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Technical Bulletin
Designing Fiber Optic Communications Products For Manufacturers

Guidelines for Designers and Manufacturers of Fiber Optic Products

This is intended as an overview of the overall process of designing, testing and specifying a fiber optic system or component. It's a guide for engineering, manufacturing, marketing and tech support designed to help answer these questions: Should you use fiber optics in your communications products? What are its advantages and disadvantages? Isn't fiber optics still too new for everybody to adopt it? Is it hard to design products using fiber optics? How do you specify them to allow users to choose the proper product for their application? How do you assist users in the adoption and application of these products.

This short guide is designed to help answer those questions for users pondering the choices. To learn more about topics in fiber optics and cabling, you can take free online courses at Fiber U (www.fiberu.org) or search the Table of Contents of the FOA Guide on the FOA website (www.foa.org).

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. By 1990, submarine fiber optic cables were already connecting the continents and fiber LANs at 100Mb/s were commonplace. In the early 2000s, gigabit LANs and fiber to the home (FTTH) were in wide use.

If you use the Internet or make a wireless or wired phone call today, you are undoubtedly talking on fiber optics, since it has replaced virtually all other means of communications. Most large office buildings have fiber in the building itself.

CATV also discovered fiber optics in the mid-1990s, along with cable modems to deliver the first – ans still dominant – broadband services.

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 links to wireless access points (APs) are still copper based, mainly to take advantage of POE – power over ethernet to power the APs.

Fiber optics offers an unrivaled level of security. It cannot be easily 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. Its 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 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 is 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 one optical fiber has already outlived a half-dozen generations of copper wiring.

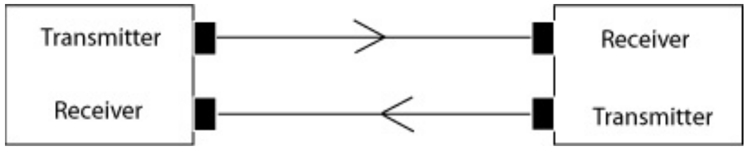
1.2. Technology says go fiber

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, fiber is used at 100-200 Mb/s for datacom applications on multimode fiber (do we need too elaborate on fiber types?), this same fiber is usable up to 1-2 Gb/s. And singlemode fiber offers virtually unlimited bandwidth.

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. Using two fibers is 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.



The exception to the 2-fiber duplex link is the passive optical network (PON) developed for FTTH and now also used in LANs. A PON sends signals in both directions on one singlemode fiber through a fiber splitter that acts as a switch to connect multiple users. Upstream and downstream communications use different wavelengths of light to prevent corsstalk.

Fiber optic transmitters use 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 some older, 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 glass fibers use light at 850 nm, referred to as “short wavelength” and 1300 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 insure no light is present unless you know the far end of the fiber is disconnected.

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. Guidelines For Engineering

Here are some guidelines for engineering, testing and supporting fiber optic products for use by manufacturers of fiber optic communications systems. A good reference for designing fiber optic products is the *Handbook of Fiber Optic Data Communication* (HoFODC) by Casimer DeCusatis, chapters 2-6, which offers basic information and even representative circuits.

3.1. Decide what communications protocol is to be sent over the fiber optic communications product.

a. Analog or digital?
b. Industry standard (RS-232, IEEE C37.94, SONET, video, Ethernet – what version?, etc.)
c. Proprietary
d. Bit rate (digital) or bandwidth (analog)

3.2. Determine the distance the product be designed to cover and transmission speed.

a. Distance and speed will determine the type of fiber, source type and wavelength of transmission
b. The table below is for low speed systems.
c. Systems operating at speeds at or over 100 Mb/s may have bandwidth considerations for LED/MM transmission. See the FOA Online Reference Guide for “Specifications For Fiber Optic Links and Systems” for complete information.
d. The table below is only estimates of typical systems

Max Distance*	50 m	100 m	1 km	25 km	80 km
Fiber Type	POF	MM SI HCS	MM GI	SM	SM
Source Type	650 nm LED	650/850 nm LED	850 nm VCSEL	1310 nm Laser	1310 nm Laser

Loss range	10 dB	9 dB	6 dB	14 dB	40 dB

* May be less depending on the bandwidth required for the link.

