



Calculating Fiber Loss and Distance

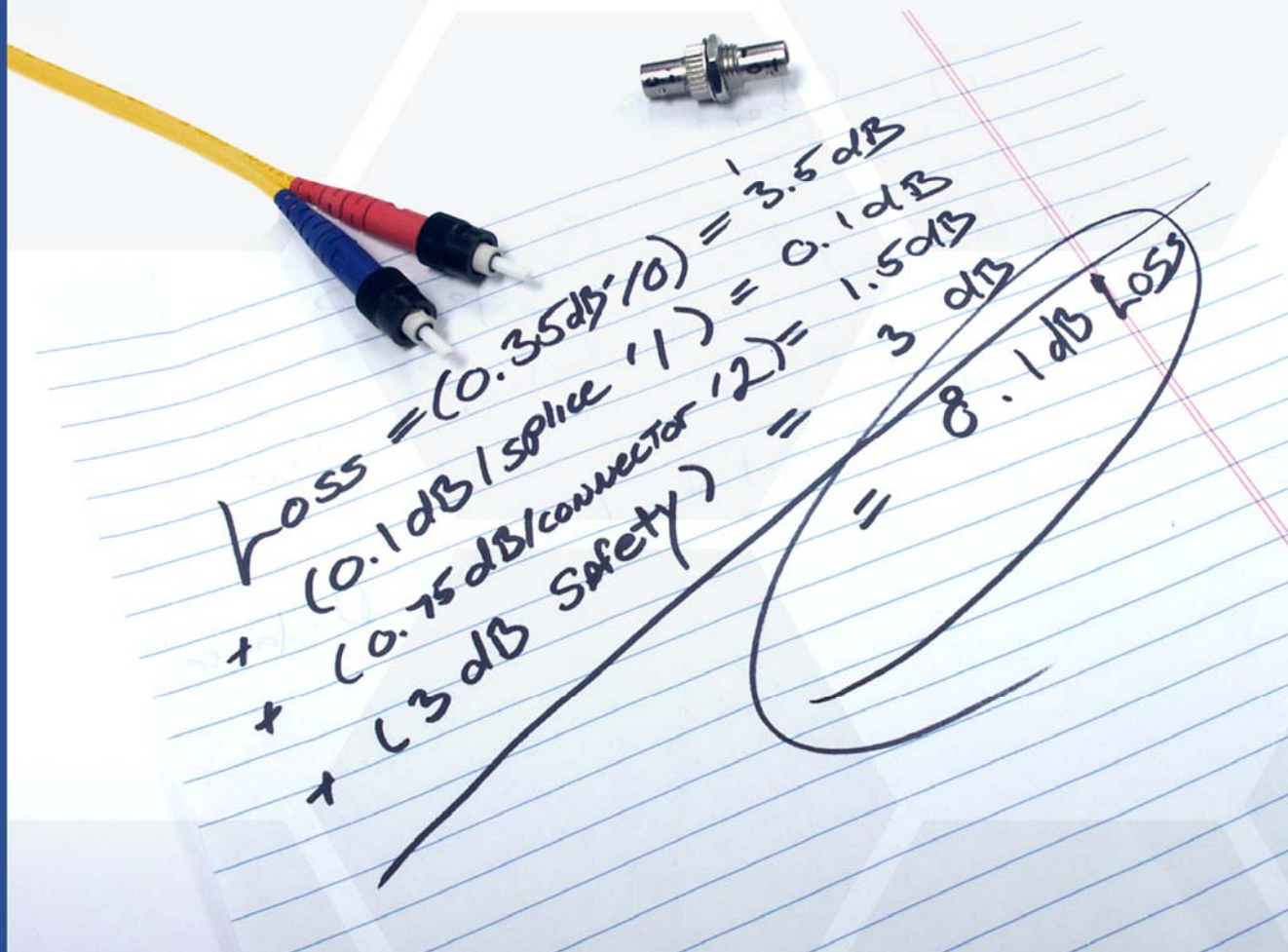


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Introduction

Fiber optic networking can be a daunting undertaking, but it really is not as difficult as it seems. Understanding factors such as fiber modes, fiber launch power, receive sensitivity, fiber cable attenuation, and fiber budgets will make fiber installation projects run much smoother and more efficiently.

