

64G Fibre Channel strawman update

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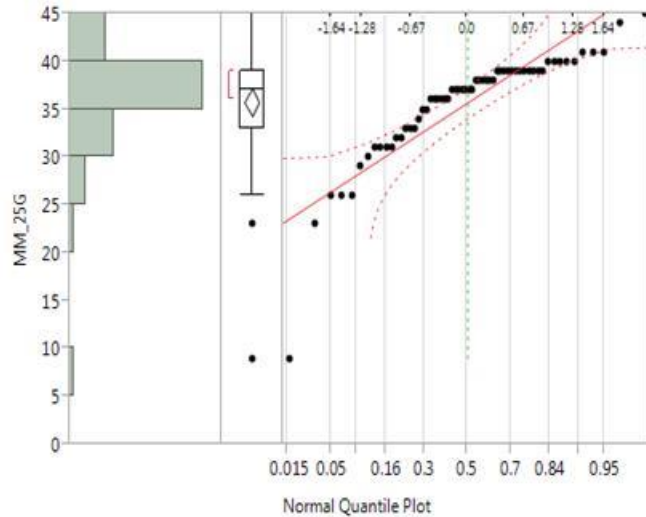
Background

- Ethernet (802.3cd) has adopted baseline specs for 53.1 Gb/s PAM4 (per fibre) for MMF links
 - 840 to 860 nm VCSEL based link
 - FEC supported: RS(544,514)
 - Target BER for optics: 2.4×10^{-4} - reduced to 1.09×10^{-4}
 - Reach: 100 m OM4
- Good starting point for 64G Fibre Channel
 - Expect FEC supported RS(544,514), or similar.
 - Target BER for optics: 1.09×10^{-4} used here
 - (2.4×10^{-4} used in Oct presentation)
 - 57.8 Gb/s PAM4 signaling format
- ... higher symbol rate and lower target BER than 50 Gb/s Ethernet
 - higher transmitter and link penalties by about 2.4 dB (1.5 dB)
 - and receiver penalties by about 0.5 dB (0.3 dB)

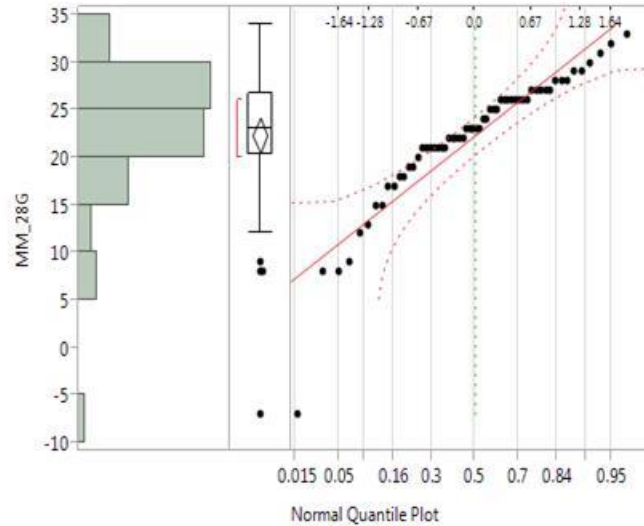
57.8 Gb/s FC vs 53.1 Gb/s Ethernet PAM4

- Spreadsheet modeling of upper PAM4 eye at 57.8Gb/s, using same model parameter values for Ethernet and Fibre Channel
 - same Rx bandwidth and Tx RIN, rise-fall time, OMA and spectral width
 - Receiver loses 0.5 dB sensitivity
 - Transmitter eye closure increases by 0.4 dB
 - Fiber ISI penalty increases by 0.6 dB
 - RIN penalty increases by 1.3 dB (due to increased eye closure), also increases received eye jitter by 0.15 UI
 - 'consequent penalty' increases by 0.5 dB
 - Overall, a loss of 2.9 dB of link budget, and an estimated TDECQ increase of 2.3 dB
- Biggest penalty change is due to RIN, indicates ~ 1 dB better RIN performance is needed to close link for a TDECQ of 5 dB
 - The effects of RIN, Tx and fibre ISI, are captured in TDECQ

