Technical Feasibility of 50 Gbit/s PAM4 using VCSELs from 850nm to 1060nm

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Technical feasibility in support of CSD

NGMMF Study Group, IEEE Interim, Geneva, Switzerland

Supporters and their affiliation

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- Jonathan King, Finisar
- Jonathan Ingham, FIT
- Paul Kolesar, CommScope
- Jim Young, CommScope

The MMF PMD landscape by fiber count, Baud rate, and modulation format

Technology (per fiber)	1 fiber pair	2 fiber pairs	4 fiber pairs	8 fiber pairs	16 fiber pairs
25G-λ NRZ	25G-SR		100G-SR4		400G-SR16
50G-λ NRZ				400G-SR8	
50G-λ PAM4	50G-SR	100G-SR2	200G-SR4	400G-SR8	
100G-λ PAM4	200G-SR1.2	200G-SR2	400G-SR4		
2x50G-λ PAM4		200G-SR2.2	400G-SR4.2		
4x25G-λ NRZ		200G-SR2.4	400G-SR4.4		
4x50G-λ PAM4	200G-SR1.4	400G-SR2.4			

These PMDs require 50 Gbit/s PAM4 at multiple wavelengths

Existing or in-progress IEEE standard

Multi-Wavelength Nomenclature

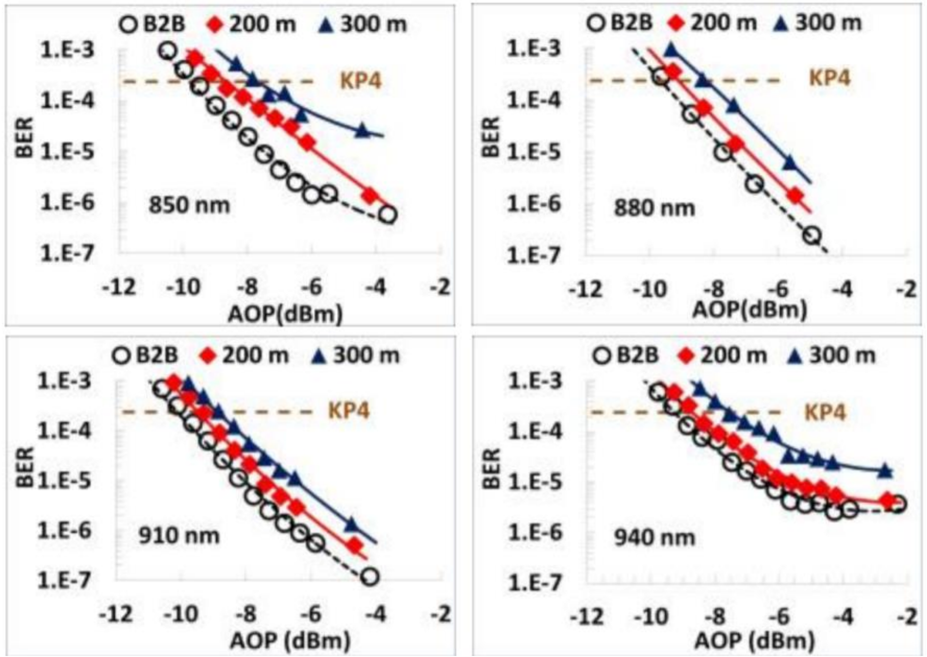
SRm.n   m = # fiber pairs   n = # wavelengths

Technical Feasibility

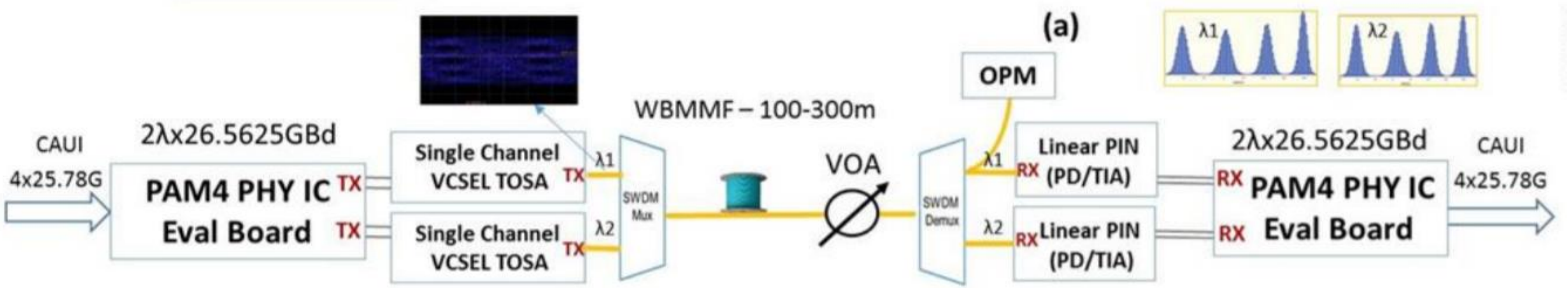
- 50 Gbit/s PAM4 at 850nm over MMF is technically feasible
  - 802.3cd, for example 200G-SR4
  - 4 fiber pairs, 1 wavelength, 50 Gbit/s PAM4 at 850nm
  - 70m OM3, 100m OM4, 100m OM5
- Wavelength division multiplexing (WDM) over MMF is technically feasible
  - Commercially available NRZ systems
  - SWDM4 (850, 880, 910, and 940nm), BiDi (850, and 900nm)
- Is it feasible to do both WDM *and* 50 Gbit/s PAM4 over MMF?
- At what wavelengths is 50 Gbit/s PAM4 over MMF feasible?
  - Literature review
  - 850, 880, 905, 910, 940, 980 and 1060nm

