

64G Fibre Channel strawman

October 2016

Jonathan King, Finisar

T11/16-419v0

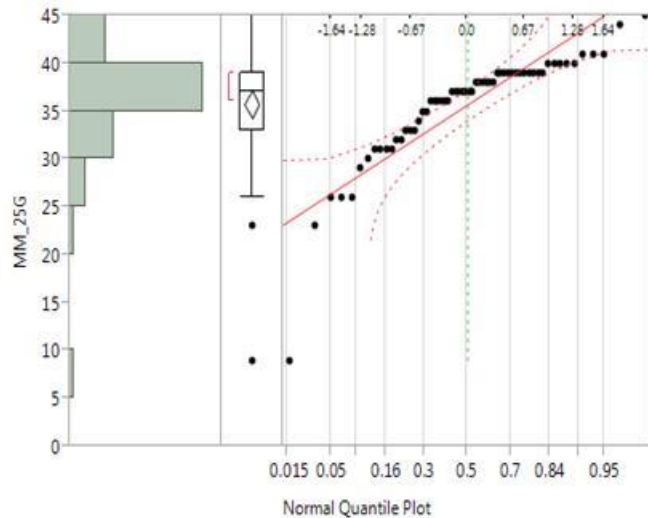
Background

- 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(544,528)
 - Target BER for optics: 2.4×10^{-4}
 - Reach: 100 m OM4
- Good starting point for 64G Fibre Channel
 - Expect FEC supported RS(544,528), or similar.
 - Target BER for optics: 2.4×10^{-4}
 - 57.8 Gb/s PAM4 signaling format
- ... but higher symbol rate:
 - increases transmitter and link penalties by about 1 dB
 - and receiver penalties by about 0.5 dB

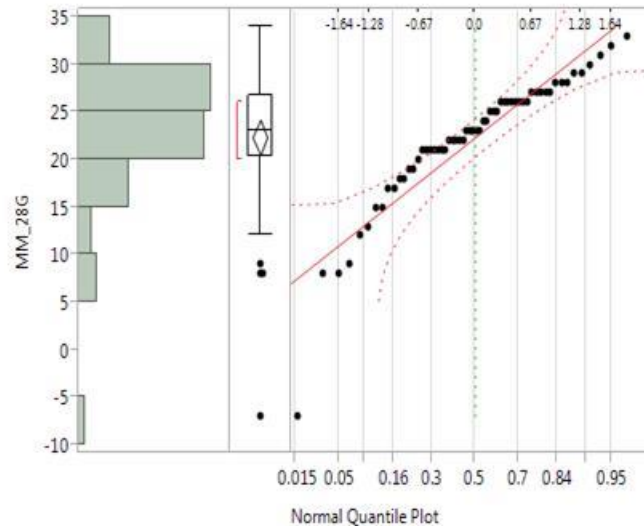
57.8 Gb/s vs 53.1 Gb/s PAM4

- 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 0.3 dB sensitivity
 - Transmitter eye closure increases by 0.4 dB
 - Path penalty increases by 0.2 dB
 - RIN penalty increases by 0.7 dB (due to increased eye closure), also increases received eye jitter by 0.07 UI
 - 'consequent penalty' increases by 0.2 dB
 - Overall, a loss of 1.8 dB of link budget, and an estimated TDECQ increase of about 1dB

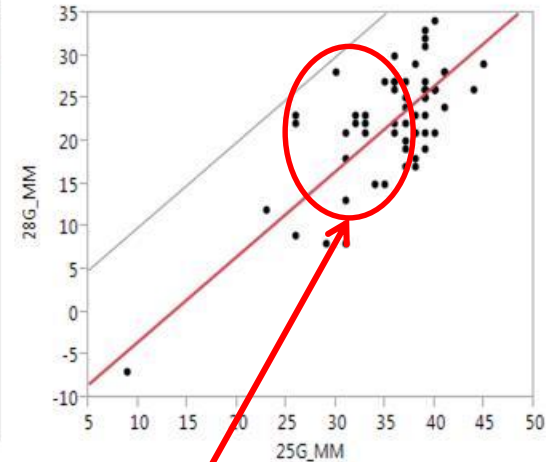
Shows up in 25G vs 28G NRZ data



| 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 |

- Mask margin measurements show ~ 0.5 to 1 dB additional eye closure for 28G operation

Choices for 64GFC

- The higher penalties due to higher bit rate leaves two main options
 - 1) Shorter reach
 - For same optics as Ethernet transceivers, 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

