THE FABULOUS, FAST MOVING, FEVER PITCH, FOREVER ACCELERATING FIBER FRENZY

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Paul Neveux, Jr., Ph.D. - Superior Essex International, LP
Tony Irujo - OFS
Darryl Heckle - Corning
Robert Reid - Panduit
Fiber Optics Technology Consortium

Overview:

• Part of the Telecommunications Industry Association (www.tiaonline.org) Until 2013, we had been known as the Fiber Optics LAN Section (FOLS). Our new name was chosen to reflect our expanding charter.

• Formed 24 years ago

• Mission: to educate users about the benefits of deploying fiber in customer-owned networks

• FOTC provides vendor-neutral information
Fiber Optics Technology Consortium

Current Members

- AFL
- CommScope
- Corning
- EXFO
- Fluke Networks
- General Cable
- OFS

Current Members

- Legrand
- Panduit
- Sumitomo Electric Lightwave
- Superior Essex
- The Siemon Company
- Viavi
Fiber Optics Technology Consortium

- Maintain a website with Fiber FAQs, White Papers and other resources – www.tiafotc.org.
- Developed and maintain a free Cost Model that allows users to compare installed first costs of several architectures.
- Host a webinar series throughout the year with all webinars available on demand.
- Speak at industry conferences like BICSI
- Contribute to industry publications – Like BICSI News.
- Conduct market research – like the surveys today
Fiber Optics Technology Consortium

• Recent Webinars Available on Demand
  • Keeping up with High Speed Migration in the Data Center
  • Data Center Design, Planning & Upcoming Changes to TIA-942
  • Best Practices for Achieving Tier 1 Fiber Certification

• Visit [www.tiafotc.org](http://www.tiafotc.org) or our channel on BrightTalk

• Webinars are eligible for CEC credit for up to two years after they are first broadcast. Email [liz@goldsmithpr.com](mailto:liz@goldsmithpr.com) if you have completed a webinar and want to receive your CEC.
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IEEE Standards Update

PAUL NEVEUX, Jr., Ph.D.

Director, Premises Optical Fiber / OEM Market Management
Superior Essex International, LP
IEEE Copper Standards
New IEEE Twisted Pair Standards

• IEEE 802.3bz: 2.5/5 Gb Ethernet
  • At least 100 meters over CAT 6; less for Cat 5e: Alien X-talk
  • Applications include Wi-Fi and PoE++
  • Side Benefit: Currently, all desktop/laptops have 1Gb Ethernet built in will allow manufacturers to offer faster wired speeds to desktop/laptop by building in 2.5/5 G instead

• IEEE P802.3bq: 25/40 Gb Ethernet over twisted pair copper
  • Requires CAT 8 shielded twisted pair cable
  • Published June 2016
IEEE Mobile and Wireless
### Current Wireless Standards

<table>
<thead>
<tr>
<th>Wireless Standard</th>
<th>Data Rate (Mb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>2</td>
</tr>
<tr>
<td>802.11b</td>
<td>11</td>
</tr>
<tr>
<td>802.11a,g</td>
<td>54</td>
</tr>
<tr>
<td>802.11n</td>
<td>600</td>
</tr>
<tr>
<td>802.11ac</td>
<td>1300</td>
</tr>
<tr>
<td>802.11ac (Wave 2)</td>
<td>6900</td>
</tr>
</tbody>
</table>
IEEE 802.11ac

Coverage design with 7.2 Mb/s cell edge

Capacity design with 216.7 Mb/s cell edge

Source: Aruba
## Wireless Standards in Development

<table>
<thead>
<tr>
<th>Wireless Standard</th>
<th>Task Group Name</th>
<th>Data Rate (Gb/s)</th>
<th>Expected Publication Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11ax</td>
<td>High Efficiency (HE) Wireless LAN</td>
<td>10</td>
<td>December 2019</td>
</tr>
<tr>
<td>802.11ay</td>
<td>Enhanced Throughput for Operation in License-Exempt Bands above 45 GHz</td>
<td>20</td>
<td>November 2019</td>
</tr>
<tr>
<td>802.11az</td>
<td>Next Generation Positioning (NGP)</td>
<td>N/A</td>
<td>1Q 2022</td>
</tr>
<tr>
<td>802.11ba</td>
<td>Wake-up Radio (WUR) Operation</td>
<td>N/A</td>
<td>2Q 2018</td>
</tr>
</tbody>
</table>
IEEE 802.11ax: High Efficiency Wireless

<table>
<thead>
<tr>
<th>Parameter</th>
<th>802.11ac</th>
<th>802.11ax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bands</td>
<td>5 Hz</td>
<td>2.4 and 5 Ghz</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>20, 40, 80, 80+80 &amp; 160 MHz</td>
<td>20, 40, 80, 80+80 &amp; 160 MHz</td>
</tr>
<tr>
<td>FFT Size</td>
<td>64, 128, 256, 512</td>
<td>128, 256, 512, <strong>1024, 2048</strong></td>
</tr>
<tr>
<td>Subcarrier Spacing</td>
<td>312.5 kHz</td>
<td><strong>78.125 kHz</strong></td>
</tr>
<tr>
<td>OFDM Symbol Duration</td>
<td>3.2 μs + 0.8/0.4 μs CP</td>
<td><strong>12.8 μs + 0.8/1.6/3.2 μs CP</strong></td>
</tr>
<tr>
<td>Highest Modulation</td>
<td>256-QAM</td>
<td><strong>1024-QAM</strong></td>
</tr>
<tr>
<td>Data Rates</td>
<td>433 &lt;bps (80 MHz, 1 SS)</td>
<td>600.4 &lt;bps (80 MHz, 1 SS)</td>
</tr>
<tr>
<td></td>
<td>6933 Mbps (160 MHz, 8 SS)</td>
<td>9607.8 Mbps (160 MHz, 8 SS)</td>
</tr>
</tbody>
</table>
802.11ay Wireless above 45 GHz

• Environment
  • Crowded public spaces (airports, malls, etc.)
  • Link distance up to 10 cm to 1 km with line of sight (distance affects speed)
  • Devices stationary during use; one device per WAN

• Application
  • Mass data downloads (video, pictures, etc.)
  • Jitter not critical – key metric is user’s transfer time: < 1 second
  • Application exits once task is complete
Fiber Required for Aggregation

• New copper and wireless applications will require larger “pipes” to backhaul information to the data center
• The new bottleneck will be from the telecom closet to the data center unless higher throughput media, like fiber, are used.
• All these new applications will require higher throughputs in the data center.
Optical Fiber Ethernet Update
IEEE Standards
## 10, 40 and 100 Gb Ethernet on MMF

