Implementation Agreement for 800LR Coherent Interface

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ABSTRACT: This Implementation Agreement specifies requirements for 800LR coherent interfaces intended for unamplified single wavelength campus links up to 10km.

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1 Introduction

This implementation agreement (IA) defines a single-wavelength 800G coherent line interface for single-span, unamplified, point-to-point, up to 10km fixed wavelength links (e.g. campus applications).

The 800G coherent line interfaces defined in this IA are designed to support either a single 800GE client or two 400GE clients. The scope of this IA includes definitions of Ethernet client mappings (including interleaving of 400GE services into the 800G line), forward-error correction (FEC), modulation and optical specifications for these interfaces. The IA aims to enable interoperable, cost-effective, low power 800LR implementations in small form-factor pluggable modules with port densities equivalent to client optics. No restriction on the physical form-factor of the modules is implied by this IA.

Figure 1 is a reference diagram for the 800LR application. The IA defines a single-channel line interface which operates on a link which is defined only in terms of the channel characteristics in this implementation agreement.

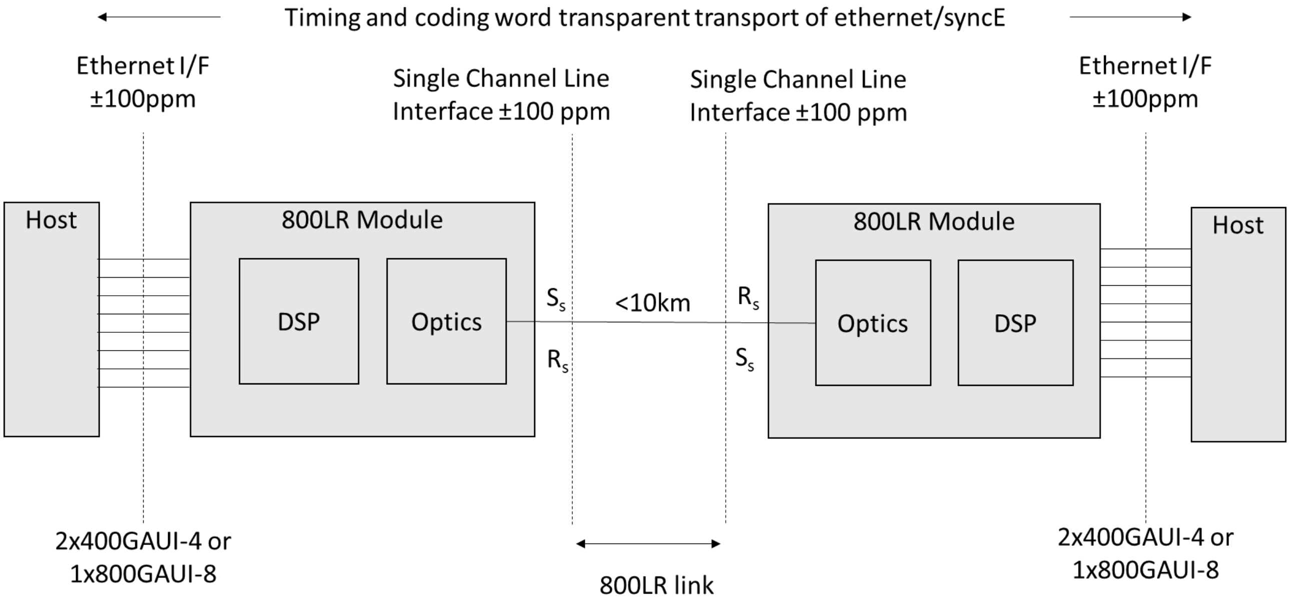


Figure 1: 800LR Reference Diagram

Note that the timing tolerance is tighter for 800GE clients and may be better in some 400GE client cases.

2 800LR Use Case

The single channel unamplified <10km use case is shown in Figure 2. For unamplified links, the reach is determined by the transmitter output power, receiver sensitivity and link loss characteristics. This use case is covered by application codes 0x01 and 0x02 in this IA.

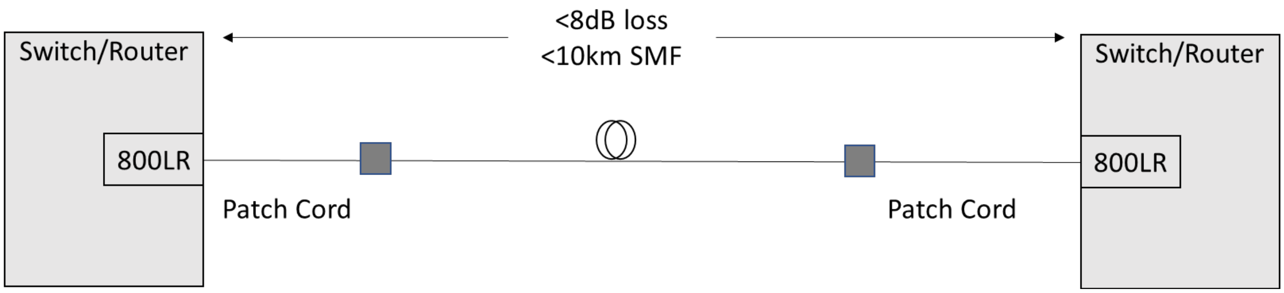


Figure 2: Switch/Router line card with 800LR interfaces

There are two modes of operation in scope of this IA: concatenated and segmented FEC. The main difference between the two modes is the functions implemented in the 800LR module, for example regeneration of the outer FEC code. More details on operating modes are described in clause 8.

3 800LR Client Interfaces

This IA defines adaptation of Ethernet clients shown in Table 1 into the 800LR interface. The adaptation for each client is described in Section 8.

Client Type	Chip-to-Module interface	Number of clients
400GBASE-R	400GAUI-4	2
800G-ETC-R	800G-ETC	1
800GBASE-R	800GAUI-8	1

Table 1: Client types and interfaces

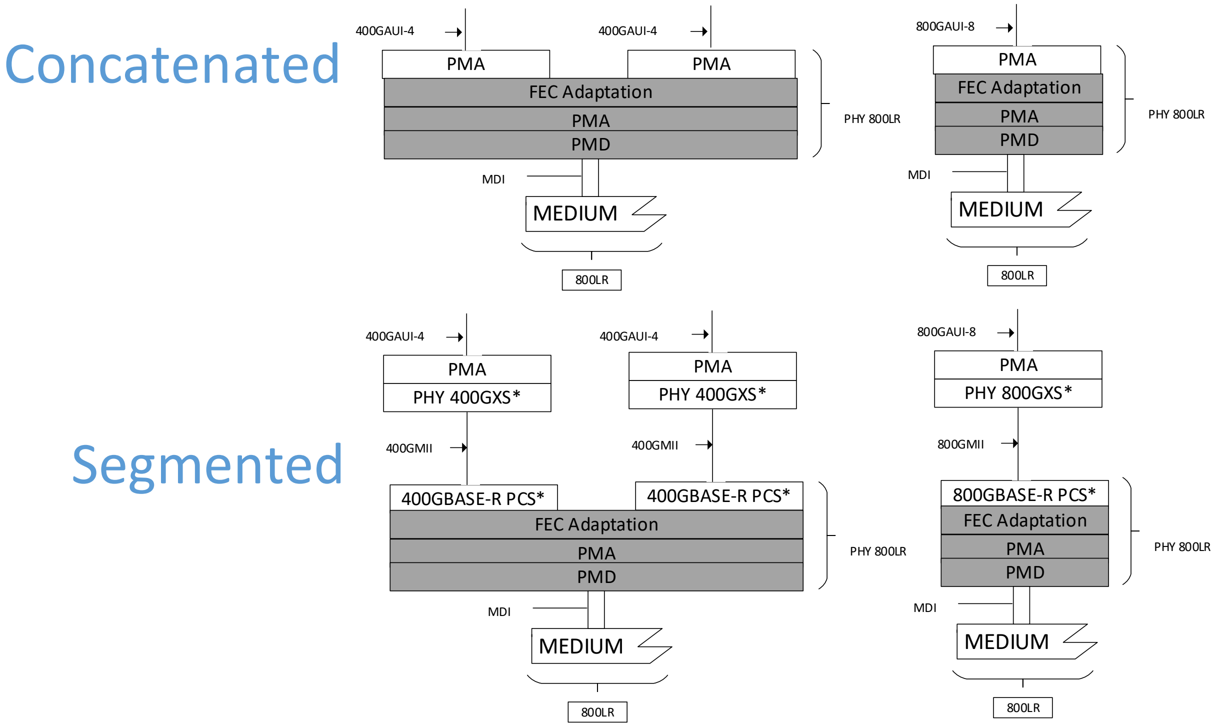
NOTE – 800G-ETC-R and 800GBASE-R are functionally compatible; the IA will generically use ‘800GE’ to refer to both clients.

4 800LR Client Adaptation

Contrary to other line interfaces (such as those defined in [OIF 800ZR] and [ITU-T G.709.3]), 800LR does not define a frame structure that is separate from the FEC structure. Instead, the client signal(s) are adapted directly into the 800LR FEC structure. In the case of two 400GE clients, the clients are interleaved using a permutation function (as defined in section 9.1)

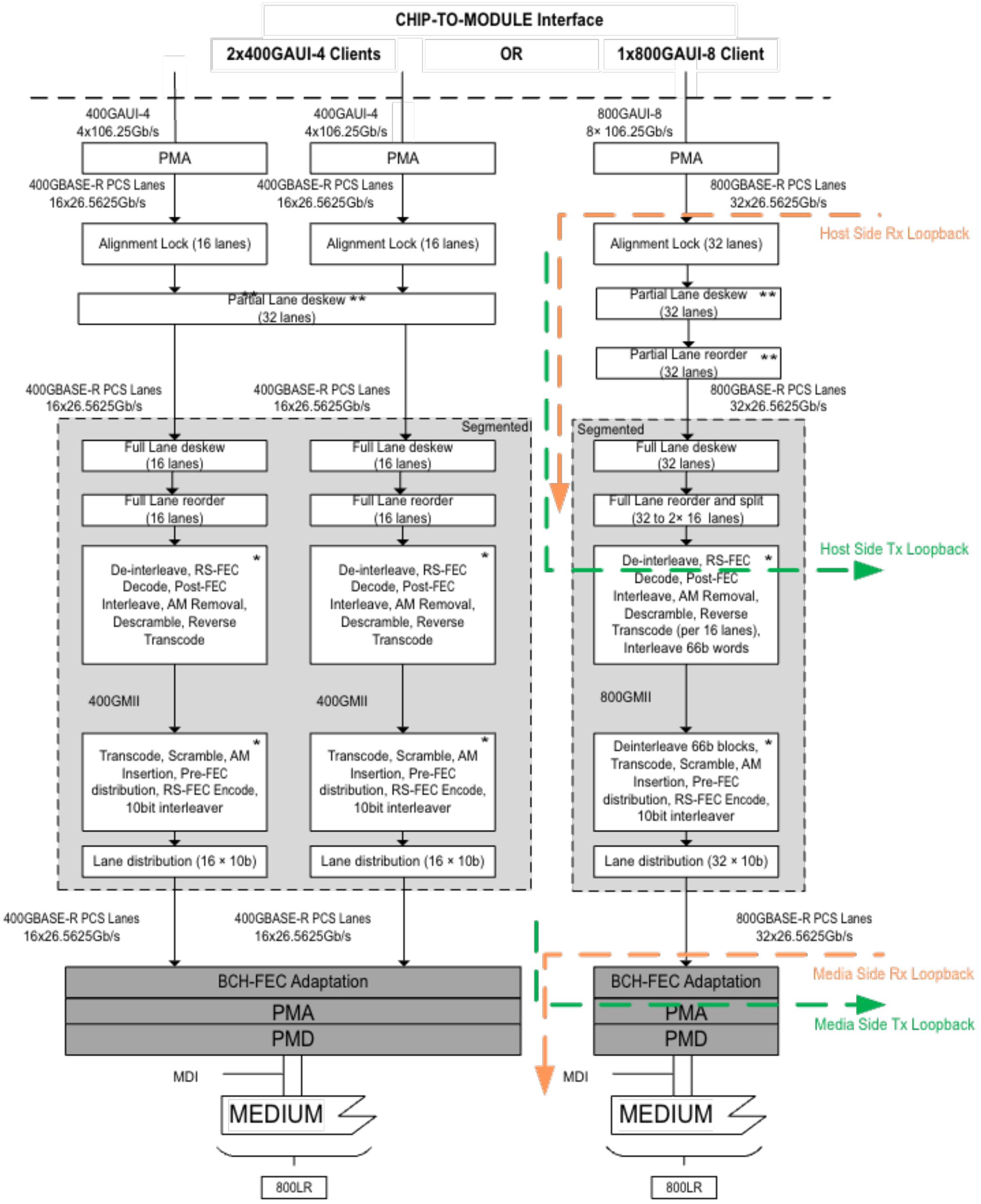
There is no OAM associated with an 800LR interface. Clients are transported in a bit transparent and timing transparent manner. All clients are synchronous to each other and to the 800LR signal. As such, there is no rate adjustment process.

