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## Information Technology -

## Fibre Channel - Methodologies for Signal Quality Specification - MSQS

Draft Technical Report

Secretariat International Committee for Information Technology Standardization (INCITS)

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### ABSTRACT

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**Introduction (This introduction is not part of this technical report)**

This document is an INCITS technical report on the definitions, measurement requirements, and allowed values of jitter on FC links. MJSQ supersedes the previously published MJS technical report (NCITS TR-25-1999). MJSQ represents a significant advance over MJS and obsoletes some concepts documented in MJS.

This technical report compiles and provides additional information beyond that supplied in MJS to clarify the jitter and signal quality specification clauses of the FC-PH-n and FC-PI-n standard set. The existing jitter specifications are incomplete as a result of changes in how the electronics industry is implementing Fibre Channel systems today compared to how systems were expected to be implemented in the past. Examples of such changes are the requirements for practically effective interoperability and signal margin specifications for SAN applications, use of adaptive or predictive compensation schemes implemented in active elements or ports, and higher speed at longer distance.

The goals of this technical report are:

- To define and describe the relationships between different kinds of jitter
- To document the jitter and signal quality measurement requirements that allow Fibre Channel developers to design low-cost, multi-GBaud links having bit error ratios below  $10^{-12}$  using interoperable and interchangeable components between the interoperability points
- To specify measurement methods that are reproducible and that more closely relate to observed bit error ratios in operating links
- To enable standardized specification enforcement for compliance testing.

It was originally a goal to document detailed measurement specifications for the different kinds of variant and interoperability points defined in FC-PH-n and FC-PI. This goal was superseded by a more attainable goal of specifying some representative measurements in sufficient detail to demonstrate the required methods.

This Methodologies for Jitter and Signal Quality (MJSQ) technical report is generated by an Ad Hoc group of companies interested in providing a standard low cost interface for FC applications. This Ad Hoc group is sanctioned by and operates under the jurisdiction of the T11.2 technical committee of INCITS.

This technical report is informative and advisory only. Certain contents of this document may be incorporated into appropriate standards in the future.



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## **Fibre Channel Methodologies for Signal Quality Specification - MSQS**

### **1 Scope**

MJSQ supersedes the previously published MJS technical report (NCITS TR-25-1999). MJSQ represents a significant advance over MJS and obsoletes some concepts documented in MJS.

The measurement methods and specifications are intended to be used as part of a total signal performance compliance requirement set where the phase content of the signal is involved. A more generalized concept for jitter compliance testing is developed where the phase properties of the signals at signals levels other than the nominal receiver switching point are considered as well as the phase properties at the nominal receiver detection threshold. The purpose of this report is to provide background information for revising and expanding the signal specifications presently contained within the FC-PH-n, FC-PI-n, and 10GFC standards and draft standards. The MJSQ technical report is used as a basis for many of the signal specification methodologies in these documents. A further purpose is to increase the general understanding of jitter in multi-GBaud serial transmissions for application to transports other than FC. Documenting high speed serial signal measurement methods provides encouragement to instrument companies to create compatible measurement systems and fixturing capable of supporting 1 GBaud and higher transmission rates and more generalized jitter concepts.

Although this document is optimized for use with Fibre Channel, the measurement methodologies are applicable to a broad range of serial transmission schemes.

This technical report applies to fully functional Fibre Channel subsystem and FC port implementations as well as to the individual components that comprise the link. This allows device and enclosure level qualification and the inclusion of system jitter contributions such as power supply noise, motor noise, crosstalk, and signal rejuvenaters.

A major goal of MJSQ is to improve the relationship between measurements on signals and receiver performance in terms of bit errors.

The report adds to or extends previous work in the following areas:

- a) Exposing serious implementation errors commonly found from improper use of BERT's and sampling oscilloscopes (improper use of time references and improper extraction of total jitter from sampling oscilloscopes)
- b) Algorithms for separating jitter components
- c) Complete specifications for executing tests including test fixtures, instrumentation specifications, calibration schemes, measurement processes, and data output formats - examples for several electrical and optical applications
- d) Methodology for specifying launched and received signals when pre-emphasis or receiver signal processing is used
- e) Inclusion of events occurring at all signal levels within the allowed eye opening at the specified total population probability (e.g.,  $10^{-12}$ )
- f) Extending the receiver tolerance methodology to consider effects of different population distributions.

The MJSQ Technical Report is informative and advisory only. Certain contents of this document may be incorporated into the appropriate INCITS standards in the future.

## 2 References

### 2.1 General

The documents named in this section contain provisions that, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All standards and technical reports are subject to revision, and parties to agreements based on this technical report are encouraged to investigate the possibility of applying the most recent editions of the following list of documents. Members of IEC and ISO maintain registers of currently valid international standards.

Some references may not be specifically cited in the text but contain information generally related to the subject matter of MJSQ.

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### 2.2 Approved references

Approved references are those that have been approved by a standards organization.

Approved ANSI standards;

Approved and draft regional and international standards (ISO, IEC, CEN/CENELEC and ITU); and

Approved foreign standards (including BSI, JIS and DIN).