<table>
<thead>
<tr>
<th>Ethernet Speed</th>
<th>IEEE</th>
<th>Designation</th>
<th>Fiber Type</th>
<th>Number of Fibers</th>
<th>Maximum Link Length (m)</th>
<th>Maximum Channel Insertion Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Gb</td>
<td>802.3ae</td>
<td>10GBASE-SR</td>
<td>OM3</td>
<td>2</td>
<td>300</td>
<td>2.6</td>
</tr>
<tr>
<td>40 Gb</td>
<td>802.3ba</td>
<td>40GBASE-SR4</td>
<td>OM3</td>
<td>8</td>
<td>100</td>
<td>1.9</td>
</tr>
<tr>
<td>40 Gb</td>
<td>802.3ba</td>
<td>40GBASE-SR4</td>
<td>OM4</td>
<td>8</td>
<td>150</td>
<td>1.5</td>
</tr>
<tr>
<td>100 Gb</td>
<td>802.3ba</td>
<td>100GBASE-SR10</td>
<td>OM3</td>
<td>20</td>
<td>100</td>
<td>1.9</td>
</tr>
<tr>
<td>100 Gb</td>
<td>802.3ba</td>
<td>100GBASE-SR10</td>
<td>OM4</td>
<td>20</td>
<td>150</td>
<td>1.5</td>
</tr>
<tr>
<td>100 Gb</td>
<td>802.3bm</td>
<td>100GBASE-SR4</td>
<td>OM4</td>
<td>8</td>
<td>100</td>
<td>1.9</td>
</tr>
</tbody>
</table>
# 40 and 100 Gb Ethernet on SMF

<table>
<thead>
<tr>
<th>Ethernet Speed</th>
<th>IEEE</th>
<th>Designation</th>
<th>Wave-lengths (nm)</th>
<th>Number of Fibers</th>
<th>Max. Link Length</th>
<th>Max. Channel Insertion Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 Gb</td>
<td>802.3ba</td>
<td>40GBASE-IR4</td>
<td>$4\lambda_{1260 \text{ to } 1355}$</td>
<td>2</td>
<td>2 km</td>
<td>4.0</td>
</tr>
<tr>
<td>40 Gb</td>
<td>802.3ba</td>
<td>40GBASE-LR4</td>
<td>$4\lambda_{1260 \text{ to } 1355}$</td>
<td>2</td>
<td>10 km</td>
<td>6.7</td>
</tr>
<tr>
<td>100 Gb</td>
<td>802.3ba</td>
<td>100GBASE-LR4</td>
<td>$4\lambda_{1260 \text{ to } 1355}$</td>
<td>2</td>
<td>10 km</td>
<td>6.3</td>
</tr>
</tbody>
</table>
IEEE 802.3bs – 200/400 Gb/s Ethernet

- Implementation for MMF:
  - 16 x 25 Gb/s (32 fibers)
- Full duplex operation
- Media Distances
  - 100 m over OM4/5 MMF
  - 70 m over OM3 MMF
  - 10 km, 2 km, 500 m over SMF
- Expected Jan 2018 Publication
IEEE 802.3cd -
50 Gb/s (Single Lane), NG 100/200 Gb/s Ethernet

• 50 Gb/s Ethernet PHYs
  • MMF with lengths up to at least 100 m (OM4/5; 50GBASE-SR)
  • SMF with lengths up to at least 2 km and lengths up to at least 10 km

• 100 Gb/s Ethernet PHYs
  • MMF with lengths up to at least 100 m (OM4/5; 100GBASE-SR2)
  • Duplex SMF with lengths up to at least 500 m

• 200 Gb/s Ethernet PHYs
  • MMF with lengths up to at least 100 m (OM4/5; 200GBASE-SR4)
New IEEE Study Group

- 200/400G Ethernet over OM3/4/5 Fiber
- 4 Wavelengths over at least 100 meters using OM5 Fiber
- Reach for OM3/4 to be determined
- Actual objectives still to be determined
IEEE P802.3ca 100G-EPON Task Force

• Support subscriber access networks using point to multipoint topologies on optical fiber

• Provide specifications for physical layers operating over a single SMF strand and supporting symmetric and/or asymmetric MAC data rates of:
  • 25 Gb/s in downstream and less than or equal to 25 Gb/s in upstream
  • 50 Gb/s in downstream and less than or equal to 50 Gb/s in upstream
  • 100 Gb/s in downstream and less than or equal to 100 Gb/s in upstream

• Support coexistence with 10G-EPON

• Optical power budgets to accommodate channel insertion losses equivalent to those supported by the 10G-EPON standard

• Wavelength allocation allowing concurrent operation with 10G-EPON PHYs

• Wavelength allocation allowing concurrent operation of 25G-EPON and G-PON reduced wavelength set (1290nm-1330nm) PHYs
IEEE P802.3cc 25 Gb/s Ethernet over SMF

• Provide physical layer specification which support 25 Gb/s operation over at least 10 km on (duplex) SMF.
• Provide physical layer specification which support 25 Gb/s operation over at least 40 km on (duplex) SMF.
• Provide appropriate support for OTN
• Target market is campus, WAN, and MANs
• Approved as a standard on December 6, 2017
TIA Standards Update

Cindy Montstream, EE, RCDD/NTS, CPLP
Director of Technology Support & Training
Data Communications Division, Legrand

Chair, TIA TR-42.3
FOTC Standards Chair
TIA Standards Update

TR-42 | TELECOMMUNICATIONS CABLELING SYSTEMS

• Develops standards for telecommunications cabling infrastructure

• Standards are grouped into 3 categories: Common, Premises and Cabling & Components

• Standards cover many different premises, i.e. data center, commercial building, residential, healthcare facility, education facility, etc.
New Media Types & Connector
OM5: Wide Band Multimode Fiber

ANSI/TIA-492AAAE
Wide Band Multimode (WBMMF)

- 50μ Laser Optimized Multimode Fiber
  - Use cost effective MM VCSEL technology
- Optimized to support at least 4 wavelengths
- OM5 designation
- Backwards compatible
  - Continue to support legacy 850nm OM4 applications
- No additional field testing required
- Field polished the same way as any other MMF
- Published 06/2016
ANSI/TIA-604-18 (FOCIS 18)

- 1x16 and 2x16 Multifiber Push-On connector
  - Has offset key
- 1x16 is similar to 12-fiber MPO & 2x16 similar to 24-fiber MPO (FOCIS 5)
  - Requires new FOCIS document because connector requires different distance between guide holes
- Supports 1st generation of 400 GbE over MMF
Standards Integrating New Media Types

- **ANSI/TIA-568.0-D Addendum 1**  
  (Generic Telecommunication Cabling)
  - Recognized fiber now stated as --multimode optical fiber cabling  
    (ANSI/TIA-568.3-D) 2-fiber (or higher fiber count); (updated reference & recommendation of OM3 or higher
  - OM5 added to application MM fiber table

- **ANSI/TIA-568.1-D Addendum 1**  
  (Commercial Building Telecommunication Cabling)

