Next-gen 200 and 400 Gb/s PHYs over Fewer MMF Pairs Call For Interest Consensus Presentation

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Charlotte Interim

Agenda

- **Overview Discussion**
  - Robert Lingle, Jr. (OFS)
- **Presentations**
  - Market Drivers
    - Dale Murray (LightCounting), tentative
  - Technical Feasibility
    - Jonathan Ingham (FIT), Jonathan King (Finisar)
  - Why Now?
    - Robert Lingle, Jr. (OFS)
- **Straw Polls**

Introductions for today’s presentation

- Presenter and Expert Panel:
  - David Piehler, Dell EMC (tentative)

CFI objectives

- To gauge the interest in next-gen 200 and 400Gb/s PHYs over fewer MMF pairs

- We do not need to:
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose a solution
  - Create a PAR or 5 Criteria
  - Create a standard
- Anyone in the room may vote or speak

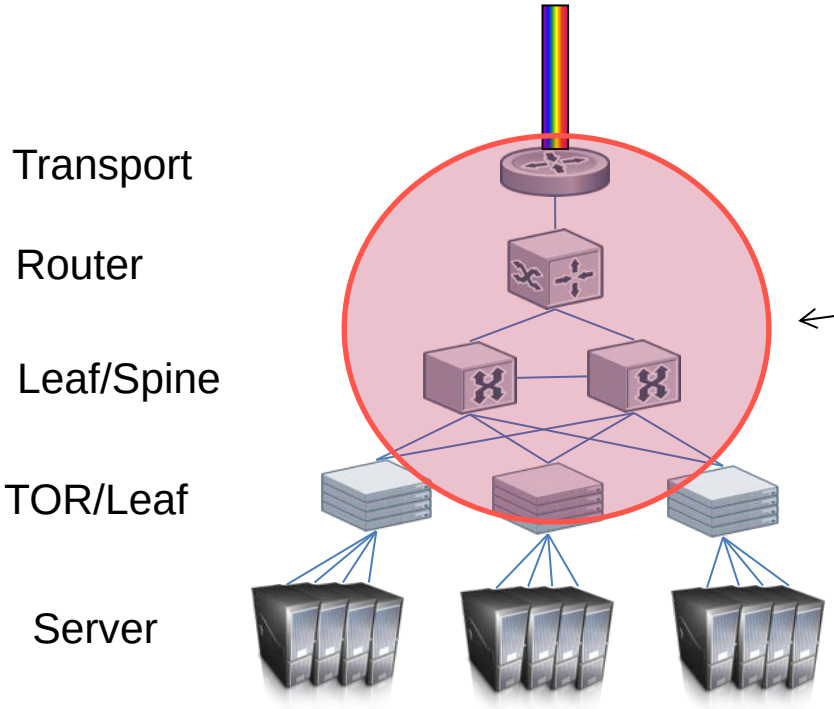
Overview: motivation

Leverage technologies in advanced stages of development to create cost-optimized lower fiber-count solutions, over installed base and greenfield MMF cabling, for 200 and 400 Gb/s

Global web-scale data centers and cloud based services – as well as the *largest* enterprise datacenters - are presented as leading applications.

Synergy with broader enterprise networking extends the application space and potential market adoption.

What are we talking about?

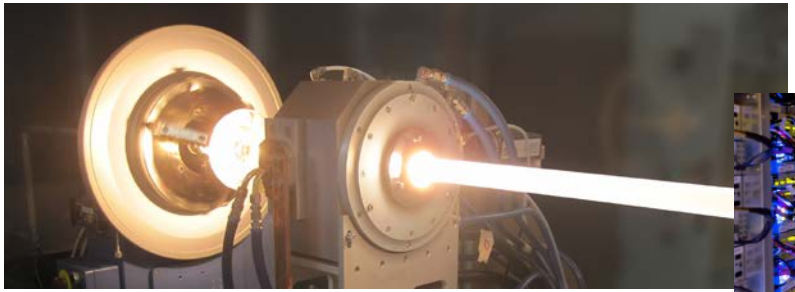


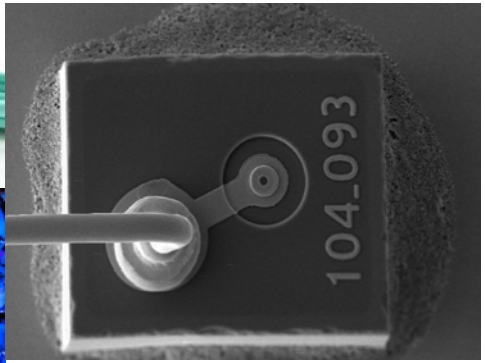
Applications for early adoption of next-generation MMF PMDs include connectivity in web2.0 and *largest* enterprise data centers for

- switch-to-switch
- switch-to-router
- router-to-transport

Other applications may arise later when the broad enterprise market needs higher speeds

