# 100G-CLR4
# Revision 1.5.2

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Specification for
100 Gb/s Coarse Wavelength Division Multiplex
Optical Data Transmission

The companies that prepared this version of the specification acknowledge the work of the IEEE 802.3 standards efforts. These CLR4 Specifications are based on much of the work the IEEE standards body has developed for 40GBase-LR4 and 100GBase-LR4 industry standards. This technical document has been created with inputs from a few companies. This document is offered to transceiver users and suppliers as a basis for discussion and comment. However it is not a warranted document, each transceiver supplier will have their own datasheet. If the user wishes to find a warranted document, they should consult the datasheet of the chosen transceiver supplier.



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# 1 Introduction

Warehouse scale data centers are seeking high-speed interconnects, with low-power consumption, high-port density, low cost, duplex-SMF, and with some applications requiring low latency. Volumes are large enough to demand transceiver solutions that address data-center specific needs. A broad set of data-center stakeholders are interested in contributing to, and influencing interface standards.

The motivation for the 100G-CLR4 Specification is to provide an open, 100 Gb/s (4x25.78 GBd), CWDM, single-mode, and with duplex fiber transceiver interface specification optimized for data-center specific needs.

The 100G-CLR4 specifications is designed specifically to address data center product requirements of:

- Low power-consumption.
- Compact transceiver form factor: The 100G-CLR4 Specification is transceiver form-factor agnostic, with QSFP28 as the initial form factor.
- Compatibility with SMF connectors and cable infrastructure for present and future data-centers, as well as telecom client-side interfaces.
- Application supports operation with and without Forward-Error-Correction (FEC): Enables use with FEC for increased link margin or operation without FEC for lower power consumption and lower latency.
- A variety of opto-electronic implementation approaches and technologies.
- Reach up to 2 km based on practical cabling design such as structured cabling or point-to-point cabling.

CLR4 specification supports a reach of 2 km and follows the IEEE 802.3 CL 88 100Gbase-LR4 standard but based on CWDM grid as defined by IEEE 802.3 CL87 40Gbase-LR4. The electrical interface is based on CAUI-4 as defined by IEEE 802.3 CL83E. The CLR4 and 40Gbase-LR4 wavelength grid are based on CWDM with 20 nm spacing which allow for uncooled operation, which lowers module power and optics cost.

Additionally, we acknowledge the work done by the IEEE 802.3ba and IEEE 802.3bm committees in their efforts in developing underlying standards.

# 2 Reference Documents

The following list identifies industry standards documentation used to complete this design specification package:

IEEE 802.3ba-2010 Media Access Control Parameters, Physical Layers and Management Parameters for 40 Gb/s and 100 Gb/s Operation: Clause 87, Clause 88
IEEE 802.3bm/D3.3-2014 Physical layer Specifications and Management Parameters for 40 Gb/s and 100 Gb/s Operation Over Fiber Optics Cables: Annex 83E CAUI-4 Chip-to-module
IEEE 802.3bj-2014 Physical Layer Specifications and Management Parameters for 100 Gb/s Operation Over Backplanes and Copper Cables: Clause 91 RS-FEC

OIF-CEI-03.1-2014 Common Electrical I/O (CEI) - Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O: Chapter 13

InfiniBand: Vol.2 Rel. 1.3.1 Draft Feb 2014, EDR
SFF-8636: Common Management Interface
SFF-8661: QSFP28 4X Pluggable Module
SFF-8662: QSFP28 4X Connector (Style A)
SFF-8663: QSFP28 cage (Style A)
SFF-8665: QSFP28 4X Pluggable Transceiver Solution
SFF-8672: QSFP28 4X Connector (Style B)
SFF-8679: 4X Base Electrical Specifications

# 3 100G-CLR4 Functional Description

The 100G-CLR4 Optical Module electrical interfaces is based on IEEE 802.3 CL 83E CAUI-4 host to module retimed interface. The 100G-CLR4 optical interface is based on duplex SMF with CWDM grid compatible with IEEE 802.3 CL 87 40Gbase-LR4. It performs Transmit and Receive functions that convey data between the Host and the media.

# 4 Overview of the CWDM System

## 4.1 Optical Subsystem Block Diagram

Figure 1 shows a block diagram of the optical subsystem. The electrical and optical interface compliance points are identified as TP1 for the electrical input signals, TP2 for the optical output signal, TP3 for the optical input signal and TP4 for the electrical output signal. TP1 and TP4 are informative reference points respectively for module stress input calibration and host input calibration. Reference test fixtures/compliance boards (MCB/HCB), are used to access the electrical signals for signal calibration at TP1 and TP4.

The electrical signals, compliance boards and measurements test methods are defined in IEEE802.3bm, Annex 83E Chip-to-module, OIF-CEI-3.01, and according to SFF-86xx (QSFP28) specifications. The optical transmit signal is defined at the output end of a single mode fiber patch cord (TP2), between 2 m and 5 m in length. Unless specified otherwise, all optical transmitter measurements and tests defined are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3). Unless specified otherwise, all optical receiver measurements and tests are made at TP3.

