Survey on Fiber Optic Connectors and Cables

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SURVEY OF FIBER OPTIC CONNECTORS AND CABLES

BY

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ABSTRACT

Today the world of fiber optics is bigger than ever. What is available to the engineer and the technician is now only apparent to the well informed. Not all engineers and technicians have a background or an education in the field of fiber optics. This report is intended to be an informative preliminary guide to those readers whose interest lies in the field of fiber optics.

The advantages of fiber optic systems are discussed and compared to conventional systems. Although a fiber optic system includes transmitters and receivers, this report concentrates primarily on fiber optic connectors and cables. It also includes a look at the characteristics of the fibers themselves.

The basis for this report is information obtained from a survey taken from a select number of manufacturers of fiber optic connectors and fiber optic cables. Available fiber optic connectors range from reusable to permanently installed, cheap to expensive, plastic to stainless steel. Some require special tools and preparation including the use of epoxy, whereas others can be used in the field quickly without any special tools or epoxy. Since many connectors,
however, require epoxy, this report introduces six different types of epoxies, showing their characteristics and listing their applications.

The fiber cable has become a widely appreciated medium for data and information transmission systems. The consumer has many choices from one or two fibers per cable to a bundle fiber cable. The cables have many designs which lead to various applications. These cable designs and their characteristics are summarized and discussed.

There are many other optical devices that are available and on the market. Among these devices are many types of optical couplers. Although these devices were not covered in this report, the coupling from one fiber to another (attached side by side) was investigated theoretically. The case where internal reflection in the fiber’s core created an evanescent field in the cladding (this is when the angle of incidence is greater than the critical angle) was emphasized. This shows that the power in the evanescent field is imaginary (reactive), and the angle of refraction is also imaginary. However, when the evanescent field extends on out to the second fiber’s cladding, and continues until it reaches and enters the second fiber’s core, power then exists; thus, optical power was transferred by way of an evanescent field.
ACKNOWLEDGEMENTS

I wish to express my deepest feelings of gratitude to the many people who helped me obtain a goal that will live with me, and be cherished by me, the rest of my life.

I would like to thank my wife Linda, and our two sons, John and Michael, for their patience in spending lots of time doing things without me while I pursued both my Bachelor of Science and Master of Science in Engineering degrees.

I would also like to thank my committee members, all of whom I have learned many things from, for their time, and assistance in helping me achieve my goal.

A special thanks to Dr. Richard N. Miller, who directed the committee. First, for his guidance in suggesting I should consider returning to the University of Central Florida to pursue a master's degree. Second for the many hours he has spent working with me, and third for his friendship.
Lastly, but most meaningful to me, I wish to thank my mother and father, Betty and Raymond Ostlund, for their many years of support, love, and encouragement. Since the day they fulfilled my brother's wish of wanting a younger brother (adopting me when I was four years old), I have felt and continue to feel that my brother and I possess two of the most wonderful parents God could offer. I love them both and appreciate their dedication to my life. I also appreciate their love and dedication to my family, who I love tremendously!
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CHAPTER 1

FIBER OPTIC SYSTEMS

Introduction

Communication systems employing lightwave technology use optical fibers as the communication medium. These fiber optic systems are now widely appreciated for their immunity to electromagnetic noise in addition to achieving very large bandwidths. Both of these will be expounded upon in this chapter. This chapter is also introductory in nature. It is intended to provide the reader with a general understanding of the characteristics of optical fibers and cables used in today's fiber optic systems. At this point, the question "Why choose a fiber optic system over a conventional system?" should be answered. This is best illustrated by considering some of the important advantages of a fiber optic system:

(1) EMI Immunity

The FCC (Federal Communications Commission) has forced the communication industry, through its regulations, to become more aware of EMI (electromagnetic interference). This means an increase in the shielding of copper wires, forcing designers to use shielded or coaxial cables rather
than twisted pairs or ribbon cables. The increase in the cost of shielding for a copper wire system leads the designer to consider a cost effective fiber optic system. A fiber optic system's transmission line, the fiber, is immune to ambient electromagnetic interference, electrical noise, ringing, and echoes. It does not generate any electrical noise itself nor is it plagued with crosstalk. The fiber can also have greater signal protection since it has typically a $10^{-7}$ or better bit error rate. This added signal reliability can reduce costs by replacing complex error checking routines with simpler routines.

(2) Small Size

A small fiber, for instance one with a 125 micron diameter core in a 3.5 millimeter jacket, can carry the same amount of information as an 800 millimeter 900-pair copper cable (see Figure 1 for an illustrated comparison between an optical fiber and a copper cable). To appreciate how small the fiber's core is, consider a five millimeter diameter pencil lead used in a mechanical pencil. The lead's diameter is 40 times that of the fiber's core, which implies the lead's cross sectional area is 1600 times that of the fiber's core. If the fiber were to replace the bundled pairs of copper wires, there would be an area reduction of 228 to 1. This is a significant size reduction which is especially important for underwater cables and in areas of
overcrowded transmission wires. It may give the extra room needed in an overcrowded conduit, so that an increase in the capacity of the existing conduit can be achieved. Also, since fibers are not made of heavy copper but made of glass or plastic, the size reduction along with the fiber's composition creates a substantial weight savings.

![Image of size comparison between a single optical fiber and a 900-pair copper cable bundle.](image)

Figure 1. A Size Comparison between a Single Optical Fiber and a 900-Pair Copper Cable Bundle.

(3) Large Bandwidth

The bandwidth of a transmission medium determines how much information the carrier wave can carry. As the carrier frequency increases, the carrying capacity of the wave increases. Fiber optic systems use light as the carrier. Light is several orders of magnitude higher than the highest radio frequencies. Thus, fibers have very large bandwidths (approaching the multi-gigahertz-kilometer range). Large
bandwidths are wanted as they determine the speed that data can be transferred. If the concept of multiplexing is used, several channels can be sent over a single fiber. For example, in telephony the fiber's bandwidth is large enough to accommodate 672 voice channels at once in one direction, through one fiber. If, for instance, wavelength division multiplexing is employed, the capacity could be increased to 2,688 voice channels. In the area of computers, hardware and cabling cost could be reduced via multiplexing paralleled bus lines into serial form for transmission over a fiber optic link. Note this technique would not be practical for interconnections between a computer's CPU (central processing unit) and its peripherals. Most are connected in a parallel form, while a fiber optic system lends itself to serial applications.

Fiber Characteristics

An optical fiber has an inner cylinder usually made of glass called the core. The core is surrounded by a cylindrical shell of glass or plastic of a lower refractive index called the cladding. The optical fiber has two main characteristics that are used to classify it. One is its refractive index profile, and the other is whether one mode (single mode) or several modes (multimode) of light will travel (propagate) through it.
The refractive index of a medium (denoted by "N") is defined as the ratio of the velocity of light in a vacuum (N=1), to the velocity of light in that medium. This is also referred to as the "index of refraction." Thus, the refractive index profile is a description of the refractive indices of the fiber's core and cladding material as a function of the fiber's radius. If the fiber core's refractive index profile is uniform, the fiber is termed "step index." If the fiber core's refractive index is parabolic, then it is termed "graded index."

To understand the second characteristic used to classify optical fibers, a look at the way light travels in a fiber is necessary. The way light travels in a fiber is described by its "modes." If light propagates only down the center of the fiber, the "optical axis," it is termed "single mode." If one path of light propagates down the optical axis along with others bouncing within the fiber's core off the core-cladding interface, it is termed "multimode." The number of modes is determined by how many light rays stay within the core of the fiber. This is accomplished by what is called "total internal reflection." Total internal reflection is based on the light ray's angle of incidence (with respect to the normal) as it strikes the core-cladding interface. This angle must be greater than the "critical angle" or the light ray will be lost through
the cladding instead of being reflected back into the core. It should be noted that the angles of the light rays as they enter the fiber determine at what angle the rays strike the core-cladding interface as shown in Figure 2. The largest entrance angle that will assure internal reflection is denoted by "Bmax." The "numerical aperture" (NA) determines the coupling efficiency between the light source, LED (light emitting diode) or laser, and the optical fiber. It is mathematically defined by the equation: $NA = (N_{core}^2 - N_{cladding}^2)^{1/2}$, where $N_{core}$ is the refractive index of the core and $N_{cladding}$ is the refractive index of the cladding. It can also be found by the following equation: $NA = \sin B_{max}$.

\[
N_1 = \text{Refractive Index Of Air (1.0)} \\
N_1 \sin (B_{max}) = (N_{core}^2 - N_{cladding}^2)^{1/2}
\]

Figure 2. Light Propagation in an Open-End Fiber.
CHAPTER 2

FIBER OPTIC CONNECTORS

Introduction

This chapter will show what is available in the fiber optic connector market. This will be achieved by examining the products that are being produced by a sampled number of corporations. The types of fiber optic connectors vary, and are dependent upon such parameters as fiber size, cost, application, and use of epoxy.

Typically metal fiber optic connectors are higher priced than plastic ones and offer shielding for use near electronic components. The size of the fiber dictates two styles of fiber optic connectors, the small fiber (SFR style), and the large fiber (LFR style). The SFR style is more expensive than the LFR style; in general, the smaller the fiber, the more it costs. Another fiber optic connector is the SMA style connector (see page 11). In some corporations this connector is more expensive. Its higher price is partially due to accessories, as it comes typically in a complete connector kit. It is primarily used for high-temperature applications and offers more elasticity than the other types of connectors. This chapter continues
with a no-epoxy style fiber optic connector known as a DNP (dry nonpolish), followed by what is available through the chosen corporations in the SMA, LFR, and SFR connector styles, respectively. The chapter finishes with a look at the application and characteristics of six types of epoxies, and concludes with a table showing a comparison of the fiber optic connectors covered by this report. The comparison included such things as relative cost and use of epoxies.

**DNP Style**

Fiber optic connectors which are currently available come in many styles as cited above to satisfy the wants and specification of the consumer. Two of the main needs of the consumer are "time" and "money." AMP Incorporated, located in Harrisburg, Pennsylvania, has provided a solution for the consumer's quest for assembly time and economics. One of the many styles of connectors that are manufactured by AMP is the OPTIMATE DNP fiber optic connector (Figure 3). This connector style provides low-cost optical terminations for cable, but does have limitations on data rate (bandwidth capability) and the link length of the system. Typical data rate and run length are 10 megabits and 20 meters (78.7 feet), respectively. The big plus here is that this style of connector was designed to be used with low-cost plastic fiber (1000 micron diameter) and low-cost active devices, thus, keeping the cost of the system down. These connectors
are simple to use and do not require any special tools or adhesives. The cable is cut and stripped of the jacketing then pushed through a plug assembly. The connect/disconnect time is very quick and has an audible snap action. This type of connector also features low loss (less than three decibels (dB)) and repeatable coupling efficiency.

Figure 3. AMP's Optimate DNP Fiber Optic Connectors.
The OPTIMATE DNP connector system is based on either a single or dual plug. The mechanism for alignment for these plugs consists of two opposing "V" grooves for the fiber. This keeps the insertion loss below three dB. The plug is accurately centered into a receptacle by way of four protrusions and is attached to a fiber cable by a retention clip. This retention clip can be obtained for use about the cable jacket or inserted into the plug. A typical insertion force of three pounds is needed for assembly, and a typical extraction force (cable from the plug) of six pounds or better is needed for disassembly.

The OPTIMATE DNP connector system incorporates a complete line of products for the assembly of both dual and single channel cable, as well as the interface to emitters and detectors. See Appendix A for three systems using AMP DNP products. The product family includes:

1. Splice  
2. Single position plug  
3. Single position device mount (TO 18)  
4. Single position device mount (TO 92)  
5. Single position bulkhead receptacle  
6. Dual position bulkhead receptacle  
7. Dual position plug  
8. Retention clip
It is recommended that the OPTIMATE DPN connector system using the 1000 micron plastic fiber is best suited for devices which operate in the red visible range at approximately 620 nanometer wavelength. The basis for this recommendation is due primarily to the plastic fiber low attenuation characteristics at this wavelength. Non-visible devices will work with plastic fiber and an OPTIMATE DNP connector; however, they will be somewhat length-limited due to the fiber attenuation at a given wavelength.