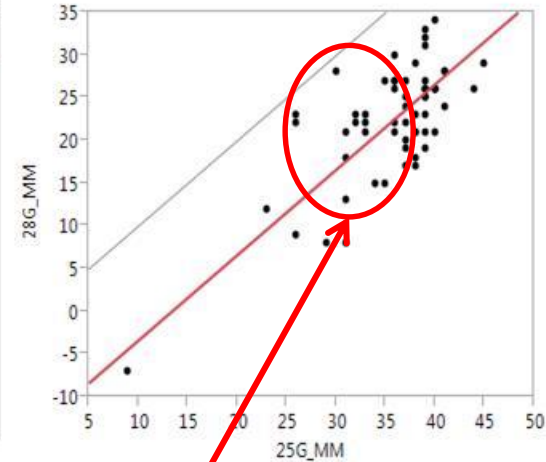
Shows up in 25G vs 28G NRZ data



Summary Statistics	
Mean	35.716667
Std Dev	5.6481335
Std Err Mean	0.7291709
Upper 95% Mea	37.175734
Lower 95% Mean	34.257599
N	60



Summary Statistics	
Mean	22.35
Std Dev	6.8811336
Std Err Mean	0.8883505
Upper 95% Mea	24.127585
Lower 95% Mean	20.572415
N	60



$28G_MM = -13.36667 + 1 * 25G_MM$

Summary of Fit	
RSquare	.
RSquare Adj	.
Root Mean Square Error	4.815113
Mean of Response	22.35
Observations (or Sum Wgts)	60

- Measurements consistent with ~ 1 dB additional eye closure for 28G operation (vs 25G)

Choices for 64GFC

- The higher penalties due to higher bit rate and lower target ER leaves two main options
 - 1) Shorter reach
 - For same optics as Ethernet transceivers but with a 1 dB increase in Tx_OMA, the max reach for Fibre Channel would be 50 m over OM4.
 - TDECQ reference receiver would need to change to reflect higher bandwidth channel.
 - or
 - 2) Higher performance optics
 - Lower yield (higher cost) to keep 100 m target reach.
 - TDECQ reference receiver bandwidth same as IEEE 50GBASE-SR
 - Tougher Tx and Rx tests

Option 2: maintaining 100 m OM4 for 64GFC

- Raise max TDECQ spec to 5 dB, screen for higher performance transmitters
 - Components may need a combination of improved performance characteristics
 - RIN improvement (~ 1 dB), or $\sim 10\%$ faster VCSEL
 - 1 dB higher Tx_OMA
 - 0.5 dB improvement in USRS receiver
 - *Only change to optical specs is higher TDECQ (5 dB) and SECQ (and consequent specs) to screen transmitters for TDECQ over temperature, and use tougher SRS test for receiver (5 dB SECQ).*

Strawman 64GFC Transmitter characteristics

Description	Value	Unit
Signaling rate, each lane, (range)	28.9 ± 100ppm	GBd
Modulation format	PAM4	
Center wavelength (range)	840 - 860	nm
RMS spectral width	0.6	nm
Average launch power, each lane (max)	+4	dBm
Average launch power, each lane (min)	-6	dBm
Optical Modulation Amplitude (OMA _{outer}), each lane (max) ^a	+3	dBm
Optical Modulation Amplitude (OMA _{outer}), each lane (min) ^{ab}	-4	dBm
Launch power in OMA _{outer} minus TDECQ (min) ^a	-5 <i>TBC</i>	dBm
Transmitter and dispersion eye closure (TDECQ), each lane (max) ^a	5 <i>TBC</i>	dB
Average launch power of OFF transmitter, each lane (max)	-30	dBm
Extinction ratio (min) ^a	3	dB
Encircled Flux	≥ 86% at 19 μm ≤ 30% at 4.5 μm	

^a OMA_{outer} and TDECQ are being defined in IEEE 802.3bs; the reference equalizer is a T/2 spaced 5 tap FFE (*TBC*) for MMF links

