



# Next-gen 200 and 400 Gb/s PHYs over Fewer MMF Fiber Pairs than in Existing Ethernet Projects and Standards

*CFI Consensus Presentation*

Robert Lingle Jr., OFS

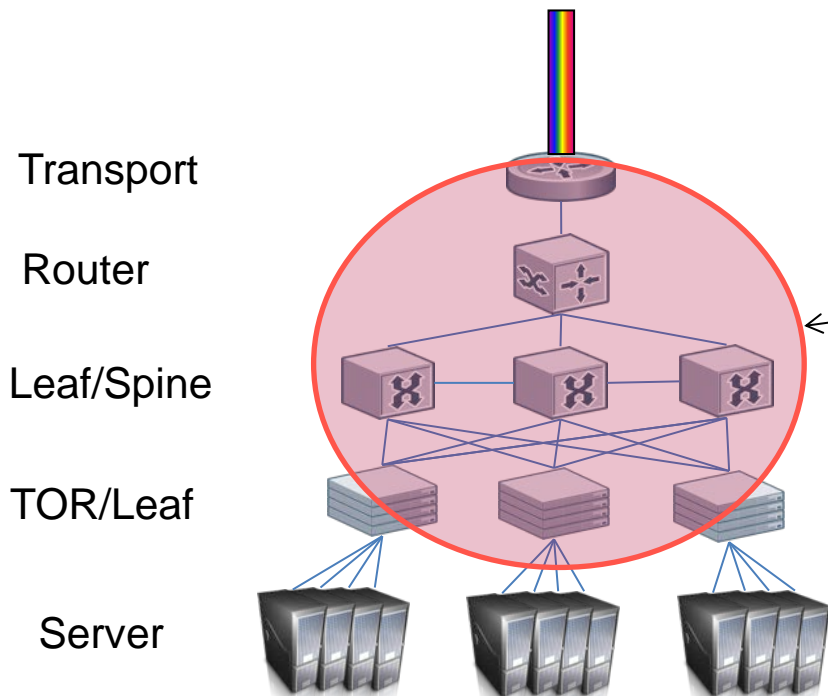
November 7, 2017

IEEE 802.3 Plenary, Orlando

# CFI objectives

- To measure the interest in next-gen 200 and 400Gb/s PHYs over fewer MMF pairs than in existing Ethernet projects and standards
- 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
- RESPECT ... give it, get it

# 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

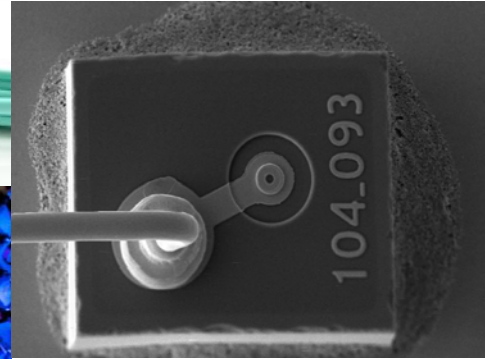
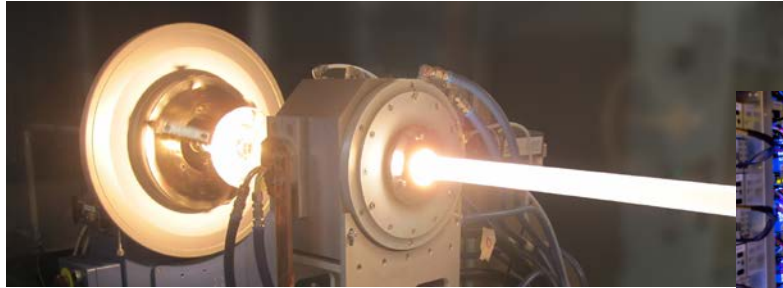
Other applications may arise later when the broad enterprise market needs higher speeds

