

400G-FR4 Technical Specification

100G Lambda MSA Group

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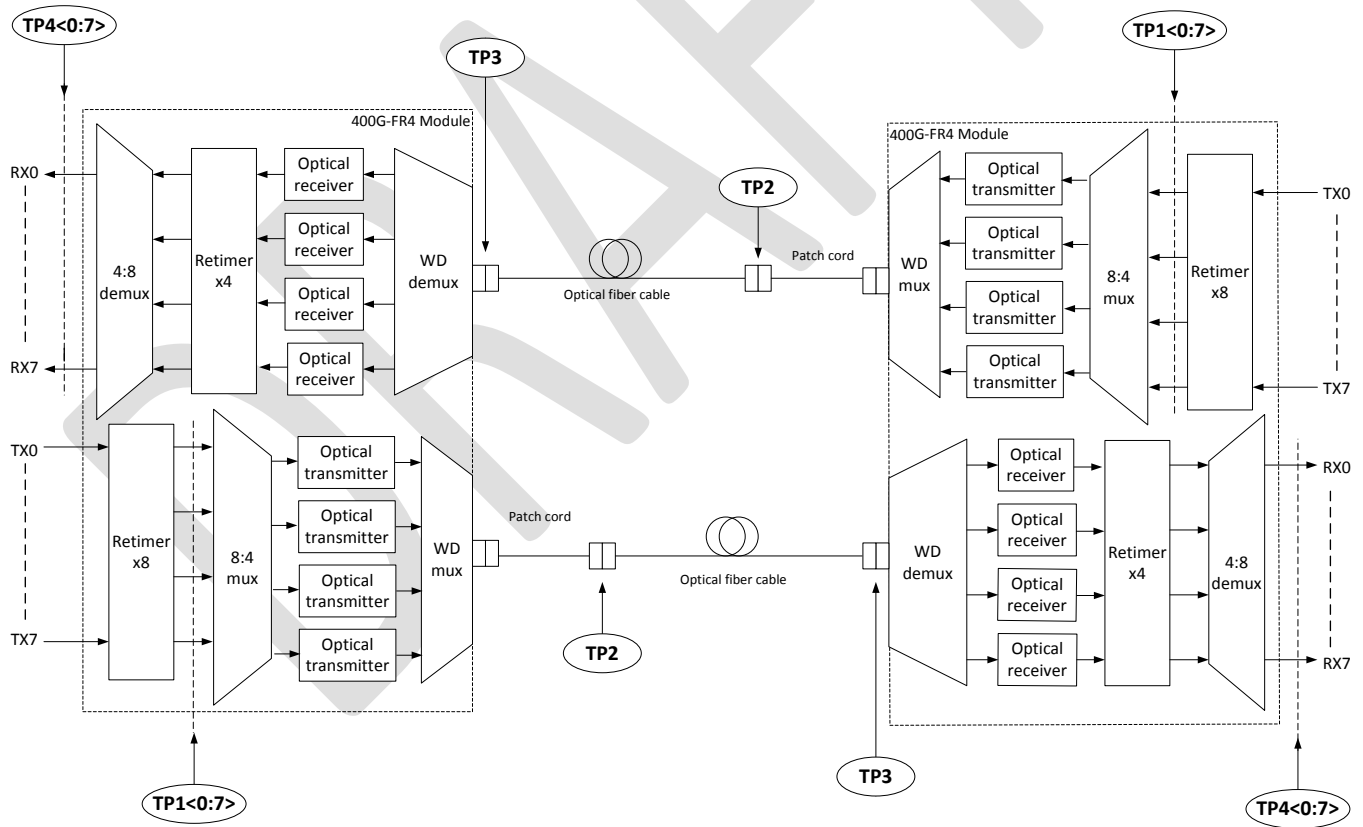
1 GENERAL

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 2 kilometers. 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-FR4 transceivers are possible and none are precluded by this MSA.

1.2 400G-FR4 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-FR4 transmit/receive paths

1.3 FUNCTIONAL DESCRIPTION

400G-FR4 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 could be implemented in compliance with applicable electrical interface specifications.

1.7 FEC REQUIREMENTS

The system is required to enable FEC in accordance with clause 121.1.1 of IEEE-Std 802.3bs™. The option to bypass the FEC correction function is not supported.

1.8 MECHANICAL DIMENSIONS

Mechanical dimensions are defined in module form factor MSA specifications.

2 400G-FR4 OPTICAL SPECIFICATIONS

2.1 WAVELENGTH-DIVISION-MULTIPLEXED LANE ASSIGNMENTS

The wavelength range for each lane of the 400G-FR4 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 a 400G-FR4 PMD is 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., operating at 2.5 km meets the operating range requirement of 2 m to 2 km).

