

APPLICATION NOTE

INTRODUCTION

The use of fiber optics in local area networks (LANs), such as ARCNET, has increased due to the inherent advantages of using fiber. High data rates can be maintained without electromagnetic or radio frequency interference (EMI/RFI). Longer distances can be achieved over that of copper wiring. For the industrial commercial user, fiber offers high-voltage isolation, intrinsic safety and elimination of ground loops in geographically large installations. ARCNET will function with no difficulty over fiber optics as long as some simple rules are followed.

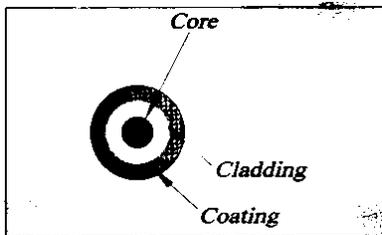
CABLING BASICS

Optical fiber consists of three basic elements: Core, cladding and the coating. The core constructed of ether glass or plastic provides the Basic means for transmitting the light engergy down the cable. The cladding prevents the light from exiting the core and being absorbed by the Cable itself. The coating provides protection of the core while providing

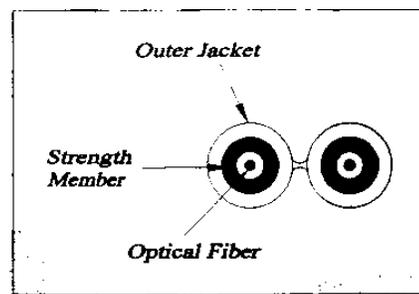
strength. Final protection is provided by an overall jacket that may consist of other strength and protective elements.

Fiber Size

Optical fibers are classified by their diameter in microns (1 micron = one-millionth of a meter). Frequently the core, cladding and coating are specified using slashes (/) to separate the values. For example, 50/125/250 means the core is 50µm, the cladding is 125µm and the coating is 250µm. These dimensions all pertain to the concentric diameters of the various elements. A short form way of specifying the fiber is to only list the core and cladding sizes. In the above example, this fiber would be classified as 50/125. Core sizes range from as small as 5µm to as high as 1000µm. Depending upon the core size, either one or two modes of light transmission will be experienced. The two modes are called single-mode and multimode,.



A single fiber consists of three basic elements.



Fiber optic cable is available as paired cable with an appearance similar to "zip cord."

Single-Mode Operation

With very small diameter fibers in the range of 5 to 10 μm , all light rays have a tendency to propagate along the axis of the fiber. Since there is only one path for the light to take, the light is termed to be experiencing a single-mode of operation. As the core diameter increases, the light rays have the option of traveling at an angle to the core axis while attempting to exit through the cladding. This second effect is called multimode operation.

Multimode Operation

With fiber core sizes of 50, 62.5 and above, multimode operation will be experienced. Not only will the light transfer down the axis of the fiber, but it will also travel away from the axis and toward the cladding. The cladding helps reflect the light rays back toward the fiber axis. The cladding provides this effect because it has a lower index of refraction than the core.

Index of Refraction

The index of refraction of a material (n) is defined as the ratio of the speed of light in a vacuum compared to the speed of light in the material. When light passes from one material to another with a different density, part of the light will be reflected and the remainder refracted. The angle of the

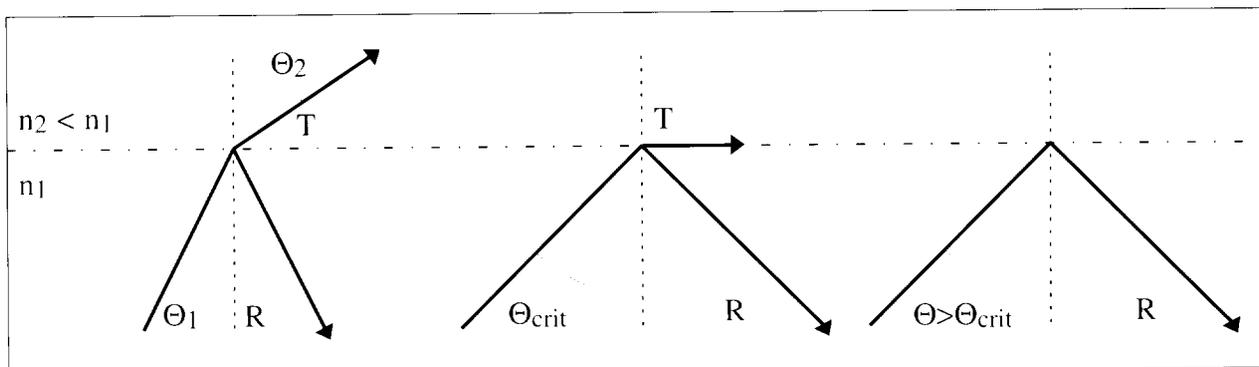
refracted ray will be different from the incident wave and will obey Snell's Law:

