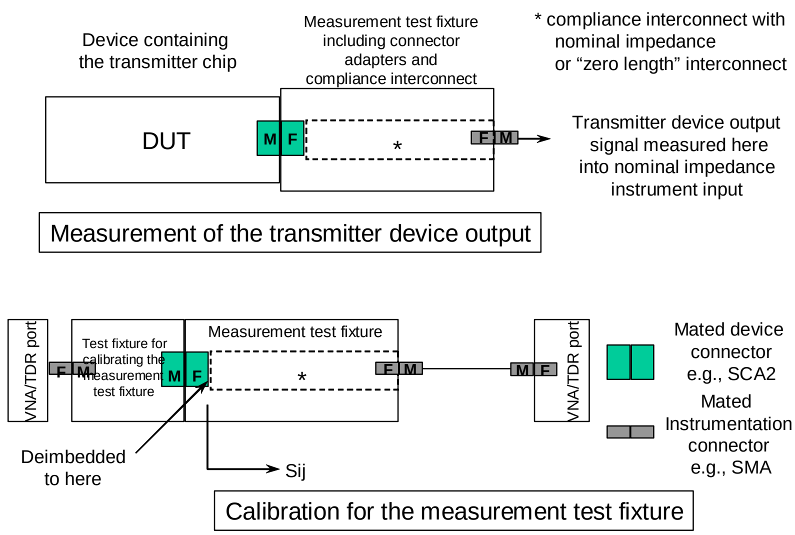


Figure B.5 – Measurement conditions for transmitter device signal output specifications

In the lower portion of figure B.5 a cable assembly connecting the measurement test fixture to the instrumentation port is shown. This cable assembly is considered part of the instrumentation and is not specifically shown in the top portion of figure B.5 nor in other similar figures in this annex. The gender of the connector that connects the instrument or the instrument plus the connecting cable to the set up may need to be changed in specific instrumentation connections.

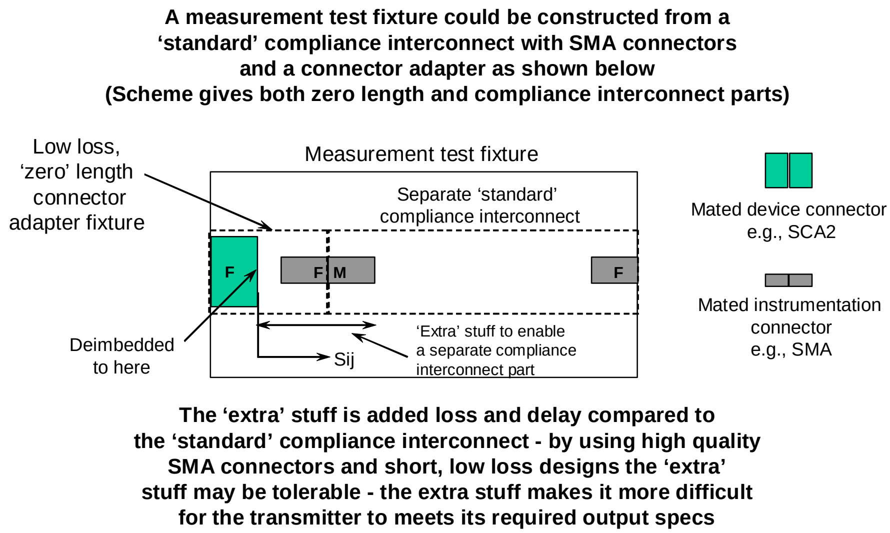


Figure B.6 – Transmitter device output signal measurement test fixture details

B.5 Measurement conditions for signal tolerance (DST) at the transmitter device

The measurement conditions required for the signal tolerance (DST) at the differential transmitter device interoperability point are shown in figure B.7. Two required cases are described in this figure: one where the transmitter device is directly attached to the receiver device and the other where the transmitter device is attached to the receiver device through an interconnect assembly (cable assembly or PCB).

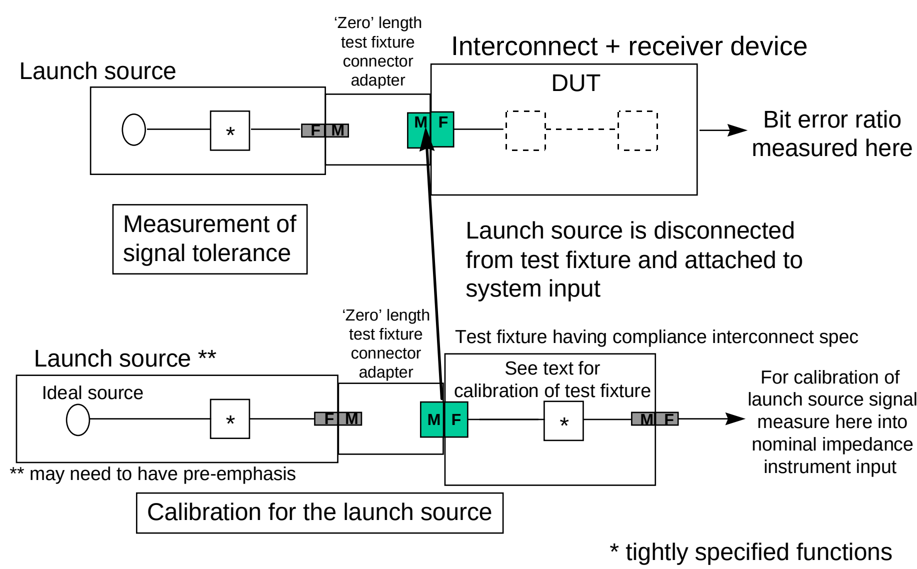
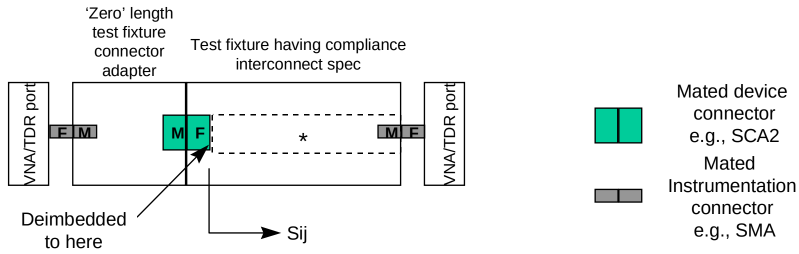


Figure B.7 – Measurement conditions for system signal tolerance

The test fixture for this measurement is shown in figure B.8.



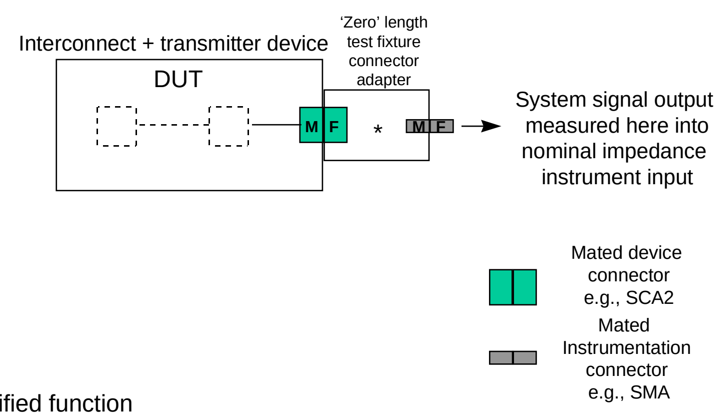
Note that this test fixture is <u>identical</u> to the 'measurement' test fixture used for the transmitter device output signal (even the connector genders and pins used in the SCA-2 connector are the same)

* tightly specified function

Figure B.8 – Calibration of test fixture for transmitter device signal tolerance

B.6 Measurement conditions for signal output (DSO) at the receiver device

The measurement conditions for the signal output at the receiver device are shown in figure B.9.



* tightly specified function

Figure B.9 – Measurement conditions for signal output at the receiver device

The interconnect could be the zero length interconnect where the transmitter device is connected directly to the receiver device.

B.7 Measurement conditions for signal tolerance (DST) at the receiver device

The measurement conditions required for the signal tolerance (DST) at the differential receiver device interoperability point are shown in figure B.10. Two required cases are described in this figure: one where the transmitter device is directly attached to the receiver device and the other where the transmitter device is attached to the receiver device through an interconnect assembly (cable assembly or PCB).

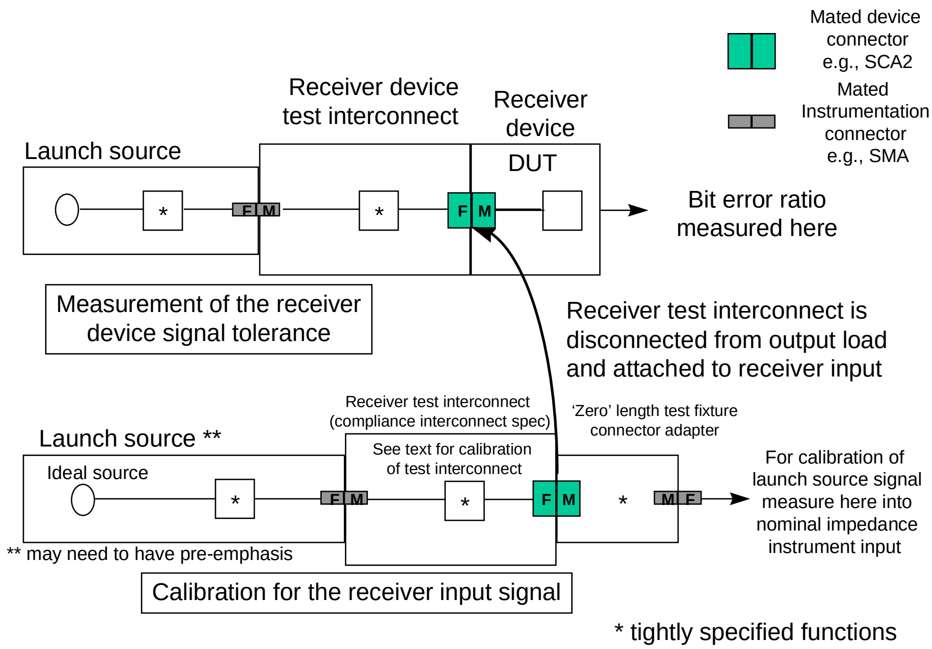
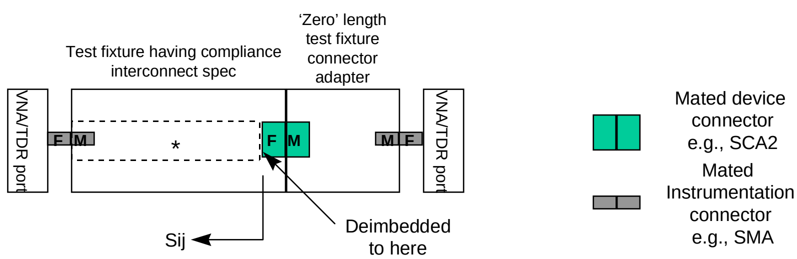


Figure B.10 – Measurement conditions for receiver device signal tolerance



Note that this is not identical to the 'measurement' test fixture used for the transmitter output signal even though the connector genders are the same. The pins used in the SCA-2 connector are for the Rx (not the TX) and the signals flow the other way. The S22 measurement here is the same as the S11 measurement for the transmitter output signal but on different pins

Also note that the S21 and S12 are used mainly to create the desired jitter in this application and are not as critical

* tightly specified function

Figure B.11 – Calibration of interconnect test fixture for receiver device signal tolerance

B.8 S-parameter measurements

B.8.1 Introduction

Properties of link elements that are linear may be represented by S-parameters. There are two problematic areas when applying S-parameters to differential electrical links:

– XX-00-200x Physical Interface-4 7.00

- Naming conventions
- Use of single-ended vector network methods on differential and common mode systems.

This clause explores both of these areas.

Measurement architecture for the most common conditions are described in some detail.

B.8.2 Naming conventions in high speed serial links

Significant confusion has existed concerning the naming of Sij in FC links (see definitions for insertion loss and return loss). The confusion may happen when numbers are assigned to i and j in specific cases. Another confusion factor may come from naming the type of measurement to be performed.

There are basically two types of measurement: (1) return loss from the same port of the element and (2) transfer function or insertion loss across the element. In common parlance a return loss measurement may be referred to as an S11 measurement and the transfer function or insertion loss may be referred to as S21.

When a return loss measurement is performed on port 2 of the element, the measurement is reporting the S22 property of the element even though it is exactly the same kind of measurement that is done for the S11 of the element on port 1.

A port number convention is used where the downstream port is always port 2 and the upstream port is always port 1. The stream direction is determined by the direction of the primary signal launched from the transmitter device to the receiver device.

Measurement types should not be referred to as S11 or S21 but rather by the return loss, insertion loss (or transfer function).

Figure B.12 shows the port naming conventions for link elements and loads.

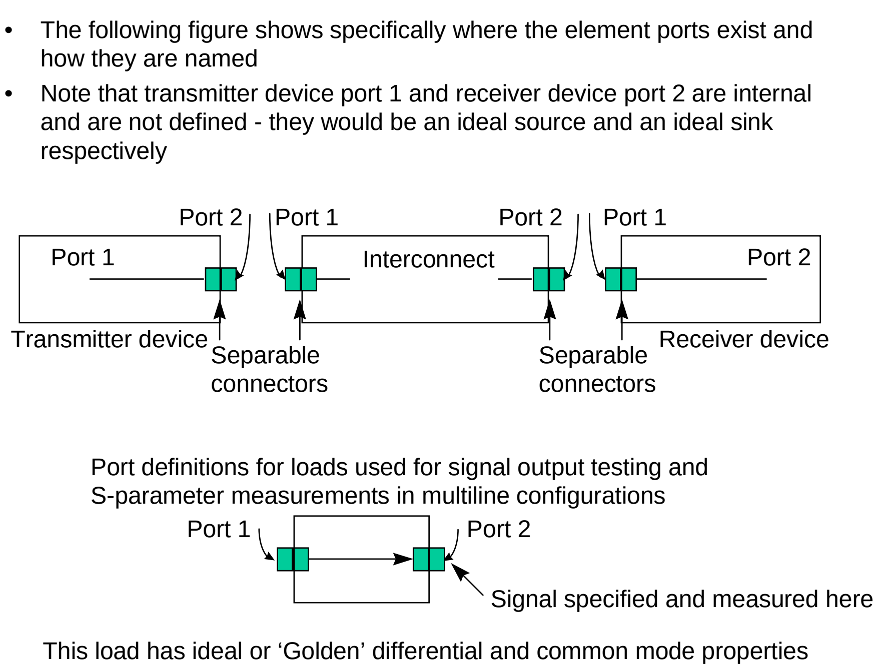


Figure B.12 – Sij nomenclature conventions

B.8.3 Use of single-ended instrumentation in differential applications

Figure B.13 shows the connections that would be made to a four port vector network analyzer (VNA) or a time domain network analyzer (TDNA) for measuring S parameters on a four single-ended port 'black box' device. These analyzers recognize incident signals denoted by the 'A' subscript and reflected signals from the same port denoted by the 'B' subscript.

All the measurements specified in this document relate to differential signal pairs. It requires all four analyzer ports to measure the properties of two differential ports.

VNA ports are all single-ended and the differential and common mode properties for differential ports are calculated internal to the VNA. If using a TDNA consult the details for the specific instrument.

