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FIBRE CHANNEL

Physical Interface-6

REV 1.00

INCITS working draft proposed
American National Standard
for Information Technology

April 26, 2013

Secretariat: Information Technology Industry Council

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

NOTE:

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POINTS OF CONTACT:

Steven Wilson (T11 Chairman)
Brocade Communications Systems, Inc.
1745 Technology DR
San Jose, CA 95131
(408) 333-8128 Fax: (408) 333-6655
E-Mail: swilson@brocade.com

Claudio DeSanti (T11 Vice Chairman)
Cisco Systems, Inc.
170 W. Tasman Dr.
San Jose, CA 95134
(408) 853-9172 Fax: (408)-853-9172
E-Mail: cds@cisco.com

Hossein Hashemi (Editor)
Emulex Corporation
3333 Susan Street
Costa Mesa, CA 92626
(714) 885-3609 Fax: (714) 885-3794
E-Mail: hossein.hashemi@emulex.com

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Project 2221-D

American National Standard for Information Technology

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

Secretariat

Information Technology Industry Council

Approved (not yet approved)

American National Standards Institute, Inc.

Abstract

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American National Standard

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Foreword

(This Foreword is not part of INCITS Project 2221-D.)

This standard was developed by Task Group T11.2 of Accredited Standards Committee INCITS during 2011, 2012, and 2013. The standards approval process will be started in 2013. This document includes annexes that are informative and are not considered part of the standard.

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

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

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	A	Robert Reid
	A	Steve Skiest
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	A	Dean Wallace
	A	Ed McGlaughlin
	A	Skip Jones
TE	P	Kim Whitman
	A	Andrew Nowak
	A	Michael Fogg

A list of Emeritus members of T11 is given below.

Indivitual
Bill Ham
Gary Stephens
Shelto Van Doom
Robert Kembel
Horst Truestedt
James Coomes
Joseph R, Mathis
Bill Martin

A list of Advisory members of T11 is given below.

Company	Type	Member
Crossroads Systems	P	Bill Moody
DSI A*Star	P	Khin Mi Aung
FCI	P	Miguel Conde
	A	David Sideck

Company	Type	Member
Futurewei	P	Serge Manning
	A	Xiaoyan Ge
	A	Xiaoyan He
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Hitachi DS	P	Eric Hibbard
	A	Vincent Franceschini
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Virtual Instruments	P	Skip Bacon
VMware	P	Neil Maclean
	A	Sandeep Uttamchandani
	A	Lawrence Lamers

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

Tom Palkert, Chair
Dean Wallace, Vice-Chair
Richard Johnson, Secretary

Company	Type	Member
Agilent	P	Joachim Vobis
	A	Stephen Didde
	A	Steve Sekel
Amphenol	P	Gregory McSorley
	A	Michael Wingard
	A	Alex Persaud
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	A	Richard Case
	A‘	Paul Kolesar
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	A	Bhavesh Patel
EMC	P	Gary S. Robinson
	A	David Black
	A	Erik Smith
	A	Louis Ricci
Emulex	P	Hossein Hashemi
	A	Gautam Shiroor

Company	Type	Member
FCI	P	Miguel Conde
	A	David Sideck
Finisar	P	Chris Yien
	A	Richard Johnson
Fujitsu	P	Sandy Wilson
	A	Eugene Owens
	A	Jim DeCaires
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QLogic	P	Dean Wallace
	A	Mark Owen
	A	Mike Dudek
	A	Craig W. Carlson

Company	**Type**	**Member**
Tyco Electronics	P	Kim Whitman
	A	Andrew Nowak
	A	Michael Fogg
Vitesse	P	Marty Spadaro
	A	Gary Paules

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

Indivitual
Bill Ham
Shelto Van Doom

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

Excelight	P	Mark Furumai
	A	Eddie Tsumura
Hitachi GST	P	Dan Colegrove
PMC-Sierra	P	Rick Hernandez
	A	Peichen Chang
ST	P	Gianfranco Scherini
	A	Massimo Pozzoni
TI	P	Rajeev Jain
	A	Stephen Hubbins

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Revision History

1) Revision 0.00 Initial blank document.

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

3) Revision 0.03 released for further comments.

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

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

1 Scope

This international standard describes the physical interface portions of high performance electrical and optical link variants that support the higher level Fibre Channel protocols including FC-FS-4 (reference [29]).

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

2 Normative references

2.1 General

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

Copies of the following documents can be obtained from ANSI: Approved ANSI standards, approved and draft international and regional standards (ISO, IEC), and other approved standards (including JIS and DIN).

2.2 Normative references

2.2.1 Approved references

[1] **ANSI/INCITS 450, FC-PI-5,** Fibre Channel Physical Interfaces - 5

[2] **ANSI/INCITS 450, FC-PI-3,** Fibre Channel Physical Interfaces - 3

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

[4] **ANSI/INCITS 424-2007, FC-FS-3,** Fibre Channel Framing and Signaling 3

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

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

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

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

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

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

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

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

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

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

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

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

[19] **IEEE 802.3-2008,** IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications

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

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

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

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

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

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

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

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

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

2.3 References under development

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

[29] **ANSI/INCITS 1861D, FC-FS-4,** Fibre Channel Framing and Signaling 3

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

[31] SFF-8402, 0.8mm Card Edge Connector for 28Gb/s Applications

[32] CEI-28G-VSR, OIF2010.404.08

2.4 Informative references

none.

3 Definitions and conventions

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

3.1 Definitions

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

3.1.2 **β_T, β_R:** beta T, beta R; interoperability points used for establishing signal budget at the disk drive connector nearest the alpha point unless the point also satisfies the definition for delta or gamma when it is either a delta or a gamma point. The beta point specifications are intra-enclosure specifications.

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

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

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

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

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

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

3.1.9 **bandwidth:** in FC-PI-5 context, the corner frequency of a low-pass transmission characteristic, such as that of an optical receiver.

3.1.10 **baud:** a unit of signaling speed, expressed as the maximum number of times per second the signal may change the state of the transmission line or other medium. (Units of baud are symbols/sec.) NOTE: With the Fibre Channel transmission scheme, a symbol represents a single transmission bit.

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, coaxial cable, connectors, splices, etc.) between a transmitter and a receiver.

3.1.17 center wavelength (laser): the value of the central wavelength of the operating, modulated laser. This is the wavelength where the effective optical power resides. See IEC 61280-1-3 (reference [14]).

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

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

3.1.20 compliance point: a normative interoperability point. Compliance points include beta, gamma, delta, and epsilon points for transmitters and receivers.

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

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

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

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

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

3.1.26 deterministic jitter: see jitter, deterministic.

3.1.27 device: see FC device.

3.1.28 disparity: the difference between the number of ones and zeros in a Transmission Character. See FC-FS-3 (reference [29]).

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

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

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

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

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

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

3.1.35 extinction ratio: the ratio of the high optical power to the low optical power. See FC-MSQS (reference [30]).

3.1.36 eye contour: the locus of points in signal level - time space where the CDF remains at a fixed defined value. For 32GFC the CDF= 1E-6 contour in the actual signal population determines whether a jitter eye mask violation has occurred. Either time jitter or signal level jitter may be used to measure the eye contour.

3.1.37 fall time: the time interval for the falling edge of a signal to transit between specified percentages of the signal amplitude. In the context of FC-PI-5, the measurement points are the 80% and 20% voltage levels.

3.1.38 FC0: See FC-FS-4 (reference [29]).

3.1.39 FC1: See FC-FS-4 (reference [29]).

3.1.40 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.

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

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

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

3.1.44 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 [5]) with a 3dB bandwidth of (nominal signalling rate)/1667.

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

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

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

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

3.1.49 interoperability point: points in a link or TxRx connection 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.

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

3.1.51 jitter: the instantaneous deviations of a signal edge times at a defined signal level of the signal from the reference times. The reference time is the jitter-timing-reference specified in 6.2.3 of FC-MJSQ (reference [5]) that occurs under a specific set of conditions. In this document, jitter is defined at the average signal level.

3.1.52 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.

3.1.53 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.

3.1.54 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 [5]).

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

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

3.1.57 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.

3.1.58 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.

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

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

3.1.61 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.

3.1.62 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.

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

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

3.1.65 jitter, uncorrelated, UJ: uncorrelated jitter is a measure of any jitter that is not correlated to the data stream. See FC-MSQS (reference [30]).

3.1.66 JSPAT: the JSPAT (scrambled jitter pattern) is a 500 bit pattern that has been developed for transmit jitter, DDPWS, WDP and RN testing for 8GFC. See FC-MSQS (reference [30]).

3.1.67 JTSPAT: the JTSPAT is a 1180 bit pattern intended to be used for receive jitter tolerance testing for 8GFC. See FC-MSQS (reference [30]).

3.1.68 level:
1. A document artifice, e.g. FC0, 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.

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

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

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

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

3.1.73 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.

3.1.74 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.

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

3.1.76 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 [7]).

3.1.77 OM1: 62.5/125 um multimode fiber with a minimum overfilled launch bandwidth of 200 MHz-km at 850 nm and 500 MHz-km at 1300 nm in accordance with IEC 60793-2-10 Type A1b fiber. See reference [8].

3.1.78 OM2: 50/125 um multimode fiber with a minimum overfilled launch bandwidth of 500 MHz-km at 850 nm and 500 MHz-km at 1300 nm in accordance with IEC 60793-2-10 Type A1a.1 fiber. See reference [8].

