American National Standard for Information Technology–

Fibre Channel – Physical Interface-7 (FC-PI-7)

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 [23]) and FC-FS-5 (reference [25]).

FC-PI-7 includes 64GFC and 256GFC. 32GFC and 128GFC are described in FC-PI-6 reference [1]) and FC-PI-6P reference [2]) respectively.16GFC, 8GFC and 4GFC are described in FC-PI-5 (reference [3]). Older technologies of 2GFC and 1GFC are listed in FC-PI-2 (reference [5]).

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-6,** Fibre Channel Physical Interfaces - 6

[2] **ANSI/INCITS 479-2011, FC-PI-6P,** Fibre Channel Physical Interfaces - 6P

[3] **ANSI/INCITS 479-2011, FC-PI-5,** Fibre Channel Physical Interfaces - 5

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

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

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

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

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

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

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

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

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

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

[14] **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.

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

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

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

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

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

[20] **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

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

[22] **OIF2014.230.03** OIF-CEI-56G-VSR-PAM4 Very Short Reach Interface

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

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

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.

[25] **ANSI/INCITS 1861D, FC-FS-5,** Fibre Channel Framing and Signaling 5

[26] **IEEE 802.3bs** 200 Gb/s and 400 Gb/s Ethernet Task Force

[27] **ANSI/INCITS _____, FC-MSQS-3,** Fibre Channel Methodologies for Signal Quality Specification 3

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, β_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, coaxia~~l 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 [14]).

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 []).~~

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 [15]).

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 []).

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 []).

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 [6]), 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 [7]).

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 [17]).

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 [6]) 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 [6]).

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 [7]).~~

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 [8]).~~

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 [9].~~

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 [9].

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 [9].

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 [7]).

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 64GFC, this level is BER < 10^{-X}. See also the definitions for stressed receiver sensitivity and unstressed receiver sensitivity. See FC-MSQS (reference [7]) and FC-MSQS-2 (reference [27]).

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 [10].

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 [10].

3.1.83 ~~P_{alloc}: the effective system power/voltage budget used in TWDP and WDP calculations. See FC-MSQS (reference [7]).~~

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 []).~~

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 [14]).

3.1.107 stressed receiver sensitivity: the amplitude of optical modulation in the stressed receiver test given in FC-MSQS-2 (reference [27]).

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 [7]).

3.1.109 synchronization: bit synchronization, defined above, and/or Transmission-Word synchronization, defined in FC-FS-4 (reference []). 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 symbol~~bit~~: a symbol of duration one unit interval that represents one or more ~~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 []) 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 [16].

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~~symbol.

3.1.126 **unstressed receiver sensitivity:** the amplitude of optical modulation in the unstressed sensitivity receiver test in. See FC-MSQS-2 (reference [27]).

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 [7]).

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
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
~~ULP~~	~~Upper Level Protocol~~

Table 2 – Acronyms and other abbreviations

VECP	vertical eye closure penalty
WDP	waveform distortion penalty

3.2.3.2 Signaling rate abbreviations

Abbreviations for the signaling 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
64GFC	28 900 MBd	6 400 MB/s
128GFC	112 200 MBd	12 800 MB/s
256GFC	115 600 MBd	25 600 MB/s

4 FC-PI-7 functional characteristics

4.1 General characteristics

Fibre Channel is structured as a set of hierarchical functions as illustrated in Figure 1. The FC-PI-x standards define the physical link, the lowest level denoted FC-0, in the Fibre Channel system. The physical layer interface is designed for flexibility and allows the use of several physical interconnect technologies to meet a wide variety of system application requirements.

The FC-FS-x standards define the signaling protocol and services at the next higher levels. Transmission codes and Forward Error Correction (FEC), where applicable, are defined in the FC-FS-x standards.

FC-PI-7 describes the physical link for serial and parallel data streams supporting a signaling rate of 64GFC and 256GFC respectively in multimode and single mode fibers as defined in 4.13. Serial lane variants include, 64GFC-SW for MM variant and 64GFC-LW and 64GFC-PSM for single mode variant. Parallel lane variants include, 256GFC-SW4 for MM variant with channels consisting of multiple multimode fibers in a cable, 256GFC-PSM-4 for SM variant with channels consisting of multiple single mode fibers in a cable, and 256GFC-CWDM4 for SM variant using duplex channels with wavelength division multiplexing. Lane skew restrictions for parallel data stream variants are shown in 4.14

Fibre Channel 64GFC and 256GFC links use 256B/257B transmission code; see FC-FS-4 (reference [23]) and FC-FS-5 (reference [25]). This code includes Forward Error Correction (FEC) Reed Solomon (544,514) which is required to achieve the link BER objectives. The BER of each TxRx connection in a 64GFC link, as observed prior to error correction, is defined to be 1.09×10^{-4} 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 not worse than 10^{-15}.

64 GFC has transmitter and receiver clock tolerances of ±100 ppm. A TxRx Connection bit error ratio (BER) of $\leq 1.09 \times 10^{-4}$ 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-7 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-7 is not required for such applications. For closed or integrated links the system designer shall ensure that a BER of better than 1.09×10^{-4} is delivered.

