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Working Draft
INCITS 559-202x / Rev 1.01

FIBRE CHANNEL

Physical Interface-7P

REV 1.01

INCITS working draft proposed
American National Standard
for Information Technology

April 7, 2020

Secretariat: Information Technology Industry Council

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INCITS ®
559-202x

American National Standard
for Information Technology

Fibre Channel —
Physical Interface-7P (FC-PI-7P)

Secretariat

Information Technology Industry Council

Approved (not yet approved)

American National Standards Institute, Inc.

Abstract

ABSTRACT: This standard describes the point-to-point physical interface portions of Fibre Channel optical link and backplane 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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Information Technology Industry Council
1101 K Street NW, Suite 610, Washington DC 20005

Foreword

(This Foreword is not part of INCITS 559-202x.)

This standard was developed by Task Group T11.2 of Accredited Standards Committee INCITS during 2019 and 2020. The standards approval process will be started in 2020. 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, 1101 K Street NW, Suite 610, Washington DC 20005.

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

At the time it approved this standard, INCITS had the following members:

Technical Committee T11 on Lower Level Interfaces, that reviewed this standard, had the following members:

Steve Wilson, Chair
Craig Carlson, Vice-Chair
Patty Driever, Secretary

MEMBERSHIP TABLES TO BE ADDED AT THE TIME OF PUBLICATION

A list of Emeritus members of T11 is given below.

A list of Advisory members of T11 is given below.

Task Group T11.2 on Fibre Channel Protocols, that developed and reviewed this standard, had the following members:

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Dean Wallace, Vice-Chair
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A list of Emeritus members of T11.2 is given below.

A list of Advisory members of T11.2 is given below.

Acknowledgments

The technical editor would like to thank the following individuals for their special contributions to this standard:

Jonathan King for optical link budget

John Petrilla for electrical link budget

Mike Dudek for backplane solution

Dean Wallace for leadership

Revision History

1) Revision 0.01

    Initial blank document.

2) Revision 1.00

    Incorporated comments in T11-2019-00342-v001.

    Incorporated comments in T11-2020-00043-v000.

2) Revision 1.01

    Incorporated RFC database in T11-2020-00059-v003.

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

1 Scope

This standard describes the physical interface portions of high performance optical link variants that support the higher level Fibre Channel protocols including FC-FS-4 (reference [1]) and FC-FS-5 (reference [2]).

FC-PI-7P specifies the parallel four-lane variant 256GFC. 64GFC is described in FC-PI-7 (reference [3]) and 128GFC is described in FC-PI-6P (reference [4]), respectively.

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 Approved references

[1] **INCITS 488-2016, FC-FS-4,** Fibre Channel Framing and Signaling - 4

[2] **INCITS 545-2018, FC-FS-5,** Fibre Channel Framing and Signaling - 5

[3] **INCITS 543-2019, FC-FP-7,** Fibre Channel Physical Interfaces - 7

[4] **INCITS 533-2016, FC-PI-6P,** Fibre Channel Physical Interfaces - 6P

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

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

[7] **INCITS TR-50-2014, FC-MSQS-2,** Fibre Channel Methodologies for Signal Quality Specification 2

[8] **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

[9] **IEC 60793-2-10:2019,** 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] **IEEE 802.3™-2018,** IEEE Standard for Ethernet

[14] **IEC 61754-7-1,** Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces - Part 7-1: Type MPO connector family - one fibre row

[15] **IEEE 802.3cd-2018,** Media Access Control Parameters for 50 Gb/s and Physical Layers and Management Parameters for 50 Gb/s,100 Gb/s, and 200 Gb/s Operation

[16] **IEEE 802.3cn-2019,** Physical Layers and Management Parameters for 50 Gb/s, 200 Gb/s, and 400 Gb/s Operation over Single-Mode Fiber

[17] **IEEE 802.3cm-2020,** Physical Layer and Management Parameters for 400 Gb/s over Multimode Fiber

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 contacts of the transmitter and receiver in an FC device or retiming element.

3.1.2 **γ_T, γ_R:** gamma T, gamma R; interoperability points used for establishing signal budgets. Gamma T is the optical transmitter interface compliant point defined as the output of a 0.5 m to 2 m patchcord connected to the external enclosure connector.

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

3.1.4 **alpha T, alpha R:** See α_T, α_R (3.1.1).

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

3.1.6 **average power:** The optical power measured using an average-reading power meter when transmitting valid transmission characters.