# Agenda

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

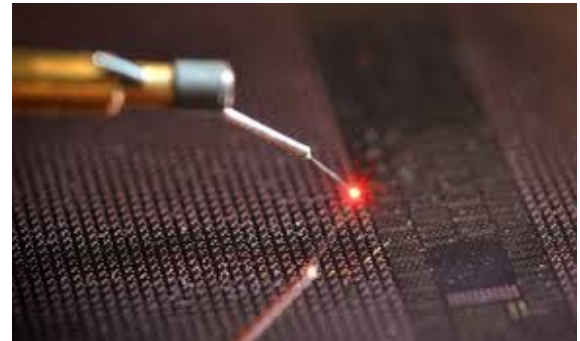
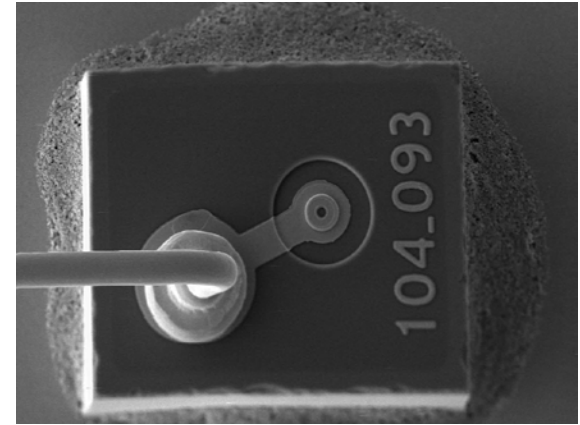


# Market drivers



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

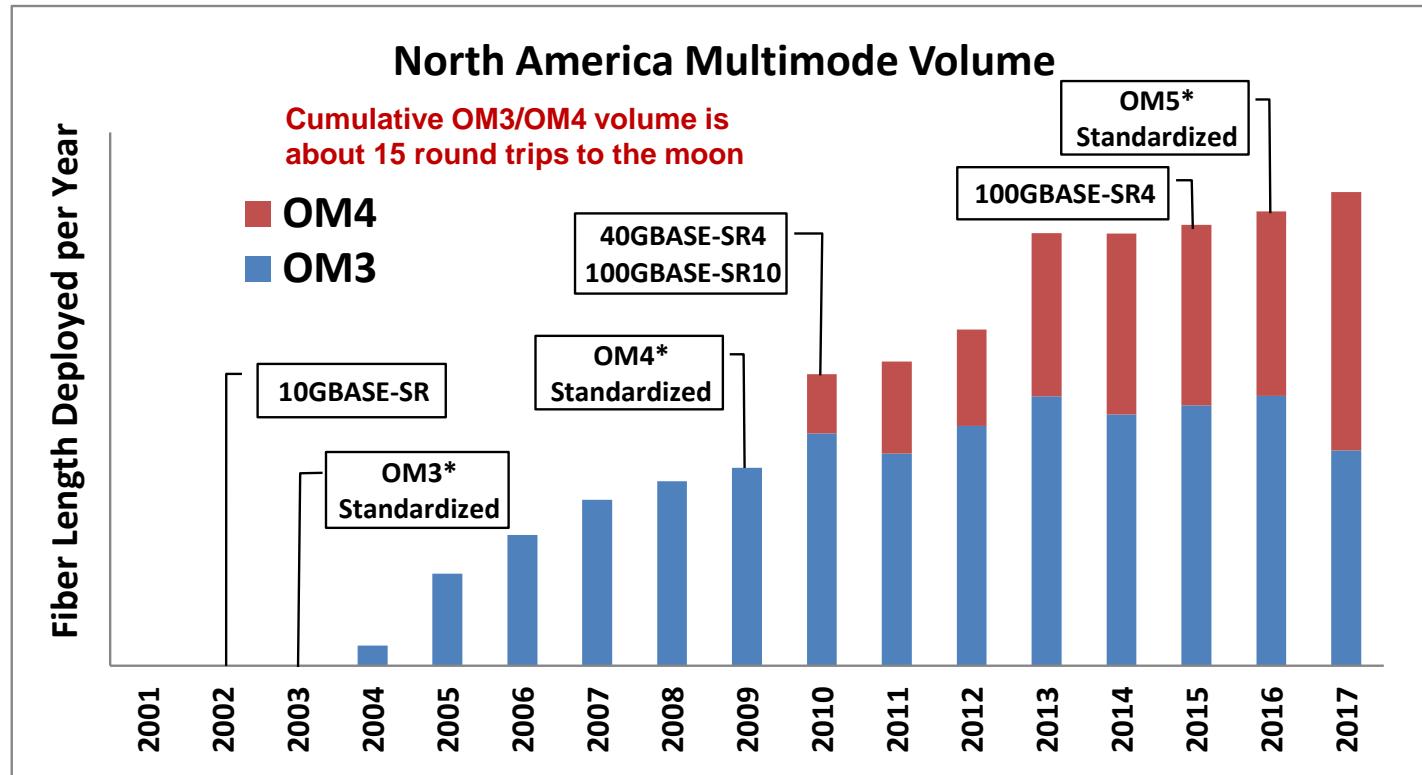
- Relaxed alignment tolerances
  - Several microns vs. sub-micron
  - Allows passive alignment in module
  - Better cost/loss trade-off for connectors
- Connectors more resilient to dirt
  - Cleaning SMF connectors is common issue
- Lower drive currents
  - 5-10mA vs. 50-60mA
- On-wafer testing



