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AIRPORT FIBER OPTIC DESIGN GUIDELINES

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FOREWORD

This order provides the basic procedures and guidance for the design of a fiber optics network at airports. It further provides for the selection of specialized components for a fiber optics system to interconnect air traffic control, communications, navigation and surveillance facilities.

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CHAPTER 1. GENERAL

1. PURPOSE. This order supplements Order 6950.23A, Cable Loop Systems at Airport Facilities, which established the program, planning and implementation for airport cable loop systems. This order further provides guidance towards the design of the fiber optics cable loop at airports as well as the selection of the specialized components of the fiber optics system.

2. DISTRIBUTION. This order is distributed to branch level in Program Engineering, Systems Engineering and Program Management, Air Traffic Plans and Requirements Services, the Office of Airport Standards and to division level in the Office of Flight Standards in Washington headquarters; to branch level in regional Airway Facilities, Air Traffic and Airports divisions; to division level in the FAA Depot at the Mike Monroney Aeronautical Center; to division level in the Systems Maintenance Service, Test and Evaluation, Aircraft and Airsystems Technology, and Facilities Divisions at the FAA Technical Center; and to all Airway Facilities sectors, sector field offices, sector field units and sector field office units.

3. SCOPE. This guideline applies to all Level III, IV and V airports, and in particular, those airports included in FAA Order 6950.26, Airport Selection Criteria for Power and Signal Distribution.

4. BACKGROUND. The following describes briefly the goals of the cable loop program and the rationale supporting the goals.

a. Modernization. The FAA is modernizing the National Airspace System (NAS). The goals of this modernization program are to increase the capacity of the national airspace, to enhance the safety of airspace operations, to increase the productivity of the FAA facilities operations, and to improve the cost effectiveness of the NAS operations. An overall upgrading of facilities and equipment reliability will contribute to these goals. Installing highly-reliable fiber optic loop communications systems at FAA facilities is part of this modernization process.

b. Airport Cable Loop Designs. Airport cable loop designs allow the simultaneous bi-directional transmission of signals using multiple fibers. This provides inherent redundancy and increased reliability. The loop design may in fact be hybrid in nature and contain within the network, point-to-point segments other than fiber, such as radio frequency (RF) segments.

5. ENVIRONMENTAL CONDITIONS. Refer to the appropriate maintenance handbook for the proper environmental conditions for operating, storage and installation of specific equipment referenced herein.

6.-19. RESERVED.

CHAPTER 2. FIBER OPTICS AS A COMMUNICATIONS MEDIUM

20. INTRODUCTION. Fiber optics is a collective term that includes optical fibers, cables, connectors, couplers/splitters, transmitters and receivers. Digital or analog signals are transmitted by modulating an opto-electronic source, e.g. a light-emitting diode (LED) into one end of a fiber optic cable and detecting the modulation at the far end of the cable. Many signals can be multiplexed, using time-or frequency-domain division, on a single fiber, or if the bandwidth requirement dictates can be transmitted individually. Fiber optic cables are now standardized, readily available and are suitable for duct installation or direct earth burial (DEB). For further information on fiber optic cable for airport applications, refer to FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable.

21. ADVANTAGES OF FIBER OPTIC CABLE. Several advantages result from using fiber optics cable for communication systems. Some of these are listed below:

Immunity to EMI and lightning:	Cable is unaffected in extreme electromagnetic interference (EMI) environments.
Wide bandwidth[1]:	Up to 800 MHz-km per fiber using the cable specified by FAA-E-2761a.
Low signal loss:	As low as 1 dB/km using the cable specified by FAA-E-2761a.
Transmitter is electrically isolated from the receiver:	Simplifies link design because there are no ground loops. There are no requirements for maintaining a reference potential such as "ground".
Small physical size and weight:	Cables containing as many as 6 fibers in individual protective jackets are less than 1/2-inch in diameter, and often can be pulled into existing ducts, an advantage, especially when there would be insufficient room for copper conductors.
Low cost:	Fiber optic links compete effectively with other digital point-to-point communication systems, and offer the advantage of longer service life and reduced installation costs.
Collocation with power cables: (in compliance with NEC, 1987, Article 770.)	Totally dielectric cables may be collocated in the same trench, safe from induced voltages from adjacent power cables.
Secure:	No energy is emitted from a fiber optic cable.
Safe:	May be used in an explosive atmosphere with no hazard.
No need for ground:	Nonmetallic fiber optic cable does not require grounding.

[1]. Component of the system bandwidth calculation attributed exclusively to the fiber.

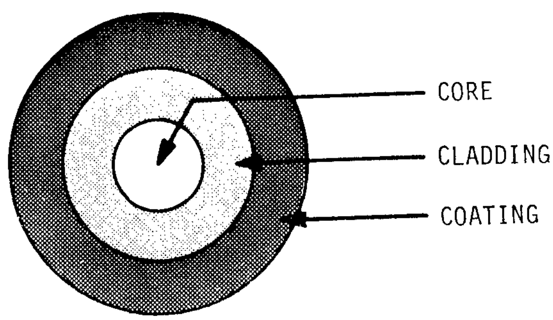
a. Airport Communications. Fiber optics is especially attractive for airport communications because it is not susceptible to, nor does it emit interfering signals. It is able to accommodate all facility communications equipment on just a few fibers and existing fiber optic capacity can be expanded through the use of multiplexers, thereby avoiding future trenching and material costs.

b. Loop Systems. Loop systems are one or more transmission systems having closed paths that provide inherent redundancy in the event that any single link is severed. For airport cable loop systems, the options for loop configurations, the communication protocols used to determine communication priorities, and the construction of the fiber optic loops are all essentially site dependent. The basic requirements for each are discussed in greater detail in chapter 3.

22. BASIC ELEMENTS. This paragraph describes the physical make-up of optical fiber, and discusses characteristics of the types of optical fibers in use today.

a. Fiber Structure. The three basic parts of an optical fiber are shown in a cross-section view on figure 2-1.

FIGURE 2-1. OPTICAL FIBER CROSS-SECTION



(1) Core. The core is the central part of the fiber through which light is transmitted. The amount of light coupled into a fiber is directly proportional to the square of the diameter of its core.

(2) Cladding. Cladding is an outer layer of glass, the optical properties of which, complement those of the core to facilitate the transmission of light down the fiber. The relatively large diameter of the cladding makes the fiber easier to handle when a splice is to be made or the fiber is to be prepared for an interface connection.

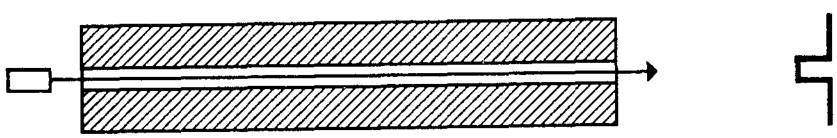
(3) Coating. Coatings are usually multilayers of plastic applied to absorb shock and provide protection from abrasion. These coatings are available from 250 microns to 1000 microns. Mechanically or chemically strippable coatings are commercially available.

b. Fiber Size. The size of an optical fiber is commonly referred to by the outer diameter of its core and cladding. For example: 50/125 indicates a fiber with a core of 50 microns, and a cladding of 125 microns. Coating is not normally referred to since it is not essential to the actual transmission of light although it does enhance transmission characteristics. It is normally removed when joining or connecting fibers. One micron (μm) is equal to one-millionth of a meter and for comparison, a sheet of paper is approximately 125 microns thick.

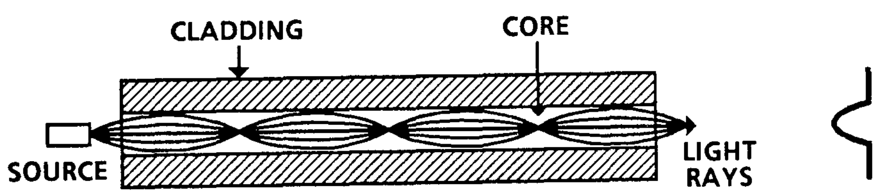
23. FIBER TYPES. Fiber types can be distinguished by the number of possible paths for light rays to travel within the fiber core. Fiber types are discussed in terms of modes, single mode or multimode. A mode is one of many possible solutions to the wave equation that is derived from Maxwell's equations. The superposition of modes result in composite waves, the normal projection of which are rays. A ray exists for each of the composite waves.

The first type of fiber to be discussed is single-mode (sometimes called monomode) fiber. It provides only a single path along which light rays may travel. See figure 2-2a. There are two types of multiple-mode (multimode) fibers. These are called graded-index and step-index fibers and are shown in figure 2-2b and 2-2c respectively. FAA-E-2761a specifies graded-index fiber. Discussion of the other types of fiber are for interest only so that the reader may gain a better understanding of basic fiber types and why one type is preferable in airport applications to other types.

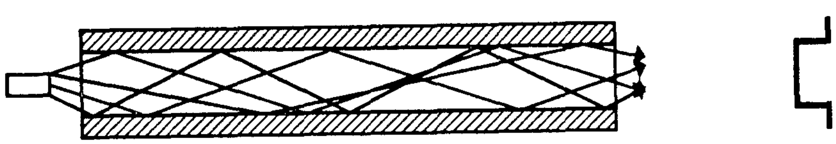
FIGURE 2-2. THREE TYPES OF OPTICAL FIBER



a) Single Mode (Monomode)



b) Graded Index (Multimode)



c) Step Index (Multimode)

a. Step-Index. Step-index multimode fiber derives its name from the distinct, step-like difference in the refractive index of the core and the cladding. Common step-index fibers have core diameters of 100, 200 and 300 microns. Step-index fiber limits the system bandwidth to approximately 20 MHz•km

b. Graded-Index. Unlike step-index fiber, the profile of the index of refraction is approximately parabolic. Figure 2-2b shows a representative profile as well as the effect that this grading has on the light rays travelling down the fiber. The limitation of system bandwidth attributable to graded-index fiber is on the order of 1 GHz•km. Graded-index fibers are commercially available with core diameters of 50, 62.5, 85 and 100 microns.

c. Single Mode. The single mode fiber allows only a single mode to be efficiently transmitted. This eliminates any limitation attributable to intermodal effects. The core of a single mode fiber is extremely small, approximately six to ten microns. The single mode fiber has a significantly higher information carrying capacity than either of the two multimode types, and its bandwidth extends into the tens of, and perhaps even as much as 100, GHz•km.

24. LIGHT SOURCES AND DETECTORS. This paragraph discusses the characteristics of optical sources and detectors, and the rationale for selecting certain devices over others.

a. Light Sources.

(1) Light-Emitting Diodes vs. Laser Diodes. Although it is possible to transmit a significantly greater bandwidth over a much longer distance using a laser diode device, light-emitting diodes (LEDs) are preferred and are specified in the applicable FAA equipment. Specifically, LEDs provide:

(a) the probability of a significantly longer device life expectancy,

(b) simplified cooling methods,

(c) sufficiently low optical power so as to obviate concern for eye safety,

(d) simple circuit operation and design,

(e) significantly lower acquisition cost, and

(f) more than adequate capability for the intended application.

b. LED-Based Communication Links. Optical characteristics critical to LED-based communication link design are: (1) power coupled into a multimode 50/125 fiber, (2) operating wavelength, (3) spectral width (full width at one-half maximum power), (4) risetime and falltime, and (5) source aging. These characteristics are discussed in the following paragraphs.

(1) Power Coupling. Output power from surface-emitting LEDs into a solid hemisphere can be two to three milliwatts. However, the power coupled into an optical fiber pigtail will be less because of the narrow acceptance cone of the optical fiber (determined by its numerical aperture (NA)) and the core diameter. The essential characteristics when considering an LED-pigtail assembly are the

output power from the pigtail, the core/cladding dimensions and the NA. The typical coupling loss is 14 dB from a LED to a fiber pigtail. Thus if the total output from the LED is 2.5 mW and the NA is assumed to be 0.20, the power coupled into the fiber pigtail and available from the output end is only 0.1 mW (100 microwatts), or -10 dBm (decibels relative to 1 mW).

(2) Wavelength and Spectral Width. The operating wavelength of the LED is selected to coincide with the wavelength-attenuation characteristics specified for the fiber. Spectral widths for 1300-nm LEDs are typically 80 to 100 nanometers, and for 850-nm LEDs are typically 50 nanometers, or less.

(3) Risetime and Falltime. Risetime and falltime of the LED and the detector must be considered so that the required systems data rate is not arbitrarily limited by these values.