3.3. Choose components based on performance parameters determined in #2 above. Ref: HoFODC, Chapters 2,3,5,6,7

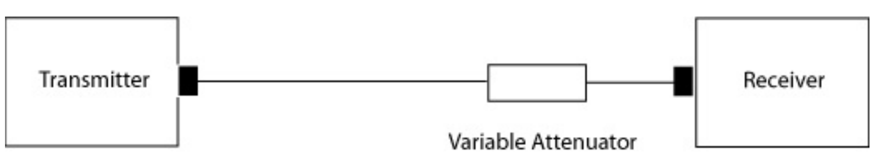
a. Pick LEDs, lasers, photodetectors, etc. appropriate for transmitter and receiver to design the electronics from scratch.
b. Review, choose and test complete transmitter, receiver or transceiver modules if purchasing functional assemblies
c. Evaluate IC solutions for laser drivers, transimpedance amplifiers, clock recovery, etc.
d. Discuss needs with as many manufacturers as possible to get a wide spectrum of data on components.

3.4. Design, build and test prototypes to confirm performance per requirements. Ref: HoFODC, Chapters 2,3,4,5,6,7,17

a. Acquire representative components and build prototype circuits
b. Breadboards may work for low speed systems, but high speeds requires full PCB design by RF-competent designers
c. Check transmitters for “eye diagrams” and receivers for noise, waveforms, etc.
d. Include testing requirements in design, including an operating mode for measuring transmitter power (for example transmitting a 50% duty cycle clock for measuring average power as specified) and loopback testing if possible (where short attenuator is connected between transmitter and receiver for quick functional test)

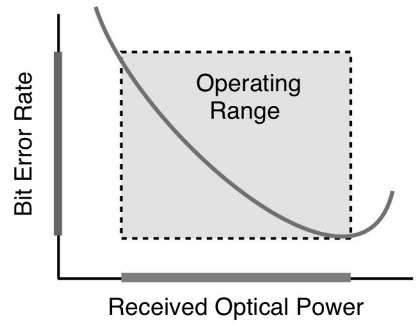
3.5. Test modules for functionality, using short lengths of fiber and variable attenuators at the receiver to simulate cable plant loss. It may be necessary to use longer lengths of cable if bandwidth issues with multimode fiber are important. Ref: HoFODC, Chapters 6,7,9.

Test Set-Up:

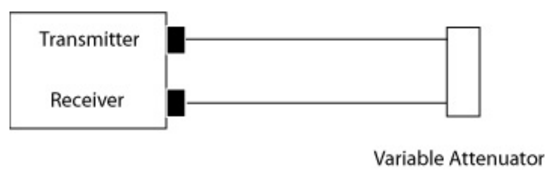


a. Test data transmission at specified data rates
b. Determine data transmission at min/max link loss to establish margins
    i. Will it operate with 0 dB loss (short patchcord) or overload?
    ii. What is minimum loss it will tolerate?
    iii. What is maximum loss system will tolerate?
c. Test with all specified fiber variations (e.g. 50/125 vs 62.5/125)

d. Create a BER/receiver power plot as a function of receiver power. This will be translated to link loss by establishing typical transmitter coupled power.



e. BER/receiver power plot will define minimum and max power link will tolerate for specifications.
f. Test sources for typical transmitter power coupled into representative fibers of all specified sizes. Variations in transmitter power may be higher than variations in receiver sensitivity.
g. Lowest transmitter power and minimum receiver power should determine link power margin for specifications
h. Data provided to customers in product spec sheet should include table of coupled transmitter power, minimum and maximum receiver power and optical loss margin.
i. If the product is designed for loopback testing, see if the product will work with the attenuation specified on loopback. Use a variable attenuator to create a loopback and test for operation. Fixed loopbacks can be used if a low-cost version is desired for shipping with product for diagnostics.



3.6. Test for field and environmental performance. Ref: HoFODC, Chapter 9
a. Choose conditions appropriate for specified operating conditions in normal applications
b. Include optical interface components (connectors primarily) as they can be affected by temperature or condensation
c. Test for sensitivity to highly reflective terminations on singlemode networks using long cable assemblies with multimode terminations which will have high back reflection on one end. Test with reflective connectors on transmitter end, looking for nonlinearities in laser output and at receiver end for noise susceptibility.