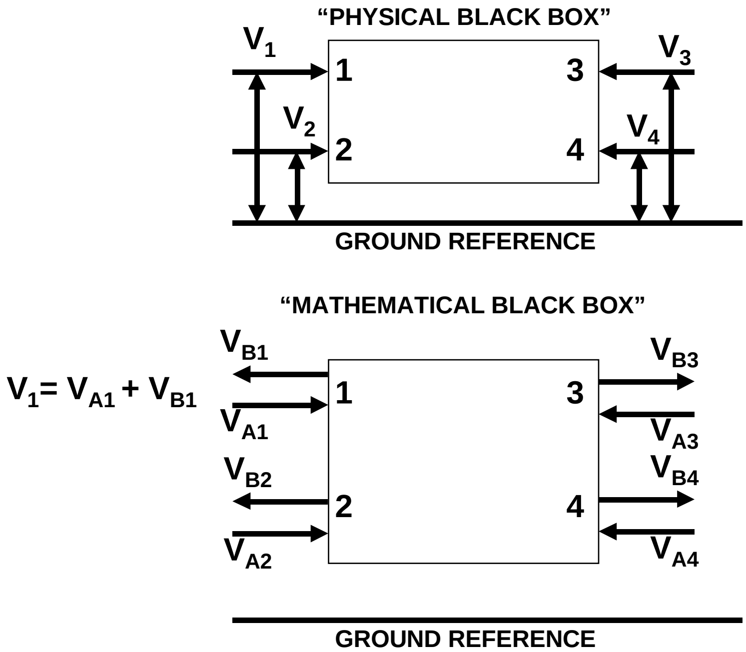


Figure B.13 – Four single-ended port or two differential port element

B.9 Measurement configurations for link elements

B.9.1 Overview

Special test fixtures are required to make S-parameter measurements partly because the connectors used on real link elements are different from those used on instrumentation. The goal is for these test fixtures to be as 'invisible' as possible.

Annex B.9 describes the measurement configurations used for the four conditions required for 4GFC and 8GFC. All of these measurements are return loss in FC-PI-4. A more complete set of S-parameters is used as part of the calibration process for test fixtures.

B.9.2 Transmitter device return loss

Figure B.14 shows the configuration to be used for the transmitter device return loss measurement.

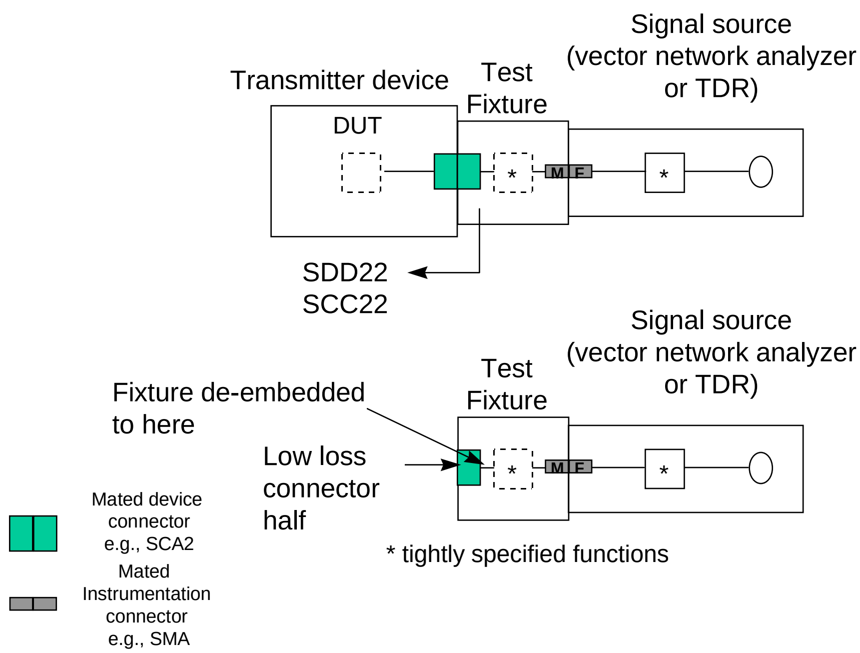


Figure B.14 – Conditions for upstream return loss at the transmitter device connector

Notice that the test fixture uses low loss connectors to avoid penalizing the transmitter device under test for the test fixture half of the connector. If the test fixture half of the device connector is poor then the transmitter device has to be that much better to accommodate.

The test fixture losses up to the mounting points for the device connector are de-embedded using the methods described in figure B.4.

B.9.3 Receiver device return loss

Figure B.15 shows the configuration to be used for the receiver device return loss measurement.

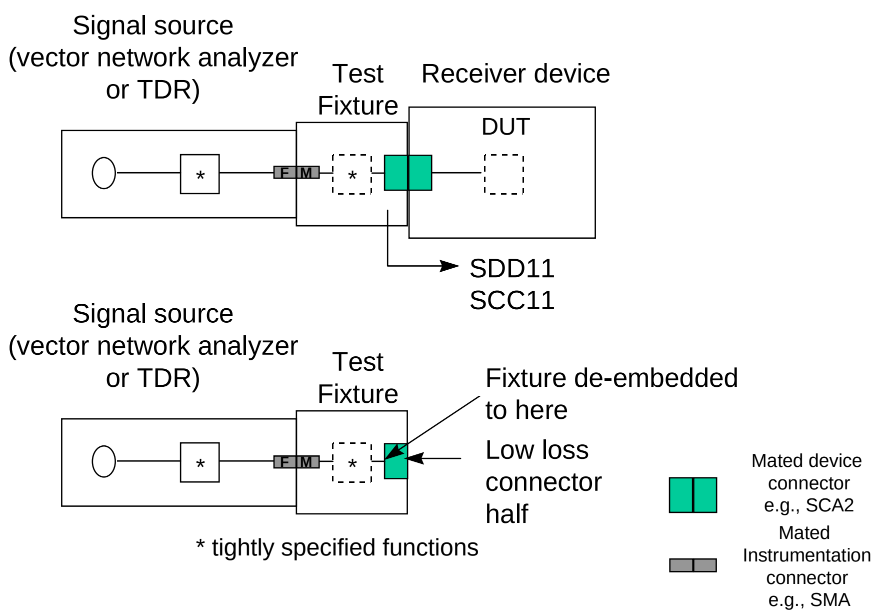


Figure B.15 – Conditions for downstream return loss at the receiver device connector

Notice that the test fixture uses low loss connectors to avoid penalizing the receiver device under test for the test fixture half of the connector. If the test fixture half of the device connector is poor then the receiver device has to be that much better to accommodate.

The test fixture losses up to the mounting points for the device connector are de-embedded using the methods described in figure B.4.

B.9.4 Return loss at the transmitter device connector (interconnect input)

Figure B.16 shows the conditions for making the return loss measurement into the interconnect attached to the transmitter device.

This measurement, like the signal tolerance measurement at the transmitter device connector, requires both the interconnect and the receiver device to be in place and the combination is measured. If the receiver device is replaced by an ideal load then the return loss will not represent in service conditions. If the interconnect is very lossy then the effects of the load on the far end (where the receiver device would be) are not significant and an ideal load may be used. However, if the interconnect is not very lossy as in the ‘zero length’ case, then the measured return loss may be dominated by the properties of the receiver device and not the properties of the interconnect.

For short links this return loss performance may be the limiting factor for the entire link due to severe unattenuated reflections that create large deterministic jitter.

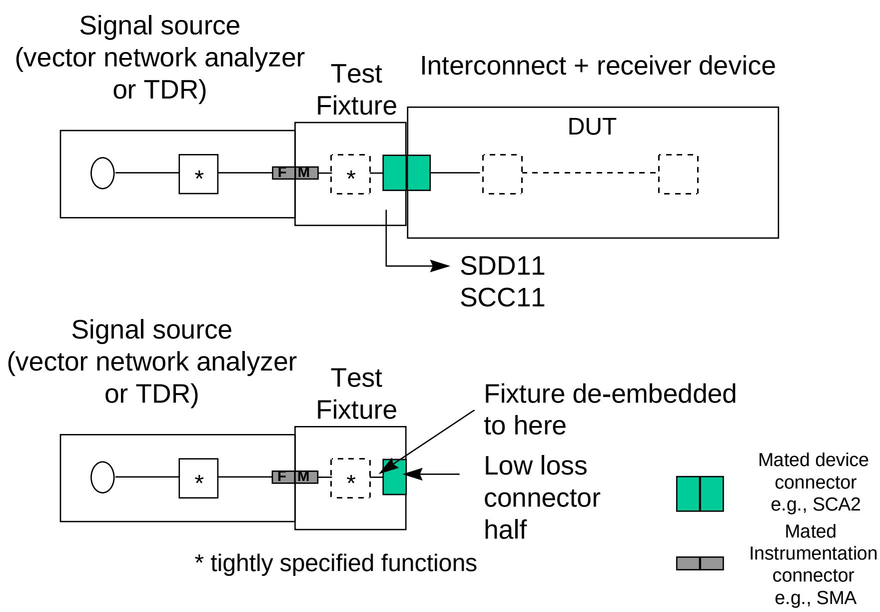


Figure B.16 – Conditions for downstream return loss at the transmitter device connector

B.9.5 S22 at the receiver device connector (interconnect output)

Figure B.17 shows the conditions for making the return loss measurement out of the interconnect attached to the receiver device.

This measurement is unique in that it requires both the interconnect and the transmitter device to be in place and the combination is measured. This is similar to a reverse direction signal tolerance measurement. If the transmitter device is replaced by an ideal load then the return loss will not represent in service conditions. If the interconnect is very lossy then the effects of the load on the far end (where the transmitter device would be) are not significant and an ideal load may be used. However, if the interconnect is not very lossy as in the 'zero length' case, then the measured return loss may be dominated by the properties of the transmitter device and not the properties of the interconnect.

For short links this return loss performance may be the limiting factor for the entire link due to severe unattenuated reflections that create large deterministic jitter.

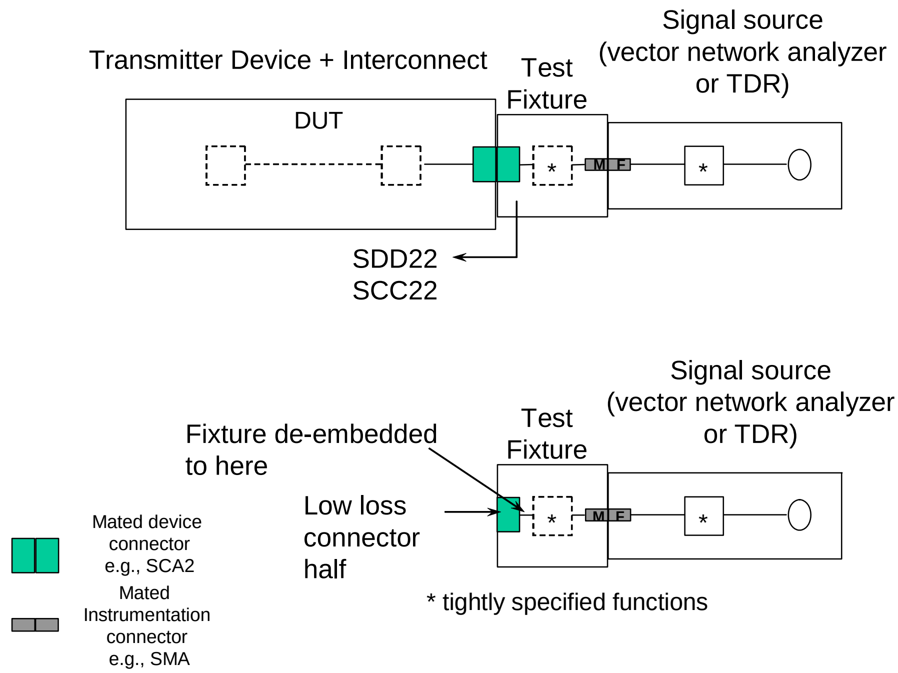


Figure B.17 – Conditions for upstream return loss at the receiver device connector

B.10 Summary for S-parameter measurements

S-parameters are the preferred method of capturing the linear properties of link elements. Complex, but tractable, methods are required to use single-ended instruments for differential (and common mode) applications. Careful attention to test configuration details is essential.

A frequency domain spectrum output is required for all S-parameters and specifying pass fail limits to such a spectrum may over constrain the system because some peaks and properties are benign to the application. This methodology of masks is nevertheless used in FC-PI-2 and FC-PI-4 for return loss requirements for the 400-DF-EL-S and 800-DF-EL-S variants.

Annex C (informative)
Optical cable plant usage

The worst-case power budget and link penalties for the multimode cables specified in sub-clause 6.4 are shown in table C.1. In some cases, it may be desirable to use an alternative multimode cable plant to those described in sub-clause 6.4. This may be due to the need for operation in locations where alternative lower bandwidth cables are presently installed. These fiber types have not been studied (note 2), nor is their use provided in the main body of this document. Their cable plant usage is described in tables C.2.

Table C.1 – Worst case (nominal bandwidth) multimode cable link power budget

Parameter	**Unit**	**SN**				**SA** (note 5)	**Note**
50µm (OM2) MMF							
Overfilled Launch Modal Bandwidth	MHz*km	500					1
Data rate	MB/s	100	200	400	800	800	
Operating distance	m	0.5-500	0.5-300	0.5-150	0.5-50	0.5-100	
Link power budget	dB	7	6	6.08	6	6.8	
Intersymbol interference	dB	1.85	2.26	2.71	2.94	3.23	
Additional link penalties	dB	1.27	0.96	1.03	0.83	0.86	2
Channel insertion loss	dB	3.85	2.62	2.06	1.68	1.85	
Allocation for additional loss	dB	0.03	0.16	0.28	0.55	0.86	3
62.5µm (OM1) MMF							
Overfilled Launch Modal Bandwidth	MHz*km	200					1
Data rate	MB/s	100	200	400	800	800	
Operating distance	m	0.5-300	0.5-150	0.5-70	0.5-21	0.5-40	
Link power budget	dB	7	6	6.08	6	6.8	
Intersymbol interference	dB	3.14	3.09	3.21	3.00	3.21	
Additional link penalties	dB	0.86	0.71	0.78	0.65	0.85	2
Channel insertion loss	dB	3.00	2.10	1.78	1.58	1.64	
Allocation for additional loss	dB	0.00	0.10	0.31	0.77	1.10	3
50µm (OM3) MMF							
Effective Modal Bandwidth	MHz*km	2000					1, 4
Data rate	MB/s	100	200	400	800	800	
Operating distance	m	0.5-860	0.5-500	0.5-380	0.5-150	0.5-300	
Link power budget	dB	7	6	6.08	6	7.8	
Intersymbol interference	dB	1.00	1.14	1.94	2.79	2.88	
Additional link penalties	dB	1.36	1.51	1.24	0.93	1.93	2
Channel insertion loss	dB	4.62	3.31	2.88	2.04	2.59	
Allocation for additional loss	dB	0.02	0.04	0.02	0.24	0.40	3

Table C.1 – Worst case (nominal bandwidth) multimode cable link power budget

Parameter	Unit	SN	SA (note 5)	Note

Notes:

1 Modal bandwidth at 850 nm.

2 Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [40].

3 The allocation for additional loss may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance. However, the total connection and splice loss shall not exceed 3.0 dB.