Approved ANSI technical reports

[1] ANSI X3.230-1994 - Fibre Channel - Physical and Signaling Interface (FC-PH)

[2] ANSI X3.297-1997 - Fibre Channel Physical and Signalling Protocol - 2 (FC-PH-2)

- [3] ANSI X3.303-1997 - Fibre Channel Physical and Signalling Protocol - 3 (FC-PH-3)  
The three documents above are collectively referred to as FC-PH-n
- [4] ANSI X3.TR-18:1997 - 10-bit Interface Technical Report (10-bit Interface TR)
- [5] INCITS TR-25-1999 01-Sept-1999, Methodologies for Jitter Specification (MJS)
- [6] IEEE 802.3z, Media Access Control Parameters, Physical Layer, Repeater and Management Parameters for 1000 Megabit per Second Operation, May 06, 1998 (Gigabit Ethernet)
- [7] INCITS 352 -2002, Fibre Channel Physical Interfaces, Rev 13 (FC-PI)
- [8] Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria (GR-253-CORE, Sept 2000)
- [9] ANSI T1.105, *Synchronous Optical Network (SONET) Basic Description Including Multiplex Structures, Rates, and Formats*
- [10] ANSI T1.105.06, *SONET: Physical Layer Specifications*
- [11] INCITS 364 -2003, Fibre Channel 10 Gigabit (10 GFC)
- [12] IEEE P802.3ae, Media Access Control Parameters, Physical Layer, Repeater and Management Parameters for 10 Gb/s Operation (10 Gigabit Ethernet)
- [13] IEEE Std 1057-1994 "IEEE Standard for Digitizing Waveform Recorders"
- [14] IEEE Std. 181, 1977 Transitions, Pulses, and Related Waveforms
- [15] IEEE Std. 194, 1977 Pulse Terms and Definitions
- [16] OFSTP-4A (EIA/TIA-526-4A) - Optical Eye Pattern Measurement Procedure, Nov. 1997
- [17] IEEE Std 610.7-1995

### **2.3 References under development**

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

- [18] INCITS T11 1506-D, Fibre Channel Physical Interfaces - 2 (FC-PI-2)
- [19] INCITS T11 1625-D, Fibre Channel Physical Interfaces - 3 (FC-PI-3)
- [20] INCITS T11 1647-D, Fibre Channel Physical Interfaces - 4 (FC-PI-4)  
These three documents above and FC-PI are collectively referred to as FC-PI-n.

### **2.4 Informative references**

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- [24] SFF-8415 - HPEI (High Performance Electrical Interconnect) Measurement Methodology and Signal Integrity Requirements (under development)
- [25] SFF-8412 - High speed serial testing and performance requirements for passive duplex optical connections

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<http://www.pcisig.com/specifications/pciexpress/>
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[http://www.ieee802.org/3/ae/public/adhoc/serial\\_pmd/documents/10GEPBud3\\_1\\_16a.xls](http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/10GEPBud3_1_16a.xls)
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- [37] Dennis Kucera and Paul Meyers, "Automated extraction of pulse-parametrics from multi-valued functions"; US Patent 5,343,405, Tektronix, Inc. Aug. 30, 1994.
- [38] GR-253 - Issue 2 December 1995 - SONET
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- [40] "Twisted Magnet Wire Transmission Line" Peter Lefferson, IEEE Trans on Parts, Hybrids, and Packaging, Vol. PHP-7, No. 7, pp 148-154, December 1971.
- [41] D. H. Wolaver, Phase-Locked Loop Circuit Design, Englewood Cliffs, NJ: Prentice Hall, 1991.
- [42] Tektronix, Sampling oscilloscope techniques, Technique primer 47W-7209 found at:  
[http://www.tek.com/Measurement/cgi-bin/framed.pl?Document=/Measurement/App\\_Notes/sampling\\_primer/sampling2.html&FrameSet=oscilloscopes](http://www.tek.com/Measurement/cgi-bin/framed.pl?Document=/Measurement/App_Notes/sampling_primer/sampling2.html&FrameSet=oscilloscopes).

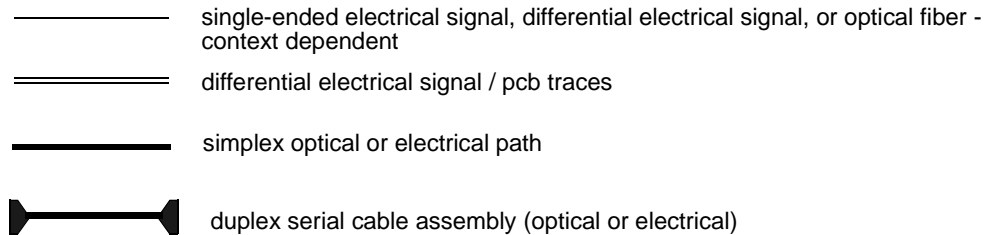
### 3 Definitions and conventions

#### 3.1 Overview

The acronyms, definitions, conventions, and symbols in clause 3 apply in this document.

#### 3.2 Conventions

All drawings in this document conform to the conventions in figure 1.



**Figure 1 - Drawing conventions**

In the event of conflicts between the text, tables, and figures in this document, the following precedence shall be used: text, tables, and figures.