(4) Source Aging. LEDs degrade slowly with use. The power output for a given input current gradually decreases, and the LED eventually fails. Failure of the LED is defined as a reduction to one-half of the value of the original power output for a given drive current. Therefore, system design dictates that the loop power loss budget be calculated on the assumption that the power output of the source is 3 dB less than its actual initial value.

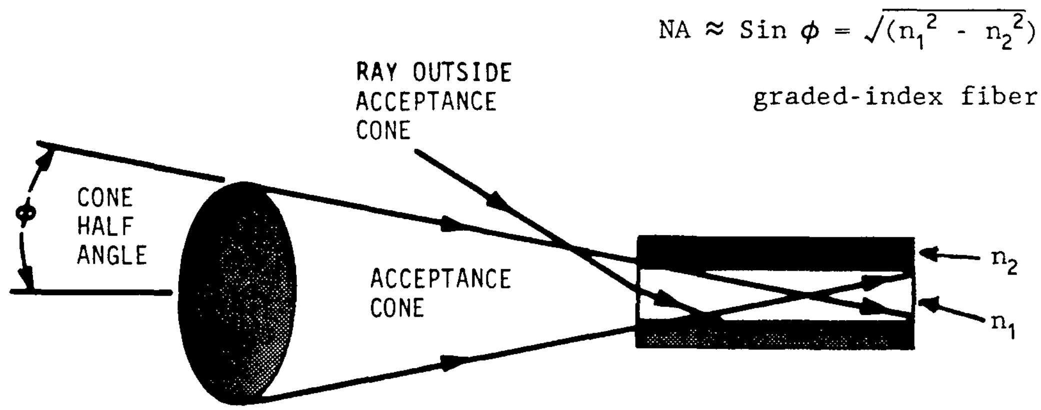
c. Detectors. Pin diodes are preferred over avalanche photodiodes (APD) for receiver designs despite the 6dB or more disadvantage in gain for reasons similar to those cited for selecting LEDs over laser devices.

25. OPTICAL COLLECTION FACTOR. As mentioned earlier, core diameter is one determinant of how much optical power can be coupled to a fiber. Obviously, the larger the core, the more surface area at the interface that is exposed to light. A change in core from 50 μm to 100 μm represents an increase of four times in the amount of light transmitted. The other measure of a fiber's ability to collect optical power is the numerical aperture (NA).

a. Numerical Aperture. NA is a measure of the fiber's ability to accept light rays that are not parallel to the fiber axis, and transmit them down the core such as shown in figure 2-3. A large difference between the refractive indices of the core and cladding means a larger NA. For equal core sizes, a fiber with a larger NA will accept more light. A power increase by about a factor of two is achieved by going from an NA of 0.20 to one of 0.29.

b. Optical Source/Emitter. Optical source/emitter packaging is designed to couple light into a fiber according to core size. Using a light source not designed for a particular fiber's core size will cause less than optimum light coupling for the system. The effects of core size and numerical aperture have been combined into an optical coupling factor normalized for (referenced to) 100/140 in table 2-1.

FIGURE 2-3. A FIBER'S ACCEPTANCE CONE HALF-ANGLE



n_1 = maximum refraction index of core

n_2 = index of refraction of cladding

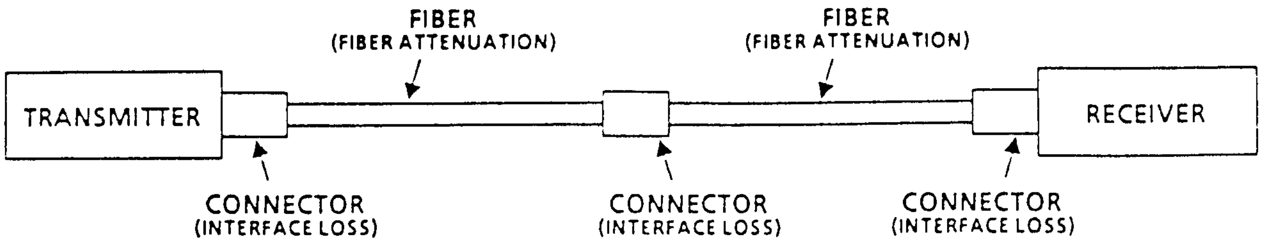
TABLE 2-1. OPTICAL PERFORMANCE OF TYPICAL GRADED-INDEX FIBERS

Core dia (μm)	Cladding dia (μm)	Buffer dia (μm)	Numerical Aperture	Optical Coupling Factor (dB)
50	125	250	0.20	-9.5
62.5	125	250	0.29	-4.3
85	125	250	0.26	-2.6
100	140	250	0.30	0

26. SYSTEM DESIGN. When selecting components for a fiber optic system, there are two optical fiber factors that affect transmission performance: bandwidth and transmission loss. Transmitter and receiver design combine with the characteristics of the fiber to establish performance limits of the system.

a. Transmission Loss. In addition to changes in the optical pulse shape which result in frequency or bandwidth limitations, there are also reductions in the level of optical power that must be considered. The more significant causes of optical attenuation in optical fiber systems are: optical fiber loss, macrobending losses, connector loss, splice loss and coupling loss. Some of these losses are shown in figure 2-4, and described in greater detail in the following subparagraphs.

FIGURE 2-4. SOURCES OF TRANSMISSION LOSS IN AN OPTICAL LINK



(1) Optical Fiber Loss. Light is subject to transmission losses associated with a propagation medium.

(a) Propagation Loss. Propagation losses occur in the fiber due to absorption and scattering. These occur over distance, and the amount of loss depends upon the specific fiber, its size, purity and the amount and type of dopant used to produce the refraction indices. Attenuation coefficient or the per unit distance amount of optical power loss due to absorption and scattering of optical radiation at a specified wavelength is expressed in decibels per kilometer (dB/km). Since attenuation is an accepted synonym for the fiber optic expression, attenuation coefficient, and since the term is extensively understood in the more familiar radio frequency and microwave transmission applications, it will be used herein as well to avoid unnecessary confusion.

(b) Optimum Wavelengths. Fibers are optimized for operation at certain wavelengths. For example, a loss of less than 1dB/km is attainable in 50/125 μm multimode fiber operating at 1300 nm, and less than 3.5 dB/km is attainable for the same fiber operating at 850 nm. Two wavelength regions, 850-nm or 1300-nm, are the areas most often specified for multimode fiber optic transmission because transmitters and receivers operating at these wavelengths are commonly available. Optical fibers have also been optimized at the 1550-nm region for single mode transmission.

(2) Microbending Loss. Without support, an optical fiber is subject to losses of optical power caused by microbending. Microbends are minute fiber deviations caused by lateral forces which cause optical power loss from the core. Cables are designed to minimize microbending losses.

(3) Macrobending Loss. Macrobends are relatively large bends in fibers such as those found in splice trays, splice enclosures, and in optical patch cords. For the fibers specified by FAA-E-2761a, excess loss will occur when a bend radius is less than 1.5 inches. Particular attention is required at the time of installation and during subsequent maintenance procedures.

(4) Connector Loss. Connector loss is a function of the physical interface of one fiber core to another fiber core. Some of the loss conditions include axial offset, angular, tilt and rotation of the tilt misalignment, as well as end separation of the surfaces. Other loss conditions result from "matching" fibers having different physical characteristics, or the rotational misalignment of cores which are not perfectly circular or concentric with respect to the cladding, or numerical apertures. Some of these loss conditions are shown on figure 2-5. Scratches and/or dirt contamination of the connector surfaces can severely reduce system performance, but most often, the connector loss is due to misalignment or end separation. Depending upon connector type, different fiber optic terminating techniques are used:

(a) Epoxy and Polish. The fiber is epoxied in place in an alignment sleeve, then polished at the endface.

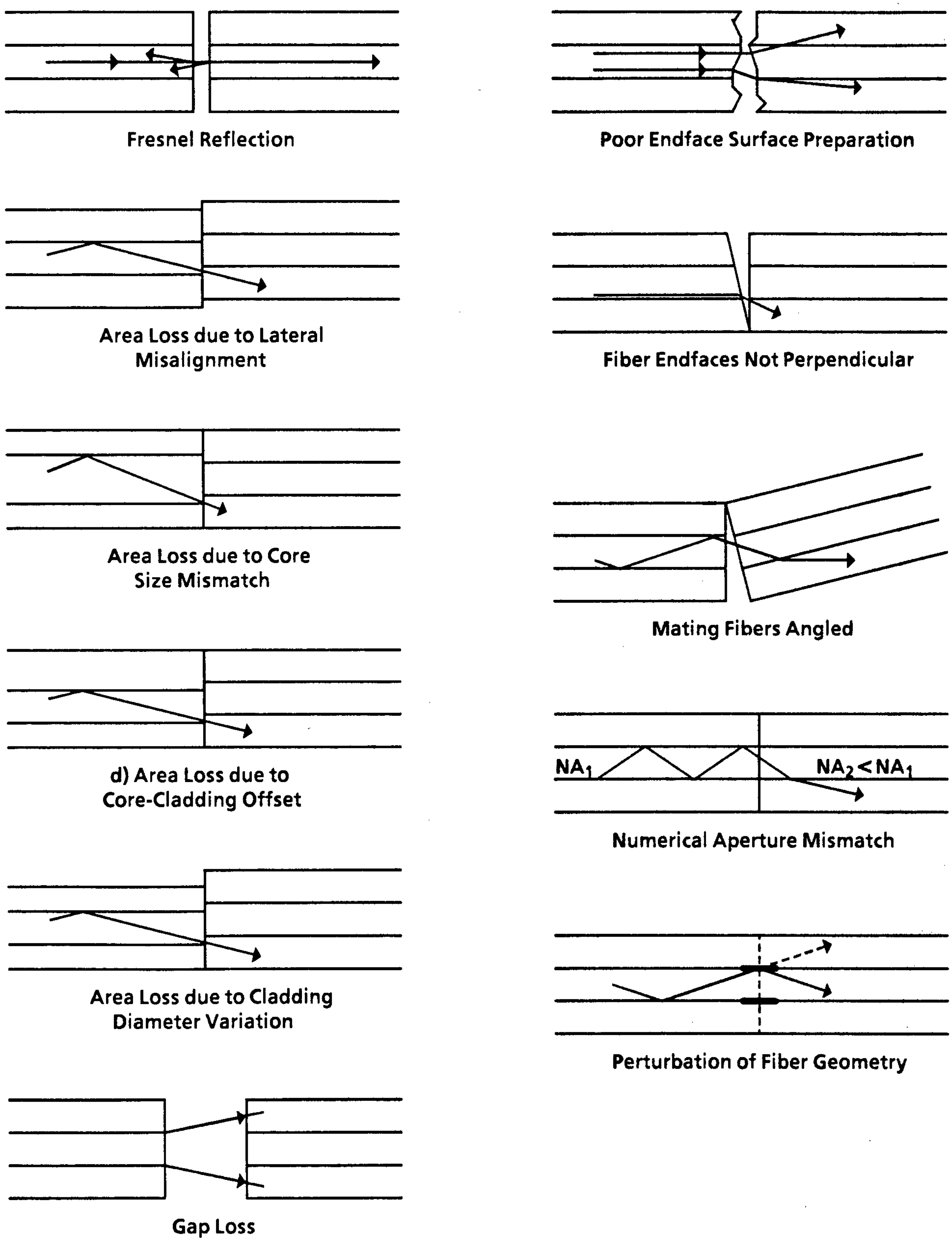
(b) Optical and Mechanical. Both lenses and rigid alignment tubes may be used. In addition, index matching mediums may be employed. The optical power loss of a connector-to-connector interface typically runs between 0.5 and 1.5dB, depending upon the style of the connector and the quality of the preparation.

(5) Splice Loss. Two fibers may be joined in a permanent fashion by welding, fusion, chemical bonding, or mechanical joining. A splice loss that is introduced to the system may be 0.10 dB or less. Various connector and splice loss conditions are shown in figure 2-5. For simplicity, these illustrations are for ray paths in a step-index fiber. The effects of the various defects on the paths in a graded-index fiber are similar. In all illustrations, the direction of transmission is from left to right. Some loss mechanisms are affected by the direction of transmission; others are not.

(a) Fresnel Reflection is caused by the refractive index mismatch between the fiber endface and the surrounding air. This is analogous to the reflection of an electrical signal at the end of an unterminated electrical transmission line. For an ordinary glass fiber, it is approximately 0.18 dB. Where there are two reflective surfaces (e.g., at a pair of mated connectors), the loss will be approximately 0.36 dB. In mated connectors, Fresnel reflection may be reduced by the application of an index-matching gel. It is not necessary for systems designed with adequate margin, and particularly not advisable for field applications where the potential for contamination exists during routine maintenance procedures. In mechanical splices using adhesives to secure the fibers, the refractive index of the adhesive approximates that of the fibers, thus reducing the amount of reflection.