3.1.79 OM3: 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 1500 MHz-km at 850nm and 500 MHz-km at 1300 nm as well as an effective laser launch bandwidth of 2000 MHz-km at 850 nm in accordance with IEC 60793-2-10 Type A1a.2 fiber. See reference [8].

3.1.80 OM4: 50/125 um laser optimized multimode fiber with a minimum overfilled launch bandwidth of 3500 MHz-km at 850 nm and 500 MHz-km at 1300 nm as well as an effective laser launch bandwidth of 4700 MHz-km at 850 nm in accordance with IEC 60793-2-10 Type A1a.2 fiber. See reference [8].

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

3.1.82 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 [30]).

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

3.1.84 optical receiver sensitivity: the minimum acceptable value of received signal at point gamma R. to achieve a BER < 10^{-12}. See also the definitions for stressed receiver sensitivity and unstressed receiver sensitivity. See FC-MSQS (reference [30]).

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

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

3.1.87 OS1: dispersion unshifted single-mode fiber in accordance with IEC 60793-2-50 Type B1.1 fiber. See reference [9].

3.1.88 OS2: dispersion unshifted, low water peak, single-mode fiber in accordance with IEC 60793-2-50 Type B1.3 fiber. See reference [9].

3.1.89 P_{alloc}: the effective system power/voltage budget used in TWDP and WDP calculations. See FC-MSQS (reference [30]).

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

3.1.91 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.

3.1.92 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.

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

3.1.94 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.

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

3.1.96 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.

3.1.97 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.

3.1.98 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.

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

3.1.100 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.

3.1.101 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.

3.1.102 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.

3.1.103 $RIN_{12}OMA$: relative Intensity Noise. Laser noise in dB/Hz with 12 dB optical return loss, with respect to the optical modulation amplitude.

3.1.104 rise time: the time interval for the rising edge of a signal to transit between specified percentages of the signal amplitude. In the context of FC-PI-5, the measurement points are the 80% and 20% voltage levels.

3.1.105 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.

3.1.106 running disparity: a binary parameter indicating the cumulative disparity (positive or negative) of all transmission characters since the most recent of (a) power on, (b) exiting diagnostic mode, or (c) start of frame. See FC-FS-3 (reference [29]).

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

3.1.108 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.

3.1.109 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.

3.1.110 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.

3.1.111 spectral width (RMS): the weighted root mean square width of the optical spectrum. See IEC 61280-1-3 (reference [14]).

3.1.112 stressed receiver sensitivity: the amplitude of optical modulation in the stressed receiver test given in FC-MSQS (reference [30]).

3.1.113 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 [30]).

3.1.114 synchronization: bit synchronization, defined above, and/or Transmission-Word synchronization, defined in FC-FS-3 (reference [29]). An FC-1 receiver enters the state “Synchronization-Acquired” when it has achieved both kinds of synchronization.

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

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

3.1.117 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.

3.1.118 transmission code: a means of encoding data to enhance its transmission characteristics. The transmission code specified by FC-FS-3 (reference [29]) is byte-oriented, with both valid data bytes and special (control) codes encoded into 10-bit transmission characters.

3.1.119 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.

3.1.120 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.

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

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

3.1.123 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 [19].

3.1.124 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.

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

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

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

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

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

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

3.1.131 unstressed receiver sensitivity: the amplitude of optical modulation in the unstressed sensitivity receiver test in. See FC-MSQS (reference [30]).

3.1.132 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 [30]).

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

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

3.2 Editorial conventions

3.2.1 Conventions

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

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

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

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

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

Table 1 – ISO convention

Alternative ISO	ISO as used in this document	American
2 048	2 048	2048
10 000	10 000	10,000
1 323 462,9	1 323 462.9	1,323,462.9

3.2.2 Keywords

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

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

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

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

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

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

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

3.2.2.8 optional: Characteristics that are not required by FC-PI-5. However, if any optional characteristic is implemented, it shall be implemented as defined in FC-PI-5.

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

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

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

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

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

3.2.3 Abbreviations, acronyms, and symbols

Abbreviations, acronyms and symbols applicable to this standard are listed in table 2. Definitions of several of these items are included in sub-clause 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
dB	decibel
dBm	decibel (relative to 1 mW)
DDJ	data dependent jitter
DDPWS	data dependent pulse width shrinkage
DJ	deterministic jitter
DUT	device under test
ECL	Emitter Coupled Logic
EIA	Electronic Industries Association
EMC	electromagnetic compatibility
EMI	electromagnetic interference
FC	Fibre Channel
FEC	Forward error correction
GBd	gigabaud
hex	hexadecimal notation
IEEE	Institute of Electrical and Electronics Engineers
ITU-T	International Telecommunication Union - Telecommunication Standardization (formerly CCITT)
JBOD	Just Bunch of Disks
LOS	loss of signal
LW	long wavelength
MB	megabyte = 10^6 bytes
MBd	megabaud
MM	multimode
NA	not applicable
NC-DDJ	non-compensable data dependent jitter
NEXT	near-end crosstalk
OMA	optical modulation amplitude
PMD	physical medium dependent
ppm	parts per million
RFI	radio frequency interference
RIN	relative intensity noise
RJ	random jitter
RMS	root mean square
RN	relative noise
Rx	receiver
SERDES	Serializer/Deserializer
SM	single-mode
S/N(SNR)	signal-to-noise ratio
SW	short wavelength
TCTF	transmitter compliance transfer function
TDP	transmitter and dispersion penalty
TDR	time domain reflectometry
TIA	Telecommunication Industries Association
TJ	total jitter
TWDP	transmitter waveform and distortion penalty
Tx	transmitter
TxRx	a combination of transmitter and receiver
UI	unit interval = 1 bit period
UJ	uncorrelated jitter
ULP	Upper Level Protocol
VECP	vertical eye closure penalty
WDP	waveform distortion penalty

3.2.3.2 Signaling rate abbreviations

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

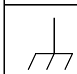
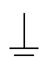
Table 3 – Signaling rate abbreviations

Abbreviation	Signaling rate	Data rate
1GFC	1 062.5 MBd	100 MB/s
2GFC	2 125 MBd	200 MB/s
4GFC	4 250 MBd	400 MB/s
8GFC	8 500 MBd	800 MB/s
16GFC	14 025 MBd	1 600 MB/s
32GFC	28 050 MBd	3 200 MB/s

3.2.3.3 Symbols

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

Table 4 – Symbols

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

4 FC-PI-6 functional characteristics

4.1 General characteristics

FC-PI-6 describes the physical link, the lowest level, in the Fibre Channel system. It is designed for flexibility and allows the use of several physical interconnect technologies to meet a wide variety of system application requirements.

The FC-FS-4 protocol is defined to operate across connections having a bit error ratio (BER) detected at the receiving port of less than or equal to 10^{-6}. It is the combined responsibility of the component suppliers and the system integrator to ensure that this level of service is provided at every port in a given Fibre Channel installation.

FC-PI-6 has the following general characteristics.

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

1) Optical - the state with the higher optical power

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

Serial data streams are supported at signaling rate of 32GFC. 32GFC has transmitter and receiver clock tolerances of ±100 ppm. A TxRx Connection bit error rate (BER) of $\leq 10^{-6}$ as measured at its receiver is supported. The basis for the BER is the encoded serial data stream on the transmission medium during system operation.

FC-PI-6 defines ten different specific physical locations in the FC system. Eight are interoperability points and two are reference points. No interoperability points are required for closed or integrated links and FC-PI-6 is not required for such applications. For closed or integrated links the system designer shall ensure that a BER of better than 10^{-6} as required by FC-FS-4 is delivered.

The requirements specified in FC-PI-6 shall be satisfied at separable connectors where interoperability and component level interchangeability within the link are expected. A compliance point is a physical position where the specification requirements are met. The compliance points are defined at separable connectors, since these are the points where different components can easily be added, changed, or removed. There is no maximum number of interoperability points between the initiating FC device and the addressed FC device as long as (1) the requirements at the interoperability points are satisfied for the respective type of interoperability point and (2) the end to end signal properties are maintained under the most extreme allowed conditions in the system. The description and physical location of the specified interoperability points are detailed in 4.13. All specifications are at the interoperability points in a fully assembled system as if measured with a non-invasive probe except where otherwise described. Figure 1 show the reclocker locations for 32GFC multi-mode and single-mode variants.

It is the combined responsibility of the component (the separable hardware containing the connector portion associated with an interoperability point) supplier and the system integrator to ensure that intended interoperability points are identified to the users of the components and system. This is required because not all connectors in a link are interoperability points and similar connectors and connector positions in different applications may not satisfy the FC-PI-6 requirements.