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

3.1.8 **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.)

3.1.9 **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.

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

3.1.11 **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.

3.1.12 **cable plant:** All passive communications elements (e.g., optical fiber, cable, connectors, splices, etc.) between a transmitter and a receiver.

3.1.13 **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 [8]).

3.1.14 **character:** A defined set of *n* contiguous bits where *n* is determined by the encoding scheme.

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

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

3.1.17 delta T, delta R: See δ_T, δ_R (3.1.3).

3.1.18 device: See FC device.

3.1.19 dispersion: A term in this document used to denote pulse broadening and distortion from all optical causes. The causes of dispersion in optical transmissions are modal, chromatic and polarization mode dispersion. Modal dispersion is caused by the difference in the propagation velocity of the guided modes in a multimode fiber. Chromatic dispersion, due to the difference in propagation of the various spectral components, of the signal and optical source. Polarization mode dispersion is caused by fiber defects, that makes the propagation velocity dependent of the light polarization state.

3.1.20 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.

3.1.21 extinction ratio outer: The ratio of the highest optical power to the lowest optical power in the presence of a PAM4 signal (i.e., levels 3 and 0 in Figure 6(B), clause 5). See IEEE 802.3™-2018,(reference [13]), clause 121.8.6.

3.1.22 FC-0 level: The level in the Fibre Channel architecture and standards that defines transmission media, transmitters and receivers, and their interfaces. See Figure 1 (clause 4.1) and FC-FS-4 (reference [1]) clause 4.

3.1.23 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 [1]).

3.1.24 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 and external connectors.

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

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

3.1.27 gamma T, gamma R: See γ_T, γ_R (3.1.2).

3.1.28 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.

3.1.29 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, γ_T, γ_R, δ_T, δ_R.

3.1.30 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-7P 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.

3.1.31 link: A duplex or parallel optics TxRx Connection, using two or more fibers to transport optical signals.

3.1.32 MB/s: An abbreviation for megabytes (10^6 bytes) per second.

3.1.33 OM3: Cabled optical fiber containing 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 1500 MHz-km at 850 nm 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 60793-2-10:2019 A1-OM3 fiber. See reference [9].

3.1.34 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 60793-2-10:2019 A1-OM4 fiber. See reference [9].

3.1.35 OM5: Cabled optical fiber containing 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 3500 MHz-km at 850 nm, 1850 MHz-km at 953 nm and 500 MHz-km at 1300 nm as well as an effective laser launch bandwidth of 4700 MHz-km at 850 nm and 2470 MHz-km at 953 nm in accordance with IEC 60793-2-10:2019 A1-OM5 fiber. See reference [9].

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

3.1.37 optical modulation amplitude, (OMA_{outer}): The difference in optical power between settled and averaged values of the highest and the lowest optical levels of a PAM4 signal (i.e., levels 3 and 0 in Figure 6(B), clause 5). OMA is typically expressed in mW or dBm. See IEEE 802.3™-2018 (reference [13]).

3.1.38 optical receiver sensitivity: The minimum acceptable value of received signal at point gamma R to achieve a defined level of BER. For 256GFC, this level is for a BER = 1.09×10^{-4}. See also the definitions for stressed receiver sensitivity and unstressed receiver sensitivity. See IEEE 802.3™-2018 (reference [13]).

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

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

3.1.41 pulse amplitude modulation, four levels, PAM4: A modulation scheme where two bits are mapped into four signal amplitude levels to enable transmission of two bits per symbol.

3.1.42 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.

3.1.43 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.

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

3.1.45 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.

3.1.46 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.

3.1.47 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.

3.1.48 reflections: Power returned by discontinuities in the physical link.

3.1.49 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, skew rate, and edge to edge timing. Repeaters have jitter transfer characteristics. Types of repeaters include retimers, reclockers, and amplifiers.

3.1.50 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.

3.1.51 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.

3.1.52 signal: The entire voltage or optical power waveforms within a data pattern during transmission.

3.1.53 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 or microwatts.

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

3.1.55 signal tolerance: The ability of the link downstream from the receive interoperability point (γ_R or δ_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.

3.1.56 spectral width (RMS): The weighted root mean square width of the optical spectrum. See IEC 61280-1-3 (reference [8]).

3.1.57 stressed eye closure for PAM4 (SECQ): SECQ is a measure of the test signal applied to an optical receiver to measure its stressed receiver sensitivity. See FC-PI-7, Clause 5.4.6 and 5.5.6 (reference [3]).

