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To: INCITS Members

Reply To: Rachel Porter

Subject: Public Review and Comments Register for the approval of:

INCITS 512-201x, Information technology - Fibre Channel - Switch Fabric - 6 (FC-SW-6)

Due Date: The public review is from April 11, 2014 to May 26, 2014.

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FIBRE CHANNEL

Physical Interface-6

REV 3.10

INCITS working draft proposed
American National Standard
for Information Technology

October 25, 2013

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. This standard is recommended for new implementations but does not obsolete the existing Fibre Channel standards.

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ANSI ®
Project 2221-D

American National Standard for Information Technology

Fibre Channel — Physical Interface-6 (FC-PI-6)

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 INCITS Project 2221-D.)

This standard was developed by Task Group T11.2 of Accredited Standards Committee INCITS during 2011, 2012, and 2013. The standards approval process will be started in 2013. 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.

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Revision History

1) Revision 0.00 Initial blank document.

2) Revision 0.02 Initial release of tables for informal comment.

3) Revision 0.03 released for further comments.

4) Revision 1.00 released for T11.2 formal Ballot.

5) Revision 1.10 released for further comments in preparation for T11 formal Ballot.

6) Revision 2.00 released for T11 formal Ballot.

7) Revision 2.10 released to confirm T11 Ballot resolutions

8) Revision 2.20 released to correct minor edits

9) Revision 3.00 released to incorporate T11/14-017v0.

10) Revision 3.10 released to clarify note 4, table 16, in Clause 7.

Contents

List of Figures

List of Tables

American National Standard
for Information Technology–

Fibre Channel –
Physical Interface-6 (FC-PI-6)

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-4 (reference [18]).

FC-PI-6 includes 32GFC. 16GFC, 8GFC and 4GFC are described in FC-PI-5 (reference [1]). Older technologies of 2GFC and 1GFC are listed in 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 479-2011, FC-PI-5,** Fibre Channel Physical Interfaces - 5

[2] **ANSI/INCITS 460-2011, FC-PI-3,** Fibre Channel Physical Interfaces - 3

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

[4] **ANSI/INCITS TR-35-2006, FC-MJSQ,** Fibre Channel Methodologies for Jitter and Signal Quality Specification

[5] **ANSI/INCITS TR-46-2011, FC-MSQS,** Fibre Channel Methodologies for Signal Quality Specification

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

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

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

[9] IEC 60825-1, Safety of laser products - Part 1: Equipment classification and requirements, latest edition.

[10] IEC 60825-2, Safety of laser products - Part 2: Safety of optical fiber communication systems, latest edition.

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

[12] 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.

[13] IEC 61280-2-2, Fiber optic communication subsystem test procedure - Part 2-2: Digital systems - Optical eye pattern, waveform, and extinction ratio measurements

[14] IEEE Std 802.3™-2012, IEEE Standard for Ethernet.

[15] OIF-CEI-03.0, Common electrical I/O (CEI) - Electrical and jitter interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O

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

[17] 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

2.3 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.

[18] ANSI/INCITS 1861D, FC-FS-4, Fibre Channel Framing and Signaling 4

[19] ANSI/INCITS 1734DT, FC-MSQS-2, Fibre Channel Methodologies for Signal Quality Specification 2

[20] IEEE P802.3bj, 100 Gb/s Backplane and Copper Cable

[21] OIF2010.404.15 OIF CEI-28G-VSR Very Short Reach Interface

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:** the difference between the upper -3 dB frequency and the lower -3 dB frequency of the amplitude response of a Fibre Channel component.

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.

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 [12]).

3.1.18 character: a defined set of n contiguous bits where n is determined by the encoding scheme.

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

3.1.21 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.

3.1.22 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.

3.1.23 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.

3.1.24 delta T, delta R: see δ_T, δ_R.

3.1.25 deterministic jitter: see jitter, deterministic.

3.1.26 device: see FC device.

3.1.27 disparity: the difference between the number of ones and zeros in a Transmission Character. See FC-FS-4 (reference [18]).

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

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

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

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

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

3.1.33 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.

3.1.34 extinction ratio: the ratio of the high optical power to the low optical power. See IEC 61280-2-2 (reference [13]).

3.1.35 FC-0 level: The level in the Fibre Channel architecture and standards that defines transmission media, transmitters and receivers, and their interfaces. See FC-FS-4 (reference [18]).

3.1.36 FC-1 level: The level in the Fibre Channel architecture and standards that defines the transmission protocol that includes the serial encoding, decoding, and error control. See FC-FS-4 (reference [18]).

3.1.37 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.

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

3.1.39 fiber optic cable: a jacketed optical fiber or fibers.

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

3.1.41 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 [4]), as modified for 32GFC. For 16GFC and lower speeds the 3dB bandwidth is (nominal signalling rate)/1667. For 32GFC the 3dB bandwidth is (nominal signalling rate)/2805.

3.1.42 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.

3.1.43 integrated crosstalk noise: an estimate of the noise due to crosstalk. It is calculated from the S parameters of the channel and takes into account the spectrum, risetime, and amplitude of the crosstalk sources. See clause 10.4 of FC-MSQS (reference [5]).

3.1.44 insertion loss deviation: the insertion loss deviation ILD is the difference between the measured insertion IL and the fitted insertion loss ILfitted. See clause 10.2.6.4 and clause 12.2 in OIF-CEI-03.0 (reference [15]).

3.1.45 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.

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

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

3.1.48 interoperability point: points in a link or TxRx connection for which 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.

3.1.49 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.

3.1.50 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 [4]) that occurs under a specific set of conditions. In this document, jitter is defined at the average signal level.

3.1.51 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.

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

3.1.53 jitter, deterministic (DJ): jitter with non-Gaussian probability density function. Deterministic jitter is always bounded in amplitude and has specific causes. Deterministic jitter comprises (1) correlated DJ (data dependent (DDJ) and duty cycle distortion (DCD)), and (2) DJ that is 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 [4]).

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

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, even-odd: Even-odd jitter is defined as the magnitude of the difference between the average deviation of all even-numbered transitions and the average deviation of all odd-numbered transitions, where determining if a transition is even or odd is based on possible transitions but only actual transitions are measured and averaged.

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

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

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

3.1.61 jitter tolerance: 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.

3.1.62 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 [5]).

3.1.64 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-6 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.

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

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

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

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

3.1.69 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.

3.1.70 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.

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

3.1.72 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 [6]).

3.1.73 OM2: cabled optical fiber containing 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 [7].

3.1.74 OM3: cabled optical fiber containing 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 [7].

3.1.75 OM4: cabled optical fiber containing 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.3 fiber. See reference [7].

3.1.76 optical fiber: any filament or fiber, made of dielectric material, that guides light.

3.1.77 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 [5]).

3.1.78 optical receiver sensitivity: the minimum acceptable value of received signal at point gamma R to achieve a defined level of BER. For 32GFC, this level is BER < 10^{-6}. See also the definitions for stressed receiver sensitivity and unstressed receiver sensitivity. See FC-MSQS (reference [5]) and FC-MSQS-2 (reference [19]).

3.1.79 optical path penalty: a link optical power penalty to account for signal degradation other than attenuation.

3.1.80 optical return loss (ORL): see return loss.

3.1.81 OS1: cabled optical fiber containing dispersion unshifted single-mode fiber in accordance with IEC 60793-2-50 Type B1.1 fiber specified at 1.0 dB/1.0 dB at 1310nm/1550nm respectively. See reference [8].

3.1.82 OS2: cabled optical fiber containing dispersion unshifted, low water peak, single-mode fiber in accordance with IEC 60793-2-50 Type B1.3 fiber or bend-insensitive fiber in accordance with IEC 60793-2-50 Type B6 fiber specified at 0.4 dB/0.4 dB/0.4 dB at 1310nm/1383nm/1550nm respectively. See reference [8].

3.1.83 P_{alloc}: the effective system power/voltage budget used in TWDP and WDP calculations. See FC-MSQS (reference [5]).

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

3.1.85 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.

3.1.86 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.

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

3.1.88 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.

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

3.1.90 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.

3.1.91 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.

3.1.92 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.

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

3.1.94 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.

3.1.95 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.

3.1.96 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.

3.1.97 $RIN_{12}OMA$: relative Intensity Noise. Laser noise in dB/Hz with 12 dB optical return loss, with respect to the optical modulation amplitude.

3.1.98 $RIN_{20}OMA$: relative Intensity Noise. Laser noise in dB/Hz with 20 dB optical return loss, with respect to the optical modulation amplitude.

3.1.99 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.

3.1.100 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-4 (reference [18]).

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

3.1.102 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.

3.1.103 side-mode suppression ratio: ratio of the power in the dominant spectral mode to the power in the strongest side mode.

3.1.104 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.

3.1.105 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.

3.1.106 spectral width (RMS): the weighted root mean square width of the optical spectrum. See IEC 61280-1-3 (reference [12]).

3.1.107 stressed receiver sensitivity: the amplitude of optical modulation in the stressed receiver test given in FC-MSQS-2 (reference [19]).

3.1.108 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 [5]).

3.1.109 synchronization: bit synchronization, defined above, and/or Transmission-Word synchronization, defined in FC-FS-4 (reference [18]). An FC-1 receiver enters the state “Synchronization-Acquired” when it has achieved both kinds of synchronization.

3.1.110 transceiver: a transmitter and receiver combined in one package.

3.1.111 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.

3.1.112 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.

3.1.113 transmission code: a means of encoding data to enhance its transmission characteristics. The transmission code specified by FC-FS-4 (reference [18]) is byte-oriented, with both valid data bytes and special (control) codes encoded into 10-bit transmission characters.

3.1.114 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.

3.1.115 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.

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

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

3.1.118 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 [14].

3.1.119 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.

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

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

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

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

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

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

3.1.126 unstressed receiver sensitivity: the amplitude of optical modulation in the unstressed sensitivity receiver test in. See FC-MSQS-2 (reference [19]).

3.1.127 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 [5]).

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

3.1.129 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-6. However, if any optional characteristic is implemented, it shall be implemented as defined in FC-PI-6.

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 2. Definitions of several of these items are included in subclause 3.1.

3.2.3.1 Acronyms and other abbreviations

Table 2 – Acronyms and other abbreviations

Bd	baud
BER	bit error ratio
BUJ	bounded uncorrelated jitter
CDF	cumulative distribution function
dB	decibel
dBm	decibel (relative to 1 mW)
DCD	duty cycle distortion
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
ICN	integrated crosstalk noise
ILD	insertion loss deviation
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 Industry 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

Table 2 – Acronyms and other abbreviations

ULP	Upper Level Protocol
VECP	vertical eye closure penalty
WDP	waveform distortion penalty

3.2.3.2 Signaling rate abbreviations

Abbreviations for the signalling rates are frequently used in this document. Table 3 shows the abbreviations that are used and the corresponding signalling rates.

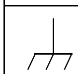
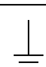
Table 3 – Signaling rate abbreviations

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
32GFC	28 050 MBd	3 200 MB/s

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-6 functional characteristics

4.1 General characteristics

FC-PI-6 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.

Fibre Channel 32GFC links use 256B/257B transmission code; see FC-FS-4 (reference [18]). This code includes Forward Error Correction (FEC) which is required to achieve the link BER objectives. The BER of each TxRx connection in a 32GFC link, as observed prior to error correction, is defined to be 10^{-6} or better. 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. When these conditions are satisfied, it is expected that the link BER after error correction will be undetectably low.

