Improved Mining Safety, Communications and Productivity Through the Use of Fiber Optics

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ABSTRACT

Modern and efficient coal mining facilities utilize improved control methods and increased mechanization to achieve optimum productivity. The use of fiber optics for reliable communications to monitor, analyze and control the equipment and facilities during the mining process will increase safety and production efficiency. This paper provides an overview of fiber optic interconnect technology applicable to coal production.

INTRODUCTION

Increased material volumes, long distances, high performance and growing demands on operating safety requires faster and more reliable communications. Fiber optic communication systems are uniquely suited to connect real time data from environmental and equipment sensors to ensure peak production while maintaining the highest safety standards. Safety, harsh environment, and bandwidth requirements necessitate the transition from copper wire based to fiber optic based systems for signal transmission.

An appendix is included at the end of this paper entitled “An Introduction to Fiber Optics” as an educational reference and as an introduction to fiber optics for those unfamiliar with this technology.

Real-Time Data

“Real time” is the actual time in which a physical process under computer study or control occurs. It also means occurring immediately or as quickly as required. A “real-time” system must respond to a signal, event, or request fast enough to safely maintain user control of the process. Typically, real time is on the order of milliseconds or sub-milliseconds.

In other words, “real-time” operating systems are systems that respond to input immediately or with an imperceptible delay. “Real-time” often refers to process control and feedback mechanisms within embedded systems.

For example, space flight computers must respond to changing conditions in order to keep a spacecraft on course. Industrial robots must respond quickly in order to keep the assembly line moving at full speed. Antilock brakes and other driving assist systems must respond to changing road conditions immediately in order to benefit the driver and vehicle. A smoke detector will let us know the instant smoke is detected at that location and is a real time system – smoke is detected as soon as it is available, usually before it can be seen. An improved real time system would employ temperature and air sensors located inside the mine and would report where a fire is, how hot it is, where it is going and where good air can be found.

How does this apply to mining? In a mine with wide range of gases, a real time monitoring system is needed to analyze the concentration of carbon monoxide, methane, hydrogen sulfide and other gases continuously. With the increasing use of diesel engines in underground mines, engine emissions must be continuously monitored using defined thresholds in real-time.

PUTTING FIBER OPTIC COMMUNICATIONS TO USE

The aim of this paper is to point out improvements in communications, and equipment monitoring technologies in the underground coal mining industry and the various ways they can be enhanced. The simultaneous requirements of HMI and SCADA systems controls and environmental monitoring systems, along with belt drives, fan controls, power centers, and other equipment underground can only be met through the use of fiber optics technology under *all* operating environments because a fiber optics cable system safely ensures data reliability.

Fiber optic cables and connectors are unaffected by noise, lightning, interference from RF, EMF, EMI, and Harmonics from the VFD drives common in mining. Intra-system communication is achieved with a fiber optic backbone consisting of the cable plant and the necessary connections. With the backbone installed, we can start putting the equipment in-place.

The general parts of the fiber optic linked system include**:**

- Centralized control rooms with video camera systems
- VOIP (voice-over-internet protocol) phone systems (underground and above ground)
- Emergency communication systems
- Environmental sensors (carbon monoxide, methane, hydrogen sulfide, and other gases)
- Longwall systems and sub systems
- Complex conveyor belt system controls
- Automation of remote system controls
- Conveyor belt scale and coal ash analysis systems
- Fire detection systems
- Conveyor belt video inspection systems
- Laser safety in underground coal mines (a must!)

With these advancements in technology, fiber optic implementations help improve processes, quality, and safety providing the lowest lifetime cost per ton in coal mining, preparation and processing.

Central Control Rooms for Mining, Video Camera Systems

The control room performs the centralized functions of monitoring, operating and controlling the mine, prep plant, and all other equipment. This involves data recording, controlling the complex belt conveyor-system, car-loading, car-unloading systems and other required functions and needed systems. The control room analyzes several thousands of in and outgoing processing variables, which are often relayed locally and up to several miles away. Fiber optic communication are uniquely suited to connect real time data from environmental and equipment sensors to ensure peak production while maintaining the highest safety standards.

With the heavy demands on the data/control networks, fiber optics offers the only viable solution with the necessary bandwidth to carry this enormous amount of data. An installed fiber optic network is not typically bandwidth-limited, as are copper-based networks. This information can now be visually displayed and streamlined – helping operators to make faster, safer, and more effective decisions. This data can also be sent to HMI/SCADA applications.

Using the installed fiber optic network, the data sent to the HMI/SCADA software is in real time and aids in effective decision-making based on real time status/event listings. In addition to the controlling, monitoring and recording of data, numerous other data related options are now available to help quality system management.

The coal industry maintains a positive attitude towards automation on the basis of enhanced safety. Many production mining equipment items are controlled remotely via fiber optic connection systems to solve some of the problems encountered in communications and machine control at the face.

These include video camera networks. Cameras are positioned at all transfer points and along the belt lines, load-outs, silos, bins, stockpiles, and inside of plant. Security cameras are at the gates for incoming and outgoing and on the scales for incoming trucks and outgoing trucks. These video camera signals are sent through the fiber optic backbone to the central control room where the control room operators can visually monitor operations.

All of these signals run on the fiber optic network, providing a complete fiber optic linked package.

VOIP Phone System Underground and Above Ground and Emergency Communication Systems

Reliable communications are essential to coal mining and coal mining safety and must be maintained in good working condition. There are three forms of communication: 12-volt mine page, PBX phone system, and a two-way radio system. If any one of these systems malfunctions, they must be repaired as quickly as possible. Communication lines emanate from the surface and enter the mine through a series of communication bore holes.

To address problems associated with these communications systems, VOIP phone system have been introduced allowing mines to tie above ground and underground communications into one system using an underground Ethernet fiber optic backbone system. One such system uses Cisco ATA 180 Series Analog Telephone Adaptors. The Analog Telephone Adaptor (ATA) products are standards-based communication devices that deliver true, next-generation voice-over-IP.

The ATA 180 series are mixed-environment adaptors that interface legacy analog telephones, and other analog devices to IP based telephony networks thereby allowing companies to protect their investments in analog phones and speaker phones, and migrate to IP at their own pace. The ATA 180 series is installed at the subscriber's premises supporting two voice ports, each with its own independent telephone number.

The ATA 186 supports a single 10/100BaseT Ethernet port. This adaptor can make use of existing Ethernet LANs. In addition, the ATA 188 has an internal Ethernet switch which allows for a direct connection to a 10/100BASE-T Ethernet network via an RJ-45 interface, with single LAN connectivity for both the ATA 188 and a co-located other Ethernet-based device by turning any analog telephone into an IP telephone. See *Figure 1* for a system diagram.