4.2 Compliance test points

The requirements specified in FC-PI-7 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 [3]). 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 2 shows the reclocker locations for 64GFC 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-7 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, du-

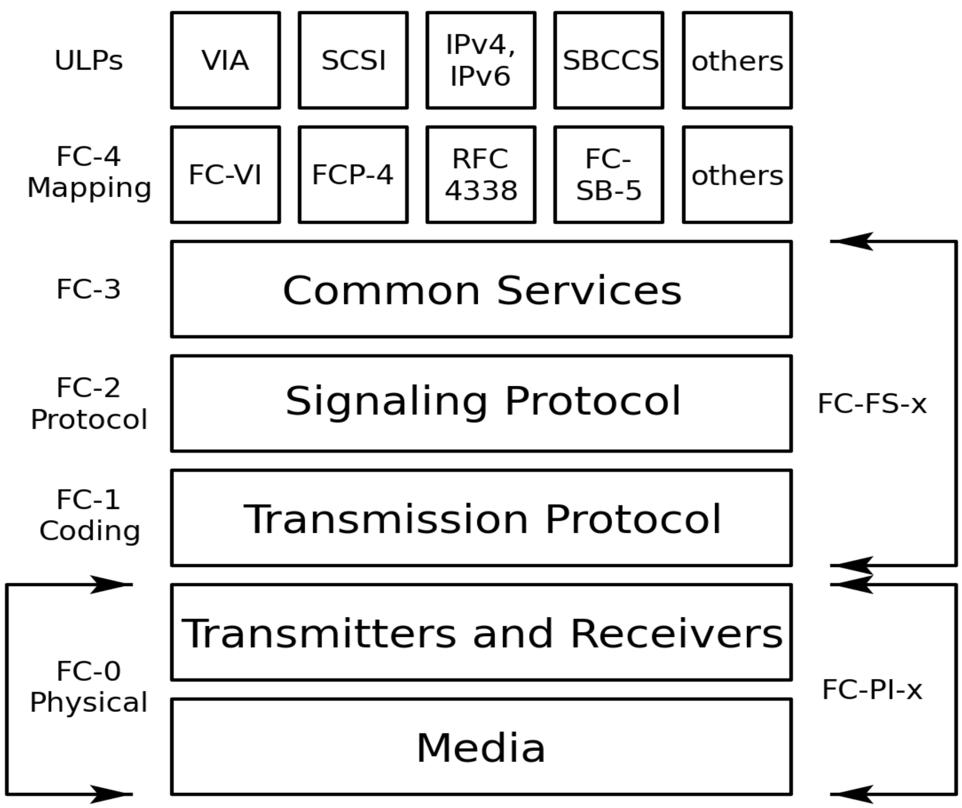

Figure 1 – Fibre Channel hierarchy

plex 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.

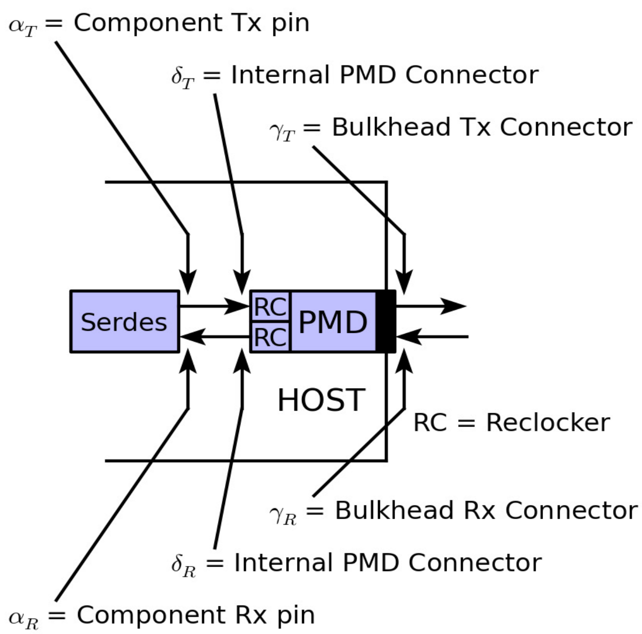

Figure 2 – Reclocker location for all 32GFC PMDs

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 and FC-FS-5 occur at the logical encoded data interfaces. As these are logical data constructs, no physical implementation is implied by FC-FS-4 and FC-FS-5. FC-PI-7 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-7 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-7 and protocols defined in FC-FS-4 and FC-FS-5 are 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-7 clauses associated with that technology. An example of this would be ensuring that optical power levels associated with eye safety are maintained.

4.3 FC-0 states

4.3.1 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.

4.3.2 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.

4.4 Limitations on invalid code

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

4.5 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.

4.6 Loss of signal (Rx_LOS) function

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

4.7 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 X ms from the time the speed negotiation algorithm asks for a speed change for 16GFC. A repeater shall achieve compliant operation within X ms following an application of a compliant signal at its input. For 16GFC and 32GFC, the transmitter stabilization time shall be X 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 4.5) 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 64GFC. The transmit training signal is defined in FC-FS-5 (reference [25]).