50 Gbit/s PAM4 at 850, 880, 910, and 940nm over 300m OM5*

- F. Chang, et al., OFC 2017, Tu2B.2
- Authors from Inphi, OFS, SiFotonics, and Finisar



(a)



(b)

* Wideband Multimode Fiber (paper predates OM5 name adoption)

50 Gbit/s PAM4 at 855 and 907nm over 400m OM5* and 200m OM4

- Y. Sun et al., IWCS 2017
- OFS
- Bidirectional
- Packaged transceiver w/ FEC enabled

Table 3. AOP and DPP at FEC threshold using the 100G-PAM4-BiDi transceiver.

		Rx sensitivity (dBm)		DPP (dB)	
	length(m)	855nm	907nm	855nm	907nm
B2K	6	-10.3	-10.8		
OM5_1	300	-10.3	-10.6	0.1	0.2
	400	-6.9	-7.2	3.4	3.6
OM5_2	300	-10.1	-10.4	0.2	0.4
	350	-9.9	-10.0	0.5	0.8
	400	-8.6	-9.4	1.8	1.4
	450	0.6	0.0	11.0	10.8
Std. OM4	200	-7.0	-7.2	3.3	3.6

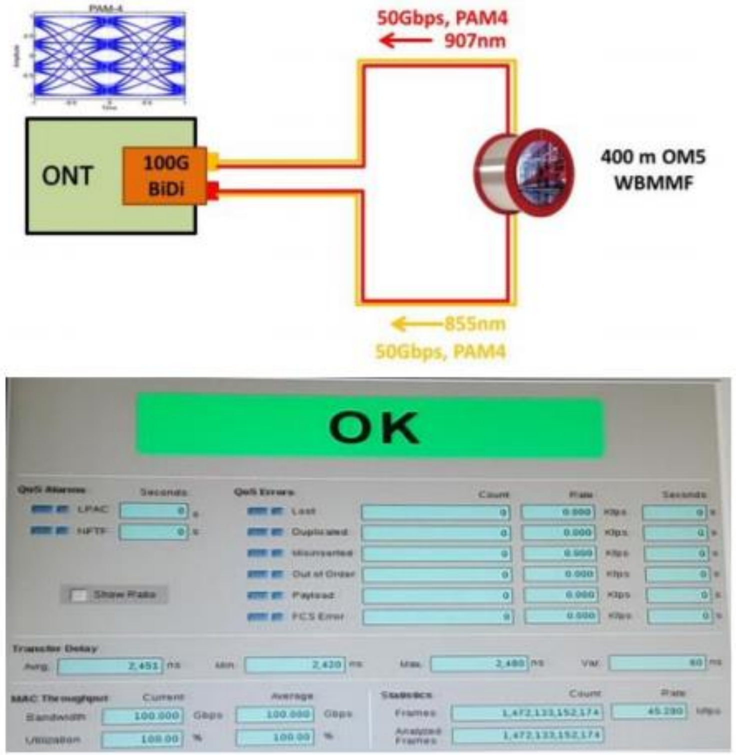
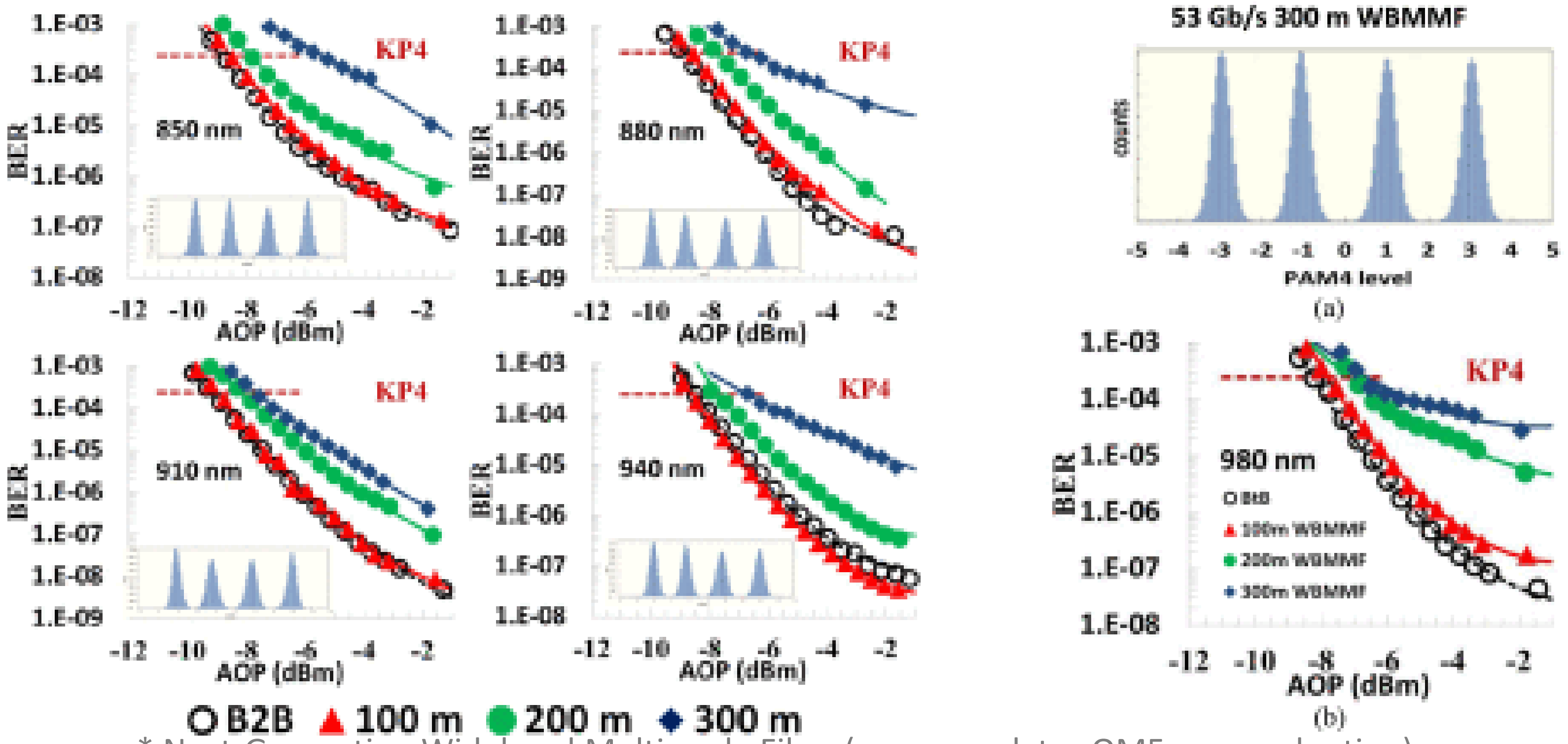


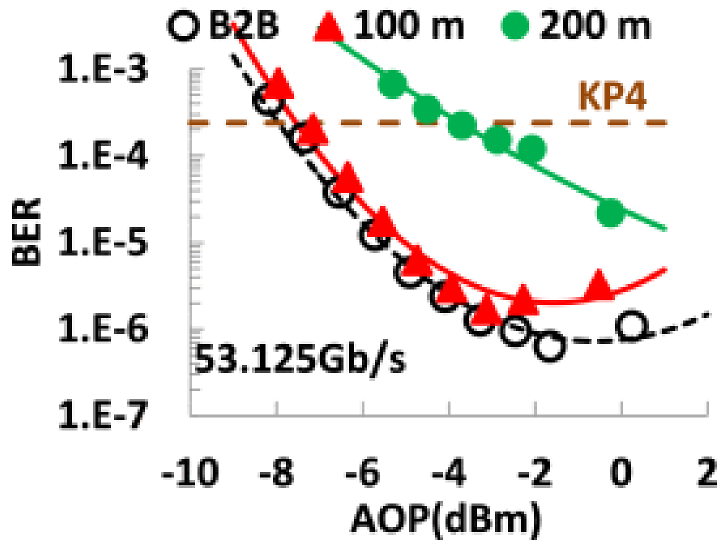
Figure 6. Schematic (top) of 100G-PAM4-BiDi transmission over 400 m OM5 fiber using full Ethernet traffic of an optical network tester (ONT). A screenshot of the results displayed on the ONT in a three day live demo is shown below.

