

<h1>400G-ER4-30</h1> <h2>Technical Specification</h2> <h3>100G Lambda MSA Group</h3>

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## 400G-ER4-30 Technical Specification 1.0

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### Revisions

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## CONTENTS

CONTENTS.....	3
TABLES.....	4
FIGURES.....	4
1 GENERAL .....	5
1.1 SCOPE .....	5
1.2 400G-ER4-30 MODULE BLOCK DIAGRAM .....	5
1.3 FUNCTIONAL DESCRIPTION .....	6
1.4 HARDWARE SIGNALING PINS .....	6
1.5 MODULE MANAGEMENT INTERFACE .....	6
1.6 HIGH SPEED ELECTRICAL CHARACTERISTICS .....	6
1.7 FEC REQUIREMENTS.....	6
1.8 MECHANICAL DIMENSIONS.....	6
2 400G-ER4-30 OPTICAL SPECIFICATIONS .....	7
2.1 WAVELENGTH-DIVISION-MULTIPLEXED LANE ASSIGNMENTS .....	7
2.2 OPTICAL SPECIFICATIONS.....	7
2.2.1 400G-ER4-30 transmitter optical specifications.....	8
2.2.2 400G-ER4-30 receive optical specifications.....	9
2.2.3 400G-ER4-30 illustrative link power budgets .....	10
3 DEFINITION OF OPTICAL PARAMETERS AND MEASUREMENT METHODS .....	11
3.1 TEST PATTERNS FOR OPTICAL PARAMETERS .....	12
3.2 SKEW AND SKEW VARIATION.....	12
3.3 WAVELENGTH AND SIDE MODE SUPPRESSION RATIO (SMSR).....	12
3.4 AVERAGE OPTICAL POWER .....	12
3.5 OPTICAL MODULATION AMPLITUDE ( $OMA_{outer}$ ).....	13
3.6 TRANSMITTER AND DISPERSION EYE CLOSURE PENALTY (TDECQ) .....	13
3.6.1 TDECQ reference equalizer .....	14
3.7 TRANSMITTER EYE CLOSURE FOR PAM4 (TECQ).....	14
3.8 OVER/UNDER-SHOOT.....	14
3.9 TRANSMITTER POWER EXCURSION .....	14
3.10 EXTINCTION RATIO .....	14
3.11 TRANSMITTER TRANSITION TIME .....	14
3.12 RELATIVE INTENSITY NOISE ( $RIN_{15}$ OMA) .....	15
3.13 RECEIVER SENSITIVITY .....	15
3.14 STRESSED RECEIVER SENSITIVITY .....	15
4 FIBER OPTIC CABLING MODEL .....	16
5 CHARACTERISTICS OF THE FIBER OPTIC CABLING (CHANNEL) .....	17
5.1 OPTICAL FIBER CABLE.....	17
5.2 OPTICAL FIBER CONNECTION .....	17
5.2.1 Connection insertion loss.....	17
5.2.2 Maximum discrete reflectance .....	17
5.3 MEDIUM DEPENDENT INTERFACE (MDI) REQUIREMENTS.....	18

6 400G-ER4-30 MODULE COLOR CODING ..... 18

**TABLES**

Table 2-1: Wavelength-division-multiplexed lane assignments..... 7  
Table 2-2: 400G ER4-30 operating ranges ..... 7  
Table 2-3: 400G ER4-30 transmit characteristics..... 8  
Table 2-4: 400G ER4-30 receive characteristics..... 9  
Table 2-5: 400G ER4-30 illustrative power budgets ..... 10  
Table 2-6: 400G ER4-30 Maximum values for each discrete reflectance..... 11  
Table 3-1: Test patterns ..... 11  
Table 3-2: Test pattern definitions and related subclauses ..... 12  
Table 3-3: Transmitter compliance channel specifications ..... 13  
Table 4-1: Fiber optic cabling (channel) characteristics ..... 16  
Table 5-1: Optical fiber and cable characteristics..... 17  
Table 6-1: 400G ER4-30 Module Color Coding ..... 18

**FIGURES**

Figure 1-1: Block diagram for 400G ER4-30 transmit/receive paths..... 5  
Figure 2-1: Illustration of transmitter  $OMA_{outer}$  versus TDECQ and receiver sensitivity versus  
TECQ for 400G ER4-30 ..... 10  
Figure 4-1: Fiber optic cabling model ..... 16