**SMA Style**

AMP's SMA style connectors (Figure 4) provide a way of connecting small fibers (as small as 125 microns) and large bundles of fiber (as large as 1,140 microns) together. Their body and coupling nut are constructed with corrosion-resistant metal. AMP has available an environmental sealing for the protection of plugs, active device mounts (ADM), and bulkhead couplings. AMP also has available for cable to cable connections a bulkhead mounting adapter. See Appendix B for AMP's SMA style connector data sheets.
Figure 4. SMA Style Fiber Optic Connectors by AMP.

Optelecom, located in Gaithersburg, Maryland, offers low-loss connector designs for glass core fibers with plastic or glass cladding layers. They consist of corrosion-resistant metal that provides the RF shielding for
mating electronics. Both designs are available for terminating 200 micron plastic clad silica (PCS), 100/140 micron, or 50/125 micron fiber cable. For rapid field termination Optelecom's OB-10 fiber optic connector (Figure 5) is recommended. This design clamps the fiber in place, crimps the strength members to the termination, and cleaves the fiber precisely flush with the ferrule end. With this design there is no need to use epoxy, or perform polishing procedures. Thus the hardware can be easily reuse if the fiber is contaminated or broken. Optelecom's low loss connectors have external dimensions which match with the standard SMA style housing for electro-optic devices or in-line splice alignment sleeves (Optelecom's OB-11S), shown also in Figure 5. See Appendix C for Optelecom's specification sheet.

Figure 5. Optelecom's Fiber Connector and Splice.
Optical Fiber Technologies, Incorporated (OFTI), Nutting Lake, Massachusetts, manufactures many epoxy-style and no-epoxy-style SMA fiber optic connectors. Their 200 series epoxy-style SMA connectors are for single-channel, single-fiber operations. They feature losses of less than two dB per splice and are to be used with fibers from 125 to 230 microns in diameter.

The series 200 and 200 "S" are made of stainless steel and are intermateable with Amphenol 905 and 906 respectively. (Amphenol Optical Products, Danbury Connecticut, is another large manufacturer of fiber optic connectors, and is not one of the sampled corporations in this report.)

The series 200 "CCAD" made of zinc die cast, and the series 200 "SA" made of aluminum, are also intermateable with Amphenol 905 and 906 respectively. Both are less expensive and lighter weight than the stainless steal series 200 and 200 "S."

OFTI also produces epoxy SMA style ceramic series fiber optic connectors. These series are the 200 "SC", 200 "SCSM", and the 200 "NOFC". The ceramic ferrule offers extreme durability due to the thermal, mechanical, and chemical stability of high purity ceramics (99.99% Al₂O₃).
The 200 "SC" series connectors are intermateable with Amphenol 906 style connectors and used with multimode (200 "SC") and single mode (200 "SCSM") fibers and cables. The 200 "SC" series connector is used with either a 50/125 or a 100/140 micron fiber with 1.0 dB and 0.5 dB loss per splice, respectively. (Note the numerical representation of the fibers above. This is explained in the third chapter on page 28.) The 200 "SCSM" series connector has less than two dB loss per splice and is used with 125 micron O.D. (outer diameter) single mode fibers. The OFTI 200 "NOFC" series connector is used with 125 micron and 140 micron multimode fiber and cable, with less than 1.0 dB loss per splice. This ceramic ferrule connector is intermateable with Amphenol 905.

The no-epoxy style SMA fiber optic connectors by OFTI are the 200-NE, 200S-NE, 200 CCAD-NE, 200SA-NE, and the 200SC-NE series, where NE is defined as "no-epoxy." Their descriptions and features are the same as their respective counterparts with the exception of not requiring epoxy.

**LFR Style**

The OPTIMATE LFR (large fiber) single position fiber optic connector (Figure 6), manufactured by AMP, can be used with a large single plastic clad fiber (typically with a diameter of 400 microns or larger) without having to strip
the fiber. This is dependent upon the manufacturer of the fiber. The LFR style connector can also be used with bundled fibers up to 2180 microns in diameter, and features termination to glass or plastic fibers by using AMP's hand-crimping tool. The connector has less than a three dB loss in a splice connection and provides a universal end to the cable to which it is applied. On the inside of the connector there is a tapered plastic ferrule which is used to accommodate different diameter cables, making the insertion of the cable easier. (See the LFR specification sheet in Appendix D.) The typical assembly steps are:

1. Strip Cable
2. Apply Epoxy to Fiber
3. Slide on Connector Assembly
4. Crimp with Hand Tool
5. Mate with Compression Bushing before Epoxy Cures
6. Polish Fibers
Figure 6. AMP's Optimate LFR Fiber Optic Connectors.

**SFR Bonded Connector**

AMP's SFR (small fiber resilient) bonded connector terminates small fibers down to 125 microns in diameter (over cladding). The SFR features repeatable coupling efficiency with an average insertion loss of 1.0 dB. This feature is accomplished by the design of a resilient material which is used for the connector's ferrule. An additional design factor of the SFR is the sealing of the optical interface for a fiber-to-fiber or fiber-to-active
device/ferrule junction. This factor adds to the increased efficiency of the connector. The resiliency of the plastic ferrule absorbs any tolerance of the fiber diameter. (See Appendix E for specification sheet on the SFR bonded connector.) The biggest feature the SFR bonded connector offers is its compatibility with AMP’s ADM’s (active device mounts) for mounting semiconductor devices.

Augat Incorporated, located in Attleboro, Massachusetts, manufactures the 698-JSC connector series. This series consist of reliable single-channel optical connectors. A connector is attached to a cable by simple crimping; however, crimpless, epoxyless attachment is also provided. Both yield a cable retention equivalent to the cable’s recommended maximum tensile loading. The only adhesive used is a small drop of a rapid-curing epoxy applied to the fiber at the ferrule’s tip. The fiber must then be polished. (Augat recommends their 698-JSC-T301 polishing tool.) The coupling nut has a knurled surface to permit easy fingertip tightening. The connector is an all-metal construction that provides strength and rigidity. The insertion loss is low, typically less than 1.0 dB, and remating repeatability is excellent.
Augat recommends:

698-JSC-141 be used with Siecor 144 cable (140 micron fiber)

698-JSC-121 be used with Siecor 174 cable (125 micron fiber)

(Siecor's cables are discussed in the next chapter.)

Seiko Instruments and Electronics Ltd. (point of contact is Seiko Instruments U.S.A. Inc., Torrance, California) produces, besides quartz watches, fiber optic connector ferrules and connector plugs. As in machining jewel bearings for watches, Seiko has obtained ultra-precision machining of fiber optic connector ferrules. This perfection increases the performance of the fiber optic connector and markedly reduces the misalignment problem during fiber connection.

Seiko manufactures the following fiber optic connector ferrules:

1. SF-1A, ultra-high-performance ferrule for single mode fiber.
2. SF-1B, high-performance ferrule for multimode fiber.
These ferrules feature a highly reliable ceramic center piece approximately five millimeters in length, located on the inside of the ferrule. This ceramic piece holds the optical fiber, eliminating any alignment work. The field performance of these ferrules with optical fibers is excellent. They are weather resistant, and the insertion and fastening of a fiber to a ferrule is extremely simple. Note that the clearance between the optical fiber and the capillary hole of the ferrule must be approximately 0.5 microns or better to achieve a smooth connector assembly. The capillary hole has a 125 micron diameter. Upon request to Seiko, this value can be set to any value between 80 and 150 microns.

Seiko's fiber optic connectors consist of two parts (which were previously mentioned), the connector plug and the ferrule. Together they create a versatile connector which features a floating ferrule construction that is resistant to shock and vibration and an anti-rotation mechanism that prevents scarring of the fiber, while maintaining stability for repeated mating.

Seiko's SAP-1 is an optical fiber connector plug that is perfect for single mode fibers. Best of all if you choose the best quality ferrule, the SF-1A, it will yield a high-precision connector for a single mode fiber. The SAP-1
is used with a single fiber cord that has an outside diameter of three millimeters or fiber outside diameter of 125 microns.

The SAP-2 is typically used with multimode fiber. It is slightly larger than SAP-1 and is used primarily with single fiber covered with polyvinylchloride (PVC) with a 3.0 millimeter diameter cord.

For fiber-to-fiber connections, a connector plug is applied to both fibers (with the plug ferrule inside). An adapter such as Seiko’s SAA-1 is used where each plug connects to it in a plug-adapter-plug manner shown in Figure 7. Connection losses are typically 0.5 dB ± 0.2 dB using a SAP-2 connector plug.

Figure 7. Seiko’s Fiber Optic Connector Plugs (SAP-1) and an Adapter (SAA-1) are Shown Connected in a Plug-Adapter-Plug Manner.
The fabrication process requires the fiber end to be polished. The fiber polisher OFL-1A offered by Seiko was developed exclusively for grinding and polishing an optical fiber fitted in a plug ferrule. It is a simple operation that needs no special skills. The fiber polisher is compact and portable. Twelve different plug ferrules can be polished at one time. The whole process of grinding, lapping, and polishing can be done in less than 30 minutes.

For fiber-to-source or fiber-to-detector needs, a receptacle, Seiko’s SAR-1 or SAR-2, is used. (The SAR-2 needs a SF-1 ferrule inside.) Both are constructed to fit the SAP-2 connector plug.

**Epoxies**

Many of the fiber optic connectors covered in this report require some form of epoxy. OFTI offers six different types which are equivalent to six of Epoxy Technology Incorporated’s brand, "EPO-TEK." Table 1 shows the specifications of these epoxies. They are available from OFTI in pre-weighed, four-gram packs. One 4-gram pack
will terminate about 25 connectors. OFTI (1984) recommends that their epoxy products can be used for, but not limited to, the following:

Epoxy Application Listing

USE

DESCRIPTION

A - Plastic and glass fiber optic potting, lens and prism cementation

B - Casting or potting optically clear components such as LED displays

C - Fast curing at room temperature

D - Excellent spectral transmission in thin bond lines

E - High temperature applications

F - Glass fiber optic potting for good visual indication of the amount of wicking

G - Coating or potting optically sensitive components

H - Little or no electrical resistance change under high humidity conditions

I - Probably safe for in vivo applications

J - Autoclavable

K - Bonding glass fiber to SMA connectors

L - Bonding of fiber optic cable jacket to connector for non-crimp type connectors
# Table 1

## Epoxy Characteristics

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RT = room temperature (70°C)
TEMP = temperature
Hr = hour
min = minute
ON = overnight
cps = 10^-2 pascal seconds
psi = pounds per square inch
A-L = See epoxy recommended application listing.
Cost Comparison

In conclusion to this chapter, Table 2 gives a quick comparison of what the chosen manufacturers offer in the way of fiber optic connectors along with their relative costs. Some of these chosen manufacturers have provided price sheets for their products. These may be found in Appendix F. These sheets also cover the many other accessories available for use in the fiber optic field. Browsing through them is highly recommended.
## TABLE 2
FIBER OPTIC CONNECTOR COMPARISON