Certain words and terms used in this American National Technical Report have a specific meaning beyond the normal English meaning. These words and terms are defined either in clause 3 or in the text where they first appear.

All parametric data are specified in terms of fundamental MKSA units - meters, kilograms, seconds, amperes - and their derivatives - ohms, henrys, mhos, farads, volts, coulombs, etc.

Decimals are indicated with a comma (e.g., two and one half is represented as 2,5).

Decimal numbers with more than three significant digits on either side of the decimal point are separated into groups of three digits by means of a space, for example, 2,997 924 58 x 10<sup>8</sup> or 1 062,5 MegaBaud.

Units prefixed by k, M, and G refer to 1E3, 1E6, and 1E9 respectively, not 2<sup>10</sup>, 2<sup>20</sup>, and 2<sup>30</sup>.

An alphanumeric list (e.g., a, b, c or A, B, C) of items indicate the items in the list are unordered.

A numeric list (e.g., 1,2,3) of items indicate the items in the list are ordered (i.e., item 1 shall occur or complete before item 2).

**Bold fonts**, when used in body text, indicates additional emphasis.

#### 3.3 Keywords

Expected: anticipated to be true, assumed to exist

May: Indicates flexibility of choice with no implied preference; also means that the ability exists in the referenced topic.

Optional: Features that are not required to be implemented by this document. However, if any optional feature defined by this document is implemented, it shall be implemented as defined in this document.

Shall: Indicates a requirement for compliance to this document. Since this is a technical report there are no enforceable requirements.

Should: Indicates flexibility of choice with a preferred alternative; equivalent to the phrase "it is recommended".

### 3.4 Acronyms

ARB	A specific primitive bit sequence as defined in FC-PH
BER	Bit Error Ratio
BERT	Bit Error Rate Tester
BUJ	Bounded Uncorrelated Jitter
BWJ	Baseline Wander Jitter
CDF	Cumulative Distribution Function
CDR	Clock and Data Recovery
CJTPAT	Compliant Jitter Tolerance PATtern
CRC	Cyclic Redundancy Check
CRPAT	Compliant Random PATtern
CRU	Clock Recovery Unit
CSPAT	Compliant SSO pattern
DCD	Duty Cycle Distortion
DJ	Deterministic Jitter
DDJ	Data Dependent Jitter
DIJ	Dispersion Induced Jitter
DTS	Direct Time Synthesis
DUT	Device Under Test
EOF	End Of Frame; a primitive bit sequence as defined in FC-PH
EQ	EQUIvalent time (OscilloSCOpe)
ESD	Electrostatic Discharge
FC	Fibre Channel
FCS	Fibre Channel Standard
FFT	Fast Fourier Transform
FUT	Fiber Under Test
HA	Host Adapter
HDD	Hard Disk Drive
IDLE	A specific primitive bit sequence as defined in FC-PH
ISI	Inter-Symbol Interference
JBOD	Just a Bunch Of Disks
JTPAT	Jitter Tolerance test PATtern
LPDDJ	Low Probability Data Dependent Jitter
MM	Multi Mode (fiber)
OFSTP	Optical Fiber System Test Practice
PBC	Port Bypass Circuit
PDF	Probability Density Function
PLL	Phase Locked Loop
PMD	Physical Media Dependent sublayer
R_RDY	Receive Ready, a specific primitive bit sequence as defined in FC-PH
RBC	Recovered Byte Clock (one tenth of signaling rate as defined in 10 bit TR [4])
RJ	Random Jitter
RIJ	Reflection Induced Jitter
RPAT	Random Pattern
RSS	Root-Sum-of-Squares

RT	Real Time (oscilloscope) or retimer (link component)
RX	Receive
SERDES	SERializer and DESerializer function. The CDR function is included in the deserializer.
SM	Single Mode (fiber)
SPAT	Simultaneous Switching Outputs (SSO) Pattern
SOF	Start Of Frame; a primitive bit sequence defined in FC-PH
SSO	Simultaneous Switching Outputs
TBC	Transmit Byte Clock
TIA	Timing Interval Analyzer
TJ	Total Jitter
TX	Transmit
UI	Unit Interval
WMV	Waveform Mask Violation (event where the allowable limits are exceeded)