3.1.58 stressed receiver sensitivity: The amplitude of optical modulation in the stressed receiver test at which the receiver supports the BER requirement.

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

3.1.60 transceiver: A transmitter and receiver combined in one package.

3.1.61 transmission symbol: A symbol of duration one unit interval that represents one or more logical values..

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

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

3.1.64 transmitter and dispersion eye closure for PAM4 (TDECQ): TDECQ is a measure of an optical transmitter's vertical eye closure through a real or simulated worst case optical channel. See FC-PI-7, Clause 5.4.5 and 5.5.5 (reference [3]).

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

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

3.1.67 unit interval (UI): The nominal duration of a single transmission symbol.

3.1.68 unstressed receiver sensitivity: The amplitude of optical modulation in the unstressed receiver test at which the receiver supports the BER requirement.

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 clauses.

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 clauses.

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 In table 1.

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

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

3.2.2.7 optional: Characteristics that are not required by FC-PI-7P. However, if any optional characteristic is implemented, it shall be implemented as defined in FC-PI-7P.

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

3.2.2.9 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.

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

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

3.2.2.12 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 3.1.

3.2.3.1 Acronyms and other abbreviations

Table 2 – Acronyms and other abbreviations

Bd	baud
BER	Bit Error Ratio
dB	Decibel
dBm	Decibel (relative to 1 mW)
DUT	Device Under Test
EIA	Electronic Industries Association
EMC	Electromagnetic Compatibility
EMI	Electromagnetic interference
FC	Fibre Channel
FEC	Forward Error Correction
FFE	Feed Forward Equalizer
GBd	Gigabaud
hex	Hexadecimal notation
IEEE	Institute of Electrical and Electronics Engineers
ITU-T	International Telecommunication Union - Telecommunication Standardization (formerly CCITT)
LOS	Loss Of Signal
LW	Long Wavelength
MB	Megabyte = 10^6 bytes
MBd	Megabaud
MM	Multimode
MPO	Multi-fiber Push On
NA	Not Applicable
NEXT	Near-End Crosstalk
O/E	Optical to electrical conversion
OMA	Optical Modulation Amplitude
PAM4	Pulse Amplitude Modulation, four levels
PMD	Physical Medium Dependent
ppm	Parts per million
RJ	Random Jitter
RLM	Level separation mismatch ratio
RMS	Root mean square
RN	Relative Noise
Rx	Receiver
SECQ	Stressed eye closure for PAM4 signals
SER	Symbol Error Ratio
SERDES	Serializer/Deserializer
SM	Single-Mode
SNDR	Signal-to-Noise and Distortion Ratio
S/N(SNR)	Signal-to-Noise Ratio
SW	Short Wavelength
TDECQ	Transmitter and dispersion eye closure for PAM4
TIA	Telecommunication Industry Association
TJ	Total Jitter
Tx	Transmitter
TxRx	A combination of transmitter and receiver
VEC	Vertical Eye Closure
UI	Unit Interval = 1 symbol period

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 signaling rates.

Table 3 – Signaling rate abbreviations

Abbreviation	Signaling rate	Number of Lanes	Data rate
1GFC	1 062.5 MBd	1	100 MB/s
2GFC	2 125 MBd	1	200 MB/s
4GFC	4 250 MBd	1	400 MB/s
8GFC	8 500 MBd	1	800 MB/s
16GFC	14 025 MBd	1	1 600 MB/s
32GFC	28 050 MBd	1	3 200 MB/s
64GFC	28 900 MBd	1	6 400 MB/s
128GFC	112 200 MBd	4	12 800 MB/s
256GFC	115 600 MBd	4	25 600 MB/s

4 FC-PI-7P 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. Reed Solomon (544,514) Forward Error Correction (FEC) is required to achieve the 256GFC link BER objectives. It is expected that the link BER after correction will be better than 10^{-15}.

FC-PI-7P describes the physical link for a four-lane data stream supporting a signaling rate of 256GFC. The 256GFC variants include 256GFC-SW for MM variant. It is the responsibility of the component suppliers and the system integrator to ensure that this level of service is provided at every port in a given Fibre Channel installation. FC-PI-7P defines optical and electrical interoperability points at specific physical locations in the FC system. No interoperability points are required for closed or integrated links and FC-PI-7P is not required for such applications. For closed or integrated links the system designer shall ensure that a BER as observed prior to error correction is better than the values specified in FC-PI-7P. The BER for the electrical and optical sections of a FC-PI-7P link shall meet requirements shown in 4.11.