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

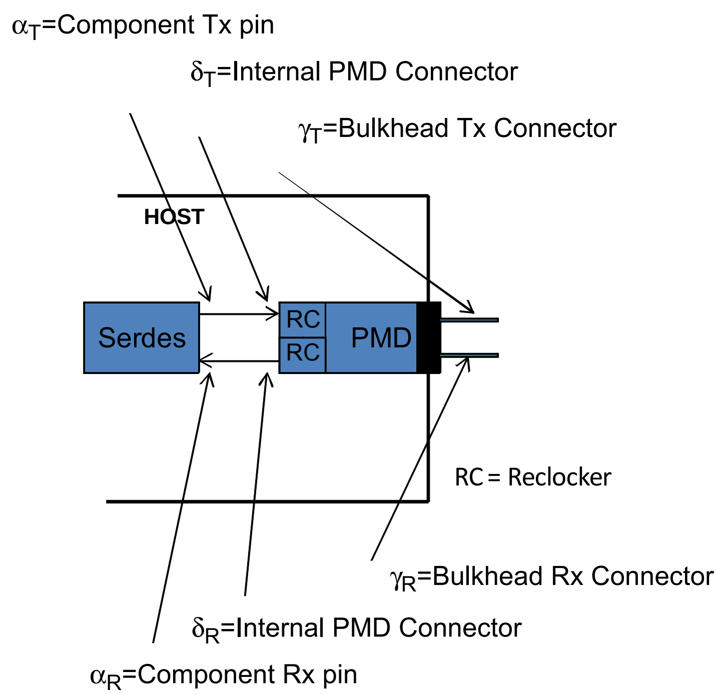


Figure 1 – reclocker location for all 32GFC PMDs

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

The interface to FC-FS-4 occurs at the logical encoded data interfaces. As these are logical data constructs, no physical implementation is implied by FC-FS-4. FC-PI-6 is written assuming that the same single serial data stream exists throughout the link as viewed from the interoperability points. Other possible schemes for transmitting data, for example using parallel paths, are not defined in FC-PI-6 but could occur at intermediate places between interoperability points.

Physical links have the following general requirements:

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

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

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

The interface between FC-PI-6 and FC-FS-4 is intentionally structured to be technology and implementation independent. That is, the same set of commands and services may be used for all signal sources and communication schemes applicable to the technology of a particular implementation. As a result of this, all safety or other operational considerations that may be required for a specific communications technology are to be handled by the FC-PI-6 clauses associated with that technology.

An example of this would be ensuring that optical power levels associated with eye safety are maintained.

4.2 FC-0 states

4.2.1 Transmitter states

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

4.2.2 Receiver states

The function of the receiver device is to convert the incoming data from the form required by the communications media employed, retime the data, and present the data and an associated clock to the FC-1 level.

4.3 Limitations on invalid code

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

4.4 Receiver initialization time

The time interval required by the receiver from the initial receipt of a valid input to the time that the receiver is synchronized to the bit stream and delivering valid retimed data within the BER requirement, shall not exceed 20 ms. Should the retiming function be implemented in a manner that requires direction from a higher level to start the initialization process, the time interval shall start at the receipt of the initialization request.

4.5 Loss of signal (Rx_LOS) function

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

4.6 Speed agile ports that support speed negotiation

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

a) The port transmitter shall be capable of switching from compliant operation at one speed to compliant operation at a new speed within 1 ms from the time the speed negotiation algorithm asks for a speed change for 8GFC. A repeater shall achieve compliant operation within 1 ms following an application of a compliant signal at its input. For 16GFC and 32GFC, the transmitter stabilization time shall be 3 ms or less (allowing up to two repeaters in the path).

b) The port receiver shall attain Transmission_Word synchronization within the receiver stabilization time (sub-clause 4.4) when presented with a valid input stream or from the time the algorithm asks for a receiver speed change if the input stream is at the new receive rate set by the port implementing the algorithm.

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

4.7 Transmission codes

32GFC shall use 64b/66b codes for transmission.

4.8 Frame scrambling and emission lowering protocol

32GFC uses 64b/66b coding and scrambling that is inherent in the code as defined in FC-FS-4 (reference [29]).

4.9 Transmitter training

32GFC EA variants shall transmit the transmitter training signal during the link speed negotiation, but the transmitter training is optional. Transmitter training is defined in FC-FS-4 (reference [29]).

4.10 Forward error correction (FEC)

32GFC variants shall use FEC as defined in FC-FS-4 (reference [29]).

4.11 Test patterns

32GFC shall use the test patterns stated in FC-MSQS-2 (reference [30]).

4.12 Fibre Channel variants nomenclature

The nomenclature for the Fibre Channel variants is illustrated in figure 2. Receiver type and fiber type indicates assumptions used for developing link budgets and does not indicate a requirement on receiver or fiber implementations

100-SM-LC-L

SPEED
3200 -- 3 200 MB/s
1600 -- 1 600 MB/s
1200 -- 1 200 MB/s
800 -- 800 MB/s
400 -- 400 MB/s
200 -- 200 MB/s
100 -- 100 MB/s

TRANSMISSION MEDIA
SM -- single-mode optics connecting to a gamma point (OS1, OS2)
M5 -- multimode 50 µm optics connecting to a gamma point (OM2)
M5E -- multimode 50 µm optics connecting to a gamma point (OM3)
M5F -- multimode 50 µm optics connecting to a gamma point (OM4)
M6 -- multimode 62.5 µm optics connecting to a gamma points (OM1)
SE -- unbalanced copper connecting to any interoperability point
DF -- balanced copper connecting to any interoperability point

INTEROPERABILITY POINT TYPE (formerly transceiver)
SN -- gamma point short wave LASER (850 nm) with limiting optical receiver
SA -- gamma point short wave LASER (850 nm) assuming a linear optical receiver
LL -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a limiting optical receiver
LC -- gamma point for long wave LASER cost reduced (1310 nm) with limiting optical receiver
LZ -- gamma point for long wave LASER (1490 nm) with limiting optical receiver
LA -- gamma point long wave LASER (1310 nm / 1550 nm) assuming a linear optical receiver
EL -- any electrical point (includes SN PMD delta points) that assumes a non-equalizing reference receiver (with or without a compliance interconnect)
EA -- any electrical point that assumes equalizing receivers

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

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

Figure 2 – Fibre Channel variant nomenclature

4.13 Interoperability points (informative)

This sub-clause contains examples of interoperability points in various configurations. The parameter values for 32GFC delta points are measured at the standard test equipment connector interface of standardized test fixtures described in FC-MSQS-2 (reference [30]). These examples are useful to illustrate how the definitions of the interoperability and reference points may appear in practical systems. This subclause also shows an illustration of the two different signal specification environments defined in FC-PI-6, intra-enclosure and inter-enclosure, with all the different configurations of interoperability points that are possible within the same link.

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

Figure 3 shows details of an example involving FC devices contained within an enclosure.

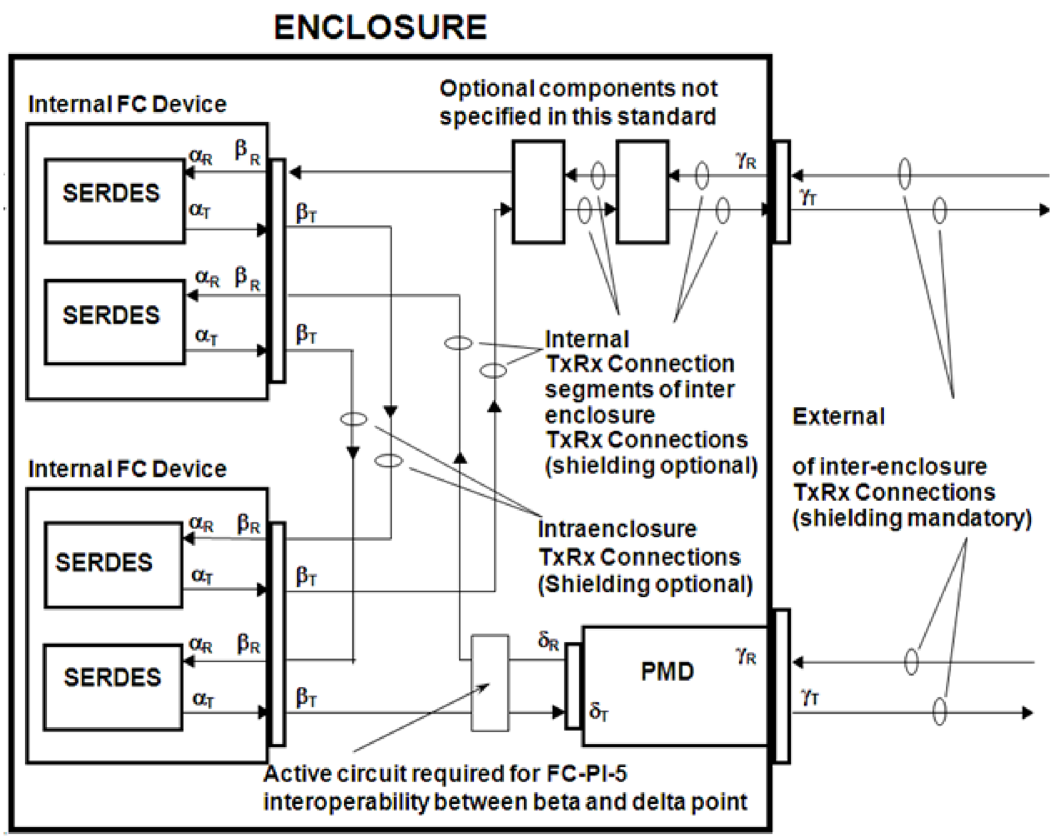


Figure 3 – Example of physical location of reference and interoperability points

Figure 4 shows another example of a complete duplex link between a host system adapter and a disk drive both with and without delta points.