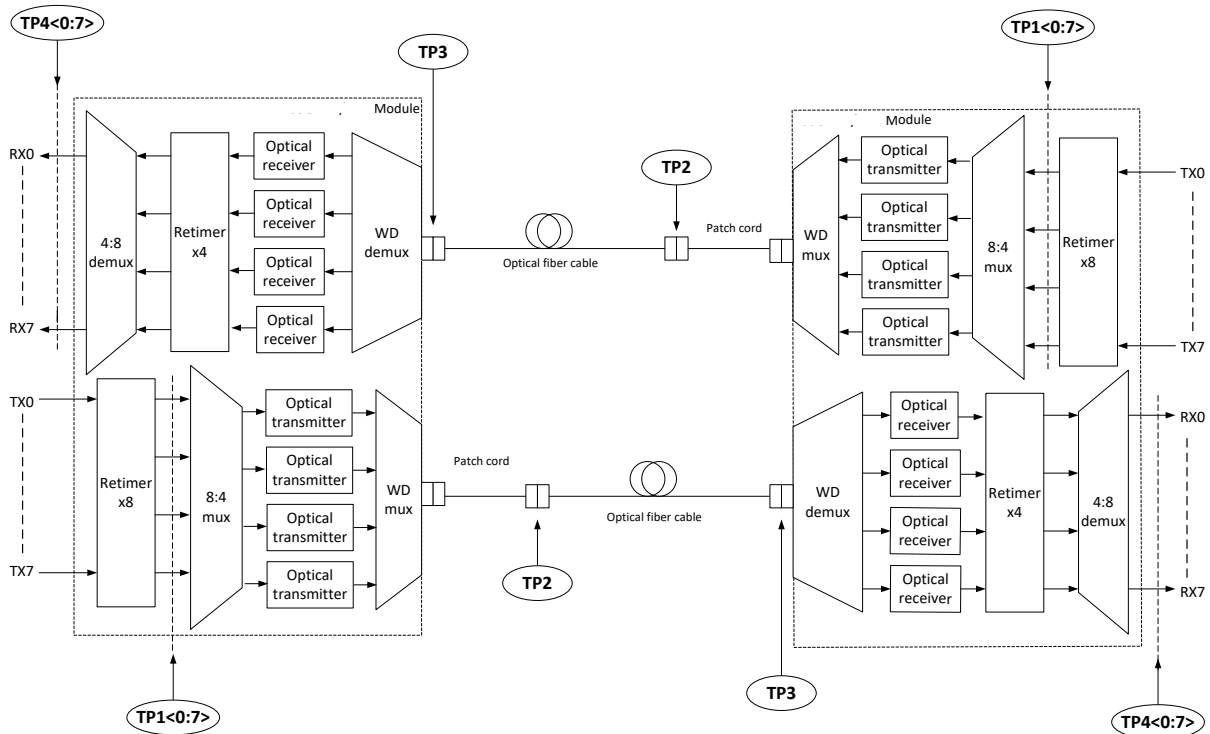
# 1 GENERAL

## 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 30 kilometers (400G-ER4-30). 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-ER4-30 transceivers are possible and none are precluded by this MSA.

## 1.2 400G-ER4-30 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-ER4-30 transmit/receive paths

### ***1.3 FUNCTIONAL DESCRIPTION***

400G-ER4-30 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-ER4-30 link relies on the host system implementing the 400GBASE-R PCS layer in accordance with IEEE Std 802.3™-2022 Clause 119. 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-ER4-30 OPTICAL SPECIFICATIONS

### 2.1 WAVELENGTH-DIVISION-MULTIPLEXED LANE ASSIGNMENTS

The wavelength range for each lane of the 400G-ER4-30 PMD is defined in Table 2-1. Polarization of  $L_0$ ,  $L_3$  is orthogonal at TP2 to polarization of  $L_1$ ,  $L_2$ .

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

Lane	Center wavelength	Wavelength range
$L_0$	1304.58 nm	1304.06 to 1305.1 nm
$L_1$	1306.85 nm	1306.33 to 1307.38 nm
$L_2$	1309.14 nm	1308.61 to 1309.66 nm
$L_3$	1311.43 nm	1310.9 to 1311.96 nm

### 2.2 OPTICAL SPECIFICATIONS

The operating range for 400G-ER4-30 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-ER4-30 PMD operating at 22 km meets the operating range requirement of 2 m to 30 km).

**Table 2-2: 400G-ER4-30 operating ranges**

PMD type	Required operating range
400G-ER4-30	2 m to 30 km

### 2.2.1 400G-ER4-30 transmitter optical specifications

The 400G-ER4-30 transmitter shall meet the specifications defined in Table 2-3.