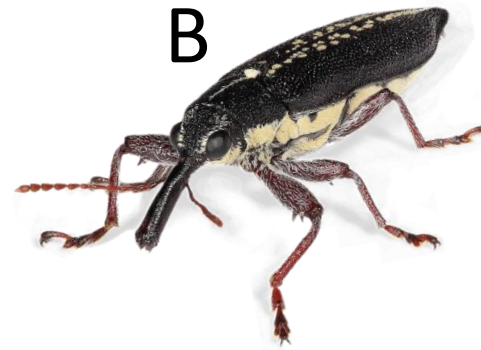
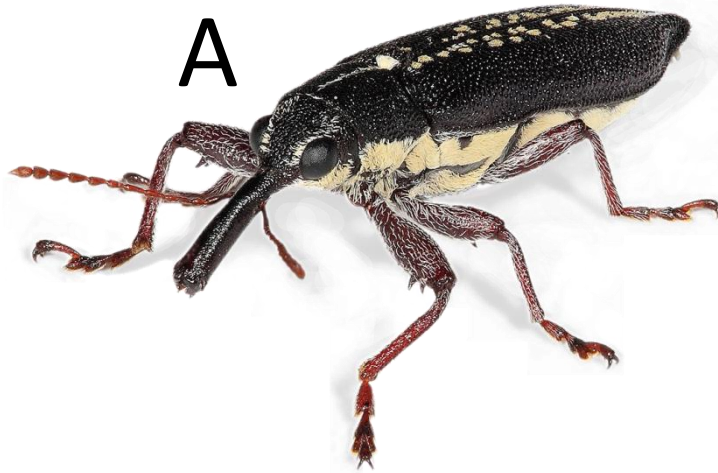
- 1) Higher performance optics
 - Lower yield, higher cost, to keep 100 m target reach.
 - TDECQ reference receiver bandwidth same as IEEE 50GBASE-SR

Option 2, maintaining 100 m OM4 for 64GFC

- A. Keep TDECQ spec at 4 dB, screen for higher performance transmitters
 - e.g. Transmitters may need a combination of
 - 1dB lower RIN
 - 10% faster VCSEL
 - centre wavelength >845 nm at all temperatures
 - ~0.5 dB higher OMA
 - *Use same optical specs as IEEE, screen transmitters for TDECQ over temperature, same level of stress for SRS test.*
- B. Raise max TDECQ spec to 5 dB, screen for higher performance transmitters
 - Transmitters may need a combination of up to
 - no RIN change
 - 10% faster VCSEL
 - 1.2 dB higher OMA
 - *Only change to optical specs is higher TDECQ and SECQ (and consequent specs) screen transmitters for TDECQ over temperature, and use tougher SRS test for receiver (5dB SECQ)*

Neither of these is pretty !

The lesser of two weevils ?



Probably option B...

Screen transmitters for TDECQ max of 5 dB

and use 5 dB SECQ test source for SRS test at 1 dB higher OMA
(no new screens for RIN or spectral width at module level)

Strawman 64GFC Transmitter 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 |
| 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 ($\text{OMA}_{\text{outer}}$), each lane (max) ^a | +3 | dBm |
| Optical Modulation Amplitude ($\text{OMA}_{\text{outer}}$), each lane (min) ^{ab} | -4 | dBm |
| Launch power in $\text{OMA}_{\text{outer}}$ 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 | $\geq 86\%$ at $19\ \mu\text{m}$ $\leq 30\%$ at $4.5\ \mu\text{m}$ | |

^a $\text{OMA}_{\text{outer}}$ and TDECQ are defined in IEEE 802.3bs; the 5 tap T/2 reference is *TBC* for MMF links

^b Even if TDECQ is <1dB, $\text{OMA}_{\text{outer}}$ must be at least this value

Strawman 64GFC receiver characteristics

| Description | Value | Unit |
|---|-----------------------------|--------------------------------|
| Signaling rate, each lane, (range) | $26.5625 \pm 100\text{ppm}$ | 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 2.4×10^{-4} |
| Receiver sensitivity ($\text{OMA}_{\text{outer}}$), each lane (max) ^{ab} | -7 <i>TBC</i> | dBm at 2.4×10^{-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 defined in 802.3bs, the 5 tap T/2 reference is *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 |