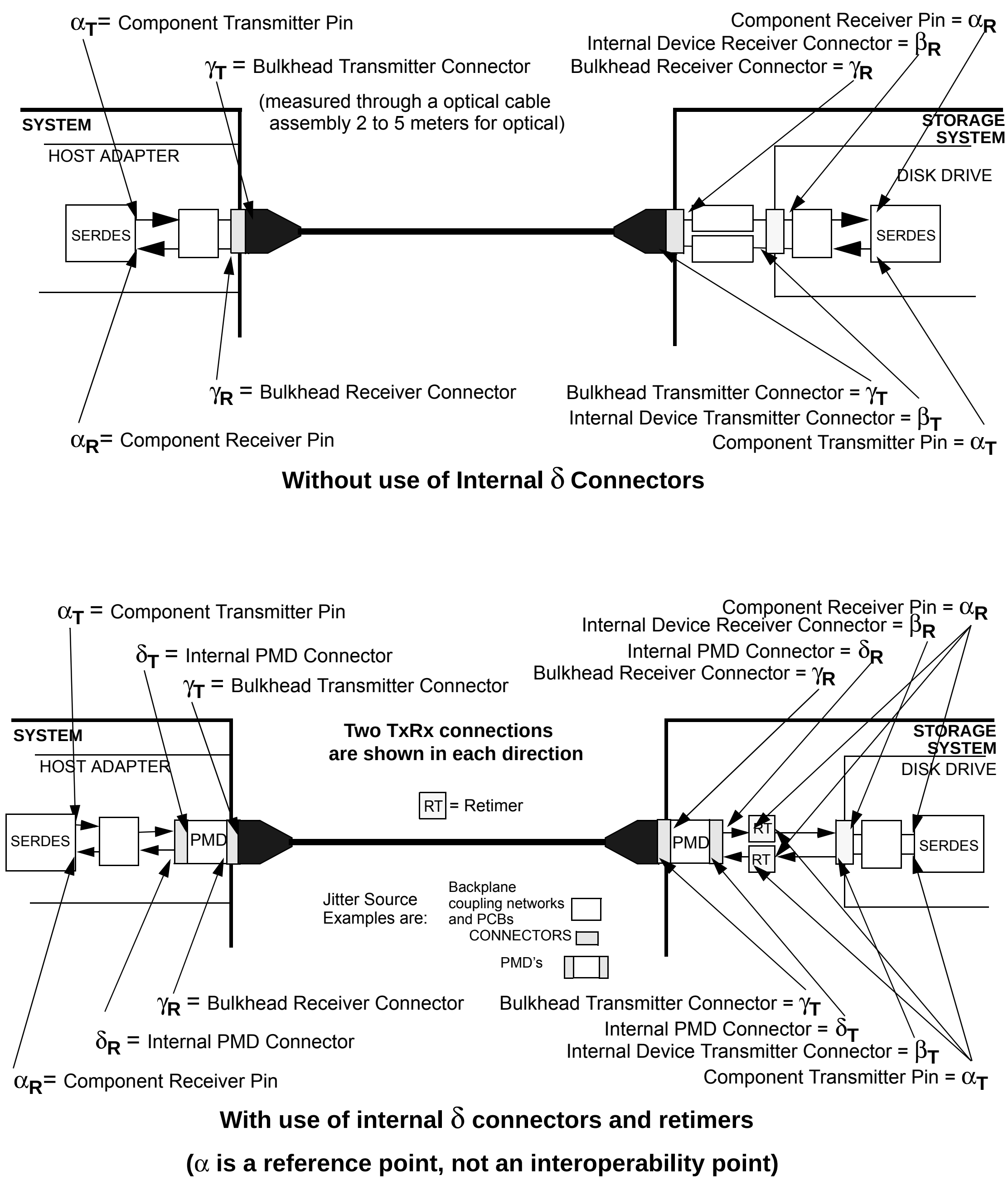


Figure 4 – Interoperability points examples at connectors

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

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

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

4.14 FC-PI-6 variants

Table 5 and Table 6 list variants by FC-PI-6 nomenclature, a reference to the clause containing the detailed requirements, and some key parameters that characterize the variant. The nomenclature is illustrated in figure 2.

The lengths specified in table 5 and table 6 are the minimum lengths supported with transmitters, media, and receivers all simultaneously operating under the most degraded conditions allowed. Longer lengths may be achieved by restricting parameters in the transmitter, media, or receiver. If such restrictions are used on the link components then interoperability at interoperability points within the link and component level interchangeability within the link is no longer supported by this standard.

Table 5 – Fibre Channel variants not in this document

note 1	**100** (note 2)	**200** (note 2)	**400** (note 3)	**800** (note 3)	**1600** (note 3)
SM OS1, OS2	**100-SM-LC-L** 1 300 nm 0.5 m - 10 km	**200-SM-LC-L** 1 300 nm 0.5 m - 10 km	**400-SM-LC-L** 1 300 nm 0.5 m-10 km	**800-SM-LC-L** 1 300 nm 0.5 m-10 km	**1600-SM-LC-L** 1 300 nm 0.5 m-10 km
	100-SM-LL-V 1 550 nm 0.5 m - 50 km	**200-SM-LL-V** 1 550 nm 0.5 m - 50 km	**400-SM-LC-M** 1 300 nm 0.5 m-4 km	**800-SM-LC-I** 1 300 nm 0.5 m-1.4 km	**1600-SM-LZ-I** 1 490 nm 0.5 m-2 km
MM 62.5 µm OM1	**100-M6-SN-I** 780/850 nm 0.5 m - 300 m	**200-M6-SN-I** 850 nm 0.5 m - 150 m	**400-M6-SN-I** 4850 nm 0.5 m-70 m	**800-M6-SN-S** 4850 nm 0.5 m-21 m	**1600-M6-SN-S** 850 nm 0.5 m-15 m
				800-M6-SA-S 4850 nm 0.5 m-40 m	
MM 50 µm OM2	**100-M5-SN-I** 780/850 nm 0.5 m - 500 m	**200-M5-SN-I** 850 nm 0.5 m - 300 m	**400-M5-SN-I** 850 nm 0.5 m-150 m	**800-M5-SN-S** **850 nm** **0.5 m-50 m**	**1600-M5-SN-S** **850 nm** **0.5 m-35 m**
				800-M5-SA-I 850 nm 0.5 m-100 m	
MM 50 µm OM3	**100-M5E-SN-I** 780/850 nm 0.5 m - 860 m	**200-M5E-SN-I** 850 nm 0.5 m - 500 m	**400-M5E-SN-I** 850 nm 0.5 m-380 m	**800-M5E-SN-I** **850 nm** **0.5 m-150 m**	**1600-M5E-SN-I** **850 nm** **0.5 m-100 m**
				800-M5E-SA-I 850 nm 0.5 m-300 m	
MM 50 µm OM4			**400-M5F-SN-I** 850 nm 0.5 m-400 m	**800-M5F-SN-I** 850 nm **0.5 m-190 m**	**1600-M5F-SN-I** **850 nm** **0.5 m-125 m**
				800-M5F-SA-I 850 nm 0.5 m-300 m	**1600-SM-LC-L** 1 300 nm 0.5 m-10 km
EL Balanced	**100-DF-EL-S**	**200-DF-EL-S**	**400-DF-EL-S**	**800-DF-EL-S**	**1600-DF-EL-S**
EA Balanced				**800-DF-EA-S**	**1600-DF-EA-S**
EL Unbalanced	**100-SE-EL-S**	**200-SE-EL-S**			

Notes:

1 For 10GFC variant refer to 10GFC (reference [1]) and FC-PI-3 (reference [2]).

2 This is obsoleted technology. For information refer to FC-PI-2 (reference [3]).

3 Information about these variants can be found in FC-PI-5 (reference [1])

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

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

5 Optical interface specification

5.1 TxRx connections

Clause 5 defines the optical signal characteristics at the interface connector. Each conforming optical FC port shall comply with the requirements specified in clause 5 and other applicable clauses. Fibre Channel 32GFC optical links require forward error correction to achieve link BER objectives; see FC-FS-4 (reference [29]). In the presence of forward error correction, the bit error ratio at the receiving port shall be undetectable low. In the absence of forward error correction, Fibre Channel optical links shall not exceed a BER of $1x10^{-6}$ under any compliant conditions; see FC-MSQS-2 (reference [30]). The parameters specified in this clause support meeting that requirement.

A link, or TxRx connection, may be divided into TxRx connection segments (see figure 3). In a single TxRx connection individual TxRx connection segments may be formed from differing media and materials, including traces on printed wiring boards and optical fibers. This clause applies only to TxRx connection segments that are formed from optical fiber.

If electrically conducting TxRx connection segments are required to implement these optical variants, they shall meet the specifications of the appropriate electrical variants defined in clause 6.

5.2 Laser safety issues

The optical output shall not exceed Class 1 maximum permissible exposure limits under any condition of operation, per IEC 60825-1 (reference [10]) and IEC 60825-2 (reference [11]).

5.3 SM data links

5.3.1 SM general information

Table 7 gives the variant names, a general link description, and the gamma compliance point specifications for 10-km single-mode optical fiber links running at 32GFC.