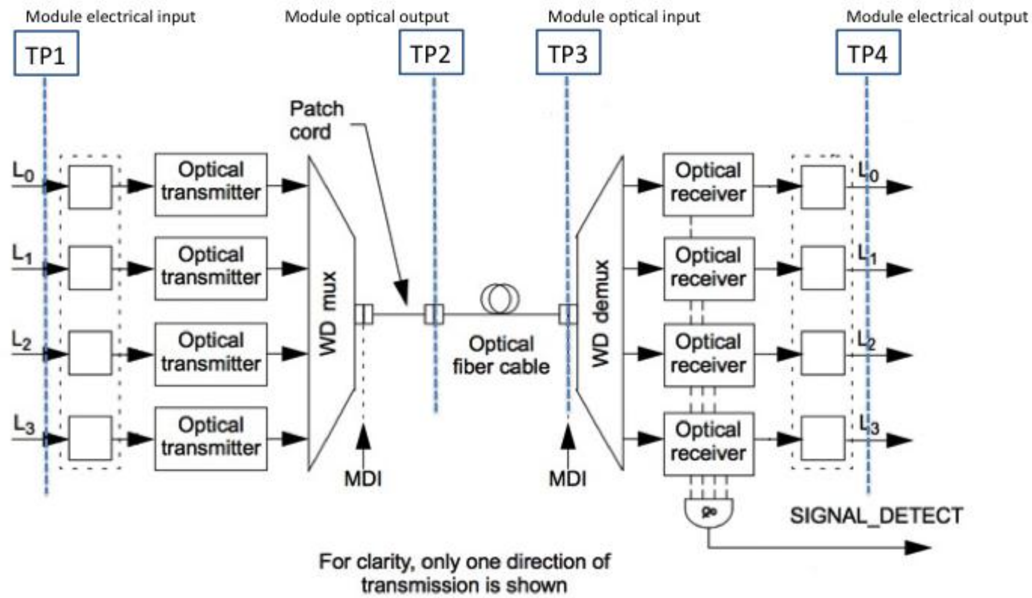


**Figure 1: Block Diagram of a CWDM Optical Interconnect. WD: Wavelength Division**

# 5 100G-CLR4 Functional Specifications

## 5.1 Module Transmit function (IEEE802.3, clause 88.5.2)

The module Transmit function shall convert the four lane CAUI-4 signals into four separate optical signal streams. The four optical signal streams shall then be wavelength division multiplexed and delivered to the MDI, all according to the transmit optical specifications in this document.

## 5.2 Module Receive Function (IEEE802.3, clause 88.5.3)

The module Receive function shall demultiplex the composite optical signal stream received from the optical media into four separate optical signal streams. The four optical signal streams shall then be converted into four lane CAUI-4 signals, all according to the receive optical specifications in this document.

## 5.3 Module Global Signal Detect Function (IEEE802.3, clause 88.5.4)

The module global signal detect function shall report the state of SIGNAL_DETECT. The SIGNAL_DETECT parameter is signaled continuously, so that a message is generated when a change in the value of SIGNAL_DETECT occurs.

SIGNAL_DETECT shall be a global indicator of the presence of optical signals on all four lanes. The module receiver is not required to verify whether a compliant optical input signal is being received. No response time requirements on the generation of the SIGNAL_DETECT parameter are imposed.

Implementations must provide adequate margin between the input optical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the module including the effects of crosstalk, power supply noise, etc.

**Table 1: Signal Detect Conditions**

| Receive conditions | SIGNAL_DETECT |
|---|---|
| For any lane: Average optical power at TP3 ≤ –30 dBm | FAIL |
| For all lanes:<br>Optical power at TP3 ≥ receiver sensitivity (max) in OMA AND compliant optical input signal | OK |
| All other conditions | Unspecified |

Various implementations of the Signal Detect function are permitted, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the optical signal and implementations that respond to the average optical power of the modulated optical signal.

## 5.4 Module Lane-by-Lane Signal Detect Function (IEEE802.3, clause 88.5.5)

Various implementations of the Signal Detect function are permitted. Each signal_detect_i, where i represents the lane number in the range 0:3, shall be continuously set in response to the magnitude of the optical signal on its associated lane.

## 5.5 Module Global Transmit Disable Function (IEEE802.3, clause 88.5.7)

1. When the TX_disable variable is set to one, this function shall turn off all of the optical transmitters so that each transmitter meets the requirements of the average launch power of the OFF transmitter.
2. If a TX_fault is detected, then the module may set the TX_disable to one, turning off the optical transmitter in each lane.

## 5.6 Module Lane-by-Lane Transmit Disable Function (IEEE802.3, clause 88.5.8)

1. When a TX_disable_i variable is set to one, this function shall turn off the optical transmitter associated with that variable so that the transmitter meets the requirements of the average launch power of the OFF transmitter.
2. If a TX_fault is detected, then the module may set each TX_disable_i to one, turning off the optical transmitter in each lane.

If the TX_disable_i function is not implemented, an alternative method shall be provided to independently disable each transmit lane for testing purposes.