<table>
<thead>
<tr>
<th>COMPANY NAME</th>
<th>CONNECTOR TYPE</th>
<th>MATERIAL</th>
<th>EPOXY</th>
<th>RELATIVE COST</th>
<th>QUANTITY</th>
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</thead>
<tbody>
<tr>
<td>AMP</td>
<td>DNP</td>
<td>P</td>
<td>N</td>
<td>$0.57/each</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMA</td>
<td>M</td>
<td></td>
<td>$21.00/kit</td>
<td></td>
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<tr>
<td></td>
<td>LFR</td>
<td>P</td>
<td>Y</td>
<td>$2.93/each</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SFR</td>
<td>M</td>
<td></td>
<td>$4.94/1-99</td>
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<tr>
<td>OPTELE-COM</td>
<td>OB-10</td>
<td>M</td>
<td>N</td>
<td>$150.00/10 pkg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OB-11S</td>
<td>M</td>
<td>N</td>
<td>$100.00/10 pkg</td>
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</tr>
<tr>
<td>OFTI</td>
<td>S</td>
<td>M</td>
<td>Y</td>
<td>$21.63/1-25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CCAD</td>
<td>Z</td>
<td>Y</td>
<td>$5.88/1-25</td>
<td></td>
</tr>
<tr>
<td>(200 series)</td>
<td>SA</td>
<td>A</td>
<td>Y</td>
<td>$8.54/1-25</td>
<td></td>
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<tr>
<td>see</td>
<td>SC</td>
<td>M AND C</td>
<td>Y</td>
<td>$21.95/1-25</td>
<td></td>
</tr>
<tr>
<td>also</td>
<td>SCSM</td>
<td>C</td>
<td>Y</td>
<td>$92.15/1-25</td>
<td></td>
</tr>
<tr>
<td>Appendix F</td>
<td>NOFC</td>
<td>M AND C</td>
<td>Y</td>
<td>$42.70/1-25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE</td>
<td>M</td>
<td>N</td>
<td>$15.81/1-25</td>
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</tr>
<tr>
<td></td>
<td>S-NE</td>
<td>M</td>
<td>N</td>
<td>$22.70/1-25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CCAD-NE</td>
<td>Z</td>
<td>N</td>
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<td></td>
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<td>N</td>
<td>$10.35/1-25</td>
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<tr>
<td></td>
<td>SC-NE</td>
<td>M AND C</td>
<td>N</td>
<td>$22.70/1-25</td>
<td></td>
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<tr>
<td>AUGUT</td>
<td>JSC SERIES</td>
<td>M</td>
<td>Y</td>
<td>$20.50/1-9</td>
<td></td>
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<tr>
<td></td>
<td>M</td>
<td>Y</td>
<td>$17.50/10-24</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>DSC SERIES</td>
<td>(NC)</td>
<td></td>
<td>$15.50/1-9</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>$12.50/10-24</td>
<td></td>
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<tr>
<td>SEIKO</td>
<td>SA-1</td>
<td>M, A, and C</td>
<td>Y</td>
<td>$158.00/1-49</td>
<td></td>
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<tr>
<td></td>
<td>SA-2</td>
<td>M, A, and C</td>
<td></td>
<td>$92.00/1-49</td>
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<td>see</td>
<td>SC-1</td>
<td>(NC)</td>
<td></td>
<td>$65.60/1-49</td>
<td></td>
</tr>
<tr>
<td>Appendix F</td>
<td>SE-1</td>
<td>(NC)</td>
<td></td>
<td>$58.60/1-49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SG-1</td>
<td>(NC)</td>
<td></td>
<td>$65.60/1-49</td>
<td></td>
</tr>
</tbody>
</table>

M = metal  
Z = zinc diecast  
A = aluminium  
P = plastic  
C = ceramic  
NE = no-epoxy  
pkg = package  
NC = not covered in this report
CHAPTER 3

FIBER OPTIC CABLES

Introduction

The utilization of fiber optic medium in the development of new data and information transmission systems has created an ever-expanding field for cable manufacturing. The needs of the rapidly expanding electronics industry have led to demands for an increase in quality, performance, and service. This simultaneously requires the industry to achieve a greater reduction in the size and cost of many of the basic cables, connectors, and components which encompass a fiber optic system.

There are many manufacturers in the current market that produce quality products in the fiber optic cable field. Unfortunately, the scope of this work prohibits the inclusion of all these various manufacturers. Therefore, for simplicity, the products of just two manufacturers, Pirelli and Siecor, have been chosen at random to be discussed. This will still give the reader plenty of opportunity to gather insight into what is now available in the fiber optic cable field. The reader should also note
from the following discussions, the specific design criteria emphasized by both manufacturers.

Pirelli's Multifiber Cables

Pirelli Cable Corporation, Wallingford, Connecticut, one of the world's largest producers of communication cable, has developed numerous multi-channel fiber optic cables, suitable for various applications. The need to increase the quality and performance of cable manufacturing has led Pirelli to design six different cable combinations. These designs are derived from a basic cable design which has the ability to accommodate up to 108 separate optical fibers. (This fiber configuration is classified as a loose tube design.) Included in these designs is the accommodation of differing fiber sizes, from the single mode (classified by Pirelli as monomode) 10/125 micron, to the multimodes, 50/125 micron, and 110/140 micron. The numerical specification of the fiber identifies the diameter sizes of the core and cladding respectively. For example, the fiber size 10/125 micron, mentioned above, indicates a fiber with a core diameter of 10 microns and a cladding diameter of 125 microns.
Pirelli's six cable designs are broken down into three major divisions, each consisting of two different cabling materials. The resulting cable designs achieved by these combinations are illustrated in Table 3.

<table>
<thead>
<tr>
<th>CABLING:</th>
<th>LOOSE</th>
<th>GEL FILLED</th>
<th>TIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATERIAL:</td>
<td>TUBE</td>
<td>LOOSE TUBE</td>
<td>BUFFER</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METALLIC:</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIELECTRIC:</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
</tbody>
</table>

The design classification of Pirelli's basic cables are identified as A, B, C, D, E, and F. These six design classifications have been subdivided by Pirelli into two additional categories. There are four designs (A, B, C, and D) which are suited for outside aerial installation, provided the cable is secured to a messenger wire. These four designs are also suitable for duct or direct burial installation, and are referred to as "outside plant cables" (Figure 8). The two remaining designs (E and F) meet the necessary requirements for any installations that are not exposed to external weather conditions. These cables are referred to as "inside plant cables" (Figure 9).
Design A

Design B

Design C

Design D

Figure 8. Outside Plant Cables. (Pirelli, 1984)
Although all of the six designs are similar in many aspects, they achieve somewhat differing results. The tight buffer design, for example, provides a more compact and lighter weight cable type. The loose tube design series (empty and gel filled), on the other hand, provides the characteristics of extra elongation. However, in the loose tube design series, the extra elongation characteristic requires slightly larger cable diameters and weights. Designs B and D are alternatives for the A and C designs respectively, when extra mechanical protection is desired. Design F is also an alternative to design E when extra strength is needed and where no metal conductors are allowed in the communication path.
The incorporation of the metallic sheathing (designs A, B, and C) helps to provide additional protection and resistance from external forces. This style of cable, one with a metallic strength member, has the advantage of being less expensive than cables using an epoxy/fiberglass core. Another feature available for this style of cable is substituting steel for the aluminum in the sheathing. This substitution of material is designed for cable which will be used for direct burial and/or cable which is required to be rodent proof.
The advantages of these six basic designs for the multifiber cables are numerous. Several of the major advantages that Pirelli lists for these cables include a wide information bandwidth, very low propagation loss, immunity from EMI, and also immunity from RFI. The abrasion resistance and flexibility of the cable plus complete electrical isolation are cited as additional major advantages.

The various applications of the multifiber style of cabling includes toll grade transmission systems, cable television trunking, local area network systems and high bandwidth links. The importance of this type of cable is illustrated by the necessity of achieving a medium for secure communications.

One- and Two-Channel Fiber Optic Cable

The diversification of the fiber optic cable industry is illustrated by the variety of styles and designs currently available. Pirelli has developed single- and dual-channel cable designs which have proven to be successful in meeting the requirements of communication networks.

To meet low-loss fiber requirements, Pirelli manufactures all-glass fibers using the modified vapor
deposition technique (MCVD). These fibers are obtainable from a range of core sizes from 10 microns to 125 microns. Again, their application lies where requirements call for low attenuation and high bandwidths. The 10 micron core fiber is excellent for single mode operation. It should be noted here that this small size fiber would require a precision connector, along with a laser light source. Together this combination will yield extremely high data rates over very long distances. The multimode fibers include the standard telecommunication fiber size of 50/125 microns.

By way of another technique, Pirelli offers a hard plastic clad silica fiber (HCS) which has a large core of 200-microns. The problem with large core fibers is that the bandwidth and the attenuation performance are reduced in comparison to small core fibers. This is illustrated by the run length. The 200-micron core is typically useful only up to one kilometer.

To obtain a larger core area, a bundle of small fibers is needed. Pirelli manufactures a flexible all-glass bundle of fibers. Each fiber has a high numerical aperture to improve the light coupling with inexpensive LED's (light emitting diodes). However, the attenuation of this glass is very high. This reduces the usefulness of the bundle fiber
to a run length of only 50 meters. Note also that radiation hard fibers of the MCVD or HCS types, and step index fibers, are also obtainable in all the various core sizes from Pirelli.

Pirelli continues their cable design alphabetically with designs G, H, J, K, L, and M. These designs are for one- and two-channel fiber optic cables. These cable designs are broken down into four types of cables:

1. Single-fiber cable (designs G and H, Figure 10)
2. Two-fiber cable (designs J and K, Figure 11)
3. Two-fiber zip cable (design L, Figure 12)
4. Bundle fiber cable (design M, Figure 13)
Designs G, J, and L are loose tube designs incorporating a kevlar braid as the strength member to add flexibility. Designs H and K are tight buffer designs incorporating longitudinal kevlar for the strength member. These are somewhat more compact and lighter weight than the G, J, and L designs and are more suitable for vertical rise applications.
Combining two single-fiber cables to make one cable is what designs J, K, or L have accomplished. The two-fiber cable (design J or K), has additional resistance against abrasion, crush, and impact due to its outer jacket. The two-fiber zip cable (design L) does not have an outer jacket about the two single-channel cables (Figure 12). Instead, it has a thin web between them that is easily separated.
The individual fiber cable jackets, as well as the outer jacket for the two-fiber cable, are constructed with either PVC (polyvinylchloride) or polyurethane. The advantages offered by polyurethane are: it is more flame retardant, solvent retardant, lighter weight, and operates over a wider temperature range. However, it is more expensive than the PVC. The standard lengths available for the designs G, H, J, K, and L are 1.0 and 2.1 kilometers.

As mentioned earlier, the bundle fiber cable (design M) has typically a maximum run length of 50 meters due to its high attenuation characteristic. However, the longest continuous length of bundle cable obtainable from Pirelli is 150 meters. This bundle fiber cable (design M) comes with
two types of material for its outer jacket, PVC and Tefzel (Tefzel is trade-mark of DuPont). The Tefzel outer jacket permits operation in the wide range of $-55^\circ C$ to $+150^\circ C$.

![Diagram of Fiber Cable](image)

**Design M**

Figure 13. Bundle Fiber Cable. (Pirelli, 1984)

**Fiber Optic Plenum Cables**

Pirelli also offers a new fiber optic plenum cable. It is available in four designs. Design N is a one-fiber cable. Design P is a two-fiber cable, and design Q and R are four- and five-fiber cables. This type of cable has been classified by Underwriters Laboratory (UL) for use in building plenum areas without the use of metallic conduit. This is primarily due to the low smoke and flame spread fluoropolymer cable jacket, along with the fact that the cable contains no metallic elements. This cable design is excellent for use in high voltage environments without any
worry of a short circuit. Each standard fiber mentioned earlier can be used with this cable design. Also each fiber is individually strengthened with kevlar. This makes it easy for fan-outs at the end of a cable run.

**Siecor's Cable Designs**

Siecor Corporation, Hickory, North Carolina, does it all with regards to the cable industry, from copper cables and coaxial cables to fiber optic cables. Their fiber optic cables employ all three types of fibers: multimode, single mode, and large core. Their cable designs are similar to designs of copper wire cable. Since a copper wire stress strain behavior is much different than that of a fiber, the key objective in the design would be to isolate the fiber from all mechanically or environmentally induced stresses. This will avoid fiber fatigue or failure. On a microscopic level, if the fiber is locally deformed, part of the signal power will be coupled out of the fiber. This problem, better known as "microbending," must be minimized. This minimization can be accomplished by the fiber cable construction. A well-constructed fiber optic cable under stress-free conditions will maintain stable mechanical and optical characteristics typically for 20 to 40 years, even in the presence of humidity and water.
Siecor offers a number of sheath configurations to protect the cable's core during installation and in its operating environment. For duct and aerial cables, the outer sheath is made of polyethylene. For buried cables, corrugated steel tape armoring is placed between double layers of polyethylene sheathing.

