400G-LR4-10 Technical Specification

100G Lambda MSA Group

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Revisions

Rev	Date	Description
1.0	September 15, 2020	Initial Release
2.0		
3.0		

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TABLES

FIGURES

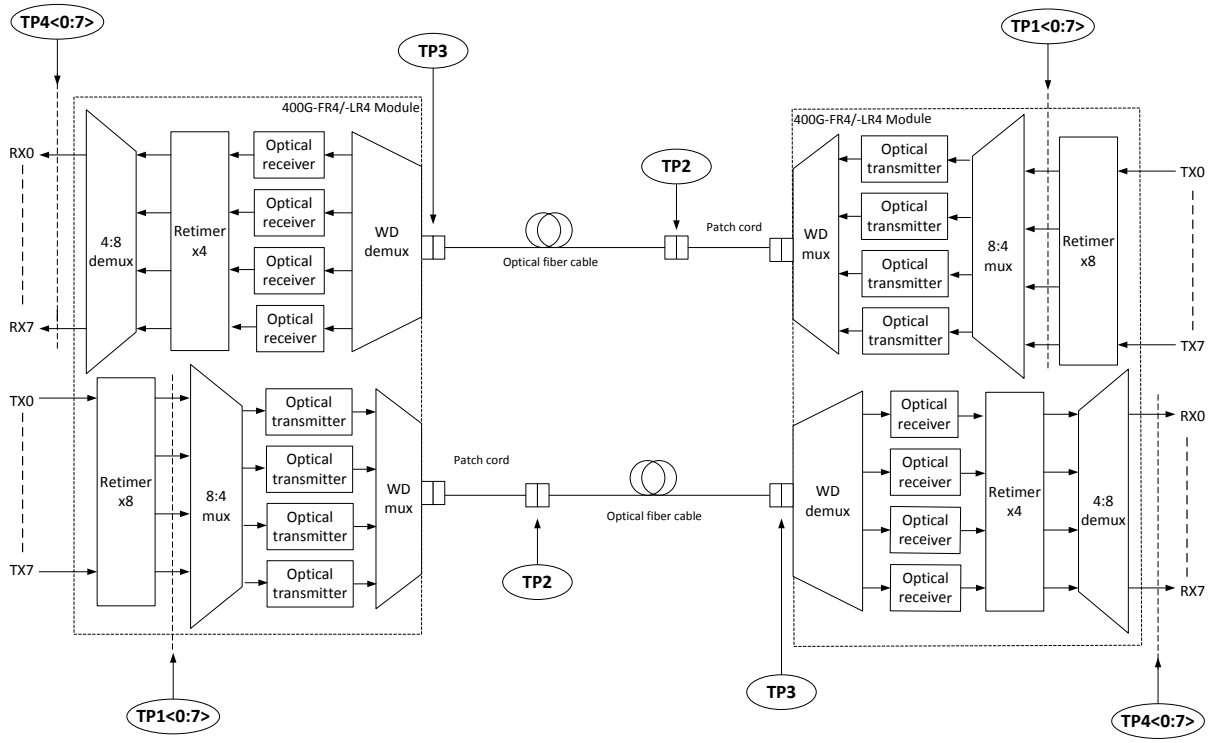
1 GENERAL

1.1 SCOPE

This Multi-Source Agreement (MSA) defines 4 x 100 Gbps Coarse Wavelength Division Multiplex (CWDM) optical interface for 400 Gbps optical transceivers for Ethernet applications. Forward error correction (FEC) is required to be implemented by the host in order to ensure reliable system operation. Two transceivers communicate over single mode fibers (SMF) of length from 2 meters to at least 10 kilometers (400G-LR4-10). The transceiver electrical interface is not specified by this MSA but can have, for example, eight lanes in each direction with a nominal signaling rate of 53.125 Gbps per lane or four lanes in each direction with a nominal signaling rate of 106.25 Gbps per lane.

A variety of form factors for the 400G-LR4-10 transceivers are possible and none are precluded by this MSA.

1.2 400G-LR4-10 MODULE BLOCK DIAGRAM



WD = Wavelength division

NOTE – Specification of the retime function is beyond the scope of this MSA.

