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

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## Abstract

Traditional fiber cabling systems that support high bandwidth enterprise applications are being extended into industrial plant floor applications. At the machine control level, current needs for easy to deploy, robust fiber solutions that support 100Mb/s communications exist. For many EtherNet/IP applications requiring fiber, the use of currently available cabling systems presents unique challenges regarding robustness, support of real-time, low latency communication, and deployment ease by factory personnel. These challenges tend to inhibit the use of fiber and increase Total Cost of Ownership (TCO).

Recently, fiber manufacturers have introduced Hard Clad Silica (HCS®) fibers with improved bandwidth. These fibers are environmentally and mechanically robust and address difficult installation challenges. Through fundamental fiber design, these industrial fibers enable rapid and simple LC connector field termination with simple hand tools and a short learning curve. ODVA standards recognize the LC connector in both sealed and unsealed applications and high volume transceiver manufacturers have standardized the small form factor LC as the Media Device Interface of choice for 1000Mb/s and beyond channels. This paper addresses current 100Mb/s applications with EtherNet/IP devices as well as the need for easy to deploy higher-bandwidth links requiring 1Gb/s transmission.

## Keywords

Hard Clad Silica Fiber (HCS), Graded-index HCS (GiHCS™), LC Connector, SFF (Small Form Factor), SFP (Small Form factor Pluggable), Graded Index Multimode Fiber, Bit Error Rate (BER), Structured Cabling System (SCS), SFP Modular Transceiver, Channel, 1G Ethernet, Power Budget, Return Loss, IEEE 802.3z, Insertion Loss, Structured Cabling System (SCS), Crimp & Cleave (C&C)

## Introduction

Enterprise fiber structured cabling solutions are being deployed in Industrial Ethernet applications. Traditionally, these solutions fit at the top of the network, i.e., Micro Data Center and Zone solutions. Industrial Ethernet now propagates in the lower tiers of the network, such as control and device layers. In these areas the enterprise structured cabling model does not provide a strong value proposition. Additionally, the skill of typical personnel implementing control and device-level networks often excludes fiber installation best practices. A “fear of fiber” mentality prevents widespread deployment and acceptance of fiber in such harsh environments.

There exists a need for a rapid deployment, direct-attach cabling system that is “electrician friendly”. At the core of the proposed solution is a LC compatible crimp/cleave connector coupled with multimode Graded-Index Hard Clad Silica (GiHCS) fiber in industrialized cable form factors. These systems are compatible with mini switch and embedded switch solutions from vendors.

# HCS® (Hard Clad Silica) Fiber Technology

## What is HCS?

Hard-clad silica (HCS, sometimes called Polymer Clad Fiber - PCF) are optical fibers with cores of pure silica glass (diameter: typically 200 µm) and a hard optical cladding made of special plastic (diameter: 230 µm typically). The hard cladding layer imparts unique properties on these fibers, serving to provide total internal reflection, enhancing the fundamental strength of the fiber, and providing a crimp-worthy thin coating for simple and reliable connectorization in the field.

HCS fibers have traditionally been "step-index" structures with large silica cores and medium bandwidth, supporting transmission rates of less than 100 Mb/s. Traditional HCS fibers are suitable for distances at such data rates of several tens of meters to several hundred meters and have commonly been used in applications such as ControlNet (see details on ControlNet 1786-RPFS Repeater Module and ControlNet Fiber Media Planning and Installation Guide for more information):

http://www.ab.com/en/epub/catalogs/12762/2181376/214372/1809768/3489009/Repeaters.html

http://literature.rockwellautomation.com/idc/groups/literature/documents/in/cnet-in001-en-p.pdf

By comparison, all-plastic step-index optical fibers (POF) have lower bandwidth and only support transmission rates less than 40 Mb/s. They also have relatively high attenuation and are, therefore, power limited and supporting maximum distances of just several tens of meters.

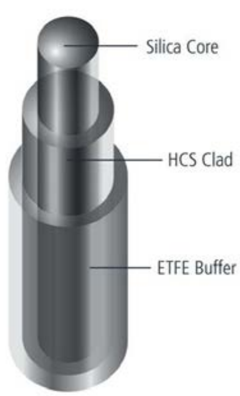



*Figure 1. Traditional 200/230 HCS® Fiber*

| | |
|---|---|
| Core Diameter | 200 ±4µm |
| HCS Cladding Diameter | 230 +0/-10µm |
| ETFE Buffer Diameter | 500 ±30µm |
| Core/Clad Offset | <5µm |
| Index profile | Step Index |
| NA (Numerical Aperture) | 0.37 |
| Attenuation @ 850nm | <6 dB/km |
| Bandwidth | ~10 MHz*km |
| Operating Temperature | -65 to +125 deg C |
| Proof Test Level | >150 kpsi |

Graded Index glass fibers, like those used in enterprise structured cabling systems, have very high bandwidth with the ability to support Gb/s and multi-Gb/s data rates at significant reach. The attenuation in these fibers is low, therefore such fibers can extend application distance from several hundred meters to a few kilometers, covering the overwhelming majority of industrial networking applications encountered with Ethernet/IP.

Several fiber manufacturers produce high bandwidth multimode "Graded Index" HCS variants (62.5/200/230 OM1-compatible and 50/200/230 OM2-compatible). The need for such fibers in industrial automation applications is driven by numerous factors, namely:

- Industrial Applications - SI (Step Index) HCS® industrial fibers have been successfully deployed in harsh conditions for many years, as a result such fibers and quick terminating connectors are familiar within the industrial market space.
- The rise of Industrial Ethernet (Ethernet/IP) - seamless integration of the factory and Enterprise networks with growing demand for higher bandwidth (>10 MHz*km) throughout.
- Requirements for robust and easily installed fiber systems with the above characteristics.

