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FIBRE CHANNEL

Physical Interface-5

(FC-PI-5)

REV 6.00

INCITS working draft proposed
American National Standard
for Information Technology

September 21, 2010

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, 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-5 (FC-PI-5)

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-00-201x.)

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 0.01 Initial draft.

2) Revision 1.00 released for T11.2 ballot.

3) Revision 2.00 released for T11 ballot.

4) Revision 3.00 released for T11 ballot again.

5) Revision 4.00 released to final review

6) Revision 5.00 released to INCITS

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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-3 (reference [33]) and the higher Upper Level Protocols (ULPs) associated with HIPPI, SCSI, IP and others.

FC-PI-5 includes 16GFC, 8GFC and 4GFC. FC-PI-5 supersedes FC-PI-4 (reference [2]). For older technologies such as 2GFC and 1GFC refer to FC-PI-2 (reference [3]).

2 Normative references

2.1 General

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), and other approved standards (including JIS and DIN).

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 450, FC-PI-4,** Fibre Channel Physical Interfaces - 4

[3] **ANSI/INCITS 404-2006, FC-PI-2,** Fibre Channel Physical Interfaces - 2

[4] **ANSI/INCITS 364-2003, FC-10GFC,** Fibre Channel 10 Gigabit

[5] **ANSI/INCITS 364-2003 AM-1, FC-10GFC Amendment 1,** Fibre Channel 10 Gigabit Amendment 1

[6] **ANSI/INCITS 424-2007, FC-FS-2,** Fibre Channel Framing and Signaling 2

[7] **ANSI/INCITS 424-AM1, FC-FS-2 AM-1**, Fibre Channel Framing and Signaling 2, Amendment 1

[8] **ANSI/INCITS 460, FC-PI-3,** Fibre Channel Physical Interfaces 3

[9] **ANSI/INCITS TR-35-2004, FC-MJSQ,** Fibre Channel - Methodologies for Jitter and Signal Quality Specification

[10] **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.

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

[12] **IEC 60793-1-43,** Optical fibers - Part 1-43: Measurement methods and test procedures - Numerical aperture

[13] **IEC 60793-2-10,** Optical fibers - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibers

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

[15] **IEC 60825-2,** Safety of laser products - Part 2: Safety of optical fiber communication systems [OFCS] Edition 3.1 January 2007

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

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

[18] **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

[19] **IEC 61280-4-1,** Fiber-optic communication subsystem test procedures - Part 4-1: Cable plant and links - Premises cabling attenuation measurement

[20] **IEC 61300-3-6,** Fiber optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-6: Examinations and measurements - Return loss

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

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

[23] **IEEE 802.3-2008,** 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

[24] **SFF-8431,** Specification for Enhanced Small Form Factor Pluggable Module "SFP+"

[25] **SFF-8432,** Specification for IPF (Improved Pluggable Formfactor)

[26] **SFF-8433,** Specification for IPF (Improved Pluggable Formfactor) Cage

[27] **SFF-8443,** Specification for IPF Stacked (Improved Pluggable Formfactor) Cage

[28] **SFF-8083,** Specification for Improved 0.8 mm Card Edge Connector

[29] **SFF-8435,** Specification for Maximizing Card Edge Contact Tolerance Technique

[30] **TIA-492AAAB,** Detail Specification for 50-μm core diameter/125-μm cladding diameter class Ia graded-index multimode optical fibers

[31] **TIA-492AAAC,** Detail Specification for 850-nm Laser-Optimized, 50-μm core diameter/125-μm cladding diameter class Ia graded-index multimode optical fibers

[32] TIA-492AAAD, Detail Specification for 850-nm Laser-Optimized, 50-μm core diameter/125-μm cladding diameter class Ia graded-index multimode optical fibers suitable for manufacturing OM4 cabled optical fiber

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.

[33] ANSI/INCITS 1861D, FC-FS-3, Fibre Channel Framing and Signaling 3

[34] ANSI/INCITS 1734DT, FC-MSQS, Fibre Channel Methodologies for Signal Quality Specification

[35] SFF-8081, 0.8mm Card Edge Connector for 16Gb/s Applications

2.3 Informative references

none.

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 disk drive 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. The beta point specifications are intra-enclosure specifications.

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

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

3.1.5 **ε_T, ε_R:** epsilon T, epsilon R; interoperability points used for establishing signal budget at internal connectors mainly in blade applications. The epsilon point specifications are for intra-enclosure specifications.

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 transmission characters.

3.1.9 **bandwidth:** in FC-PI-5 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 unless specifically indicated otherwise.

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

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 where the effective optical power resides. See IEC 61280-1-3 (reference [18]).

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: a normative interoperability point. Compliance points include beta, gamma, delta, and epsilon 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 nominal bit period and the minimum value of the zero-crossing-time differences 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 device: see FC device.

3.1.28 disparity: the difference between the number of ones and zeros in a Transmission Character. See FC-FS-3 (reference [33]).

3.1.29 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.

3.1.30 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. 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.

3.1.31 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.

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

3.1.33 epsilon T, epsilon R: see ε_T, ε_R.

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 FC-MSQS (reference [34]).

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-5, 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 optic cable: a jacketed optical fiber or fibers.

3.1.41 gamma T, gamma R: see γ_T, γ_R.

3.1.42 Golden PLL: this function 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. It conforms to the requirements in 6.10.2 of FC-MJSQ (reference [9]) with a 3dB bandwidth of (nominal signalling rate)/1667.

3.1.43 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.

3.1.44 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.

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

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

3.1.47 interoperability point: points in a link or TxRx Connection that this standard defines signal requirements to enable interoperability. This includes both compliance points and reference points. See α_T, α_R, β_T, β_R, γ_T, γ_R, δ_T, δ_R, ε_T, and ε_R.

3.1.48 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.

3.1.49 **jitter:** the instantaneous deviations of a signal edge times at a defined signal level of the signal from the reference times. The reference time is the jitter-timing-reference specified in 6.2.3 of FC-MJSQ (reference [9]) that occurs under a specific set of conditions. In this document, jitter is defined at the average signal level.

3.1.50 **jitter, bounded uncorrelated (BUJ):** the part of the deterministic jitter that is not aligned in time to the high probability DDJ and DCD in the data stream being measured. Sources of BUJ include, (1) power supply noise that affects the launched signal, (2) crosstalk that occurs during transmission and (3) clipped Gaussian distributions caused by properties of active circuits. BUJ usually is high population DJ, with the possible exception of power supply noise.

3.1.51 **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.

3.1.52 **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 uncorrelated 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 (reference [9]).

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

3.1.54 **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.

3.1.55 **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.

3.1.56 **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.

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

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

3.1.59 **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.

3.1.60 **jitter tolerance:** the ability of the link or receiver downstream from the receive interoperability point (γ_R, β_R, or δ_R) to recover transmitted bits in an incoming bit stream in the presence of specified jitter in the signal. Jitter tolerance is defined 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 defined at the minimum allowed signal amplitude unless otherwise specified. See also signal tolerance.

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

3.1.62 jitter tracking: the ability of a receiver to tolerate low frequency jitter.

3.1.63 jitter, uncorrelated, UJ: uncorrelated jitter is a measure of any jitter that is not correlated to the data stream. See FC-MSQS (reference [34]).

3.1.64 JSPAT: the JSPAT (scrambled jitter pattern) is a 500 bit pattern that has been developed for transmit jitter, DDPWS, WDP and RN testing for 8GFC. See FC-MSQS (reference [34]).

3.1.65 JTSPAT: the JTSPAT is a 1180 bit pattern intended to be used for receive jitter tolerance testing for 8GFC. See FC-MSQS (reference [34]).

3.1.66 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-5 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

3.1.67 level 1 DJ: term used in this document for the effective DJ value that is used for DJ compliance purposes. See jitter, deterministic.

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

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

3.1.70 MB/s: an abbreviation for megabytes (10^6) per second.

3.1.71 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.

3.1.72 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.

3.1.73 node: a collection of one or more FC ports controlled by a level above FC-2.

3.1.74 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 (reference [12]).

3.1.75 OM1: 62.5/125 um multimode fiber with a 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. See reference [13].

3.1.76 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. See reference [13].

3.1.77 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. See reference [13].

3.1.78 OM4: 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 3500 MHz-km at 850 nm and 500 MHz-km at 1300 nm as well as an effective laser launch bandwidth of 4700 MHz-km at 850 nm in accordance with IEC 60793-2-10 Type A1a.2 fiber. See reference [13].

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 FC-MSQS (reference [34]).

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 FC-MSQS (reference [34]).

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 B1.1 fiber. See reference [14].

3.1.86 OS2: dispersion unshifted, low water peak, single-mode fiber in accordance with IEC 60793-2-50 Type B1.3 fiber. See reference [14].

3.1.87 P_{alloc}: the effective system power/voltage budget used in TWDP and WDP calculations. See FC-MSQS (reference [34]).

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

3.1.89 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.

3.1.90 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.

3.1.91 receiver device: the device containing the circuitry accepting the signal from the TxRx Connection.

3.1.92 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 trans-impedance amplifiers.

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

3.1.94 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) signal at its input.

3.1.95 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

3.1.96 reflectance: the ratio of reflected power to incident power for given conditions of spectral composition, polarization and geometrical distribution. In optics, the reflectance is frequently expressed as "reflectance density" or in percent; in communications applications it is generally expressed as:

$$10\log\frac{P_r}{P_i}(dB)$$

where
P_r is the reflected power and P_i is the incident power.

3.1.97 reflections: power returned by discontinuities in the physical link.

3.1.98 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.

3.1.99 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.

3.1.100 return loss: the ratio (expressed in dB) of incident power to reflected power at the same port. 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.

3.1.101 $\mathbf{RIN_{12}OMA}$: relative Intensity Noise. Laser noise in dB/Hz with 12 dB optical return loss, with respect to the optical modulation amplitude.

3.1.102 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-5, the measurement points are the 80% and 20% voltage levels.

3.1.103 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.

3.1.104 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-3 (reference [33]).

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

3.1.106 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.

3.1.107 signal tolerance: the ability of the link downstream from the receive interoperability point (γ_R, β_R, δ_R, or ε_R) to recover transmitted bits in an incoming data stream in the presence of a specified signal. Signal tolerance is defined at specified signal amplitude(s). 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. See also jitter tolerance.

3.1.108 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.

3.1.109 spectral width (RMS): the weighted root mean square width of the optical spectrum. See IEC 61280-1-3 (reference [18]).

3.1.110 stressed receiver sensitivity: the amplitude of optical modulation in the stressed receiver test given in FC-MSQS (reference [34]).

3.1.111 stressed receiver vertical eye closure power penalty: the ratio of the nominal optical modulation amplitude to the vertical eye opening in the stressed receiver test. See FC-MSQS (reference [34]).

3.1.112 synchronization: bit synchronization, defined above, and/or Transmission-Word synchronization, defined in FC-FS-3 (reference [33]). An FC-1 receiver enters the state “Synchronization-Acquired” when it has achieved both kinds of synchronization.

3.1.113 transceiver: a transmitter and receiver combined in one package

3.1.114 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.

3.1.115 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.

3.1.116 transmission code: a means of encoding data to enhance its transmission characteristics. The transmission code specified by FC-FS-3 (reference [33]) is byte-oriented, with both valid data bytes and special (control) codes encoded into 10-bit transmission characters.

3.1.117 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.

3.1.118 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.

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

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

3.1.121 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, clause 52.9.10. See reference [23].

3.1.122 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 receiver.

3.1.123 T_rise / T_fall: the adjusted 20% to 80% rise and fall time of the optical signal.

3.1.124 TR_filter / TF_filter: the measured 20% to 80% rise or fall time of a fourth order Bessel-Thomson filter with a step input.

3.1.125 TR_meas / TF_meas: the measured 20% to 80% rise or fall time of the optical signal.

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

3.1.127 TxRx connection segment: that portion of a TxRx connection delimited by separable connectors or changes in media.

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

3.1.129 unstressed receiver sensitivity: the amplitude of optical modulation in the unstressed sensitivity receiver test in. See FC-MSQS (reference [34]).

3.1.130 voltage modulation amplitude (VMA): VMA is the difference in electrical voltage between the stable one level and the stable zero level, see FC-MSQS (reference [34]).

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

3.1.132 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, 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 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 period is used as the decimal demarcation. A comparison of the American and ISO conventions are shown below:

Table 1 – ISO convention

Alternative ISO	ISO as used in this document	American
2 048	2 048	2048
10 000	10 000	10,000
1 323 462,9	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 an 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-5. However, if any optional characteristic is implemented, it shall be implemented as defined in FC-PI-5.

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 in table 3. Definitions of several of these items are included in 3.1

3.2.3.1 Signaling rate abbreviations

Abbreviations for the signalling rates are frequently used in this document. Table 2 shows the abbreviations that are used and the corresponding signalling rates.

Table 2 – Signaling rate abbreviations

Abbreviation	Signaling rate	Data rate
1GFC	1 062.5 MBd	100 MB/s
2GFC	2 125 MBd	200 MB/s
4GFC	4 250 MBd	400 MB/s
8GFC	8 500 MBd	800 MB/s
16GFC	14 025 MBd	1 600 MB/s

3.2.3.2 Acronyms and other abbreviations

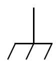
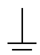
Table 3 – Acronyms and other abbreviations

Bd	baud
BER	bit error ratio
BUJ	bounded uncorrelated jitter
dB	decibel
dBm	decibel (relative to 1 mW)
DDJ	data dependent jitter
DDPWS	data dependent pulse width shrinkage
DJ	deterministic jitter
DUT	device under test
ECL	Emitter Coupled Logic
EIA	Electronic Industries Association
EMC	electromagnetic compatibility
EMI	electromagnetic interference
FC	Fibre Channel
FEC	Forward error correction
GBd	gigabaud
hex	hexadecimal notation
IEEE	Institute of Electrical and Electronics Engineers
ITU-T	International Telecommunication Union - Telecommunication Standardization (formerly CCITT)
JBOD	Just Bunch of Disks
LOS	loss of signal
LW	long wavelength
MB	megabyte = 10^6 bytes
MBd	megabaud
MM	multimode
NA	not applicable
NC-DDJ	non-compensable data dependent jitter
NEXT	near-end crosstalk
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
RN	relative noise
Rx	receiver
SERDES	Serializer/Deserializer
SM	single-mode
S/N(SNR)	signal-to-noise ratio
SW	short wavelength
TCTF	transmitter compliance transfer function
TDP	transmitter and dispersion penalty
TDR	time domain reflectometry
TIA	Telecommunication Industries Association
TJ	total jitter
TWDP	transmitter waveform and distortion penalty
Tx	transmitter
TxRx	a combination of transmitter and receiver
UI	unit interval = 1 bit period
UJ	uncorrelated jitter
ULP	Upper Level Protocol
VECP	vertical eye closure penalty
WDP	waveform distortion penalty

3.2.3.3 Symbols

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

Table 4 – Symbols

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

4 FC-PI-5 structure and concepts (informative)

4.1 Fibre Channel structure

This clause provides an overview of the structure, concepts and mechanisms used in FC-PI-5 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-5 and FC-FS-3 (reference [33]).

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.

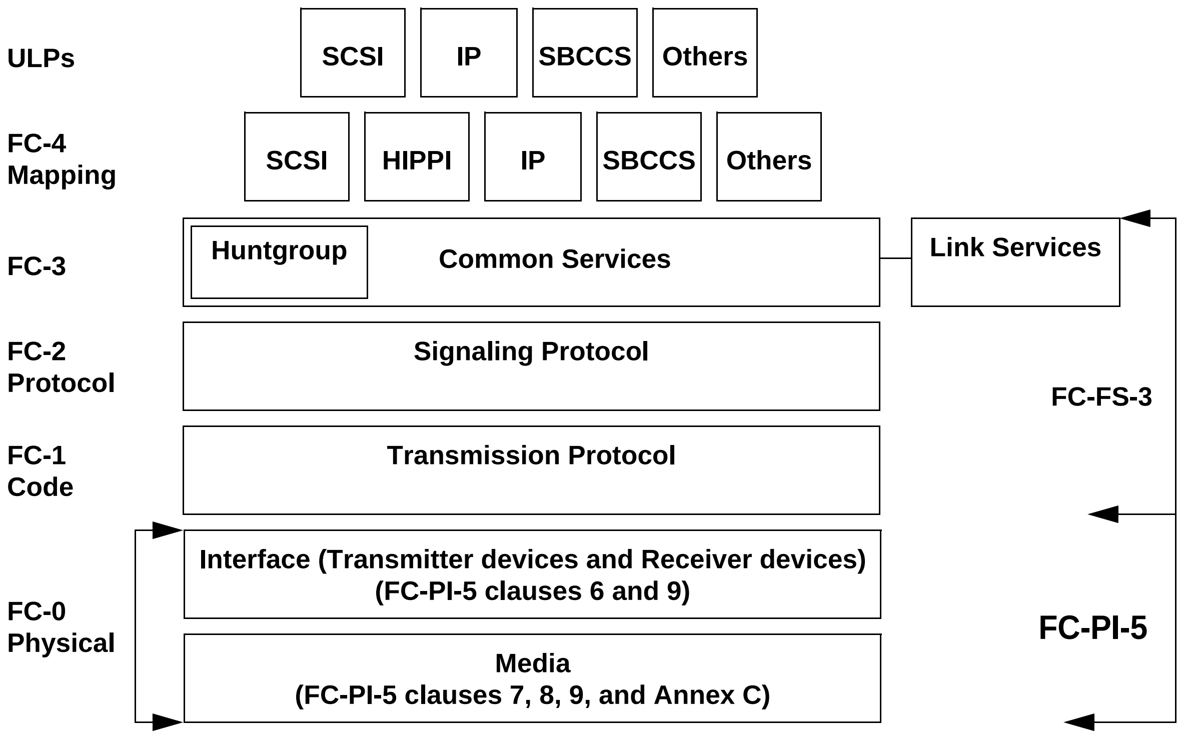


Figure 1 – Fibre channel structure

The Physical interface (FC-0), specified in FC-PI-5, 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-3. 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.

FC-PI-5 and FC-FS-3 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-5 and FC-FS-3 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-5 and FC-FS-3.

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

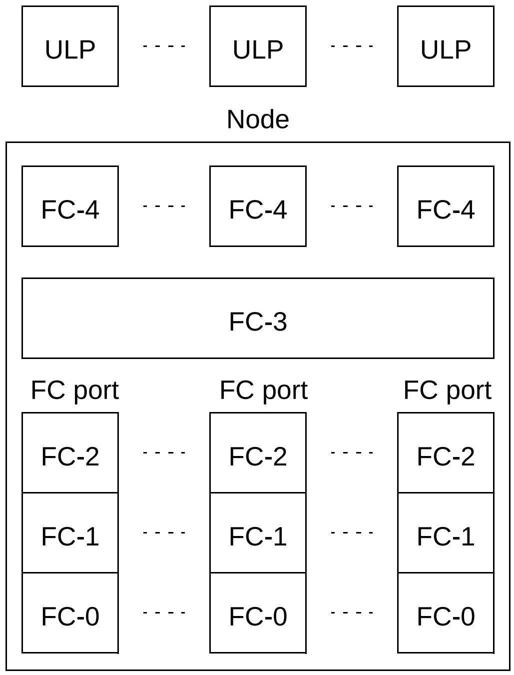


Figure 2 – Node functional configuration

4.2 FC-0 general description

The FC-0 level of FC-PI-5 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 FC 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.

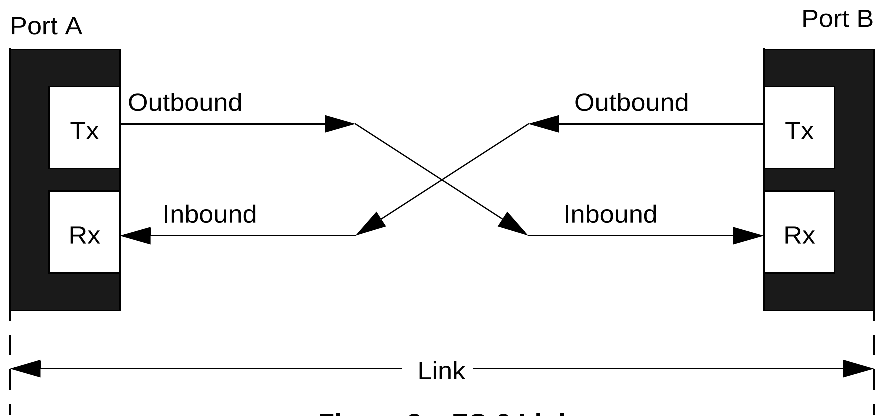


Figure 3 – FC-0 Link

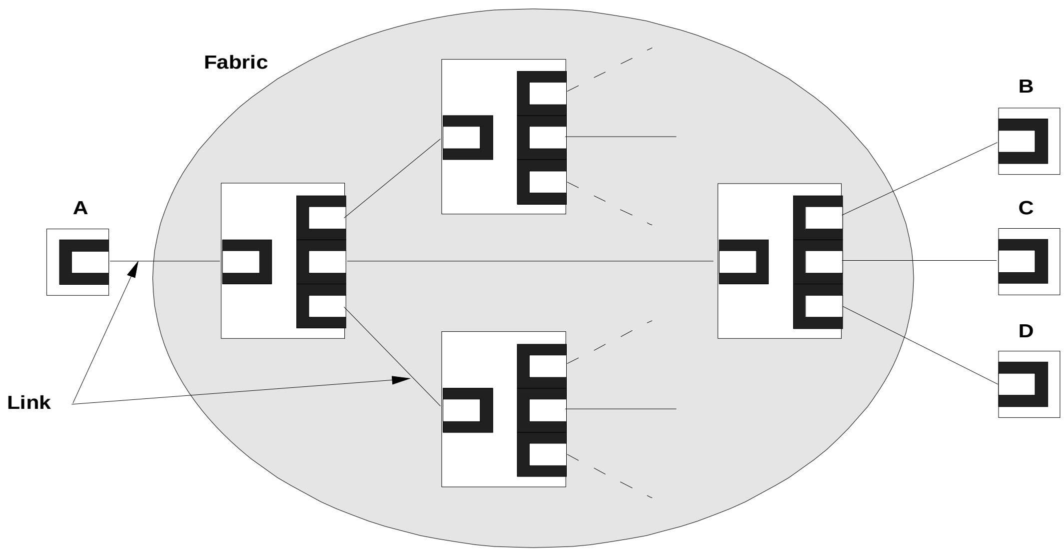


Figure 4 – Fabric

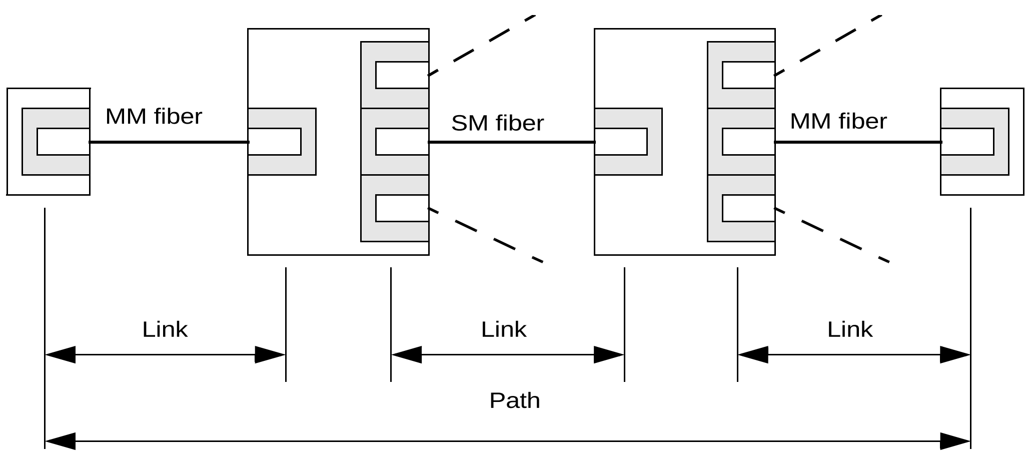


Figure 5 – FC-0 Path

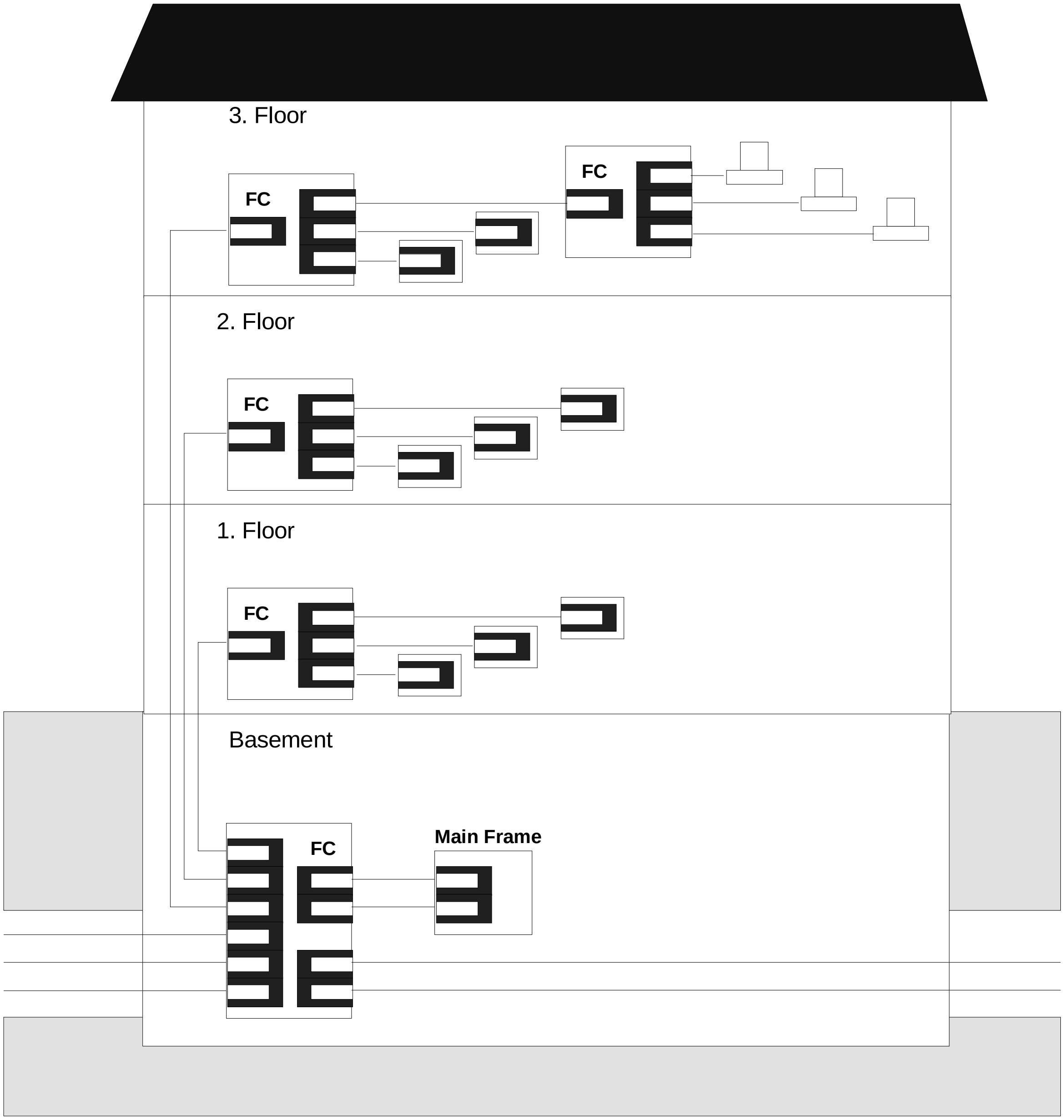


Figure 6 – Fibre channel building wiring

4.3 FC-0 interface overview

The interoperability points are shown in figures 10, 11, 12 and 13. The “α” points are for reference only.

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

The link distance capabilities specified in FC-PI-5 are based on ensuring interoperability across multiple vendors supplying the technologies (both transceivers and cable plants) under the tolerance limits specified in FC-PI-5. 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-5.

5 FC-PI-5 functional characteristics

5.1 General characteristics

FC-PI-5 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-3 protocol is defined to operate across connections having a bit error ratio (BER) detected at the receiving port of less than or equal to 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-5 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 4GFC, 8GFC, and 16GFC. All data rates have transmitter and receiver clock tolerances of ±100 ppm. A TxRx Connection bit error rate (BER) of ≤ 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-5 defines ten different specific physical locations in the FC system. Eight are interoperability points and two are reference points. No interoperability points are required for closed or integrated links and FC-PI-5 is not required for such applications. For closed or integrated links the system designer shall ensure that a BER of better than 10^{-12} as required by FC-FS-3 is delivered.