Table 2-2: 400G-FR4 operating range

PMD type	Required operating range
400G-FR4	2 m to 2 km

2.2.1 400G-FR4 transmitter optical specifications

The 400G-FR4 transmitter shall meet the specifications defined in Table 2-3.

Table 2-3: 400G-FR4 transmit characteristics

Description	Value	Unit
PAM4 Signaling rate, each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range)	1264.5 to 1277.5	nm
	1284.5 to 1297.5	
	1304.5 to 1317.5	
	1324.5 to 1337.5	
Side-mode suppression ratio (SMSR), (min)	30	dB
Total average launch power (max)	9.3	dBm
Average launch power, each lane (max)	3.5	dBm
Average launch power, each lane ^a (min)	-3.3	dBm
Outer Optical Modulation Amplitude (OMA outer), each lane (max)	3.7	dBm
Outer Optical Modulation Amplitude (OMA outer), each lane ^b (min)	-0.3	dBm
Difference in launch power between any two lanes (OMA _{outer}) max	4	dB
Launch power in OMA minus TDECQ, each lane (min) for ER ≥ 4.5dB	-1.7	dBm
Launch power in OMA minus TDECQ, each lane (min) for ER < 4.5dB	-1.6	dBm
Transmitter and dispersion penalty Eye Closure for PAM4 (TDECQ), each lane (max)	3.4	dB
Average launch power of OFF transmitter, each lane (max)	-20	dBm
Extinction ratio (min)	3.5	dB
Optical return loss tolerance (max)	17.1	dB
Transmitter reflectance ^c (max)	-26	dB
RIN _{17.1} OMA (max)	-136	dB/Hz
^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 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.		

2.2.2 400G-FR4 receive optical specifications

The 400G-FR4 receiver shall meet the specifications defined in Table 2-4.

Table 2-4: 400G-FR4 receive characteristics for ER>4.5dB

Description	Value	Unit
PAM4 Signaling rate, each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range)	1264.5 to 1277.5	Nm
	1284.5 to 1297.5	
	1304.5 to 1317.5	
	1324.5 to 1337.5	
Damage threshold, each lane (min) ^a	4.5	dBm
Average receive power, each lane (max)	3.5	dBm
Average receive power, each lane ^b (min)	-7.3	dBm
Receive power, each lane (OMA _{outer}) (max)	3.7	dBm
Difference in receive power between any two lanes (OMA _{outer}) (max)	4.1	dB
Receiver reflectance (max)	-26	dB
Stressed receiver sensitivity (OMA _{outer}), each lane ^c (max)	See Figure 2-1	dBm
Conditions of stressed receiver sensitivity test:		
Stressed eye closure for PAM4 (SECQ), lane under test	0.9 to 3.4	dB
OMA _{outer} of each aggressor lane	1.5	dBm
^a The receiver shall be able to tolerate, without damage, continuous exposure to an optical signal having this average power level		
^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 3.10) for BER = 2.4x10 ⁻⁴ . A compliant receiver shall have stressed receiver sensitivity (OMA _{outer}), each lane values below the mask of Figure 2-1, for SECQ values between 0.9 and 3.4 dB. See 3.10		