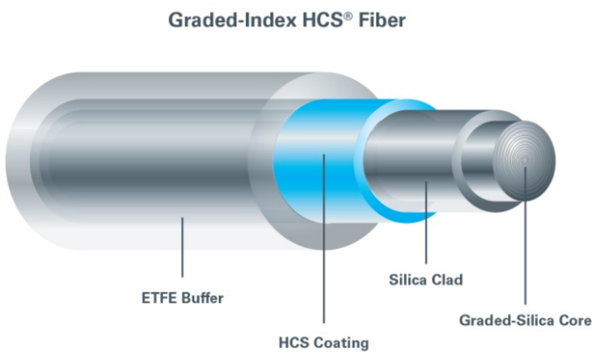



*Figure 2. 62.5/200/230 Graded-index HCS® Fiber*

| | | |
|---|---|---|
| Core Diameter | 62.5 ±3µm | 50 ±3µm |
| Cladding Diameter | 200 ±4µm | 200 ±4µm |
| Coating Diameter | 228 ±10µm | 230 ±10µm |
| Buffer Diameter | 500 ± 30µm | 500 ± 30µm |
| Core/Coating Offset | <5µm | <5µm |
| Index Profile | Graded Index | Graded Index |
| NA (Numerical Aperture) | 0.275 ± 0.02 | 0.20 ± 0.02 |
| Attenuation @ 850 nm | <3.5 dB/km | <2.8 dB/km |
| Attenuation @ 1300 nm | <1.2 dB/km | <1.0 dB/km |
| Bandwidth-Length @850nm | >200 MHz*km | >400 MHz*km |
| Bandwidth-Length @1300nm | >500 MHz*km | >400 MHz*km |
| Operating Temperature | -65 to +125 deg | -65 to +125 deg |
| Proof Test Level | >150kpsi | >150kpsi |

### HCS and High Strength Optical Fiber

HCS fibers are designed for and used in applications that demand robust mechanical performance. These fibers are the best choice for industrial data links, factory automation, and utility applications, often found in harsh environments that require high mechanical integrity and reliability at the fiber level. The fiber's HCS coating, while facilitating easy field connections, makes possible the vision of "electrician friendly" field fiber terminations.

Silica, the glass used to make optical fiber, is a brittle material by itself. Brittle materials are characterized by the dependence of their mechanical strength on the severity of surface flaws (Griffith flaws), rather than fundamental material strength. When bent or under tensile load, these surface flaws act as stress concentrators and grow in size and eventually result in catastrophic failure of the material or breakage when in the form of optical fiber.

The strength of silica optical fiber is time-dependent and the degradation of fiber strength over time is known as *static fatigue*. In the presence of moisture crack propagation accelerates as water molecules act as catalysts to crack growth by reducing the surface energy of the glass.

HCS coating technology, applied during the draw process on the pristine fiber surface, chemically bonds to the silica substrate. These chemical bonds significantly improve the mechanical properties of the silica fiber, making the coating virtually impermeable to moisture ingress.

By isolating the silica surface from moisture in the environment fiber strength is greatly enhanced and static fatigue is significantly retarded. Managing static fatigue through HCS technology enables the optical fiber to withstand the tight, long-term bends, often found in the confined spaces of industrial installations.

## Fiber Connector System

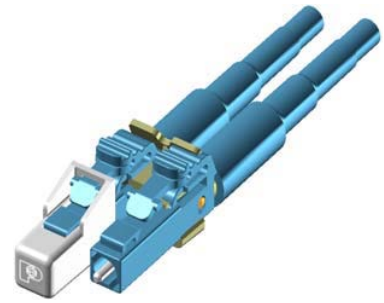
### The LC Connector in Fiber Management and Transceivers

Small Form-Factor (SFF) transceivers (GBICs) on LAN equipment have been overshadowed by the Small Form-factor Pluggable (SFP) ('pluggable' versions of the SFF) transceiver in recent years. Industrial Automation equipment vendors are now offering SFP modular transceivers on their switch lines for Gb/s Ethernet Uplinks. 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 'propriety' non-MSA (Multi-Source Agreement) interfaces such as TosLink or Versatile Link.

The optical receptacle on the SFP for Fibre Channel and Gb/s 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.

The LC connector is the natural progression/replacement for the SC, but is also displacing applications traditionally held by other connector systems such as the MT-RJ. The LC is popular as a 10 Gb/s Ethernet connector and is also the standard fiber interface for 1394B S800 (Firewire/iLink Home and Commercial Video) and for the InfiniBand Trade Association. To support the trend and seamless integration of readily available SFP transceivers in industrial networks, it is imperative that we provide a practical LC field-connection solution for harsh environments.

1GBASE-SX SFP Modular Transceiver



FOCIS-10 LC Connector

*Figure 4. The SFP Modular transceiver and the accompanying LC connector.*

The LC Connector is an industry standard FOCIS-10 (TIA Fiber Optic Connector Intermateability Standard) compatible plug interface that provides a dependable, repeatable means of mating the precision ferrule used to align and secure the fiber.

The LC connector, due to its reduced footprint, provides twice the interconnect density in cabling system patching bays. The LC also provides advantage on electronics (hubs, switches, etc.) through its reduced size.

<u>10/100M & 1G Ethernet Physical Layer Considerations</u>

### IEEE 802.3u - 100BASE-FX

The Fast Ethernet over Fiber-Optic at 100 Mb/s application (100BASE-FX - 12.5MB/s with autonegotiation) is a version of Fast Ethernet over optical fiber. It uses a 1300 nm near-infrared (NIR) light wavelength transmitted via two strands of optical fiber, one for receive (RX) and the other for transmit (TX). The standard specifies a maximum distance capability of 2 kilometers (6,600 ft) for full-duplex over FDDI-grade (Fiber Distributed Data Interface) multi-mode optical fiber. The optical power budget for a channel built with these transceivers is several dB for OM1 fiber (1.5dB maximum of connector insertion loss allocation within this budget).

### IEEE 802.3z - 1000BASE-SX

Gb/s Ethernet over Fiber-Optic at 1 Gb/s (1000BASE-SX - 125 MB/s) is a fiber optic gigabit Ethernet standard for operation over multi-mode fiber. The standard calls for a near infrared (NIR) light operating wavelength between 770 and 860 nm but is typically referred to as 850 nm. The standard specifies a distance capability between 220 meters (62.5/125 µm fiber with low modal bandwidth) and 550 meters (50/125 µm fiber with high modal bandwidth).

The channel is designed, and commonly described, around connector Insertion Loss (IL) of 1.5dB max. We can see from the chart in Figure 5 that the reach of OM2 50/125 micron multimode fiber channel with 1.5dB of IL is 550 meters. It is possible (and desirable) to allow for higher levels of insertion loss in the 1000BASE-SX channel.

This may be required as higher numbers of connectors are desired in the channel or if a tradeoff is made to allow for simpler (and higher loss) connectors to be used in such channels.

If we model higher IL in the channel (for example, 4dB) channel reach must be de-rated to compensate (in this case from 550 meters to 300 meters).