### 3.5 Definitions

- 3.5.1**  $\alpha_T, \alpha_R$ : 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.
- 3.5.2**  $\beta_T, \beta_R$ : Beta T, Beta R; interoperability points used for establishing signal budget at the internal connector nearest the alpha point unless the point also satisfies the definition for delta or gamma where it is either a delta or a gamma point
- 3.5.3**  $\delta_T, \delta_R$ : Delta T, Delta R; interoperability points used for establishing signal budget at the internal connector of a removable PMD element.
- 3.5.4**  $\gamma_T, \gamma_R$ : Gamma T, Gamma R; interoperability points used for establishing signal budgets at the external enclosure connector.
- 3.5.5** **Alpha T, Alpha R:** see  $\alpha_T, \alpha_R$ .
- 3.5.6** **attenuation:** the transmission medium power loss expressed in units of dB.
- 3.5.7** **average power:** the optical power measured using an average reading power meter when transmitting valid 8B/10B transmission characters.
- 3.5.8** **bandwidth:** in jitter context, the corner frequency of a low-pass transmission characteristic, such as that of an optical receiver. The modal bandwidth of an optical fiber medium is expressed in units of MHz-km.
- 3.5.9** **bathtub curve:** a description of the shape of a BER or CDF curve that has steep walls to a noise floor (a flat bottom) where the probability of population is small
- 3.5.10** **Baud:** a unit of signaling speed, expressed as the maximum number of times per second the signal may change the state of the transmission line or other medium. (Units of Baud are symbols/sec) Note: With the Fibre Channel transmission scheme, a symbol represents a single transmission bit. [(Adapted from IEEE Std. 610.7-1995 [A16].12)].
- 3.5.11** **Beta T, Beta R:** see  $\beta_T, \beta_R$ .
- 3.5.12** **bit error ratio (BER):** the probability of a correct transmitted bit being erroneously received in a communication system. For purposes of this report BER is the number of bits output from a receiver that differ from the correct transmitted bits, divided by the number of transmitted bits.
- 3.5.13** **bit clock:** clock used in a jitter measurement that generates a single positive and a single negative transition per unit interval for the purpose of triggering the measuring device. Note that the bit clock frequency is twice the fundamental frequency of an alternating 1010... data stream and is equal numerically to the Baud.

- 3.5.14 bulkhead:** the boundary between the shielded system enclosure (where EMC compliance is maintained) and the external interconnect attachment
- 3.5.15 cable plant:** all passive communications elements (e.g., optical fiber, twisted pair, coaxial cable, connectors, splices, etc.) between a transmitter and a receiver.
- 3.5.16 clock data recovery (CDR):** the function is provided by the SERDES circuitry responsible for producing a regular clock signal from the serial data and for aligning this clock to the serial data bits. The CDR uses the recovered clock to recover the data.
- 3.5.17 character:** a defined set of  $n$  contiguous bits where  $n$  is determined by the encoding scheme. For FC that uses 8b10b encoding,  $n = 10$ .
- 3.5.18 coaxial cable:** an unbalanced electrical transmission medium consisting of concentric conductors separated by a dielectric material with the dimensions and material arranged to give a specified electrical impedance.
- 3.5.19 compliance point:** an interoperability point where the interoperability specifications are met. Compliance points may include beta, gamma, and delta points for transmitters and receivers.
- 3.5.20 component:** entities that make up the link. Examples are connectors, cable assemblies, transceivers, port bypass circuits and hubs.
- 3.5.21 connector:** electro-mechanical or opto-mechanical components consisting of a receptacle and a plug that provides a separable interface between two transmission media segments. Connectors may introduce physical disturbances to the transmission path due to impedance mismatch, crosstalk, etc. These disturbances may introduce jitter under certain conditions.
- 3.5.22 coupler:** a connector that mates two like media together.
- 3.5.23 cumulative distribution function (CDF):** the integral of the PDF from - infinity to a specific time or from a specific time to + infinity.
- 3.5.24 delta function:** a pulse with zero width and unity amplitude. See also Dirac delta function.
- 3.5.25 Delta T, Delta R:** see  $\delta_T$ ,  $\delta_R$ .
- 3.5.26 deterministic jitter, (level 1 DJ):** the value returned by the calculation for DJ defined in clause 8. Any valid CDF may be used as input to this calculation. DJ used for compliance and budgeting is level 1 DJ. See also jitter, deterministic.
- 3.5.27 Dirac delta function:** a pulse with zero width and unity area. See also delta function.
- 3.5.28 dispersion:** (1) A term in 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.
- 3.5.29 dual-Dirac:** a pair of Dirac delta functions.
- 3.5.30 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 and is approximately the same quantitatively as that observed with clock like patterns in definition (1). 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.

- 3.5.31 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  $\sigma_1$  and  $\sigma_2$ . Equivalent to level 1 DJ. See clause 8.
- 3.5.32 electrical fall time:** the time interval for the falling edge of an electrical pulse to transit between specified percentages of the signal amplitude. In the context of MJSQ the measurement points are the 80% and 20% voltage levels.
- 3.5.33 electrical rise time:** the time interval for the rising edge of an electrical pulse to transit between specified percentages of the signal amplitude. In the context of MJSQ, the measurement points are the 20% and 80% voltage levels.
- 3.5.34 enclosure:** the outermost electromagnetic boundary (that acts as an EMI barrier) containing one or more FC devices.
- 3.5.35 event:** the measured deviation of a single signal edge time at a defined signal level of the signal from a reference time. The reference time is the jitter-timing-reference specified in x. Events are also referred to as jitter events or signal events without changing the meaning. Examples include a sample in a sampling oscilloscope, a single TIA measurement, an error or non error reported by a BERT at a reference time and signal level.
- 3.5.36 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.
- 3.5.37 eye contour:** the locus of points in signal level - time space where the CDF =  $1E-12$  in the actual signal population determines whether a jitter eye mask violation has occurred. Either time jitter or signal level jitter may be used to measure the eye contour.
- 3.5.38 FC device:** an entity that contains the FC protocol functions and that has one or more of the connectors defined in this document. Examples are: host bus adapters, disk drives, and switches. Devices may have internal connectors or bulkhead connectors.
- 3.5.39 FC device connector:** a connector defined in this document that carries the FC serial data signals into and out of the FC device.
- 3.5.40 Gamma T, Gamma R:** see  $\gamma_T$ ,  $\gamma_R$ .
- 3.5.41 Golden PLL:** a function that conforms to the requirements in sub clause x that 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.
- 3.5.42 internal connector:** a connector, whose purpose is to carry the FC signals within an enclosure (may be shielded or unshielded).
- 3.5.43 internal FC Device:** an FC device whose FC device connector is contained within an enclosure.
- 3.5.44 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.
- 3.5.45 jitter:** the collection of instantaneous deviations of a signal edge times at a defined signal level of the signal from the reference times for those events. The reference time is the jitter-timing-reference specified in x that occurs under a specific set of conditions.