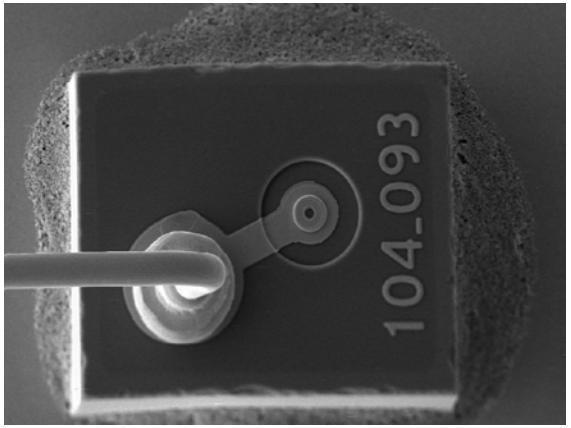
Market Drivers

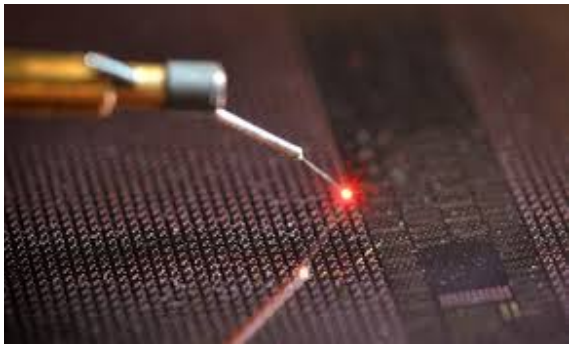




Historically VCSEL-MMF links have been seen by many as the lowest cost and power short-reach interconnect

- Relaxed alignment tolerances
  - Several microns vs. sub-micron
  - Allows passive alignment in module
  - Better cost/loss trade-off for connectors
- Connectors more resilient to dirt
  - Cleaning SMF connectors is common issue
- Lower drive currents
  - 5-10mA vs. 50-60mA
- On-wafer testing

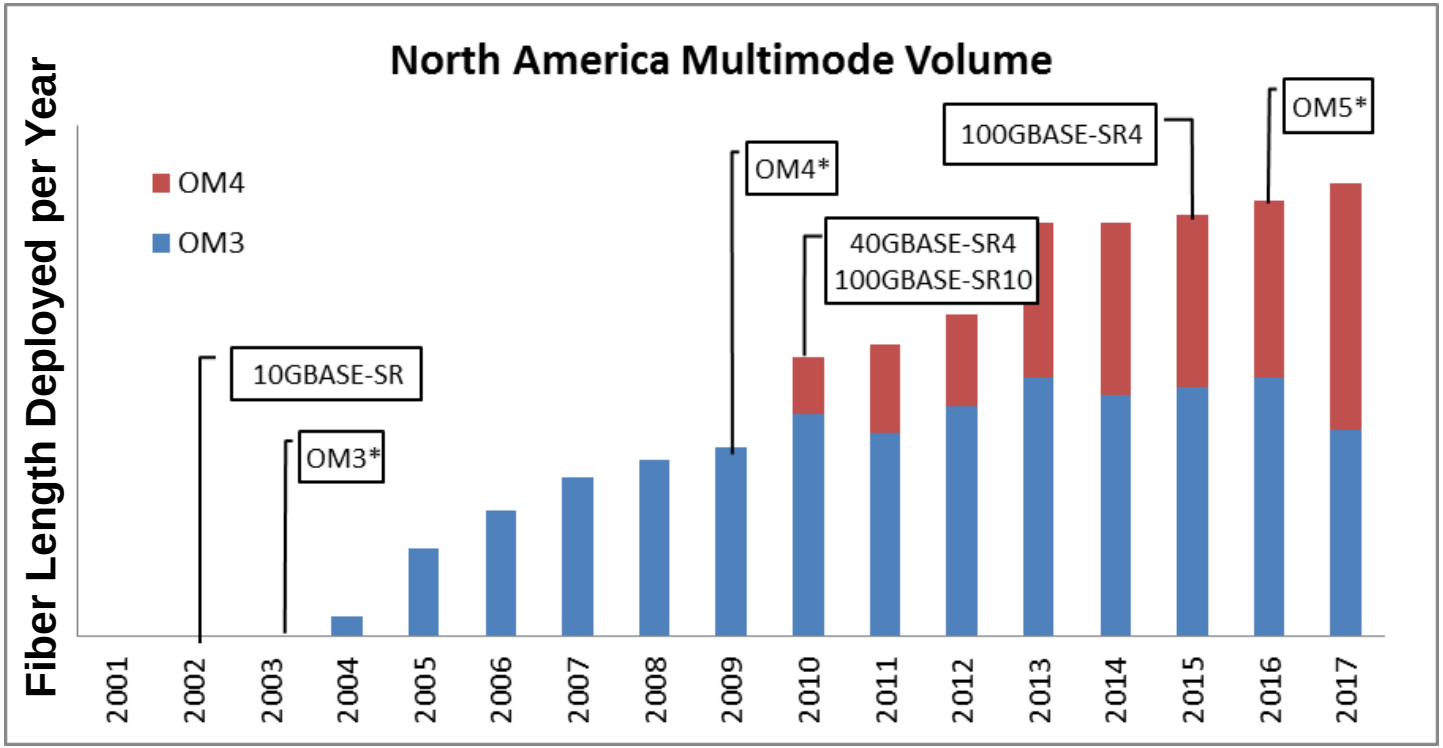




10/40/100G have been widely deployed over MMF

- Large installed base of duplex OM3/OM4 MMF deployed for 10GBASE-SR
- Large installed base of parallel OM3/OM4 MMF deployed for 40GBASE-SR4 and 100GBASE-SR4
- Industry investment in MMF cabling continues, including wideband OM5, now standardized