- **ANSI/TIA-1179-A** (Healthcare)
  - OM4 is minimum MMF recommended
  - Min 2 fiber backbones
  - Array connectors
Standards Integrating New Media Types

- **ANSI/TIA-942-B** (Datacenter)
  - Cabinets should be at least 48” deep & wider than 24”
  - Max length for direct attach cables in EDA – 7m (were 10m)
  - Direct attach cabling between rows is not recommended
  - Added MPO-16 / 32 & MPO-24
  - Recommends pre-terminated cabling

- **ANSI/TIA-862-B Addendum 1** (Intelligent Building)
  - 2 fiber minimum

- **ANSI/TIA-4966 Addendum 1** (Education)
  - OM4 or OM5
Optical Fiber Cabling Components

ANSI/TIA-568.3-D

- Now components & cabling (testing, polarity, etc.)
  - Polarity from TIA-568.0
  - Testing from TIA-568.0
  - Passive optical network component specs

- Splitters are part of budget
  - Specifies encircle flux launch conditions for testing MMF @ 850 nm
    - Eliminates testing @ 1300 nm
  - Raises min. return loss of SM connections & splices from 26 dB to 35 dB
Optical Fiber Cabling Components

ANSI/TIA-568.3-D continued….

- Lowers OM3 & OM4 attenuation @ 850nm to 3.0 dB/km
- Accounts for insertion loss of reference-grade test conditions
- Demotes OM1, OM2 & OS1 to not-recommended
- Adds specification for wideband multimode fiber
- Adds specification for OSP microduct cable
- Published 09/2016
In Process & New Work
Optical Fibers and Cables

- Ongoing work:
  - Revising TIA-598D
    - Addendum 1: Specs for colors 13-16
      - TG formed for round robin on color measurement for colors 13-16;
      - 2nd industry ballot
    - Addendum 2: Jacket color for WBMMF
      - Approval of Lime for jacket color for OM5 fiber applications.
Optical Fiber Systems
New project:
TIA-568.3-D Addendum 1
Scope:
- Use of OM5 name
- Use of OS1a name
- Color for OM5 connecting hardware
- Connecting hardware color definitions
- Reference-grade to standard-grade loss allocation
- MPO testing

<table>
<thead>
<tr>
<th>Mated termination combination</th>
<th>Multimode (dB/connection)</th>
<th>Single-mode (dB/connection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference-grade to standard-grade</td>
<td>0.3&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.5&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Standard-grade to standard-grade</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Note 1 – This value is taken from ANSI/TIA-526-14, Table F.1.
Note 2 – This value is taken from ANSI/TIA-526-7, Table G.1.
New Work

- **ANSI/TIA-570-C (Residential)**
  - Submitted for 2\(^{nd}\) industry ballot

- **ANSI/TIA-758-B (OSP)**
  - Project request to start C revision approved
  - 1\(^{st}\) industry ballot based on editors schedule

- **Places of Assembly Task Group**
  - Working on potential standard for Airports, Stadiums, Theaters, etc.
Additional Information Available
FOTC Website
Summary of current TIA standards

http://www.tiafotc.org
FOTC Website
LAN Standards, News & Trends 2017

http://www.tiafotc.org

Library > Webconferences
Optical Fiber Technology

Tony Irujo
Sales Engineer
OFS
Two Basic Optical Fiber Types

1. Multimode
   - 62.5 micron
   - 50 micron
   - 850 nm & some 1300 nm

2. Singlemode
   - ~8 micron
   - Operating Wavelengths: 1310 - 1625 nm
Multimode Fiber

- Light Signal travels along many paths
- Pulse spreading occurs due to **Modal Dispersion** or **Differential Mode Delay** (DMD)
- Pulse spreading limits **Bandwidth**
Modal Dispersion / DMD Minimized in OM3 and especially OM4 MM Fiber
Singlemode Fiber

*Small core guides only one mode*

- Eliminates modal dispersion.
- Enables tremendous transmission capacity over very long distances.
Multimode or Singlemode?  Speed, Reach, Cost...

- From 10G to 100G and beyond, Multimode fiber supports reaches in the ~100 to 600 meter range (~300 to 2000 ft), depending on fiber type used (OM3, OM4, OM5), as well as transceiver type.
- Beyond 500 – 600 meter range, Singlemode fiber is necessary.

*Generally, the total installed cost of a Multimode system continues to be less expensive than that of a Singlemode system, due to cost of the optics.*
Keeping up with Rising Data Rates

## Fiber is up to the task

<table>
<thead>
<tr>
<th>Multimode Fiber Designation</th>
<th>Multimode Fiber Type</th>
<th>Description</th>
<th>Recommended Application Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM1</td>
<td>62.5 um</td>
<td>“FDDI”-Grade</td>
<td>1 Gb/s</td>
</tr>
<tr>
<td>OM2</td>
<td>50 um</td>
<td>Dual Window</td>
<td>1 - 10 Gb/s</td>
</tr>
<tr>
<td>OM3</td>
<td>50 um</td>
<td>Laser Optimized</td>
<td>10 - 100 Gb/s</td>
</tr>
<tr>
<td>OM4</td>
<td>50 um</td>
<td>Laser Optimized Extended Reach</td>
<td>10 - 400 Gb/s</td>
</tr>
<tr>
<td>OM5</td>
<td>50 um</td>
<td>Wideband for SWDM</td>
<td>40 - 400+ Gb/s on fewer fibers</td>
</tr>
</tbody>
</table>
New Multimode Fiber Technology
Multimode traditionally operates at one wavelength

850 nm
OM5 WideBand Multimode – Multiple Wavelengths

- λ = 850 nm
- λ ~880 nm
- λ ~910 nm
- λ ~940 nm

Mux

Demux

2018 BICSI Winter Conference & Exhibition
Orlando, FL | February 4-8
OM5 WideBand MMF will take advantage of Wavelength Division Multiplexing (WDM) technology.