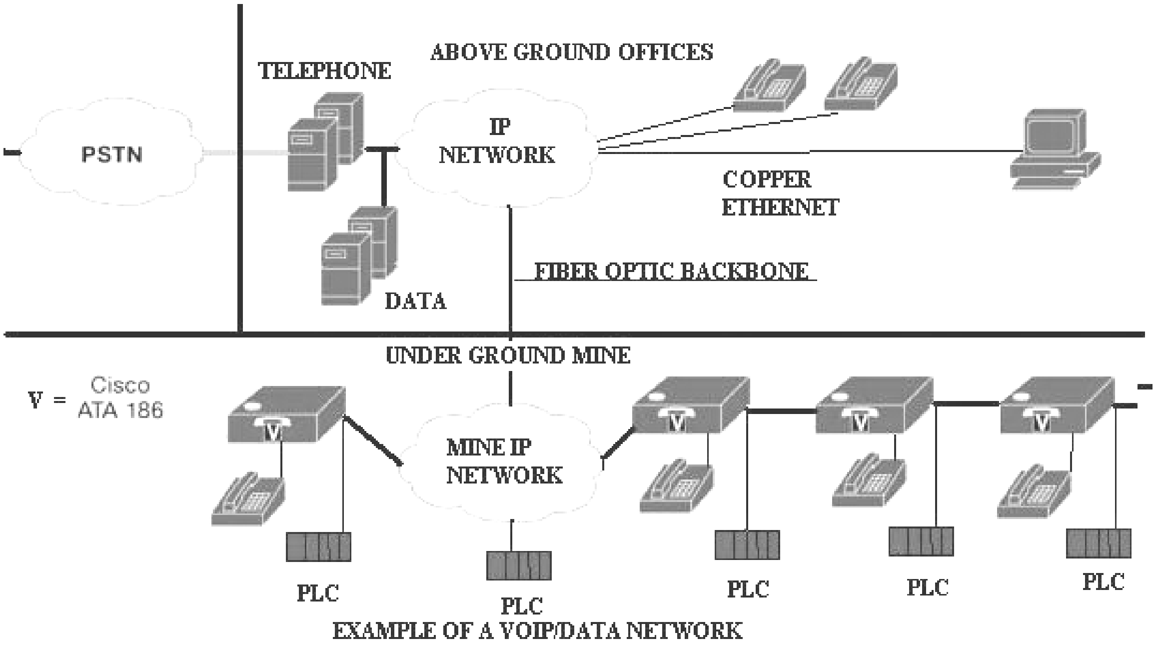


Figure 1. VOIP System Diagram

Emergency Communication Systems

The underground emergency communication systems can also be run on the fiber optic backbone. In the event of an emergency, there are two (2) dedicated fiber optic cable strands in the backbone system reserved for this use only. With the current low fiber optic cable, it is relatively inexpensive to do this.

In the real world, spare fibers are called “dark fiber,” meaning that it is unused and can form a reliable communication system. Only safe low power transmissions are sent down the fiber in this application.

This fiber remains unused until an emergency. The connectors are labeled as **The Underground Emergency Communication System.** These fiber are marked in the cross connect boxes allowing the use of a fiber optic talk set(s). As the search team advance into the mine they can tie the fiber through to the next cross connect box with a jumper stored at each cross connect box.

The team can plug in their talk set to the connector in the cross connect box and talk to the office, safely relaying information back to them as to their location is in the mine. See *Figure 2* for a figure showing the fiber optic backbone and cross connect box.

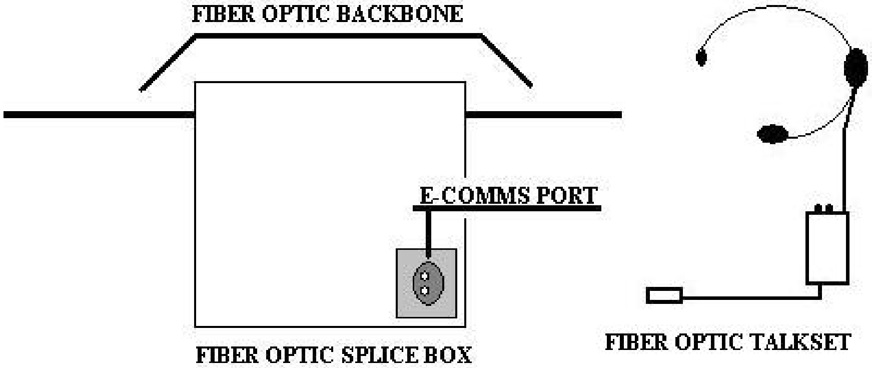


Figure 2. Cross Connect Box

Monitoring Systems

Monitoring systems must be flexible to allow the addition or removal of sensors and to facilitate monitoring over extended periods of time. For example, a good communication system in an underground coalmine are Ethernet LAN based components, real-time monitoring of gases and geo-technical sensors. New technology developments include: an intrinsically safe (IS) protocol converter, which converts Modbus data to Ethernet protocol, and an IS Ethernet switch, which forms the basis of an underground local area network. Low-cost, networked smart sensors are being developed for diverse industry needs that tie directly to fiber optic backbones.

The continuous monitoring of hazardous gasses using fiber optic based or linked sensors would reap tremendous safety improvements and benefits be they poisonous or flammable gasses.

Interfacing the smart sensors to the control networks and supporting the wide variety of protocols require installed fiber optic networks and backbones. This can include video camera networks. These cameras are installed at belt transfer points, feeder breakers, and car unloading points. The video camera signal is sent down the fiber optic backbone to the central control rooms where the control room operator monitors operations.

Total Longwall Automation

Total longwall automation will require the development of numerous sets of technology from sophisticated software and hardware, to improving the reliability of machine sensors. Longwall mining is a highly productive method of mining coal underground but like all underground mining methods, safety is a key factor. Most importantly, success with each of these discrete projects will deliver an immediate benefit to current longwall operations. An important part of the research is to make longwall operations more consistent and reliable. Improving the reliability of the numerous sensors used underground to gather data, is an important initial target.

Longwall mining systems have increased in size over the last decade. One of the largest shearers in Australia is capable of cutting a seam height of nearly 5m. Greater health risks have arrived with increased size.

Exposing workers to increased dust, gas and noise is of major concern to the industry. One solution is to remove workers from proximity to the mining environment through process automation.

While longwall mining is highly productive, it is a method that is susceptible to changing ground conditions. Human operators are not always able to see and analyze these conditions. The result is inconsistent operation and fluctuations in productivity. Automation of longwall mining removes some of the inconsistencies inherent in manual operations.

The key to longwall automation is knowing the three-dimensional position and orientation of the longwall shearer and the surrounding environments. Functions such as steering the shearer, and keeping the face straight are all determined by where the shearer is in space. Until recently, the ability to know in real-time the location of the shearer had eluded researchers. The ability to put fiber optic cabling all the way to the shearer allows us to tie the complete system together as one.

Automation and longwall mining tests have been done in the U.S. and Australia by large OEMs (DBT, JOY). Additional work has been done in Australia is by the CSIRO group. These organizations have issued a very good technical and white papers including *Ethernet on a Longwall Shear and Longwall Technology workshop*; *Horizon Sensor for Advanced Coal Extraction (ACE) Dr. Larry G. Stolarczyk and Gerald L. Stolarczyk Raton Technology Research, Inc. Raton, New Mexico and Kenneth L. Perry. Salt Lake City, Utah, presented at National Mining Association MINExpo International 9/11/1996 Las Vegas, Nevada; An Experiment in Autonomous Navigation of an Underground Mining Vehicle IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION, VOL. 15, NO. , FEBRUARY 1999 Steven Scheding, Gamini Dissanayake, Eduardo Mario Nebot, and Hugh Durrant-Whyte*

CSIRO researchers are at work on longwall automation at mines in both NSW and QLD. The first commercial outcome of the project will be an automated face alignment package. Details of this work can be found on their longwall automation website: www.longwallautomation.org

Industry Benefits

The benefits for the industry of longwall automation will be higher, more consistent production rates and the removal of workers from more hazardous and dusty areas in a longwall mine. The aim of researchers over the next three years is to reach the point where a longwall can run in semi-automated mode, with a worker monitoring system operation, observing changing conditions, and intervening if something goes wrong. Improving horizon control will be another of the early benefits researchers hope to deliver to existing coalmines.