* Wideband Multimode Fiber

50 Gbit/s PAM4 at 850, 880, 910, 940, and 980nm over 300m OM5* and 1060nm over 200m OM5*

- Y. Sun, et al., Journal of Lightwave Technology, Aug 2017
- Authors from OFS, Inphi, Furukawa, and Finisar
- Demonstrates 8 wavelength window with 30nm channel spacing



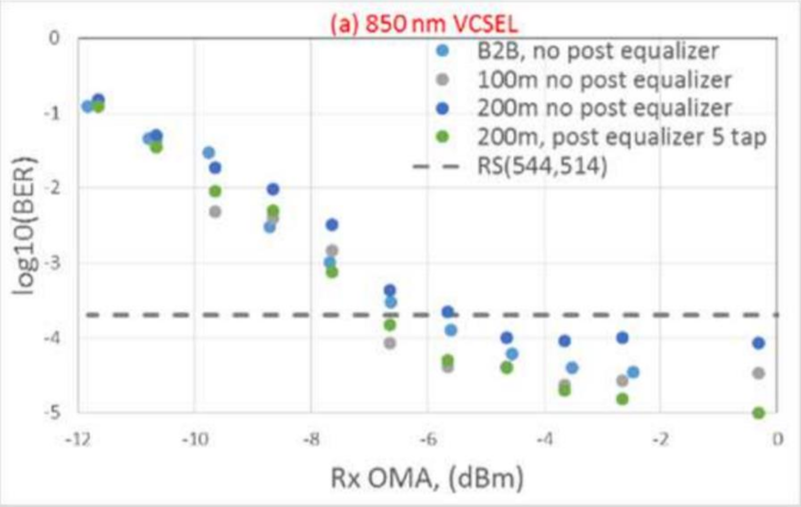


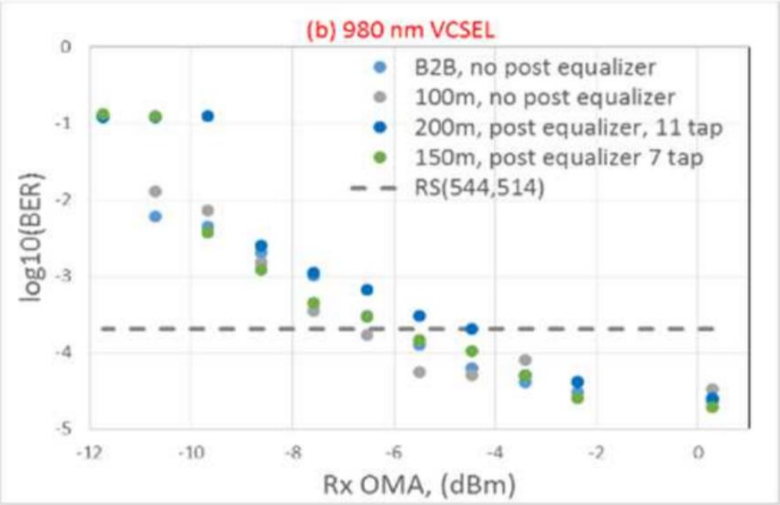
1060nm

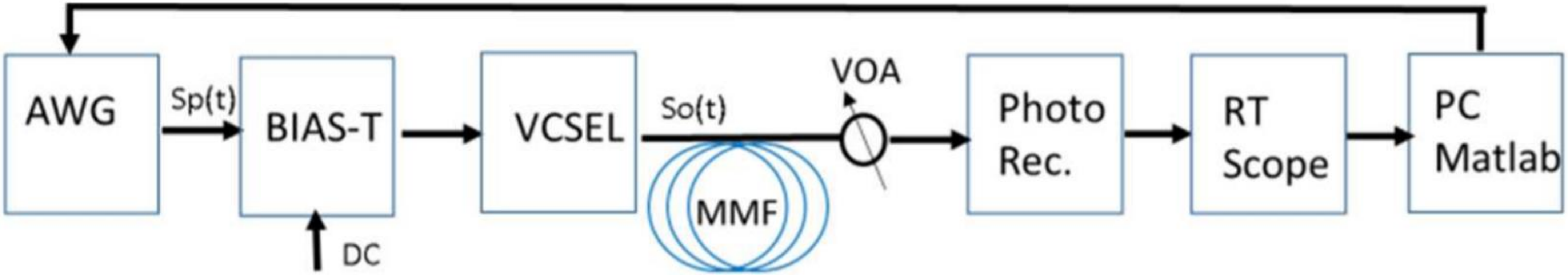
* Next-Generation Wideband Multimode Fiber (paper predates OM5 name adoption)