- 3.5.46 jitter, baseline wander induced (BWJ):** a form of DDJ that is caused by the effects of the transfer function of a of a high-pass filter circuit in the signal transmission process. Coupling circuits may cause ISI effects that produce correlated deterministic jitter.
- 3.5.47 jitter, bounded and uncorrelated (BUJ):** the part of the deterministic jitter that is not aligned in time to the HPDDJ 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.
- 3.5.48 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. For example when using media that attenuates the peak amplitude of the bit sequence consisting of alternating 0,1,0,1... more than peak amplitude of the bit sequence consisting of 0,0,0,0,1,1,1,1... the time required to reach the receiver threshold with the 0,1,0,1... is less than required from the 0,0,0,0,1,1,1,1.... The run length of 4 produces a higher amplitude that takes more time to overcome when changing bit values and therefore produces a time difference compared to the run length of 1 bit sequence. 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.
- 3.5.49 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). DJ is characterized by its bounded, peak-to-peak value. Level 1 DJ, per 3.5.26 and 3.5.66, is defined by an assumed CDF form and may be used for compliance testing.
- 3.5.50 jitter, dispersion induced (DIJ):** a form of DDJ that is caused by dispersion in the signal transmission process. Dispersion may cause ISI effects that produce correlated deterministic jitter.
- 3.5.51 jitter, periodic (PJ):** spectral peaks in the BUJ frequency spectrum
- 3.5.52 jitter, reflection induced (RIJ):** a form of DDJ caused by reflections in the signal transmission process. Reflections may cause ISI effects that produce correlated deterministic jitter.
- 3.5.53 jitter, sinusoidal (SJ):** single tone jitter applied during signal tolerance testing.
- 3.5.54 jitter distribution:** a general term describing either PDF or CDF properties.
- 3.5.55 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 (see x and x).
- 3.5.56 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. See x
- 3.5.57 jitter output:** the quantity of jitter at a specific physical position in the link.
- 3.5.58 jitter, random, RJ:** jitter that is characterized by a Gaussian distribution and is unbounded.
- 3.5.59 jitter, residual:** jitter that remains after the DDJ and the DCD is removed.
- 3.5.60 jitter, total, TJ:** total jitter in UI is calculated from (1 - jitter eye opening) where jitter eye opening is measured in UI.
- 3.5.61 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 (see x). The jitter timing reference may be different from other timing references available in the system.

- 3.5.62 jitter transfer:** the ratio as a function of jitter frequency between the jitter output and jitter input for a link element (component, device, or system) often expressed in dB. A negative dB jitter transfer indicates the element removed jitter. A positive dB jitter transfer indicates the element added jitter. A 0 dB jitter transfer indicates the element had no effect on jitter.
- 3.5.63 jitter tolerance for links:** the ability of the link downstream from the receive interoperability point ( $\gamma_r$ ,  $\beta_r$ , or  $\delta_r$ ) to recover transmitted bits in an incoming data stream in the presence of specified jitter in the signal. Jitter tolerance is measured 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 Ports require that the Port be capable of reporting bit errors. For receivers that are not embedded in FC Ports the bit error detection and reporting may be accomplished by instrumentation attached to the output of the receiver. Jitter tolerance is always measured using the minimum allowed signal amplitude unless otherwise specified. See also signal tolerance.
- 3.5.64 jitter tolerance for receivers:** the ability of a receiver to recover transmitted bits in an incoming data stream in the presence of specified jitter in the signal. Jitter tolerance is measured by the amount of jitter required to produce a specified bit error ratio. The reference point for the jitter tolerance of the receiver is the  $\alpha_R$  point. 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 always measured using the minimum allowed signal amplitude unless otherwise specified. See also signal tolerance.
- 3.5.65 level:**
1. A document artifice, e.g. FC-0, used to group related architectural functions. No specific correspondence is intended between levels and actual implementations.
  2. In FC-PI-n 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
- 3.5.66 level 1 DJ:** term used in this document for the effective DJ value that is used for DJ compliance purposes.
- 3.5.67 limiting amplifier:** an active non-linear circuit with amplitude gain that keeps the output levels within specified levels, but are generally not designed to reduce jitter and may increase jitter.
- 3.5.68 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.
- 3.5.69 optical fall time:** the time interval required for the falling edge of an optical pulse to transit between specified percentages of the signal amplitude. For lasers the transitions are measured between the 80% and 20% points.
- 3.5.70 optical fiber:** any filament or fiber, made of dielectric material, that guides light.
- 3.5.71 optical modulation amplitude:** the positive difference in 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. A long string for 8B10B encoding should be considered to be 5 bits high or 5 bits low.