(b) Areal Mismatch Losses. Areal mismatch losses are a result of the receiving fiber not fully nor effectively capturing the light rays emanating from the transmitting fiber and generally include lateral misalignment, core misalignment, and core cladding offset in which a loss may be minimized by rotating one fiber with respect to the other. Still another loss is through cladding diameter variation which in most types of splices and in connectors, the alignment of the fiber relies on the outside diameter of the fiber. If, because of manufacturing tolerances, the outside diameter of one fiber is greater than the other, a corresponding mismatch will exist.

FIGURE 2-5. TYPICAL FIBER OPTIC CABLE LOSS CONDITIONS



(c) Gap Loss. A gap between the fibers results in some of the light rays emanating from the transmitting fiber diverging beyond the cone of the receiving fiber.

(d) Poor Endface Surface Preparation. If there is poor endface preparation: a fractured break instead of a clean, uniformly flat, perpendicular cleavage, or large deep scratch(es) instead of a good polished endface, then light will be scattered at the joint and subsequently dissipated.

(e) Fiber Endfaces Not Perpendicular. If one or both fiber ends are not perpendicular, then there will be losses attributable to a combination of factors, some intuitively obvious from "ray" diagrams. Lack of fiber end perpendicularity is especially harmful in joining single-mode fibers, where ray diagrams do not fully describe the problems.

(f) Mating Fibers Angled. If connecting fibers axes are angled, not all of the light rays emanating from the transmitting fiber will be captured by the acceptance cone of the receiving fiber.

(g) Numerical Aperture Mismatch. If the numerical aperture of the transmitting fiber is greater than that of the receiving fiber, then even if there are no mechanical imperfections and the fibers are in perfect contact, there will be a power loss due to the fact that the receiving fiber cannot support the higher order modes of propagation. In terms of a ray analysis, not all of the rays of the transmitting fiber will be captured by the acceptance cone of the receiving fiber.

(h) Perturbation of Fiber Geometry. When two fibers are joined by fusion, there will be some disturbance to the waveguide geometry (core-cladding boundary) caused by the fusion process, creating a loss at the splice.

(6) Coupling Loss. Loss between the fiber and the signal source is a function of both the device and the cross-sectional area of the fiber core. Although LEDs emit light in a broader radiation pattern than laser diodes, LEDs, nonetheless, couple sufficient light into a 50 μm, or greater, fiber core. Lasers are significantly more effective than LEDs for coupling light into single-mode fiber. There is no notable coupling loss between the fiber and detector when the physical interface is per industry standards.

(7) Receiver Sensitivity. Receivers are specified in terms of the amount of optical power required to achieve a given signal-to-noise ratio (SNR), or in the case of digital signals, bit error rate (BER).

b. Bandwidth - There are four independent components in the expression to calculate system bandwidth; however, only the parameters which are attributable to characteristics of the fiber will be discussed. They are as follows:

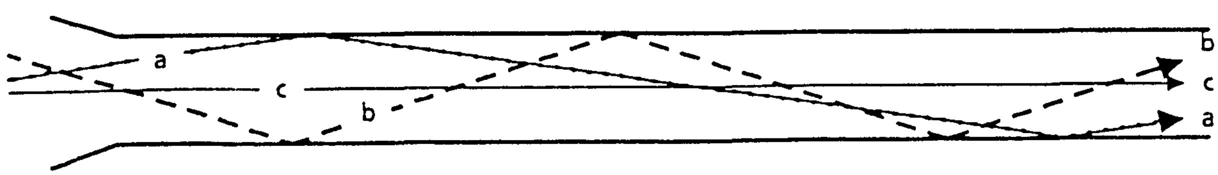
(1) Source risetime and transmitter electronics risetime combine for the optical transmitter risetime, T_t.

(2) Detector risetime and receiver electronics risetime combine for the receiver risetime, T_r.

(3) Intermodal delay is a characteristic associated with multimode fiber. It is a measure of the difference in arrival times at the detector of modes which have been emitted by a source simultaneously, but which are differentially propagated within a fiber.

(4) Chromatic dispersion is a component dependent upon the wavelength and the spectral width of the source.

(a) Intermodal Pulse Broadening. As discussed earlier, a mode is one of many possible solutions to the wave equation. Consider for simplicity, the ray optics example of a step-index fiber where rays of light are simultaneously incident within the acceptance angle of a longitudinal cross-section of fiber. The figure shows that ray "a" having a shorter distance to travel than ray "b", will arrive at the far end before ray "b" arrives. In one extreme, a ray "c" which has normal incidence travels in a straight line parallel to, or coincident with the axis, and at the other extreme, the ray "b" which has an incidence angle just within the acceptance angle travels a path, which for the angle of incidence, is the longest. The cumulative difference (intermodal delay) or amount of time that ray "b" is delayed in arriving at the detector is directly proportional to the length of the fiber. Grading the index of refraction reduces the differences in propagation time extremes.



The effect of grading the index is that light propagating through a medium having a decreasingly smaller index of refraction does so at an increasing rate of speed. The longer path lengths associated with rays captured at the extremes of the acceptance cones are compensated for by light which is propagating at a greater rate of speed. There is only one wavelength for which a particular fiber formulation can have optimum bandwidth. The formulation of the graded-index fiber specified in FAA-E-2761a is such that the wavelength of the optimum bandwidth is approximately 1100 nm; resulting in a bandwidth of 400 MHz-km at 850 nm and a bandwidth of 800 MHz-km at 1300 nm, or

T_i (850 nm) $\approx$ 0.8 ns/km, and

T_i (1300 nm) $\approx$ 0.4 ns/km.

(b) Chromatic Dispersion. Chromatic dispersion is a parameter, the per unit value of which is dependent upon the wavelength of the transmitted light and the spectral width of the source. Silica based fiber is commonly formulated such that it exhibits "zero" dispersion somewhere within the range of 1290-1310 nm. At 850 nm, however, the dispersion is in the order of 110 picoseconds per nm of FWHM[2] spectral width per kilometer. The contribution of the spectral bandwidth, T_d, is calculated by multiplying the FWHM spectral width by 110 picoseconds and the distance in kilometers.

(c) System Bandwidth Calculation. System bandwidth is calculated as follows, where B_w is the -3dB bandwidth.

$$B_w \approx 0.35/1.1 \sqrt{(T_t^2 + T_r^2 + T_i^2 + T_d^2}$$

where:

T_t = Optical transmitter risetime (in ns),

T_r = Optical receiver risetime (in ns),

T_i = Intermodal delay per kilometer times link distance (relates to the "spread" in modal group velocities).

T_d = Chromatic dispersion per kilometer times link distance (relates to spectral width especially at 850 nm; not particularly of consequence at 1300 nm).

NOTE

Since detectors are square-law devices, the 3dB optical bandwidth transforms to a 6dB electronic bandwidth.

It is important to note that an 850-nm LED having a relatively narrow spectral bandwidth of 35 nm FWHM will be a noticeably limiting factor of system bandwidth. Fortunately 1300-nm LEDs, although at the time of this writing more costly, will transfer the limitation in system bandwidth to the intermodal bandwidth of the fiber which for the fiber specified by FAA-E-2761A is more than adequate for FAA needs at a respectable 800 MHz-km. The 850-nm devices will continue to be used for relatively short links in which bandwidth is not of concern. The cost differential between 850-nm and 1300-nm devices will continue to diminish - ultimately, it will approach a value which will preclude the specification of 850-nm devices.

27. CABLING DESIGN CONSIDERATIONS. Considerations of tensile strength, ruggedness, durability, flexibility, size, resistance to the environment, flammability, temperature range and appearance are equally important in cabling optical fiber as well as electronic cable. However, fiber is considerably more fragile physically than copper, and therefore, packaging concepts for the two materials are different. The following paragraphs discuss the physical capabilities of fiber optic cables and some means of protecting fiber optic cable installations.

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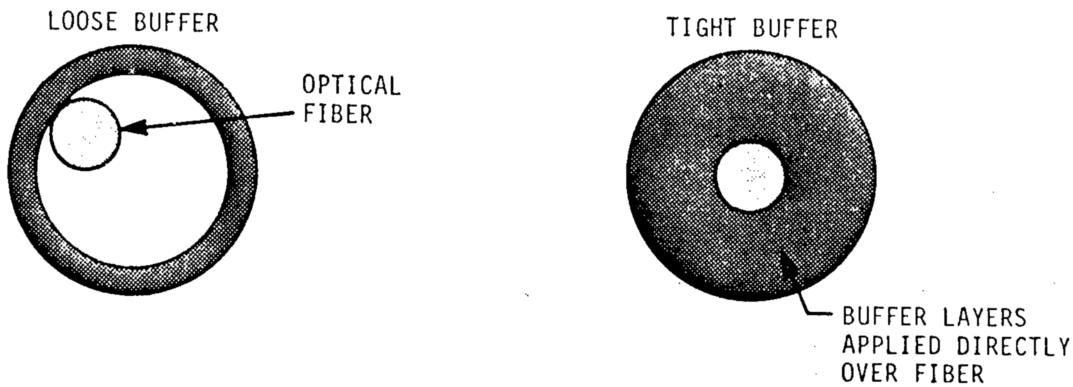
2. Data sheets normally provide the Full Width Half Maximum (FWHM) value.

a. Fiber Protection. The optical fiber is a very small waveguide. In an environment free from stress or external forces, this waveguide transmits light with minimum loss, or attenuation. However, an unsupported fiber is subject to a loss of optical power caused by microbending as discussed in paragraph 26. To handle this problem, two first-level means for protection of fiber have been developed; loose buffer, and tight buffer. These are shown in figure 2-6.

FIGURE 2-6. EXAMPLES OF LOOSE AND TIGHT BUFFER CONSTRUCTION



(1) Loose Buffer. In loose buffer construction, the fiber is contained in a plastic tube that has an inner diameter considerably larger than the fiber itself. The loose tube isolates the fiber from the exterior mechanical forces acting on the cable. By controlling the amount of fiber inside the tube, the amount of allowable temperature variation can be increased and, therefore, the degree of attenuation over a temperature range is minimized.

(2) Tight Buffer. The other fiber packaging technique, tight buffer, uses a direct extrusion of plastic over the basic fiber coating. Tight buffer construction serves to protect the fiber from crushing and impact loads, and to a certain degree, reduces the microbending losses that would otherwise be induced during cabling. Tight buffer design, however, provides only minimal isolation for the fiber from the stresses of temperature variations. While relatively more flexible than loose buffer, if the tight buffer is deployed with sharp bends or twists, optical losses are likely to exceed nominal specifications due to macrobending.

(3) Both Buffer Constructions. Both loose buffer and tight buffer constructions have inherent advantages. The loose buffer tube offers lower cable attenuation from microbending for any given fiber, plus a high level of isolation from external forces. Under continuous mechanical stress, the loose tube permits more stable transmission characteristics. The tight buffer construction permits smaller, lighter-weight designs for similar fiber configuration, and generally yields a more flexible, crush resistant cable. Advantages of both tight and loose buffers are summarized in table 2-2.

b. Physical Choices. Decisions must be made about cabling the fiber to meet installation strength requirements and protection from the environment. For installation of a cable, mechanical properties such as tensile strength, impact resistance, flexing and bending are important. Environmental requirements concern the resistance to moisture, chemicals, and other types of atmospheric or in-ground conditions.

TABLE 2-2. LOOSE AND TIGHT BUFFER TRADEOFFS

Cable Parameter	Cable Structure	
	Loose Tube	Tight Buffer
Bend radius	Larger	Smaller
Diameter	Larger	Smaller
Tensile strength, installation	Higher	Lower
Impact resistance	Lower	Higher
Crush resistance	Lower	Higher
Attenuation change at low temperatures	Lower	Higher

c. Mechanical Protection.

(1) Normal cable loads sustained during installation may ultimately place the fiber in a tensile-stress state. The levels of stress may cause microbending losses which result in an attenuation increase and possible fatigue effects. To buffer the fiber from stress loads in short-term installation and long-term application, various internal strength members are added to the optical cable structure. Such strength members provide the tensile load properties similar to electronic cables, and keep the fibers free from stress by minimizing elongation and contraction. In some cases, they also act as temperature stabilization elements. Table 2-3 indicates the relative performance considerations for each of the common strength members. Optical fiber stretches very little before it breaks, so the strength members must have low elongation at the expected tensile loads. Aerial cable installation, for example, must be protected from excessive tensile loading from wind and ice. Impact resistance, flexing and bending are other mechanical factors affecting choice of strength members.

