100G-FR and 100G-LR Technical Specifications

100G Lambda MSA

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Revisions

Rev	Date	Description
1.0		Initial Release
2.0	2018-09-18	Update to reference optical Tx and Rx test methods from IEEE Std 802.3cd

CONTENTS

TABLES

FIGURES

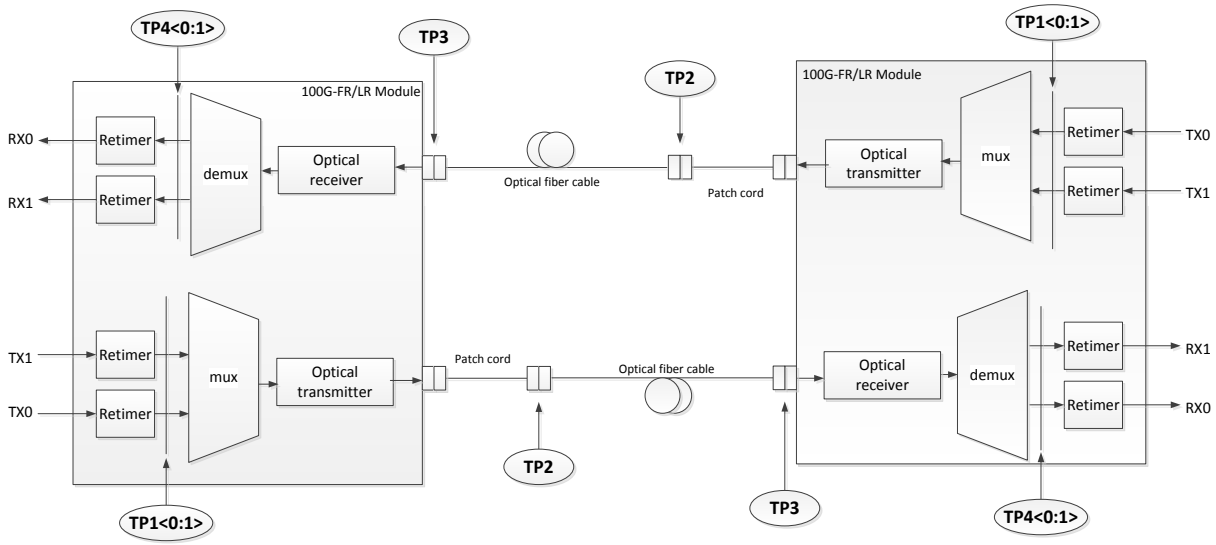
1 GENERAL

1.1 SCOPE

This Multi-Source Agreement (MSA) defines single lane 100 Gbps 2km and 10km optical interface for 100 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 2 kilometers using the 100G-FR specification and 2 meters to at least 10 kilometers using the 100G-LR specification. The transceiver electrical interface is not specified by this MSA but can have, for example, four lanes in each direction with a nominal signaling rate of 26.5625 Gbps, two lanes in each direction with a nominal signaling rate of 53.125 Gbps per lane or a single lane in each direction with a nominal signaling rate of 106 .25 Gbps per lane.

A variety of form factors for the 100G-FR and LR transceivers are possible and none are precluded by this MSA.

1.2 100G-FR AND 100G-LR MODULE BLOCK DIAGRAM



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

Figure 1-1: Block diagram for 100G-FR and 100G-LR transmit/receive paths

1.3 FUNCTIONAL DESCRIPTION

100G-FR and 100G-LR modules comply with the requirements of this document and have the following common features: one optical transmitter; one optical receiver with signal detect and a duplex optical connector for single-mode fiber. The optical connector type is vendor specific but can include SC, LC, MPO 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 FEC REQUIREMENTS

The host system is required to enable RS(544,514) FEC ("KP4 FEC") in accordance with clause 91 of IEEE Std 802.3-2018™. Operation with other FEC codes is beyond the scope of this MSA.

1.7 HIGH SPEED ELECTRICAL CHARACTERISTICS

The detailed high speed electrical characteristics are not defined by this MSA. 100GE modules could be implemented in compliance with applicable electrical interface specifications.

1.8 MECHANICAL DIMENSIONS

Mechanical dimensions are defined in module form factor MSA specifications.