Two architectures are shown in Figure 3. The concatenated mode only uses an inner FEC adaptation, whereas the segmented FEC mode uses an extender sublayer model to regenerate the outer FEC code tied to the PCS. Some XS (extender sublayer) and PCS processes are optional depending on the mode of operation.



* Logical Equivalent Implementation

Figure 3: 400GE/800GE Clients to 800LR architecture



* Logical Equivalent Implementation
** Partial deskewing and reordering not needed when implementing full processes in segmented architectures

Figure 4: 400GE/800GE Clients to 800LR TX data path

The client adaptation process for each 400GE/800GE client into the BCH-FEC structure includes the following steps for transmit towards 800LR media/line. Some of these are not present in concatenated architecture, as shown in Figure 4.

1. PMA adaptation
2. Alignment lock

3. Lane de-skew
4. Lane re-order (and split) and 10b de-interleave
5. RS-FEC decode and post-FEC interleave
6. AM removal and extraction of rx_am_sf<2:0> fields
7. Descramble
8. Reverse transcode (transdecode) to 66b blocks
9. Transcode to 257b blocks
10. Scramble
11. AM insertion and population of rx_am_sf<2:0> fields
12. Pre-FEC distribution and RS-FEC encode
13. 10b interleaving and lane distribution

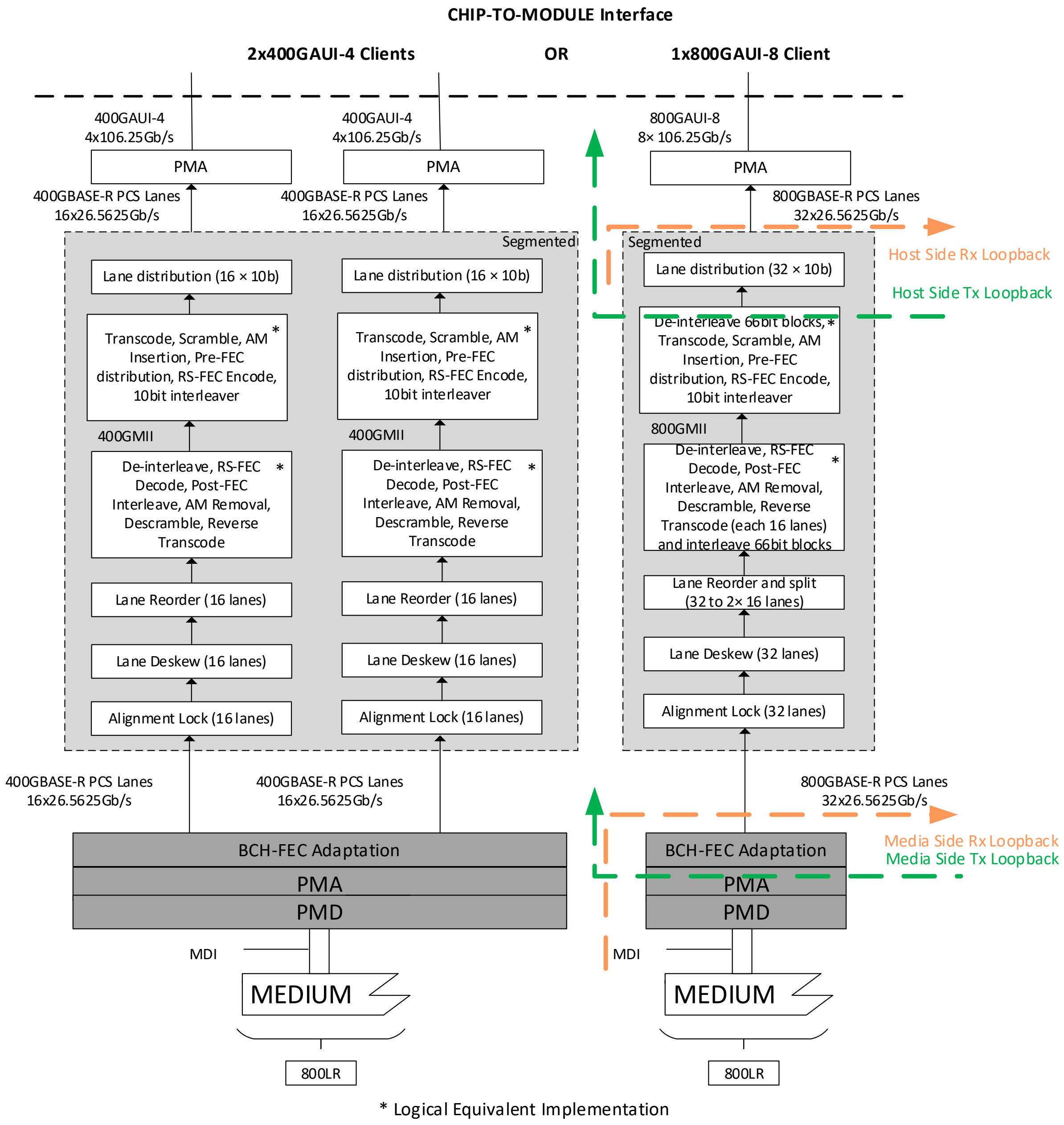


Figure 5: 400GE/800GE Clients to 800LR RX data path

NOTE – 2x400GE clients are synchronous and there are no rate adaptation functions performed.

The client adaptation process for each 400GE/800GE client from the media/line BCH-FEC includes the following steps for receive from 800LR media/line. The ordering is inverse with respect to the transmit direction. Some of these are not present in concatenated architecture, as shown in Figure 5.

1. Alignment lock
2. Lane de-skew

3. Lane re-order (and split) and 10b de-interleave
4. RS-FEC decode and post-FEC interleave
5. AM removal and extraction of rx_am_sf<2:0> fields
6. Descramble
7. Reverse transcode (transdecode) to 66b blocks
8. Transcode to 257b blocks
9. Scramble
10. AM insertion and population of rx_am_sf<2:0> fields
11. Pre-FEC distribution and RS-FEC encode
12. 10b interleaving and lane distribution
13. PMA adaptation

These steps are described in detail in the following sections.

4.1 PMA Adaptation

This implementation agreement supports the client interfaces listed in Table 1.

The 400GAUI-4 signal for each 400G Ethernet client is processed in the transmit direction using the PMA procedures described in Clause 120 of [IEEE 802.3] with amendments from [IEEE 802.3ck], to extract sixteen PCS lanes for each client. The inverse process is used in the receive direction.

The 800GAUI-8 for the 800GBASE-R client described in Clause 173 of [IEEE 802.3df] or the 800G-ETC chip-to-module interface as described in [ETC 800G] is processed in the transmit direction to extract 32 PCS lanes. The inverse process is used in the receive direction.

4.2 Alignment Lock and Lane De-skew

The PCS lanes of the client signal(s) are individually processed in the transmit direction to achieve alignment lock on each individual lane (at the 20b boundaries). Following alignment lock, the lanes are partially de-skewed to align all 32 lanes of 800GE client signal or two 400GE client signals to 20-bit RS-FEC symbol boundaries. Full de-skew to align the alignment markers of all lanes is only required for segmented architecture.

The 400GBASE-R client lanes are processed using the procedures described in Clause 119 of the [IEEE 802.3] with amendments described in [IEEE 802.3ck]. When there are two 400GBASE-R clients, the first is in lanes 0 to 15 and the second in lanes 16 to 31.

The 800GBASE-R and 800G-ETC-R client lanes are processed using procedures in Clause 172 of [IEEE 802.3df] and as described in the [ETC 800G], respectively.

4.3 Lane Reorder and Interleave/Distribution

In the transmit direction for concatenated architecture, the lanes of 800GBASE-R (800G-ETC-R) client signals are partially reordered so that the lanes from one 400G flow are present in either PCS lanes 0-15 or PCS lanes 16 to 31. Full PCS lane reordering is optional process and only required for segmented architecture. In the receive direction, the encoded RS-FEC codewords are interleaved and distributed to PCS lanes.

The 400GBASE-R client lanes are processed using the procedures described in Clause 119 of the [IEEE 802.3] with amendments described in [IEEE 802.3ck].

The 800GE client lanes are processed using procedures in Clause 172 of [IEEE 802.3df] and as described in the [ETC 800G].

4.4 RS-FEC Decode and Encode

RS-FEC processing is required in the segmented FEC architecture and is not performed in the concatenated FEC architecture. The FEC processes are identical in the receive and transmit direction.

The FEC codewords of the client signals are decoded to correct for any accumulated errors. A local degrade signal is generated for each 400GBASE-R or 800GBASE-R (800G-ETC-R) client signals for insertion into the rx_am_sf<2:0> LD field.

For 400GBASE-R clients, the RS-FEC sublayer is described in Clause 119 of [IEEE 802.3] with amendments described in [IEEE 802.3ck]. Error marking is based on uncorrectable errors and behavior is described in [IEEE 802.3].

For 800GBASE-R (800G-ETC-R) client, the RS-FEC sublayer is described in Clause 172 of [IEEE 802.3df] and the [ETC 800G] applies. Error marking is based on uncorrectable errors and behavior is described in [IEEE 802.3].

4.5 Alignment Marker and Scrambling

Alignment markers are always present in both client PMA and 800LR line signals. They are transparently passed through in concatenated FEC architecture and they are removed then re-inserted in both directions in segmented FEC architecture. The am_sf<2:0> bits are extracted and re-inserted automatically.

The 257b blocks are scrambled and descrambled following the procedures in Clause 119.2.4.3 of [IEEE 802.3].

4.6 Client Type and Error Signaling

Client types supported are identified in Table 1, and these are homogenous across an 800LR line interface. In other words, there are no mismatch of different client types supported. There is no overhead on the 800LR line signal associated to identifying client types and client failures. Client AM values can be optionally monitored to identify client types from the client PMA in the transmit direction and from the 800LR line in the receive direction.

The 400GBASE-R clients can be identified by their AM values as described in Clause 119 of [IEEE 802.3] with amendments described in [IEEE 802.3ck].

For 800GBASE-R client can be identified by their AM values as described in Clause 172 of [IEEE 802.3]. 800G-ETC-R can be identified by the [ETC 800G] defined AM values.

On any client failures, there are no consequent actions towards the transmitted media/line. The structure, coding, scrambling and clocking is dependent on all the client signal(s) being present and operational. As such, if one 400GBASE-R client signal is failed, neither signal is transmitted over the line interface. Similarly, on line failures, there are no consequent actions towards the host received clients.

Table 2 specifies the errors detected at the media interface.

Defects	Description
LOL	Loss of DSP frame lock
LOA (Optional)	Loss of Alignment Lock or incorrect AM client type values (ref. 802.3 Clause 119)
FED (Optional)	RS-FEC Excess Degrade Detected
FDD	BCH-FEC Degrade Detected

Table 2: Error detection – Media to Host (receive)

Table 3 specifies the errors detected at the Host Interface (per Ethernet client).

Defects	Description
LOL/LOA	Loss of Alignment Lock (ref. 802.3 Clause 119)
LOS	Loss of signal
FED (Optional)	RS-FEC Excess Degrade Detected
FDD (Optional) [1]	RS-FEC Degrade Detected

Table 3: Error detection – Host to Media (transmit)

[1] FDD has programmable threshold value, inject of LD in rx_am_sf based on FDD will occur if FDD detection is enabled. FDD is performed on outer RS-FEC code and is optional on media and host since RS-FEC decoding is in segmented mode only.