(2) Cable strength members which are typically used in fiber optic cable include Kevlar™ aramid yarn, fiberglass epoxy rods, and steel wire. On an equal weight basis, Kevlar is considerably stronger than steel. Kevlar and fiberglass epoxy rods are often the choice when all-dielectric construction is required. Steel is sometimes used where extremely cold temperature performance is required, since it can offer better temperature stability, however, it does conduct electricity.

TABLE 2-3. STRENGTH MEMBER COMPARISON OF DIFFERENT MATERIALS

Material	Break (lb.)	Diameter (in.)	Elongation break (%)	Weight Lb. (K ft)
Fiberglass epoxy rod	480	0.045	3.5	1.4
Steel	480	0.062	0.7	7.5
Kevlar aramid yarn	944	0.093	2.4	1.8

d. Environmental Protection. As with conventional wire cables, the outermost jacket ultimately protects the innards from the external environment. In addition, the various plastics used as jackets exhibit different characteristics when exposed to the physical and chemical effects of the operating environment. Typical tradeoff characteristics of various jacketing materials are listed in table 2-4. Fiber optic cables are available with numerous combinations of jacket materials suitable for installation in underground ducts, aerial suspension, direct earth burial, plenum or cable raceways.

e. Recommended Cable. Specification FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable provides a selection of cables for the various environmental conditions.

28. FIBER OPTIC CABLE INSTALLATIONS.

a. Typical Power and Fiber Optic Cable Installation at Airports. Power cables in the loop are generally routed underground between loads. Both power cables and fiber optic cables are routed: in the same duct bank for short runs or in areas around buildings, or in a direct earth burial (DEB) trench for long, unobstructed runs. Although it is acceptable to install cable in a DEB trench for long unobstructed runs, it is generally desirable to run power cables and fiber optic cables in ducts.

(1) Installation of Fiber Optic and Power Cables in Same Trench. To minimize installation costs, totally dielectric fiber optic cable may be run together with power cables in the same duct. Wherever practical, the fiber optic cable may be placed in the same duct with barriers or separation in accordance with NEC provisions. Generally, fiber optic runs are free of splices between terminals. Optical fiber terminations and conversions to electrical signals will be made inside the protection of buildings.

(2) Manholes. Although the power and totally dielectric fiber optic cables may be run together, it is recommended that they have separate manholes to promote safety during maintenance. It also makes maintenance easier.

(3) Entering Buildings. Armored fiber optic cable should be terminated and grounded in manholes or handholes at least ten feet from the building. Cable entry into a building shall be via a ferrous (rigid) conduit. After being grounded, the armor shall extend a minimum of five feet into the conduit and the entrance to the conduit appropriately sealed. Fiber optic duplex cable is used from the point of demarcation upon entry to the building. Diversity of the cable paths within the

facility including points of entry into a facility should be considered for critical applications. Interior fiber optic cable should be installed in a manner which ensures that the cable is protected from being curled, coiled or twisted to the point that the minimum allowable bend radius limit has been violated. Installing it in a 1/2" PVC conduit is one approach; however, other less conservative techniques will be adequate. In general, the maximum vertical rise without intermediate support is 250 feet. Supports should be of a type that distribute the load and prevent bend radius problems.

TABLE 2-4. TRADEOFFS OF VARIOUS JACKETING MATERIALS

Attribute	Poly propylene	Poly urethane	Nylon	Teflon	Poly vinyl chloride	Low-density poly ethylene	Cellular poly ethylene	High-density poly ethylene
Resistance to abrasion	F-G	O	E	E	F-G	F-G	F	E
Electrical properties	E	P	P	E	F-G	E	E	E
Flammability resistance	P	F	P	O	E	P	P	P
Resistance to nuclear radiation	F	G	F-G	P	G	G	G	G
Corrosion resistance to water	E	P-G	P-F	E	E	E	E	E
Corrosion resistance to acid	E	F	P-F	E	G-E	G-E	G-E	G-E
Resistance to aliphatic hydrocarbons such as kerosene, gasoline, etc.	P-F	G	G	E	P	P-F	P-F	P-F
Resistance to aromatic hydrocarbons such as toluel, benzol, etc.	P-F	P	G	E	P-F	P	P	P
Resistance to halogenated hydrocarbons such as degreasing agents	P	P	G	E	P-F	P	P	P
Resistance to alcohol	E	P	P	E	G-E	E	E	E
Resistance to oxidation	E	E	E	O	E	E	E	E
Resistance to heat	E	G	E	O	F	G	G	G-E
Resistance to oil immersion	F	E	E	O	F	G	G	G-E
Resistance to weathering, ultraviolet radiation from solar exposure	E	G	E	O	G-E	E	E	E
Flexibility at low temperatures	P	G	G	O	P-G	E	E	E
Resistance to ozone exposure	E	E	E	E	E	E	E	E

KEY: P = Poor, F = Fair, G = Good, E = Excellent, O = Outstanding

(4) Inner ducting. Inner ducts should be used to avoid subjecting the fiber optic cable to the stresses associated with pulling the power cable, and to facilitate future cable installations.

(5) Bending Radius. The minimum bending radius of the fiber optic cable must not be less than the radius specified in FAA-E-2761a, during any phase of installation or operation.

(6) Labeling. The fiber optic communications cable and the power cables should be clearly and continuously labeled at all accessible points and in the manholes as specified in the appropriate local, state and federal electrical and safety codes. This minimizes the possibility that maintenance personnel might confuse the power cable for the fiber optic communications cable or vice versa.

b. Safety Concerns. Personnel safety is of paramount importance at all times. The major safety concern in placing fiber optic cables in close proximity to power cables is preventing the transmission of power cable fault current or other electrical current by the armor of the fiber optic cable. Such currents would endanger personnel working on the cables. Totally dielectric fiber optic cables inherently prevent the transmission of fault currents because of the absence of conductive paths. Therefore, totally dielectric fiber optic communication cables may be placed with power cables without compromising safety.

29.-39. RESERVED.

CHAPTER 3. FIBER OPTIC CABLE LOOP SYSTEMS

SECTION 1. BASIC REQUIREMENTS

40. CHARACTERISTICS. Loop systems are transmission systems having closed paths that provide inherent redundancy in the event that any single link is severed. The advantage of a fiber optic loop is that it can be implemented with as few as two fibers by using networking equipment and is in contrast to traditional field cable which normally requires multiple pairs per facility. Some of the characteristics are discussed below.

a. Configurations. There are two basic loop configurations to consider: one is when the loop is shared by only two facilities, and the other is when the loop is shared by three or more facilities.

b. Protocol. A loop that is shared by three or more facilities must have some form of effective protocol to govern which facility is to have access at any given time, and to ensure that the integrity of the data being transmitted is maintained. Possible protocols might be:

(1) Token ring network where the supervisory function moves with the token,

(2) Time-division protocol such as a synchronous, time-division multiplexed network using for example, a digitized voice/data channel bank where all facilities have equal access, or

(3) Fixed master-slave relationship (poll-select) where a slave is addressed and responds according to a predetermined protocol.

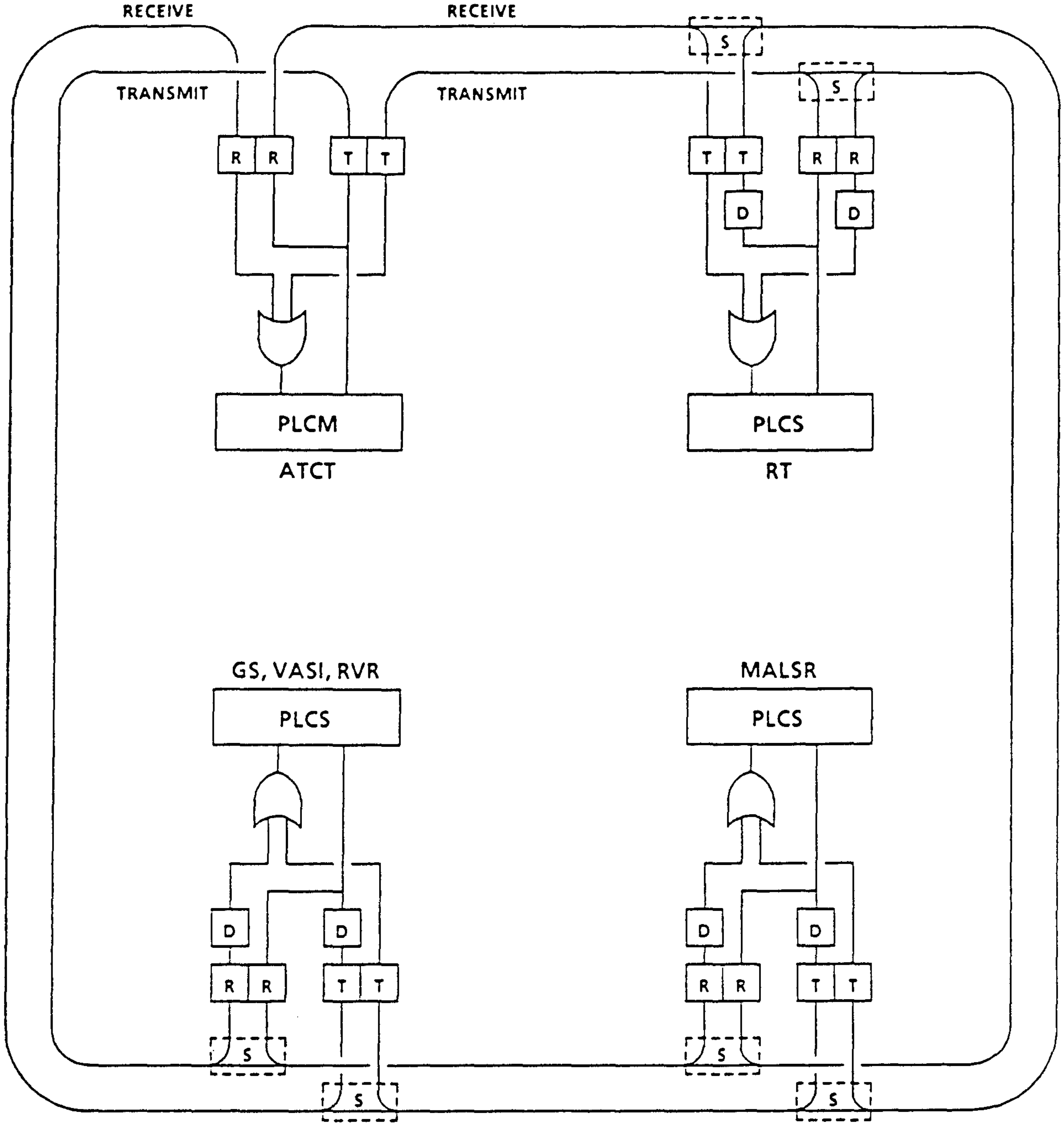
c. Construction. A fiber optic loop can be constructed in one of two basic configurations: a ring bus where there is a transmit loop and a receive loop, and within which, passive optical signal splitter devices are configured to allow bidirectional transmission using only two fibers (figure 3-1); or counter-rotating rings where the signal is retransmitted at each facility except at the master/supervisor (see figure 3-2).

d. System Constraints. The following describes the constraints of the ring bus structure and counter-rotating ring structure.

(1) Ring Bus. The ring bus structure is severely limited by a reduction in power at each node along the loop. This creates a major drawback which is inherent when the loop has been optimized for transmitting in both directions.