4 A minimum effective modal bandwidth-length product of 2000 MHz*Km is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA-492AAAC-A and IEC 60793-2-10, or IEEE 802.3 clause 52, with a 50 µm fiber meeting either the DMD specifications or the EMBc specifications in TIA-492AAAC-A and IEC 60793-2-10.

5 The OM1 and OM2 budgets are based on 0.45 nm spectral width while the OM3 budget is based on 0.65 nm spectral width.

Table C.2 – Alternate (lower bandwidth) multimode cable link power budget

Parameter	Unit	50µm MMF					Note
Overfilled Launch Modal Bandwidth	MHz*km	400					1
Data rate	MB/s	100	200	400	800-SN	800-SA	
Operating distance	m	0.5-450	0.5-260	0.5-130	0.5-40	0.5-80	2
Stressed receiver sensitivity	mW (dBm)	0.058 (-12.4)	0.100 (-10.0)	0.141 (-8.5)	0.151 (-8.2)	0.209 (-6.8)	2, 3, 6
Stressed receiver vertical eye closure penalty	dB	1.2	1.58	2.02	3.44	NA	
Link power budget	dB	7	6	6	6	6.8	
Intersymbol interference	dB	2.11	2.51	2.97	2.93	3.23	
Additional link penalties	dB	1.18	0.91	0.98	0.82	0.85	4
Channel insertion loss	dB	3.61	2.47	1.99	1.64	1.79	
Allocation for additional loss	dB	0.10	0.11	0.06	0.61	0.93	5

Notes:

1 Modal bandwidth at 850 nm.

2 See sub-clause 6.4. for other specifications.

3 See annex A.1.1.1.

4 Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [40].

5 The allocation for additional loss may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance. However, the total connection and splice loss shall not exceed 3.0 dB.

6 The stressed receiver values for 800 MB/s links refer to the test method described in IEEE 802.3-2005 clause 52.9.9.

Table C.3 – Alternate (lower bandwidth) multimode cable link power budget

Parameter	Unit	62.5μm MMF					Note
Overfilled Launch Modal Bandwidth	MHz*km	160					1
Data rate	MB/s	100	200	400	800-SN	800-SA	
Operating distance	m	0.5-250	0.5-120	0.5-55	0.5-15	0.5-30	2
Stressed receiver sensitivity	mW (dBm)	0.071 (-11.5)	0.112 (-9.5)	0.150 (-8.2)	0.151 (-8.2)	0.218 (-6.6)	2, 3, 6
Stressed receiver vertical eye closure penalty	dB	2.38	2.13	2.14	3.30	NA	
Link power budget	dB	7	6	6	6	6.8	
Intersymbol interference	dB	3.33	3.08	3.12	2.79	3.21	
Additional link penalties	dB	0.87	0.70	0.78	0.90	0.84	4
Channel insertion loss	dB	2.76	1.98	1.72	1.56	1.61	
Allocation for additional loss	dB	0.04	0.24	0.38	0.75	1.14	5

Notes:

1 Modal bandwidth at 850 nm.

2 See sub-clause 6.4. for other specifications.

3 See annex A.1.1.1.

4 Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [40].

5 The allocation for additional loss may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance. However, the total connection and splice loss shall not exceed 3.0 dB.

6 The stressed receiver values for 800 MB/s links refer to the test method described in IEEE 802.3-2005 clause 52.9.9.

Annex D (informative)
Structured cabling environment

D.1 Specification of Operating Distances

Operating distances of Fibre Channel links described in clause 6 are based on a variety of specifications including:

- Fiber properties regarding attenuation, core diameter, bandwidth length product and chromatic dispersion.
- Laser properties regarding launch power, spectral characteristics, jitter and rise/fall times.
- Receiver properties regarding sensitivity, cutoff frequency and jitter tolerance.
- Link properties regarding connection loss and unallocated link margin.

D.2 Higher Connection Loss Operating Distances

In structured cabling environments, the connection loss may exceed the 1.5 dB of connection loss used to calculate link distance in clause 6. The primary difference between table D.1 and the MM cable plant tables in clause 8 is a difference in the allocation for connection and splice loss. The maximum link distances for multimode fiber are calculated based on an allocation of 2.4 dB (based on statistical sampling) total connection and splice loss. The connection insertion loss allowance is designed to support usage of two cross-connects in the channel link budget. The insertion loss is specified for a connection that consists of a mated pair of optical connectors. Different loss characteristics may be used provided the loss requirements of table D.1 are met. 800-M6-SN-S limiting is not recommended to be used in structured cabling environments where the connection loss would exceed 1.5 dB, so the operating distances were not included in table D.1. 800-M5-SN-I limiting at 3.0 dB of connection loss is also not a supported configuration.

Table D.1 – M6 Higher Connection Loss Operating Distances

FC-0	800-M6-SA-S (linear)	400-M6-SN-I	200-M6-SN-I	100-M6-SN-I
Operating Range with 2.4 dB of Connection Loss	0.5-36	0.5-60	0.5-120	0.5-250
Loss Budget (for 2.4 dB connector loss)	2.54	2.65	2.90	3.65
Operating Range with 3.0 dB of Connection Loss	0.5-30	0.5-40	0.5-90	0.5-200
Loss Budget (for 3.0 dB connector loss)	3.11	3.16	3.36	4.01

Table D.2 – M5 Higher Connection Loss Operating Distances

FC-0	800-M5-SN-S (limiting)	800-M5-SA-I (linear)	400-M5-SN-I	200-M5-SN-I	100-M5-SN-I
Operating Range with 2.4 dB of Connection Loss	0.5-35	0.5-90	0.5-120	0.5-250	0.5-420
Loss Budget (for 2.4 dB connector loss)	2.53	2.72	2.85	3.35	4.37
Operating Range with 3.0 dB of Connection Loss	NA	0.5-80	0.5-70	0.5-170	0.5-300
Loss Budget (for 3.0 dB connector loss)	NA	3.28	3.26	3.64	4.41

Table D.3 – M5E Higher Connection Loss Operating Distances

FC-0	800-M5E-SN-I (limiting)	800-M5E-SA-I (linear)	400-M5E-SN-I	200-M5E-SN-I	100-M5E-SN-I
Operating Range with 2.4 dB of Connection Loss	0.5-110	0.5-260	0.5-290	0.5-400	0.5-660
Loss Budget (for 2.4 dB connector loss)	2.80	3.31	3.45	3.9	4.8
Operating Range with 3.0 dB of Connection Loss	NA	0.5-200	0.5-150	0.5-270	0.5-500
Loss Budget (for 3.0 dB connector loss)	NA	3.7	3.54	4.01	4.81

D.3 Operating Distance Estimator Using Connection Loss Lines

The operating distances in clause 6 are based on using a single type of fiber, but structured cabling environments may use M5 and M5E fibers within one link. This section shows the user how to determine if a link is operating within the specification and if it can be extended. To calculate the operating distance, the user needs to know the type of fiber, the length of the fiber and optionally the connection loss between the fibers. With these simple parameters, the user can estimate the operating distance of the link.

The link estimator is an approximation and actual distance may vary depending on a given implementation. This model applies to implementations with M5E compliant modules.

NOTE – The user should not mix M5 or M5E patchcords with M6 patchcords because the cores of the fibers do not match. The core diameter of the M6 patchcord is 62.5 um while the core diameter of the M5 and M5E patchcord is 50 um. The diameter mismatch leads to the area of the M6 fiber being 56% larger in area than the M5 or M5E fiber. The mode selective loss created by mixing these fiber types is likely to create a link that does not work or works intermittently.

The connection loss line link estimator defined in this clause helps the user determine if a link that mixes M5 and M5E fiber is within the specification. Figure D.1 through figure D.5 are graphs based on supported distances for M5 and M5E fiber. The first three graphs have a connection loss line for 1.5 dB, 2.4 and 3.0 dB of connection loss. The link budgets for limiting 800 MB/s were not calculated for link loss budgets of 3.0 dB because the link would not have enough margin to operate correctly. The area below the connection loss lines represent the operating distance of the standard.