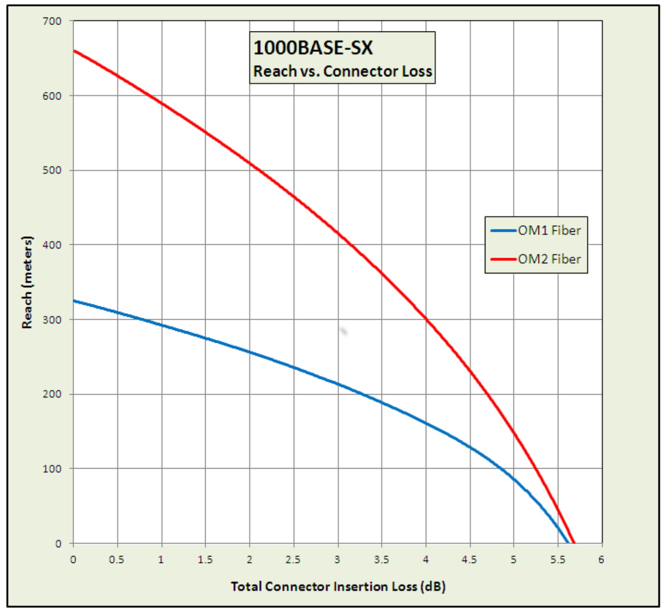



*Figure 5. Reach vs. Connector Loss*

A simple use case for the two types of fiber transceiver technology (100BASE-FX and 1000BASE-SX) is shown in Figure 6. A 1GBASE-SX channel is running over a fiber Structured Cabling System connecting an edge/workgroup switch to a SFP transceiver uplink in a DIN railed mounted automation style switch. A fiber switch port in the Stratix is "direct attach" connected to a ControlLogix Communications module, supporting 10/100 Ethernet over LC connector-based multimode fiber.

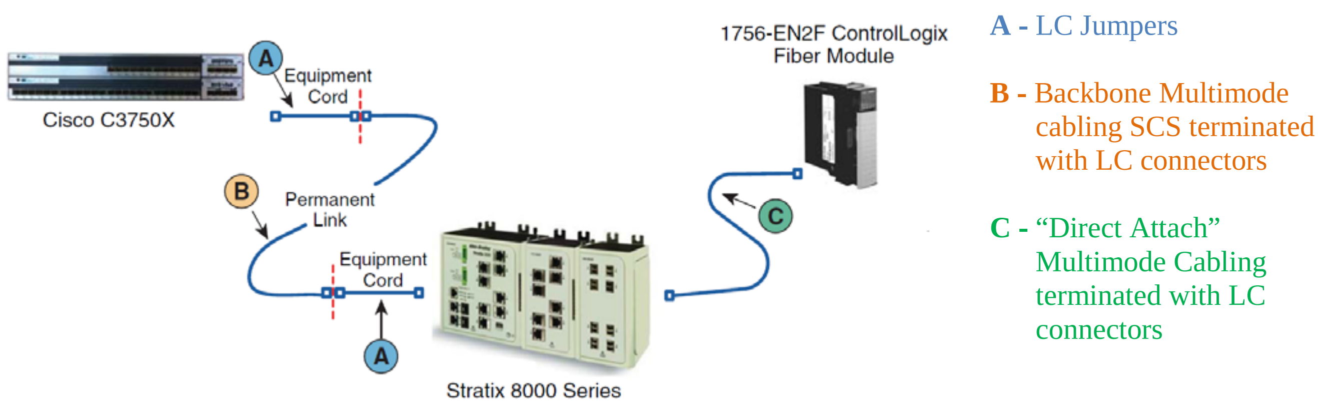



*Figure 6. Example of two types cabling models*

A "direct attach" fiber cabling model for device-level Ethernet with easy to install LC fiber connectors is preferred for these reasons:

- Installation is 'static' - low or no MACs (Moves, Adds and Changes)
- Local labor skill level with fiber is low - e.g., factory maintenance
- Uncontrolled environment not suitable for Cam or polish connectors (cleanliness)
- Cost/time - Conventional SCS are precluded
- Installation is temporary and will not change - e.g., Manufacturers product life cycle

It is also preferred that the same termination and fiber technology can be deployed in the Structured Cabling model between the zone switch uplinks and the closet/micro-data center switch (in the case depicted above the Cisco C3750X). The performance of such links is evaluated further in this paper.

HCS® LC Connector

The design goals of this connector include:

- Ability to terminate OM1 & OM2-compatible HCS fiber in the field
- Terminates like a CATV 'F' connector - less than a minute termination
- Shortest field termination learning curve of LC connector in the industry
- Ability to perform connector end-face finishing operation (fiber cleaving) in seconds
- Ability to support aramid yarn-less cable constructions in both Zip and Break-out formats
- “Push-Pull” functionality - De-mate function similar to SC-style connector

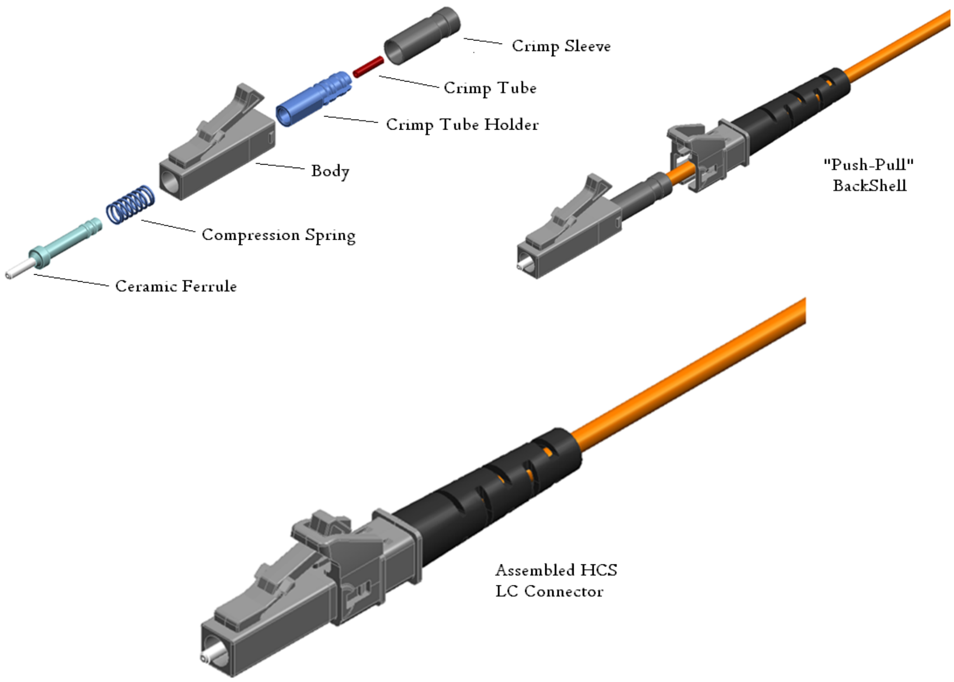



*Figure 7. Exploded View of the HCS® LC Connector.*

This LC connector is a two-piece “Optical Disconnect” style connector that comes assembled and ready for fiber insertion and crimping. The “Push Pull” backshell must be pre-mounted on the cable prior to termination and docks into the back of the connector assembly after the crimping and cleaving operation, thus completing the connector.
This connector is a FOCIS-10 LC connector that can be used to terminate OM1 & OM2-compatible HCS fiber onto standard “aramid yarn-less” HCS zip cord and breakout cables (described in this paper) in less than a minute. This connector is not intended for singlemode fiber use.