$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2$$

Where n_1 , and n_2 are the corresponding indexes of refraction and the two angles are measured relative to a perpendicular axis to the boundary of the two materials. At some angle called the critical angle, Θ_2 becomes 90° . For all values of Θ_1 , greater than the critical angle, total internal reflection will occur. This is the fundamental principle of fiber optic communications. The light energy is constrained to the inner core. The cladding with its lower index of refraction provides the total internal reflection necessary for proper operation.

Multimode Signal Distortion

In multimode operation, light waves travel down the axis of the fiber as well as a zigzag course bouncing off of the cladding. Since some of the light rays take a longer trip when they exit the far end of the core (due to its zigzag course), distortion of the original signal will occur as it recombines with the light ray that took the shorter path down the axis of the core. This results in pulse broadening at the receiver end. This distortion is called modal dispersion because the paths of the light rays are at different lengths. To counteract this



Total internal reflection occurs when the incident angle exceeds the critical angle.

multimode phenomenon, graded index fiber was developed.

With graded index fiber, the index of refraction is highest along the center axis of the fiber and gradually decreases from the axis to the circumference. Light travels slower with a higher index of refraction and faster with a lower index of refraction.

With this approach, the light that travels down the center axis is deliberately slowed to match the time required for light to travel a zigzag course nearer the circumference. The result is less distortion and higher bandwidth.

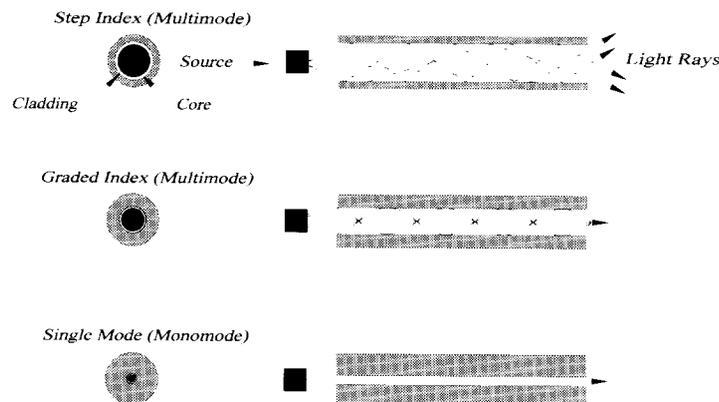
Bandwidth requirements are generally not an issue with ARCNET's 2.5 Mbps signaling. Multimode fibers have bandwidth specifications in frequency-distance units (Mhz-km) which depend upon the operating wavelength which will be discussed later. Doubling the distance halves the signaling rate; however, even at minimal bandwidth specifications (100 Mhz-km or so), the attenuation limitations of increased fiber length will be met before the bandwidth limitations.

Lower bandwidth fiber exists in a 200µm core diameter. This is step index fiber meaning that only one index of refraction

exists in the core and another in the cladding. This fiber is intended for shorter runs and is easier to connect and is more resilient to physical abuse due to its larger core size. This fiber can also be used for ARCNET.