The first field trial of the Landmark face alignment system in combination with DBT roof supports was conducted at Broadmeadow Mine, Central Queensland, during week beginning 13th February 2006. The primary objective of the trial was to observe and document the closed-loop control of the Landmark automated face alignment system under closely monitored longwall-production conditions.

This objective was successfully achieved on the third day of the trial. The trial provided an opportunity to identify software bugs and operational deficiencies that had not been detected under bench test conditions and possible enhancements for inclusion in future software releases. The results of the trial can be seen in Figure 3, which shows a sequence of face profiles from the oldest at the bottom to the latest at the top of the plot. The profiles describe the tail-maingate horizontal path of the shearer operating in UniDi cutting.

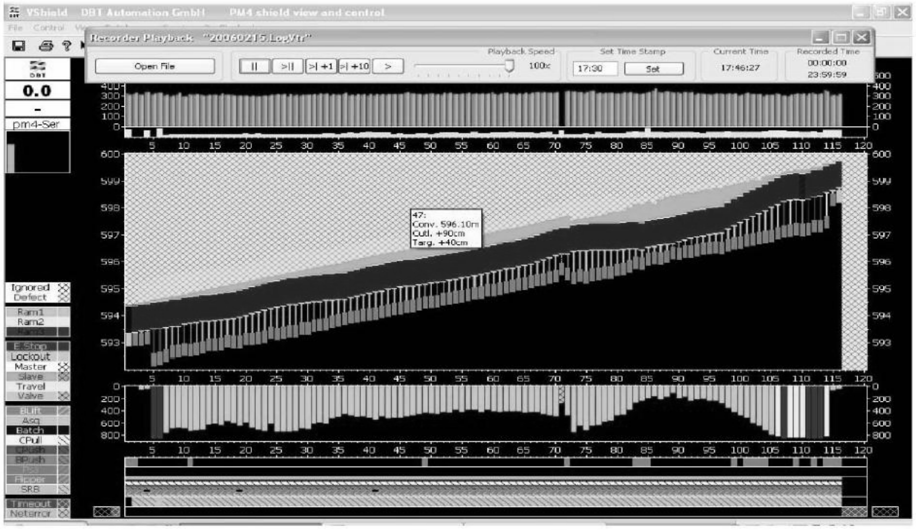


Figure 3: Screen display of the VShield system showing Shield Advance for Shear

Complex Conveyor Belt System Controls

In a complex conveyor belt system, the starting sequence, flow separations, ascent and descent angles, bulk weights and distribution, changing operating conditions (particularly difficult to define are belt tensions and longitudinal oscillations) as well as emergency and repair modes and other critical factors must be taken into consideration and monitored during operation. The latest drive and motor technology, such as the VFD drive, are now being linked through fiber optic cabling systems. This provides clean and problem free communication solutions satisfying almost all types of conveyor belt systems. A specially written SCADA program is embedded in the speed and synchronizing controller to synchronize the VFD drives located at the ends of the conveyor systems.

This separation of the synchronizing, load balancing and protection functions into a dedicated speed and synchronizing controller ensures that the core functions required for the long conveyor operation are always solved at the highest priority. Moreover, a fiber optic controlled conveyor system is unaffected by other data intensive routine functions like alarm handling, interlocks, and reporting, which can slow down the system under certain critical conditions in a copper wire based system. This also ensures smooth starting/stopping of the four motors. An adaptive load balancing/sharing algorithm ensures minimum power consumption (a very important criterion considering the large drive ratings and varying load patterns).

This is very important, as the slightest mismatch while starting, stopping or running can cause belt fatigue and premature failure of the conveyor. The conveyor system is the lifeline of the plant. The system cannot afford to have failures, and/or long downtime due to unplanned maintenance procedures or repairs. With the use of fiber optic technology, we can make communication failures a thing of the past. Real time data on tripping of any drives, belt slippage, load/speed imbalances, overloads, power failures, etc., can be and is immediately available.

Automation of Remote System Controls

Automation of system control is extremely important when using a remote conveyor belt system. The starting sequence, blending of minerals, remote load-outs, storage bins, ship loading, harmonic monitoring systems on gearboxes, belt scales, methane and carbon monoxide sensors, cameras, ash monitoring systems, and plant wide and belt-system fire-detection sensors can be controlled and monitored fiber optically.

Conveyor Belt Scale System

Conveyor belt scales are integrated weighing devices that use a simple integral calculus summation process to measure the quantity of conveyed material. Two variables are involved: weight and speed.

A weight function measures the weight of a small section of a conveyor. The gross weight on the scale is the weight of the belt, the belt conveyor idler and the material on the belt. The net weight of material is the gross weight less the weight of the supported section of the belt and the scale idler. The total weight sensed at any particular position of the conveyor is the sum of all particles in the weighing area with respect to their individual triangular waveforms and their position in the scale weighing area. This weight function is a representation of the weight per unit distance at any one point on the conveyor belt usually represented in lbs/ft or kg/m.

Speed is the second variable to be measured. Most modern speed sensors are rotary digital pulse generators or encoders.

Formulas Used for Commonly Displayed Data

$$\text{Total Weight} = (\text{Weight/unit distance}) \times \text{distance}$$

$$\text{Rate} = \frac{\text{Change of total weight}}{\text{Time}}$$

$$\text{Belt Speed} = \frac{\text{Distance}}{\text{Time}}$$

As the conveyor moves a small discrete distance as measured by the speed sensor, a portion of the weight is measured. If the belt loading is 50 lb/ft. and the belt moves 1/100 of a foot then the totalizer adds 0.5 pound to the total. This happens at a relatively high speed. A conveyor traveling at 300 ft/min generates 30,000 additions per minute and 500 readings per second. Multiple readings per pulse are used to attain higher resolutions.

This equates to 4000 analog weight readings per second in the above example. The best cable for this use would be a hybrid type constructed of both fiber optic and copper wire using the fiber for data transmission and the copper for power. This ensures data reliability and a data signal unaffected by noise, lightning, and interference from RF, EMF, EMI, and the harmonics, allowing the scale to be located where needed regardless of the environment.

In-Line Coal Analysis

In-line coal analyzers began to be developed in the late 1970s and early 1980s in the United States, Australia, and Europe. The late 1980s and the entire decade of the 1990s saw evolution, rather than revolution, in these instruments. Many of these changes were driven by the users' demand for less expensive gauges. Among those improvements were:

- PGNAA (Prompt Gamma Neutron Activation Analysis) analyzers with an integrated input hopper and sample conveyor in smaller footprints
- Dual-gamma ash meters with swing-arm sensors
- Ash gauges based upon natural gamma emitters in the ash (potassium and thorium)
- CNA (Controlled Neutron Analysis) using a fully controlled electric neutron source utilizing the robust PFTNA (Pulsed Fast & Thermal Neutron Analysis) analysis techniques

The best cable for this application is a hybrid type built with fiber optics and copper lines. Using the fiber for data and copper for power ensures data reliability with the data unaffected by the environment. This allows the measurement equipment to be placed where needed. It also allows the operator to send the contents where it needs to be for mixing grading or dumping. See *Pictures 1 and 2* of in-line coal analyzers.