^b Even if TDECQ is <1dB, OMA_{outer} must be at least this value

Strawman 64GFC receiver characteristics

Description	Value	Unit
Signaling rate, each lane, (range)	$28.9 \pm 100\text{ppm}$	GBd
Modulation format	PAM4	
Center wavelength (range)	840 - 860	nm
Damage threshold (min)	+5	dBm
Average receive power, each lane (max)	+4	dBm
Average receive power, each lane (min)	-7.9	dBm
Receive power, each lane ($\text{OMA}_{\text{outer}}$) (max)	+3	dBm
Receiver reflectance (max)	-12	dB
Stressed receiver sensitivity ($\text{OMA}_{\text{outer}}$), each lane (max) ^a	-2 <i>TBC</i>	dBm at 1.09×10^{-4}
Receiver sensitivity ($\text{OMA}_{\text{outer}}$), each lane (max) ^{ab}	-7 <i>TBC</i>	dBm at 1.09×10^{-4}
Conditions of stressed receiver sensitivity test		
Stressed eye closure (SECQ), lane under test ^a	5 <i>TBC</i>	dB
OMA of each aggressor lane	+3 <i>TBC</i>	dBm

^a $\text{OMA}_{\text{outer}}$ and SECQ are being defined in 802.3bs, the reference equalizer is a T/2 spaced 5 tap FFE (*TBC*) for MMF links

^b Receiver sensitivity is informative

Strawman 64GFC illustrative link budget

Parameter	OM3	OM4	Unit
Effective modal bandwidth at 850 nm	2000	4400	MHz.km
Power budget (for max TDECQ)	7.0 <i>TBC</i>		dB
Operating distance	70	100	m
Channel insertion loss	1.8	1.9	dB
Allocation for penalties (for max TDECQ)	5.1 <i>TBC</i>		dB
Additional insertion loss allowed	0.1	0	dB