Siecor, like Pirelli, has loose tube and tight buffered cable designs. The loose tube cable design shows the above requirement of being stress-free. The cable consists of a loosely spiraling fiber, or group of fibers, in a buffer tube. The tube has a much larger diameter than the fiber or group of fibers. This effectively decouples each fiber from the cable structure. During cable contractions or expansions (elongations) the fiber can float outward or inward, as shown in Figure 14. The buffer tube is then filled with a gel compound to prevent any moisture from entering the cable and also to act as a lubricant. The gel permits each fiber to float inside the tube. If moisture were to get into the tube and freeze, this would stress the fiber's surfaces creating unwanted microbends. The gel filled fiber optic cable also offers good temperature stability and a maintenance free alternative to pressurized systems. Siecor's tight buffered cables are based on a modular design incorporating individually strengthened fiber subunits.
Long Distance Cabling

Optical cable for long haul application is also provided by Siecor. Siecor suggests its field proven "loose tube" design for permanent systems over 2-3 kilometers. Their products are available with 50 or 100 micron core fibers, as well as single mode fibers. Bandwidths range from 100 megahertz-kilometer for the 100 micron core to multi-gigahertz-kilometer with single mode fibers. Cable attenuation ranges from one dB per kilometer to five dB per kilometer. The products use 850, 1300, and 1500 nanometer sources.

A closer look at Siecor's single mode fiber optic cable reveals a cable with a fiber count from 1 to 144. The silica fiber used in this type of cable has diameters of 8.7 micrometers for the core and 125 micrometers for the cladding (8.7/125 micron fiber) in lengths up to five kilometers.
An overall look at Siecor reveals that they manufacture many more types of fiber cable for just about any application. For instance:

1) Siecor’s ESR fiber cable. A 50 micron core extended spectral response (ESR) cable used ideally for interbuilding interconnections where high data rate trunks are used. Bandwidths of 400 megahertz-kilometer are standard. This cable may be used at any length up to eight kilometers without the aid of a repeater. Also its operation is suitable with sources with wavelengths in the infrared range (800 - 1300 nanometers).

2) Siecor’s "fat" fiber cable. A 100 micron core fiber commonly used for short high-performance systems. It has an NA of 0.29; this, in combination with its core size, improves LED input coupling by six to eight dB over a 50 micron core fiber. The larger core diameter also minimizes connector losses and offers a potential savings if a lower cost connector can be used without a decrease in performance. Typical run lengths for the fat fiber are 10 to 2000 meters.

Conclusion

Fiber cables exist for just about all applications. Both Pirelli and Siecor manufacture many designs of cables with different sizes and numbers of fibers. Not included in this report are Siecor’s series 4, series 4 fan-out, series
6, series 8, or the series 8 minibundle; each has its unique application. Most, however, follow the basic designs discussed in this chapter.
CHAPTER 4

EVANESCENT FIELD COUPLING

Introduction

The coupling of optical power from one fiber to another fiber has many applications in fiber optic systems; however, unwanted coupling between fibers may be detrimental to a system. This chapter will discuss how optical power is coupled from one fiber to another. This information should provide some insight into the use of optical couplers, and for the prevention of unwanted coupling.

Light propagating in a fiber can be described by its electromagnetic fields. For instance, consider the reflection and refraction of the electric field at the core-cladding interface of a step index fiber. This is where the two differing dielectric mediums intersect. This will also be the mathematical starting point when this chapter shows how optical coupling is achieved through an evanescent field. An evanescent field exists in the fiber's cladding when there is total internal reflection of light inside the fiber's core. This occurs when the angle of the incident wave is greater than the "critical angle." (The
critical angle is the angle of incidence that causes the angle of refraction to be 90 degrees, which in turn causes total internal reflection.) For the case of the incident angle larger than the critical angle, it will be shown mathematically that the refraction angle will be an imaginary angle and that an "evanescent field" exists.

The power in an evanescent field is imaginary (reactive); however, it will be shown that by adding a third dielectric region, one with a higher index of refraction, real optical power will be coupled to the third region by the evanescent field. This process can be accomplished with two fibers placed side by side. The evanescent field in the cladding of one fiber will travel through the cladding of the second fiber to the core of the second fiber. Since the core's index of refraction is higher than the cladding, the optical power in the evanescent field becomes real. Therefore, the optical signal has crossed from one fiber to the second, thus, the creation of an "evanescent field coupler."

**Review of Electromagnetic Theory**

This chapter will use the rectangular coordinate system rather than the cylindrical system (typically used with fibers), primarily for simplicity and understanding. As a
review, Maxwell’s equations govern the behavior of time varying electromagnetic fields. His equations are first-order linear coupled differential equations relating vector field quantities. These equations seem to be simple to use since they are first order equations; however, this is not the case. These equations are coupled equations and are very difficult to use when solving boundary condition problems. A simpler equation, known as the "wave equation," is a decoupled, one vector only, second-order differential equation. This equation is much nicer to use and is derivable from Maxwell’s equations in terms of either the electric field intensity, or the magnetic field intensity. The wave equation in sinusoidal steady state form for both field intensities are known as the "Helmholtz equations" (Cherin, 1983).

\[ \nabla^2 \vec{E} + k^2 \vec{E} = 0 \]
\[ \nabla^2 \vec{H} + k^2 \vec{H} = 0 \]

Where \( k \) is often referred to as the wave number and is defined as:

\[ k = \omega \sqrt{\mu \epsilon} = \omega / \nu = 2\pi / \lambda \]

We can define a propagation vector \( \vec{k} \) as:

\[ \vec{k} = k \hat{A} \]

Where \( \hat{A} \) is the unit vector perpendicular to the surfaces of constant phase, in the direction of propagation.

\[ \hat{A} = n_x \hat{a}_x + n_y \hat{a}_y + n_z \hat{a}_z \]
The solution for each component of the Helmholtz equation is a propagating wave. For example the x component of the electric field is of the form:

\[ E_x = E_x^+ \exp(-jk\cdot r) + E_x^- \exp(+jk\cdot r) \]

Where \( r \) is the radius vector describing the coordinate at which the field is observed.

\[ r = x\hat{a}_x + y\hat{a}_y + z\hat{a}_z \]

The actual physical field (with its time dependence included) for each component of the electric and magnetic fields, propagating in the \( \pm n \) directions, is of the form:

\[ \psi = A^+ \cos(wt-kn\cdot r) + A^- \cos(wt+kn\cdot r) \]

The Evanescent Field

Consider Figure 15: a TEM wave (a wave with both the electric and magnetic fields perpendicular to the direction of propagation) is incident upon a dielectric boundary. To describe the fields associated with the TEM wave as it interacts with the boundary, certain boundary conditions must be satisfied. These boundary condition are:

1. The tangential components of the \( \vec{E} \) field and the \( \vec{H} \) field must be continuous.

\[ \hat{n} \times (\vec{E}_2 - \vec{E}_1) = 0 \]
\[ \hat{n} \times (\vec{H}_2 - \vec{H}_1) = 0 \]
2. The normal components of the B field and the D field must be continuous.

\[ \hat{n} \cdot (\vec{B}_2 - \vec{B}_1) = 0 \]
\[ \hat{n} \cdot (\vec{D}_2 - \vec{D}_1) = 0 \]

Figure 15. A TEM Wave Incident upon a Dielectric Boundary.

The incident wave's electric field can be decomposed into two components (polarizations): perpendicular and parallel polarization. Different answers result for the amplitudes of the reflected and transmitted waves. For the purpose of this chapter, either one of the polarizations will suffice. Therefore, the choice of perpendicular
polarization will be used to continue this discussion. The incident $\bar{E}$ field, with the time component "$\exp(\pm j\omega t)$" suppressed, can be written as:

$$\bar{E}_i = E_i \exp(-jk_0 \cdot \bar{r}) \hat{a}_x$$

where

$$\bar{k}_0 = k_1 \hat{n}_0$$

substituting in for $\bar{k}_0$ and $\bar{r}$ yields

$$\bar{E}_i = E_i \exp[-jk_1(\cos \theta_1 \hat{a}_x - \sin \theta_1 \hat{a}_y) \cdot (x \hat{a}_x + y \hat{a}_y + z \hat{a}_z)] \hat{a}_x$$

performing the dot product yields

$$\bar{E}_i = E_i \exp[-jk_1(z \cos \theta_1 - y \sin \theta_1)] \hat{a}_x$$

The reflected and transmitted $\bar{E}$ fields can be written as:

$$\bar{E}_r = E_r \exp(-jk_1 \cdot \bar{r}) \hat{a}_x$$

where

$$\bar{k}_1 = k_1 \hat{n}_1$$

and

$$\bar{E}_t = E_t \exp(-jk_2 \cdot \bar{r}) \hat{a}_x$$

where

$$\bar{k}_2 = k_2 \hat{n}_2$$

Using the same procedure used above in deriving the incident $\bar{E}$ field, the reflected and the transmitted $\bar{E}$ fields are found to be respectively:

$$\bar{E}_r = E_r \exp[-jk_1(-z \cos \theta_1 - y \sin \theta_1)] \hat{a}_x$$

and

$$\bar{E}_t = E_t \exp[-jk_2(z \cos \theta_2 - y \sin \theta_2)] \hat{a}_x$$
The magnetic fields $\vec{H}_1, \vec{H}_R, \vec{H}_T$ can be calculated from the following equations:

$$
\vec{H}_1 = (\vec{A}_0 \times \vec{E}_1) / \eta_1 \\
\vec{H}_R = (\vec{A}_1 \times \vec{E}_R) / \eta_2 \\
\vec{H}_T = (\vec{A}_2 \times \vec{E}_T) / \eta_2
$$

where

$$
\eta_1 = \sqrt{\mu_0 / \varepsilon_1} \\
\eta_2 = \sqrt{\mu_0 / \varepsilon_2}
$$

Two interesting relationships are derived next by applying a boundary condition. By applying boundary conditions, the unknown parameters $E_R$, $E_T$, and $\theta_2$ can also be derived. Manipulations of the boundary condition for the tangential components of the $E$ fields at $z=0$ yields:

$$
\hat{n} \times (\vec{E}_2 - \vec{E}_1) = 0 \\
\hat{n} \times \vec{E}_2 - \hat{n} \times \vec{E}_1 = 0 \\
\hat{n} \times \vec{E}_1 = \hat{n} \times \vec{E}_2 \\
\hat{n} \times (\vec{E}_1 + \vec{E}_R) = \hat{n} \times \vec{E}_T \\
-\hat{n} \times (E_1 \exp[-jk_1(z \cos \theta_1 - y \sin \theta_1)]\hat{a}_x + E_R \exp[-jk_1(-z \cos \theta_1 - y \sin \theta_1)]\hat{a}_x) = \\
-\hat{n} \times E_T \exp[-jk_2(z \cos \theta_2 - y \sin \theta_2)]\hat{a}_x
$$

which reduces to

$$(E_1 + E_R)\exp[jk_1y \sin \theta_1]\hat{a}_x = E_T \exp[jk_2y \sin \theta_2]\hat{a}_y$$

The two interesting relationships mentioned earlier are obtained from the above equation. The first comes from the
continuity of magnitudes, which requires that

\[ E_1 + E_r = E_t \]

and the second comes from the continuity of phase, which requires that

\[ k_1 \sin \theta_1 = k_2 \sin \theta_2 \]

or

\[ \sin \theta_1 / \sin \theta_2 = k_2 / k_1 \equiv \text{Snell's law} \]

Note that

\[ k_2 / k_1 = \omega \sqrt{\varepsilon_2 / \varepsilon_1} = \sqrt{\varepsilon_2} / \sqrt{\varepsilon_1} = n_2 / n_1 \]

Thus, Snell's law maybe rewritten as:

\[ \sin \theta_1 / \sin \theta_2 = n_2 / n_1 \]

The reflection and transmission coefficients, "Fresnel's equations" can be derived by applying the same technique above to the boundary condition that involves the tangential components of the \( \vec{H} \) fields. These equations are:

\[ R = E_r / E_i = (\eta_2 \cos \theta_1 - \eta_1 \cos \theta_2) / (\eta_2 \cos \theta_1 + \eta_1 \cos \theta_2) \]

and

\[ T = E_t / E_i = 2 \eta_2 \cos \theta_1 / (\eta_2 \cos \theta_1 + \eta_1 \cos \theta_2) \]

respectively.

