Towards technical feasibility of 100 Gb/s per lane optical PMDs supporting 100 m OM4 MMF

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Adopted physical layer specification objectives

- Define a physical layer specification that supports 100 Gb/s operation over 1 pair of MMF with lengths up to at least 50 m
- Define a physical layer specification that supports 200 Gb/s operation over 2 pairs of MMF with lengths up to at least 50 m
- Define a physical layer specification that supports 400 Gb/s operation over 4 pairs of MMF with lengths up to at least 50 m

Motivation to exceed 50 m minimum reach

- For switch-to-server applications, 50 m reach is expected to be sufficient. See young_100GSR_adhoc_01_042320
- However, for switch-to-switch applications, 50 m reach is expected to be insufficient. See swanson_100GSR_adhoc_01_040920
- For switch-to-switch applications, a reach of 100 m OM4 (as in Clauses 95, 112, 123, 138 and 150) is highly desirable. PMDs that support this reach are expected to have significantly broader market potential than those that support 50 m only
- Historically, 70 m has been the corresponding reach on OM3. However, it is sensible to define the test methodology for the eventual PMDs, particularly the TDECQ reference response, based on the 100 m OM4 reach. The OM3 reach would be chosen such that the link exhibits a small margin relative to the 100 m OM4 link

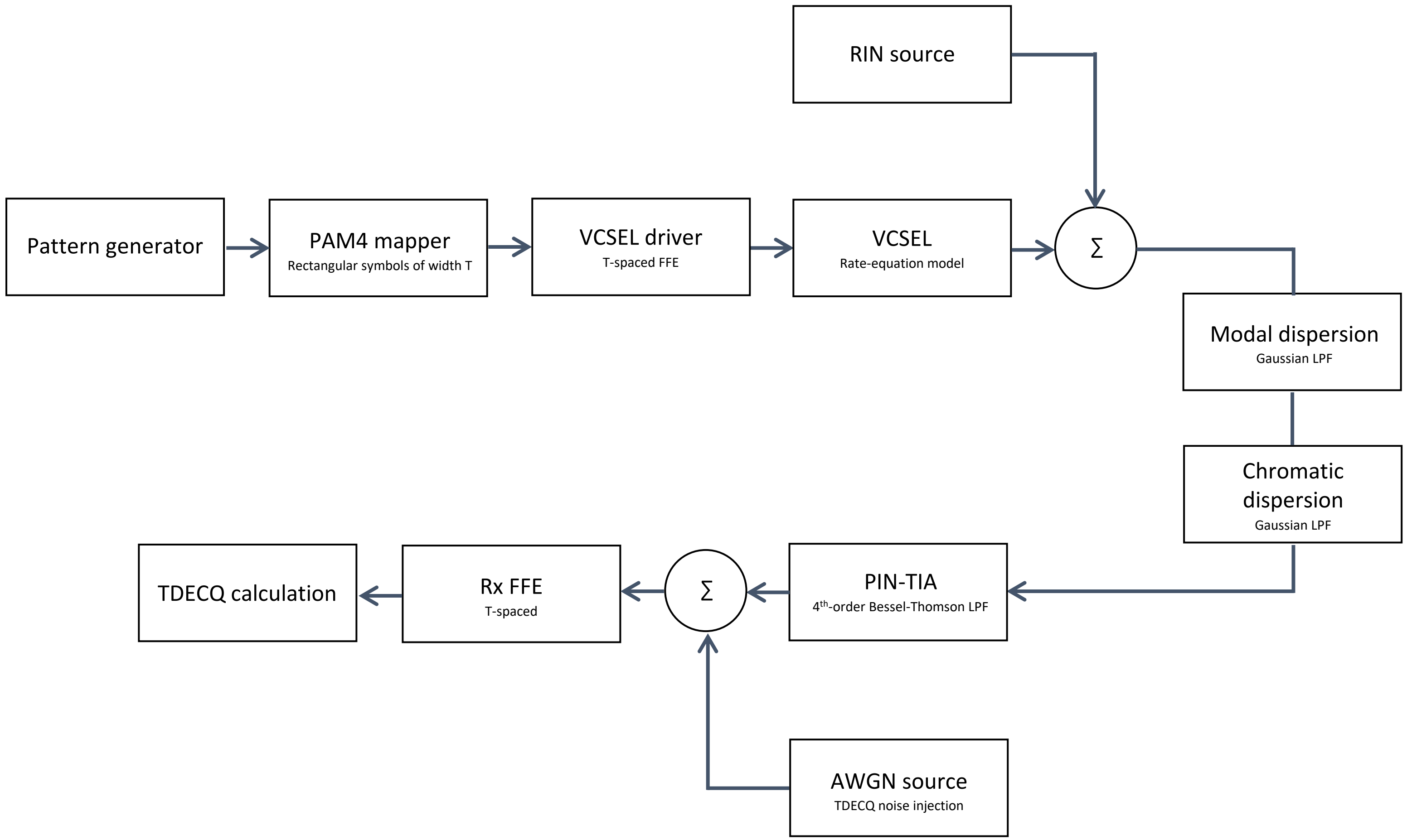
Wavelength

- Operation close to 850 nm provides maximum aggregate bandwidth, i.e. modal and chromatic bandwidth combined, for all types of MMF under consideration
- Whilst the chromatic bandwidth would be higher for 940 nm operation, this benefit does not offset the reduction in modal bandwidth
- A starting point for discussion would be the lower wavelength range adopted for Clause 150, i.e. 844 nm to 863 nm. This allows operation close to the peak worst-case modal bandwidth for all types of MMF under consideration, whilst avoiding the reduced chromatic bandwidth towards 840 nm
- Further advantages of operation close to 850 nm are that it is likely to maximize the supply base of VCSELs and benefit from a common supply base with applications that require backwards compatibility