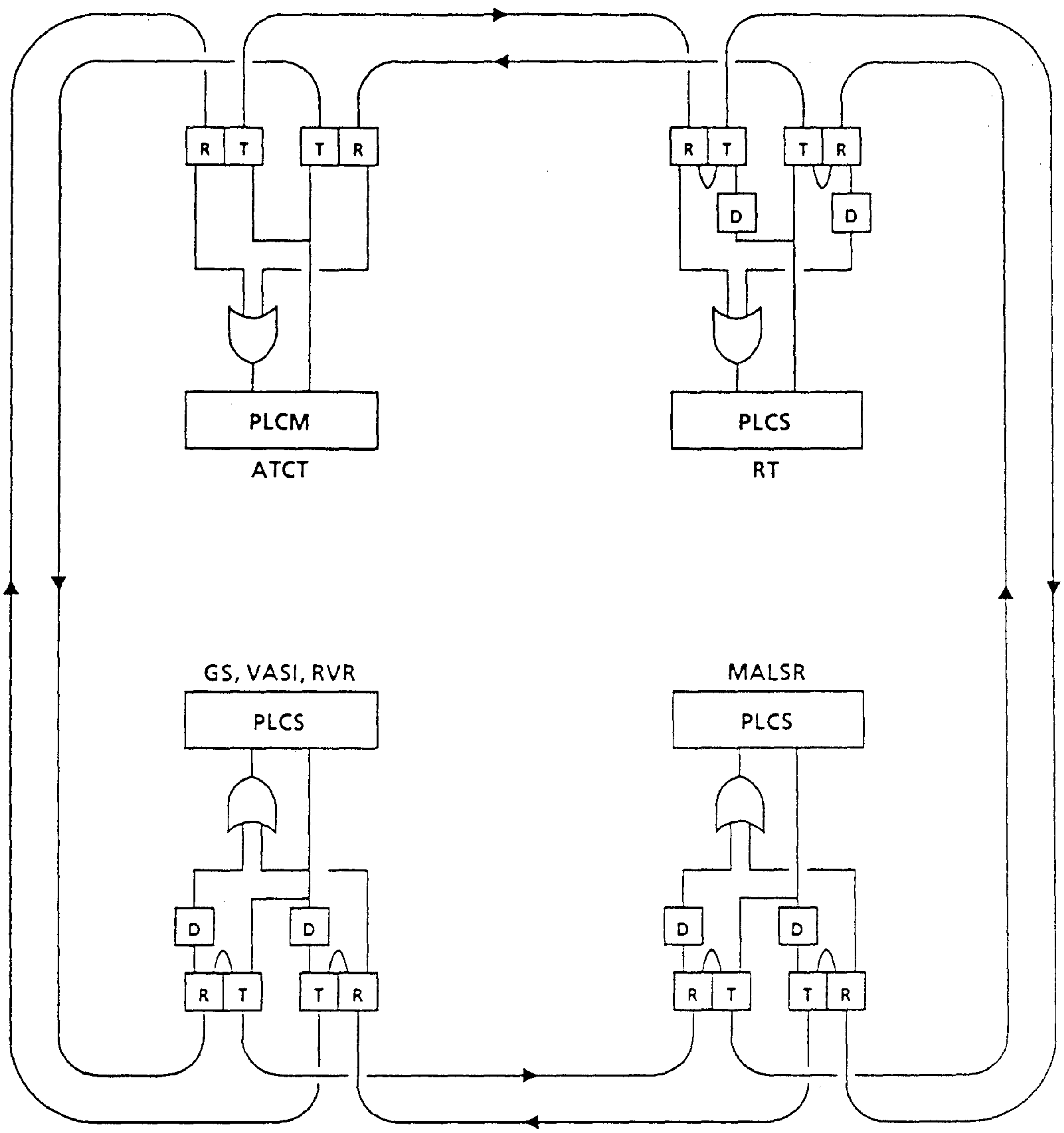
(2) Counter-Rotating Ring. The counter-rotating ring structure is not constrained in any obvious way by the number of facilities serviced by the loop as would be the case for a passively-coupled ring bus structure where a reduction in power occurs at every facility. However, the counter-rotating ring is limited by the amount of pulse broadening which is introduced as a result of a pulse being retransmitted repeatedly. The extent of the limitation is a function of the data rate and the effective slew rates of elements comprising the signal path.

FIGURE 3-1. RING BUS CONFIGURATION



LEGEND
PLCM MASTER PROGRAMMABLE CONTROLLER
PLCS SLAVE PROGRAMMABLE CONTROLLER
D DELAY
R FIBER OPTIC RECEIVER
T FIBER OPTIC TRANSMITTER
S OPTICAL SPLITTER

FIGURE 3-2. TWO COUNTER-ROTATING RINGS



LEGEND
PLCM MASTER PROGRAMMABLE CONTROLLER
PLCS SLAVE PROGRAMMABLE CONTROLLER
D DELAY
R FIBER OPTIC RECEIVER
T FIBER OPTIC TRANSMITTER

For example, at a 19.2 Kbps Non-Return-to-Zero (NRZ) data rate, a pulse width increase of as little as 2 to 3 microseconds per transmission, in conjunction with pulse jitter, can affect the bit error rate (BER) after as few as 6 or 7 repetitions. Networks including more than 6 or 7 facilities would need, therefore, to either periodically recondition the signal or more closely control both the amount of pulse broadening, and jitter.

e. Recommended Protocols. The two recommended protocols for multiple facility loops (both being implemented using a counter-rotating ring structure) are a master with multiple slaves configuration, and time-division multiplexing. Not being burdened with the operations associated with sharing of the supervisory functions, both approaches offer acceptable performance in a real time environment.

41. MASTER-SLAVE RELATIONSHIP. Facilities in the system (ATCT, RT, ASR, etc.) are distributed about the airport at locations governed by their individual installation requirements. In a master-slave relationship each facility on the loop receives all the data transmitted on the loop, but accepts and reacts only to the information addressed to it. It is implicit in the concept that intelligent devices such as programmable logic controllers (PLC) are placed at each facility in the network for which a master-slave relationship is in effect. The principle advantages of this approach are that a loop can be designed and implemented using conventional PLCs, fiber optic modems/transceivers (standard interfaces such as EIA-232 and EIA-422), and a simple interfacing unit. The resulting configuration is modular at the facility level.

a. System Operation. This paragraph along with figure 3-3 describes the operation of a master-slave configuration using counter-rotating rings. In a counter-rotating ring configuration, two loops are used. One ring transmits in a clockwise (cw) direction, while the other transmits in a counterclockwise (ccw) direction. This provides a fully redundant system that is unaffected by a single failure in either loop.

(1) The ATCT (master) transmits interrogation or command signals into the loop. These signals are received by a facility (slave), regenerated and transmitted to the next facility in the loop.

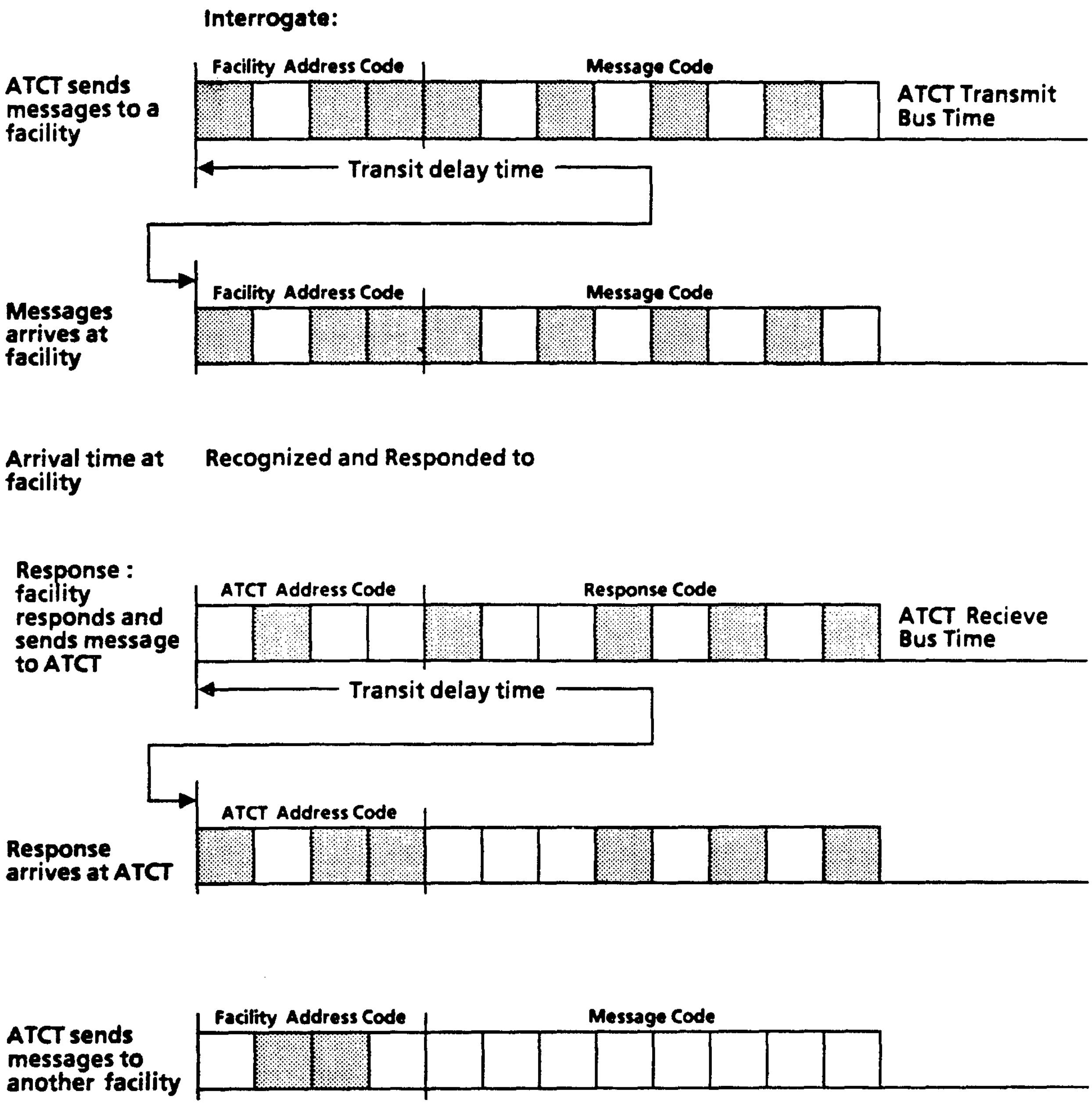
(2) The signals typically consist of a facility address code followed by the message (command, control or status) for that facility (figure 3-2). A facility's response to an ATCT interrogation takes the form of an immediate message into the loop. When the ATCT has received a response it repeats the sequence until all facilities have been interrogated and have responded.

(3) If a facility fails to respond within a prescribed time and after a predetermined number of polls, diagnostic operations are initiated at the ATCT to determine the failure mode. When a message becomes garbled during transmission, a request to retransmit will be generated.

(4) The ATCT receiving equipment is configured to prevent retransmission of signals.

(5) Both the cw and the ccw transceivers receive signals from their respective directions as well as retransmit them. Although the two signals are identical, they are not synchronous at any given facility because the lengths of the transmission paths are different. Therefore, some accommodation is necessary, using

FIGURE 3-3. DIALOG BETWEEN ATCT AND ANOTHER FACILITY

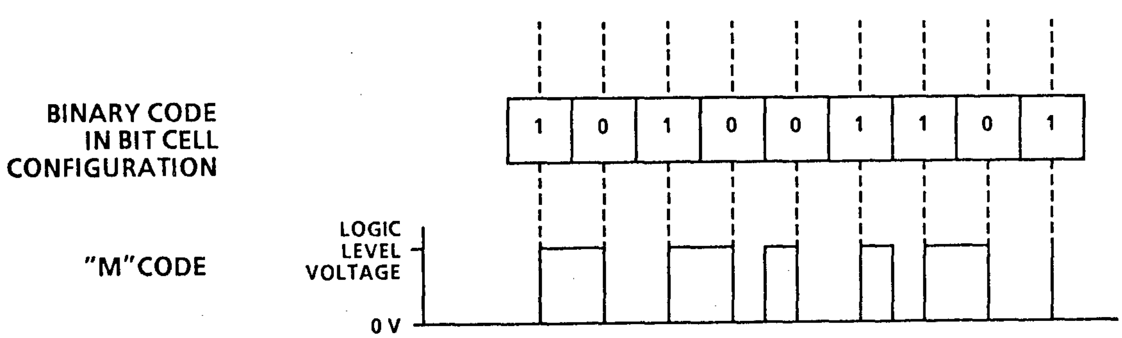


one of two methods. One is to correct for the difference in arrival times. The other method is to preferentially accept either of the two signals based on a criterion such as signal quality or some other predetermined preference, or a combination of the two methods.

(a) A digital signal is transmitted at the ATCT bidirectionally to a facility. The signal arriving first is delayed and logically OR'ed with the later of the two signals using a module defined by FAA-E-2809, Airport Facility Fiber Optic Interface. The response from the facility to the ATCT is also transmitted bidirectionally, however, the signal which would have otherwise arrived at the ATCT first is delayed using the same module as described above. At the ATCT, both signals arrive, within tolerance of the delay logic, at the same time and are logically OR'ed. This approach provides the distinct advantage of uninterrupted and undisturbed communications in the event of a cable break or a single component failure in either ring. An exclusive-OR logic circuit is incorporated for fault detection.