FC-PI-6 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 a signaling rate of 32GFC as defined in table 3. 32GFC has transmitter and receiver clock tolerances of ±100 ppm. A TxRx Connection bit error rate (BER) of ≤ 10^{-6} 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-6 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-6 is not required for such applications. For closed or integrated links the system designer shall ensure that a BER of better than 10^{-6} is delivered.

The requirements specified in FC-PI-6 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 clause 5.13 of FC-PI-5 (reference [1]). 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 1 shows the reclocker locations for 32GFC 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-6 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.

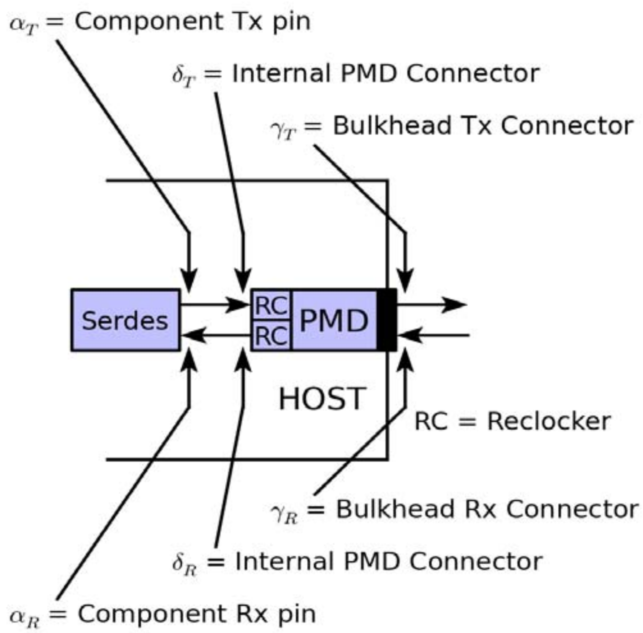


Figure 1 – Reclocker location for all 32GFC PMDs

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-4 occurs at the logical encoded data interfaces. As these are logical data constructs, no physical implementation is implied by FC-FS-4. FC-PI-6 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-6 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-6 and FC-FS-4 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-6 clauses associated with that technology. An example of this would be ensuring that optical power levels associated with eye safety are maintained.

4.2 FC-0 states

4.2.1 Transmitter 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.

4.2.2 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.

4.3 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.

4.4 Receiver stabilization 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.

4.5 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.

4.6 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 8GFC. A repeater shall achieve compliant operation within 1 ms following an application of a compliant signal at its input. For 16GFC and 32GFC, 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 4.4) 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.

d) The transmit training signal is used for speed negotiation for 32GFC. The transmit training signal is defined in FC-FS-4 (reference [18]).

4.7 Transmission codes

32GFC variants rely on the implementation of FEC, transcoding, and scrambling as defined in FC-FS-4 (reference [18]). The actual FEC, transcoding, and scrambling hardware is at the FC-1 layer and is not defined in FC-PI-6.

4.8 Frame scrambling and emission lowering protocol

32GFC uses coding and scrambling that is inherent in the code as defined in FC-FS-4 (reference [18]).

4.9 Speed negotiation and transmitter training

For 32GFC the transmitter training signal (TTS) shall be used for speed negotiation for both optical and electrical links. If the link is a passive electrical link, the transmit training signal will be used for speed negotiation and then transmit training will be done. If the link is an optical link, the transmit training signal is used for speed negotiation and transmit training is not performed. The transmit training signal consists of a frame marker, control field, status field, and training pattern.

The frame marker consists of a signal that is 16UI high and 16UI low. The control field and the status field are both 16 bit fields. The control and status field are Differential Manchester Encoded (DME). A DME bit has a length of 8UI and the following properties.

1. There is a data transition at each cell boundary.
2. A mid cell data transition signals a logic 1.
3. The absence of a mid cell data transition signals a logic 0.

The DME encoded status and control field is 256UI.

The training pattern is 4096UI, 4094UI of PRBS11 followed by 2UI of 0.

During speed negotiation for 32GFC, the previously reserved bits 14, 15 in the control field are set to 1 to serve as an extended marker. The speed negotiation bit 14 in the status field is set to 1. The other bits in the control and status field are set to 0.

The table below highlights the bit sequence for the frame marker, control, and status fields during speed negotiation. This is followed by the 4096UI training pattern. This sequence is repeated until speed negotiation is completed.

Table 5 – Transmitter training signal frame marker, control, and status field bit sequence

Frame marker, control status field bits	Identifier
1111 1111 1111 1111	Frame Marker
0000 0000 0000 0000	
1111 0000 1111 0000	Extended Marker
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 1111	Speed negotiation bit high
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	

The table gives an indication of the spectral content of the 288UI that comprise the training frame during speed negotiation. This is then followed by 4096UI training pattern which is composed of PRBS11.

4.10 Forward error correction (FEC)

32GFC variants rely on the implementation of FEC as defined in FC-FS-4 (reference [18]). The actual FEC hardware is at the FC-1 layer and is not defined in FC-PI-6.

4.11 Test patterns

32GFC shall use the test patterns stated in FC-MSQS-2 (reference [19]).

4.12 Fibre Channel variants nomenclature

The nomenclature for the Fibre Channel variants is illustrated in figure 2. 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
3200 -- 3 200 MB/s
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 PMD delta points for limiting optical receivers) 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 2 – Fibre Channel variant nomenclature

4.13 FC-PI-6 variants

Table 6 and Table 7 list variants by FC-PI-6 nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize the variant. The nomenclature is illustrated in figure 2.

The lengths specified in table 6 and table 7 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 6 – Fibre Channel variants not in this document

note 1	**100 (**note 2)	**200 (**note 2)	**400 (**note 3)	**800 (**note 3)	**1600 (**note 3)
SM OS1, OS2	**100-SM-LC-L** 1 300 nm 0.5 m - 10 km	**200-SM-LC-L** 1 300 nm 0.5 m - 10 km	**400-SM-LC-L** 1 300 nm 0.5 m-10 km	**800-SM-LC-L** 1 300 nm 0.5 m-10 km	**1600-SM-LC-L** 1 300 nm 0.5 m-10 km
	100-SM-LL-V 1 550 nm 0.5 m - 50 km	**200-SM-LL-V** 1 550 nm 0.5 m - 50 km	**400-SM-LC-M** 1 300 nm 0.5 m-4 km	**800-SM-LC-I** 1 300 nm 0.5 m-1.4 km	**1600-SM-LZ-I** 1 490 nm 0.5 m-2 km
MM 62.5 µm OM1	**100-M6-SN-I** 780/850 nm 0.5 m - 300 m	**200-M6-SN-I** 850 nm 0.5 m - 150 m	**400-M6-SN-I** 850 nm 0.5 m-70 m	**800-M6-SN-S** 850 nm 0.5 m-21 m	**1600-M6-SN-S** 850 nm 0.5 m-15 m
				800-M6-SA-S 850 nm 0.5 m-40 m	
MM 50 µm OM2	**100-M5-SN-I** 780/850 nm 0.5 m - 500 m	**200-M5-SN-I** 850 nm 0.5 m - 300 m	**400-M5-SN-I** 850 nm 0.5 m-150 m	**800-M5-SN-S** **850 nm** **0.5 m-50 m**	**1600-M5-SN-S** **850 nm** **0.5 m-35 m**
				800-M5-SA-I 850 nm 0.5 m-100 m	
MM 50 µm OM3	**100-M5E-SN-I** 780/850 nm 0.5 m - 860 m	**200-M5E-SN-I** 850 nm 0.5 m - 500 m	**400-M5E-SN-I** 850 nm 0.5 m-380 m	**800-M5E-SN-I** **850 nm** **0.5 m-150 m**	**1600-M5E-SN-I** **850 nm** **0.5 m-100 m**
				800-M5E-SA-I 850 nm 0.5 m-300 m	
MM 50 µm OM4			**400-M5F-SN-I** 850 nm 0.5 m-400 m	**800-M5F-SN-I** 850 nm **0.5 m-190 m**	**1600-M5F-SN-I** **850 nm** **0.5 m-125 m**
				800-M5F-SA-I 850 nm 0.5 m-300 m	
EL Balanced	**100-DF-EL-S**	**200-DF-EL-S**	**400-DF-EL-S**	**800-DF-EL-S**	**1600-DF-EL-S**
EA Balanced				**800-DF-EA-S**	**1600-DF-EA-S**
EL Unbalanced	**100-SE-EL-S**	**200-SE-EL-S**			

Notes:

1. For 10GFC variant refer to 10GFC (reference [1]) and FC-PI-3 (reference [2]).
2. This is obsoleted technology. For information refer to FC-PI-2 (reference [3]).
3. Information about these variants can be found in FC-PI-5 (reference [1])

Table 7 – Fibre Channel Variants in FC-PI-6

	3200
SM **OS1, OS2**	**3200-SM-LC-L** 1 300 nm 0.5 m-10 km sub-clause 5.3
MM 50 µm **OM2**	**3200-M5-SN-S** 850 nm 0.5 m-20 m sub-clause 5.4
MM 50 µm **OM3**	**3200-M5E-SN-S** 850 nm 0.5 m-70m sub-clause 5.4
MM 50 µm **OM4**	**3200-M5F-SN-I** 850 nm 0.5 m-100 m sub-clause 5.4
EA Balanced	**3200-DF-EA-S** clause 6

5 Optical interface specification

5.1 TxRx connections

Clause 5 defines the optical signal characteristics at the interface connector. Each conforming optical FC port shall comply with the requirements specified in clause 5 and other applicable clauses. Fibre Channel 32GFC optical links require forward error correction (FEC) to achieve link BER objectives. In the absence of forward error correction, Fibre Channel optical links shall not exceed a BER of $1x10^{-6}$ under any compliant conditions; see FC-MSQS-2 (reference [19]). The parameters specified in this clause support meeting that requirement.

A link, or TxRx connection, may be divided into TxRx connection segments; see figure 10 in FC-PI-5 (reference [1]). 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 6.

5.2 Laser safety issues

The optical output shall not exceed Class 1 maximum permissible exposure limits under any condition of operation, per IEC 60825-1 (reference [9]) and IEC 60825-2 (reference [10]).

5.3 SM data links

5.3.1 SM general information

Table 8 gives the variant names, a general link description, and the gamma compliance point specifications for 10-km single-mode optical fiber links running at 32GFC.

