Is Your Network Ready for 100 Gig?
Specifying Optical Fiber for the Next Generation

John Kamino
OFS
Product Manager – Multimode Fiber
jkamino@ofsoptics.com
Agenda

• Fiber Market Drivers
• Fiber Types and Standards
• Application Standards
• Multimode Fiber Value Proposition
• Conclusions
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IP Traffic Growth

• Global IP traffic will quadruple from 2011 to 2016
• Annual global IP traffic will reach 1.3 zettabytes (1.3x10^{21} bytes) by the end of 2016
• 31% of traffic will be from non-PC devices by 2016
• In 2016 wired devices will account for 39% of IP traffic, while Wi-Fi and wireless devices will account for 61%
• By 2016 the number of IP devices will be nearly 3x the global population

May 30, 2012
IP Traffic Growth

Mobile: Includes mobile data and Internet traffic generated by handsets, notebook cards, and mobile broadband gateways

Internet: Denotes all IP traffic that crosses an Internet backbone

Managed IP: Includes corporate IP WAN traffic, IP transport of TV/VoD

May 30, 2012
Internet Applications

- **YouTube**
  - August 2012 – 72 hours of video uploaded every minute \(^1\)
  - August 2012 – 3 billion hours of video watched/month \(^1\)

- **Apple**
  - July 2012 – Apple sells 17 million new iPads and 26 million iPhones in 2Q2012\(^2\)
  - March 2012 – Apple iTunes hits 25 billion app downloads \(^2\)

- **Facebook**
  - June 2012 – 955 million active users, 552 million daily users

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\(^1\) [http://www.youtube.com/t/press_statistics/](http://www.youtube.com/t/press_statistics/)
\(^4\) [http://newsroom.fb.com/content/default.aspx?NewsAreaId=22](http://newsroom.fb.com/content/default.aspx?NewsAreaId=22)
What is happening today

- **Cloud Computing**
  - Migration to hosted services

- **High Performance Computing**
  - Increased optical density – 40x over previous generations

“Optical Interconnect Opportunities in Supercomputers and High End Computing”
OFC 2012 Tutorial
March 6, 2012
Alan Benner

http://www.princeton.edu/~ddix/cloud-computing.html
**Life after IEEE P802.3ba**

- End-users through the prior HSSG: The next speed of Ethernet must begin when 100GbE done!
- HSSG Bandwidth Forecast for “Core Networking”
  - 2013: 400 Gb/s
  - 2015: 1 Tb/s
- Other bandwidth trends?
- 2011 Formation of:
  IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc

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- IEEE 802.3 Ethernet Bandwidth Assessment Report approved by IEEE 802.3 Working Group – July 2012
- Next step - initiation requested of a Higher Speed Ethernet Consensus Industry Connections activity

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http://www.ieee802.org/802_tutorials/2012-07/BWATutorial_D1_12_0716.pdf
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# Fiber Types

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>ISO/IEC 11801 ANSI/TIA-568-C.3 (cable)</th>
<th>IEC 60793-2-10 (fiber)</th>
<th>TIA/EIA (fiber)</th>
<th>ITU-T (fiber)</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.5/125</td>
<td>OM1&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>A1b</td>
<td>492AAAAA</td>
<td>---</td>
</tr>
<tr>
<td>50/125</td>
<td>OM2&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>A1a.1</td>
<td>492AAAB</td>
<td>G.651.1</td>
</tr>
<tr>
<td>50/125</td>
<td>OM3</td>
<td>A1a.2</td>
<td>492AAAC</td>
<td>---</td>
</tr>
<tr>
<td>50/125</td>
<td>OM4</td>
<td>A1a.3</td>
<td>492AAAD</td>
<td>---</td>
</tr>
<tr>
<td>Std SM</td>
<td>OS1</td>
<td>B1.1</td>
<td>492CAAAA</td>
<td>G.652.A or B</td>
</tr>
<tr>
<td>Low Water Peak SM</td>
<td>OS2&lt;sup&gt;(5)&lt;/sup&gt;</td>
<td>B1.3</td>
<td>492CAAB</td>
<td>G.652.C or D</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> OM1 is typically 62.5µm, but can also be 50µm

<sup>(2)</sup> OM2 is typically 50µm, but can also be 62.5µm

<sup>(5)</sup> OS2 is referenced in the standard ISO/IEC 24702 "Generic Cabling for Industrial Premises"
## Multimode Fiber Types, Performance Grades

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Wavelength (nm)</th>
<th>Max Loss (dB/km)</th>
<th>Min Bandwidth (MHz·km)</th>
<th>OFL BW</th>
<th>EMB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OM1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>850</td>
<td>3.5</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
<td>500</td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>OM2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>850</td>
<td>3.5</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OM3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>850</td>
<td>3.5</td>
<td>1500</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OM4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>850</td>
<td>3.5</td>
<td>3500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
<td>500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**OMx designations are from ISO/IEC 11801 International Cabling Standard**