Continuing with the \( \vec{E} \) field equation for the wave that crossed the dielectric boundary \( \vec{E}_t \) (previously mentioned), it should be noted that this equation is written in terms of the cosine and sine of the refraction angle \( \theta_2 \). To rewrite this equation in terms of the incident angle \( \theta_1 \), a
trigonometric identity and Snell's law must be applied. The trigonometric identity is:
\[ \cos \theta_2 = \sqrt{1 - \sin^2 \theta_2} \]
and Snell's law rewritten becomes:
\[ \sin \theta_2 = \left( \frac{n_1}{n_2} \right) \sin \theta_1 \]
substituting in Snell's law yields
\[ \cos \theta_2 = \sqrt{1 - \left( \frac{n_1}{n_2} \right)^2 \sin^2 \theta_1} \]
Thus, \( \bar{E}_T \) can now be written as:
\[ \bar{E}_T = E_t \exp\left[jk_2(y(n_1/n_2)\sin \theta_1 - z\sqrt{1 - (n_1/n_2)^2 \sin^2 \theta_1})\right] \]

The above equation is very important. It describes the transmitted field in the second dielectric region. The radical in that equation exists when the incident angle is less than the critical angle, and goes to zero at the critical angle. If the incident angle is greater than the critical angle, then the radical becomes imaginary. Also note, the square root of a number can be + or -. For this case the - is chosen so that the term becomes \(-j\). This is due to energy consideration at the point where \( z \) approaches infinity (Cherin 1983). Thus, for the case when the incident angle is greater than the critical angle we have:
\[ \bar{E}_T = E_t \exp\left[jk_2(y(n_1/n_2)\sin \theta_1 - jz\sqrt{(n_1/n_2)^2 \sin^2 \theta_1 - 1})\right] \]
This equation fits the form:

$$E_T = E_e \exp(j \beta y) \exp(-\alpha z) \hat{a}_x$$

where

$$\beta = k_2 (n_1/n_2) \sin \theta_1$$

and

$$\alpha = k_2 \sqrt{(n_1^2/n_2^2) \sin^2 \theta_1} - 1$$

From the above equations, it is observed that there is a wave propagating in the \(-y\) direction along the reflecting surface; however, this wave is attenuated as it moves away from the boundary in the \(z\) direction. The attenuated field in the \(z\) direction is an evanescent field.

The time average power flow in an electromagnetic field is obtained from the real part of the Poynting vector \(\vec{S}\) (Cherin 1983).

$$P_{av} = \text{Re} \ \vec{S} = 0.5 \ \text{Re} \ (\vec{E} \times \vec{H}^*)$$

This equation can be rewritten by substituting in the complex conjugate of the transmitted wave's \(\vec{H}\) field. The \(\vec{H}\) field was shown earlier in terms of the \(\vec{E}\) field. This substitution yields:

$$P_{av} = 0.5 \ \text{Re} \ [(|E_e|^2 / \eta_2) \hat{a}_z]$$

where

$$\hat{a}_z = (\cos \theta_2 \ \hat{a}_x - \sin \theta_2 \ \hat{a}_y)$$

Note here, the cosine of \(\theta_2\) is the term that was rewritten in terms of the incident angle earlier, and proved to be imaginary. Therefore, the power in the \(z\) direction is
imaginary, or stated another way, the power in the evanescent field is imaginary. Also, since the cosine of $\theta_2$ is imaginary, then the angle of refraction, $\theta_2$, is and must be imaginary.

At this point the wave equation for the electric field is known in the second dielectric region. A third dielectric region is added, see Figure 16. This region has a higher index of refraction than the second region. The equation for the transmitted wave through the second boundary into the third region will be found next. This is analogous to entering a second fiber's core if two fibers were connected side by side (core to claddings to core).
Figure 16. Optical Coupling Through the Dielectric Regions of Two Fibers Side by Side.
To find the transmitted $\vec{E}$ field through the second boundary, the same procedure as was done earlier through the first boundary is used again. The incident wave on the second boundary may be written in terms of the transmitted wave just found in region two:

$$\vec{E}_{i2} = \vec{E}_T = E_t \exp[jky] \exp[-\alpha z] \hat{a}_x$$

However, for the ease of calculations, the transmitted wave in terms of $\theta_2$ will be used as the incident wave to the second boundary instead of the above form.

$$\vec{E}_{i2} = \vec{E}_T = E_t \exp[-jk_2(z \cos \theta_2 - y \sin \theta_2)] \hat{a}_x$$

The reflected wave and the transmitted wave for the second boundary are respectively:

$$\vec{E}_{r2} = \vec{E}_{r2} \exp[-jk_3 \vec{r}_2] \hat{a}_x$$

and

$$\vec{E}_{t2} = \vec{E}_{t2} \exp[-jk_4 \vec{r}_2] \hat{a}_x$$

where

$$\vec{k}_3 = k_2 \hat{n}_3, \quad \vec{k}_4 = k_1 \hat{n}_4$$

$$\hat{n}_3 = -\cos \theta_2 \hat{a}_x - \sin \theta_2 \hat{a}_y$$

$$\hat{n}_4 = \cos \theta_3 \hat{a}_x - \sin \theta_3 \hat{a}_y$$

and

$$\vec{r}_2 = x \hat{a}_x + (y+dy) \hat{a}_y + (z-dz) \hat{a}_z$$

Note $dy$ and $dz$ compensate for keeping the same axis location.
at the first boundary. Performing the dot products yields the following equations:

\[
\vec{E}_{r2} = E_{r2} \exp[-jk_2(-(z-dz)\cos \theta_2 - (y+dy)\sin \theta_2)]\hat{a}_x
\]

and

\[
\vec{E}_{t2} = E_{t2} \exp[-jk_1((z-dz)\cos \theta_3 - (y+dy)\sin \theta_3)]\hat{a}_x
\]

At this point, the boundary condition for the tangential component of the \( \vec{E} \) field at \( z=dz \) is applied.

\[
\hat{n} \times (\vec{E}_{t2} + \vec{E}_{r2}) = \hat{n} \times \vec{E}_{t2}
\]

Substituting in the previous \( \vec{E} \) field equations and performing the cross products yields:

\[
E_t \exp[-jk_2(dz \cos \theta_2 - y \sin \theta_2)]\hat{a}_y + E_r \exp[jk_2(y+dy)\sin \theta_2]\hat{a}_y = E_t \exp[jk_1(y+dy)\sin \theta_3]\hat{a}_y
\]

From this equation the continuity of magnitudes requires:

\[
E_t + E_r = E_t
\]

and the continuity of phase would lead to an equation relating the phase of the third region to the phase of the first region. However, this can be accomplished by an alternate method using Snell's law for the second boundary

\[
\sin \theta_3 = \frac{n_2}{n_1} \sin \theta_2
\]

and rewriting Snell's law for the first boundary by solving for \( \sin \theta_1 \)

\[
\sin \theta_1 = \frac{n_2}{n_1} \sin \theta_2
\]

From the above two equations, it is easily seen that

\[
\sin \theta_3 = \sin \theta_1 \text{ or } \theta_3 = \theta_1
\]
Thus, $E_{t2}$ can now be written in terms of $\theta_1$:

$$E_{t2} = E_{t2} \exp[-jk_1((z-dz)\cos \theta_1 - (y+dy)\sin \theta_1)] \hat{E}_x$$

The amplitude $E_{t2}$ can be written as a function of $E_1$ by using the magnitude of Fresnel's transmission coefficient equations at both boundaries

$$E_{t2} = E_1 |\mathcal{T}_2|$$

where

$$\mathcal{T} = 2n_2\cos \theta_1/[n_2\cos \theta_1 + n_1\cos \theta_2]$$

and

$$\mathcal{T}_2 = E_{t2}/E_t = 2n_1\cos \theta_2/[n_1\cos \theta_2 + n_2\cos \theta_1]$$

Thus

$$\mathcal{T}_2 = 4n_1n_2\cos \theta_1\cos \theta_2/[n_2\cos \theta_1 + n_1\cos \theta_2]^2$$

Replacing $\cos \theta_2$ with the trigonometric identity with Snell's law incorporated in it, as shown earlier on page 53, will yield a complicated expression that has real and imaginary terms (complex). Finding the magnitude of this expression, and multiplying by $E_1$, will yield the amplitude of the electric field in the second fiber's core ($E_{t2}$). This equation is cumbersome, and is easily obtained as stated above.

The time average power flow in the electric field in the third region can be obtained from

$$P_{av} = 0.5 \text{ Re}[|(E_{t2})^2| / \eta_1] \hat{n}_4$$

where

$$\hat{n}_4 = (\cos \theta_1 \hat{a}_x - \sin \theta_1 \hat{a}_y)$$
CONCLUSION

This chapter demonstrated that optical coupling is achievable between fibers through the basic concepts of electromagnetic theory. The case of identical step index fibers with one fiber containing a propagating TEM wave was chosen for simplicity. For propagation to occur, the wave's angle of incidence must be greater than or equal to the critical angle. For the case of the incident angle greater than the critical angle, an evanescent field exists outside the first fiber's core. This field is rapidly attenuated as it travels away from the core. This field can enter another fiber through the cladding of the second fiber if both fibers are connected side-by-side. It should be noted that as the energy coupled into the second fiber increases, it also has an evanescent field which will couple energy back to the first fiber. If the fibers are left connected the energy will continue to cross back and forth between the fibers. For successful coupling, the distance between the cores needs to be in the range of microns, with a small difference between the core and cladding indices of refraction. The bottom line is the amount of coupling between two optical fibers depends upon:

1. The types of modes they are carrying
2. The separation between the fiber's cores
3. The loss of the surrounding medium in which the fibers are embedded
CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This research report basically covered four areas. It first looked at why today's communication industry is choosing fiber optic systems over conventional systems. It showed this by noting the important advantages that fiber optic systems offer which are making them cost effective. Two of the other areas covered are two of the important parts of a fiber optic system, the fiber optic connector and the fiber optic cable. The major emphasis was to describe the various fiber optic connectors and cables currently being manufactured by a few leading corporations in the fiber optic field. The final area covered evanescent field coupling. It showed that optical power can be coupled from one fiber to another.

Fiber Optic Systems

The fiber optic system offers a number of advantages over a conventional system. The fiber, which is the transmission medium of the system, is immune to ambient electromagnetic interference, electrical noise, ringing, and echoes. It does not generate any electrical noise itself,
nor is it plagued with crosstalk. Its size is very small, allowing it the capability, for instance, to replace a large bundle of copper wires in an over crowded conduit. This would effectively increase the conduit's capacity and provide a substantial weight savings. Fibers also have very large bandwidths approaching a multi-gigahertz-kilometer range. Large bandwidths are wanted as they determine the transfer rate of the data. Lastly, the optical fiber has two classifying characteristics. One is its refractive index profile, and the other is whether one mode (single-mode) or several modes (multimode) of light will propagate through it. This was illustrated in Chapter 1 of this report by showing how light travels in a fiber. For additional background information in the use of fiber optics, AMP Incorporated has a small 253-page paperback book entitled "Designers Guide to Fiber Optics." At the time of this report there was no charge for this book, and it was easily obtained by a phone call to AMP [(717) 564-0100].

Fiber Optic Connectors

The second part of this report deals with fiber optic connectors. It was found that the types of fiber optic connectors varied and were dependent upon such things as fiber size, cost, application, and use of epoxy. In this report the products of five fiber optic connector manufacturers were discussed.
The choice of what type of connector to use seems to be the most obvious problem that must be dealt with. This choice should first be based on the size of the fiber or bundle of fibers. After this has been determined, other information is needed, such as:

Is the connection permanent or temporary? This would determine whether or not to choose a connector that requires epoxy or one that has a high repeatable coupling efficiency.

Is shielding near by sensitive electronic components a criterion? If it is, then a stainless steel connector would be chosen over a plastic one.

Are cost, connector loss, connection assembly time, and fiber preparation major concerns? The answer to all of these questions will help pinpoint what type of connector to choose in order to meet a specified application.

