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Technical Bulletin

User's Guide To Fiber Optics

Guidelines For Users Of Fiber Optic Communications Products
Should you use fiber optics for your communications system? What are its advantages and disadvantages? Isn't fiber optics still too new for everybody to adopt it? Is it hard to design and install fiber optic networks? Do they require maintenance? This short guide is designed to help answer those questions for users pondering the choices. This document is based on the FOA books (see references) and the FOA Online Reference Guide. You should also download a copy of the NECA/FOA 301 fiber optic installation standard as a reference.

1. Introduction
        One often sees articles written about fiber optic communications networks that implies that fiber optics is "new." That is hardly the case. The first fiber optic link was installed in Chicago in 1976 and by 1980, commercial long distance links were in use and fiber optic data links for RS-232 were available. Since that beginning, fiber has become very commonplace in the communications infrastructure.
        If you make a long distance call today, you are undoubtedly talking on fiber optics, since it has replaced over 90% of all the voice circuits for long distance communications. Most large office buildings have fiber in the building itself. Only the last link to the home, office and phone are not fiber and installations of fiber to the home are growing rapidly.
        CATV also has discovered fiber optics, along with compressed digital video. Most large city CATV systems have been converted to fiber optic backbones which allow voice and data transmission in addition to video.
        The LAN backbone also has become predominately fiber-based. The back-end of mainframes and storage area networks (SANs) are almost totally fiber. Only the desktop is a holdout, currently a battlefield between the copper and fiber contingents.
        Fiber optics offers an unrivaled level of security. It cannot be jammed or tapped and is immune to interference. It is widely used for security cameras, perimeter alarms and other critical systems in military, government, utility and civilian applications.
        Fiber optics really is the medium of choice for long distance, high bandwidth or secure communications. Lets look at why it is, how to evaluate the economics of copper versus fiber and how to design fiber networks with the best availability of options for upgradeability in the future.

1.1 It's really all a matter of economics

Fiber optics has become widely used in telecommunications because of its enormous bandwidth and distance advantages over copper wires. Commercial systems today carry more phone conversations over a pair of fibers than could be carried over thousands of copper pairs and can be run hundreds of kilometers between all-optical repeaters. Material costs, installation and splicing labor and reliability are all in fiber's favor, not to mention space considerations.

In CATV, fiber pays for itself in enhanced reliability and the ability to offer enhanced services. The enormous number of repeaters used in a broadcast cable network are a big source of failure. CATV systems' tree and branch architecture means and upstream failure causes failure for all downstream users. Reliability is a big issue, since viewers are a vocal lot if programming is interrupted! The ability to offer Internet access has created significant revenue streams for CATV operators also.

For LAN and other datacom applications, the economics are less clear today. For low bit rate applications over short distances, copper wire is undoubtedly a better choice. As distances go over 50 to 100 meters and speeds above 10 Mb/s, fiber begins to look more attractive. Upgradeability usually tilts the decision to fiber, as optical fiber has already outlived a dozen generations of copper wiring. A new choice for LANs has been created by the widespread acceptance of fiber to the home (FTTH) technology. FTTH components can be used to build optical LANs (OLANs) that can be cheaper and more energy efficient than traditional LANs. See OLANs in the FOA Guide.

1.2. Technology says go fiber

Fiber's advantages over copper result from the physics of transmitting with photons instead of electrons. In glass, optical attenuation is much less than the attenuation of electrical signals in copper and much less dependent on signal frequency. We all know that fiber optic transmission neither radiates RFI nor is susceptible to interference, making it the only choice for secure communications. Unlike copper wires that radiate signals capable of interfering with other electronic equipment, fiber is totally benign. Utility companies even run power lines with fibers imbedded in the wires for both communications and network management!

The bandwidth/distance issue is what usually convinces the user to switch to fiber. Although with today's applications, multimode fiber is used at 100-1000 Mb/s for datacom applications on multimode fiber and is usable up to 10 Gb/s. Singlemode fiber offers virtually unlimited bandwidth, especially with DWDM (dense wavelength division multiplexing.)