4.6.1 Defect Definition

The loss of lock defect (dLOL) is based on pilot symbols. The 800LR DSP frame structure and pilot sequence are described in Section 11.1. The dLOL is asserted if DSP frame alignment is lost for 3ms. After assertion, the defect is cleared only if the DSP frame alignment is detected continuously for 3ms.

4.7 Test Signals

4.7.1 Idle Test Signal

An Ethernet idle as defined in [IEEE 802.3] can optionally be used in segmented modes as a test pattern towards the media on the 800LR optical link. The idle test pattern is functionally inserted/monitored at the MII as shown in Figure 4 and Figure 5. The idle patterns are 257b encoded, scrambled, RS-FEC encoded and contain AM, the structure being compatible to an 800LR line.

The pattern received from the media is compared to an expected idle pattern, and post-FEC errors can be counted/derived from the comparison.

4.7.2 BCH-FEC PRBS Test Signal

The BCH PRBS is optionally used for validating the BCH-FEC/DSP framing, symbol mapping and PS insertion. The required PRBS31 is per IEEE 802.3 with initial state being all 1's and is shown in Figure 6.

- Generation/checking is to/from the media interface.

- The PRBS generator is inserted in the TX data path and replaces the entire client.
- PRBS is starting at lane 0 and 10 bits interleaved across 32 lanes

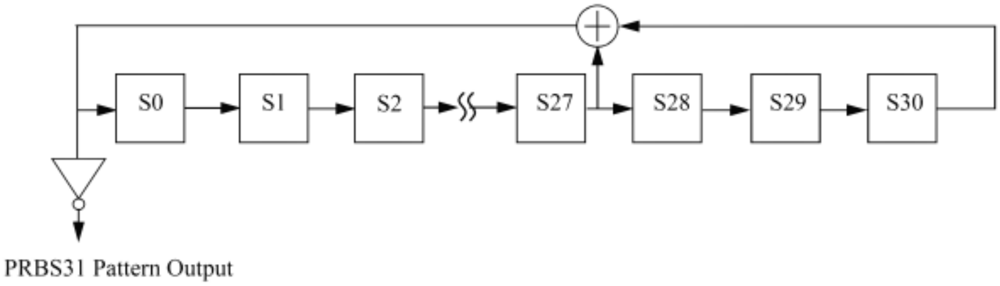


Figure 6: BCH-FEC PRBS31 generator

5 800LR Forward Error Correction (FEC)

The 800LR FEC adaptation consists of 3 main functions shown in Figure 7 below: Lane permutation, convolutional interleaver and BCH-FEC encoder/decoder. 800LR uses a nested FEC scheme, with the Ethernet PCS hard-decision RS(544,514) outer code from the client signal and a soft-decision BCH(126,110) inner code. This provides 10.35 dB of net coding gain, with ~14.5% additional overhead compared to RS-FEC-encoded client signal.

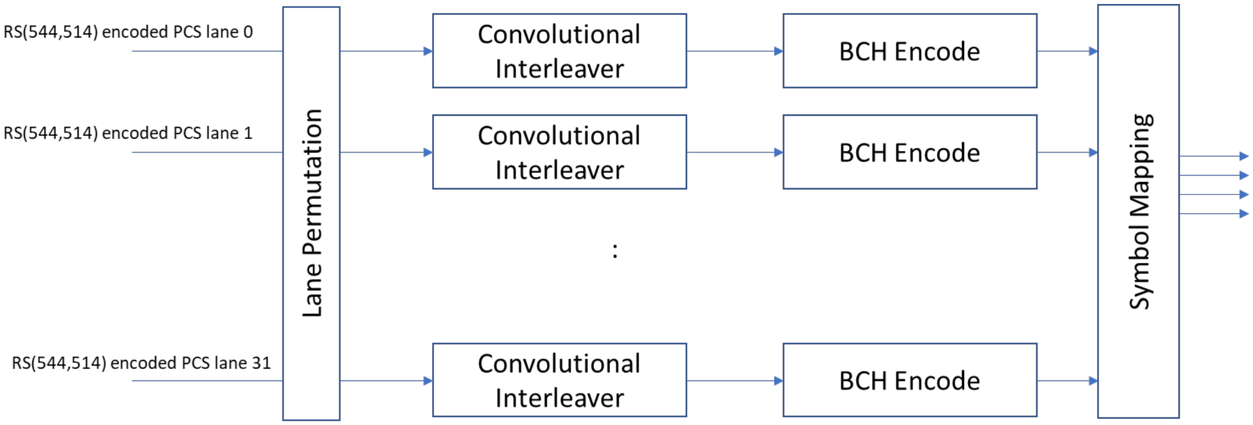


Figure 7: 800LR FEC Adaptation

5.1 Lane Permutation Function

Full PCS lane reordering and deskewing are optional processes (see sections 8.2 and 8.3). A lane permutation function is required to provide 10b symbols from 4 interleaved RS(544,514) codewords on each lane into the convolutional interleavers. The permutation function swaps 10-bit Reed-Solomon symbols from PCS lane *n* with PCS lane (*n+16*) for *n=0..15*. The PCS lanes 0 to 15 contain symbols from two interleaved Reed-Solomon codewords labeled A and B in Figure 8 below. The PCS lanes 16 to 31 contain symbols from two different interleaved Reed-Solomon codewords labeled C and D below. The simple permutation is shown in Figure 8. The yellow boxes are 10-bit symbols from lane *n* and the blue boxes are 10-bit symbols from lane (n+16). Permutation functions are identical in both transmit and receive directions. The permutation function ensures proper mix RS symbols.

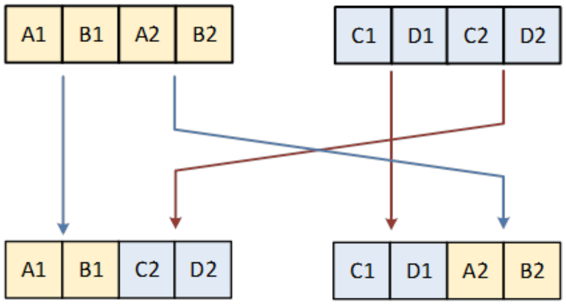


Figure 8: Lane Permutations

Note that the symbols from codewords in PCS lanes 0 to 15 may be organized as ABAB or BABA. Likewise, the symbols codewords in PCS lanes 16 to 31 may be organized as CDCD or DCDC.

5.2 Convolutional Interleaver

A FEC lane convolutional interleaver serves to spread out the transmission order of consecutive units of 40 bits (4 10b RS symbols) from the RS(544,514) encoded PCS lanes, which ensures no more than one 10b RS symbol from each RS codeword is included in the 110b input of the BCH-FEC encoding. The convolutional interleaver is of depth 3, that is, it consists of 3 parallel delay lines (rows), as illustrated in Figure 9. Each delay operator "D" represents a storage element of 40b. From one row to the next lower row, six delay operators are added. The bit ordering at the input of the convolutional interleaver block is preserved at the output. There are 32 total convolutional interleavers for an 800LR interface, one per PCS lane.

At time i, the input and output switches are aligned at row i ($i = 0$ to 2)

- A block of 40 bits is read from row i
- The contents of row i are shifted to the right by 40 bits
- A block of 40 bits is written to row i
- The switch position is updated to $i + 1$ (mod 3)

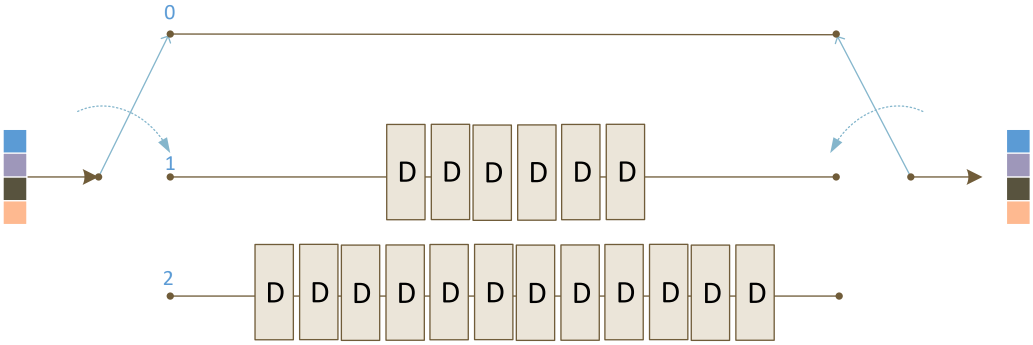


Figure 9: Convolutional Interleaver

Initialization of the convolutional interleaver switches (to their topmost positions) is defined to occur at the start of every DSP frame which will be detailed in clause 11.

5.3 BCH FEC

The BCH code defined by the generator polynomial is derived starting with a BCH (127,113) code that is shortened to a (124,110) code and then extended to the final (126,110) code by adding even and odd parity check bits.

The code is defined by the primitive polynomial of the Galois Field, and the cyclic generator polynomial for the BCH code. The generator polynomial includes two parity bits. One parity bit is for even bits and one parity bit is for odd bits.

The BCH(126,110) uses the following generator polynomial with systematic encoding:

$$g(x) = M1(x) \cdot M3(x) \cdot (x^2 + 1) = (x^7 + x^3 + 1)(x^7 + x^3 + x^2 + x + 1)(x^2 + 1)$$
$$= x^{16} + x^{14} + x^{11} + x^{10} + x^9 + x^7 + x^5 + x^3 + x + 1$$

The bits at the encoder input are taken in order to form a 110-bit pattern representing the coefficients of a polynomial $\mathrm{m}(x)$ of degree 109. Assuming the bits at the encoder input stream are numbered starting at 0 for the first arriving bit, bit 0 maps to the coefficient of x^{109}.

$\mathrm{m}(x)$ is multiplied by x^{16} and divided (modulo 2) by $g(x)$, producing a remainder $\mathrm{r}(x)$ of degree 15 or less.

The coefficients of $\mathrm{r}(x)$ are considered a 16-bit check sequence, where x^{15} is the most significant bit. The 16 check bits are appended to the message to form the code polynomial $c(x)= x^{16}m(x) + r(x)$

The coefficients of $\mathrm{c}(x)$ are the encoded codeword where the coefficients are transmitted in order starting with the coefficient of x^{125}. The ordering ensures that the systematic message bits are transmitted first in the same order they were received at the encoder input followed by the check/parity bits.

5.4 FEC Degrade Defects

The 800LR link shall provide detection and signaling of Link Degrade (LD) for use by switch/routers with soft reroute capabilities. This functionally is optional and only relevant in segmented modes since the RS-FEC is not terminated in concatenated modes. Figure 10 illustrates the bidirectional signaling between an 800LR transceiver and two Routers (A and B). Pre-FEC BER from the BCH-FEC and RS-FEC (see FDD in Table 2 and Table 3) monitors are used to detect and insert link degrade at both the 800LR optical link and the Ethernet client PCS interfaces.

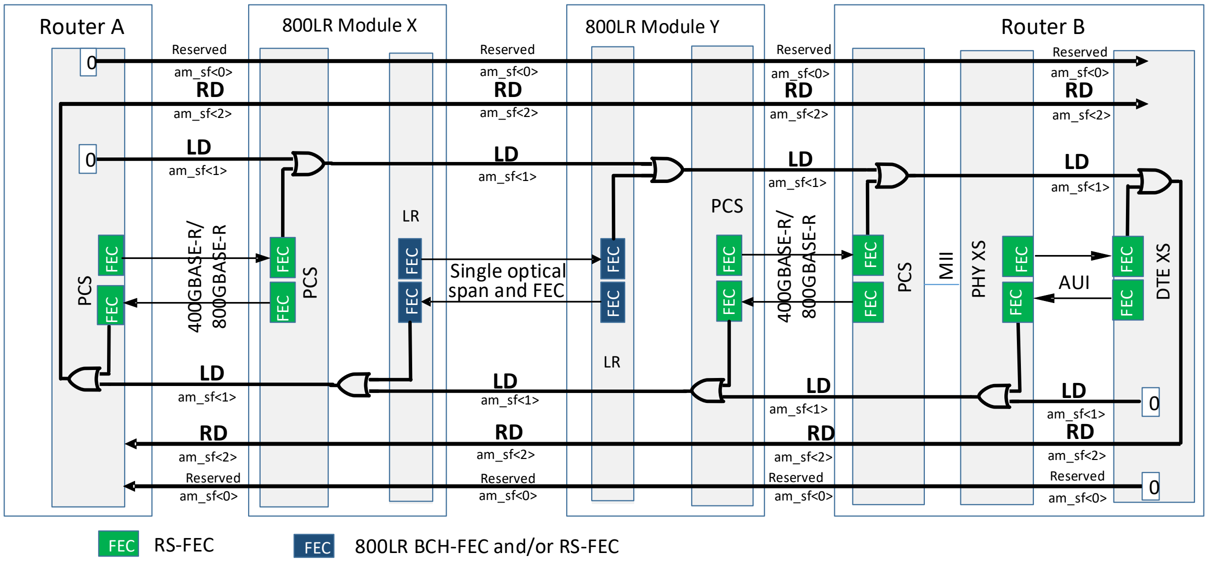


Figure 10: Local/Remote Degrade interworking between Switch/Router and 800LR transceiver

For 400GE and 800GE client types, [IEEE 802.3] defines three bits in the AM field (am_sf<2:0>) to carry Link Degrade Indication (LDI). Bit am_sf<2> is defined as a Remote Degrade (RD) signal, bit am_sf<1> is defined as a Local Degrade (LD) signal and bit am_sf<0> is reserved. For 800G-ETC clients, the am_sf<2:0> bits are identical and present in both 400G streams at the client interface.

