Baseline proposal for a 400 Gb/s optical PMD supporting four MMF pairs

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IEEE P802.3cm 400 Gb/s over Multimode Fiber Task Force

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Adopted physical layer specification objectives

- Define a physical layer specification that supports 400 Gb/s operation over 4 pairs of MMF with lengths up to at least 100 m

- Define a physical layer specification that supports 400 Gb/s operation over 8 pairs of MMF with lengths up to at least 100 m

Motivation (1)

- Expect broad market potential for a four-fiber-pair MMF PMD at 400 Gb/s. For example, this provides an attractive upgrade path for users of the successful 100GBASE-SR4 PMD

- Current MMF infrastructure is mainly single-fiber-pair or four-fiber-pair. Hence, standardization of a four-fiber-pair MMF PMD at 400 Gb/s helps to maintain the relevance of this infrastructure

- Large industry investment in MMF WDM in recent years:

  (i) proven and widely-adopted two-wavelength transceivers such as 40G Bi-Di and 100G Bi-Di
  (ii) SWDM MSA four-wavelength specifications
  (iii) completion of TIA-492AAAE and subsequent OM5 standardization

Motivation (2)

- Technical feasibility already demonstrated for RS(544, 514) FEC-supported 26.5625 GBd PAM4 modulation using uncooled VCSELs
- The above is under standardization as 50GBASE-SR, 100GBASE-SR2 and 200GBASE-SR4 in Clause 138 and is expected to form the basis of 400GBASE-SR8
- Existing WDM transceivers, such as SWDM and Bi-Di, support MMF with transmission in ranges compatible with the consensus of 844 to 863 nm and 900 to 918 nm in this proposal
- In particular, 100G Bi-Di uses RS(544, 514) FEC and 26.5625 GBd PAM4 modulation to achieve 70 m, 100 m and 150 m reach over OM3, OM4 and OM5, respectively

OM3 and OM4 performance

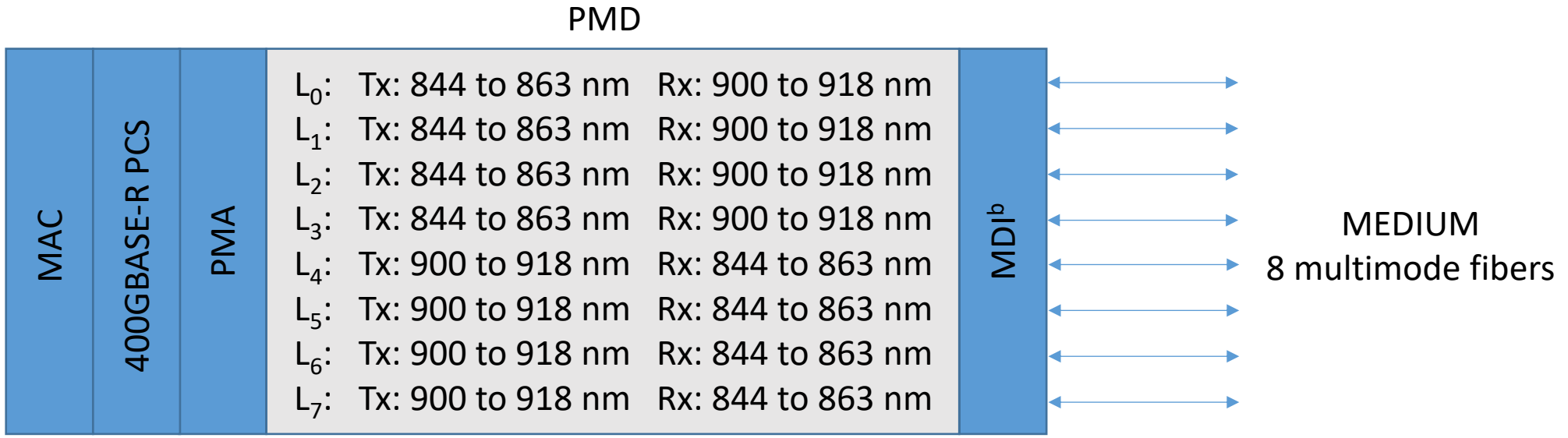
- Field-proven WDM products exist using OM3 and OM4 with transmission in the wavelength ranges in this proposal
- Guidance from fiber manufacturers has been received regarding performance of OM3 and OM4 in these wavelength ranges
- IEC is in the process of providing formal guidance on OM3 and OM4 bandwidth over the entire 840 to 953 nm wavelength range (see draft IEC 60793-2-10). This is expected to be adopted by TIA