(b) The simplest implementation of the second approach is to sense for the presence of a carrier, and to switch to standby when the carrier of the primary is no longer detected. The carrier simply meant to imply that there is a measurable signal for both the ones and zeroes such as in a Manchester "M" encoding scheme (see figure 3-4). Although this approach almost certainly results in a loss of communications for a one-bit interval, there are many applications for which it would be acceptable. It also offers the advantage of a reduced number of components with an attendant increase in reliability. In figure 3-4, a "one" is discriminated by a "zero" volt to logic level transition within a plus/minus tolerance of the midpoint of the bit cell; a zero is the complement.

FIGURE 3-4. MANCHESTER "M" ENCODING SCHEME



42. TIME-DIVISION MULTIPLEXING. Each facility in the loop receives data on the loop, but accepts and reacts only to the data in the serial stream during the assigned time cells for a specific facility. The design concept is modular at the channel level, clearly a potential advantage when there are enough data/voice channels to be transmitted per facility to warrant this approach. Associated with the performance characteristics and the number of channels, which can be accommodated by a T-carrier with voice/data channel bank, is a corresponding size and cost factor which dictates that the deployment of such be evaluated on a site-by-site basis. The same concept, in reduced scale, uses synchronous/ asynchronous multiplexed transceivers with drop and insert capability as described in FAA-E-2820, Fiber Optic, Multiplexing, Drop and Insert Modem which in general, although having less channel capacity and reduced performance characteristics, also has significantly lower cost.

a. System Operation. The following describes the operation of a time-division multiplexer.

(1) A synchronous bit stream is transmitted into the loop. For drop and insert, the signal is received, and retransmitted at each facility.

(2) The bit stream provides transmit and receive time cells for every channel module, even if it is not in use.

b. Channel Banks. Many of the voice channel modules used by the telecommunications industry include an "E" (ear) lead and an "M" (mouth) lead which is used to transmit signaling information such as IDLE/BUSY. This capability can be used to pass transmitter keying information to the remote transmitter sites. Neither the T-carrier voice/data channel bank, nor the multiplexed synchronous transceiver with drop and insert capability provide the means to request the retransmission of data if the message is garbled during transmission. This approach, if it is a requirement, relies on the source and destination devices monitoring the integrity of transmitted messages and requesting retransmission when needed.

SECTION 2. DETAILED REQUIREMENTS

43. SYSTEM DESIGN CONSIDERATIONS AND PROCEDURES. This paragraph discusses the characteristics of the air traffic control communications, control and indication signals found at airport facilities, how they are classified, catalogued and partitioned for transmission over fiber optic cable loop systems. Each of the equipment specifications referenced herein addresses reliability/ availability and maintainability; the requirements were defined in the context of NAS SS 1000. Without any known exceptions this is achieved by implementing the system with some degree of redundancy. Included are discussions of transmission noise, losses and delays.

a. Air Traffic Control Signals. This paragraph discusses the characteristics of air traffic control signals to be handled by fiber optic cable loop systems.

(1) Airport Facilities. Airports typically have the following types of facilities generating or receiving air traffic control signals:

(a) ALS Approach Lighting System

(b) ALSF Approach Lighting System with Flashers

(c) ASR Airport Surveillance Radar

(d) ATCBI Air Traffic Control Beacon Indicator

(d) ATCT Air Traffic Control Tower

(e) DME Distance Measuring Equipment

(f) GS Glide Slope

(g) IM Inner Marker

(h) LOC Localizer

(i) MALSR Medium-Intensity Approach Lighting System with Runway Alignment Indicator Lights

(j) MLS Microwave Landing System

(k) MM Middle Marker

(l) MODE S Mode S

(m) OM Outer Marker

(n) RTR Remote Transmitter/Receiver

(o) RVR Runway Visual Range

(p) VOR VHF Omnidirectional Range

(2) Signal Bandwidth. The signals communicated between the ATCT and the other facilities listed above are classified as low, audio or video frequency. In preparation of the airport communications cable loop design, list all current and proposed facility frequencies as classified in the following paragraphs.

(3) Low-Frequency Signals. Low-frequency signals found at an airport range from direct current (DC) to approximately 70 Hz, and are:

(a) Binary (on/off) for control or status indicators,

(b) Analog for remote meter indicators or DC potentiometer voltage levels

(c) RVR pulses.

These signals are transmitted in one of the above forms to and from the ATCT and the other facilities to indicate status, and to provide control information on various relay operations or meter circuits. Since these change slowly, bandwidth requirements and information rates are low. There may be 200 or more low-frequency signals at a activity Level III, IV or V airport.

(4) Audio-Frequency Signals. Audio-frequency (voice band) signals are in the frequency range from 300 to 3400 Hz. These signals have traditionally been transmitted between the ATCT and the RTRs over two wires balanced to ground. There are other voice grade circuits in an airport loop system such as the instrument landing system (ILS) control and readback tones.

(5) Video-Frequency Signals. The video-frequency signals found at an airport range up to 6.7 MHz and consist of analog video and triggers pulses. They are transmitted from the ASR site to the ATCT. The most frequently encountered video-frequency signals are:

(a) Normal video,

(b) Beacon video,

(c) Beacon triggers,

(d) Moving target indicator (MTI) video, and

(e) Normal video triggers.

(6) Signal Types. Generally, the airport signals of interest include, but are not limited to those listed in table 3-1.

b. Cataloging Signals. After classifying signals by frequency, the next step is to catalog all such data with respect to pertinent specifics such as facility location, demarcation box, terminal block number, terminal number, electrical interface parameters, etc.

TABLE 3-1 AIRPORT SIGNAL TYPES

Low Frequency	Audio Frequency	Video Frequency
Readback/status control	Air/ground voice	Normal video/trigger
Runway visual range	Audio control/ readback tones	Moving target indicator video
Meter circuits	Mode S and ASR-9 modem signals	Beacon video/trigger
General communi-cations		Azimuth change pulse*
		Azimuth reference pulse*

* Although the repetition rates of ACP and ARP are low, the frequency content of the required pulse rise and fall times is high.

c. System Partitioning. In order to retain a modular approach, especially for facilities which do not have shared-maintenance personnel, the recommended network design is one having four basic functional subsystems, each having an appropriate number of fibers assigned to it. One subsystem is radar signals which include normal video with trigger, beacon video with trigger, moving target indicator video, azimuth reference pulses and azimuth change pulses. A second subsystem radar control and readback. A third subsystem provides for voice signals and a the fourth for general communications. The approach using four subsystems has the added advantage of providing the option of an airport communications network being installed in easily defined increments. In the overall scheme, there will be instances, however, where it is clearly and logically appropriate to integrate the system functionality of each of the functional partitions above, or some combination or subset thereof. All of these subsystems are discussed in greater detail in the following subparagraphs.

(1) Radar Signals. Except for the ASR-9, the recommended equipment for transmitting radar signals is defined by FAA-E-2790, Fiber Optic, Video Airport Surveillance Radar Transmission System. Guidance for implementation is provided within the system configuration section of FAA-E-2790. For the ASR-9, a fiber optic multiplexing transceiver appropriate for that system is defined in FAA-E-2820, Fiber Optic, Multiplexing, Drop and Insert Modem.

(2) Radar Control and Readback. The recommended equipment for multiplexing and demultiplexing the control and readback signals are programmable logic controllers (PLCs) as specified by FAA-E-2789, Monitor and Control, Programmable Logic Controllers. This equipment provides a high degree of flexibility and the capability for possible role expansion. It includes the integration of functions normally associated with the general communication subsystem as well as some requirements still undefined, such as environmental remote maintenance monitoring. The decision to include such capabilities must be evaluated on a site-by-site basis, and only after careful consideration of possible systemic impact.

(3) Voice. T-carrier and channel bank equipment are recommended for voice communications. Drop and insert capability should be considered when two or more transmitter or receiver sites are included within the loop or system of loops. The signalling circuits of the channel module can be configured to to effect transmitter keying. An example of a level-shifting technique is shown in figure 3-5. In the near future, voice communications between the ATCT and the RTR will be handled by radio control equipment (RCE). Transmit keying will no longer be +48 vdc, but a digital control signal. The FAA specification describing the channel bank and T-carrier equipment is FAA-E-2810, T-carrier with Drop and Insert.

(a) Channel Banks. The flexibility of having both main and standby channel banks can be exploited to simplify system design, and reduce system cost. Specifically, the main channels should be transmitted using one system and the standbys should be transmitted using the backup. Partitioning the system in this manner eliminates the need for additional crossover equipment by relying on the FAA's existing manual capability to do so at the ATCT cab and the TRACON.

(b) Antenna Changeover Signals. Antenna changeover signals can be transmitted using the general communications subsystem; however, there will be instances where this is not feasible. In these situations, there are two options; multiplex the signals onto an EIA-232 compatible line and transmit them using a data module in place of a voice channel, or use the transmitter keying signal to energize a corresponding latching coaxial antenna changeover switch.

(c) Other Applications. In addition to voice, the channel bank equipment can be used to transmit ASR-9 modem signals as well as the control and readback tones of a localizer or glide slope when they are within reasonable distance of a site with a channel bank. Yet another application for the channel bank is to remote alarm information for the RMMS, provided the equipment is co-located with a channel bank.

(4) General Communications. Signals in the general communications loop are for:

(a) Monitor and control of a power loop,

(b) Glide slope and localizer control/readback,

(c) Runway visibility data and control,

(d) Runway lighting and control/readback,

(e) Antenna changeover, and

(f) Environmental sensor signals.

The programmable logic controller having an extensive variety of I/O interface modules is a near-ideal solution for integrating a diversity of signals into a common network. The general communications loop can be implemented in one of the possible approaches given below:

(a) Counter-Rotating Asynchronous Rings, one clockwise and the other counterclockwise, using transceivers and a means to multiplex and demultiplex such as a PLC, or

(b) Multiplexed Transceivers/Modems with "drop-and-insert", a synchronous ring structure with asynchronous capability, can also be configured in counter-rotating rings, a more flexible, but more costly means for equal performance which is justified only if requirements for multiple data channels are present. Multiplexed transceivers/modems with "drop-and-insert" can be an appropriate solution for networking a number of facilities such as RVRs or remote maintenance monitoring systems (RMMSs) which have similar communications requirements. The RMMSs are mostly EIA-232 synchronous compatible; the "Tasker" or transmissometer type RVRs, however, are not, and will require interface modules such as those specified in FAA-E-2809, Airport Facility Fiber Optic Interface. Specification FAA-E-2820, Fiber Optic, Multiplexing, Drop and Insert Modem provides information on modules for both requirements.

d. Signal-to-Noise Ratio and Bit Error Rate. The signal-to-noise ratio (SNR) for transmitting analog and digital signals, and the bit error rate (BER) resulting from transmitting digital signals are discussed in the following paragraphs.

(1) Signals Sent in Analog Form. Signals sent in analog form over the fiber usually require a higher SNR than those in digital format. The digitizing process, although requiring greater bandwidth (not a problem in fiber optic technology), allows the optical signals to be sent as pulses, which require less power while achieving a comparable signal-to-noise-ratio.

(2) Binary Signals. For binary signals representing relay or switch status, an SNR of 17.3 dB is required. For slowly varying analog signals, a band of 2 percent uncertainty at full scale is acceptable. This translates into an SNR of 17 dB.

(3) Pulse Modulated Signals. For pulse-code modulation (PCM) fiber optic carrier systems that multiplex many voice channels, the accepted (BER) standard of the industry is 10^{-9}. This corresponds to an SNR of 21.5 dB, or an absolute power ratio of 141:1.

(4) Video Signals The SNR of the MTI and normal video signal is set to 4:1 at the sensor site. The SNR must be preserved accurately so that when the signal is received at the tower targets can be extracted from the "noise". In order to ensure that the ability to do this is not significantly degraded by noise introduced during the transmission process, An SNR of at least 35dB is specified for the transmission system. FAA-E-2790 specifies that the condition for normal operation will yield a SNR of at least 45 dB.

e. Losses. The following discusses how optical power losses are determined.

(1) Loss Determination. In a fiber optic loop system, signal losses must be determined in order to insure that sufficient optical power is present at each receiver to preserve an acceptable SNR (and corresponding BER). All losses must be considered between the transmitter LED at one end of the link, and the receiver photodiode at the other end of the link.

(2) Counter-Rotating Ring Losses. For the counter-rotating ring configuration, because the signal is regenerated at each facility, the consideration of link loss is limited to identifying the longest link in the system, and includes splicing, connectorization, and macrobending losses. When using 850-nm light sources, the attenuation is 3.5 dB per kilometer, and when using 1300-nm light sources, the attenuation is 1.0 dB per kilometer as specified by FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable. To this, splicing losses at $\approx$ 0.1dB/splice and connector losses at $\approx$ 1.5 dB/mated connector must be added.