Table 8 – Single-mode link classes (OS1, OS2)

Single mode link parameters (note 1)	**Unit**	**3200-SM-LC-L**	**Note**
Nominal signaling rate	MBd	28 050	2
Operating distance	m	0.5 -10 000	
Transmitter (gamma-T)			
Type		Laser	
Center wavelength, max.	nm	1325	
Center wavelength, min.	nm	1295	
Optical modulation amplitude, min.	mW(dBm)	0.631(-2.0)	3,5
Side-mode suppression ratio, min.	dB	30	
-20 dB spectral width, max.	nm	1	
Average launched power, max.	dBm	+2.0	
Average launched power, min.	dBm	-5.0	4
$RIN_{20}OMA$, max.	dB/Hz	-130	6
Extinction Ratio, min	dB	4.0	
Transmitter and dispersion penalty (TDP), max	dB	2.7	7
Receiver (gamma- R)			
Average received power, max.	dBm	+2.0	
Rx jitter tracking test, OMA	mW(dBm)	0.120(-9.2)	8
Rx jitter tracking test, frequency and pk-pk amplitude	(kHz,UI)	(500,1) (100,5)	8
Unstressed receiver sensitivity, OMA	mW(dBm)	0.072(-11.4)	6,9
Return loss of receiver, min.	dB	26	

Notes:

1. See: IEC 60793-2-50 (reference [8]), Type B1.1 and IEC 60793-2-50 (reference [8]), Type B1.3, and IEC 60793-2-50 (reference [8]), Type B6 Optical fibers - Part 2: Product Specifications.
2. 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).
3. See FC-MSQS (reference [5]).
4. The values are calculated using an infinite extinction ratio at the lowest allowed transmit OMA.
5. 3200-SM-LC-L optical modulation amplitude in dBm shall also exceed -5.0+TDP.
6. See FC-MSQS-2 (reference [19]).
7. Transmitter and dispersion penalty (TDP) determines the contribution of RIN, the rise/fall times, and chromatic dispersion. See FC-MSQS-2 (reference [19])
8. Receiver jitter tracking is defined in FC-MSQS-2 (reference [19]).
9. For 32GFC with FEC, receiver sensitivity is defined at 10^{-6} BER level, not 10^{-12} BER level.

5.3.2 SM optical output interface

The optical transmit signal is defined at the output end of a patch cord between one half and five meters in length.

Optical modulation amplitude (OMA) is defined as the difference in optical power between a logic-1 and a logic-0, as defined in FC-MSQS (reference [5]).

The optical power is defined by the methods of IEC 61280-1-1 (reference [11]), 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 figure 1). The parameters specifying the mask of the transmitter eye diagram are shown in figure 3. See FC-MSQS (reference [5]).

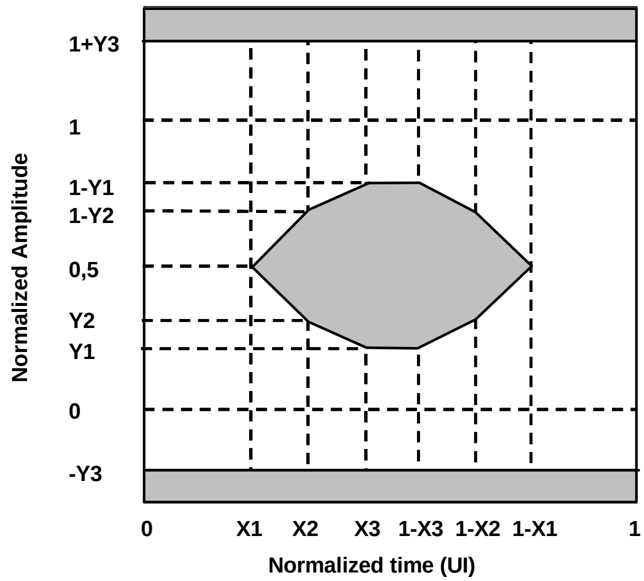


Figure 3 – SM transmitter eye mask for 32GFC

Table 9 shows the mask parameters of figure 3. 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/2805. The mask applies at a probability of 10^{-3}.

Table 9 – SM transmitter eye mask parameters for 32GFC

	32GFC	
	Value	**Unit**
X1	0.22	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.31	
Y2	0.33	
Y3	0.50	

5.3.3 SM optical input interface

The receiver shall operate within the BER requirement (10^{-6}) when the input power falls in the range given in table 8 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 3.

5.4 MM data links

5.4.1 MM general information

Table 10 gives the variant names, a general link description, and the gamma compliance point specifications for multi-mode optical fiber links running at 32GFC.

Table 10 – Multimode link classes

Multimode link parameters	Unit	3200-SN	Note
Nominal signaling rate	MBd	28 050	1
Operating distance (OM2)	m	0.5 - 20	2
Operating distance (OM3)	m	0.5 - 70	2,9
Operating distance (OM4)	m	0.5 - 100	
Transmitter (gamma-T)			
Source type		Laser	
Center wavelength, min.	nm	840	
Center wavelength, max.	nm	860	
RMS spectral width, max.	nm	0.570	
Average launched power, max.	mW(dBm)	1.585(2)	3
Average launched power, min.	mW(dBm)	0.240(-6.2)	4
Optical modulation amplitude, min.	mW(dBm)	0.479(-3.2)	5
Vertical Eye Closure Penalty ($VECP_q$), max	dB	3.13	5,7,8
$RIN_{12}OMA$, max.	dB/Hz	-129	6
Encircled flux			9
Receiver (gamma- R)			
Average received power, max.	mW(dBm)	1.585(2)	
Unstressed receiver sensitivity, OMA	mW(dBm)	0.095(-10.2)	6,10,11
Return loss of receiver, min.	dB	12	
Rx jitter tracking test, OMA	mW(dBm)	0.295(-5.3)	6,7,12
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)	(500,1) (100,5)	6
Stressed test source			
Stressed receiver sensitivity, OMA	mW(dBm)	0.263(-5.8)	6,10,13
Receiver vertical eye closure penalty	dB	3.10	5,7,14
Receiver DJ	UI	0.10	5,7,15

Notes:

1 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).

2 The operating ranges shown here are based on MM fiber bandwidths given in table 20 of FC-PI-5 (reference [1])and a 1.5 dB total connector loss. For link budget calculations methodology see FC-MSQS (reference [5]) and FC-MSQS-2 (reference [19]). For details see subclause 8.2 in FC-PI-5 (reference [1])

3 Defined by average received power, max.

4 The value is calculated using an infinite extinction ratio at the lowest allowed transmit OMA.

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

6 See FC-MSQS-2 (reference [19]).

7 The reference receiver shall have a bandpass conforming to a 21 GHz fourth-order Bessel Thomson filter.

8 VECPq for 3200-SN is calculated with a 1,0 equalizer and a Gaussian filter with a 24.7 GHz -3 dBo (optical) bandwidth for fiber simulation.

9 Encircled flux specifications in accordance with TIA-492AAAC-A (reference [16]) and IEC 60793-2-10 (reference [7]) or IEEE 802.3 clause 52 (reference [14]).

10 For 32GFC with FEC, receiver sensitivity is defined at 10^{-6} BER level, not 10^{-12} BER level.

11 The unstressed receiver sensitivity is informative only

12 This is the optical input amplitude for testing compliance to the jitter tracking at gamma R.

13 The stressed receiver sensitivity value in the table are for system level BER measurements that include the effects of actual reclocker circuits.

14 Receiver vertical eye closure penalty, VECP, is a test condition for measuring stressed receiver sensitivity and is not a required characteristic of the receiver.

15 Receiver DJ is a test condition for measuring stressed receiver sensitivity and not a required condition of the receiver.

5.4.2 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.

The general laser pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see figure 1). 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 4.

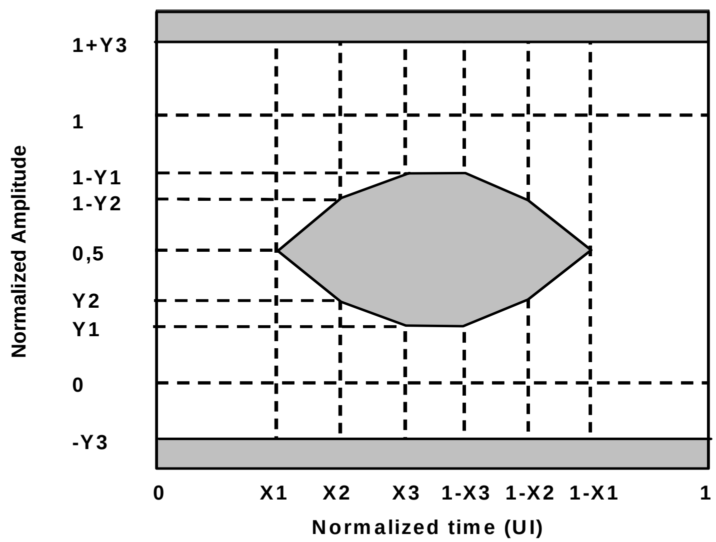


Figure 4 – MM transmitter eye mask for 32GFC

Table 11 – MM transmitter eye mask values for 32GFC

	32GFC	
	Value	**Unit**
X1	0.30	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.37	
Y2	0.40	
Y3	0.40	

Table 11 shows the mask parameters of figure 4. 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/2805. 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.

5.4.3 MM optical input interface

The receiver shall operate with a maximum BER of 10^{-6} when the input power falls within the range given in table 10 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 4.

6 Electrical interface specification - single lane variants

This clause defines the electrical Tx and Rx parameters for the channel between a host ASIC and a transceiver module plugged into a separable connector at the Fibre Channel delta-T/delta-R compliance points. The existence of a compliance point is determined by the existence of a connector at that point in a TxRx connection. Annex C provides the channel electrical characteristics. Significant material from OIF CEI-28G-VSR (reference [21]) was utilized in developing this clause.

6.1 General electrical characteristics

Each conforming electrical FC device shall be compatible with this serial electrical interface to allow interoperability within an FC environment. Fibre Channel 32GFC links use the 256B/257B transmission code; see FC-FS-4 (reference [18]). This code includes Forward Error Correction which is required to achieve the link BER objective. Prior to error correction, Fibre Channel 32GFC TxRx connections shall not exceed a BER of 10^{-6} under any compliant conditions. The parameters in this clause support meeting that requirement. At this level of BER performance, it is expected that the BER after error correction will be undetectably low.

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 12.

Table 12 – General electrical characteristics

	Units	3200-DF-EA-S
Data rate (note 1)	MB/s	3 200
Nominal symbol rate	MBd	28 050
Tolerance	ppm	±100
Differential Impedance	Ω (nom)	100
Notes: 1 The data rate may be verified by determining the time to transmit at least 200 000 transmission bits (10 max length FC frames).		

6.2 Compliance test point definitions

6.2.1 Test method

The interoperability points are generally defined for Fibre Channel systems as being immediately after the mated connector. For the delta points this is not an easy measurement point, particularly at high frequencies, as test probes cannot be applied to these points without affecting the signals being measured, and de-embedding the effects of test fixtures is difficult. For delta point measurements reference test points are defined with a set of defined test boards for measurement consistency. The delta point specifications in FC-PI-6 are to be interpreted as being at the RF connector outputs and inputs of the reference compliance boards.

In order to provide test results that are reproducible and easily measured, this document defines two test boards that have RF connector interfaces for easy connection to test equipment. One is designed for insertion into a host, and one for inserting modules. The reference test boards' objectives are:

- Satisfy the need for interoperability at the electrical level.

- Allow for independent validation of host and module.
- The PCB traces are targeted at 100 Ω differential impedance with nominal 7% differential coupling.

Testing compliance to specifications in a high-speed system is delicate and requires thorough consideration. Using common test boards that allow predictable, repeatable, and consistent results among vendors will help to ensure consistency and true compliance in the testing.

The reference test boards provide a set of overlapping measurements for module and host validation to ensure system interoperability.

6.2.2 Host test points

Host system transmitter and receiver compliance are defined by tests in which a Host Compliance Board is inserted, as shown in figure 5, in place of the module. The test points are B and C.