- Same as commonly used on Singlemode fiber:
  - CWDM (Course Wavelength Division Multiplexing)
  - DWDM (Dense Wavelength Division Multiplexing)

- For Multimode, it will be called **SWDM** – *Short Wavelength Division Multiplexing*
Parallel QSFP Multimode Fiber Migration Path

<table>
<thead>
<tr>
<th></th>
<th>10G/Fiber</th>
<th>25G/Fiber</th>
<th>25G/λ - 4λ/Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>10G</td>
<td>⬠</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>25G</td>
<td>N/A</td>
<td>⬠</td>
<td>N/A</td>
</tr>
<tr>
<td>40G</td>
<td>⬠</td>
<td>⬠</td>
<td>N/A</td>
</tr>
<tr>
<td>100G</td>
<td>⬠</td>
<td>⬠</td>
<td>⬠</td>
</tr>
<tr>
<td>400G</td>
<td>N/A</td>
<td>⬠</td>
<td>⬠</td>
</tr>
</tbody>
</table>

SWDM
# Duplex Multimode Fiber Migration Path

<table>
<thead>
<tr>
<th></th>
<th>10G/Fiber</th>
<th>25G/Fiber</th>
<th>25G/λ - 4λ/Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>10G</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>25G</td>
<td>N/A</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>40G</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>100G</td>
<td></td>
<td></td>
<td><img src="#" alt="Colors" /></td>
</tr>
<tr>
<td>400G</td>
<td>N/A</td>
<td><img src="#" alt="Colors" /></td>
<td></td>
</tr>
</tbody>
</table>

![SWDM Arrow](#)
Singlemode Fiber
## Singlemode Fiber Types
(by ISO 11801 Cabling Standard convention)

<table>
<thead>
<tr>
<th>SM Cabled Fiber Designation</th>
<th>Wavelength (nm)</th>
<th>Max CABLE Loss (dB/km)</th>
<th>Cable Type</th>
<th>Typical Reach (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS1</td>
<td>1310 &amp; 1550</td>
<td>1.0</td>
<td>Typically Tight Buffer</td>
<td>2000</td>
</tr>
<tr>
<td>OS1a</td>
<td>1310, <strong>1383</strong>, 1550</td>
<td>1.0</td>
<td>Typically Tight Buffer</td>
<td>2000</td>
</tr>
<tr>
<td>OS2</td>
<td>1310, 1383, 1550</td>
<td>0.4</td>
<td>Typically Loose Tube</td>
<td>10,000</td>
</tr>
</tbody>
</table>
### Singlemode Fiber Types
(by ITU-T Fiber Recommendation convention)

<table>
<thead>
<tr>
<th>SM Fiber Designation / Category</th>
<th>SM Fiber Sub-Type / Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>G.652</strong></td>
<td>G.652.A or G.652.B</td>
<td>Legacy</td>
</tr>
<tr>
<td></td>
<td>G.652.C or <strong>G.652.D</strong></td>
<td>Low Water Peak</td>
</tr>
<tr>
<td><strong>G.657</strong></td>
<td>G.657.A1</td>
<td>Bend-Insensitive</td>
</tr>
<tr>
<td></td>
<td>G.657.A2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G.657.B2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G.657.B3 / A3</td>
<td></td>
</tr>
</tbody>
</table>
Multimode vs. Singlemode Cost Considerations

**MM continues to be more cost effective than SM for short reach**

- **Cost of optics (transceivers) dominates link.**
- **Power Consumption of MM optics is typically less than SM.**

<table>
<thead>
<tr>
<th>PMD</th>
<th>Fiber Type</th>
<th>Relative Transceiver Cost</th>
<th>Power Consumption (Watts, max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10GBASE-SR</td>
<td>MM</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10GBASE-LR</td>
<td>SM</td>
<td>2</td>
<td>1 – 1.5</td>
</tr>
<tr>
<td>40GBASE-SR4</td>
<td>MM</td>
<td>4</td>
<td>1.2 – 1.5</td>
</tr>
<tr>
<td>40GBASE-LR4</td>
<td>SM</td>
<td>20</td>
<td>3.5</td>
</tr>
<tr>
<td>100GBASE-SR10</td>
<td>MM</td>
<td>8</td>
<td>3.5 – 4</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>SM</td>
<td>100</td>
<td>3.5 – 5</td>
</tr>
</tbody>
</table>

Cost References:
- [www.sanspot.com](http://www.sanspot.com)
- [www.cdw.com](http://www.cdw.com)

Power Consumption References:
- [www.finisar.com](http://www.finisar.com)
- [www.fit-foxconn.com](http://www.fit-foxconn.com)

June 2017																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									

**2018 BICSI Winter Conference & Exhibition**

Orlando, FL | February 4-8
Conclusions

✓ Data Rates are increasing at ever faster rates (10G → 40G → 100G → 200G → 400G)

✓ OM1 and OM2 MM fibers are becoming obsolete. OM3 & OM4 are the current “work horse” MM fibers. OM5 is the next generation of MM for high speed SWDM applications (Data Centers).

✓ Industry has moved to Low / Zero Water Peak SM fiber (G.652.D) Industry steadily moving to Bend-Insensitive SM fibers (G.657.xx)

✓ MM links continue to be more economical than SM for short reach (transceiver cost).
Fiber Market Trends

Darryl Heckle
Global Multimode Product Line Manager
Corning Incorporated
Bandwidth Drivers
It’s All About The Cloud

<table>
<thead>
<tr>
<th>Companies</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rackspace</td>
<td>YouTube</td>
</tr>
<tr>
<td>Salesforce</td>
<td>Facebook</td>
</tr>
<tr>
<td>Google</td>
<td>Amazon Web Services</td>
</tr>
<tr>
<td>Microsoft</td>
<td>Netflix</td>
</tr>
</tbody>
</table>
Global Network Traffic Growth Forecast

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internet Users</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% of population)</td>
<td>44%</td>
<td>58%</td>
</tr>
<tr>
<td><strong># Devices &amp; Connections</strong></td>
<td>2.3</td>
<td>3.5</td>
</tr>
<tr>
<td>(per capita)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Avg. Speeds</strong></td>
<td>27.5 Mbps</td>
<td>53.0 Mbps</td>
</tr>
<tr>
<td><strong>Avg. Traffic</strong></td>
<td>12.9 Gb</td>
<td>35.5 Gb</td>
</tr>
<tr>
<td>(per capita per month)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Cisco VNI, 2017
Global Consumer IP Traffic Growth

*Video Applications Driving Growth*

---

**Source:** Cisco VNI, 2017

---

27% CAGR

---

*2018 BICSI Winter Conference & Exhibition*

Orlando, FL | February 4-8
Internet Applications

Mobile access driving growth

- **Facebook** (as of Sept 2017)
  - 2.07 billion active users, 1.37 billion daily users

Source: [http://newsroom.fb.com/Key-Facts](http://newsroom.fb.com/Key-Facts)
Internet Applications

Significant growth for on demand video

- **Netflix** (2017 Forecast)
  - 115.55 million members
  - $11.7 billion revenue

Source: http://ir.netflix.com/index.cfm
Ethernet Market
Ethernet Transceivers Sales

SMF and MMF device sales continue to grow

MMF and SMF transceiver speeds

Strong growth in 10G MMF; 100G SMF

Fiber Market Trends
NA Multimode Fiber Volume by Type
OM3+4 volume growing; OM1+2 declining

Note: OM5 not reported separately.
NA Multimode Fiber Mix by Type

OM3+4 share growing at expense of OM1+2

Note: OM5 not reported separately.
MM vs. SM in the Enterprise

All Cable Types

Source: Burroughs NA MM Market Report
MM vs. SM in the Enterprise

Tight Buffer Cable

Source: Burroughs NA MM Market Report
Conclusions

✓ Bandwidth demands continue to increase
  ✓ Mobile usage; video; social media

✓ Ethernet device demand continues to increase
  ✓ Strong growth in MMF 10G networks
  ✓ SMF devices growing, fastest at 100G