2 100G-FR AND 100G-LR OPTICAL SPECIFICATIONS

2.1 OPTICAL SPECIFICATIONS

The operating range for the 100G-FR and 100G-LR PMDs are defined in Table 2-1. A compliant PMD operates on single-mode fibers according to the specifications defined in Table 4-1 and characteristics in Table 5-1. A PMD that exceeds the required operating range while meeting all other optical specifications is considered compliant (e.g., operating at 2.5 km meets the operating range requirement of 2 m to 2 km).

Table 2-1: 100G-FR and 100G-LR operating range

PMD type	Required operating range
100G-FR	2 m to 2 km
100G-LR	2 m to 10 km

2.1.1 100G-FR and 100G-LR transmitter optical specifications

The 100G-FR and 100G-LR transmitters shall meet the specifications defined in Table 2-2.

Table 2-2: 100G-FR and 100G-LR transmit characteristics

Description	100G-FR Value	100G-LR Value	Unit
PAM4 Signaling rate, (range)	53.125 ± 100 ppm	53.125 ± 100 ppm	GBd
Wavelength (range)	1304.5-1317.5	1304.5- 1317.5	nm
Side-mode suppression ratio (SMSR), (min)	30	30	dB
Average launch power, (max)	4	4.5	dBm
Average launch power,[a] (min)	-2.4	-1.4	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), (max)	4.2	4.7	dBm
Outer Optical Modulation Amplitude (OMA_{outer}),[b] (min)	-0.2	0.7	dBm
Launch power in OMA_{outer} minus TDECQ, (min): for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 -1.6 -1.5	 -0.7 -0.6	dBm
Transmitter and dispersion penalty eye closure for PAM4 (TDECQ), (max)	3.4	3.4	dB
TDECQ – $10*\log_{10}(C_{eq})$ (max)[d]	3.4	3.4	dB
Average launch power of OFF transmitter, (max)	-15	-15	dBm
Extinction ratio (min)	3.5	3.5	dB
Optical return loss tolerance (max)	17.1	15.6	dB
Transmitter reflectance[c] (max)	-26	-26	dB
Transmitter transition time (max)	17	17	ps
$RIN_{17.1}$ OMA (max) for FR, $RIN_{15.6}$ OMA (max) for LR	-136	-136	dB/Hz

[a] Average launch power, (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] Even if the TDECQ < 1.4 dB for an extinction ratio of ≥ 4.5 dB or TDECQ < 1.3 dB for an extinction ratio of < 4.5 dB, the OMA_{outer} (min) must exceed this value.

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

[d] C_{eq} is a coefficient defined in IEEE Std 802.3-2018 clause 121.8.5.3 which accounts for reference equalizer noise enhancement.

2.1.2 100G-FR and 100G-LR receive optical specifications

The 100G-FR and 100G-LR receiver shall meet the specifications defined in Table 2-3.

Table 2-3: 100G-FR and 100G-LR receive characteristics

Description	100G-FR Value	100G-LR Value	Unit
PAM4 Signaling rate, (range)	53.125 ± 100 ppm	53.125 ± 100 ppm	GBd
Wavelength (range)	1304.5 to 1317.5	1304.5 to 1317.5	nm
Damage threshold, (min)[a]	5.5	5.5	dBm
Average receive power, (max)	4.5	4.5	dBm
Average receive power,[b] (min)	-6.4	-7.7	dBm
Receive power, (OMA_{outer}) (max)	4.7	4.7	dBm
Receiver reflectance (max)	-26	-26	dB
Receiver sensitivity (OMA_{outer}),[c] (max)	Equation (1)	Equation (2)	dBm
Stressed receiver sensitivity (OMA_{outer}),[d] (max)	-2.5	-4.1	dBm
Conditions of stressed receiver sensitivity test[e]:			
Stressed eye closure for PAM4 (SECQ)	3.4	3.4	dB
SECQ – $10*\log_{10}(C_{eq})$ (max) [e]	3.4	3.4	dB
[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, (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]Receiver sensitivity (OMA_{outer}), (max) is informative and is defined for a transmitter with a value of SECQ up to 3.4 dB for 100G-FR and 3.4 dB for 100G-LR.			
[d]Measured with conformance test signal at TP3 (see 3.11) for the BER specified in IEEE Std 802.3cd clause 140.1.1.			
[e]These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.			
[e] C_{eq} is a coefficient defined in IEEE Std 802.3-2018 clause 121.8.5.3 which accounts for reference equalizer noise enhancement.			