3.7. Perform required reliability analysis
a. Use industry standards for paper analysis and actual testing
b. Ask manufacturers for all relevant reliability data on components

c. De-rate components as necessary for adverse environments

3.8. Build and test preproduction run

a. Develop understanding of possible component and specification variations by repeating margin and environmental testing on a number of products
b. Be aware of fiber optic source variability over production lots and environmental conditions, especially LEDs over temperature
c. Feed back results to design and make proper changes before committing to production

3.9. Specify needs and keep ongoing statistics from production

a. Look for variability in production or vendor lots
b. Find out what to NOT test to save costs

3.10. Specify the product consistently across the product line, as in the example below, for marketing literature and instruction manuals:

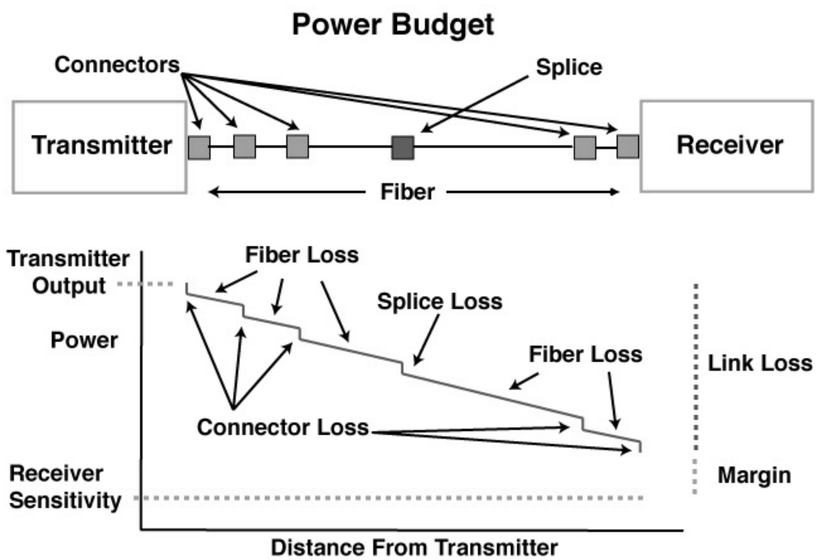
Model	Product #, if several products covered in same table
Electrical Interface	EIA-232, etc., unless covered in other specs
Optical Interface	Industry standard, proprietary, etc.
Fiber type	POF, HCS, GI Multimode or Singlemode
Connector Type	ST, SC, LC or ?
Source Type	LED, VCSEL, Laser
Source wavelength (nm)	650, 850, 1300, 1310, 1550 nm As specified
TX Power (min, dBm)	As specified, coupled into specified fiber
RX Sensitivity (dBm)	As specified
System Margin	Calculated from specs above

3.11. Engineering or marketing should create comparison charts to help customers find the right product, using the data format below:

Model	Product #	Additional Column For each Product #
Electrical Interface	Ethernet, EIA-232, etc.	
Optical Interface	Industry standard, proprietary, etc.	
Data Rate (kb/s)	As specified	
Time Transfer Signal	As specified	
Fiber Compatibility	POF, HCS, GI Multimode or Singlemode	
Approximate Range (m)	Listed for each compatible fiber, e.g. see right:	HCS: 6 km 50/125: 15 km 62.5/125: 15 km
Product Specifications	Page # For Full Specs	

3.12. Calculating Link Power Budget/Range

Range should be calculated from the system power budget using a loss budget created using industry appropriate component values (e.g. from TIA-568 for worst-case losses) and solving the loss budget for length. Since those values are conservative, the calculated range can be considered conservative. For typical cable plant loss estimation purposes, you may use a model similar to below, which includes 5 connector pairs, including the patchcords on each end to connect the equipment to the cable plant, and one splice (which can be deleted on short runs). See http://www.foa.org/tech/lossbudg.htm for a detailed explanation of the loss budget calculation.



Thus the loss can be calculated as:
Connector loss for 5 connectors @ 0.75 dB = 3.75 dB
Splice loss for 1 splice @ 0.3 dB = 0.3 dB
Connector and splice loss = 4.05 dB (rounding off to 4dB is OK)

Fiber loss is normally calculated from the length of the run in km multiplied by the loss in dB/km at the source wavelength and fiber type.