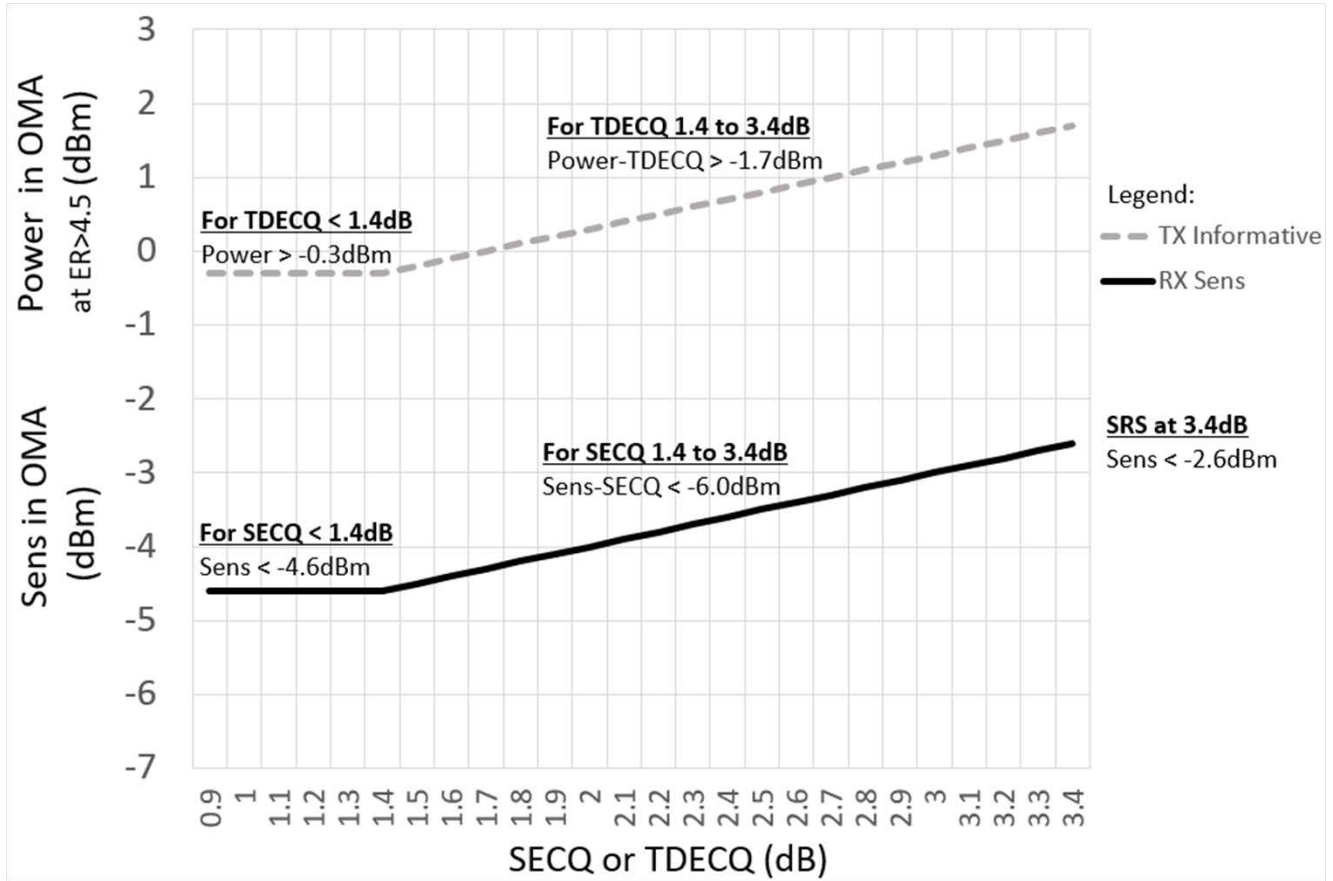


Figure 2-1: Stressed receiver sensitivity mask for 400G-FR4

2.2.3 400G-FR4 illustrative link power budget

An illustrative power budget and penalties for 400G-FR4 are shown in Table 2-5.

Table 2-5: 400G-FR4 illustrative power budget

Description	Value	Unit
Power budget (for max TDECQ)	7.7	dB
Operating distance	2.0	km
Channel insertion loss	4.0	dB
Maximum discrete reflectance	See Table 2-6	dB
Allocation for penalties (for max TDECQ)	3.7	dB
Additional insertion loss allowed	0	dB

Table 2-6: 400G-FR4 Maximum value for each discrete reflectance

Number of discrete reflectance above -55dB	Maximum value for each discrete reflectance	Unit
1	-25	dB
2	-31	dB
4	-35	dB
6	-38	dB
8	-40	dB
10	-41	dB

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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: Patterns for optical parameter testing

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

^aThese sub-clauses make reference to relevant clauses of IEEE Std 802.3bs™.

3.1 TEST PATTERNS FOR OPTICAL PARAMETERS

Table 3-2: Patterns for optical parameter testing

Parameter	Pattern	Sub-clause ^a
Wavelength	Square wave, 3, 4, 5, 6 or valid 400G-FR4 signal	122.8.2
Side mode suppression ratio	3, 5, 6 or a valid 400G-FR4 signal	--
Average optical power	3, 5, 6 or a valid 400G-FR4 signal	122.8.3
Optical modulation amplitude (OMA_{outer})	4 or 6	122.8.4
Transmitter and dispersion eye closure for PAM4 (TDECQ)	6	122.8.5
Extinction ratio	4 or 6	122.8.6
$RIN_{17.1}$ OMA	Square wave	122.8.7
Stressed receiver conformance test signal calibration	6	122.8.9.2
Stressed receiver sensitivity	3 or 5	122.8.9

^aThese sub-clauses make reference to relevant clauses of IEEE Std 802.3bs™.

3.2 SKEW AND SKEW VARIATION

The skew and skew variation is specified in IEEE Std 802.3bs™ Clause 122.3.2.

3.3 WAVELENGTH

Measure per TIA/EIA-455-127-A or IEC 61280-1-3.

