Overview of Today's Multimode & Singlemode Optical Fibers - Standards and Practical Usage

N.E. Region BICSI Meeting
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Agenda

- Review of Multimode and Singlemode Fibers
- Fiber Standards
- Application Considerations
  - Specifications / Performance based on standards
  - Practical Performance opportunities
- What’s in store for the future of optical fiber
Two Basic Optical Fiber Types

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

2. Single-mode
- ~8 micron core
- 1310 - 1625 nm Wavelengths

Larger cores and lower wavelengths drive source and system costs down.
Modal Dispersion in MMF

- 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

Input Pulse

Output Pulse

1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1

1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
Singlemode Fiber

Small core guides only one mode

- Eliminates modal dispersion.
- Enables tremendous transmission capacity over very long distances.
Fiber Standards
Multimode Fiber Types

Described in the industry using primarily the ISO/IEC 11801 designations

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>ISO/IEC 11801</th>
<th>Industry Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.5/125</td>
<td>OM1&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>A1b</td>
</tr>
<tr>
<td>50/125</td>
<td>OM2&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>A1a.1</td>
</tr>
<tr>
<td>50/125</td>
<td>OM3</td>
<td>A1a.2</td>
</tr>
<tr>
<td>50/125</td>
<td>OM4</td>
<td>A1a.3</td>
</tr>
</tbody>
</table>

ISO/IEC 11801: IEC 60793-2-10 | TIA/EIA | ITU-T
---|---|---
492AAAA | --- | ---
492AAAB | G.651.1 | ---
492AAAC | G.651.1 | ---
492AAAD | G.651.1 | ---

<sup>(1)</sup> OM1 is typically a 62.5um fiber, but can also be a 50um fiber.

<sup>(2)</sup> OM2 is typically a 50um fiber, but can also be a 62.5um fiber.
# Multimode Fiber Types

## Multimode

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>ISO Designation</th>
<th>Attnenuation&lt;sup&gt;(1)&lt;/sup&gt; - Typical Cabled Max. (dB/km)</th>
<th>Bandwidth (MHz-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ISO Designation</td>
<td>850nm</td>
<td>1300nm</td>
</tr>
<tr>
<td>62.5/125</td>
<td>OM1</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>50/125</td>
<td>OM2</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>50/125</td>
<td>OM3</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>50/125</td>
<td>OM4</td>
<td>3.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> The ISO/IEC 11801 standard stipulates max cabled attenuation. The IEC and TIA fiber standards call for lower (and varied) bare fiber attenuation.
## Singlemode Fiber Types

<table>
<thead>
<tr>
<th>SM Fiber Type</th>
<th>ISO / IEC 11801</th>
<th>TIA</th>
<th>IEC 60793-2-50</th>
<th>ITU-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>OS1</td>
<td>492CAAA</td>
<td>B1.1</td>
<td>G.652.A or B</td>
</tr>
<tr>
<td>Low Water Peak</td>
<td>OS2</td>
<td>492CAAB</td>
<td>B1.3</td>
<td>G.652.C or D</td>
</tr>
</tbody>
</table>
## Singlemode Fiber Types (continued)

<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</td>
<td>1.0</td>
<td>Typically Tight Buffer</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>1383</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS2</td>
<td>1310</td>
<td>0.4</td>
<td>Typically Loose Tube</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>1383</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**OSx designations are from ISO/IEC 11801 International Cabling Standard**
Singlemode Fiber Types – Low & Zero Water Peak
(G.652.C & D and G.657.A)

- **Conventional SMF** (G.652A or B)
- **LWP SMF** (G.652C or D)
- **ZWP SMF** (G.652D)

![Diagram showing loss vs wavelength for different fiber types](image-url)
# Singlemode Fiber Types – Bend-Insensitive

*(G.657.xx)*

<table>
<thead>
<tr>
<th>Minimum Design Radius</th>
<th><strong>Category A</strong> <em>(G.652D Compliant)</em></th>
<th><strong>Category B</strong> <em>(G.652D Compatible)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td><strong>G.657.A1</strong></td>
<td></td>
</tr>
<tr>
<td>7.5 mm</td>
<td><strong>G.657.A2</strong></td>
<td><strong>G.657.B2</strong></td>
</tr>
<tr>
<td>5.0 mm</td>
<td></td>
<td><strong>G.657.B3</strong></td>
</tr>
</tbody>
</table>

- **For traditional Longer Reach Applications**
- **For Shorter Reach Applications** *(FTTH, MDU, in-building wiring)*
Fiber Type and Application Considerations
MM or SM?  Speed, Reach, Cost...