4.8 Transmission codes

64GFC and 256GFC variants rely on the implementation of FEC, transcoding, and scrambling as defined in FC-FS-5 (reference [25]). The actual FEC, transcoding, and scrambling hardware is at the FC-1 layer and is not defined in FC-PI-7.

4.9 Frame scrambling and emission lowering protocol

64GFC and 256GFC variants use coding and scrambling that is inherent in the code as defined in FC-FS-5 (reference [25]).

4.10 Speed negotiation and transmitter training

For 64GFC and 256GFC variants 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 64GFC, 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 4 – 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	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	Extended Marker
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 0000	
1111 1111 0000 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	
0000 0000 1111 1111	Speed negotiation bit high
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.

4.11 Forward error correction (FEC)

64GFC and 256GFC variants rely on the implementation of FEC as defined in ~~FC-FS-4 (reference ISO Text) and~~ FC-FS-5 (reference [25] The actual FEC hardware is at the FC-1 layer and is not defined in FC-PI-~~6~~7.

PRBS11.

4.12 Test Patterns

64GFC and 256GFC variants shall use the test patterns stated in FC-MSQS-3 (reference [27]).

4.13 FC-PI-7 variants

Table 5 and list variants by FC-PI-7 nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize the variant. The lengths specified in table 5 and are the minimum lengths supported with transmitters, media, and receivers all simultaneously operating under the most degraded conditions allowed. Longer lengths may be achieved by restricting parameters in the transmitter, media, or receiver. If such restrictions are used on the link components then interoperability at interoperability points within the link and component level interchangeability within the link is no longer supported by this standard.

Table 5 – Fibre Channel Variants in FC-PI-7 serial lane

SM **OS1, OS2**	**64GFC-LW** 1 300 nm 0.5 m-10 km sub-clause 5.4
	64GFC-PSM 1 300 nm 0.5 m-500 m sub-clause 5.4
MM 50 µm **OM3**	**64GFC-SW** 850 nm 0.5 m-70 m sub-clause 5.5
MM 50 µm **OM4, OM5**	**64GFC-SW** 850 nm 0.5 m-100 m sub-clause 5.5

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

SM **OS1, OS2**	**256GFC-CWDM4** 1 300 nm 0.5 m-2 km sub-clause 5.4
	256GFC-PSM4 1 300 nm 0.5 m-500 m sub-clause 5.4
MM 50 µm **OM3**	**256GFC-SW4** 850 nm 0.5 m-70 m sub-clause 5.5
MM 50 µm **OM4, OM5**	**256GFC-SW4** 850 nm 0.5 m-100 m sub-clause 5.5

4.14 Skew constraints

The skew (relative delay) between the lanes must be kept within limits so that the information on the lanes can be reassembled by the RS-FEC sublayer. Skew is defined as the difference in the times of the earliest lane and the latest lane for a one to zero transition. Skew variation may be introduced due to variations in electrical, thermal, or environmental characteristics. Skew variation is defined as the change in skew between any lane and any other lane over the entire time that the link is in operation.Skew and skew variation must be kept within limits as shown in table 7. See Fig. 4 in FC-PI-6P, (reference [2]).

Table 7 – Skew and skew variation constraints for 256GFC

Test Point	Skew	Skew variation
δ_T	ns	ps
γ_T		
γ_R		
δ_R		
α_R		

4.15 MPO optical interface

Mechanical, optical performance, and intermatability for the MPO connector system are specified in IEC 61754-7-1 (reference Spec Ref #n). Figure 3 shows the MPO optical interface. The PSM4 optical transceiver requires an MPO female plug connector with a down-angled interface, whereas the multi-mode optical transceiver requires a flat interface.