✓ OM4 demand continues to increase
Standard and Non-standard Transceivers Update

Robert Reid, Sr. Technical Manager
Panduit Inc.
### Current Transceiver Form Factors (>=10G)

<table>
<thead>
<tr>
<th>SFP</th>
<th>SFP+</th>
<th>XFP</th>
<th>SFF</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>XENPAK</td>
<td>X2</td>
<td>GBIC</td>
<td>CXP</td>
</tr>
<tr>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>QSFP</td>
<td>QSFP+</td>
<td>CFP</td>
<td>CFP2</td>
</tr>
<tr>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Transceiver Macro Trends

• **Support of Installed Base:** 16/32GFC, 40GbE, 100GbE, 128GFC support (& beyond) on installed MMF

• **Lane rates > 25 Gb/s:** Technology enabling VCSEL operation at 50 Gb/s and beyond (future generations of single/multi lane optics)

• **Wideband MMF (OM5):** Standardization of wideband multimode fiber enabling SWDM transmission onto single fibers reducing fiber count (duplex-LC interface) for 40GbE, 32GFC and above

• **Emergence of Cost Effective SM Optics:** Driven by large volumes consumed by H-Scale entities
### 10G Transceiver History

<table>
<thead>
<tr>
<th>Item</th>
<th>300 Pin</th>
<th>XENPAK</th>
<th>X2</th>
<th>XFP</th>
<th>SFP+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (sq. in.)</td>
<td>10</td>
<td>6.75</td>
<td>5</td>
<td>2.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Density</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>16/32</td>
<td>48</td>
</tr>
</tbody>
</table>
>10G Transceiver Roadmap

High Cost
- Low Risk Designs
- Low Volume

Low Cost
- High Volume
- Tooling Intensive

CFP
CFP2
CXP
QSFP28
Ethernet Roadmap

From http://www.ethernetalliance.org/roadmap/
## Media Device Interface (10G to 100G)

<table>
<thead>
<tr>
<th>Application</th>
<th>10GBASE-SR</th>
<th>25GBASE-SR</th>
<th>40GBASE-SR4</th>
<th>100GBASE-SR10</th>
<th>100GBASE-SR4**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>10 Gbps</td>
<td>25 Gbps</td>
<td>40 Gbps</td>
<td>100 Gbps</td>
<td>100 Gbps</td>
</tr>
<tr>
<td>IEEE Std</td>
<td>802.3ae</td>
<td>TBD</td>
<td>802.3ba</td>
<td>802.3ba</td>
<td>802.3bm</td>
</tr>
<tr>
<td>Form Factor</td>
<td>SFP+</td>
<td>TBD</td>
<td>QSFP+</td>
<td>CFP, CXP</td>
<td>QSFP28, CFP4</td>
</tr>
<tr>
<td>Reach*</td>
<td>300/400m</td>
<td>70/100m?</td>
<td>100/150m</td>
<td>100/150m</td>
<td>70/100m</td>
</tr>
<tr>
<td># of Fibers</td>
<td>2</td>
<td>2</td>
<td>12 (8 used)</td>
<td>24 (20 used)</td>
<td>12 (8 used)</td>
</tr>
<tr>
<td>Connectors</td>
<td>Duplex LC</td>
<td>Duplex LC</td>
<td>12f MPO</td>
<td>24f MPO (2 x 12)</td>
<td>12f MPO</td>
</tr>
</tbody>
</table>

**IEEE P802.3bm approved May 10, 2015**

*IEEE 802.3ae approved TBD
**IEEE 802.3ae approved TBD

1.5 dB Link Budget
40GBASE-eSR4 ‘Extended’

• “Extended Reach” transceivers now available from multiple vendors
• Operates as 4 x 10G
  • QSFP+ has 2.5X edge-density as 10GBASE-S
• Operates as 1 x 40G
  • 300m/400m (OM3/OM4) vs. 100m/150m for SR4
• Lower cost alternative to SM (40GBASE-LR4 QSFP+)
  • Lower CAPEX - Estimated 75%
  • Lower OPEX - 50% power dissipation (1.5W vs. 3.5W)
Bidirectional SFPs

- BiDi - short for bidirectional
- 40G Ethernet over two fibers (100G coming!)
- Allows use of existing LC infrastructure
- Uses Wavelength Division Multiplexing – 2 x 20 Gbps signals
‘Universal’ Transceivers

• Addresses customer concerns around the reduced distances with 40GBASE-SR4
• Migrations from existing 10 to 40GbE networking without requiring redesign/expansion of fiber network
• Supports operation over 150 m of OM3 or OM4
• Can be used for up to 500 m and with both 40GBASE-LR4 and 40GBASE-LRL4
Embedded Multispeed Ports

12 Port MXP Triple-speed line card for Arista 7500E Series switch
Channel mapping for 24f MXP triple-speed port
Fibre Channel Higher Speed Optics

- FC 32G PI-6 (bit rate 28.05Gbps)
  - Published & SFP+ Transceivers shipping

- FC 128G PI-6P (Aggregate bit rate 4x28.05 Gbps)
  - MMF: 4 parallel lanes of 32G with breakout use cases implied
  - SMF two options: 4 parallel fibers & CDWM

- FC 64G per fiber PI-7 & PI-7P (bit rate 56.1 Gbps per fiber)
  - Combine both 64GFC/256GFC (breakout?)
  - Modulation format (PAM-4) and 2/4 wavelength solutions
  - WideBand MMF is being introduced as a solution and cable plant models based on TIA/IEC standards being modeled

Brocade FC Optics
64G QSFP

2km SM version for ICL & 16G MM reach version for switch port app’s
# Fiber Channel Roadmap

<table>
<thead>
<tr>
<th>Product Naming</th>
<th>Throughput (Mbytes/s)</th>
<th>Line Rate (Gbaud)</th>
<th>T11 Specification Technically Complete (Year)*</th>
<th>Market Availability (Year)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1GFC</td>
<td>200</td>
<td>1.0625</td>
<td>1996</td>
<td>1997</td>
</tr>
<tr>
<td>2GFC</td>
<td>400</td>
<td>2.125</td>
<td>2000</td>
<td>2001</td>
</tr>
<tr>
<td>4GFC</td>
<td>800</td>
<td>4.25</td>
<td>2003</td>
<td>2005</td>
</tr>
<tr>
<td>8GFC</td>
<td>1,600</td>
<td>8.5</td>
<td>2006</td>
<td>2008</td>
</tr>
<tr>
<td>32GFC</td>
<td>6,400</td>
<td>28.05</td>
<td>2013</td>
<td>2016</td>
</tr>
<tr>
<td>128GFC</td>
<td>25,600</td>
<td>4X28.05</td>
<td>2014</td>
<td>2018</td>
</tr>
<tr>
<td>64GFC</td>
<td>12,800</td>
<td>56.1</td>
<td>2017</td>
<td>2019</td>
</tr>
<tr>
<td>256GFC</td>
<td>51,200</td>
<td>4X56.1</td>
<td>2017</td>
<td>2019</td>
</tr>
<tr>
<td>128GFC</td>
<td>25,600</td>
<td>TBD</td>
<td>2020</td>
<td>Market Demand</td>
</tr>
<tr>
<td>256GFC</td>
<td>51,200</td>
<td>TBD</td>
<td>2023</td>
<td>Market Demand</td>
</tr>
<tr>
<td>512GFC</td>
<td>102,400</td>
<td>TBD</td>
<td>2026</td>
<td>Market Demand</td>
</tr>
<tr>
<td>1TFC</td>
<td>204,800</td>
<td>TBD</td>
<td>2029</td>
<td>Market Demand</td>
</tr>
</tbody>
</table>