Deployment of OM3 MMF ramped up after standards were complete, with OM4 ramping up next after standards issued



*** Dates are ANSI/TIA standardization dates, not ISO/IEC**

2017 estimated - 1H17 volume annualized

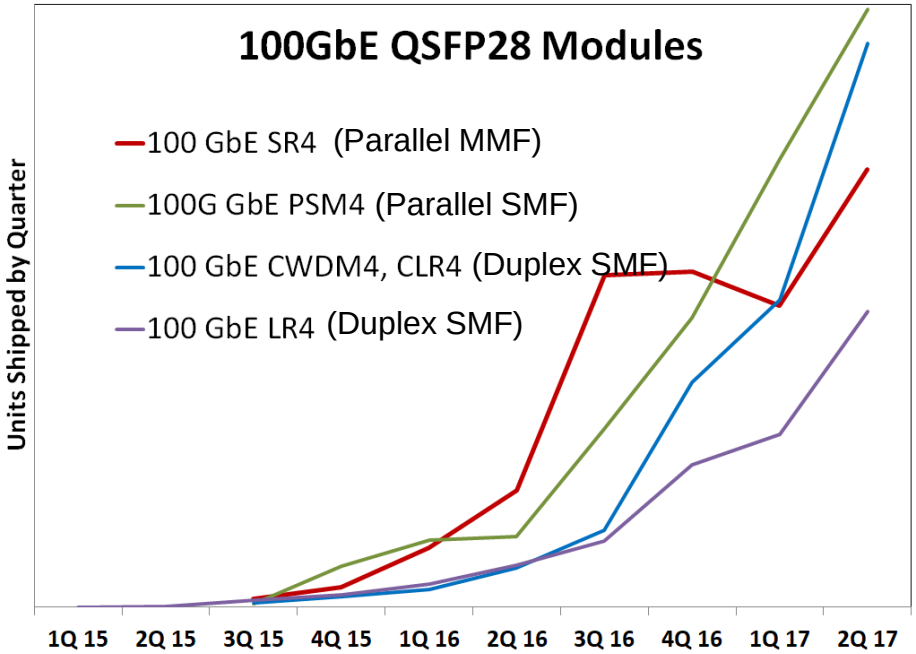
Used with permission: Matthew Burroughs North America Multimode Reports

Market applications of 400G short reach

- Initial volume applications in switch-router & switch-switch connections
  - in the cloud
  - *largest* enterprise DCs

- Smaller volumes used for low-cost router-transport in telecom & the cloud, CO transformation at service providers, and laboratory development applications in telecom and the cloud

100GBASE-SR4 in QSFP28 was required by web2.0 and largest enterprise data centers as soon as 100G switches entered the market



100GbE QSFP28 Consumption

Chart courtesy of Dale Murray, LightCounting

- Chart shows units shipped
- Modules for MMF cabling had largest share in 2016
- LightCounting predicts strong growth for all four module types.

Comments on prospects for 400GBASE-SR4, by Chongjin Xie, Sr. Director of Infrastructure Service at Alibaba

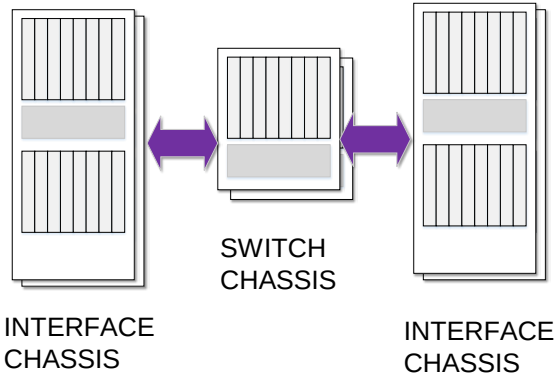
- Alibaba uses 100GBASE-SR4 heavily for 100m switch-switch connections now
- 100GBASE-SR4 links over MMF cabling are lower cost for Alibaba today than PSM4 or CWDM4 links over SMF cabling
- Alibaba expects to deploy 100G switching for approximately three years, perhaps moving to 400G in 2019
- He hopes to have 400GBASE-SR4.n available in 2019 and strongly supports its standardization in IEEE

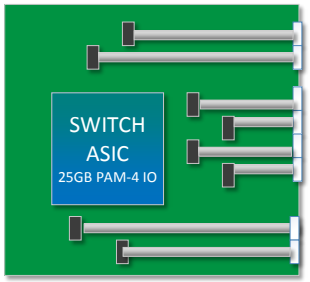
Comments on a switch vendor's experience of demand for 100Gb/s MMF optics, from David Piehler (Dell EMC)