50 Gbit/s PAM4 at 850 and 980nm over 200m OM5*

- J. M. Castro, et al., OFC 2016, Tu2G.2
- Panduit and Prysmian





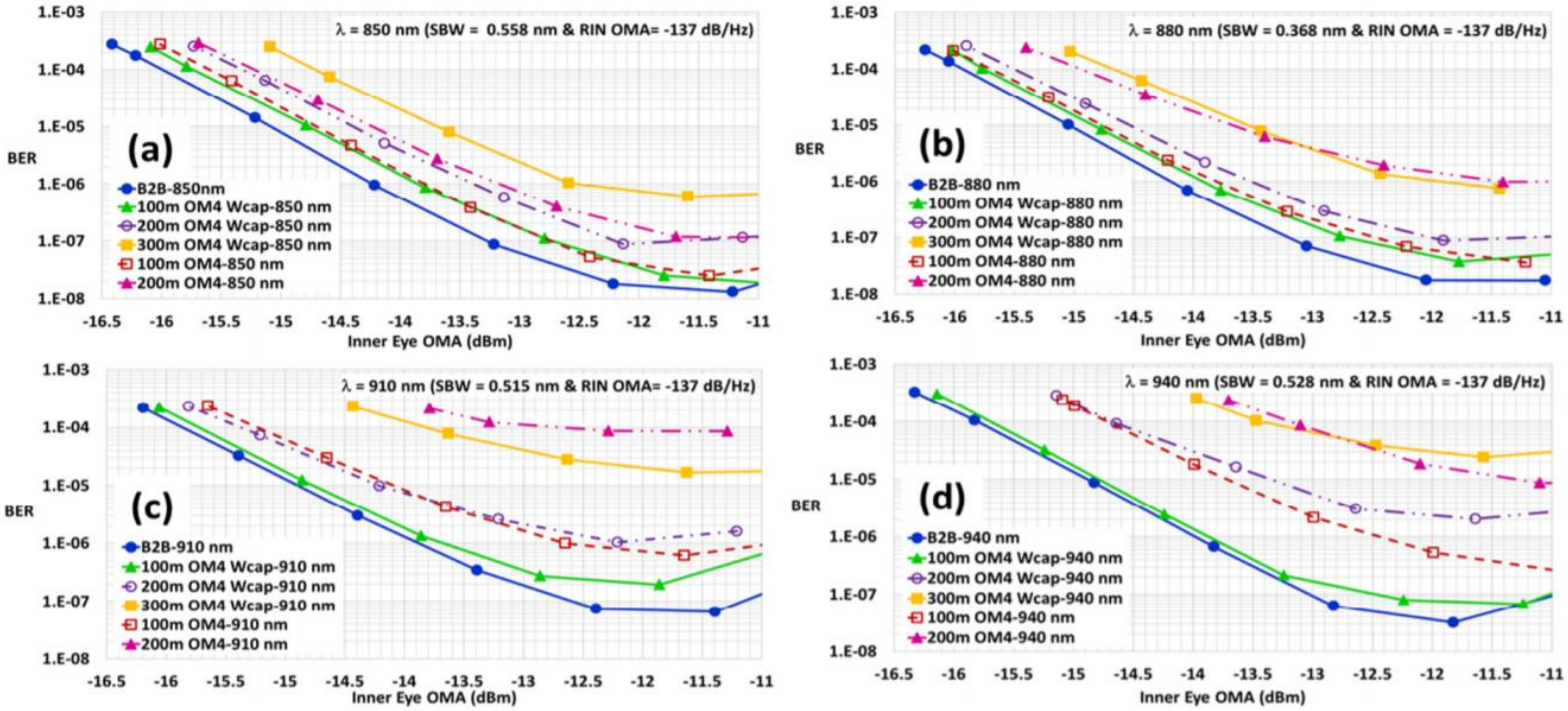


* Wideband Multimode Fiber (paper predates OM5 name adoption)