*Note: TBD stands for To Be Determined.*
New Fiber Challenges

• Newer network designs (e.g., Flat Networks) require more transmission media to enable scalable and higher density solutions

• Large Enterprise/Webscale DCs are challenged to deal with significant transitions in the market to higher speed and longer reach channels

• Seamless infrastructure migration plans are necessary as data center port speeds are increasing (10Gb to 40Gb to 100Gb)
Hyperscale Market Segmentation

Cloud/SP customers want REACH & cost effective 100G!!!!
100G SMF Standards Activity

IEEE802.3bm task force named three contending technologies for SMF (link distance ≤2km) at its final closure in 2014.

- CWDM (coarse wavelength-division-multiplexing),
- PSM4 (parallel single-mode fibers with 4 lanes in each direction)
- PAM-8/16 (pulse amplitude modulation with 8/16 levels)

Several multi-source-agreement (MSA) consortia formed.

- PSM4 is called “100G PSM4” (psm4.org/)
- CWDM/CWDM4 (cwdm4-msa.org/) & CLR4 (clr4-alliance.org/)
- Companies working on 100G PAM-4, no MSA has been formed
Emergence of SM Solutions

• Industry Consortium - Low cost solution to extend reach within the DC for 100G interconnect
• Use of FEC to keep costs down (de-spec’d optics) 4 integrated modulators & one CW 1.3mm DFB laser
  • MPO connector with support for 8 active fibers
  • Reach <500 meters (<3.0dB of connector IL in cable plant)
  • Breakout possible (same cabling components as 128G FC)
**CWDM4 & CWDM4-OCP**

- **100G CWDM4-MSA**
  - QSFP-28 form-factor
  - Single-mode duplex fiber

- **CWDM4-OCP**:
  - Relaxed specification for DCs
  - Reduced temperature range
  - Reduced link budget

<table>
<thead>
<tr>
<th></th>
<th>CWDM4-OCP Relaxed Specification</th>
<th>CWDM4 MSA Base Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach</td>
<td>500 m</td>
<td>2000 m</td>
</tr>
<tr>
<td>Link loss</td>
<td>3.5 dB</td>
<td>5 dB</td>
</tr>
<tr>
<td>Operating Case Temperature</td>
<td>15-55 deg C</td>
<td>0-70 deg C</td>
</tr>
</tbody>
</table>

CWDM4-OCP version (FaceBook)
100G Xconnect Channel Compare

Data presented will differ according due to unique installation and application requirements
From http://www.ethernetalliance.org/roadmap/
400G Candidate Technology

- **Serial** - Signaling rate of VCSEL transmitter (40GHz to 60GHz has been demonstrated)
- **Parallel** - Multiple lane aggregation (SR4, SR10, SR16)
- **WDM** - Wide Band MMF designed to take advantage of this (new fiber designed to enable 4+ wavelengths)
- **Encoding** - Conventional is NRZ (two symbols – symbol rate same as bit rate). PAM-4 encodes two bits in one transmission interval
VI Systems demonstrates the performance of their latest generation of 850nm vertical surface emitting laser (VCSEL) to transmit at a data rate of 54 Gbit/s over 2.2 km of multimode fiber.

BERLIN, Germany, Apr 11, 2016

Customer samples of the VCSEL driver and TIA chip are available now June 27, 2017
“Brute Force” - Multiple Lanes

• Move toward 16 fiber units?

• Discussions in IEEE/TIA to support:
  • 32/16-pin MPO connectors (TR 42.13)
    • Polarity descriptions that cover n-number of fiber units (TR 42.11)
    • 4 new fiber colors to support 16-fiber ribbons bundles (TR 42.12)

• Likely upgrade paths (MM) results in units of 4 fibers:
  • $40 \div 10$ per fibre $= 8$ (2x4F) fibers
  • $100 \div 25$ per fibre $= 8$ (2x4F) fibers
  • $400 \div 25$ per fibre $= 32$ (2x16F) fibers
SWDM Module Technology

- Multiple VCSELs at different wavelengths around 850 nm
- Passive optical multiplexing of light occurs within the module
- On Rx side, demultiplexing (using the same type of passive optic)
“Multi-Source Agreement” (MSA) defining use of the 840nm to 953nm wavelengths for the WDM transmission over WBMMF & non-WBMMF......40G/100G SWDM4 released.

Pros:

• Extends lifetime of MMF solutions
• Provides legacy (OM3/OM4) cable solution for 40G+
• >100G ‘Toolbox’ item (encoding, line rate & parallel)

Cons:

• SWDM ecosystem - transceivers/fiber expensive
• Transceiver complexity, power consumption
• SWDM doesn’t support breakout
SWDM Wavelengths (2\(\lambda\) vs. 4\(\lambda\))

4\(\lambda\) SWDM
- Tighter specs
- Higher WDM insertion loss
- Increased cross-talk penalty
- Higher power VCSELs required
- Higher power dissipation

2\(\lambda\) SWDM Proposed in P802.3cd
- Larger guard band
- Wider spectral windows
- Lower WDM IL
PAM-4 Multilevel Encoding

- 4 distinct pulse amplitudes used
- Amplitude represented by two bits 00, 01, 11, and 10 (a ‘symbol’)
- One of the four amplitudes is transmitted in a symbol period, there are two bits transmitted in parallel (data rate doubled)
- PAM-4 modulation is twice as bandwidth-efficient as binary modulation
## Options for Next Gen MMF PMDs