Bi-directional approach

- Both bi-directional and co-directional approaches are technically feasible
- A bi-directional approach offers the simplicity of only one VCSEL launch into each end of a fiber. Hence it is easier to condition the launch to meet encircled flux requirements.
- Only one VCSEL launch into each end of a fiber results in greater margin to eye safety limits
- Signal routing in a bi-directional transceiver is easily achieved by appropriate design of the retimer IC package
- A roadmap exists to support breakout from a bi-directional “400GBASE-SR4.2” transceiver to four 100G Bi-Di transceivers
- 100G Bi-Di is a multi-vendor solution

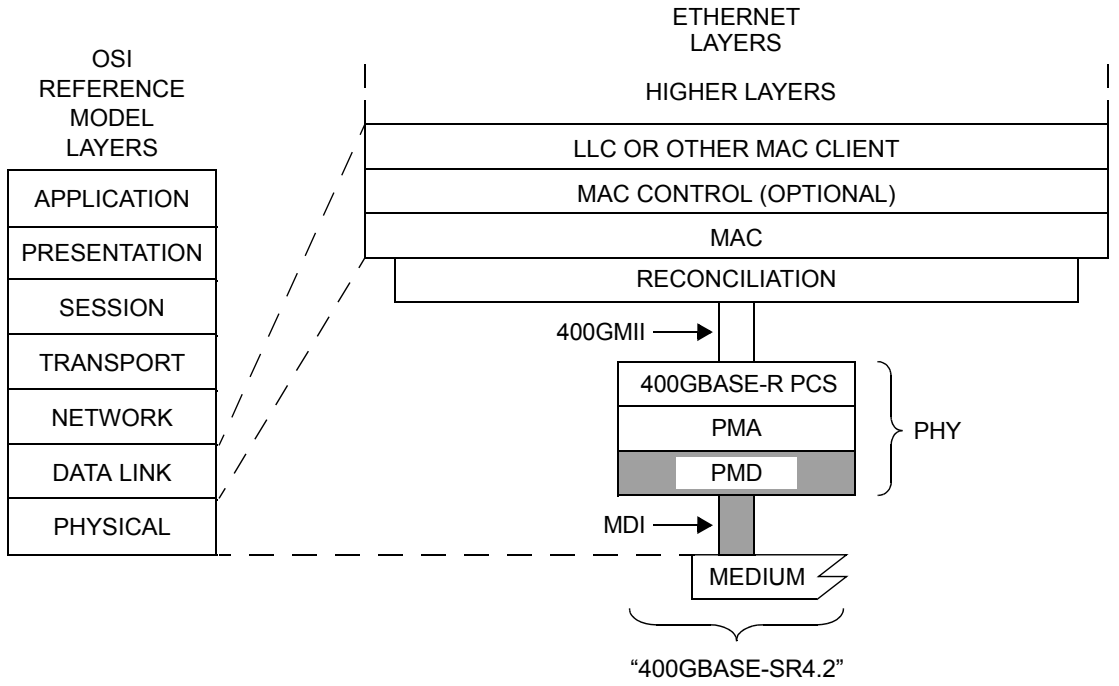
Baseline proposal

- Bi-directional WDM transmission with required operating range of 0.5 m to 70 m OM3, 0.5 m to 100 m OM4 and 0.5 m to 150 m OM5
- Using the RS(544, 514) FEC in the 400GBASE-R PCS, then for each lane: 26.5625 GBd PAM4 modulation with a pre-FEC BER requirement[a] of 2.4 x 10^{-4}



[a]Provided that the error statistics are sufficiently random to meet an appropriate frame loss ratio requirement (to be determined).
[b]MDI lane assignment to be determined.

Position in 802.3 architecture



400GMII = 400 Gb/s MEDIA INDEPENDENT INTERFACE
LLC = LOGICAL LINK CONTROL
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER

PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

SR = PMD FOR MULTIMODE FIBER

Transmit center wavelength ranges

Lane	Transmit center wavelength range
L_0 to L_3	844 to 863 nm
L_4 to L_7	900 to 918 nm

- These ranges are a result of consensus building in the ad-hoc teleconferences held after the May 2018 interim. See ingham_3cm_adhoc_01a_062118 and king_3cm_adhoc_01_062818
- The range for L_0 to L_3 is shifted higher than the conventional 840 to 860 nm range in order to benefit from improved VCSEL speed
- ≈40 nm guard band allows very low cost filter technology
- VCSELs compatible with these specifications are commercially available from multiple component vendors
- Mature VCSEL technology and volume production: compatible VCSELs are used in SWDM and Bi-Di transceivers. For Bi-Di transceivers, VCSEL shipments to date of several million with device hours in the tens of billions for each range