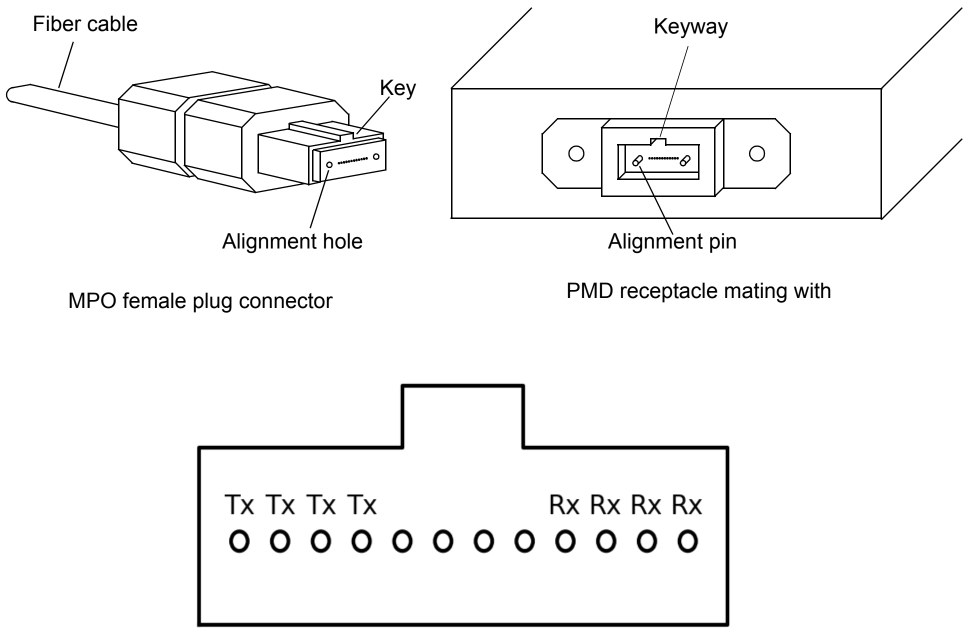

Figure 3 – PMD

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 64GFC and 256GFC 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 1.09×10^{-4} under any compliant conditions; see FC-MSQS-3 (reference [27]). 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 6.1.09x10-4

5.2 Laser safety issues

Optical transceivers shall conform to Hazard Level 1M laser requirements as defined in IEC 60825-1 (reference [11]) and IEC 60825-2 (reference [12]) under any condition of operation.

5.3 Optical Signal Modulation Format

A four level pulse amplitude modulation or PAM-4 is the modulation format utilized in all the optical variants defined in PI-7. To generate a PAM-4 signal, two logical bits are mapped to a Gray-coded symbol described in IEEE 802.3bs (reference [26]) and FC-FS-5 (reference [25], IEEE. An non-corrupted PAM-4 signal is depicted in Fig. 3 a. The PAM-4 levels 0 and 3 represent the lowest and maximum optical power. Additionally, the levels 0 and 3 can represent the most negative or most positive voltage when evaluated after the O/E conversion.

PAM-4 signal generates three eye diagrams: top, middle and bottom, as shown in Fig 3 b. These eyes can present different height and width. Moreover, signals produced by direct modulated lasers can produce eye skew, see FC-MSQS-3 (reference [27]), which penalize the optimum sampling of the signals.

Transmission dispersion eye closure for PAM-4 or, TDECQ, see IEEE 802.3bs (reference [26]), is used to evaluate the quality of the received optical signal, by estimating the total power budget penalty of the received eyes in comparison with an ideal PAM-4 eye. The computation of TDECQ, utilizes measurements average power and outer OMA as well as BER requirements in absence of error correction codes. Note that PI-7 channels, TDECQ is computed using a BER of 1.09×10^{-4} instead of the BER of 2.4×10^{-4} used in reference [26]. For each optical variant, TDECQ as well as the average power and OMA is specified in the tables shown in clause 5.

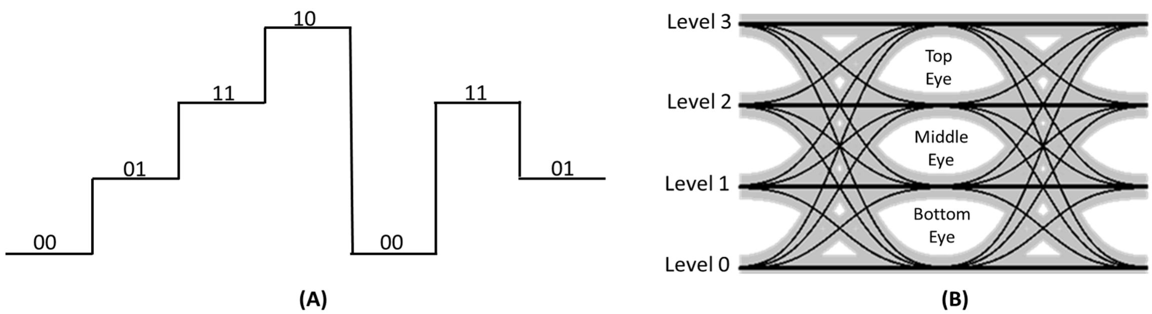

Figure 4 – Optical Eye Diagram of a PAM-4 Signal

5.4 SM data links

5.4.1 SM general information

Table 8 gives the variant name, a general link description, and the gamma compliance point specifications for 10-km single-mode optical fiber links running at 64GFC.

Table 9 gives the variant name, a general link description, and the gamma compliance point (figure 4) specifications for single-mode optical fiber links running at 256GFC-CWDM4.

Table 10 gives the variant name, a general link description, and the gamma compliance point (figure 4) specifications for single-mode optical fiber links running at 256GFC-PSM4.

5.4.2 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.

5.4.3 SM optical input interface

The receiver shall operate within the uncorrected BER requirement of $1.09x10^{-4}$1 when the input power falls within the range given in table 8 for 64GFC, table 9 for 256GFC-CWDM4 and table 10 for 256GFC-PSM4.