## 5.7 Module Transmit Fault Function (IEEE802.3, clause 88.5.9)

If the module has detected a local fault on any transmit lane, it shall set the TX_fault variable to one.

## 5.8 Module Receive Fault Function (IEEE802.3, clause 88.5.11)

If the module has detected a local fault on any receive lane, it shall set the RX_fault variable to one.

# 6 Optical Specifications

## 6.1 Wavelength-Division-Multiplexed Lane Assignments

The wavelength range for each lane of the 100G–CLR4 optical module is defined in Table 2. The center wavelengths are members of the CWDM wavelength grid defined in ITU-T G.694.2 and are spaced at 20 nm.

**Table 2 Wavelength Range**

| Lane | Center wavelength | Wavelength range |
|---|---|---|
| L0 | 1271 nm | 1264.5 to 1277.5 nm |
| L1 | 1291 nm | 1284.5 to 1297.5 nm |
| L2 | 1311 nm | 1304.5 to 1317.5 nm |
| L3 | 1331 nm | 1324.5 to 1337.5 nm |

NOTE—There is no requirement to associate a particular electrical lane with a particular optical lane, as the host system is capable of receiving lanes in any arrangement.

The operating ranges for the 100G–CLR4 module are defined in Table 3. A 100G-CLR4 that exceeds the operating range requirement while meeting all other optical specifications is considered compliant (e.g., operating at 2200 m meets the operating range requirement of 2 m to 2000 m).

**Table 3: Operating Ranges**

| Module type | Required operating range |
|---|---|
| 100G–CLR4 | 2 m to 2 km |

## 6.2 100G–CLR4 Transmitter Optical Specifications

The 100G–CLR4 transmitter shall meet the specifications defined in Table 4 without FEC.

**Table 4: 100G-CLR4 Optical Transmit Characteristics**

| Description | Min | Typical | Max | Unit |
|---|---|---|---|---|
| Signaling rate, each lane (range) | 25.78125 ± 100ppm | | | Gb/s |
| BER | 1e-12 | | | |
| Lane wavelength range | 1264.5 to 1277.5<br>1284.5 to 1297.5<br>1304.5 to 1317.5<br>1324.5 to 1337.5 | | | nm |
| Operating link reach | 2 | | 2000 | m |
| Side-mode suppression ratio (SMSR) | 30 | | | dB |
| Total average launch power | | | 8.5 | dBm |
| Average launch power, each lane | -6.5 | | 2.5 | dBm |
| Optical Modulation Amplitude (OMA) each lane[1] | -4 | | 2.5 | dBm |
| Launch power in OMA minus TDP each lane | -5 | | | dBm |
| Transmitter & dispersion penalty (TDP) each lane[2] | | | 3.3 | dB |
| Average launch power of OFF transmitter each lane | | | -30 | dBm |
| Extinction ratio | 3.5 | | | dB |
| RIN20 OMA | | | -130 | dB/Hz |
| Optical return loss tolerance | | | 20 | dB |
| Transmitter reflectance | | | -20 | dB |
| Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3} | {0.25, 0.42, 0.46, 0.28, 0.3, 0.4} | | | |

[1] Even if the TDP < 1.0dB, the OMA (min) must exceed this value.

[2] A tradeoff regarding the transmitter launch power can be made.

## 6.3 100G–CLR4 Receive Optical Specifications

The 100G–CLR4 receiver shall meet the specifications defined in Table 5 without FEC.

**Table 5: 100G-CLR4 Optical Receive Characteristics**

| Description | Min | Typical | Max | Unit |
|---|---|---|---|---|
| Signaling rate, each lane (range) | 25.78125<br>± 100 ppm | | | Gb/s |
| BER[1] | 1e-12 | | | |
| Lane wavelength range | 1264.5 to 1277.5<br>1284.5 to 1297.5<br>1304.5 to 1317.5<br>1324.5 to 1337.5 | | | nm |
| Damage threshold[2] | 3.5 | | | dBm |
| Average receive power, each lane[3] | -10 | | 2.5 | |
| Receive power, each lane (OMA) | | | 2.5 | |
| Difference in receive power between any two lanes (OMA) | | | 5.5 | |
| Receiver reflectance | | | -26 | dB |
| Receiver sensitivity (OMA), each lane[4] | | | -8.1 | dBm |
| Stressed receiver sensitivity (OMA), each lane[5] | | | -5.6 | dBm |
| Vertical eye closure penalty[6], each lane | | | 1.95 | dB |
| Stressed eye J2 Jitter[6], each lane | | | 0.3 | UI |
| Stressed eye J9 Jitter[6], each lane | | | 0.5 | UI |

[1]Note that CLR4-compliant optical interfaces are designed to achieve a link BER of $1x10^{-15}$ if FEC is applied – see section 6.5.4.

[2]The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.

[3]Average receive power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.

[4]Receiver sensitivity (OMA), each lane (max) is informative.

[5]Measured with conformance test signal at TP3 for BER = $10^{-12}$.

[6]Vertical eye closure penalty, stressed eye J2 Jitter, and stressed eye J9 jitter are test conditions for measuring stressed receiver sensitivity. They are not characteristics of the receiver. A max. TDP of 3.3 dB is assumed.