- 3.5.72 optical rise time:** the time interval required for the rising edge of an optical pulse to transit between specified percentages of the signal amplitude. For lasers the transitions are measured between the 20% and 80% points.
- 3.5.73 physical media dependent (PMD):** a transmit and receive network used to launch into a specific type of electrical or optical interconnect or to receive from a specific type of electrical or optical interconnect. The details of the network design depend on the type of interconnect.
- 3.5.74 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.
- 3.5.75 Port bypass circuit (PBC):** an active multiplexer that is used to bypass FC ports or other ports that are unused or nonfunctional. PBC's that do not re-time the signals to a local clock are considered part of the interconnect.
- 3.5.76 probability density function (PDF):** a histogram of the jitter event population.
- 3.5.77 random:** random in this document always refers to Gaussian distribution. These distributions may apply to time jitter or signal level noise.
- 3.5.78 receiver (Rx):** an electronic component (Rx) that converts an analog serial input signal (optical or electrical) to an electrical (retimed or non-retimed) logic output signal.
- 3.5.79 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 photodiodes and transimpedance amplifiers.
- 3.5.80 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) data at its input.
- 3.5.81 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.
- 3.5.82 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.
- 3.5.83 return loss:** the ratio (expressed in dB) of incident power to reflected power, when a component or assembly is introduced into a link or system. May refer to optical power or to electrical power in a specified frequency range.
- 3.5.84 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.
- 3.5.85 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.
- 3.5.86 signal:** the entire voltage or optical power waveforms within a data pattern during transmission
- 3.5.87 signal level:** the instantaneous intensity 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 intensity is usually given in units of power: dBm and microwatts.

- 3.5.88 signal amplitude:** a property of the overall signal that describes the peak or peak to peak values of the signal level . When signal transitions interfere with or overlap each other in a signal the effective signal amplitude may be expressed as a vertical waveform eye opening (e. g. optical modulation amplitude).
- 3.5.89 signal tolerance:** the ability of the link downstream from the receive interoperability point ( $\gamma_r$ ,  $\beta_r$ , or  $\delta_r$ ) to recover transmitted bits in an incoming data stream in the presence of a specified signal. Signal tolerance is measured by the amount of jitter required to produce a specified bit error ratio at a specified signal amplitude. The required signal tolerance performance depends on the frequency content of the jitter and on the amplitude of the signal. 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. Signal tolerance is always measured using the minimum allowed signal amplitude and maximum allowed jitter unless otherwise specified. See also jitter tolerance.
- 3.5.90 spectral noise floor:** the Fourier transform of the jitter remaining after BUJ is removed from residual jitter.
- 3.5.91 transceiver:** a transmitter and receiver combined in one package.
- 3.5.92 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.
- 3.5.93 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.
- 3.5.94 transmission code:** a means of encoding data to enhance its transmission characteristics. The transmission code specified by FC-FS is byte-oriented, with both valid data bytes and special (control) codes encoded into 10-bit transmission characters.
- 3.5.95 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.
- 3.5.96 transmitter (Tx):** a circuit (Tx) that converts a logic signal to a signal suitable for the communications media (optical or electrical).
- 3.5.97 TxRx connection:** the complete signal path between a transmitter in one FC device and a receiver in another FC device.
- 3.5.98 unit interval (UI):** the normalized (dimensionless) nominal duration of a single transmission bit. Unit interval is a measure of time that has been normalized such that 1/Baud seconds is 1 UI.
- 3.5.99 waveform mask violation, WMV:** a recorded signal event where an incursion occurs into the jitter eye opening in the signal level/time space defined for a particular CDF level for the signal population. For some compliant receivers this event could produce a link bit error. Note that a maximum of one WMV event may be recorded within a single bit period. Multiple incursions into the eye opening from the same signal within the same bit time shall be counted only once. WMV's are not failures unless the number exceeds that allowed.
- 3.5.100 word:** in Fibre Channel protocol, a string of four contiguous bytes occurring on boundaries that are zero modulo 4 from a specified reference.

## 4 Background for MJSQ

### 4.1 Overview

Clause 4 describes the historical background of MJS and MJSQ and some of the reasons that the original MJS technical report was produced. The concepts and terminology in this clause are more fully developed throughout MJSQ and may not be fully understood without exploring the remainder of MJSQ.

### 4.2 Relationship to SONET and receiver tolerance requirements

The methodologies in this document are extensions of the SONET [8], [9], [10] jitter specification concepts. In SONET the term 'network interface jitter' is used in approximately the same way as the term 'jitter' is used in this document. SONET also defines a term 'frame jitter' that is not equivalent to the term 'jitter' used in this document.