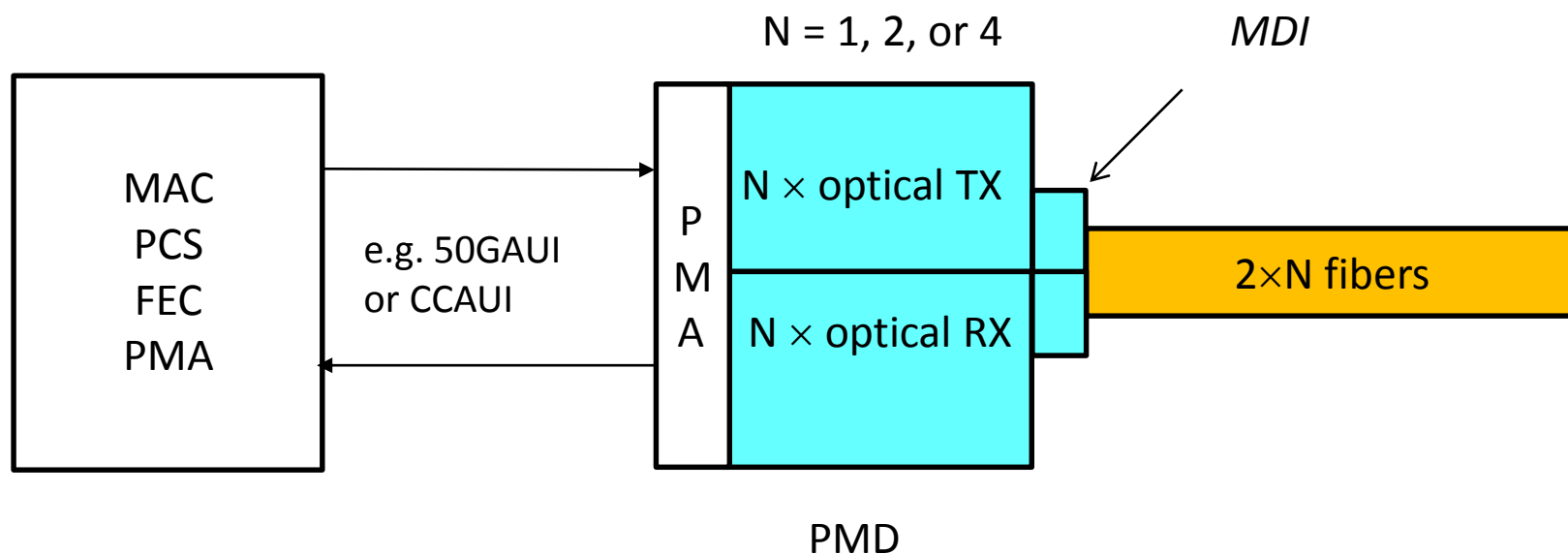
Concluding notes

- Strawman spec's are just a starting point
- We need to gather data for real components at Fibre Channel rates
 - expect 6 to 12 months of work before the specs start to stabilize
 - driver + VCSEL performance
 - TDECQ measurements and system tests
 - receiver performance

Back up

Ethernet 50Gb/s MMF lanes

- One, two, or four optical lanes per direction for 50GBASE-SR, 100GBASE-SR2, or 200GBASE-SR4
- Each lane @ 26.5625 GBd PAM4 over 100 m OM4 fiber.
 - Exact signaling rate is determined by project's choice of FEC.
- 850 nm sources and receivers
 - Assumes target BER (prior to error correction) around 2.4×10^{-4} and random error statistics



50G Ethernet: Transmitter characteristics (each lane), TP2

Description	Value	Unit
Signaling rate, each lane, (range)	26.5625 ± 100ppm	GBd
Modulation format	PAM4	
Center wavelength (range)	840 - 860	nm
RMS spectral width	0.6	nm
Average launch power, each lane (max)	+4	dBm
Average launch power, each lane (min)	-6	dBm
Optical Modulation Amplitude (OMA _{outer}), each lane (max) ^a	+3	dBm
Optical Modulation Amplitude (OMA _{outer}), each lane (min) ^{ab}	-4 <i>TBC</i>	dBm
Launch power in OMA _{outer} minus TDECQ (min) ^a	-5 <i>TBC</i>	dBm
Transmitter and dispersion eye closure (TDECQ), each lane (max) ^a	4 <i>TBC</i>	dB
Average launch power of OFF transmitter, each lane (max)	-30	dBm
Extinction ratio (min) ^a	3	dB
Encircled Flux	≥ 86% at 19 μm ≤ 30% at 4.5 μm	

^a OMA_{outer} and TDECQ are defined in 802.3bs; the 5 tap T/2 reference equalizer is *TBC* for MMF links

^b Even if TDECQ is <1dB, OMA_{outer} must be at least this value

50G Ethernet Receiver characteristics (each lane) at TP3

Description	Value	Unit
Signaling rate, each lane, (range)	26.5625 ± 100ppm	GBd
Modulation format	PAM4	
Center wavelength (range)	840 - 860	nm
Damage threshold (min)	+5	dBm
Average receive power, each lane (max)	+4	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 (OMA _{outer}), each lane (max) ^a	-3 <i>TBC</i>	dBm at 2.4 x 10 ⁻⁴
Receiver sensitivity (OMA _{outer}), each lane (max) ^{ab}	-7 <i>TBC</i>	dBm at 2.4 x 10 ⁻⁴
Conditions of stressed receiver sensitivity test		
Stressed eye closure (SECQ), lane under test ^a	4 <i>TBC</i>	dB
OMA of each aggressor lane	+3	dBm

^a OMA_{outer} and SECQ are defined in 802.3bs, the 5 tap T/2 reference equalizer is *TBC* for MMF links

^b Receiver sensitivity is informative

50G Ethernet: Illustrative link power budget (each lane)

Parameter	OM3	OM4	Unit
Effective modal bandwidth at 850 nm	2000	4400	MHz.km
Power budget (for max TDECQ)	6.0 <i>TBC</i>		dB
Operating distance	70	100	m
Channel insertion loss	1.8	1.9	dB
Allocation for penalties (for max TDECQ)	4.1 <i>TBC</i>		dB
Additional insertion loss allowed	0.1	0	dB