**OFL BW** = Overfilled Launch Bandwidth

**EMB** = Effective Modal Bandwidth

*(also known as “Laser” BW)*
Multimode Fiber Types and Reach

![Graph showing reach and bandwidth by multimode fiber type](image-url)
Multimode Fiber Types and Reach
• Revision TIA-942-A published August 2012
  – Major modifications from ANSI/TIA-942 in **Optical**
    • OM3 and OM4 are now the only recognized multimode media types. OM4 is recommended. OM1 and OM2 fibers are no longer recognized.
    • LC connector is the recognized single fiber (simplex and duplex fiber) connector.
    • MPO is the recognized multi-fiber connector
    • Removed 100 m length limitation on optical fiber horizontal cabling. Now based on individual application requirements.
So What Is Going On With Bend-Insensitive Multimode Fibers (BIMMF)?
Benefits of Bend-Insensitive Multimode Fiber

• Bend-insensitive multimode fiber (BIMMF) provides an opportunity to re-design cable management for improved space efficiency

• Denser, more compact trays and shelves improve airflow and cooling in data center racks and cabinets

• Smaller bend radii allow shorter distances between an adapter faceplate and door front

• BIMMF provides relief from strict cable management policies for standard multimode fiber, but bend radius control and good installation and routing practices must not be abandoned!
# Bend-Insensitive Multimode Fiber Simplified

<table>
<thead>
<tr>
<th>MacroBend Test</th>
<th>Diameter</th>
<th>Standard 50/125 Fiber</th>
<th>Bend-Insensitive Multimode Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 turns 37.5 mm radius</td>
<td>Baseball 36.8 mm radius</td>
<td>850 nm ≤ 0.5 dB 1300 nm ≤ 0.5 dB</td>
<td>850 nm ≤ 0.5 dB 1300 nm ≤ 0.5 dB</td>
</tr>
<tr>
<td>2 turns 15 mm radius</td>
<td>Golf Ball 22.4 mm radius</td>
<td>850 nm ≤ 1.0 dB 1300 nm ≤ 1.0 dB</td>
<td>850 nm ≤ 0.1 dB 1300 nm ≤ 0.3 dB</td>
</tr>
<tr>
<td>2 turns 7.5 mm radius</td>
<td>Dime 9.0 mm radius</td>
<td>NOT DEFINED</td>
<td>850 nm ≤ 0.2 dB 1300 nm ≤ 0.5 dB</td>
</tr>
</tbody>
</table>
What is the Status of Bend-Insensitive Multimode Fiber?

IEC/TIA Standardization process is well underway

- Joint IEC/TIA Task force chaired by OFS’ Dave Mazzarese is leading standardization effort
  - Currently reviewing multimode core diameter and Numerical Aperture (NA) measurement procedures
    - IEC60793-1-43 Numerical Aperture Draft under review
    - IEC60793-1-20 Core Diameter
      » Round Robin underway
  - Reviewing system performance of BIMMFs to determine if current EMB measurement and characterization methods are adequate
    - IEC60793-1-49 DMD Specification being revised to account for leaky modes
  - Documents will be adopted as TIA FOTPs

**Significant progress is being made!**
Comparison of Waveguides

Standard Multimode Fiber

Bend-Insensitive Multimode Fiber

Guided Modes

Leaky Modes

Multimode Fiber Core - Index of Refraction Profile

Trench Added to Index Profile for Improved Macrobend Performance

Standard Core Cross-Section

BIMMF Core Cross-Section
“Halo” provides a visual indicator of BIMMF

A properly designed BIMMF trench has no effect on system performance!

End Face Photographs Of Standard Fiber And BIMMF

Standard 50 µm Fiber

BIMMF 50 µm Fiber
What parameters impact system performance?

• Interoperability / Connection properties
• Bandwidth
• Reliability

It is desirable for optical fibers to be **optimized** for system performance.
Matching Core Size and Numerical Aperture is essential for low loss connections!

<table>
<thead>
<tr>
<th>Fiber Design</th>
<th>Core Diameter</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m</td>
<td>1000 m</td>
<td></td>
</tr>
<tr>
<td>Standard 50 μm</td>
<td>50 μm</td>
<td>0.20</td>
</tr>
<tr>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIMMF Design 1</td>
<td>51 μm</td>
<td>0.21</td>
</tr>
<tr>
<td>0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIMMF Design 2</td>
<td>50 μm</td>
<td>0.21</td>
</tr>
<tr>
<td>0.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Matching long length core diameter and NA provide best connection performance
Leaky modes distort short-length Core Diameter and NA values in BIMMFs
Matched Long Length Measurements Provide Best Compatibility!