**Table 2-3: 400G-ER4-30 transmit characteristics**

Description	400G-ER4-30	Unit
PAM4 Signaling rate each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range) <sup>a</sup>	1304.06 to 1305.1 nm 1306.33 to 1307.38 nm 1308.61 to 1309.66 nm 1310.9 to 1311.96 nm	nm
Side-mode suppression ratio (SMSR) (min)	30	dB
Total average launch power (max)	11.6	dBm
Average launch power each lane (max)	5.6	dBm
Average launch power each lane <sup>b</sup> (min)	0	dBm
Outer Optical Modulation Amplitude (OMA <sub>outer</sub> ) each lane (max)	6.4	dBm
Outer Optical Modulation Amplitude (OMA <sub>outer</sub> ) each lane (min) for TDECQ < 1.4 dB for 1.4 dB ≤ TDECQ ≤ 3.9 dB	3 1.6 + TDECQ	dBm dBm
Channel Power Difference (max)	3	dB
Transmitter and dispersion eye closure for PAM4 (TDECQ) each lane (max) with  CD  < 16ps/nm	3.5	dB
Transmitter and dispersion eye closure for PAM4 (TDECQ) each lane (max) with  CD  > 16ps/nm	3.9	dB
Transmitter eye closure for PAM4 (TECQ) each lane (max)	3.5	dB
TDECQ – TECQ  (max), with  CD  < 16ps/nm	2.3	dB
TDECQ – TECQ  (max), with  CD  > 16ps/nm	2.7	dB
Average launch power of OFF transmitter, each lane (max)	-15	dBm
Extinction ratio, each lane (min)	5	dB
Transmitter transition time (max)	17	ps
Transmitter over/under-shoot (max)	22	%
Transmitter power excursion (max)	3.9	dBm
RIN <sub>15</sub> OMA (max)	-136	dB/Hz
Optical return loss tolerance (max)	15	dB
Transmitter reflectance <sup>c</sup> (max)	-26	dB
<sup>a</sup> Polarization of L <sub>0</sub> , L <sub>3</sub> is orthogonal to polarization of L <sub>1</sub> , L <sub>2</sub> at TP2. Polarization extinction ratio is greater than 10 dB.		
<sup>b</sup> 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.		
<sup>c</sup> Transmitter reflectance is defined looking into the transmitter.		



### 2.2.2 400G-ER4-30 receive optical specifications

The 400G-ER4-30 receiver shall meet the specifications defined in Table 2-4.

**Table 2-4: 400G-ER4-30 receive characteristics**

Description	400G-ER4-30	Unit
PAM4 Signaling rate each lane (range)	53.125 ± 100 ppm	GBd
Lane wavelengths (range)	1304.06 to 1305.1 nm 1306.33 to 1307.38 nm 1308.61 to 1309.66 nm 1310.9 to 1311.96 nm	nm
Damage threshold each lane (min) <sup>a</sup>	-2.4	dBm
Average receive power each lane (max)	-3.4	dBm
Average receive power each lane <sup>b</sup> (min)	-14.7	dBm
Receive power each lane (OMA <sub>outer</sub> ) each lane (max)	-2.6	dBm
Difference in receive power between any two lanes (OMA <sub>outer</sub> ) (max)	3.6	dB
Receiver reflectance (max)	-26	dB
Receiver sensitivity (OMA <sub>outer</sub> ) each lane (max) for TECQ < 1.4 dB for 1.4 dB ≤ TECQ ≤ 3.9 dB	-12.5 -13.9 + TECQ	dBm dBm
Stressed receiver sensitivity (OMA <sub>outer</sub> ) each lane <sup>c</sup> (max)	-10.0	dBm
<b>Conditions of stressed receiver sensitivity test<sup>d</sup>:</b>		
Stressed eye closure for PAM4 (SECQ) lane under test	3.9	dB
OMA <sub>outer</sub> of each aggressor lane	-6.4	dBm
<sup>a</sup> 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.		
<sup>b</sup> 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.		
<sup>c</sup> Measured with conformance test signal at TP3 (see 3.14) for the BER specified in IEEE Std 802.3™-2022 Clause 124.1.1.		
<sup>d</sup> These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.		