Host compliance points are defined as the following:

- B: host output at the output of the Host Compliance Board. Electrical output and host return loss specifications shall be met at this point.
- C: host input at the input of the Host Compliance Board. Host return loss specifications shall be met at this point.

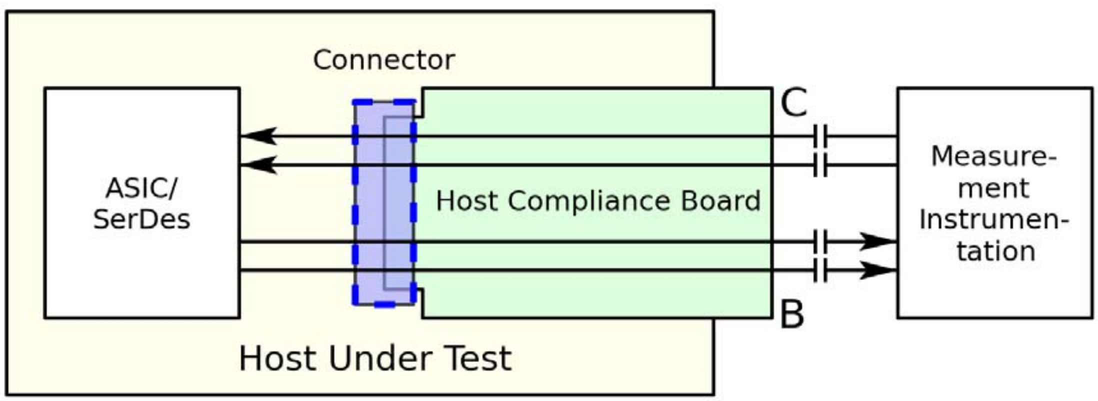


Figure 5 – Host Compliance Board

6.2.3 Module test points

Module transmitter and receiver compliance are defined by tests in which the module is inserted into the Module Compliance Board as shown in figure 6.

Module test points are defined as the following:

- B': Module electrical input at the input of the Module Compliance Board. Module return loss specifications shall be met at this point.
- C': Module electrical output at the output of the Module Compliance Board. Module output and module return loss specifications shall be met at this point.

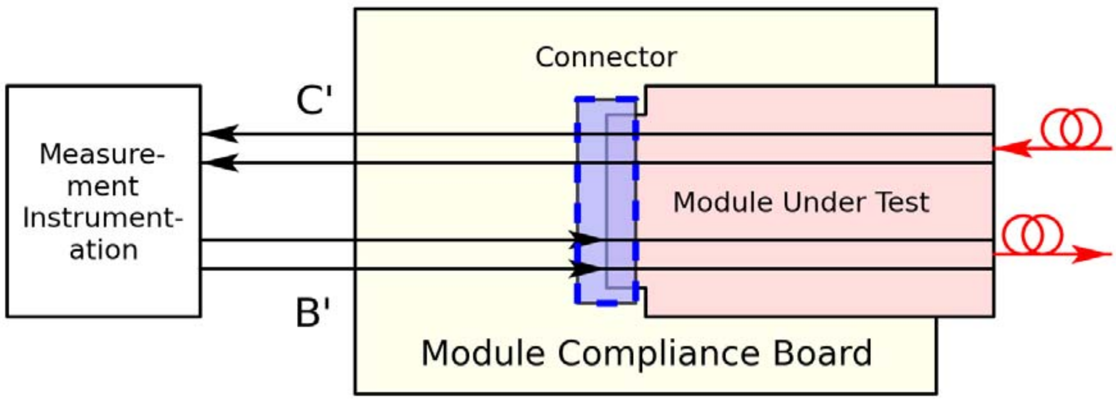


Figure 6 – Module Compliance Board

6.2.4 Host input calibration point

The host receiver input tolerance signal is calibrated through the Host Compliance Board at the output of the Module Compliance Board as shown in figure 7. The opposite data path is excited with an asynchronous test source with PRBS31 or 32GFC IDLE. See table 14 for electrical characteristics. The host input calibration point is at C'' with specifications for input signals being calibrated at C''. Note that the point C'' has additional trace loss beyond the edge connector pins.

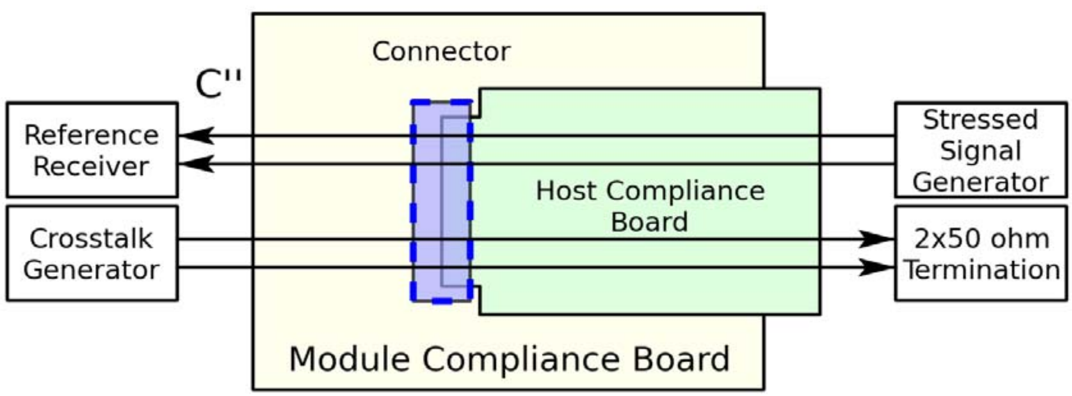


Figure 7 – Host input calibration point C''

6.2.5 Module input calibration point

The module electrical input tolerance signal is calibrated through the Module Compliance Board at the output of the Host Compliance Board as shown in figure 8. The opposite data path is excited with an asynchronous test source with PRBS31 or 32GFC IDLE. See table 14 for electrical characteristics. The module input calibration point is at B'' with specifications for input signals being calibrated at B''. Note that point B'' has additional trace loss beyond the module pins.

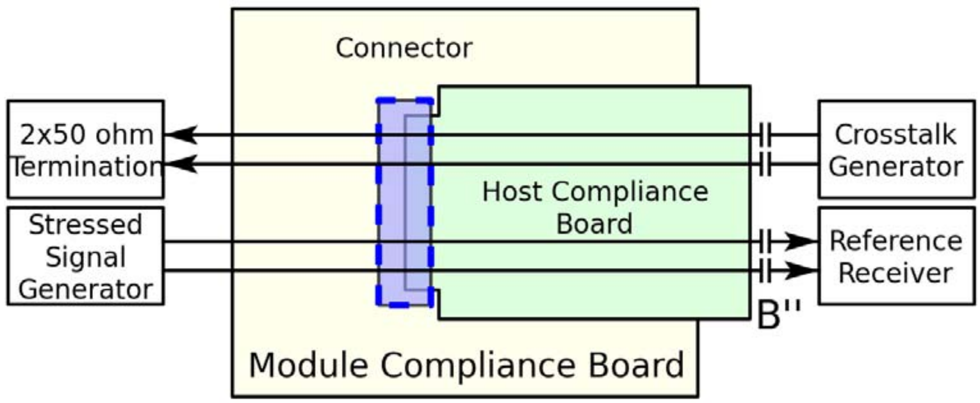


Figure 8 – Module input calibration point B"

6.3 Transmitted signal characteristics

This subclause defines the interoperability requirements of the transmitted signal at the driver end of a TxRx connection. Details for the measurement process are specified in FC-MSQS-2 (reference [19]), as adapted from OIF (reference [21]).

Hosts and modules shall meet the appropriate specifications defined in table 13.

Table 13 – Transmitter compliance requirements

Parameter	**Host output**		**Module electrical output**		**Units**	**Notes**
	Min	**Max**	**Min**	**Max**		
Compliance point	B (figure 5)		C' (figure 6)			note 1
Differential voltage pk-pk	-	900	-	900	mV	
Common mode noise rms	-	17.5	-	17.5	mv	
Differential termination resistance mismatch	-	10	-	10	%	note 2
Differential return loss SDD22	-	equation 1 figure 10	-	equation 1 figure 10	dB	note 3
Common mode to differential conversion SDC22	-	equation 3 figure 12	-	equation 3 figure 12	dB	note 4
Differential to common mode conversion SCD22						
Common mode return loss SCC22	-	-2	-	-2	dB	note 5
Source transition time 20%-80%	10	-	9.5	-	ps	
Common mode voltage	-0.3	2.8	-	-	V	note 6
Vertical eye closure	-	-	-	4	dB	note 7
Eye width at 10^{-6} probability EW6	0.46	-	0.65	-	UI	
Eye height at 10^{-6} probability EH6	50	-	250	-	mV	
Crosstalk parameters						
Signal calibration point	C" (figure 7)		B" (figure 8)			note 1, note 8
Signal application point	C (figure 5)		B' (figure 6)			
Crosstalk amplitude differential voltage pk-pk	900		900		mV	
Crosstalk transition time 20%-80%	9.5		10		ps	note 9

Notes:

1. See compliance test point definitions in subclause 6.2
2. At 1 MHz
3. See subclause 6.6.1 for differential return loss SDD22
4. See subclause 6.6.2 for common mode to differential conversion SCD22 and differential to common mode conversion SDC22
5. From 250 MHz to 30 GHz
6. Referred to host ground
7. Open eye is generated through the use of a Continuous Time Linear Equalizer (CTLE). See FC-MSQS-2 (reference [19]) for test configurations and test methods. The module may need equalization to achieve the required eye opening
8. Host crosstalk calibration is specified by Figure 3.1 (diagram on the right) and clause 3.2.3; module crosstalk calibration is specified by Figure 3.3 (diagram on the right) and clause 3.2.3 of FC-MSQS-2 (reference [19])
9. Crosstalk transition times are measured at the input of the compliance test board

6.4 Receive signal characteristics

This subclause defines the interoperability requirements of the delivered signal at the receive device end of a TxRx connection. Details for the measurement process are specified in FC-MSQS-2 (reference [19]), as adapted from OIF (reference [21]).

Hosts and modules shall meet the appropriate specifications defined in table 14.