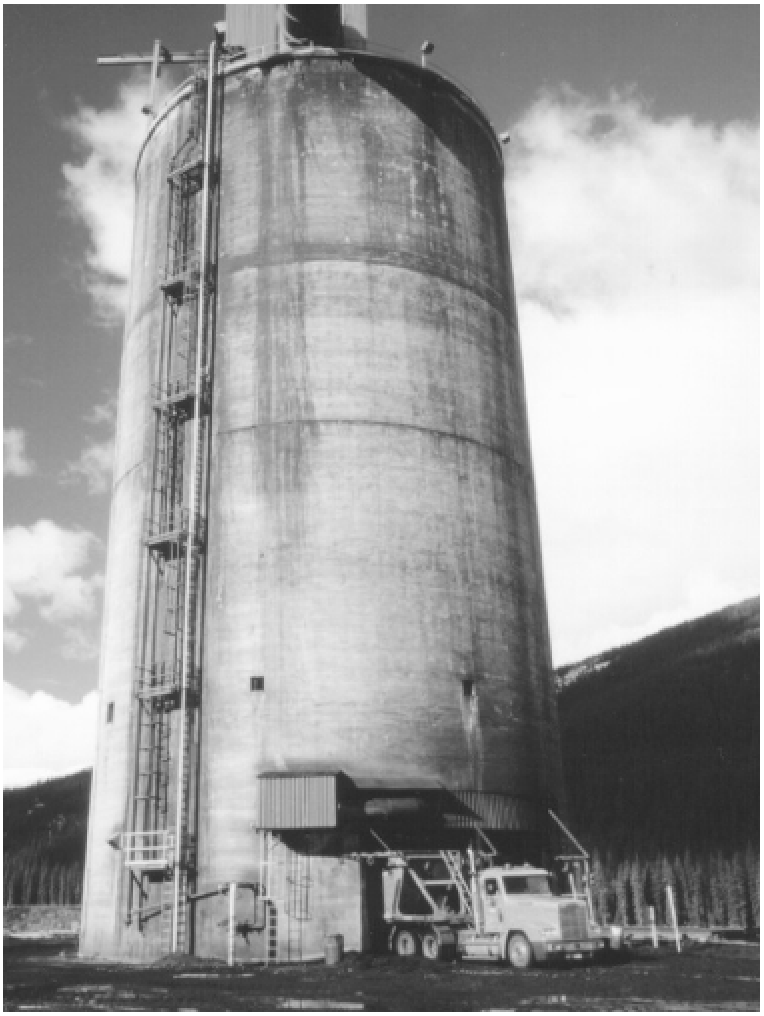
Pictures 1 and 2. In-line coal analyzers

FIRE DETECTION

We need to add fiber optically linked fire detection to this discussion. The following three applications are commonly used. There are many more types available:

- Conveyor belt line fire detection

- MILL/Silo fire detection (See *Picture 3*)
- Railcar fire detection



Picture 3. Silo Picture

Conveyor Fire Detector

The transportation of coal on any form of conveyor system has the potential to ignite, with the ultimate outcome being a fire. Coal (even in small amounts) is a very good insulator, so that fire, which is burning beneath the surface, may not be immediately obvious. A single point temperature-measurement system can detect a hot spot, but is just as often likely to miss one. A temperature scanning system, which looks at the entire width of the conveyor at any one time, is an ideal solution. It scans at a wide angle (the entire conveyor width), at high speed and with a fast response. Every hot spot is detected as the entire coal surface is viewed. The scanner is capable of detecting even small hot objects on the conveyor with its high-speed scanning detector. The scanner outputs the hottest temperature on the conveyor directly to a plant control system or suitable customer alarm system.

These signals are sent back to SCADA in the control room over the fiber optic cable backbone. The processor powers the scanner and also provides the signal outputs.

Conveyor belts are expensive and replacements can carry long lead times. Maximize belt life and plant productivity by detecting hot spots before problems occur. Quick response and hottest temperature tracking reduce plant-operating costs, while reducing damage, decreasing downtime and improving safety.

Mill/Silo Fire Detection

Advance warning of the onset of coal mill and silo fires through the build-up of carbon monoxide (CO) is now possible through CO detection systems. The savings in costs of repairs following a mill fire would pay for the system many times over. This detection system is specifically designed to detect rapid build-up of carbon monoxide inside pulverizing coal mills and silos. It continuously monitors the atmosphere, and responds very quickly to any significant increase in the levels of CO, created at the onset of a fire.

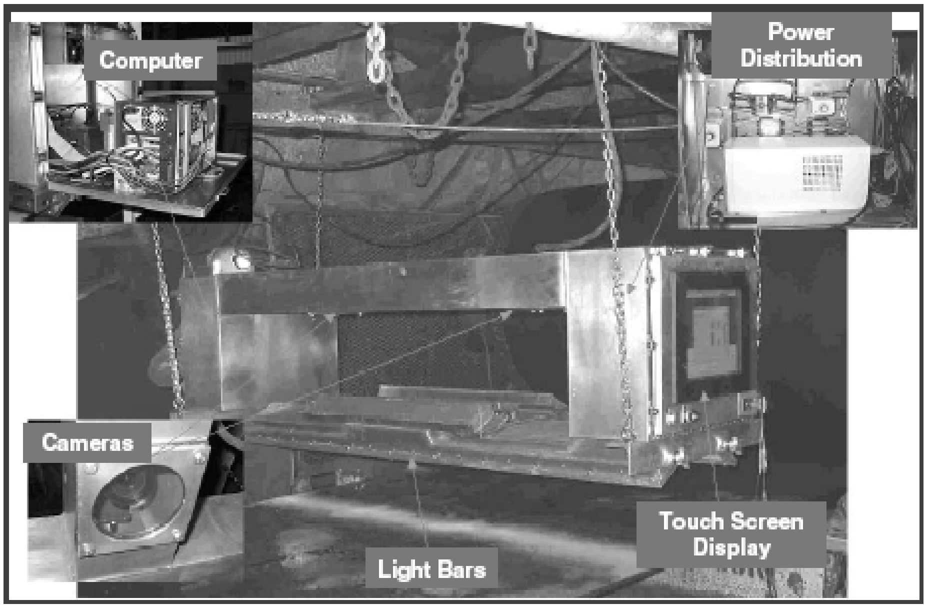
This provides the operator with advance warning to enable preventative action to be taken before damage to the plant, or injury to personnel occurs. Monitoring of CO, as opposed to or in addition to temperature sensing, provides much earlier detection of combustion and subsequent prevention of a mill fire. The system detects changes significantly faster — in time to prevent damage. These signals are sent back to SCADA in the control room over the fiber optic cable backbone.

Railcar Fire Detector

The transportation of coal by rail brings with it the potential risk of fire. Coal stored and moved in rail cars can provide the conditions necessary for coal to smolder, which, if undetected, can lead to fire. Certain types of coal, notably Powder River Basin (PRB) coal, are particularly susceptible to spontaneous fires when transported, stored or ground. The self-heating of coal is well documented, expanding the need for fire detection from the transportation, storage and processing of coal in all areas of the plant. The system scans the coal as it is unloaded and drops from the railcar through under-track grates into a storage hopper (track hopper). Hot spots or smoldering coal is detected and fire prevention actions can be taken. As each rail car arrives at the plant and unloads the coal, the curtain of falling coal is temperature checked using an infrared temperature scanner. This is located trackside and mounted horizontally to view the passing coal as it leaves the railcar. Hot spots are identified and used to trigger alarms to prevent widespread fire in the storage hopper or the subsequent conveyor system. The system looks for and alarms the “hottest temperature.” This peak output can be set to provide an ignition alarm. These signals are sent back to SCADA in the control room over the fiber optic cable backbone.