## 6.4 100G-CLR4 Illustrative Link Power Budgets

An illustrative power budget and penalties for 100G-CLR4 optical channels are shown in Table 6 without host system FEC.

**Table 6: 100G –CLR4 Illustrative Link Power Budget**

| Parameter | 100G-CLR4 |
|---|---|
| Operating distance max. (km) | 2 |
| Fiber loss (dB/km) | 0.5 |
| Total Channel loss (dB) | 2.5 |
| TDP (dB) | 3.3 |
| Total Power Budget (dB)[1] | 5.8 |

[1] 0.4 dB max. MPI penalty is included in the power budget

## 6.5 System Performance with FEC

In systems with IEEE 802.3 Clause 91 (RS-FEC) applied the link budget can be increased to accommodate for longer reach or higher cable and connector loss.

### 6.5.1 100G–CLR4 Transmit Optical Specifications With FEC

The 100G–CLR4 transmitter shall meet the specifications defined in Table 7 in systems with IEEE 802.3 Clause 91, RS-FEC (528, 514) applied. If the transmitter meets the parameters in Table 4 it will meet the parameters in Table 7 by default.

**Table 7: 100G-CLR4 Optical Transmit Characteristics**

| Description | Min | Typical | Max | Unit |
|---|---|---|---|---|
| Signaling rate, each lane (range) | | 25.78125<br>± 100 ppm | | Gb/s |
| Pre-FEC BER | | $2.1 \times 10^{-5}$ | | |
| Lane wavelength range | | 1264.5 to 1277.5<br>1284.5 to 1297.5<br>1304.5 to 1317.5<br>1324.5 to 1337.5 | | nm |
| Operating link reach | 2 | | 2000 | m |
| Side-mode suppression ratio (SMSR) | 30 | | | dB |
| Total average launch power | | | 8.5 | dBm |
| Average launch power, each lane | -6.5 | | 2.5 | dBm |
| Optical Modulation Amplitude (OMA) each lane [1] | -4 | | 2.5 | dBm |
| Launch power in OMA minus TDP each lane | -5 | | | dBm |
| Transmitter & dispersion penalty (TDP) each lane[2] | | | 2.7 | dB |
| Average launch power of OFF transmitter each lane | | | -30 | dBm |
| Extinction ratio | 3.5 | | | dB |
| $RIN_{20}OMA$ | | | -130 | dB/Hz |
| Optical return loss tolerance | | | 20 | dB |
| Transmitter reflectance | | | -20 | dB |
| Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3} | | {0.31, 0.4, 0.45, 0.34, 0.38, 0.4} | | |

[1] Even if the TDP < 1.0 dB, the OMA (min) must exceed this value.
[2] A tradeoff regarding the transmitter launch power can be made.

### 6.5.2 100G–CLR4 Receive Optical Specifications With FEC

The 100G–CLR4 receiver shall meet the specifications defined in Table 8 in systems with IEEE 802.3 Clause 91 (RS-FEC) applied.

**Table 8: 100G-CLR4 Optical Receive Characteristics With FEC**

| Description | Min | Typical | Max | Unit |
|---|---|---|---|---|
| Signaling rate, each lane (range) | | 25.78125 ± 100 ppm | | Gb/s |
| Pre-FEC BER | | $2.1 \times 10^{-5}$ | | |
| Lane wavelength range | | 1264.5 to 1277.5<br>1284.5 to 1297.5<br>1304.5 to 1317.5<br>1324.5 to 1337.5 | | nm |
| Damage threshold[1] | 3.5 | | | dBm |
| Average receive power, each lane[2] | -12.5 | | 2.5 | |
| Receive power, each lane (OMA) | | | 2.5 | |
| Difference in receive power between any two lanes (OMA) | | | 5.5 | |
| Receiver reflectance | | | -26 | dB |
| Receiver sensitivity (OMA), each lane[3,4] | | | -10.9 | dBm |
| Stressed receiver sensitivity (OMA), each lane,[3,5] | | | -8.5 | dBm |
| Vertical eye closure penalty[3,6], each lane | | | 1.95 | dB |
| Stressed eye J2 Jitter[3,6], each lane | | | 0.33 | UI |
| Stressed eye J4 Jitter[3,6], each lane | | | 0.48 | UI |

[1]The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.
[2]Average receive power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.
[3]With-FEC numbers provided for reference; each parameter is met if the equivalent CLR4 parameter without FEC is met
[4]Receiver sensitivity (OMA), each lane (max) is informative at BER = $2.1 \times 10^{-5}$.
[5]Measured with conformance test signal at TP3 for BER = $2.1 \times 10^{-5}$.
[6]Vertical eye closure penalty, stressed eye J2 Jitter, and stressed eye J4 Jitter are test conditions for measuring stressed receiver sensitivity. They are not characteristics of the receiver. A max. TDP of 3 dB is assumed.

### 6.5.3 100G-CLR4 Illustrative Link Power Budget

An illustrative power budget and penalties for 100G-CLR4 optical channels are shown in Table 9 with IEEE 802.3 Clause 91 (RS-FEC) applied.