4.2 Compliance test points

The requirements specified in FC-PI-7P shall be satisfied at separable connectors where interoperability and component level interchangeability within the link are expected. A block diagram of 256GFC-SW4 is shown in Figure 2. A compliance point is a physical position where the specification requirements are defined and can be measured. The compliance points are defined at separable connectors, since these are the points where different components can easily be added, changed, or removed. The description and physical location of the specified interoperability points are detailed in 5.13 of FC-PI-5 (reference [5]). 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 3 shows the compliance points for 256GFC variants.

It is the 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-7P 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.

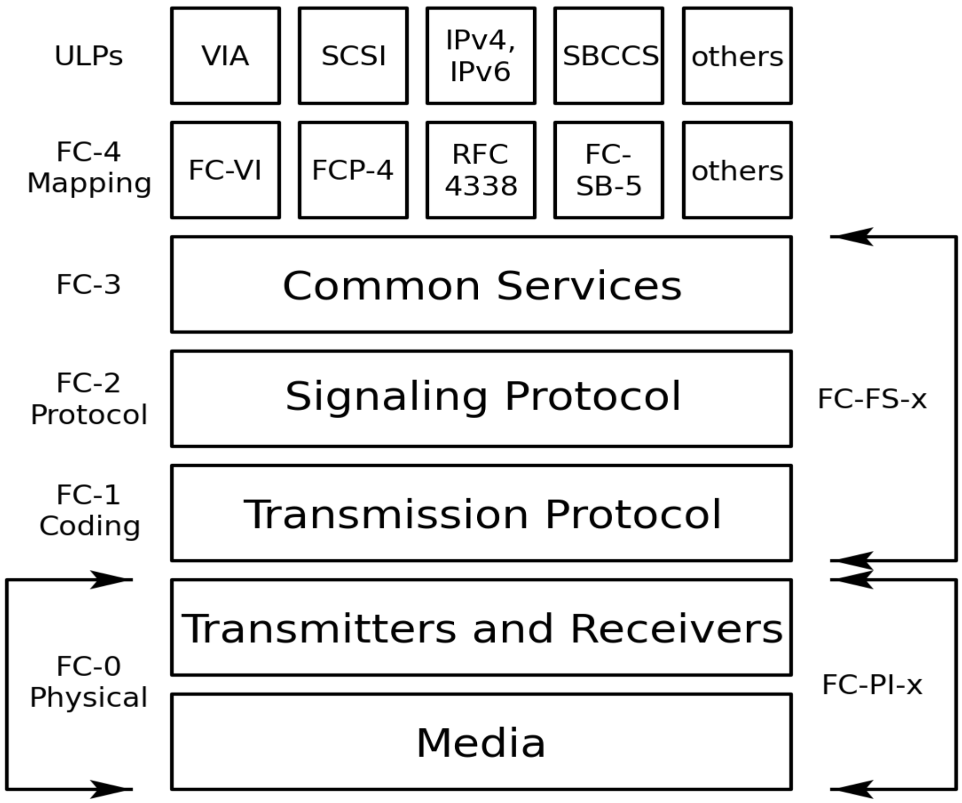

Figure 1 – Fibre Channel hierarchy

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-7P is written assuming that the four-lane data stream exists throughout the link as viewed from the interoperability points.