PCS/FEC/PMA reuse

- Reuse of the Clause 91 PCS and Clause 119 PCS, based on RS(544, 514) FEC, is strongly advised, together with the corresponding PMAs
- This renders P802.3db a "PMD-only" project, simplifying the work of the Task Force and ensuring compatibility with the 100 Gb/s per lane C2M interfaces being developed in P802.3ck
- Hence, in this study, TDECQ is evaluated at a SER of 4.8×10^{-4}

Simulation block diagram



- In this study, TDECQ is used as the figure of merit for the Tx
- 4.5 dB is assumed to be an acceptable limit on TDECQ (as in Clauses 138 and 150)

Simulation parameters

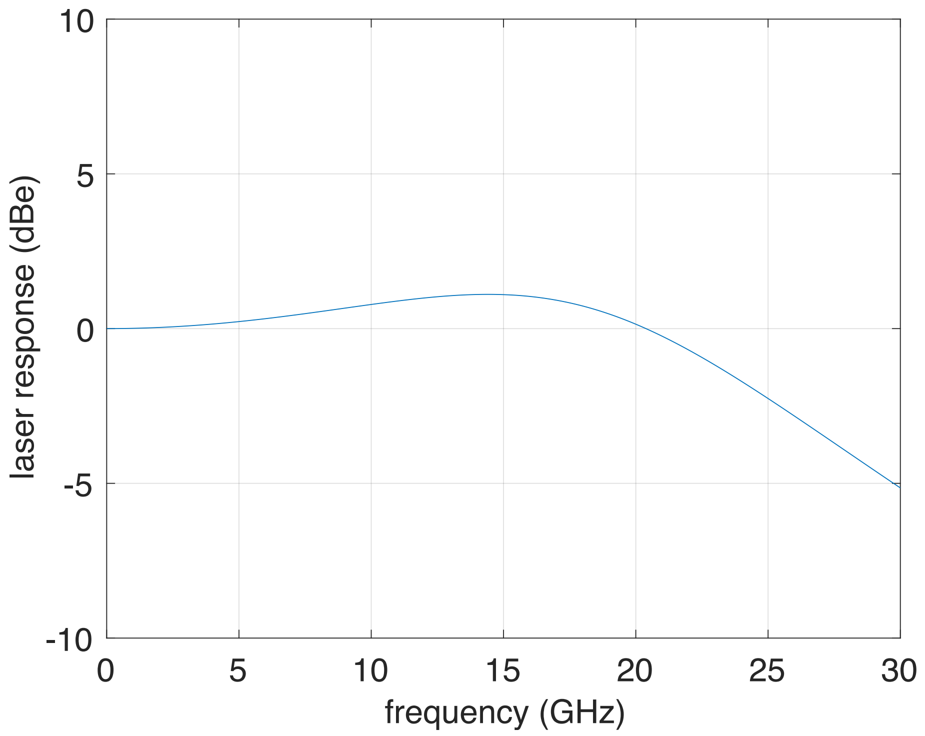
Tx
53.125 GBd PAM4 with SSPRQ
VCSEL driver with 3-tap T-spaced FFE (tap coefficients: –0.3, 1, –0.3)
VCSEL driver output transition time (measured with VCSEL driver FFE tap coefficients of 0, 1, 0): 12 ps (20% - 80%)
100G VCSEL (rate-equation model based on a recent prototype) with –3 dBe at ≈27 GHz
Wavelength: 844 nm (for worst-case aggregate MMF bandwidth of Clause 150 lower wavelength range)
Spectral width (rms): 0.6 nm
RIN: –145 dB/Hz
Outer ER for RIN calculation: 3 dB

OM3 and OM4 MMF
Gaussian LPFs for both modal and chromatic dispersion
EMB from guidance in IEC 60793-2-10
Zero-dispersion wavelength: 1316 nm
Zero-dispersion slope: 0.102750 ps/(nm^2 km)
See abbott_100GSR_01_0120 for justification of these assumptions