5.4.3.1 64GFC-LW1

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

Single mode link parameters (note 1)	**Unit**	**64GFC-LW1**	**Note**
Nominal signaling rate	MBd	28 900	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)	TBD	
Side-mode suppression ratio, min.	dB	TBD	
-20 dB spectral width, max.	nm	TBD	
Average launched power, max.	dBm	TBD	
Average launched power, min.	dBm	TBD	
$RIN_{20}OMA$, max.	dB/Hz	TBD	
Extinction Ratio, min	dB	TBD	
Transmitter and dispersion penalty (TDP), max	dB	TBD	
Transmitter eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-3} hits per sample		TBD	
Receiver (gamma- R)			
Average received power, max.	dBm	TBD	
Rx jitter tracking test, OMA	mW(dBm)	TBD	
Rx jitter tracking test, frequency and pk-pk amplitude	(kHz,UI)	TBD	
Unstressed receiver sensitivity, OMA	mW(dBm)	TBD	
Return loss of receiver, min.	dB	TBD	
SRS eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-5} hits per sample		TBD	

Notes:

1 See: IEC 60793-2-50 (reference [10]), Type B1.1 and IEC 60793-2-50 (reference [10]), Type B1.3, and IEC 60793-2-50 (reference [10]), 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

5.4.3.2 256GFC-CWDM4

Table 9 – Single-mode wavelength division multiplex link classes (OS1, OS2)

Single mode wavelength division multiplex link parameters	Unit	256GFC-CWDM4	Note
Nominal signaling rate per wavelength	MBd	115 600	1
Operating distance	m	2 000	2
Transmitter (gamma-T)			
Center wavelength	nm	1264.5-1277.5 1284.5-1297.5 1304.5-1317.5 1324.5-1337.5	
Side mode suppression per wavelength (min)	dB	TBD	
Total launched average power (max)	mW (dBm)	TBD	
Tx average optical power, each wavelength (max)	mW (dBm)	TBD	
Extinction ratio, each wavelength (min)	dB	TBD	
Tx OMA, each wavelength (max)	mW (dBm)	TBD	
Tx OMA, each wavelength, at max TDP (min)	mW (dBm)	TBD	
Tx OMA, each wavelength (min)	mW (dBm)	TBD	
Launch power in OMA minus TDP, each wavelength (min)	mW (dBm)	TBD	
Transmitter and dispersion penalty (TDP), each wavelength (max)	dB	TBD	
Transmitter eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-3} hits per sample		TBD	
Channel			
Channel insertion loss (max)	dB	TBD	
Receiver (gamma- R)			
Damage threshold, each wavelength (min)	mW (dBm)	TBD	
Average received power, each wavelength (max)	mW (dBm)	TBD	
Average received power, each wavelength (min)	mW (dBm)	TBD	
Received power (OMA), each wavelength (max)	mW (dBm)	TBD	
Receiver reflectance (max)	dB	TBD	
Rx sensitivity in OMA, each wavelength (max)	mW (dBm)	TBD	
Stressed receiver sensitivity (OMA), each wavelength (max)	mW (dBm)	TBD	
Conditions of stressed receiver sensitivity test			
Vertical eye closure penalty, each wavelength	dB	TBD	
Stressed eye J2 jitter, each wavelength	UI	TBD	
Stressed eye J4 jitter, each wavelength	UI	TBD	
SRS eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-5} hits per sample		TBD	

Notes:

1 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).

2 Operating distance is given for OS2 cable. See IEC 60793-2-50 (reference [10]), type B1.3, and type B6 Optical fibers - Part 2: Product Specifications. B.1.3 is regular OS2 and B6a is bend insensitive OS2.

5.4.3.3 256GFC-PSM4

Table 10 – Single-mode parallel fiber link classes (OS1, OS2)

Single mode parallel fiber link parameters	Unit	256GFC-PSM4	Note
Nominal signaling rate per fiber lane	MBd	115 600	1
Operating distance	m	500	2
Transmitter (gamma-T)			
Center wavelength, max.	nm	1325	
Center wavelength, min.	nm	1295	
Side-mode suppression ratio (min)	dB	TBD	
Total average launch power (max)	mW(dBm)	TBD	
Average launch power, each lane (max)	mW(dBm)	TBD	
Average launch power, each lane (min)	mW(dBm)	TBD	
Optical Modulation Amplitude (OMA), each lane (max)	mW(dBm)	TBD	3
Transmitter and dispersion penalty (TDP), each lane (max)	dB	TBD	
Transmit OMA, each lane (min)	mW(dBm)	TBD	
Average launch power of OFF transmitter, each lane (max)	mW(dBm)	TBD	
Extinction ratio (min)	dB	TBD	
Optical return loss tolerance (max)	dB	TBD	
Transmitter reflectance (max)	dB	TBD	
Transmitter eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-3} hits per sample		TBD	
Channel			
Channel insertion loss (max)	dB	TBD	
Receiver (gamma-R)			
Damage threshold each lane (min)	mW(dBm)	TBD	
Average receive power, each lane (max)	mW(dBm)	TBD	
Average receive power, each lane (min)	mW(dBm)	TBD	
Receive power, each lane (OMA) (max)	mW(dBm)	TBD	
Receiver reflectance (max)	dB	TBD	
Receiver sensitivity (OMA), each lane (max)	mW(dBm)	TBD	
Stressed receiver sensitivity (OMA), each lane (max)	mW(dBm)	TBD	
Vertical eye closure penalty, each lane	dB	TBD	
Stressed eye J2 jitter, each lane	UI	TBD	
Stressed eye J4 jitter, each lane	UI	TBD	
Stressed eye mask definition {X1,X2,X3,Y1,Y2,Y3} Hit ratio 10^{-5} hits per sample		TBD	
OMA of each aggressor lane	mW(dBm)	TBD	