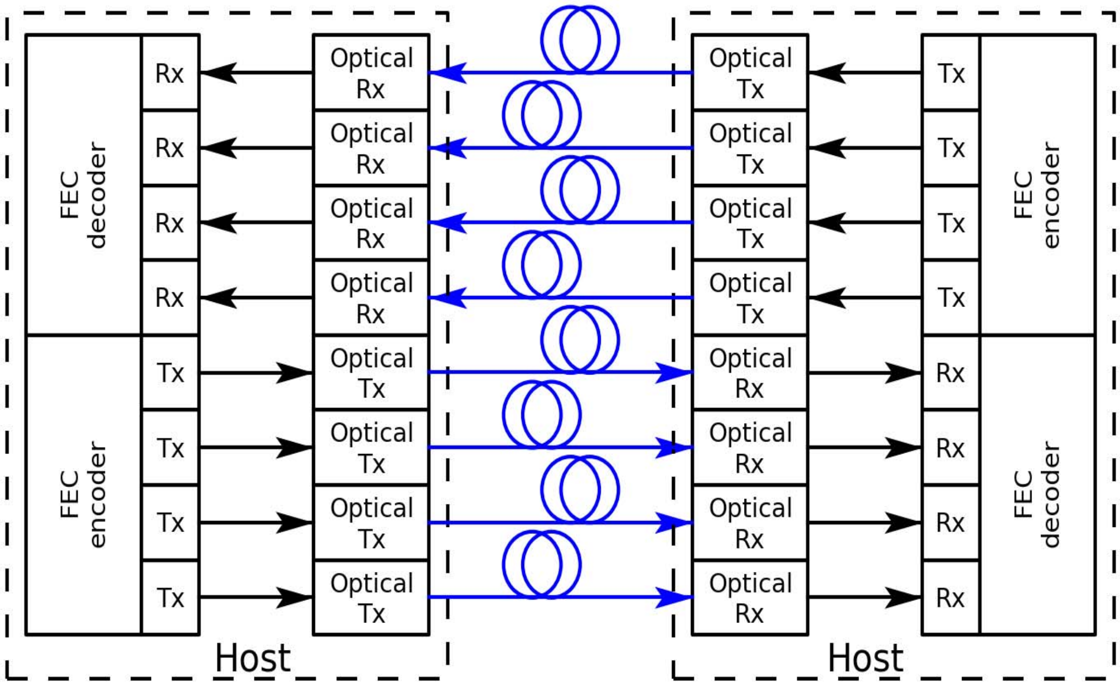

Figure 2 – 256GFC-SW4 block diagram

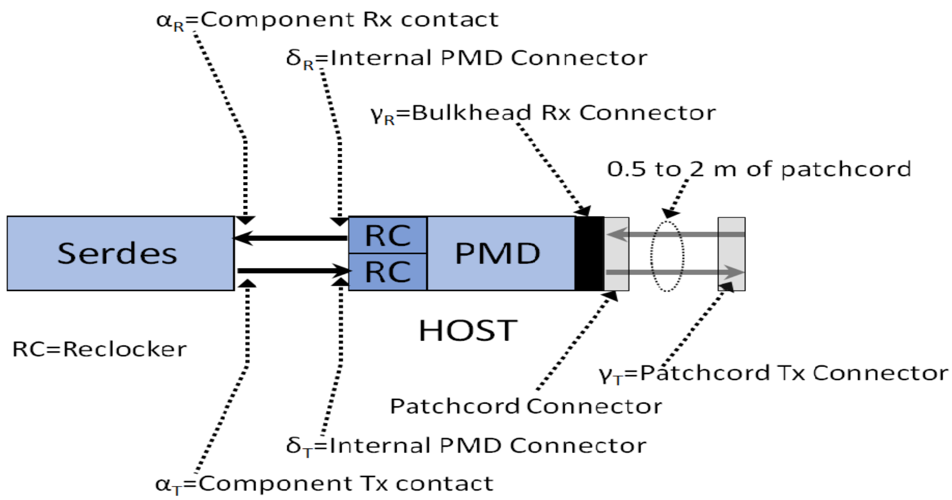

Figure 3 – Compliance points for 256GFC PMDs

Physical links have the following general requirements:

a) Physical point-to-point data links.

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-7P 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-7P 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 functions

4.3.1 Transmitter functions

The transmitter function is to convert the signal received from the FC-1 level into the proper signal for the transmission media.

4.3.2 Receiver functions

The function of the receiver is to recover and retime the incoming signal from the transmission media, convert into the proper signal for the FC-1 level and present the signal 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 is defined in FC-FS-5 (reference [2]). 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 functions 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 and training

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

a) The transmitter or the repeater shall be capable of switching from compliant operation at one speed to compliant operation at a new speed within the time periods determined in clause 8 of FC-FS-5 (reference [2]).The FC-1 level shall attain Transmission_Word synchronization within the receiver stabilization time (subclause 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.

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

c) The transmit training signal used for speed negotiation is defined in FC-FS-5 (reference [2]).

4.8 Transmission codes

256GFC variants rely on the implementation of FEC, transcoding, and scrambling as defined in FC-FS-5 (reference [2]). The actual FEC, transcoding, and scrambling hardware is at the FC-1 layer and is not defined in FC-PI-7P.

4.9 Frame scrambling and emission lowering protocol

256GFC variants use coding and scrambling that is inherent in the code as defined in FC-FS-5 (reference [2]).