# 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

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

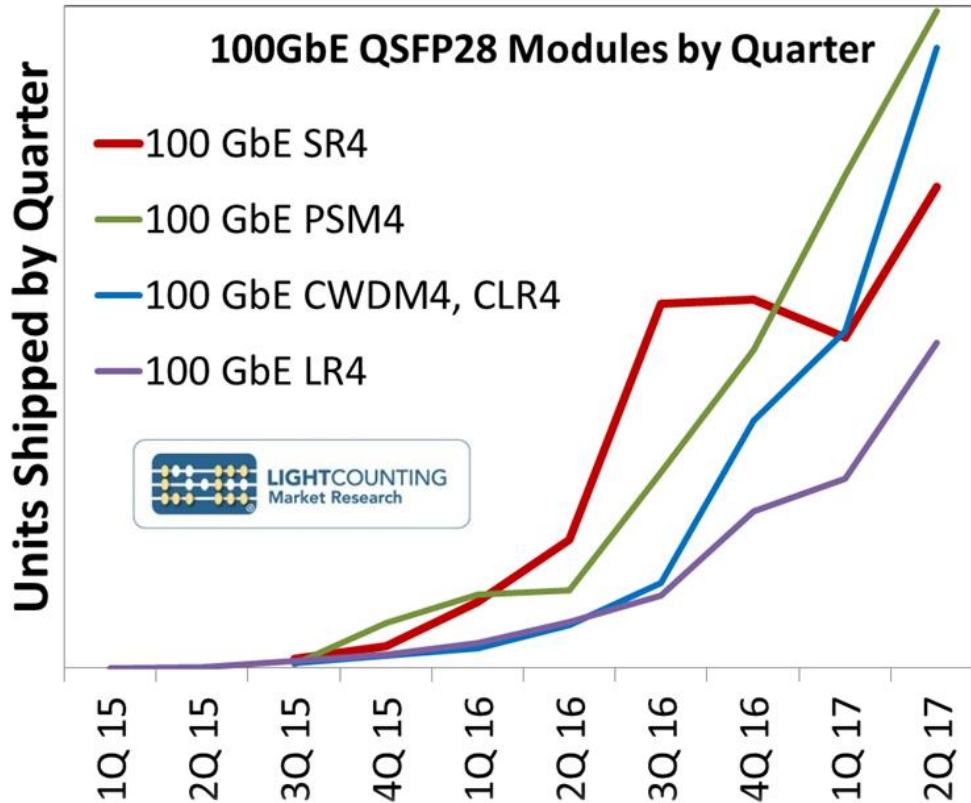


\* Dates are ANSI/TIA standardization dates, not ISO/IEC  
2017 estimated by annualizing 1H17 volume

Used with permission: Matthew Burroughs North America Multimode Reports



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



- Modules for MMF cabling had largest share of units shipped in 2016
- LightCounting predicts strong growth for all four module types.
- MMF is not dead!
- Deployment of 4-pair 100G links today suggests need for an upgrade path to 400G

# Market applications of 400G short reach

- Initial volume applications in switch-switch connections
  - in the cloud
  - *largest* enterprise DCs
- Smaller volumes used for low-cost switch-router & router-transport in telecom & the cloud, CO transformation at service providers, and laboratory development applications in telecom and the cloud

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

- Uses 100GBASE-SR4 heavily for 100m switch-switch connections
- 100GBASE-SR4 links over MMF cabling are lower cost for Alibaba today than PSM4 or CWDM4 links over SMF cabling
- Expects to deploy 100G switching for approximately three years, perhaps moving to 400G in 2019
- Hopes to have 400GBASE-SR4 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

The introduction of data center functionality into Service Provider central offices for NFV/SDN has created a new space for short reach interconnects in the  $\leq 100\text{m}$  range