**Table 9: 100G–CLR4 Illustrative Link Power Budget With FEC**

| Parameter | 100G-CLR4 |
|---|---|
| Operating distance (km) | 2 |
| Fiber loss (dB/km) | 0.5 |
| Total Channel loss (dB) | 5.9 |
| TDP (dB) | 2.7 |
| Total Power Budget (dB)[1] | 8.6 |

[1] 0.4 dB max. MPI penalty is included in the power budget

### 6.5.4 Additional Notes on Specifications With FEC and Lower BER Operation

- As mentioned in the notes to Table 5 above, CLR4 links operating at a BER of $10^{-12}$ and meeting the CLR4 transmit and receive optical characteristics outlined in Sections 6.2 and 6.3 are designed to achieve a link BER of $1x10^{-15}$ after FEC is applied.
- CLR4 specifications with FEC are provided for reference; CLR4 specifications with FEC are met by design if the CLR4 specifications without FEC are met, so it is not necessary to test and verify both sets of parameters.
- CLR4 specifications with FEC ensure interoperation with CWDM4 MSA draft revision 1.0 interfaces with a post-FEC BER of $10^{-12}$.

# 7 Definition of Optical Parameters and Measurement Methods

All transmitter optical measurements shall be made through a short patch cable, between 2 m and 5 m in length, unless otherwise specified.

## 7.1 Test Patterns for Optical Parameters

While compliance is to be achieved in normal operation, specific test patterns are defined for measurement consistency and to enable measurement of some parameters. Table 10 gives the test patterns to be used in each measurement, unless otherwise specified, and also lists references to the references in which each parameter is defined. Any of the test patterns given for a particular test in Table 11 may be used to perform that test. The test patterns used in this clause are shown in Table 10.

**Table 10: Test Patterns**

| Pattern | Pattern description | Defined in |
|---|---|---|
| Square wave | Square wave (8 ones, 8 zeros) | IEEE802.3 Clause 83.5.10 |
| 3 | PRBS31 | IEEE802.3 Clause 83.5.10 |
| 4 | PRBS9 | IEEE802.3 Clause 83.5.10 |
| 5 | RS-FEC scrambled idle pattern[1] | IEEE802.3 Clause 82.2.10 (IEEE802.3 Clause 91)[1] |

[1] Scrambled idle pattern is encoded with Clause 91 RS-FEC .

**Table 11: Test-Pattern Definitions**

| Parameter | Pattern |
|---|---|
| Wavelength | 3, 5 |
| Side mode suppression ratio | 3, 5 |
| Average optical power | 3, 5 |
| Optical modulation amplitude (OMA) | Square wave or 4 |
| Transmitter and dispersion penalty (TDP) | 3 or 5 |
| Extinction ratio | 3, 5 |
| $RIN_{20}OMA$ | Square wave or 4 |
| Transmitter optical waveform | 3, 5 |
| Stressed receiver sensitivity | 3 or 5 |
| Calibration of OMA for receiver tests | Square wave or 4 |
| Vertical eye closure penalty calibration | 3 or 5 |
| Receiver 3 dB electrical upper cutoff frequency | 3, 5 |

## 7.2 Skew and Skew Variation

Refer to IEEE Std 802.3TM-2012 Clause 87.8.2. CLR4 transceivers shall comply with the skew and skew variation limits of clause 88.3.2.

## 7.3 Wavelength

The wavelength of each optical lane shall be within the ranges given in Table 8 if measured per TIA/EIA–455–127–A or IEC 61280–1–3. The lane under test is modulated using the test pattern defined in Table 11.

## 7.4 Average Optical Power

The average optical power of each lane shall be within the limits given in Table 4 if measured using the methods given in IEC 61280–1–1, with the sum of the optical power from all of the lanes not under test below –30 dBm, per the test setup in IEEE802.3 clause 88.8.3 Figure 53–6.

## 7.5 Optical Modulation Amplitude (OMA)

OMA shall be as defined in IEEE802.3 clause 88.8.4 for measurement with a square wave (8 ones, 8 zeros) test pattern or IEEE802.3 clause 68.6.2 (from the variable measured OMA in IEEE802.3 clause 68.6.6.2) for measurement with a PRBS9 test pattern.

## 7.6 Transmitter and Dispersion Penalty (TDP)

Transmitter and dispersion penalty (TDP) shall be as defined in IEEE802.3 clause 88.8.5 with the exception that each optical lane is tested individually using an optical filter to separate the lane under test from the others.

The optical filter passband ripple shall be limited to 0.5 dB peak-to-peak and the isolation is chosen such that the ratio of the power in the lane being measured to the sum of the powers of all of the other lanes is greater than 20 dB (see ITU-T G.959.1 Annex B). The lanes not under test shall be operating with PRBS31 or valid data streams.

## 7.7 Reference Transmitter Requirements

The reference transmitter is a high-quality instrument-grade device, which can be implemented by a CW laser modulated by a high-performance modulator. The basic requirements are as follows:

a) Rise/fall times of less than 12 ps at 20% to 80%.
b) The output optical eye is symmetric and passes the transmitter optical waveform test
c) In the center 20% region of the eye, the worst-case vertical eye closure penalty as defined in IEEE802.3 clause 87.8.11.2 is less than 0.5 dB.
d) Total Jitter less than 0.2 UI peak-to-peak.
e) RIN of less than –138 dB/Hz.