Fiber Type	Multimode		Singlemode	
Wavelength (nm)	850	1300	1300	1550
Fiber Attenuation dB/km (Premises)	3.5	1.5	1	1
Outside Plant			0.5	0.5

To calculate range, use these steps (example):

a. From testing (above), determine loss margin, for example 10 dB

b. Subtract from loss margin 4dB for connection losses = 10 dB – 4 dB = 6 dB
c. Using fiber loss at the wavelength of the transmitter, calculate distance: @ 1300 nm, multimode, loss is 1.5 dB/km, so 6 dB/1.4 dB/km = 4 km
d. Thus the typical range of this link would be 4 km.

Using this example, the customer can calculate their own network range based on the number of connectors and splices and the length of the run.

High bitrate networks, e.g. 1-10 Gb/s, operating on multimode fiber may have a range limited by dispersion not cable plant loss or link power budget. The distance of these high speed links will be determined by the grade of multimode fiber (OM1-4) selected. The FOA website lists these specifications for many types of communications systems in the FOA Online Guide page “Specifications for fiber optic llinks and systems, including FTTx.”

3.13. Fiber Optic Equipment Engineering Needs

a. Fiber optic patchcords in various fiber types and connector styles appropriate for products, with lengths according to needs.
b. Fiber optic loss test set consisting of fiber optic test source, power meter and adapters for connectors being used. Besides using the power meter to test source power and receiver sensitivity, they can be used to test patchcords to verify their performance.
c. Variable attenuators for measuring link margin.
d. If eye diagrams or waveforms are analyzed, a optical-to-electrical converter for an oscilloscope will be needed, but it can be designed using common parts.
e. Engineering may need other components for building test fixtures for manufacturing.

4. Manufacturing

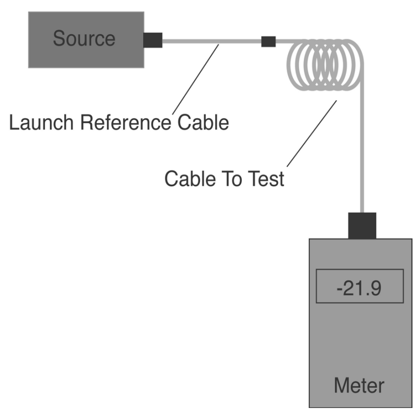
With fiber optic products, as with any electronic product, careful control of the manufacturing process is important to the quality of the product. Product reliability starts with proper design, but component procurement, inspection, handling before the manufacturing process begins are also very important. Once on the manufacturing floor, following correct procedures is mandatory to produce consistently good product. Even packaging and shipping are important for all products. Here are some guidelines we have learned from our experiences.

4.1. Purchasing

a. Start with a comprehensive product specification produced by engineering.
b. Identify and qualify vendors.
c. Some components like connectors may have lower cost substitutes, but none should be purchased without qualification.

4.2. Incoming Inspection

a. All products should be inspected for correct part type, grade, manufacturer and quantity.
b. Recording batch number or build dates will assist in tracking troublesome parts.
c. Electrical inspection may be needed for components with highly variable performance, for example to sort transmitters by power level for use in different grades of products.
d. In the past, burn-in of optoelectronics was common, but with today's reliability, it is not generally necessary.
e. Until a vendor is qualified, all fiber optic cables should be tested according to TIA FOTP-171, single-ended and reversed, as shown below. Qualified vendors should be required to test in the same manner and correlation tests performed as part of the qualification process.



   i. The loss reference should be set at the end of the launch reference cable, then the cable under test is attached with a mating adapter and the loss measured.
   ii. On short cables with negligible fiber loss, the loss is the loss of the connector mated pair.
   iii. The cable is reversed and the opposite end of the cable under test is mated to the reference cable and the loss tested.
   iv. This method provides a loss for each end of the cable separately and is considered the correct way to test patchcords.

Note: While TIA-568 standards for user installation allow 0.75 dB per connector, this is to allow the use of prepolished/splice connectors which have inherently high loss due to the use of an internal splice. While each user sets their own limits, normal patchcords purchased for use internally should be tested to a tighter standard, usually in the range of 0.3-0.5 dB loss tested in this manner. We recommend using a 0.3 dB incoming inspection limit and a 0.5 dB test limit when retesting patchcords used internally for degraded performance. Patchcords used for field test should always be 0.5 dB or better when tested against reference patchcords or other similar test patchcords unless other standards are considered more appropriate (as for fiber types other than singlemode or multimode 50/125 or 62.5/125.)