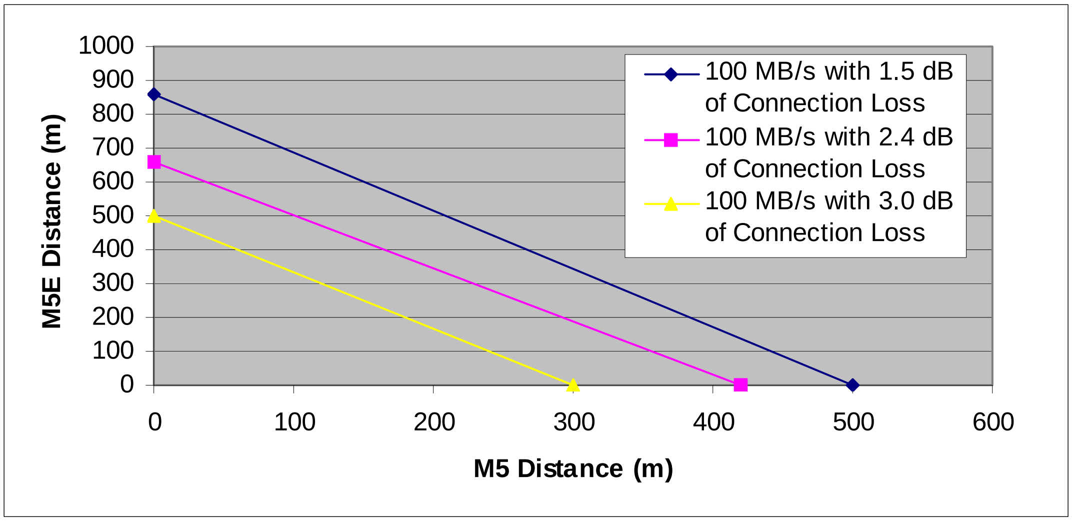


Figure D.1 – Supported distances on mixed 100 MB/s links

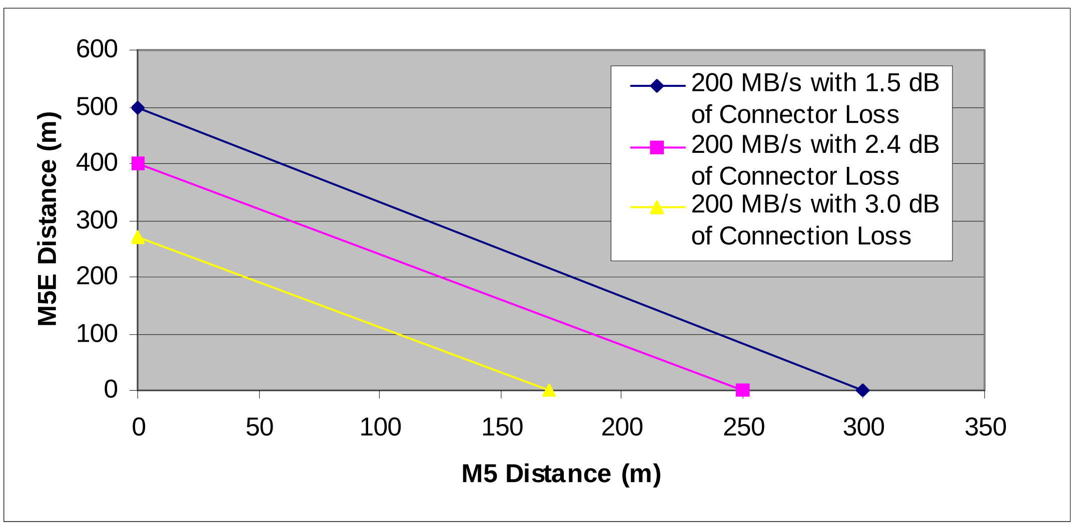


Figure D.2 – Supported distances on mixed 200 MB/s links

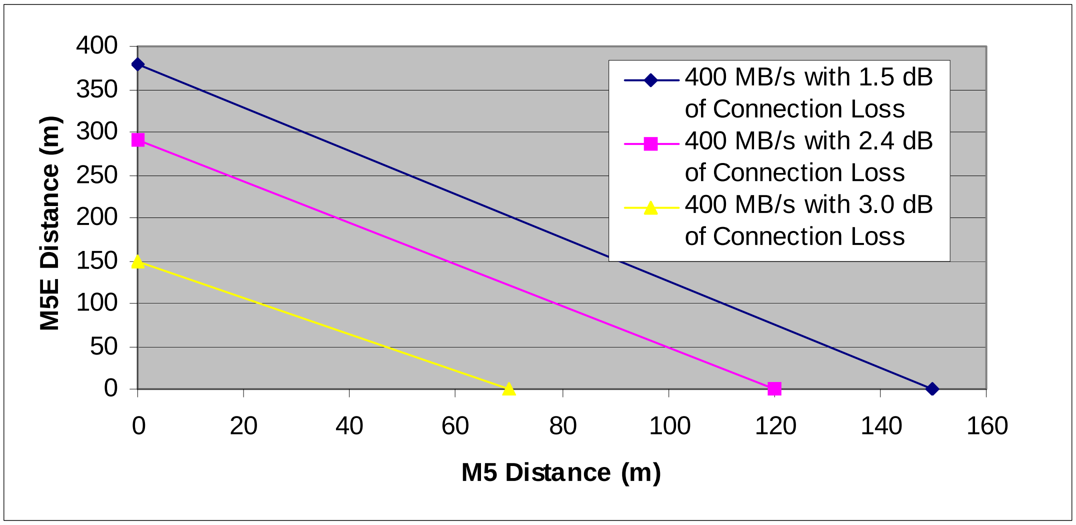


Figure D.3 – Supported distances on mixed 400 MB/s links

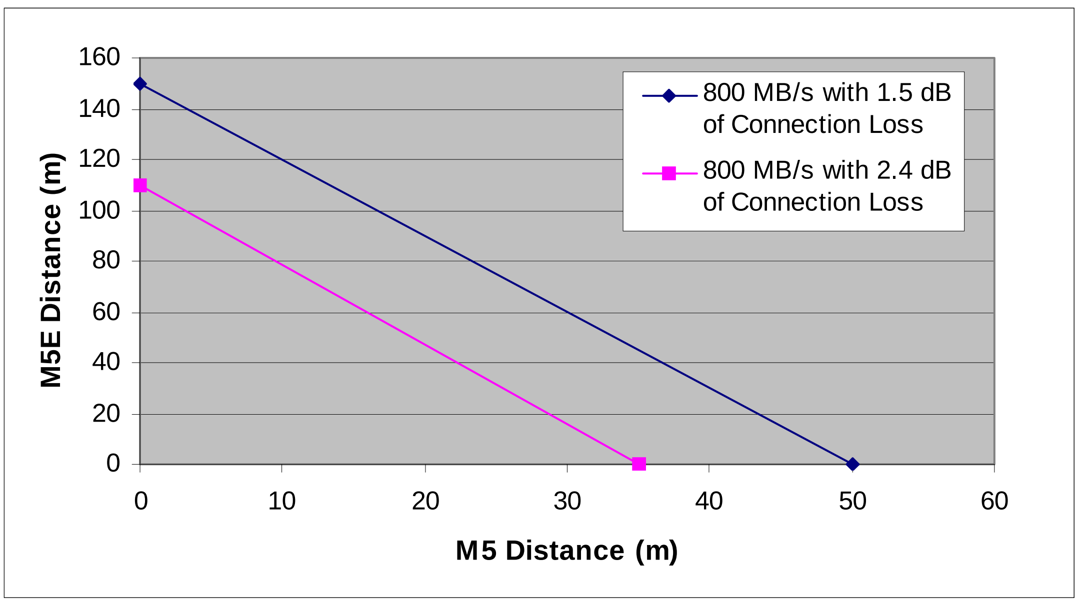


Figure D.4 – Supported distances on mixed limiting 800 MB/s links

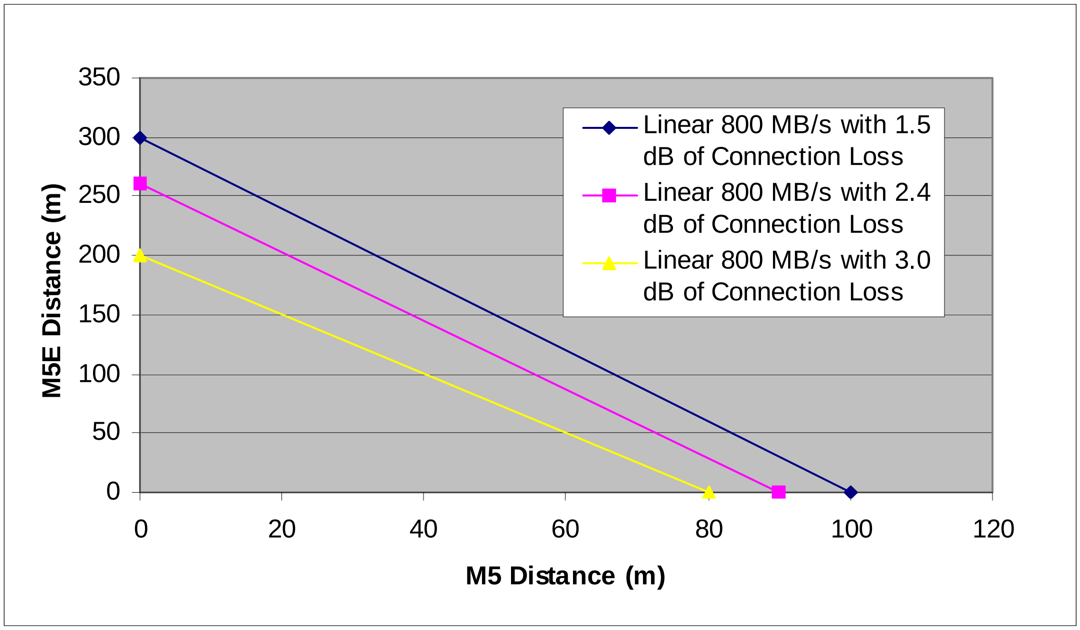


Figure D.5 – Supported distances on mixed linear 800 MB/s links

An example of how to use the graph to calculate link distance may help the user to see the usefulness of these graphs. If the user has a 400 MB/s link that is composed of 100 meters of M5 fiber and 80 meters of M5E fiber, the user can follow this procedure to see the possible ways to extend the link:

1) Draw a line on each axis that represents the current distance of the link for each fiber type.

2) The intersection of the lines shows the operating point of the link as seen in figure D.6. If the intersection of the lines is under a given connection loss line, the link length is supported by the standard. In this example, the link is above the 2.4 dB and 3.0 dB connection loss line so the link is not supported with these high connection losses. The intersection of the lines is below the 1.5 dB connection loss line so the link can be extended if the connection loss does not exceed 1.5dB.

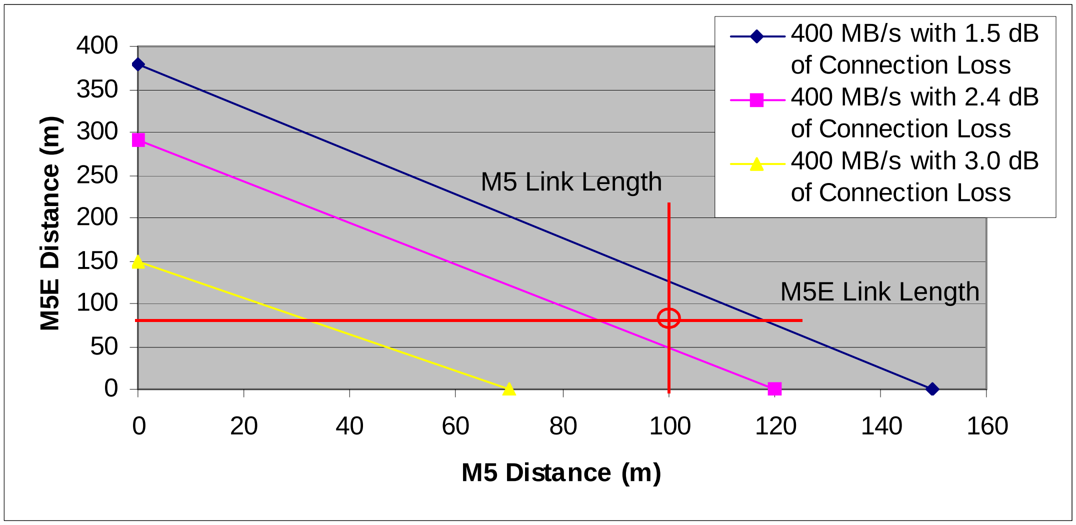


Figure D.6 – Example on mixed 400 MB/s link

D.3.1 Extending an Existing Link with M5E Fiber

If the user would like to extend a link with M5E fiber, the user can calculate the maximum distance of the M5E link with the following equation:

Maximum length of M5E fiber = C - R * Existing Length of M5

C = Maximum operating distance of M5E link

R = Operating distances of M5E / Operating Distance of M5

Table D.4 – Equation Parameters for Adding M5E Fiber

Speed (MB/s)	1.5 dB of Connection Loss		2.4 dB of Connection Loss		3.0 dB of Connection Loss	
	C	R	C	R	C	R
100	860	1.72	660	1.57	500	1.67
200	500	1.67	400	1.60	270	1.59
400	380	2.53	290	2.42	150	2.14
800 Limiting	150	3.00	110	3.14	Not supported	
800 Linear	300	3.00	260	2.89	200	2.50

For example, if the user has a 400 MB/s link that is composed of 80 meters of M5E fiber and 100 meters of M5 with 1.5 dB of connection loss, then the user would find the values for the C and R that are 380 and 2.53. The resulting equation would be:

Maximum length of M5E fiber = 380 - 2.53*100 = 380 - 253 = 127 meters

Since 80 meters of M5E fiber are already in place, 47 meters of M5E fiber may be added to the link.

An 800 MB/s limiting link does not support 3.0 dB of Connection loss.

D.3.2 Extending an Existing Link with M5 Fiber

If the user would like to extend a link with M5 fiber, the user can calculate the maximum distance of the M5 link with the following equation:

Maximum length of M5 fiber = D - S * Existing Length of M5E

D = Maximum Operating distance of M5 link

S= Operating distances of M5 / Operating Distance of M5E

Table D.5 – Equation Parameters for Adding M5 Fiber

Speed (MB/s)	1.5 dB of Connection Loss		2.4 dB of Connection Loss		3.0 dB of Connection Loss	
	D	S	D	S	D	S
100	500	0.58	420	0.64	300	0.6
200	300	0.60	250	0.63	170	0.63
400	150	0.39	120	0.41	70	0.47
800 Limiting	50	0.33	35	0.32	Not supported	
800 Linear	100	0.33	90	0.33	80	0.40

For example, if the user has a 800 MB/s limiting link that is composed of 20 meters of M5E fiber and 15 meters of M5 with 2.4 dB of connection loss, then the user would find the values for the D and S that are 35 and 0.32. The resulting equation would be:

Maximum length of M5 fiber = 35 - 0.32*20 = 35 - 6.4 = 28.6 meters

Since 15 meters of M5 fiber are already in place, then 13.6 meters of M5 fiber may be added to the link as long as the connection loss remains below 2.4 dB.

D.4 Notes on operating distances

Products compliant to FC-PI-4 typically exceed the standard so that products pass tests easily and provide high yields. Since link lengths were defined using worst case values for all specifications, the typical distance or loss that an installed link supports often exceeds the distance or loss specified in clause 6, however, this standard is developed to ensure that the target bit error rate of 10^{-12} is met even if compliant parts only just meet the specifications.

Annex E (normative)
Tx_Off and Rx_Loss of Signal detection

E.1 Background

This annex extends the optical and electrical interface specifications of clauses 6 and 9, in the areas of transmitter-off behavior and the (optional) receiver loss-of-signal function. It gives the background, scope, and qualitative and quantitative requirements for Tx_off and Rx_LOS in FC physical interfaces.

There are cases where a Fibre Channel device is connected to another device whose transmitter is not operational, or is connected to a transmission medium with nothing on the far end. In these cases, the first device shall not react as if a normal TxRx connection existed. For example, an arbitrated-loop hub must keep those ports bypassed.

The most problematic case is that of a normal-strength encoded signal from a remote device that is not responding to its serial input, e.g. during its power-on selftest. That case is prohibited by FC-AL-2, that requires that a port's transmitter shall be disabled when the port cannot participate in normal protocols.

FC-PI-4 gives the name Tx_Off to the state of a disabled optical or electrical transmitter, and specifies the maximum signal amplitude that may be launched into the transmission medium. The Tx_Off requirement exists to enable, or facilitate, an attached FC device to reject the link.

Tx_Off by itself is not a universally sufficient solution, because of the extreme sensitivity of typical receivers. An optical receiver, even with no light, generates noise voltage that a de-serializer will detect commas, K28.5's, and even LIPs with predictable frequency. Erroneous "detection" of a valid pattern is even more likely with an electrical receiver, given near-end crosstalk from the local transmitter (NEXT), and pattern-rate deterministic noise voltage from a remote transmitter that is "Off".

Fortunately, it is generally practical to make a receiver with an amplitude-sensitive signal detect function, known in FC-PI-4 by the complementary name Rx_LOS (Receiver Loss of Signal). In order to be useful, this must reliably discriminate between the smallest valid input signal and the largest invalid input signal.

E.2 Scope

The Rx_LOS function is optional in FC-PI-4. Many FC devices don't need it. This group includes some devices with only one port, whose behavior is "don't care" when standing alone. It also includes devices that can do without it, because they conduct an elaborate and hard-to-fool exchange with the remote device. But many Fibre Channel devices do require a robust Rx_LOS function. They include autonomous port-bypass circuits, e.g. hub ports, whose relatively simple valid-pattern tests is fooled by crosstalk and Tx_Off leakage waveforms.

The Tx_Off functional requirement is mandatory for all ports supporting FC-AL-2, and any other FC device that could disrupt a system by transmitting without properly responding to the received signal.

Likewise, the Tx_Off amplitude limits given in FC-PI-4 are mandatory for all FC-AL-2 ports, and other devices that are expected to work with Rx_LOS ports.

Interoperable Rx_LOS implementations require generally accepted bounds on the signal detect threshold. The lower bound depends on the maximum Tx_Off level. In addition, for electrical links, it depends on the local transmitter output and the NEXT ratio of the attached cable plant. Unfortunately, NEXT limits and methods of measurement are outside the scope of this FC-PI-4 release. Therefore, Rx_LOS detection thresholds shall be given as expressions in which NEXT is a variable.

E.3 Functional and Timing Specifications

E.3.1 Component specifications

Component specifications are outside the scope of FC-PI-2 and FC-PI-4. The requirements given here apply to the transmission media interface and an (implied) service interface between the FC-PI-4 and FC-FS-2 layers.

E.3.2 Tx_Off

The Tx_Off (disabled) state is mandatory in some kinds of FC ports, and optional in others. The mandatory group includes, among others, all ports supporting FC-AL-2. Where implemented, Tx_Off control timing shall meet the requirements in the following table.

Table E.1 – Tx_Off timing

Turn-off time	t_off	max 100 µs	Assertion of Disable to fall of output amplitude below the specified maximum Tx_Off level. During this period, the TxRx connection BER and the far end Rx_LOS response are unspecified.
Turn-on time	t_on	max 2 ms	Negation of Disable to rise of output amplitude above the specified minimum valid level in the link budget. During this period, the TxRx connection BER and the far end Rx_LOS response are unspecified.

E.3.3 Rx_LOS

The receiver of an FC device may implement an Rx_LOS function, that continuously generates an Rx_LOS signal in response to the amplitude of the incoming serial data. Rx_LOS is intended to indicate the absence of a deliberate input signal.

Assertion of Rx_LOS shall imply that the amplitude of incoming serial data is less than the minimum level allowed by the link budget. This typically indicates a disconnected or broken cable, or a transmitter at the far end that is disabled, broken, or powered off. The converse is not necessarily true. A poor quality link may provide enough signal for Rx_LOS to remain negated, even though the signal level is noncompliant and the BER objective is not met.

Rx_LOS shall not depend on, or imply anything about, the input data format or encoding.

Rx_LOS may squelch the received serial and/or parallel data stream.

Rx_LOS response time shall comply with the following table.

Table E.2 – Rx_LOS timing

Assert delay	t_los_on	max 100 µs	From fall of input signal below LOS detection threshold. The TxRx connection may become noncompliant before that threshold is reached.
Negate delay	t_los_off	max 1 ms	From rise of input signal above LOS detection threshold. The TxRx connection may remain noncompliant after that threshold is reached.

The signal detection circuitry shall be designed such that the Rx_LOS output does not rapidly change state with small variations in received power. Hysteresis and time averaging are two possible approaches to this requirement.

E.4 Optical Tx_Off and Rx_LOS Signal Levels

The launched power from an optical transmitter in the Tx_Off state shall not exceed -35 dBm (avg). That limit applies to both shortwave and longwave, for all speed variants in FC-PI-4.

The value of Rx_LOS, where implemented, shall be generated according to the following table:

Table E.3 – Optical Rx_LOS Detection Thresholds

Receive Conditions	Rx_LOS value
Input_optical_power < -31 dBm (avg)	Asserted
Input_optical_power > specified receiver sensitivity AND Modulation parameters comply with FC-PI-2 limits	Negated
All other conditions	Unspecified

This standard is designed to permit various detector implementations, including those responding to average optical power as well as those responding to the 8b/10b modulation amplitude.

E.5 Electrical Tx_Off Signal Levels

The output voltage of an electrical transmitter in the Off state shall not exceed the value specified in table 23.

The Tx_Off voltage limit applies to the gamma-T compliance point, and is not defined for any other compliance point. It includes the worst-case effect of any crosstalk within the FC device from the adjacent receiver path. For compliance testing, Tx_Off voltage should be measured while a maximum strength, minimum rise time 8b/10b signal is applied to the gamma-R point of the same port.

E.6 Electrical Rx_LOS Signal Levels

The value of Rx_LOS, where implemented, shall be generated according to the following table:

Table E.4 – Electrical Rx_LOS Detection Thresholds

Receive Conditions	Rx_LOS value
V_{input}(receiver) < Rx_LOS threshold (see below)	Asserted
V_{input}(receiver) > minimum differential sensitivity	Negated
All other conditions	Unspecified

The actual threshold of each receiver, below which Rx_LOS is asserted, shall be no less than the sum of:

- The maximum voltage coming from a remote transmitter in the Tx_Off state
- The maximum NEXT voltage. This is the product of the local transmitter output voltage and the maximum tolerable NEXT ratio of the cable plant, that may be a function of the local transmitter rise time. This standard does not presently set limits on cable plant NEXT ratios.
- Maximum voltage at the receiver input from other local sources of noise. This includes NEXT sources between the alpha and gamma points.