The behavior is identical for both receive and transmit directions in segmented modes, since the RS-FEC decodes and then encodes in both directions. In the host-to-media transmit datapath, the additional processing consists of ORing the ingress LD status in the am_sf<1> bit of the 400GBASE-R/800GBASE-R client signal(s) with the local host interface RS-FEC degrade status and signaled on the am_sf<1> bit to the media interface. In the media-to-host datapath, the signaled on the am_sf<1> bit from the media interface is ORed with the BCH-FEC and RS-FEC degrade status and signaled on the am_sf<1> bit to the local host.

6 800LR Symbol Mapping and Polarization Distribution

The 8 bits in a DP-16QAM symbol are considered to belong to 8 different bit classes. Each class may have different BER due to constellation position and differences in PDL noise between the two polarizations. To provide robustness to noise correlation and error bursts, the symbol mapping procedure ensures that the bits within each BCH-FEC codeword are equally distributed among the eight classes of bits.

In each signaling dimension, the mapping from binary label to symbol amplitude is defined as follows:

$$(0,0)\rightarrow -3,\ (0,1)\ \rightarrow -1, (1,1)\rightarrow +1, (1,0)\rightarrow +3$$

Suppose bits of BCH encoder output for time k (for k=0,1⋯95, where k is aligned to start of DSP frame), and lane p (for p=0,1,⋯31) are denoted:

$(m_{109}^{k,p}, m_{108}^{k,p}, \dots, m_0^{k,p}, r_{15}^{k,p}, r_{14}^{k,p}, \dots, r_0^{k,p})$ are the coefficients of $(x^{125}, x^{124}, \dots, x^{16}, x^{15}, x^{14}, \dots, x^0)$ of c(x) respectively, where the information bits are denoted $m_{109}^{k,p}, m_{108}^{k,p}, \dots, m_0^{k,p}$ and the check/parity bits are denoted $r_{15}^{k,p}, r_{14}^{k,p}, \dots, r_0^{k,p}$

Bit shuffling: Information bit $m_q^{k,p}$ of lane p is rotated to position $(q\text{-}20{*}p)\ \%\ 110$ prior to mapping.

Mapping: Suppose $S_h^k = \left(s_{XI}^{k,h}, s_{XQ}^{k,h}, s_{YI}^{k,h}, s_{YQ}^{k,h}\right)$ denote the DP-16QAM symbols (prior to pilot insertion) for $\mathrm{h}=0,1,\cdots,503$

- $s_{XI}^{k,h}$ is formed from bits $[2\ \times \mathrm{h}\%63 + \mathrm{h}\%2,\ 2 \times \mathrm{h}\%63 + (\mathrm{h}+1)\%2]$ of lane $4 \times \left\lfloor \frac{h}{63} \right\rfloor + (2\mathrm{h} + \left\lfloor \frac{h}{2} \right\rfloor \%2)\%4$
- $s_{XQ}^{k,h}$ is formed from bits $[2 \times \mathrm{h}\%63 + \mathrm{h}\%2,\ 2 \times \mathrm{h}\%63 + (\mathrm{h}+1)\%2]$ of lane $4 \times \left\lfloor \frac{h}{63} \right\rfloor + (2\mathrm{h} + \left\lfloor \frac{h}{2} \right\rfloor \%2 + 1)\%4$
- $s_{YI}^{k,h}$ is formed from bits $[2 \times \mathrm{h}\%63 + \mathrm{h}\%2,\ 2 \times \mathrm{h}\%63 + (\mathrm{h}+1)\%2]$ of lane $4 \times \left\lfloor \frac{h}{63} \right\rfloor + (2\mathrm{h} + \left\lfloor \frac{h}{2} \right\rfloor \%2 + 2)\%4$
- $s_{YQ}^{k,h}$ is formed from bits $[2 \times \mathrm{h}\%63 + \mathrm{h}\%2,\ 2 \times \mathrm{h}\%63 + (\mathrm{h}+1)\%2]$ of lane $4 \times \left\lfloor \frac{h}{63} \right\rfloor + (2\mathrm{h} + \left\lfloor \frac{h}{2} \right\rfloor \%2 + 3)\%4$

where a % b indicates modulo division.

7 800LR DSP Framing

A DSP frame is defined at the output of the symbol mapper and polarization distribution. The DSP frame is defined as a set of 96×64=6144 DP-16QAM symbols. Pilot symbols (PS) shall be inserted every 64 symbols (1 pilot symbol, 63 payload symbols). The details of the DSP frame are shown in Figure 11.

Each DSP Frame is aligned to 32 BCH(126,110) codewords and aligned to the 32 FEC lanes.

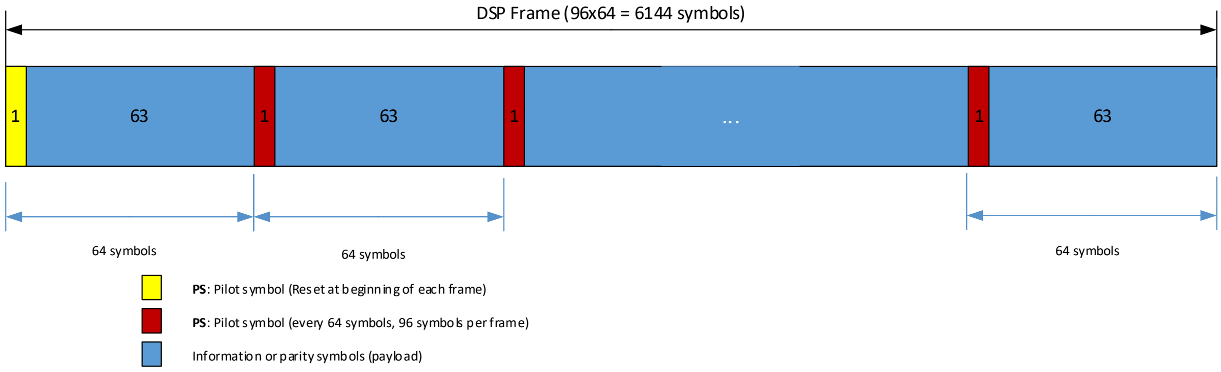


Figure 11: DSP frame format

7.1 Pilot Sequence

One symbol from a pilot sequence is inserted every 64 symbols in each DSP frame. The pilot sequence uses only the outer symbols of the 16QAM constellation and consists of a fixed sequence of 96 symbols formed from a PRBS9 pattern mapped to QPSK with different seeds for the X and Y polarizations as shown in Figure 12.

- Seeds are selected so that the pilot sequence are DC balanced
- The pilot sequence is a PRBS9 pattern initialized at the beginning of the DSP Frame

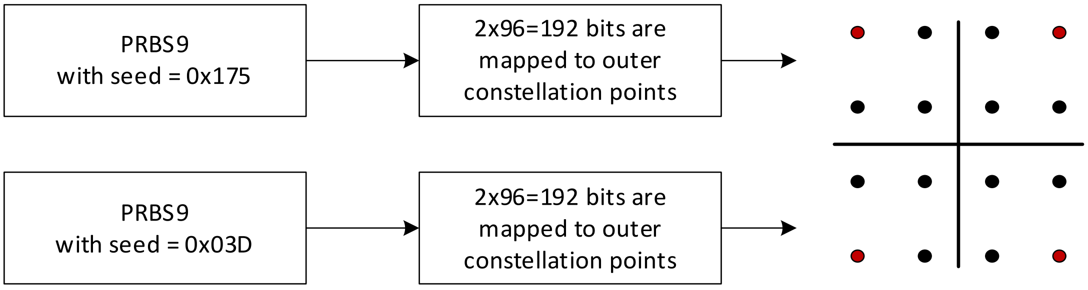


Figure 12: QPSK mapped pilot sequence

The generator polynomial and seed values for the pilot sequence are shown in Table 4.

Generator polynomial	Seed X	Seed Y
$x^9 + x^8 + x^5 + x^4 + 1$	0x175	0x03D

Table 4: PRBS9 polynomial and seed values for pilot sequence

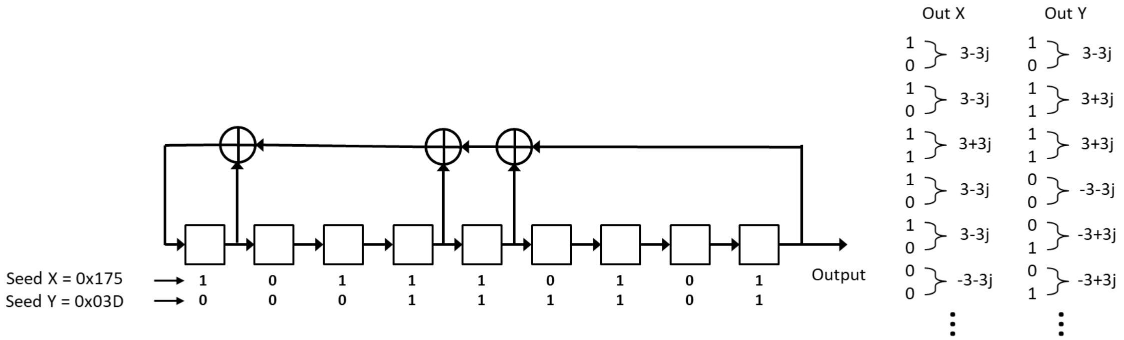


Figure 13: Pilot seed and sequencing

The complete pilot sequence is shown in Table 5.