<table>
<thead>
<tr>
<th>Technology (per fiber)</th>
<th>1 fiber pair</th>
<th>2 fiber pairs</th>
<th>4 fiber pairs</th>
<th>8 fiber pairs</th>
<th>16 fiber pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>25G-λ. NRZ</td>
<td>25G-SR</td>
<td></td>
<td>100G-SR4</td>
<td></td>
<td>400G-SR16</td>
</tr>
<tr>
<td>50G-λ. PAM4</td>
<td>50G-SR</td>
<td>100G-SR2</td>
<td>200G-SR4</td>
<td></td>
<td>400G-SR8</td>
</tr>
<tr>
<td>2x50G-λ. PAM4</td>
<td>100G-SR1.2</td>
<td>200G-SR2.2</td>
<td>400G-SR4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4x25G-λ. NRZ</td>
<td>100G-SR1.4</td>
<td>200G-SR2.4</td>
<td>400G-SR4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4x50G-λ. PAM4</td>
<td>200G-SR1.4</td>
<td>400G-SR2.4</td>
<td>800G-SR4.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Existing IEEE Standards**
- **In Progress**

**SRm.n**
- \( m \) = # of Fiber Pairs
- \( n \) = # of Wavelengths

### Technology options for 200 & 400 Gb/s links over fewer MMF fiber pairs
400GBASE-SR4 Example

400G VCSEL 100m SR4 OM4 MMF, (Two VCSEL λ, 4+4 MPO)
DD-QSFP (or OSFP) Form Factor

- 8x50Gbps PAM4 Dual λ VCSEL [looks like SR4 to the end user]
- 4+4 MMF MPO up to 100m OM4
- Uses Same Fiber as 40G SR4 and 100G SR4
- 850nm and 910nm High Reliability VCSEL Sources
- Two VCSEL Wavelengths per Fiber
- Runs at 8x50G but Uses Fiber Like a 4x100G Link
- Commercially available 8x50Gbps Retimer ICs
- Lower cost than any 400G SMF media
- Low power dissipation than any 400G SMF media
### 400G MSAs

<table>
<thead>
<tr>
<th></th>
<th>CFP8</th>
<th>QSFP-DD</th>
<th>OSFP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size (HxLxT)</strong></td>
<td>40x102x9.5</td>
<td>18.35x89.4x8.5</td>
<td>22.58x107.8x13.0</td>
</tr>
<tr>
<td><strong>Terminal Capacity</strong></td>
<td>12-18W</td>
<td>7-10W</td>
<td>12-15W</td>
</tr>
</tbody>
</table>
CFP8 - Targeted @ 400G

- 8 lane version of CFP MSA
- Supports up to 16 lanes vs. 4 of QSFP or QSFP28
- Each of the 16 lanes operates at 25G
- Max. 16 OSFPs per std. linecard slot
- Backward compatible to QSFP & QSFP28
QSFP DD - Targeted @ 400G

- Quad Small Form Factor Pluggable Double Density
- Supports 8 lanes vs. 4 of QSFP or QSFP28
- Each of the 8 lanes operates at 50G (4x rate of QSFP28)
- Max. 36 OSFPs per std. linecard slot
- Backward compatible to QSFP & QSFP28
OSFP - Targeted @ 400G

- Octal Small Form Factor Pluggable
- Slightly Wider & Deeper than QSFP
- Not Backwards Compatible with QSFP or QSFP28
- Max. 32 OSFPs per std. linecard slot
- Roadmap to produce 800G (4x100G)
QSFP DD & OSFP - New MDI
Future Technology for MMF

Mode Division Multiplexing

- Has been used to extend the capability of ‘legacy’ MMF (62.5/125)
- May require the development of a new breed of MM fibers to optimize for many channels
  - “Few Moded Fibers”
  - (I call these ‘Oligo’-mode fibers)
High Speed migration options

Rodney Casteel RCDD/NTS/OSP/DCDC
CommScope – Sr. Field Application Engineer
Chair – TIA Fiber Optic Technology Consortium
Data Centers undergoing change

- Bandwidth Explosion
- Cloud Computing
- Internet of Things
Data Center Model
Traditional 3-Tier Architecture Model
Data Center Model: Leaf/Spine design

- **Leaf Switches**
  - Server Connections

- **Spine Switches**
Data Center Model

Two options for cabling infrastructure architecture:

1. Serial Duplex
   - With SM limited by equipment
   - With standard OM 3/4 multimode limited by existing serial transceivers
   - With WBMMF more options for long term higher speed migration

2. Parallel
   - Can be used with SM and MM fiber
   - Can be used with WBMMF
   - Requires more fibers
WHAT IS HIGH SPEED?

How does your roadmap compare?

Ethernet speed roadmap

- Ethernet speed
- Speed in development
- Possible future speed

Courtesy of Ethernet Alliance
<table>
<thead>
<tr>
<th>Application</th>
<th>Standard</th>
<th>Fiber</th>
<th>Rated Reach</th>
<th>Max. Channel Loss at Rated Reach (dB)</th>
<th>Connection and Splice Loss Allocation at Rated Reach (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-Gigabit Ethernet</td>
<td>10GBASE-SR</td>
<td>MM</td>
<td>400 m (OM4)</td>
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<td>MM</td>
<td>300 m</td>
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<tr>
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<td>220 m</td>
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<td>4.0</td>
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<td>2.6 to 3.0 depending on discrete reflectance</td>
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<td>Standard</td>
<td>Fiber</td>
<td>Rated Reach</td>
<td>Max. Channel Loss at Rated Reach (dB)</td>
<td>Connection and Splice Loss Allocation at Rated Reach (dB)</td>
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<td>200-Gigabit Ethernet</td>
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<td>3.0</td>
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<td>MM</td>
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<td>200 m (OM5)</td>
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<td>0.8</td>
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<td>440 m (OM5)</td>
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<td>2.0</td>
</tr>
<tr>
<td>100G-SWDM4</td>
<td>MM</td>
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<td>150 m (OM5)</td>
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<td>1.4</td>
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<td>3200-M5E-SN-S</td>
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<td>3200-M5F-SN-I</td>
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<td>1.5</td>
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<td>3200-SM-LC-L</td>
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<td>10 km</td>
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<td>2.0</td>
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<td>128GFC-SW4</td>
<td>MM</td>
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<td>128GFC-PSM4</td>
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<td>128GFC-CWDM4</td>
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<td>64GFC</td>
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<td>256GFC</td>
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<td>100G-PSM4</td>
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<td>500 m</td>
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<td>3.0</td>
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<tr>
<td>100G-CDWM4</td>
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<td>5.0</td>
<td>3.9</td>
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<tr>
<td>100G-LRL4</td>
<td>SM</td>
<td></td>
<td>2 km</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Technologies Enabling Higher Capacity per Fiber

- **PAM4**
  - More Efficient Modulation
  - Enabling 50Gb per lane

- **SWDM**
  - More Efficient Fiber Usage
  - Enabling 4 λ per fiber

- **WBMMF**
  - More Efficient Fiber
  - Supporting 4 λ per fiber to practical distances
# Higher Speed Strategies

