

Benefits of Fiber Optics for Underground Mine Communications

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ABSTRACT

Fiber optic networks provide highly reliable and intrinsically safe communications systems for underground mines. Comprised of small strands of glass, optical fiber cables can transmit light at very high speeds. Since these cables do not contain electrical conductors, they are intrinsically safe for use in underground hazardous locations. By eliminating spark hazards, the risk of ignition from flammable gasses is minimized. Furthermore, since optical fibers are composed of glass, they are immune to induced currents, cross talk and EMI generated by large AC motors and other electrical equipment used in mining operations.

Fiber optic cables and connectors are designed and qualified for use in mines by validating the mechanical strength required to install and operate the cable in an underground environment. Pull strength, crush resistance, impact strength and flexibility are key characteristics of qualified cables. Resistance to flame spread, per local code requirements such as MSHA, are additional requirements. In this article, we will review the basics of optical fiber, cable and connection systems for use in underground mines and show how these elements are specified and deployed in an underground installation.

INTRODUCTION

In underground mining, communications infrastructure is a vital component of the operation. Underground communication networks are the critical link between operations underground and personnel at the surface. Mines are constantly changing and the mining process is highly mobile. As the operation has advanced, equipment and people are constantly moving. The potential for explosive gases, rock falls, wet locations, temperature extremes, confined spaces, high voltage and electromagnetic interference are a few of the hazards the underground network must survive. Furthermore, the demands on the network have increased through convergence of data. By adding surveillance video feeds, sensor data, miner tracking data, machine control signals, mine phones and production data to a singular network, the need for bandwidth over a distance which grows daily has become paramount to effective underground operations.

Fiber optic networks offer a reliable, high speed, low latency, intrinsically safe, interference proof, flexible and modular option for evolving underground mine communication systems. Optical fiber systems are also capable of handling the convergence of data over long distances. Designed to be modular for ease of maintenance and expansion and portable to facilitate changes in the network infrastructure, optical fiber systems enhance safety by eliminating spark hazards found in conventional copper cabling solutions. Optical fiber systems are readily available and easy to deploy and maintain.

Fiber optic communication systems use pulses of light to transmit data. First developed in the 1970s, fiber optic systems have revolutionized communications in our modern world. Massive amounts of data are successfully transmitted via fiber optics every day. From online transactions and Internet searches to live HD video feeds transmitted around the globe, fiber optic communication systems are at the core of the modern information age. The process of communicating over fiber optics involves only a few basic steps. First, the data must be converted to light. Second, the encoded light pulse is transmitted over the fiber optic network. Finally, the light pulse is converted back into a conventional electronic digital signal. Transmitting and receiving optical signals is accomplished through readily available transceivers that utilize devices such as Light Emitting Diodes (LEDs) and Vertical Cavity Surface Emitting Lasers (VCSELs), a form of laser diode commonly used in fiber optic transmission systems. The fiber optic network consists of several components including optical fiber, optical cable and optical connecting systems.

Optical fiber is a very thin strand of glass that is used to carry the light pulses from the transmitter on the sending side to the detector on the receiving side. Optical fiber consists of three basic layers—the core which is the glass region where the signal travels; the cladding which is

a glass region that traps the signal in the core; and a polymeric coating or primary buffer that provides a basic level of protection to the fiber while it is being further processed. Transmission of light through an optical fiber works through the principle of total internal reflection. By changing the index of refraction of the glass in the core compared to the index of refraction of the glass in the cladding, the transmission path the light takes as it travels through the fiber is prescribed. By controlling the angle at which the light is coupled into the fiber, the cladding can effectively act as a mirror and completely reflect any light that tries to escape through the cladding. Figure 1 illustrates this phenomenon.