The extensions to SONET implicitly specify the assumed receiver CDR characteristic. The specification for the frequency response of the clock recovery circuit is determined by defining a jitter tolerance mask for the clock and data recovery function. Jitter occurring below the characteristic frequency is tracked and modifies the recovered clock frequency whereas jitter above the characteristic frequency is not tracked. This PLL characteristic exists for digital as well as analog (PLL-based) CDR's. Figure 2 schematically shows this tracking or frequency response characteristic. Additionally, at certain frequencies jitter peaking may occur whereby the output jitter is greater than the input jitter. It should be noted that the jitter peaking and CDR bandwidth property of some CDR's is a potential source of jitter degradation when used in repeaters within the interconnect. This document does not specify a separate requirement for jitter peaking and CDR bandwidth.

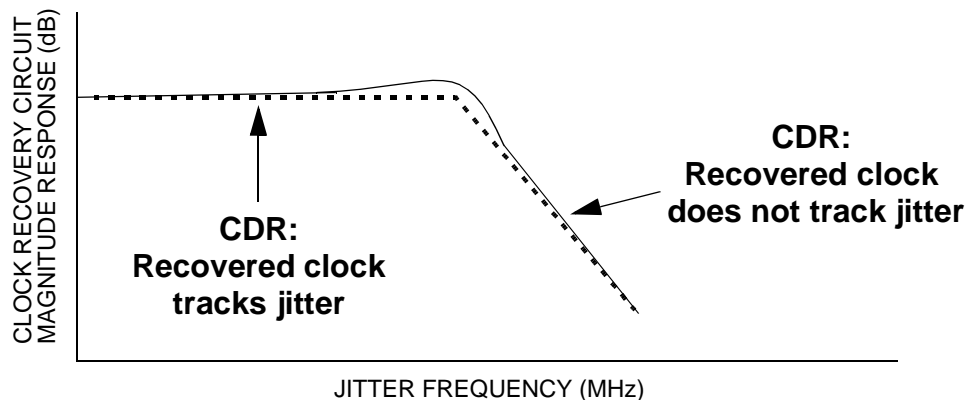
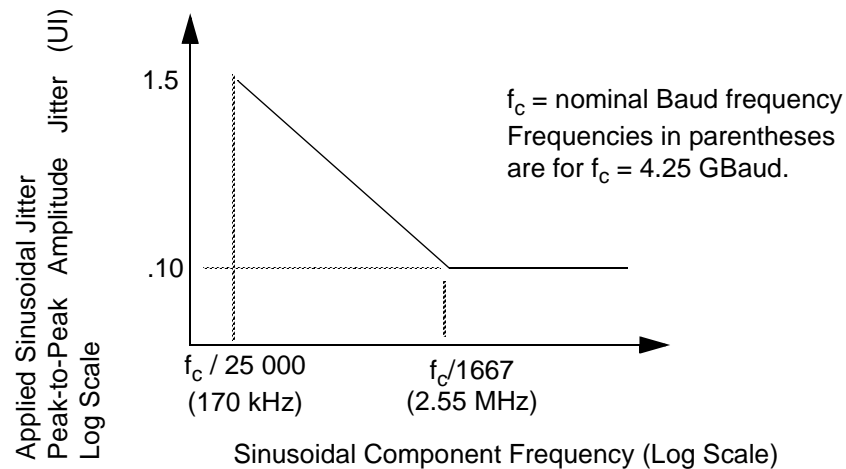


Figure 2 - PLL response

A spectral characteristic is imposed on the specification to differentiate between jitter that may be benign to a link's bit error ratio performance because of the receiver's ability to track low frequencies and jitter that is detrimental to a link's bit error ratio performance. The jitter tolerance specification in figure 3 creates a jitter tolerance spectral requirement that is not currently specified in the FC-PH document. The implication of this specification is that jitter output specifications at all compliance points include frequency content based on the jitter tolerance mask.

When comparing this jitter specification to SONET jitter specification, the jitter tolerance masks are based on different test conditions.



**Figure 3 - Mask of the sinusoidal component of jitter tolerance - Log-Log Plot**

For most receivers high frequency jitter has greater impact on bit error ratio than low frequency jitter because the receiver is capable of tracking the low frequency jitter. Jitter specifications that include frequency content require additional testing; but lower systems costs may be achieved with the relaxation of the clock stability requirements.

A real example of being able to build lower cost systems by imposing the spectral characteristics to jitter relates to using lower cost reference clocks for the serializer clock multiplier PLL. Clock synthesizers are lower cost than crystal oscillators. Analysis of low-cost clock synthesizers shows an unacceptably large jitter content. Further analysis shows that most of the clock jitter is low frequency that passes unattenuated out of the optical or electrical transmitter. However, the receiver CDR reliably tracks this low frequency jitter and recovers the data.

### 4.3 Relationship to earlier FC standards

The ANSI Fibre Channel specification X3.230-1994 (FC-PH) [1] only specifies measurement techniques for jitter. Two jitter generation measurement techniques are specified in X3.230-1994. One measurement is for deterministic jitter using a special Fibre Channel K28.5 pattern that contains the longest and shortest runs. The other measurement is for random jitter using a special Fibre Channel defined character, K28.7, that is a "clock-like" data sequence assumed not to contain deterministic jitter. The deterministic jitter measurement results in a peak to peak value and the random jitter measurement results in an RMS value. Per the FC-PH Annex J, the peak to peak value of random jitter is 14 times the RMS value for a  $10^{-12}$  bit error ratio. Total jitter is equal to peak to peak random jitter plus peak to peak deterministic jitter.