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

Single mode link parameters (note 1)	**Unit**	**3200-SM-LC-L**	**Note**
Nominal signaling rate	MBd	28 050	2
Operating distance	m	0.5 -10 000	
Transmitter (gamma-T)			
Type		Laser	
Center wavelength, max.	nm	1325	
Center wavelength, min.	nm	1295	
Optical modulation amplitude, min.	mW(dBm)	0.631(-2.0)	3,4,5
Side-mode suppression	dB	30	
-20 dB spectral width	nm	1	
Average launched power, max.	dBm	+2.0	
Average launched power, min.	dBm	-5.0	4
$RIN_{20}OMA$, max.	dB/Hz	-130	6
Extinction Ratio, min	dB	4.0	
Transmitter and dispersion penalty (TDP), max	dB	2.7	7
Receiver (gamma- R)			
Average received power, max.	dBm	+2.0	
Rx jitter tracking test, OMA	mW(dBm)	0.120(-9.2)	8
Rx jitter tracking test, frequency and pk-pk amplitude	(kHz,UI)	(10000,0.05) (100,5)	8
Unstressed receiver sensitivity, OMA	mW(dBm)	0.072(-11.4)	6,9
Return loss of receiver, min.	dB	26	

Notes:

1 See: IEC 607932-2-50 (reference [9]), Type B1.1 and IEC 607932-2-50 (reference [9]), Type B1.3, and IEC 60793-2-50 (reference [9]), Type B6 Optical fibers - Part 2: Product Specifications.

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

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

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

5 3200-SM-LC-L optical modulation amplitude in dBm shall also exceed -5.0+TDP.

6 See FC-MSQS-2 (reference [30]).

7 Transmitter and dispersion penalty (TDP) determines the contribution of RIN, the rise/fall times, and chromatic dispersion. See FC-MSQS-2 (reference [30])

8 Receiver jitter tracking is defined in FC-MSQS-2 (reference [30]).

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

5.3.2 SM optical output interface

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

Optical modulation amplitude (OMA) is defined as the difference in optical power between a logic-1 and a logic-0, as defined in FC-MSQS-2 (reference [30]).

The optical power is defined by the methods of IEC 61280-1-1 (reference [13]), with the port transmitting an idle sequence or other valid Fibre Channel traffic.

The general laser transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see sub-clause 4.13). Conformance with the mask diagram is not to be used for determining compliance with the specifications for rise / fall time and jitter. The parameters specifying the mask of the transmitter eye diagram are shown in figure 5. See FC-MSQS (reference [5]).

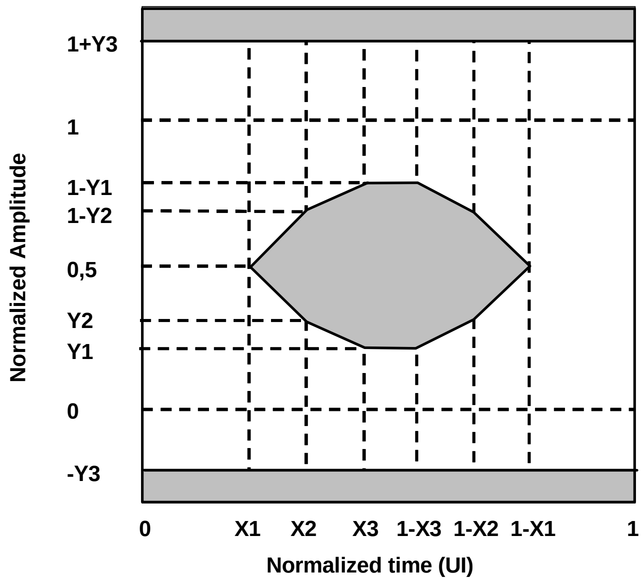


Figure 5 – SM transmitter eye mask for 32GFC

Table 8 shows the mask parameters of figure 5. The test or analysis shall include the effects of a single pole high-pass frequency-weighting function, that progressively attenuates jitter at 20 dB/decade below a frequency of signaling rate/2578. The mask applies at a probability of 10^{-3}.

Table 8 – SM transmitter eye mask parameters for 32GFC

	16GFC	
	Value	**Unit**
X1	0.22	UI
X2	0.40	UI
X3	0.45	UI
Y1	0.31	
Y2	0.33	
Y3	0.50	

5.3.3 SM optical input interface

The receiver shall operate within the BER requirement (10^{-6}) when the input power falls in the range given in table 7 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 5.

5.4 MM data links

5.4.1 MM general information

Table 9 gives the variant names, a general link description, and the gamma compliance point specifications for multi-mode optical fiber links running at 32GFC.

Table 9 – Multimode link classes

FC-0	Unit	3200-SN	Note
Nominal signaling rate	MBd	28 050	1
Operating distance (M5)	m	0.5 - 20	2
Operating distance (M5E)	m	0.5 - 70	
Operating distance (M5F)	m	0.5 - 100	
Fiber core diameter	µm	50	3
Transmitter (gamma-T)			
Source type		Laser	
Center wavelength, min.	nm	840	
Center wavelength, max.	nm	860	
RMS spectral width, max.	nm	0.570	
Average launched power, max.	dBm		5
Average launched power, min.	dBm	0.240(-6.2)	4
Optical modulation amplitude, min.	mW(dBm)	0.479(-3.2)	6,7
Vertical Eye Closure Penalty ($VECP_q$), max	dB	3.13	6,7,8
RIN_{20}OMA, max.	dB/Hz	-129	6
Encircled flux			9
Receiver (gamma- R)			
Average received power, max.	dBm	2	
Unstressed receiver sensitivity, OMA	mW(dBm)	0.095(-10.2)	6,10,11
Return loss of receiver, min.	dB	12	
Rx jitter tracking test, OMA	mW(dBm)	0.295(-5.3)	7,12,13
Rx jitter tracking test, jitter frequency and pk-pk amplitude	(kHz,UI)	(10000,0.05) (100,5)	13
Stressed test source			
Stressed receiver sensitivity, OMA	mW(dBm)	0.263(-5.8)	6,14
Receiver vertical eye closure penalty	dB	3.10	6,7,15
Receiver component of DJ	UI	0.03	6,7,16
Receiver DJ	UI	0.10	

Notes:

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

2 The operating ranges shown here are based on MM fiber bandwidths given in table 20 of FC-PI-5 (reference [1])and a 1.5 dB total connector loss. For link budget calculations methodology see FC-MSQS (reference [5]) and FC-MSQS-2 (reference [30]).

3 For details see sub-clause 8.2 in FC-PI-5 (reference [1])

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

5 Defined by average received power, max.

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

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

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

9 Encircled flux specifications in accordance with TIA-492AAAC-A (reference [27]) and IEC 60793-2-10 (reference [8]) or IEEE 802.3 clause 52 (reference [19]).

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

11 The unstressed receiver sensitivity is informative only

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

13 See FC-MSQS-2 (reference [30]).

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

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

16 Receiver DDPWS and Receiver DJ are test conditions for measuring stressed receiver sensitivity and are not required conditions of the receiver. The effect of DDPWS is included in the required DJ.

5.4.2 MM optical output interface

The optical transmit signal shall comply with all requirements at the output end of any patch cord between one-half and five meters in length.

The general laser pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at point γ_T (see sub-clause 4.13). These characteristics include rise time, fall time, pulse overshoot, pulse undershoot, and ringing. The parameters specifying the mask of the transmitter eye diagram are shown in figure 6.

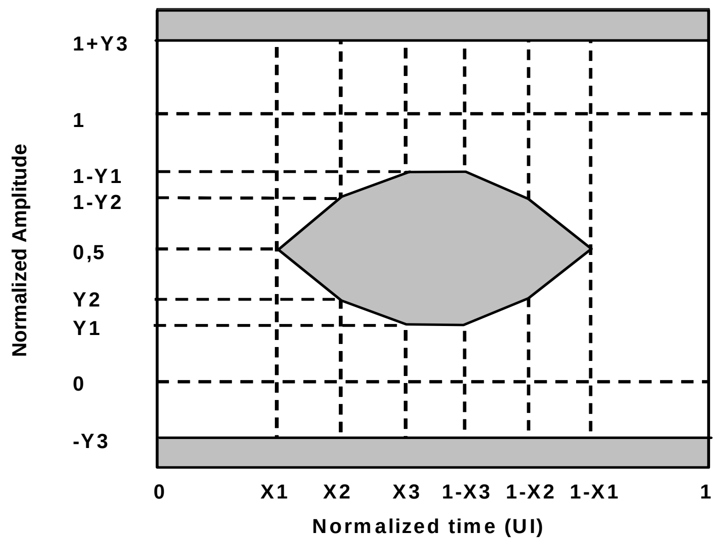


Figure 6 – MM transmitter eye mask for 32GFC

Table 10 – MM transmitter eye mask values for 32GFC

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

The signal in figure 6 shall be measured using a jitter timing reference, e.g., Golden PLL. The mask applies at a probability of $1x10^{-3}$.

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

5.4.3 MM optical input interface

The receiver shall operate with a maximum BER of $1x10^{-6}$ when the input power falls within the range given in table 9 and when driven through a cable plant with a data stream that fits the eye diagram mask specified in figure 6.

6 Electrical interface specification - Compliance points

This clause defines the electrical requirements at the compliance points in a TxRx connection. The existence of these point is determined by the existence of a connector at that point in a TxRx connection.

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. All Fibre Channel TxRx connections described in this clause shall operate within the BER objective (10^{-6}). The parameters specified in this clause support meeting that requirement under all conditions.

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 11.

Table 11 – General electrical characteristic

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

6.2 Electrical characteristics

This sub-clause defines the interoperability requirements of the transmitted signal at the driver end of a TxRx connection. Test loads for interoperability points are defined in sub-clause 6.2.1. Details for the measurement process are specified in FC-MSQS-2 (reference [30]).