The requirements specified in FC-PI-5 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. The compliance points are defined at separable connectors, since these are the points where different components can easily be added, changed, or removed. 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 are detailed in 5.13. All specifications are at the interoperability points in a fully assembled system as if measured with a non-invasive probe except where otherwise described. Figure 7 and figure 8 show the reclocker locations for 16GFC multi-mode and single-mode variants.

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-5 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.

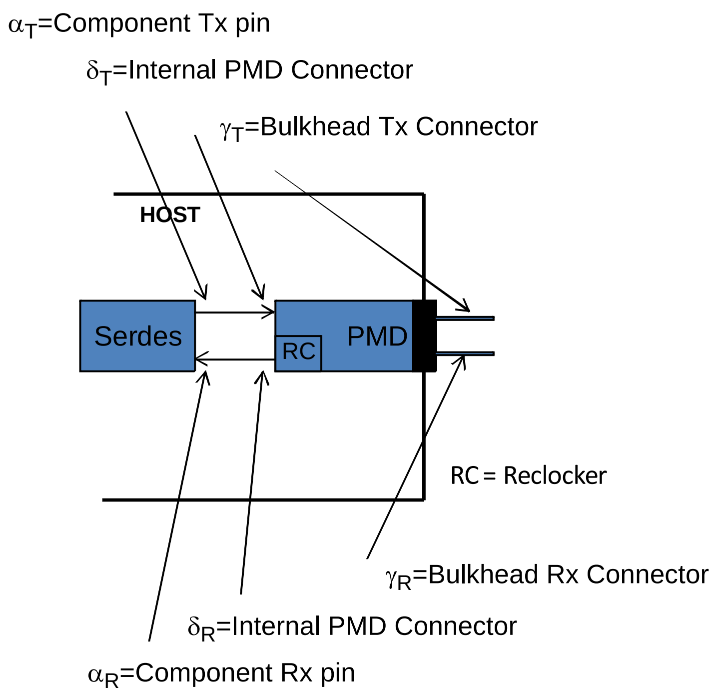


Figure 7 – reclocker location for 1600-SM-LC-L and 1600-SM-LZ-I

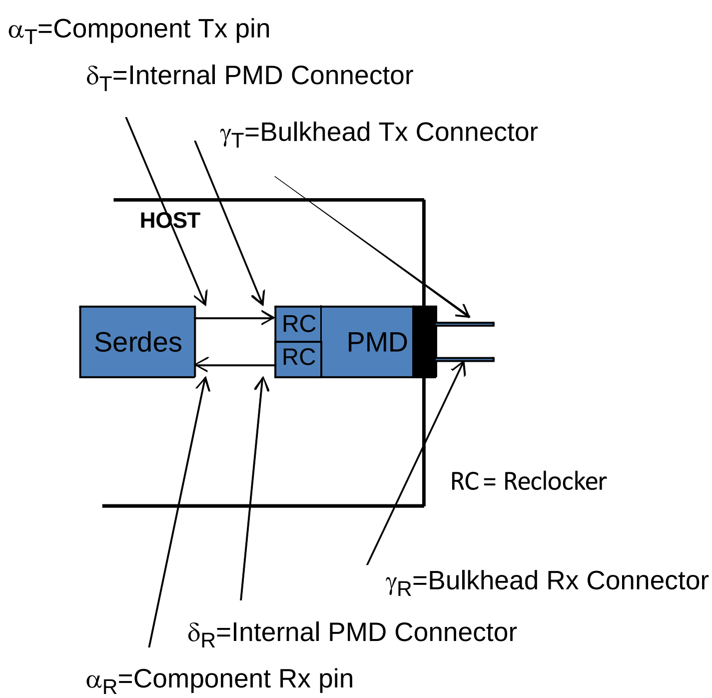


Figure 8 – reclocker location for 1600-M5-SN-S, 1600-M5E-SN-I and 1600-M5F-SN-I

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.

The interface to FC-FS-3 occurs at the logical encoded data interfaces. As these are logical data constructs, no physical implementation is implied by FC-FS-3. FC-PI-5 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-5 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 connections 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-5 and FC-FS-3 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-5 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. For transition parameters look into annex E.

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 22. 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 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**: See annex E.

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 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.

5.4 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 20 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.

5.5 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.

5.6 Speed agile ports that support speed negotiation

This subclause specifies the requirements on speed agile ports that support speed negotiation.

a) 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 for 4GFC and 8GFC. A repeater shall achieve compliant operation within 1 ms following an application of a compliant signal at its input. For 16GFC, the transmitter stabilization time shall be 3 ms or less (allowing up to two repeaters in the path).

b) The port receiver shall attain Transmission_Word synchronization within the receiver stabilization time (sub-clause 5.4) when presented with a valid input stream or 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.

c) The port transmitter and port receiver shall be capable of operating at different speeds at the same time during speed negotiation.

5.7 Transmission codes

4GFC and 8GFC shall use 8b/10b codes for transmission. 16GFC shall use 64b/66b codes for transmission.

5.8 Frame scrambling and emission lowering protocol

4GFC does not use scrambling. 8GFC shall use frame scrambling and emission lowering protocol as stated in FC-FS-3 (reference [33]). 16GFC shall use 64b/66b coding and scrambling is inherent in the code as defined in FC-FS-3 (reference [33]).

5.9 Transmitter training

4GFC and 8GFC shall not use transmitter training. 16GFC EL variants shall not use transmitter training. 16GFC EA variants shall transmit the transmitter training signal during the link speed negotiation, but the transmitter training is optional. Transmitter training is defined in FC-FS-3 (reference [33]).

5.10 Forward error correction (FEC)

4GFC, 8GFC, and 16GFC EL variants shall not support FEC. 16GFC EA variant may optionally use FEC. The support for FEC shall be indicated during transmission training signal time.

5.11 Test patterns

8GFC and 16GFC shall use the test patterns stated in FC-MSQS (reference [34]). 4GFC shall use the test patterns in FC-MJSQ (reference [9]).

5.12 FC-PI-5 nomenclature

The nomenclature for the Fibre Channel variants is illustrated in figure 9. Receiver type and fiber type indicates assumptions used for developing link budgets and does not indicate a requirement on receiver or fiber implementations

100-SM-LC-L

SPEED
1600 -- 1 600 MB/s
1200 -- 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)
M5F -- multimode 50 μm optics connecting to a gamma point (OM4)
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)
SN -- gamma point short wave LASER (850 nm) with limiting optical receiver
SA -- gamma point short wave LASER (850 nm) assuming a linear optical receiver
LL -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a limiting optical receiver
LC -- gamma point for long wave LASER cost reduced (1310 nm) with limiting optical receiver
LZ -- gamma point for long wave LASER (1490 nm) with limiting optical receiver
LA -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a linear optical receiver
EL -- any electrical 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 equalizing receivers

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 9 – Fibre Channel variant nomenclature

5.13 Interoperability points (informative)

This subclause contains examples of interoperability points in various configurations. The parameter values for 8GFC and 16GFC delta and epsilon points are measured at the standard test equipment-connector interface of standardized test fixtures described in FC-MSQS (reference [34]). These examples are useful to illustrate how the definitions of the interoperability and reference points may appear in practical systems. This subclause also shows an illustration of the two different signal specification environments defined in FC-PI-5, 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 10 shows details of an example involving FC devices contained within an enclosure.

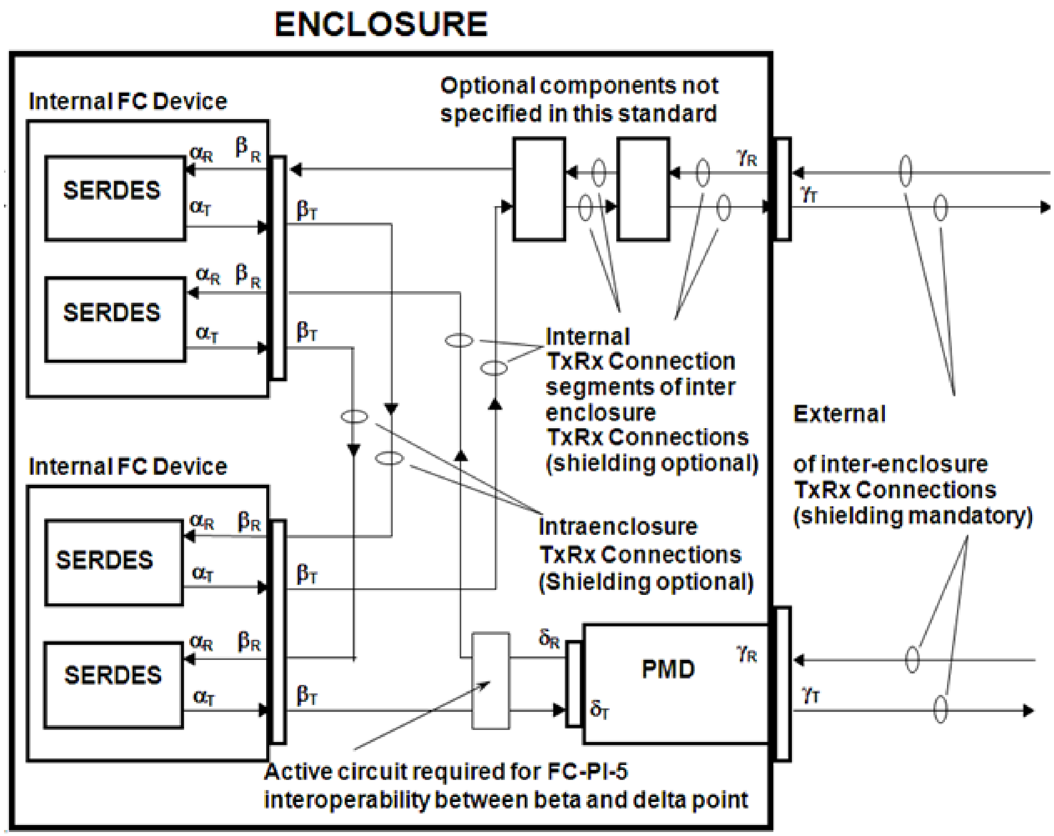
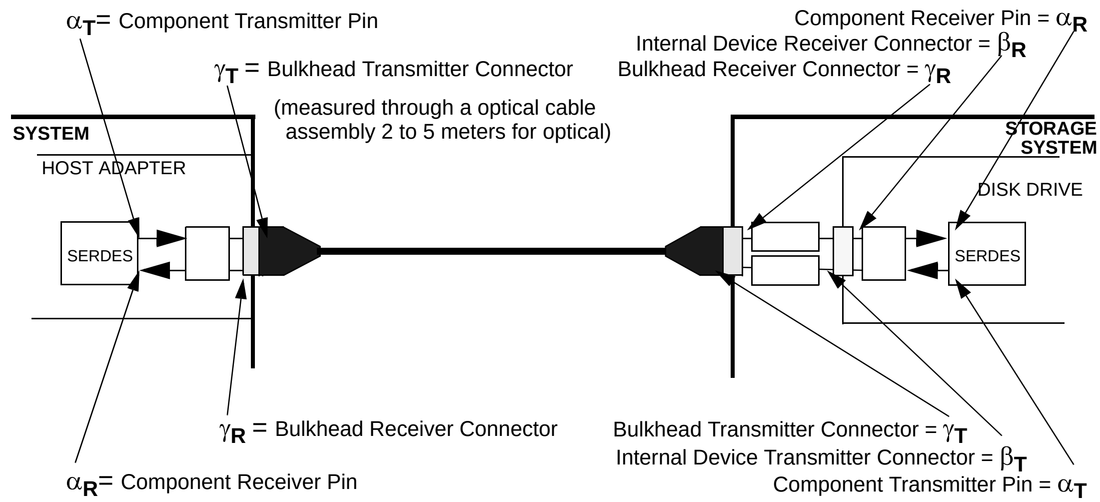
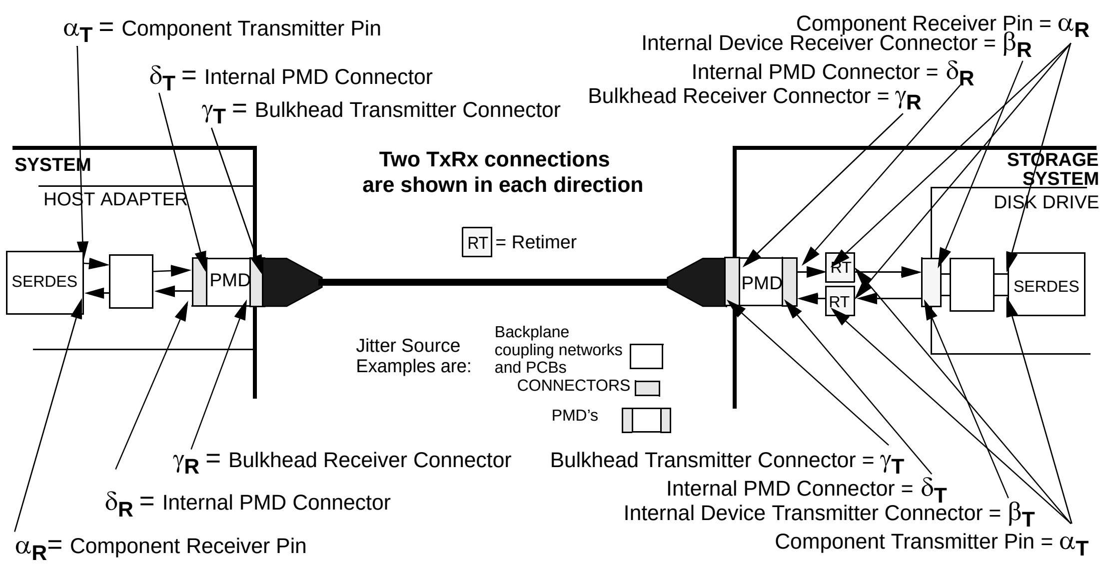


Figure 10 – Example of physical location of reference and interoperability points

Figure 11 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

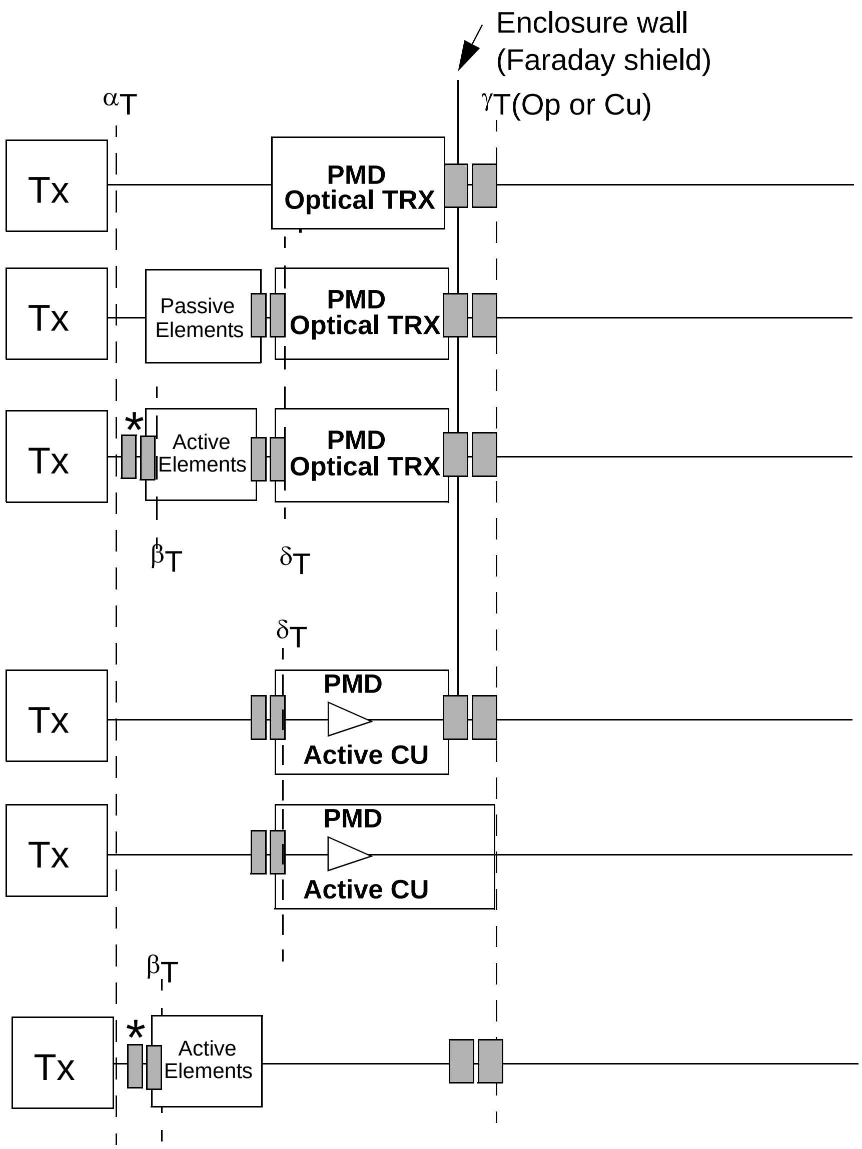


With use of internal δ connectors and retimers

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

Figure 11 – Interoperability points examples at connectors

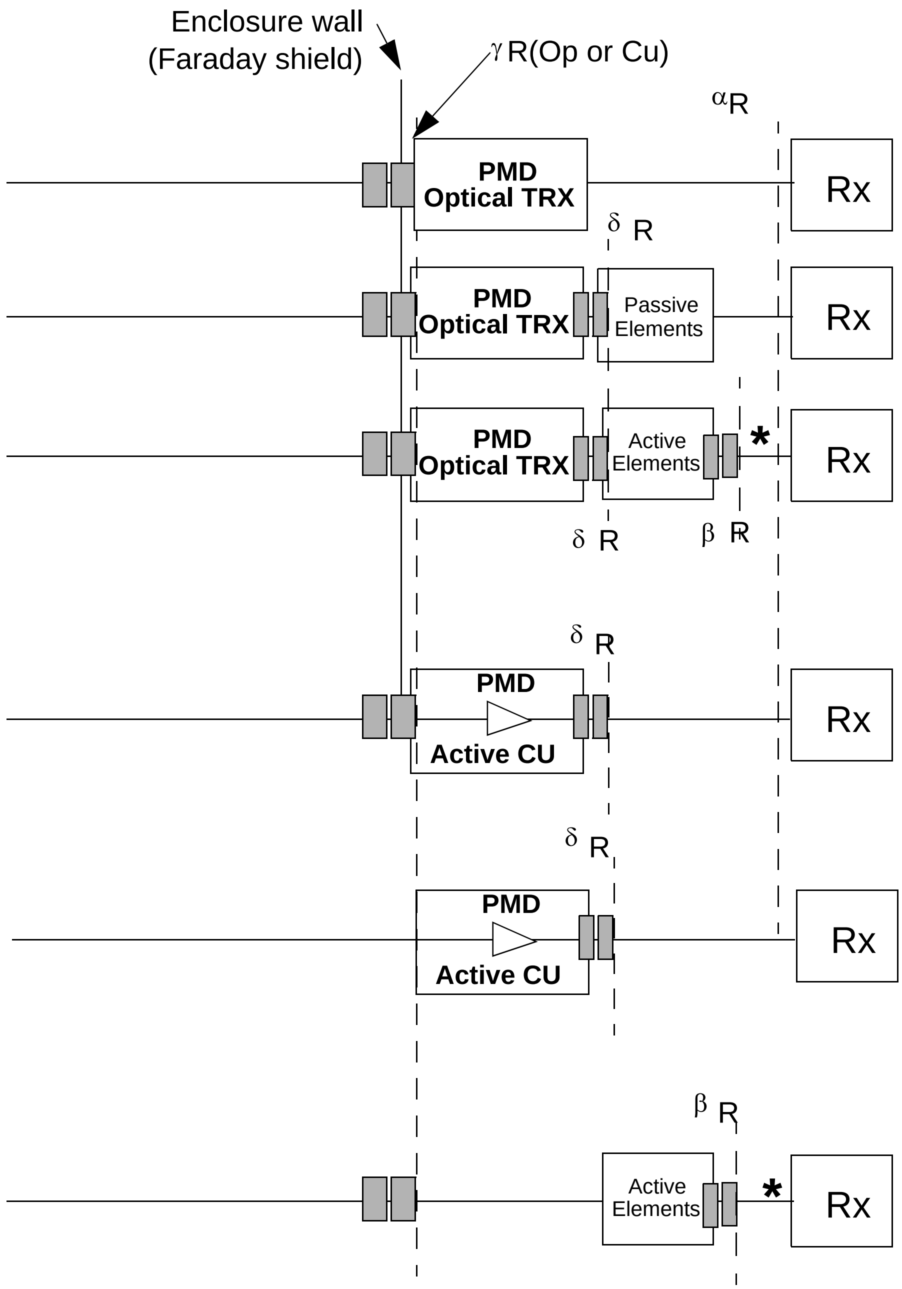
Figures 12 and 13 show more detailed examples of the Tx and Rx ends of simplex links with pointers to the physical location of the interoperability and reference points.



*** Inter-enclosure configurations with beta points require active circuits for FC-PI-5 interoperability between beta and delta or, if no delta point exists, between beta and gamma.**

Figure 12 – Tx interoperability points (examples)

Figure 14 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-5 interoperability between beta and delta or, if no delta point exists, between beta and gamma.**

Figure 13 – Rx interoperability points (examples)

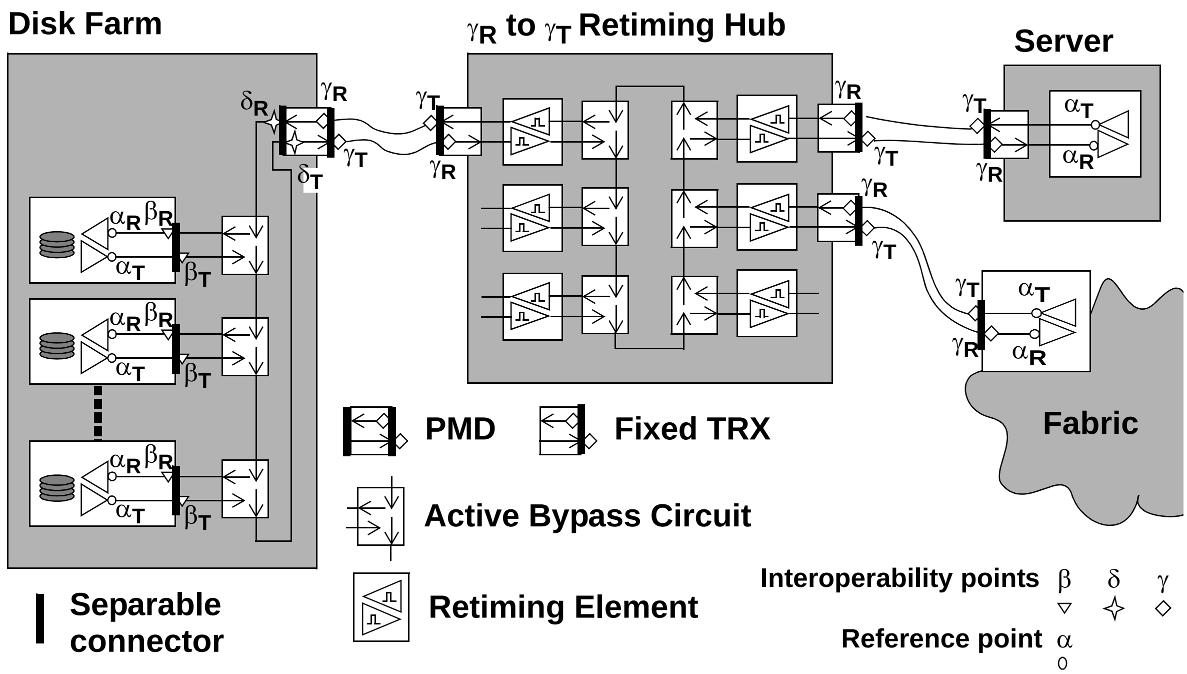


Figure 14 – Hub interoperability points (example)

Figure 15 shows examples of fabric and point to point configurations. For clarity, only simplex connections are illustrated.

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 16 shows an overview of the signal specification architecture used in FC-PI-5. 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.

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-enclosure and inter-enclosure environments. If retimers are used to provide this function, independent jitter budgets are also preserved.

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-5. Alpha points only exist within enclosures.

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.

The configuration on the left of figure 16 is independent of that on the right. However, the compatibility between appropriate connecting points have been assumed.

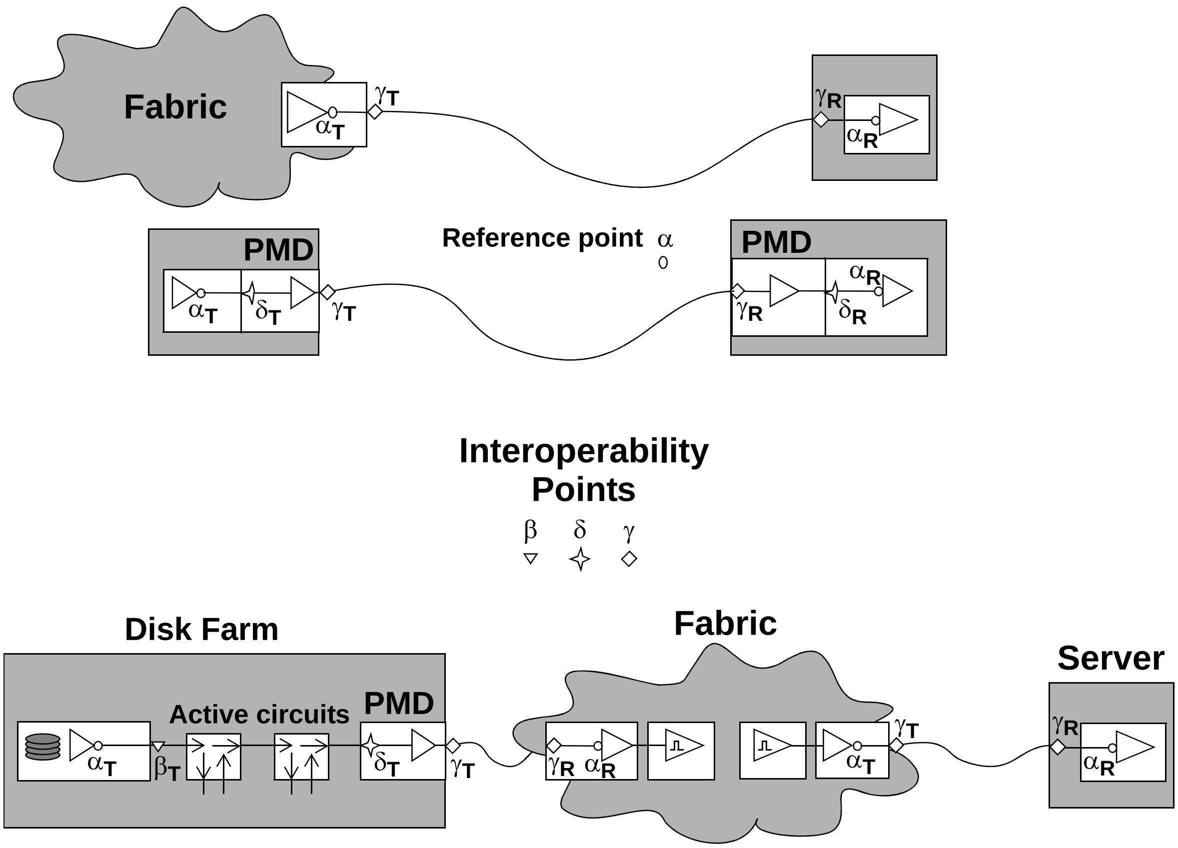


Figure 15 – Examples of interoperability points

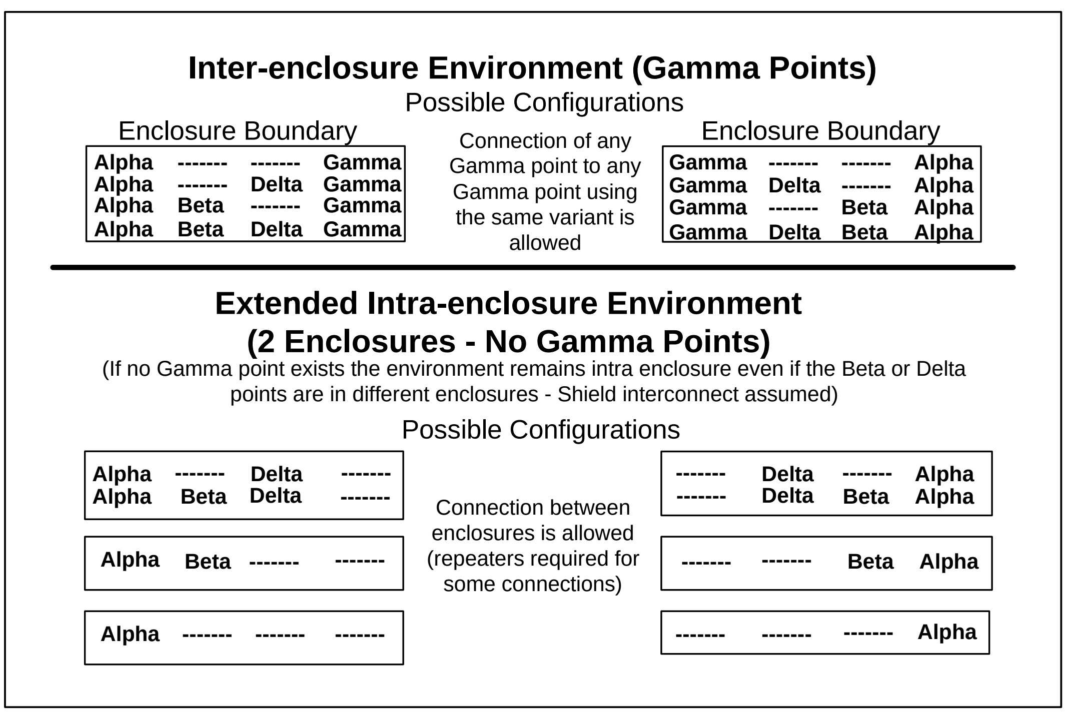


Figure 16 – Overview of the signal specification architecture

5.14 Electrical TxRx connections

5.14.1 TxRx general overview

TxRx Connections may be divided into TxRx Connection Segments (See figure 10). Figure 17 shows the beta compliance point in detail. Figure 18 shows the details of the epsilon compliance point. The beta and epsilon compliance points are intra-enclosure interoperability points. 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 subclause 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 17. 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 19. 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.