E.7 Methods of Measurement for Electrical Rx_LOS Thresholds (informative)

The stated bounds on Rx_LOS thresholds imply a significant trade-off between process margins and NEXT tolerance. For example, a relatively demanding NEXT bound of 3% would limit the total non-deliberate input voltage to less than 150 mV. The Rx_LOS threshold could vary from that level to almost 400 mV, a ratio of 2.7:1. To support a more conservative NEXT allowance of 7%, while the local transmitter is allowed to drive 2000 mV and the remote transmitter 70 mV, the minimum Rx_LOS threshold is around 220 mV, allowing no more than 1.8:1 process variation.

In some cases, circuit design can control the effective Rx_LOS threshold voltage to tighter tolerances. But another, more broadly applicable approach promises to increase the margins substantially. The key is to measure and add up worst-case noise voltage in a way that is not so conservative with respect to the measurement of worst-case signal voltages. This issue is under investigation, and quantitative details may be added in a future amendment or technical report.

The proposed experiment is to compare the thresholds of typical Rx_LOS circuits, measured with two different stimulus waveforms (each variably attenuated). In one case the input is a normal NRZ data signal, calibrated by scope measurement of its vertical eye opening. In the other case the input is a “spiky” NEXT and/or Tx_Off waveform, calibrated by scope measurement of peak-to-peak voltage. We expect that Rx_LOS threshold values measured with noise waveforms will be significantly higher than those measured with data eyes. This would give system designers more margin in the trade-off between Rx_LOS threshold control and NEXT tolerance.

There is another argument saying that the upper bound on Rx_LOS threshold is not unreasonably tight with respect to the lower. Data signals are measured by vertical eye opening, but LOS circuits look at the rectified average or peak voltage. When noise is added to a data waveform it closes the eye, but always increases the peak and the rectified average voltage. So in a system designed to tolerate a finite amount of noise (NEXT etc.), with minimum input the peak voltage will significantly exceed the vertical eye. One likely conclusion: "It is unlikely that practical limits on NEXT will be driven by the need for manufacturable Rx_LOS detectors. The critical constraint is the effect of NEXT on eye closure and link budget.”

Annex F (normative)
Scrambled test patterns

F.1 General overview

Annex F describes two test patterns that represent scrambled data and should be used for compliance testing of transmitters and receivers that will be operated using scrambling. When using these patterns the scrambler / de-scrambler must be disabled. Tables in this annex are read from left to right.

The previous compliance patterns described in FC-MJSQ (such as CRPAT and CJTPAT) shall still be used for 1GFC, 2GFC, and 4GFC.

F.2 Scrambled jitter pattern (JSPAT)

The JSPAT (scrambled jitter pattern) is a 500 bit pattern that has been developed for transmit jitter, DDPWS, WDP and RN testing. The pattern is a repetitive 500 bit pattern that has a negative starting and ending disparity. The pattern is listed in table F.1. The D character is listed and the ten bit representation is listed below the D character.

Table F.1 – Scrambled jitter pattern (JSPAT)

D1.4	D16.2	D24.7	D30.4	D9.6	D10.5
0111010010	0110110101	0011001110	1000011101	1001010110	0101011010
D16.2	D7.7	D24.0	D13.3	D23.4	D13.2
1001000101	1110001110	0011001011	1011000011	0001011101	1011000101
D13.7	D1.4	D7.6	D0.2	D21.5	D22.1
1011001000	0111010010	1110000110	1001110101	1010101010	0110101001
D23.4	D20.0	D27.1	D30.7	D17.7	D4.3
0001011101	0010110100	1101101001	1000011110	1000110001	1101010011
D6.6	D23.5	D7.3	D19.3	D27.5	D19.3
0110010110	0001011010	1110001100	1100101100	1101101010	1100100011
D5.3	D22.1	D5.0	D15.5	D24.7	D16.3
1010010011	0110101001	1010010100	0101111010	0011001110	1001001100
D1.2	D23.5	D20.7	D11.7	D20.7	D18.7
0111010101	0001011010	0010110111	1101001000	0010110111	0100110001
D29.0	D16.6	D25.3	D1.0	D18.1	D30.5
1011100100	0110110110	1001100011	1000101011	0100111001	1000011010
D5.2	D21.6				
1010010101	1010100110				

F.3 Jitter tolerance scrambled pattern (JTSPAT)

The JTSPAT is a 1180 bit pattern intended to be used for receive jitter tolerance testing for scrambled systems. The JTSPAT pattern has two copies of JSPAT and an additional 18 characters intended to cause extreme late and early phases in the PLL followed by a sequence likely to cause an error (i.e. an isolated bit following a long run). This pattern was developed to stress the receiver within the boundary conditions established by scrambling. The pattern is listed in table F.2.

Table F.2 – Jitter tolerance scrambled pattern (JTSPAT)

D1.4	D16.2	D24.7	D30.4	D9.6	D10.5
0111010010	0110110101	0011001110	1000011101	1001010110	0101011010
D16.2	D7.7	D24.0	D13.3	D23.4	D13.2
1001000101	1110001110	0011001011	1011000011	0001011101	1011000101
D13.7	D1.4	D7.6	D0.2	D21.5	D22.1
1011001000	0111010010	1110000110	1001110101	1010101010	0110101001
D23.4	D20.0	D27.1	D30.7	D17.7	D4.3
0001011101	0010110100	1101101001	1000011110	1000110001	1101010011
D6.6	D23.5	D7.3	D19.3	D27.5	D19.3
0110010110	0001011010	1110001100	1100101100	1101101010	1100100011
D5.3	D22.1	D5.0	D15.5	D24.7	D16.3
1010010011	0110101001	1010010100	0101111010	0011001110	1001001100
D1.2	D23.5	D29.2	D31.1	D10.4	D4.2
0111010101	0001011010	1011100101	0101001001	0101011101	0010100101
D5.5	D10.2	D21.5	D10.2	D21.5	D20.7
1010011010	0101010101	1010101010	0101010101	1010101010	0010110111
D11.7	D20.7	D18.7	D29.0	D16.6	D25.3
1101001000	0010110111	0100110001	1011100100	0110110110	1001100011
D1.0	D18.1	D30.5	D5.2	D21.6	D1.4
1000101011	0100111001	1000011010	1010010101	1010100110	0111010010
D16.2	D24.7	D30.4	D9.6	D10.5	D16.2
0110110101	0011001110	1000011101	1001010110	0101011010	1001000101
D7.7	D24.0	D13.3	D23.4	D13.2	D13.7
1110001110	0011001011	1011000011	0001011101	1011000101	1011001000
D1.4	D7.6	D0.2	D21.5	D22.1	D23.4
0111010010	1110000110	1001110101	1010101010	0110101001	0001011101
D20.0	D27.1	D30.7	D17.7	D4.3	D6.6
0010110100	1101101001	1000011110	1000110001	1101010011	0110010110
D23.5	D7.3	D19.3	D27.5	D19.3	D5.3
0001011010	1110001100	1100101100	1101101010	1100100011	1010010011
D22.1	D5.0	D15.5	D24.7	D16.3	D1.2
0110101001	1010010100	0101111010	0011001110	1001001100	0111010101
D23.5	D27.3	D3.0	D3.7	D14.7	D28.3
0001011010	1101100011	1100010100	1100011110	0111001000	0011101100
D30.3	D30.3	D7.7	D7.7	D20.7	D11.7
0111100011	1000011100	1110001110	0001110001	0010110111	1101001000
D20.7	D18.7	D29.0	D16.6	D25.3	D1.0
0010110111	0100110001	1011100100	0110110110	1001100011	1000101011
D18.1	D30.5	D5.2	D21.6		
0100111001	1000011010	1010010101	1010100110		

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F.4 Encapsulated JSPAT and JTSPAT

JSPAT or JTSPAT can be encapsulated in a valid FC frame, or a sync character can be added to the start of either pattern as long as the starting disparity of the data in table F.1 and table F.2 is negative.

Unlike CJTPAT and other test patterns JTSPAT relies on specific running disparity to create the desired test bit pattern. In order to create a routable frame for some types of testing, the frame header with a valid D_ID and S_ID is needed. This can throw off the running disparity by the time the payload is reached.

F.4.1 Example:

The only difference between the 2 frames is the S_ID (FCH 0002), but the 1st byte of the payload is positive running disparity in the bad frame by having a different bit pattern than desired.

Table F.3 – Good frame with correct running disparity

FC 001	**8b hex**	BC	B5	56	56
	8b/10b byte	-K28.5	D21.5	D22.2	D22.2
	10b bits	0011111010	1010101010	0110100101	0110100101
FCH 001	**8b hex**	22	02	04	00
	8b/10b byte	+D2.1	-D2.0	-D4.0	-D0.0
	10b bits	0100101001	1011010100	1101010100	1001110100
FCH 002	**8b hex**	00	02	04	00
	8b/10b byte	-D0.0	-D2.0	-D4.0	-D0.0
	10b bits	1001110100	1011010100	1101010100	1001110100
FCH 003	**8b hex**	20	28	00	00
	8b/10b byte	-D0.1	+D8.1	-D0.0	-D0.0
	10b bits	1001111001	0001101001	1001110100	1001110100
FCH 004	**8b hex**	01	00	00	00
	8b/10b byte	-D1.0	-D0.0	-D0.0	-D0.0
	10b bits	0111010100	1001110100	1001110100	1001110100
FCH 005	**8b hex**	80	38	00	03
	8b/10b byte	-D0.4	-D24.1	+D0.0	+D3.0
	10b bits	1001110010	1100111001	0110001011	1100010100
FCH 006	**8b hex**	00	00	00	00
	8b/10b byte	-D0.0	-D0.0	-D0.0	-D0.0
	10b bits	1001110100	1001110100	1001110100	1001110100
Pld 0001	**8b hex**	81	50	F8	9E
	8b/10b byte	-D1.4	-D16.2	+D24.7	+D30.4
	10b bits	0111010010	0110110101	0011001110	1000011101

Table F.4 – Bad frame with wrong running disparity

FC 001	**8b hex**	BC	B5	56	56
	8b/10b byte	-K28.5	D21.5	D22.2	D22.2
	10b bits	0011111010	1010101010	0110100101	0110100101
FCH 001	**8b hex**	22	02	04	00
	8b/10b byte	+D2.1	-D2.0	-D4.0	-D0.0
	10b bits	0100101001	1011010100	1101010100	1001110100
FCH 002	**8b hex**	00	02	04	00
	8b/10b byte	-D0.0	-D2.0	-D5.0	+D0.0
	10b bits	1001110100	1011010100	1010011011	0110001011
FCH 003	**8b hex**	20	28	00	00
	8b/10b byte	+D0.1	-D8.1	+D0.0	+D0.0
	10b bits	0110001001	1110011001	0110001011	0110001011
FCH 004	**8b hex**	01	00	00	00
	8b/10b byte	+D1.0	+D0.0	+D0.0	+D0.0
	10b bits	1000101011	0110001011	0110001011	0110001011
FCH 005	**8b hex**	80	38	00	03
	8b/10b byte	+D0.4	+D24.1	-D0.0	-D3.0
	10b bits	0110001101	0011001001	1001110100	1100011011
FCH 006	**8b hex**	00	00	00	00
	8b/10b byte	+D0.0	+D0.0	+D0.0	+D0.0
	10b bits	0110001011	0110001011	0110001011	0110001011
Pld 0001	**8b hex**	81	50	F8	9E
	8b/10b byte	+D1.4	+D16.2	-D24.7	-D30.4
	10b bits	1000101101	1001000101	1100110001	0111100010

F.4.2 A method to correct the pattern starting disparity

All SOFs are negative running disparity, giving us a known starting point at the beginning of the frame. Running disparity changes only on a non-neutral running disparity character. By counting the number of neutral running disparity character leading up to the data pattern, it can be determined if the running disparity needs to be corrected. Correcting the running disparity can be done easily by substituting the last character before the data pattern begins.

Assume that the frame header is in an array Tx_frame(n). Value is hex without leading 0x. That the D_ID / S_ID or any other value are ready for transmit. Assumes that the PARAM value may be changed to correct the running disparity.

Tx_frame(0) 22020400 R_CTL / D_ID
Tx_frame(1) 00020500 CS_CTL / S_ID
Tx_frame(2) 20280000 Type / FCTL
Tx_frame(3) 01000000 SEQ_ID / DF_Ctl / SEQ_Cnt
Tx_frame(4) 80380003 OX_ID / RX_ID
Tx_frame(5) 00000000 PARAM

Code uses the neutral disparity 8B codes as shown in table F.5.

Table F.5 – Neutral disparity bytes (8b hex)

00	01	02	04	08	0F	10	17	18	1B
1D	1E	1F	23	25	26	27	29	2A	2B
2C	2D	2E	31	32	33	34	35	36	39
3A	3C	43	45	46	47	49	4A	4B	4C
4D	4E	51	52	53	54	55	56	59	5A
5C	63	65	66	67	69	6A	6B	6C	6D
6E	71	72	73	74	75	76	79	7A	7C
80	81	82	84	88	8F	90	97	98	9B
9D	9E	9F	A3	A5	A6	A7	A9	AA	AB
AC	AD	AE	B1	B2	B3	B4	B5	B6	B9
BA	BC	C3	C5	C6	C7	C9	CA	CB	CC
CD	CE	D1	D2	D3	D4	D5	D6	D9	DA
DC	E0	E1	E2	E4	E8	EF	F0	F7	F8
FB	FD	FE	FF						

Here is an example code to correct the running disparity.

```
set neutral_running disparity_count 0      ;# initialize neutral running disparity count
for {set n 0} {$n <= 5} { incr n  }        ;# for each of the FC Hdr words
   {                                       ;# pattern begins in 1st Payload word
   set FC_Hdr_word $Tx_frame($n)           ;# get the next FC Header word
   puts "FC_Hdr_word: $FC_Hdr_word"
                                           ;# look at one byte at a time
   set start_char_position 0               ;# set starting char position in word
   set end_char_position 1                 ;# set end char position in word
   for {set byten 1} {$byten <= 4} { incr byten  }
      {                                    ;# for each byte
      set hex_char "0x"                    ;# get the hex 8B code from Frame
      append hex_char [ string range $FC_Hdr_word $start_char_position $end_char_position ]
      set found [lsearch $Neutral_Dis $hex_char]        ;# lookup if 8B code is neutral disparity
      if { $found != -1 }
         {                                 ;# found in neutral running disparity table?
         incr neutral_running disparity_count           ;# YES, increment count
         }
      incr start_char_position 2           ;# update for next byte position
      incr end_char_position 2
      }                                    ;# for next byte of FC Hdr
   }                                       ;# for next word of FC Hdr
if { [expr $neutral_running disparity_count % 2] == 0 }
   {                                       ;# neutral disparity count Even
   set Tx_frame(5)       00000003          ;# change the parameter word to cause
   }                                       ;# the proper disparity for SJTpat
```

Example frames after correcting running disparity is shown in table F.6.