45 Gbit/s PAM4 at 850, 880, 910, and 940nm over 300m OM5* and 100m OM4

- R. Motaghian, et al., OFC 2016, Th3G.2
- Finisar and Prysmian

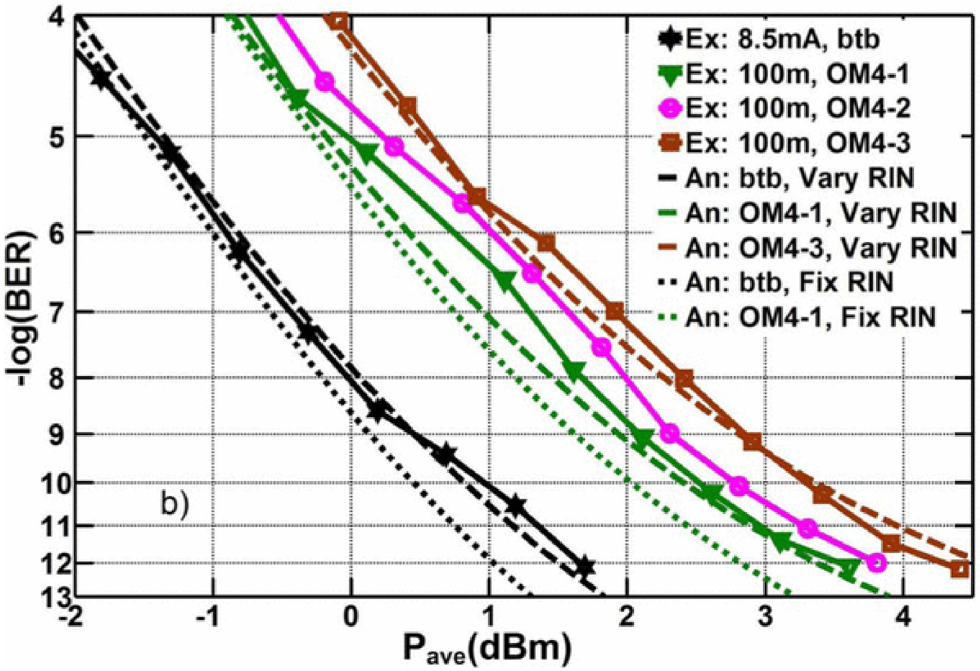
OM4 Wcap = OM5

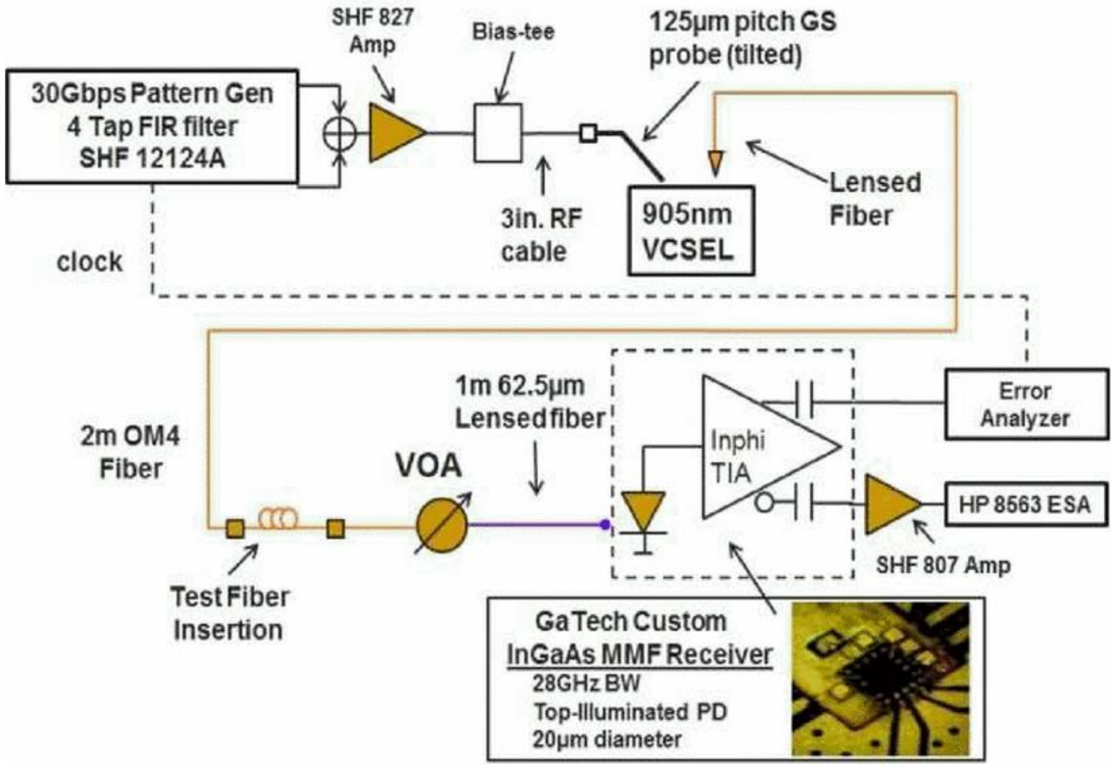


* Wideband OM4 Fiber (paper predates OM5 name adoption)