- Sold 100GBASE-SR4 into large enterprise DC space in 2016
  - Could also have sold 100G duplex MMF transceivers in 2016 had they been commercially available
- There is demand for MMF solutions with the highest speeds, and the lowest fiber counts
- He expects this trend to play out again for >100 Gb/s speeds

Multichassis Switch Expansion

- MMF provides optimum inter-chassis interconnect when single-chassis capability is exceeded
  - 500m typically desired but 50-70m sufficient
- 25 GBaud PAM-4 MMF transceivers remove the need for gearbox between PAM-4 ASIC IO and on-board transceivers
- PAM-4 + WDM significantly reduces fiber bulk and cost e.g. 6400 → 800 fibers for an 80 Tb system (4 wavelengths), i.e. 200 Gb/s per fiber as in the 400GBASE-2.4 option





FABRIC CARD

The introduction of compute / storage clusters into service provider central offices for NFV/SDN has created a new space for short reach interconnects in the ≤100m range

Central Office Floor

Compute / Storage Cluster Room

- Space designated inside CO for non-NEBS compliant datacom gear must be upgraded for fire safety & cooling
- Smaller size is friendly to <100m reach for standardized MMF links
- Deploying 40 & 100Gb/s MMF links now

- NEBS-compliant, telecom grade equipment allowed relaxed fire code rating of the facilities in traditional central offices
- SMF often preferred in CO's in spite of higher cost, since connections may be required from one floor to another

(NEBS = National Equipment-Building System)

Existing 400GBASE-SR16 does not fulfill the needs of the datacenter market

- 400GBASE-SR16 may not be a high-volume datacenter module
  - CFP8 will not be a common front panel port in datacenter switches
  - 32-fiber link with atypical connector will offset the low-cost nature of the transceiver.
  - Restricted to 16x25G electrical interface (400GAUI-16)
    - No path to 400GAUI-8 without reverse gearbox
- A lower fiber-count MMF solution is expected to have lowest cost for short-reach 400G

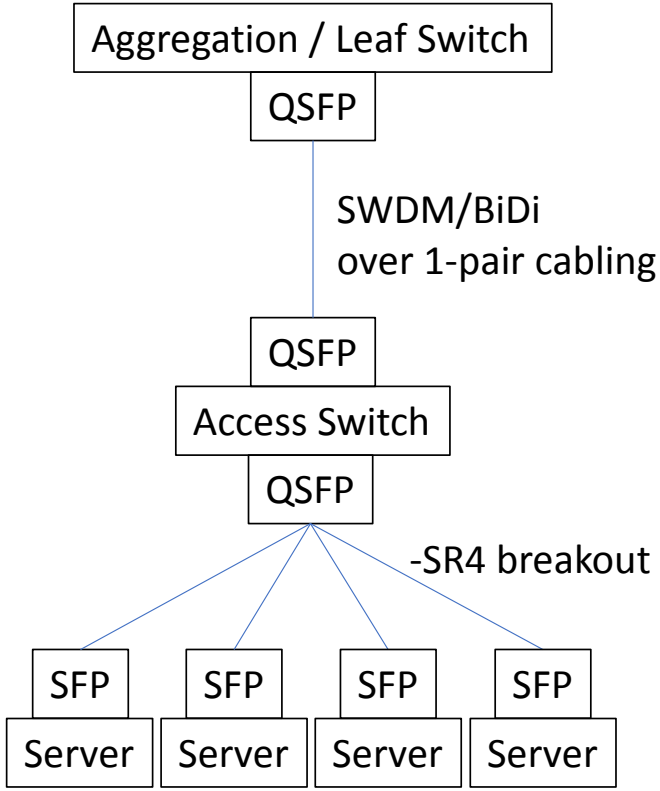
Benefits of 400GBASE-SR4 (for example) over 400GBASE-SR16 for the datacenter market

- Operates on same cabling as previous SR4 modules
  - No special connector
- Suitable for all 400G form factors
  - CFP8, QSFP-DD, OSFP
- No reverse gearbox with 400GAUI-8 interface

Market need for a 200G module for duplex MMF

- 200G switching is expected to find acceptance in parts of the cloud and enterprise DC networking space on same time frame as 400G
- 200GBASE-SR4 is already being standardized in 802.3cd to support parallel MMF cabling
- The early demand for 100G duplex MMF optics suggests that large enterprise data centers may need 200G duplex optics as well
  - Believe there is value for the industry in a *standardized* solution for 200G over single pair of MMF

Server-uplink evolution in large enterprise datacenters requires higher speed, duplex MMF connections



Generation	Server Rate	Up-link Rate
1	10G	40G
2	25G	100G
3	50G	200G

The same MMF cabling infrastructure can serve at least three generations using primarily duplex connectivity

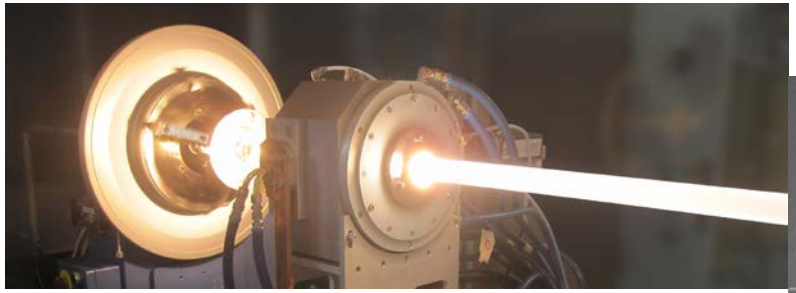
"The ability to support 100, 200 and 400G over a duplex multi-mode optical fiber path at data center useful distances would be of considerable value."