Figure 1-1: Block diagram for 400G-LR4-10 transmit/receive paths

1.3 FUNCTIONAL DESCRIPTION

400G-LR4-10 modules comply with the requirements of this document and have the following common features: four optical transmitters; four optical receivers with signal detect; wavelength division multiplexer and demultiplexer; and a duplex optical connector for single-mode fiber. The optical connector type is vendor specific but can include SC, LC or CS types.

1.4 HARDWARE SIGNALING PINS

Hardware signaling pins are specified in the respective module form factor MSAs.

1.5 MODULE MANAGEMENT INTERFACE

The contents of the various ID registers shall comply with the requirements of the module MSA and the respective standards.

1.6 HIGH SPEED ELECTRICAL CHARACTERISTICS

The detailed high-speed electrical characteristics are not defined by this MSA. 400GE modules should be implemented in compliance with applicable electrical interface specifications.

1.7 FEC REQUIREMENTS

The 400G-LR4-10 link relies on the host system implementing the 400GBASE-R PCS layer in accordance with clause 119 of IEEE Std 802.3-2018™. The PCS layer includes implementation of RS(544,514) FEC encode and decode functions.

1.8 MECHANICAL DIMENSIONS

Mechanical dimensions are defined in module form factor MSA specifications.

2 400G-LR4-10 OPTICAL SPECIFICATIONS

2.1 WAVELENGTH-DIVISION-MULTIPLEXED LANE ASSIGNMENTS

The wavelength range for each lane of the 400G-LR4-10 PMD is defined in Table 2-1. The center wavelengths are spaced at 20 nm.

Table 2-1: Wavelength-division-multiplexed lane assignments

Lane	Center wavelength	Wavelength range
L_0	1271 nm	1264.5 to 1277.5 nm
L_1	1291 nm	1284.5 to 1297.5 nm
L_2	1311 nm	1304.5 to 1317.5 nm
L_3	1331 nm	1324.5 to 1337.5 nm

2.2 OPTICAL SPECIFICATIONS

The operating range for 400G-LR4-10 PMDs are defined in Table 2-2. A compliant PMD operates on single-mode fibers according to the specifications defined in Table 4-1 and characteristics in 5.1. A PMD that exceeds the required operating range while meeting all other optical specifications is considered compliant (e.g., a 400G-LR4-10 PMD operating at 12 km meets the operating range requirement of 2 m to 10 km).

Table 2-2: 400G-LR4-10 operating ranges

PMD type	Required operating range
400G-LR4-10	2 m to 10 km

2.2.1 400G-LR4-10 transmitter optical specifications

The 400G-LR4-10 transmitter shall meet the specifications defined in Table 2-3.

Table 2-3: 400G-LR4-10 transmit characteristics

Description	400G-LR4-10	Unit
PAM4 Signaling rate, each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Side-mode suppression ratio (SMSR), (min)	30	dB
Total average launch power (max)	11.1	dBm
Average launch power, each lane (max)	5.1	dBm
Average launch power, each lane[a] (min)	–2.7	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.4	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min) for TDECQ < 1.4 dB for 1.4 dB ≤ TDECQ ≤ 3.9 dB	 0.3 –1.1 + TDECQ	 dBm dBm
Difference in launch power between any two lanes (OMA_{outer}) max	4	dB
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.9	dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	3.9	dB
|TDECQ – TECQ| (max)	2.5	dB
Average launch power of OFF transmitter, each lane (max)	-16	dBm
Extinction ratio, each lane (min)	3.5	dB
Transmitter transition time (max)	17	ps
Transmitter over/under-shoot (max)	25	%
Transmitter peak-to-peak power (max)	5.2	dBm
$RIN_{15.6}$ OMA (max)	–136	dB/Hz
Optical return loss tolerance (max)	15.6	dB
Transmitter reflectance[b] (max)	–26	dB

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

[b] Transmitter reflectance is defined looking into the transmitter.

2.2.2 400G-LR4-10 receive optical specifications

The 400G-LR4-10 receiver shall meet the specifications defined in Table 2-4.

