Making Connections: Navigating Fiber Optic Cabling and Interconnection Requirements

microwave photonic systems

“Expand Your RF Horizons”
Microwave Photonic Systems, Inc. is a full service design and integration engineering firm, that specializes in the development and manufacture of RF/Microwave and fiber optic components, cable assemblies, modules and systems.

Microwave Photonic Systems, Inc. provides products and services to a wide array of military and commercial customers, who operate in the Broadband, Defense, Telecommunications, SATCOM, and Wireless markets.

Microwave Photonic Systems, Inc. was incorporated supporting the RF Optical Market since 1999.
Purpose – Fiber Optic Cabling and Interconnection Fundamentals

• Provide Basic Education on Fiber Optic Technology

• Review Optical Cable and Connector Types

• Define Key Terms used in the Fiber “Conversation”

• Discuss Measurement and Analysis Techniques / Standards

• Emphasize Importance of Connector End-face Geometry and Cleanliness

• Equip Project Stakeholders with Knowledge to Make Performance & Cost-Wise Decisions
Where is fiber?

- Anywhere data can be transported
- Data Centers / Cloud Computing / CCTV Networks
- Fiber to the “X” (FTTX) Applications such as Cable Television
  - FTTH (Fiber to the Home), FTTC (Fiber to the Classroom),
- Industrial Oil, Mining and Gas
- Satellite Communications & Earth Terminals
- Signal Repeaters for Railways, Subways, Tunnels
- Metro Area Networks, Public Wi-Fi, CCTV Networks
- In-Building Distributed Antenna Systems
- Commercial Broadcast & Entertainment
Why use fiber?

- Data carrying capacity much greater than copper
- Loss over distance much less than coax cables
- Uniform loss over frequency (RF over Fiber Applications)
- Scalable solutions from low to high density
- Lightweight, Easy to Install, Long Lasting
- Immunity to Lightning Strikes & RF Interference
- Mature and robust technology readily available
Basic Fiber Optic Communication System

- Digital Data – Ones & Zero's – Ethernet over Fiber

- Analog Signals – Amplitude Modulated - RF over Fiber
Types of Optical Sources and Optical Detectors

- Different Sources for Different Applications
- Optical Source May Vary From One Network to Another
- Knowing The Device Helps Select Proper Optical Cable

<table>
<thead>
<tr>
<th>Light Source</th>
<th>LED</th>
<th>FP</th>
<th>DFB</th>
<th>VCSEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Distance</td>
<td>Short Range</td>
<td>Medium Range</td>
<td>Long Range</td>
<td>Medium Range</td>
</tr>
<tr>
<td>Transmission Speed</td>
<td>Low Speed</td>
<td>High Speed</td>
<td>Very High Speed</td>
<td>High Speed</td>
</tr>
<tr>
<td>Transmission Frequency</td>
<td>Wide Spectral Width</td>
<td>Medium Spectral Width</td>
<td>Narrow Spectral Width</td>
<td>Narrow Spectral Width</td>
</tr>
<tr>
<td>Cost</td>
<td>Low Cost</td>
<td>Moderate Cost</td>
<td>High Cost</td>
<td>Low Cost</td>
</tr>
</tbody>
</table>
Optical Fiber & Cable Construction

- Many different vendors with many different variations
- Only a few key “glass” manufacturers
  - Corning, Alcoa Fujikura Ltd (AFL)
- All others specialize in making the cables
  - Jacketing, Coloring, Armoring
- Design trade-offs exists across all variants
  - Single Fiber, Multi-Fiber, Distribution vs Breakout, Ribbonized
Multimode Fiber

Multimode Fiber:
- Larger Core
- Shorter Distances/ Lower Bandwidth
- Graded-Index / Step Index
- More Common in Legacy Systems
Why Singlemode over Multimode?