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>10G NRZ Parallel TX RX</th>
<th>25G NRZ Parallel TX RX</th>
<th>50G PAM4 Parallel TX RX</th>
<th>10, 25, 50G WDM &amp; Parallel TX RX</th>
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</thead>
<tbody>
<tr>
<td>40G</td>
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<td>![40G WDM]</td>
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<tr>
<td>100G</td>
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<td>![100G WDM]</td>
<td>![100G WDM]</td>
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<td>![400G WDM]</td>
<td>![400G WDM]</td>
<td>![400G WDM]</td>
<td>![400G WDM]</td>
</tr>
</tbody>
</table>

*Parallel fibers remain essential to support break-out functionality

- **4λ WDM enabling factor of 4 fiber count reduction**

Imagine running 10G, 40G, 100G, 200G over the same WBMMF cable plant using duplex LC connections *

## Legend
- **Parallel fiber transmission**
- **WDM transmission**
- **WDM + parallel transmission**
# 40G/100G Applications and Multimode Fiber

Maximum reach based on Standards, MSAs and/or vendor specifications

<table>
<thead>
<tr>
<th>Standard</th>
<th># fibers</th>
<th>maximum distance</th>
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<tbody>
<tr>
<td>40GBASE-SR4</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>OM3</td>
<td>100 m</td>
<td></td>
</tr>
<tr>
<td>OM4/OM5</td>
<td>150 m</td>
<td></td>
</tr>
<tr>
<td>40G-BiDi</td>
<td>(2)</td>
<td></td>
</tr>
<tr>
<td>OM3</td>
<td>100 m*</td>
<td></td>
</tr>
<tr>
<td>OM4</td>
<td>150 m*</td>
<td></td>
</tr>
<tr>
<td>OM5</td>
<td>200 m</td>
<td></td>
</tr>
<tr>
<td>40GBASE-eSR4</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>OM3</td>
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<td>300 m</td>
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<tr>
<td>OM4/OM5</td>
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<td>400 m</td>
</tr>
<tr>
<td>40G-SWDM4</td>
<td>(2)</td>
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</tr>
<tr>
<td>OM3</td>
<td></td>
<td>240 m*</td>
</tr>
<tr>
<td>OM4</td>
<td></td>
<td>350 m*</td>
</tr>
<tr>
<td>OM5</td>
<td></td>
<td>440 m</td>
</tr>
<tr>
<td>100GBASE-SR4</td>
<td>(8)</td>
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</tr>
<tr>
<td>OM3</td>
<td>70 m</td>
<td></td>
</tr>
<tr>
<td>OM4/OM5</td>
<td>100 m</td>
<td></td>
</tr>
<tr>
<td>100GBASE-SR10</td>
<td>(20)</td>
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<tr>
<td>OM3</td>
<td>100 m</td>
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</tr>
<tr>
<td>OM4/OM5</td>
<td>150 m</td>
<td></td>
</tr>
<tr>
<td>100GBASE-eSR4</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>OM3</td>
<td></td>
<td>200 m</td>
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<tr>
<td>OM4/OM5</td>
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<td>300 m</td>
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<tr>
<td>100G-SWDM4</td>
<td>(2)</td>
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<tr>
<td>OM3</td>
<td>75 m*</td>
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</tr>
<tr>
<td>OM4</td>
<td>100 m*</td>
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<tr>
<td>OM5</td>
<td>150 m</td>
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</tbody>
</table>

*OM3/OM4 effective modal bandwidth only specified at 850 nm

"In addition to supporting the same 850nm and 1300nm applications as OM4, OM5 provides advantage in the support of future applications using WDM in the wavelength range 850nm to 953nm" (FDIS ISO/IEC 11801-1)
MPO Options

- HIGHER DENSITY
- FEWER COMPONENTS
- MORE COST EFFECTIVE

24 FIBER

- GLOBALLY RECOGNIZED STANDARD
- LARGE EMBEDDED BASE
- SUPPORTS MULTIPLE POLARITY SCHEMES

12 FIBER

- SAME AS 12 EXCEPT ONLY USES 8 FIBERS
- NOT REALLY A STANDARDS RECOGNIZED INTERFACE
- USED MOSTLY FOR –SR4 APPLICATIONS

8 FIBER
Array Connectivity = Application Support Flexibility

<table>
<thead>
<tr>
<th>Multiple 2-fiber applications on 12f cabling</th>
<th>MPO 12 active fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>40G-SR4 breakout to 10G-SR</td>
<td>MPO 8 active fibers</td>
</tr>
<tr>
<td>120Gb/s breakout to 10G-SR</td>
<td>MPO 24 active fibers</td>
</tr>
<tr>
<td>120Gb/s breakout to 40G-SR4</td>
<td>MPO 24 active fibers</td>
</tr>
<tr>
<td>100G-SR10 on 12f cabling</td>
<td>MPO 20 active fibers</td>
</tr>
</tbody>
</table>

6 x duplex LC

4 x duplex LC

12 x duplex LC

3 x MPO 8 active fibers each

2 x MPO 10 active fibers each
Cabling Infrastructure Migration from 10G to 40G

Existing 10G Connections using MPO trunk cabling

Migration to (2) 40G connections while retaining existing MPO cabling

Migration to (3) 40G connections while retaining existing MPO cabling with 100% fiber utilization in trunk cables
Cabling Infrastructure Migration from 10G to 40G

Existing (2) 40G connections using MPO cabling

Migration to 100G connection while retaining existing MPO trunk cabling and adapter panels
**Cabling Infrastructure Breakout of 10G from 40G**

1. **40G breakout to (4) 10G LC using existing 10G cabling**
   - 12f each
   - 4 duplex cords

2. **(2) 40G breakout to (8) 10G LC**
   - 12f each
   - 12f
   - 4

3. **(3) 40G breakout to (12) 10G LC with 100% fiber utilization in trunk cables**
   - 12f each
   - 12f
   - 12f
   - 4
Cabling Infrastructure Breakout of 10G from 100G/120G

120G MPO to (12) 10G LC with individual 10G circuit routing granularity
Cabling Infrastructure Breakout of 40G from 100G/120G

120G MPO breakout to (3) 40G MPO

120G MPO breakout to (3) 40G MPO with 100% fiber utilization in trunk cables
Migration from 10G to 100G with –SR4 and OM4

10GBASE-SR

Server Ethernet Switch

IDA

HDAMDA

OM4 Trunk

OM4 Trunk

100GBASE-SR4

MDA

HDA

Server

OM4 Trunk

Trunk cabling is retained
Migration from 10G to 100G with –SR4 and OM5

All cabling is retained
SUMMARY

Two options for cabling infrastructure architecture:
1. Serial Duplex
2. Parallel

Three options for MPO interface
1. 8 fiber
2. 12 fiber
3. 24 fiber

Many options for Migration Path
1. OM3/OM4
2. OM5
3. SM
THE FABULOUS, FAST MOVING, FEVER PITCH, FOREVER ACCELERATING FIBER FRENZY

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