Table 2-4: 400G-LR4-10 receive characteristics

Description	400G-LR4-10	Unit
PAM4 Signaling rate, each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Damage threshold, each lane (min)[a]	6.1	dBm
Average receive power, each lane (max)	5.1	dBm
Average receive power, each lane[b] (min)	–9	dBm
Receive power, each lane (OMA_{outer}), each lane (max)	4.4	dBm
Difference in receive power between any two lanes (OMA_{outer}) (max)	4.3	dB
Receiver reflectance (max)	–26	dB
Receiver sensitivity (OMA_{outer}), each lane (max) for TECQ < 1.4 dB for 1.4 dB ≤ TECQ ≤ 3.9 dB	 –6.8 –8.2 + TECQ	 dBm dBm
Stressed receiver sensitivity (OMA_{outer}), each lane[c] (max)	–4.3	dBm
Conditions of stressed receiver sensitivity test[d]:		
Stressed eye closure for PAM4 (SECQ), lane under test	3.9	dB
OMA_{outer} of each aggressor lane	-0.4	dBm

[a] The receiver shall be able to tolerate, without damage, continuous exposure to an optical signal having this average power level. The receiver does not have to operate correctly at this input power.

[b] 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.

[c] Measured with conformance test signal at TP3 (see 3.14) for the BER specified in IEEE Std 802.3-2018 clause 124.1.1.

[d] These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

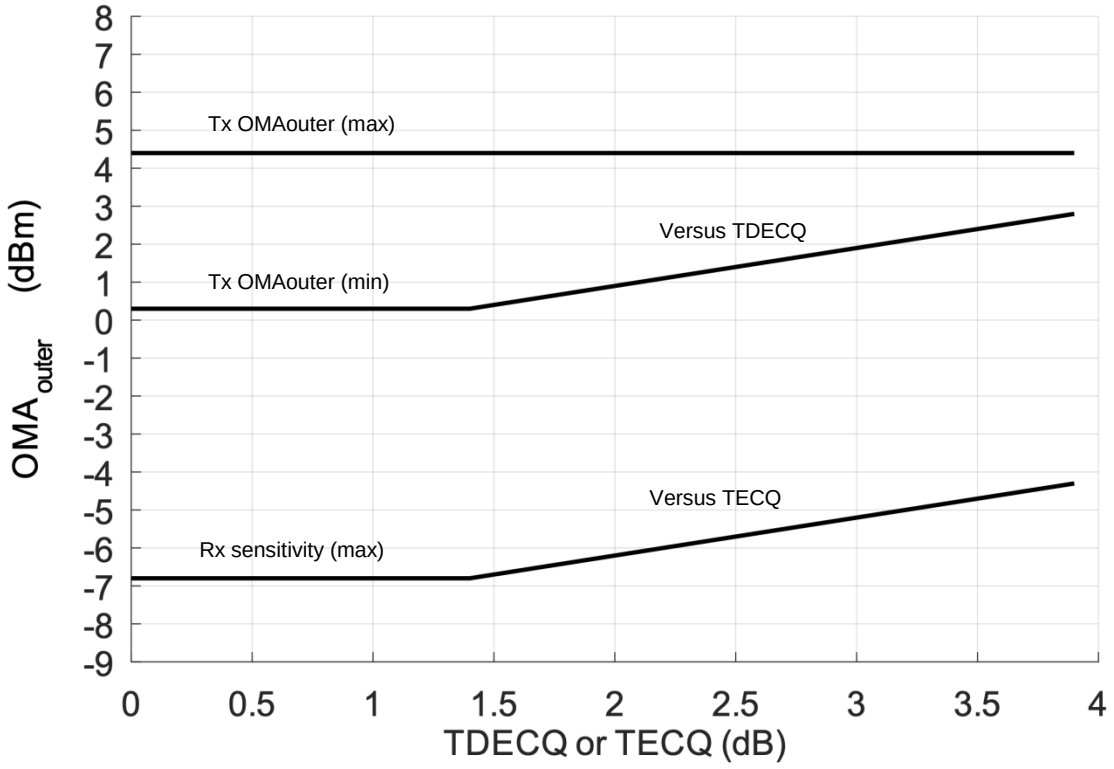


Figure 2-1: Illustration of transmitter OMA_{outer} versus TDECQ and receiver sensitivity versus TECQ for 400G-LR4-10

2.2.3 400G-LR4-10 illustrative link power budgets

Illustrative power budgets and penalties for 400G-LR4-10 are shown in Table 2-5.

Table 2-5: 400G-LR4-10 illustrative power budgets

Description	400G-LR4-10	Unit
Power budget (for maximum TDECQ)	11	dB
Operating distance	10	km
Channel insertion loss[a]	6.3	dB
Maximum discrete reflectance	See Table 2-6	dB
Allocation for penalties[b] (for max TDECQ)	4.7	dB
Additional insertion loss allowed	0	dB
[a] The channel insertion loss is calculated using the maximum distance specified in Table 2-2 and cabled optical fiber attenuation of 0.47 dB/km plus an allocation for connection and splice loss given in 5.2.1.		
[b] Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.		