Average Insertion Loss Data
Interoperability with Standard Fiber
N=216

- BIMMF 1 has more than 0.1dB better performance than BIMMF 2!
- 2 meter to 2 meter
- 300 meter to 300 meter
What parameters impact system performance?

- Interoperability / Connection properties
- Bandwidth
- Reliability

It is desirable for optical fibers to be optimized for system performance.
Standard Multimode Fibers

Higher order modes quickly attenuated
No effect on bandwidth
Maximum transmission distance!
Good BIMMFs control leaky mode behavior!

Leaky Modes Propagate in all BIMMF designs
Poor leaky mode control can degrade bandwidth and jeopardize system performance!
System Performance is not comparable for these fibers!

OM4 BI-MMF Systems Link Performance
550 meter link - 10Gb/s

System performance degraded by an additional 1.8 dB!
What parameters impact system performance?

- Interoperability / Connection properties
- Bandwidth
- Reliability

It is desirable for optical fibers to be optimized for system performance.
Fiber Reliability is Critical!

- Fiber reliability is a function of:
  - Mechanical Reliability
    - Inherent glass quality – intrinsic strength
    - Proof test level – extrinsic strength
    - Packaging – cable design
    - Deployment
  - Optical Reliability
    - Maintaining optical signal through the link
    - Sufficient bandwidth to support future system upgrades
Should you do this?

- What is the expected lifetime of this jumper?

Fiber bend radius approximately 1-2 mm

Expected time to mechanical failure
1 mm bend ~ 1 month
2 mm bend ~ 5 years
Summary of Bend-Insensitive Multimode Fiber

- Bend-insensitive fibers offer significantly improved bending loss, and can improve cable management problems in today’s high density interconnects.
- It is prudent to balance macrobend performance with other fiber parameters including bandwidth and interoperability to optimize system performance.
- Bend-insensitive multimode fiber standardization is currently underway.
  - Significant progress is being made and technical content completion is targeted for the end of 2012.
- Bend-insensitive fiber is **NOT** a substitute for proper cable management.
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• Conclusions
Evolution of Short Reach Applications
## Ethernet Link Distance/ Application Mapping

<table>
<thead>
<tr>
<th>Application</th>
<th>Data Center Building Backbone</th>
<th>Lg. Data Center Building Backbone</th>
<th>Very Lg. Data Center Building Backbone</th>
<th>Building Backbone Campus Backbone</th>
<th>Campus Backbone</th>
<th>Campus Backbone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100Mb/s 100BASE-FX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Gb/s 1000BASE-SX</td>
<td>OM3/OM4 Multimode Fiber</td>
<td>OM4 Multimode Fiber</td>
<td>OS1/OS2 Single-mode Fiber</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Gb/s 10GBASE-SR</td>
<td>OM4 Multimode Fiber</td>
<td></td>
<td></td>
<td>OM4 Multimode Fiber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 Gb/s 40GBASE-SR4</td>
<td>OM4 Multimode Fiber</td>
<td>OS1/OS2 Single-mode Fiber</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 Gb/s 100GBASE-SR10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Link Distance</td>
<td>33m</td>
<td>83m</td>
<td>100m</td>
<td>150m</td>
<td>275m</td>
<td>300m</td>
</tr>
</tbody>
</table>
40G & 100G Ethernet (IEEE 802.3ba)

Reach & Media:

✓ **40 Gb/s** for servers, HPC, SAN, NAS
  - 10 km on SMF (1310nm) 40GBASE-LR4
  - 100 m on OM3 MMF (850nm) 40GBASE-SR4
  - 150 m on OM4 MMF (850 nm) 40GBASE-SR4
  - 7 m over copper 40GBASE-CR4
  - 1 m over backplane 40GBASE-KR4

✓ **100 Gb/s** for switching, routing, aggregation
  - 40 km on SMF (1310nm) 100GBASE-ER4
  - 10 km on SMF (1310nm) 100GBASE-LR4
  - 100 m on OM3 MMF (850nm) 100GBASE-SR10
  - 150 m on OM4 MMF (850nm) 100GBASE-SR10
  - 7 m over copper 100GBASE-CR10
High Speed Short Reach Technologies: Multiple Fiber Parallel Systems

for 40G:

- One 12-fiber cable
  - duplex link
  - 8 active fibers
- 12 fiber MPO connector
- One wavelength per fiber
- 4 x 10 Gb/s
High Speed Short Reach Technologies: Multiple Fiber Parallel Systems

**for 100G:**
- Two 12 fiber cables, or 24 fiber Cable
  - 20 Active
  - Duplex link
- MPO connector
  - 2 x 12 fiber
  - 1 x 24 fiber
- One wavelength per fiber
- 10 x 10 Gb/s
40G & 100G Ethernet – MDI Recommendations

References MPO interface req’s/specs of IEC 61754-7.