Hosts and modules shall meet the appropriate specifications defined in table 12, table 13, table 15, and table 16. Note that the direction of a given lane (host-to-module or module-to-host) will determine which of the listed tables give applicable specifications.

6.2.1 Compliance Point Specifications

Figure 7 below gives the reference model and test points associated with host-to-module and module-to-host test points.

Reference test fixtures, called compliance boards, are used to access the electrical specification parameters. The output of the Host Compliance Board (HCB) provides access to the host-to-module electrical signal (host electrical output) defined at point B. Additional module electrical input specifications, for host-to-module communication, are defined at point B’, the input of the Module Compliance Board (MCB). The output of the Module Compliance Board (MCB) provides access to the module to host electrical signal (module electrical output) defined at point C’. Additional host electrical input specifications, for module-to-host communication, are defined at point C, the input of the Host Compliance Board (HCB).

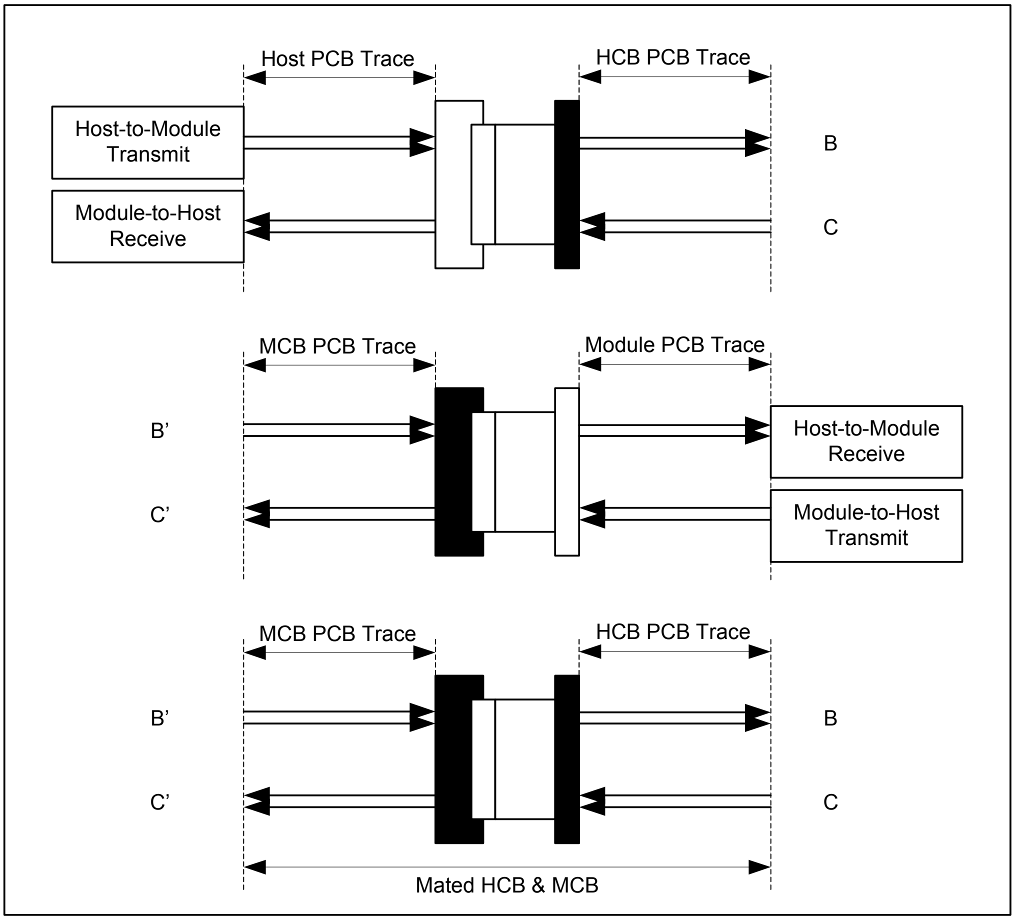


Figure 7 – Measurement points using compliance boards

6.2.2 Host-to-Module Electrical Specifications

Each host-to-module lane shall meet the specifications of table 12 and table 13. Definitions and methodologies can be found in FC-MSQS-2 (reference [30]).1

Table 12 – Host-to-Module Electrical Specifications at point B

Parameter	Units	Direction	Min.	Max.	Notes
Differential Voltage pk-pk	mV	Host Output		900	
Common Mode Noise rms	mV	Host Output		17.5	
Differential Termination Mismatch	%	Host Output		10	note 1
Differential Return Loss	dB	Host Output			note 2
Common to Differential Mode Conversion (SDC22)	dB	Host Output			note 3
Transition Time: 20/80%	ps	Host Output	10		note 4
Common Mode Voltage	V	Host Output	-0.3	2.8	note 5
Eye width at 10^{-6} probability	UI	Host Output	0.46		note 4,6
Eye height at 10^{-6} probability	mV	Host Output	100		note 4,6

Notes:

1. At 1 MHz. See FC-MSQS-2 (reference [30]).
2. See equation 6-1.
3. See equation 6-2.
4. See FC-MSQS-2 (reference [30]).
5. Referred to ground.
6. Open eye is generated through the use of a reference Continuous Time Linear Equalizer (CTLE)

Table 13 – Host-to-Module Electrical Specifications at point B’

Parameter	Units	Direction	Min.	Max.	Notes
Overload Differential Voltage pk-pk	mV	Module Input	900		note 1
Differential Termination Mismatch	%	Module Input		10	note 2
Differential Return Loss	dB	Module Input			note 3
Common to Differential Mode Conversion (SDC11)	dB	Module Input			note 4
Stressed Receiver Test		Module Input			note 1

Notes:

1. See FC-MSQS-2 (reference [30]).
2. At 1 MHz. See FC-MSQS-2 (reference [30]).
3. See equation 6-1.
4. See equation 6-2.

Table 14 – Crosstalk parameters for Host Output test and Module input test calibration

Parameter	units	Used in test	Target value
Crosstalk Amplitude differential voltage pk-pk	mV	Host Output test and module stressed receiver test calibration	900
Crosstalk transition time 20-80%	ps	Host Output test and module stressed receiver test calibration	9.5

6.2.3 Module-to-Host Electrical Specifications

Each module-to-host lane shall meet the specifications of table 15 and table 16. Definitions and methodologies can be found in FC-MSQS-2 (reference [30]).

Table 15 – Module-to-Host Electrical Specifications at point C'

<table>
<tr><th>Parameter</th><th>Units</th><th>Direction</th><th>Min.</th><th>Max.</th><th>Notes</th></tr>
<tr><td>Differential Voltage, pk-pk</td><td>mV</td><td>Module Output</td><td></td><td>900</td><td></td></tr>
<tr><td>Common Mode Noise, rms</td><td>mV</td><td>Module Output</td><td></td><td>17.5</td><td></td></tr>
<tr><td>Differential Termination Mismatch</td><td>%</td><td>Module Output</td><td></td><td>10</td><td>note 1</td></tr>
<tr><td>Differential Return Loss</td><td>dB</td><td>Module Output</td><td></td><td></td><td>note 2</td></tr>
<tr><td>Common Mode to Differential Conversion Return Loss</td><td>dB</td><td>Module Output</td><td></td><td></td><td>note 3</td></tr>
<tr><td>Transition Time: 20/80%</td><td>ps</td><td>Module Output</td><td>9.5</td><td></td><td rowspan="4">note 4</td></tr>
<tr><td>Vertical Eye Closure (VEC)</td><td>dB</td><td></td><td></td><td>6.5</td></tr>
<tr><td>Eye width at 10^{-6} probability</td><td>UI</td><td>Module Output</td><td>0.57</td><td></td></tr>
<tr><td>Eye height at 10^{-6} probability</td><td>mV</td><td>Module Output</td><td>240</td><td></td></tr>
<tr><td colspan="6">Notes:
1 At 1 MHz.
2 See equation 6-1.
3 See equation 6-2.
4 See FC-MSQS-2 (reference [30]).</td></tr>
</table>

Table 16 – Module-to-Host Electrical Specifications at point C

<table>
<tr><th>Parameter</th><th>Units</th><th>Direction</th><th>Min.</th><th>Max.</th><th>Notes</th></tr>
<tr><td>Overload Differential Voltage pk-pk</td><td>mV</td><td>Host Input</td><td>900</td><td></td><td>note 1</td></tr>
<tr><td>Differential Termination Mismatch</td><td>%</td><td>Host Input</td><td></td><td>10</td><td></td></tr>
<tr><td>Differential Return Loss</td><td>dB</td><td>Host Input</td><td></td><td></td><td>note 2</td></tr>
<tr><td>Common Mode to differential conversion Loss</td><td>dB</td><td>Host Input</td><td></td><td></td><td>note 3</td></tr>
<tr><td>Stressed Receiver Test</td><td></td><td>Host Input</td><td></td><td></td><td>note 1</td></tr>
<tr><td>Common Mode Voltage</td><td>V</td><td>Host Input</td><td>-0.3</td><td>2.8</td><td>note 4</td></tr>
<tr><td colspan="6">Notes:
1 See FC-MSQS-2 (reference [30]).
2 See equation 6-1.
3 See equation 6-2.
4 Common mode is generated by host.</td></tr>
</table>

Table 17 – Crosstalk for Module Output and Host stressed receiver test calibration

Parameter	units	Used in test	Target value
Crosstalk Amplitude differential voltage pk-pk	mV	Module Output test and host stressed receiver test calibration	900
Crosstalk transition time 20%-80%	ps	Module Output test and host stressed receiver test calibration	10

6.2.4 Return Loss

When measured at the respective test point, return loss shall not exceed the limits given in equation 6-1 as illustrated in figure 8 for f_b=28 GHz.

