Updated baseline proposal for the 100 Gb/s MMF objective using two-wavelength PAM4 transmission

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Contents

Adopted MMF objectives

- Define a single-lane 50 Gb/s PHY for operation over MMF with lengths up to at least 100 m

- Define a two-lane 100 Gb/s PHY for operation over MMF with lengths up to at least 100 m

- Define 200 Gb/s PHYs for operation over MMF with lengths up to at least 100 m

Motivation

- Broad market potential for a duplex MMF solution at 100 Gb/s
- Technical feasibility of FEC-supported 26.5625 GBd PAM4 modulation demonstrated using uncooled VCSELs, building on NRZ electronics and optoelectronics developed for 25 Gb/s lanes in multiple 802.3 and T11 standards
- Large industry investment in multimode WDM in recent years, evidenced by: (i) field-proven products such as Cisco 40G Bi-Di; (ii) 100 Gb/s demonstrations by multiple vendors at OFC and ECOC; (iii) formation of SWDM Alliance to encourage adoption of cost-effective solutions for duplex MMF; (iv) recent completion of TIA-492AAAE WBMMF standard

Motivation (cont.)

- A two-fibers-per-direction solution is unconventional and poorly matched to the requirements of typical cabling installations
- Transceiver cost for a two-wavelengths-per-direction solution is expected to be similar to a two fibers per direction solution
- A two-wavelengths-per-direction solution provides a compelling route to a future 400 Gb/s PMD based on four fibers per direction
- Maintains the attractiveness of MMF cabling infrastructure
- The newly-standardized WBMMF supports links up to 150 m
- In this update, the TP2 and TP3 characteristics have been revised for close agreement with the adopted baseline proposals for 50GBASE-SR and 200GBASE-SR4

Cabling cost

- Expect cabling cost for a two-fibers-per-direction solution to be **approximately twice** the cost for a duplex solution

Transceiver cost

Component	Quantity for two-fibers-per-direction transceiver	Quantity for two-wavelength transceiver
100GAUI-2 CDR	1	1
26.5625 GBd PAM4 VCSEL driver	2	2
26.5625 GBd PAM4 TIA	2	2
VCSEL	2	2
PIN	2	2
Tx optical coupling module	1	1
Rx optical coupling module (without grating)	1	0
Rx optical coupling module (with grating)	0	1
MPO connector	1	0
LC connector	0	1

Transceiver cost (cont.)

- Grating is a low-cost component (particularly with wide wavelength spacing of the two channels)
- Almost negligible cost of grating is compensated by the use of LC connectors rather than MPO connectors
- Expect very similar assembly costs for the two modules

OM3 & OM4 MMF performance

- Guidance from fiber manufacturers has been received regarding performance of OM3 and OM4 MMF in the 900 nm to 916 nm wavelength range

- Field-proven WDM products exist using OM3 and OM4 MMF with transmission in the 900 nm to 916 nm wavelength range

- Independent verification of feasibility of transmission over OM3 and OM4 in the 900 nm to 916 nm wavelength range:

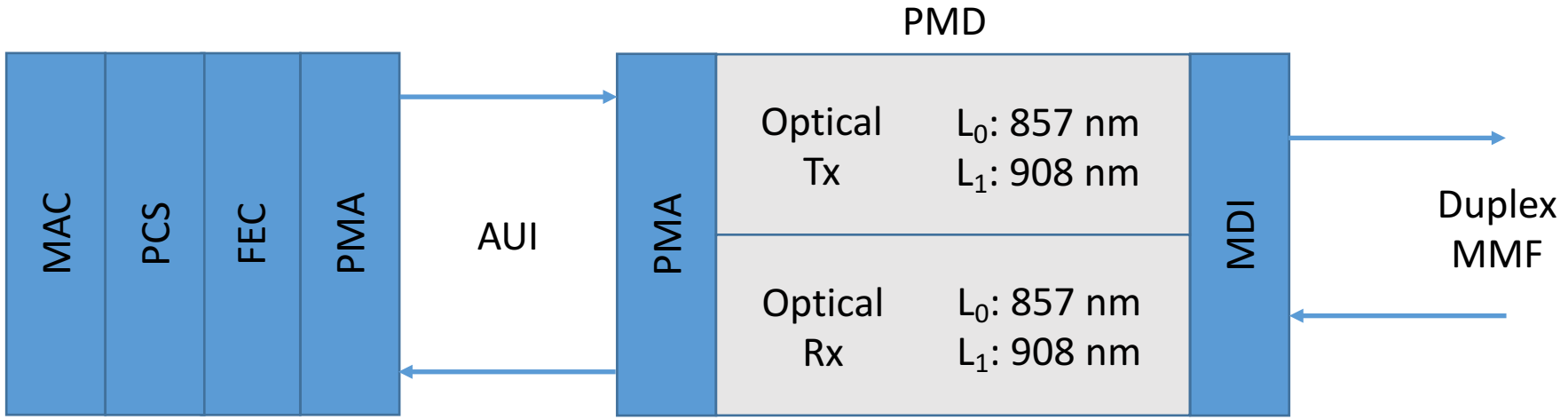
  “Evaluation of extended reach capability of 40G Bi-Di VCSEL-based WDM transmission over OM4 multimode fibers”