Table 2-6: 400G-LR4-10 Maximum values for each discrete reflectance

Number of discrete reflectance above -55dB	Maximum value for each discrete reflectance
	400G-LR4-10
1	-22 dB
2	-29 dB
4	-33 dB
6	-35 dB
8	-37 dB
10	-39 dB

3 DEFINITION OF OPTICAL PARAMETERS AND MEASUREMENT METHODS

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

Table 3-1: Test patterns

Pattern	Pattern Description	Defined in[a]
Square wave	Square wave (8 threes, 8 zeroes)	120.5.11.2.4
3	PRBS31Q	120.5.11.2.2
4	PRBS13Q	120.5.11.2.1
5	Scrambled idle	119.2.4.9
6	SSPRQ	120.5.11.2.3
[a] These sub-clauses make reference to relevant clauses of IEEE Std 802.3-2018.		

3.1 TEST PATTERNS FOR OPTICAL PARAMETERS

Table 3-2: Test pattern definitions and related subclauses

Parameter	*Pattern*	*Reference*
Wavelength	Square wave, 3, 4, 5, 6 or valid 400GBASE-R signal	3.3
Side mode suppression ratio	3, 5, 6 or valid 400GBASE-R signal	3.3
Average optical power	3, 5, 6 or valid 400GBASE-R signal	3.4
Optical modulation amplitude (OMA_{outer})	4 or 6	3.5
Transmitter and dispersion eye closure for PAM4 (TDECQ)	6	3.6
Transmitter eye closure for PAM4 (TECQ)	6	3.7
Extinction ratio	4 or 6	3.8
Transmitter transition time	Square wave or 6	3.9
Transmitter over/under-shoot	6	3.10
Transmitter peak-to-peak power	6	3.11
$RIN_{15.6}$ OMA	Square wave	3.12
Receiver sensitivity	3 or 5	3.13
Stressed receiver conformance test signal calibration	6	3.14
Stressed receiver sensitivity	3 or 5	3.14

3.2 SKEW AND SKEW VARIATION

The skew and skew variation is specified in IEEE Std 802.3-2018 clause 124.3.

3.3 WAVELENGTH AND SIDE MODE SUPPRESSION RATIO (SMSR)

The wavelength and SMSR of each optical lane shall be within the ranges given in Table 2-3 if measured per IEC 61280-1-3. The lane under test is modulated using the test pattern defined in Table 3-2.

3.4 AVERAGE OPTICAL POWER

The average optical power of each lane shall be within the limits given in Table 2-3 if measured using the methods given in IEC 61280-1-1. The average optical power is measured using the test pattern defined in Table 3-2, with the test setup in IEEE Std 802.3-2018 Figure 53-6.

3.5 OPTICAL MODULATION AMPLITUDE (OMA_{outer})

The OMA_{outer} of each lane shall be within the limits given in Table 2-3. The OMA_{outer} is measured using a test pattern specified for OMA_{outer} in Table 3-2. It is the difference between the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in IEEE Std 802.3-2018 Figure 124–3. Each lane may be tested individually with all other lanes turned off, or by using an optical filter if the other lanes are active.

3.6 TRANSMITTER AND DISPERSION EYE CLOSURE PENALTY (TDECQ)

The TDECQ of each lane shall be within the limits given in Table 2-3 if measured using the methods specified in IEEE Std 802.3-2018 clauses 121.8.5.1, 121.8.5.2, and 121.8.5.3 using a reference equalizer as described in section 3.6.1, with the following exceptions:

- The transmitter is tested using an optical channel that meets the requirements listed in Table 3-3.
- The signaling rate of the test pattern generator is as given in Table 2-3 and uses the test pattern specified for TDECQ in Table 3-2.
- The combination of the O/E converter and the oscilloscope has a fourth-order Bessel-Thompson filter response with a bandwidth of approximately 26.5625 GHz to at least 1.3 x 53.125 GHz and at frequencies above 1.3 x 53.125 GHz the response should not exceed –20 dB.
- The normalized noise power density spectrum, *N(f)* in Equation (121-9), is equivalent to white noise filtered by a fourth-order Bessel-Thompson response filter with a bandwidth of 26.5625 GHz.
- P_{th1}, P_{th2}, and P_{th3} are varied from their nominal values by up to +/-1% of OMA_{outer} in order to optimize TDECQ. The same three thresholds are used for both the left and the right histogram.