Operating Wavelengths

Fiber optic transmitters and receivers are generally classified to operate in either of three frequencies. These frequencies have been found to have the lowest attenuation across a band of frequencies. The regions of lowest attenuation are called windows. The particular frequencies the industry uses are 850 nm, 1300 nm and 1550 nm. The two lower wavelengths offer cost/performance tradeoffs that are of interest in ARCNET applications. The 850 nm technology is readily available at the lowest cost. However, fiber optic cable attenuation is higher in the 850 nm band than in the 1300 nm band and the bandwidth is usually less. This attenuation is what limits the fiber optic segment lengths when using ARCNET. The 1300 nm receivers and transmitters are costly but are recommended when long distances are expected to be encountered. The 850 nm technology is generally used with multimode applications, while the 1300 nm technology is used with either single-mode or multimode operation.



Step index fiber has the lowest bandwidth, while single-mode fiber offers the highest.

Because of cost, the 1550 nm technology has not been implemented with ARCNET.

Fiber Optic Transmitters

CCSI uses both 850 nm and 1300 nm fiber optic transmitters in its hubs and network interface modules (NIMs). These transmitters are available with either ST or SMA connectors and must be specified at time of order. The ST connector operates similar to a small coaxial BNC connector. It prevents overtightening and provides repeatable insertion loss. The SMA connector is more traditional and has a continuous thread.

In fiber optic implementations, a separate transmitter and receiver are used instead of a transceiver. Instead of a single coaxial cable, fiber optic links use a duplex cable for NIM-to-hub, hub-to-hub connections. A transmitter at point A connects to a receiver at point B. Point B's transmitter attaches to point A's receiver. Transmitters and receivers are color coded. The light gray bodied parts are transmitters while the dark gray parts are receivers. Remember that "light comes from the light gray parts."

Transmitter Modulation

When operating ARCNET over coaxial cable, a dipulse signal is generated which approximates a single sine wave to represent a logic 1. This dipulse is generated by a transceiver from two signals P1 and P2 which are each 100 ns wide (at 2.5 Mbps) with P2 immediately following P1. The P1, P2 sequence only occurs for logic "1" data. Both pulses are absent for logic "0" data.

For fiber optic transmitters, only P1 is used to drive the device. Actually P2 could be used instead or the logical OR of P1 and

P2. However, all CCSI fiber optic products use P1.

Transmitter Power

Transmitters are rated in dBm with 0 dBm corresponding to 1 milliwatt of power. Transmitter output can vary from device to device, so CCSI 100% tests transmitters to ensure that none are shipped below the minimum specified by CCSI. Transmitter output also depends upon the fiber size. More energy is launched into larger fiber sizes; therefore, a power rating is given for all the popular sizes.

Stated power levels are measured using a fiber optic meter and a three meter length of cable. Since two fiber optic connectors are required to connect the transmitter to the meter, two connector losses are included when transmitter power is specified. Transmitter power is approximately proportional to drive current. CCSI drives its transmitters between 60 and 100 mA. To prevent overdrive of the receiver when using large fiber cores, CCSI provides a jumper, which when removed, limits the current thereby providing a 2 dB reduction in signal.

Minimum transmitter power levels at 25°C are listed below for 850 nm and 1300 nm devices.

Minimum Transmitter Output Power (25°C)			
Fiber Size (microns)	NA (Numerical Aperture)	Xmit Power 850 nm-dBm	Xmit Power 1300 nm-dBm
single mode	N/A	N/A	-22
50/125	0.200	-18.8	-14.0
62.5/125	0.275	-15.0	-13.0
100/140	0.300	-9.5	N/A
200/230-PCS	0.400	-16	N/A

Receiver Sensitivity

CCSI uses two types of receiver circuits depending upon the wavelength of operation. For 850 nm a lower gain digital receiver is used. For 1300 nm operation, a high gain analog receiver is used. The analog receiver is used at 1300 nm because this frequency range is used when long distances are to be achieved. Receiver sensitivities are listed below.

Minimum Receiver Sensitivities (25°C)		
Fiber Size (Microns)	Sensitivity 850 nm-dBm	Sensitivity 1300 nm-dBm
Single mode	N/A	-35
50/125	-25.4	-35
62.5/125	-25.4	-35
100/140	-25.4	-35
200/230	-25.4	N/A

Optical Power Budget

When specifying a fiber optic installation, attention must be paid to the available optical power budget. The power budget is the difference between the light source strength minus receiver sensitivity expressed in dB. This value must be compared to the link loss budget which is based upon the optical cable and optical connectors. The link loss budget must be less than the power budget. The difference is called the power margin which provides an indication of system robustness.