The termination process consists of simple fiber preparation (stripping), crimping and cleaving to finish the fiber end. Cleaving is performed in a tool designed to accept the connector (process steps below).

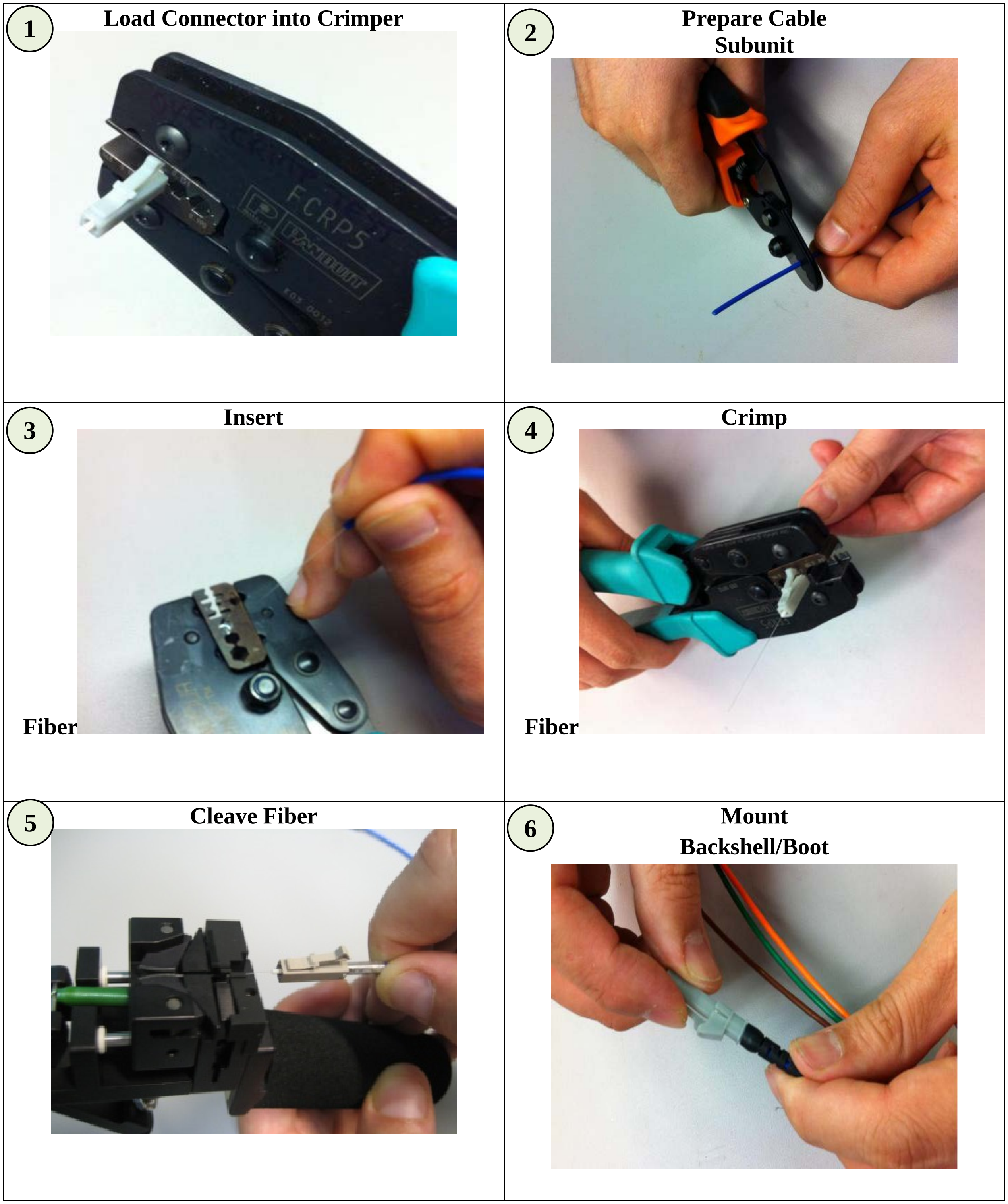


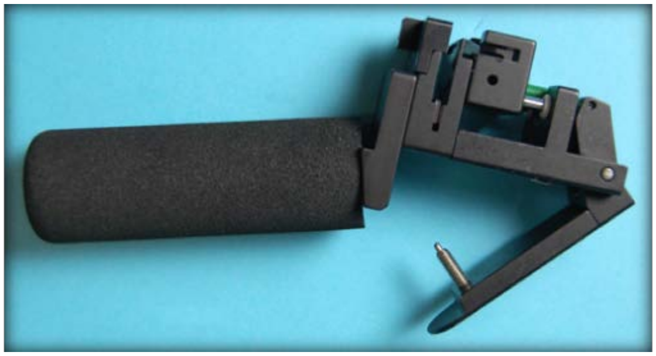

*Figure 8. The termination process for HCS® fiber.*

## HCS LC Connector Cleaving Tool

Integral to this system is the cleaving tool which performs the fiber end finishing operation as shown above. Shown immediately below (left) is the cleave tool.

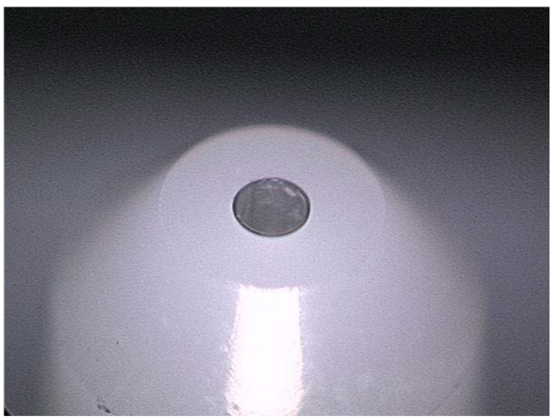
**LC Connector Cleaving Tool**

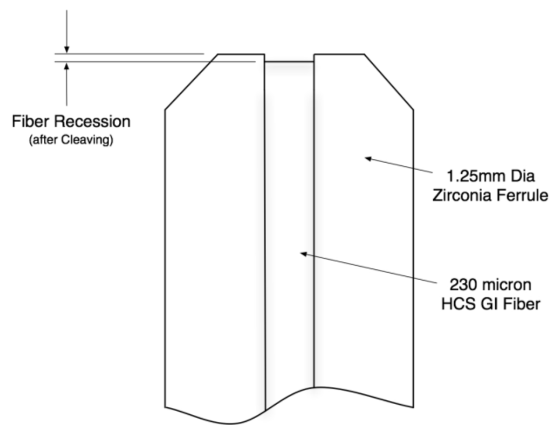


This tool incorporates a tensioning mechanism that grips the fiber exiting the connector and applies a known strain. A diamond cleaving blade is indexed on the nose of the ceramic ferrule and scores the fiber, cleaving it and producing the finish shown in the micrograph of the connector end-face shown below (left) and the detail image below that.