## Central Office Floor

### Datacom Gear Room

- Datacom gear requires that room be upgraded for fire safety & cooling load
  - Smaller size is friendly to  $< 100\text{m}$  reach for standardized MMF links
  - Deploying 40 & 100Gb/s MMF links now
- 
- SMF often preferred in CO's in spite of higher link cost, since connections may be required between floors
  - Telecom grade equipment allowed relaxed fire code rating and lower cooling load in traditional central offices

# 400GBASE-SR4.2 (as an example) is a better fit to the data center market than existing 400GBASE-SR16

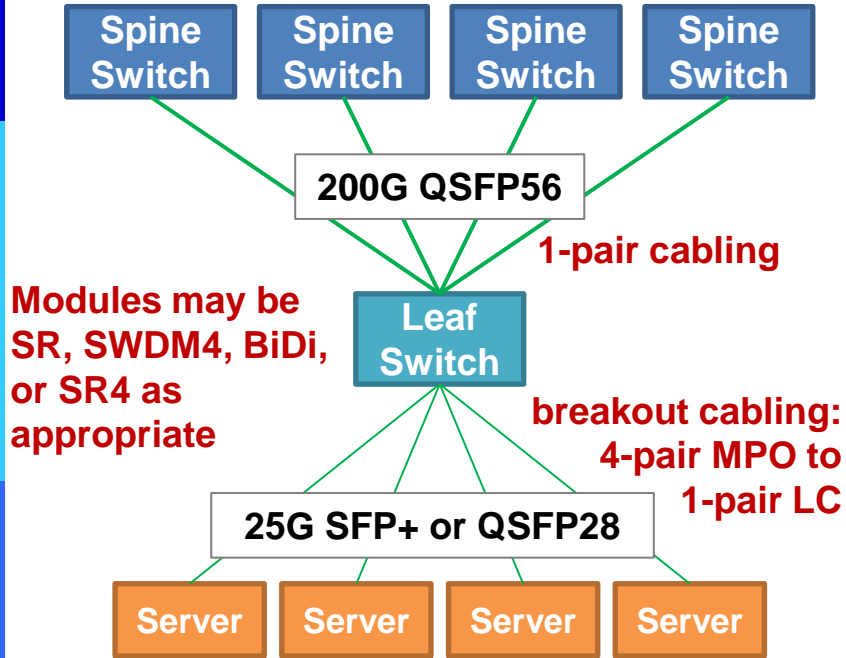
	400GBASE-SR16	400GBASE-SR4.2
Design Intent	400G with 25G SerDes; originally aimed at CDFP form factor, now CFP8	400G based on 50 Gb/s SerDes; fits into OSFP and QSFP-DD
Electrical Interface	Requires gearbox to operate with 400GAUI-8	Native to 400GAUI-8
Cabling Medium	Requires 16f pair cabling, not commonly available	Operates on commonly available array cabling
Optical Connector	Atypical 32f MPO	Typical MPO
Transceiver Form Factor	Incompatible with likely target form	Compatible with target forms
Cost Implications	Higher – more fibers, more ICs, low port availability	Lower – fewer fibers, fewer ICs, existing cabling

Note: using the SRm.n nomenclature, m = # of fiber pairs, n = number of wavelengths

# 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

There is a need to support multiple generations of uplink rates on duplex MMF cabling, driven by server & uplink speed evolution in large enterprise datacenters



Generation 3 Example

Generation	Server Rate	Up-link Rate
1 → 2	10G	40G → 100G
3	25G	200G
4	50G	400G

The same MMF cabling infrastructure can serve multiple generations using primarily duplex connectivity

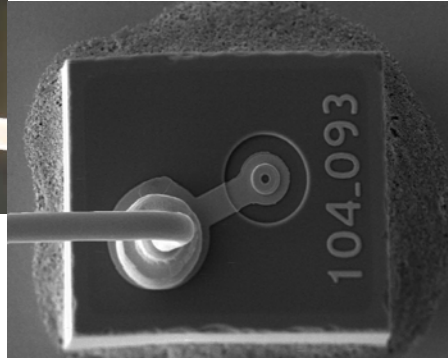
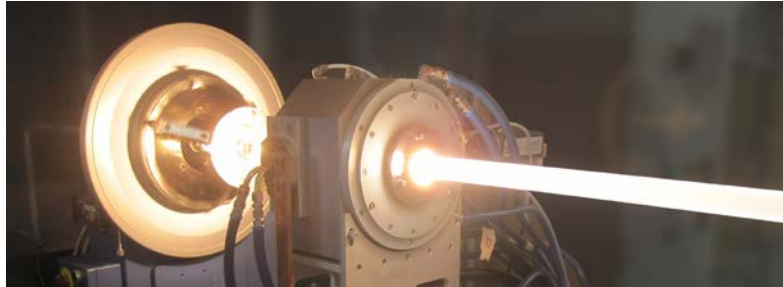
“The ability to support 100, 200 and 400G over a duplex multi-mode optical fiber path at data center useful distances would be of considerable value.”