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.

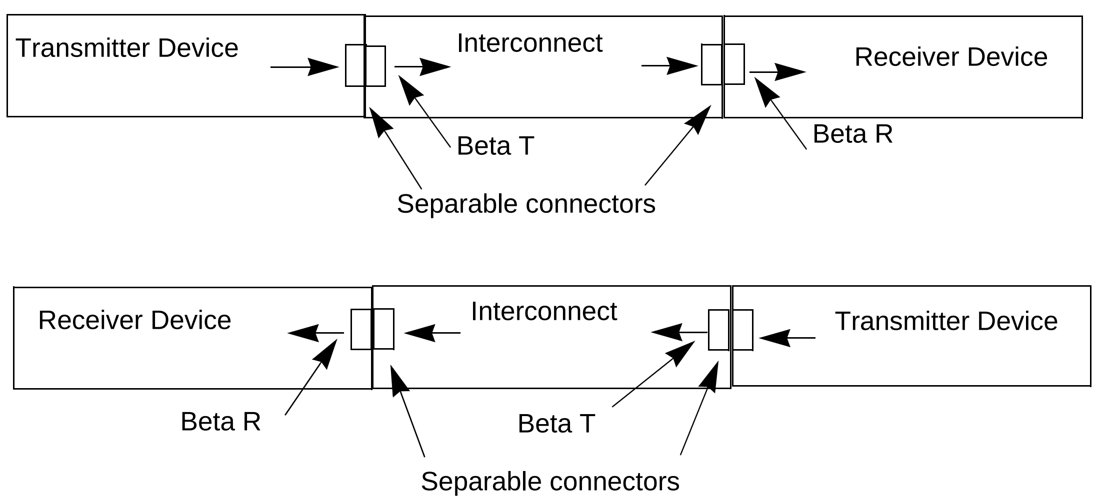


Figure 17 – Duplex beta TxRx connections example

5.14.2 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 embedded (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 exam-

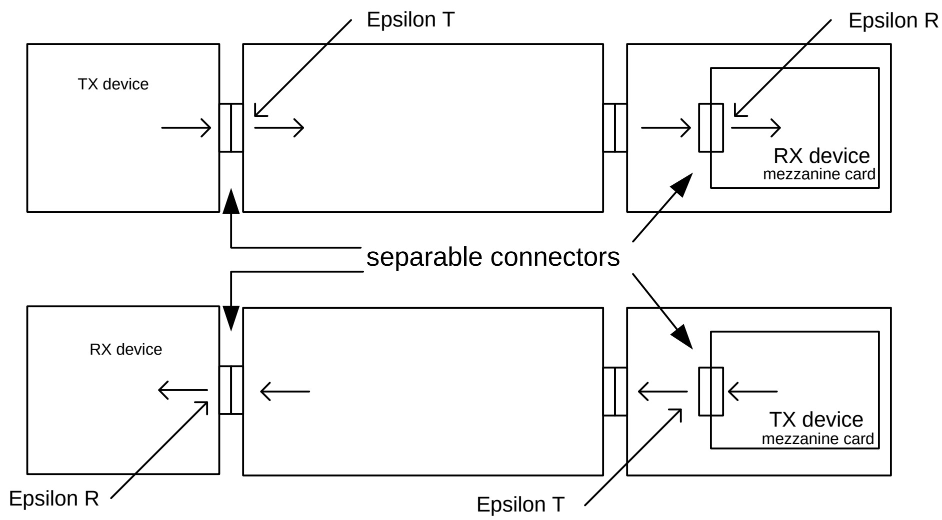


Figure 18 – Epsilon TxRx connection examples

ple, 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 19, both cases typically exist for duplex links - note that one may use the internal virtual connector (shown dotted) for system design.

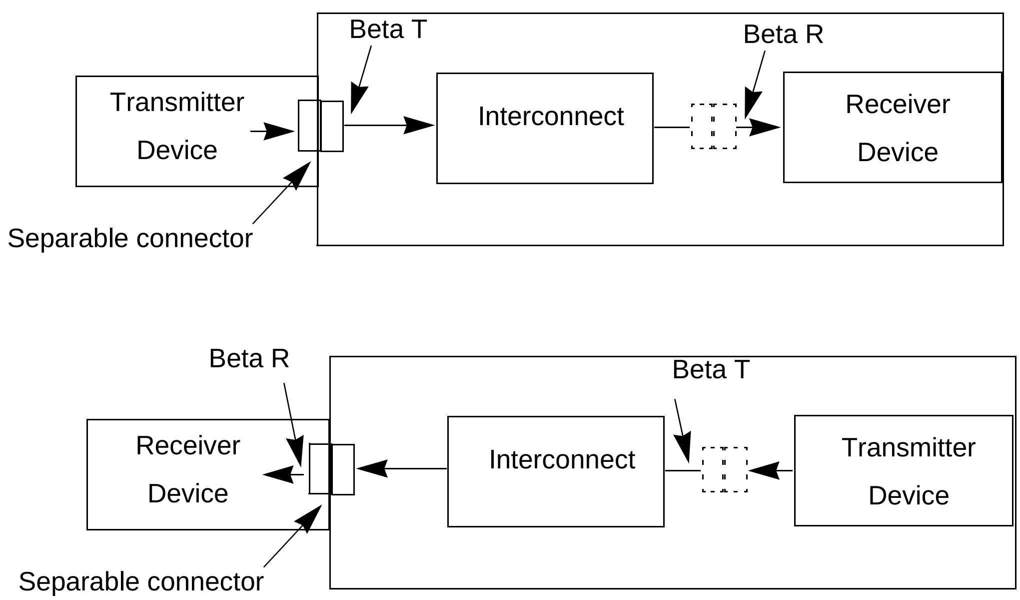


Figure 19 – Partially Separable links examples

5.15 FC-PI-5 variants

Table 5 and Table 6 list variants by FC-PI-5 nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize the variant. The nomenclature is illustrated in figure 9.

The lengths specified in table 5 and table 6 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.

Table 5 – Fibre Channel variants not in this document

<table>
<tr><th></th><th>100</th><th>200</th><th>1 200</th></tr>
<tr><td rowspan="2">SM
OS1, OS2</td><td>100-SM-LC-L
1 300 nm
2 m - 10 km
note 2</td><td>200-SM-LC-L
1 300 nm
2 m - 10 km
note 2</td><td rowspan="6">note 1</td></tr>
<tr><td>100-SM-LL-V
1 550 nm
2 m - 50 km
note 2</td><td>200-SM-LL-V
1 550 nm
2 m - 50 km
note 2</td></tr>
<tr><td>MM 62.5 µm
OM1</td><td>100-M6-SN-I
780/850 nm
0.5 m - 300 m
note 2</td><td>200-M6-SN-I
850 nm
0.5 m - 150 m
note 2</td></tr>
<tr><td>MM 50 µm
OM2</td><td>100-M5-SN-I
780/850 nm
0.5 m - 500 m
note 2</td><td>200-M5-SN-I
850 nm
0.5 m - 300 m
note 2</td></tr>
<tr><td>MM 50 µm
OM3</td><td>100-M5E-SN-I
780/850 nm
0.5 m - 860 m
note 2</td><td>200-M5E-SN-I
850 nm
0.5 m - 500 m
note 2</td></tr>
<tr><td>EL Balanced</td><td>100-DF-EL-S
note 2</td><td>200-DF-EL-S
note 2</td></tr>
<tr><td>EL Unbalanced</td><td>100-SE-EL-S
note 2</td><td>200-SE-EL-S
note 2</td><td>NA</td></tr>
<tr><td colspan="4">Notes:
1 For these variants refer to 10GFC (reference [1]) and FC-PI-3 (reference [8]).
2 This is obsoleted technology. For information refer to FC-PI-2 (reference [3]).</td></tr>
</table>

Table 6 – Fibre Channel Variants in FC-PI-5

	400	800	1600
SM OS1, OS2	**400-SM-LC-L** sub-clause 6.3 1 300 nm 2 m-10 km	**800-SM-LC-L** sub-clause 6.3 1 300 nm 2 m-10 km	**1600-SM-LC-L** sub-clause 6.3 1 300 nm 0.5 m-10 km
	400-SM-LC-M sub-clause 6.3 1 300 nm 2 m-4 km	**800-SM-LC-I** sub-clause 6.3 1 300 nm 2 m-1.4 km	**1600-SM-LZ-I** sub-clause 6.3 1 490 nm 0.5 m-2 km
MM 62.5 μm OM1	**400-M6-SN-I** annex A 850 nm 0.5 m-70 m	**800-M6-SN-S** annex A 850 nm 0.5 m-21 m	**1600-M6-SN-S** annex A 850 nm 0.5 m-15 m
		800-M6-SA-S annex D 850 nm 0.5 m-40 m	
MM 50 μm OM2	**400-M5-SN-I** sub-clause 6.4 850 nm 0.5 m-150 m	**800-M5-SN-S** sub-clause 6.4 850 nm 0.5 m-50 m	**1600-M5-SN-S** sub-clause 6.4 850 nm 0.5 m-35 m
		800-M5-SA-I annex D 850 nm 0.5 m-100 m	
MM 50 μm OM3	**400-M5E-SN-I** sub-clause 6.4 850 nm 0.5 m-380 m	**800-M5E-SN-I** sub-clause 6.4 850 nm 0.5 m-150 m	**1600-M5E-SN-I** sub-clause 6.4 850 nm 0.5 m-100 m
		800-M5E-SA-I annex D 850 nm 0.5 m-300 m	
MM 50 μm OM4	**400-M5F-SN-I** sub-clause 6.4 850 nm 0.5 m-400 m	**800-M5F-SN-I** sub-clause 6.4 850 nm 0.5 m-190 m	**1600-M5F-SN-I** sub-clause 6.4 850 nm 0.5 m-125 m
		800-M5F-SA-I annex D 850 nm 0.5 m-300 m	
EL Balanced	**400-DF-EL-S** clause 9	**800-DF-EL-S** clause 9	**1600-DF-EL-S** clause 9
EA Balanced		**800-DF-EA-S** clause 9	**1600-DF-EA-S** clause 9

6 Optical interface specification

6.1 TxRx connections

Clause 6 defines the optical signal characteristics at the interface connector. Each conforming optical FC port shall comply with the requirements specified in clause 6 and other applicable clauses. Fibre Channel links shall not exceed a BER (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 10). 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 fiber.

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.

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 IEC 60825-2 (reference [15]) and CDRH 1040.10 regulations 21CFR, chapter I, subchapter J (reference [10]).

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 7 gives the variant names, a general link description, and the gamma compliance point specifications for 10-km single-mode optical fiber links running at 4GFC, 8GFC, and 16GFC, a 4-km single-mode fiber link running at 4GFC, a 1.4-km single-mode fiber link running at 8GFC, and a 2-km single -mode fiber link running at 16GFC. For 1GFC and 2GFC refer to FC-PI-2 (reference [3]).

Table 7 – Single-mode link classes[1] (OS1, OS2)

FC-0	Unit	400-SM-LC-L	400-SM-LC-M	800-SM-LC-L	800-SM-LC-I	1600-SM-LC-L	1600-SM-LZ-I	Note
Nominal signaling rate	MBd	4 250		8 500		14 025		8
Operating distance	m	2 -10 000	2 - 4 000	2 -10 000	2 -1 400	0.5 -10 000	0.5 -2 000	
Transmitter (gamma-T)								
Type		Laser						
Center wavelength, max.	nm	1370		1360		1325	1500	2
Center wavelength, min.	nm	1260				1295	1485	2,14
RMS spectral width, max.	nm	figure 23	figure 24	NA	figure 25	NA		2
Optical modulation amplitude, min.	mW (dBm)	0.290 (-5.4)	0.150 (-8.2)	0.290 (-5.4)	0.174 (-7.6)	0.631 (-2.0)	0.473 (-3.25)	2,5,11
Side-mode suppression	dB	NA		30	NA	30		
-20 dB spectral width	nm			1		1	1	
Average launched power, max.	dBm							3
Average launched power, min.	dBm	-8.4	-11.2	-8.4	-10.6	-5.0	-6.25	4
Rise/Fall time (20% - 80%), max.	ps	90		NA				6,10
$RIN_{12}OMA$, max.	dB/Hz	-118	-120	-128	-128	-130		5
Extinction Ratio, min	dB	NA		3.5			3.0	
Transmitter and dispersion penalty (TDP), max	dB	NA		3.2	note 12	4.4	3	12
Receiver (gamma- R)								
Average received power, max.	dBm	-1	-1	+0.5	+0.5	+2.0	+2.0	
Rx jitter tolerance test, OMA	mW (dBm)	0.048 (-13.2)	0.048 (-13.2)	0.066 (-11.8)	0.066 (-11.8)	0.095 (-10.2)	0.095 (-10.2)	
Rx jitter tracking test, frequency and pk-pk amplitude	(kHz,UI)	NA		(510, 1) (100, 5)	(510, 1) (100, 5)	(840,1) (168,5)	(840,1) (168,5)	13
Unstressed receiver sensitivity, OMA	mW (dBm)	0.029 (-15.4)	0.029 (-15.4)	0.042 (-13.8)	0.042 (-13.8)	0.063 (-12.0)	0.063 (-12.0)	5,9
Return loss of receiver, min.	dB	12						
Receiver electrical 3 dB upper cutoff frequency, max	GHz	5.0	5.0	12	12	18	18	7

Table 7 – 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, and IEC 60793-2-50, Type B6 Optical fibers - Part 2: Product Specifications.
2 Trade-offs are available between center wavelength, RMS spectral width, and minimum optical modulation amplitude for transmitters other than 800-SM-LC-L and 16GFC. See figure 23 to figure 25.
3 Lesser of Class 1 laser safety limits (CDRH and IEC 60825-2) or receiver power, max.
4 The values are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.
5 See FC-MSQS (reference [34]).
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-5 figure 20 for 4GFC, and figure 21 for 8GFC and 16GFC. If a filter is used, the effects shall be removed. See FC-MSQS (reference [34]).
7 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 FC-MSQS (reference [34]).
8 The signaling rate shall not deviate by more than ±100 ppm from the nominal data rate over all periods equal to 200 000 transmitted bits (~10 max length frames).
9 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.
10 Rise and fall time is controlled by transmitter and dispersion penalty (TDP) for 8GFC and 16GFC.
11 For 800-SM-LC-L optical modulation amplitude in dBm shall also exceed -7.0+TDP. For 1600-SM-LC-L, optical modulation amplitude in dBm shall also exceed -5.2+TDP.
12 Transmitter and dispersion penalty (TDP) determines 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.
13 Receiver jitter tracking is defined in FC-MSQS (reference [34]).
14 The minimum center wavelength in FC-PI-2 for 1GFC, 2GFC, and 4GFC was 1265 nm. The minimum center wavelength has been extended to 1260 nm.

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 sub-clause 8.1.2.

Optical modulation amplitude is defined as the difference in optical power between a logic-1 and a logic-0, as defined in FC-MSQS (reference [34]).

The optical power is defined by the methods of IEC 61280-1-1 (reference [17]), 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 sub-clause 5.13). Conformance with the mask diagram is not to be used for determining compliance with the specifications for rise / fall time and jitter. The parameters specifying the mask of the transmitter eye diagram are shown in figure 20 and figure 21. See FC-MSQS (reference [34]).

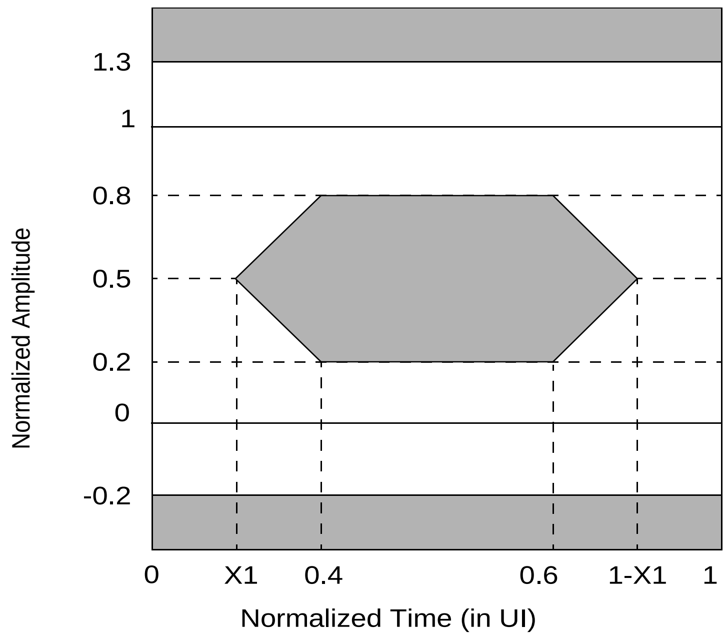


Figure 20 – SM transmitter eye diagram mask for 4GFC

In figure 20, X1 shall be half the value given for total jitter at the gamma T point given in table 9. 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.

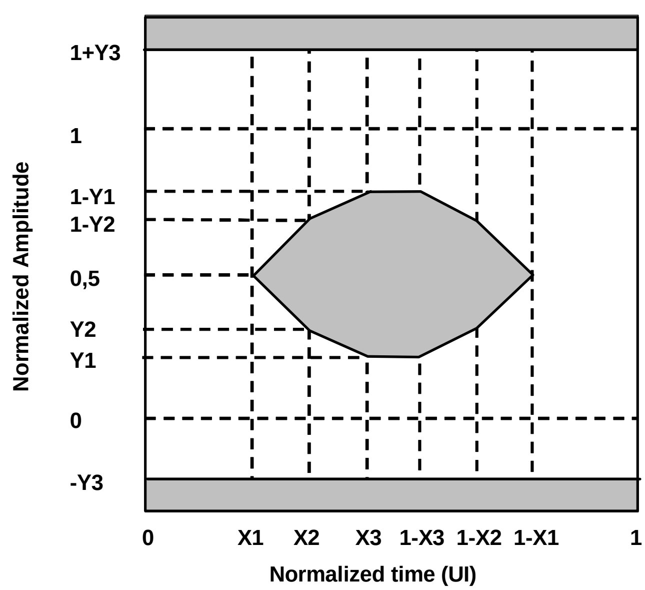


Figure 21 – SM transmitter eye mask for 8GFC, and 16GFC

Table 8 shows the mask parameters of figure 21. 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 8 – SM transmitter eye mask parameters for 16GFC and 8GFC

	8GFC		16GFC	
	Value	**Unit**	**Value**	**Unit**
X1	0.25	UI	0.30	UI
X2	0.40	UI	0.40	UI
X3	0.45	UI	0.45	UI
Y1	0.32		0.35	
Y2	0.35		0.39	
Y3	0.40		0.50	

6.3.3 SM optical input interface

The receiver shall operate within the BER requirement (10^{-12}) when the input power falls in the range given in table 7 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 20 and figure 21.

6.3.4 SM jitter budget

This clause defines, for every interoperability point, the allowable jitter (see table 9, jitter output) and the jitter that shall be tolerated (see table 10). See FC-MJSQ, sub clause 11.2 and FC-MSQS (reference [34]).

Receiver TJ and DJ shall comply to the listed values in table 9, over all allowable optical power input ranges and extinction ratios, as listed in table 7.

Table 9 – SM jitter output, pk-pk, max

<table>
<tr><th></th><th>Unit</th><th>β_T</th><th>δ_T</th><th>γ_T</th><th>γ_R</th><th>δ_R</th><th>β_R</th></tr>
<tr><td colspan="8">**400-SM-LC-M and 400-SM-LC-L** (note 4)</td></tr>
<tr><td>**Deterministic (DJ)[3]**</td><td rowspan="2">UI</td><td rowspan="2">NA</td><td>0.14</td><td>0.26</td><td>0.28</td><td>0.39</td><td rowspan="2">NA</td></tr>
<tr><td>**Total (TJ)[1,2,3]**</td><td>0.26</td><td>0.44</td><td>0.48</td><td>0.64</td></tr>
<tr><td colspan="8">**800-SM-LC-I and 800-SM-LC-L** (note 4, 6)</td></tr>
<tr><td>**Deterministic (DJ)[3]**</td><td rowspan="3">UI</td><td rowspan="3">NA</td><td>0.17</td><td colspan="2" rowspan="3">note 5</td><td>0.42</td><td rowspan="3">NA</td></tr>
<tr><td>**Data Dependent Pulse Width Shrinkage (DDPWS)**</td><td>0.11</td><td>0.36</td></tr>
<tr><td>**Total (TJ)[1,2,3]**</td><td>0.31</td><td>0.71</td></tr>
<tr><td colspan="8">**1600-SM-LC-L and 1600-SM-LZ-I** (note 4, 6, 8)</td></tr>
<tr><td>**Deterministic (DJ)[3]**</td><td rowspan="4">UI</td><td rowspan="4">NA</td><td>0.31</td><td colspan="2" rowspan="4">note 5</td><td>0.22</td><td rowspan="4">NA</td></tr>
<tr><td>**Data Dependent Pulse Width Shrinkage (DDPWS)**</td><td>0.11</td><td>0.14</td></tr>
<tr><td>**UJ (rms)[3,7]**</td><td>0.03</td><td>NA</td></tr>
<tr><td>**Total (TJ)[1,2,3]**</td><td>0.45</td><td>0.36</td></tr>
<tr><td colspan="8">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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34].
7 UJ (rms) is the rms value of the uncorrelated jitter. See FC-MSQS (reference [34]).
8 reclocker on Rx side has been assumed.</td></tr>
</table>

Table 10 – SM jitter tolerance, pk-pk, min.

<table>
<tr><th></th><th>Unit</th><th>β_T</th><th>δ_T</th><th>γ_T</th><th>γ_R</th><th>δ_R</th><th>β_R</th></tr>
<tr><td colspan="8">400-SM-LC-L and 400-SM-LC-M (note 4)</td></tr>
<tr><td>Sinusoidal swept freq.(SJ)[3]
2 550 kHz to > 5 MHz</td><td rowspan="3">UI</td><td rowspan="3">NA</td><td colspan="4">0.10</td><td rowspan="3">NA</td></tr>
<tr><td>Deterministic (DJ)
2 550 kHz-2 125 MHz</td><td>0.14</td><td>0.26</td><td>0.28</td><td>0.39</td></tr>
<tr><td>Total (TJ)[1,2]</td><td>0.31</td><td>0.49</td><td>0.53</td><td>0.69</td></tr>
<tr><td colspan="8">800-SM-LC-L and 800-SM-LC-I (note 4, 8)</td></tr>
<tr><td>Sinusoidal swept freq.(SJ)[3]
5 098 kHz to > 20 MHz</td><td rowspan="4">UI</td><td rowspan="4">NA</td><td colspan="2" rowspan="4">note 5</td><td rowspan="4">note 6</td><td>note 7</td><td rowspan="4">NA</td></tr>
<tr><td>Data Dependent Pulse Width Shrinkage (DDPWS)</td><td>0.36</td></tr>
<tr><td>Deterministic (DJ)
5 098 kHz-4 250 MHz</td><td>0.42</td></tr>
<tr><td>Total (TJ)[1,2]</td><td>0.71</td></tr>
<tr><td colspan="8">1600-SM-LC-L and 1600-SM-LZ-I (note 4, 8, 9)</td></tr>
<tr><td>Sinusoidal swept freq.(SJ)[3]
10 196 kHz to > 35 MHz</td><td rowspan="4">UI</td><td rowspan="4">NA</td><td>0.10</td><td rowspan="4">note 5</td><td rowspan="4">note 6</td><td>note 7</td><td rowspan="4">NA</td></tr>
<tr><td>Data Dependent Pulse Width Shrinkage (DDPWS)</td><td>0.11</td><td>0.14</td></tr>
<tr><td>Deterministic (DJ)
8.4 MHz-7 000 MHz</td><td>0.31</td><td>0.22</td></tr>
<tr><td>Total (TJ)[1,2]</td><td>0.45</td><td>0.36</td></tr>
</table>

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 22, 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. Receiver sensitivity requirements at gamma R replace jitter tolerance.
7. Receiver jitter tracking is measured using the procedure described in FC-MSQS (reference [34]). 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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).
9. reclocker on Rx side has been assumed.

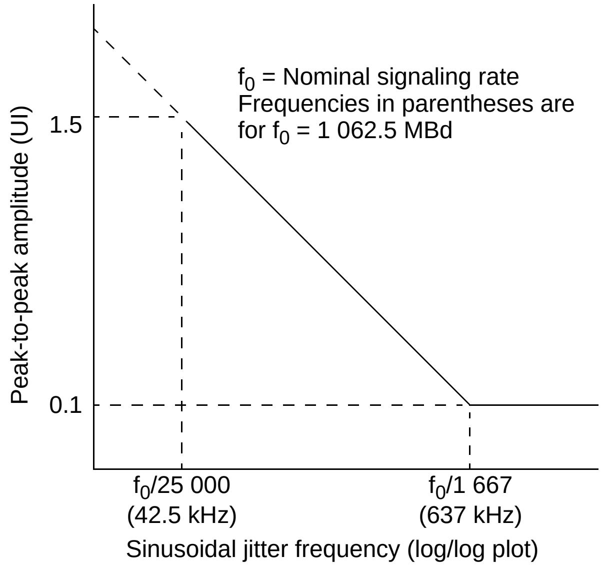


Figure 22 – Sinusoidal jitter mask

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 23 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.