Conveyor Belt Video Inspection System

When coal is transported to the surface on a conveyer belt and this belt breaks or otherwise has to be stopped for maintenance, coal production comes to a halt until the belt is started again. Depending on the mine and the location of the break, this can cost tens of thousands of dollars in lost revenues. Automated conveyor belt video inspection systems monitor the belt where it is most likely to fail, namely the belt splices. Video inspection systems provide images of the belt splices to the mine personnel who can then evaluate these images and take action prior to belt splice failure. Once again, data and or video from these systems can be linked into the network safely through fiber. See *Picture 4*.



Picture 4. Belt Video System

Detecting and correcting potential failures before they happen minimizes mining downtime. This is because the repair of a splice before it fails can be accomplished in a significantly shorter amount of time than it takes to repair a broken belt. The advantage of applying this system will be an improvement in the productivity and profits for the mine. It also is much safer by avoiding the repercussions of breaking belts. The belt video inspection system hardware consists of cameras for imaging the belt, lighting for illuminating the belt, a computer for digitizing and analyzing the camera image, a flat panel touch screen display for a user/operator interface and power distribution components. Depending on the level of control room integration, the computer, screen and power distribution components would be used in multiple roles for multiple sub-systems. Mine personnel can review splices several times a day with minimal effort.

Mines utilizing belt video inspection systems can measure cost savings from avoided downtime, better maintenance planning, simpler review of a belt line's current splice status, and group planning of action items for a splice.

The belt inspection system is capable of:

- Detecting mechanical splices.
- Generating a digital image of the splice.
- Keeping a record of the splices for viewing a history of deterioration.

- Displaying the mechanical splice on the user interface and publish the image over the fiber optic network to the SCADA system in the control room.

These systems have been installed in many western US mines; with approximately 10 systems resident in the Consol mines in the East.

LASER Safety in Underground Coal Mines

Laboratories from several countries took part in studying methane-air ignitions. In addition to the US, other participating laboratories are located in Australia, United Kingdom, and Germany.

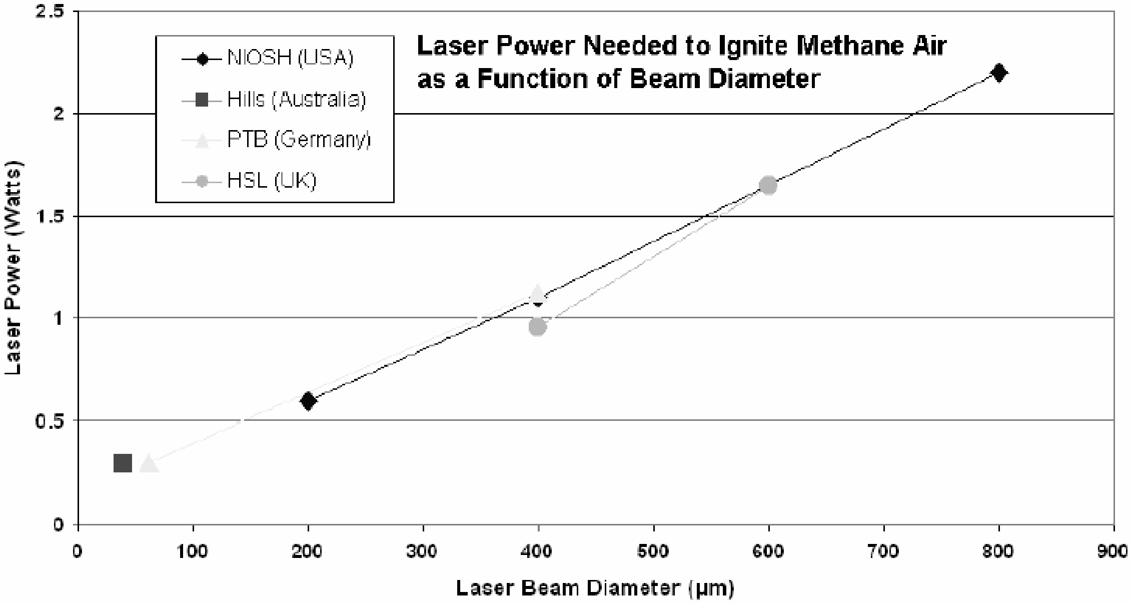
NIOSH (National Institute for Occupational Safety and Health) also performed additional experiments with explosive coal dust clouds.

These experiments confirmed that more power is needed to ignite coal dust clouds than is needed to ignite methane-air. Researchers also observed that the amount of laser power needed to create explosions was proportional to the laser beam diameter for the coal dust clouds, as well as for methane-air.

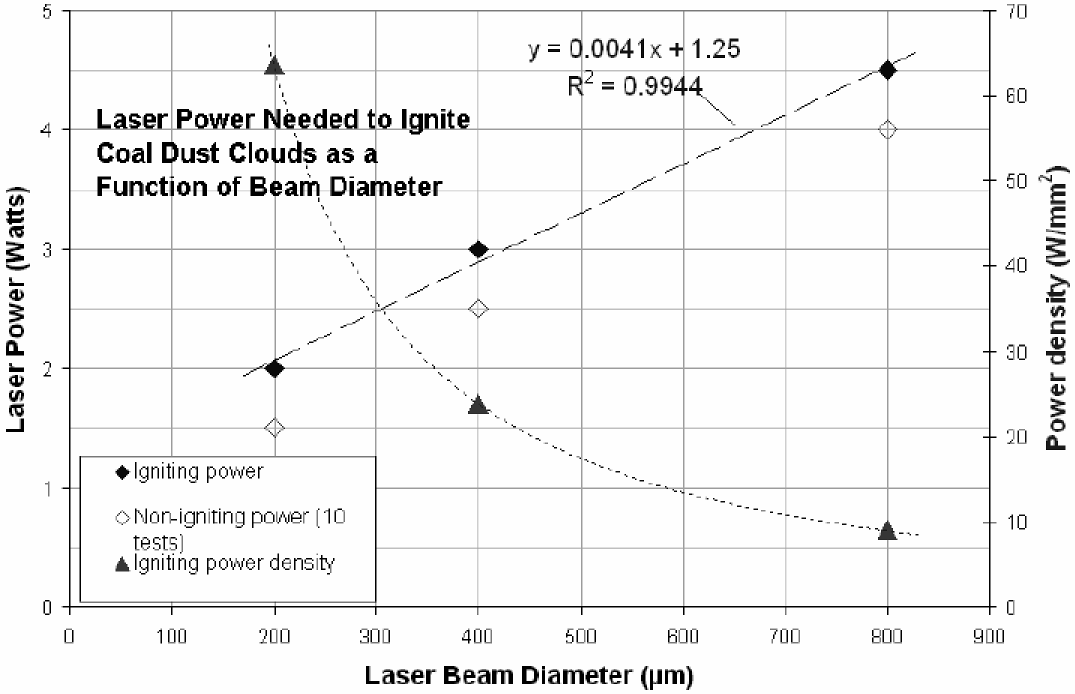
This suggests that explosions could be prevented even for relatively powerful beams by ensuring that the beam diameter is large enough to reduce the beam intensity.

http://www.cdc.gov/niosh/mining/topics/electrical/lasersafety.htm 1

The following graphs show "ignition curves" of laser power versus beam diameters. Explosions can be prevented by ensuring that laser systems operate well below these ignition curves.