- Modes can take different paths within Multi-Mode Fiber
- Different paths = different transit times between TX and RX
- Modes that take the high angle path arrive later than those of the low angle path.
- Different transit times cause “Dispersion” of the optical signal
- Dispersion causes pulse spreading
- Pulse Spreading Limits Available Bandwidth. Note: This is true for both digital and analog transmission distances
- Dispersion limits the bandwidth of multimode fiber to 1 GHz/km
Single Mode Fiber

Singlemode Fiber:
- Smaller Core
- Longer Distances
- Greater Bandwidth
- Most commonly used today
### Visually Identifying Optical Cables

<table>
<thead>
<tr>
<th>Buffer/jacket color</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Single-mode optical fiber</td>
</tr>
<tr>
<td>Orange</td>
<td>Multi-mode optical fiber</td>
</tr>
<tr>
<td>Aqua</td>
<td>10 Gig laser-optimized 50/125 μm MM optical fiber</td>
</tr>
<tr>
<td>Grey</td>
<td>Outdated color code for MM optical fiber</td>
</tr>
<tr>
<td>Blue</td>
<td>Sometimes used to designate Polarization-Maintaining optical fiber</td>
</tr>
</tbody>
</table>
# Useful Quick Reference Tables

<table>
<thead>
<tr>
<th>Name</th>
<th>Diameter</th>
<th>Jacket Colors</th>
<th>Optical Source</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM1</td>
<td>62.5/125 μm</td>
<td>Orange</td>
<td>LED</td>
<td>200MHz•Km</td>
</tr>
<tr>
<td>OM2</td>
<td>50/125 μm</td>
<td>Orange</td>
<td>LED</td>
<td>500MHz•Km</td>
</tr>
<tr>
<td>OM3</td>
<td>50/125 μm</td>
<td>Aqua</td>
<td>VCSEL</td>
<td>2000MHz•Km</td>
</tr>
<tr>
<td>OM4</td>
<td>50/125 μm</td>
<td>Aqua</td>
<td>VCSEL</td>
<td>4700MHz•Km</td>
</tr>
</tbody>
</table>

## Color Coding

<table>
<thead>
<tr>
<th>Color Coding</th>
<th>Jacket</th>
<th>Jacket Nomenclature</th>
<th>Connector</th>
<th>Connector Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM1 62.5-μm Multimode</td>
<td>Orange</td>
<td>62.5/125</td>
<td>Beige</td>
<td>Beige</td>
</tr>
<tr>
<td>OM2 50-μm Multimode</td>
<td>Orange</td>
<td>50/125</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>OM3 50-μm Multimode</td>
<td>Aqua</td>
<td>850 50/125</td>
<td>Aqua</td>
<td>Black</td>
</tr>
<tr>
<td>OS1 APC Single-mode</td>
<td>Yellow</td>
<td>SM/NZDS, SM</td>
<td>Green (MPD is black)</td>
<td>Green</td>
</tr>
<tr>
<td>OS1 UPC Single-mode</td>
<td>Yellow</td>
<td>SM/NZDS, SM</td>
<td>Blue</td>
<td>Blue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interface Type</th>
<th>Fiber Optic Patch Cable Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE-SX</td>
<td>Multimode OM1, OM2 Cable</td>
</tr>
<tr>
<td>1000BASE-LX</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>1000BASE-EX</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>1000BASE-ZX</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>10GBASE-SR</td>
<td>Multimode OM3, OM4 Cable</td>
</tr>
<tr>
<td>10GBASE-LR</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>10GBASE-ER</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>10GBASE-ZR</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>40GBASE-SR4</td>
<td>Multimode OM3, OM4 Cable</td>
</tr>
<tr>
<td>40GBASE-LR4</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>40GBASE-ER4</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>100GBASE-SR10</td>
<td>Multimode OM3, OM4 Cable</td>
</tr>
<tr>
<td>100GBASE-SR4</td>
<td>Multimode OM3, OM4 Cable</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>Single-mode Cable</td>
</tr>
<tr>
<td>100GBASE-ER4</td>
<td>Single-mode Cable</td>
</tr>
</tbody>
</table>
Many different vendors – Common Standards
Design trade-offs exists across all variants
Vendor base has various quality levels