2. Understanding Fiber Optic Communications

Fiber optic links are the communications pathways between devices. A link is bidirectional, usually with signals transmitted in two directions on two different fibers although passive optical networks (PONs) used in fiber to the home (FTTH) use bidirectional transmission in a single fiber. Using two fibers is usually the cheapest way, since the optical fiber itself is now about as cheap as kite string and fishing line! The link connects electronic signals from two devices that need to communicate, just like a copper cable. The link has a transmitter that converts electronic signals from communications equipment to optics and a receiver that converts the signal back to electronics at the other end.
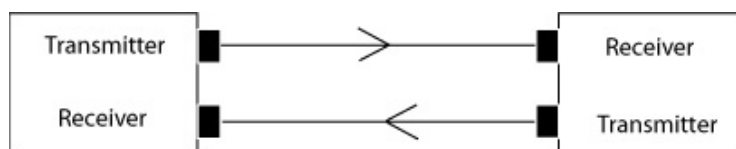
Fiber optic transmitters use LEDs or semiconductor lasers to convert electronic signals to optical signals. LEDs, similar to those used everywhere for indicators, except transmitting in the infrared region beyond human perception are used for slower links, up to about 100 million bits per second (Mb/s), for example fast Ethernet LANs. Faster links use infrared semiconductor lasers because they have more bandwidth, up to tens of billions of bits per second (Gb/s). Lasers have more power, so they can also go longer lengths, as in outside plant applications such as long distance telecom or CATV.

As noted, transmitters use infrared light. Infrared light has lower loss in the fiber, allowing longer cable runs. Typically multimode glass fibers use light at 850 nm, referred to as "short wavelength" and singlemode fiber operates at 1310, 1470 or 1550 nm, called "long wavelength."

Since the light being transmitted through the optical fiber is beyond the range of human sight, you cannot look at the end of a fiber and tell if light is present. In fact, since some links carry high power, looking at the end of the fiber, especially with a microscope which concentrates all the light into the eye, can be dangerous. Before examining a fiber visually, always check with a power meter to ensure no light is present unless you know the far end of the fiber is disconnected and use a microscope equipped with a laser filter.

At the receiver end, a photodiode converts light into electrical current. Photodiodes must be matched to the transmitter type, wavelength, power level and bit rate as well as the fiber size to optimize performance. It's the receiver that ultimately determines the performance of the link, as it needs adequate power to receive data reliably. Receivers have a certain amount of internal noise which can interfere with reception if the signal is low, so the power of the optical signal at the receiver must be at a minimal level.

The power at the receiver is determined by the amount of light coupled into the fiber by the transmitter diminished by the loss in the fiber optic cable plant. The installer will test the cable plant for loss after construction, comparing it to a loss calculated from typical component values called the "loss budget." Transmitter power can be measured when the networking equipment is installed using a patchcord attached to the transmitter.

Networks adapt the generic fiber optic link described above to a specific network's needs. An Ethernet link will be optimized for the bit rate and protocol of the version of Ethernet to be used, for example Gigabit Ethernet. Video links may be analog or digital, depending on the camera, and may include camera controls in one direction and video in the other. Industrial links may be based on RS-232 or RS-422 protocols.

Most computer or telecommunications networks have adopted standards for fiber optic transmission as well as copper wiring and wireless. However, sometimes the user has equipment with copper interfaces but wants to use fiber. Then they can use fiber optic media converters, which do exactly what their name suggests. Media converters will convert from one media to another, typically UTP copper to optical fiber, coax to optical fiber or multimode to singlemode fiber. Media converters are like transmitters

and receivers in that they must be specified for specific network applications to insure the proper operation in that application.

Since so many link types exist, it is impossible to generalize on fiber optic link characteristics. When designing or installing fiber optic cabling, the contractor can either design to cabling standards, which allows use with any network or communications system designed for those standards, or for a specific network, which may allow optimizing the cable plant. If the actual network to use the fiber optic cabling is not known, the best plan is to design, install and the test cable plant based on standardized fiber optic component specifications rather than any specific network needs.