Table 14 – Receiver compliance requirements

Parameter	Host input		Module electrical input		Units	Notes
	Min	Max	Min	Max		
Return loss, mode conversion, and common mode voltage requirements						
Compliance point	C (figure 5)		B’ (figure 6)			note 1
Differential termination resistance mismatch	-	10	-	10	%	
Differential return loss SDD11	-	equation 1 figure 10	-	equation 1 figure 10	dB	note 2
Common mode to differential conversion SDC11	-	equation 2 figure 11	-	equation 2 figure 11	dB	note 3
Differential mode to common conversion SCD11						
Common mode voltage	-0.3	2.8	-	-	V	note 4
Crosstalk signal requirements						
Signal calibration point	B" (figure 8)		C" (figure 7)			note 1, note 5
Signal application point	B (figure 5)		C’ (figure 6)			
Crosstalk amplitude differential voltage pk-pk	900		900		mV	
Crosstalk source transition time 20%-80%	10		9.5		ps	note 6
Stressed receiver test requirements						
Signal calibration point	C" (figure 7)		B" (figure 8)			note 1
Signal application point	C (figure 5)		B’ (figure 6)			
Random jitter, peak-to-peak, 10^{-6} BER	-	0.09	-	0.09	UI	note 7, note 8
Eye width at 10^{-6} probability EW6	0.65	-	0.46	-	UI	
Eye height at 10^{-6} probability EH6	250	-	50	-	mV	

Notes:

1. See compliance test point definitions in subclause 6.2
2. See subclause 6.6.1 for differential return loss SDD22
3. See subclause 6.6.2 for common mode to differential conversion SCD22 and differential to common mode conversion SDC22
4. Referred to host ground. Common mode voltage is generated by the host.
5. During the module electrical input test, the crosstalk signal is generated by the module from an incoming optical signal. For purposes of calibrating the module stress signal, a worst case crosstalk signal is required to be producd by an electronic signal generator. See FC-MSQS-2 (reference [19]).
6. Crosstalk transition times are measured at the input of the compliance test board
7. Uncorrelated bounded jitter is added to meet the EW6 requirement at 10^{-6}. See FC-MSQS-2 (reference [19]) for test configurations and test methods.
8. Host crosstalk calibration is specified by Figure 3.2 (diagram on the right) and clause 3.2.3; module crosstalk calibration is specified by Figure 3.4 (diagram on the right) and clause 3.2.3 of FC-MSQS-2 (reference [19])

6.5 Receive jitter tracking compliance

The sinusoidal jitter tracking test measures the ability of the receiver to track low frequency jitter. This test is done without other added jitter impairments to understand the ability of the device under test to track low frequency jitter.

Table 15 – Minimum jitter tolerance

Parameter	Low	High
Jitter frequency	100 kHz	500 kHz
Jitter amplitude, pk-pk	5 UI	1 UI

The following figure shows the jitter tracking template:

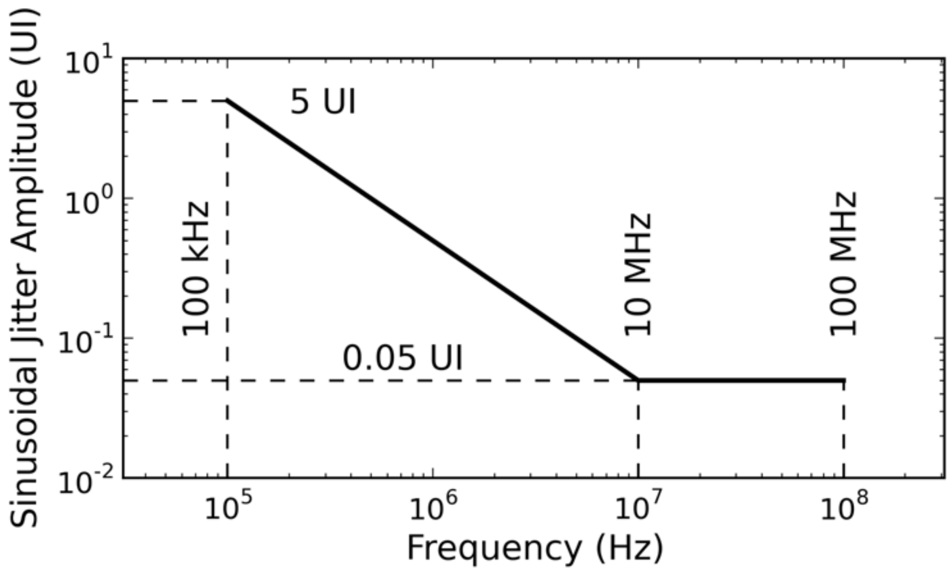


Figure 9 – Receiver jitter tracking template

For additional testing details see MSQS-2 (reference reference [19]).

6.6 Differential return loss and mode conversion requirements

6.6.1 Differential return loss

When measured at the respective test point, return loss shall not exceed the limits given in equation 1 as illustrated in figure 10.

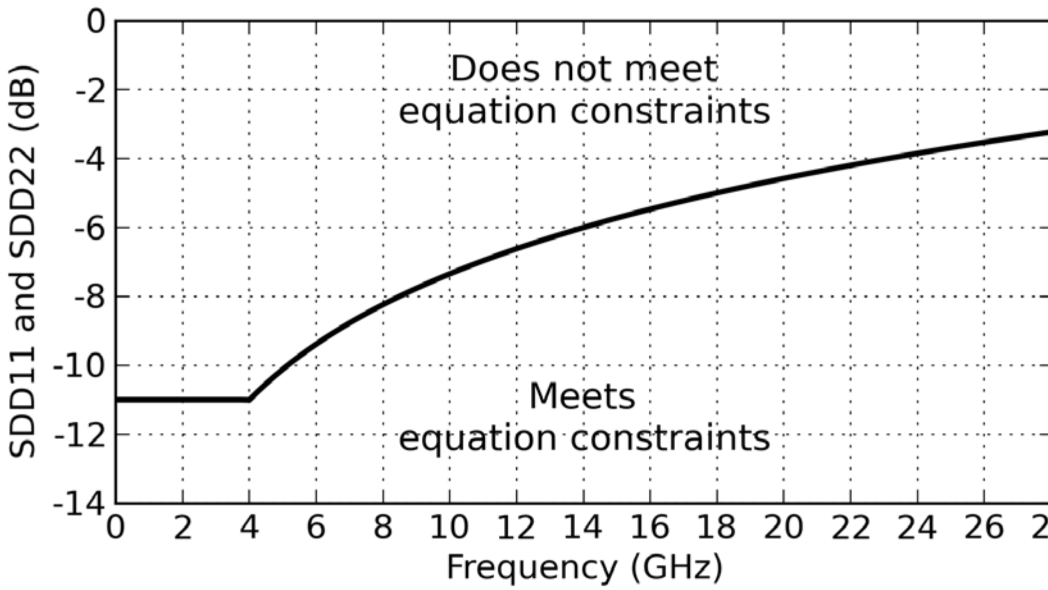


Figure 10 – SDD11 and SDD22 for all compliance points

Return loss equation at the appropriate test points:

$$SDD11, SDD22\ (\text{dB}) < \begin{cases} -11 & 0.05 < f < 4\ \text{GHz} \\ -6.0 + 9.2 \cdot \log_{10}(f/14.025\ \text{GHz}) & 4 < f < 28.05\ \text{GHz} \end{cases} \quad (1)$$

6.6.2 Common to differential mode and differential to common mode conversion

The common to differential mode and differential to common mode conversion specifications are intended to limit the amount of unwanted signal energy that is allowed to be generated due to conversion of common mode voltage to differential mode voltage or vice versa.

When measured at the respective test point, common to differential mode or differential to common mode conversion SDC11 and SCD11 shall not exceed the limits given in equation 2 as shown in figure 11.

$$SDC11, SCD11\ (\text{dB}) < \begin{cases} -22 + 14 \cdot f/28.05\ \text{GHz} & 0.05 < f < 14.025\ \text{GHz} \\ -18 + 6 \cdot f/28.05\ \text{GHz} & 14.025 < f < 28.05\ \text{GHz} \end{cases} \quad (2)$$

When measured at the respective test point, common to differential mode or differential to common mode conversion SDC22 and SCD22 shall not exceed the limits given in equation 3 as shown in figure 12.

$$SDC22, SCD22\ (\text{dB}) < \begin{cases} -25 + 20 \cdot f/28.05\ \text{GHz} & 0.05 < f < 14.025\ \text{GHz} \\ -18 + 6 \cdot f/28.05\ \text{GHz} & 14.024 < f < 28.05\ \text{GHz} \end{cases} \quad (3)$$

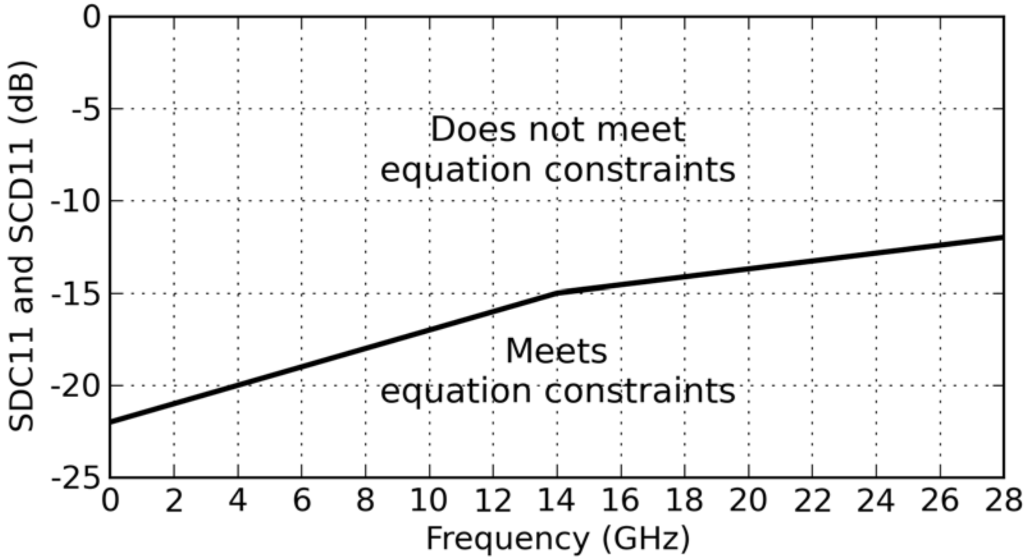


Figure 11 – SDC11 and SCD11 for receiver input

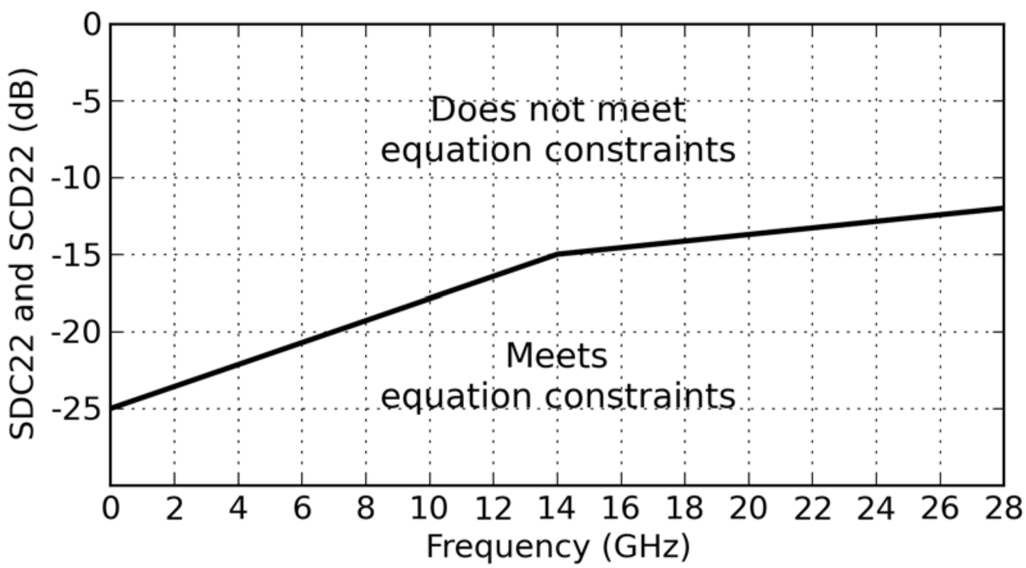


Figure 12 – SDC22 and SCD22 for transmitter output

7 Backplane specification

This clause defines the electrical requirements at the reference point α for TxRx connections using a passive electrical medium that meets the requirements of subclause 7.5. The reference points α_T and α_R are brought to observable compliance points A and D respectively using the test fixtures defined in subclause 7.2 (figure 13). This clause closely follows IEEE P802.3bj (reference [20]).