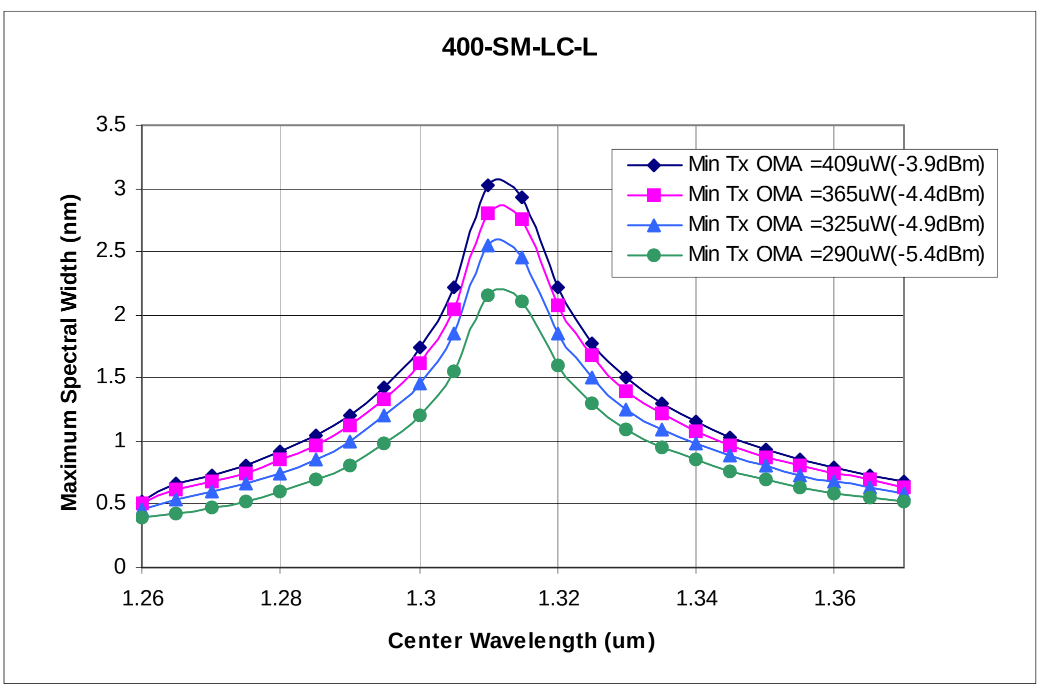


Figure 23 – 4GFC SM 10 km link

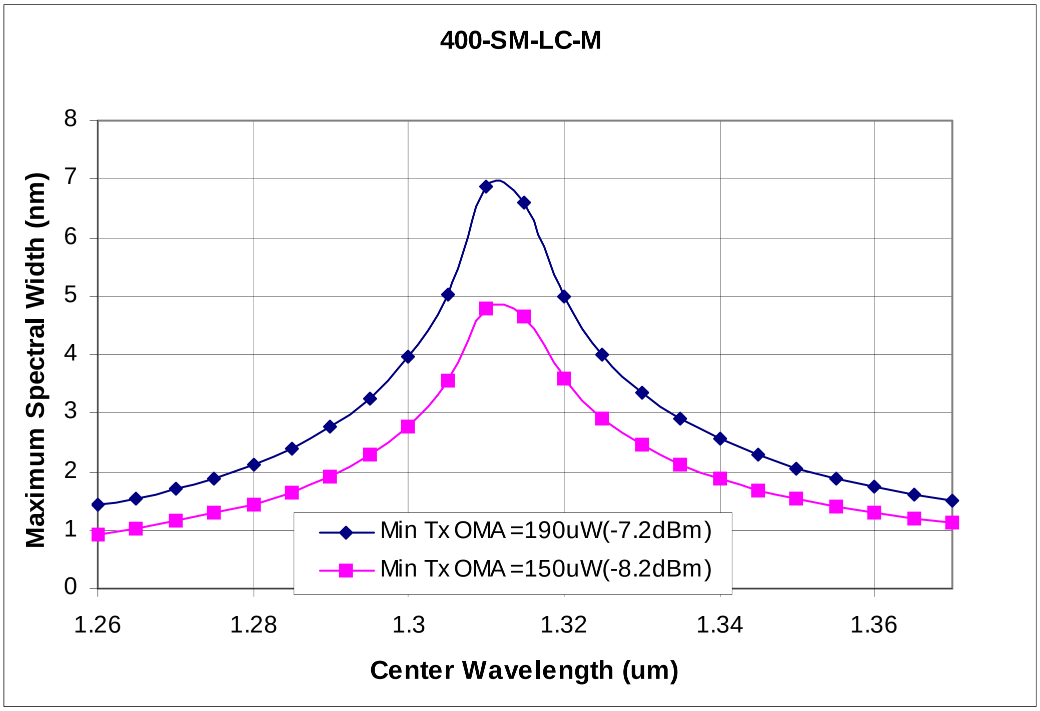


Figure 24 – 4GFC SM 4 km link

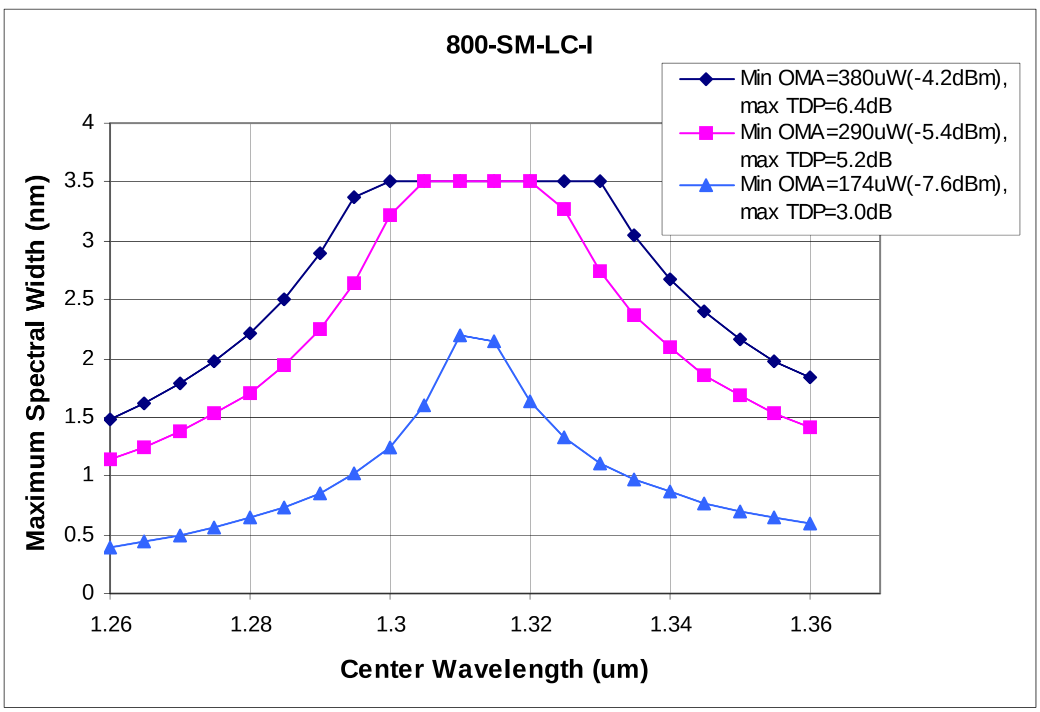


Figure 25 – 8GFC SM 1.4 km link

6.4 MM data links

6.4.1 MM general information

Table 11 gives the variant names, a general link description, and the gamma compliance point specifications for multi-mode optical fiber links running at 4GFC, 8GFC, and 16GFC. The specifications in the tables are intended to allow compliance to Class 1 laser safety.

Table 11 – Multimode link classes

FC-0	Unit	400-SN	800-SN	1600-SN	Note
Nominal signaling rate	MBd	4 250	8 500	14 025	10
Operating distance (M5)	m	0.5 - 150	0.5 - 50	0.5 - 35	1
Operating distance (M5E)	m	0.5 - 380	0.5 - 150	0.5 - 100	
Operating distance (M5F)	m	0.5 - 400	0.5 - 190	0.5 - 125	
Fiber core diameter	μm	50			2
Transmitter (gamma-T)					
Source type		Laser			
Center wavelength, min.(M5)	nm	830	840		14
Center wavelength, min.(M5E, M5F)	nm	840			
Center wavelength, max.	nm	860			
RMS spectral width, max.(M5)	nm	0.85	0.65	0.59	14
RMS spectral width, max.(M5E, M5F)	nm	0.65			
Average launched power, max.	dBm				3
Average launched power, min.	dBm	-9	-8.2	-7.8	4
Optical modulation amplitude, min.	mW (dBm)	0.247 (-6.1)	0.302 (-5.2)	0.331 (-4.8)	5
Rise/Fall time (20% - 80%), max.	ps	90	note 16		6
Transmitter waveform distortion penalty (TWDPo), max	dB	NA	4.3	NA	17
Vertical Eye Closure Penalty ($VECP_q$), max	dB	NA	NA	2.56	
RIN_{12}OMA, max.(M5)	dB/Hz	-118	-128	-128	7,14
RIN_{12}OMA, max.(M5E, M5F)	dB/Hz	-120	-128	-128	
Encircled flux (M5E, M5F)					18
Receiver (gamma- R)					
Average received power, max.	dBm	0			
Unstressed receiver sensitivity, OMA	mW (dBm)	0.061 (-12.1)	0.076 (-11.2)	0.089 (-10.5)	5,9
Return loss of receiver, min.	dB	12			
Rx jitter tolerance test, OMA	mW (dBm)	0.154 (-8.1)	0.200 (-7.0)	0.214 (-6.7)	13,19
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz, UI)	NA	(510, 1) (100, 5)	(840,1) (168,5)	15
Receiver electrical 3 dB upper cutoff frequency, max	GHz	5.0	12	18	8
Receiver electrical 10 dB upper cutoff frequency, max	GHz	12	NA	NA	
Stressed test source					
Stressed receiver sensitivity, OMA (M5)	mW (dBm)	0.138 (-8.6)	0.151 (-8.2)	0.170 (-7.7)	5,11
Stressed receiver sensitivity, OMA (M5E, M5F)	mW (dBm)	0.126 (-9.0)			
Receiver vertical eye closure penalty (M5)	dB	1.67	3.1	2.5	12
Receiver vertical eye closure penalty (M5E, M5F)	dB	0.75			
Receiver DCD component of DJ (at Tx)	UI	0.085	NA		
Receiver DDPWS component of DJ	UI	NA	0.238	0.14	20
Receiver DJ	UI		0.322	0.220	20

Table 11 – Multimode link classes

Notes:

1 The operating ranges shown here are based on MM fiber bandwidths given in table 20 and a 1.5 dB total connector loss. For link budget calculations methodology see FC-MSQS (reference [34]).

2 For details see sub-clause 8.2

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

4 The values are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.

5 See FC-MSQS (reference [34]).

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 FC-MSQS (reference [34])

7 See FC-MSQS (reference [34]).

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 FC-MSQS (reference [34]).

9 The unstressed receiver sensitivity is informative only. See FC-MSQS (reference [34]).

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

11 See FC-MSQS (reference [34]). The stressed receiver sensitivity values in the table are for system level BER measurements that include the effects of actual reclocker circuits. It is recommended for receivers not including a reclocker 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 See FC-MSQS (reference [34]). Receiver vertical eye closure penalty, VECP, is a test condition for measuring stressed receiver sensitivity and is not a required characteristic of the receiver. The values for 16GFC and 8GFC are calibrated with a 11 GHz and 7.5 GHZ fourth-order Bessel-Thomson filter respectively. The 4GFC VECP calibrations are with a wide band receiver.

13 For 1600-SN OMA is defined through a 11 GHz fourth-order Bessel-Thomson filter. For 800-SN OMA and RIN are defined through a 7.5-GHz fourth-order Bessel-Thomson filter.

14 The Tx specifications for 400-M5E-SN-I and 400-M5F-SN-I are tighter than for 400-M5-SN-I.

15 Receiver jitter tracking is defined in FC-MSQS (reference [34]).

16 Transmitter deterministic performance is controlled by TWDPo or VECPo.

17 $VECP_q$ for 1600-SN is calculated with a 1,0 equalizer and a Gaussian filter with a 16.6 GHz -3 dB (optical) bandwidth for the fiber simulation. TWDPo for 800-SN is calculated with a 1,0 equalizer and a Gaussian filter with a 9.84-GHz -3 dB (optical) bandwidth for the fiber simulation.

18 Encircled flux specifications in accordance with TIA-492AAAC-A and IEC 60793-2-10 or IEEE 802.3 clause 52 (reference [23]).

19 This is the optical input amplitude for testing compliance to the jitter tolerance at gamma R specified in table 14.

20 Receiver DDPWS and Receiver DJ are test conditions for measuring stressed receiver sensitivity and are not required characteristic of the receiver. The values for 16GFC and 8GFC are calibrated with a 11 GHz and a 7.5 GHz, fourth-order Bessel-Thomson filter respectively. See FC-MSQS (reference [34]). The effect of DDPWS is included in the required DJ.

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 pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see sub-clause 5.13). 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 26 and figure 27.

In figure 26, X1 shall be half the value given for total jitter at the gamma T point given in table 13. 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 FC-MSQS (reference [34]).

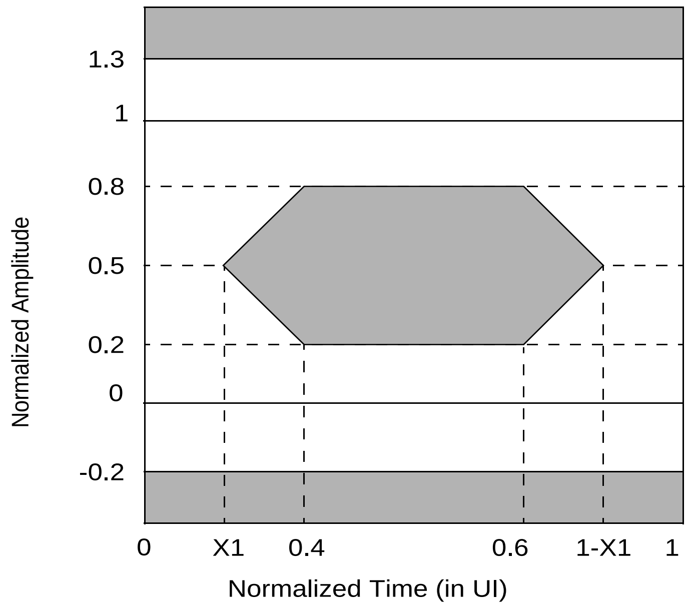


Figure 26 – MM transmitter eye mask for 4GFC

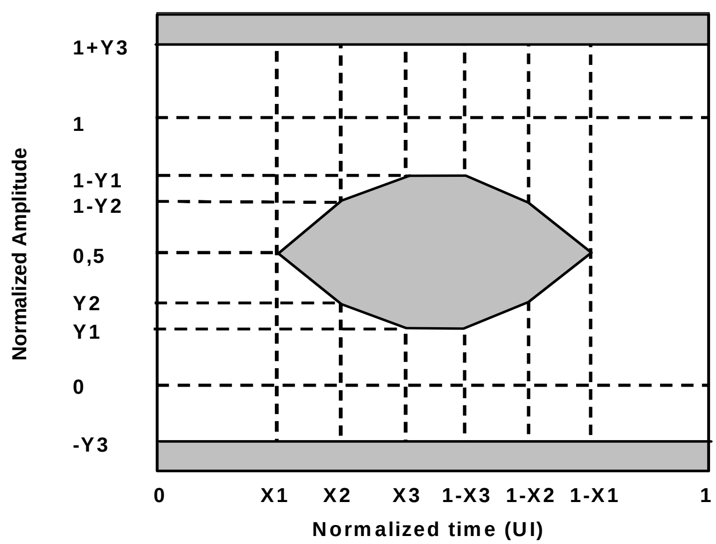


Figure 27 – MM transmitter eye mask for 8GFC and 16GFC

Table 12 – MM transmitter eye mask values for 16GFC and 8GFC

	8GFC & 16GFC	
	Value	**Unit**
X1	0.25	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.32	
Y2	0.35	
Y3	0.40	

The signal in figure 27 shall be measured using a jitter timing reference, e.g., Golden PLL. The mask applies at a probability of 10^{-3}.

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.

6.4.3 MM optical input interface

The receiver shall operate with a maximum BER of 10^{-12} when the input power falls within the range given in table 11 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 26 or figure 27. See FC-MSQS (reference [34]).

6.4.4 MM jitter budget

This 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 and FC-MSQS (reference [34]).

Receiver jitter shall comply to the listed values in table 13, over all allowable optical power input ranges between the maximum average power input and receiver jitter tolerance test (OMA) with the stressed receiver sensitivity waveform and meeting or better than $RIN_{12}OMA$ specification, as listed in table 11.

Table 13 – MM jitter output, max

	Units	β_T	δ_T	γ_T	γ_R	δ_R	β_R
400-Mx-SN-I (note 4, 9)							
Deterministic (DJ) (pk-pk)[3]	UI	NA	0.14	0.26	0.29	0.39	NA
Total (TJ) (pk-pk)[1,2,3]			0.26	0.44	0.48	0.64	
800-Mx-SN-y (note 4, 6, 9)							
Deterministic (DJ) (pk-pk)[3]	UI	NA	0.17	note 8	note 8	0.42	NA
Data Dependent Pulse width shrinkage (DDPWS) (pk-pk)[5]			0.11			0.36	
UJ (rms)[3,7]			0.02	0.03		NA	
Total (TJ) (pk-pk)[1,2,3]			0.31	NA		0.71	
1600-Mx-SN-y (note 4, 6, 9)							
Deterministic (DJ) (pk-pk)[3]	UI	NA	0.31	note 8	note 8	0.22	NA
Data Dependent Pulse width shrinkage (DDPWS) (pk-pk)[5]			0.11			0.14	
UJ (rms)[3,7]			0.03	0.03		NA	
Total (TJ) (pk-pk)[1,2,3]			0.45	NA		0.36	

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. The effect of DDPWS is included in DJ. See FC-MSQS (reference [34]).
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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).
7. UJ (rms) is the rms value of the uncorrelated jitter. See FC-MSQS (reference [34]).
8. Jitter values at γ_T and γ_R are controlled by TWDP or $VECP_q$ and stressed receiver sensitivity.
9. Test conditions for gamma R are over the range from the Rx jitter tolerance test, OMA to the average receive power max of table 11.

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

<table>
<tr><th></th><th>Unit</th><th>β_T</th><th>δ_T</th><th>γ_T</th><th>γ_R</th><th>δ_R</th><th>β_R</th></tr>
<tr><td colspan="8">**400-Mx-SN-I** (note 4)</td></tr>
<tr><td>**Sinusoidal swept freq.(SJ) 2 550 kHz to > 5 MHz**[3]</td><td rowspan="3">UI</td><td rowspan="3">NA</td><td colspan="4">0.10</td><td rowspan="3">NA</td></tr>
<tr><td>**Deterministic (DJ) 2 550 kHz-2 125 MHz**</td><td>0.14</td><td>0.26</td><td>0.29</td><td>0.39</td></tr>
<tr><td>**Total (TJ)**[1,2]</td><td>0.31</td><td>0.49</td><td>0.53</td><td>0.69</td></tr>
<tr><td colspan="8">**800-Mx-SN-y** (note 4, 8)</td></tr>
<tr><td>**Sinusoidal swept freq.(SJ) 5 098 kHz to > 20MHz**[3]</td><td rowspan="4">UI</td><td rowspan="4">NA</td><td colspan="2" rowspan="4">note 6</td><td colspan="2">note 7</td><td rowspan="4">NA</td></tr>
<tr><td>**Deterministic (DJ) 5 098 kHz-4 250 MHz**</td><td>0.32</td><td>0.42</td></tr>
<tr><td>**Data Dependent Pulse width shrinkage (DDPWS)**[5]</td><td>NA</td><td>0.36</td></tr>
<tr><td>**Total (TJ)**[1,2]</td><td>0.55</td><td>0.71</td></tr>
<tr><td colspan="8">**1600-Mx-SN-y** (note 4, 8, 9)</td></tr>
<tr><td>**Sinusoidal swept freq.(SJ) 10 196 kHz to > 35 MHz**[3]</td><td rowspan="4">UI</td><td rowspan="4">NA</td><td>0.10</td><td rowspan="4">note 6</td><td colspan="2">note 7</td><td rowspan="4">NA</td></tr>
<tr><td>**Deterministic (DJ) 8.4 MHz-7 000 MHz**</td><td>0.31</td><td>0.22</td><td>0.22</td></tr>
<tr><td>**Data Dependent Pulse width shrinkage (DDPWS)**[5]</td><td>0.11</td><td>NA</td><td>0.14</td></tr>
<tr><td>**Total (TJ)**[1,2]</td><td>0.45</td><td>0.60</td><td>0.36</td></tr>
</table>

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 22, 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 FC-MSQS (reference [34]).

6 Not specified.

7 Receiver jitter tracking is defined in FC-MSQS (reference [34]).

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 higher symbol rate systems, and de-embedding test fixtures is complicated. Therefore, the values for 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).

9 A reclocker is required to meet the jitter budget.

7 Optical interfaces

7.1 Optical interface general information

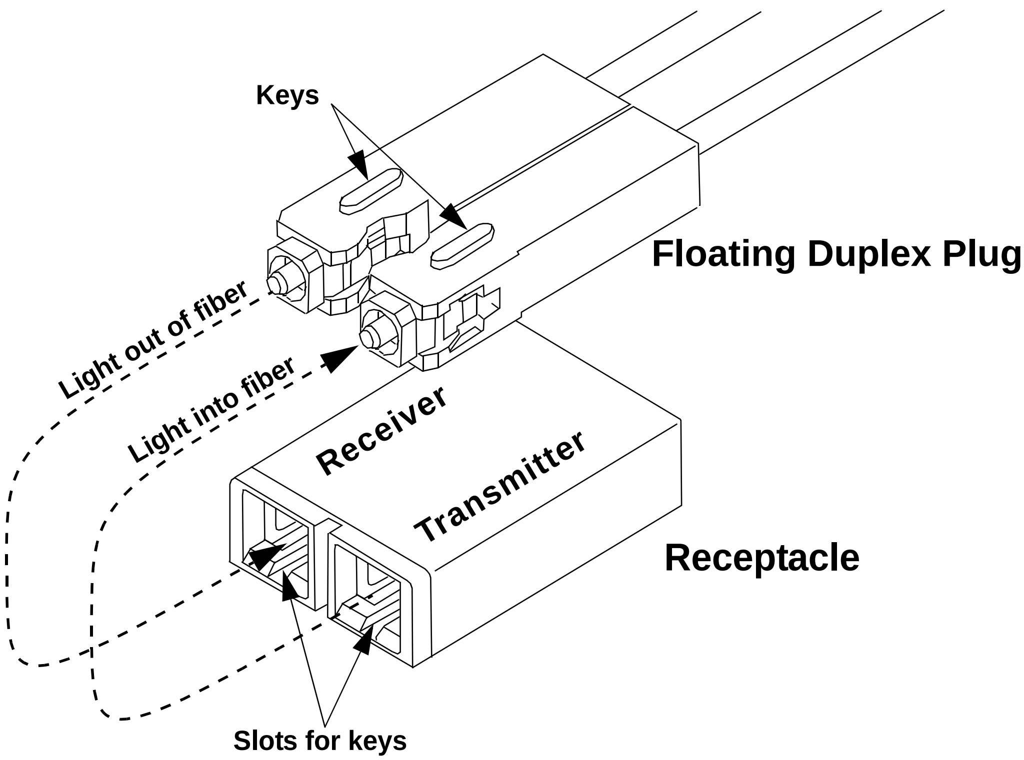
The primary function of the optical interface connector is to align the optical transmission fiber mechanically to an optical port on a component such as a receiver or a transmitter. The fiber optical interfaces are shown here for reference only. The fiber optical interfaces shall meet the optical, mechanical 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 (reference [21]), Fiber optic connector interfaces - Part 4: Type SC connector family.

Figure 28 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 28 – 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 tolerance of the distance between the center line of the active optical bores (ref DB) is increased from 12.65/12.75 mm to 12.60/12.80 mm. This is to facilitate the use of Floating Duplex SC Plug Connectors (example IEC 60874-19-1 reference [16]) 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 (reference [22]), Fiber 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 29 outlines the LC interface.

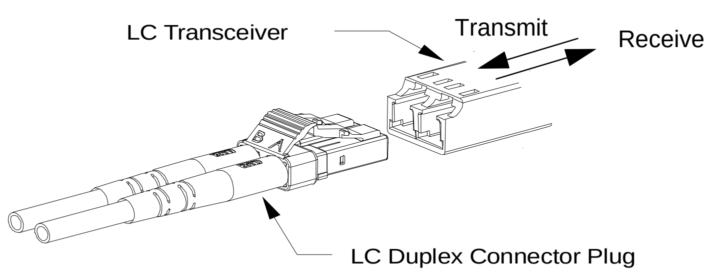


Figure 29 – Duplex LC interface

7.4 Other optical interfaces

For additional obsoleted optical connectors such as MT-RJ and MU please refer to FC-PI-2 (reference [3]).

8 Optical fiber cable plant specification

8.1 SM cable plant specification

8.1.1 SM cable plant overview

This clause specifies a single-mode cable plant for the Fibre Channel data rates of 4GFC, 8GFC, and 16GFC at their rated distance of 10 km and a single-mode cable plant for three other variants: one for 4GFC at its rated distance of 4 km, another for 8GFC at its rated distance of 1.4 km, and finally, one for 16GFC at its rated distance of 2 km.

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 cable plant 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	**400-SM-LC-M**	**400-SM-LC-L**	**800-SM-LC-L**	**800-SM-LC-I**	**1600-SM-LC-L**	**1600-SM-LZ-I**
Sub-class	6.3					
Operating Range (m)	2 -4 000	2 -10 000	2 -10 000	2 -1 400	2 -10 000	2 -2 000
Loss Budget (dB)	4.8	7.8	6.4 note 1	2.6 note 1	6.4 note 1	2.6 note 1
Notes: 1 Lower loss fiber is assumed for 16GFC and 8GFC than other speeds.						

8.1.2 SM optical fiber type

The optical fiber shall conform to IEC 60793-2-50, Type B1.1, IEC 60793-2-50, Type B1.3 and IEC 60793-2-50, Type B6 Optical fibers - Part 2: Product Specifications. All of the single-mode fibers have a nominal zero-dispersion wavelength in the 1310 nm transmission window. These fibers are commonly referred to as “dispersion-unshifted fibers.” B1.3 fibers are commonly referred to as “low water peak” single-mode fibers and B6 fibers are commonly referred to as “bend insensitive single-mode fibers.

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

Connectors and splices shall each have discrete reflectance greater than 26 dB as measured by the methods of IEC 61300-3-6 (reference [20]).

8.2 MM cable plant specification

8.2.1 MM cable plant overview

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, and 18 as appropriate are met. See annex B for examples with different connection loss.

Compliance points for operation over these cable plants are specified in 6.4. The operating ranges shown here are based on MM fiber given in table 20. For link budget calculations and other MM fibers see annex A.

Table 16 – Multimode cable plant for OM2 limiting variants

FC-0	**400-M5-SN-I**	**800-M5-SN-S**	**1600-M5-SN-S**
Data rate (MB/s)	400	800	1600
Operating range (m)	0.5 -150	0.5-50	0.5-35
Loss Budget (dB)	2.06	1.68	1.63

Table 17 – Multimode cable plant for OM3 limiting variants

FC-0	**400-M5E-SN-I**	**800-M5E-SN-I**	**1600-M5E-SN-I**
Data rate (MB/s)	400	800	1600
Operating range (m)	0.5-380	0.5-150	0.5-100
Loss Budget (dB)	2.88	2.04	1.86

Table 18 – Multimode cable plant for OM4 limiting variants

FC-0	**400-M5F-SN-I**	**800-M5F-SN-I**	**1600-M5F-SN-I**
Data rate (MB/s)	400	800	1600
Operating range (m)	0.5-400	0.5-190	0.5-125
Loss Budget (dB)	2.95	2.19	1.95

8.2.2 MM optical fiber types

The fiber optic cable shall conform to IEC 60793-2-10 Type A1a fibers (reference [13]). See table 19.

Table 19 – Multimode fiber types

Nominal Core Diameter	**Cladding Diameter**	**Nominal Numerical Aperture**	**IEC 60793-2-10**
50 μm	125 μm	0.20	Type A1a.1 (OM2)
50 μm	125 μm	0.20	Type A1a.2 (OM3)
50 μm	125 μm	0.20	Type A1a.3 (OM4)

8.2.3 MM modal bandwidth

The following normalized bandwidth values are based on nominal source wavelengths of 850 nm and 1 300 nm as described in table 20.

Table 20 – Multimode fiber

Optical fiber cable type note 1	**Fiber reference**	**Wavelength** (nm) note 5	**Overfilled modal bandwidth-length product (MHz*km)** note 2,6	**Effective modal bandwidth-length product (MHz*km)**
50/125 *µ*m 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 *µ*m (OM3)	TIA-492AAAC IEC 60793-2-10 Type A1a.2	850 1 300	1 500 500	2 000 (note 3) Not Required
850 nm laser-optimized 50/125 *µ*m (OM4)	TIA-492AAAD IEC 60793-2-10 Type A1a.3	850 1 300	3 500 500	4 700 (note 4) Not Required

Notes:

1 The designations OM2, OM3, and OM4 listed in the table correspond to the referenced cable fiber designations in ISO/IEC 11801.
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 A.
3 A minimum effective modal bandwidth-length product at 850 nm of 2 000 MHz*km for OM3 is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA 492AAAC (reference [31]) or IEC 60793-2-10 (reference [13]), with a 50-µm fiber meeting the specifications in TIA 492AAAC (reference [31]) or IEC 60793-2-10 (reference [13]) for Type A1a.2.
4 A minimum effective modal bandwidth-length product at 850 nm of 4 700 MHz*km for OM4 is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA 492AAAD (reference [32]) or IEC 60793-2-10 (reference [13]), with a 50-µm fiber meeting the specifications in TIA 492AAAD (reference [32]) or IEC 60793-2-10 (reference [13]) for Type A1a.3.
5 1 300-nm MM operation is not part of this standard.
6 OFL BW specifications are not used for OM3 and OM4 fiber variants in this standard.