## 7.8 Channel Requirements

The transmitter is tested using an optical channel that meets the requirements listed in Table 12.

**Table 12: Transmitter Compliance Channel Specification**

| Dispersion[a] (ps/nm) | | Insertion loss[b] | Optical return loss[c] |
|---|---|---|---|
| Minimum | Maximum | | |
| $0.0465 \times \lambda \times [1 - (1324 / \lambda)^4]$ | $0.0465 \times \lambda \times [1 - (1300 / \lambda)^4]$ | Minimum | 20 dB |

[a]The dispersion is measured for the wavelength of the device under test ($\lambda$ in nm). The coefficient assumes 2 km.

[b]There is no intent to stress the sensitivity of the BERT's optical receiver.

[c]The optical return loss is applied at TP2.

## 7.9 Reference Receiver Requirements

The reference receiver is required to have the bandwidth given in 7.13. The sensitivity of the reference receiver is limited by Gaussian noise. The receiver has minimal threshold offset, deadband, hysteresis, baseline wander, deterministic jitter, or other distortions. Decision sampling has minimal uncertainty and setup/hold times.

The nominal sensitivity of the reference receiver, S, is measured in OMA using the setup of IEEE802.3 Figure 52–12 without the test fiber and with the transversal filter removed. The sensitivity S must be corrected for any significant reference transmitter impairments including any vertical eye closure. It is measured while sampling at the eye center or corrected for off-center sampling. It is calibrated at the wavelength of the transmitter under test.

For all transmitter and dispersion penalty measurements, determination of the center of the eye is required. Center of the eye is defined as the time halfway between the left and right sampling points within the eye where the measured BER is greater than or equal to $1x10^{-3}$.

The clock recovery unit (CRU) used in the TDP measurement has a corner frequency of 10 MHz and a slope of 20 dB/decade. When using a clock recovery unit as a clock for BER measurements, passing of low-frequency jitter from the data to the clock removes this low-frequency jitter from the measurement.

## 7.10 Test Procedure

The test procedure is as defined in IEEE802.3 Clause 52.9.10.4 with the exception that all lanes are operational in both directions (transmit and receive), each lane is tested individually using an optical filter to separate the lane under test from the others and the BER of $1x10^{-12}$ ($2.1x10^{-5}$ with FEC) is for the lane under test on its own.

## 7.11 Extinction Ratio

The extinction ratio of each lane shall be within the limits given in Table 4 if measured using the methods specified in IEC 61280–2–2, with the sum of the optical power from all of the lanes not under test below –30 dBm. The extinction ratio is measured using the test pattern defined in Table 10. NOTE—Extinction ratio and OMA are defined with different test patterns (see Table 11).

## 7.12 Relative Intensity Noise ($RIN_{20}OMA$)

RIN shall be as defined by the measurement methodology of IEEE802.3 Clause 52.9.6 with the following exceptions:

a) The optical return loss is 20 dB.
b) Each lane may be tested individually with the sum of the optical power from all of the lanes not under test being below –30 dBm, or if other lanes are operating, a suitable optical filter may be used to separate the lane under test.
c) The upper –3 dB limit of the measurement apparatus is to be approximately equal to the signaling rate (i.e., 25.8 GHz).

## 7.13 Transmitter Optical Waveform (Transmit Eye)

The required optical transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 2. The transmitter optical waveform of a port transmitting the test pattern specified in Table 11 shall meet specifications of Table 4 when using a receiver with the fourth-order Bessel-Thomson response having a transfer function given by Equation 1:

**Equation 1: Bessel Thomson Filter**

$$H(y) = \frac{105}{105 + 105y + 45y^2 + 10y^3 + y^4}$$

where:

$$y = 2.114p \; ; \quad p = \frac{j\omega}{\omega_r} \; ; \quad \omega_r = 2\pi f_r \; ; \quad f_r = \text{Reference frequency in GHz}$$

Normalized times of 0 and 1 on the unit interval scale are determined by the eye crossing, i.e. measured at the average value of the eye pattern. A clock recovery unit (CRU) is used to trigger the oscilloscope for mask measurements. It has a high-frequency corner bandwidth of 10 MHz and a slope of –20 dB/decade. The CRU tracks acceptable levels of low-frequency jitter and wander. The filter nominal reference frequency *f*r is 19.34 GHz and the filter tolerances are as specified for STM-64 in ITU-T G.691. The Bessel-Thomson receiver is not intended to represent the noise filter used within a compliant optical receiver, but is intended to provide uniform measurement conditions at the transmitter. Compensation may be made for variation of the reference receiver filter response from an ideal fourth-order Bessel-Thomson response.