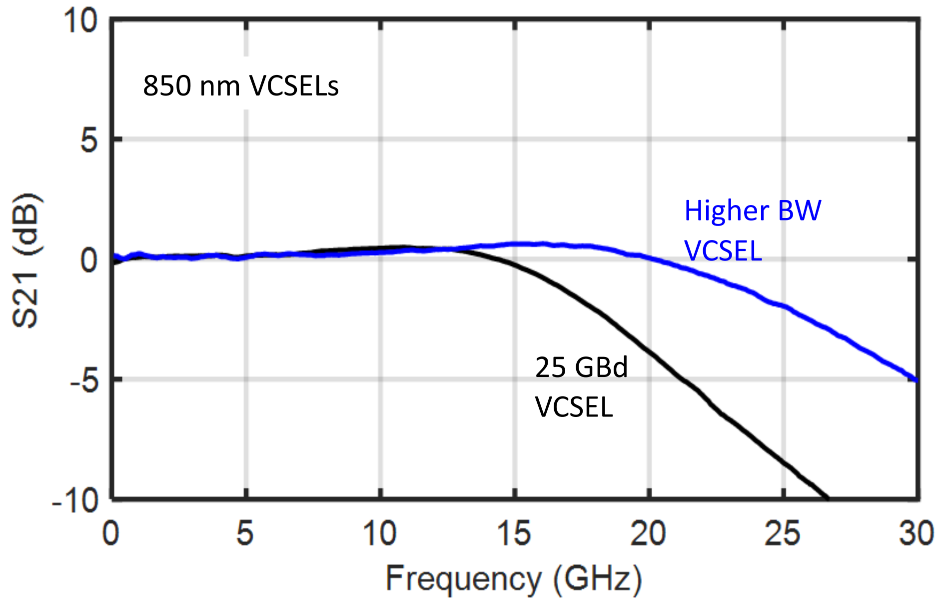
Rx
TDECQ reference LPF: 4th-order Bessel-Thomson with –3 dBe at 26.5625 GHz
TDECQ reference FFE: T-spaced with variable taps
TDECQ calculated at target SER of 4.8 x 10^{-4}

- These parameters are default values. In later slides, some parameters are varied to generate trends

VCSEL model



VCSEL frequency response from rate-equation model at 8 mA bias current



Measured frequency response

- A rate-equation-based VCSEL model has been created to reproduce key features of the S_{21} characteristic for a recent prototype