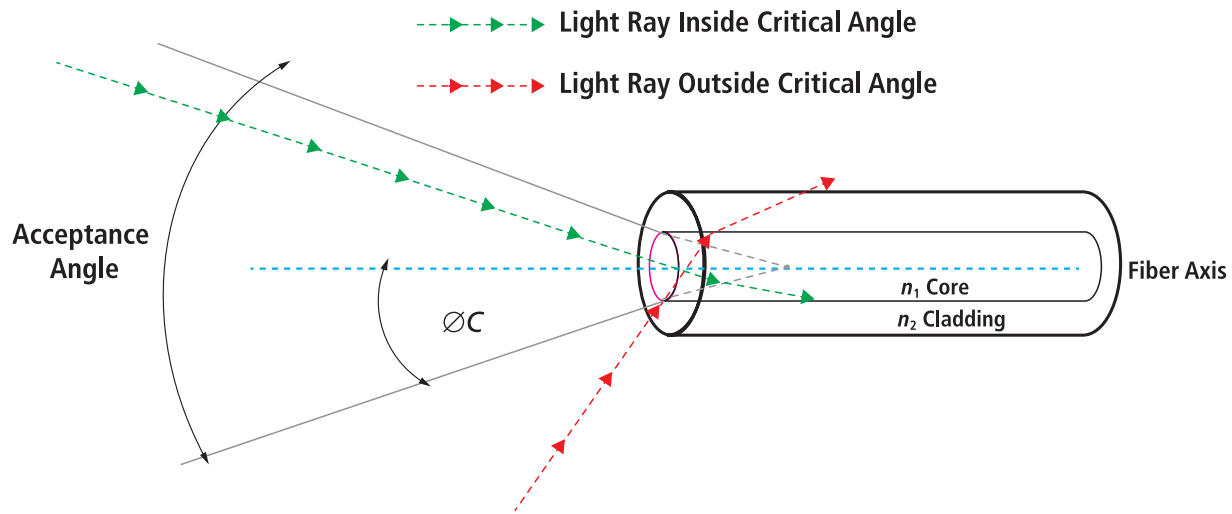


Figure 1—Make up of optical fiber showing total internal reflection

Traditionally, underground mining networks have utilized multimode optical fiber. Multimode fiber, as the name implies, allows multiple modes of light to travel along its length. This type of optical fiber has a larger core diameter and accepts light coupled from a larger angle and from a broader spectral source, such as an LED. Multimode fiber offers plenty of bandwidth to support Ethernet protocols over short distances and is more than adequate for signaling for machine control and miner tracking over short distances. The core size of multimode fiber is commonly 62.5 micron or 50 micron versus approximately 9 micron for single-mode optical fibers.

The ability to transmit data over distance is commonly referred to as the bandwidth distance product. Because of the larger core size in a multimode optical fiber, the bandwidth distance product can present a limitation for very large underground networks. Additionally, multimode fiber has significantly higher intrinsic light attenuation, or the loss of the optical power, which is another limiting factor in large underground networks. Measured in decibels, attenuation is described by the equation:

$$-10\log(\text{Power Out/Power In})$$

In a typical multimode system using 62.5 micron fiber with an LED light source operating at 850 nm, the intrinsic attenuation of the fiber is approximately 3 dB per kilometer. Since attenuation is measured on a logarithmic scale, 3 dB equates to an optical power loss of about 50 percent. On the other hand, by utilizing a VCSEL-based transceiver operating at 1300 nm, the intrinsic attenuation of the fiber is typically around 1 dB per kilometer. Single-mode fiber attenuation is typically less than 0.5 dB per kilometer.

So far, the discussion of attenuation has been limited to intrinsic attenuation due to absorption and scattering of light within the optical fiber itself. It is important to understand that attenuation in optical systems can be exacerbated by external factors. Transmission loss in an optical fiber can be severely affected by improper handling, extreme stressors during installation or the operating condition of the cable. For example, bending cables in a radius that is smaller than the specified value can result in macro bending attenuation. In this instance, light is allowed to escape

through the cladding region of the optical fiber due to a change in the angle of incidence of the light ray traveling through the fiber. Additional sources of attenuation include micro bending of the optical fiber. This occurs when a lateral force is applied to an optical fiber such that the waveguide is deformed microscopically. The effect on the transmission path of light traveling within the glass is similar to that of a macro bend whereby the deformation causes a change in the geometry of the fiber structure allowing light to escape through the cladding.

In recent years, optical fibers have improved significantly, exhibiting lower intrinsic attenuation, higher bandwidth distance product and greater performance in bending. However, it is important for the network operator to understand the basic tenets of these issues in order to get the most out of the underground network. Since underground mines are growing daily and networks are extending further and further underground, maintaining head room in the optical power budget is important. To work properly in extreme environmental conditions found in underground mines, optical fibers should be packaged in robust cables that are capable of preserving these critical transmission properties.

Effective optical cable designs incorporate features proven to protect and preserve the optical budget for extended durations in extreme conditions. Factors affecting the cable such as tensile loading, bending, crushing, impact forces, moisture, chemical exposure, vibration and hot or cold temperature extremes need to be considered. Multiple test methods have been developed by a variety of industry standards groups to help determine appropriate performance specifications for cables. Many of these industry groups have focused on specific applications or installation environments such as typical telecommunications closets or structured cabling within commercial buildings. While these groups have developed standards that are excellent for qualifying cables for these applications, it is important to recognize that optical cables going into harsh environments, such as underground mines, may need additional performance attributes. Some in the industry have looked to military specifications as the ultimate in ruggedness. While these are certainly high-performing cables, in many instances a combination of specifications is more relevant. For example, as robust as military cables may seem, one important criterion that is commonly omitted from these cables is that of optical fiber strain.