Notes:
1. 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).
2. Operating distance is given for OS2 cable. See IEC 60793-2-50 (reference [10]), type B1.3, and type B6 Optical fibers - Part 2: Product Specifications. B.1.3 is regular OS2 and B6a is bend insensitive OS2.
3. See FC-MSQS (reference [7]).
4.

5.5 MM data links

5.5.1 MM general information

Table 11 gives the variant names, a general link description, and the gamma compliance point specifications for multi-mode optical fiber links running at 64GFC and 256GFC. The receiver shall operate with a maximum BER of $1.09\mathrm{x}10^{-4}$1 when the input power falls within the range given in table 11.

Table 11 – Multimode link classes

Multimode link parameters	Unit	6400-SW1	25600-SW4	Note
Nominal signaling rate	MBd	28 900	115 600	1
Operating distance (OM3)	m	0.5 - 70	0.5 - 70	2,3,4
Operating distance (OM4)	m	0.5 - 100	0.5 - 100	
Modulation Format		PAM-4	PAM-4	
Transmitter (gamma-T)				
Source type		Laser	Laser	
Center wavelength, min.	nm	840	840	
Center wavelength, max.	nm	860	860	
RMS spectral width, max.	nm	0.6	0.6	
TDECQ (max)	dB	5	5	5
Average launched power, max.	mW(dBm)	2.512 (+4)	2.512 (+4)	6
Average launched power, min.	mW(dBm)	0.251 (-6)	0.251 (-6)	7
OMA_{outer} ,max.	mW(dBm)	1.995 (+3)	1.995 (+3)	8
OMA_{outer} ,min.	mW(dBm)	0.398 (-4)	0.398 (-4)	8,9
Launch power in OMA_{outer} minus TDECQ (min)	mW(dBm)	0.3162(-5)	0.3162(-5)	
OMA_{outer} extinction ratio (min)	dB	3	3	10
Encircled flux		≥86% at 19 µm ≤30% at 4.5 µm		3
Receiver (gamma- R)				
Damage Threshold, each lane (min)	mW(dBm)	3.162(+5)	3.162(+5)	11
Average received power, max.	mW(dBm)	2.512(+4)	2.512(+4)	
Average received power, min.	mW(dBm)	0.162(-7.9)	0.162(-7.9)	
Receive power (OMA_{outer}) (max), mW (dBm)	mW(dBm)	1.995(+3)	1.995(+3)	
Return Loss of Receiver, min.	dB	12	12	
Stressed receiver sensitivity, OMA_{outer} each lane (max)	mW(dBm)	0.631(-2)	0.631(-2)	
Receiver sensitivity, OMA_{outer} each lane (max)	mW(dBm)	0.1995(-7)	0.1995(-7)	
Stressed test source				
Stressed eye closure (SECQ)	dB	5	5	
OMA of each aggressor	mW(dBm)	NA	1.995(+3)	

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 [7]) and FC-MSQS-2 (reference [27]).

3 Encircled flux specifications in accordance with TIA-492AAAC-A (reference [19]) and IEC 60793-2-10 (reference [9]) or IEEE 802.3 clause 52 (reference [16]).

4 See ___[] for channel loss (TBD)

5 Transmitter Dispersion Eye Closure for PAM4 signals, TDECQ, see IEEE 802.3bs (reference [26]). For PI-7,TDECQ, must be computed using a BER of $1.09x10^{-4}$.

6 Defined by average received power, max

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

8 For definitions of Outer Optical Modulation Amplitude, OMA_{outer} ,see IEEE 802.3bs (reference [26]).

9 Even if TDECQ < 1 dbl OMA_{outer} (min) must exceed this value

10 For definition of OMA_{outer} extinction ratio see [TBD]

11 The receivers should be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level. The receiver does not have to operate correctly at this received power.

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 [22]) 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 64GFC and 256GFC links use the 256B/257B transmission code; see FC-FS-4 (reference [23]) and see FC-FS-5 (reference [25]). This code includes Forward Error Correction which is required to achieve the link BER objective. Prior to error correction, Fibre Channel 64GFC TxRx connections shall not exceed a BER of 1.09×10^{-4} 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	6400-DF-EA-S	25600-DF-EA-S
Data rate (note 1)	MB/s	6 400	256 000
Nominal symbol rate	MBd	28 900	28 900
Tolerance	ppm	±100	±100
Differential Impedance	Ω (nom)	100	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.