  X. Chen, J. E. Hurley, S. Bickman, J. Abbott, B. Chow, D. Coleman, M.-J. Li

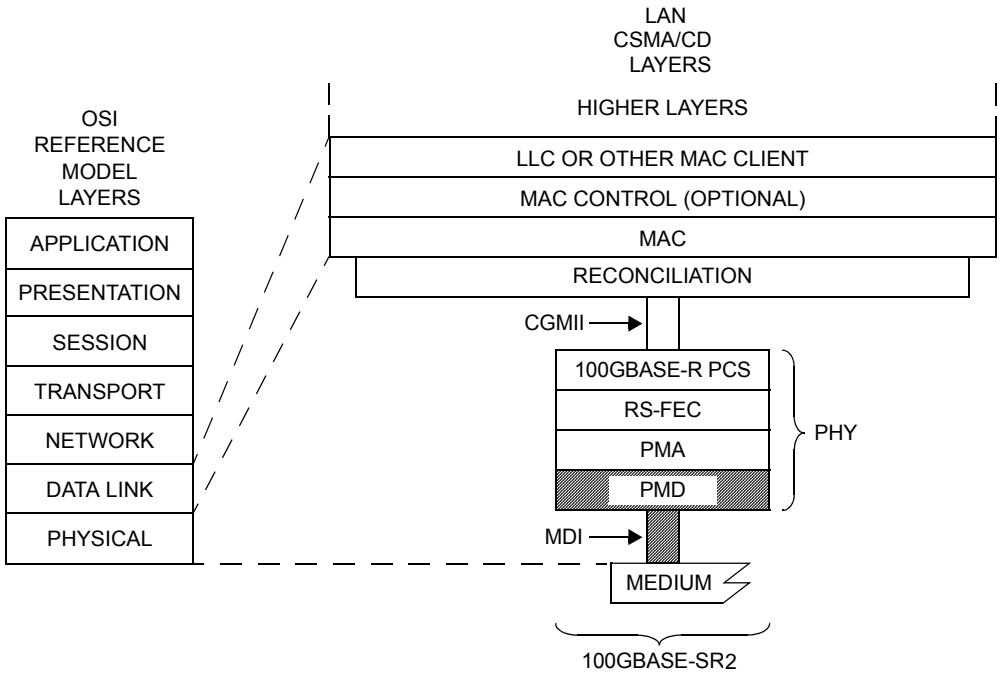
  Proc. SPIE, vol. 9772, February 2016

Baseline proposal for 100GBASE-SR2

- Co-directional WDM transmission (with center wavelengths of 857 nm for L_0 and 908 nm for L_1) over 70 m OM3, 100 m OM4 and 150 m WBMMF
- With RS(544, 514) FEC, then for each lane: 26.5625 GBd PAM4 modulation with pre-FEC BER target of 2.4×10^{-4}



Position in 802.3 architecture



CGMII = 100 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
RS-FEC = REED-SOLOMON FORWARD ERROR CORRECTION
SR = PMD FOR MULTIMODE FIBER