Index	**Pilot X**	**Pilot Y**	**Index**	**Pilot X**	**Pilot Y**	**Index**	**Pilot X**	**Pilot Y**	**Index**	**Pilot X**	**Pilot Y**
1	3-3j	3-3j	**25**	-3+3j	-3-3j	**49**	3+3j	-3+3j	**73**	-3-3j	-3+3j
2	3-3j	3+3j	**26**	-3-3j	-3+3j	**50**	-3-3j	3-3j	**74**	3+3j	-3+3j
3	3+3j	3+3j	**27**	3+3j	3-3j	**51**	3-3j	3+3j	**75**	-3+3j	-3-3j
4	3-3j	-3-3j	**28**	3+3j	-3-3j	**52**	-3-3j	3+3j	**76**	3-3j	3-3j

5	3-3j	-3+3j	**29**	3+3j	3-3j	**53**	3+3j	-3-3j	**77**	-3+3j	-3-3j
6	-3-3j	-3+3j	**30**	-3-3j	-3-3j	**54**	-3-3j	3-3j	**78**	3+3j	-3+3j
7	3+3j	-3-3j	**31**	-3+3j	-3-3j	**55**	3-3j	3-3j	**79**	-3+3j	-3-3j
8	-3+3j	-3+3j	**32**	3-3j	-3-3j	**56**	3+3j	-3-3j	**80**	-3+3j	-3-3j
9	-3+3j	-3-3j	**33**	3+3j	-3+3j	**57**	-3-3j	-3+3j	**81**	-3+3j	3+3j
10	-3+3j	3-3j	**34**	-3+3j	3+3j	**58**	-3-3j	3-3j	**82**	3+3j	3+3j
11	-3-3j	-3-3j	**35**	-3-3j	3-3j	**59**	3-3j	-3-3j	**83**	3-3j	3+3j
12	-3+3j	3-3j	**36**	-3-3j	-3-3j	**60**	-3+3j	-3+3j	**84**	3+3j	3+3j
13	3+3j	3+3j	**37**	3-3j	-3+3j	**61**	3-3j	3+3j	**85**	-3+3j	3-3j
14	-3+3j	-3-3j	**38**	3+3j	-3+3j	**62**	-3+3j	-3-3j	**86**	3-3j	3-3j
15	-3-3j	3+3j	**39**	3-3j	-3-3j	**63**	3+3j	-3-3j	**87**	-3-3j	3+3j
16	3-3j	-3+3j	**40**	3+3j	3-3j	**64**	3-3j	3+3j	**88**	-3-3j	3+3j
17	-3+3j	-3+3j	**41**	3+3j	3+3j	**65**	3-3j	-3+3j	**89**	3+3j	3-3j
18	3-3j	3-3j	**42**	-3+3j	3-3j	**66**	-3+3j	3+3j	**90**	-3+3j	-3+3j
19	3-3j	3+3j	**43**	-3+3j	-3-3j	**67**	3+3j	-3+3j	**91**	-3-3j	3+3j
20	-3-3j	-3+3j	**44**	-3-3j	-3-3j	**68**	-3-3j	3-3j	**92**	3-3j	-3-3j
21	3-3j	3+3j	**45**	-3-3j	-3+3j	**69**	-3+3j	-3+3j	**93**	3-3j	3-3j
22	3-3j	3+3j	**46**	-3-3j	-3+3j	**70**	-3-3j	-3-3j	**94**	-3+3j	3+3j
23	3+3j	3-3j	**47**	3+3j	3-3j	**71**	3+3j	3-3j	**95**	3-3j	3+3j
24	-3+3j	3+3j	**48**	-3-3j	3-3j	**72**	3+3j	-3+3j	**96**	-3-3j	3+3j

Table 5: 800LR Pilot Sequence

7.2 Channel Mappings

X and Y indicate a pair of mutually orthogonal polarizations of any orientation and I and Q are mutually orthogonal phase channels in each polarization. The four datapath channels are therefore labeled XI, XQ, YI, and YQ.

All coherent channel mappings provided in Table 6 are allowed for the TX signal. The Rx should work in all cases because it can unambiguously identify the polarization and phase of the signal based on the PS.

The Tx mapping is specified in Table 6 by two designations: X:Y and I,Q where a ":" is used to separate X &Y, a "," is used to separate I&Q.

Mapping	X:Y	I,Q	Notes
[0,x]	X:Y		Polarization cannot be interleaved

[1,x]	Y:X		
[x,0]		I,Q:I,Q	Same across Polarization
[x,1]		Q,I:Q,I	
[x,2]		I,Q:Q,I	Flip across Polarization
[x,3]		Q,I:I,Q	

Table 6: Channel Mappings

7.3 Client Expansion Rate

The 800LR optical signal is DP-16QAM with a symbol rate of 123.6 GS/s (989.1 Gbps).

Offset	Ethernet Client	BCH-FEC 126/110	PS 64/63	Symbol Rate (Baud)
-100ppm	849,915,000,000	973,539,000,000	988,992,000,000	123,624,000,000
0ppm	850,000,000,000	973,636,363,636	989,090,909,091	123,636,363,636
+100ppm	850,085,000,000	973,733,727,272	989,189,818,182	123,648,727,273

Table 7: 800LR expansion rate table

The 800LR line is synchronous to the Ethernet client(s), with a 126/110 ratio to account for the BCH-FEC adaption and a 64/63 ratio to account for the pilot insertion.

8 Optical Specification

The 800LR optical parameters are organized by Application Codes (defined in Table 8) for the Tx, Rx, and the Optical Channel.

Ref	Application Description	Maximum Loss Budget	Application Code – Name
12.0.100	10km or less, unamplified, point-to-point, single channel links – O-band.	8dB	***0x01*** – 800LR–O
12.0.200	10km or less, unamplified, point-to-point, single channel links – C-band.	5dB	***0x02*** – 800LR– C

Table 8: 800LR Applications codes

Note: All specifications are defined after calibration and compensation, at EOL over temperature.

Transmitter specifications are relative to S_s, whereas Receiver specifications are relative to Rs as shown in Figure 1.

Bold italicized items found in tables indicate a reference to a Coherent Common Management Interface Spec [C-CMIS] or a Common Management Interface Specification [CMIS] defined function, state, or status condition.

8.1 800LR Unamplified, Single Channel, O-band – Application Code (0x01)

This section defines optical parameters for the unamplified, single channel, O-band, Application Code (**0x01**).

8.1.1 Optical Channel Specifications

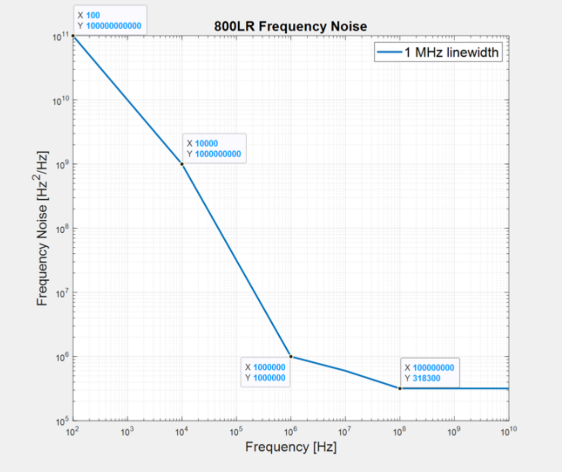
The 800LR O-band optical channel specifications are given in Table 9.

Ref.	Parameter	Unit	Min	Max	Conditions/Comments
12.1.100	Channel Frequency	THz	228.675	228.675	Center at 1311nm to align with existing IEEE IMDD specifications
12.1.120	Post-FEC BER			10^{-15}	For optical systems that conform to this IA. Post-FEC BER is after outer RS FEC.
12.1.150	Loss	dB	0	8	
12.1.160	Chromatic Dispersion	ps/nm	-12.3	10.1	Frequency dependent change in phase velocity due to fiber. Based on G.652, values consistent with 802.3-2022, (ex: Table 122-16) for a wavelength of 1311nm and 10 km link.
12.1.161	Optical Return Loss at S_s	dB	24		See definition in 8.5.1.
12.1.162	Discrete Reflectance between S_s and R_s	dB		-27	See definition in 8.5.2.
12.1.170	Maximum Differential Group Delay (DGD_{max})	ps		5	See definition in 8.5.3.
12.1.172	Polarization Rotation Speed	krad/s		50	See definition in 8.5.4.
12.1.175	Polarization Dependent Loss	dB		0.5	

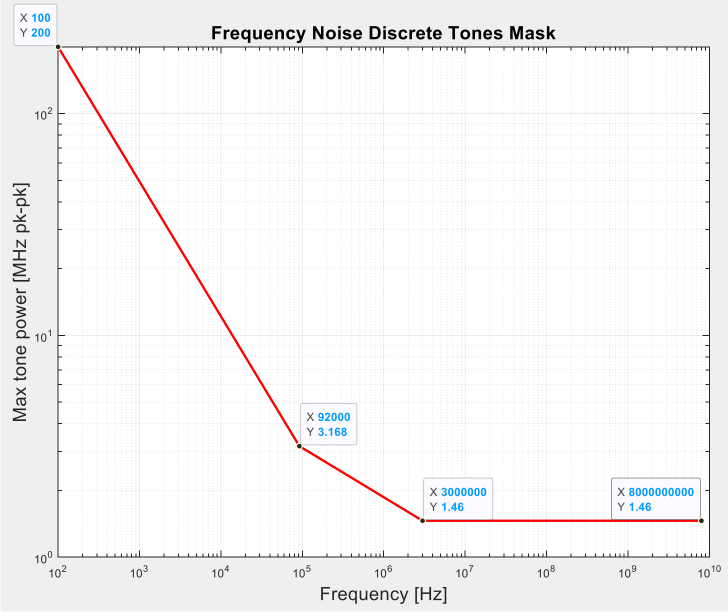
Table 9 800LR O-band Optical Channel Specifications

8.1.2 Transmitter Optical Specifications

<table>
<tr><th>Ref</th><th>Parameter</th><th>Unit</th><th>Min</th><th>Max</th><th>Conditions/Comments</th></tr>
<tr><td>12.1.200</td><td>Tx Laser frequency accuracy</td><td>GHz</td><td>-20</td><td>20</td><td>Offset from channel frequency set point.</td></tr>
<tr><td>12.1.201</td><td>Maximum Tx laser frequency slew rate: Pre-acquisition</td><td>GHz /s</td><td></td><td>+/-10</td><td>Maximum slew rate of Tx laser frequency during hunt for acquisition procedure defined in Section 8.7.</td></tr>
<tr><td>12.1.202</td><td>Maximum Tx laser frequency slew rate: Post-acquisition</td><td>GHz /s</td><td></td><td>1</td><td></td></tr>
<tr><td>12.1.203</td><td>Laser Relative Frequency tracking accuracy</td><td>GHz</td><td>-0.9</td><td>0.9</td><td>Relative link LO offset accuracy achieved through laser frequency adjustments</td></tr>
<tr><td>12.1.205</td><td>TX spectrum minimum mask</td><td>(GHz, dB)</td><td>(61.8,-10
(64.6,-20
64.6,-35)</td><td></td><td>See definition and mask in Section 8.5.6.</td></tr>
<tr><td>12.1.210a</td><td>Laser frequency noise</td><td>Hz^2/ Hz</td><td colspan="3">Maximum laser frequency noise defined by mask,



<table>
<tr><th>Frequency [Hz]</th><th>1-sided frequency noise power spectral density (PSD) [Hz^2/Hz]</th></tr>
<tr><td>**1.0e2**</td><td>1.0E+11</td></tr>
<tr><td>**1.0e4**</td><td>1.0E+09</td></tr>
<tr><td>**1.0e6**</td><td>1.0E+06</td></tr>
<tr><td>**1.0e7**</td><td>6.0E+05</td></tr>
<tr><td>**1.0e8**</td><td>3.1831E+05</td></tr>
<tr><td>**1.0e**10</td><td>3.1831E+05</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Ref</th><th>Parameter</th><th>Unit</th><th>Min</th><th>Max</th><th>Conditions/Comments</th></tr>
<tr><td></td><td></td><td></td><td colspan="3">Mask does not apply to spurs. Measurement resolution bandwidth shall be within 10^{-1} to 10^{-6} of the frequency of interest.
High frequency component of the phase noise (100MHz and above) is consistent with a 1MHz laser linewidth. The receiver LO has the same linewidth.</td></tr>
<tr><td>12.1.210b</td><td>Laser frequency noise – discrete tone amplitude</td><td>MHz</td><td colspan="3">Maximum laser frequency noise discrete tone amplitude defined by mask:


<table>
<tr><th>Frequency [Hz]</th><th>Max tone power [MHz pk-pk]</th></tr>
<tr><td>1.0e2</td><td>200</td></tr>
<tr><td>9.2e4</td><td>3.1678</td></tr>
<tr><td>3.0e6</td><td>1.46</td></tr>
<tr><td>8.0e9</td><td>1.46</td></tr>
</table>
Tone power [MHz pk-pk] is calculated as:
$TonePower_{pkpk} = 2 * \sqrt{2} * \sqrt{\int Tone},$
where $\int Tone =$ laser frequency noise PSD (Hz^2/Hz) at tone frequency multiplied by measurement resolution bandwidth (Hz) at tone frequency.
If there is more than one discrete tone present, the relative power of each tone normalized to the mask are summed squared, and the result must be less than 1, i.e. $\sum_i \left[{}^{TonePower_i}/_{MaxTonePower_i}\right]^2 \le 1$</td></tr>
<tr><td rowspan="2">12.1.211</td><td rowspan="2">Laser RIN</td><td rowspan="2">dB / Hz</td><td></td><td>-145</td><td>0.2GHz≤ f ≤10GHz Avg</td></tr>
<tr><td></td><td>-140</td><td>0.2GHz≤ f ≤10GHz Peak</td></tr>
<tr><td>12.1.212</td><td>Laser side-mode suppression ratio (SMSR)</td><td>dB</td><td>30</td><td></td><td></td></tr>
</table>