EMB

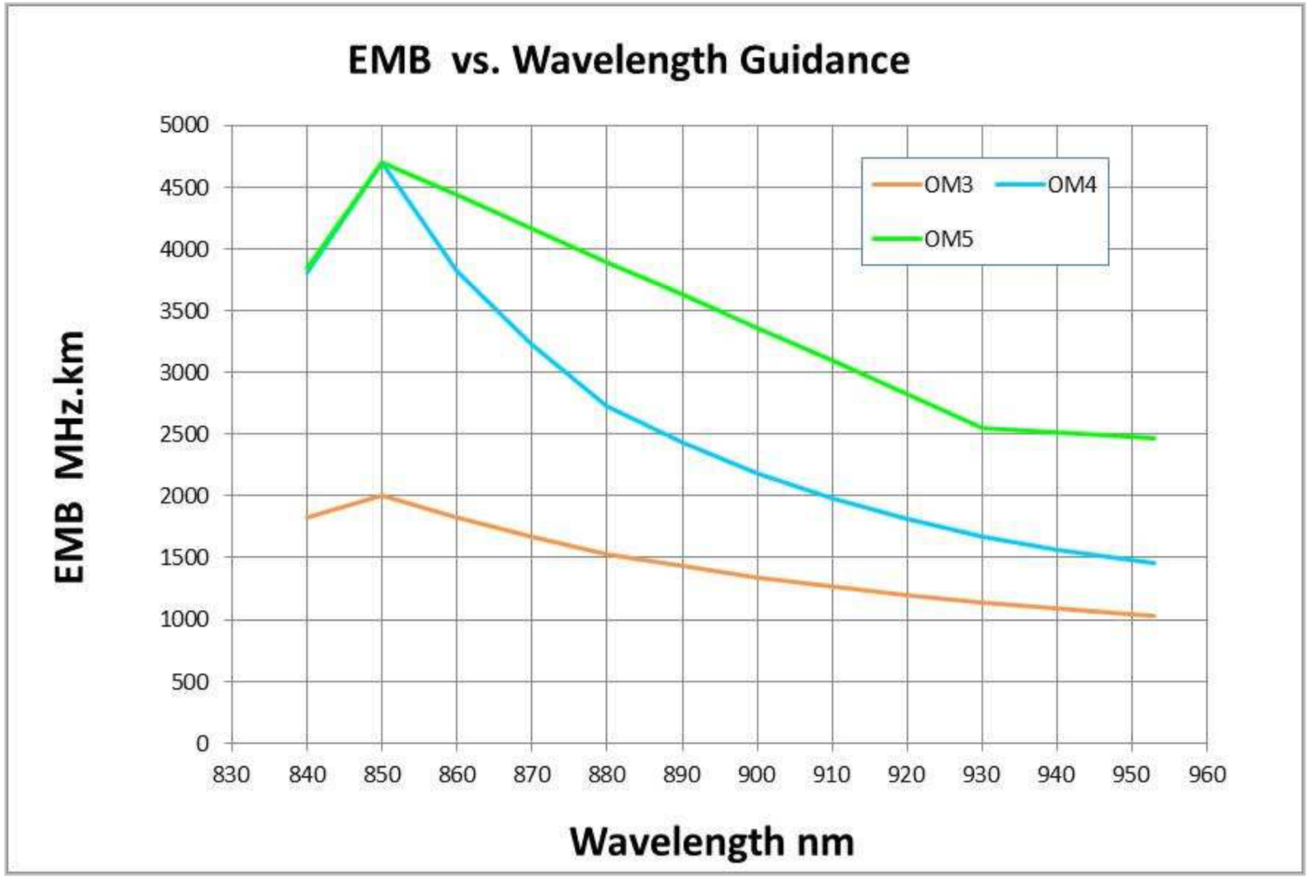
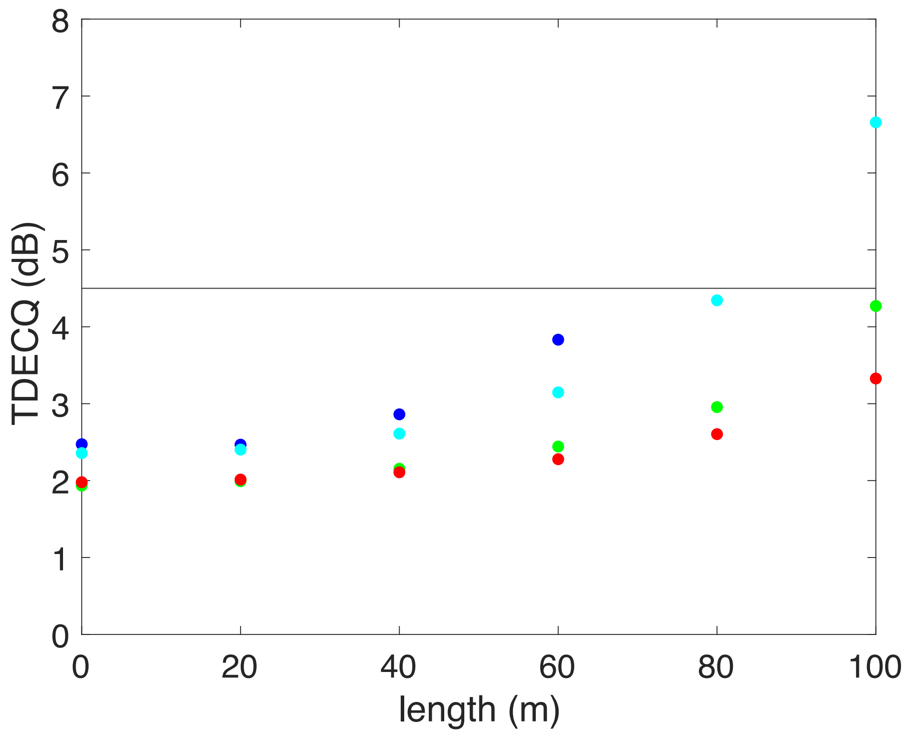
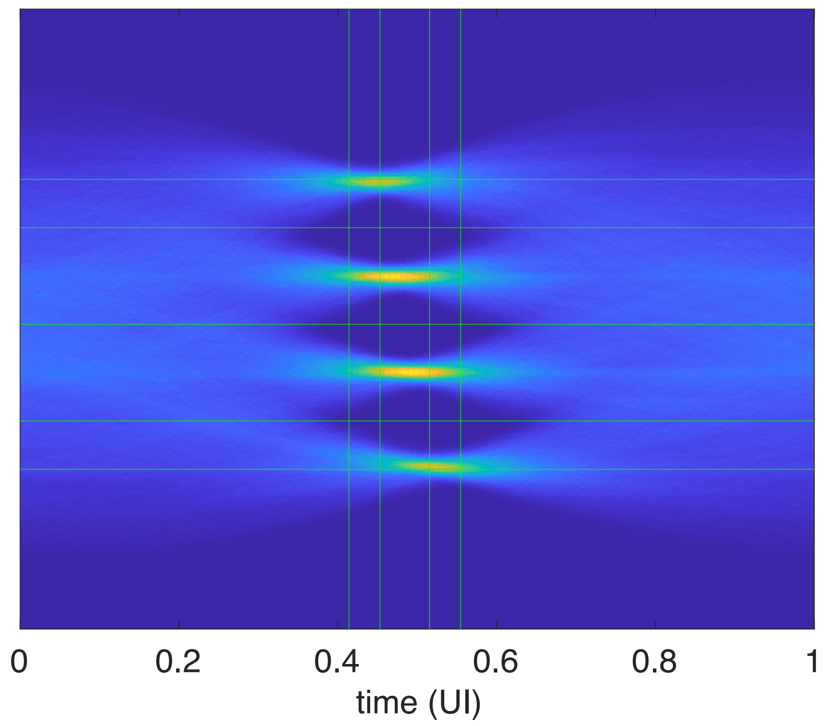


Figure reproduced from “OM3, OM4, OM5 modal bandwidth over wavelengths for WDM,” P. Kolesar, J. Abbott, P. Pondillo, S. Swanson, M. Bigot, A. Amezcua, R. Samamra, K. Balemarthy, R. Shubochkin, J. Castro, R. Pimpinella, B. Lane and B. Kose, IEEE 802.3 Next-Generation 200 Gb/s and 400 Gb/s MMF PHYs Study Group, Geneva, January 2018