Since the fiber is under load when cleaved, the fiber will slightly recess into the nose of the ferrule (typically about 10 microns).

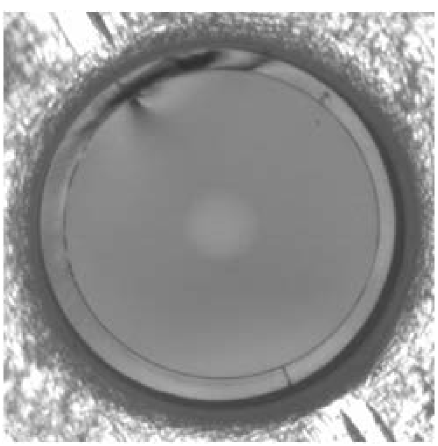
**LC Connector Ferrule after Cleaving**






**Fiber Recession after Cleaving**

**Fiber Endface Detail after Cleaving**



Photomicrograph of typical cleaved 50/200/230 micron HCS® fiber looking end on into the ceramic ferrule.

Note cleaving vestige at 11 o'clock and near mirror surface present over majority of fiber endface.

*Figure 9. HCS LC connector cleaving tool and Typical Termination Results*

## Fiber Cable Styles

Industrial networks operating at 1Gb/s max. require either a graded index OM1 or OM2-grade fiber. Several manufacturers produce a version of their HCS fiber with optional OM1 or OM2-compatible fiber in the core. We foresee the need for these fibers to be supplied in a duplex zip cord cable and a 2-fiber and 4-fiber breakout cable. Cabling systems are intended for open pathway and zone/control panel builds and are hence dual rated LSZH and Riser.

These cables eliminate the aramid yarn that exists in standard 50/125µm zip and distribution cables. This new system relies only on the optical fiber as a crimp substrate and strength member, significantly simplifying the termination process. These cables are described below.

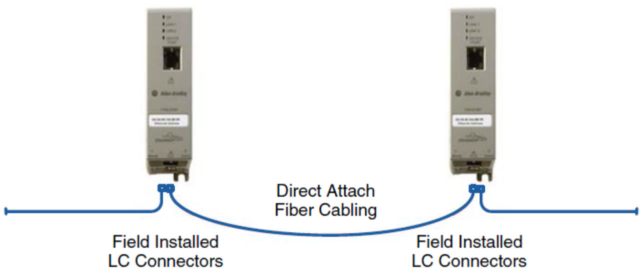
| Description | Cable Section | MICE | Application |
|---|---|---|---|
| **Device Cable (Duplex Zip)**<br><br>For indoor use, GiHCS® zip cord cables (GI 50/200/230 or GI 62.5/200/230) are built around two, 2.2mm 'aramid yarn-less' fiber units. Taking advantage of the durability and toughness of new smaller-core GiHCS optical fibers, these tight-buffer cables are protected with a tough Riser/Low Smoke Zero Halogen rated jacket. |  | $M_1I_2C_2E_3$ | In Control Panel or Telecommunications Enclosure (zone box) deployments of 10/100M and 1G Ethernet where the need for field installable custom made-to-length fiber patch cables is a requirement. If run outside enclosures, a protected pathway is required. |
| **2-Fiber Breakout Cable**<br><br>For indoor/outdoor use, these GiHCS fiber breakout cables(GI 50/200/230 or GI 62.5/200/230) are built around two, 2.2mm 'aramid yarn-less' fiber units with two plastic filler rods and have a Riser/Low Smoke Zero Halogen rated jacket, glass central strength member and ripcord for fiber element access. |  | $M_3I_3C_3E_3$ | 10/100M and 1G Ethernet deployments between Control Panels and/or Telecom Enclosures (zone boxes) where the cable penetrates a bulkhead gland and field terminates to structured cabling or directly to electronics. Can be deployed in an open pathway. |
| **4-Fiber Breakout Cable**<br><br>For indoor/outdoor use, these GiHCS fiber breakout cables(GI 50/200/230 or GI 62.5/200/230) are built around four, 2.2mm 'aramid yarn-less' fiber units and have a Riser/Low Smoke Zero Halogen jacket, glass central strength member and ripcord for fiber element access. |  | $M_3I_3C_3E_3$ | 10/100M and 1G Ethernet deployments between Control Panels and/or Telecom Enclosures (zone boxes) where the cable penetrates a bulkhead gland and field terminates to structured cabling or directly to electronics. Can be deployed in an open pathway. |

*Table 1. Standard OM1 & OM2 Zip and Breakout Cables*

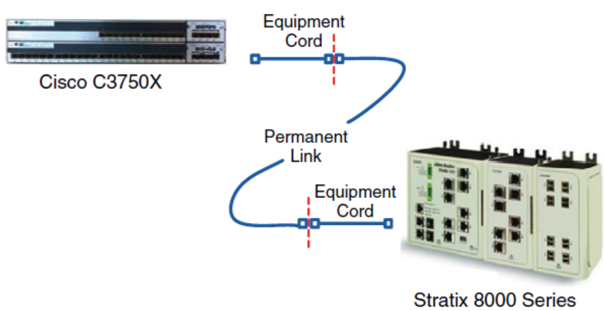
## Topologies/Use Cases for EtherNet/IP HCS Fiber

EtherNet/IP applications can involve both direct attach, point-to-point cabling as well as structured cabling approaches.  Structured cabling is often used for uplinks and switch-to-switch connections to allow for link verification and testing. Direct attach provides flexibility for point-to-point connections between devices, embedded switches, 3 port switches or converters.