Table F.6 – Good frame with corrected running disparity

FC 001	**8b hex**	BC	B5	56	56
	8b/10b byte	-K28.5	D21.5	D22.2	D22.2
	10b bits	0011111010	1010101010	0110100101	0110100101
FCH 001	**8b hex**	22	02	04	00
	8b/10b byte	+D2.1	-D2.0	-D4.0	-D0.0
	10b bits	0100101001	1011010100	1101010100	1001110100
FCH 002	**8b hex**	00	02	04	00
	8b/10b byte	-D0.0	-D2.0	-D4.0	-D0.0
	10b bits	1001110100	1011010100	1101010100	1001110100
FCH 003	**8b hex**	20	28	00	00
	8b/10b byte	-D0.1	+D8.1	-D0.0	-D0.0
	10b bits	1001111001	0001101001	1001110100	1001110100
FCH 004	**8b hex**	01	00	00	00
	8b/10b byte	-D1.0	-D0.0	-D0.0	-D0.0
	10b bits	0111010100	1001110100	1001110100	1001110100
FCH 005	**8b hex**	80	38	00	03
	8b/10b byte	-D0.4	-D24.1	+D0.0	+D3.0
	10b bits	1001110010	1100111001	0110001011	1100010100
FCH 006	**8b hex**	00	00	00	00
	8b/10b byte	-D0.0	-D0.0	-D0.0	-D0.0
	10b bits	1001110100	1001110100	1001110100	1001110100
Pld 0001	**8b hex**	81	50	F8	9E
	8b/10b byte	-D1.4	-D16.2	+D24.7	+D30.4
	10b bits	0111010010	0110110101	0011001110	1000011101
FC 001	**8b hex**	BC	B5	56	56
	8b/10b byte	-K28.5	D21.5	D22.2	D22.2
	10b bits	0011111010	1010101010	0110100101	0110100101
FCH 001	**8b hex**	22	02	04	00
	8b/10b byte	+D2.1	-D2.0	-D4.0	-D0.0
	10b bits	0100101001	1011010100	1101010100	1001110100
FCH 002	**8b hex**	00	02	04	00
	8b/10b byte	-D0.0	-D2.0	-D5.0	+D0.0
	10b bits	1001110100	1011010100	1010011011	0110001011
FCH 003	**8b hex**	20	28	00	00
	8b/10b byte	+D0.1	-D8.1	+D0.0	+D0.0
	10b bits	0110001001	1110011001	0110001011	0110001011
FCH 004	**8b hex**	01	00	00	00
	8b/10b byte	+D1.0	+D0.0	+D0.0	+D0.0
	10b bits	1000101011	0110001011	0110001011	0110001011

Table F.6 – Good frame with corrected running disparity

FCH 005	**8b hex**	80	38	00	03
	8b/10b byte	+D0.4	+D24.1	-D0.0	-D3.0
	10b bits	0110001101	0011001001	1001110100	1100011011
FCH 006	**8b hex**	00	00	00	00
	8b/10b byte	+D0.0	+D0.0	+D0.0	+D3.0
	10b bits	0110001011	0110001011	0110001011	1100010100
Pld 0001	**8b hex**	81	50	F8	9E
	8b/10b byte	-D1.4	-D16.2	+D24.7	+D30.4
	10b bits	0111010010	0110110101	0011001110	1000011101

Annex G (normative)
Test methodology for 800 GBaud systems

G.1 General overview

The interoperability points are defined in FC-PI-4 as being immediately after the mated connector. For the delta points this is not an easy measurement point particularly at high frequencies, as test probes cannot be applied to these points without affecting the signals being measured, and de-embedding the effects of test fixtures is difficult. For 8GFC delta point measurements reference test points are defined with a set of defined test boards for measurement consistency. The delta point specifications in FC-PI-4 are to be interpreted as being at the SMA outputs and inputs of the reference compliance test boards.

In order to provide test results that are reproducible and easily measured, this document defines two test boards that have SMA interfaces for easy connection to test equipment. One is designed for insertion into a host, and one for inserting SFP+ modules. The reference test boards' objectives are:

- Satisfy the need for interoperablity at the electrical level.
- Allow for independent validation of host, and Module.
- The PCB traces are targeted at 100 Ω differential impedance with nominal 7% differential coupling.

Testing compliance to specifications in a high-speed system is delicate and requires thorough consideration. Using common test boards that allow predictable, repeatable and consistent results among vendors will help to ensure consistency and true compliance in the testing.

The reference test boards provide a set of overlapping measurements for Module, and Host validation to ensure system interoperablity.

G.2 Test point definitions

G.2.1 Host test points

Host system transmitter and receiver compliance are defined by tests in which a host compliance test board is inserted as shown in figure G.1 in place of the module. Test card construction should be such that it meets the requirements specified by annex G.4. The test points are B and C.

Host compliance points are defined in as the following:

- B: host output at the output of the host compliance test board. Delta T output and host return loss specifications shall be met at this point,
- C: host input at the input of the host compliance test board. Delta R host return loss specifications shall be met at this point.

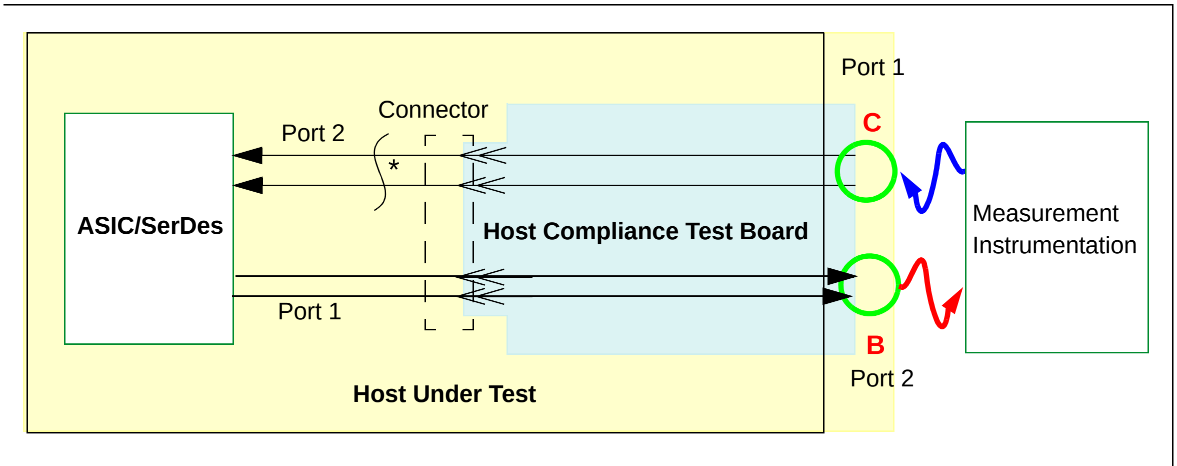

Figure G.1 – Host compliance test board

G.2.2 Module test points

Module transmitter and receiver compliance are defined by tests in which the module is inserted into the module compliance test board as shown in figure G.2. Test card construction should be such that it meets the requirements specified by annex G.5. For improved measurement accuracy, the deviation from nominal insertion loss given in annex G.5 may be calibrated out.

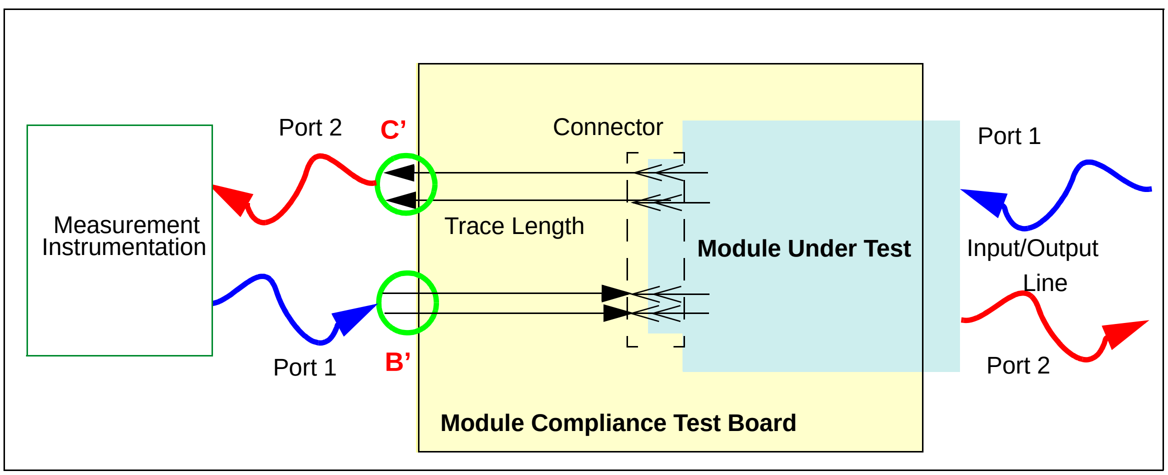

Figure G.2 – Module compliance test board

Module test points are defined as the following:

- B': module transmitter input at the input of the module compliance test board. Delta T module return loss specifications shall be met at this point.
- C': SFP+ module receiver output at the output of the module compliance test board. Delta R output and module return loss specifications shall be met at this point.

G.2.3 Module input calibration points

The module transmitter input tolerance signal is calibrated through the module compliance test board at the output of the host compliance test board as shown in figure G.3. The opposite data path is excited with an asynchronous test source with the JSPAT signal. The module input calibration point is at B” with specifications for input signals at delta T being calibrated at B”. Note that point B” has additional trace loss beyond the module pins.

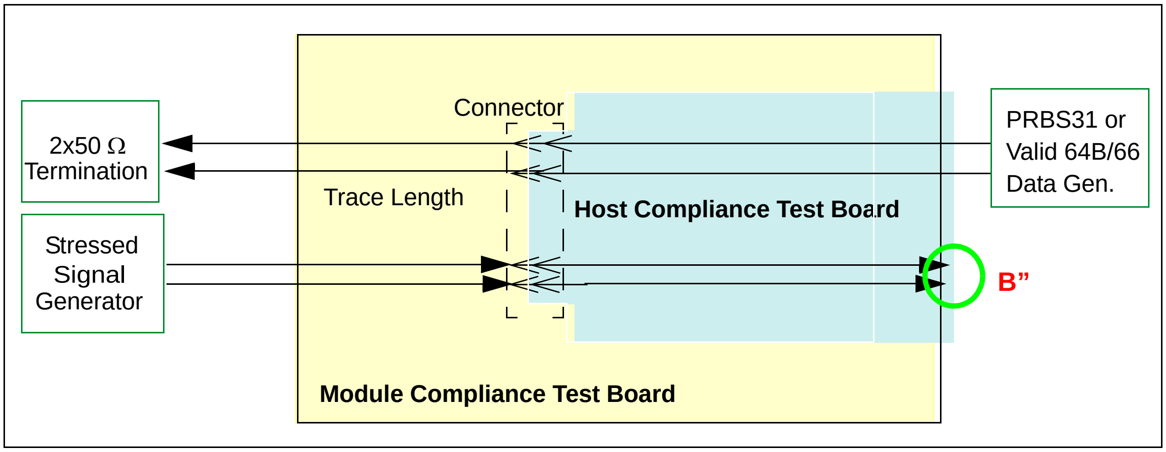

Figure G.3 – Module input calibration point B”

G.2.4 Host input calibration point

The host receiver input tolerance signal is calibrated through the host compliance test board at the output of the module compliance test board as shown in figure G.4. The host input calibration point is at C” with specifications for input signals at delta R being calibrated at C”. Note that the point C” has additional trace loss beyond the SFF-8083 connector pins.

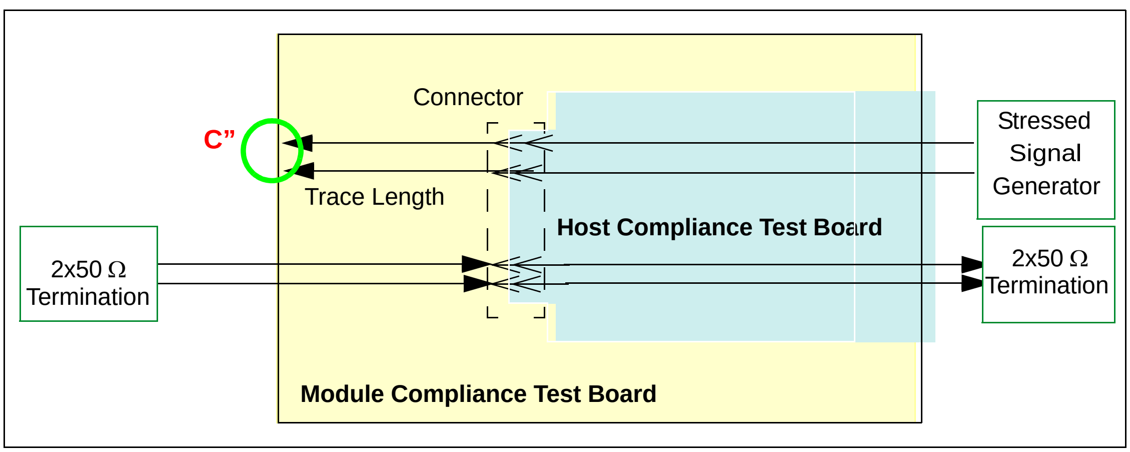

Figure G.4 – Host input calibration point C”

G.3 Compliance test boards

Compliance test boards are made of manufacturable length of PCB trace with specific properties for construction of the host compliance test board, and the module compliance test board. Compliance test boards are intended to ease building practical test boards with non-zero loss. The 8GFC FC-PI-4 specifications incorporate the effect of non-zero loss reference test boards which improve the return loss and slightly slow down edges. The boards described here are identical to those described in the SFP+ specification (SFF-8431).

G.3.1 Host compliance test board loss

The recommended response of the host compliance test board PCB excluding the SFP+ connector is given by.

$$SDD21(dB) = (-0.01 - 0.25 \times \sqrt{f} - 0.0916 \times f) \qquad \text{from 0.25 to 15 GHz}$$

variable f (frequency) is in GHz. SDD21 loss is defined from SMA connectors excluding the mating pads as defined by SFF-8083. From 0.25 to 11.1 GHz the discrepancy between measured insertion loss and the specified SDD21(dB) shall be within ±15% of the insertion loss in dB or ±0.1 dB, whichever is larger. For frequencies above 11.1 GHz and up to 15 GHz the discrepancy between measured insertion loss and the specified SDD21(dB) shall be within ±25% of the insertion loss in dB.

The channel transfer characteristic is shown approximately in figure G.5.