Table 3-3: Transmitter compliance channel specifications

Type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
400G-LR4-10	$0.23*\lambda*[1-(1324/\lambda)^4]$	$0.23*\lambda*[1-(1300/\lambda)^4]$	Minimum	15.6 dB	0.8 ps
[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 10 km for 400G-LR4-10.					
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.					
[c] The optical return loss is applied at TP2, i.e. after a 2 meter patch cord.					

3.6.1 TDECQ reference equalizer

The reference equalizer for 400G-LR4-10 is as specified in IEEE Std 802.3cd clause 140.7.5.1 with the following exception:

— Tap1, tap2 or tap3 has the largest magnitude coefficient, which is constrained be at least 0.8.

3.7 TRANSMITTER EYE CLOSURE FOR PAM4 (TECQ)

The transmitter eye closure for PAM4 (TECQ) is a measure of the optical transmitter's eye closure at TP2. The TECQ of each lane shall be within the limits given in Table 2-3 if measured using a test pattern specified for TECQ in Table 3-2. The TECQ of each lane shall be measured using the methods specified for TDECQ in 3.6, except that the test fiber is not used.

3.8 EXTINCTION RATIO

Extinction ratio is measured using the methods specified in IEEE Std 802.3-2018 clause 124.8.6.

3.9 TRANSMITTER TRANSITION TIME

The transmitter transition time shall be within the limits given in Table 2-3 if measured using a test pattern specified for transmitter transition time in Table 3-2.

The test description for transmitter transition time is in IEEE Std 802.3cd clause 140.7.7.

3.10 TRANSMITTER OVER/UNDER-SHOOT

The transmitter over/under-shoot percentage of each lane shall be within the limits given in Table 2-3 if measured using a test pattern specified for transmitter over/under-shoot in Table 3-2.

The test description for transmitter over/under-shoot is in IEEE draft Std 802.3cu clause 151.8.9.

3.11 TRANSMITTER PEAK-TO-PEAK POWER

The transmitter peak-to-peak power of each lane shall be within the limits given in Table 2-3 if measured using a test pattern specified for transmitter peak-to-peak power in Table 3-2.

The test description for transmitter peak-to-peak power is in IEEE draft Std 802.3cu clause 151.8.10.

3.12 RELATIVE INTENSITY NOISE ($RIN_{15.6}OMA$)

RIN shall be as defined by the measurement methodology of IEEE Std 802.3-2018 clause 52.9.6 with the following exceptions:

a. The optical return loss is 15.6 dB for 400G-LR4-10.
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.
c. The upper –3 dB limit of the measurement apparatus is to be approximately equal to the signaling rate (i.e., 53.2 GHz).
d. The test pattern is according to Table 3-2.

3.13 RECEIVER SENSITIVITY

The receiver sensitivity of each lane shall be within the limits given in Table 2-3 if measured using a test pattern specified for receiver sensitivity in Table 3-2.

The conformance test signal applied at TP3 meets the requirements for a 400G-LR4-10 transmitter followed by an attenuator. An optical demultiplexer may be used to separate the lane having the wavelength for the lane under test as specified in Table 2-4 for calibrating the TECQ.

The TECQ of the conformance test signal is measured according to 3.6, except that the test fiber is not used. The measured value of TECQ is then used to calculate the limit for receiver sensitivity (OMAouter) as specified in Table 2-4.

3.14 STRESSED RECEIVER SENSITIVITY

Stressed receiver sensitivity of each lane shall be within the limits given in Table 2-4 for 400G-LR4-10 if measured using the method defined in IEEE draft 802.3cu clause 151.8.13, using the test pattern specified for SRS in Table 3-2. The BER is required to be met for the lane under test on its own.

4 FIBER OPTIC CABLING MODEL

The fiber optic cabling model is shown in Figure 4-1.