50 Gbit/s PAM4 at 905nm over 100m OM4

- S. Pavan, et al., ECOC 2014, P.7.23
- Georgia Tech

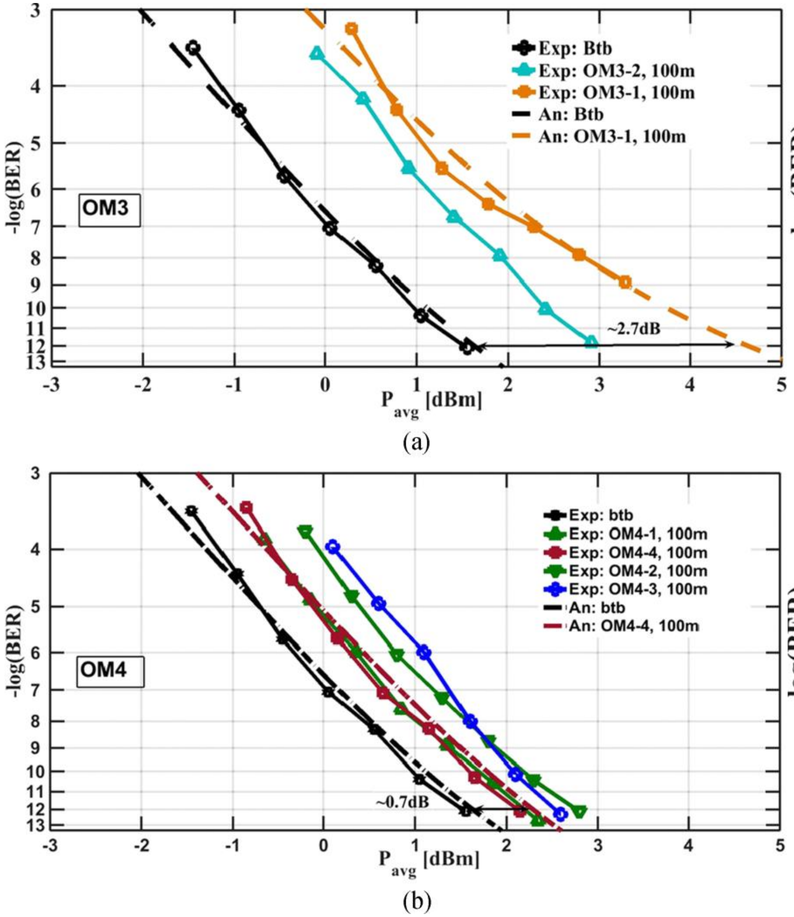




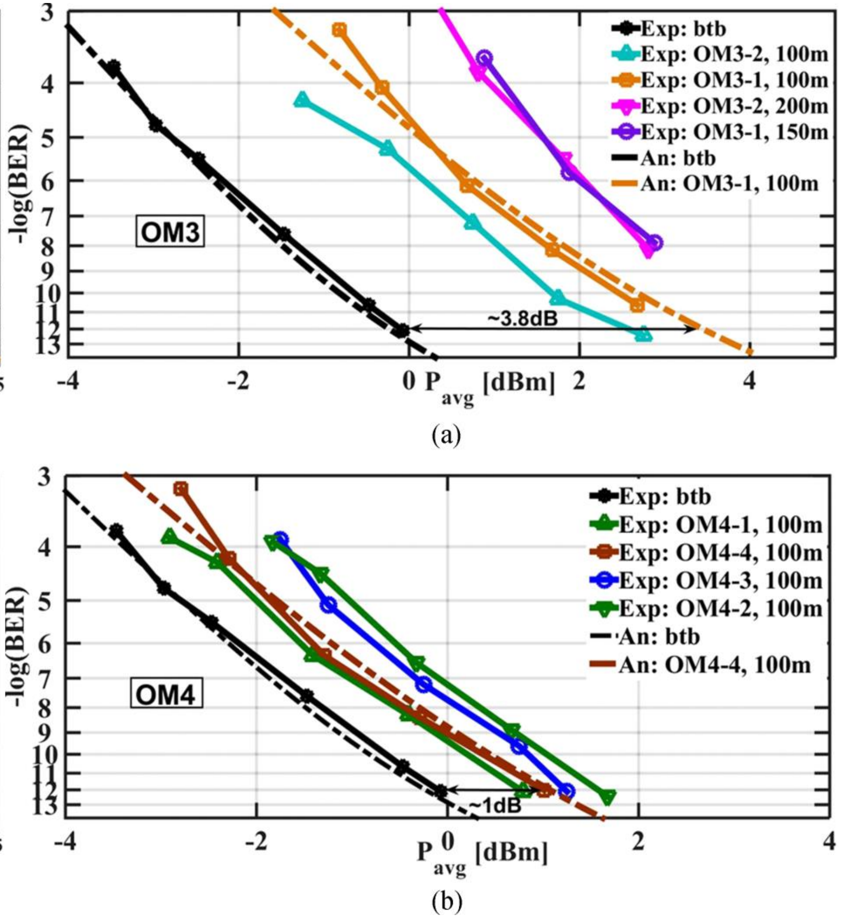
50 Gbit/s PAM4 at 850 and 1050nm over 100m OM3 and 100m OM4