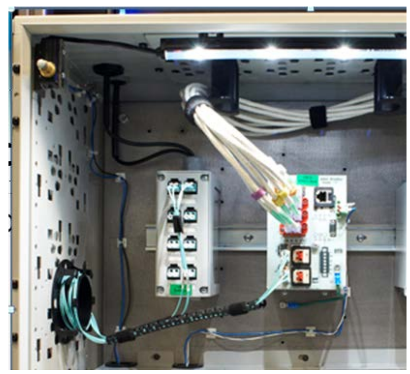



1. Direct Attach with Field Installed Connectors


Example of Direct Attach Application

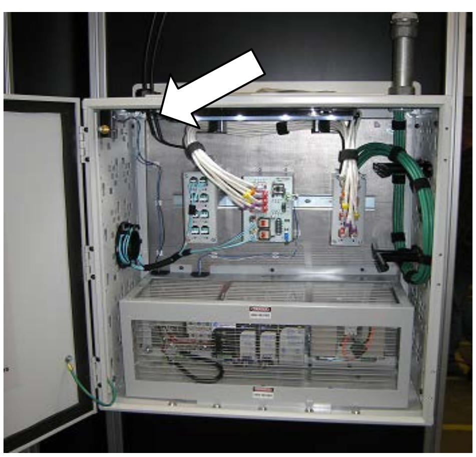



2. Structured Cabling with Permanent Link and Equipment Cords



Structured Cabling example with patching (DIN rail mounted patch box is shown)

*Figure 10.  Cabling Models for DLR & 1Gb/s Backbone EtherNet/IP applications.*



**Bulkhead "Pass Through" for HCS® Breakout Cable**

An environmentally sealed pass-through gland allows multiple fiber cables to be routed internally to the zone enclosure (or control panel) to allow patching for a structured cabling system or to facilitate a direct attach application as shown in Figure 10 with breakout style cables.

*Figure 11.  Multiple fiber cables being routed to a Zone Enclosure for patching in a structured cabling system.*

## Pathways

HCS Cable Value Analysis

For most applications, breakout cable constructions using the HCS® cables described previously do not require a closed pathway such as conduit.

Deployment of HCS breakout cables in an open pathway system such as the Panduit J-Mod that are terminated with Crimp and Cleave style connectors provide a cost saving compared to standard non-HCS cables pulled into conduit and terminated with standard Cam-style or field polish connectors.

*Figure 12. J-Hook Open Pathway System*

A cost model to compare the Total Installed Cost (TIC) of the two cabling systems mentioned above is shown below. The assumptions made in developing this model follow:

- Conventional cabling is 4-fiber distribution cable deployed in 1.5” dia., 1/8” wall HDPE conduit
- HCS cabling is 4-fiber LSZH, Breakout style cable (as shown in Table 1)
- Conventional cabling is a 4-fiber enterprise, distribution style, tight buffered cable
- Both fibers are OM1-compatible(62.5/125 vs. 62.5/200/230)
- Both cables are installed on the J-Hook system and penetrate enclosures on each end. They are also terminated inside each enclosure
- Cam-style connectors are installed on the conventional cabling system, while the HCS crimp/cleave system is installed on the HCS cabling

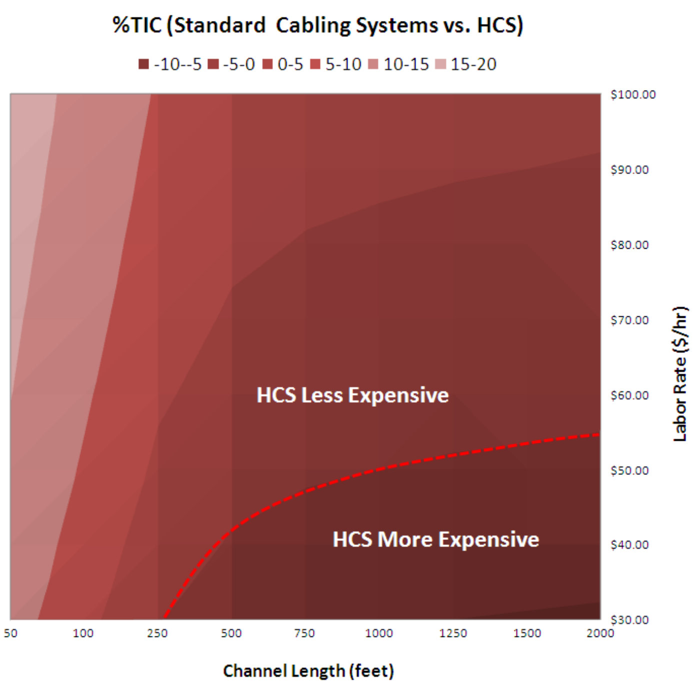



*Figure 13. Cost model of HCS cabling vs. conventional cabling.*

The cost model graphic on the left shows how the TIC of HCS cabling is less expensive than conventional cabling installation in the following general instances:

A. When the link length between control panels or TEs served by the cabling is less than 250 feet
B. When the installation labor rate is higher than~ $55/hr.

In general, for longer runs with a low labor rate, conventional fiber cabling systems present lower TIC. Also, the 1Gb/s Ethernet channel reach for HCS systems with higher insertion loss and low return loss connectors will not approach the application standards-based reach of the 1G channel because the channel must be de-rated in reach.

## Performance Data

1000BASE-SX Channel Performance

One drawback of a crimp/cleave connector system is the mated fibers are not in physical contact. Therefore, a small air gap exists between the fiber end faces. As a result, there will be a small insertion loss penalty due to the separation of the fiber ends (air gap):

$$L(x) = -10log\left(1 - \frac{xNA}{4a}\right)$$

Where ‘x’ is the air gap length, ‘NA’ is the numerical aperture of the fiber and ‘a’ is the core radius. For a 50 micron core fiber with 0.20 NA and a 20 micron gap, the calculated gap loss is about 0.18dB. For a 62.5 micron core fiber with 0.27 NA the calculated gap loss is about 0.19dB.

When light encounters a discontinuity in optical media, such as a glass-to-air boundary, a portion of the optical power known as a Fresnel Reflection - ‘R’ is reflected. The magnitude of the loss due to this reflection depends on the difference in refractive indices of the two media and is expressed as:

$$L(n_{core}) = -10\log(1 - R) = -10log\left\{1 - 2 * \left(\frac{n_{gap} - n_{core}}{n_{gap} + n_{core}}\right)^2\right\}$$

where $n_{gap}$ is the index of refraction of the gap (air, n=1) and $n_{core}$ is the effective index of refraction of the core (≅ 1.47 for GI MM fibers). For a GI MM fiber, the reflection loss is about 0.33dB.