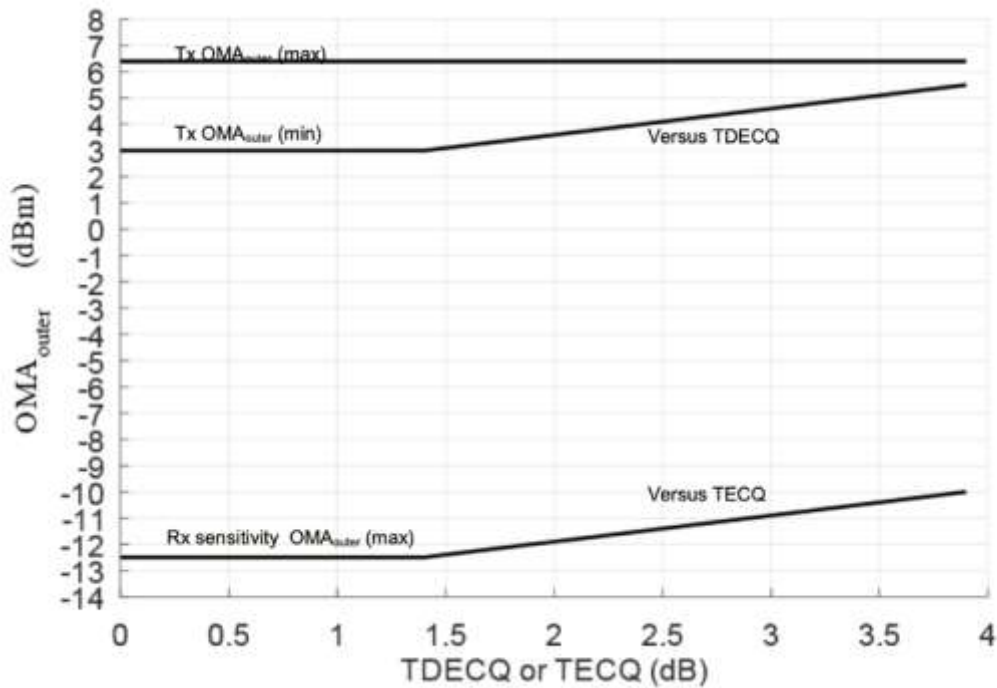


Figure 2-1: Illustration of transmitter OMA<sub>outer</sub> versus TDECQ and receiver sensitivity versus TECQ for 400G-ER4-30

### 2.2.3 400G-ER4-30 illustrative link power budgets

Illustrative power budgets and penalties for 400G-ER4-30 are shown in Table 2-5.

Table 2-5: 400G-ER4-30 illustrative power budgets

Description	400G-ER4-30	Unit
Power budget (for maximum TDECQ)	19.4	dB
Operating distance	30	km
Channel insertion loss (max) <sup>a</sup>	15	dB
Channel insertion loss (min) <sup>a</sup>	9	
Maximum discrete reflectance	See Table 2-6	dB
Allocation for penalties <sup>b</sup> (for max TDECQ)	4.4	dB
Additional insertion loss allowed	0	dB
<sup>a</sup> 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.		
<sup>b</sup> Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.		

**Table 2-6: 400G-ER4-30 Maximum values for each discrete reflectance**

Number of discrete reflectance above -55dB	Maximum value for each discrete reflectance
	400G-ER4-30
1	-19 dB
2	-27 dB
4	-32 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 <sup>a</sup>
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

<sup>a</sup> These sub-clauses make reference to relevant clauses of IEEE Std 802.3™-2022.

### 3.1 TEST PATTERNS FOR OPTICAL PARAMETERS

Table 3-2: Test pattern definitions and related subclauses

<i>Parameter</i>	<i>Pattern</i>	<i>Reference</i>
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 <sub>outer</sub> )	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
Over/under-shoot	6	
Transmitter power excursion	6	
Extinction ratio	4 or 6	3.8
Transmitter transition time	Square wave or 6	3.11
RIN <sub>15</sub> 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™-2022 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™-2022 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™-2022 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™-2022 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  $1.3 \times 53.125$  GHz and at frequencies above  $1.3 \times 53.125$  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 <sup>a</sup> (ps/nm)		Insertion loss <sup>b</sup>	Optical return loss <sup>c</sup>	Max mean DGD
	Minimum	Maximum			
400G-ER4-30	$0.69 * \lambda * [1 - (1324/\lambda)^4]$	$0.69 * \lambda * [1 - (1300/\lambda)^4]$	Minimum	15 dB	0.8 ps
<sup>a</sup> The dispersion is measured for the wavelength of the device under test ( $\lambda$ in nm). The coefficient assumes 30 km for 400G-ER4-30.					
<sup>b</sup> There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.					
<sup>c</sup> 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-ER4-30 is as specified in IEEE Std 802.3™-2022 Clause 140.7.5.1 with the following exception:

- Tap1, tap2 or tap3 has the largest magnitude coefficient, which is constrained to 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 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 Std 802.3™-2022 Clause 151.8.7.