Transmitter power is typically measured at three meters of cable and, therefore, includes the loss due to at least two connectors. The outputs vary so CCSI tests each device to ensure that a minimum output power is achieved. The output power also varies with core sizes. In general, larger cores launch more energy.

Receiver sensitivity also varies so again CCSI tests for the least sensitive receiver. The difference between the weakest transmitter and least sensitive receiver is the worst case power budget which CCSI specifies. Realized power budgets will exceed this value since the probability of the worst case transmitter being matched with the worst case receiver is remote. However, CCSI recommends using the stated power budgets for each core size.

Link Loss Budget

Fiber optic cable attenuation is usually specified by the cable manufacturer. Use this figure to determine the maximum distance of the fiber link. It is necessary to include losses due to cable terminations. Connectors usually create a loss of from 0.5 to 1 dB. For example, assume a 1500 meter run of 62.5 cable which the cable manufacturer specifies as having a cable attenuation of 3.5 dB per 1000 meters. The cable loss will be 5.25 dB. Assuming two connector losses of 0.5 dB each, the link loss budget would be 6.25 dB which is within the 10.4 dB power budget specified by CCSI. The 4.15 dB difference represents a high degree of margin. A 3 dB margin is what is typically recommended.

Overdrive

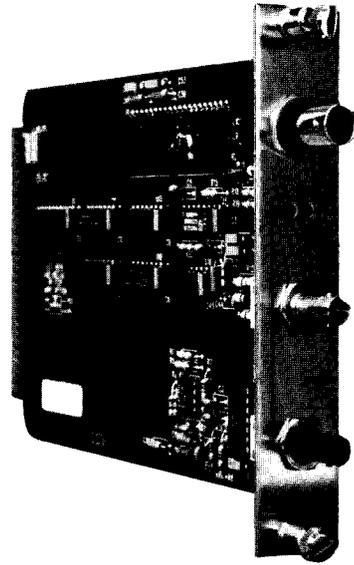
Overdrive occurs when too little fiber optic cable is used resulting in insufficient attenuation thereby saturating the receiver. To correct this condition, a jumper can be removed in each fiber optic transceiver to reduce the gain sufficiently to allow for a zero length of fiber optic cable to be installed between a transmitter and receiver. This is potentially a problem with 100 micron cable. By removing the jumper, a 2 dBm reduction in output power is achieved. All CCSI 850 nm receiver circuits have a dynamic range of at least 15 dB measured

MODHUB Series of Modular Active Hubs

CCSI provides a series of modular active hubs and associated expansion modules that support coaxial, twisted-pair and fiber optic cabling. Cabling technologies can be mixed by selecting the appropriate expansion modules. With a modular approach, network size and layout can be flexibly accommodated even in the field. Fiber Optic expansion modules exist that support either 850 nm (-FOG) or 1300 nm (-FG3) technology.



Expansion modules are inserted into a MODHUB modular active hub. Cabling media can be mixed within one hub by selecting the appropriate EXP expansion modules.



The EXP-CXS/FG3-ST provides one port of 1300 nm fiber optics and one coaxial cable port.

Permissible Cable Lengths

Transceiver	Description	Cable	Connectors	Cable Length		Notes
				Min	Max	
-FOG	duplex fiber optic	50/125	SMA or ST	0 ¹	3000ft/915m	4.3 dB/km max
-FOG	duplex fiber optic	62.5/125	SMA or ST	0 ¹	6000ft/1825m	4.3 dB/km max
-FOG	duplex fiber optic	100/140	SMA or ST	0 ¹	9000ft/2740m	4.0 dB/km max
-FG3	duplex fiber optic	single mode	ST	0	46000ft/14000m	0.5 dB/km max
-FG3	duplex fiber optic	50/125	ST	0	32800ft/10000m	1.5 dB/km max
-FG3	duplex fiber optic	62.5/125	ST	0	35000ft/10670m	1.5 dB/km max

¹ May require a jumper change on the EXP module to achieve this distance.

at 25°C. The 1300 nm receiver circuits have a dynamic range of at least 22 dB. Over this range, the receiver will except varying levels of signal without overload.