**40GBASE-SR4**

- Left 4 fibers are Tx
- Right 4 fibers are Rx
- (inner 4 fibers unused)

**100GBASE-SR10**

- Inner 10 fibers, Top Row are Rx
- Inner 10 fibers, Bot Row are Tx
- (outermost fibers both rows unused)

- Inner 10 fibers, Left Side are Tx
- Inner 10 fibers, Right Side are Rx
- (outermost fibers each side unused)

- Inner 10 fibers, Top are Rx
- Inner 10 fibers, Bot are Tx
- (outermost fiber Top & Bot unused)

**Option A**

(recommended)

**Option B**

**Option C**
• Reduced reach of 100 m on OM3, 150 m on OM4 compared to 10G (300 m on OM3, 550 m on OM4) is due to relaxation of transmitter spectral width:
  – from 0.45 to 0.65 nm

There have been no changes to the fiber itself!

• 150 m on OM4 expected to support 95%+ of Data Center links.
Why is OM4 important to 100G?

Alan Flatman – Principal Consultant, LAN Technologies, UK
“Long Data Center Links vs. Length”
IEEE802.3ba, Jan. 2008, Flatman_01_0108
Ethernet – Next Generation

- Next Generation 100 Gb/s Optical Ethernet Study Group
  - 4x25 Gb/s transmission
  - Different options discussed – not all will be chosen

<table>
<thead>
<tr>
<th></th>
<th>SM/MM</th>
<th>Wavelength (nm)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel</td>
<td>MM</td>
<td>850</td>
<td>100-150 m</td>
</tr>
<tr>
<td>Parallel</td>
<td>SM</td>
<td>1310</td>
<td>0.5-2 km</td>
</tr>
<tr>
<td>Duplex</td>
<td>SM</td>
<td>1310</td>
<td>8/16 level signaling</td>
</tr>
<tr>
<td>WDM</td>
<td>SM</td>
<td>1310/1550</td>
<td>Integrated Photonics</td>
</tr>
</tbody>
</table>

Bicsi®
Can Multimode Fiber Transmit 25 Gb/s?

25 Gb/s Test bed at GA Tech

- Pattern Generator
- 40GHz Bias-Tee
- VIS 40G VCSEL
- XYZ stage
- 40GHz 15dB Amplifier
- 2ft RF cable
- 150um pitch GSG probe
- 50um glass
- 62.5um Lensed fiber
- High Speed TIA
- 50GHz Sampling Scope
- 50GHz Sampling Scope

C. Patrick Caputo - Georgia Institute of Technology
Stephen E. Ralph - Georgia Institute of Technology
Yi Sun - OFS

Georgia Tech College of Engineering

Bicsi
Early 25 Gb/s Transmission Test Results

Open Eye Diagram

25 Gb/s transmission over 200 m OM4 fiber!!!
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Comparison between Single-mode and Multimode Fiber Systems

Traditionally, optoelectronics have driven the cost difference between single-mode and multimode

- Single-mode CWDM system
  - Pro: Lower cabling cost
  - Con: Significantly higher transceiver cost
  - Con: Higher power consumption
  - Con: Larger size

- OM3 and OM4 multimode parallel systems
  - Pro: Much lower transceiver cost using existing 10 Gb/s VCSELs
  - Pro: Lower power consumption
  - Pro: Smaller footprint
  - Con: Higher cabling cost
100 Gb/s Link Cost Comparison
SM vs MM

Source data: SanSpot.com August 2012
PEPPM.org, last update June 2012
Power Consumption

• Lower power consumption critical as link density and speed increase
  – 100G CFP single-mode transceivers consume 20+ watts
  – 100G CXP multimode transceivers consume ~5 watts

• Savings ~ 15 watts/transceiver

• Cooling – another 15 watts/transceiver
Single-mode vs. Multimode Module Size

- Significantly larger footprint for single-mode CFP module
- Much lower faceplate density
  - 4 single-mode modules in 1U footprint vs. 16-32 multimode modules!
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Conclusions

• OM3 and OM4 Multimode Fiber is the media of choice for short reach 100 Gb/s transmission rates
  – In the data center and enterprise “sweet spot”
  – Only multimode fibers recognized in ANSI/TIA-942-A
    • OM4 fiber recommended

• 100 Gb/s 4X25 solution could be a painless infrastructure upgrade from 40 Gb/s 4x10 technology
Thank You!