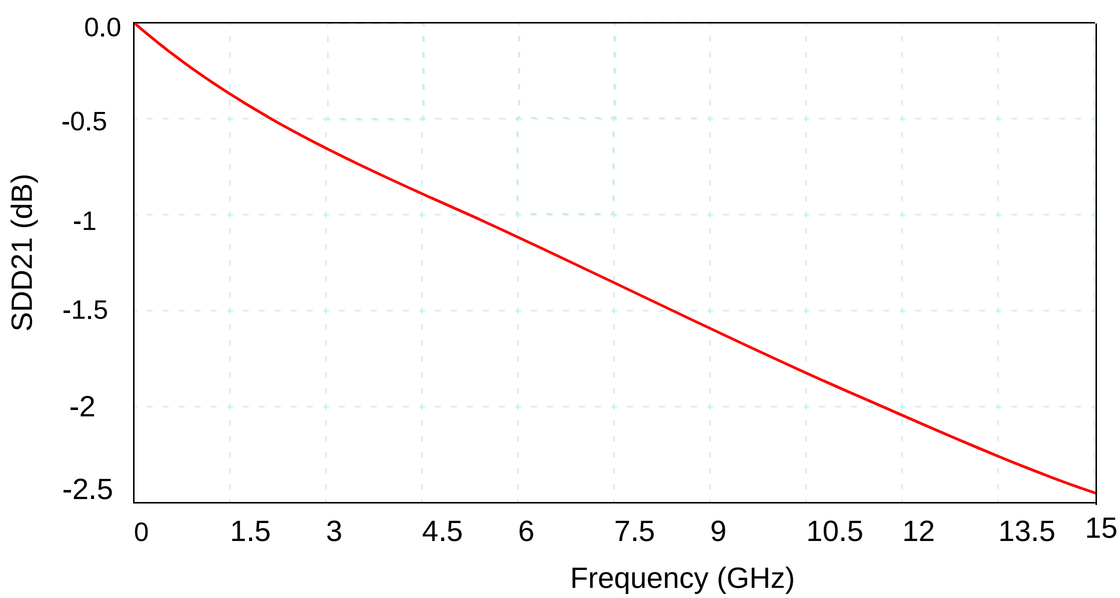

Figure G.5 – Loss of host compliance test board

SFP+ connector response is defined by SFF-8083:

G.3.2 Module compliance test board loss

The recommended response of the module compliance test board PCB excluding the SFP+ connector is given by:

$$SDD21(dB) = (-0.00045 - 0.1135 \times \sqrt{f} - 0.04161 \times f)$$ from 0.25 to 15 GHz

variable *f* (frequency) is in GHz. SDD21 loss is defined from SMA connectors excluding the mating pads as defined by SFF-8083. From 0.25 to 11.1 GHz any discrepancy between measured insertion loss and the specified SDD21(dB) shall be within ±15% of the insertion loss in dB or ±0.1 dB, whichever is larger. For frequencies over 11.1 GHz and up to 15 GHz the discrepancy between measured insertion loss and the specified SDD21(dB) shall be within ±25% of the insertion loss in dB.

The channel transfer loss is shown approximately in figure G.6.

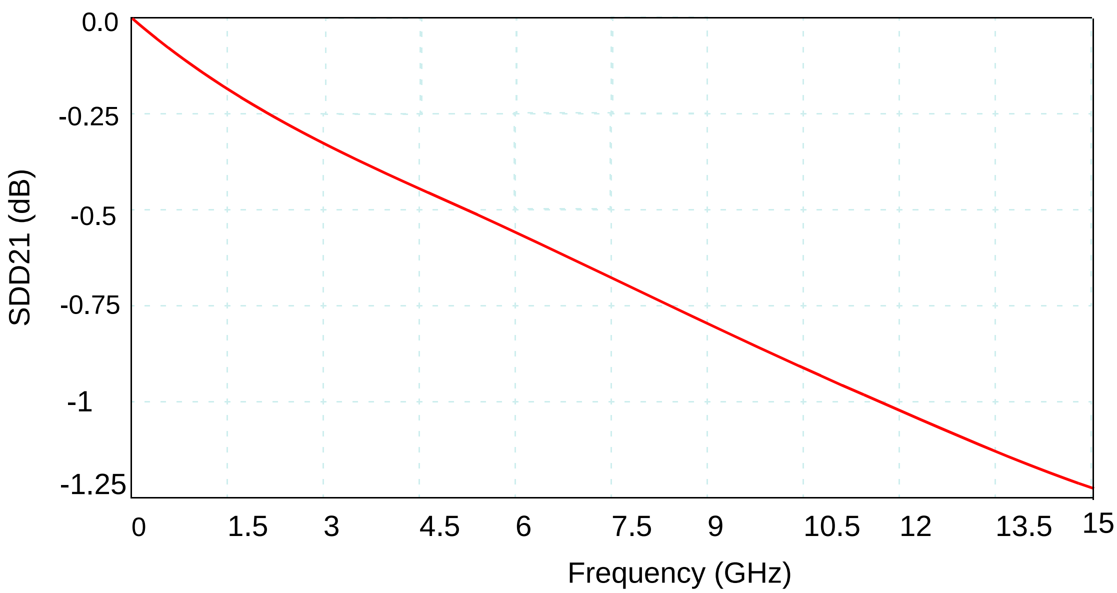

Figure G.6 – Loss of module compliance test board

SFP+ connector response is defined by SFF-8083.

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G.4 Host compliance test board

G.4.1 Host compliance test board material and layer stack-up

Host compliance test board stack-up shown in figure G.7 is based on Roger 4350B/ FR4-6 with six layers. The board is compliant with requirements of SFF-8432.

1. Top Layer	Signal	17 µm Cu / 0.5 oz + 1.25 µm Nickel + 2.5 µm Gold
0.168 mm / 6.6 mils Rogers 4350B		
2. Layer	Ground	17 µm Cu / 0.5 oz
0.14 mm / 5.5 mils FR4-6		
3. Layer	Signal 1	17 µm Cu / 0.5 oz
0.178 mm / 7 mils FR4-6		
4. Layer	Signal 2	17 µm Cu / 0.5 oz
0.14 mm / 5.5 mils FR4-6		
5. Layer	Power	17 µm Cu / 0.5 oz
0.168 mm / 6.6 mils Rogers 4350B		
6. Bottom Layer	Signal	17 µm Cu / 0.5 oz + 1.25 µm Nickel + 0.25 µm Gold

Figure G.7 – Host compliance test board stack-up

G.4.2 Host compliance test board part list

The host compliance test board part list is given below.

Table G.1 – Host compliance test board part list

Qty	RefDes	Value	Description
2	C5, C6	0.1 UF	CAP 0.1UF 10% X7R 10V 0402 SMT LFR
3	D1, D2, D3	GREEN	LED SINGLE GREEN 120 DEG 0603 SMT LFR
2	D4, D5	Blue	LED SINGLE BLUE 120 DEG 0603 SMT LFR
1	J1	Conn3	Con, Header 3 pins, straight - Tyco PN#3-644695-3
4	J2, J3, J4, J5	EDGE SMA	CON SMA JACK R/A 50 OHM 18GHZ GOLD LFR - Rosenberger PN# 32K243-40ME3
1	J6	CONN1X3P	CON HDR 1X3 100MIL PITCH LOCKING THT LFR - Molex PN# 22-23-203
5	R1, R2, R3, R4, R5	1.0 KΩ	RES 1.00K 1% 1/10W 0603 SMT LFR
1	SW1	SPST	SWT DIP SWITCH 4POS SMT LFR - ITT Cannon PN# TDA04H0SB1

Note: table G.1 does not use all in sequence part numbers.

G.4.3 Schematic of Host Compliance Test Board

Schematic of host compliance test board is shown in figure G.8.

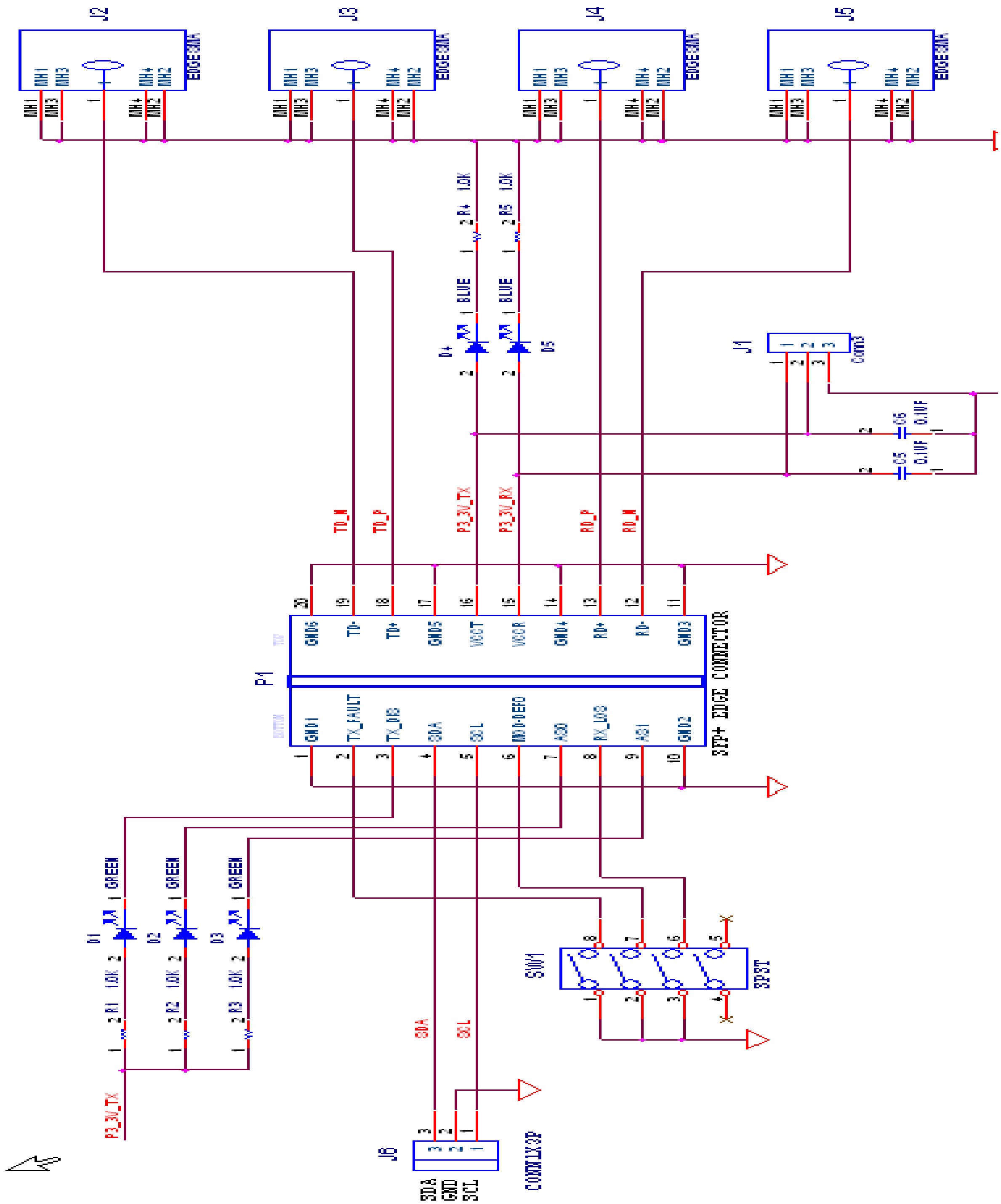

Figure G.8 – Host compliance test board

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G.5 Module compliance board

The module compliance test board allows predictable, repeatable and consistent results among module vendors and will help to ensure consistency and true compliance in the testing of modules.

G.5.1 Module Compliance Test Board Material and Layer Stack-up

Module Compliance Test Board stack-up shown in figure G.9 is based on ten layers Rogers 4350B/FR4-6 material.

1. Top Layer	Signal	17 μm Cu / 0.5 oz + 1.25 μm Nickel + 2.5 μm Gold
0.168 mm / 6.6 mils Rogers 4350B		
2. Layer	Gnd	17 μm Cu / 0.5 oz
0.382 mm / 15 mils FR4-6		
3. Layer	Gnd	34 μm Cu / 0.5 oz
0.076 mm / 3 mils FR-4		
4. Layer	VccR	34 μm Cu / 0.5 oz
0.076 mm / 3 mils FR4-6		
5. Layer	Gnd	34 μm Cu / 0.5 oz
0.076 mm / 3 mils FR4-6		
6. Layer	VccT	34 μm Cu / 0.5 oz
0.076 mm / 3 mils FR4-6		
7. Layer	Gnd	34 μm Cu / 0.5 oz
0.076 mm / 3 mils FR4-6		
8. Layer	Signal	34 μm Cu / 0.5 oz
0.382 mm / 15 mils FR4-6		
9. Layer	Gnd	17 μm Cu / 0.5 oz
0.168 mm / 6.6 mils Rogers 4350B		
10. Bottom Layer	Signal	17 μm Cu / 0.5 oz + 1.25 μm Nickel + 2.5 μm Gold

Figure G.9 – Module compliance test board stack up

G.5.2 Schematic of module compliance test board

Schematic of module compliance test board is shown in figure G.10.

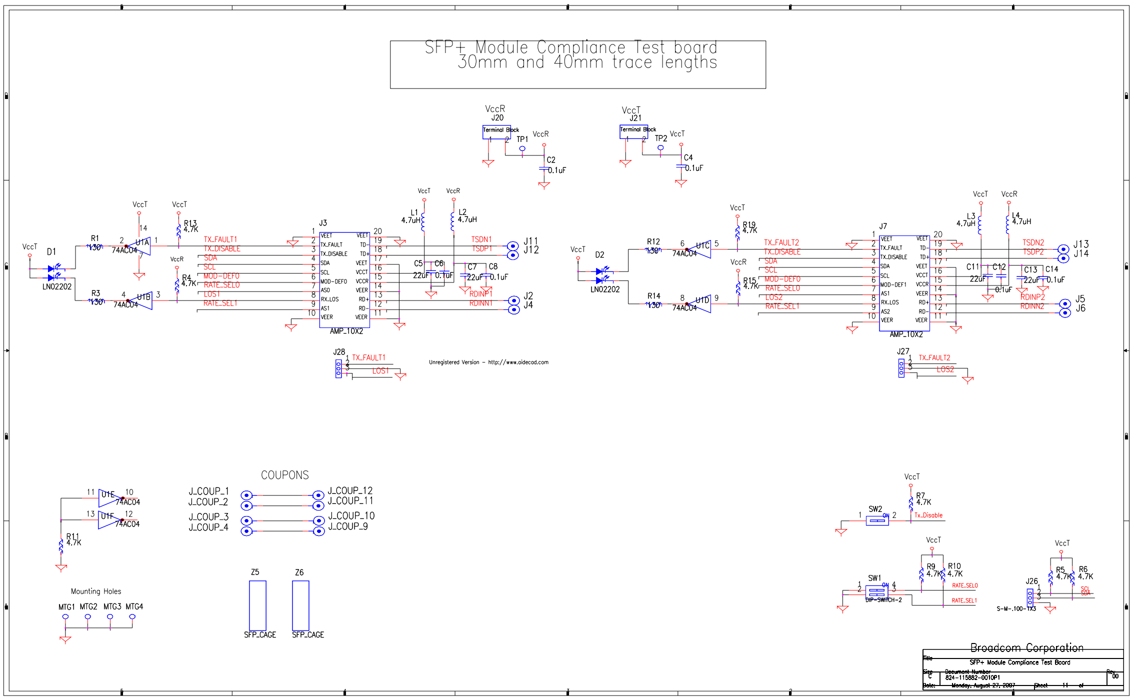

Figure G.10 – Schematic of module compliance test board

G.5.3 Module compliance test board part list

Component part list for the SFP+ compliance test board is given in table G.2.