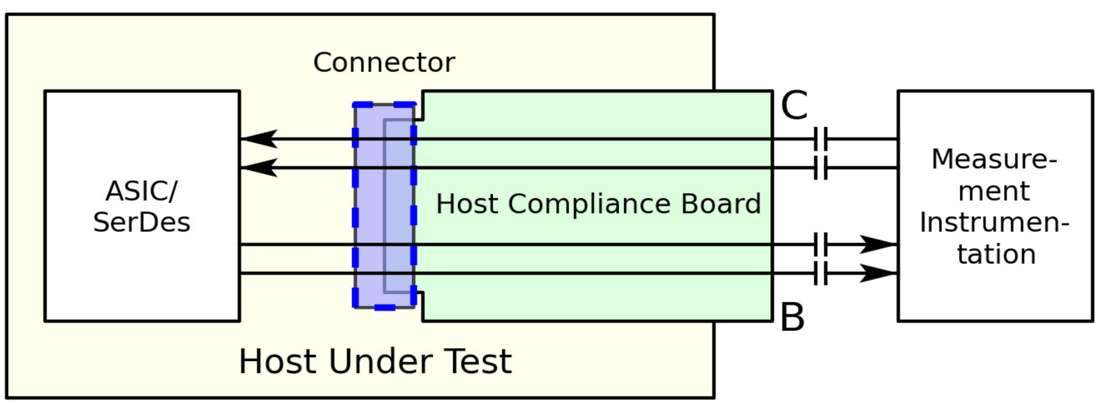

Figure 5 – Host Compliance Board

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.

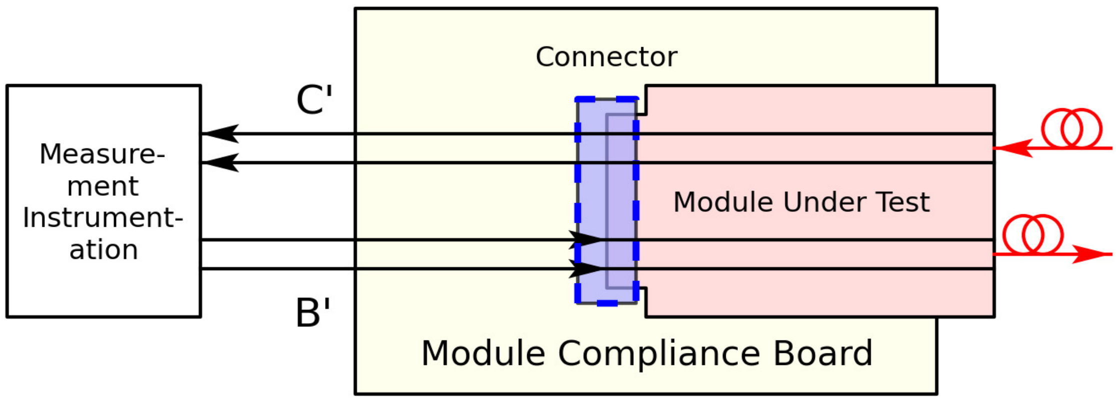

Figure 6 – Module Compliance Board

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 64GFC 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.

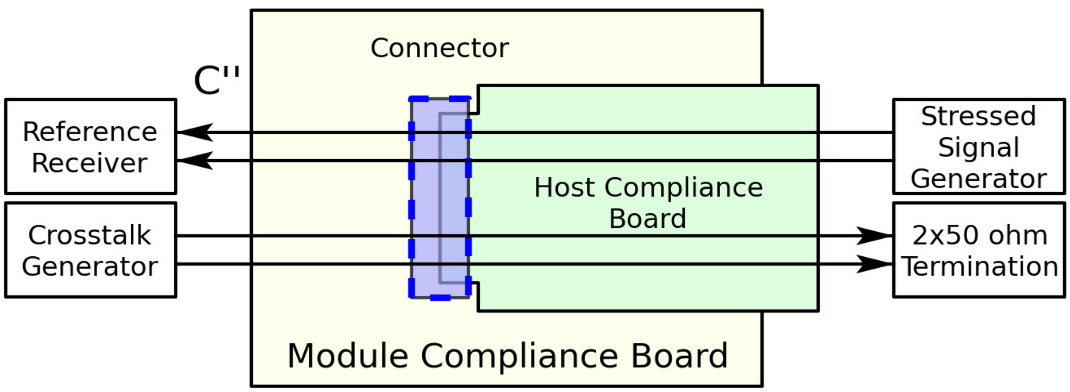

Figure 7 – Host input calibration point C''

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 64GFC 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.