TDECQ vs OM4 link length



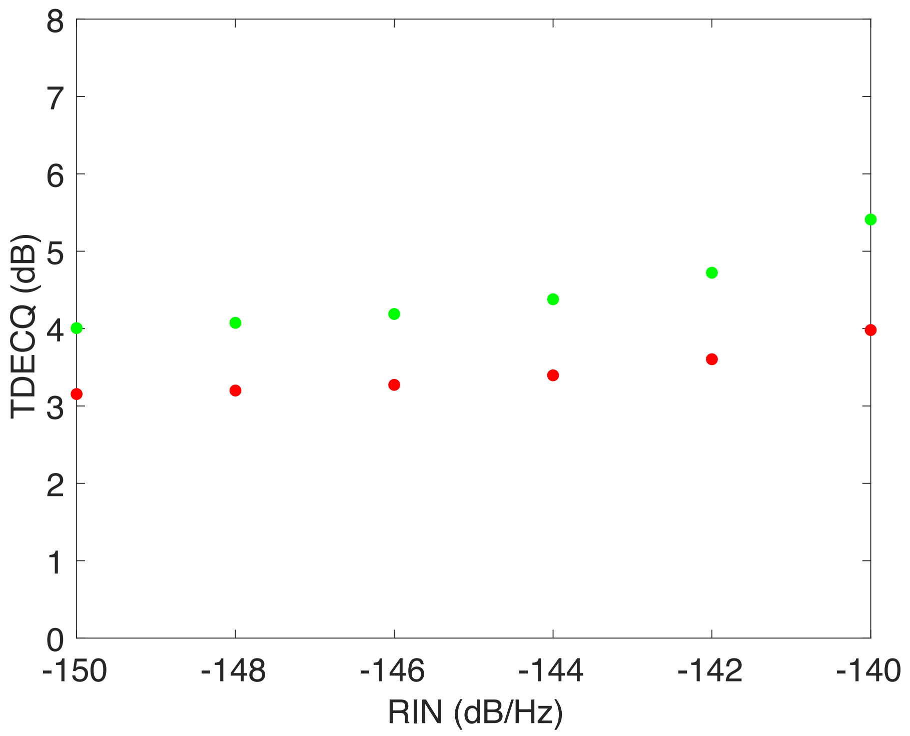
TDECQ versus OM4 link length for 5-tap Rx FFE (blue), 7-tap Rx FFE (cyan), 9-tap Rx FFE (green) and 23-tap Rx FFE (red)
If TDECQ is not measurable at a particular length, then a data point is not shown



Eye diagram after 100 m OM4 with 9-tap Rx FFE
Rx noise not depicted; green lines show outer levels, thresholds and optimally-positioned time windows for TDECQ

- 100 m OM4 is feasible, but requires at least a 9-tap Rx FFE

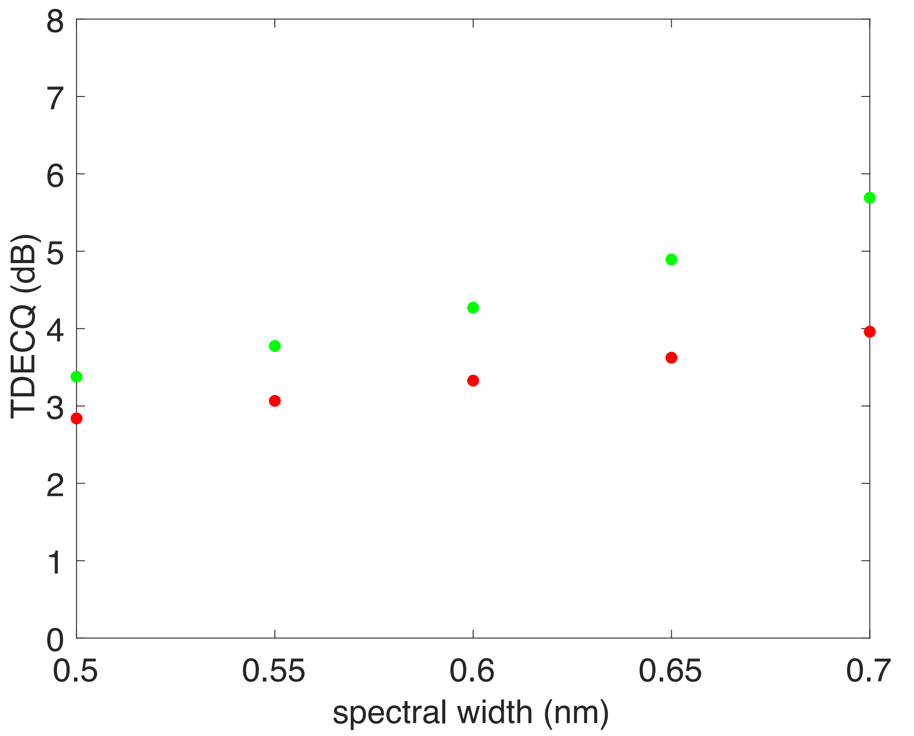
TDECQ for 100 m OM4 vs RIN



TDECQ for 100 m OM4 versus RIN for 9-tap Rx FFE (green) and 23-tap Rx FFE (red)

- Improvement in RIN beyond –145 dB/Hz would not provide significant reduction of TDECQ