- **Up to 10G**  *(Enterprise & Campus Backbones, “Simple” Data Centers)*
  - Multimode up to **600m** (~2000 ft)
    - OM3 to 300m
    - OM4+ to 600m

- **40G & 100G**  *(Data Centers, High Performance Computing)*
  - Multimode up to **150m** (~500 ft)
    - OM3 to 100m
    - OM4 to 150m

*Total installed cost of a Multimode system continues to be less expensive than the cost of a Singlemode system.*
Extended Reach 40G Transceivers for Multimode

- Avago AFBR-79E3PZ QSFP+ eSR4
- Finisar FTL410QD2C QSFP+
- IBM QSFP+ 40GBase-eSR4 (00FE325)

Support up to 300m/400m using OM3/OM4 MMF
MM continues to be cost effective for short reach

- Cost of optics (transceivers) dominates link.
- Power Consumption of MM optics is 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>1.5</td>
</tr>
<tr>
<td>40GBASE-SR4</td>
<td>MM</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>40GBASE-LR4</td>
<td>SM</td>
<td>10</td>
<td>3.5</td>
</tr>
<tr>
<td>100GBASE-SR10</td>
<td>MM</td>
<td>18</td>
<td>3.5</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>SM</td>
<td>60</td>
<td>8</td>
</tr>
</tbody>
</table>

Cost References:
- www.sanspot.com
- www.cdw.com
- Oct. 2014

Power Consumption References:
- www.finisar.com
- www.avagotech.com
- Oct. 2014
Which Multimode Should I Use?

62.5 um? (OM1)
50 um? (OM2, OM3, OM4...)

- Data Center and Cabling Standards are starting to drop OM1 62.5um fiber, and even OM2 50um, calling out Laser-Optimized OM3 & OM4 only, with “OM4 preferred”.

- OM3 or OM4 required for reasonable LAN / Campus 10G backbone distances.

- Only OM3 and OM4 can be used for 40G and 100G.

- Mixing different types or grades of multimode not recommended, but technically feasible if absolutely necessary.
  
  - Can mix 50um and 62.5um in a system when separated by active electronics.
  
  - If connected together directly, you may incur large one-way connection loss.
  
  - Overall reach of link de-rated based on lesser bandwidth.
North America Multimode Product Mix
Primarily Enterprise Applications

North American MMF Product Mix Trend
(Note: OM3 Data includes OM4 through 4Q2009)

Source: Burroughs MM Report, 2Q-14

Source: Burroughs MM Report, 2Q-14
Increasingly tight system attenuation requirements!

1.5 dB for 40/100 Gb/s Ethernet on OM4 fiber!!
### 40 & 100G on Multimode – Tight Loss Budgets

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Loss Budget</th>
<th>Reach</th>
<th>Fiber Atten</th>
<th>Connection Loss Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM3</td>
<td>1.9 dB</td>
<td>100m</td>
<td>0.35 dB</td>
<td>1.55 dB</td>
</tr>
<tr>
<td>OM4</td>
<td>1.5 dB</td>
<td>150m</td>
<td>0.525 dB</td>
<td>0.975 dB</td>
</tr>
</tbody>
</table>
Minimizing Channel Insertion Loss

- Use low-loss fiber.
  - Allows for lower cable attenuation.

- Use fiber with tighter Glass Geometry specs. 
  \textit{(Clad Diameter, Clad Non-Circularity, Core / Clad Concentricity)}.
  - Provides for better core-to-core alignment for minimal connection / splice loss.

- Use fiber with exceptional DMD control and tighter DMD specs.
  - Incurs less ISI (Bandwidth) penalty, providing more headroom and reliability.
Improved Glass Geometry Specs provides better core-to-core alignment for minimal connection loss.

- Smaller gap between ferrule and fiber
- Core better centered
- Better matching of NA
Glass Geometry Specs for Minimizing Connection Loss

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Industry Standard Specs</th>
<th>Recommended Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical Aperture (NA)</td>
<td>0.200 ± 0.015</td>
<td>0.200 ± 0.010</td>
</tr>
<tr>
<td>Clad Diameter</td>
<td>125.0 ± 2 µm</td>
<td>125.0 ± 0.8 µm</td>
</tr>
<tr>
<td>Clad Non-Circularity</td>
<td>≤ 2%</td>
<td>≤ 0.7%</td>
</tr>
<tr>
<td>Core-Clad Concentricity</td>
<td>≤ 3 µm</td>
<td>≤ 1.0 µm</td>
</tr>
</tbody>
</table>

*Can save several tenths of a dB per connection.*
40G on Multimode (40GBASE-SR4)

Parallel Transmission

Multiple Fibers – 4 each direction

for 40G:

- One 12-fiber cable
  - duplex link
  - 8 active fibers
- 12 Fiber MPO connector
- One wavelength per fiber
- 4 x 10 Gb/s
for 100G:

- Two 12f Cables, or 24f Cable
  - 20 Active
  - Duplex link
- MPO connector
  - 2 x 12 fiber
  - 1 x 24 fiber
- One wavelength per fiber
- 10 x 10 Gb/s
**FUTURE 100G on Multimode** (100GBASE-SR4)