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, or table 18. 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 61280-4-1 (reference [19]).

For informative loss budgets for different distances see annex B.

8.2.5 MM optical return loss

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

8.3 Connectors and splices

Connectors and splices 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 B for connector losses different than 1.5 dB.

9 Electrical interface specification - single lane variants

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.

9.1 General electrical characteristics

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.

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 which 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 21.

Table 21 – General electrical characteristic

	Units	**400-DF-EL-S** note 1	**800-DF-EL-S** note 1	**800-DF-EA-S** note 1	**1600-DF-EL-S** note 1	**1600-DF-EA-S** note 1
Data rate note 2	MB/s	400	800		1600	
Nominal symbol rate	MBd	4 250	8 500		14 025	
Tolerance	ppm	±100				
Gamma bulk cable						
Impedance	Ω (nom)	150	NA			
Delta PCB & direct attached cable						
Impedance	Ω (nom)	100				
Epsilon PCB						
Impedance	Ω (nom)	NA	NA	100	NA	100
Beta PCB						
Impedance	Ω (nom)	100	NA	100	NA	

Notes:
1 The impedances shown 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).

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 interoperability points are defined in sub-clause 9.10. The 400-DF-EL-S shall also meet the requirements of a compliance interconnect specified in sub-clause 9.9. Details for the measurement process are specified in FC-MSQS (reference [34]).

Table 22 – 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>400-DF-EL-S
note 5</th><th>800-DF-EL-S
note 5</th><th>800-DF-EA-S</th><th>1600-DF-EL-S
note 5</th><th>1600-DF-EA-S</th></tr>
<tr><td colspan="8">Beta T point</td></tr>
<tr><td rowspan="4">Eye mask
Figure 40
note 1</td><td>B</td><td>mV</td><td rowspan="4">See sub-clause 9.2.2</td><td rowspan="8">NA</td><td rowspan="4">See sub-clause 9.6</td><td rowspan="8" colspan="2">NA</td></tr>
<tr><td>A</td><td>mV</td></tr>
<tr><td>X1</td><td>UI</td></tr>
<tr><td>X2</td><td>UI</td></tr>
<tr><td>Rise / Fall Time
20--80%
note 4,6</td><td>Min</td><td>ps</td><td>60
note 7</td><td>40
note 7</td></tr>
<tr><td>Return Loss</td><td></td><td>dB</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>30</td><td>30
note 4</td></tr>
<tr><td>Common mode voltage, (spectral peak) (rms)</td><td>Max</td><td>mV</td><td>NA</td><td>20
note 12</td></tr>
<tr><td colspan="8">Epsilon T point (note 11)</td></tr>
<tr><td rowspan="4">Eye mask
Figure 40
note 1</td><td>B</td><td>mV</td><td rowspan="8" colspan="2">NA</td><td rowspan="4">See sub-clause 9.6</td><td rowspan="8">NA</td><td rowspan="4">See sub-clause 9.7.1</td></tr>
<tr><td>A</td><td>mV</td></tr>
<tr><td>X1</td><td>UI</td></tr>
<tr><td>X2</td><td>UI</td></tr>
<tr><td>Rise / Fall Time 20--80%
note 4,6</td><td>Min</td><td>ps</td><td>40
note 7</td><td>24
note 7</td></tr>
<tr><td>Return Loss</td><td></td><td>dB</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>30
note 4</td><td>30
note 4</td></tr>
<tr><td>Common mode voltage, (spectral peak) (rms)</td><td>Max</td><td>mV</td><td>20
note 12</td><td>20
note 13</td></tr>
<tr><td colspan="8">Delta T Point (note 11)</td></tr>
<tr><td rowspan="4">Eye Mask
Figure 40
note 1,10</td><td>B</td><td>mV</td><td>800</td><td colspan="3">350</td><td rowspan="4">See sub-clause 9.7.1</td></tr>
<tr><td>A</td><td>mV</td><td>325</td><td colspan="3">90</td></tr>
<tr><td>X1</td><td>UI</td><td colspan="4">note 2</td></tr>
<tr><td>X2</td><td>UI</td><td>X1+0.19</td><td colspan="3">0.5</td></tr>
<tr><td>Return Loss</td><td></td><td>dB</td><td colspan="5">See sub-clause 9.2.4</td></tr>
<tr><td>Common Mode Voltage, (rms)</td><td>Max</td><td>mV</td><td>30</td><td colspan="4">30
note 4</td></tr>
<tr><td>Common mode voltage, (spectral peak) (rms)</td><td>Max</td><td>mV</td><td>NA</td><td colspan="2">20
note 12</td><td colspan="2">20
note 13</td></tr>
</table>

Table 22 – Signal output and return loss requirements at β_T, ε_T, δ_T and γ_T

		Units	**400-DF-EL-S** note 5	**800-DF-EL-S** note 5	**800-DF-EA-S**	**1600-DF-EL-S** note 5	**1600-DF-EA-S**
Gamma T Point							
Eye mask Figure 40 note 1	B	mV	See sub-clause 9.2.2	NA			
	A	mV					
	X1	UI					
	X2	UI					
Rise / Fall Time 20--80% note 4,6	Min	ps	60 note 7				
Return loss		dB	See sub-clause 9.2.4				
Transmitter off voltage (Tx_off) note 3	Max	mV (p-p)	70				
Common Mode Voltage, (rms)	Max	mV	30				
Eye mask normalized amplitudes, at all points							
Y1			0.2 note 1, 8	note 9			
Y2			0.1				

Notes:

1 Transmitters shall meet both the absolute and normalized amplitude requirements.
2 The value of X1 shall be half the value for total jitter given table 29. The signal shall be measured using a jitter timing reference, e.g., Golden PLL. See sub-clause 9.5.
3 The ‘transmitter off voltage’ is the maximum voltage measured at point γ_T (across a resistive load as defined in sub-clause 9.10) when the transmitter is logically turned off or is un-powered.
4 Rise/fall time and common mode voltage measurements are to be made using an oscilloscope with a bandwidth including probes of at least 1.8 times the signaling rate. See FC-MSQS (reference [34]).
5 All specifications are based on differential measurements unless specifically listed otherwise.
6 To eliminate the effects of pre-compensation, the minimum rise time shall be measured on a clock-like sequence consisting of alternating one and zero symbols with a period of 2 unit intervals.
7 Informative only.
8 Relative (Y1 and Y2) values do not apply to measurements at the output of a TCTF. See table 23 for applicable absolute values
9 Relative eye mask is not required for 8GFC and 16GFC.
10 DC blocking shall be provided on the receive side of the delta-T point connection.
11 The values listed in this table are at the appropriate compliance points which for delta and epsilon 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 8GFC and 16GFC delta and epsilon points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).
12 From 50 MHz to 8.5 GHz, each spectral component of the Tx common mode voltage shall be less than the specified value when measured with a 1 MHz measurement bandwidth while transmitting ARB (ff).
13 From 50 MHz to 14 GHz, each spectral component of the Tx common mode voltage shall be less than the specified value when measured with a 1 MHz measurement bandwidth while transmitting 64b/66b encoded IDLE or PRBS31.

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 30. One, shown in the top half of figure 30, is the zero length interconnect case, and the other, shown in the bottom half of figure 30 is measured through a transmitter compliance transfer function. The signal requirements shall meet the output voltage and timing requirements listed in table 23 and table 29 measured through the transmitter compliance function as described in 9.9.

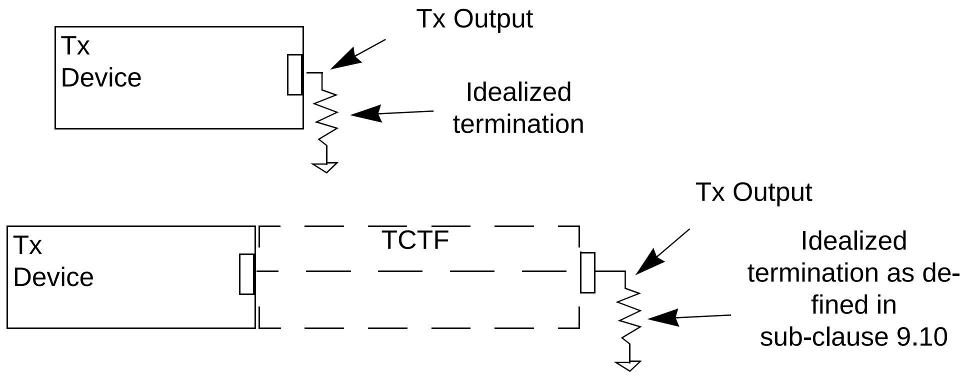


Figure 30 – Transmit device output, Zero length and through TCTF

Table 23 – Transmitted signal mask requirements for 400-DF-EL-S variant

		Units	β_T	γ_T
Eye Mask figure 40	**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 29. 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 31. The signal amplitude shall be adjusted to the minimum allowed at the interoperability point in table 24. The signal amplitude also shall not exceed the value of B stated in table 22 at any point in time. The BER shall be better than 10^{-12}. The values for the system input tolerance signal are listed in table 24.

Table 24 – 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 40	**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 29. The signal shall be measured using a jitter timing reference, e.g., Golden PLL.
2 Delta points are not calibrated through a TCTF.

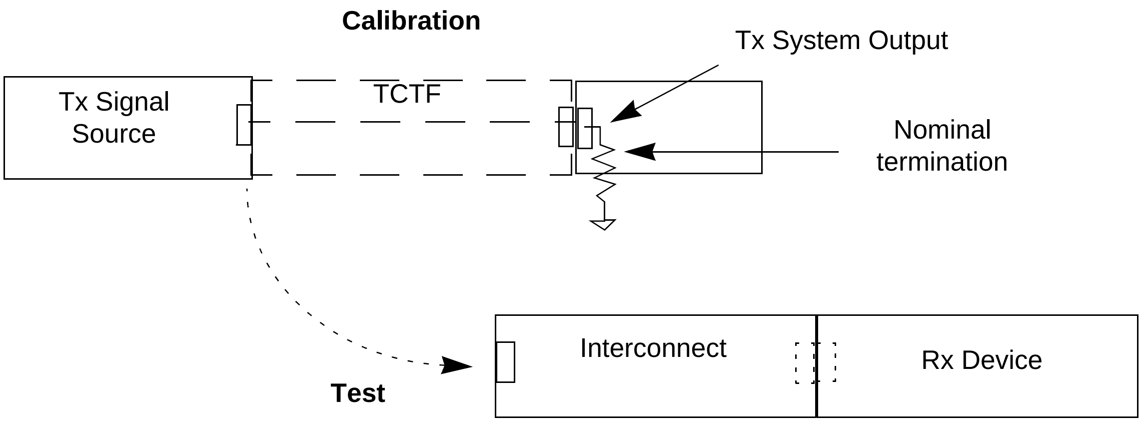


Figure 31 – Transmit, system (interconnect + receiver device) input tolerance test

9.2.4 Return loss at the transmitter compliance points

There are five return loss requirements at any transmit device connector. One is the differential S parameter of the transmit device itself, (SDD22). The second is the differential S parameter of the downstream system (SDD11). The third is the common mode S parameter of the device itself (SCC22) and SCC11 for 1600-DF-EL-S and 1600-DF-EA-S variants. These are shown in figures 33 and 34. The fourth requirement is the differential to common mode conversion ratio of the device itself (SCD22) and the fifth is the differential to common mode conversion ratio of the downstream system (SCD11). The S parameter requirements are listed in table 25. See FC-MSQS (reference [34]) for test methodology.

Table 25 – S parameter 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	33	-12	-5.0	0	11.3	50	3 200
β_T SDD11		-12	-5.0				
δ_T SDD22	34	-12	-6.0				
δ_T SDD11		-12	-9.0				
γ_T SDD22	33	-12	-5.0				
γ_T SDD11		-12	-5.0				
β_T SCC22		-6	-3.0				
δ_T SCC22	34	-6	-4.0				
γ_T SCC22	33	-6	-3.0				

Table 25 – S parameter at the Transmit Compliance Points

Compliance point	**Figure**	**L** (dB)	**N** (dB)	**H** (dB)	**S** (dB/dec)	**Fmin** (MHz)	**Fmax** (MHz)
800-DF-Ex-S (note 1,2)							
β_T SDD22	33	-10	-5.9	0	13.33	50	8 500
β_T SDD11		-10	-8.0	0	13.33		
β_T SCC22		-6	-3.0	0	13.33		
β_T SCD11		-10	-10.0	-10	0		
β_T SCD22		-10	-10.0	-10	0		
ε_T SDD22		-10	-5.9	0	13.33		
ε_T SDD11	33	-10	-8.0	0	13.33	50	8 500
ε_T SCC22		-6	-3.0	0	13.33		
ε_T SCD11		-10	-10.0	-10	0		
ε_T SCD22		-10	-10.0	-10	0		
δ_T SDD22	34	-10	-5.9	0	13.33		
δ_T SDD11		-10	-6.4	0	10.00		
δ_T SCC22		-6	-2.0	0	4.00		
δ_T SCD11		-10	-10.0	-10	0		
δ_T SCD22		-10	-10.0	-10	0		
γ_T SDD22	NA						
γ_T SDD11							
γ_T SCC22							
1600-DF-EL-S (note 1,2)							
δ_T SDD22	34	-10	-5.9	0	13.33	50	14 000
δ_T SDD11		-10	-6.4	0	10.00		
δ_T SCC22		-6	-2.0	0	4.00		
δ_T SCC11		-6	-2.0	0	4.00		
δ_T SCD11		-10	-10.0	-10	0		
δ_T SCD22		-10	-10.0	-10	0		

Table 25 – S parameter at the Transmit Compliance Points

Compliance point	Figure	L (dB)	N (dB)	H (dB)	S (dB/dec)	Fmin (MHz)	Fmax (MHz)
1600-DF-EA-S (note 1,2)							
ε_T SDD22	33	-10	-5.9	0	13.33	50	14 000
ε_T SDD11		-10	-4.0	0	3.00		
ε_T SCC22		-6	-3.0	0	13.33		
ε_T SCC11		-6	-3.0	0	3.00		
ε_T SCD11		-6	-6.0	-6	0		
ε_T SCD22		-10	-10.0	-10	0		
δ_T SDD22	34	-10	-5.9	0	13.33		
δ_T SDD11		-10	-6.0	0	6.00		
δ_T SCC22		-6	-2.0	0	4.00		
δ_T SCC11		-6	-2.0	0	4.00		
δ_T SCD11		-6	-6.0	-6	0		
δ_T SCD22		-10	-10.0	-10	0		

Notes:
1 The S parameter requirements are given by Sxxnn in the equation. Y(f)=N+S*log(freq/0.5*symbol rate).
2 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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).

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

The variables in table 25 are represented graphically in figure 32.

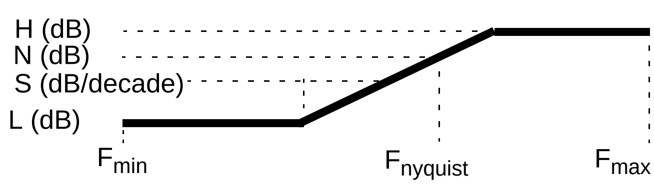


Figure 32 – Sxxnn graphical representation

Fibre Channel transmitter devices shall meet the SCC22 (and SCC11 if required) common mode S parameter as specified in table 25. The reference impedance for the differential mode S parameter measurement is 100 Ohms. The reference impedance for the common mode S parameter measurement is 25 Ohms.

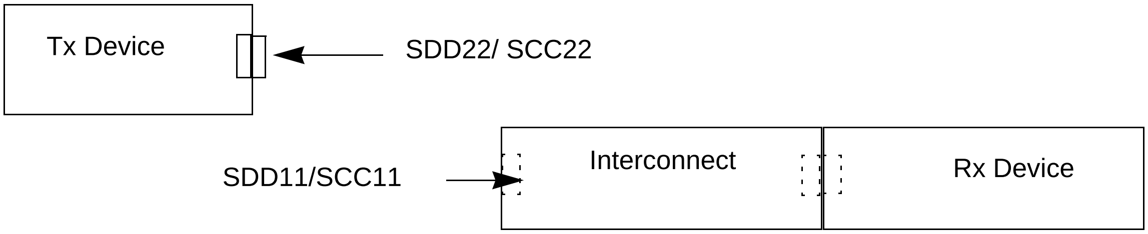


Figure 33 – Sxx at beta T, epsilon T, and gamma T

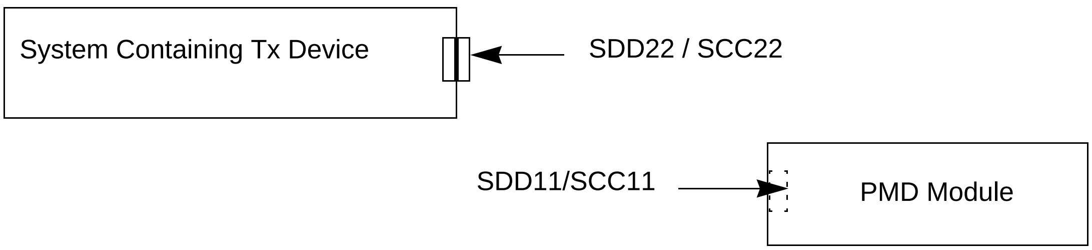


Figure 34 – Sxx at delta T

9.3 Receive device signal characteristics

9.3.1 General

This sub-clause defines the interoperability requirements of the delivered signal at the receive device end of a TxRx Connection. Test loads for interoperability points are defined in sub-clause 9.10.

Table 26 – Signal output and return loss requirements at β_R, ε_R, δ_R and γ_R

		Units	**400-DF-EL-S** note 3	**800-DF-EL-S** note 3	**800-DF-EA-S** note 3	**1600-DF-EL-S** note 3	**1600-DF-EA-S** note 3
Gamma R point							
Eye mask (note 1) figure 41	A	mV	138	NA			
	B	mV	800 note 4				
	X1	UI	note 1				
	X2	UI	0.5				
Return loss		dB	See sub-clause 9.3.3				
Common mode voltage, rms	Max	mV	40				
Delta R point (note 6)							
Eye mask (note 2,5) figure 41	A	mV	185	170	See sub-clause 9.6	170	See sub-clause 9.7
	B	mV	800 note 4	425		425	
	X1	UI	note 1			note 1	
	X2	UI	0.5			0.5	

Table 26 – Signal output and return loss requirements at β_R, ε_R, δ_R and γ_R

Return loss		dB	See sub-clause 9.3.3				
Common mode voltage, rms	Max	mV	30				NA
Epsilon R point (note 6)							
Eye mask (note 2) figure 41	A	mV	NA		See sub-clause 9.6	NA	See sub-clause 9.7
	B	mV					
	X1	UI					
	X2	UI					
Return loss		dB			See sub-clause 9.3.3		See sub-clause 9.3.3
Common mode voltage, rms	Max	mV			30		NA
Common mode voltage, spectral peak, rms	Max	mV			30		NA
Beta R point							
Eye mask (note 2) figure 41	A	mV	138	NA	See sub-clause 9.6	NA	
	B	mV	800 note 4				
	X1	UI	note 1				
	X2	UI	0.5				
Return loss		dB	See sub-clause 9.3.3		See sub-clause 9.3.3		
Common mode voltage, rms	Max	mV	40		30		

Notes:
1 The value for X1 shall be half the value given for total jitter in table 29. 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 9.5.
3 All specifications are based on differential measurements unless specifically listed otherwise.
4 All variants of type 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.
5 DC blocking shall be provided by the transmitter prior to the delta-R point.
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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).

9.3.2 DF-EL-S receiver device signal tolerance

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 35. 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 figure 36. For signal stress test apparatus see FC-MSQS (reference [34]). Signal tolerance amplitude and jitter requirements at receive interoperability points are listed in table 27.

Table 27 – DF-EL-S requirements at receive interoperability points

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">Units</th><th colspan="3">400-DF-EL-S</th><th>800-DF-EL-S</th><th>1600-DF-EL-S</th></tr>
<tr><th>β_R</th><th>δ_R</th><th>γ_R</th><th>δ_R</th><th>δ_R</th></tr>
<tr><td rowspan="4">Eye Mask figure 36</td><td>A</td><td>mV</td><td>138</td><td>170</td><td>138</td><td>170</td><td>170</td></tr>
<tr><td>B</td><td>mV</td><td colspan="3">800</td><td>425</td><td>425</td></tr>
<tr><td>X1</td><td>UI</td><td colspan="5">note 1</td></tr>
<tr><td>X2</td><td>UI</td><td colspan="5">0.5</td></tr>
<tr><td>Rx jitter tracking test, VMA (note 2)</td><td></td><td>mV</td><td colspan="3" rowspan="2">NA</td><td>340</td><td>340</td></tr>
<tr><td>Rx jitter tracking test, jitter frequency and pk-pk amplitude (note 2)</td><td></td><td>(kHz,UI)</td><td>(510, 1)
(100, 5)</td><td>(840,1)
(168,5)</td></tr>
<tr><td colspan="8">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 Receiver jitter tracking is measured using the procedure described in FC-MSQS (reference [34]).</td></tr>
</table>

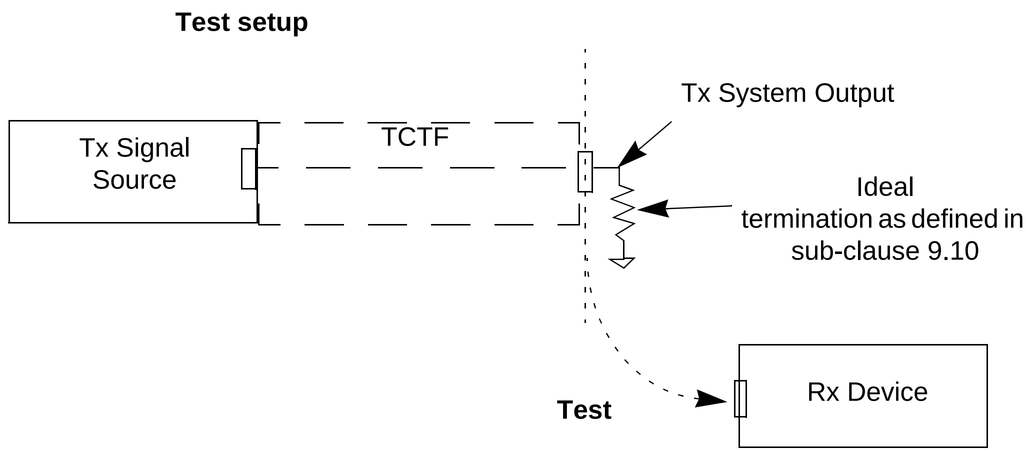


Figure 35 – Signal tolerance test set up for Rx device at beta R and gamma R

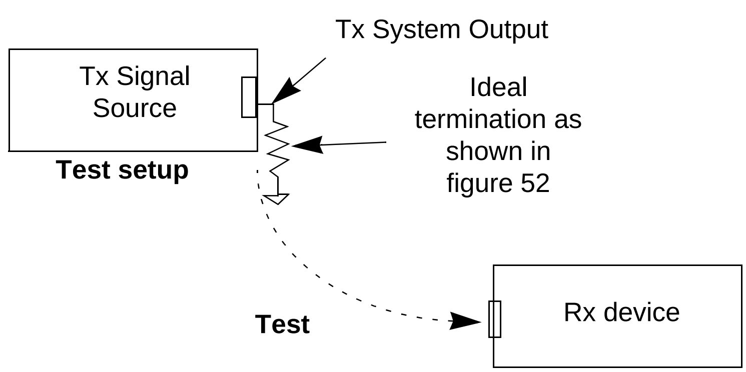


Figure 36 – Signal tolerance test set up for Rx device at delta R

9.3.3 Return loss at the receive device compliance points

There are five return loss requirements at any receive device connector. One is the differential S parameter of the receive device itself, (SDD11). The second is the differential S parameter of the upstream system (SDD22). The third is the common mode S parameter of the device itself (SCC22) and SCC11 for 1600-DF-EL-S and 1600-DF_EA-S variants. These are shown in figures 38 and 39. The fourth requirement is the differential to common mode conversion ratio of the device itself (SCD11) and the fifth is the differential to common mode conversion ratio of the upstream system (SCD22). The S parameter requirements are listed in table 28. See FC-MSQS (reference [34]) for test methodology.

Table 28 – S parameter at the receive device 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 colspan="8">400-DF-EL-S (note 1,2)</td></tr>
<tr><td>β_R SDD22</td><td rowspan="2">38</td><td>-12</td><td>-5.0</td><td rowspan="9">0</td><td rowspan="9">11.3</td><td rowspan="9">50</td><td rowspan="9">3 200</td></tr>
<tr><td>β_R SDD11</td><td>-12</td><td>-5.0</td></tr>
<tr><td>δ_R SDD22</td><td rowspan="2">39</td><td>-12</td><td>-9.0</td></tr>
<tr><td>δ_R SDD11</td><td>-12</td><td>-6.0</td></tr>
<tr><td>γ_R SDD22</td><td rowspan="3">38</td><td>-12</td><td>-5.0</td></tr>
<tr><td>γ_R SDD11</td><td>-12</td><td>-5.0</td></tr>
<tr><td>β_R SCC22</td><td>-6</td><td>-3.0</td></tr>
<tr><td>δ_R SCC22</td><td>39</td><td>-6</td><td>-7.0</td></tr>
<tr><td>γ_R SCC22</td><td>38</td><td>-6</td><td>-3.0</td></tr>
<tr><td colspan="8">800-DF-Ex-S (note 1,2)</td></tr>
<tr><td>β_R SDD22</td><td rowspan="8">38</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td><td rowspan="8">50</td><td rowspan="8">8 500</td></tr>
<tr><td>β_R SDD11</td><td>-10</td><td>-5.9</td><td>0</td><td>13.33</td></tr>
<tr><td>β_R SCC22</td><td>-6</td><td>-3.0</td><td>0</td><td>13.33</td></tr>
<tr><td>β_R SCD11</td><td>-10</td><td>-10.0</td><td>-10</td><td rowspan="2">NA</td></tr>
<tr><td>β_R SCD22</td><td>-10</td><td>-10.0</td><td>-10</td></tr>
<tr><td>ε_R SDD22</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_R SDD11</td><td>-10</td><td>-5.9</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_R SCC22</td><td>-6</td><td>-3.0</td><td>0</td><td>13.33</td></tr>
<tr><td>ε_R SCD11</td><td rowspan="2">38</td><td>-10</td><td>-10.0</td><td>-10</td><td rowspan="2">NA</td><td rowspan="7">50</td><td rowspan="7">8 500</td></tr>
<tr><td>ε_R SCD22</td><td>-10</td><td>-10.0</td><td>-10</td></tr>
<tr><td>δ_R SDD22</td><td rowspan="3">39</td><td>-10</td><td>-8.0</td><td>0</td><td>13.33</td></tr>
<tr><td>δ_R SDD11</td><td>-10</td><td>-6.4</td><td>0</td><td>10.00</td></tr>
<tr><td>δ_R SCC22</td><td>-6</td><td>-2.0</td><td>0</td><td>4.00</td></tr>
<tr><td>δ_R SCD11</td><td rowspan="2">38</td><td>-10</td><td>-10.0</td><td>-10</td><td rowspan="2">NA</td></tr>
<tr><td>δ_R SCD22</td><td>-10</td><td>-10.0</td><td>-10</td></tr>
<tr><td>γ_R SDD22</td><td colspan="7" rowspan="3">NA</td></tr>
<tr><td>γ_R SDD11</td></tr>
<tr><td>γ_R SCC22</td></tr>
</table>

Table 28 – S parameter at the receive device compliance points

Compliance point	Figure	L (dB)	N (dB)	H (dB)	S (dB/dec)	Fmin (MHz)	Fmax (MHz)
1600-DF-EL-S (note 1,2)							
δ_R SDD22	39	-10	-8.0	0	13.33	50	14 000
δ_R SDD11		-10	-6.4	0	10.00		
δ_R SCC22		-6	-2.0	0	4.00		
δ_R SCC11		-6	-2.0	0	4.00		
δ_R SCD22		-10	-10	-10	0		
δ_R SCD11		-10	-10	-10	0		
1600-DF-EA-S (note 1,2)							
ε_R SDD22	38	-10	-4.0	0	3.00	50	14 000
ε_R SDD11		-10	-6.0	0	13.33		
ε_R SCC22		-6	-3.0	0	3.00		
ε_R SCC11		-6	-3.0	0	13.33		
ε_R SCD22		-6	-6.0	-6	0		
ε_R SCD11		-10	-10	-10	-10		
δ_R SDD22		-10	-6.0	0	6.00		
δ_R SDD11		-10	-6.0	0	13.33		
δ_R SCC22		-6	-2.0	0	4.00		
δ_R SCC11		-6	-2.0	0	4.00		
δ_R SCD22		-6	-6.0	-6	0		
δ_R SCD11		-10	-10	-10	0		

Notes:

1. The S parameter requirements are given by Sxxnn in the equation. Y(f)=N+S*log(freq/0.5*symbol rate).
2. 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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).