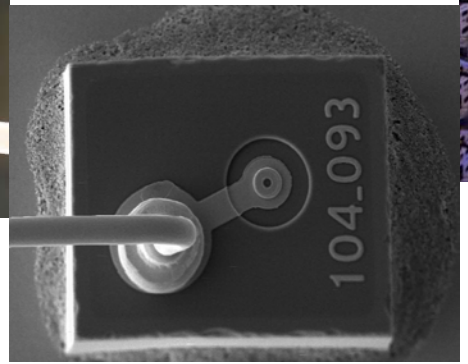
Large Enterprise DC Architect

Fiber-to-the-Desk is required for certain real-time, interactive applications using high-resolution video & geospatial information and machine-to-machine comms

- Duplex MMF cable is the preferred medium
- 100G is the next speed target
- Higher speeds will follow

Technology Feasibility





Technologies for next-gen MMF PMDs

- PMDs for 400G over 4 MMF pairs and 200G over < 4 MMF pairs will require two technologies
  1. Multiple wavelengths on MMF – introduced in 2013
  2. VCSELs supporting 50Gb/s PAM4 signaling – sampling now

- OM5 provides longer reach when using multiple wavelengths over MMF, but is not required

Technical options exist for 200/400G over fewer MMF pairs

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 PAM4	50G-SR	100G-SR2	200G-SR4	**400G-SR8**	
2x50G-λ PAM4	100G-SR1.2	**200G-SR2.2**	**400G-SR4.2**		
4x25G-λ NRZ	100G-SR1.4	**200G-SR2.4**	**400G-SR4.4**		
4x50G-λ PAM4	**200G-SR1.4**	**400G-SR2.4**	800G-SR4.4		

Examples of technologies for 200 & 400 Gb/s links over fewer MMF fiber pairs

Existing IEEE standard

In progress in 802.3bs, cd

Multi-Wavelength Nomenclature

SRm.n m = # fiber pairs

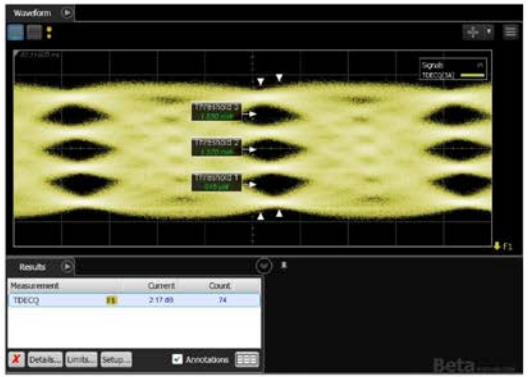
n = # wavelengths

50Gb/s PAM4 over MMF in IEEE 802.3cd

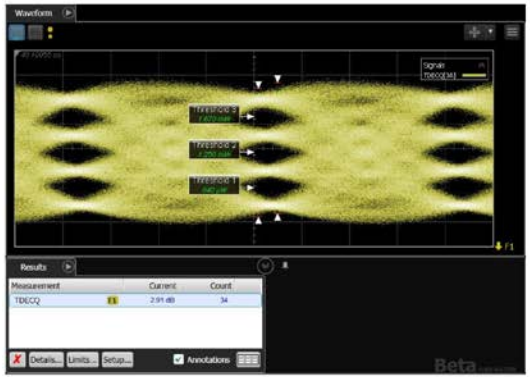
- 802.3cd has an objective to “Define single-lane 50 Gb/s PHY for operation over MMF with lengths up to at least 100m”
- 26.5625 GBd signaling with PAM4 modulation was selected to implement 50 Gb/s
- Could re-use RS(544,514,10) FEC from clauses 134 (50G), 91 (100G), and 119 (200G and 400G) if appropriate in this project

Feasibility of two-wavelength PAM4 over MMF

- Transmission of 26.5625 GBd PAM4 over 70 m worst-case OM3 MMF
- TDECQ measured for 855 nm and 908 nm VCSEL-based transmitters



855 nm Tx
TDECQ: 2.2 dB



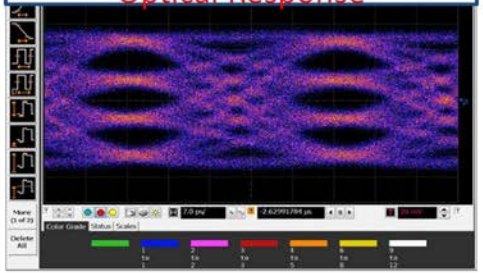
908 nm Tx
TDECQ: 2.9 dB

- For both wavelengths, transmission over worst-case MMF results in TDECQ values within the 4 dB requirement for MMF PMDs in P802.3cd