Delay Budget

Every attempt should be made to ensure that the ARCNET system will function with the standard or default timeouts. This would simplify the installation and maintenance of the network since all ARCNET controllers default to the lesser timeout setting upon power up without any software intervention.

Component	Delay (µs)
Active Hub	0.32/hub
IBM Type 3 cable	0.17/100 feet
50/125 fiber cable	0.15/100 feet
62.5/125 fiber cable	0.15/100 feet
100/140 fiber cable	0.15/100 feet
Coaxial cable	0.12/100 feet

Use the accompanying chart to sum all the delays encountered between the two geographically furthest nodes. Include the delays resulting from both hubs and cables. Notice that the propagation delay for coaxial cable is less than fiber optic cabling. We recommend that the user consider that fiber optic cable is equivalent to 1.25 times coaxial cable in terms of delay. This conversion is helpful when comparing distance limitations to that of coaxial cable. If the total amount of one-way direction delay for the worst case situation exceeds 31 µs, then the timeouts must be extended.

CUSTOMER INITIATED TEST

The GEDS division of the General Electric Company uses fiber optics to interconnect individual Speedtronic Mark V turbine controls with operator interfaces. In a paper dated February 7, 1994, and entitled "Speedtronic Mark V Fiber Optics for the

Stage Link," tests were conducted on their fiber optic link. What follows is an excerpt of that paper.

Tests were performed at the controls factory in Salem in October of 1992. A pair of optical hubs connected with optical cable were inserted into an operating Stage Link. The hubs were MOD HUB-16s, made by Contemporary Control Systems, Inc. The optical fiber cable was provided by the Optical Cable Corporation and had 62.5/125µm glass. ST stainless steel connectors were used to connect the various fibers. In addition to the normal traffic caused by Mark V panel and the load of a Smart Remote historian, a special software program was installed to send many messages and to assess the error rate.

The objective of the test was to connect the actual components to be recommended, and then extend the optical cable length to the point of failure of the link. In this way, the power budget margins and robustness of the recommended system could be assessed.

The test was initiated with 6,004 feet of optical cable and worked perfectly. Additional lengths of cable were added to this amount up to 11,562 feet, which involved three additional mated pairs of connectors. No errors were found at this distance. No more fiber was available, so a connector was separated until the link failed. This happened with an additional loss of only 0.8 dB. This calculated to be the equivalent of about 875 more feet of cable.

For a length of continuous fiber, having connectors only on each end, the link is calculated to fail at 14,000 feet when brand new and installed properly. Since it is rated for 6000 feet, the margin is about 2:1. Another way to assess the margin is by the power budget; available link budget is 14

dB, with 7 dB link budget (6000 feet of cable and the two end connectors at 0.5 dB each), this leaves 7 dB margin which is more than what is required for reliable service and long lifetime.

More light enters the larger diameter (100/140@im) optical cable. A short length of terminated cable was used to measure the input power using this optical cable. The total power output was measured at 5 dB more than the 62.5/125@tm cable. Based on the results of the above test, and assuming a loss of 3 dB/Km in the 100/140gm cable, the larger cable should fail at 21,000 feet (which exceeds the allowable total Stage Link maximum distance). The manufacturer's specified distance for this cable is 9,000 feet. The calculated distance margin is therefore about 2.3.

One fiber segment is specified to operate as far as 6000 feet with 62.5/125gm fiber, and 9000 feet for the 100/140gm fiber, by the

hub manufacturer. These distance limitations have been incorporated into the Stage Link layout rules.

GEDS' position is that fiber optic sections used in the Stage Link must not be longer than the specified 6,000 and 9,000 feet for the two fiber diameters. If your application significantly exceeds these distances, another hub must be added to amplify the optical signals. If the distance is only slightly beyond the specified distance, you might opt to take responsibility for the link performance. By choosing excellent hubs and cable combined with expert installation will result in a system that can be measured to have the 6 dB suggested margin. This decision is a matter of balancing the risk that system degradation can require premature hub and cable maintenance against the cost of finding a place to house the added repeater and providing the reliable AC needed to keep it operating.

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