WDM lane assignments

Lane	Center wavelength	Wavelength range
L_0	857 nm	844 nm to 870 nm
L_1	908 nm	900 nm to 916 nm

- These wavelengths are proposed on the basis of being close to optimal for two-wavelength solutions
- Note that interoperation with four-wavelength solutions (defined in future 802.3 standards or outside 802.3) is not expected to be required and therefore not a criterion in this wavelength proposal

Transmit characteristics

Description	Value	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm	GBd
Lane wavelength range: lane L_0	844 to 870	nm
lane L_1	900 to 916	nm
Modulation format	PAM4	
RMS spectral width	0.6	nm
Total average launch power (max)	+6.5	dBm
Average launch power, each lane (max)	+3.5	dBm
Average launch power, each lane (min)	-6	dBm
OMA_{outer}, each lane (max)	+3	dBm
OMA_{outer}, each lane (min)[a]	-4	dBm
OMA_{outer} – TDECQ, each lane (min)	-5 TBC	dBm
TDECQ, each lane (max)	4 TBC	dB
Average launch power of OFF transmitter, each lane (max)	-30	dBm
Extinction ratio (min)	3	dB
Encircled flux	≥ 86% @ 19 μm, ≤ 30% @ 4.5 μm	

Transmit characteristics are at TP2

TDECQ is under development in P802.3bs for SMF PMDs; TDECQ configuration (including reference receiver) for MMF PMDs is TBD

[a] Even if TDECQ < 1 dB, OMA_{outer} must be at least this value

Receive characteristics

Description	Value	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm	GBd
Lane wavelength range: lane L_0	844 to 870	nm
lane L_1	900 to 916	nm
Modulation format	PAM4	
Damage threshold (min)	+7.5	dBm
Average receive power, each lane (max)	+3.5	dBm
Average receive power, each lane (min)	-7.9	dBm
Receive power, each lane (OMA_{outer}) (max)	+3	dBm
Receiver reflectance (max)	-12	dB
Stressed receiver sensitivity, each lane (OMA_{outer}) (max)	-2.9 TBC	dBm
Receiver sensitivity, each lane (OMAouter) (max)[a]	-7 TBC	dBm
Conditions of stressed receiver sensitivity test:		
Stressed eye closure (SECQ), lane under test	4 TBC	dB
OMA of each aggressor lane	+3	dBm

Receive characteristics are at TP3
TDECQ and SECQ are under development in P802.3bs for SMF PMDs; TDECQ and SECQ configuration (including reference receiver) for MMF PMDs is TBD
[a] Receiver sensitivity is informative

Illustrative link power budget (850 nm)

Parameter	OM3	OM4	WBMMF	Unit
Effective modal bandwidth at 850 nm	2000	4700	4700	MHz km
Power budget for max TDECQ	6	6	6	dB
Operating distance	70	100	150	m
Channel insertion loss	1.8	1.9	1.9	dB
Allocation for penalties (for max TDECQ)	4.1 TBC	4.1 TBC	4.1 TBC	dB
Additional insertion loss allowed	0.1	0	0	dB

Illustrative link power budget (916 nm)

Parameter	OM3	OM4	WBMMF	Unit
Effective modal bandwidth at 916 nm	1400	1900	2950	MHz km
Power budget for max TDECQ	6	6	6	dB
Operating distance	70	100	150	m
Channel insertion loss	1.7	1.8	1.8	dB
Allocation for penalties (for max TDECQ)	4.1 TBC	4.1 TBC	4.1 TBC	dB
Additional insertion loss allowed	0.2	0.1	0.1	dB

Conclusions

- Baseline proposal for 100GBASE-SR2 based on FEC-supported 26.5625 GBd PAM4 modulation
- Two wavelengths per direction allows support of duplex MMF with broad market potential
- FEC-supported 26.5625 GBd PAM4 approach is re-used from adopted 50GBASE-SR and 200GBASE-SR4, facilitating easy standardization, using same metrics, e.g. TDECQ
- Builds on substantial industry investment in multimode WDM by multiple vendors
- OM3 & OM4 MMF performance at the proposed wavelengths is field proven
- WBMMF support allows 150 m reach
- Provides a path to a future four-fiber 400 Gb/s PMD