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

The variables in table 28 are represented graphically in figure 37.

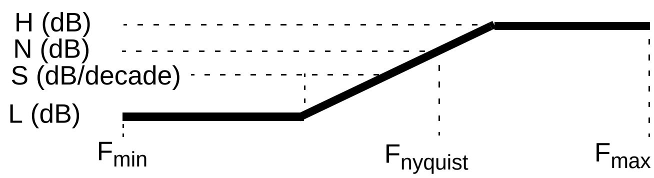


Figure 37 – Sxxnn graphical representation

Fibre Channel receiver devices shall meet the SCC22 (and SCC11 if required) common mode S parameter within the frequency ranges specified in table 28. The reference impedance for the differential mode S parameter measurement is 100 Ohms. The reference impedance for the common mode S parameter measurement is 25 Ohms.

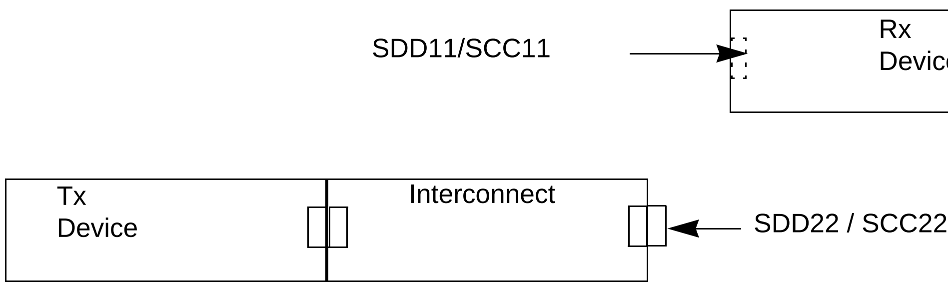


Figure 38 – Sxx at the beta R, epsilon R, and gamma R

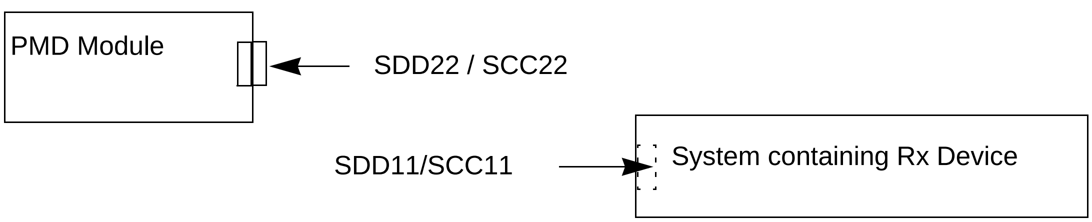


Figure 39 – Sxx at delta R

9.4 Jitter characteristics

This clause defines, at every electrical compliance point, the allowable jitter output, specified in table 29, and the jitter that shall be tolerated, specified in table 30. 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 30 except Data Dependent Pulse Width Shrinkage that has been defined in FC-MSQS (reference [34]). 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 9 and table 13 for the values of the optical variants.

Table 29 – Max jitter output

Units: UI	β_T	ε_T	δ_T note 12	γ_T	γ_R	δ_R note 12	ε_R	β_R
400-DF-EL-S Inter-enclosure (note 2,3)								
Deterministic	NA		0.14	0.37 note 5	0.37	0.39	NA	
Total (note 1)			0.26	0.57 note 5	0.57 note 7	0.59		
400-DF-EL-S Intra-enclosure (note 2,3)								
Deterministic	0.33 note 4	NA						0.33
Total (note 1)	0.52 note 4							0.52 note 6
800-DF-EL-S Inter-enclosure (note 2,3,10)								
Deterministic	NA		0.17	NA		0.42	NA	
Data Dependent Pulse width shrinkage (DDPWS) (note 8)			0.11			0.36		
Total (note 1)			0.31			0.71		
800-DF-EA-S Intra-enclosure (note 2, 3,10)								
Deterministic	See sub-clause 9.6.1		NA				See sub-clause 9.6.1	
UJ (rms)								
Total (note 1)								
800-DF-EA-S Inter-enclosure (note 2, 3,9,10)								
Deterministic	NA		0.17	NA			NA	
Data Dependent Pulse width shrinkage (DDPWS) (note 8)			0.11					
UJ (rms)			0.02					
Total (note 1)			0.31					
1600-DF-EL-S Inter-enclosure (note 2,3,10)								
Deterministic	NA		0.31	NA		0.22	NA	
Data Dependent Pulse width shrinkage (DDPWS) (note 8)			0.11			0.14		
UJ (rms)			0.03			NA		
Total (note 1)			0.45			0.36		
1600-DF-EA-S Intra-enclosure (note 2, 3,10)								
Total (note 1,11,13)	NA	0.24	NA					
1600-DF-EA-S Inter-enclosure (note 2, 3,9,10)								
Total (note 1,11,13)	NA		0.24	NA				

Table 29 – Max jitter output

Units: UI	$\beta_{\mathbf{T}}$	$\varepsilon_{\mathbf{T}}$	$\delta_{\mathbf{T}}$ note 12	$\gamma_{\mathbf{T}}$	$\gamma_{\mathbf{R}}$	$\delta_{\mathbf{R}}$ note 12	$\varepsilon_{\mathbf{R}}$	$\beta_{\mathbf{R}}$

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 9.9 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 9.9 and (b) measured through a zero length interconnect.
6 Pre-compensation at the transmitter may be used to cancel DDJ at beta 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 0.33 UI.
7 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.
8 DDPWS is measured according to FC-MSQS (reference [34]).
9 This variant is delta to delta connection and, therefore, media agnostic.
10 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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).
11 Total jitter excludes data dependent jitter for 1600-DF-EA-S variants. See FC-MSQS (reference [34]).
12 For delta point connections involving optical links, the jitter specification of clause 6 take precedence.
13 1600-DF-EA-S shall comply with sub-clause 9.7.1.

Table 30 – Min Jitter tolerance

<table>
<tr><th>Units: UI pk-pk</th><th>β_T</th><th>ε_T</th><th>δ_T
note 15</th><th>γ_T</th><th>γ_R</th><th>δ_R
note 15</th><th>ε_R</th><th>β_R</th></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>
<tr><td colspan="9">800-DF-EL-S Inter-enclosure (note 1, 5, 10, 14)</td></tr>
<tr><td>Deterministic (DJ)
5098 KHz to 4250 MHz
note 9</td><td colspan="2" rowspan="3">NA</td><td colspan="2" rowspan="2">note 11</td><td rowspan="3">NA</td><td>0.47</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Data Dependent Pulse width shrinkage (DDPWS UI)</td><td>0.36</td></tr>
<tr><td>Total (note 2)</td><td colspan="2">note 11</td><td>0.71</td></tr>
<tr><td colspan="9">800-DF-EA-S Intra-enclosure (note 1, 5, 12, 14)</td></tr>
<tr><td>Jitter Tracking test, jitter frequency and pk-pk amplitude (kHz, UI)
note 13</td><td colspan="2" rowspan="3">See sub-clause 9.6.1</td><td colspan="4" rowspan="3">NA</td><td colspan="2" rowspan="3">See sub-clause 9.6.1</td></tr>
<tr><td>Deterministic (DJ)
5098 KHz to 4250 MHz
note 9</td></tr>
<tr><td>Total (note 2)</td></tr>
<tr><td colspan="9">1600-DF-EL-S Inter-enclosure (note 1, 5, 10, 14)</td></tr>
<tr><td>Deterministic (DJ)
8413 KHz to 7.0125 MHz
note 9</td><td colspan="2" rowspan="3">NA</td><td rowspan="3">note 11</td><td colspan="2" rowspan="3">NA</td><td>0.22</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Data Dependent Pulse width shrinkage (DDPWS UI)</td><td>0.14</td></tr>
<tr><td>Total (note 2)</td><td>0.36</td></tr>
</table>

Table 30 – Min Jitter tolerance

Units: UI pk-pk	β_T	ε_T	δ_T note 15	γ_T	γ_R	δ_R note 15	ε_R	β_R
1600-DF-EA-S Intra-enclosure (note 1, 5, 12, 14)								
Jitter Tracking test, jitter frequency and pk-pk amplitude (kHz, UI) note 13	NA	note 11	NA				(840, 1) (168, 5)	NA
1600-DF-EA-S Inter-enclosure (note 1, 5, 12, 14)								
Jitter Tracking test, jitter frequency and pk-pk amplitude (kHz, UI) note 13	NA		note 11	NA		(840, 1) (168, 5)	NA	

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 44 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 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 of sub-clause 9.9.

7 Shall meet γ_R jitter tolerance specification calibrated through the γ_T compliance interconnect. See FC-MSQS (reference [34]) 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 reclocker.

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 24 or table 27.

11 Delta T, Epsilon T, and gamma T tolerances are not specified for 8GFC and 16GFC variants

12 For the equalizing receiver the jitter tolerance specification is replaced by the stressed receiver sensitivity specification. See sub-clause 9.6.

13 Receiver jitter tracking is defined in FC-MSQS (reference [34]).

14 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 8GFC and 16GFC delta points are to be interpreted as at the standard test equipment connector interface of the standardized test fixtures described in FC-MSQS (reference [34]).

15 For delta point connections involving optical links, the jitter specification of clause 6 take precedence.

9.5 Eye masks

9.5.1 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 unless specified otherwise. Current equivalent time sampling oscilloscope technology is not practical for measuring compliance to this eye contour. See FC-MJSQ, clause 6 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.

9.5.2 Transmitter device eye mask at β_T, δ_T and γ_T

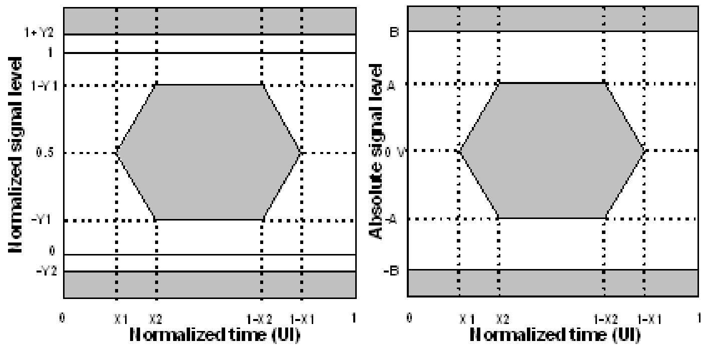


Figure 40 – Normalized (left) and absolute (right) eye diagram masks at β_T, δ_T and γ_T

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, 800-DF-EA-S, 1600-DF-EL-S, and 1600-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.

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

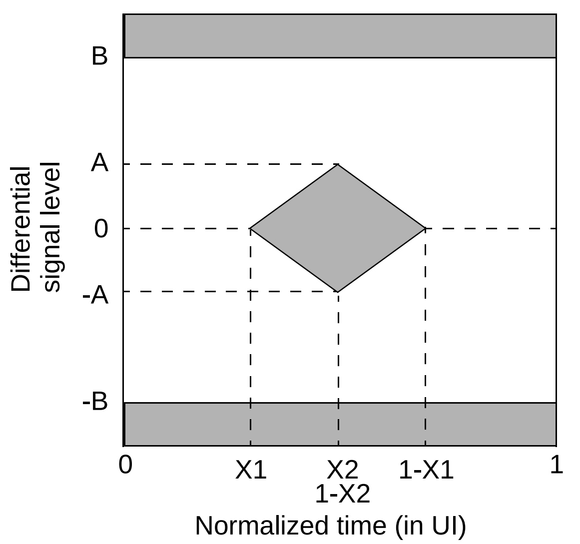


Figure 41 – Eye diagram mask at β_R, δ_R, and γ_R for EL variants

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 5.11 for test pattern requirements on ports not under test while the signal measurement is performed.

9.5.4 Jitter tolerance masks

Tolerance eye masks at β_T, δ_T and γ_T shall be based on figure 40 and shall be constructed using the X2, A and B values given in table 22 and the A value given in table 24 for the 400-DF-EL-S variant. X1 values shall be half the value for total jitter given in table 30 for jitter value frequencies above signaling rate/1 667.

Note that the x_T tolerance masks are identical to the output masks (in accordance with table 22) except that X1 and X2 values are each increased by half the amount of the sinusoidal jitter values given in table 30.

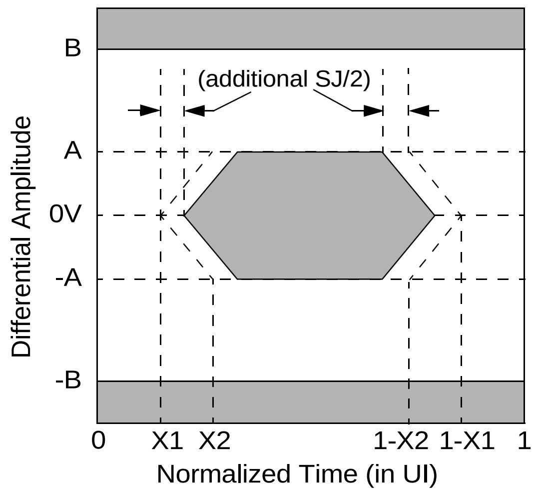


Figure 42 – Deriving the tolerance mask at the interoperability T points

Tolerance eye masks at β_R, δ_R and γ_R shall be based on figure 41 and shall be constructed using the X2 and B values given in table 26. X1 shall be half the value for total jitter given in table 30 for jitter frequencies above signaling rate/1 667. However, the leading and trailing edge slopes of figure 41 (with ALL values from table 22) shall be preserved. As a result the amplitude value of A will be less than that given in table 26 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 26 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 (in accordance with table 22), again due to the addition of sinusoidal jitter.

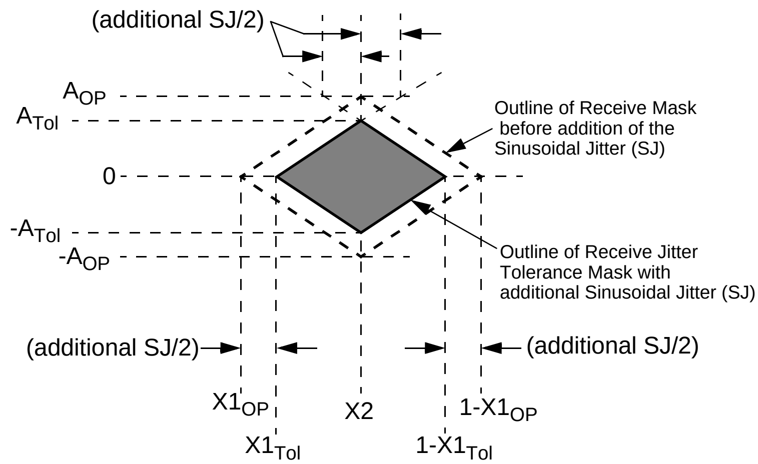


Figure 43 – Deriving the tolerance mask at the interoperability R points

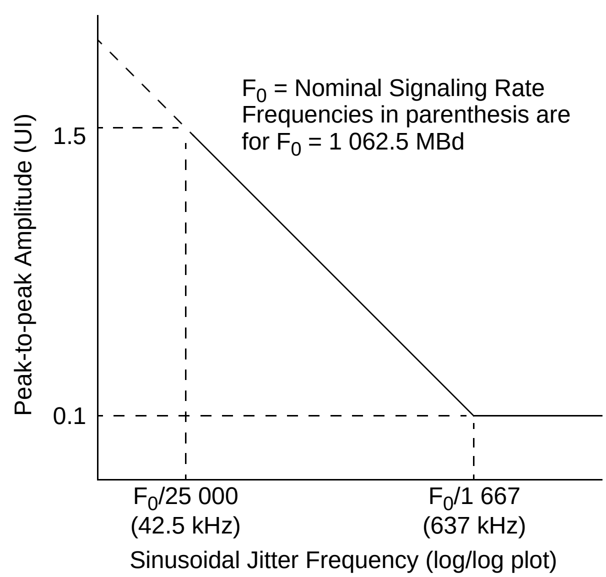


Figure 44 – Sinusoidal jitter mask

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

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

9.6.1 800-DF-EA-S at beta and epsilon compliance points

The signal output requirements for 800-DF-EA-S at beta T and epsilon T is shown in table 31. A compliant beta point shall meet both case 1 and case 2; however, these could be with different transmit pre-emphasis. A compliant epsilon point shall meet case 1, case 2, and case 3; however, these could be with different transmit pre-emphasis.

Table 31 – Signal requirements for 800-DF-EA-S at beta T and epsilon T

TCTF index		Units	Beta T Point		Epsilon T Point		
			case 1	case 2	case 1	case 2	case 3
Differential output voltage (pk-pk)	Max	mV	1 200		1 200		
VMA (note 1)	Max	mV	1 200		1 200		
	Min	mV	665		665	665	535
UJ, 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 FC-MSQS (reference [34]).
2 Uncorrelated jitter is measured using the procedure described in FC-MSQS (reference [34]).
3 TWDP and NC-DDJ are measured using the procedure described in FC-MSQS (reference [34]) and defined using a reference receiver with 1 feed-forward and 3 feedback taps.

The signal requirements for 800-DF-EA-S tolerance test at beta R and epsilon R are given in table 32. For beta and epsilon compliance points, the receiver device shall accept differential input amplitudes produced by a 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 31. 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. A compliant beta point shall tolerate both case 1 and case 2. A compliant Epsilon point shall tolerate case 1, case 2 and case 3.

Table 32 – Signal requirements for 800-DF-EA-S epsilon R and beta R

Test index	Units	Beta R Point		Epsilon R Point		
		case 1	case 2	case 1	case 2	case 3
VMA (note 1)	mV	540	470	540	470	300
BUJ (note 2)	UI	0.035		0.035		
RJ, 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 FC-MSQS (reference [34]).

2 Bounded uncorrelated jitter (BUJ) and random jitter (RJ) are measured at the input to the ISI filter per the procedure defined in FC-MSQS (reference [34]). Peak-to-peak RJ includes all but 10^{-12} of the population.

3 Random interference (RI) is applied at the receiver device input per the signal tolerance procedure defined in FC-MSQS (reference [34]). 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 FC-MSQS (reference [34]) and defined using a reference receiver with 1 feed-forward and 3 feedback taps.

5 Receiver jitter tracking is defined in FC-MSQS (reference [34]).

9.7 Signal characteristics for 1600-DF-EA-S variants

This sub-clause defines the performance requirements at delta T and delta R, and epsilon T and epsilon R for 16GFC linear variants.

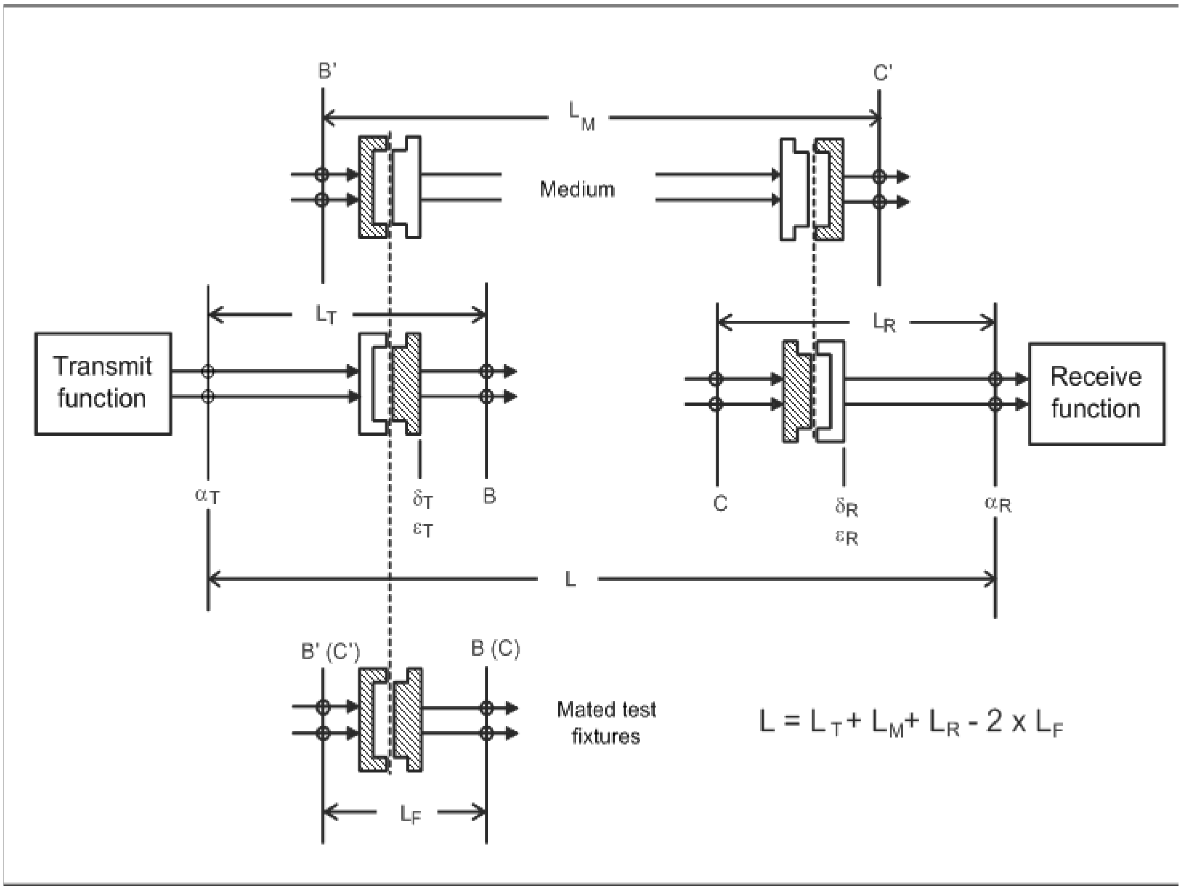


Figure 45 – 1600-DF-EA-S reference model

9.7.1 Transmitted output waveform

The transmit device includes programmable equalization to compensate for frequency-dependent loss of the channel and facilitate data recovery at the receiver. The functional model for the transmit equalizer is the three tap transversal filter shown in figure 46.

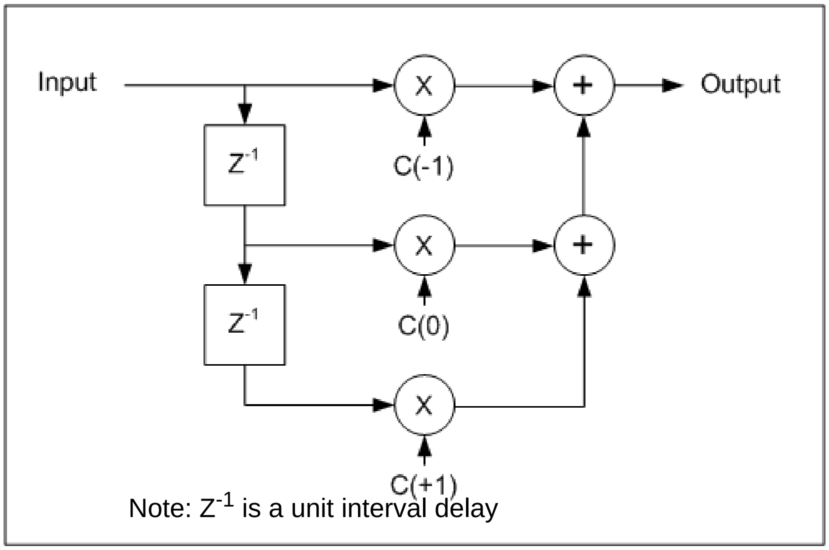


Figure 46 – Transmit device equalizer function model

The state of the equalizer and hence the transmitted output waveform may be manipulated via the Transmitter Training process defined in FC-FS-3 clause 9 or an unspecified management interface. The transmit function responds to a set of commands issued by the link partner's receive function and conveyed by a back-channel communications path. This command set includes instructions to

a) increment coefficient c(n),

b) decrement coefficient c(n),

c) hold coefficient c(n) at its current value, or

d) set the coefficients to a pre-defined value "preset" or "initialize".

In response, the transmit device relays status information to the link partner's receive function. The status messages indicate that

a) the requested update to coefficient c(n) has completed,

b) coefficient c(n) is at its minimum value,

c) coefficient c(n) is at its maximum value, or

d) coefficient c(n) is ready for the next update request.

The following process is defined for the verification of transmit equalizer performance.

1) The transmitter under test is "preset" such that $c(-1)$ and $c(1)$ are zero and $c(0)$ is its maximum value.

2) Capture at least one complete cycle of the test pattern PRBS9 at test point B (as defined in FC-MSQS reference [34]) per sub-clause 9.7.1.4.

3) Compute the linear fit to the captured waveform per sub-clause 9.7.1.5.

4) Define t_x to be the time where the rising edge of the linear fit pulse, p, from step 3 crosses 50% of its peak amplitude.

5) Sample the linear fit pulse, p, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.

6) Use p_i to compute the vector of coefficients, w, of a N_w-tap symbol-spaced transversal filter that equalizes for the transfer function from the transmit function to test point B per sub-clause 9.7.1.6.

The parameters of the pulse fit and equalizing filter are given in table 33.

Table 33 – Parameters of the pulse fit and equalization filter

Parameter	Value, UI
Linear fit pulse length, N_p	8
Linear fit pulse delay, D_p	2
Equalizer length, N_w	8
Equalizer delay, D_w	2

The differential output voltage at test point B in the steady state, v_f, is estimated by

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

where, p is the linear fit pulse from step 3 and M is the number of samples per symbol as defined in sub-clause 9.7.1.4. The peak value of the linear fit pulse from step 3, p_{max}, shall satisfy the requirements of table 34. The RMS value of the error between the linear fit and measured waveform from step 3, σ_e, shall satisfy the requirements of table 34.

Table 34 – Transmitter output waveform requirements

Parameter	Condition	Units	Class I	Class II
Steady state output voltage, v_f	Max	V	0.600	
	Min	V	0.360	0.340
Linear fit pulse peak, p_{max}	Min	V	0.73 x v_f	0.60 x v_f
RMS error, σ_e	Max		0.037 x v_f	
Normalized coefficient step size, Δ_c	Max		0.05	
	Min		0.0083	
Maximum post-cursor equalization ratio, R_{pst}	Min		4	
Maximum pre-cursor equalization ratio, R_{pre}	Min		1.54	
Sum of the magnitudes of normalized coefficients, S_c	Max		0.600 / v_f	
(c(0) + c(1) – c(–1))/(c(0) + c(1) + c(–1))	Initial		1.29 ± 10%	
(c(0) – c(1) + c(–1))/(c(0) + c(1) + c(–1))	Initial		2.57 ± 10%	

For each configuration of the transmit equalizer:

7) Configure the transmitter under test as required by the test.

8) Capture at least one complete cycle of the test pattern PRBS9 at test point B per sub-clause 9.7.1.4.

9) Compute the linear fit to the captured waveform per sub-clause 9.7.1.5.
10) Define t_x to be the time where the rising edge of the linear fit pulse, p, from step 9 crosses 50% of its peak amplitude.
11) Sample the linear fit pulse, p, at symbol-spaced intervals relative to the time $t_0 = t_x + 0.5$ UI, interpolating as necessary to yield the sampled pulse p_i.
12) Equalize the sampled pulse p_i using the coefficient vector, w, computed in step 6 per sub-clause 9.7.1.6 to yield the equalized pulse q_i.

The RMS value of the error between the linear fit and measured waveform from step 9, σ_e, shall satisfy the requirements of table 34.

The normalized amplitude of coefficient $c(-1)$ is the value of q_i at time $t_0 + (D_p - 1)$ UI. The normalized amplitude of coefficient $c(0)$ is the value of q_i at time $t_0 + D_p$ UI. The normalized amplitude of coefficient $c(1)$ is the value of q_i at time $t_0 + (D_p + 1)$ UI.

9.7.1.1 Coefficient step size

The magnitude of the change in the normalized amplitude of coefficient c(n), Δ_c, shall satisfy the requirements of table 34. A request to "increment" a coefficient shall result in positive change in that coefficient value while a request to "decrement" a coefficient shall result in a negative change in the coefficient value.

The change in the normalized amplitude of the coefficient is defined to be the difference in the value measured prior to the assertion of the “increment” or “decrement” request (e.g. the coefficient update request for all coefficients is “hold”) and the value upon the assertion of a coefficient status report of “update complete” for that coefficient.