4.3. Product Test in Manufacturing

a. Product testing should include optoelectronic and data performance.
b. Test transmitter output power coupled into fiber, receiver at min/max input values
c. Use loopback testing for faster testing and burn-in under operating conditions. Automatic test equipment can use optical loopbacks to simplify testing, instead of using a “golden transceiver,” fiber optic cables and attenuators.

4.4. QC

Follow all normal QC procedures

4.5. Fiber Optic Equipment For Manufacturing

a. Fiber optic patchcords in various fiber types and connector styles appropriate for products, with lengths according to needs.
b. Fiber optic loss test set consisting of fiber optic test source, power meter and adapters for connectors being used. Besides using the power meter to test source power and receiver sensitivity, they can be used to test patchcords to verify their performance.
c. Variable attenuators for measuring link margin.
d. Inexpensive loopback attenuators for test and burn-in.
e. If eye diagrams or waveforms are analyzed, a optical-to-electrical converter for an oscilloscope will be needed, but it can be designed using common parts.
f. Engineering may provide custom test fixtures for manufacturing.

5. Marketing And Field Service

Marketing should translate the performance of the products into understandable documentation for the customer, to help them choose and use the product easily. Since many users may be working with fiber optic products for the first time, it’s important to keep everything as simple as possible, be consistent in nomenclature and specifications and follow industry standards and convention. Providing the customer with complete, easily-understood documentation will simplify field support and service.

5.1. Help the customer find the right product for their application.

5.1.1. Users are often looking for a fiber optic solution for a communication product that currently uses copper wire, so the first selection criterion should be the data communication protocol or standard.

5.1.2. Users may be looking for either something that will use currently available fiber or will transmit a certain distance between facilities, so cover these two criteria next.

5.1.3. Most systems use a few standard connectors (ST, SC, LC being the most popular) but hybrid patchcords can make the change between them, so connector type is something necessary to know but not a major decision point.

5.1.4. Use the format suggested above (Engineering #11) for datasheets and instruction manuals or a similar format as deemed appropriate, but always try to use the same format for all products so customers can compare products.

5.1.5. Provide the customer with basic educational materials (in print or on a website) like the “User’s Guide” or send them to Lennie Lightwave’s Guide on the web (www.lennielightwave.com) to familiarize them with the issues of fiber optics and installing networks using fiber.

5.1.6. Be able to assist the customer in finding qualified installers. Use the FOA installer database (http://www.foa.org/) if you do not have a qualified list yourself.

5.1.7. Create a training program on the basics of fiber optics. If the customer is just managing the installation, a single day seminar is adequate and is probably good for the company to offer, while the customer contemplating a large outside plant network installation may want a full week of training, available from many sources, including over 100 FOA-Approved Schools, listed at http://www.foa.org/foa_aprv.htm.

5.1.8. Field service should be trained on testing and troubleshooting and equipped for fast response in solving on-site problems. Installation training (termination and splicing) training may also be advisable for crews that will be doing troubleshooting and repair.

5.1.9. Topics to publish (print or web) guidelines for customers:

a. Designing networks
b. Choosing communications products
c. Installing systems
d. Testing and troubleshooting (include test equipment needed, standards, using loopbacks)
e. Documenting
f. Restoration

5.2. Fiber Optic Equipment Needs For Field Service

5.2.1. Fiber optic patchcords in various fiber types and connector styles appropriate for products, with lengths according to needs. Field service should always have extra stock and be prepared to replace bad customer patchcords. Patchcords should be tested before use to the same limits as incoming inspection: 0.3 dB loss when new, 0.5 dB max for use, unless other standards are considered more appropriate (as for fiber types other than singlemode or multimode 50/125 or 62.5/125.)

5.2.2. Fiber optic loss test set consisting of fiber optic test source, power meter and adapters for connectors being used. Besides using the power meter to test source power and receiver sensitivity, they can be used to test patchcords to verify their performance.

5.2.3. OTDR for troubleshooting long cable links.

5.2.4. Visual fault locator for tracing and troubleshooting short cable links.

5.2.5. Loopback attenuators for fast product diagnostics.

5.2.6. It may be advisable to have a fiber optic termination kit for quick onsite repairs.

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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