Ref	Parameter	Unit	Min	Max	Conditions/Comments
12.1.213b	Tx clock phase noise (PN); Maximum total integrated random jitter	UI_{rms}		0.015	Weighted integrated random jitter: $\boldsymbol{\sigma_{rj} = \frac{1}{2\pi f_c}\sqrt{2\int_{f_1}^{f_2} 10^{\frac{\mathcal{L}(f)+W(f)}{10}}}}$ Where, • $f_c = f_{baud}/256$ (483MHz) • f_1 = 10kHz • $f_2 = f_c/2$ • $\mathcal{L}$ (f) is the phase noise (dBc/Hz) excluding spurs • $W(f) = \begin{cases} 20\log_{10}\frac{f}{3\times10^6} & f < 3MHz \\ 0 & f \geq 3MHz \end{cases}$
12.1.213c	Tx clock phase noise (PN); Maximum total periodic jitter	UI_{pp}		0.03	Weighted total periodic jitter: $\boldsymbol{PJ_{pp} = 2\sqrt{2\sum_{i=0}^{N}\sigma_{pj,i}^2}}$ $\boldsymbol{\sigma_{pj,i} = \frac{1}{\sqrt{2}\pi f_c}10^{\frac{s_i+W(f_i)}{20}}}$ Where, • $f_c = f_{baud}/256$ (483MHz) • s_i is the spur magnitude in dBc • f_i is the spur frequency in Hz • $W(f) = \begin{cases} 20\log_{10}\frac{f}{3\times10^6} & f < 3MHz \\ 0 & f \geq 3MHz \end{cases}$ • N = number of spurs
12.1.215	Tx output power	dBm	-9.5	-4	Transmit output power over temperature and aging.
12.1.221	Total output power with TX disabled	dBm		-20	***OutputDisableTx*** == true
12.1.230	Inband (IB) OSNR	dB/ 12.5 GHz	40		Inband OSNR is defined as the Tx signal power between the -20dB Tx Spectrum Mask (12.1.205) frequency points, referenced to an optical noise bandwidth of 12.5GHz at the Tx signal peak frequency.
12.1.240	Transmitter reflectance	dB		-20	Looking into Tx
12.1.241	Transmitter back reflection tolerance	dB		-24	Light reflected relative to Tx output power back to transmitter while still meeting Tx optical performance requirements.

Ref	Parameter	Unit	Min	Max	Conditions/Comments
12.1.250	Transmitter polarization dependent power	dB		1.5	Power difference between X and Y polarization.
12.1.260	X-Y Skew	ps		5	
12.1.270a	DC I-Q offset (mean per polarization)	dB		-26	See definition and equation in 8.5.5
12.1.270b	I-Q instantaneous offset	dB		-20	Same formula definition as 12.1.270a, however, any averaging period shall be $\leq$ 1us to be consistent with the timescales of Rx DSP operations. Specification applies at any point in time. Allows for modulator bias controls/errors.
12.1.271	Mean I-Q amplitude imbalance	dB		1	
12.1.272	I-Q phase error	deg	-5	+5	
12.1.273	I-Q skew	ps		0.75	

Table 10 800LR O-band Transmitter Optical Specifications

8.1.3 Receiver Optical Specifications

The receiver optical tolerance specifications include margin for Tx and line impairments.

Ref	Parameter	Min	Max	Unit	Conditions/Comments
12.1.300	Frequency offset between received carrier and LO	-40	40	GHz	Preacquisition range supported by firmware driven hunt for acquistion procedure defined in 12.7. 12.1.311 Sensitivity is guaranteed for frequency offset limits defined in 12.1.203.
12.1.305	Chromatic dispersion (CD) Tolerance	-15	15	ps/ nm	Tolerance to chromatic dispersion including 12.1.200.
12.1.311	Sensitivity (after link)	-17.5		dBm	Measured after the link, while maintaining the maximum post-FEC BER defined in 12.1.120.
12.1.315	Optical input power (Max)		-4	dBm	Maximum Rx optical input power while maintaining the maximum post-FEC BER defined in 12.1.120.
12.1.340	Optical return loss	20		dB	At Rx connector input.
12.1.350	Rx Power Imbalance		2	dB	
12.1.360	Combined optical channel penalty		0.5	dB	

Table 11 800LR O-band Receiver Optical Specifications

8.2 800LR Unamplified, Single Channel, C-band – Application Code (0x02)

This section defines optical parameters for the unamplified, single channel, C-band, Application Code (0x02).

8.2.1 Optical Channel Specifications

The 800LR C-band optical channel specifications are given in Table 9 with the exception of the parameters in Table 12 which use the same three last digits of the Table 9 reference numbers.

Ref.	Parameter	Unit	Min	Max	Conditions/Comments
12.2.100	Channel Frequency	THz	192.669	192.669	Center at 1556nm to align with existing IEEE IMDD specifications
12.2.150	Loss	dB	0	5	
12.2.160	Chromatic Dispersion	ps/nm	0	185.5	Frequency dependent change in phase velocity due to fiber. Based on G.652, values consistent with 802.3-2022, (ex: Table 122-16) for a wavelength of 1556nm and 10km or less link.

Table 12 800LR C-band Optical Channel Specifications

8.2.2 Transmitter Optical Specifications

The 800LR C-band transmitter optical specifications are given in Table 10 with the exception of the parameters in Table 13 which use the same three last digits of the Table 10 reference numbers.

Ref	Parameter	Unit	Min	Max	Conditions/Comments
12.2.215	Tx output power	dBm	-12.5	-6	Transmit output power over temperature and aging.
12.2.230	Inband (IB) OSNR	dB/ 12.5 GHz	40		Inband OSNR is defined as the Tx signal power between the -20dB Tx Spectrum Mask (12.1.205) frequency points, referenced to an optical noise bandwidth of 12.5GHz at the Tx signal peak frequency.

Table 13 800LR C-band Transmitter Optical Specifications

8.2.3 Receiver Optical Specifications

The 800LR C-band receiver optical specifications are given in Table 11 with the exception of the parameters in Table 14 which use the same three last digits of the Table 11 reference numbers.

The receiver optical tolerance specifications include margin for Tx and line impairments.

Ref	Parameter	Min	Max	Unit	Conditions/Comments
12.2.311	Sensitivity (after link)	-17.5		dBm	Measured after the link, while maintaining the maximum post-FEC BER defined in 12.1.120.

Ref	Parameter	Min	Max	Unit	Conditions/Comments
12.2.315	Optical input power (Max)		-6	dBm	Maximum Rx optical input power while maintaining the maximum post-FEC BER defined in 12.1.120.

Table 14 800LR C-band Receiver Optical Specifications

8.3 Module Requirements TX (Informative)

Ref	Parameter	Min	Max	Unit	Conditions/Comments
12.3.100	Transmitter disable time		100	ms	Time from setting ***OutputDisableTx*** bit until the transmitter optical output fails below the Tx output power given by (12.1.221).
12.3.110	Transmitter turn-up time: Warm start		180	s	The maximum time from ***ModuleLowPwr*** to ***DataPathActivated*** state. This includes ***ModulePwrUp***, ***DPInit***, and ***DPTxTurnOn***.
12.3.112	Transmitter turn-up time: Cold start		200	s	The maximum time from de-assertion of ***ResetS*** to ***DataPathActivated*** state with ***LoPwrS*** == false. Allows an additional 20s beyond 12.2.110 for stabilization from cold.

Table 15 Module TX Requirements

8.4 Module Requirements RX (Informative)

Ref	Parameter	Default	Min	Max	Unit	Conditions/Comments
12.4.100	Receiver Acquisition Time			10	s	Time to fully acquire signal after ***Rx_LOS*** de-assert, with Data Path already in the ***DataPathActivated*** state. Valid 800LR optical Rx input signal present.
12.4.110	Receiver turn-up time: Cold start			200	s	Time to fully acquire signal after module reset. Valid 800LR optical Rx input signal present.
12.4.112	Input total power monitor accuracy		-3.0	3.0	dB	Over the Rx input power range: (12.1.310) to (12.1.315).
12.4.120	***OpticalPowerLowAlarmFlagRx*** Assert Threshold	-20			dBm	Rx Total Power. RxLOS is independent and defined by ***RxLOSType***=011b
12.4.122	***OpticalPowerLowAlarmFlagRx*** Hysteresis	1.0			dBm	***OpticalPowerLowAlarmFlagRx*** cleared.

Table 16 Module RX Requirements

8.5 Optical Parameter Definitions

8.5.1 Optical return loss at S_S

Reflections are caused by refractive index discontinuities along the optical path. If not controlled, they can degrade system performance through their disturbing effect on the operation of the optical source, or through multiple reflections which lead to interferometric noise at the receiver. Reflections from the optical path are controlled by specifying the:

- minimum optical return loss of the cable plant at the source reference point (S_s), including any connectors; and
- maximum discrete reflectance between source reference point (S_s) and receive reference point (R_s)

Reflectance denotes the reflection from any single discrete reflection point, whereas the optical return loss is the ratio of the incident optical power to the total returned optical power from the entire fiber including both discrete reflections and distributed backscattering such as Rayleigh scattering.

8.5.2 Discrete reflectance between S_S and R_S

Optical reflectance is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point. The maximum number of connectors or other discrete reflection points which may be included in the optical path must be such as to allow the specified overall optical return loss to be achieved.

8.5.3 Differential Group Delay (DGD)

Differential group delay (DGD) is the time difference between the fractions of an optical signal transmitted in the two principal states of polarization. For distances greater than several kilometers, and assuming random (strong) polarization mode coupling, DGD in a fiber can be statistically modelled as having a Maxwellian distribution.

Due to the statistical nature of polarization mode dispersion (PMD), the relationship between maximum instantaneous DGD (DGD_{max}) and mean DGD (DGD_{mean}) can only be defined probabilistically. The probability of the instantaneous DGD exceeding any given value of DGD_{max} can be inferred from its Maxwellian statistics.

For purposes of this IA the ratio of DGD_{max} to DGD_{mean} is defined as 3.3, corresponding to a 4.1×10^{-6} probability of the instantaneous DGD exceeding DGD_{max}.

8.5.4 Polarization rotation speed

The polarization rotation speed is the rate of rotation in Stokes space of the two polarizations of the optical signal at point R_s measured in krad/s.

8.5.5 I-Q offset

I-Q offset is measured separately on each polarization and is calculated using the following formula:

$$P_{excess} = \frac{\mathrm{I}_{\mathrm{mean}}^2 + \mathrm{Q}_{\mathrm{mean}}^2}{\mathrm{P}_{\mathrm{Signal}}}$$

$$IQ_{\mathrm{offset}} = 10\log_{10}(\mathrm{P}_{\mathrm{excess}})$$

Instantaneous I-Q offset is measured with an averaging period ≤ 1 µs to be consistent with the timescales of receiver DSP operations.

8.5.6 Tx Minimum Spectral Mask

Compliant transmitters are required to provide a minimum excess bandwidth to guarantee multi-vendor clock recovery interoperability. This is specified by application of a minimum mask to the spectrum acquired using an optical spectrum analyzer. At baseband frequency, the spectrum is normalized relative to the average measured power from the transmitter over a ± 20GHz window (excluding DC frequency). Three piece-wise linear lines define the normative Lower Mask in Figure 14. There is **no** normative Upper Mask.

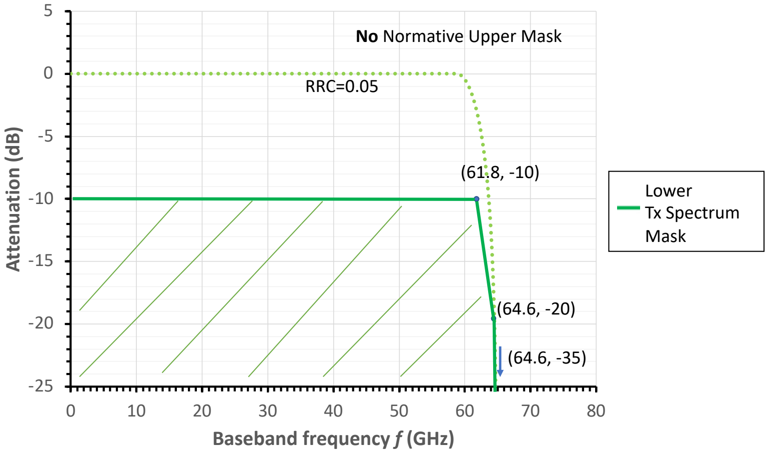


Figure 14: Transmit Minimum Spectral Mask

8.6 Performance Monitors for Interoperability

Table 17 provides the list of C-CMIS Rx signal quality performance monitors (PMs), the definitions for which are given in Sections 8.6.1-8.6.5. These are optional advertised PMs in C-CMIS. All the Rx signal quality PMs (EVM_{xx},MER,eSNR) are implementation dependent and not representative of the absolute signal quality at the optical input. They are a measure of the electrical signal quality at the decision device.