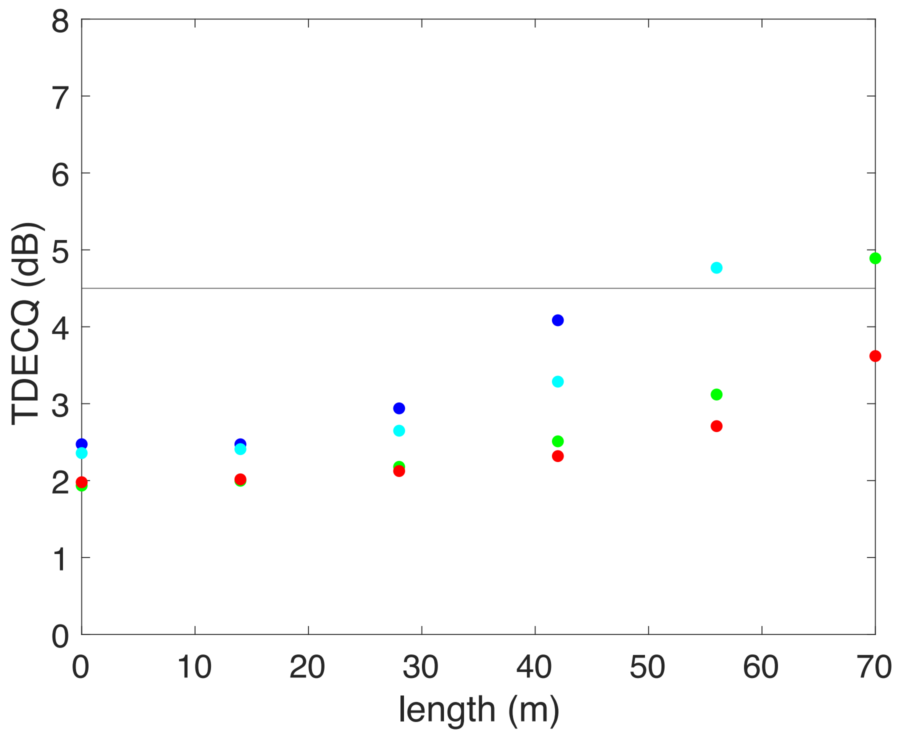
TDECQ for 100 m OM4 vs spectral width



TDECQ for 100 m OM4 versus spectral width for 9-tap Rx FFE (green) and 23-tap Rx FFE (red)

- Increased chromatic dispersion results in ≈2 dB change in TDECQ between 0.5 nm and 0.7 nm spectral width, for a 9-tap Rx FFE

TDECQ vs OM3 link length



TDECQ versus OM3 link length for 5-tap Rx FFE (blue), 7-tap Rx FFE (cyan), 9-tap Rx FFE (green) and 23-tap Rx FFE (red)

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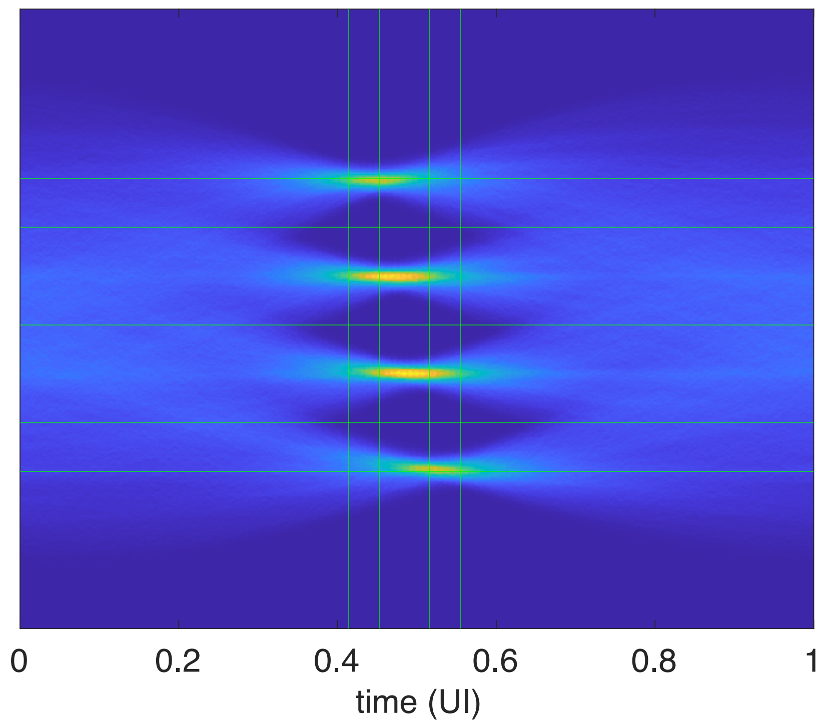
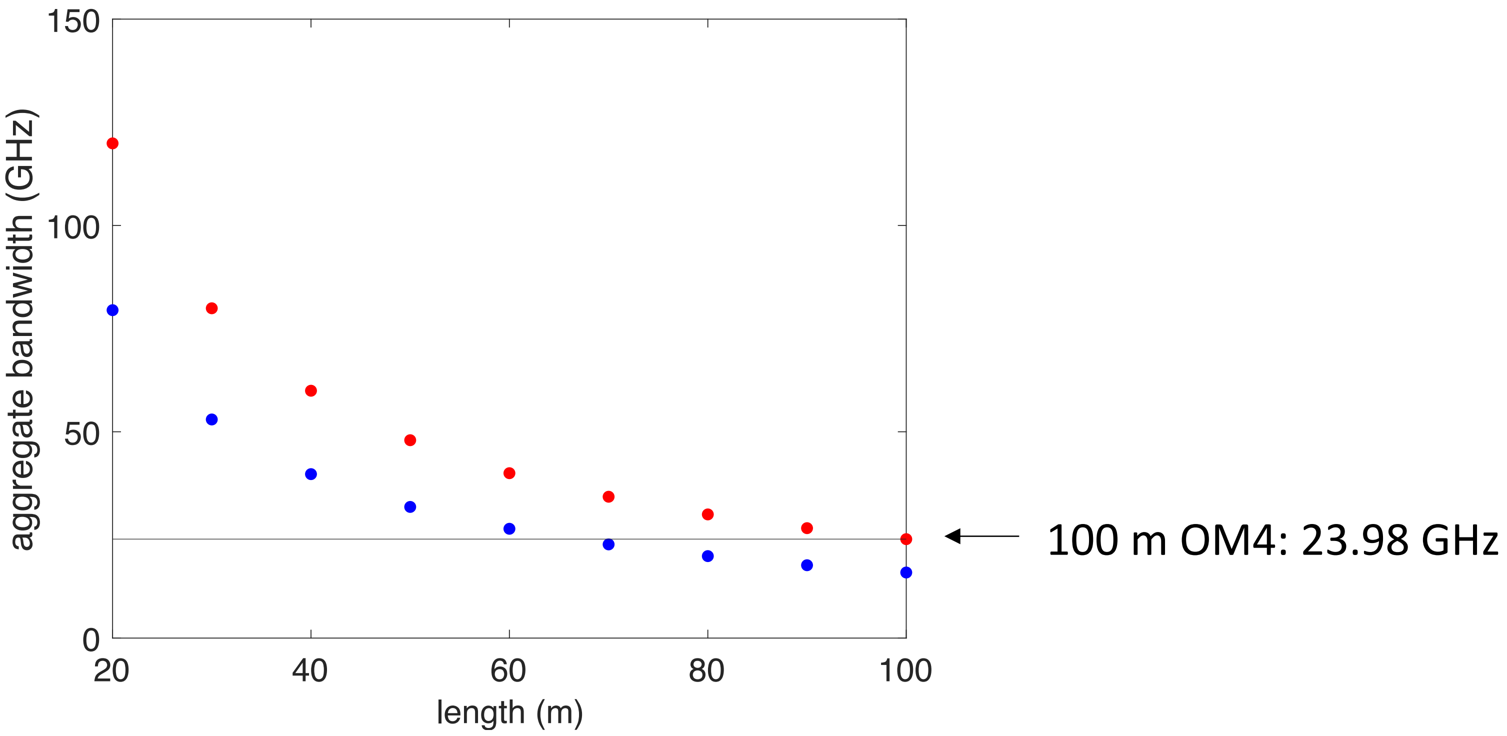