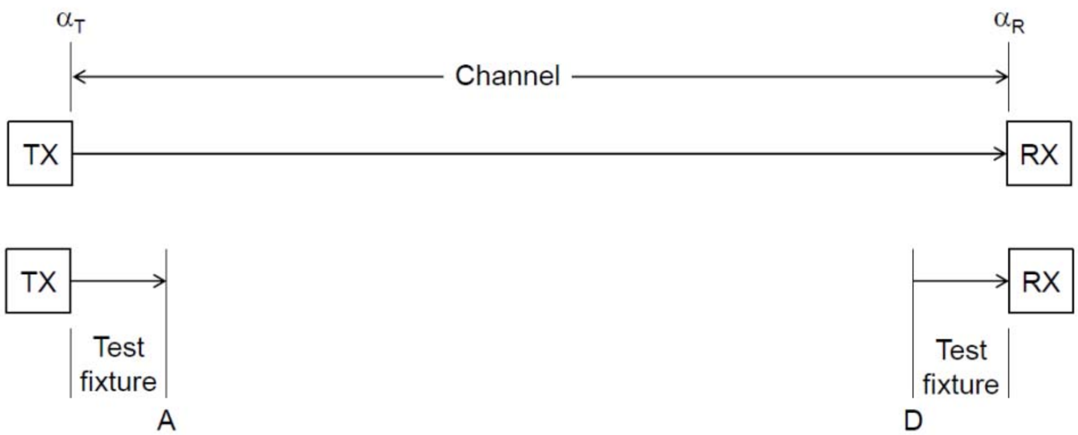


Figure 13 – Test fixture and test points

7.1 TxRx Connections

Fibre Channel 32GFC links use the 256B/257B transmission code; see FC-FS-4 (reference [18]). This code includes Forward Error Correction which is required to achieve the link BER objective. Prior to error correction, Fibre Channel 32GFC electrical TxRx connections shall not exceed a BER of 10^{-6} under any compliant conditions. The parameters in this clause support meeting that requirement. At this level of BER performance, it is expected that the BER after error correction will be undetectably low.

7.2 Test fixtures

Unless noted otherwise, measurements of the transmitter are made at test point A as shown in figure 13. Unless noted otherwise, measurements of the receiver are made at test D as shown in figure 13.

The test fixture insertion loss shall meet equation 4.

$$1.3 \le IL(f) \le 1.7 \text{ dB} \qquad f = 14 \text{ GHz} \tag{4}$$

The reference insertion loss of the test fixture shall meet equation 5 for frequency *f* in GHz from 50 MHz to 28.050 GHz; see figure 14.

$$IL_{ref}(f) = -0.0015 + 0.144 \cdot \sqrt{f} + 0.069 \cdot f \tag{5}$$

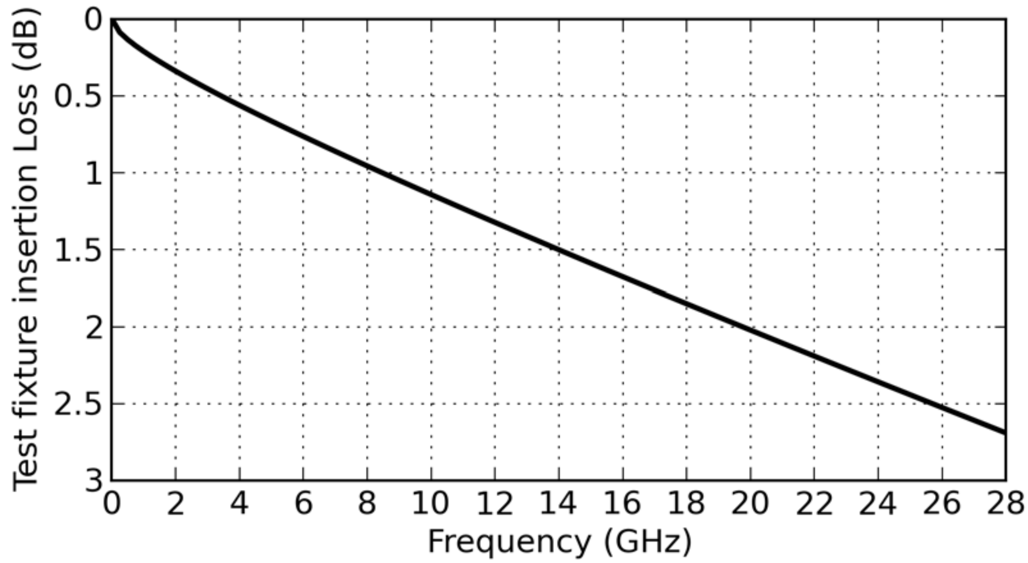


Figure 14 – Test fixture reference insertion loss

The test fixture insertion loss deviation (see IEEE P802.3bj, reference [20]) shall meet equation 6.

$$|ILD(f)| \le 0.1dB \qquad 0.05 \le f \le 14 \text{ GHz} \tag{6}$$

The test fixture differential return loss shall meet equation 7 (figure 15).

$$RL_d(f) \ge \begin{cases} 20 - f & 0.05 \le f \le 5 \text{ GHz} \\ 15 & 5 < f \le 13 \text{ GHz} \\ 20.57 - 0.4286f & 13 < f \le 28 \text{ GHz} \end{cases} \tag{7}$$

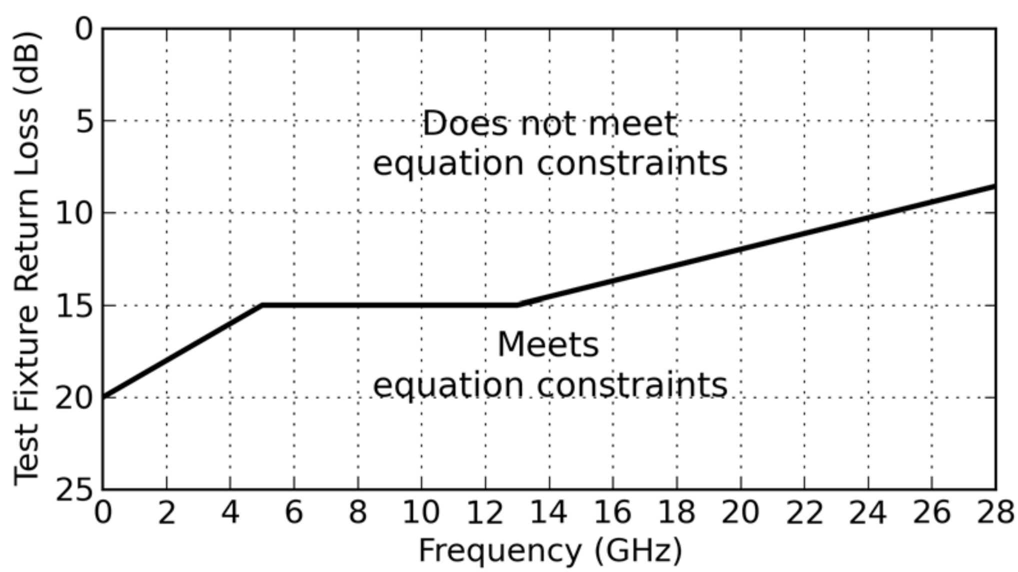


Figure 15 – Test fixture differential return loss

The test fixture common-mode return loss shall meet equation 8.

$$RL_{cm}(f) \geq 10dB \qquad 0.05 \leq f \leq 14 \text{ GHz} \tag{8}$$

7.3 Transmitter specification

The transmitter shall meet the specification in table 16 as measured at test point A.

Table 16 – Transmitter electrical specifications at A

Parameter	Unit	Value	Note
Nominal signaling rate	MBd	28 050	note 1
Differential peak output voltage, max			
Transmitter enabled	mV	1200	
Transmitter disabled	mV	30	note 2
DC common-mode output voltage, max	V	1.9	
DC common-mode output voltage, min	V	0	
AC common-mode output voltage, RMS max.	mV	12	
Differential output return loss, min	dB	equation 9	
Common-mode output return loss, min	dB	equation 10	
Output waveform			note 3
Steady state voltage v_f, max	V	0.6	
Steady state voltage v_f, min	V	0.4	
Linear fit pulse peak, min	V	0.71 v_f	
Normalized coefficient step size, min		0.0083	
Normalized coefficient step size, max		0.05	
Pre-cursor full-scale range, min		1.54	
Post-cursor full-scale range, min		4	
Signal-to-noise-and-distortion ratio, min	dB	27	
Output jitter, max			note 4
Even-odd jitter	UI	0.035	
Effective bounded uncorrelated jitter, peak-to-peak	UI	0.1	
Effective total uncorrelated jitter, peak-to-peak	UI	0.19	note 4

Notes:
1. 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).
2. Definition required to support FC-EE.
3. Output waveform parameters defined by IEEE P802.3bj 93.8.1.5, reference [20]. The linear fit pulse response is computed using $N_p=14$ and $D_p=2$. Output noise and distortion parameters are defined by IEEE P802.3bj 93.8.1.6, reference [20].
4. Jitter parameters are defined by IEEE P802.3bj 92.8.3.9, reference [20]. ETUJ = EBUJ + 9*ERJ, in which ETUJ = effective total uncorrelated jitter (peak-to-peak), EBUJ = effective bounded uncorrelated jitter (peak-to-peak), ERJ = effective random jitter (rms), and the factor of 9 assumes a BER of 10^{-6}.

The coefficients are initialized by transmitter training (see FC-FS-4 [18]) upon reset or receipt of the initialize command. When initialized the value of the coefficients shall satisfy the following conditions: [c(0)+c(1)-c(-1)] / [c(0)+c(1)+c(-1)] is 1.29 ± 10%, and [c(0)-c(1)+c(-1)] / [c(0)+c(1)+c(-1)] is 2.57 ± 10%.