Even though vendors try to simplify the task of calculating maximum fiber distances and signal losses, in reality vendors do not typically have all of the variables (fiber characteristics, number of splices and other physical parameters) necessary to accurately provide such distance and loss specifications for each specific installation. The best any vendor can do is help customers identify the variables and provide standard, industry accepted quantities for those variables to enable the customer to calculate the data (distances, budgets, etc.) they need. A vendor's estimate is no substitute for an actual measurement.

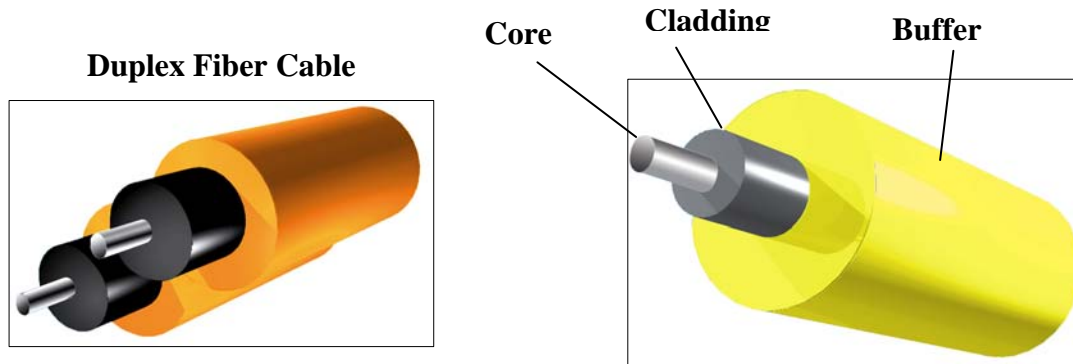
This paper, combined with further assistance from IMC Networks' Fiber Consulting Services (FCS: 800-624-1070 / 949-465-3000), will provide enough information to hit the ground running with virtually any fiber networking project.

Fiber Advantages

Fiber is most commonly associated with long distance connection. Today, however, it is rapidly gaining market share in LAN topologies, considered the domain of copper cabling. With the increase in size and scope, LANs are connecting to Metropolitan Area Networks (MANs), Fiber To The Premises (FTTx) is becoming a reality, pricing is coming down, installation is easier than in the past, and more and more products supporting fiber are available every day. The rising popularity of fiber is owed mainly to the following attributes:

- It has exceptional bandwidth, and can carry many signals concurrently
- It is immune to electromagnetic interference
- It has no electromagnetic emissions
- It does not corrode as rapidly as copper based cabling
- It is resistant to eavesdropping
- It is virtually "future proof"
- It has the capability to operate in conjunction with any current, or proposed, LAN/WAN standard
- It is lightweight

Fiber Cable Structure



Fiber optic cable consists of three components:

- Core— a very narrow strand of high quality glass
- Cladding— again, made of high quality glass with a slightly different index of refraction (usually within 1 - 2%) of the core
- Buffer/Outer Jacket— usually constructed from plastic and/or Coverall fibers (depending on the specification and use for the fiber)

The light signal is injected into the fiber via an LED, VCSEL or laser in one of two ways: single-mode or multi-mode. For installations demanding higher power/quality, laser transmitters are normally used.

Multi-Mode Fiber

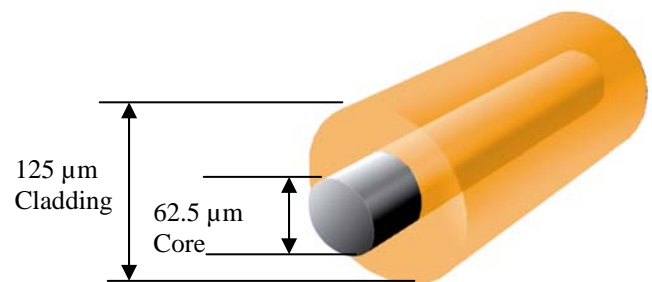
This is the classic fiber optic cabling and is far and away the most prevalent fiber type in use today inside buildings. It is the fiber type the IEEE, ANSI, TIA, and ISO standards organizations typically define in fiber LAN specifications.

The most commonly installed core size is 62.5 micrometers (μm) and the outer cladding size is 125 μm . Note: Other core sizes available are 50 μm , 100 μm , etc.



- 62.5/125 μm , 50/125 μm
- Multiple light paths
- Relatively inexpensive
- Modal-bandwidth limited
- Primarily used for LANs

The 'multi' in multi-mode comes from the fact that light travels down the cable in multiple paths. Essentially, the light beam is 'bounced' off the cladding as it travels down the core. There are actually two distinct methods:



- Step index - the light path is irregular and highly angular
- Graded index - the light path is sinuous and regular in nature

Of the two methods, graded index is the current standard used by nearly all LAN/WAN equipment. Because of the light transmission characteristics of multi-mode the quality of the fiber cable need not be high. In addition, multi-mode transmitters are relatively inexpensive and plentiful.