Eye diagram after 60 m OM3 with 9-tap Rx FFE

Rx noise not depicted; green lines show outer levels, thresholds and optimally-positioned time windows for TDECQ

- 70 m OM3 is a more challenging target than 100 m OM4
- 60 m OM3 may be a more appropriate target

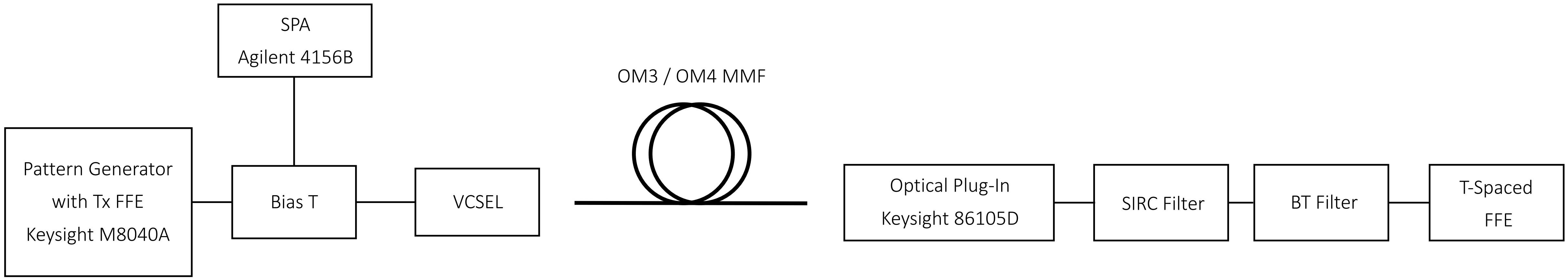
Aggregate bandwidth of OM3 and OM4



Aggregate bandwidth versus length for
OM3 (blue) and OM4 (red)

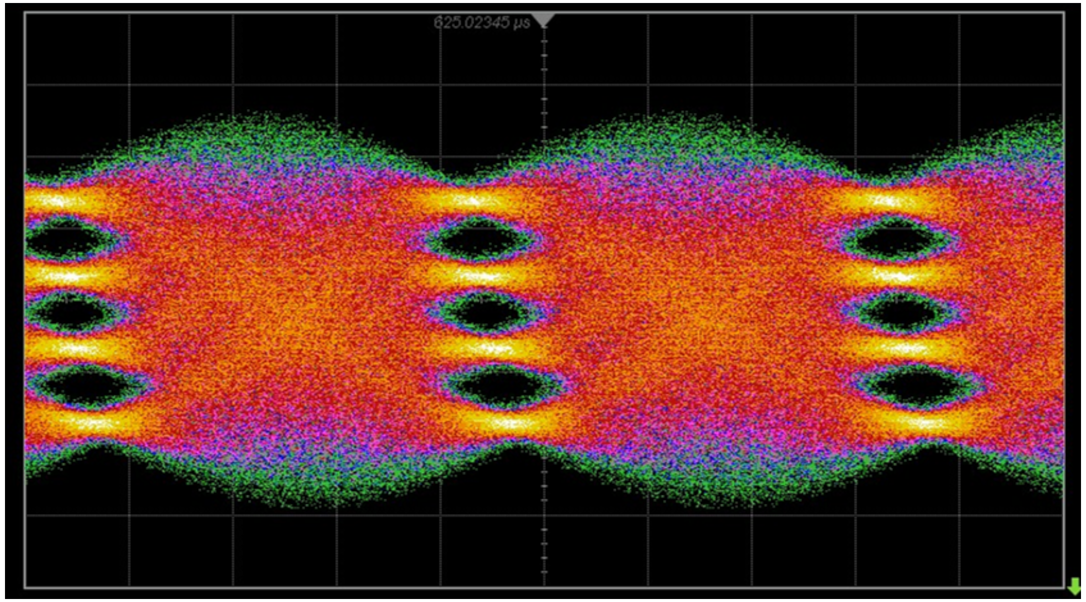
- Aggregate bandwidth (–3 dBo) calculated for 0.6 nm spectral width at 844 nm
- 70 m OM3 exhibits a lower aggregate bandwidth than 100 m OM4
- 60 m OM3 exhibits a small bandwidth margin relative to 100 m OM4