4.10 Forward error correction (FEC)

256GFC variants rely on the implementation of FEC as defined in FC-FS-5 (reference [2]) The actual FEC hardware is at the FC-1 layer and is not defined in FC-PI-7P.

4.11 Bit error ratio per link locations and segments

FC links may be divided in optical and electrical segments as illustrated in Figure 4. The value of the maximum BER at those locations shall meet the specified limits defined in Table 4.

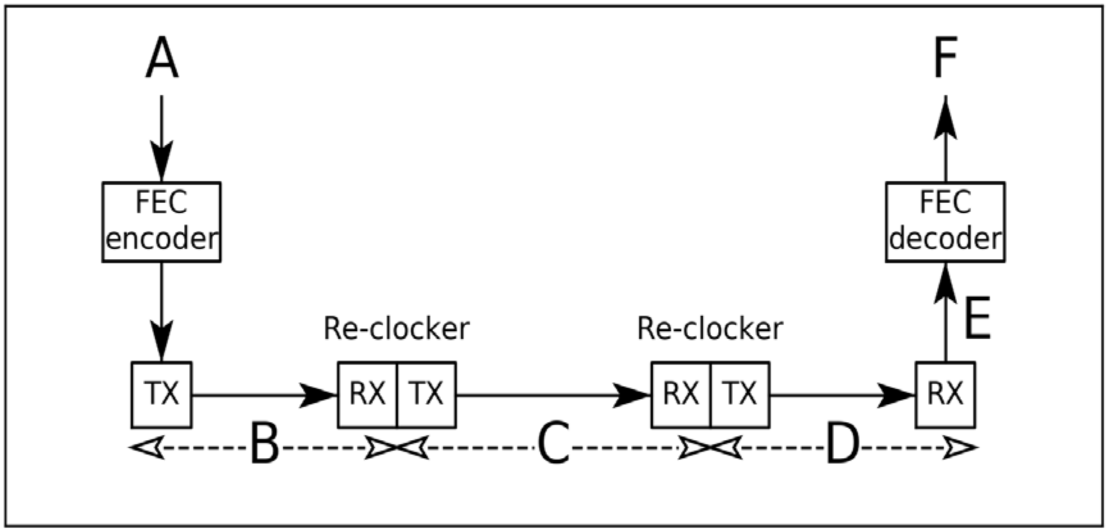

Figure 4 – BER per Segment

Table 4 – BER per link Location / Segment

Location / Segment	Description	BER Segment	BER Cumulative
A	Initial Signal	0	0
B	Host Tx to Module electrical link	1.09×10^{-5}	
C	Optical Link	1.09×10^{-4}	
D	Module to Host Rx electrical link	1.09×10^{-5}	
E	Cumulative uncorrected BER for A-E		1.31×10^{-4}
F	Final FEC BER for A-F		1.0×10^{-15}

Notes:

1. Location / Segments refer to Figure 4.
2. For segment A-D the BER limits are defined prior FEC.
3. Cumulative uncorrected BER prior FEC is shown in location E.
4. This assumes the optical link has an error propagation probability of 0.1 and the electrical links both have an error propagation probability of 0.5.
5. BER limits in segments A to D ensure final BER at location F.

4.12 FC-PI-7P variants

Table 5 lists the FC-PI-7P variants, their nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize them. The lengths specified in Table 5 are the minimum ranges supported with transmitters, media, and receivers all simultaneously operating under the most degraded conditions allowed.

MM 50 μm **OM3**	**256GFC-SW** 850 nm 0.5 m-70 m subclause 5.4
MM 50 μm **OM4, OM5**	**256GFC-SW** 850 nm 0.5 m-100 m subclause 5.4

Table 5 – Fibre Channel Variants in FC-PI-7P

4.13 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 6. See Figure 3 for a definition of the test points.

Table 6 – Skew and skew variation constraints for 256GFC

Test Point	Skew	Skew variation
δ_T	**29 ns**	**200 ps**
γ_T	**54 ns**	**600 ps**
γ_R	**134 ns**	**3.4 ns**
δ_R	**160 ns**	**3.8 ns**
α_R	**180 ns**	**4.0 ns**

4.14 MPO optical interface

Mechanical, optical performance, and intermateability for the MPO connector system are specified in IEC 61754-7-1 (reference [14]). Figure 5 shows the MPO optical connector and device receptacle.