44. CABLE. This paragraph describes the primary and environmental characteristics of fiber optic cable, selection rationale, and maintenance considerations for cable loop systems in general.

a. Primary Characteristics. The opto-electronic characteristics of primary interest in the selection of fiber waveguide are attenuation (in dB/km), bandwidth (in MHz-km), and Numerical Aperture (NA). NA is defined as the sine of the acceptance cone half angle (a measure of the fiber's ability to accept light rays that are not parallel to the fiber core axis. Attenuation and bandwidth requirements are commonly used to specify cable performance. Refer to specification FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable for more information.

b. Fiber for FAA Use. The fiber to be used by the FAA for telecommunication purposes (multimode) has a 50/125-micron core/cladding dimension ratio, with a NA of 0.20 to 0.24. The following attenuation and bandwidth characteristics are given for the dual window wavelengths of 850-nm and 1300-nm.

Wavelength	850 nm	1300 nm
Attenuation:	< 3.5 dB/km	< 1.0 dB/km
Bandwidth:	> 400 MHz-km	> 800 MHz-km

c. Environmental Characteristics. The cable must meet environmental and certain other site-specific requirements such as resistance to the effects of immersion in jet fuel, (for which a fluoropolymer such as polyvinylidine fluoride or other suitable material, is specified). Specification FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable provides further guidance in specifying cable type.

d. Other Maintenance Considerations. This paragraph addresses the repair of damage to the fiber optic cable.

(1) Breakage. After a fiber optic cable has been buried, it is possible that it will be crushed or severed accidentally. This is most likely to occur when heavy earth-moving construction equipment is used in the airport area. The fiber optic loop system will be the most susceptible to damage during facility changes or extensions to runways.

(2) Splicing. The general repair procedure is to cut out the damaged section and splice in a replacement section of cable. Each splice introduces power loss at the junction. When semiautomatic fusion splicing apparatus is used on multimode fiber, the loss is typically 0.3 dB or less. It can be reduced to nearly 0.1 dB if the core concentricity, core and cladding diameters, grading coefficient, and numerical aperture parameters have been closely controlled as specified in FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable. For quick restoration of service in an emergency, a glass tube mechanical splice is low cost, fast, and provides an optical loss comparable to fusion splicing. Fibers are identified by colored buffer tubes or distinctive coloration in the protective coating.

45. AIRPORT LOOP SYSTEM DESIGN. This paragraph provides suggestions and procedures for acquiring the types of information and allocating resources necessary to develop a detailed airport fiber optic cable loop system design.

a. Airport Information Required. The step-by-step process outlined on figure 3-5 is the best way to determine the detail hardware requirements for any given airport. It should include:

(1) planned facilities to be interlinked,

(2) proposed facilities to be relocated,

(3) proposed or anticipated facilities to be added,

(4) types of information to be communicated such as data, voice video and power control,

(5) types and quantity of equipment to be requested.

b. Information Resources. This paragraph identifies those preliminary tasks and requirements to aid in planning the most efficient and effective installation: (1) existing airport layout drawing, (2) current aerial photograph, (3) airport master plan, (4) recent airport modification drawings, (5) visits to each facility to map internal equipment locations, (6) visits to each facility to document equipment and type of signal to be transmitted/ received, (7) discussions with airport manager about foreseeable airport modifications and site specific requirements, and, (8) determine FAA facility modifications and updates.

(1) Airport Layout Drawing. An up-to-date set of airport layout drawings are necessary since they are the best source of information for detailing the loop layout. Items such as underground pipelines, existing underground duct systems, open water or swamps, solid rock terrain, ground fault areas, and existing communication cables should be indicated. Normally, when required, ducts shall be installed parallel to, or perpendicular to runways or building restriction lines. Cable routings when practicable shall avoid runway/taxiway crossings and other critical areas to minimize the impact upon scheduling of construction and maintenance activities.

(2) Aerial Photographs. Current aerial photographs should be obtained to supplement the airport layout drawings. The photographs should be annotated to identify the locations of facilities, and a vellum positive produced from which blue-line drawings of the overall airport and portions of the airport can be made. Loop layouts and distances can be accurately determined from the blue-line prints.

(3) Airport Master Plan. If a master plan exists and is of recent issue, it can be a good source of information. If it is more than 5 years old, steps should be initiated to update the master plan.

(4) Planned Airport Modifications. As planned airport modifications are part of the selection criteria, it is more than likely that detailed drawings of planned renovations exist. One or two sets should be obtained for planning the fiber optic communications loop.

(5) Facility Mapping. Each facility which is anticipated to be in the loop should be visited to study and sketch to scale the facility and the location of the demarcation box. For multiple-floor facilities, all cable shafts, raceways and access points should be identified and noted. Likewise, false floors and ceilings should be noted.

(6) Facility Equipment and Signal Documentation. The facility review should include a list of the facility equipment by manufacturer, type, and current FAA revision level, where applicable. At each junction box, a list of the signal leads which are entering/exiting the facility, their source/destination, signal characteristics and a brief description of their function must be prepared.

FIGURE 3-5. DETAILED COMMUNICATION LOOP LAYOUT

- INFORMATION GATHERING
  - DETAIL BY FACILITY (PRESENT AND FUTURE)
    - -- LENGTH OF RUNS IN FACILITY
    - -- LOCATIONS WITHIN FACILITY FIRST FLOOR
    - -- NUMBER AND TYPE OF SIGNALS
    - -- TYPE OF CABLE
    - -- NUMBER OF FIBER LOOPS
    - -- QUANTITY AND TYPE OF I/O
    - -- NUMBER AND TYPE OF PLC
    - -- NUMBER AND TYPE OF TRANSMITTERS AND RECEIVERS
  - OVERALL LOOP LAYOUT
    - -- INDIVIDUAL UNINTERRUPTED INTERFACILITY CABLE LENGTHS
    - -- OVERALL LOOP LENGTHS
    - -- DUCT REQUIREMENTS
    - -- MANHOLE REQUIREMENTS
    - -- LOOP SIGNAL LOSSES (DB)
    - -- PHYSICAL OBSTRUCTIONS ABOVE AND BELOW GROUND

c. Overall Loop Layout. This paragraph discusses the information obtained in paragraph 45.b for the overall loop layout shown in figure 3-5, and applies it to an overall airport communication loop layout such as that shown in figure 3-6. It is important at this point of the loop design process to recognize that in certain instances, it will be a previously installed point-to-point fiber optic link which is the precursor to a loop configuration. The loop is created by providing one or more links to provide closure and a means to multiplex, or demultiplex, signals on the loop in order to utilize the pre-existing fibers. It is also important to recognize that a loop system may include some point-to-point elements which may or may not be intended to be the precursors to future loops.

Furthermore, a loop design must consider the consequences of common failure points. Independent multiplexing subsystem (subloops) will reduce the number of common failure points, thereby reducing the risk of catastrophic failures. Redundant multiplexing subsystems are generally warranted when/where concern for critical functions exist.

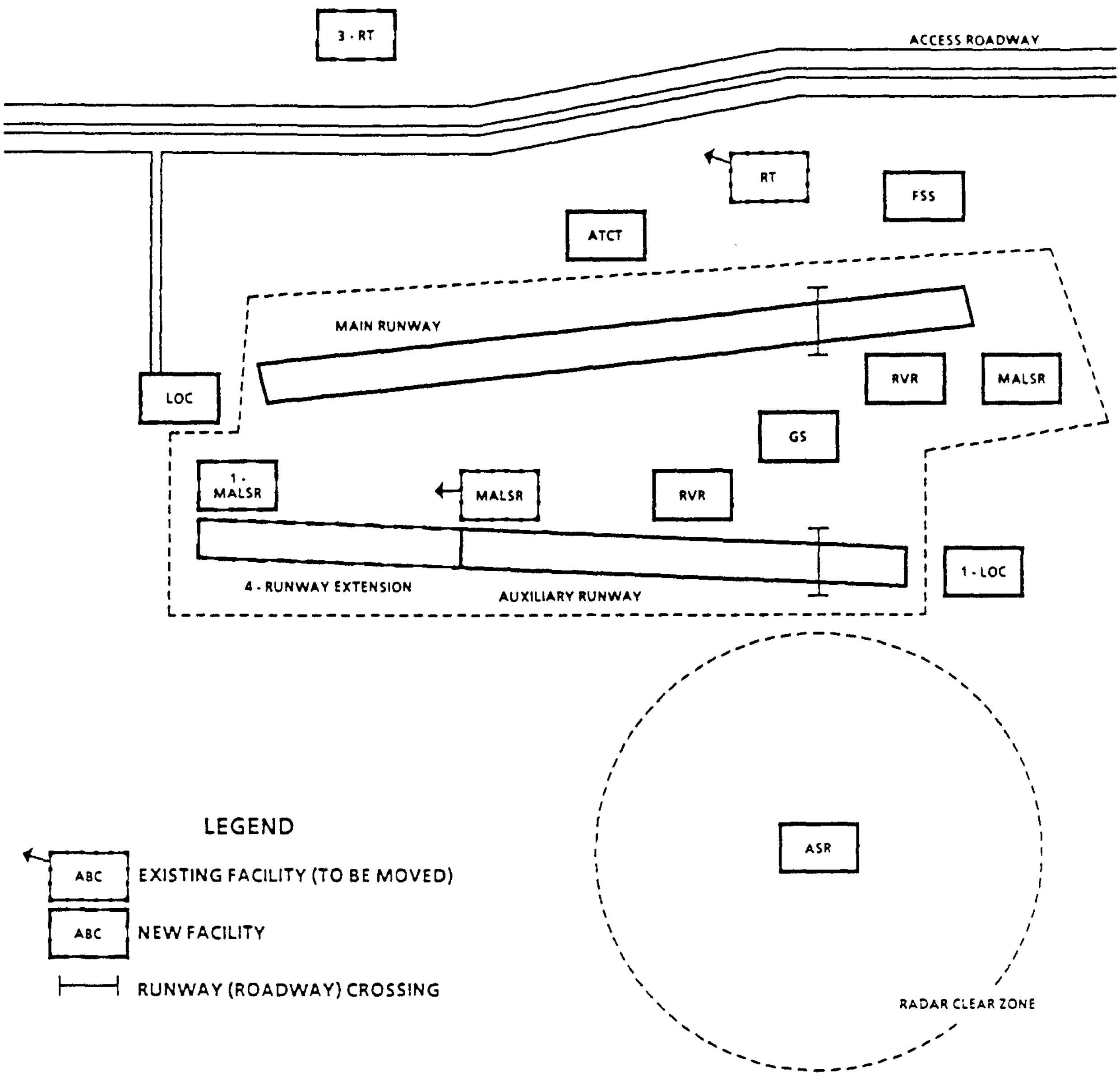
(1) Facilities to be Incorporated. Identify on the aerial photographs or copies of the airport plan drawing the facilities to be incorporated in the communications loop(s). In addition to the information given in the detailed loop layout (figure 3-5) include and identify the following: (a) relocation sites, (b) new sites, (c) proposed sites, (d) proposed installation dates, (e) proposed commissioning dates, and (f) fly-by test requirements. Note that for facilities requiring fly-by testing, the exact location is indeterminate, and could vary by plus or minus 300 feet. This process is illustrated in figure 3-7 for a hypothetical airport. This airport, modeled after Meadows Field Airport in Bakersfield, California is used throughout the remainder of this process as an example.

(2) Overall Loop Drawing. With information acquired by interviewing cognizant authorities, examining the master plan and drawings of the current airport layout, make a scaled layout of the airport. Create a first-draft communications loop system in the process, keeping in mind the possibility of utilizing existing cables and ducts as discussed in the next paragraph, or direct earth burial (DEB). Figure 3-8 shows where three basic loops are created, but which also utilize a portion of the existing duct system.

(a) Present Cable Locations. Locate and identify each of the cable paths and types of presently existing communications, power cables and ducting between the ATCT and each equipment site. Both the communications and power ducts should be shown, because with proper planning, fiber optic communication cables can share the same duct with power cables. These details should be laid out on a facility loop drawing such as shown on figure 3-6. The existing and planned facility loop drawing should show and identify current facility locations, proposed new locations for facilities to be relocated, and planned new facilities.