Laser power needed to ignite methane air as a function of beam diameter.



Laser power needed to ignite coal dust clouds as a function of beam diameter.

There are a number of papers written by the team at NIOSH that deal with Laser Safety in under coalmines. These are recommend reading for all and are available at the NIOSH web site, see address below.

Web site
http://www.cdc.gov/niosh/mining/topics/electrical

It is good to know that the entire fiber optic network switches and fiber optic hubs work well below this range. Many if not most fiber optic based systems now use LED emitters as opposed to lasers making this a moot point.

Conclusion
The advent and use of fiber optics in modern mining equipment and mining contributes to improving safety, increasing producibility and reducing costs. Fiber optic networks enable effective real time monitoring, controlling and data distribution in mining operations. The ever-increasing amount of information transmitted to central locations in modern mining necessitates the use of fiber optic based systems. Health and well being considerations and emergency situations can now rely on the inherent safety of fiber optic communications.

Appendix A

An Introduction to Fiber optics

Why Fiber Optics?

- Severe environmental conditions
  - Contamination
  - Extreme temperature/pressure
  - Electrical noise
- Cost
- High bandwidth
- Safety
- Low weight/high density/small size
- Superior optical performance
- Ruggedization requirements
- EMI, Security Concerns and Noise Immunity

The Beginning of Fiber Optics

1870 – John Tyndall's – Light pipe experiment demonstrated Total Internal Reflection.
- First research into guided transmission of light.

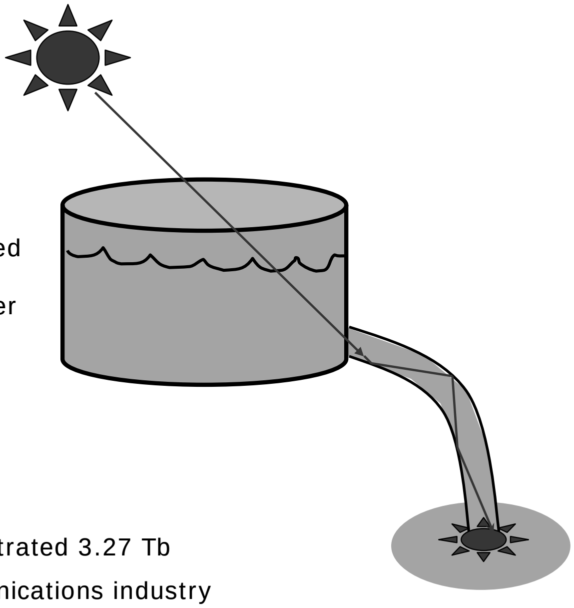
1960 – The first laser
(**L**ight **A**mplification through **S**timulated **E**mission of **R**adiation)
-enabling technology that allowed fiber to transmit data

1977 – The first fiber optic phone systems installed by AT&T, GTE & Sprint

1995 – DWDM – 16 channel used on OC-192 Systems

2000 – DWDM – 132 channel demonstrated 3.27 Tb

2005 – FTTH news dominates communications industry



Basic Components of Fiber

- **Transmitter –** Converts electrical signal into a light signal.
  - LED –Light Emitting diode
  - VCSEL -Vertical Cavity Surface Emitting Laser
  - LD – Laser Diode
- **Fiber Optic Cable –** Medium for carrying the light
- **Receiver –** Accepts the light and converts it back to an electrical signal Photodiode
- **Connectors –** Connects the fiber to the source, detector, or other fibers

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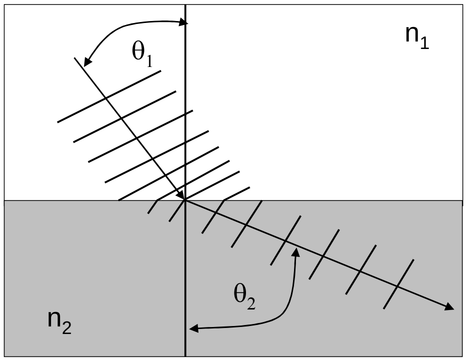
Light Guiding Principles
Snell's Law

- $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ **(Snell's Law)**
  - **n is the *index of refraction***

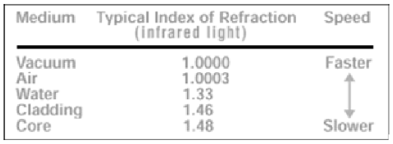


Snell's Law – Is the relationship between the incident rays and the refracted rays

Index of refraction (IOR)

n=c/v

Where:
C= the speed of light in a vacuum (186,000 mi/s)
V= the speed of light in the material



Medium	Typical Index of Refraction (infrared light)	Speed
Vacuum	1.0000	Faster
Air	1.0003	↑
Water	1.33	↕
Cladding	1.46	↓
Core	1.48	Slower

As light travels from one medium to another, the speed changes

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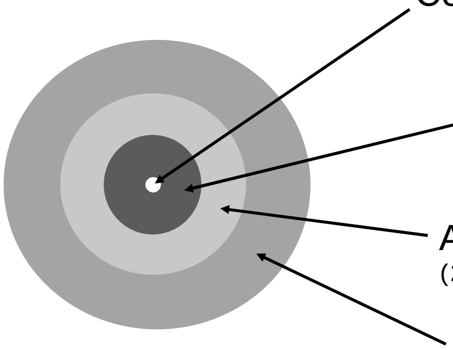
Typical Fiber
Cross Section

- Common Communications Wavelengths
  - 850nm
  - 1310nm
  - 1550nm



Core (9-100 μm)

Cladding (125/140 μm)

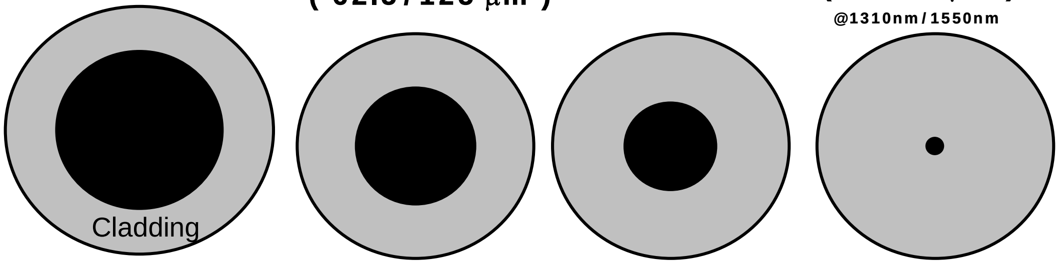
Acrylate Coating (250 μm)

Buffer Layer (900 μm)

Common Optical Fiber Types

Multimode Fiber
(62.5 / 125 µm)