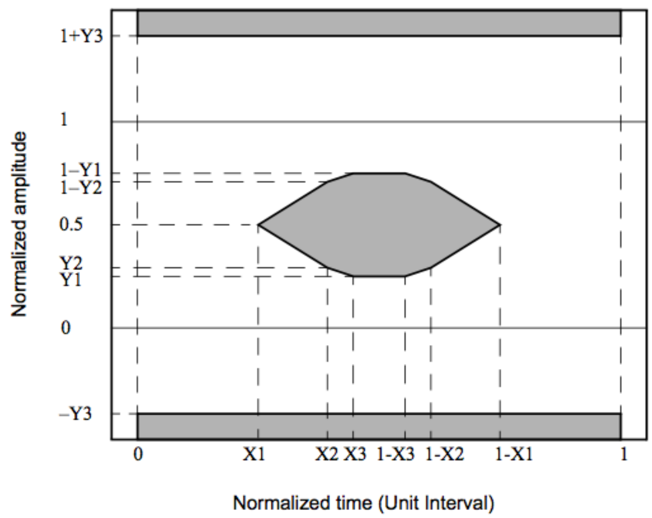


**Figure 2: Transmit Eye Mask**

## 7.14 Receiver Sensitivity

Receiver sensitivity, which is defined for an ideal input signal, is informative and compliance is not required. If measured, the test signal should have negligible impairments such as intersymbol interference (ISI), rise/fall times, jitter and RIN. Instead, the normative requirement for receivers is stressed receiver sensitivity.

## 7.15 Stressed Receiver Sensitivity

Stressed receiver sensitivity shall be within the limits given in Table 1 if measured using the method defined in IEEE 802.3 87.8.11 with the following exceptions:

a) Added sinusoidal jitter is as specified in Table 13.
b) The stressed eye J2 Jitter, stressed eye J9 Jitter, and vertical eye closure penalty are as given in Table 5.
c) The test pattern is as given in Table 10.
d) The reference receiver used to verify the conformance test signal is required to have the bandwidth given in 7.13.

**Table 13: Applied Sinusoidal Jitter**

| Frequency range | Sinusoidal jitter, peak-to-peak (UI) |
|---|---|
| f < 100 kHz | Not specified |
| 100 kHz < f ≤ 10 MHz | $5 \times 10^5 / f$ |
| 10 MHz < f < 10 LB[a] | 0.05 |

[a]LB = loop bandwidth; upper frequency bound for added sine jitter should be at least 10 times the loop bandwidth of the receiver being tested.

# 8 Safety, Installation, Environment, and Labeling

## 8.1 General Safety

All equipment subject to this clause shall conform to IEC 60950-1.

## 8.2 Laser Safety

100G-CLR4 optical transceivers shall conform to Class 1 laser requirements as defined in IEC 60825–1 and IEC 60825–2, under any condition of operation. This includes single fault conditions whether coupled into a fiber or out of an open bore. Conformance to additional laser safety standards may be required for operation within specific geographic regions.

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

## 8.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

## 8.4 Environment

Normative specifications in this document shall be met by a system integrating a 100G–CLR4 module over the life of the product while the product operates within the manufacturer's range of environmental, power, and other specifications.

It is recommended that manufacturers indicate in the literature associated with the PHY the operating environmental conditions to facilitate selection, installation, and maintenance. It is further recommended that manufacturers indicate, in the literature associated with the components of the optical link, the distance and operating environmental conditions over which the specifications of this clause will be met.

## 8.5 Electromagnetic Emission

A system integrating a 100G–CLR4 module shall comply with applicable local and national codes for the limitation of electromagnetic interference.

## 8.6 Temperature, Humidity, and Handling

The optical link is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). Specific requirements and values for these parameters are considered to be beyond the scope of this standard.

## 8.7 Module Labeling Requirements

It is recommended that each PHY (and supporting documentation) be labeled in a manner visible to the user, with at least the applicable safety warnings and the applicable port type designation (e.g., 100G–CLR4). Labeling requirements for Class 1 lasers are given in the laser safety standards referenced in 8.2.

# 9 Fiber Optic Cabling Model

## 9.1 Characteristics of the Fiber Optic Cabling (Channel)

The fiber optic cable requirements are satisfied by cables containing IEC 60793–2–50 type B1.1 (dispersion un-shifted single-mode), type B1.3 (low water peak single-mode), or type B6_A (bend insensitive) fibers and the requirements in Table 14 where they differ.

**Table 14: Optical Fiber and Cable Characteristics**

| Description | Value | Unit |
|---|---|---|
| Nominal fiber specification wavelength | 1310 | nm |
| Cabled optical fiber attenuation (max) | 0.43[a] or 0.5[b] | dB/km |
| Zero dispersion wavelength (λ0) | 1300 ≤ λ0 ≤ 1324 | nm |
| Dispersion slope (max) (S0) | 0.093 | $ps/nm^2$ km |

[a]The 0.43 dB/km at 1295 nm attenuation for optical fiber cables is derived from Appendix I of ITU-T G.695.

[b]The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA/EIA 568-B.3-2000. Table 15 below exhibits connector loss for links comprised of numbers of various LC and MPO connectors, where FEC is optional and where FEC is required.