Large Enterprise DC Architect





# Technical feasibility



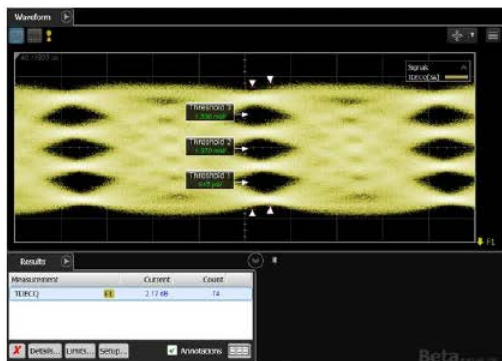
# Technologies for next-gen MMF PMDs

- PMDs for 400G over 4 MMF pairs and 200G over < 4 MMF pairs will require three technologies
  1. Multiple wavelengths on MMF – introduced in 2013
  2. VCSELs supporting 50Gb/s PAM4 signaling – sampling now
  3. Parallel cabling with MPO termination – in production for years

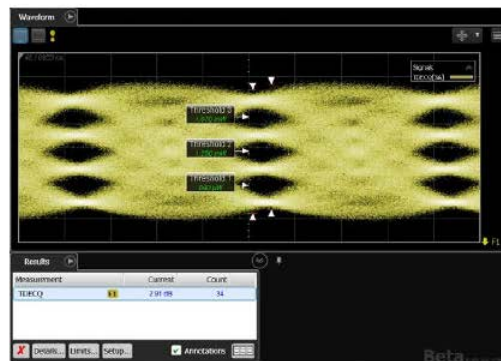
## 50Gb/s PAM4 over MMF in IEEE 802.3cd

- 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

- 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

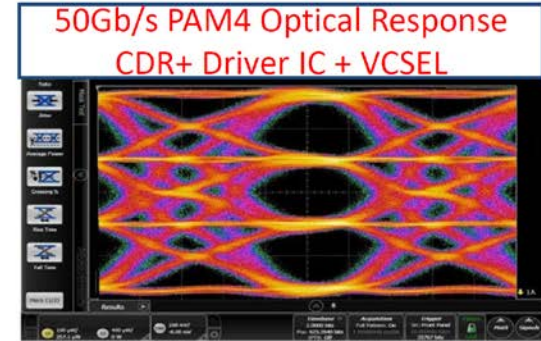
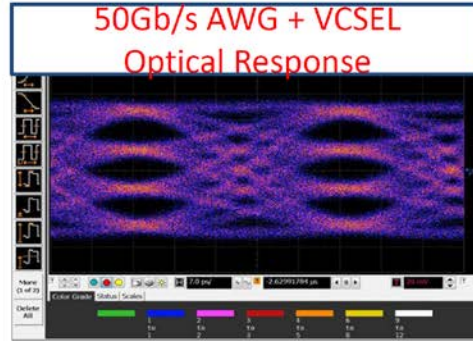