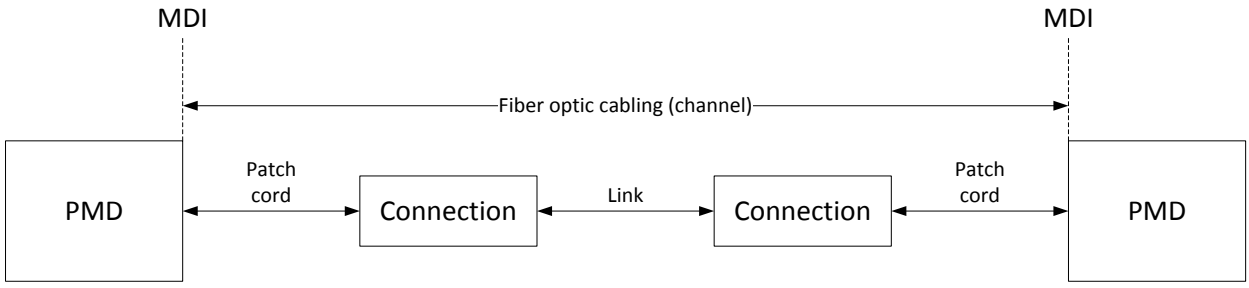


Figure 4-1: Fiber optic cabling model

The channel insertion loss is given in Table 4-1. A channel may contain additional connectors as long as the optical characteristics of the channel, such as attenuation, dispersion, reflections and polarization mode dispersion meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with IEC 61280-4-2 using the one-cord reference method. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards.

Table 4-1: Fiber optic cabling (channel) characteristics

Description	400G-LR4-10	Unit
Operating distance (max)	10	km
Channel insertion loss [a,b] (max)	6.3[c]	dB
Channel insertion loss (min)	0	dB
Positive dispersion[b] (max)	33.1	ps/nm
Negative dispersion[b] (min)	-58.7	ps/nm
DGD_max[d]	5	ps
Optical return loss (min)	22	dB
[a] These channel loss values include cable, connectors and splices.		
[b] Over the wavelength range 1264.5 to 1337.5 nm.		
[c] Using 0.47 dB/km at 1264.5 nm attenuation for optical fiber cables derived from Appendix I of ITU-T G.695 may not support operation at 10 km for 400G-LR4-10 under worst case conditions.		
[d] Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system must tolerate.		

5 CHARACTERISTICS OF THE FIBER OPTIC CABLING (CHANNEL)

The 400G-LR4-10 fiber optic cabling shall meet the specifications defined in Table 4-1. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together.

5.1 OPTICAL FIBER CABLE

The fiber optic cable requirements are satisfied by cables containing ITU-T G.652.B (dispersion unshifted), type G.652.D (low water peak, dispersion unshifted), or type G.657.A1, or type G.657.A2 (bend insensitive) fibers, or the requirements in Table 5-1 where they differ.

Table 5-1: Optical fiber and cable characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.47[a]	dB/km
Zero dispersion wavelength (λ_0)	$1300 \leq \lambda_0 \leq 1324$	nm
Dispersion slope (max) (S_0)	0.092	ps/nm^2km
[a] The 0.47 dB/km at 1264.5 nm attenuation for optical fiber cables is derived from Appendix I of ITU-T G.695.		

5.2 OPTICAL FIBER CONNECTION

An optical fiber connection, as shown in Figure 4-1, consists of a mated pair of optical connectors.

5.2.1 Connection insertion loss

The maximum link distance for 400G-LR4-10 is based on an allocation of 2 dB for connection and splice loss. For example, this allocation supports four connections with an average insertion loss per connection of 0.5 dB. Connections with different loss characteristics may be used provided the requirements of Table 4-1 are met.

5.2.2 Maximum discrete reflectance

The maximum discrete reflectance shall be less or equal to the value shown in Table 2-6.

5.3 MEDIUM DEPENDENT INTERFACE (MDI) REQUIREMENTS

The PMD is coupled to the fiber optic cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” (as shown in Figure 4-1). 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 and IEC 61753-021-2.

NOTE---Transmitter compliance testing is performed at TP2 i.e. after a 2-meter patch cord, not at the MDI.

6 400G-LR4-10 MODULE COLOR CODING

Transceiver modules compliant to the 400G-LR4-10 Specifications use a color code to indicate the application. This color code can be on a module bail latch, pull tab, or other visible feature of the module when installed in a system. The color code scheme is specified in Table 6-1.

Table 6-1: 400G-LR4-10 Module Color Coding

Color Code	Application
Blue	400G-LR4 10 km reach