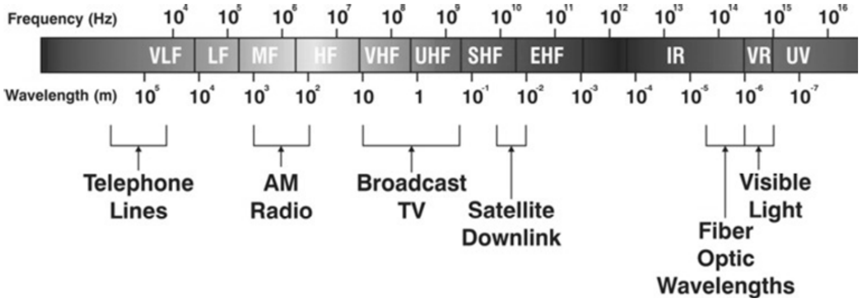
Single Mode Fiber
(9 / 125 µm)
@1310nm / 1550nm



Multimode Fiber
(100 / 140 µm)

Multimode Fiber
(50 / 125 µm)

Electromagnetic Spectrum

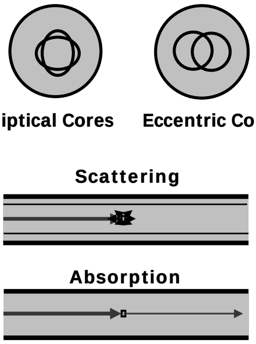


Frequency	Fiber Type
850nm	Multi-Mode
1300/1310nm	Multi-Mode/Singlemode
1550nm	Singlemode
1625nm	Singlemode
1330nm - 1520nm	Singlemode

Attenuation

Intrinsic Losses

Loss due to <u>Fiber Irregularities</u>



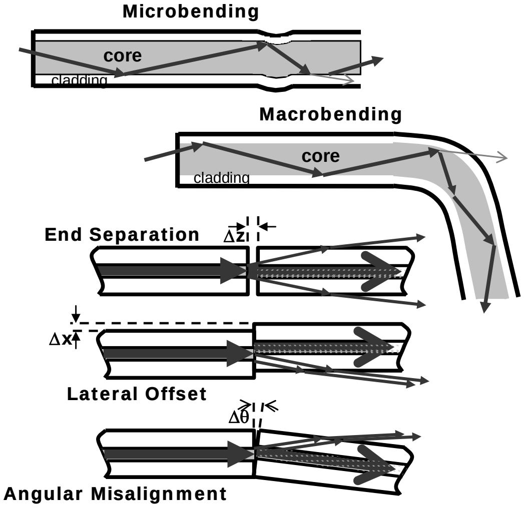
Elliptical Cores

Eccentric Cores

Scattering

Absorption

Extrinsic Losses



Microbending

Macrobending

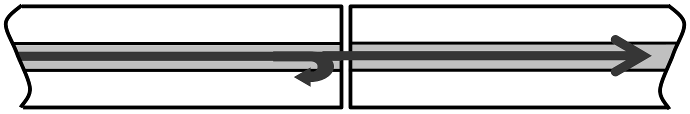
End Separation

Lateral Offset

Angular Misalignment

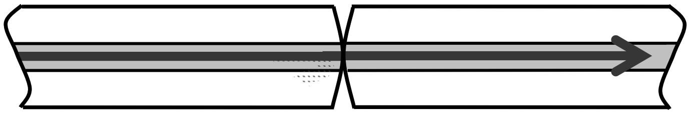
PC Fiber Optic Connectors: Back Reflection / Return Loss

Flat Endface – High back reflection due to air gap



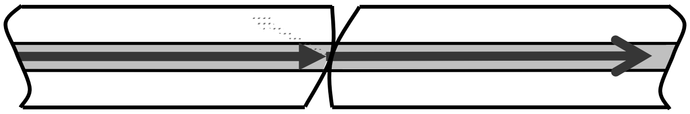
Rounded Endface – Lower back reflection – reduced air gap

PC / UPC



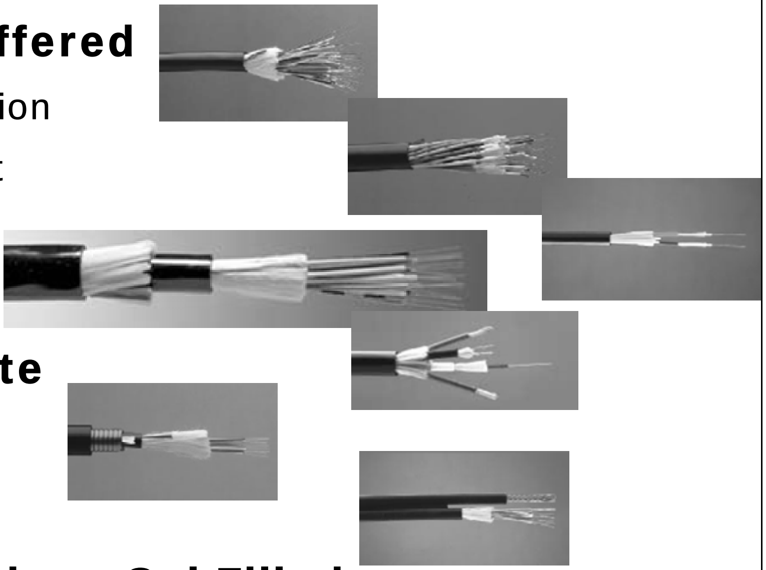
Angled and Rounded Endface – Very Low Back Reflection

APC



Fiber Optic Cable Types

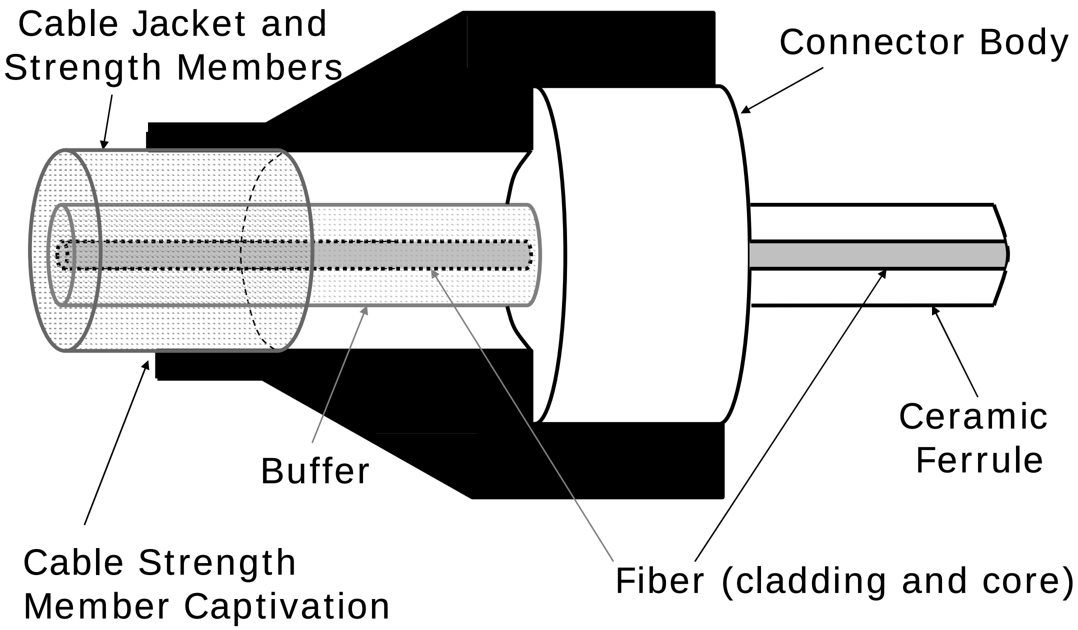
- **Tight Buffered**
  - Distribution
  - Breakout
  - Tactical
- **Hybrid**
- **Composite**
- **Armored**
- **Aerial**
- **Loose Tube – Gel Filled**