Experimental set-up



- OM3: EMB ≈ 2000 MHz km @ 850 nm
- OM4: EMB ≈ 4700 MHz km @ 850 nm

Eye diagram after 100 m OM4

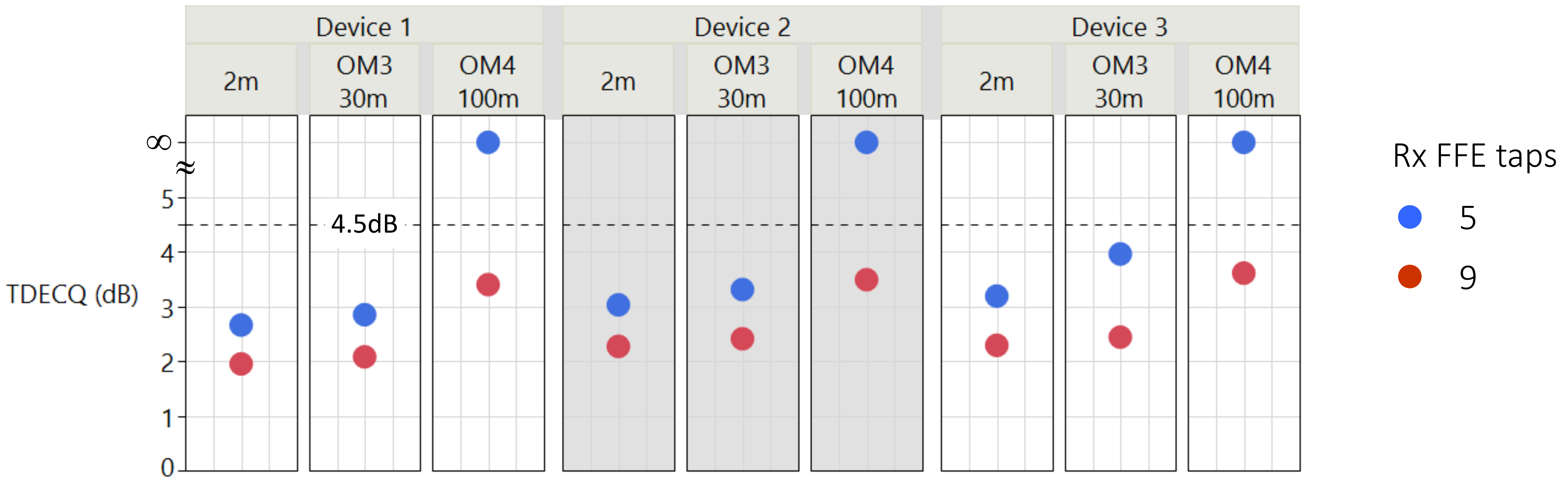


TDECQ: 3.5 dB

Modulation format	PAM4
Symbol rate	53.125 GBd
Pattern	PRBS15Q
Tx FFE	3-tap T-spaced
SER target for TDECQ	4.8 x 10^{-4}
DCA optical plug-in bandwidth	34 GHz
DCA SIRC bandwidth	38.3 GHz
DCA BT filter bandwidth	26.6 GHz
DCA FFE	9-tap T-spaced
Temperature	75 °C
Center wavelength	863 nm
RMS spectral width	0.42 nm
Outer ER	3 dB

- 100 m OM4 link: TDECQ within 4.5 dB with a 9-tap Rx FFE

TDECQ vs Rx FFE taps



- 30 m OM3 link: 5-tap Rx FFE is sufficient for TDECQ within 4.5 dB
- 100 m OM4 link: TDECQ within 4.5 dB with a 9-tap Rx FFE, but not measurable with a 5-tap Rx FFE

Conclusions

- Both simulation and experimental studies show encouraging evidence of the technical feasibility of exceeding the 50 m reach of the current objectives
- 100 m OM4 is suggested as a target for a baseline proposal, enabling broad market potential for switch-to-switch applications. 60 m may be an appropriate corresponding target for OM3
- Operation close to 850 nm is recommended
- To ensure economic feasibility in the support of longer target reaches, the length of the TDECQ reference equalizer may need to be greater than 5 taps