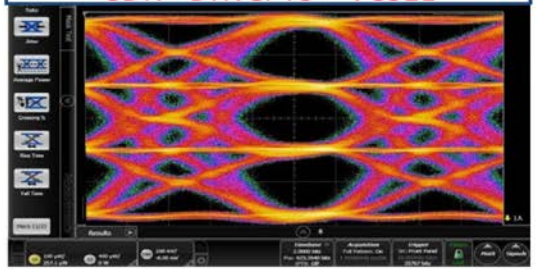
Finisar demonstration of 50G PAM4 over MMF from king_GE_NGOATH_01_0116

Bench top PAM4 experiments using 25Gb/s VCSELs

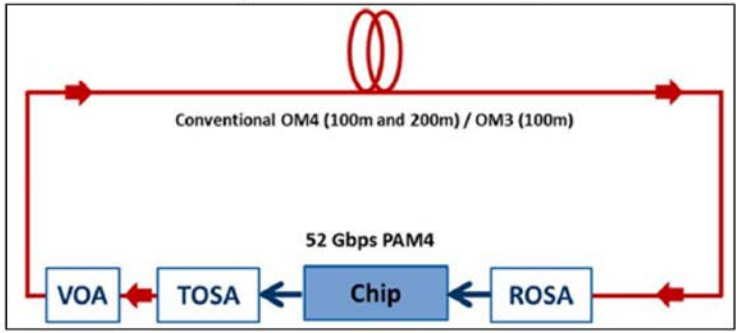
50Gb/s AWG + VCSEL
Optical Response

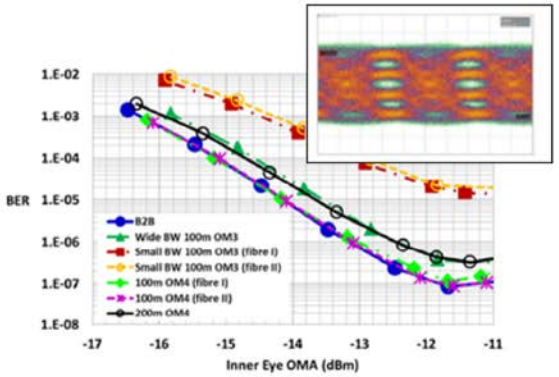


50Gb/s PAM4 Optical Response
CDR+ Driver IC + VCSEL



and early PAM4 PHY evaluation….

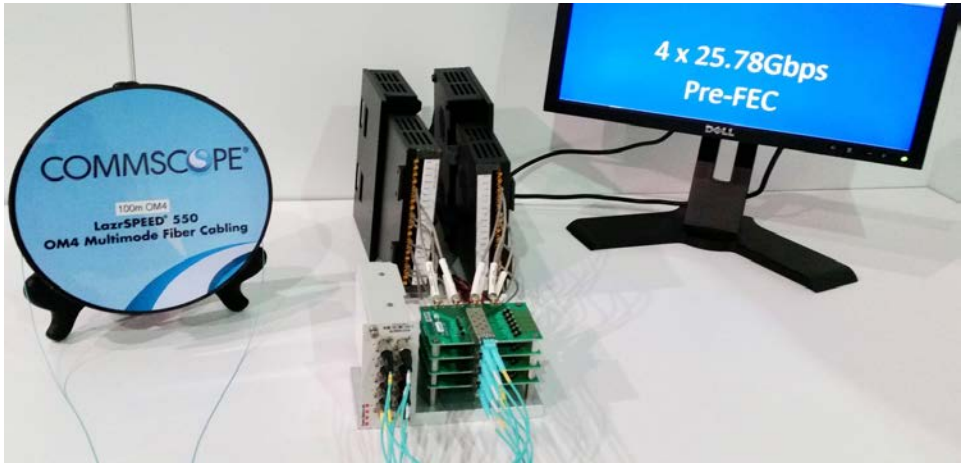




Technical feasibility of four wavelengths over MMF

Finisar announced a VCSEL-based 100 Gb/s SWDM4 product, with technical demonstration at OFC 2015.

- Error free operation over 150 m on OM4, 275 m on a sample OM5
- Same 30 nm channel spacing as 40 Gb/s, centered at 850, 880, 910, 940 nm
- Balances cost and performance of mux/demux optics, VCSEL wavelength pass-bands, and fiber wavelength range over which modal bandwidth is critical

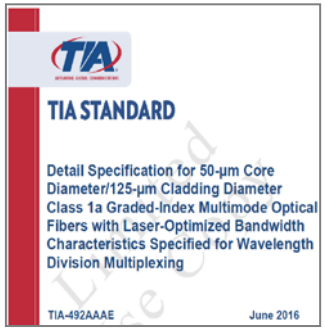


Adding wavelengths & PAM4 to MMF modules preserves the historical cost & power advantage over SMF modules

- Tolerances for mux/demux are significantly more relaxed in the case of MMF than SMF
- More costly circuits are needed to implement PAM4 for both fiber types
- Reduction of laser RIN for PAM4 is not more difficult for VCSELs than for DFBs
- Packaging for VCSEL sources at 50Gb/s PAM4 is based on known technology, whereas packaging for 1310nm sources at 100 Gb/s per lane PAM4 has required significant development