Transmitter differential return loss at A shall meet equation 9 (figure 16).

$$RL_d(f) \geq \begin{cases} 12.05 - f & 0.05 \leq f \leq 6 \text{ GHz} \\ 6.5 - 0.075f & 6 < f \leq 21 \text{ GHz} \end{cases} \quad (9)$$

Transmitter common-mode return loss at A shall meet equation 10 (figure 17).

$$RL_{cm}(f) \geq \begin{cases} 9.05 - f & 0.05 \leq f \leq 6 \text{ GHz} \\ 3.5 - 0.075f & 6 < f \leq 21 \text{ GHz} \end{cases} \quad (10)$$

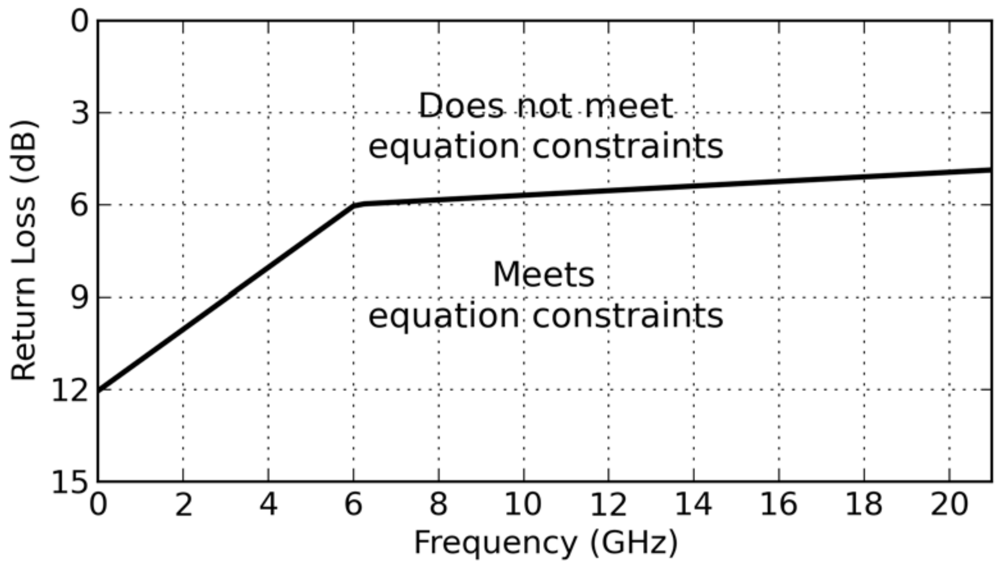


Figure 16 – Transmitter and receiver differential return loss limit

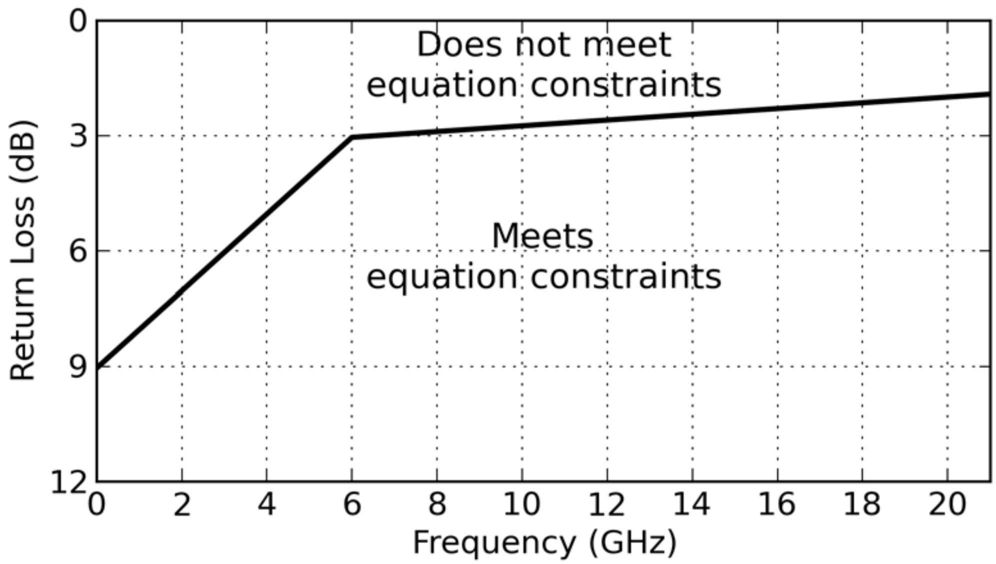


Figure 17 – Transmitter common mode return loss

7.4 Receiver specification

Table 17 – Summary of receiver characteristics at test point D

Parameter	Value	Units	Note
Differential input return loss, min.	equation 9	dB	-
Differential to common mode return loss, min.	equation 11	dB	-
Interference tolerance	table 18	-	note 1
Jitter tolerance	table 19	-	note 2

Notes:
1 See subclause 7.4.2
2 See subclause 7.4.3

7.4.1 Receiver input return loss

Receiver differential return loss at D shall meet equation 9 (the same as the transmitter differential return loss; see figure 16).

Receiver differential to common-mode return loss at D shall meet equation 11 (figure 18).

$$RL_{cd}(f) \geq \begin{cases} 25 - 1.44f & 0.05 \leq f \leq 6.95 \text{ GHz} \\ 15 & 6.95 < f \leq 21 \text{ GHz} \end{cases} \quad (11)$$

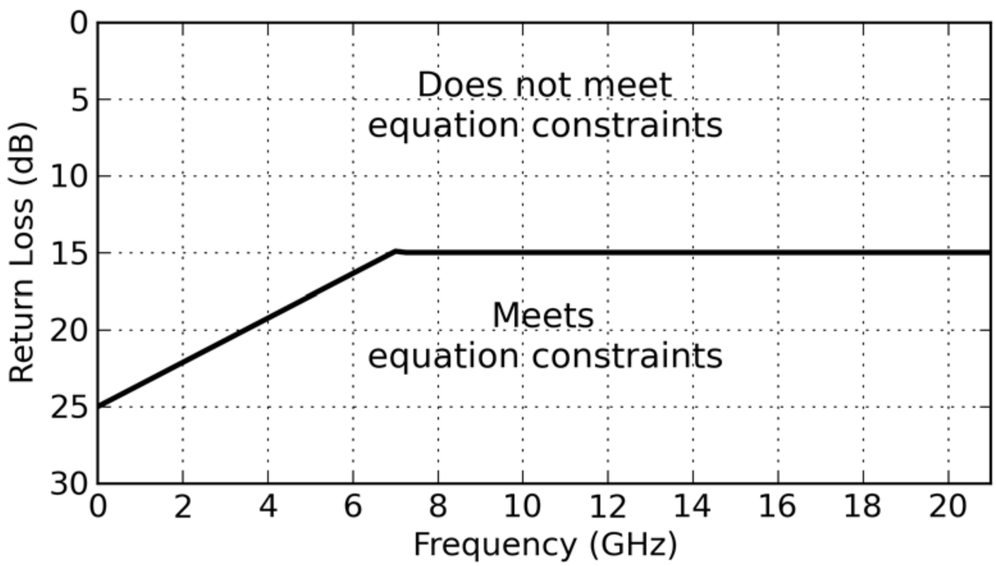


Figure 18 – Receiver differential to common-mode return loss limit

7.4.2 Receiver interference tolerance

The receiver interference tolerance test setup and method are defined in IEEE P802.3bj (reference [20]) Annex 93C. References to TP0 correspond to α_T, references to TP0a correspond to A, references to TP5A correspond to D, and references to TP5 correspond to α_R. The receiver shall meet the FEC symbol error ratio requirement with the channel defined for each test listed in table 18. The test channel parameters represent the minimum stress to be applied to the receiver under test in order to demonstrate compliance.

The test transmitter meets the specifications in subclause 7.3 as measured at TP0a (see IEEE P802.3bj, reference [20], Figure 93C-2). The test transmitter is constrained such that for any transmit equalizer setting the differential peak-to-peak voltage is less than or equal to 800 mV and the pre- and post-cursor equalization ratios are less than or equal to 1.54 and 4 respectively. The lowest frequency f_{NDS1} for constraints on the noise spectral density is 1 GHz. The test pattern to be used is PRBS31 or any valid 32GFC output. The return loss measured at TP5 replica (see IEEE P802.bj, reference [20], figure 93C-4) meets the requirements of equation 7.

The Channel Operating Margin (COM) of the test channel is computed using IEEE P802.3bj (reference [20]) 93A.2. The values of the parameters required for the calculation of COM are given in table 20 with the following exceptions. The COM parameter σ_{RJ} is set to the measured value of effective random jitter. The COM parameter A_{DD} is set to half the measured value of effective bounded uncorrelated jitter, and the COM parameter SNR_{TX} is set to the value of SNDR measured at TP0a.

Table 18 – Receiver interference tolerance parameters

Parameter		Test 1 values		Test 2 values		Units	Notes
		Min	Max	Min	Max		
FEC symbol error ratio		-	10^{-5}	-	10^{-5}	-	note 1
Insertion loss at 14 GHz		-	16	35	-	dB	note 2
Coefficients of fitted inserion loss							
	a_0, max	-0.9	0.9	-0.9	0.9	dB	
	a_1, max	0.0	3.3	0.0	3.3	$dB/Hz^{1/2}$	note 3
	a_2, max	0.0	-	0.0	-	dB/Hz	
	a_4, max	0.0	0.022	0.0	0.043	dB/Hz^2	
RSS_DFE4		0.05	-	0.05	-	UI	note 4
COM, including the effects of broadband noise		-	3.0	-	3.0	dB	

Notes:

1. The FEC symbol error ratio is the number of 10-bit symbols received with errors divided by the total number of 10-bit symbols transmitted (see IEEE P802.3bj, reference [20], 93C.2).
2. Measured between TPt and TP5 (see IEEE P802.3bj, reference [20], Figure 93C-4).
3. Coefficients are calculated from the insertion loss measured between TPt and TP5 using the method of IEEE P802.3bj (reference [20]) 93A.3 with f_{min} = 0.05 GHz, f_{max} = 28.05 GHz, and maximum Δf = 0.01 GHz.
4. Figure of merit for the test channel that is defined in IEEE P802.3bj (reference [20]) 93A.2.

7.4.3 Receiver jitter tolerance

The receiver jitter tolerance test setup and method are defined in IEEE P802.3bj (reference [20]) 93.8.2.4. References to TP0 correspond to α_T, references to TP0a correspond to A, references to TP5a correspond to D, and references to TP5 correspond to α_R. The receiver shall provide a FEC symbol error ratio of 10^{-5} or better with each pair of jitter frequency and peak-to-peak amplitude values listed in table 19.

The test transmitter meets the specifications in subclause 7.3. The test transmitter is constrained such that for any transmit equalizer setting the differential peak-to-peak voltage is less than or equal to 800 mV and the pre- and post-cursor equalization ratios are less than or equal to 1.54 and 4 respectively. The test pattern to be used is PRBS31 or any valid 32GFC output.

The test channel satisfies the requirements for insertion loss and coefficients of the fitted insertion loss listed for test 2 in table 18.

Table 19 – Receiver jitter tolerance parameters

Parameter	Case A Values	Case B Values	Units
Jitter frequency	500	100	kHz
Peak-to-peak jitter amplitude	1	5	UI

7.5 Channel specification

The channel operating margin (COM) is computed using the procedure defined in IEEE P802.3bj (reference [20]) and the parameters defined in table 20. References to test point TP0 correspond to α_T and references to TP5 correspond to α_R. Channel operating margin (COM) shall be greater than or equal to 3 dB. This minimum value allocates margin for the practical limitations of the receiver implemention as well as the largest step size allowed for the transmitter equalizer coefficients.