Since some connectors use epoxy, Table 1 was provided to illustrate six types of epoxies along with their characteristics. These epoxies can be obtained in sample packets from OFTI. Table 2 shows a comparison between the different fiber optic connectors manufactured by the corporations chosen in this report. Table 2 also shows the relative cost of each of these connectors.
Fiber Optic Cables

The third part of this report dealt with fiber optic cables. Two cable manufacturers were chosen to gather insight into what is available now in the fiber optic cable field. These corporations, Pirelli and Siecor, manufacture numerous cable products.

Pirelli cable products provide the consumer with two major choices when deciding what type of cable should be used. The first is "multichannel" cables and the second is "one- and two- channel" cables. For systems needing many fiber optic lines (channels), the multichannel cables offer six varieties of cable designs. These cable designs were discussed in detail in Chapter 3 of this report. The fiber sizes available are 10/125 micron step index fiber for single mode operation, and 50/125 or 100/140 micron graded index fiber for multimode operation.

Pirelli's one- and two- channel cables offer four more choices:

1. Single-fiber cables
2. Two-fiber cables
3. Two-fiber zip cables
4. Bundled fiber cable
The fiber sizes available for these cables are 10/125 micron single mode step index, 50/125, 85/125, 100/140, and 125/200 micron multimode graded index, 200/230 micron "hard plastic clad silica" (HCS) step index, and 56/68 micron step index (used in the 200 fiber bundled cable).

Bundled fiber cable offers a larger core area, and thus has a higher numerical aperture (NA). This results in better light coupling efficiency at the interfaces. However, bandwidth and attenuation performance decreases significantly because of the increased core size. This performance decrease results in having to limit the cable length.

Pirelli also offers a plenum cable design which is excellent for use in high voltage environments. Any of the standard optical fibers can be ordered with this design. Cables with more than five fibers can be specially ordered.

Siecor offers cables with similar designs as Pirelli. One major concept that is incorporated in both corporation’s cables is the choice of loose tube or tight buffer cable design. The loose tube cable design employs a stress-free, loosely spiraling fiber or group of fibers in a buffer tube. The effect is excellent when the cable is stressed with either contraction or elongation as the fiber or fibers
float outward or inward respectively, effectively decoupling themselves from the cable. This design is used especially in long-distance cabling. Tight buffer designs provide a compact light weight cable.

Siecor single mode fiber cable can have a fiber count from 1 to 144. These silica fibers are sized at 8.7/125 microns and can be obtained in lengths up to 5 kilometers.

Siecor's "Fat" fiber cable has a 100 micron diameter core and has typical run lengths 10 to 2000 meters. The large core diameter minimizes connector losses.

Siecor’s cable designs were discussed in more detail in Chapter 3 of this report. It should be emphasized that cable selection is based solely on application, environment, and cost. As a guide for both multimode and single mode wave guides the first order design parameters are the numerical aperture (NA), the core diameter, the profile shape, and the outside diameter. Functionally these impact on the system’s optical losses and bandwidth, in addition to mechanical properties such as intrinsic strength and bending radius. The multimode design for a given application depends on the relative importance of these functional requirements. For short distance applications input coupling is important while for most longer distance
applications the effect of external perturbations and/or inner connections tends to dominate.

The cable manufacturers were not revealing cable cost but insisted the cost must be discussed on an individual basis. However, a representative of Pirelli stated that cables were purchased by the meter and typically ranged from $0.90 to $3.60 per meter.

There are other parts of a fiber optic system that were not covered in this report, but have a great impact on the system's effectiveness and performance. The sources and the detectors used are just as important, and require sufficient investigation. The area of cable and fiber splicing should also be investigated.

Evanescent Field Coupling

Optical coupling plays an important role in other optical devices such as the "Directional Coupler." The fourth and final part of this report showed that optical power can be coupled from one fiber to another. This was done by describing the reflected and refracted paths of the electric field of a TEM wave propagating in a fiber. This showed that an evanescent field existed outside the core and rapidly attenuated as it traveled away from the core. It also showed that this field, if allowed to travel into a
second fiber, can couple energy into that fiber. Lastly, if the fibers stay connected together the field that builds up in the second fiber will generate a field that will build up in the first fiber. Thus, the energy will continue to cross back and forth between the fibers. The coupling of energy between fibers depends upon:

1. The types of modes they are carrying
2. The separation between the fiber's cores
3. The loss of the surrounding medium in which the fibers are embedded

This subject matter was presented to show that optical coupling between fibers is possible. It was kept on as simple a basis as possible, for the sole purpose of understanding the concepts. Further work in this area has been done by well known authors such as D. Marcuse, E. A. J. Marcatili, and Allan W. Synder. Their works cover many areas to include the coupling coefficient between optical fibers and power transfer between them.
APPENDIX A

AMP'S DNP PRODUCTS
AMP OPTIMIZE DNP
Fiber Optic Connectors

Splice and Retention Clip
Splice — Part No. 228051-1
Retention Clip — Part No. 228046-1

Single Position Plug Assembly
Part No. 228087-1

Dual Position Plug Assembly
Part No. 228088-1

Single Position Device Mounts
TO-18 — Part No. 228043-1
TO-92 — Part No. 228040-1

Dimensioning:
Unless otherwise specified, all dimensions in millimeters and inches. Values in brackets are equivalent U.S. customary units.
AMP OPTIMATE DNP
Fiber Optic Connectors

Single Position Bulkhead Receptacle
Part No. 228042-1

Dual Position Bulkhead Receptacle
Part No. 228045-1

Designers' Kit
Part No. 228084-1

Contents of Kit:

<table>
<thead>
<tr>
<th>Description</th>
<th>Qty</th>
<th>Part Number</th>
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<td>228051-1</td>
</tr>
<tr>
<td>Retention Clip</td>
<td>4</td>
<td>228046-1</td>
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<tr>
<td>Single Position Plug Assembly</td>
<td>16</td>
<td>228087-1</td>
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<td>Dual Position Plug Assembly</td>
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</tr>
<tr>
<td>Single Position Device Mount (TO-1B)</td>
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<tr>
<td>Single Position Device Mount (TO-82)</td>
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<td>228040-1</td>
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<td>Single Position Bulkhead Receptacle</td>
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<tr>
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<td>Fiber Cable</td>
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<td>Hot Knife</td>
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<td>Strip Tool</td>
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</tr>
<tr>
<td>Tray</td>
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</tr>
<tr>
<td>Case</td>
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<td>—</td>
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<td>Cutting Fixture, Dual Beaded</td>
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<tr>
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<td>228837-1</td>
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Dimensioning:
Unless otherwise specified, all dimensions in millimeters and inches.
Values in brackets are equivalent U.S. customary units.
APPENDIX B

SMA STYLE CONNECTOR SHEETS
SMA Style Fiber Optic Connector

Note: Components can be supplied individually or in kit form as shown on page 4.

Contact Body Assembly

Alignment Ferrule

Fiber Size  
μm  

125  
140  
200  
230  
250  
300  
400  
500  
600  
750  
1140  

Body Code  

Gray  
Green  
White  
Yellow  
Red  
Gray  
Green  
White  
Yellow  

Contact Body Assembly  
Part Number  
227992.1  
227992.2  
227992.3  
227992.4  
227992.5  
227992.6  
227992.7  
227992.8  
227992.9  
227992.0  
1-227992.1  

Typical Cable Construction:
- Outer Jacket (primary if inner jacket not present)
- Strength Member (if present)
- Primary Inner Jacket
- Buffer
- Fiber
- Shrink Tubing (2 sizes)

Metal Retainers:
- Straight
- Stepped

Metal Retainer: Straight' Stepped

Typical Cable Stripping Information

With Strength Members

Without Strength Members

Alignment Ferrule

Fiber Size μm

125-250  
250-610  
750 & 1140  

Primary Jacket O.D.

0.51-1.52
0.51-2.11
3.05 Max

A Diameter

0.25
0.61
1.20

Color

Black
Green
None

Ferrule Part Number

227993.1
227993.2

*For environmental sealing, order optional "O" Ring, Part No. 19195-2.
SMA Style Fiber Optic Connector

**Metal Retainers**

- **Straight**
  - Part No. 227294-2

- **Stepped**
  - (See chart below)

**Retainer Selection Chart**

<table>
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<tr>
<th>Cable O.D. Range</th>
<th>Style</th>
<th>Retainer Part Number</th>
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<tbody>
<tr>
<td>4.32-4.3</td>
<td>170-193</td>
<td>Straight 227294-2</td>
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<tr>
<td>3.18-3.61</td>
<td>125-142</td>
<td>Stepped 227292-2</td>
</tr>
<tr>
<td>3.61-4.32</td>
<td>112-170</td>
<td>Stepped 227293-2</td>
</tr>
</tbody>
</table>

*Retainers are required for all cables with strength members, except where strength members are fiberglass. Retainers are not required for cables without strength members and may not be needed for those with fiberglass strength members.*

**Heat Shrink Tubing**

<table>
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<tr>
<td>Without Retainers</td>
<td>.250</td>
<td>187</td>
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</table>

**Bulkhead Mount Coupling**

- **227293-2**

**TO-18/TO-46 Active Device Mount (ADM)**

- **Description**
  - TO-18/TO-46 Body
  - TO-18/TO-46, Panel Mount** (with seal)
  - TO-18/TO-46, PC Board Mount**
  - TO-18/TO-46, PC Board/Panel Mount** (with seal)

**F.O.A.C. Active Device Mount (ADM)**

**Heat Shrink Tubing Usage**

- **Part Number**
  - 228052-1
  - 228055-1

**Panel Cutout**

- **Part Number**
  - 228052-1
  - 228055-1
### OPTICAL CABLE CONNECTORS

#### MINIMUM SIGNAL POWER FROM OPTELECOM TRANSMITTERS INTO FIBER

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<tr>
<th>CONNECTOR TYPE</th>
<th>OB-10 (200)</th>
<th>OB-10 (140)</th>
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<td>500</td>
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#### FIBER COUPLED POWER

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<td>20</td>
<td>14</td>
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<td>dBµ</td>
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<td>3100T (Analog Transmitter)</td>
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<td>4121 (Modem)</td>
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<td>4481/85 (RS232 Multiplexer)</td>
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<td>dBµ</td>
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<tr>
<td>5100 (Digital Mux)</td>
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<td>dBµ</td>
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<td>507X (Analog Transmitter)</td>
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#### FIBER-FIBER SPLICE LOSS

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#### TERMINATION DIMENSIONS

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<td>min.</td>
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<tr>
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<td>min.</td>
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<tr>
<td>Pull strength</td>
<td>50</td>
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#### FIELD TERMINATION KITS

**OB-10T**

**KIT INCLUDES:**

1. Carrying Case
2. Cleaving Tool
3. Crimp Tool
4. .010 Strip Tool
5. Wire Strippers
6. Illuminated Microscope
7. Knives
8. Bottle of Solvent (Penetone 676)
9. Spare Crimp Rings
10. Spare Shrink Tubes

Other Standard Products From OPTELECOM:

- Terminations, Single Fiber
- Digital Data Interfaces—Duplex RS232C Compatible
- Analog Signal Interfaces—Simplex CCTV Compatible
- Time Division Multiplexers
- Optical Cables

15640 Luane Drive
Gaithersburg, Md. 20877
301/840-2121
APPENDIX D

LFR SPECIFICATION SHEET
**Typical Assembly**

**Step 1**
Strip cable.

**Step 2**
Epoxy fiber (where required).

**Step 3**
Slide on connector assembly.

**Step 4**
Crimp with hand tool.

**Step 5**
Mate with compression bushing before epoxy cures.

**Step 6**
Polish fibers.

*Note: Use epoxy as recommended by fiber manufacturer and polishing procedure described in AMP Instruction Sheet IS 2878-2.*

---

**Hand Tools**

- CERTI-CRIMP Hand Tool
  Part No. 80564-2
- CHAMP Hand Tool
  Part No. 220193-1

---

**Dimensions:**
All dimensions in millimeters and inches. Values in brackets are equivalent U.S. customary units.
Chart contains dimensions in millimeters over inches.