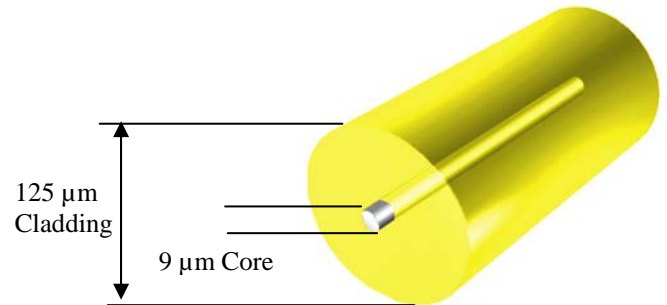
Single-Mode Fiber

For more demanding applications a second fiber cable type - single-mode - is available. Single-mode fiber uses a smaller core diameter, between 8 and 12 μm (9 being the average), with the same cladding diameter as multi-mode.

- 9/125 μm
- Single light path
- Somewhat more costly
- More difficult to terminate
- Essentially unlimited bandwidth
- Primarily used for MAN/WANs



Unlike multi-mode, single-mode fiber does NOT take multiple paths. A single light beam is transmitted down the fiber and does not interact with the cladding/core boundary. Until recently, single-mode was an expensive solution compared to multi-mode. However, the price of the cable is now nearing that of multi-mode and the active optics required for single-mode are becoming less expensive.



Wavelengths

There are several light wavelengths used for Ethernet:

- 850 nm multi-mode: Standard for 10Base-FL 10 Mbps Ethernet and 100Base-SX 100 Mbps Short Wavelength Ethernet. (See <http://www.fols.org/alliance.html> for more information on the 100 Mbps Short Wavelength Alliance.) Also used for 1000Base-SX Gigabit Ethernet.
- 1300 nm multi-mode: Standard for 100Base-FX 100 Mbps Ethernet. Also used by other high-speed LAN protocols such as FDDI, ATM/OC-3, etc.
- 1310 nm single-mode: Standard for 1000Base-LX Gigabit Ethernet. Also commonly used for applications where greater distance is required than can be achieved with multi-mode fiber.
- 1550 nm single-mode: Not an Ethernet standard, but used extensively for long-haul telecommunications at speeds of up to 40 Gbps (OC-768).

Fiber Standards

To further understand how fiber optics fit into a network, it is useful to have a basic knowledge of the standards set by the IEEE (<http://www.ieee.org>). IEEE is a membership organization that includes engineers, scientists and students in electronics and allied fields.

The following chart shows the different fiber optic standards as defined by the IEEE.

Standard	Data Rate (Mbps) †	Cable Type	IEEE Standard Max. Distance
10Base-FL	10	Multi-mode: 850 nm; 50/125µm or 62.5/125µm	2 km
100Base-FX	100	Multi-mode: 1300 nm; 50/125µm or 62.5/125µm	2 km
100Base-SX*	100	Multi-mode: 850 nm; 50/125µm or 62.5/125µm	300 m
100Base-LX	100	Single-mode: 1310nm, 1550nm, 9/125µm	100 km
1000Base-SX	1000	Multi-mode: 850 nm; 62.5/125µm Multi-Mode; 850 nm; 50/125µm	220 m 550 m
1000Base-LX	1000	Multi-mode: 1300 nm; 50/125µm or 62.5/125µm Single-mode; 1310 nm; 9/125µm	550 m 2 km
1000Base-LH*	1000	Single-mode: 1550 nm; 9/125µm	70 km

* 100Base-SX (short wavelength multi-mode) and 1000Base-LH (long-haul single-mode) are not formally adopted standards, but are commonly understood and used in fiber optic networking

† 4B5 encoding on Fast Ethernet and Gigabit Ethernet result in actual bit rates of 125 Mbps and 1250 Mbps respectively

Fiber Terminology

Up to this point, this document has provided only very basic information on fiber optic cabling. More information and consulting is available through IMC Networks' Fiber Consulting Division (FCS). Before getting into the actual fiber budget calculations, there are several commonly used terms that are useful to know:

- **Launch Power:** This is the amplitude (or energy) of the light as it leaves the fiber transmitter. This energy level is typically measured in decibels relative to 1 mW (dBm).
- **Receive Sensitivity:** This is the minimum energy required for the fiber receiver to detect an incoming signal. This energy level is also measured in decibels relative to 1 mW (dBm).
- **Receive Saturation:** This defines the maximum power input before overdriving the receiver. Overdriving the receiver can create data errors or failure to detect any data at all. This energy level is measured in decibels relative to 1 mW (dBm).
- **Fiber Budget:** This is simply the result after subtracting the Receive Sensitivity from the Launch Power. Power budgets are not a measure of energy and are measured in decibels (dB).
- **Attenuation:** Reduction of signal strength during transmission. Attenuation is the opposite of amplification, and is normal when a signal is sent from one point to another. If the signal attenuates too much, it becomes unintelligible, which is why most networks require repeaters at regular intervals. Attenuation is measured in decibels.
- **Modal dispersion (or intermodal dispersion):** Occurs in multimode fibers, because light travels in multiple modes (reflective paths), and each path results in a different travel distance. Modal dispersion is a major distance limitation with multimode fibers.

Calculating Fiber Loss and Distance

From this point forward, all data transmitted over the fiber link is considered to be Full-Duplex (FDX). It is critical to note that in a Half-Duplex (HDX) environment the timing considerations limit the fiber link distances and these limitations apply no matter what fiber is being used.

Since there are two distinct types of fiber cable, and three commonly used wavelengths - 850 nm, 1300 nm and 1550 nm - the attenuation measurement will vary depending upon which cable and wavelength is in use. Attenuation is measured in dB and is either quoted as attenuation in dB/km, or via an attenuation chart giving the attenuation for the entire fiber run. Note that the decibel scale is logarithmic - a loss of 99% of the light over a given length of fiber is expressed as "-20 dB", a loss of 99.9% is "-30 dB", etc.

Fiber Loss Variables

- Attenuation: Fiber cabling has losses from absorption and back reflection of the light caused by impurities in the glass. Attenuation is a function of wavelength and needs to be specified for the particular wavelength in use.
- Modal Dispersion: The higher the data rate, the shorter the distance the signal can travel before modal dispersion creates an inability to accurately detect a "1" from a "0". Modal dispersion is only a concern with multi-mode cable and is directly proportional to the data rate.
- Dispersive Losses: While single-mode fiber is not subject to modal dispersion, other dispersion effects cause pulse spreading and limit distance as a function of data rate. Chief among these is chromatic dispersion, where the broader spectrum of certain transmitter types can result in varying travel times for different parts of a light pulse. Chromatic dispersion typically only starts to become a limiting factor at Gigabit speeds.
- Splices: Although small and often insignificant, there is no perfect loss-less splice. Many errors in loss calculations are made due to a failure to include splices. Average splice loss in single-mode cable is usually less than 0.01 dB.
- Connectors: Like splices, there is no perfect loss-less connector. It is important to note that even the highest quality connectors can get dirty. Dirt and dust can completely obscure a fiber light wave and create huge losses. Typically, connector loss can vary from 0.15 dB (LC), to 0.5 dB (ST-II). Using 0.5 dB loss per connector is commonly used and is the worst case scenario, assuming a cleaned and polished connector is used. There will always be a minimum of two connectors per fiber segment, so remember to multiply connector loss by two.
- Safety Buffer: It is common to add a couple dB of loss as a design margin. Allowing 2 to 3 dB of loss can take fiber aging, poor splices, temperature and humidity, etc., into account and ensure a solid system.

To determine minimum/maximum losses and maximum distances the above variables must be identified. Failure to identify even one of these variables can create potential problems. The ideal method in determining losses is to actually measure the losses once the fiber has been laid. Always test and validate the losses once the fiber is laid. (Note that all calculations assume Full Duplex (FDX) mode of operation.)

Fiber Loss Table

The numbers listed are averages, and are standard for new fiber. Numbers for any installation may vary.

Wavelength/Mode	Fiber Core Diameter	Attenuation per Kilometer*	Attenuation per Splice	Attenuation Per Connector	Modal Bandwidth (MHz-km)
850 nm multi-mode	50 μm	2.40 dB	0.1 dB	0.75 dB	500
850 nm multi-mode	62.5/125 μm	3.00 dB	0.1 dB	0.75 dB	200
1300 nm multi-mode	50 μm	0.70 dB	0.1 dB	0.75 dB	500
1300 nm multi-mode	62.5/125 μm	0.75 dB	0.1 dB	0.75 dB	500
1310 nm single-mode	9 μm	0.35 dB	0.01 dB	0.75 dB	N/A
1550 nm single-mode	9 μm	0.22 dB	0.01 dB	0.75 dB	N/A

* Attenuation is based on published specifications for Corning's InfiniCor and SMF-28 standard fiber

Calculating Signal Loss

There are commonly two different calculations required with fiber. Each assumes that there are known values for different sets of variables.