3.4 AVERAGE OPTICAL POWER

Measure using the methods given in IEEE Std 802.3bs™ Clause 122.8.3 with all channels not being measured turned off.

3.5 OPTICAL MODULATION AMPLITUDE (OMAOUTER)

Refer to IEEE Std 802.3bs™ Clause 122.8.4. 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)

TDECQ shall be as defined in IEEE Std 802.3bs™ Clause 122.8.5

3.6.1 Channel requirements

The transmitter is tested using an optical channel that meets the requirements found in 802.3bs™ Clause 122.8.5.2 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			
400G-FR4	$0.0465 * \lambda * [1 - (1324/\lambda)^4]$	$0.0465 * \lambda * [1 - (1300/\lambda)^4]$	Minimum	17.1 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 400G-FR4.

^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.

3.6.2 Reference receiver requirements

Refer to 802.3bs™ Clause 122.8.5.1.

3.7 EXTINCTION RATIO

Extinction ratio is measured using the methods specified in IEEE 802.3bs™ Clause 122.8.6.

3.8 RELATIVE INTENSITY NOISE

RIN is measured using the methods specified in IEEE 802.3bs™ Clause 122.8.7.

3.9 RECEIVER SENSITIVITY

Receiver sensitivity, which is defined for an ideal input signal, is informative and compliance is not required.

3.10 STRESSED RECEIVER SENSITIVITY

Stressed receiver sensitivity shall be within the limits given in Table 2-4 for 400G-FR4 if measured using the method and conformance test signal defined in IEEE Std 802.3bs™ Clause 122.8.9 using the test pattern specified for SRS in Table 3-2, with the following exceptions:

- The SECQ of the stressed receiver conformance test signal is measured according to IEEE Std 802.3bs™ Clause 124.8.5, except that the test fiber is not used.
- The signaling rate of the test pattern generator and the extinction ratio of the E/O converter are as given in Table 2-4 using test patterns specified in Table 3-2.
- The required values of the “Stressed receiver sensitivity (OMA_{outer}), each lane (max)”, “Stressed eye closure for PAM4 (SECQ), lane under test”, and “OMA_{outer} of each aggressor lane” are given in Table 2-4.

The BER is required to be met for the lane under test on its own.

Stressed receiver sensitivity is defined with all transmit and receive lanes in operation. Any of the patterns specified for Stressed receiver sensitivity in Table 3-2 is sent from the transmit section of the PMD under test. The signal being transmitted is asynchronous to the received signal.

4 FIBER OPTIC CABLING MODEL

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

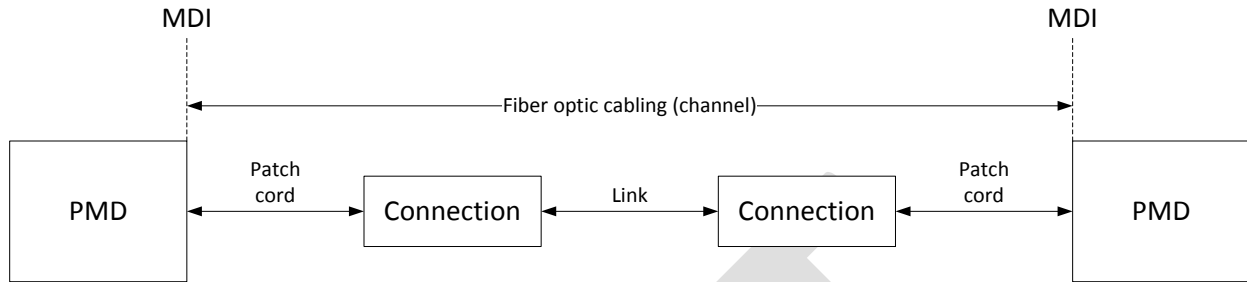


Figure 4-1: Fiber optic cabling model

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-FR4	Unit
Operating distance (max)	2	Km
Channel insertion loss ^{a,b} (max)	4	dB
Channel insertion loss (min)	0	dB
Positive dispersion ^b (max)	6.7	ps/nm
Negative dispersion ^b (min)	-11.9	ps/nm
DGD_max ^c	3.0	Ps
Optical return loss (min)	25	dB
a) These channel loss values include cable, connectors and splices.		
b) Over the wavelength range 1264.5 to 1337.5 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 400G-FR4 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 ² km
^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 distances for single-mode fiber are calculated based on an allocation of 3 dB total connection and splice loss. For example, this allocation supports six 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 61753-1-1 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-FR4 Module Color Coding

Transceiver modules compliant to the 400G-FR4 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-FR4 Module Color Coding

Color Code	Application
TBD	400G-FR4 2 km reach