- S. Pavan, et al., Journal of Lightwave Technology, May 2017
- Georgia Tech

MMF Type	Name	Wavelengths Tested [nm]	EMBc [GHz·km] @850 nm	DMD slope
OM3	OM3-1	850, 1050	2.05	L-MMF
	OM3-2	850, 1050	2.86	L-MMF
OM4	OM4-1	850, 1050	5.6	L-MMF;
	OM4-2	850, 1050	5.6	R-MMF
	OM4-3	850, 1050	6	R-MMF
	OM4-4	850, 1050	10	R-MMF
Prototype WB-MMF	WB-MMF	1050	3.2	-



850nm



1050nm

Technical feasibility of 2 and 4 wavelengths with 50 Gbit/s PAM4 over at least 100m OM3, OM4, and OM5 has been demonstrated in the literature

Author	Affiliations	Source	Data Rate (Gbit/s)	Length @ 850 nm	Length @ 880 nm	Length @ 905-910 nm	Length @ 940 nm	Length @ 980 nm	Length @ 1060 nm
F. Chang	Inphi, OFS, SiFotonics, Finisar	OFC 2017	53.125	300m OM5	300m OM5	300m OM5	300m OM5	-	-
Y. Sun	OFS	IWCS 2017	50	200m OM4 400m OM5	-	200m OM4 400m OM5	-	-	-
Y. Sun	OFS, Finisar, Inphi	JLT 2017	53.125	300m OM5	300m OM5	300m OM5	300m OM5	300m OM5	200m OM5
J. Castro	Panduit, Prysmian	OFC 2016	50	200m OM5	-	-	-	200m OM5	-
R. Motaghian	Finisar, Prysmian	OFC 2016	45	100m OM4 300m OM5	100m OM4 300m OM5	100m OM4 300m OM5	100m OM4 300m OM5	-	-
S. Pavan	Georgia Tech	ECOC 2014	51.56	-	-	100m OM4	-	-	-
S. Pavan	Georgia Tech	JLT 2017	51.56	100m OM3 100m OM4					100m OM3 100m OM4

Conclusions

- Reviewed 50 Gbit/s PAM4 over MMF in literature
- Results at 850, 880, 905, 910, 940, 980, and 1060nm reported

- Literature supports technical feasibility for PMDs such as:
  - 200G-SR1.4: 1 fiber pair, 4 wavelengths, 25 Gbaud PAM4, 50 Gbit/s per wavelength
  - 400G-SR4.2: 4 fiber pairs, 2 wavelengths, 25 Gbaud PAM4, 50 Gbit/s per wavelength
- Supports potential objectives over MMF with lengths up to at least 100m

Bibliography

- F. Chang *et al.*, "First demonstration of PAM4 transmissions for record reach and high-capacity SWDM links over MMF using 40G/100G PAM4 IC chipset with real-time DSP," *2017 Optical Fiber Communications Conference and Exhibition (OFC)*, Los Angeles, CA, 2017, pp. 1-3.
- Y. Sun, *et al*., "High Speed Short Reach Optical Interconnect over OM4 and OM5 Multimode Optical Fiber," *Proceedings of the 66th IWCS Conference*, Orlando, FL 2017, pp. 791-796.
- Y. Sun *et al*., "SWDM PAM4 Transmission From 850 to 1066 nm Over NG-WBMMF Using 100G PAM4 IC Chipset With Real-Time DSP," in *Journal of Lightwave Technology*, vol. 35, no. 15, pp. 3149-3158, Aug.1, 1 2017.
- J. M. Castro *et al*., "200m 2×50 Gb/s PAM-4 SWDM transmission over wideband multimode fiber using VCSELs and pre-distortion signaling," *2016 Optical Fiber Communications Conference and Exhibition (OFC)*, Anaheim, CA, 2016, pp. 1-3.
- S. M. R. Motaghian *et al*., "180 Gbps PAM4 VCSEL transmission over 300m wideband OM4 fibre," *2016 Optical Fiber Communications Conference and Exhibition (OFC)*, Anaheim, CA, 2016, pp. 1-3.
- S. K. Pavan , J. Lavrencik and S. E. Ralph, "Experimental demonstration of 51.56 Git/s PAM-4 at 905nm and impact of level dependent RIN, *European Conference on Optical Communication*, Cannes, France, 2014, pp. 1-3.
- S. K. Pavan, J. Lavrencik and S. E. Ralph, "VCSEL-Based PAM-4 Links up to 62 Gbit/s Over OM3, OM4, and WB-MMF: Performance Comparison at 850 nm and 1050 nm," in *Journal of Lightwave Technology*, vol. 35, no. 9, pp. 1614-1623, May1, 1 2017.

Thank You

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