### **3.9 TRANSMITTER POWER EXCURSION**

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

The test description for transmitter power excursion is in IEEE Std 802.3™-2022 Clause 151.8.8.

### **3.10 EXTINCTION RATIO**

Extinction ratio is measured using the methods specified in IEEE Std 802.3™-2022 Clause 124.8.6.

### **3.11 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 802.3™-2022 Clause 140.7.7.

### **3.12 RELATIVE INTENSITY NOISE ( $RIN_{15}$ OMA)**

RIN shall be as defined by the measurement methodology of IEEE Std 802.3<sup>TM</sup>-2022 Clause 52.9.6 with the following exceptions:

- a. The optical return loss is 15 dB for 400G-ER4-30.
- 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 ( $OMA_{outer}$ ) for 400G-ER4-30 shall be within the limits given in Table 2-4 if measured using a test pattern for receiver sensitivity in Table 3-2.

The conformance test signal at TP3 meets the requirements for a 400G-ER4-30 transmitter followed by an attenuator.

The TECQ of the conformance test signal is measured according to IEEE Std 802.3<sup>TM</sup>-2022 Clause 140.7.5, except that the test fiber is not used. The measured value of TECQ is then used to calculate the limit for receiver sensitivity ( $OMA_{outer}$ ) as specified in Table 2-4.

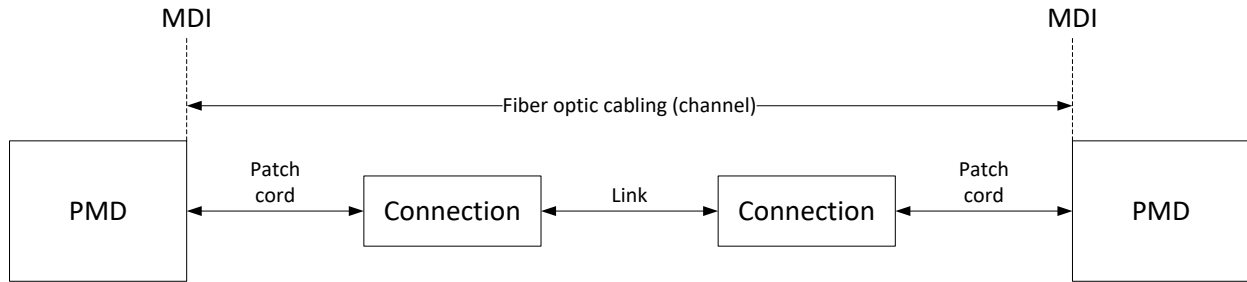
### **3.14 STRESSED RECEIVER SENSITIVITY**

Stressed receiver sensitivity shall be within the limits given in Table 2-4 if measured using the method defined in IEEE Std 802.3<sup>TM</sup>-2022 Clause 140.7.10 with the following exceptions:

- With the Gaussian noise generator on and the sinusoidal jitter and sinusoidal interferer turned off, the  $RIN_x$  OMA of the SRS test source should be no greater than the value specified in Table 2-3.
- 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 3-1.
- The required values of the Stressed receiver sensitivity ( $OMA_{outer}$ ) (max) and Stressed eye closure for PAM4 (SECQ) are as given in Table 2-4.

## 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-ER4-30	Unit
Operating distance (max)	30	km
Channel insertion loss <sup>a,b</sup> (max)	15 <sup>c</sup>	dB
Channel insertion loss (min)	9	dB
Positive dispersion <sup>b</sup> (max)	32.6	ps/nm
Negative dispersion <sup>b</sup> (min)	-56.3	ps/nm
DGD_max <sup>d</sup>	4.3	ps
Optical return loss (min)	19	dB

<sup>a</sup> These channel loss values include cable, connectors and splices.

<sup>b</sup> Over the wavelength range 1304.06 to 1311.96 nm.

<sup>c</sup> 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 30 km for 400G-ER4-30 under worst case conditions.

<sup>d</sup> 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-ER4-30 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 <sup>a</sup>	dB/km
Zero dispersion wavelength ( $\lambda_0$ )	$1300 \leq \lambda_0 \leq 1324$	nm
Dispersion slope (max) ( $S_0$ )	0.092	ps/nm <sup>2</sup> km
<sup>a</sup> 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-ER4-30 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-ER4-30 MODULE COLOR CODING**

Transceiver modules compliant to the 400G-ER4-30 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-ER4-30 Module Color Coding**

<b>Color Code</b>	<b>Application</b>
Red	400G-ER4 30 km reach