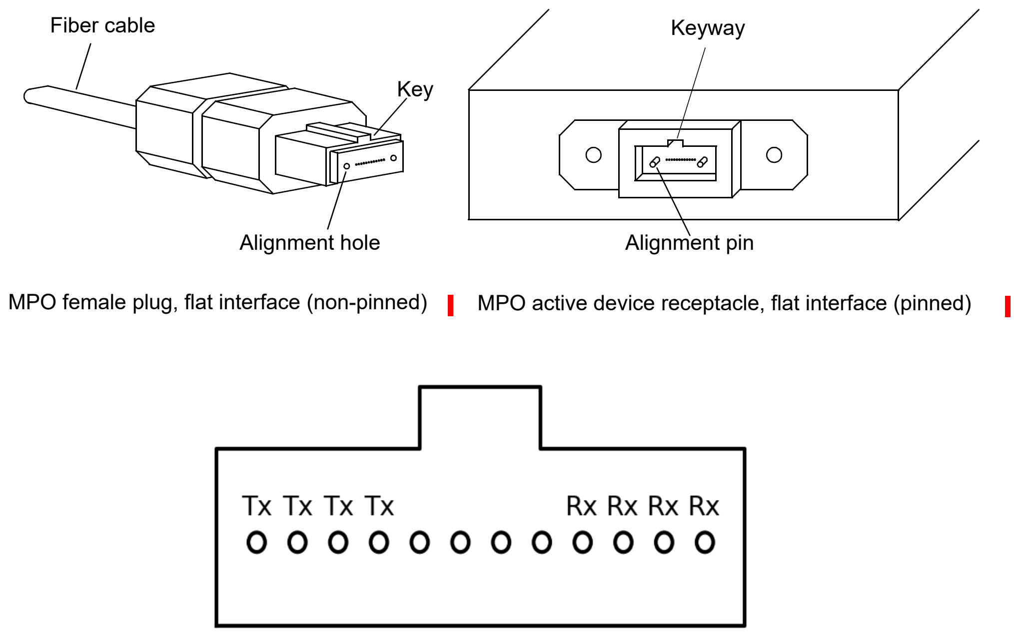

Figure 5 – PMD receptacle mating with MPO optical interface and lane assignments

5 Optical interface specification

5.1 TxRx connections

This clause defines the optical signal characteristics at the external enclosure connector. Each conforming optical FC port shall comply with the requirements specified in clause 5 and other applicable clauses. Fibre Channel four-lane 256GFC optical links require forward error correction (FEC) to achieve link BER objectives. Fibre Channel four-lane 256GFC optical links shall not exceed an uncorrected BER of 1.09 $x10^{-4}$ under any compliant conditions. 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 [5]). 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 segment defined in clause 6.

5.2 Laser safety issues

The optical output of the laser transceiver shall not exceed Class 1 maximum permissible exposure limits under any condition of operation per IEC 60825-1 (reference [11]), and the optical output for the fiber optic system shall not exceed Hazard 1M maximum permissible exposure limits under any condition of operation per IEC 60825-2 (reference [12]). This includes single fault conditions whether coupled into a fiber or out of an open bore. Conformance to newer version of IEC 60825 standards or additional laser safety standards may be required for operation within specific geographic regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product’s laser, safety features, labeling, use, maintenance, and service. This documentation explicitly defines requirements and usage restrictions on the host system necessary to meet these safety certifications.

5.3 Optical signal modulation format

A four level pulse amplitude modulation (PAM4) is the modulation format utilized in all the optical variants defined in FC-PI-7P. To generate a PAM4 signal, two logical bits are mapped to a Gray-coded symbol described in IEEE 802.3™-2018, (reference [13]) and FC-FS-5 (reference [2]). A non-corrupted PAM4 signal is depicted in Figure 6(A). The PAM4 levels 0 and 3 represent the lowest and maximum steady state optical power. Additionally, the levels 0 and 3 can represent the most negative or most positive voltage when evaluated after the O/E conversion.

PAM4 signal generates three eye diagrams: top, middle and bottom, as shown in Figure 6(B). These eyes can present different height and width. Moreover, signals produced by direct modulated lasers can produce eye skew, which penalize the optimum sampling of the signals.