Table 20 – Channel Operating Margin (COM) parameters

Parameter	Symbol	Value	Unit
Nominal signaling rate	f_b	28 050	MBd
Maximum start frequency	f_{min}	50	MHz
Maximum step frequency	Δf	10	MHz
Device package mode			
Single-ended device capacitance	C_d	0.25	pF
Transmission line length, test 1	Z_p	12	mm
Transmission line length, test 2	Z_p	30	mm
Single-ended package capacitance at package-to-board interface	C_b	0.18	pF
Single-ended reference resistance	R_0	50	Ohms
Single-ended termination resistance	R_d	55	Ohms
Transmitter differential peak output voltage			
Victim	A_v	0.4	V
Far-end aggressor	A_{fe}	0.4	V
Near-end aggressor	A_{ne}	0.6	V
Receiver -3dB bandwidth	f_r	0.75 x f_b	MHz
Transmitter equalizer, pre-cursor coefficient	c(-1)		
Minimum value		-0.18	
Maximum value		0	
Step size		0.02	
Transmitter equalizer, post-cursor coefficient	c(1)		
Minimum value		-0.38	
Maximum value		0	
Step size		0.02	
Continuous time filter, DC gain	g_{DC}		
Minimum value		-12	dB
Maximum value		0	dB
Step size		1	dB
Continuous time filter, zero frequency	f_z	f_b / 4	GHz
Continuous time filter, pole frequencies	$\{f_{p1}, f_{p2}\}$	$\{f_b / 4, f_b\}$	GHz
Number of signal levels	L	2	
Level separation mismatch ratio	R_{LM}	1	
Transmitter signal-to-noise ratio	SNR_{Tx}	27	dB
Number of samples per unit interval	M	32	
Decision feedback equalizer (DFE) length	N_b	14	UI
Normalized DFE coefficient magnitude limit	$b_{max}(n)$	1 for n=1 to N_b	
Random jitter, RMS	σ_{RJ}	0.01	UI
Deterministic jitter, peak	A_{DD}	0.05	UI
One-sided noise spectral density	η_0	5.2×10^{-8}	V^2/GHz
Target detector error ratio	DER_0	10^{-6}	

7.6 Support for Energy Efficient Fibre Channel

The optional Energy Efficient Fibre Channel capability provides a protocol and associated physical layer functions that allow a Fibre Channel link to operate in a lower power mode.

The following functions are required to support this capability.

7.6.1 Transmitter disable and enable

When Energy Efficient Fibre Channel (see FC-FS-4, reference [18], clause 10) is supported, the following requirements also apply. The peak-to-peak differential output voltage shall be less than 30 mV within 500 ns of the transmitter being disabled (tx_mode=QUIET). When the transmitter is disabled, the peak-to-peak differential output voltage shall be greater than 720 mV within 500 ns of the transmitter being enabled. The transmitter is enabled by the assertion of tx_mode=ALERT and the preceding requirement applies when the transmitted symbols are the alert signal defined in FC-FS-4 (reference [18]) subclause 10.4 and the transmitter equalizer coefficients are assigned their preset values. The transmitter shall meet the requirements of subclause 7.3 within 1 µs of the transmitter being enabled. When the transmitter is disabled, the DC common-mode output voltage shall be maintained to within ±150 mV of the value for the enabled transmitter.

7.6.2 Energy detect

When Energy Efficient Fibre Channel (see FC-FS-4, reference [18], clause 10) is supported, the following requirements also apply. The value of energy_detect is set to zero when rx_mode is first set to QUIET. While rx_mode is set to QUIET, energy_detect shall be set to one within 500 ns of the application of the alert signal defined in FC-FS-4 (reference [18]) subclause 10.4, with peak-to-peak differential voltage of 720 mV as measured at A, to the input of a channel that meets the requirements of subclause 7.5. While rx_mode is set to QUIET, energy_detect shall not be set to one when the voltage applied to the input of the channel is less than or equal to 60 mV peak-to-peak differential.

Annex A (informative)
Optical cable plant usage

The worst-case power budget and link penalties for the multimode cables specified in sub-clause 5.4 are shown in table 21.

Table 21 – Worst case (nominal bandwidth) multimode cable link power budget

Parameter	Unit	SN	Note
50µm (OM2) MMF			
Overfilled Launch Modal Bandwidth	MHz*km	500	note 1
Data rate	MB/s	3200	
Operating distance	m	0.5-20	
Link power budget	dB	7.00	
Intersymbol interference	dB	3.18	
Additional link penalties	dB	1.80	note 2
Channel insertion loss	dB	1.57	
Allocation for additional loss	dB	0.45	note 3
50µm (OM3) MMF			
Effective Modal Bandwidth	MHz*km	2000	note 1, note 4
Data rate	MB/s	3200	
Operating distance	m	0.5-70	
Link power budget	dB	7.00	
Intersymbol interference	dB	3.25	
Additional link penalties	dB	1.88	note 2
Channel insertion loss	dB	1.75	
Allocation for additional loss	dB	0.12	note 3
50µm (OM4) MMF			
Effective Modal Bandwidth	MHz*km	4700	note 1, note 5
Data rate	MB/s	3200	
Operating distance	m	0.5-100	
Link power budget	dB	7.00	
Intersymbol interference	dB	3.14	
Additional link penalties	dB	2.00	note 2
Channel insertion loss	dB	1.86	
Allocation for additional loss	dB	0.00	note 3

Table 21 – 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 FC-MSQS (reference [5]) and FC-MSQS-2 (reference [19]). 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 (reference [16]) or IEC 60793-2-10 (reference [7]) 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 (reference [17]) or IEC 60793-2-10 (reference [7]) with a 50-µm fiber meeting the specifications in TIA 492AAAD or IEC 60793-2-10 for Type A1a.3.			

Annex B (informative)
Structured cabling environment

B.1 Specification of operating distances

Operating distances of Fibre Channel links described in clause 5 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 5. Different allocations for connection loss result in changes to the maximum operating range. Table 22 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 22 – 3200-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)	20 / 3.04	65 / 2.64	80 / 2.36	100 / 1.86	110 /1.48
M5E (OM3)	15 / 3.03	45 / 2.64	60 /2.24	70 / 1.87	80 / 1.41
M5 (OM2)	NA	15 / 2.52	15 / 2.52	20 / 2.02	25 / 1.29
OS1 / OS2	8250 / 6.52	9250 / 6.42	10000 / 6.34	11000 / 6.21	11750 / 6.11

Annex C (informative)
Recommended electrical channel

The channel consists of Host PCB trace, Module PCB trace, vias, AC coupling capacitor, and one connector, not necessarily in this order (figure 19). The recommended PCB trace differential impedance is 100 ± 10 Ω.

Figure 19 – Typical FC-PI-6 electrical channel construction

The informative host to module channel consists of a high insertion loss channel that is 17 dB at Nyquist and a lower insertion loss channel that is 7 dB at Nyquist.

The informative host to module channel characteristics are in the tables below.

Table 23 – Informative host to module channel characteristics, high loss channel

Parameter	Symbol	Value	Units
Insertion loss	SDD21	17	dB
Insertion loss deviation	ILDrms	0.18	dBrms
Integrated crosstalk noise	ICNrms	1.8	mVrms

An example full channel model is shown in figure 20 below. Note that in practice the channel is not measurable as appropriate test points are not accessible.

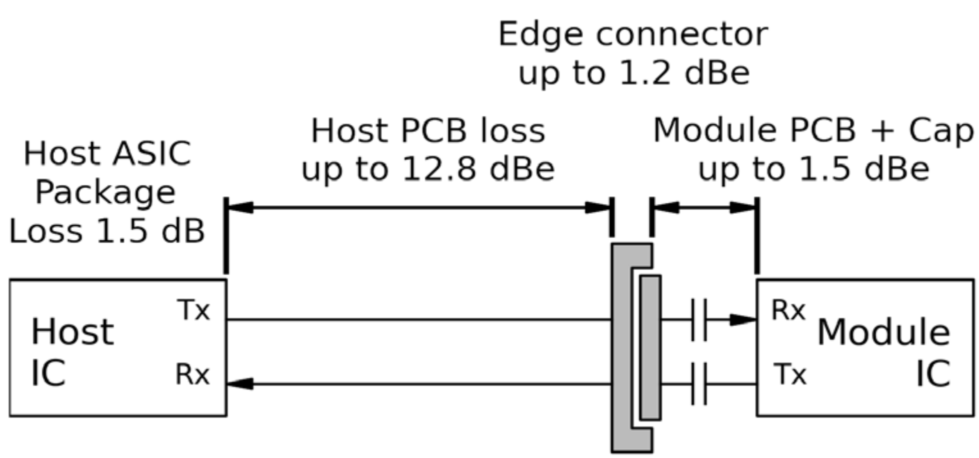


Figure 20 – FC-PI-6 full channel electrical reference model, high loss channel

If the host ASIC package loss exceeds 1.5 dB in figure 20, then the host PCB loss must be reduced to compensate. The total insertion loss is 17 dB for the high loss channel and the various components that make up the channel loss will vary but the total should still equal 17 dB.

Table 24 – Informative host to module channel characteristics, lower loss channel

Parameter	Symbol	Value	Units
Insertion loss	SDD21	7	dB
Insertion loss deviation	ILDrms	0.18	dBrms
Integrated crosstalk noise	ICNrms	1.8	mVrms

C.1 Insertion loss

Host insertion loss and module insertion loss are recommended limits only. Achieving these recommended limits does not signify compliance nor guarantee successful communication between two devices. Equation 12 (illustrated in figure 21) represents the highest recommended insertion loss of the full channel.

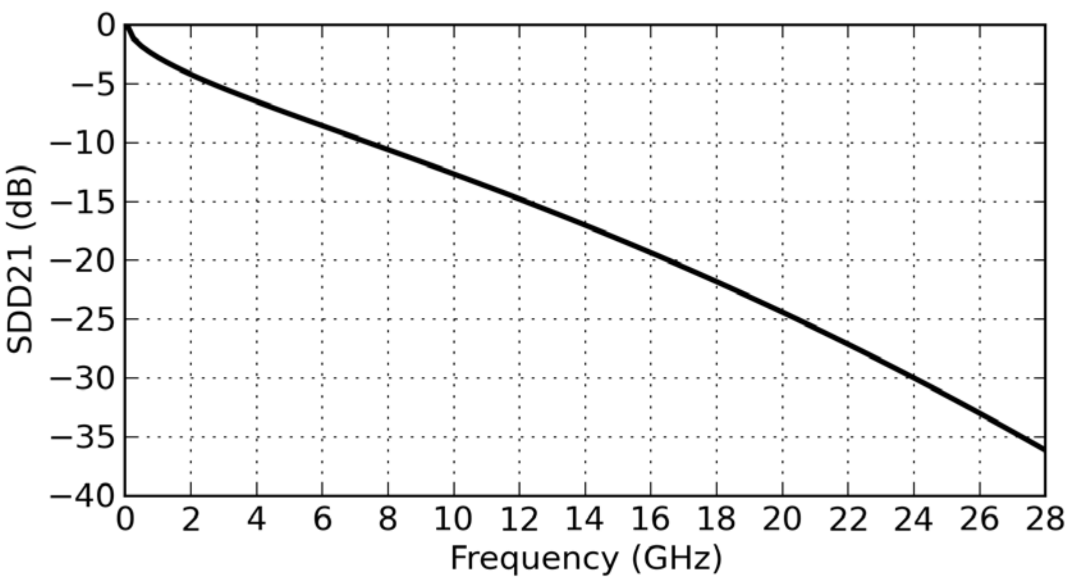


Figure 21 – Recommended minimum SDD21 of the electrical channel

$$H(f)\ (\mathrm{dB}) = 0.3144 - 14.2 \cdot \sqrt{(f/28.05)} - 4.17 \cdot (f/28.05) - 14.92 \cdot (f/28.05)^2 \qquad \textbf{(12)}$$

In equation 12, frequency f is in units of GHz.