- The maximum signal loss across a piece of pre-existing fiber.
- The maximum fiber distance given known budget and loss variables.

The first calculation below will calculate signal loss through a known length of fiber. Calculating maximum signal loss is simply the sum of all worst case variables within a fiber segment. The numbers shown in the table above are average losses. Actual losses could be higher or lower depending upon many factors.

Fiber Loss Formula

$$\begin{aligned}
 \text{Loss} &= (\text{Fiber Attenuation} \times \text{km}) \\
 &+ (\text{Splice Attenuation} \times \text{\# of splices}) \\
 &+ (\text{Connector Attenuation} \times \text{\# of connectors}) \\
 &+ (\text{Safety Margin})
 \end{aligned}$$

= Total Loss

Example using 10 km run of 1310 SM fiber

$$\begin{aligned}
 \text{Loss} &= (0.35 \text{ dB} \times 10) &&= 3.50 \text{ dB} \\
 &+ (0.01 \text{ dB/splice} \times 1) &&= 0.01 \text{ dB} \\
 &+ (0.75 \text{ dB/connector} \times 2) &&= 1.50 \text{ dB} \\
 &+ (3 \text{ dB Safety}) &&= 3.00 \text{ dB}
 \end{aligned}$$

= 8.01 dB total loss

Calculating the signal strength exiting a cable is only half the job. To avoid overdriving a fiber receiver and eliminate data loss problems it is equally important to calculate the maximum signal strength. Overdriving a receiver is most common when using single-mode products with very low fiber attenuation. It is safe to assume average numbers for fiber loss, but the actual losses should be measured once the fiber has been deployed, to verify previous measurements and avoid performance problems.

Calculating fiber distance includes not only the loss variables described above, but requires the launch power and receive sensitivity specifications on the fiber products. The equation can get a bit complicated, as many vendors provide a launch power range. Therefore, when calculating distance, the lowest launch power should be used to calculate a worst case distance. The highest specified launch power is used to verify that the receiver is not being overdriven.

Calculating Budget and Fiber Distances

Distance is calculated first by calculating the power budget. This is found by subtracting the receive sensitivity from the launch power.

$$\text{Power Budget} = (\text{Launch Power}) - (\text{Receive Sensitivity})$$

For example, assume a fiber switch with a -17 dBm minimum launch power is connecting to a media converter with a worst case receive sensitivity of 30 dBm:

$$\text{Power Budget} = (-17 \text{ dBm}) - (-30 \text{ dBm}) = 13 \text{ dB}$$

It may seem odd that subtracting two numbers with dBm as the unit of measure results in a number with dB as the unit of measure. This is because a dBm is a logarithmic ratio of power relative to 1 mW. Subtraction of two logarithmic ratios is the equivalent of dividing the two power measurements directly, resulting in a unitless number expressed in dB.

Because power budget can be calculated either using decibels or Watts, it is useful to know how to convert between decibels (dBm) and Milliwatts (mW). The two formulas are shown below

<p>To convert from dBm to mW (ex: -30 dBm):</p> $\text{mW} = 10^{(\text{dBm}/10)}$ $= 10^{(-30/10)} = 10^{-3} = 0.001 \text{ mW}$	<p>To convert from mW to dBm (ex: 0.020 mW):</p> $\text{dBm} = 10 \log_{10}(\text{mW})$ $= 10 \log_{10}(0.020) = 10 \times -1.7 = -17 \text{ dBm}$
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The Power Budget formula can be expressed in mW rather than dBm. Using the dBm to mW conversion shown above, -17 dBm becomes 0.020mW, -30 dBm becomes 0.001mW, and since subtracting logarithms is the equivalent of dividing two regular numbers, the formula becomes:

$$\text{Power Budget} = 0.020 \text{ mW} / 0.001 \text{ mW} = 20$$

This means the system can sustain a total loss of 95% of the transmitted light, or 1/20th of the transmitted light must reach the receiver.

The use of dB and dBm as units allows addition and subtraction of reasonable-sized numbers rather than multiplication and division of very large or very small numbers.