*Will utilize 25 Gb/s per fiber.*

**25Gb/s transmission over 200m of OM4 Fiber**
Multiple Fibers – 4 each direction

- One 12-fiber cable
  - duplex link
  - 8 active fibers
- 12 Fiber MPO connector
- One wavelength per fiber
- 4 x 25 Gb/s
Multiple Lasers and Detectors on one fiber

Lasers

Combiner

Cladding

Detectors

Splitter

40G & 100G on Singlemode

Wavelength Division Multiplexing (CWDM) Transmission

40GBASE-LR4: 4 x 10G = 40G
100GBASE-LR4: 4 x 25G = 100G
Future Fiber Technology
Multimode

• Will continue to employee parallel (multiple) fibers.
  – 16f x 25G or possibly 8f x 50G for 400G
• Also exploring CWDM on multimode fiber for 400G
  – Ideally 4 wavelengths per fiber.
  – Results in a combination of CWDM and multiple fibers.
    ▪ e.g. 4f x 4λ x 25G
• Logical upgrade path 40G → 100G → 400G.
  – Already set precedent of multiples of 8 fibers (4 each direction).
    ▪ 40G: 4f x 10G
    ▪ 100G: 4f x 25G

Singlemode

• Will continue to employ CWDM on single fibers.
Future Fiber Technology

- **CWDM on Multimode Fiber**
  - Several presentations made at recent TIA meeting showing feasibility.
  - Considering operation in the 850 to ~950nm range.
  - Involves Transceiver vendors.

- **Bend-Insensitive Singlemode Fiber**
  - General increase in use of BI SM Fiber in large Data Centers.
    - Preparation for deployment of WDM multi-wavelength systems for higher speeds.
## Bend-Insensitive Singlemode Fibers

**Good Bend and Splicing Performance**

<table>
<thead>
<tr>
<th>ITU-T Fiber Type</th>
<th>Nominal MFD</th>
<th>1550nm Loss @ Bend Radius</th>
<th>Splicing to G.652.D Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.652.D</td>
<td>9.2 um</td>
<td>0.05 dB @16 mm</td>
<td>Seamless</td>
</tr>
<tr>
<td>G.657.A1</td>
<td>8.9 um</td>
<td>0.75 dB @10 mm</td>
<td>OK</td>
</tr>
<tr>
<td>G.657.A2</td>
<td>8.8 um</td>
<td>0.50 dB @7.5 mm</td>
<td>OK</td>
</tr>
<tr>
<td>G.652.D &amp; G.657.A1</td>
<td>9.2 um</td>
<td>0.75 dB @10 mm</td>
<td>Seamless</td>
</tr>
</tbody>
</table>
A move toward 16 fiber units

- Ethernet transmission speeds are moving from 10G per lane to 25G per lane to support higher data rates.

- Likely upgrade paths for multimode fiber results in units of 4 fibers:
  - $40G \div 10G \text{ per fiber} = 4 \text{ fibers}$
  - $100G \div 25G \text{ per fiber} = 4 \text{ fibers}$
  - $400G \div 25G \text{ per fiber} = 16 \text{ fibers}$

- 16 fiber units work better than 12 fiber units in supporting full fiber utilization.

- Proposals in TIA to support include:
  - Polarity descriptions that cover n-number of fiber units (TR 42.11)
  - 16-pin MPO connector (TR 42.13)
  - 4 new fiber colors to support 16-fiber ribbons / bundles (TR 42.12)
Multimode Fiber Manufacturing
Minimize Modal Dispersion / DMD – Maximize Bandwidth

Input Pulse

Output Pulse

1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0
Refractive Index Profile in MMF

An optimized Refractive Index Profile minimizes DMD and maximizes Bandwidth.

Equalizes arrival times of all the modes.

Refractive Index Profile

$(Graded\ Index)$

$n = \frac{c}{v_g}$
OFS’ Modified Chemical Vapor Deposition (MCVD) Process for Multimode Preform Mfg

- Each layer sintered prior to deposition of the next layer.
- Inside process is immune to contamination.
Fiber
Draw
Tower

- Downfeed motor
- X-Y preform positioner
- Furnace
- Clad diameter measurement gage
- Cooling tube
- Coating applicator
- Clad-Coating Concentricity monitor
- Coating Cure
- Coating diameter measurement gage
Final Test & Measurement

- **Prooftest**
  - 1% strain, 100 kpsi

- **OTDR**
  - Length
  - Attenuation, Attenuation Uniformity, Point Discontinuities

- **Optical**
  - Attenuation, Bandwidth, Hi-Res DMD, Numerical Aperture (MM)
  - Attenuation, Cutoff, Mode Field Diameter, Dispersion, PMD (SM)

- **Geometry**
  - Glass-- Core & Clad Diameter, Non-Circularity, Eccentricity
  - Coating-- Diameter, Non-Circularity, Eccentricity

- **Final Visual & Specification Verification**