9.7.1.2 Coefficient range

When sufficient “increment” or “decrement” requests have been received for a given coefficient, the coefficient will reach a lower or upper bound based on the coefficient range or restrictions placed on the minimum steady state differential output voltage or the maximum peak-to-peak differential output voltage.

With $c(-1)$ set to zero and both $c(0)$ and $c(1)$ having received sufficient “decrement” requests so that they are at their respective minimum values, the ratio $R_{pst} = (c(0) - c(1))/(c(0) + c(1))$ shall satisfy the requirements of table 34.

With $c(1)$ set to zero and both $c(-1)$ and $c(0)$ having received sufficient “decrement” requests so that they are at their respective minimum values, the ratio $R_{pre} = (c(0) - c(-1))/(c(0) + c(-1))$ shall satisfy the requirements of table 34.

Note that a coefficient may be set to zero by first asserting a coefficient "preset" request and then manipulating the other coefficients as required by the test.

In addition transmitter shall not implement an update request that would cause the sum of the magnitudes of the normalized coefficients, S_c, to exceed the maximum value given in of table 34.

9.7.1.3 Coefficient initialization

When the transmit device is directed to “initialize”, the coefficients of the transmit equalizer shall be set to values given in table 34.

These requirements apply upon the assertion a coefficient status report of “update complete” for all coefficients.

9.7.1.4 Waveform acquisition

The transmitter under test repetitively transmits the specified test pattern. The waveform shall be captured with an effective sample rate that is *M* times the signaling rate of the transmitter under test. The value of *M* shall be an integer not less than 7. Averaging multiple waveform captures is recommended.

The captured waveform shall represent an integer number of repetitions of the test pattern totaling *N* bits. Hence the length of the captured waveform should be *MN* samples. The waveform should be aligned such that the first *M* samples of waveform correspond to the first bit of the test pattern, the second *M* samples to the second bit, and so on.

9.7.1.5 Linear fit to the waveform measured at test point B

Given the captured waveform *y*(k) and corresponding aligned symbols *x*(n) derived from the procedure defined in sub-clause 9.7.1.4, define the *M*-by-*N* waveform matrix *Y* as shown below.

$$Y = \begin{bmatrix} y(1) & y(M+1) & \dots & y(M(N-1)+1) \\ y(2) & y(M+2) & \dots & y(M(N-1)+2) \\ \dots & \dots & \dots & \dots \\ y(M) & y(2M) & \dots & y(MN) \end{bmatrix}$$

Rotate the symbols vector *x* by the specified pulse delay D_p to yield x_r.

$$x_r = \begin{bmatrix} x(D_p+1) & x(D_p+2) & \dots & x(N) & x(1) & \dots & x(N-D_p) \end{bmatrix}$$

Define the matrix *X* to be an *N*-by-*N* matrix derived from x_r as shown here.

$$X = \begin{bmatrix} x_r(1) & x_r(2) & \dots & x_r(N) \\ x_r(N) & x_r(1) & \dots & x_r(N-1) \\ \dots & \dots & \dots & \dots \\ x_r(2) & x_r(3) & \dots & x_r(1) \end{bmatrix}$$

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

$$P = YX_1^{\,T}(X_1X_1^{\,T})^{-1}$$

The superscript "T" denotes the matrix transpose operator.

$$E = PX_1 - Y = \begin{bmatrix} e(1) & e(M+1) & \dots & e(M(N-1)+1) \\ e(1) & e(M+2) & \dots & e(M(N-1)+2) \\ \dots & \dots & \dots & \dots \\ e(M) & e(2M) & \dots & e(MN) \end{bmatrix}$$

The error waveform, $e(k)$, is then read column-wise from the elements of E. Define P_1 to be a matrix consisting of the first N_p columns of the matrix P as shown below.

$$P_1 = \begin{bmatrix} P(1) & P(M+1) & \dots & P(M(N_p-1)+1) \\ P(2) & P(M+2) & \dots & P(M(N_p-2)+2) \\ \dots & \dots & \dots & \dots \\ P(M) & P(2M) & \dots & P(MN_p) \end{bmatrix}$$

The linear fit pulse response, $p(k)$, is then read column-wise from the elements of P_1.

9.7.1.6 Removal of the transfer function between the transmit function and test point B

Rotate sampled pulse response P_i by the specified equalizer delay D_w to yield P_r.

$$P_r = \begin{bmatrix} P_i(D_w+1) & P_i(D_w+2) & \dots & P_i(N_p) & P_i(1) & \dots & P_i(N_p - D_w) \end{bmatrix}$$

Define the matrix P_2 to be an N_p-by-N_p matrix derived from P_r.

$$P_2 = \begin{bmatrix} P_r(1) & P_r(N_p) & \dots & P_r(2) \\ P_r(2) & P_r(1) & \dots & P_r(3) \\ \dots & \dots & \dots & \dots \\ P_r(N_p) & P_r(N_p-1) & \dots & P_r(1) \end{bmatrix}$$

Define the matrix P_3 to be the first N_w columns of P_2. Define a unit pulse column vector x_p of length N_p. The value of element $x_p(D_p + 1)$ is 1 and all other elements have a value of 0. The vector of filter coefficients w that equalizes p_i is then defined by:

$$w = (P_3{}^T P_3)^{-1} P_3{}^T x_p$$

Given the column vector of equalizer coefficients, *w*, the equalized pulse response q_i is determined by:

$$q_i = P_3 w$$

9.7.2 Receive device signal tolerance

For 1600-DF-EA-S delta R variants, the receive device shall tolerate signals received at the delta R point that are generated by the test signal generator defined in FC-MSQS (reference [34]). Tolerance, as defined in FC-MSQS, is the ability to receive the signal with a BER less than 10^{-12}. The parameters of the test signal generator are given in table 35.

Table 35 – Test channel for delta R

Parameter	Units	Value
IL(f) at 7.0125 GHz (note 1)	dB	20.5
Fitted insertion loss, a_1	dB/root-GHz	3.2
Fitted insertion loss, a_2	dB/GHz	1.4
Fitted insertion loss, a_4	dB/GHz^2	0.04
Total crosstalk voltage, RMS	mV	4.2
Notes: 1 This is a reference to the measured and not the fitted insertion loss.		

For 1600-DF-EA-S epsilon R variants, the receive device shall tolerate signals received at the epsilon R point that are generated by the test signal generator defined in FC-MSQS (reference [34]). The parameters of the test signal generator are given in table 36 and table 37.

Table 36 – Test channel for epsilon R, class I

Parameter	Units	Test 1	Test 2
IL(f) at 7.0125 GHz (note 1)	dB	14.0	24.0
Fitted insertion loss, a_1	dB/root-GHz	2.2	3.8
Fitted insertion loss, a_2	dB/GHz	1.0	1.7
Fitted insertion loss, a_4	dB/GHz^2	0.02	0.05
Total crosstalk voltage, RMS	mV	8.0	2.8
Notes: 1 This is a reference to the measured and not the fitted insertion loss.			

For 1600-DF-EA-S epsilon R variants, a receive device satisfying the class I recommendations defined in sub-clause 9.7.3.2 shall tolerate test signals generated according to either class I or class II requirements. A receive device satisfying the class II recommendations shall tolerate test signals generated according to the class II requirements.

Table 37 – Test channel for epsilon R, class II

Parameter	Units	Test 1	Test 2
IL(f) at 7.0125 GHz (note 1)	dB	10.5	20.5
Fitted insertion loss, a_1	dB/root-GHz	1.7	3.2
Fitted insertion loss, a_2	dB/GHz	0.8	1.4
Fitted insertion loss, a_4	dB/GHz^2	0.02	0.04
Total crosstalk voltage, RMS	mV	8.0	4.2
Notes: 1 This is a reference to the measured and not the fitted insertion loss.			

9.7.3 Electrical channel characteristics

The parameters that are used to describe the electrical channel are defined in FC-MSQS (reference [34]).

Definition of parameters

The parameters used to calculate the passive electrical channel characteristics are defined in table 38..

Table 38 – Definition of parameters

Parameter	Symbol	1600-DF-EA-S	Units
Symbol rate	f_b	14.025	GBd
Maximum measurement start frequency	f_1	0.050	GHz
Minimum measurement stop frequency	f_N	14.000	GHz
Victim peak differential output amplitude	A_t	400	mV
Near-end aggressor peak differential output amplitude	A_{nt}	600	mV
Far-end aggressor peak differential output amplitude	A_{ft}	600	mV
Near-end aggressor 20 to 80% rise and fall times	T_{nt}	24	ps
Far-end aggressor 20 to 80% rise and fall times	T_{ft}	24	ps

9.7.3.1 Target end-to-end channel characteristics (informative)

The requirements for 1600-DF-EA-S variants are based on a channel spanning alpha T to alpha R with the characteristics defined in table 39.

Table 39 – Channel characteristics

Parameter	Condition	Units	α_T to α_R
***IL*(*f*) at 7.0125 GHz (note 1)**	Max.	dB	25.0
Fitted insertion loss, a_1	Max.	dB/root-GHz	7.20
Fitted insertion loss, a_2	Max.	dB/GHz	3.10
Fitted insertion loss, a_4	Max.	dB/GHz^2	0.12
Insertion loss deviation (ILD)	Max.	dB	note 2
Integrated crosstalk noise, RMS	Max.	mV	8.0
Gain to noise ratio (GNR)	Min.	dB	19.0

Notes:

1 This is a reference to the measured and not the fitted insertion loss. The limit on the insertion loss at the fundemental frequency may prohibit the fitted insertion loss coefficients from having their maximum values simultaneously.
2 For ILD equations refer to sub-clause 9.7.3.5.

9.7.3.2 Recommended transmit and receive device characteristics (informative)

It is recommended that the characteristics of transmission path from alpha T to B or from C to alpha R satisfy the requirements defined in table 40. See annex D for definition of points B and C.

Note that the media connecting epsilon T to epsilon R may not be symmetric. For example, the transmit device may be a mezzanine card on a server blade while a receive device may be a switch blade or vice versa. To account for this asymmetry, two classes of recommendations are offered. Class I devices correspond to mezzanine cards or similar devices with a lower loss transmission path to the compliance point. Class II devices correspond to switch blades or devices with a higher loss transmission path to the compliance point. Class I devices will interoperate with class I or class II devices when combined with a backplane media meeting the requirements sub-clause 9.7.3.4 to form a complete link. Class II devices will only interoperate with Class I devices. The mechanical properties of the connectors for class I and class II devices are expected to ensure devices are combined properly to ensure the proper operation of the link.

For delta point applications, transmit and receive devices are assumed to satisfy class II recommendations.

Table 40 – Characteristics of the transmission path from alpha T to B or C to alpha R

Parameter	Condition	Units	α_T to B or C to α_R	
			Class I	Class II
***IL*(*f*) at 7.0125 GHz (note 1)**	Max.	dB	3.00	6.50
Fitted insertion loss, a_1	Max.	dB/root-GHz	0.80	1.50
Fitted insertion loss, a_2	Max.	dB/GHz	0.30	0.70
Fitted insertion loss, a_4	Max.	dB/GHz^2	0.04	0.04
Insertion loss deviation (ILD)	Max.	dB	note 2	

Notes:

1 This is a reference to the measured and not the fitted insertion loss. The limit on the insertion loss at the fundemental frequency may prohibit the fitted insertion loss coefficients from having their maximum values simultaneously.

2 For ILD equations refer to sub-clause 9.7.3.5.

9.7.3.3 Passive direct attach copper cable assembly characteristics

The characteristics of a passive direct attach copper cable assembly measured between compliance points B’ and C’ shall satisfy the requirements of table 41. See FC-MSQS (reference [34]) for definition of points B’ and C’.

Table 41 – Passive direct attach copper cable assembly characteristics

Parameter	Condition	Units	B’ to C’
***IL*(*f*) at 7.0125 GHz (note 1)**	Max.	dB	16.0
Fitted insertion loss, a_1	Max.	dB/root-GHz	4.60
Fitted insertion loss, a_2	Max.	dB/GHz	0.70
Fitted insertion loss, a_4	Max.	dB/GHz^2	0.04
Insertion loss deviation (ILD)	Max.	dB	note 2
Integrated crosstalk noise, RMS	Max.	mV	4.00

Notes:

1 This is a reference to the measured and not the fitted insertion loss. The limit on the insertion loss at the fundemental frequency may prohibit the fitted insertion loss coefficients from having their maximum values simultaneously.

2 For ILD equations refer to sub-clause 9.7.3.5.

9.7.3.4 Passive electrical backplane characteristics

The characteristics of a passive electrical backplane measured between compliance points B’ and C’ shall satisfy the requirements of table 42. Note that despite the use of the term backplane, the media connecting B’ to C’ may the concatenation of a server blade and mid-plane or any other topology that satisfies the performance requirements. See FC-MSQS (reference [34]) for definition of points B’ and C’.

Table 42 – Passive electrical backplane characteristics

Parameter	Condition	Units	B' to C'
***IL*(*f*) at 7.0125 GHz (note 1)**	Max.	dB	19.5
Fitted insertion loss, a_1	Max.	dB/root-GHz	2.50
Fitted insertion loss, a_2	Max.	dB/GHz	2.50
Fitted insertion loss, a_4	Max.	dB/GHz^2	0.04
Insertion loss deviation (ILD)	Max.	dB	note 2
Integrated crosstalk noise, RMS	Max.	mV	8.0
Gain to noise ratio (GNR)	Min.	dB	19.0

Notes:

1. This is a reference to the measured and not the fitted insertion loss. The limit on the insertion loss at the fundemental frequency may prohibit the fitted insertion loss coefficients from having their maximum values simultaneously.
2. For ILD equations refer to sub-clause 9.7.3.5.

9.7.3.5 Insertion loss deviation

The insertion loss deviation for host channel and cable assembly is given by:

$$(ILD_{hc}, ILD_{ca})(dB) \le \begin{cases} 0.75 & 0.05 \le f < 3.50 \\ 0.4286f - 0.75 & 3.50 \le f < 7.00 \\ 2.25 & 7.00 \le f \le 10.5 \end{cases}$$

$$(ILD_{hc}, ILD_{ca})(dB) \ge \begin{cases} -0.75 & 0.05 \le f < 3.50 \\ 0.75 - 0.4286f & 3.50 \le f < 7.00 \\ -2.25 & 7.00 \le f \le 10.5 \end{cases}$$

The insertion loss deviation for the channel is shown in the equations below:

$$ILD_{ch}(dB) \le \begin{cases} 1.0 & 0.05 \le f < 1.75 \\ 1.714f - 2.0 & 1.75 \le f < 3.50 \\ 4.0 & 3.50 \le f < 7.00 \\ 1.429f - 6.0 & 7.00 \le f \le 10.5 \end{cases}$$

$$ILD_{ch}(dB) \ge \begin{cases} -1.0 & 0.05 \le f < 1.75 \\ 1.0 - 1.143f & 1.75 \le f < 3.50 \\ -3.0 & 3.50 \le f \le 10.5 \end{cases}$$

9.8 Grounding and shielding requirements at interoperability points

Figures 47 through 49 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.

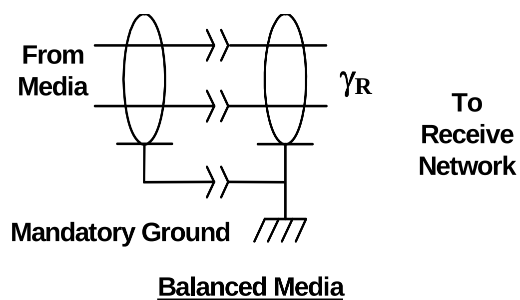


Figure 47 – Inter-enclosure receiver compliance point γ_R

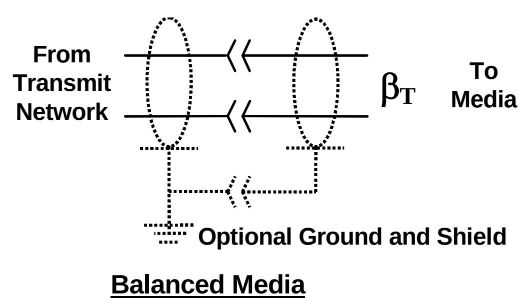


Figure 48 – Intra-enclosure transmitter compliance point β_T

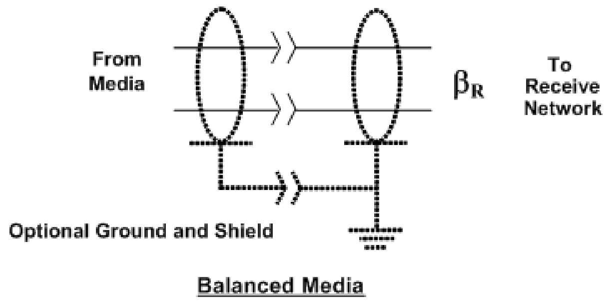


Figure 49 – Intra-enclosure receiver compliance point β_R

9.9 Transmitter Compliance Transfer Function

9.9.1 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 not a statement of the performance requirements for the interconnect.

9.9.2 400-DF-EL-S intra-enclosure Transmitter Compliance Transfer Function

The TCTF for the intra-enclosure 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:

$$|S_{21}| \le |S_{21}|_{limit} = -20\log_{10}(e)(a_1\sqrt{f} + a_2 f + a_3 f^2)$$

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 50.

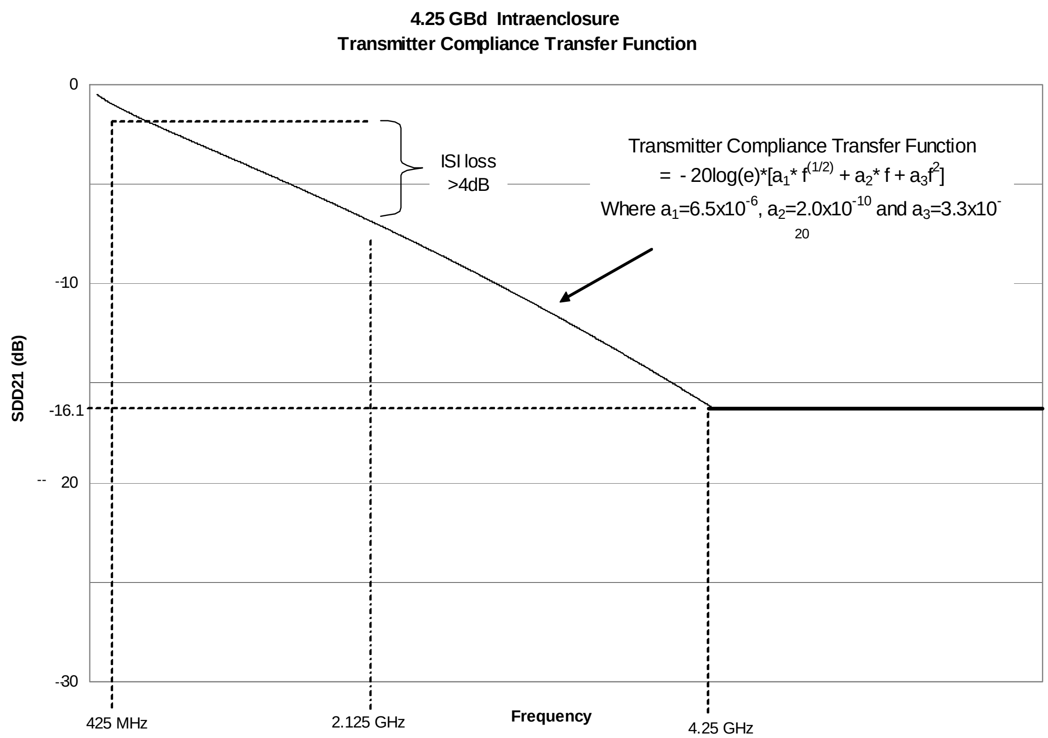


Figure 50 – 400-DF-EL-S Intra-enclosure Transmitter Compliance Transfer Function

9.9.3 400-DF-EL-S inter-enclosure 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 156 ps. 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 51 below.

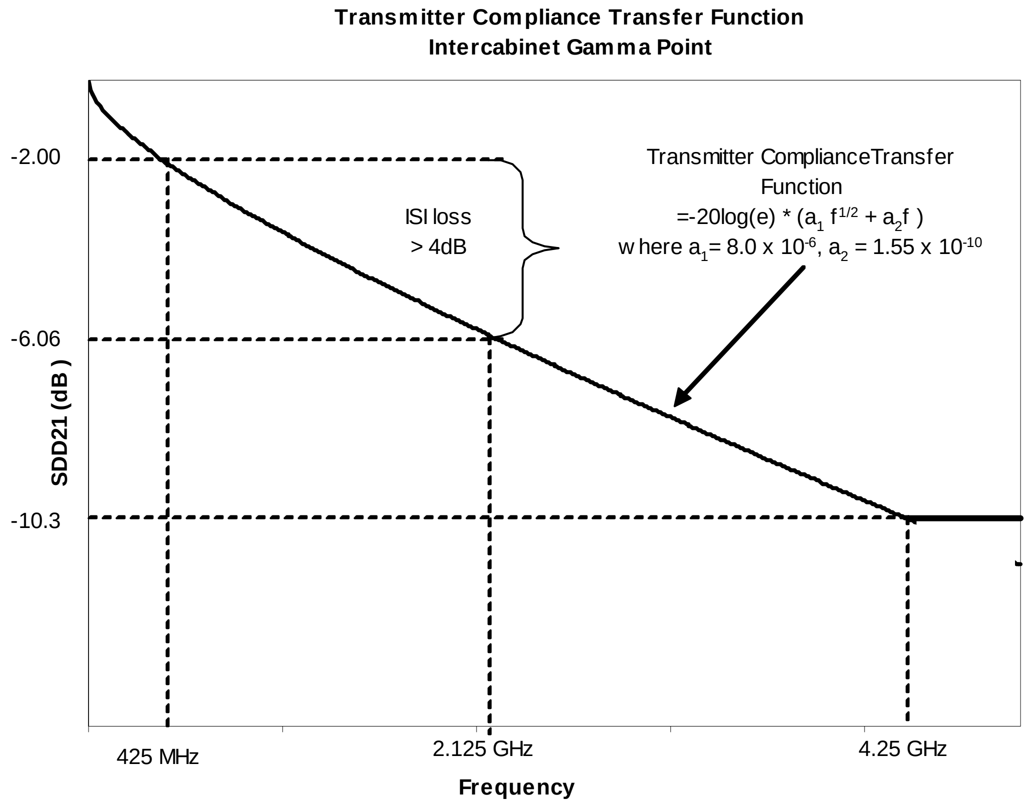
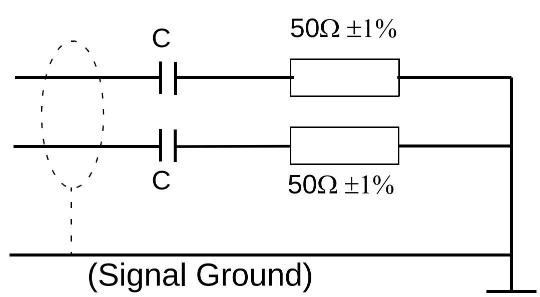


Figure 51 – 400-DF-EL-S Inter-enclosure transmitter compliance transfer

9.10 Test loads

The test load for a measurement shall be chosen to match the impedance specified for the compliance point in table 21. See figure 52 for 100-Ohm test loads.

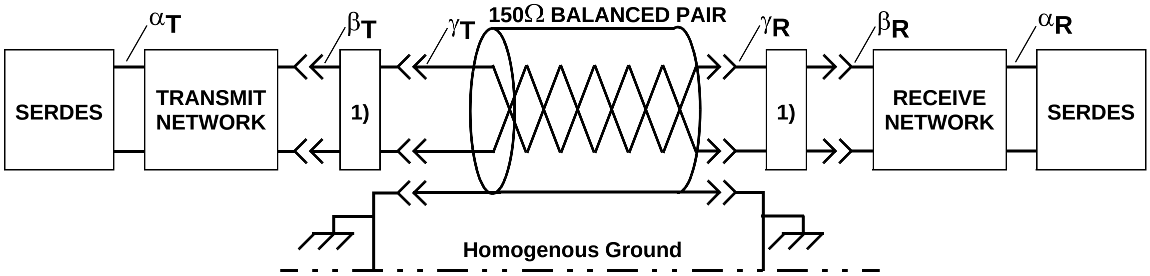


NOTE: Capacitors are required if output under test is not DC isolated. Value of C is 100 nF for 16GFC and 10 nF for 8GFC and 4GFC.

Figure 52 – 400, 800, and 1600 variants100 Ohm test load

9.11 Example TxRx connections

Figure 53 is an example of a typical differential TxRx connection showing the compliance points.



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

Figure 53 – Example of inter-enclosure TxRx with 150Ω balanced cable

9.12 SFP+ form factor implementation (informative)

For SFP+ implementation of FC-PI-5 variants, the following references is provided.

1) SFF-8431 (reference [24]) shall be used for definition of signals and pin configuration.

2) SFF-8432 (reference [25]), SFF-8433 (reference [26]), and SFF-8443 (reference [27]) shall be used for definition of cage and module.

3) SFF-8081 (reference [35]), for the card edge connector for 16GFC.

4) SFF-8083 (reference [28]) and SFF-8435 (reference [29]) shall be used for connector properties.

Annex A (informative)
Optical cable plant usage

The worst-case power budget and link penalties for the multimode cables specified in 6.4 are shown in table A.1. In some cases, it may be desirable to use an alternative multimode cable plant to those described in 6.4. This may be due to the need for operation in locations where alternative lower bandwidth cables are presently installed. Their cable plant usage is described in table A.2. However it should be noted that in FC-PI-5 in contrast to FC-PI-4 the normative specifications for the fiber optic system are with 50µm fiber only rather than with both 50µm and 62.5µm fiber. Equipment meeting FC-PI-5 specifications may not operate as shown in table A.2 unless it is also meets the table 11 specifications when tested with OM1 type fiber.

Table A.1 – Worst case (nominal bandwidth) multimode cable link power budget

Parameter	Unit	SN			Note
50µm (OM2) MMF					
Overfilled Launch Modal Bandwidth	MHz*km	500			1
Data rate	MB/s	400	800	1600	
Operating distance	m	0.5-150	0.5-50	0.5-35	
Link power budget	dB	6.08	6	5.70	6
Intersymbol interference	dB	2.71	2.94	2.84	
Additional link penalties	dB	1.03	0.83	1.23	2
Channel insertion loss	dB	2.06	1.68	1.63	
Allocation for additional loss	dB	0.28	0.55	0.00	3
50µm (OM3) MMF					
Effective Modal Bandwidth	MHz*km	2 000			1, 4
Data rate	MB/s	400	800	1600	
Operating distance	m	0.5-380	0.5-150	0.5-100	
Link power budget	dB	6.08	6	5.70	6
Intersymbol interference	dB	1.94	2.79	2.57	
Additional link penalties	dB	1.24	0.93	1.25	2
Channel insertion loss	dB	2.88	2.04	1.86	
Allocation for additional loss	dB	0.02	0.24	0.02	3
50µm (OM4) MMF					
Effective Modal Bandwidth	MHz*km	4 700			1, 5
Data rate	MB/s	400	800	1600	
Operating distance	m	0.5-400	0.5-190	0.5-125	
Link power budget	dB	6.08	6.00	5.70	6
Intersymbol interference	dB	1.55	2.65	2.40	
Additional link penalties	dB	1.24	1.09	1.32	2
Channel insertion loss	dB	2.95	2.19	1.95	
Allocation for additional loss	dB	0.34	0.07	0.03	3

Table A.1 – Worst case (nominal bandwidth) multimode cable link power budget

Parameter	Unit	SN	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 [34].

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 at 850 nm of 2 000 MHz*Km for OM3 is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA 492AAAC-A or IEC 60793-2-10 with a 50-μm fiber meeting the specifications in TIA 492AAAC-A or IEC 60793-2-10 for Type A1a.2.

5 A minimum effective modal bandwidth-length product at 850 nm of 4 700 MHz*Km for OM4 is ensured by combining a transmitter meeting the center wavelength and encircled flux specifications in TIA 492AAAD or IEC 60793-2-10 with a 50-μm fiber meeting the specifications in TIA 492AAAD or IEC 60793-2-10 for Type A1a.3.

6 The power budget for 400-SN is actually 6.0736 dB based on using the mW number in calculation and was rounded up to 6.08 dB.