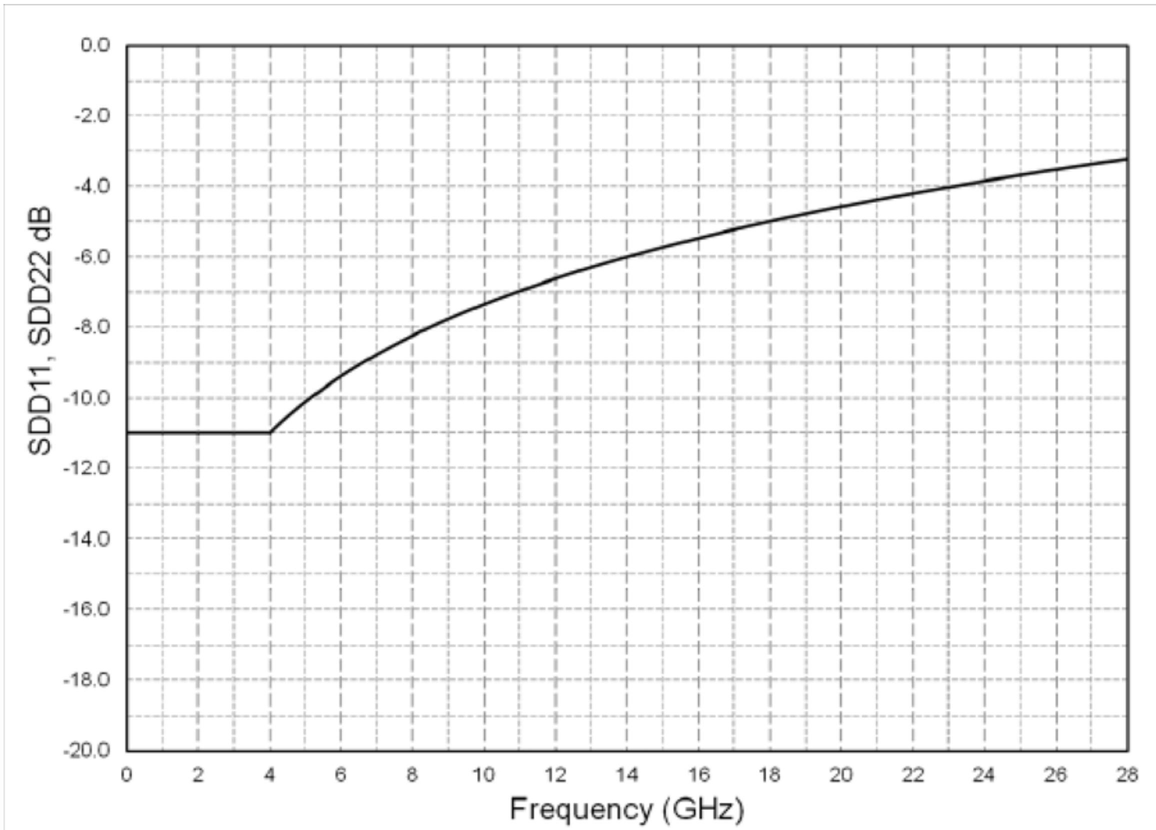


Figure 8 – SDD11, SDD22 for all compliance points (For f_b = 28 GHz)

Return loss equation for all delta points

$$(SDD11,SDD22) < \begin{cases} -11 & 0.05 < f < f_b/7 \\ -6.0 + 9.2 \times \log 2(f/f_b) & f_b/7 < f < f_b \end{cases} \qquad (6\text{-}1)$$

6.2.5 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 shall not exceed the limits given in equation 6-2 as shown in figure 9 for f_b=28 GHz.

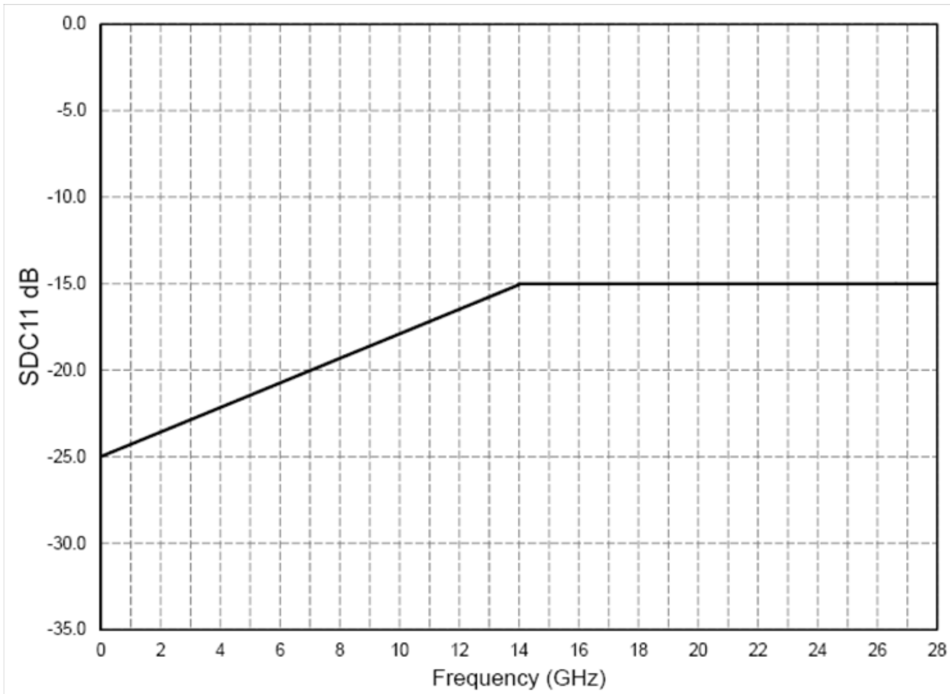


Figure 9 – SDC11 and SCD11 for all compliance points

$$SCD11, SDC11 < \begin{cases} -25 + 20 \times (f/f_b) & 0.05 < f < f_b/2 \\ -15 & f_b/2 < f < f_b \end{cases} \quad (6\text{-}2)$$

6.3 SFP+ form factor implementation (informative)

For SFP+ implementation of FC-PI-6 variants, the following references is provided.

1) SFF-8431 (reference [20]) shall be used for definition of signals and pin configuration.
2) SFF-8432 (reference [21]), SFF-8433 (reference [22]), and SFF-8443 (reference [23]) shall be used for definition of cage and module.
3) SFF-8402 (reference [31]), for the card edge connector for 32GFC.
4) SFF-8083 (reference [24]) and SFF-8435 (reference [25]) shall be used for connector properties.

7 Backplane specification

7.1 Test fixtures

Unless noted otherwise, measurements of the transmitter are made at test point A as shown in figure 10. Unless noted otherwise, measurements of the receiver are made at test D as shown in figure 10.

The test fixture insertion loss shall meet equation 7-1.

$$1.3 \le IL(f) \le 1.7 \ dB \qquad f = 14GHz \tag{7-1}$$

The test fixture insertion loss deviation (see IEEE P802.3bj/D1.4, 93A.3) shall meet equation 7-2.

$$|ILD(f)| \le 0.1dB \qquad 0.05 \le f \le 28 \tag{7-2}$$

The test fixture differential return loss shall meet equation 7-3.

$$RL_d(f) \ge \begin{cases} 20 - f & 0.05 \le f \le 5 \\ 15 & 5 < f \le 13 \\ 20.57 - 0.4286f & 13 < f \le 28 \end{cases} \tag{7-3}$$

The test fixture common-mode return loss shall meet equation 7-4.

$$RL_{cm}(f) \ge 10dB \qquad 0.05 \le f \le 28 \tag{7-4}$$

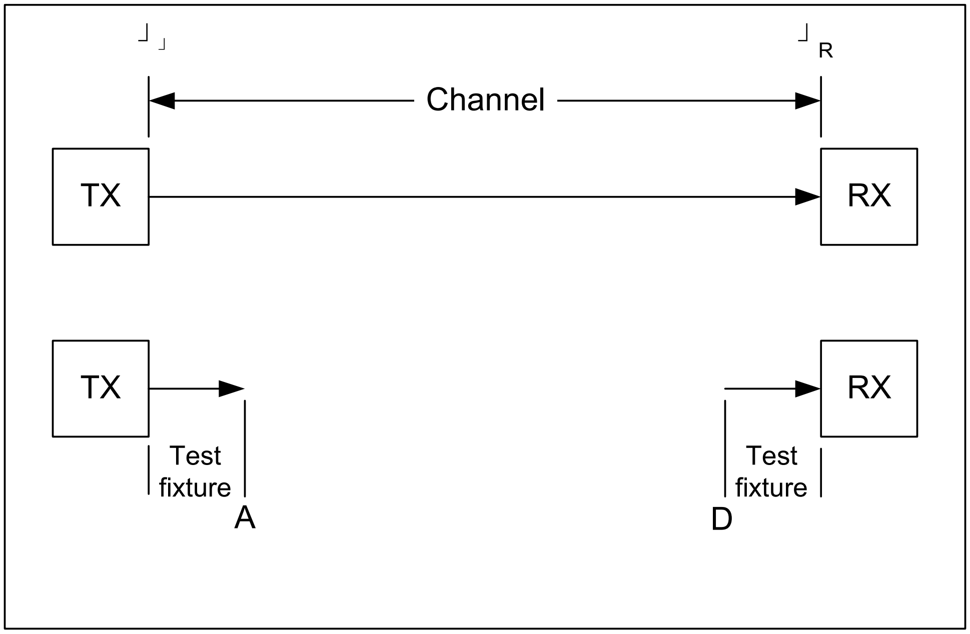


Figure 10 – Test fixtures

7.2 Transmitter specification

The transmitter shall meet the specification in table 18 as measured at test point A.