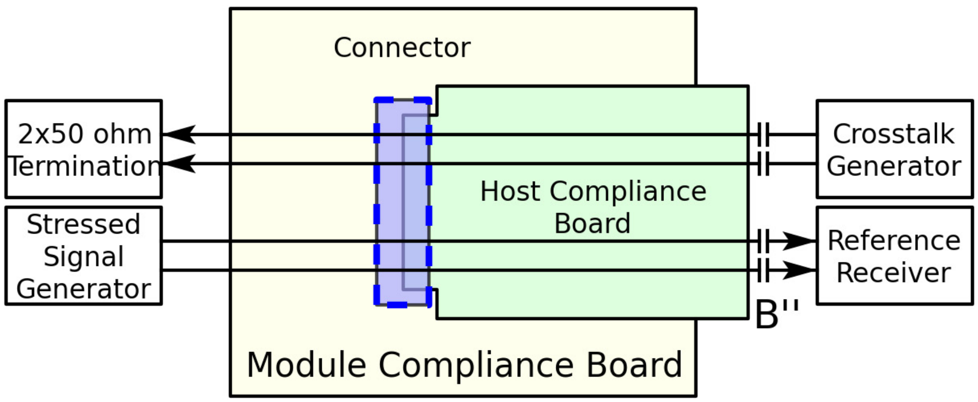

Figure 8 – Module input calibration point B"

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 [27]), as adapted from OIF (reference [18]).

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	-	TBD		TBD	mV	
Common mode noise rms	-	TBD		TBD	mv	
Differential termination resistance mismatch	-	TBD		TBD	%	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	-	TBD		TBD	dB	note 5
Source transition time 20%-80%		TBD		TBD	ps	
Common mode voltage		TBD		TBD	V	note 6
Vertical eye closure		TBD		TBD	dB	note 7
Eye width at 10^{-6} probability EW6		TBD		TBD	UI	
Eye height at 10^{-6} probability EH6		TBD		TBD	mV	
Eye Linearity		TBD		TBD		note 8
Crosstalk parameters						
Signal calibration point	C" (figure 7)		B" (figure 8)			note 1, note 9
Signal application point	C (figure 5)		B' (figure 6)			
Crosstalk amplitude differential voltage pk-pk	TBD		TBD		mV	
Crosstalk transition time 20%-80%	TBD		TBD		ps	note 10

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 [27]) for test configurations and test methods. The module may need equalization to achieve the required eye opening
8. Eye linearity = (max(AVupp, AVmid, AVlow) / min(AVupp, AVmid, AVlow)).
9. 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 [27])
10. 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 [27]), as adapted from OIF (reference [17]).

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	-	TBD		TBD	%	
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		TBD		TBD	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	TBD		TBD		mV	
Crosstalk source transition time 20%-80%	TBD		TBD		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	-	TBD		TBD	UI	note 7, note 8
Eye width at 10^{-6} probability EW6		TBD		TBD	UI	
Eye height at 10^{-6} probability EH6		TBD		TBD	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 [27]).
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 [27]) 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 [27])

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	TBD	TBD
Jitter amplitude, pk-pk	TBD	TBD

The following figure shows the jitter tracking template:

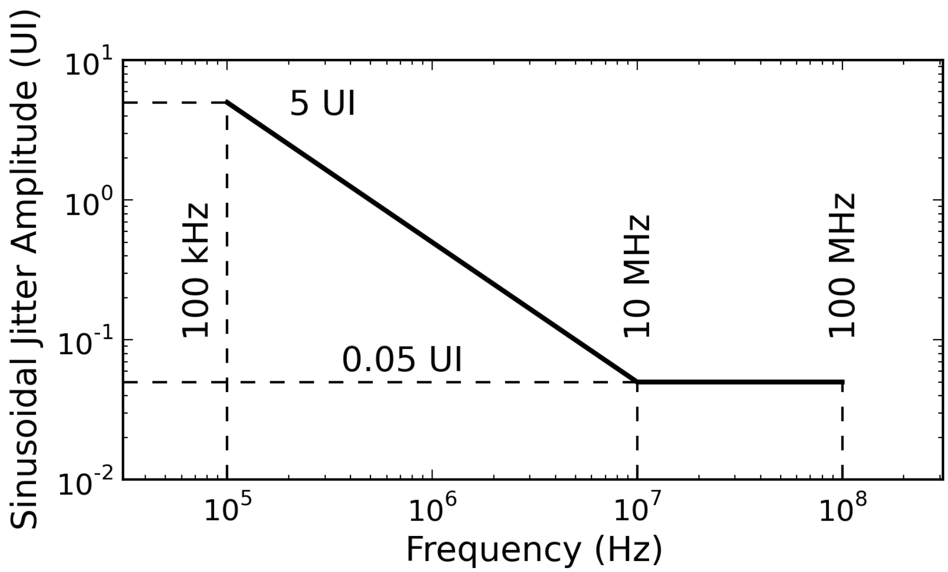

Figure 9 – Receiver jitter tracking template

For additional testing details see MSQS-2 (reference reference [27]).

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:

$$SDD11, SDD22\ (\mathrm{dB}) < \{TBD\} \qquad (1)$$

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.

$$SDC11, SCD11\ (\mathrm{dB}) < \{TBD\} \qquad (2)$$

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.

$$SDC22, SCD22\ (\mathrm{dB}) < \{TBD\} \qquad (3)$$

Figure 11 – SDC11 and SCD11 for receiver input

Figure 12 – SDC22 and SCD22 for transmitter output