Table G.2 – SFP+ module compliance test board part list

Qty	RefDes	Value	Description
6	C2, C4, C6, C8, C12, C14	0.1uF	Murata/GRM188R71C104MA01
4	C5, C7, C11, C13	22 uF	Murata/GRM21BR60J226ME39
4	D1, D2, D4, D5	RED	Panasonic/LNJ208R8ARA
12	J_COUP_2, J2, J_COUP_4, J4, J5,J6, J_COUP_9, J_COUP_11, J12, J14J_COUP_1, J_COUP_3, J_COUP_10, J11, J_COUP_12, J13	SMA	Huber&Suhner/92_SK-U50-0-3/199_NE
2	J3, J7	Con_10x2	Tyco 1888247
2	J20, J21	Terminal Block	On-Shore-Tech/EDZ5002DS
3	J26, J27, J28	S-M-.100-1X3	Molex/22-10-2031
4	L1, L2, L3, L4	4.7 uH	Toko/A914BYW-4R7M
4	R1, R3, R12, R14	130 Ω	Walsin/WR06X131JTL

Table G.2 – SFP+ module compliance test board part list

Qty	RefDes	Value	Description
10	R4, R5, R6, R7, R9, R10, R11, R13, R15, R19	4.7 kΩ	Walsin/WR06X472JTL
1	SW1	DIP-SWITCH-2	CT2062-ND
1	SW2	sw_pb_ck-k	C&K/ET01MD1AVBE
1	U1	74AC04	Fairchild/530438-00
2	Z5, Z6	SFP_CAGE	Tyco/AMP/1489962-1

Note: table G.2 does not use all in sequence part numbers.

G.6 Specification of mated host and module compliance test boards

It will include SDD21, SDD11, SCC11, SCC22, and SDD22. Also include crosstalk response.

Annex H (informative)
Passive direct attach SFP+ cable specifications

H.1 General overview

This annex describes additional requirements or exceptions to the linear epsilon host specification to implement passive direct attach SFP+ cables assemblies. Active cable assemblies operate with existing linear or limiting specifications. The compliance point for passive direct attach cables are the same as host compliance test points and the module compliance test points in annex G.

Notice that the SFP+ direct attach cable can only be used on system with common grounds. Connecting systems with different ground potential with SFP+ direct attach cable may result in a short and damage.

H.2 SFP+ Direct Attach Construction

SFP+ direct attach is constructed out of a pair of SFP+ module with the optical ports replaced with a pair of high speed cables as shown in figure H.1. SFP+ cable has build in crossover where transmitter outputs TD+/TD- on the A Sides goes to the receiver outputs RD+/RD- respectively. Edge card connector pins are defined in SFF-8431 (Table 3). The cable assembly shall incorporate DC blocking capacitors with at least 15 V rating on the RX side and on one end of the drain wire. The drain wire is connected VeeT and VeeR. The cable shield directly connects module A and B cases.

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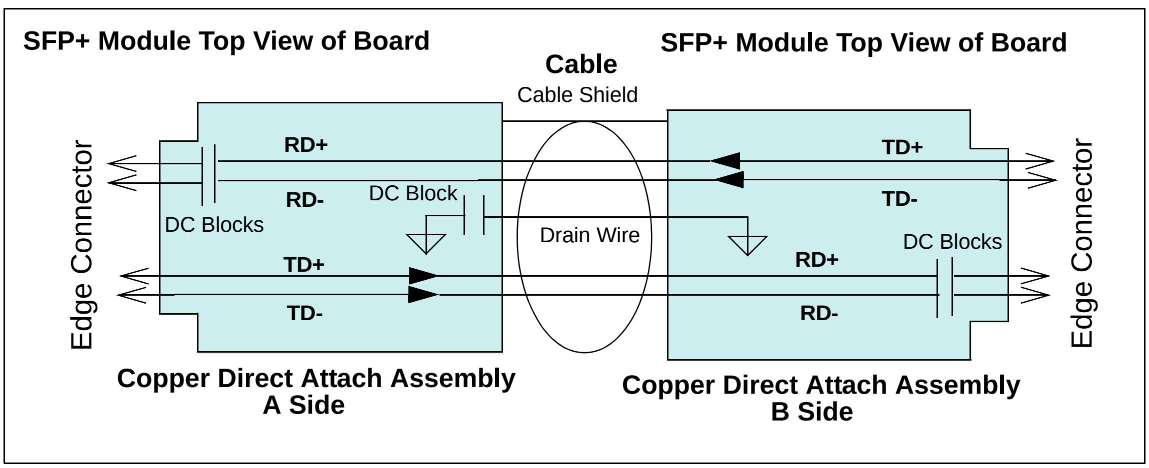

Figure H.1 – SFP+ Direct Attach Block Diagram

H.3 SFP+ Host Output Specifications for Passive Direct Attach Cables

SFP+ host supporting direct attach cables must meet transmitter output specifications of table H.1 at reference point B.

Table H.1 – SFP+ Host Transmitter Output Specifications at B for Cu

Parameters	Units	Min	Target	Max
Voltage Modulation Amplitude (p-p) VMA (note 1, 2)	mV	360		
Host Output TWDP (note 1, 2)	dB			5.5

Notes:

1 Measured with Module Compliance Test Board and OMA test pattern. Use of eight 1's and eight 0's sequence in the PRBS 9 is an acceptable alternative.

2 Host electrical output measured with LRM (1,3) Equalizer with PRBS9 for copper direct attach stressor.

TWDP is host transmitter penalty with copper cable stressor as shown in figure H.2. In the IEEE 802.3 Clause 68 TWDP code, the LRM stressor are replaced with the single copper stressor as specified in table H.2. The TWDP code time step was then adjusted from 0.75 UI to 1 UI.

H.3.1 Copper Direct Attach Stressor

Copper stressor was created from measurements of commonly available 10 m direct attach SFP+ cables. The approximate response of the copper stressor is shown in figure H.2 and the exact value listed in table H.3. The sum of all stressor was normalized to a value of 1. Compliance cable post cursor response at 12 UI must be less than 2% in amplitude relative to the main cursor, when the rising impulse is aligned at zero with amplitude in the range of zero to 0.003.

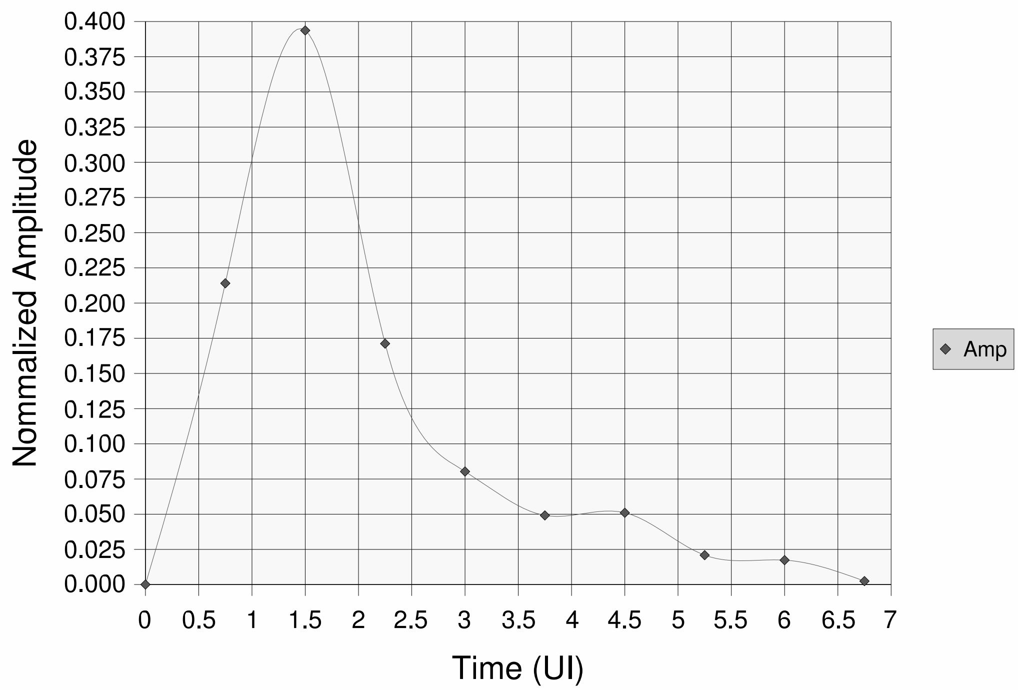

Figure H.2 – Copper Direct Attach Stressor

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Table H.2 – SFP+ Copper Stressor

Delay (UI)	0	0.75	1.5	2.25	3	3.75	4.5	5.25	6	6.75
Amplitude	<0.003	0.214	0.394	0.171	0.08	0.018	0.019	0.008	0.006	0.001

H.4 SFP+ Host Receiver Input Specifications at C for Passive Direct Attach Cables

SFP+ host receiver must meet transmitter output specifications of table H.1 at reference point B. In addition, SFP+ passive direct attach cable must meet specification in table H.3.

Table H.3 – SFP+ Host receiver input compliance test at C to support copper cables

Parameters	Units	Min	Target	Max
Waveform Distortion Penalty for Host Supporting Passive Copper, WDP (note 1)	dB		5.5	
Notes: 1 Tested with copper stressor as defined in. WDP is calibrated with reference receiver with FFE/DFE (14.5).				

H.5 SFP+ Passive Direct Attach cable Assembly Specifications

Passive direct attach cables are tested with a pair of module compliance test boards at compliance point δ_t and δ_r. SFP+ passive cable assemblies shall meet specification in table H.4 and return loss specifications at δ_t and δ_r given in table 26 and table 29.

Table H.4 – SFP+ Direct Attach Cable Assembly Specifications at B' and C'

Parameter	Units	Min	Target	Max
Single Ended Output Voltage Tolerance	V	-0.3		4.0
Output AC Common Mode Voltage, (note 1)	mV (RMS)			40
Rise Time	ps		40	
Difference Waveform Distortion Penalty (dWDP), (note 2)	dB			5
VMA Loss to Crosstalk Ratio (VCR), (note 3)	dB	32		
Notes: 1 When input common mode voltage is 30 mV RMS. 2 Defined with reference receiver with 3 T spaced DFE taps, measured with a pair of module compliance test boards. 3 The data pattern for the VCR ratio is SJPAT or valid 8B/10B data traffic.				

H.5.1 SFP+ Direct Attach Cable Test Setup

Direct attach cable testing methodology is based on the SFP+ test methodology as defined in SFF-8431. The cable is measured through a pair of module compliance test board as shown in figure H.3.

– XX-00-200x Physical Interface-4 7.00

This diagram shows the block diagram for testing NEXT on cable A side and dWDP from A side to oscilloscope 2. This procedure must be repeated for the other cable end.

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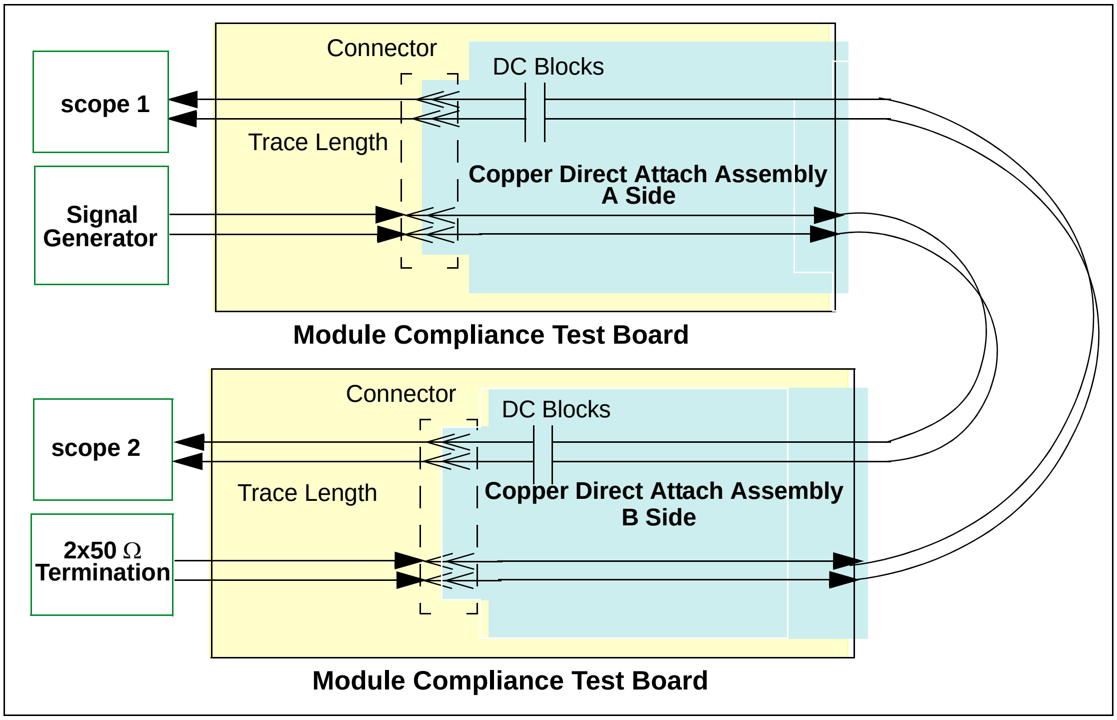

Figure H.3 – SFP+ Direct Attach Cable Measurement

H.5.2 Cable dWDP Test Procedure

The measurement procedure for dWDP is similar to TWDP procedure as defined by IEEE 802.3 Clause 68.6.6. WDP module test setup:

- The pattern generator is set to the SJPAT.
- To improve measurement accuracy, uncorrelated jitter and noise should be reduced.
- Averaging should be used to further reduce instrumentation and measurement noise so their effect on the results are negligible.
- The output of Module Compliance Test Board is calibrated with Host Compliance Test Board at B”.
- DDJ and DDPWS limit as specified in table 30 at δ_t is not required to be met.
- Stress signal output is measured unfiltered with a digital oscilloscope with 12 GHz minimum bandwidth.
- Waveform Dispersion Penalty WDP0 at δ_t output is measured with Host Compliance Board (annex G)
- Waveform Dispersion Penalty WDP1 at cable output is measured with Module Compliance Board (annex G).

- Cable difference Waveform Dispersion Penalty dWDP is defined as:

  dWDP = WDP1 - WDP0

H.5.3 Cable NEXT Measurement Procedure

Cable NEXT is measured based on the following procedure:

- The host transmitter shall operate with maximum transmitter levels allowed by Y2 in table 30.
- The rise and fall times measured through the compliance test board pair are equal to the minimum rise and fall time given in table 23.
- DDJ and DDPWS limit as specified in table 30 at B” must be met.
- The pattern for the crosstalk source is SJPAT.
- NEXT is measured in a bandwidth of 12 GHz.
- The far end Module Compliance Test Board outputs and input are terminated in to 50 Ω.
- The RMS NEXT is measured over one Baud period.
- This measurement is then repeated for the other cable end.

H.5.4 VMA to Crosstalk Ratio (VCR)

VMA to crosstalk ratio (VCR) is the ratio of the transmitter minimum VMA at δ_t divided by the cable NEXT which already incorporates reflective FEXT. The factor 0.3 in the VCR equation accounts for SFP+ host return loss.

$$VCR(dB) = 20LOG10\left|\frac{VMA\times 10^{\left(-\frac{L}{20}\right)}}{NEXT\times\left(1+0.3\times 10^{\left(-\frac{L}{20}\right)}\right)}\right|$$

Where L is the cable VMA loss. NEXT is the near end crosstalk voltage in RMS measured with SJ-PAT or valid FC data frame. Cable VMA loss and NEXT are measured with the module compliance test board.