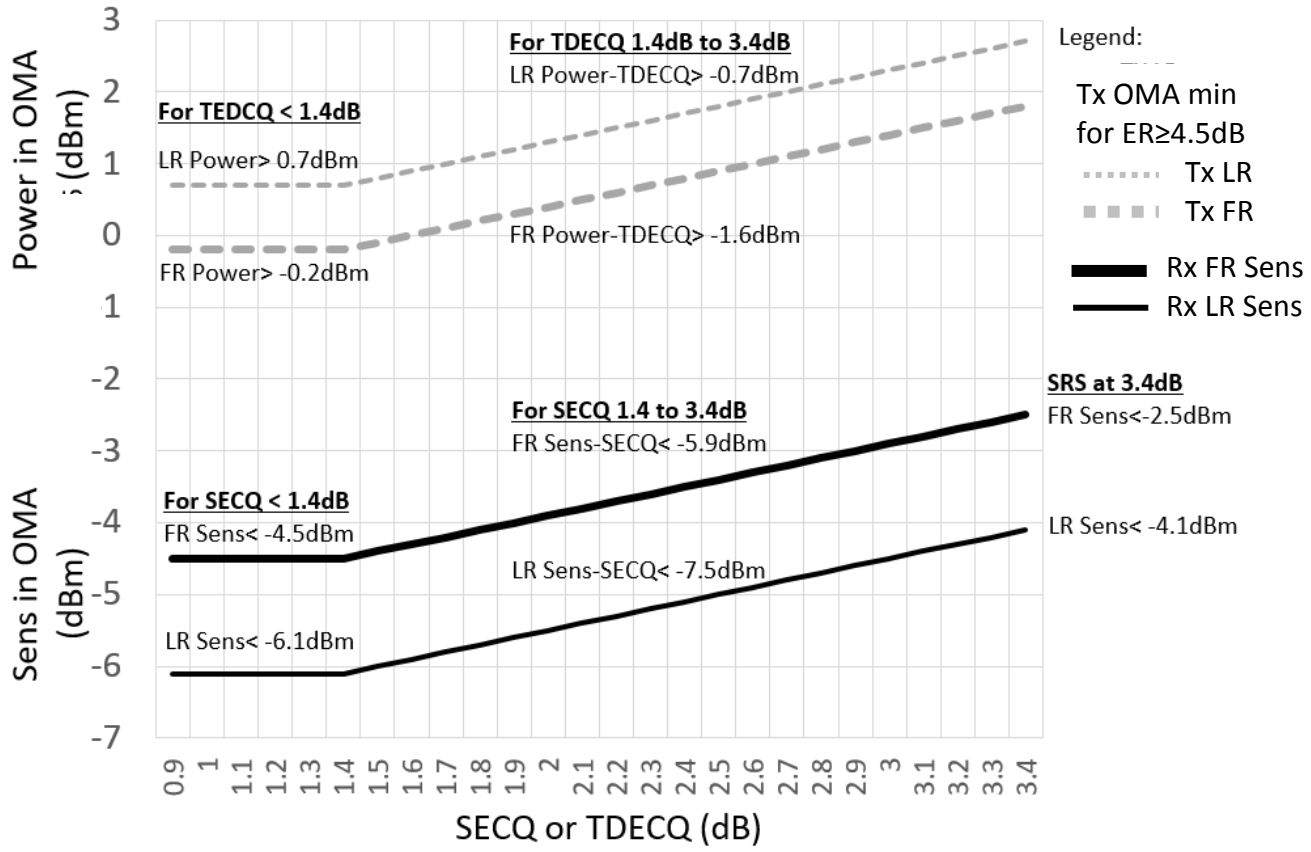


Figure 2-1: Illustration of receiver sensitivity mask for 100G-FR and LR with SECQ up to 3.4 dB

2.1.3 100G-FR and 100G-LR illustrative link power budget

An illustrative power budget and penalties for 100G-FR and 100G-LR are shown in Table 2-4.