Only one of the signal quality PMs should be used for alarming purposes. eSNR is the recommended metric since it is the only signal quality PM defined in this section that is a direct, vendor- and implementation independent function of pre-FEC BER. This property also enables the definition of an SNR Margin against eSNR at the BER threshold.

C-CMIS/CMIS PM	Data Type	LSB Scaling	Unit	Range	Accuracy
EVM[1]	U16	100/65,535	%		
MER	U16	0.1	dB		
eSNR	U16	0.1	dB	13.6 to 17.2dB	±0.1 dB
SNR Margin[2]	S16	0.1	dB	-0.5 to 4.5dB	±0.1 dB

Table 17: C-CMIS Signal Quality Performance Monitors

[1] C-CMIS PM EVM reports $EVM_{rms.}$

[2]SNR Margin is not currently a VDM observable type defined in C-CMIS/CMIS. SNR Margin is defined in OIF-C-CMIS-01.3.

Table 18 provides the list of C-CMIS/CMIS optical link performance monitors (PMs).

C-CMIS/CMIS PM	Data Type	LSB Scaling	Unit	Range	Accuracy
CD-high granularity, short link (800LR recommended)	S16	1	ps/nm		
SOP rate of change (ROC)	U16	1	krad/s		

Table 18: C-CMIS Optical Link Performance Monitors

Table 19 provides the list of C-CMIS Tx/Rx signal performance monitors (PMs).

C-CMIS PM	Data Type	LSB Scaling	Unit	Range	Accuracy
Tx Total Power	S16	0.01	dBm	As per 12.1.215 or 12.2.215	
Rx Total Power	S16	0.01	dBm	-20dBm to -4dBm	
Carrier Frequency Offset (CFO)	S16	1	MHz		
Carrier Frequency Offset (CFO low granularity)	S16	5	MHz	+/-40 GHz (12.1.300)	

Table 19: C-CMIS Tx/Rx Performance Monitors

Table 20 provides the list of C-CMIS modulator bias performance monitors (PMs).

C-CMIS PM	Data Type	LSB Scaling	Unit	Range	Accuracy
Modulator Bias X/I	U16	100/65,535	%		
Modulator Bias X/Q	U16	100/65,535	%		
Modulator Bias Y/I	U16	100/65,535	%		
Modulator Bias Y/Q	U16	100/65,535	%		
Modulator Bias X Phase	U16	100/65,535	%		
Modulator Bias Y Phase	U16	100/65,535	%		

Table 20: C-CMIS Modulator Bias Performance Monitors

8.6.1 EVM_{MAX}

EVM_{MAX}, is defined as a ratio of the root mean square (RMS) value of all the error vectors (averaged over N symbols) to the **maximum magnitude** of all the reference constellation points.

EVM$_{MAX}$ can be calculated per pol P as:

$$EVM_{MAX,lin}^{P} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left|S_{ref,i} - S_{meas,i}^{P}\right|^{2}}}{C_{MAX}}$$

Where,

$$P \in \{X, Y\}$$

$$S_{ref,k} = I_{ref,k} + Q_{ref,k} \cdot j$$

$$C_{MAX} = \max_{k}\left|S_{ref,k}\right|$$

$S_{ref,k}$ are the K complex reference constellation points used by the equalizer (MMSE, ZF, etc.) and C_{MAX} is the maximum reference constellation magnitude. $S_{meas,i}^{P}$ are the N measured constellation points at the output of the equalizer on pol P, and $S_{ref,i}$ are the N reference constellation points nearest to these measured points (assuming ML detection), i.e.

$$S_{ref,i} = \arg\max_{S_{ref,k}} p\left(S_{meas,i}^{P} \middle| S_{ref,k}\right) = \arg\min_{S_{ref,k}}\left|S_{ref,k} - S_{meas,i}^{P}\right|$$

Combining the per-pol measurements and converting the linear units to percent results in the final EVM$_{MAX}$ metric:

$$EVM_{MAX} = \sqrt{\frac{{EVM_{MAX,lin}^{X}}^{2} + {EVM_{MAX,lin}^{Y}}^{2}}{2}} \times 100\%$$

8.6.2 EVM$_{RMS}$

EVM$_{RMS}$ is defined like EVM$_{MAX}$, except that the **RMS** value of the reference constellation point magnitudes is used for normalization instead of the maximum magnitude.

EVM$_{RMS}$ can be calculated per polarization P as:

$$EVM_{RMS,lin}^{P} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left|S_{ref,i} - S_{meas,i}^{P}\right|^{2}}}{C_{RMS}}$$

Where,

$$P \in \{X, Y\}$$

$$S_{ref,k} = I_{ref,k} + Q_{ref,k} \cdot j$$

$$C_{RMS} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left|S_{ref,k}\right|^{2}}$$

$S_{ref,k}$ are the K complex reference constellation points used by the equalizer (MMSE, ZF, etc.) and C$_{RMS}$ is the RMS value of the reference constellation magnitudes. $S_{meas,i}^{P}$ are the N measured constellation points at the output of the equalizer on polarization P, and $S_{ref,i}$ are the N reference constellation points nearest to these measured points (assuming maximum-likelihood detection).

$$S_{ref,i} = \arg\max_{S_{ref,k}} p\left(S^P_{meas,i} \middle| S_{ref,k}\right) = \arg\min_{S_{ref,k}} \left|S_{ref,k} - S^P_{meas,i}\right|^2$$

Combining the per-polarization measurements and converting the linear units to percent results in the final EVM_{RMS} metric:

$$EVM_{RMS} = \sqrt{\frac{{EVM^X_{RMS,lin}}^2 + {EVM^Y_{RMS,lin}}^2}{2}} 100\%$$

8.6.3 MER

The Modulation Error Ratio, MER, is defined as a ratio of the mean squared (MS) value of the reference constellation point magnitudes to the MS value of all the error vectors (averaged over N symbols). It is essentially equal to the squared inverse of $EVM_{RMS,lin}$. However, before converting the ratio to dB, the SNR bias introduced by scaling in the equalizer is compensated. This makes MER an accurate estimate of the SNR at the input to the equalizer.

The biased MER, $\overline{MER}^P_{lin}$, can be calculated per polarization P as:

$$\overline{MER}^P_{lin} = \frac{{C_{RMS}}^2}{\frac{1}{N}\sum_{i=1}^{N}\left|S_{ref,i} - S^P_{meas,i}\right|^2}$$

Where,

$$P \in \{X, Y\}$$

$$S_{ref,k} = I_{ref,k} + Q_{ref,k} . j$$

$$C_{RMS} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left|S_{ref,k}\right|^2}$$

All variables are as defined in Section 8.6.2.

The average biased MER over both polarizations is:

$$\overline{MER}_{lin} = \frac{\overline{MER}^X_{lin} + \overline{MER}^Y_{lin}}{2}$$

The bias introduced by equalizer scaling can be derived as follows: Let S_i be the *i*-th transmitted symbol and R_i the corresponding received symbol. The two variables are expected to be equal except for a random additive noise term N_i and an equalizer scaling factor g:

$$R_i = g.(S_i + N_i)$$

Under the assumption that both, the transmitted symbols, and the noise, are uncorrelated and have zero mean, the (unbiased) SNR of this system at the input of the equalizer is

$$SNR = \frac{\sigma_S^2}{\sigma_N^2}$$

Where σ_S^2 and σ_N^2 are the signal- and noise variance, respectively.

On the other hand, the result produced by the $\overline{MER}_{lin}$calculation can be derived as follows: The estimated error in the *i*-th symbol, E_i, is

$$\begin{aligned} E_i &= R_i - S_i \\ &= \; g \cdot (S_i + N_i) - S_i \\ &= (g-1) \cdot S_i + g \cdot N_i \end{aligned}$$

and the corresponding variance (i.e., the mean squared error), ${\sigma_E}^2$:

$${\sigma_E}^2 = E\{E_i^2 - \mu_E\} = (g-1)^2{\sigma_S}^2 + g^2{\sigma_N}^2$$

Therefore

$$\overline{MER}_{lin} = \frac{{\sigma_S}^2}{{\sigma_E}^2} = \frac{{\sigma_S}^2}{(g-1)^2{\sigma_S}^2 + g^2{\sigma_N}^2}$$

Unless $g = 1$, the biased MER estimate is not equal to the SNR at the equalizer input.

$$\overline{MER}_{lin} \neq SNR$$

The required compensation is a function of the equalizer scaling factor g and depends on the h/w implementation.

For a common LMS equalizer which minimizes the mean squared error (MMSE) ${\sigma_E}^2$, the optimum gain g_{mmse} can be derived analytically:

$$g_{mmse} = \arg\min_g (g-1)^2{\sigma_S}^2 + g^2{\sigma_N}^2$$

The solution is:

$$g_{mmse} = \frac{{\sigma_S}^2}{{\sigma_S}^2 + {\sigma_N}^2}$$

Substituting g_{mmse} into the biased MER equation reveals the appropriate bias compensation:

$$\begin{aligned} \overline{MER}_{lin} &= \frac{{\sigma_S}^2}{(g_{mmse}-1)^2{\sigma_S}^2 + g_{mmse}^2{\sigma_N}^2} \\ &= \frac{{\sigma_S}^2}{\left(\frac{{\sigma_S}^2}{{\sigma_S}^2 + {\sigma_N}^2} - 1\right)^2 {\sigma_S}^2 + \left(\frac{{\sigma_S}^2}{{\sigma_S}^2 + {\sigma_N}^2}\right)^2 {\sigma_N}^2} \\ &= \left(\left(\frac{-{\sigma_N}^2}{{\sigma_S}^2 + {\sigma_N}^2}\right)^2 + \frac{{\sigma_N}^2{\sigma_S}^2}{({\sigma_S}^2 + {\sigma_N}^2)^2}\right)^{-1} \\ &= \left(\frac{{\sigma_N}^2 \cdot ({\sigma_S}^2 + {\sigma_N}^2)}{({\sigma_S}^2 + {\sigma_N}^2)^2}\right)^{-1} \\ &= \left(\frac{{\sigma_N}^2}{{\sigma_S}^2 + {\sigma_N}^2}\right)^{-1} = \frac{{\sigma_S}^2 + {\sigma_N}^2}{{\sigma_N}^2} = \frac{{\sigma_S}^2}{{\sigma_N}^2} + 1 \\ &= SNR + 1 \end{aligned}$$

Consequently, the unbiased MER, MER_{lin}, can be calculated as follows:

$$MER_{lin} = SNR = \overline{MER}_{lin} - 1$$

Unbiased MER is reported in [dB]:

$$MER = 10 \cdot \log_{10}(MER_{lin})\ dB$$

NOTE 1: MER and EVM_{RMS} are related as follows:

$$MER = 10 \cdot \log_{10}\left(\left(\frac{100\%}{EVM_{RMS}}\right)^2 - 1\right)$$

8.6.4 eSNR

eSNR is defined as the effective Signal-to-Noise ratio at the decision sampling point in dB. The method for determining the eSNR is to use an estimate of the line input BER to BH2 decoder and use the following equation to determine the eSNR,

$$eSNR_{Linear} = 10 * \left(erfcinv\left(\frac{8}{3}ber\right)\right)^2$$

$$eSNR\ dB = 10 * log_{10}(eSNR_{Linear})$$

This formula assumes AWGN, with no other Channel, Rx or Tx impairments.

Recommend Range is BER 4.7e-4 to 1.2e-2, which is 17.2 to 13.6 dB eSNR.