Transmit characteristics

Description	Value	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm	GBd
Center wavelength, L_0 to L_3 (range)	844 to 863	nm
Center wavelength, L_4 to L_7 (range)	900 to 918	nm
Modulation format, each lane	PAM4	
RMS spectral width, each lane[a] (max)	0.6	nm
Average launch power, each lane (max)	4	dBm
Average launch power, each lane (min)	–6.5	dBm
OMA_{outer}, each lane (max)	3	dBm
OMA_{outer}, each lane[b] (min)	–4.5	dBm
OMA_{outer} – TDECQ, each lane (min)	–5.9	dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	4.5	dB
Average launch power of OFF transmitter, each lane (max)	–30	dBm
Extinction ratio, each lane (min)	3	dB
Transmitter transition time, each lane (max)	34	ps
$RIN_{12}OMA$, each lane (max)	–128	dB/Hz
Optical return loss tolerance, each lane (max)	12	dB
Encircled flux, each lane[c]	≥ 86% @ 19 µm, ≤ 30% @ 4.5 µm	

Test methodology is assumed to be based on 138 (D3.3).

[a]RMS spectral width is the standard deviation of the spectrum.

[b]Even if TDECQ < 1.4 dB, OMA_{outer} (min) must exceed this value.

[c]If measured into type A1a.2, type A1a.3 or type A1a.4, 50 µm fiber, in accordance with IEC 61280-1-4.

Receive characteristics

Description	Value	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm	GBd
Center wavelength, L_0 to L_3 (range)	900 to 918	nm
Center wavelength, L_4 to L_7 (range)	844 to 863	nm
Modulation format, each lane	PAM4	
Damage threshold, each lane[a] (min)	5	dBm
Average receive power, each lane (max)	4	dBm
Average receive power, each lane[b] (min)	–8.5	dBm
Receive power (OMA_{outer}), each lane (max)	3	dBm
Receiver reflectance, each lane (max)	–12	dB
Stressed receiver sensitivity (OMA_{outer}), each lane[c] (max)	–3.5	dBm
Receiver sensitivity (OMA_{outer}), each lane[d] (max)	max(–6.6, SECQ – 8)	dBm
Conditions of stressed receiver sensitivity test[e]:		
Stressed eye closure for PAM4 (SECQ), lane under test	4.5	dB
OMA_{outer} of each aggressor lane	3	dBm

Test methodology is assumed to be based on 138 (D3.3).

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

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

[c]Measured with conformance test signal at TP3 (see 138.8.8 (D3.3)) for the BER specified (to be confirmed).

[d]Receiver sensitivity is informative and is defined for a transmitter with a value of SECQ up to 4.5 dB.

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

Illustrative link power budget

Parameter	OM3	OM4	OM5	Unit
Effective modal bandwidth at 850 nm[a]	2000	4700	4700	MHz km
Effective modal bandwidth at 918 nm	1210[b]	1850[b]	2890[a]	MHz km
Power budget (for max TDECQ)		6.6		dB
Operating distance	70	100	150	m
Channel insertion loss[c]	1.8	1.9	2	dB
Allocation for penalties[d] (for max TDECQ)		4.6		dB
Additional insertion loss allowed	0.2	0.1	0	dB

[a]Per IEC 60793-2-10.
[b]Per draft IEC 60793-2-10 (subject to confirmation by IEC and TIA).
[c]The channel insertion loss is calculated using the maximum distance specified on Slide 9 and cabled optical fiber attenuation of 3.5 dB/km at 850 nm plus an allocation for connection and splice loss given in 138.10.2.2.1 (D3.3).
[d]Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Summary

- Slides 9 to 14 provide a baseline proposal for “400GBASE-SR4.2” based on FEC-supported 26.5625 GBd PAM4 modulation
- Transmit and receive characteristics are based on Clause 138 (D3.3) facilitating easy standardization using established metrics, notably TDECQ and SECQ
- OM3 and OM4 performance in the consensus wavelength ranges is field proven and formal guidance is expected from IEC and TIA
- Bi-directional approach allows easier VCSEL launch design and larger eye safety margin, relative to a co-directional approach. 100G Bi-Di provides a path to support breakout applications