Table 2-4: 100G-FR and 100G-LR illustrative power budget

Description	100G-FR Value	100G-LR Value	Unit
Power budget (for max TDECQ) for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 7.7 7.8	 10.2 10.3	 dB
Operating distance	2.0	10.0	km
Channel insertion loss[a]	4.0	6.3	dB
Maximum discrete reflectance	See Table 2-5	See Table 2-5	dB
Allocation for penalties[b] (for max TDECQ) for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 3.7 3.8	 3.9 4.0	 dB
Additional insertion loss allowed	0	0	dB
[a]The channel insertion loss is calculated using the maximum distance specified in Table 2-1 and cabled optical fiber attenuation of 0.5 dB/km at 1304.5 nm 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 2-5: 100G-FR and 100G-LR Maximum value for each discrete reflectance

Number of discrete reflectances above -55dB	Maximum value for each discrete reflectance for FR	Maximum value for each discrete reflectance for LR	Unit
1	-25	-22	dB
2	-31	-29	dB
4	-35	-33	dB
6	-38	-35	dB
8	-40	-37	dB
10	-41	-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.

3.1 TEST PATTERNS FOR OPTICAL PARAMETERS

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 encoded by RS-FEC	82.2.11, 91
6	SSPRQ	120.5.11.2.3

[a]These sub-clauses make reference to relevant clauses of IEEE Std 802.3-2018.

Table 3-2: Test pattern definitions and related subclauses

Parameter	***Pattern***	***Reference***
Wavelength	Square wave, 3, 4, 5, 6 or valid 100GBASE-R signal	3.3
Side mode suppression ratio	3, 5, 6 or valid 100GBASE-R signal	140.7.2[a]
Average optical power	3, 5, 6 or valid 100GBASE-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
Extinction ratio	4 or 6	3.7
Transmitter transition time	Square wave or 6	3.8
$RIN_{17.1}$/$RIN_{15.6}$ OMA	Square-wave	3.9
Stressed receiver conformance test signal calibration	6	3.11
Stressed receiver sensitivity	3 or 5	3.11
[a]IEEE Std 802.3cd.		

3.2 SKEW AND SKEW VARIATION

The skew and skew variation is specified in IEEE Std 802.3-2018 clause 121.3.2.

3.3 WAVELENGTH

The wavelength and SMSR shall be within the range given in Table 2-2 if measured per IEC 61280-1-3. The transmitter is modulated using the test pattern defined in Table 3-2.

3.4 AVERAGE OPTICAL POWER

The average optical power shall be within the limits given in Table 2-2 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, per the test setup in IEEE Std 802.3-2018 Figure 53-6.

3.5 OPITICAL MODULATION AMPLITUDE (OMA_{outer})

Refer to IEEE Std 802.3cd clause 140.7.4.

3.6 TRANSMITTER AND DISPERSION EYE CLOSURE FOR PAM4 (TDECQ)

TDECQ and TDECQ – $10*\log_{10}(C_{eq})$ shall be within the limits given in Table 2-2 if measured using the methods specified in IEEE Std 802.3cd clause 140.7.5 using a reference equalizer as described in section 3.6.1 with the following exceptions:

- The optical return loss of the transmitter compliance channel is 17.1 (FR), 15.6 (LR) dB.
- The signaling rate of the test pattern generator is as given in Table 2-2 and uses a test pattern specified for TDECQ in Table 3-2.

The transmitter is tested using an optical channel that meets the requirements listed in Table 3-3.

Table 3-3: Transmitter compliance channel specifications

Type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
100G-FR	$0.0465*\lambda*[1-(1324/\lambda)^4]$	$0.0465*\lambda*[1-(1300/\lambda)^4]$	Minimum	17.1 dB	0.8 ps
100G-LR	$0.2325*\lambda*[1-(1324/\lambda)^4]$	$0.2325*\lambda*[1-(1300/\lambda)^4]$	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 2 km for 100G-FR and 10 km for 100G-LR.					
[b] There is no intent to stress the sensitivity of the BERT's optical receiver.					
[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 100G-FR and 100G-LR 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 EXTINCTION RATIO

Extinction ratio is measured using the method specified in IEEE Std 802.3cd clause 140.7.6.

3.8 TRANSMITTER TRANSITION TIME

The transmitter transition time shall be within the limits given in Table 2-2 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.

3.9 RELATIVE INTENSITY NOISE ($RIN_{17.1}OMA$ and $RIN_{15.6}OMA$)

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 17.1 dB for 100G-FR or 15.6 dB for 100G-LR.

b) The upper –3 dB limit of the measurement apparatus is to be approximately equal to the signaling rate (i.e., 53.2 GHz).