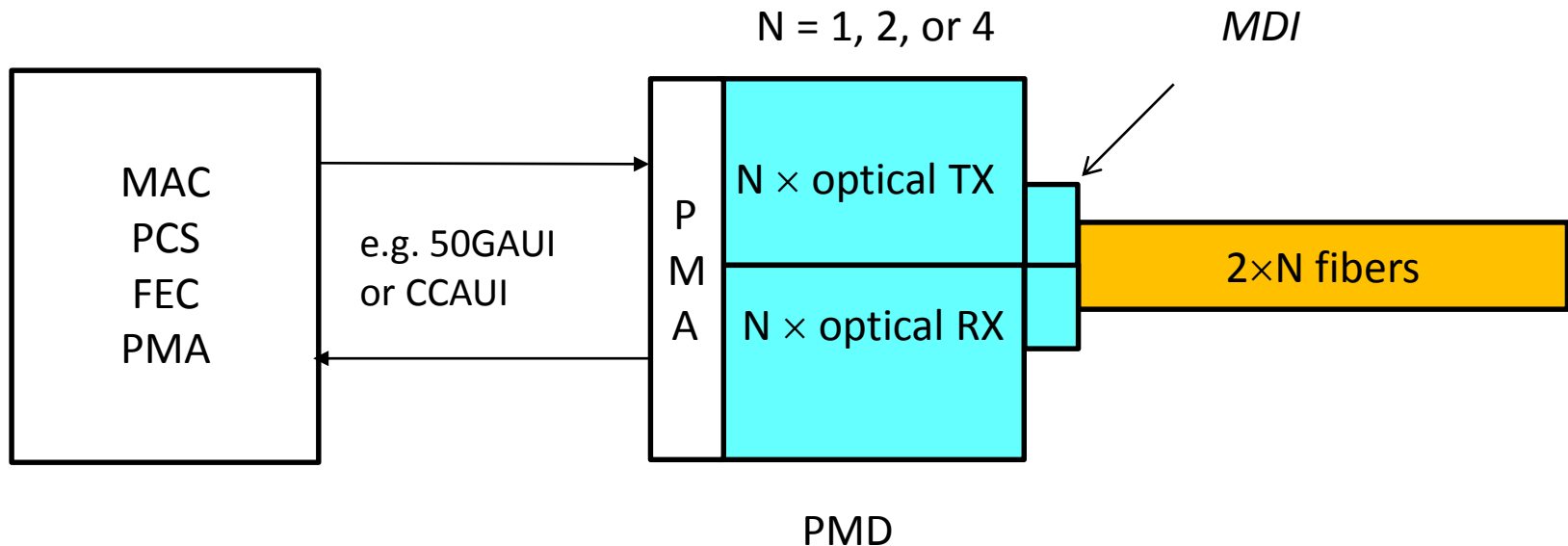
Concluding notes

- 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



IEEE Transmitter characteristics (each lane) at TP2

| Description | Value | Unit |
|---|---|------|
| Signaling rate, each lane, (range) | $26.5625 \pm 100\text{ppm}$ | 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 ($\text{OMA}_{\text{outer}}$), each lane (max) ^a | +3 | dBm |
| Optical Modulation Amplitude ($\text{OMA}_{\text{outer}}$), each lane (min) ^{ab} | -4 <i>TBC</i> | dBm |
| Launch power in $\text{OMA}_{\text{outer}}$ 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 | $\geq 86\%$ at $19\text{ }\mu\text{m}$ $\leq 30\%$ at $4.5\text{ }\mu\text{m}$ | |

^a $\text{OMA}_{\text{outer}}$ and TDECQ are defined in 802.3bs; the 5 tap T/2 reference is *TBC* for MMF links

^b Even if TDECQ is <1dB, $\text{OMA}_{\text{outer}}$ must be at least this value

IEEE Receiver characteristics (each lane) at TP3

| Description | Value | Unit |
|---|-----------------------------|--------------------------------|
| Signaling rate, each lane, (range) | $26.5625 \pm 100\text{ppm}$ | 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 | -3 <i>TBC</i> | dBm at 2.4×10^{-4} |
| Receiver sensitivity ($\text{OMA}_{\text{outer}}$), each lane (max) ^{ab} | -7 <i>TBC</i> | dBm at 2.4×10^{-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 $\text{OMA}_{\text{outer}}$ and SECQ are defined in 802.3bs, the 5 tap T/2 reference is *TBC* for MMF links

^b Receiver sensitivity is informative

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 |