## 9.2 Connector Discrete Reflectance Requirements

CLR4 links supports up to 2 mid-span connectors when the maximum connector discrete reflectance is equal or less than -26 dB per TIA-568C.

CLR4 links supports up to 6 mid-span connectors when the maximum connector discrete reflectance is equal or less than -35 dB per ISO/IEC11801.

## 9.3 Medium Dependent Interface (MDI) Requirements

The 100G-CLR4 module is coupled to the fiber optic cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling”. Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

When the MDI is a connector plug and receptacle connection, it shall meet the interface performance specifications of IEC 61753–1–1 and IEC 61753–021–2.

# Annex A. Link Budget Configuration (Informative)

## A1. Connector Reflection

CLR4 cable plants support both -26 dB connector reflectance as well as -35 dB connector reflectance with maximum connector reflection penalty (MPI) of 0.4 dB.

## A2. Connector Loss

The maximum link distance is based on an allocation of 2.5 dB (no FEC) and 5.9 dB (with FEC) total connection and splice loss. For the connector a statistical estimation approach can be taken based on the Raleigh probability distribution of the connector loss. By using a multiplier of 2.5 on the standard deviation, 98.4% of the population is covered assuming maximum MPI penalty of 0.4 dB.

## A3. Link Budget Example Without FEC

In Table 15 examples are given including all channel loss parameters for a non FEC loss budget of 2.5 dB. Tradeoffs between the number of connectors, the connector reflectance, and fiber reach can be made. In systems with less than two connectors the connector reflectance needs to better than -26 dB. If there are more than 2 connectors in the link the connector reflectance needs to be better than -35 dB.

**Table 15: Channel Loss Examples without FEC**

| LC µ | LC σ | No | Std | Sum LC | MPO µ | MPO σ | No | Std | Sum MPO | RL | MPI | All Conn | fiber | reach | Total | Budget | Margin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [dB] | [dB] | | | [dB] | [dB] | [dB] | | | [dB] | [dB] | [dB] | [dB] | [dB/km] | [km] | [dB] | [dB] | [dB] |
| 0.2 | 0.15 | **2** | 2.5 | 0.93 | 0.35 | 0.25 | **0** | 2.5 | 0.00 | 26 | 0.3 | **0.93** | 0.5 | **0.1** | **1.31** | 2.5 | **1.19** |
| 0.2 | 0.15 | **0** | 2.5 | 0.00 | 0.35 | 0.25 | **2** | 2.5 | 1.58 | 26 | 0.3 | **1.58** | 0.5 | **0.1** | **1.96** | 2.5 | **0.54** |
| 0.2 | 0.15 | **2** | 2.5 | 0.93 | 0.35 | 0.25 | **0** | 2.5 | 0.00 | 26 | 0.3 | **0.93** | 0.5 | **2** | **2.26** | 2.5 | **0.24** |
| 0.2 | 0.15 | **2** | 2.5 | 0.93 | 0.35 | 0.25 | **2** | 2.5 | 1.58 | 35 | 0.2 | **2.13** | 0.5 | **0.1** | **2.41** | 2.5 | **0.09** |

## A4. Link Budget Example With FEC

In Table 16 examples are given including all channel loss parameters for a loss budget of 5.9 dB with system FEC. Tradeoffs between the number of connectors, the connector reflectance, and fiber reach can be made. In systems with less than 6 connectors the connector reflectance needs to be better than -26 dB.

**Table 16: Channel Loss Examples with FEC**

| LC µ | LC σ | No | Std | Sum LC | MPO µ | MPO σ | No | Std | Sum MPO | RL | MPI | All Conn | fiber | reach | Total | Budget | Margin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [dB] | [dB] | | | [dB] | [dB] | [dB] | | | [dB] | [dB] | [dB] | [dB] | [dB/km] | [km] | [dB] | [dB] | [dB] |
| 0.2 | 0.15 | **4** | 2.5 | 1.55 | 0.35 | 0.25 | **0** | 2.5 | 0.00 | 26 | 0.9 | **1.55** | 0.5 | **2** | **3.41** | 5.9 | **2.49** |
| 0.2 | 0.15 | **0** | 2.5 | 0.00 | 0.35 | 0.25 | **4** | 2.5 | 2.65 | 26 | 0.9 | **2.65** | 0.5 | **2** | **4.51** | 5.9 | **1.39** |
| 0.2 | 0.15 | **2** | 2.5 | 0.93 | 0.35 | 0.25 | **2** | 2.5 | 1.58 | 26 | 0.9 | **2.13** | 0.5 | **2** | **3.99** | 5.9 | **1.91** |
| 0.2 | 0.15 | **3** | 2.5 | 1.25 | 0.35 | 0.25 | **3** | 2.5 | 2.13 | 26 | 1.7 | **2.91** | 0.5 | **2** | **5.61** | 5.9 | **0.29** |

# Annex B. Glossary

| | |
|---|---|
| PMD | Physical Media Dependent |
| MDI | Medium Dependent Interface |
| MCB | Module Compliance Board |
| HCB | Host Compliance Board |
| BER | Bit Error Rate |
| FEC | Forward Error Correction |
| RS | Reed-Solomon (cyclic error correction codes) |