The sum of these two effects creates excess loss in mated pairs of connectors that is incremental loss in comparison to that of a standard physical contact LC connector with conventional fibers. The minimum incremental loss for such a ‘gapped’ connector would be equal to the Fresnel loss alone (fibers almost touching). Both of these effects create channel impairments that must be considered when specifying HCS® connectors into 1000BASE-SX links. The net result will be that the ultimate channel length per the 802.3u standard will have to be de-rated as in the graph of Reach vs. Connector shown in Figure 5.

The reflected power is typically described in terms of return loss (RL), where a high RL means little power is reflected. In optical transmission systems, a low RL, i.e., high power reflections can interfere with the transmitted signal causing signal amplitude noise which degrades channel performance.

$$RL = -10log(R)$$

Adding connectors in a channel incrementally increases the reflected power, reducing the total RL. There is no specified limit to the maximum number of connectors one can deploy in optical channels supporting industrial Ethernet applications; practical implementations in Industrial Automation typically limit the maximum number of connectors to two mated pairs. For a channel containing two Crimp and Cleave connector pairs, twice the optical power will be reflected. Neglecting optical attenuation and connector insertion loss, the maximum reflected power is 14% which corresponds to an RL of 8.5dB.

Panduit simulated a 1Gbps optical channel link comprising multiple Crimp and Cleave connectors to measure the effect of low return loss on channel performance. The channel performance is characterized in terms of bit error rate (BER) and the performance for high and low RL is compared and evaluated.

1Gb/s Ethernet Channel Compliance Experiment

As previously discussed, the RL for multiple HCS® Crimp and Cleave connectors in most cabling systems is typically greater than 8.5dB. Therefore, to evaluate the lowest possible RL it is necessary to design an optical channel that can simulate the worst–case RL of 8.5dB or less. The experimental setup is shown in Figure 14 below:

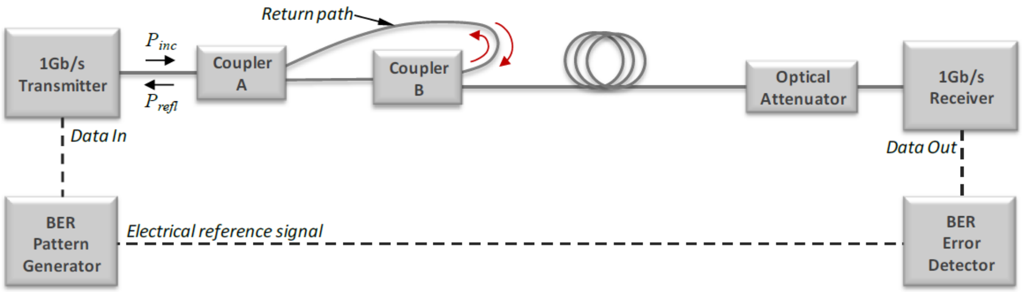



*Figure 14. Experimental setup for generating low return loss channel measurement Two 3dB couplers used to simulate high reflected power (low return loss.*

Using the measured values, the return loss for the optical test channel shown above is roughly 8dB. This is worse than expected results when using two mated pairs of Crimp and Cleave connectors in a channel.

To measure the effect of RL on 1Gbps channel performance, the test channel (Figure 14) was configured using standards compliant Ethernet SPF+ transceiver and a multimode optical attenuator. The signal return path connecting the output ports of the two optical couplers was then repeatedly disconnected and reconnected to simulate a high and low channel RL, respectively. Inspection of the data reveals a small increase in Bit Error Rate (BER) when the RL is reduced from a high > 20dB to a low of 8.0dB when the couplers are present in the channel. The average BER increases from 3.6x10e-8 to 6.8x10e-8 in the presence of worst case reflection.

It is common practice to quantify a decrease in channel performance due to noise or dispersive effects in terms of an optical power penalty. The optical power penalty is the extra optical power required that compensates for the channel degradation due to impairments, such as reflections.

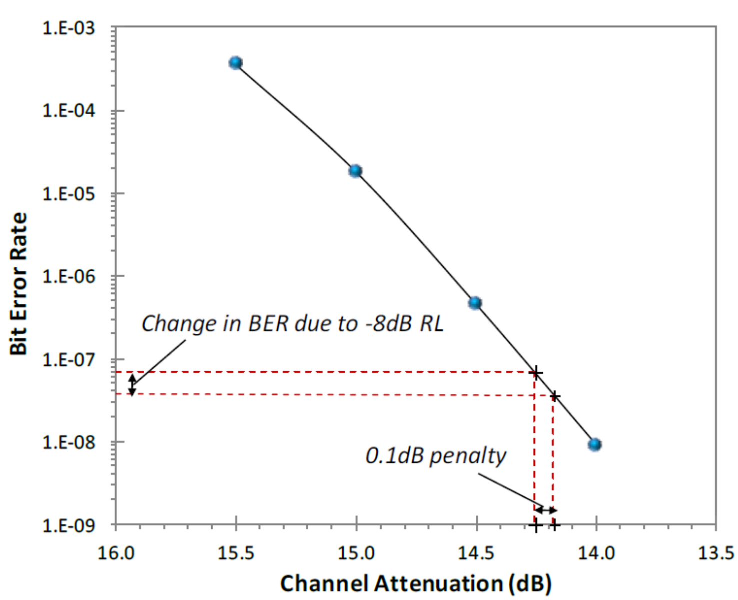



*Figure 15.*

To determine the power penalty, we must relate the BER to optical power. This can be done by plotting the BER of the channel as a function of optical attenuation (Figure 15).

The power penalty is derived by the change in BER (horizontal lines intersecting with BER curve) and the associated equivalent power on the horizontal axis resulting from the change in RL, which in this case is 0.10dB.

Based on the worst-case 1Gbps Ethernet link power budget, a 0.10dB RL penalty is well within the specified budget and therefore, the worst case RL is an acceptable attribute for Crimp and Cleave connectors.

Mechanical, Optical and Environmental Testing

The HCS® Crimp and Cleave LC connector was tested to TIA/EIA-568-C specifications for multimode connector performance. (See Table below).