---

**OPTIMATE LFR (Large Fiber)**
Single Position
Fiber Optic Connector

---

**Diagram and Text:**

**Compression Fixture**
Part No. 227390-1

**Ferrule (See Chart)**

**Cap**
Part No. 530526-1

**Crimp Ring**
Part No. 530530-7

---

**Note:** A connector assembly includes all components illustrated above. Individual components can be supplied.

---

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---

*This ferrule is designed to be used with 1 mm plastic fiber jacketed cable. Use of epoxy is not required. Termination is done by hot blade technique using AMP cut-off fixture No. 227386-2.

**Compression fixture not included.**
Active Device Mounts and Couplings*

Active Device Mount for TO-18, TO-46 (Flat Window) or TO-52
Part No. 530563-1

Active Device Mount for Modified TO-5 or TO-99
Part No. 530525-1

Active Device Mount for TO-9
Part No. 227014-1

Free Hanging Coupling
Part No. 227324-1

Active Device Mount for TO-18 Lensed (Domed)
Part No. 227015-1

Active Device Mount for TO-5 or TO-99
Part No. 530524-1

Panel Mount Coupling
Part No. 227323-1

Dimensioning:
All dimensions in millimetres and inches. Values in brackets are equivalent U.S. customary units.

*Material: Thermoplastic, black
APPENDIX E

SFR BONDED CONNECTOR SPECIFICATION SHEET
OPTIMÁTE SFR Connector Kit

Shrink Tubing

Metal Retainer Assembly

Protective Cap

Compression Fixture

A Dia.
(Over Cable Jacket)

B Dia.
(Over Fiber Cladding)

Crimp

Dimensions

Part Numbers

B Fiber Cladding Dia. (µm) | A Jacket Dia. (mm) | Plug Kit* | Ferrule Color Code | Ferrule Number | Metal Retainer Assembly Number
--- | --- | --- | --- | --- | ---
125 | 3.8 | 227285-1 | None | 227326-1 | 227286-1
125 | 3.8-4.4 | 227285-2 | None | 227326-1 | 227286-1
125 | 4.4-5.0 | 227285-3 | None | 227326-1 | 227286-1
140 | 3.8 | 227285-4 | Green | 227326-3 | 227286-1
150 | 3.8 | 227285-5 | Blue | 227326-5 | 227286-1
245 | 3.8 | 227285-6 | Red | 227326-7 | 227286-1
140 | 4.4-5.0 | 227285-7 | Green | 227326-3 | 227286-1
230 | 3.8 | 227285-8 | Yellow | 227326-9 | 227286-1
200 | 3.8 | 227285-9 | White | 1-227325-1 | 227286-1
140 | 3.8-4.4 | 1-227285-0 | Green | 227326-3 | 227286-1
230 | 3.8-4.4 | 1-227285-1 | Yellow | 227326-9 | 227286-1
245 | 3.8-4.4 | 1-227285-2 | Red | 227326-7 | 227286-1
200 | 3.8-4.4 | 1-227285-3 | White | 1-227326-1 | 227286-1
315** | 3.8 | 228791-1 | Black | 228489-1 | 227286-1

Dimensioning: All dimensions in millimetres and inches. Values in brackets are equivalent U.S. customary units.

Typical Assembly

Step 1 — Cable preparation.

Step 2 — Apply epoxy, then position ferrule on cable.

Step 3 — Position metal retainer assembly over ferrule and assemble compression fixture.

Step 4 — Crimp assembly and allow epoxy to cure.

Step 5 — Position heat shrink tubing over metal retainer assembly and shrink into place.

Step 6 — Score fiber with cleaving tool and break fiber.

Step 7 — Remove compression fixture, assemble metal polishing fixture and polish as required.

For detailed information, refer to AMP Instruction Sheet IS 2878-1.

*Kit includes: Ferrule, Metal Retainer Assembly, Compression Fixture, Heat Shrink Tubing and Protective Cap.

**For plastic clad fibers where recadding is required.
Active Device Mount Kits

For FOAC Packages and Leaded Device Packages

With Plastic Retainer
Part No. 227240-1

With Retainer and Retention Clip for High Power FOAC Devices
Part No. 227240-3

With Retention Clip
Part No. 227240-4

See AMP Data Sheet 78-512 for Ferrule Part Numbers

For JEDEC TO-Outline Devices

For Honeywell Low-Cost Plastic Sweeptip**
Inner Bore: 5.77 [227]
Nom. (Tapered)
Part No. 227646-1

For TO-18, TO-46 and TO-52 Flat Window
Part No. 227657-1

For Motorola TO-52 with Alignment Sleeve**
Inner Bore: 5.64 [230] Nom.
Part No. 228755-1

*Supplied by Honeywell Optoelectronics Division.
**Supplied by Motorola Semiconductor Products Inc.

Key
☐ These parts included with ADM Assemblies.
☐ Must be ordered separately; contact AMP incorporated.
☐ Not supplied by AMP incorporated.
Panel Mount Coupling and Tooling

Panel Mount Coupling, Die Cast, Copper-Tin Plated
Part No. 227489-3

Suggested Mounting Pattern

Typical Panel Installation

Tooling

Hand Tool
Part No. 220190-1

Die Set
Part No. 220225-1

Cleaving Tool Assembly
Part No. 227387-1

Metal Polishing Fixture

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Dimensioning:
All dimensions in millimetres and inches. Values in brackets are equivalent U.S. customary units.
APPENDIX F

CONNECTOR PRICE SHEETS
# SMA SINGLE FIBER, SINGLE CHANNEL, FIBER OPTIC CONNECTORS — MULTIMODE EPOXY STYLE

(For correct rear body or crimp adaptor size, specify buffer dia. and cable o.d.)

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<tr>
<td>2012-CCAD</td>
<td>320µ</td>
<td>&lt;2dB</td>
<td>zinc diecast</td>
<td>5.88</td>
<td>4.93</td>
<td>4.70</td>
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(EPOXY STYLE CONT.)

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<th>OFTI Part No.</th>
<th>Fiber Diameter</th>
<th>all splices loss per meter pair</th>
<th>Description</th>
<th>1-25</th>
<th>26-50</th>
<th>51-100</th>
<th>101-500</th>
<th>501-2000</th>
<th>Over 2000</th>
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<tbody>
<tr>
<td>2016-S 400µ</td>
<td>&lt;2dB</td>
<td>906 style all metal</td>
<td>21.63</td>
<td>19.75</td>
<td>18.81</td>
<td>15.07</td>
<td>12.54</td>
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<tr>
<td>2016 400µ</td>
<td>&lt;2dB</td>
<td>905 style all metal</td>
<td>12.02</td>
<td>10.97</td>
<td>10.45</td>
<td>8.91</td>
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<td>8.54</td>
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<td>4.70</td>
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<td>3.37</td>
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<td>2024-S 600µ</td>
<td>&lt;2dB</td>
<td>906 style all metal</td>
<td>21.63</td>
<td>19.75</td>
<td>18.81</td>
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<td>2024 600µ</td>
<td>&lt;2dB</td>
<td>905 style all metal</td>
<td>12.02</td>
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<td>10.45</td>
<td>8.91</td>
<td>7.75</td>
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<td>4.70</td>
<td>3.91</td>
<td>3.37</td>
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No Epoxy connectors are also available for fiber in the following diameters: 240µ (OFI 295 Series), 250µ (OFI 2010 Series), 400µ (OFI 2016 Series) and 600µ (OFI 2024 Series).

For PCS and HCS fiber:
Select 288 Series for 200µ Core PCS
Select 2012 Series for 300µ Core PCS
Select 290 Series for 230µ HCS

NOTE: SPECIAL ORDERS FOR FIBER SIZES NOT LISTED HERE WILL REQUIRE 3-4 WEEKS SHIP TIME AND A MINIMUM ORDER OF 20 PIECES METAL AND 100 PIECES CERAMIC SERIES. AN ADDITIONAL SERVICE CHARGE MAY BE APPLIED. CONSULT OFTI FOR DETAILS.
### SMA SINGLE FIBER, SINGLE CHANNEL, FIBER OPTIC CONNECTOR—SINGLEMODE

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<tr>
<td>252-SCSM</td>
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<td>&lt; 2dB 906 style (epoxy) Ceramic</td>
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### AMP* OPTIMATE® INTERMATEABLE SINGLE FIBER, SINGLE CHANNEL FIBER OPTIC CONNECTORS—EPOXY STYLE

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### AUXILIARY HARDWARE FOR FIBER OPTIC APPLICATIONS

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<td>2205</td>
<td>Splice Bushing /OPTI 200 &amp; CCA Ser. Conn.</td>
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<td>P.C. Mount Receptacle (SMA)</td>
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<td>P.C. Mount/Bulkhead Receptacle (SMA)</td>
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<td>4220</td>
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<td>SMACFC-001</td>
<td>Adapter - SMA to CFC (AMP* Optimate)</td>
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<td>5.75</td>
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<tr>
<td>X200 801</td>
<td>Pin Contact (Epoxy)</td>
<td>18.10</td>
<td>16.50</td>
<td>15.00</td>
<td>14.25</td>
<td>13.50</td>
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<td>X200 801C</td>
<td>Pin Contact (Epoxy &amp; Crimp)</td>
<td>18.10</td>
<td>16.50</td>
<td>15.00</td>
<td>14.25</td>
<td>13.50</td>
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### TOOLING AND SUPPLIES FOR FIBER OPTIC TERMINATIONS

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<thead>
<tr>
<th>Part #</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTI 1</td>
<td>MS Fiber Stripping Tool (Specify Fiber and Buffer Diameter)</td>
<td>25.00</td>
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<tr>
<td>OPTI 2</td>
<td>MSK-FO Complete Fiber Stripping Kit</td>
<td>239.00</td>
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<tr>
<td>OPTI 3</td>
<td>MSR Replacement Blades for MS Tool (Specify Size)</td>
<td>11.00/SET</td>
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<tr>
<td>OPTI 4</td>
<td>The Terminator® Complete Field Kit (Specify Fiber and Buffer Diameter)</td>
<td>975.00</td>
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<tr>
<td>OPTI 4 QA</td>
<td>The Terminator® with Length Measurement Tools</td>
<td>1432.00</td>
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<tr>
<td>OPTI 5</td>
<td>The Mini-Finishing Kit—basic kit—ideal for lab use</td>
<td>300.00</td>
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<tr>
<td>OPTI 6</td>
<td>No. 047 Crimp Tool for SMA Connectors</td>
<td>110.00</td>
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<tr>
<td>OPTI 7</td>
<td>No. 048 Crimp Tool for AMP* Connectors</td>
<td>110.00</td>
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<tr>
<td>OPTI 8</td>
<td>Fotec V100 100X Microscope</td>
<td>125.00</td>
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<tr>
<td>OPTI 9</td>
<td>15µ Lapping Film 3&quot;x8&quot; adhesive backed sheet (12 minimum)</td>
<td>.80 ea.</td>
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<td>OPTI 10</td>
<td>3µ Lapping Film 3&quot;x8&quot; adhesive backed sheet (12 minimum)</td>
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<td>OPTI 11</td>
<td>.3µ Lapping Film 3&quot;x8&quot; adhesive backed sheet (12 minimum)</td>
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<td>OPTI 13</td>
<td>&quot;Master Mite&quot; Heat Gun</td>
<td>165.00</td>
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<td>OPTI 14</td>
<td>Cable Strip Tool (&quot;Ideal&quot; type)</td>
<td>50.00</td>
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<td>OPTI 15</td>
<td>SMA Grind and Polishing Tool</td>
<td>115.00</td>
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<td>OPTI 15A</td>
<td>CFC Polishing Tool (for CFC AMP* Intermateable Connectors)</td>
<td>40.00</td>
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<td>OPTI 15L</td>
<td>Polishing Tool for Ceramic Series</td>
<td>115.00</td>
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<tr>
<td>OFTI Part #</td>
<td>Description</td>
<td>Price</td>
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<tr>
<td>OFTI 16</td>
<td>Buffer Strip - 3 oz. containers</td>
<td>7.50</td>
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<tr>
<td>OFTI 17</td>
<td>Xacto Knife</td>
<td>10.00</td>
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<tr>
<td>OFTI 18</td>
<td>2 Packs #1 Xacto Blades</td>
<td>6.50</td>
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<tr>
<td>OFTI 19</td>
<td>Glass Polishing Plate</td>
<td>15.00</td>
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<td>OFTI 20</td>
<td>Plastic Parts Box</td>
<td>1.75</td>
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<tr>
<td>OFTI 21</td>
<td>Case for Termination Kit with Foam Insert</td>
<td>150.00</td>
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<tr>
<td>OFTI 22</td>
<td>4-Gram Packs of Epoxies for Fiber Optics (minimum 25)</td>
<td>2.50</td>
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<tr>
<td>OFTI 23</td>
<td>&quot;Daniels&quot; Tool for No Epoxy Terminations</td>
<td>190.00</td>
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<tr>
<td>OFTI 24</td>
<td>Full Sleeves for S-Series Connectors (50 pc. minimum)</td>
<td>.40 ea.</td>
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<td>OFTI 25</td>
<td>1/2 Sleeves for S-Series Connectors (50 pc. minimum)</td>
<td>.40 ea.</td>
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<td>OFTI 30</td>
<td>Soft Sleeve (PVC tubing) (50 pc. minimum)</td>
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<td>OFTI 31</td>
<td>Guide to Optical Cable Termination</td>
<td>2.50</td>
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<tr>
<td>OFTI 32</td>
<td>6&quot; Dia. Diamond Lapping Plate</td>
<td>79.00</td>
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<td>OFTI 33</td>
<td>Dust Caps (1000 pc. min.)</td>
<td>.09 ea.</td>
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<td>OFTI 34</td>
<td>Sapphire Scribe</td>
<td>49.00</td>
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**SMA TEST CONNECTORS**