The methodology relying on repeated K28.7 characters for measuring RJ and repeated K28.5 for measuring DJ are flawed for the following reasons:

First, the assumption that all deterministic jitter is absent in the square-wave-like K28.7 is often incorrect. For instance, deterministic sub harmonic processes in the transmitter may show up in this measurement. Ten picoseconds of such DJ could be accounted as  $14 \cdot 10 / 2 = 70$  pS of RJ.

Second, while the maximum and minimum run length pulses in K28.5 are ideal for measuring data-dependent jitter due to cable skin effect, this method may completely miss some components of DJ. For instance, the sub harmonic process described above (or any jitter effect not synchronous with the K28.5 pattern) would be completely removed by averaging. Also, transmitter mistiming of any of the 5 edges out

of 10 missing in K28.5 would go undiscovered.

In addition to differentiating between trackable and non-trackable jitter, a need exists to clarify the existing receiver jitter tolerance allocation indicated in the informative Annex J of the FC-PH document. What is 70% eye closure? What is this intended to test? Two CDR characteristics are important for reliable serial communication: CDR loop dynamics and CDR strobe error. These CDR characteristics becomes increasingly important as repeaters are used in Disk Arrays and Hubs.

Some of the features described in MJSQ are implemented in FC-PI but some significant extensions are not. MJSQ is being developed in parallel with FC-PI-2 where most extensions are implemented.

#### **4.4 Traditional measurement methodology risks**

The workhorse for evaluating signals has been the sampling oscilloscope for many years. For the properties required of high speed serial signals ordinary sampling oscilloscopes may not be suitable.

**Using oscilloscope waveform eye mask methods with histogram measurements in present oscilloscope technology does not provide the statistical population required to accurately represent behavior at  $10^{-12}$  population levels in a reasonable measurement time period. See figure 4 for examples of this issue. See also x.** See clause 9 for more information on different measurement methodologies. Measurements are made at the appropriate physical point in the link.

The actual signal quality may be very different at the low population levels from the appearance at high populations as seen in a typical waveform eye diagram from an oscilloscope. Figure 4 shows the waveform eyes as would result on a sampling oscilloscope from two different jitter distributions that have the same jitter eye opening at the  $10^{-12}$  level. The distributions are taken at the nominal switching threshold level of the signals. Notice that EYE "A" seems to be considerably worse than EYE "B" but is actually equivalent in terms of its total jitter.

#### **Figure 4 - Waveform eye diagrams from different jitter distributions**

Traditional measurements are all recorded at the nominal receiver switching level. The most common nominal switching levels are zero differential volts for balanced electrical links and the average optical power level. Behavior at signal levels other than the nominal switching threshold is also important. For example if a signal enters the eye mask above or below the nominal switching threshold, errors may occur.

More detail concerning the important signal properties is contained in 6.2.

A signal quality measurement needs a reference time to quantify the timing properties. See x.

Signal quality acceptance criteria are specified within the allowed jitter eye opening at the specified total population probability (e.g. CDF =  $10^{-12}$ ).

A major goal of MJSQ is to specify signal quality measurement methodologies that more closely approximate the observed bit error ratio of receivers.

Signal quality measurements that include results at signal levels other than the nominal switching threshold may be termed 2-dimensional or eye contour in this document.

## **5 8GFC transmitter eye mask probability level (hit ratio)**

## **6 S Parameters**

### **6.1 Common Mode--Differential Mode Conversion**

### **6.2 Causality and Passivity**

### **6.3 Touchstone File Format**

## **7 Jitter**

### **7.1 Dual Dirac Measures of Jitter**

### **7.2 Data Dependent Jitter (DDJ) and Data Dependent Pulse Width Shrinkage (DDPWS)**

Reference FC-PI-4 A.1.3.1 and A.1.3.2.

### **7.3 Uncorrelated Jitter (UJ) and Deterministic and Total Jitter Measurements**

Reference FC-PI-4 A.1.4.2 and A.1.4.3.

## **8 Budgeting With Equalized Links**

### **8.1 Methods**

Discussion of reference equalizer and power penalty

### **8.2 Measurement Options**

#### **8.2.1 Noncompensable DDj**

#### **8.2.2 TWDP**

#### **8.2.3 WDP**

#### **8.2.4 dWDP**

#### **8.2.5 TDP**

#### **8.2.6 StatEye**

#### **8.2.7 Stressed Eye**

#### **8.2.8 Relative Noise (RN) and Signal-to-Noise Ratio Qsq**

#### **8.2.9 Metrics Derived From An Averaged Waveform (reference??)**

### **8.3 Tools**

#### **8.3.1 Matlab Code**

## **9 Classes of Equalizers**

### **9.1 Adaptation (Training for transmit and receive equalizers)**

### **9.2 Training**

### **9.3 Scrambled Data vs. Non-Scrambled Data**

### **9.4 Coding: 64b/66b vs. 8b/10b**

### **9.5 Test Patterns**

## **10 Channel Effects**

### **10.1 VCR, ICR, ILD Discussion**

Time domain (impulse) vs. frequency domain effects.

### **10.2 Stressors**