Advances in Robust, Easy to Install Fiber Cabling Systems to Support EtherNet/IP

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Technical Track
Fiber Cabling Systems for EtherNet/IP

Outline Agenda

- Historical Perspective
  - Fiber Media & Connectivity
- SFF Electronics & MDI (Media Device Interface)
  - LC FOCIS-10 Connectors
  - SFF PMD Capabilities
- New Fiber Media Variant
  - What is GI-PCF? Cable styles?
  - Media Value Proposition
  - New GI-PCF connector system
- Reference Architectures/Use Cases
- Solution & Channel Validation of GI-PCF
Historical Perspective
Fiber Use Issues

- For many fiber EtherNet/IP applications, the use of enterprise cabling systems present issues of robustness, and deployment ease by factory personnel.

- Challenges tend to inhibit fiber use and increase Total Cost of Ownership (TCO).

- At the control level, current need simple, robust fiber solutions that support 100Mb/s.

- Need for 1Gb/s uplinks with fiber on switches for resiliency/performance.
Historically, in industrial automation, several lower density fiber interfaces have been deployed such as Straight Tip (ST), Sub Miniature Assembly (SMA), Subscriber Connector (SC) and ‘proprietary’ non-MSA (Multi-Source Agreement) interfaces such as TosLink or Versatile Link.

Industrial Automation equipment vendors are now offering SFP modular transceivers on their switch lines for Gb/s Ethernet Uplinks and switch ports.
SFF Electronics & MDI

MDI – Media Device Interface
(LC Duplex Receptacle)

1GBASE-SX SFP Modular Transceiver

FOCIS-10 LC Connector
SFF Electronics & MDI

- Optical receptacle on the SFP for Ethernet is defined as an LC interface. Most major transceiver vendors, including early proponents of “MT-RJ-only” transceivers, now sell SFPs with the LC interface only.
- The LC is the clear market leader in SFF connectors.
- To support the trend of readily available SFP transceivers in industrial networks, it is imperative that we provide a practical LC field-connection solution.
The Fast Ethernet over Fiber-Optic at 100 Mb/s application (100BASE-FX - 12.5MB/s with auto-negotiation) is a version of Fast Ethernet over optical fiber.

- Uses 1300 nm wavelength transmitted via two strands of optical fiber, one for receive (Rx) and the other for transmit (Tx).

- The standard specifies a max. distance of 2 km (6,600 ft) for full-duplex over FDDI-grade (Fiber Distributed Data Interface) MM optical fiber (large power budget!)
Gb/s Ethernet over Fiber-Optic at 1 Gb/s (1000BASE-SX - 125 MB/s) is a gigabit Ethernet standard for operation over MMF.

- Standard calls for light operating wavelength at approximately 850 nm.
- The standard specifies a distance capability between 220 meters (62.5/125μm with low modal bandwidth) and 550 meters (50/125μm with high modal bandwidth).
- Have to be careful with power budget!
SFF Electronics & MDI
IEEE 802.3z - 1000BASE-SX

- Channel designed around connector Insertion Loss of 1.5dB max (2 connectors of 1.5dB each max.)
- Possible to have higher levels of IL in the 1000BASE-SX channel
- May desire higher #s of connectors in channel or allow for simpler (and higher loss) connectors to be used
New Fiber Solution
Graded Index Polymer Clad Multimode Fiber

- Recently introduced Polymer Clad Fiber (PCF) fibers with improved bandwidth
- Environmentally/mechanically robust fiber
- Rapid connector field termination (simple tools/short learning curve)
- ODVA recognizes the LC (sealed/unsealed) and transceiver OEMs have standardized the SFF LC as the MDI for 1Gb/s+
- Solution useful for 10/100Mb/s and 1Gb/s EtherNet/IP applications
New Fiber Media Variant
Graded Index Polymer Clad Multimode Fiber

62.5/200/230
Graded-index PCF Fiber

‘Traditional’
200/230 PCF
New Fiber Media Variant
Graded Index Polymer Clad Multimode Fiber

- Designed for applications and harsh environments that require high mechanical reliability at the fiber level
- Hard coating, makes possible the vision of “electrician friendly” field terminations
- Silica is a ‘brittle’ material - strength depends on surface flaw severity, not basic material strength
- Under bending/tensile load, surface flaws act as stress concentrators and grow in size resulting in catastrophic fiber failure
New Fiber Media Variant
Graded Index Polymer Clad Multimode Fiber

- Polymer clad (applied during draw) creates chemical bonds to silica, significantly improving fiber reliability
- "Bridge bonds" formed healing small flaws on the fiber surface, making it impermeable to moisture ingress
- Fiber strength enhanced, static fatigue reduced
New Fiber Media Variant
Graded Index Polymer Clad Multimode Fiber