908 nm Tx  
TDECQ: 2.9 dB

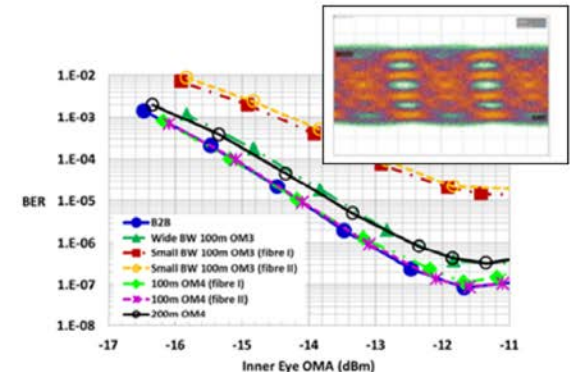
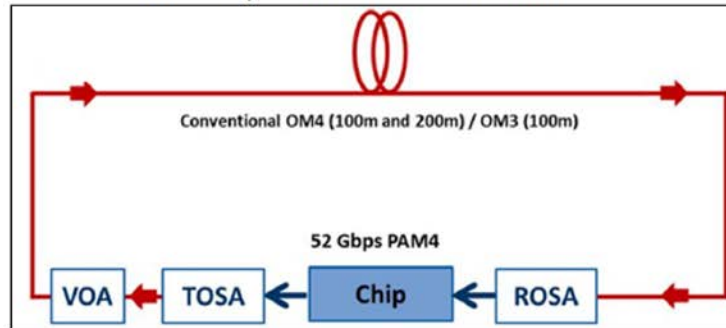
- For both wavelengths, transmission over worst-case MMF results in TDECQ values within the 4.9 dB requirement for MMF PMDs in P802.3cd

# Finisar demonstration of 50G PAM4 over MMF from king\_GE\_NGOATH\_01\_0116

Bench top PAM4 experiments using 25Gb/s VCSELs



and early PAM4 PHY evaluation...





# Technical feasibility of multiple wavelength VCSEL modules

## 40 & 100Gb/s VCSEL modules using four wavelengths are in production

SWDM MSA Technical Specifications Rev 2

# 100G SWDM4 MSA

## Technical Specifications

Optical Specifications

<http://www.swdm.org/msa>

Table 2-1: Wavelength-division-multiplexed lane assignments

Lane	Center wavelength	Wavelength range	Module electrical lane
L <sub>0</sub>	850 nm	844 to 858 nm	Tx0, Rx0
L <sub>1</sub>	880 nm	874 to 888 nm	Tx1, Rx1
L <sub>2</sub>	910 nm	904 to 918 nm	Tx2, Rx2
L <sub>3</sub>	940 nm	934 to 948 nm	Tx3, Rx3



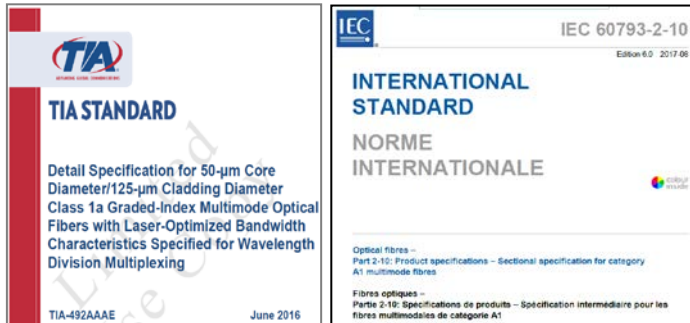
Received 4x25G  
NRZ waveforms  
over 75m OM3  
MMF

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

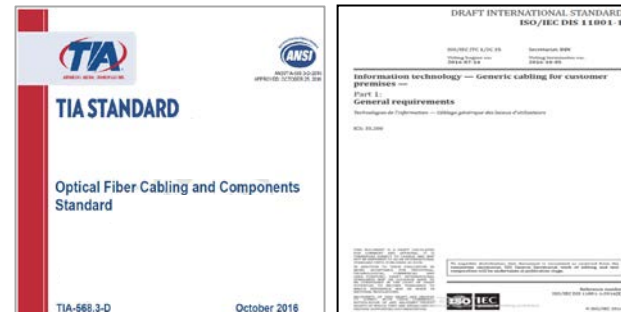
- Tolerances for mux/demux are significantly more relaxed in the case of MMF than SMF
- More costly circuits are needed to implement PAM4 for both fiber types
- Reduction of laser RIN for PAM4 is not more difficult for VCSELs than for DFBs
- Packaging for VCSEL sources at 50Gb/s PAM4 is based on known 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 CDV ballot (1Q17)
  - Application (WBMMF/OM5 operating at 850nm only): IEEE 802.3bs draft (2016), IEEE 802.3cd draft (2016), Fibre Channel FC-PI-7/64GFC (2Q17) & FC-PI-7P/256GFC MRD (4Q17)