3. Checklist For Users Of Fiber Optic Communications Products

This is intended as an overview and installation checklist for all managers and engineers on the overall process of designing, installing and operating a fiber optic communications system. Fiber optics offers major advantages for communications systems including security, distance and bandwidth. Proper application of fiber optic technology will lead to highly reliable systems. But the user must choose the proper products, design and install an appropriate cable plant, and make sure components are tested, all following appropriate industry standards. This guide is designed to provide the information necessary to ensure proper installation and usage of fiber optic systems. As references, we use our printed textbooks *The FOA Reference Guide to Fiber Optics (RGFO) and The FOA Reference Guide to Premises Cabling (RGPC) and the FOA Online Reference Guide*. These documents refer to other more detailed documents such as TIA or ISO standards.

3.1. Overview of Fiber Optic Network Design and Installation

3.1.1. Select a communications system, module or converter that fits the data format you plan to transmit. Fiber optic communications products exist for almost every type of communications system, from high speed telephone and CATV systems to simple low speed RS-232 or relay closure links. Many are media converters from standard electrical interfaces like Ethernet that have various options on data rates. Some are proprietary links for specialty equipment used for utility monitoring, industrial control, video surveillance, etc.

3.1.2. Select a fiber optic product that is specified to work over the range of your application. Note the type of fiber and other components such as connectors required for this product.
   a. Consider the range of the link as that affects the type of fiber and transceivers needed.
   b. Short links use multimode fiber and LED sources, while longer links use lasers and singlemode fibers.
   c. Most fiber optic communications products offer several versions that cover different ranges.
   d. Alternately, if you already have fiber optic cable plant installed, select a product that will operate over your fiber optic cable plant, considering both fiber type and distance.

3.1.3. Select a fiber optic cable type appropriate for the application. (RGFO, Ch 6) (RGPC, Ch 7)

    a. Determine the working environment of the fiber optic cable plant. Some applications are in office environments, some on factory floors, above ceilings and some are outdoors.

    b. Outdoors, some cables are installed aerially, either lashed to a messenger or self-supporting, some are buried directly or in conduit and some must run under water.

    c. All outdoor cables require protection from water entry and any other environmental factors particular to the installation.

    d. Each application puts requirements on the cable design that should be discussed with cable manufacturers who can recommend cable types appropriate for that application.

    e. Not all manufacturers make the same type of cable, so talking to several vendors may provide options in cables that affect price or performance.

    f. Consider installing several extra fibers in case any are damaged in installation or if additional fibers are needed for future expansion. (In fact, for critical applications, it may be advisable to install a complete backup link and/or redundant fiber optic cable plant run in a different route.)

    g. Often singlemode fibers are added to multimode cables (called a hybrid cable) in case future networks need higher bandwidth.

    h. At this stage, also decide on the installation hardware needed, such as conduit or innerduct for buried cables and hangers or lashing for aerial cables.

3.1.4. Plan ahead on splicing requirements. (RGFO, Ch 7) (RGPC, Ch 7)

    a. Long lengths of cables may need to be spliced, as fiber optic cable is rarely made in lengths longer than several kilometers due to weight and pulling friction considerations.

    b. If fibers need splicing, determine how to splice the fibers (fusion or mechanical) and what kind of hardware like splice closures are appropriate for the application.

3.1.5. Choose connectors of a style and termination type appropriately for the application. (RGFO, Ch 7) (RGPC, Ch 7)

    a. Cables will need terminations to interface with the communications products.

    b. Connectors need to be chosen appropriately or patchcords with one end terminated with connectors compatible with the communications products will be needed.

    c. Fiber optic connectors have several termination methods, some using adhesives and polishing, some using splicing, which have tradeoffs in performance.

    d. Discuss connectors with both manufacturers and installers before making this choice.

3.1.6. Ensure the calculated link loss is substantially less than the link margin of the communications products. (RGFO, Ch 4, 9) (RGPC, Ch 7)

    a. Calculate the power budget for the link.

b. Using typical component specifications and the design of the cable plant (type of fiber, length, transceiver wavelength, number of connectors and splices) you can calculate the approximate optical loss of the cable plant
c. Compare it to the link margin for the communications products you have chosen.
d. Discuss potential margin problems with communications equipment vendors.