Table A.2 – OM1 multimode cable link power budget

62.5µm MMF	Unit	SN			Note
Overfilled Launch Modal Bandwidth	MHz*km	200			1
Data rate	MB/s	400	800	1600	
Operating distance	m	0.5-70	0.5-21	0.5-15	
Rx jitter tolerance test OMA	mW (dBm)	0.164 (-7.9)	0.200 (-7.0)	NA	2
Stressed receiver sensitivity	mW (dBm)	0.148 (-8.3)	0.151 (-8.2)	0.170 (-7.7)	3
Receiver vertical eye closure penalty	dB	2.14	3.10	2.50	6
Link power budget	dB	6.08	6.00	5.70	
Intersymbol interference	dB	3.21	3.00	2.96	
Additional link penalties	dB	0.78	0.65	1.05	4
Channel insertion loss	dB	1.78	1.58	1.56	
Allocation for additional loss	dB	0.31	0.77	0.13	5

Notes:

1 Modal bandwidth at 850 nm. The operating ranges and loss budgets shown here are based on fiber bandwidth given in TIA-492AAAA-A or IEC 60793-2-10 for Type A1b (OM1) fiber.

2 This is the optical input amplitude for testing compliance to the jitter tolerance at gamma R specified in table 14.

3 Values are for system level BER measurements that include the effects of actual reclocker circuits. It is recommended that at least 0.5 dB additional margin be allocated if measurements are made with laboratory instrumentation that samples in the center of the eye. 0.5 dB 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. See FC-MSQS (reference [34]).

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 FC-MSQS (reference [34]).

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 Receiver vertical eye closure penalty, VECP, is a test condition for measuring stressed receiver sensitivity and is not a required characteristic of the receiver. The values for 16GFC and 8GFC are calibrated with a 11 GHz and 7.5 GHz fourth-order Bessel-Thomson filter respectively. The 4GFC VECP calibrations are with a wide band receiver. See FC-MSQS (reference [34]).

Table A.3 – Higher connection loss operating distances for 62.5 (OM1) MMF

Parameter	Unit	400-M6-SN-I
Operating range with 2.4 dB of connection loss	m	0.5-60
Loss budget (for 2.4 dB connector loss)	dB	2.65
Operating range with 3.0 dB of connection loss	m	0.5-40
Loss budget (for 3.0 dB connector loss)	dB	3.16

Annex B (informative)
Structured cabling environment

B.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.

B.2 Alternate connection loss operating distances

In structured cabling environments, the connection loss may be different than the 1.5 dB of connection loss used to calculate link distance in clause 6. Different allocations for connection loss result in changes to the maximum operating range. Tables B.1, B.2, and B.3 provide the maximum operating range and loss budget requirements for a range of connection loss values. These loss values may be used provided the total channel loss budget requirements are met as appropriate for the fiber type, and the loss of any single connection does not exceed 0.75 dB. The minimum operating range for the tables is 0.5 meters.

Table B.1 – 400-SN max operating distance & loss budget for different connection losses

Distance (m) / Loss Budget (dB)					
Fiber Type	Connection Loss				
	3.0 dB	2.4 dB	2.0 dB	1.5 dB	1.0 dB
M5F (OM4)	200 / 3.72	300 /3.49	370 / 3.34	400 / 2.95	450 / 2.63
M5E (OM3)	150 / 3.54	290 / 3.45	320 / 3.16	380 / 2.88	400 / 2.45
M5 (OM2)	70 / 3.26	120 / 2.85	130 / 2.49	150 / 2.06	170 / 1.64

Table B.2 – 800-SN max operating distance & loss budget for different connection losses

Distance (m) / Loss Budget (dB)					
Fiber Type	Connection Loss				
	3.0 dB	2.4 dB	2.0 dB	1.5 dB	1.0 dB
M5F (OM4)	50 / 3.18	120 / 2.83	160 / 2.58	190 / 2.19	220 / 1.80
M5E (OM3)	35 / 3.13	110 / 2.80	125 / 2.45	150 / 2.04	180 / 1.65
M5 (OM2)	NA	35 / 2.53	45 / 2.16	50 / 1.68	60 / 1.22

Table B.3 – 1600-SN max operating distance & loss budget for different connection losses

Distance (m) / Loss Budget (dB)					
Fiber Type	Connection Loss				
	3.0 dB	2.4 dB	2.0 dB	1.5 dB	1.0 dB
M5F (OM4)	NA	50 / 2.58	100 / 2.36	125 / 1.95	150 / 1.54
M5E (OM3)		40 / 2.54	75 / 2.27	100 / 1.86	120 / 1.43
M5 (OM2)		NA	25 / 2.09	35 / 1.63	40 / 1.14

Annex C (informative)
Passive direct attach SFP+ cable specifications for 8GFC

C.1 General overview

This annex describes additional requirements or exceptions to the linear delta host specification to implement passive direct attach SFP+ cables assemblies. Active cable assemblies operate with existing linear specifications. The compliance point for passive direct attach cables is the same as host compliance test points and the module compliance test points described in FC-MSQS (reference [34]).

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.

C.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 C.1. SFP+ cable has built in crossover where transmitter outputs TD+/TD- on the A Sides goes to the receiver outputs RD+/RD- respectively. The cable assembly shall incorporate DC blocking capacitors with at least 15 V rating on the high-speed differential Rx pairs. The drain wire is connected to both VeeT and VeeR. The cable shield directly connects module A and B cases. SFP+ cable impedance is recommended to be 100 ohms differential and approximately 30 ohms common mode.

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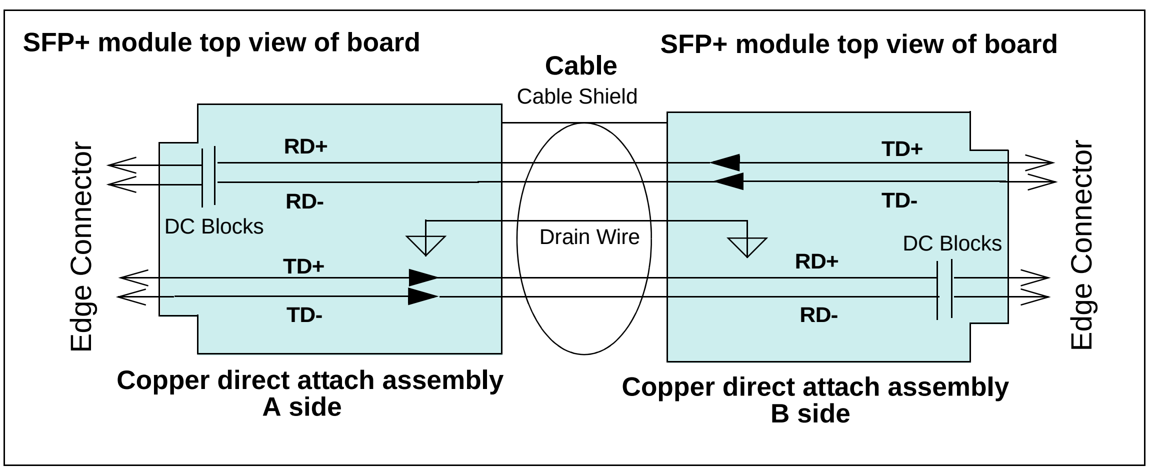

Figure C.1 – SFP+ direct attach block diagram

C.3 SFP+ host output specifications for passive direct attach cables

SFP+ host supporting direct attach cables must meet transmitter output specifications of table C.1 at reference point B in addition to the delta T specifications for 800-DF-EA-S in clause 9.

Table C.1 – SFP+ host transmitter output specifications at B for Cu

Parameters	Units	Min	Target	Max
Voltage Modulation Amplitude, VMA (pk-pk) (note 1)	mV	360		
Host Output TWDP (note 2)	dB			5.75
Transmitter Q_{sq} (note 3)		39.81		
Transmitter Rise and Fall Times	ps	40		

Notes:

1 Measured with Module Compliance Board and OMA test pattern.

2 Host electrical output measured with (1,3) Equalizer and JSPAT with passive copper direct attach stressor. See C.3.1.

3 Qsq as defined in FC-MSQS (reference [34]), but the optical OMA and noise are replaced with the electrical VMA and noise.

TWDP is host transmitter penalty with copper cable stressor. The algorithm in FC-MJSQ (reference [34]) calculates TWDPo from the captured waveform, see FC-MSQS (reference [34]).

C.3.1 Passive copper TWDP Stressor

The copper stressor was created from measurements of commonly available 5 m direct attach SFP+ cables. The copper stressor impulse response values are listed in table C.2. The sum of all stressor impulse response values at 0.5 unit intervals is normalized to a value of 1.

Table C.2 – SFP+ copper TWDP stressor impulse response

Delay (UI)	Delay (ns)	Amplitude	Delay (UI)	Delay (ns)	Amplitude
0	0	0.002	3.0	0.3528	0.040
0.5	0.0588	0.1996	3.5	0.4116	0.0277
1	0.1176	0.3312	4.0	0.4704	0.0203
1.5	0.1764	0.2218	4.5	0.5292	0.0123
2	0.2352	0.0979	5.0	0.5880	0.0043
2.5	0.2940	0.0424	5.5	0.6468	0.002

C.4 Delta R input compliance test signal specifications calibrated at C”

A host that is to support the direct attach copper option is to meet the required BER when tested with the stressed signal described in this annex in addition to the delta R specifications for 800-DF-EA-S in clause 9.

The delta R stressed input is described in C.4.1. It can be generated by a set of tapped delay lines. A suitable length of copper cable is also expected to generate the stressor described here. The stress generator shall meet the target WDP (Waveform Distortion Penalty for copper) as given in table C.3. The stress generator output shall provide the minimum Q_{sq} as given in table C.3.

This test shall be made with both the minimum and maximum values of VMA given in table C.3.

Table C.3 – Delta R 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	
Stress Generator Output Q_{sq} (note 2, 3)			29.61	
Differential Voltage Modulation Amplitude	mV	225		700
Input AC Common Mode Voltage	mV			30

Notes:

1 WDP is calibrated with reference receiver with FFE/DFE (1,3).

2 Q_{sq} as defined in FC-MSQS (reference [34]), but the optical OMA and noise are replaced with the electrical VMA and noise.

3 Square pattern with five ONEs and five ZEROs

C.4.1 Delta R stressed input pulse shape

The copper stressed input was created from measurements of commonly available 5 m direct attach SFP+ cables. The approximate pulse shape of the stressed input signal is shown in figure C.2 and the exact values of the amplitudes at 0.5 unit intervals are listed in table C.4. The sum of all amplitudes is normalized to a value of 1.

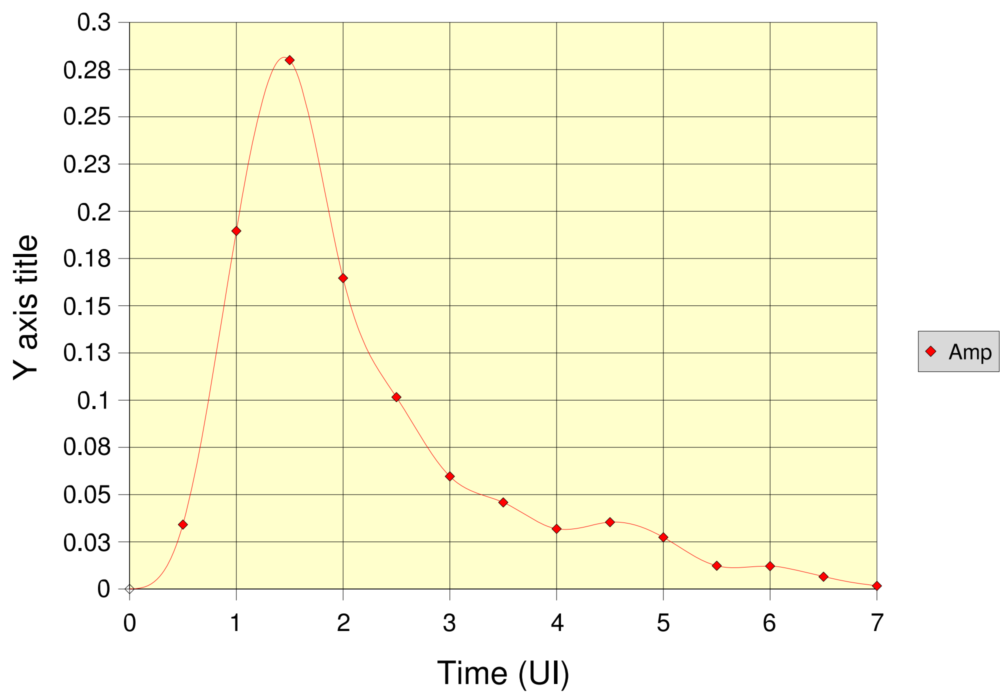

Figure C.2 – Delta R stressor supporting copper cables

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Table C.4 – Delta R stressed input pulse shape supporting copper cables

Delay (UI)	Delay (ns)	Amplitude	Delay (UI)	Delay (ns)	Amplitude
0	0	0.001	4.0	0.4704	0.0319
0.5	0.0588	0.0341	4.5	0.5292	0.0354
1	0.1176	0.1896	5.0	0.5880	0.0274
1.5	0.1764	0.2800	5.5	0.6468	0.0123
2	0.2352	0.1646	6.0	0.7056	0.0121
2.5	0.2940	0.1016	6.5	0.7644	0.0065
3.0	0.3528	0.0596	7.0	0.8232	0.0017
3.5	0.4116	0.0459			

C.5 SFP+ passive direct attach cable assembly specifications

Passive direct attach cables are tested with a pair of Module Compliance Boards at compliance point δ_t and δ_r. SFP+ passive cable assemblies shall meet the specifications in table C.5.

Table C.5 – SFP+ direct attach cable assembly specifications at B’ and C’

Parameter cable output (C’)	Units	Min	Target	Max
Single Ended Output Voltage Tolerance	V	-0.3		4.0
Output AC Common Mode Voltage, (note 1)	mV (rms)			30
Difference Waveform Distortion Penalty (dWDP), (note 2)	dB			3.25
VMA Loss to Crosstalk Ratio (VCR), (note 3)	dB	34		
VMA Loss (note 4)	dB			4
Differential Output/Input S-parameter SDDxx	SDDxx	note 5		
Common Mode Output/Input Reflection Coefficient SCCxx	SCCxx	note 5		
Parameter cable input (B”)	**Units**	**Min**	**Target**	**Max**
Input Rise and fall Time (20%-80%)	ps		40	
WDPi (note 6)	dBo		2.25	
Crosstalk Source Rise and fall time Time (20%-80%)	ps		40	

Table C.5 – SFP+ direct attach cable assembly specifications at B’ and C’

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 Boards. See C.5.2.
3. The data pattern for the VCR ratio is JSPAT or valid 8B/10B data traffic.
4. VMA loss is the ratio of VMA measured at input and output, respectively.
5. See table 25 for delta T SDD11 and table 28 for delta R SDD22 and SCC22.
6. WDPi is the WDP of the input signal as measured at B”. The input DDJ and DDPWS should be adjusted until the target WDPi is achieved.

C.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 (reference [24]). The cable is measured through a pair of Module Compliance Board as shown in figure C.3. 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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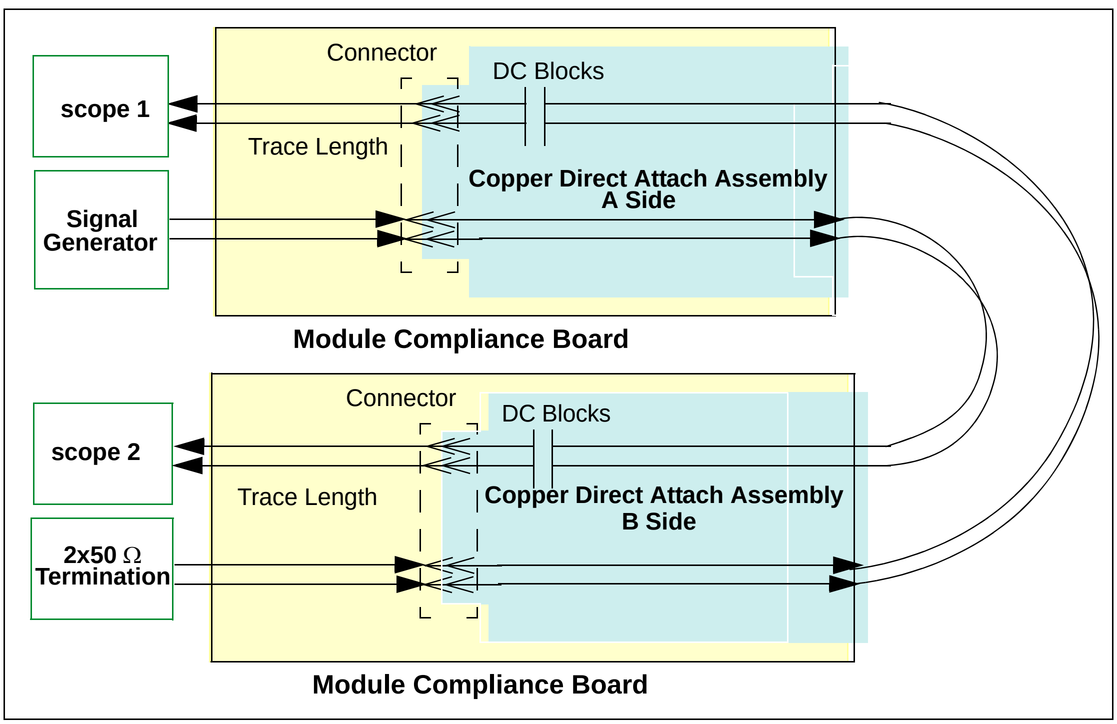

Figure C.3 – SFP+ direct attach cable measurement

WDPi and WDPo in figure C.4 use the WDP method defined in FC-MSQS (reference [34]). WDPi for copper is measured by plugging Host Compliance Board in to the Module Compliance Board 1 and then meeting the target WDPi as listed in table C.5. WDPo is measured by plugging one end of the cable into Module Compliance Board 1 and the other end into the Module Compliance Board 2.

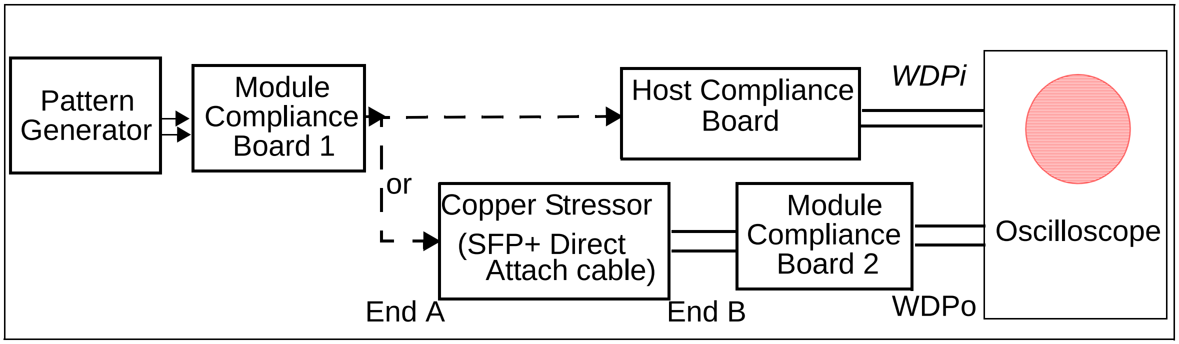

Figure C.4 – SFP+ direct attach cable NEXT dWDP test setup

C.5.2 Cable dWDP test procedure

The measurement procedure for dWDP is described below:

The pattern generator is set to the JSPAT.

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.

To calibrate WDPi per table C.5, refer to figure C.4. Plug a Host Compliance Board into the Module Compliance Board (see FC-MSQS (reference [34])) connected to the pattern generator. Adjust input rise and fall times to the target value as in table C.5.

Adjust DDJ and DDPWS to obtain WDPi given by table C.5.

DDJ and DDPWS limit as specified in table 29 at δ_t is not required to be met

Unplug the Host Compliance Board and connect the cable assembly to the Module Compliance Board as shown in figure C.4. Measure WDP_o.

dWDP = WDPo - WDPi.

C.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 for delta T by B in table 22.

The rise and fall times measured through the compliance test board pair are equal to the minimum rise and fall time given in table C.1.

DJ and DDPWS limit as specified in table 29 for delta T shall be met at B”.

The pattern for the crosstalk source is JSPAT.

NEXT is measured in a bandwidth of 12 GHz.

The far end Module Compliance Board outputs and input are terminated in 50 Ω.

The RMS NEXT is measured over one unit interval.

This measurement is then repeated for the other cable end.

C.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 the SFP+ host return loss.

$$VCR(dB) = 20LOG10\left[\frac{VMA \times 10^{\left(-\frac{L}{20}\right)}}{2 \times NEXT \times \left(1 + 0.3 \times 10^{\left(-\frac{L}{20}\right)}\right)}\right]$$

Where L is the cable VMA loss. NEXT is the near end crosstalk voltage in RMS measured with JS-PAT or valid FC data frame. Cable VMA loss and NEXT are measured with the Module Compliance Board.

Annex D (normative)
800-SA variants

D.1 8GFC linear variants

The parameters of 8GFC linear variants are defined here.

Table D.1 – Multimode link 800-SA variant

FC-0	Unit	800-SA	Note
Nominal signaling rate	MBd	8 500	8
Operating distance (M6)	m	0.5 - 40	1
Operating distance (M5)	m	0.5 - 100	
Operating distance (M5E)	m	0.5 - 300	
Operating distance (M5F)	m	0.5 - 300	
Fiber core diameter (M6)	mm	62.5	2
Fiber core diameter (M5, M5E, M5F)	mm	50	
Transmitter (gamma-T)			
Source type		Laser	
Center wavelength, min.	nm	840	
Center wavelength, max.	nm	860	
RMS spectral width, max.	nm	note 14	
Average launched power, max.	dBm		3
Average launched power, min.	dBm	-8	4
Optical modulation amplitude, min.	mW (dBm)		14
Rise/Fall time (20% - 80%), max.	ps		12
Transmitter waveform distortion penalty (TWDPo), max	dB	4.2	13
RIN_{12}OMA, max.	dB/Hz	-128	5
Encircled flux (M5E, M5F)			15
Receiver (gamma- R)			
Average received power, max.	dBm	0	
Unstressed receiver sensitivity, OMA	mW (dBm)	0.076 (-11.2)	5,7
Return loss of receiver, min.	dB	12	
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)	(510, 1) (100, 5)	11
Receiver electrical 3 dB upper cutoff frequency, max	GHz	12	6
Stressed test source			
Relative noise, RN (rms) (M6, M5)		0.039	10
Relative noise, RN (rms) (M5E, M5F)		0.054	
Stressed receiver sensitivity, OMA (M6, M5)	mW (dBm)	0.206 (-6.9)	5,10
Stressed receiver sensitivity, OMA (M5E, M5F)	mW (dBm)	0.214 (-6.7)	
WDPo (M6, M5)	dB	4.2	9,10
WDPo (M5E, M5F)	dB	3.9	
DDPWS	UI	0.21	10

Table D.1 – Multimode link 800-SA variant

FC-0	Unit	800-SA	Note
Notes: 1 The operating ranges and loss budgets shown here are based on MM fiber bandwidths given in table 20. For link budget calculations and other MM fiber bandwidths see FC-MSQS (reference [34]). 2 For details see sub-clause 8.2 3 Lesser of Class 1 laser safety limits (CDRH and EN 60825) or average received power, max. 4 The values are calculated using an infinite extinction ratio at the lowest allowed transmit OMA. 5 See FC-MSQS (reference [34]). 6 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 FC-MSQS (reference [34]). 7 The unstressed receiver sensitivity is informative only. See FC-MSQS (reference [34]). 8 The signaling rate shall not deviate by more than ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames). 9 For the receiver device testing, WDPo is defined with DDPWS already calibrated. It is defined with a 1,2 DFE EQ reference receiver (a DFE with 1 main and 2 feedback taps). It uses modified TWDP code where the ISI filter that represents the fiber is disabled. See FC-MSQS (reference [34]). 10 OMA, RN, WDPo, and DDPWS are defined through a 7.5-GHz fourth-order Bessel-Thomson filter. 11 Receiver jitter tracking is defined in FC-MSQS (reference [34]). 12 Transmitter deterministic performance is controlled by TWDPo. 13 TWDPo is calculated with a 1,2 equalizer and a Gaussian filter with a 4.92-GHz -3 dB (optical) bandwidth for the fiber simulation. 14 Trade offs are available between RMS spectral width and minimum optical modulation amplitude for 800-M6-SA-S, 800-M5-SA-I, and 800-M5E-SA-I variants. See figure D.1. 15 Encircled flux specifications in accordance with TIA-492AAAC-A (reference [31]) and IEC 60793-2-10 (reference [13]) or IEEE 802.3 clause 52 (reference [23]).			

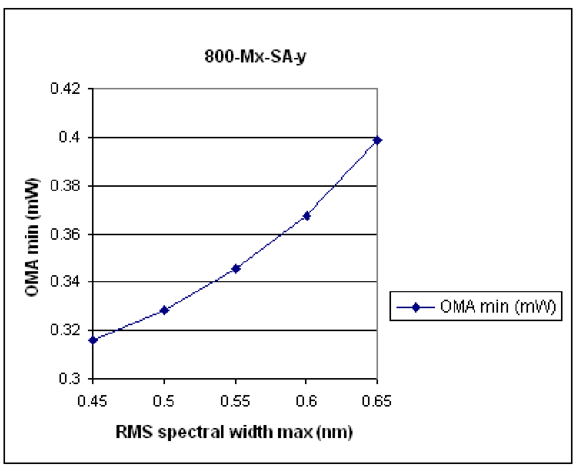

Figure D.1 – RMS spectral width and OMA trade offs

D.2 800-DF-EA-S at delta R compliance point

The delta R output shall meet the specifications defined in table D.2.

Table D.2 – signal output requirements for 800-DF-EA-S delta R

800-DF-EA-S, Inter-enclosure	δ_R
Relative noise, RN (rms)	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 FC-MSQS (reference [34]).
2 Trade-offs exist between the maximum RN and maximum WDP given in figure D.2.

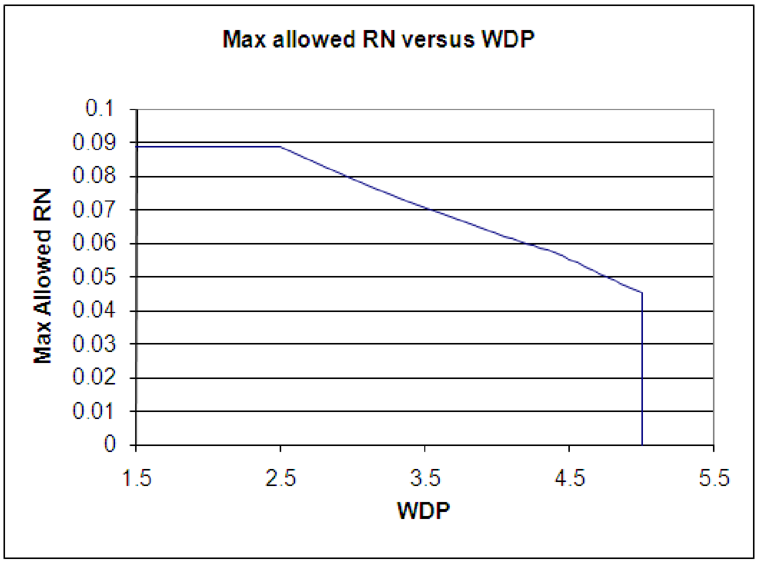

Figure D.2 – Trade-off between RN and WDP for 800-DF-EA-S delta R

Maximum WDP is 5.0 dB.
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 $0.057*10^{(4.2\text{-WDP})/10}$.
For WDP in the range of 4.2 dB and 5.0 dB maximum RN is $0.057*10^{(4.2\text{-WDP})/5.8}$.

The delta R input shall tolerate both case 1 and case 2 input signals defined in Table D.3 at all VMA levels between the minimum and maximum values. These conditions represent the maximum value of RN and maximum value of WDP.

Table D.3 – Signal tolerance requirements for 800-DF-EA-S delta R

800-DF-EA-S, Inter-enclosure	**Case 1** $\delta_{\mathbf{R}}$ note 5	**Case 2** $\delta_{\mathbf{R}}$ note 5
Relative noise, RN (rms) (note 4)	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 FC-MSQS (reference [34]).
3 Receiver jitter tracking is defined in FC-MSQS (reference [34]).
4 See FC-MSQS (reference [34]).
5 The values given in this table for delta R are through compliance boards at C". See FC-MSQS (reference [34]).

Annex E (normative)
Tx_Off and Rx_Loss

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-5 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-5 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-5. 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-5 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 FC-PI-5 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-5. The requirements given here apply to the transmission media interface and an (implied) service interface between the FC-PI-5 and FC-FS-3 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 table E.1.

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 table E.2.

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-5.

The value of Rx_LOS, where implemented, shall be generated in accordance with table E.3:

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-5 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 amplitude of the modulation of the optical signal.

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 22.

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 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 in accordance with table E.4:

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.
- 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 1 200 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.

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.”