Fiber Optic Connection Types

- **Permanent**
  - Fusion splice
- **Temporary**
  - Mechanical splice
- **Reusable**
  - Physical contact connector
  - Expanded beam

Fiber Optic Connector Basic Construction

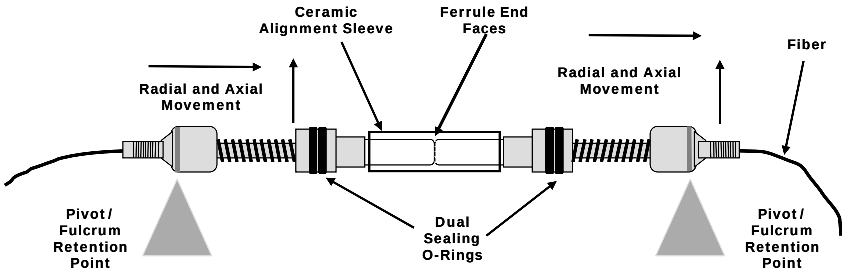


Preferred Fiber Optic Interconnect Characteristics

- **Low insertion loss**
- **Self-aligning termini**
- **Sealed termini**
- **Low cable & termination stresses**
- **Non-rotating elements**
- **Minimized contamination**
- **Mating ease**
- **Maintainable / cleanable / repairable**

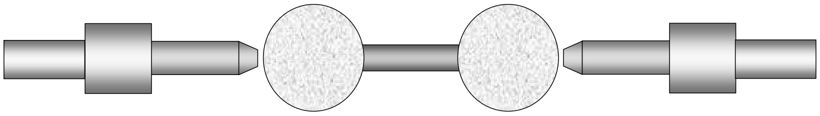
Physical Contact Joint

- Technology:
  - Fiber is inserted into a zirconia ferrule and epoxy-polished
  - Spring force on the two termini keep the two ferrules in contact
  - Polishes: PC, Ultra PC (UPC) and Angle PC (APC)



Expanded Beam

- Technology:
  - A lens, positioned in front of the fiber expands & collimates the beam
  - The beam is then re-focused to the other side of the connection
  - Lenses type: plano convex or ball lenses
  - Beam diameter: between 200µm and 500µm upon product



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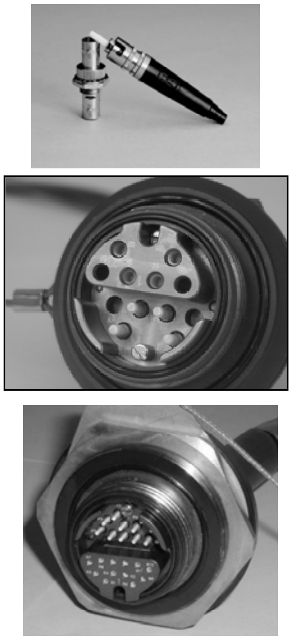
Fiber Optic Connections: Types

- **Single Fiber Connector**
  - 2.5mm ferrule: ST, SC, FC
  - 1.25 mm ferrule: LC
- **Multifiber Connector**
  - Biconic ferrule: TFOCA
  - 2.5mm ferrule: TFOCA-II®
  - 2.0mm ferrule: M28876, 4 Ch Herm, 12 Ch Pierside
  - 1.25mm ferrule: TFOCA-III®, THD48
  - Others: M38999



Common Fiber Optic Connector Types

ST Connector

LC Connector

FC Connector

MTRJ Connector

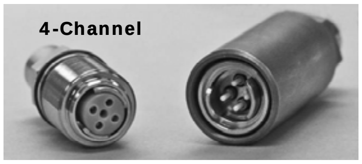
SC Connector

MTP Connector

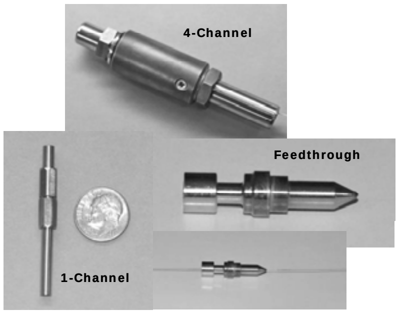
Hybrid Connectors

- Allows the customer to consolidate power and signal cables into a single assembly
- Electrical contact can be as large as 10 awg
- Up to 4 electrical contacts and 12 fiber optic contacts (SM or MM) per connector

Geophysical Products



High Pressure & High Temperature



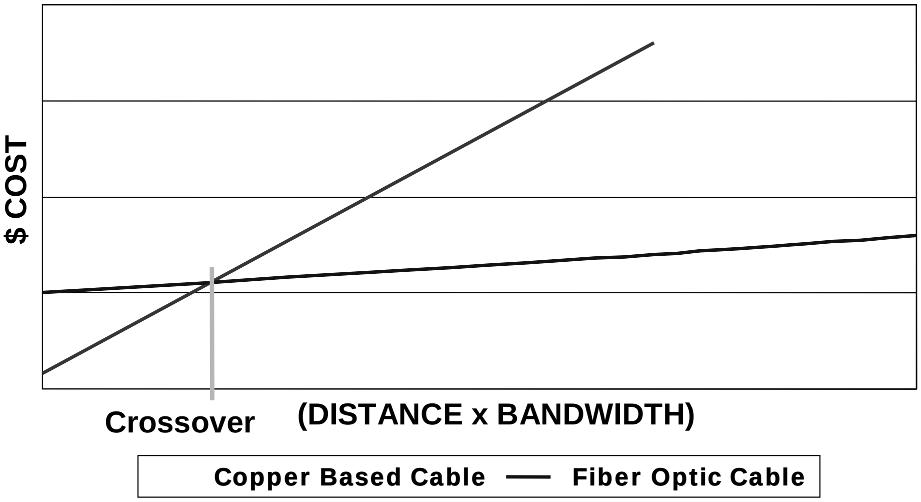
Cable Comparisons
Coax vs. Fiber

Fiber advantages over Copper

	Coaxial Cable	Fiber Optic Cable (MM)	Fiber Optic Cable (SM)
Representative Distance Bandwidth Products	100 MHz km	500 MHz km	100,000+ MHz km
Attenuation/km @ 1 GHz	>45 dB *	1 dB	0.2 dB
Cable cost ($/m)	$$$	$	$
Cable diameter (in.)	1	1/8	1/8
Data Security	Low	Excellent	Excellent
EMI Immunity	OK	Excellent	Excellent

* Andrew HFC 860 Series

Copper vs. Fiber
Application Tradeoffs



Fiber Optics Support

Training

- Basic fiber optic training recommended for all personnel involved with fiber optic interconnects
- Understanding basic interconnect technologies, concerns, and issues
- In-depth termination, polishing, cable assembly, and repair training
- Test and troubleshoot

Tools and Equipment

- Termination Kits – All the tools needed to terminate most optical connectors
- Single and multiple position termini polishing pucks and supplies to achieve optimum optical performance
- Insertion/extraction tools, assembly tools and polish restoration accessories
- Test cables, optical power meters, optical sources, and optical inspection equipment

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The following is an alphabetical list of participants in the development of this standard Peter Henderson *(Chairperson)* Tony Singleton (LASC) David Hainsworth (CSIRO) David Reid (CSIRO) Mick Webster (DBT) Azad Chacko (DBT) Calum McLeod (DBT)