3.2. Install the cable plant. (RGFO, Ch 10) (RGPC, Ch 8)
a. Using the design developed in this process, install the cable plant.
b. Some users learn to install and maintain the fiber optic cable plant themselves, while others use contractors.
c. Installers or contractors should be trained and experienced in the installation type being done, have references for previous work and be certified by independent organizations like The Fiber Optic Association.
d. Follow the guidelines in the NECA/FOA 301-2004 Standard For Installing and Testing Fiber Optic Cables, available from The National Electrical Contractors Association.
e. Do not discard excess cable from the installation, but store it for future needs in restoration if the cable plant is damaged.

3.3. Test the cable plant. *(RGFO, Ch 8) (RGPC, Ch 7)*
a. Inspect and clean fiber optic connectors before testing. Visual inspection of connectors with a microscope allows confirmation that installation was properly done and connectors are clean before testing.
b. Test the cable plant for optical loss according to industry standards. Most cable plants are tested according to standards TIA/EIA-526-14 for multimode fibers and TIA/EIA-526-7 for singlemode fibers, preferably using a one cable reference for 0dB loss.
c. Longer cables with splices should also be tested with an OTDR to verify splice quality.
d. Cables installed aerially or in areas of likely stress can also be tested with the OTDR to verify installation quality.
e. Troubleshoot any fibers that are high loss and correct the problem.

3.4. Install the communications products and test their operation. *(RGFO, Ch 10) (RGPC, Ch 8)*
a. After the cable plant is tested and known good, install the fiber optic communications equipment and test its operation.
b. Clean all connectors after removing protective caps before connecting to equipment or other cables.
c. Use any self-testing options to check operation, use BERT (bit-error rate test) equipment or transmit known data and look for errors.
d. Once a network is operating properly, it should require no maintenance – in fact, attempted maintenance on premises systems by un-qualified personnel is often a cause of damage – so it is best to lock fiber optic component enclosures to reduce unauthorized entry - a requirement for class 4 (high power)lasers.
e. Outside plant networks may need frequent visual inspection just to find damage or potential damage.

3.5. Document the fiber optic network. *(RGFO, Ch 9) (RGPC, Ch 7)*
   a. Perhaps the most important part of any installation is the final documentation.
   b. Accurate and complete documentation is invaluable in upgrading, troubleshooting or restoring a network. Documentation should include identification of all components, the paths of each cable, types of cable (and where the excess is stored for restoration), cable section lengths, locations of splices or terminations and the optical loss of each fiber measured at installation.
   c. If OTDR traces are taken, those should be stored with the documentation.
   d. Copies of all documentation should be kept at each end of the link and backups stored in a safe place.

4. Important Considerations in Fiber Optic Installation
Fiber optics offers major advantages for communications systems including security, distance and bandwidth. Proper application of fiber optic technology will lead to highly reliable systems. That means the user must install an appropriate cable plant and test every component, all following appropriate industry standards. This guide is designed to provide to those directly involved in planning and installing the fiber optic network the information necessary to ensure proper installation and usage of fiber optic systems.

4.1. Do a complete design before beginning cable plant installation. *(RGFO, Ch 9) (RGPC, Ch 7)*
   a. Establish criteria for the install, based on the communications paths required
   b. Know how many fibers of what types are needed – add extras for repairs or growth
   c. Determine hardware requirements: connectors, splices, patch panels, closures, etc.
   d. Plot the cable route and determine cable lengths
   e. Show how installed (premises, buried, conduit, innerduct, underwater, pole locations for aerial, etc.)
   f. Mark termination and splice points
   g. Attach data from link loss budget and use it as a guide for testing
   h. Don't try to build a marginal design – allow for "Murphy's Law"
   i. Follow the NECA/FOA 301 Standard For Installing and Testing Fiber Optic Cables in design and installation
   j. At the same time, design the facilities for the communications equipment, including locations, allowing for adequate spaces, power and grounding and HVAC as needed
   k. Make complete lists of what components and hardware are needed and where they are to be used