3.10 RECEIVER SENSITIVITY

For 100G-FR, receiver sensitivity is informative and is defined for a transmitter with a value of SECQ up to 3.4 dB. Receiver sensitivity should meet Equation (1), which is illustrated in Figure 2-1.
For 100G-LR, receiver sensitivity is informative and is defined for a transmitter with a value of SECQ up to 3.4 dB. Receiver sensitivity should meet Equation (2), which is illustrated in Figure 2-1.

$$RS = \max(-4.5, SECQ - 5.9)\ dBm \quad (1)$$

$$RS = \max(-6.1, SECQ - 7.5)\ dBm \quad (2)$$

Where:

RS is the receiver sensitivity, and

SECQ is the SECQ of the transmitter used to measure the receiver sensitivity.

The normative requirement for receivers is stressed receiver sensitivity.

3.11 STRESSED RECEIVER SENSITIVITY

Stressed receiver sensitivity shall be within the limits given in Table 2-3 if measured using the method defined in IEEE Std 802.3cd 140.7.10 with the following exceptions:

- With the Gaussian noise generator on and the sinusoidal jitter and sinusoidal interferer turned off, the $RIN_{17.1}OMA$ or $RIN_{15.6}OMA$ of the SRS test source should be no greater than the value specified in Table 2-2.
- The signaling rate of the test pattern generator and the extinction ratio of the E/O converter are as given in Table 2-3 using test patterns specified in Table 3-2.
- The required values of the Stressed receiver sensitivity (OMA_{outer}) (max) and Stressed eye closure for PAM4 (SECQ) and SECQ – $10*\log_{10}(C_{eq})$ (max) are as given in Table 2-3.

4 FIBER OPTIC CABLING MODEL

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

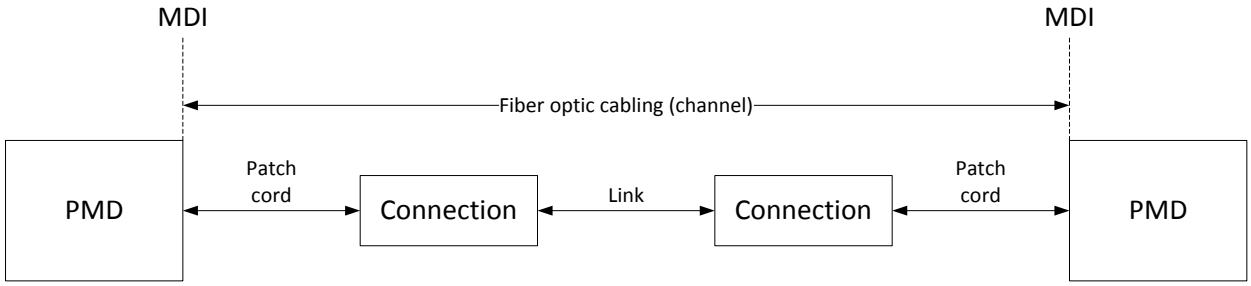


Figure 4-1: Fiber optic cabling model

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	100G-FR Values	100G-LR Values	Unit
Operating distance (max)	2	10	km
Channel insertion loss[a,b](max)	4	6.3	dB
Channel insertion loss (min)	0	0	dB
Positive dispersion[b] (max)	3.2	16.0	ps/nm
Negative dispersion[b] (min)	-3.7	-18.5	ps/nm
DGD_max[c]	3.0	8	ps
Optical return loss (min)	25	22	dB
a) These channel loss values include cable, connectors and splices.			
b) Over the wavelength range 1304.5 to 1317.5 nm.			
c) 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 100G-FR and 100G-LR 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 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 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)	0.5[a]	dB/km
Zero dispersion wavelength (λ_0)	$1300 \leq \lambda_0 \leq 1324$	nm
Dispersion slope (max) (S_0)	0.093	ps/nm^2km
[a]The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.		

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 100G-LR is based on an allocation of 2 dB total connection and splice loss. For example, this allocation supports four connections with an average insertion loss per connection of 0.5 dB. The maximum link distance for 100GBASE-FR is based on an allocation of 3 dB total connection and splice loss. 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 than the value shown in Table 2-5.

5.3 MEDIUM DEPENDENT INTERFACE (MDI) REQUIREMENT

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 61753-1-1 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 100G-FR AND 100G-LR Module Color Coding

Transceiver modules compliant to the 100G-FR and 100G-LR 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: 100G-FR and 100G-LR Module Color Coding

Color Code	Application
TBD	100G-FR
TBD	100G-LR