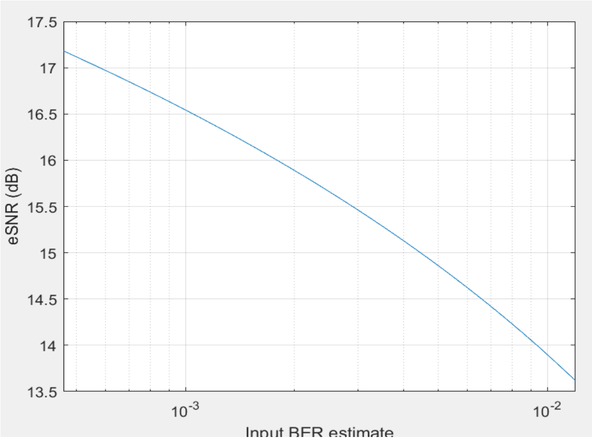


Figure 15: eSNR dB versus input BER estimate

8.6.5 SNR Margin

SNR Margin is defined as the difference between the measured eSNR, and the required eSNR at the theoretical BER threshold in dB (ReSNR.) ReSNR is 13.75dB assuming DP-16QAM and a theoretical correctible input BER threshold of 1.1%.

$$SNR\ Margin = eSNR - ReSNR = eSNR - 13.75dB$$

A positive *SNR Margin* does not necessarily guarantee post-FEC error-free operation of the modem. Note *SNR Margin* is only applicable near the FEC threshold where AWGN noise terms dominate.

8.7 Module Startup Procedure for Shared Laser

Implementations that shared the TX and LO lasers would use an algorithm as defined in this section. This is compatible to implementations that may separate the TX and LO lasers. This implementation agreement accommodates the various architectures.

- Module starts up and transmits signal with a laser accuracy to +/- 20GHz based on factory calibration settings.
- Receiver has the ability to estimate the relative LO offset to module firmware.
- Module firmware makes small adjustments to the transmit laser frequency in the direction which reduces the relative LO offset. Laser frequency changes should not exceed the specified slew rate in 12.1.201.
- Use a dead-zone to avoid unnecessary laser frequency adjustments.
- Perform periodic adjustments if the relative LO offset exceeds the dead-zone (implementation specific e.g. +/- 0.4GHz) with some margin to the worst-case relative offset specification (+/- 0.9GHz).
- Any laser adjustment needs to stay within limits required to ensure absolute accuracy (+/- 20GHz).

9 Interoperability Test Methodology, Definitions

9.1 Loopbacks

An 800LR module must be capable of minimally supporting one of the following loopback pairs. The CMIS supported loopback modes are shown in **bold.** Each pair has 1 Rx path and 1 Tx path.

- **Media Side Tx Loopback** + **Host Side Rx Loopback**
- **Host Side Tx Loopback** + **Media Side Rx Loopback**

The specific loopback mode enabled must be coordinated at each end of the link by each host. The defined loopback modes are shown in Table 21 and also illustrated in Figure 4 and Figure 5.

Loopback Mode	Description
Host Side Tx Loopback	Loopback after Alignment lock, lane de-skew and RS-FEC decoding → RS-FEC encoding, PMA sublayer. Host loop timed. Optional RS-FEC for segmented mode only.
Media Side Tx Loopback	Loopback after Tx DSP processing blocks → Before Rx DSP processing blocks
Media Side Rx Loopback	Loopback in DSP. After polarity split, symbol de-interleave, BCH FEC decoding → BCH FEC encoding, symbol mapper/symbol interleave. Media loop timed.
Host Side Rx Loopback	Loopback after distribution/interleaving block on host ingress path → Before lane alignment/reorder and deinterleave

Table 21: 800LR Loopbacks

9.2 Interoperability Test Vectors

The interoperability test vectors are used during design development to check for interoperability.

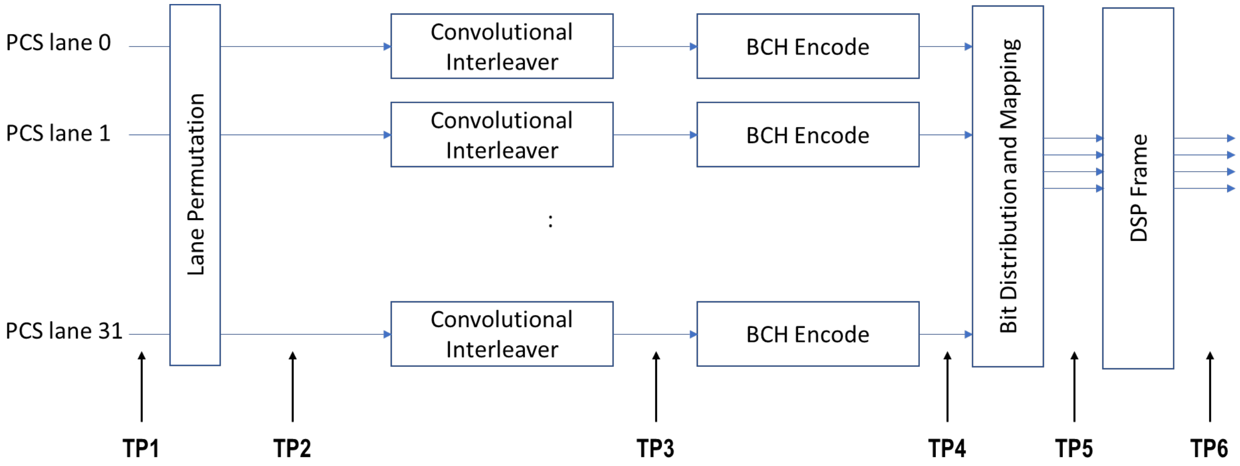


Figure 16: Test vector points

9.2.1 Idle Test Pattern Test Vectors

The idle test patterns can be found in this location:

https://www.oiforum.com/bin/c5i?mid=4&rid=7&gid=0&k1=53826&k2=10&k3=3

9.2.2 BCH-FEC Test Vectors

The PRBS test patterns can be found in this location:

https://www.oiforum.com/bin/c5i?mid=4&rid=7&gid=0&k1=53826&k2=10&k3=3

10 Summary

This 800LR IA specifies the requirements for an 800LR PHY. The 800LR PHY provides timing and code-word transparent transmission of 400GE/800GE host signals over a single carrier optical interface. This coherent interface uses non-differential DP-16QAM modulation and using a concatenated forward error correction scheme of KP4 + BCH. There are two architectures for the FEC, concatenated and segmented. This interface is designed for 10km or less, unamplified and point-to-point.

No restrictions are placed on the physical form factor by this IA. This 800LR IA builds upon the work of 800ZR IA within OIF and the work of other standards bodies including IEEE 802.3^{TM}-2018.

11 References

11.1 Normative references

- [OIF C-CMIS] Implementation Agreement for Coherent C-CMIS, IA # OIF-C-CMIS-01.2, March 2022
- [CMIS] Common Management Interface Specification (CMIS), Rev 5.2 April 2022

- [IEEE 802.3] Standard for Ethernet: IEEE Std 802.3^{TM}-2022
- [IEEE 802.3ck] IEEE Std 802.3ck-2022, IEEE Standard for Ethernet, Amendment 4: Physical Layer Specifications and Management Parameters for 100 Gb/s, 200 Gb/s, and 400 Gb/s Electrical Interfaces Based on 100 Gb/s Signaling
- [IEEE 802.3df] IEEE 802.3df-2024, IEEE Standard for Ethernet, Amendment: Media Access Control Parameters for 800Gb/s and Physical Layers and Management Parameters for 400Gb/s and 800Gb/s Operation
- [ETC 800G] Ethernet Technology Consortium 800G Specification r1.1, 8/6/2021

11.2 Informative references

- [ITU-T G.709.3] ITU-T G.709.3/Y.1331.3 (2018), Flexible OTN long-reach interfaces.

Appendix A: Glossary

Acronym	Definition	Acronym	Definition
AWGN	Additive White Gaussian Noise	NA	Not Applicable
BCH	Bose- Chaudhari-Hocquengham	NCG	Net Coding Gain
BER	Bit Error Ratio	OSNR	Optical Signal-to-Noise Ratio
CD	Chromatic Dispersion	PDL	Polarization Dependent Loss
C-CMIS	Coherent Common Management Interface Specification	PMD	Polarization Mode Dispersion
DGD	Differential Group Delay	QAM	Quadrature Amplitude Modulation
DP-mQAM	Dual Polarization – m state Quadrature Amplitude Modulation	ReSNR	Required Effective SNR
DSP	Digital Signal Processing	RMS	Root Mean Square
eSNR	Effective Signal-to-Noise Ratio	SD-FEC	Soft-Decision FEC
EOL	End of Life	SNR	Signal-to-Noise Ratio
EVM	Error Vector Magnitude	SOP	State of Polarization
FEC	Forward Error Correction	SOPMD	Second Order Polarization Mode Dispersion
HD-FEC	Hard-decision FEC		
IA	Implementation Agreement		
LD	Local Degrade		
LO	Local Oscillator		
LOS	Loss of Signal		
MER	Modulation Error Ratio		

Appendix B: List of companies belonging to OIF when document is approved

1-VIA Ltd.

Accelight Technologies, Inc.

Accton Technology Corporation

Adtran Networks SE

Advanced Fiber Resources (AFR)

Advanced Micro Devices, Inc.

AIO Core Co., Ltd

Alibaba

Alphawave Semi

Amazon

Amphenol Corp.

Anritsu

Applied Optoelectronics, Inc.

Arista Networks

Astera Labs

ATOP Corporation

Ayar Labs

BitifEye Digital Test Solutions GmbH

BizLink Technology, Inc.

Broadcom Inc.

Cadence Design Systems

Casela Technologies USA

Celero Communications Inc.

Celestica

China Telecom

CICT

Ciena Corporation

Cisco Systems

Coherent

ColorChip LTD

Cornelis Networks, Inc.

Corning

Credo Semiconductor (HK) LTD

CUbIQ Technologies

Dai Nippon Printing Co., Ltd.

Dell, Inc.

Dexerials Corporation

DustPhotonics

EFFECT Photonics B.V.

Eoptolink Technology

Epson Electronics America, Inc.

Ericsson

EXFO

Fabrinet

Foxconn Interconnect Technology Ltd

Fujikura

Fujitsu

Furukawa Electric Co., Ltd.

Global Foundries

Google

H3C Technologies Co., Ltd.

Hakusan Inc

Hewlett Packard Enterprise (HPE)

HGGenuine Optics Tech Company

Hirose Electric Co. Ltd.

Hisense Broadband Multimedia Technologies Co., LTD

Huawei Technologies Co., Ltd.

InfiniLink

Integrated Device Technology

Intel

Juniper Networks

Kandou Bus

KDDI Research, Inc.

Keysight Technologies, Inc.

KYOCERA Corporation

Lessengers Inc.

Lightmatter

Linktel Technologies Co., Ltd.

Lumentum

Lumiphase AG

LUXIC Technology Co

Luxshare Technologies International, Inc.

MACOM Technology Solutions

Marvell Semiconductor, Inc.

MaxLinear Inc.

MediaTek

Meta Platforms

Microchip Technology Incorporated

Microsoft Corporation

Mitsubishi Electric US, Inc.

Molex

Multilane Inc.

NEC Corporation

New Photonics, Ltd.

Nokia

NTT Corporation

Nubis Communications, Inc.

NVIDIA

O-Net Technologies (Shenzhen) Group Co., Limited

Omattrix Ltd Co

Omniva LLC

Optomind Inc.

Orange

PETRA

Point2 Technology

Precision Optical Technologies

Quantifi Photonics USA Inc.

Quintessent Inc.

RAM Photonics Industrial, LLC

Ranovus

Retym

Rosenberger Hochfrequenztechnik GmbH & Co. KG

Ruijie Networks Co., Ltd.

Samsung Electronics Co. Ltd.

Samtec Inc.

SCINTIL Photonics

Semtech Canada Corporation

Senko Advanced Components

SeriaLink Systems Ltd.

Sicoya GmbH

SiFotonics Technologies Inc.

Silith Technology

Socionext Inc.

Source Photonics, Inc.

Spirent Communications

Sumitomo Electric Industries, Ltd.

Sumitomo Osaka Cement

Synopsys, Inc.

TE Connectivity

Tektronix

Telefonica S.A.

TELUS Communications, Inc.

TeraHop US

Teramount

TeraSignal, LLC.

Texas Instruments

US Conec

Viavi Solutions Deutschland GmbH

Wilder Technologies, LLC

Wistron Corporation

Xphor Ltd.

Yamaichi Electronics Ltd.

ZTE Corporation