4.2. Work with vendors on component specs to get best quality and price.
   a. Vendors usually have suggestions on components like cables or hardware that can facilitate design and implementation, but always get several opinions and compare their suggestions to what you understand you need .
   b. Consider options like pre-terminated cables or air-blown fiber for short indoor cable runs

c. Remember to plan for purchasing overages on components to cover extra cable for restoration or extra connectors necessary due to yields in termination
d. Be careful of industry or manufacturer "jargon" as not everyone uses the same term in fiber optics

4.3. Have all components available before beginning installation so crews may complete the installation promptly and properly.
    a. Inventory everything received
    b. Check for shipping damage
    c. Store in a safe, dry place until used
    d. Separate as needed for each work site
    e. While at the job site, consider using guards if left onsite outdoors overnight

4.4. Use only trained, qualified installers.
    a. Installing fiber optics is not difficult, but has special issues familiar to those with experience
    b. Make sure the installers are experienced in the type of installation you are planning, as installers often specialize in aerial, underwater, or even singlemode installation
    c. Look for FOA CFOT® certification (www.thefoa.org) and good references from similar installations
    d. Review the design with the installer to familiarize them with the job and see if they have advice on how to make it easier or better but use your judgement regarding any changes suggested.

4.5. Review safety issues and establish rules for the installation. *(RGFO, Ch 1,10) (RGPC, Ch 8)*
    a. All installers and supervisors should be briefed on safety rules
    b. Ensure that you have copies of the documentation regarding your contractors bonding, insurance, workers compensation, OSHA certificates etc.
    c. Use NECA/FOA 301 Standard, Section 3 plus any applicable OSHA or other regulations

4.6. Install the cable plant. *(RGFO, Ch 10) (RGPC, Ch 8)*
    a. NECA/FOA 301, Section 5.4 offers good guidelines for installation
    b. Watch for proper handling to prevent cable damage, especially cable tension and bend radius
    c. If long lengths (>200m) are used, they can be tested by an experienced technician with an OTDR after installation but before splicing or termination if there is any question about potential damage during installation
    d. Install the hardware: NECA/FOA 301, Section 5.5
    e. Splice as needed: NECA/FOA 301, Section 6.3, generally use fusion splicing in outside plant and singlemode applications, mechanical splices limited to premises multimode cables
    f. Terminate ends: NECA/FOA 301, Section 6.2, generally multimode connectors will be installed on the cables directly while singlemode connectors will use pre-

terminated pigtails to reduce loss and back reflection which are both important to laser transceivers used with singlemode fiber, especially in short links (~<2 km)

g. All splices and terminations should be placed in appropriate hardware for protection

h. Remember to clean all connectors properly and keep dust caps on all connectors

i. All fiber optic cables should be marked with orange or yellow tags or whatever color is designated for your cable plant to identify it as fiber optic cable.

j. Carefully mark all cables and connections for identification in a manner consistent with the company documentation processes.

k. Dust caps from the connectors and couplings terminated in the enclosure belong to that enclosure and should be put in a small plastic bag and taped inside the cabinet for future use.

4.7. Test and troubleshoot the cable plant. *(RGFO, Ch 8) (RGPC, Ch 7)*

a. All cable plants must be tested for insertion loss per industry standards (TIA/EIA-526-14 for multimode, TIA/EIA-526-7 for singlemode fibers) at the wavelength(s) to be used with the transmission systems chosen

b. Insertion loss must be less than allowable link loss margin for the communications equipment being used on the fibers

c. Longer cable plants, especially singlemode and those using splices, should be tested by an experienced technician with an OTDR to verify splice loss and confirm the cable was not damaged during installation

d. Remember to clean all connectors properly and keep dust caps on all connectors

e. All test data should be recorded for cable plant acceptance and saved for future troubleshooting and restoration