Standardized Wideband MMF/OM5 improves performance with multiple wavelengths

- OM5 MMF extends the 850nm performance of OM4 out to 953nm
- Drop-in replacement for OM4 at 850nm. Fully backward-compatible with previous IEEE standards
- Accommodates at least four wavelengths on economical grid spacing
- Standards:
  - Fiber: TIA-492AAAE (2016), IEC 60793-2-10 ed. 6 (1Q17)
  - Cabling: ANSI/TIA-568.3-D (2016), ISO/IEC 11801 ed. 3 (4Q17)
  - Application (WBMMF/OM5 operating at 850nm only): IEEE 802.3bs draft (2016), IEEE 802.3cd draft (2016), Fibre Channel FC-PI-7/64GFC & 256GFC (2Q17)



Fiber Standards

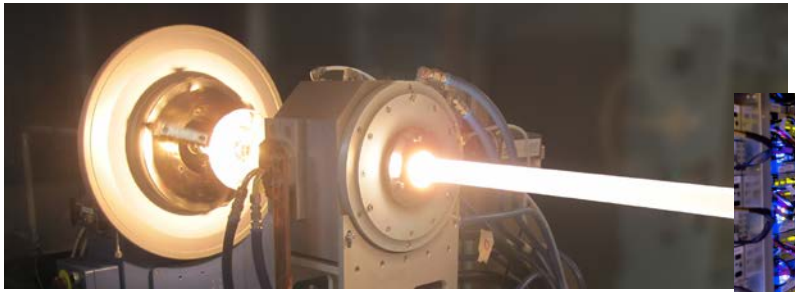
Structured Cabling Standards

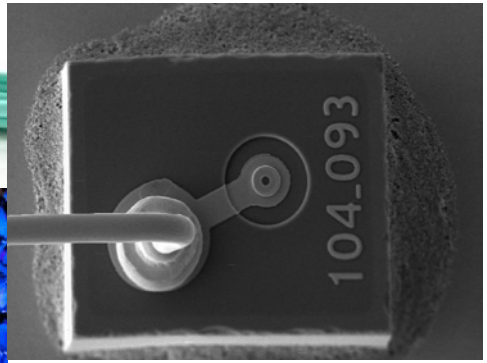
The VCSEL optical lane rate roadmap will support PMDs beyond those contemplated here

Bit Rate per Optical Lane (Gb/s)	Year	Speed for SR1.4 module	Speed for SR4 module	Speed for SR4.2 module
25	2015	100G	100G	
50	2018	200G	200G	400G
100	proofs-of-concept exist	400G	400G	800G

* Several technical presentations at OFC 2017 showed research feasibility

Why now?





The use of VCSELs & MMF persists for shorter reach, even though SMF modules are now defined for 500m reach

- Recent history shows that higher speeds over MMF are needed in the first year that new switch speeds are commercially available
- The existing 400GBASE-SR16 solution will not meet that need
  - We believe there is value for the industry in a *standardized* solution for 400GBASE-SR4.n
- There is no 200Gb/s duplex MMF PMD in existing IEEE standards
- These PMDs will be needed commercially in 2019

Strong 100GBASE-SR4 consumption now suggests strong 400GBASE-SR4 uptake in 2019-2020