### Connectors for Any Application

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Coupling Type</th>
<th>Fiber Type / Multimode</th>
<th>Polish</th>
<th>No. of Fibers</th>
<th>Typical Applications</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST</td>
<td>Twist on</td>
<td>Single mode</td>
<td>PC, UPC</td>
<td>1</td>
<td>LANs</td>
<td>Keyed</td>
</tr>
<tr>
<td>FC</td>
<td>Screw on</td>
<td>Single mode</td>
<td>PC, UPC, APC</td>
<td>1</td>
<td>Datacom, Telecommunications</td>
<td>Keyed</td>
</tr>
<tr>
<td>SC</td>
<td>Snap on</td>
<td>Single mode</td>
<td>PC, UPC, APC</td>
<td>1</td>
<td>CATV, Test Equipment</td>
<td>Keyed</td>
</tr>
<tr>
<td>LC</td>
<td>Snap on RJ45 style</td>
<td>Single mode</td>
<td>PC, UPC, APC</td>
<td>1</td>
<td>Gigabit Ethernet, Video Multimedia</td>
<td>Small Form Factor (SFF)</td>
</tr>
<tr>
<td>MU</td>
<td>Push/Pull</td>
<td>Single mode</td>
<td>PC, UPC, APC</td>
<td>1</td>
<td>Medical, Military</td>
<td>Small Form Factor (SFF)</td>
</tr>
<tr>
<td>MT-RJ</td>
<td>Snap on RJ45 style</td>
<td>Single mode</td>
<td>N/A</td>
<td>2</td>
<td>Gigabit Asynchronous Transmission Mode (ATM)</td>
<td>One of Mating Connectors must have Alignment Pins</td>
</tr>
<tr>
<td>MPO (MTP)</td>
<td>Push/Pull</td>
<td>Single mode</td>
<td>N/A</td>
<td>4, 8, 12, 16, 24</td>
<td>Active Device Transceiver, Interconnections for O/E Modules</td>
<td>One of Mating Connectors must have Alignment Pins</td>
</tr>
</tbody>
</table>
Key Terms: Insertion Loss and Return Loss
Aim to minimize Reflections and Losses
Always match proper connector to TX & RX
Different Connectors May Exist In-between TX & RX
Hybrid Adapters Allow Mating Between Different Connectors
Use Hybrid Jumpers To Transition Between Different Polishes
Remember that Connector Boot Color Reflects Polish Type
- Typically: Black = PC, Blue = UPC, Green = APC
Basic Connector Process

- Strip and Prep Cable
- Epoxy Connector
- Insert Fiber into Connector
- Crimp Assembly
- Oven Cure
- Polish
- Test
Polishing is an Artform – Built on Years of Experience

Typical oven for curing optical termini

Typical Optical Polishing Machine
Telcordia GR-326 defines connector end-face geometry requirements.
Polishing Process Impacts Optical Alignment

Good Apex

Apex Offset
A Clean End Face

9/125µm Singlemode Fiber
With core illuminated
Dirty Connectors – Poor Process / Poor Handling
Inspect 100%

- Minimum of 400X magnification optics
- Optimum is a benchtop system with large LCD for connector ends.
- A handheld inspection probe for connector receptacles.
Good vs Ugly Cables

• Optical Link Loss Budget (Power Budgets) need to be maintained in order for the system to function properly.
• Low quality fiber connectors have higher insertion loss, thereby consuming loss budgets
• Poorly polished or manufactured cables impact interoperability/intermateability. Alignment issues impact return loss and insertion loss.
• Dirty/Dusty manufacturing environments result in dirty connectors which produce bad cables and poor testing conditions for qualification.
Inside Plant – Premises Cable - Indoors