4.8. Install the communications systems.

a. Install all the active devices according to manufacturer's specifications and test for proper operation

b. If patchcords are used for connecting optical ports to the cable plant, use tested patchcords that are known to be in good condition

c. Clean all connectors after removing dust caps and before connecting to transceivers or cable plant connectors

d. Using an optical power meter and good reference test cable, test transmitter power levels to insure it is within manufacturer's specifications

e. Using an optical power meter, test receiver power levels to insure it is within manufacturer's specifications (you can use these two pieces of data to calculate the loss of the cable plant under actual use, which should correlate with insertion loss test data

f. If the power exceeds the receiver dynamic range and overloads it, reduce the power by using attenuators of a type recommended by the equipment manufacturer placed at the receiver, checking with the optical power meter to ensure the lower power level is in an appropriate range

4.9. Document the fiber optic network. *(RGFO, Ch 9,10) (RGPC, Ch 7,8)*

a. Perhaps the most important part of any installation is the documentation. Good documentation is invaluable in upgrading, troubleshooting or restoring a network
b. Documentation should include:
      i. Design data, e.g. CAD drawings and maps
      ii. Component types and manufacturers
     iii. The paths of each cable
      iv. Types of cable (and where the excess is stored for restoration)
      v. Cable section lengths
      vi. Locations of splices or terminations
     vii. Calculated loss budget
    viii. The optical loss of each fiber measured at installation
      ix. Fiber numbers/colors connected to each communications device, noting transmitter and receiver orientation
      x. Spare fibers available for expansion or use to replaced damaged fibers
      xi. Types of communications equipment
     xii. Wavelength of transmission
    xiii. Transmitter and receiver power for each transceiver (and attenuator values if used)
    xiv. OTDR traces if taken
     xv. Name and contact information for installers
c. Copies of the documentation should be kept at each end of the link and backups stored in a safe place.

4.10. Fiber optic premises networks generally do not require periodic maintenance.
a. As long as the network is communicating as expected, no maintenance should be required and the network should not be touched unless communications equipment is moved, added or changed.
b. Attempts at inspection or maintenance are a major cause of damage to cables or connectors and getting dirt into components
c. Hardware should be lockable to prevent unauthorized entry
d. Outdoor installations, being more prone to mechanical and environmental damage should be inspected as part of a regularly scheduled preventative maintenance program.

References

      There are other FOA Technical Bulletins that should be used as references for the design and planning of the network. These documents can be downloaded from the FOA Tech Topics website. In addition to those, we recommend:

The FOA Reference Guide to Fiber Optics

The FOA Reference Guide to Fiber Optic Testing

The FOA Reference Guide to Fiber Optic Network Design

The FOA Reference Guide to Premises Cabling

The FOA Reference Guide to Outside Plant Fiber Optics

FOA Online Reference Guide, FOA website, www.thefoa.org

NECA/FOA-301 Standard For Installing And Testing Fiber Optic Cables (NECA/FOA-301), *Download from FOA website*

FOA Tech Bulletins (Printable Reference Documents)
Designing and manufacturing fiber optic communications products for manufacturers of products using fiber optics . (PDF, 0.2 Mb)
Choosing, installing and using fiber optic products for communications network users. (PDF, 0.1 Mb) (this document)
Designing Fiber Optic Networks - for contractors, designers, installers and users and the reference for the FOA CFOS/D Design Certification (PDF, 1.3 MB).
Installing Fiber Optic Cable Plants. (PDF, 0.2 Mb)
Troubleshooting fiber optic cable plants and communications systems. (PDF, 0.1 Mb)
Fiber Optic Restoration - how to plan ahead and restore networks quickly. (PDF, 0.1 Mb)

Note: This information is provided by The Fiber Optic Association, Inc. as a benefit to those interested in designing, manufacturing, selling, installing or using fiber optic communications systems or networks. It is intended to be used as a overview and guideline and in no way should be considered to be complete or comprehensive. These guidelines are strictly the opinion of the FOA and the reader is expected to use them as a basis for creating their own documentation, specifications, etc. The FOA assumes no liability for their use.

Do you have comments on this technical bulletin, corrections or information to add to it to make it more complete. Please send them to the FOA at info@foa.org.

*   The Fiber Optic Association, the professional society of fiber optics, has available on its website, www.foa.org, guides for end users on fiber optic network design and installation. The FOA also has a website offering free online self-study programs, www.fiberu.org.*

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