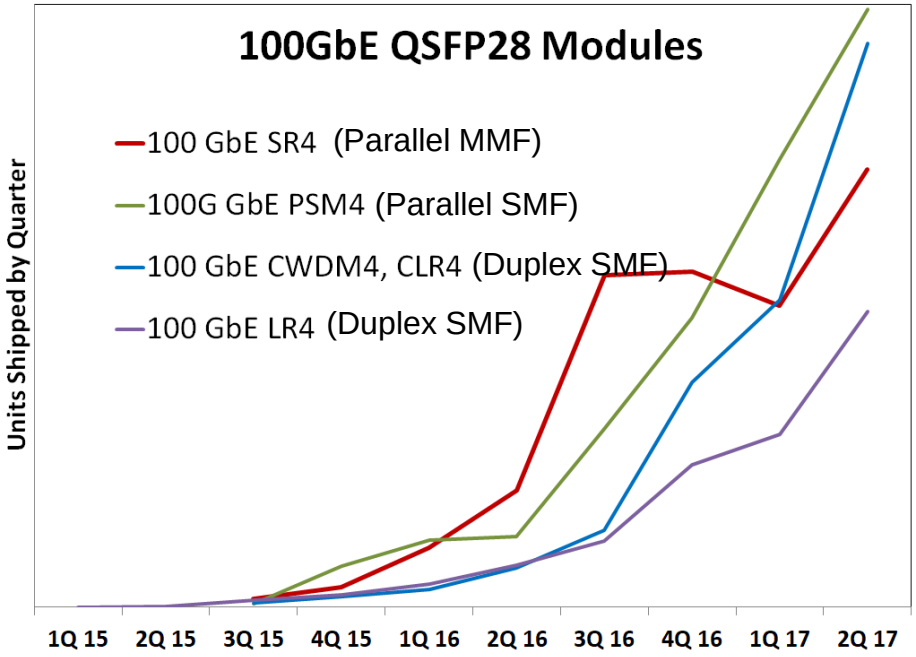
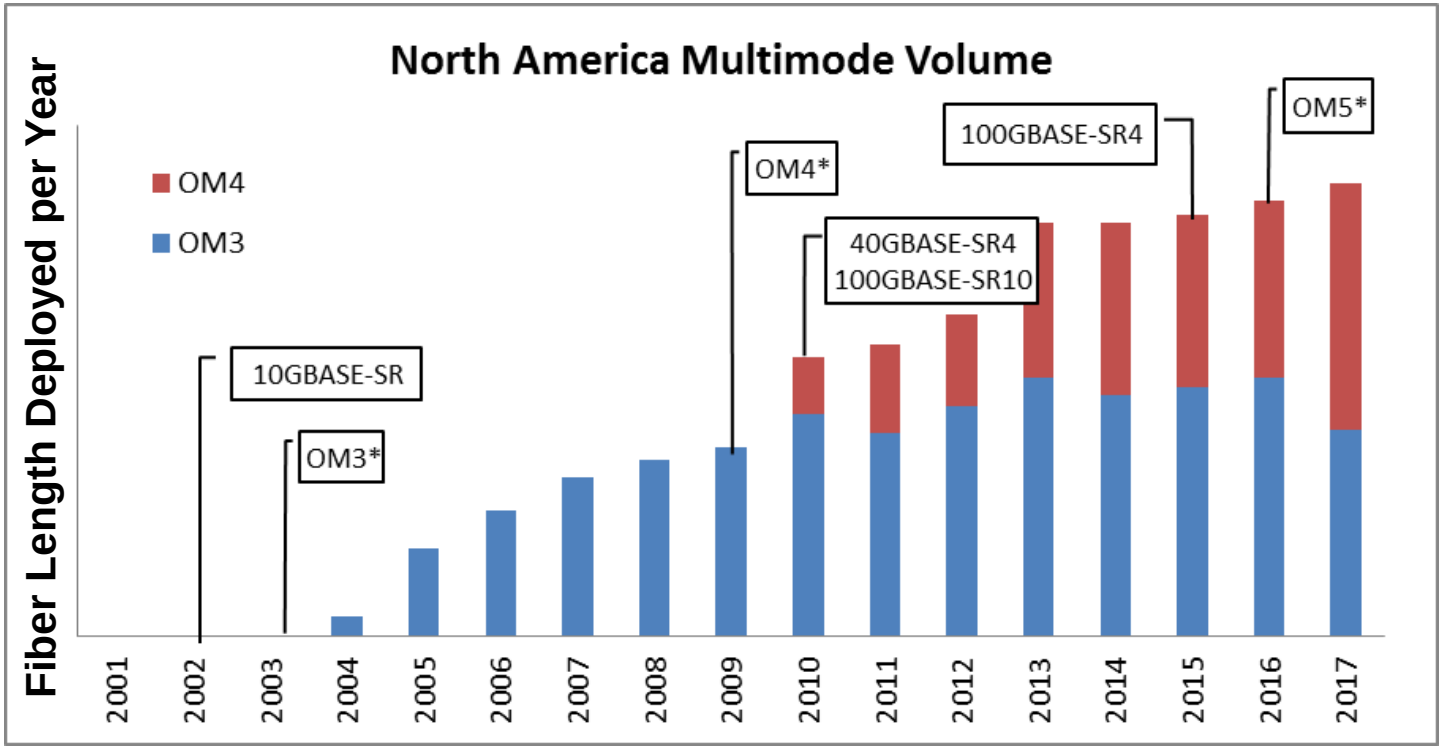


Chart courtesy of Dale Murray, LightCounting

- 100GBASE-SR4 has been used heavily by early adopters in 2016 & 2017
- The low relative cost and high technical feasibility of SR4 for short reach should be valuable to the same end-users at 400G as well

MMF cable is being deployed at a similar annual rate as in the past, and the Ethernet market will grow by standardizing lower cost PMDs for it



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Why Now?

The market for 100GBASE-SR4 over parallel MMF cabling was robust in 2016 as soon as significant deployment of 100 Gb/s switching began in the datacenter

- Cloud DCs in North America and China
- *Largest* enterprise DCs
- 100Gb/s duplex transceivers for MMF would have been deployed in 2016 had they been available
- Early adopters will deploy next-gen 200/400 Gb/s MMF PMDs if they are available

50 Gb/s ecosystem supporting 200/400G switch ASICs progresses towards ~2019 deployment

The enabling technologies exist to support next-gen MMF PMDs over fewer fiber pairs

- 50Gb/s PAM4 in development for 802.3cd; used in proprietary MMF modules sampling now
- Two and four wavelengths already used in proprietary duplex MMF transceivers
- Operation over installed base as well as new OM5 MMF cabling is supported

Data shows that the market continues to deploy MMF cabling

- Standardizing lower cost applications for MMF facilitates upgrades and improves Ethernet market
- New performance grades are accepted when they provide benefit

Contributors

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Rob Stone, Broadcom
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