- Consider Infrastructure
  - Cable Trays
  - Cable Runs
  - In-Building Conduit
  - Existing Plant Capabilities
- Consider “Future Proofing”
  - Expanded Capabilities
  - Additional Fiber Strands
  - Spares / Upgrades
- Be Aware of Mandatory Building/Design Codes:
  - Plenum Rated Cable
  - Riser Rated Cable
  - Low Smoke Zero Halogen Shipboard Cable
Outdoor Cable - Aerial Cabling

- Cable Selection Considerations
  - Lashed vs. Self Supporting
  - Armored vs. Unarmored
  - High Tensile Strength
  - Breakout Cable Strength
  - Splicing (Ribbon vs. Discrete)
- Environmental Conditions
  - Low Temperatures
  - Rodent Protection
  - UV Protection
Direct Burial

- Trenched In Ground
- Ducted or Conduit
- Armored vs Unarmored
- Water Resistant
- Rodent Protection
- May Need Pulling Eyes
Structured Cable Plant

- Total Solution
- Interconnection Plan
- Support Hardware
- Riser Diagrams
- Teleco / IDF Drawings
Testing and Certifying the Cable Plant
How to talk fiber? Key Terms!

• **Transmitter, Receiver, Transceivers:** These are all types of devices which are used to create a fiber optic link.

• **Wavelength:** Refers to the light frequency 1310, 1550 are typical. Others exists within the “ITU Grid Allocation” which defines the wavelengths that can be used in optical networks. Measured in terms of nanometers (nm)

• **Jumper Cable/Patch Cable:** Point to point cable for connectivity between patch panels. When Jumper Cables become very long, we call them “trunk cables”. Simplex = 1 Strand, Duplex = 2 Strand. Duplex cable could be crossover cables if needed.
How to talk fiber? Key Terms!

- **Insertion Loss (Attenuation):** How much signal is lost when the light transits through the cable and connectors. Measure in terms of dB.

- **Return Loss (Back Reflections):** How much signal is reflected at the connector. Good return loss means very little light is reflected in the opposite direction. Measure in terms of dB.

- **Interferometry:** Method by which you can measure and evaluate the quality of the optical connector. Connector quality and polishing process impacts end-face geometry.
How to talk fiber? Key Terms!

- **Breakout / Fanout**: Term used to define how a multi-strand fiber is “broken out” into individual strands. These strands can be called “sub-members”. Note that the term “Breakout Cable” would refer to a multi-fiber cable that has jacketed sub-members (2-3mm) which is different from “Distribution Cable” which is a Multi-fiber cable used for direct point to point connectivity, typically spliced into a panel. Sub-members are tight buffered fiber.
Defining Your Requirements

• What is the application?
  – Data Center, Shipboard, In-Building, Outside Plant?

• What is the current cable plant / infrastructure
  – Single Mode or Multimode? What kind of multimode?

• What kind of cable is needed? What are the mandatory building requirements / codes?
  – Indoor, Outdoor, Indoor/Outdoor, Mil-Tactical, Distribution, Plenum, Riser

• How many fibers?
  – Single Channel or Multi-Channel

• What type of connectors:
  – Same, Different, UPC, APC etc.

• What performance measurements are needed?
  – Insertion Loss, Return Loss, Endface Geometry

• How can we make customer deployment easier?
  – Fanouts, Breakouts, Pulling Eyes, Staggered Leads, Reels
Additional Learning Resources

• Microwave Photonic Systems – 2 or 3 Day Course
• Telcordia Standards Online:
  – Generic Requirements for Optical Fiber & Optical Fiber Cable: GR-326-CORE
• The Fiber Optic Association, Inc:
  – http://www.thefoa.org
• The International Society for Optics and Photonics
  – https://spie.org/
• Fiber Optic Institute
  – http://www.fiberoptic.institute/
Key Points / Webinar Summary

• Recognize and Identify the different types of optical connectors
• Differentiate between types of optical cabling and where they are deployed
• Understand the various steps in how an optical connection is made
• Appreciate the importance of connector cleanliness and endface geometry
• Learn how to specify an optical cable and interconnects
• Consider Microwave Photonic Systems / MPS Fiber Optics for your future requirements.
Questions & Answers