Fiber Standards



Structured Cabling Standards



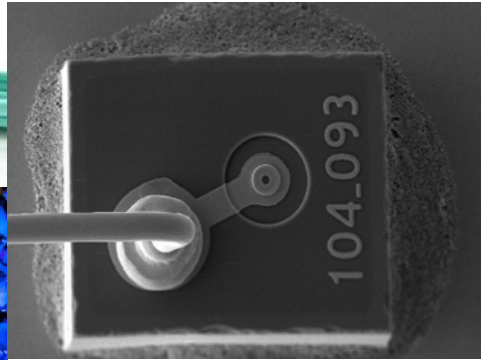
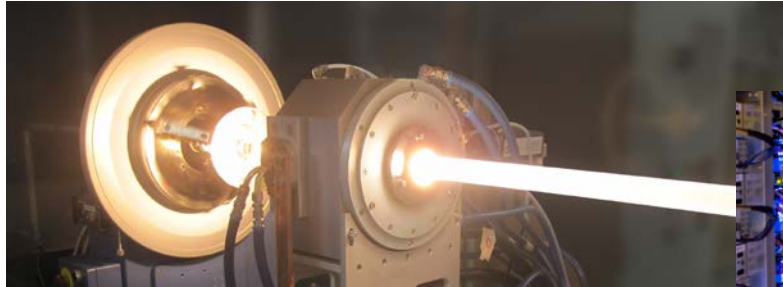
# The VCSEL optical lane rate roadmap supports future PMDs operating over MMF

Bit rate per optical lane (Gb/s)	Year for bit rate
25	2015
50	2018
100	proofs-of-concept exist*

\* Several technical presentations at OFC & ECOC 2017 showed research feasibility of 100G / lane VCSELs.



# Why now?



# Why Now?

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

- Cloud DCs in North America & China and *largest* enterprise DCs were early adopters of 100G-SR4
- The low relative cost and high technical feasibility of SR4.n for short reach should be valuable to early adopters at 400G as well
- Duplex MMF transceivers with speeds > 100G have a place in large enterprise DC switching as server I/O migrates from 10 to 25 to 50 Gb/s

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

- 50Gb/s PAM4 in development for 802.3cd; already used in proprietary modules
- Two and four wavelengths already used in proprietary duplex MMF transceivers
- Two and four wavelength operation over the installed base is supported

Data shows that the market continues to deploy MMF cabling

- Standardizing lower cost applications for MMF facilitates upgrades and enlarges Ethernet market

# Contributors

Dale Murray, LightCounting

Chongjin Xie, Alibaba

David Piehler, Dell EMC

Jonathan Ingham, FIT

Jonathan King, Finisar

Steve Swanson, Corning

John Kamino, OFS

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Mabud Choudhury, OFS

Paul Kolesar, CommScope

James Young, CommScope

Carl Rumbolo, Wells Fargo

Adrian Young, Leviton

Frank Chang, Inphi

Robert Lingle, Jr., OFS

# Supporters (55 Individuals from 38 companies)

Jeffery Maki, Juniper  
David Piehler, Dell EMC  
Ted Sprague, Infinera  
Bharath Tailor, Semtech  
Rob Stone, Broadcom  
John Johnson, Broadcom  
Frank Chang, Inphi  
Sudeep Bhoja, Inphi  
Mike Dudek, Cavium  
Dean Wallace, Cavium  
Scott Kipp, Broadcom  
Mark Kimber, Semtech  
Martin White, Cavium  
Jonathan Ingham, FIT  
Jonathan King, Finisar  
Vipul Bhatt, Finisar  
David Lewis, Lumentum  
Robert Coenen, InterOptic  
Piers Dawe, Mellanox

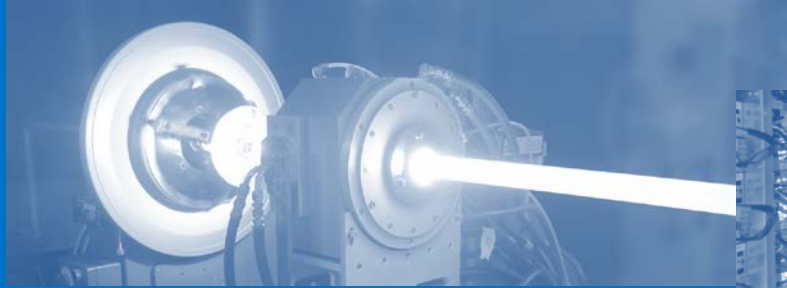
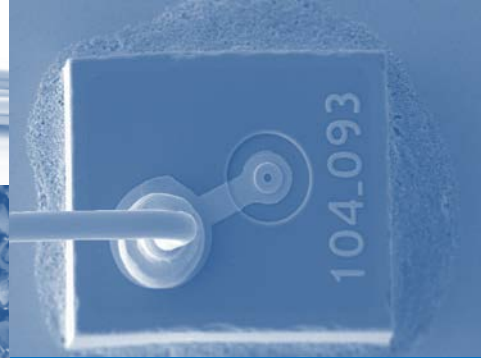
Jon Lewis, Dell EMC  
David Chen, AOI  
Ed Ulrichs, Source Photonics  
Matthias Fritsche, HARTING Electronics GmbH  
Masood Shariff, CommScope  
Adrian Amezcua, Prysmian  
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Mabud Choudhury, OFS  
Paul Kolesar, CommScope  
James Young, CommScope  
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Pavel Zivny, Tektronix  
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Jing Li, Yangtze Optical Fiber & Cable  
Runhan Wang, Yangtze Optical Fiber & Cable  
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Nathan Tracy, TE Connectivity  
Yasuhiro Hyakutake, Adamant  
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Petar Pepeljgoski, IBM