- Strength degrades vs time (*static fatigue*)
- H₂O acts as catalyst for crack growth
- Hard poly coating chemically bonds to fiber
- Significant improvement to mechanical properties - coating moisture impermeable
- Fiber strength greatly enhanced and static fatigue is significantly retarded
- Managing static fatigue with PCF enables tight, long-term bends, often found in the confined spaces of industrial installations
SFF Electronics & MDI
GI-PCF Field Terminable LC Design Goals

- Termination OM1 & OM2-compatible PCF fiber in the field
- Terminate like a CATV 'F' connector - less than a minute termination
- Short learning curve
- Ability to perform connector end-face finishing operation in seconds
- Support for aramid yarn-less cable constructions (Zip & Break-out)
- “Push-Pull” functionality
SFF Electronics & MDI
GI-PCF Field Terminable LC Design

Crimp Sleeve
Crimp Tube
Crimp Tube Holder
Body
Compression Spring
Ceramic Ferrule

"Push-Pull" BackShell

Assembled HCS LC Connector
SFF Electronics & MDI
GI-PCF LC Field Termination Process

1. Load Connector into Crimper
2. Prepare Cable Subunit
3. Insert Fiber
4. Crimp Fiber
5. Cleave Fiber
6. Mount Backshell/Boot
SFF Electronics & MDI
GI-PCF LC Field Termination Process

- Cleaving Tool (right) – performs fiber end finishing in one action
- Tool applies known strain to fiber exiting connector
- Diamond blade indexed on ceramic ferrule nose that scores fiber, producing mirror finish
- Fiber will slightly recess into the nose of the ferrule (typically about 10 microns)
Typical cleaved GI-PCF looking into ferrule
Note cleave ‘vestige’ & mirror surface
Fiber is approx. 13 microns recessed
PCF Cabling Systems

- 1Gb/s networks require either OM1 or OM2
- Duplex zip cord & 2/4 fiber breakout cable
- Elimination of aramid yarn (simplifies termination)
- Intended for open pathway and zone/control panel builds
- Dual rated LSZH and Riser
- Cables use PCF fiber as crimp substrate and strength member
Ref. Architectures/Use Cases

Architecture

ERP, Email, Wide Area Network (WAN)

Patch Management
Terminal Services
Application Mirror
AV Server

Firewall (Active)
Firewall (Standby)
Cisco ASA 5500
Cisco Catalyst Switch

Enterprise Zone
(DMZ)

FactoryTalk Application Servers
- View
- Historian
- AssetCentre
- Transaction Manager

FactoryTalk Services Platform
- Directory
- Security/Audit

Data Servers

Remote Access Server

Gbps Link for Failover Detection

Network Services
- DNS, DHCP, syslog server
- Network and security mgmt

Cell/Area zone

Rockwell Automation Stratix 8000
Layer 2 Access Switch

Cell/Area #1
Redundant Star Topology
Flex Links Resiliency

Cell/Area #2
Ring Topology
Resilient Ethernet Protocol (REP)

Cell/Area #3
Bus/Star Topology

Controller
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## Physical Infrastructure Reference

### Architecture Levels and Fiber Strategy

<table>
<thead>
<tr>
<th>Physical Level</th>
<th>Fiber Strategy</th>
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</table>
| **Cell/Area Zone**  
Levels 0-1  
End device and Controller | ▶ Noise-Immunity  
▶ High-Performance  
▶ Linking Devices  
▶ Ring or Linear Topologies |
| **Cell/Area Zone**  
Levels 0-2  
Control Panel | ▶ Secure  
▶ Testable  
▶ High Performance  
▶ Uplinks for panel-mounted switches |
## Physical Infrastructure Reference Architecture Levels and Fiber Strategy

<table>
<thead>
<tr>
<th>Physical Level</th>
<th>Fiber Strategy</th>
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<tr>
<td><strong>Manufacturing Zone</strong>&lt;br&gt;Levels 0-2&lt;br&gt;Network Zone Cabling</td>
<td>☐ Robust&lt;br&gt;☐ Cost Effective&lt;br&gt;☐ Safe Zone Architecture&lt;br&gt;☐ Distributing Fiber Connectivity across the Plant Floor</td>
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<tr>
<td><strong>Manufacturing Zone</strong>&lt;br&gt;Levels 3&lt;br&gt;Micro Data Center (core to distribution, distribution access)</td>
<td>☐ Secure&lt;br&gt;☐ High Performance Connections&lt;br&gt;☐ Plant Floor Fiber Networks to Higher Level Switches and Servers</td>
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</table>
Ref. Architectures/Use Cases
Direct Attach Model