Table 18 – Transmitter electrical specifications at A

Parameter		Unit	Value	Note
Nominal signaling rate		MBd	28 050	1
Differential peak output voltage, max				2
	Transmitter enabled	mV	1200	
	Transmitter disabled	mV	30	
DC common-mode output voltage, max		V	1.9	
DC common-mode output voltage, min		V	0	
AC common-mode output voltage, RMS max.		mV	12	
Transition time, 20-80%, min		ps	8	
Output waveform		nm	0.57	4
	Steady state voltage v_f, max	V	0.6	
	Steady state voltage v_f, min	V	0.4	
	Linear fit pulse peak, min	V	0.8 v_f	
	Normalized RMS linear fit error, max		0.037	
	Normalized coefficient step size, min		0.0083	
	Normalized coefficient step size, max		0.05	
	Pre-cursor full-scale range, min		1.54	
	Post-cursor full-scale range, min		4	
Output jitter				5
	Even-odd jitter, max	UI	0.035	
	Effective deterministic, excluding DDJ, max	UI	0.15	
	Effective random jitter, max	UI	0.15	
	Total jitter, excluding DDJ, max	UI	0.28	

Notes:
1 The signaling rate shall not deviate by more than ±100 ppm from the nominal signaling rate over all periods equal to 200 000 transmitted bits (~10 max length frames).
2 Definition required to support FC-EE.
3 Output waveform parameters defined by FC-MSQS Clause 5 (reference [5]) using parameters of table 19.
4 Transition time is defined by IEEE Std 802.3 - 2012 86A 5.3.3 (reference [19]).
5 Jitter parameters are defined by IEEE P802.3bj/D1.4, 92.8.3.6.

Table 19 – Linear fit pulse and equalizer parameters

Parameter	Symbol	Value	Units
Linear fit pulse length	N_P	8	UI
Linear fit pulse delay	D_P	2	UI
Equalizer length	N_W	8	UI
Equalizer delay	D_W	2	UI

Transmitter differential return loss at A and receiver differential return loss at D shall both meet equation 7-5.

$$RL_d(f) \geq \left\{ \begin{array}{cc} 12.05 - f & 0.05 \leq f \leq 6 \\ 6.45 - 0.075f & 6 < f \leq 21 \end{array} \right\} \quad (7\text{-}5)$$

Transmitter common-mode return loss at A shall meet equation 7-6.

$$RL_{cm}(f) \geq 6dB \qquad 0.05 \leq f \leq 21 \tag{7-6}$$

Receiver differential to common-mode return loss at D shall meet equation 7-7.

$$RL_{cd}(f) \geq \begin{cases} 25 - 1.44f & 0.05 \leq f \leq 6.95 \\ 5 & 6 < f \leq 21 \end{cases} \tag{7-7}$$

7.3 Channel specification

The channel operating margin (COM) is computed using the procedure defined in IEEE P802.3bj/D1.4 Annex 93A and the parameters defined in table 20. References to test point TP0 correspond to alpha-T and references to TP5 correspond to alpha-R. Channel operating margin (COM) shall be greater than or equal to 3 dB. This minimum value allocates margin for the practical limitations of the receiver implementing as well as the largest step size allowed for the transmitter equalizer coefficients.

Table 20 – Channel operating margin parameters

Parameter	Symbol	Value	Unit
Nominal signaling rate	f_b	28 050	MBd
Maximum start frequency	f_{min}	50	MHz
Maximum step frequency	Δf	12	MHz
Package transmission line length	z_{tl}	30	mm
Single-ended device capacitance	C_d	0.25	pF
Single-ended package capacitance	C_b	0.18	pF
Single-ended reference resistance	R_0	50	Ohms
Single-ended termination resistance	R_d	55	Ohms
Transmitter differential peak output voltage			
Victim	A_v	0.4	V
Far-end aggressor	A_f	0.4	V
Near-end aggressor	A_n	0.6	V
Receiver -3dB bandwidth	f_r	$0.75 \times f_b$	MHz
Transmitter equalizer, pre-cursor coefficient	c(-1)		
Minimum value		-0.18	
Maximum value		0	
Step size		0.02	
Transmitter equalizer, post-cursor coefficient	c(1)		
Minimum value		-0.38	
Maximum value		0	
Step size		0.02	
Continuous time filter, DC gain	g_{DC}		
Minimum value		-12	dB
Maximum value		0	dB
Step size		1	dB
Number of signal levels	L	2	
Number of samples per unit interval	M	32	
Decision feedback equalizer (DFE) length	N_b	16	UI
Normalized DFE coefficient magnitude limit	b_{max}	1	
Random jitter, RMS	σ_{RJ}	0.01	UI
Dual-Dirac jitter, peak	A_{DD}	0.07	UI
Receiver additive Gaussian noise, RMS	σ_r	1	mV
Target detector error ratio	DER_0	10^{-6}	

7.4 Receiver interface tolerance

Receiver interference tolerance is measured using the test setup define in IEEE 802.3-2012 Annex 69A or its equivalent. The receiver shall satisfy the requirements for interference tolerance summarized in table 21.

Table 21 – Receiver signal tolerance parameters

Parameter		Test1	Test2	Units	Notes
Max. BER at receiver output		10^{-6}	10^{-6}		1
Channel insertion loss at 14.05 GHz		16	30	dB	2
	a_0, max	1	1	dB	
	a_1, max	3.3	3.3	dB/$Hz^{1/2}$	
	a_2, max			dB/Hz	
	a_4, max	0.022	0.031	dB/Hz^2	
Applied sinusoidal jitter, peak-to-peak		0.115	0.115	UI	3
Applied random jitter, peak-to-peak		0.15	0.15	UI	4
Applied even-odd jitter		0.035	0.035	UI	
Applied broadband noise, RMS		TBD	TBD	mV	

Notes:
1) BER is measured prior to error correction by Reed-Solomon decoder.
2) See IEEE P802.3bj/D1.4 93A.3. For each test channel, a_0 is limited to a minimum value of -1 and a_1, a_2, and a_4 are limited to a minimum value of 0. There is no maximum value specified for a_2.
3) The frequency of the sinusoid must be greater than 100 MHz.
4) Random jitter is specified at a BER of 10^{-12}.

Annex A (informative)
Optical cable plant usage

The worst-case power budget and link penalties for the multimode cables specified in sub-clause 5.4 are shown in table A.1. In some cases, it may be desirable to use an alternative multimode cable plant to those described in sub-clause 5.4. This may be due to the need for operation in locations where alternative lower bandwidth cables are presently installed.

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

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

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

Parameter	Unit	SN	Note

Notes:

1 Modal bandwidth at 850 nm.

2 Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested. The link penalties were calculated using the methodologies in reference [30].

3 The allocation for additional loss may be combined with the channel insertion loss to meet the measured channel insertion loss but not to increase the operating distance. However, the total connection and splice loss shall not exceed 3.0 dB.

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

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

Annex B (informative)
Structured cabling environment

B.1 Specification of operating distances

Operating distances of Fibre Channel links described in clause 5 are based on a variety of specifications including:

- Fiber properties regarding attenuation, core diameter, bandwidth length product and chromatic dispersion.
- Laser properties regarding launch power, spectral characteristics, jitter and rise/fall times.
- Receiver properties regarding sensitivity, cutoff frequency and jitter tolerance.
- Link properties regarding connection loss and unallocated link margin.

B.2 Alternate connection loss operating distances

In structured cabling environments, the connection loss may be different than the 1.5 dB of connection loss used to calculate link distance in clause 5. Different allocations for connection loss result in changes to the maximum operating range. Table B.1 provide the maximum operating range and loss budget requirements for a range of connection loss values. These loss values may be used provided the total channel loss budget requirements are met as appropriate for the fiber type, and the loss of any single connection does not exceed 0.75 dB. The minimum operating range for the tables is 0.5 meters.

Table B.1 – 3200-SN max operating distance & loss budget for different connection losses

Distance (m) / Loss Budget (dB)					
Fiber Type	**Connection Loss**				
	3.0 dB	**2.4 dB**	**2.0 dB**	**1.5 dB**	**1.0 dB**
M5F (OM4)	20 / 3.04	65 / 2.64	80 / 2.36	100 / 1.86	110 /1.48
M5E (OM3)	15 / 3.03	45 / 2.64	60 /2.24	70 / 1.87	80 / 1.41
M5 (OM2)	NA	15 / 2.52	15 / 2.52	20 / 2.02	25 / 1.29
OS1 / OS2	8250 / 6.52	9250 / 6.42	10000 / 6.34	11000 / 6.21	11750 / 6.11