Alan Flatman, LAN Technologies  
Ali Ghiasi, Ghiasi Quantum  
George Zimmerman, CME Consulting  
/CommScope  
Dave Hess, CORD DATA

# Straw Polls



# Straw Poll #1

- Should a study group be formed for “Next-gen 200 and 400 Gb/s PHYs over Fewer MMF Pairs than in Existing Ethernet Projects and Standards”?
- Y: 56      N: 10      A:28
- Room count: 103



# Straw Polls #2 and #3 on participation

- I would participate in a “Next-gen 200 and 400 Gb/s PHYs over Fewer MMF Pairs than in Existing Ethernet Projects and Standards” study group
  - Tally: 33
- My company would support participation in a “Next-gen 200 and 400 Gb/s PHYs over Fewer MMF Pairs than in Existing Ethernet Projects and Standards” study group
  - Tally: 24

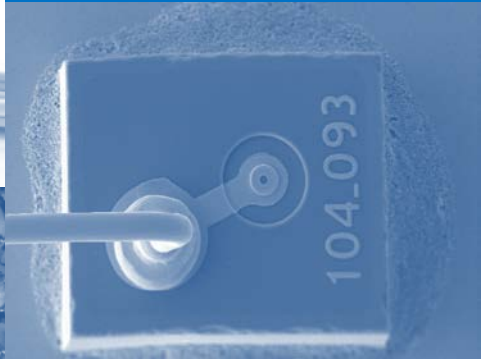


# Future Work

- Ask 802.3 at Thursday's closing meeting to form study group
- If approved:
  - Request 802 EC to approve creation of the study group on Friday
  - First study group meeting would be during January 2018 IEEE 802.3 interim meeting



# Back Up



# 40 & 100Gb/s MMF optics have been used in volume for switch-to-switch connections in data centers

- 40G SR4 for 4 pairs MMF
  - ~ 50% used in switch-to-switch links
- 40G BiDi & SWDM4 for 1 pair MMF
  - Proprietary solutions used in switch-to-switch connections
- 100G SR4 for 4 pairs MMF
  - The 100GBASE-SR4 links deployed in 2016 comprise switch-to-switch and switch-to-router connections in cloud and largest enterprise DCs
- 100G BiDi & SWDM4 for 1 pair MMF
  - Proprietary solutions; expected in 2017; market demand existed in 2016

Chart shows some of the options for 200/400G over fewer MMF pairs; but we are not choosing the solution here!

Technology (per fiber)	1 fiber pair	2 fiber pairs	4 fiber pairs	8 fiber pairs	16 fiber pairs
25G- $\lambda$ NRZ	25G-SR		100G-SR4		400G-SR16
50G- $\lambda$ PAM4	50G-SR	100G-SR2	200G-SR4	400G-SR8	
2x50G- $\lambda$ PAM4	100G-SR1.2	200G-SR2.2	400G-SR4.2	Examples of technologies for 200 & 400 Gb/s links over fewer MMF fiber pairs	
4x25G- $\lambda$ NRZ	100G-SR1.4	200G-SR2.4	400G-SR4.4		
4x50G- $\lambda$ PAM4	200G-SR1.4	400G-SR2.4	800G-SR4.4		



Existing IEEE standard  
In progress in 802.3bs, cd

Multi-Wavelength Nomenclature  
SRm.n  
m = # fiber pairs  
n = # wavelengths