Field Installed LC Connectors

Field Installed LC Connectors

Direct Attach Fiber Cabling
Ref. Architectures/Use Cases
Structured Cabling Model

Cisco C3750X

Permanent Link

Equipment Cord

Stratix 8000 Series
For most applications, PCF breakout cables don’t require closed pathway (conduit)

Deployment of PCF breakout cables in open pathway system such as J-Hooks

Cost saving compared to standard non-PCF cables pulled into conduit and terminated with Cam-style or field polish connectors
Ref. Architectures/Use Cases

SCS Model - Cost Analysis Assumptions

- Conventional cabling is 4 fiber dist. cable in 1.5” dia., 1/8” wall HDPE conduit
- PCF cabling is 4 fiber, ‘tactical’ style cable
- Both are OM1
- Both cables installed on J-Hook system and penetrate enclosures on each end (terminated inside each enclosure)
- Cam-style connectors installed on the conventional cabling system - PCF LC system is installed on PCF cabling
Ref. Architectures/Use Cases

SCS Model - Cost Analysis

%TIC (Standard Cabling Systems vs. HCS)

-10-5 -5-0 0-5 5-10 10-15 15-20

HCS Less Expensive

HCS More Expensive

Channel Length (feet)

Labor Rate ($/hr)

$100.00

$90.00

$80.00

$70.00

$60.00

$50.00

$40.00

$30.00

50 100 150 200 250 300 350 400 450 500 600 700 800 900 1000 1200 1500 1800 2000
Channel Validation w/GI-PCF
Channel Impairments

- Mated fibers not in physical contact (air gap between fibers causes a small insertion loss penalty)
- No physical contact produces reflection (added loss)
- Effects create incremental loss in connectors compared to std LC connectors with conventional fiber
- Increased impairments when using PCF connectors in 1000BASE-SX (de-rated reach per 802.3u)
- High reflections can interfere with the transmitted signal causing amplitude noise (degrading performance)
- Adding connectors incrementally increases reflections
- No limit to max. # of connectors deployed; practical implementations typically limit max. to two mated pairs
Channel Validation w/GI-PCF
Channel Testing with BERT

- Effect of RL on 1Gbps channel - channel configured using std’s compliant Ethernet SPF+ transceiver and a MMF optical attenuator
- Signal return path connecting output ports of the couplers was repeatedly disconnected and reconnected to simulate a high/low channel RL
Channel Validation w/ GI-PCF BERT Channel Results

Change in BER due to -8dB RL

0.1dB penalty
Solution Validation w/GI-PCF
Mechanical, Optical & Environmental Testing

- PCF LC tested to TIA/EIA-568-C for MM performance
- Cable retention target for industrial app’s in static environment (zone box perm. link or direct attach) is >0.5lbs (4-8 lbs target)
- Higher value (11.2 lbs) based on use case of duplex jumpers that see a high # of MACs
Solution Validation w/GI-PCF

Mechanical, Optical & Environmental Testing

**Insertion Loss Statistics (OM1 @ 850nm)**

- IL (ave.) = 0.55 dB
- IL (max) = 1.25 dB
- N = 28

**Insertion Loss Statistics (OM2 @ 850nm)**

- IL (ave.) = 0.80 dB
- IL (max) = 1.34 dB
- N = 36

**Failure Load Statistics (lb's to failure)**

**Cable Failure Load @ Optical Failure (lbF)**

Defined as the load at which there is a reflection point in the optical loss (the point at which the optical loss is unrecoverable).

- Average = 9.6 lbs
- Min = 5.1 lbs

**Cable Failure Load to Mechanical Failure (lbF)**

(See traces at right) - Linear limit of fiber extension under stress (the point at which the fiber/crimp insert become detached from the connector body).

- Average = 15.9 lbs
- Min = 12.1 lbs

Note: Results based on simplex HCS® fiber cable
GI-PCF Solution for Ethernet/IP

Summary

- PCF proven reliable in many applications (Military, Oil/Gas, utility, factory automation and Medical applications)
- New GI-PCF fiber variant provides MM graded-index, high bandwidth, long reach fiber core in the same large diameter footprint as traditional PCF solutions
- Benefits of PCF LC connectivity and fiber media in EtherNet/IP architectures for both Structured and Direct Attach cabling
GI-PCF Solution for Ethernet/IP

Summary

- Use of GI-PCF fiber media and PCF LC connector systems into 1000BASE-SX SCS-based cable plant (with limited restrictions)
- Enables widespread field installation of fiber EtherNet/IP - termination similar to POF (but longer reach, higher bandwidth)
- Opens door to high bandwidth applications at all levels of industrial networks
- Provides immediate benefit for 10/100M EtherNet/IP “direct attach” networks