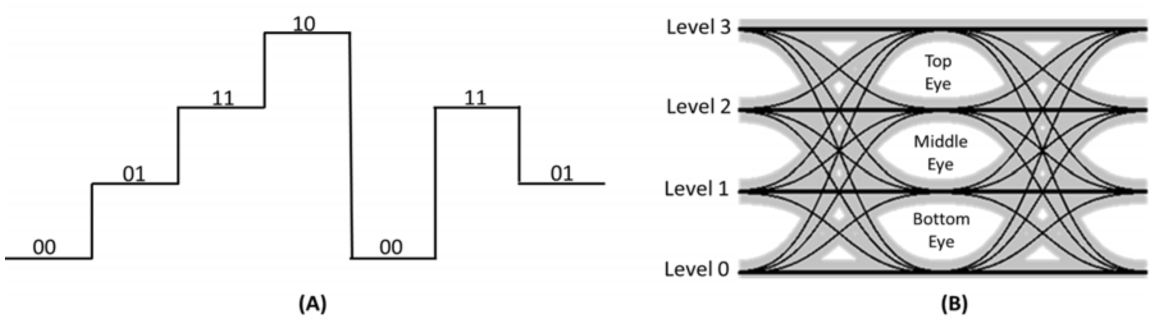

Figure 6 – Optical Eye Diagram of a PAM4 Signal

5.4 SM data links

Single-Mode data links are not supported in this standard.

5.5 MM data links

5.5.1 MM general information

Multimode general information is described in FC-PI-7, Clause 5.5.1 (reference [3]).

5.5.2 MM optical output interface

Multimode optical output interface is described in FC-PI-7, Clause 5.5.2 (reference [3]).

5.5.3 MM optical input interface

Multimode optical input interface is described in FC-PI-7, Clause 5.5.3 (reference [3]).

5.5.4 Transmitter transition time

Transmitter transition time is described in FC-PI-7, Clause 5.5.4 (reference [3]).

5.5.5 TDECQ Test

TDECQ, a measure of the optical transmitter’s vertical eye closure for PAM4, is described in FC-PI-7, Clause 5.5.5 (reference [3]).

5.5.6 SECQ Measurement

SECQ, a measure of the optical eye closure of a test PAM4 signal applied to an optical receiver to measure its stressed receiver sensitivity, is described in FC-PI-7, Clause 5.5.6 (reference [3]).

5.5.7 SRS Test

Stressed receiver sensitivity shall be within the limits described in FC-PI-7, Clause 5.5.7 and Table 7 (reference [3]).

5.5.8 Multi-Lane Testing Considerations

Stressed receiver sensitivity is defined for each lane at the BER specified in subclause 5.5.3. Measurements require lane by lane BER measurements. The measurement procedure describing testing patterns, power levels and crosstalk consideration is indicated in IEEE 802.3cd-2018 (reference [15]) subclause138.1.1.

5.6 SM Cable Plant

Single-Mode cable plants are not defined in this standard.

5.7 MM Cable Plant

Multimode cable plants are defined in FC-PI-7, Clause 5.7 (reference [3]).

6 Electrical interface specification - single lane segments

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. Conforming electrical FC devices shall use four lanes where each lane meets the requirements described in FC-PI-7, Clause 6 (reference [3]) in order to allow interoperability within an FC environment.

6.1 General electrical characteristics

The general electrical characteristics are described in FC-PI-7, Clause 6 (reference [3]), Table 9.

6.2 Compliance test point definitions

6.2.1 Test method

The test method definition is described in FC-PI-7, subclause 6.2.1 (reference [3]).

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 FC-PI-7, subclause 6.2.2 (reference [3]), Figure 5.

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 FC-PI-7, subclause 6.2.3 (reference [3]), Figure 6.

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. The calibration method is described in FC-PI-7, subclause 6.2.4 (reference [3]).

6.2.5 Module input calibration point

The module electrical input tolerance signal is calibrated using the method described in FC-PI-7, subclause 6.2.5 (reference [3]).

Annex A (informative)
Optical cable plant usage

The worst-case power budget and link penalties for the multimode cables are specified in clause 5. and are shown in FC-PI-7, Table A.1 of Annex A (reference [3]).

Annex B (informative)
Structured cabling environment

B.1 Specification of operating distances

Operating distances of Fibre Channel links described in clause 5 are described in FC-PI-7, Annex B, Clause B.1 (reference [3]).

B.2 Alternate connection loss operating distances

In structured cabling environments, the connection loss used to calculate link distance may be different from the connection loss allocations specified in clause 5. Different allocations for connection loss result in changes to the maximum operating range. The maximum operating range and loss budget requirements for a range of connection loss values are shown in FC-PI-7, Annex B, Table B.1 (reference [3]).

Annex C (informative)
Electrical channel

The Electrical channel informative annex is shown in FC-PI-7, Annex C (reference [3]).