For a given power budget for 850nm 50 μm multi-mode fiber, and making some assumptions about the number of splices and connections, it is possible to estimate the distance that a fiber of particular specifications can run. For example, using the numbers from above:

Power budget	=	13.00	dB
Losses from splices	=	-0.10	dB
Losses from connectors	=	-1.50	dB
Safety margin	=	-3.00	dB
Net Power Budget	=	8.40	dB

If the fiber is specified at a loss not to exceed 2.5 dB/km:

$$(8.40 \text{ dB}) / (2.5 \text{ dB/km}) = 3.36 \text{ km}$$

The fiber can be run for approximately 3.36 km before running out of signal strength at the end.

A Word on Modal Dispersion

Multi-mode cable tends to disperse a light wave unevenly and can create a form of jitter as the data traverses the cable. This jitter tends to create data errors as the data rate increases. In addition to calculating budget across multi-mode fiber, it is also necessary to calculate the losses resulting from modal dispersion. The maximum length of fiber will be determined by distance calculation (above) or by modal dispersion - whichever is lowest.

For example, assume the network is using 100 Mbps Fast Ethernet (which has an actual bit rate of 125 Mbps) across 850 nm multi-mode fiber. The modal dispersion of this multi-mode cable is 200 MHz-km. Use the following equation to calculate the maximum distance of a 125 Mbps (MHz) Fast Ethernet signal:

$$\text{Distance} = \frac{200 \text{ MHz-km}}{125 \text{ MHz}} = < 1.6 \text{ km}$$

Similarly, calculating the maximum distance at a 10 Mbps Ethernet data rate:

$$\text{Distance} = \frac{200 \text{ MHz-km}}{10 \text{ MHz}} = < 20.0 \text{ km}$$

Conclusion

Working with fiber is easier than it seems. Termination and splicing techniques, and the new Small Form Factor (SFP) connector and termination products have cut down significantly on the problems that once plagued fiber specialists. Within the next couple years it is expected that the costs for integrating fiber will be at par with Cat-5 or above cabling. Companies are justifying fiber as a way to future-proof their networks. Companies such as IMC Networks are making it easier still by providing the products and the information to quickly and easily step into fiber networking.

Additional Reference Information

IEEE - (Institute of Electrical and Electronics Engineers, New York). IEEE is a membership organization that includes engineers, scientists and students in electronics and allied fields. Founded in 1963, it has more than 300,000 members and is involved with setting standards for computers and communications.

<http://www.ieee.org>

TIA - (Telecommunications Industry Association) is the leading trade association in the communications and information technology industry with proven strengths in market development, trade promotion, trade shows, domestic and international advocacy, standards development and enabling e-business.

<http://www.tiaonline.org>

BICSI - A not-for-profit telecommunications association, BICSI is a world-wide resource for technical publications, training, conferences, and registration programs for low-voltage cabling distribution design and installation. BICSI has over 20,000 members residing in 85 nations.

<http://www.bicsi.org>

Cabling Design - This site is created and maintained by members of the BICSI organization.

<http://www.cabling-design.com>

Cabling U Online - This site offers technical information and training for installers and users of communications cabling.

<http://www.cableu.net>

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About IMC Networks

IMC Networks is a leading ISO 9001 certified manufacturer of hardware for Local, Wide and Metropolitan area network installations. IMC Networks provides copper-to-fiber and fiber mode conversion products as well as fiber optic repeaters to help network installers maximize the capacity of copper and fiber optic cabling infrastructures. In addition to the industry's widest variety of media connectivity products, IMC Networks offers broadband access multiplexing, bandwidth management and packet filtering products for ISPs and network managers. IMC Networks supports Ethernet, Fast Ethernet, Gigabit Ethernet, Fibre Channel, ATM and T1/E1 networking technologies, with emphasis on fiber optics.

A History of Technology Firsts

IMC Networks is a pioneer in many innovative product developments, and was the first to offer:

- Low cost packet filtering and bi-directional bandwidth control products for improving Internet access
- Affordable solutions for IP multiplexing and bandwidth allocation
- A complete range of modular and scalable products to address fiber media including single-mode, long-haul fiber requirements
- SNMP-manageable media conversion
- Modular chassis with embedded SNMP
- 10/100 media conversion products
- Gigabit copper-to-fiber media conversion
- Modular Ethernet repeaters - a design concept widely used today
- USB-powered miniature media converters
- 75Ohm CCTV to copper converters
- Compact, Industrial Ethernet Optical Demarcation devices



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