In this article we've investigated the issues around transmission properties of optical fiber and discussed how cable systems can protect and preserve the optical budget used in underground networks. However, we have yet to touch on a key parameter affecting long-term reliability of optical fiber cable systems. Since optical fiber is made of glass, optical fiber strain must be considered in order to avoid premature failure due to static or dynamic fatigue. Strain is the word used to describe the deformation that occurs when an object is stressed. In this case, the optical cable may be stressed during both installation and operating conditions. Examples of cable stress include pulling under tension during installation, bending, self-supporting cable installations, wind load, ice buildup and even thermal stress caused by extreme temperatures. In these situations, the cable design must isolate the optical fiber such that the fiber strain is limited to specific values. In most cases, the recommended fiber strain threshold is less than 0.2 percent for residual loading of 100 kpsi proof tested fiber. Multiple studies have been conducted dating back to the 1990s demonstrating that long-term reliability of optical fiber can be achieved with this performance attribute designed into the system. Typical AFL cables deployed in harsh environments are depicted in Figure 2.

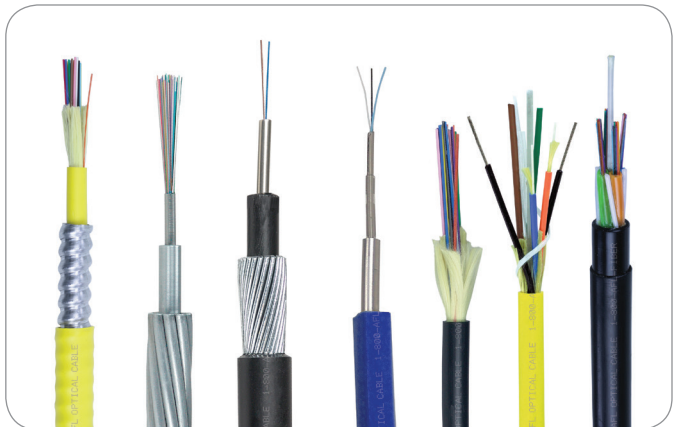


Fig. 2—AFL's optical cables for harsh environments

Above and beyond all considerations in underground confined spaces where explosive gasses may be present is that of human safety. Cable systems should meet the local safety requirements for flame spread, smoke generation and toxicity. In the United States, Mine Safety and Health Administration, or MSHA approved cables have been validated by a third party to comply with these requirements. In many international locations, the International Electrotechnical Commission, or IEC, has established similar requirements. Pre-terminated cable assemblies that have gas-blocked connectors are commonly used in underground mines due to the concern of explosive gas migration. In addition to safety, pre-terminated cable assemblies offer the added advantage of a plug and play modular network approach. Since mines are growing by the minute, plug and play modularity allows the network operator to easily and safely extend the cabling system to allow growth with the operation.

APPLICATION EXAMPLE

Oaky Creek Coal is located between the mining towns of Tieri and Middelmount in Central Queensland, Australia and produces one of the most sought after Bowen Basin coking coals.

As part of their longwall mining operation, Oaky Creek Coal runs communications systems to the coal face for control, monitoring and safety systems. Generally using Ethernet-based protocols, the system had previously utilized composite cabling, which contained both the high voltage and fiber optic cable. The use of physical contact ST connectors in the underground coal environment led to issues with contamination, ultimately causing a high failure rate.

AFC Group, an AFL company based in Australia, worked with Oaky Creek Coal to tailor their industrial plug-and-play solution to meet the requirements of one of the harshest working environments in the world. A 12-fiber cabling solution was developed for Oaky Creek Coal based on tactical tight buffered cable which is ideally suited for installations where extreme environmental conditions are present. The cable was factory terminated with expanded beam connectors, designed to eliminate physical contact, vastly reduce the cleaning requirements and enhance the system reliability.

The cabling system connects from the pump station to the distribution control board and is installed on the monorail with existing services. The flexibility of the tactical tight buffered cable means that the cabling system can be safely moved, recovered and redeployed during longwall retractions and longwall moves. The cables are simply uncoupled using the expanded beam connectors and re-connected in their new locations.

Overall, the fiber optic cabling system provides Oaky Creek Coal with a reliable and rugged system, well-suited to the harsh environment of underground coal mining. Many other mine operations around the world are taking advantage of the benefits of fiber optic systems including plug-and-play modularity, high reliability, exceptional bandwidth and intrinsic safety.



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