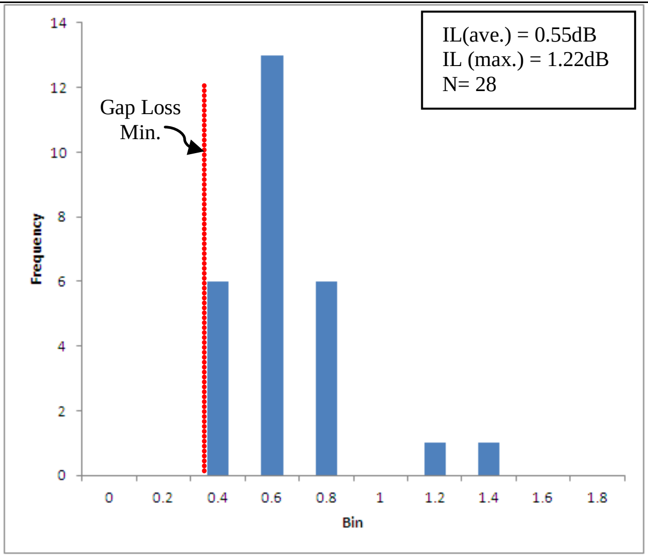
***Table 2. Testing Results***

| TEST | REQUIREMENT | METHOD | RESULT |
|---|---|---|---|
| **Insertion Loss** | Maximum IL: 0.75dB. | EIA/TIA-455-171 (FOTP-171); Method D | See IL distribution (below) |
| **Return Loss** | Minimum RL: 20dB (MM) | EIA/TIA-455-107 (FOTP-107) | NA |
| **Cable Retention*** | > 11.24 pounds for each jacketed cable channel<br>> 0.5 lbs. for each buffered fiber | EIA/TIA-455-6B (FOTP-6) | See data (below) |
| **Low Temperature** | 0°C temperature for 4 days<br>(mated connector pair) | EIA/TIA-455-188 (FOTP-188) | Complies |
| **Temperature Life** | 60°C for 4 days<br>(mated connector pair) | EIA/TIA-455-4 (FOTP-4) | Complies |
| **Impact Test** | Drop of 1.8 meters<br>(mated connector pair) | EIA/TIA-455-2 (FOTP-2) | Complies |
| **Cable Flexing** | Flex cycles (90 to -90 degrees for 100 cycles)<br>Mated connectors weighted with:<br>a) 1.1 pounds for jacketed cable<br>b) 0.5 lbs. for buffered fiber | EIA/TIA-455-1 (FOTP-1) | Exceeds Requirement |
| **Coupling Strength** | 7.4 lbs of force at a 0°angle applied at a rate of 1 inch/minute; must remain mated for 5 seconds (mated connector pair) | EIA/TIA-455-185 (FOTP-185) | Complies |
| **Durability** | 500 mating cycles | EIA/TIA-455-21 (FOTP-21) | Exceeds Requirement<br>>1000 cycles |
| **Humidity** | 4 days at 90-95% humidity at 40°C.<br>(mated connector pair) | EIA/TIA-455-5 (FOTP-5) | Complies |
| **Jacket Cable Twist** | 5 twist rotations in both clockwise and counterclockwise directions for 10 cycles:<br>a) 3.5 lbs. for jacketed cable<br>b) 5 lbs. for buffered fiber (mated pair) | EIA/TIA-455-36 (FOTP-36) | Exceeds Requirement |

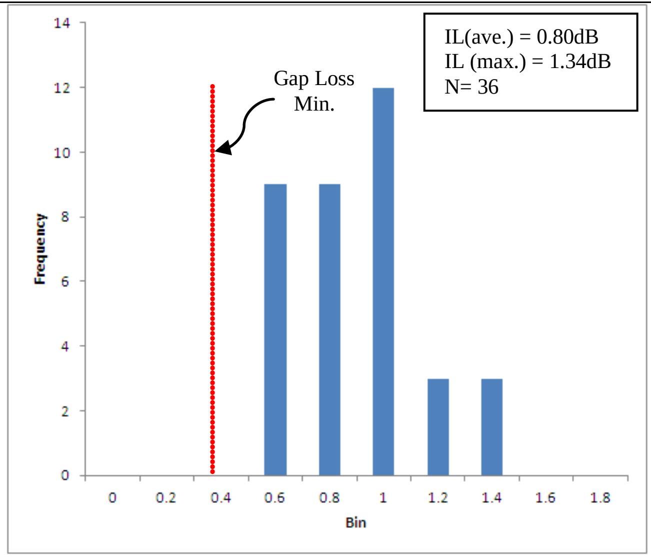
* - Target for Industrial automation applications in a static environment (zone box permanent link or direct attach cabling) is >0.5lbs (expecting 4 to 8 lbs as a design target). The higher value specified in 568 is based on a use case of duplex patch field jumpers that see a higher level of MACs (Moves, Adds and Changes).

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




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




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

Cable Failure Load @ Optical Failure (lbF)

Defined as the load at which there is a inflection 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

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

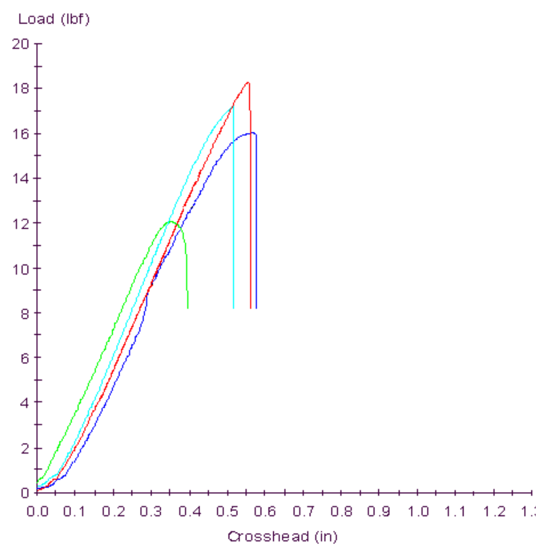



*Figure 15. Insertion loss, cable retention and failure load statistics.*

## Conclusion/Summary

Hard Clad Silica fiber media has been proven reliable in many vertical applications spanning harsh environment (Military, Oil/Gas, utility, factory automation, Industrial Fieldbus and in-vivo Medical) applications. This new GiHCS fiber variant presents a Multimode graded-index, high bandwidth, long reach fiber core in the same Hard Clad, large diameter footprint as the traditional HCS® solutions.

This paper has shown the benefits of HCS LC connectivity and fiber media solutions in EtherNet/IP architectures for both Structured Cabling and Point to Point cable plant deployments. An examination of performance metrics (Bit Error Rate) for such channels and ultimate channel reach vs. cable plant design has shown the viability of using GiHCS fiber media and field deployable "Electrician Friendly" HCS LC connector systems into 1000BASE-SX SCS-based cable plant (with limited restrictions).

GiHCS fiber technology enables widespread field installation of fiber EtherNet/IP networks by providing a termination means similar to Plastic Optical fiber connectivity (with low TCO) while provisioning longer reach, high bandwidth channels (which POF does not).

This easy to install fiber solution opens the door to new high bandwidth applications at all levels of the industrial network by building on ODVA recognized components. It also provides an immediate benefit for existing 100Mb/sec EtherNet/IP networks that are "direct attach".

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