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<th>Description</th>
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<tbody>
<tr>
<td>252 TC</td>
<td>For 50/125µ Fiber - Ceramic</td>
<td>143.00</td>
</tr>
<tr>
<td>252 TCBA</td>
<td>For 50/125µ Fiber - Stainless Steel</td>
<td>72.00</td>
</tr>
<tr>
<td>255 TC</td>
<td>For 100/140µ Fiber - Ceramic</td>
<td>143.00</td>
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<tr>
<td>255 TCBA</td>
<td>For 100/140µ Fiber - Stainless Steel</td>
<td>72.00</td>
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<tr>
<td>252 SCSMTC</td>
<td>For 50/125µ Single Mode Fiber - Ceramic</td>
<td>250.00</td>
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**SAMPLE KITS FOR EVALUATION**

<table>
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<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>OFTI 26</td>
<td>SMA (2 connectors, receptacle, bushing)</td>
<td>25.00</td>
</tr>
<tr>
<td>OFTI 27</td>
<td>CFC (2 connectors, bushing)</td>
<td>15.00</td>
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<td>OFTI 28</td>
<td>Epoxy 6-Pack (4-gram packs of 6 epoxy types)</td>
<td>65.00</td>
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<tr>
<td>OFTI 29</td>
<td>Epoxy (5 4-gram packs of any one epoxy)</td>
<td>12.50</td>
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**LENGTH MEASUREMENT EQUIPMENT TOOLS**

<table>
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<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>OFTI QA 1</td>
<td>Length Measurement gage for 906 Style SMA Connectors</td>
<td>$325.00</td>
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<tr>
<td>OFTI QA 2</td>
<td>Length Measurement gage for 905 Style SMA Connectors</td>
<td>$325.00</td>
</tr>
<tr>
<td>OFTI QA 3</td>
<td>Tenth Reading Micrometers for Checking Polishing Tool Specifications</td>
<td>$122.00</td>
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- dB loss stated are per F.O. Connector end
- 906 and 905 styles related to intermateable Amphenol® connector sizes
- Specify rear body size on connector orders (see product data sheets or consult OFTI)
- Connector pricing for quantities over 2000 will be quoted direct from Optical Fiber Technologies
- Consult OFTI regarding price and availability of connectors with hole sizes not listed.

Payment terms Net 30 days. F.O.B. Billerica, MA. Prices are subject to change without prior notice. Blanket orders are accepted on our terms and conditions and must be completed within one year from date of order and we reserve the right to bill-back if the order is cancelled or not completed within one year.

OFTI WILL NOT ACCEPT RETURNS OF GOOD PRODUCTS SHIPPED IN COMPLIANCE WITH CUSTOMERS INSTRUCTIONS. IN SOME CASES OFTI WILL EXCHANGE PARTS FOR DIFFERENT STOCK. A RESTOCKING CHARGE WILL BE APPLIED.

ANY QUERIES REGARDING POSSIBLE DISCREPANCIES SHOULD BE COMMUNICATED TO OFTI WITHIN 15 DAYS OF PRODUCT RECEIPT. SHOULD DEFECTIVE PRODUCTS BE RECEIVED, OFTI WILL REPLACE PARTS OR CREDIT CUSTOMER, PENDING OFTI’S EVALUATION.

*Amphenol is an Allied Company.
# PRICE LIST ON OFC

**Single mode Connectors - SA-1**  
Compatible to FC type connectors  

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<th>PART NO.</th>
<th>DESCRIPTION</th>
<th>1-49</th>
<th>50-99</th>
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<td>SA-1</td>
<td>Plug &amp; Adaptor &amp; Plug</td>
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<td>SF-1A</td>
<td>Ferrule</td>
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<td>SAA-2</td>
<td>Adaptor</td>
<td>40.00</td>
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**Multi mode Connectors**  

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<tr>
<td>SCA-1</td>
<td>Adaptor</td>
<td>12.00</td>
<td>10.50</td>
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<td>7.50</td>
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<tr>
<td>SF-1</td>
<td>Plug &amp; Adaptor &amp; Plug</td>
<td>58.60</td>
<td>43.50</td>
<td>37.60</td>
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<td>SF-1 Connector Parts:</td>
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<td>SEP-1</td>
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**TERMS:**  
NET 30 DAYS  
DELIVERY  
Samples of 1-24 3 Weeks  
25 Pieces or More: 6 Weeks  

**F.O.B. TORRANCE, CALIF.**  
**NOTES:** PRICES SUBJECT TO CHANGE WITHOUT NOTICE
SAMPLE PRICING

JUMPER CABLE ASSEMBLY

SINGLE MODE JUMPER CABLE ASSEMBLY

<table>
<thead>
<tr>
<th>PART NUMBERS</th>
<th>DESCRIPTION</th>
<th>1-24</th>
<th>25-49</th>
<th>50-99</th>
<th>100-249</th>
<th>250-499</th>
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</thead>
<tbody>
<tr>
<td>SA-1J-003</td>
<td>SA-1 Connectors</td>
<td>$180</td>
<td>$160</td>
<td>$140</td>
<td>$130</td>
<td>$120</td>
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<tr>
<td></td>
<td>3M 10/125 Cable</td>
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MULTI MODE JUMPER CABLE ASSEMBLY

<table>
<thead>
<tr>
<th>PART NUMBERS</th>
<th>DESCRIPTION</th>
<th>1-24</th>
<th>25-49</th>
<th>50-99</th>
<th>100-249</th>
<th>250-499</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA-2J-003</td>
<td>SA-2 Connectors</td>
<td>$120</td>
<td>$105</td>
<td>$ 95</td>
<td>$ 87</td>
<td>$ 82</td>
</tr>
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<td></td>
<td>3M 50/125 Cable</td>
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<td></td>
</tr>
<tr>
<td>SC-1J-003</td>
<td>SC-1 Connectors</td>
<td>$120</td>
<td>$105</td>
<td>$ 95</td>
<td>$ 87</td>
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<td>3M 50/125 Cable</td>
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<td>SE-1J-003</td>
<td>SE-1 Connectors</td>
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<td>$105</td>
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<td>3M 50/125 Cable</td>
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<td>SG-1 Connectors</td>
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<td>$ 95</td>
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</table>

CUSTOM JUMPER CABLES

Custom cable lengths are available. Please specify the connector part number and the cable length as follows:

Connector - J - Cable length in meters

For example: 10M 010

S.I.U. charges $3.00/M for single mode and $2.00/M for multi mode, for additional cable lengths beyond the standard length (3M).

TERMS: NET 30 DAYS
F.O.B. TORRANCE, CALIF.

NOTES: PRICES SUBJECT TO CHANGE WITHOUT NOTICE
DELIVERY: APPROXIMATE 5 WEEKS
SAMPLE PRICING

PIGTAIL ASSEMBLY

SINGLE MODE PIGTAILS

<table>
<thead>
<tr>
<th>PART NUMBERS</th>
<th>DESCRIPTION</th>
<th>1-24</th>
<th>25-49</th>
<th>50-99</th>
<th>100-249</th>
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<tbody>
<tr>
<td>SA-1P-003</td>
<td>SA-1 Connector</td>
<td>$98</td>
<td>$83</td>
<td>$73</td>
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<td>3M 10/125 Cable</td>
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MULTI MODE PIGTAILS

<table>
<thead>
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<th>PART NUMBERS</th>
<th>DESCRIPTION</th>
<th>1-24</th>
<th>25-49</th>
<th>50-99</th>
<th>100-249</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA-2P-003</td>
<td>SA-2 Connectors</td>
<td>$65</td>
<td>$55</td>
<td>$47</td>
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<td>3M 50/125 Cable</td>
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<td></td>
</tr>
<tr>
<td>SC-1P-003</td>
<td>SC-1 Connectors</td>
<td>$65</td>
<td>$55</td>
<td>$47</td>
<td>$42</td>
</tr>
<tr>
<td></td>
<td>3M 50/125 Cable</td>
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<td></td>
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<tr>
<td>SE-1P-003</td>
<td>SE-1 Connectors</td>
<td>$65</td>
<td>$55</td>
<td>$47</td>
<td>$42</td>
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<tr>
<td></td>
<td>3M 50/125 Cable</td>
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<td>3M 50/125 Cable</td>
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</table>

CUSTOM PIGTAILS

Custom cable lengths are available. Please specify the connector part number and the cable length as follows:

\[
\text{Connector} \quad \text{P} \quad \text{Cable length in meters}
\]

For Example: 10M 010

S.I.U. charges $3.00/M for single mode and $2.00/M for multi mode, for additional cable lengths beyond the standard length (3M).

TERMS: NET 30 DAYS
F.O.B. TORRANCE, CALIF.
NOTES: PRICES SUBJECT TO CHANGE WITHOUT NOTICE
DELIVERY: APPROXIMATELY 5 WEEKS
EFFECTIVE FEBRUARY 5, 1985

PRICE LIST ON FIBER CONNECTORS

PRODUCTION QUANTITIES

SINGLE MODE CONNECTOR-SA-1

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>DESCRIPTION</th>
<th>1K-2999</th>
<th>3K-4999</th>
<th>5K-7999</th>
<th>8K-9999</th>
<th>10K AND UP</th>
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</thead>
<tbody>
<tr>
<td>SF-1A</td>
<td>FERRULE</td>
<td>20.00</td>
<td>16.50</td>
<td>16.00</td>
<td>15.50</td>
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<tr>
<td>SAP-1</td>
<td>HOUSING</td>
<td>9.00</td>
<td>8.50</td>
<td>8.00</td>
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<td>7.25</td>
</tr>
<tr>
<td>SAA-1</td>
<td>ADAPTOR</td>
<td>16.00</td>
<td>14.00</td>
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MULTI-MODE CONNECTOR STOCK-SA-2

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>DESCRIPTION</th>
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<th>3K-4999</th>
<th>5K-7999</th>
<th>8K-9999</th>
<th>10K AND UP</th>
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</thead>
<tbody>
<tr>
<td>SF-1B</td>
<td>FERRULE</td>
<td>9.50</td>
<td>9.00</td>
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<td>SAP-2</td>
<td>HOUSING</td>
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TERMS: 30 DAYS
FOB: TORRANCE, CA

NOTE: PRICES SUBJECT TO CHANGE WITHOUT NOTICE

DELIVERY OF PRODUCTION QUANTITIES NORMALLY IS 12 WEEKS FROM THE DATE OF THE ORDER, PENDING FACTORY APPROVAL.
LIST OF REFERENCES