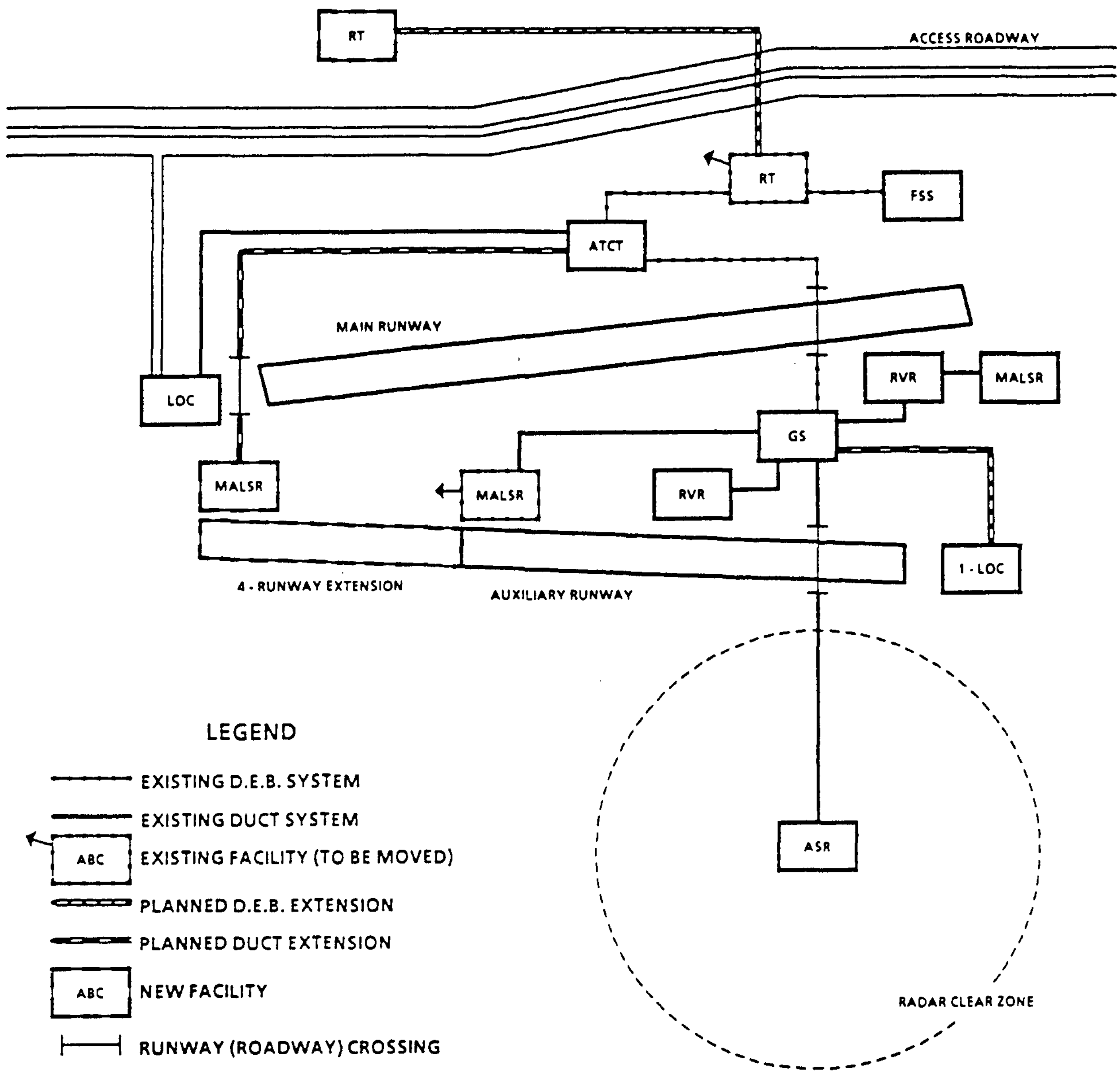
(b) Fully-Ducted Systems. An example of a fully-ducted cable loop system is shown in figure 3-8. A system of this type is far more versatile. Once the cable system enters the building restricted zone, DEB may be used. The cost effectiveness with regard to the ease and speed of recabling the loop for a faulty section should be assessed.

FIGURE 3-6. EXISTING AND PLANNED FACILITY LOCATIONS



FACILITY	DATE INSTALLED	DATE COMMISSIONED	MOVE	NEW	FLYBY REQ'D
1 - LOC				X	YES
2 - MALSR			X		NO
3 - RT				X	NO
4 - RNWY EXT				X	NO

FIGURE 3-7. IDENTIFICATION OF EXISTING AND PLANNED CABLE RUNS



(c) Manholes. Excessively long cable runs (in the order of two to three thousand feet) should be considered for direct earth burial (DEB). They should also have some service loops for maintenance or for future use, and be accessible by strategically placing manholes or handholes at about every 600 feet or fraction thereof, along the path. Round sand should be specified in the trenching operation. Round sand should tend to localize damage and in some cases may, as a result of the cable being able to move more freely between manholes, reduce the possibility of the cable from accidentally being severed during a dig up.

(3) Summary of Loop Physical Length Requirements. With the information shown in figure 3-7, prepare a tabular summary of the cable loop length requirements of all loops similar to that shown in figure 3-9. As a minimum, the table should show:

(a) Loop link from facility to facility,

(b) Loop link length,

(c) Number of manholes/handholes, and

(d) Calculated link losses for every 1000 feet at 1.1 dB at 850 nm and 0.37 dB at 1300 nm depending upon the optical wavelength used.

d. Facility Requirements. This paragraph discusses the facility requirements shown in figure 3-5 as applied to cable routing and equipment layout illustrations in figure 3-10 and figure 3-11.

(1) Cable Runs and Length. For purposes of this example, cable runs and lengths for the ATCT are shown in figure 3-10 from the entry point to the final destination on the second and fourth floors of the ATCT. All tower cab-related interfaces are assumed to be available on the fourth floor. If this is not the case, it may be advisable to consider routing them there to limit the locations of fiber optic interface equipment. All types of fiber optic cable are normally shipped on 2.2-km reels. The lengths of each link (with service and expansion allowances calculated into the total length), and the type of cable (discussed later in this section) for each link must be noted so that the proper amount of the appropriate cable can be allocated to optimize use of the cable based on 2.2-km reels.

(a) Splicing. It is recommended that when at all practicable, cables will be spliced inside a facility shelter. Open field splices should be avoided whenever possible. When it can't be avoided, low-profile, sealed above ground shelters shall be installed to house the splice enclosures. Because of the size and weight of the cable, it is both possible and practical to install full reel lengths in ducts. For paths in which numerous transitions are encountered, it is recommended that the cable be pulled out and coiled in figure-eights on the ground at convenient, intermediate manholes/handholes to limit pulling friction.

(b) Cable leader. Because the cable leader is most apt to be damaged as a result of a long tortuous cable pull, the first twenty-five feet of fiber optic cable should be discarded. An estimate of fiber attenuation utilizing optical time domain reflectometry (OTDR) techniques should be made on the fiber optic cable both before and after installation. This will help ensure that the fibers installed are continuous without flaw and should conform to allowable attenuation loss within specifications.

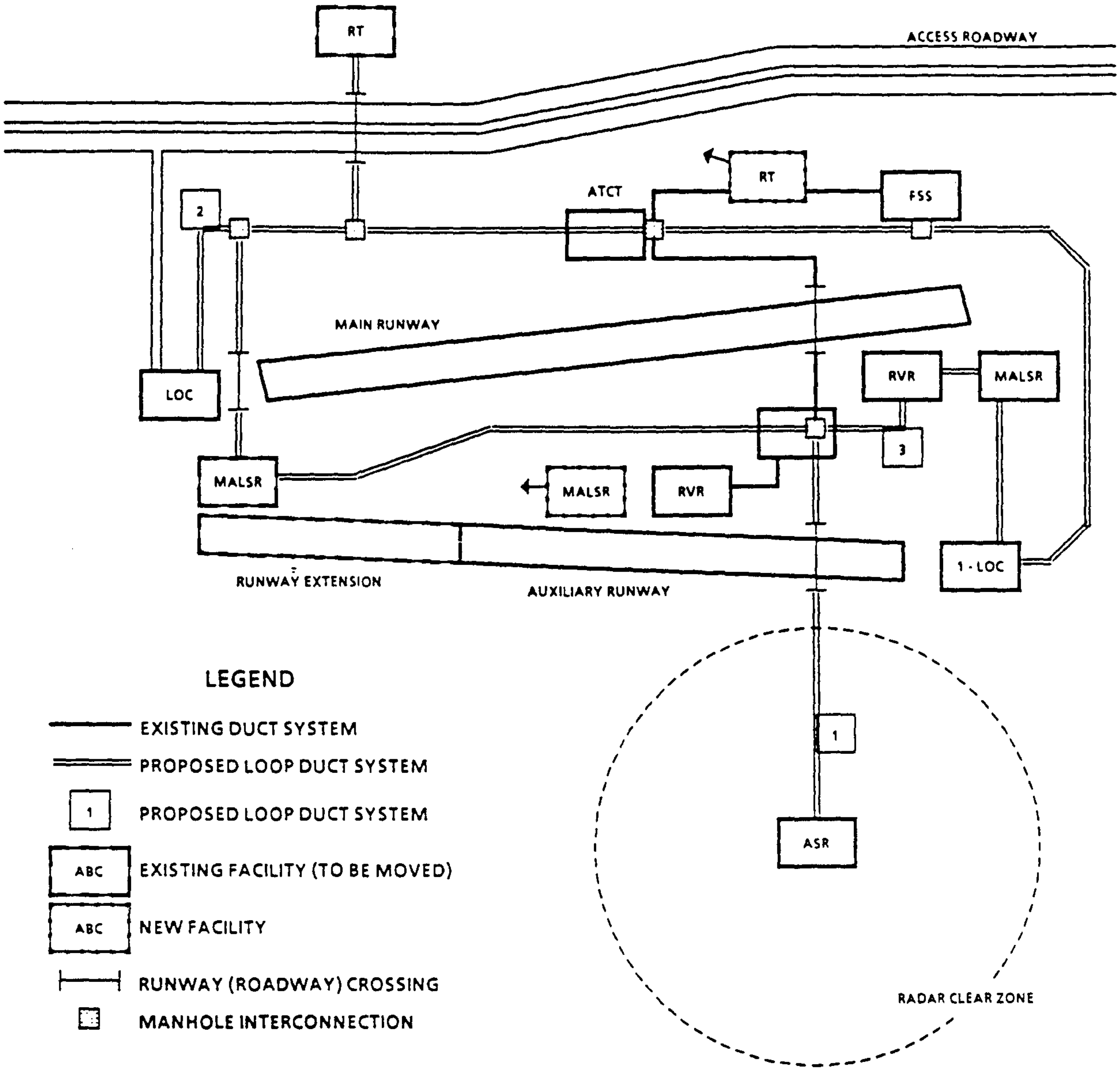
(2) Floor Plans. Sample floor plans for the second and fourth floors of the ATCT are shown in figure 3-11. The floor plans also show the location of the new fiber optic interface console and presently existing demarcation boxes. For those sites that have existing facilities with perfectly good copper conductor interconnections, it may be advisable to install a transfer switch with existing demarcation boxes that will permit easy switchover from fiber optic to copper conductor signal conveyance.

(3) Demarcation Box Signal List. It is necessary to review all cables in the demarcation box which connects that facility to all external facilities to identify each signal, its type, terminal location, input source, output destination, whether or not it passes through a transfer switch, which loop it is located in, and a brief description. This information should be tabulated similar to figure 3-12.

(4) Loop Summary. Once information of the type shown in figure 3-14 has been obtained for all facilities on each loop, a summary for each loop can be generated in a manner similar to that shown in figure 3-13. In generating this tabular summary, it is required to show each item listed with the input source identified (Input-From), and the destination (Output-To) identified as a fiber optic console at the facility listed.

(5) Standard Components.- In the design of fiber optic systems, National Procurement Specifications have been prepared. This guideline is designed to utilize as much commercially available equipment and materials as possible. In addition, many basic standard items such as cables, transceivers and video transmission equipment are expected to be available from depot stores. Appendix 1 provides guidelines for the representative configurations of airport fiber optic cable loops. Equipment selection should allow for accomodating a nominal 25 perent increase in required capacity.

FIGURE 3-8. PROPOSED LOOP DUCT SYSTEM



(6) Determining the Number of Fibers. The final and most important step in designing the communications loop layout is to detail within each loop, the number of fibers required for that loop. A diagram such as figure 3-14 must be generated for each loop, and the length and number of fibers, in increments of six must be determined. (The FAA specified cable has six fibers.) Requirements such as RMM which are known to be emerging should be allocated two fibers. A minimum of two additional fibers per link is recommended for use as spares or for future, and as yet unspecified applications.

FIGURE 3-9. FIBER OPTIC LOOP LINK LOSSES FOR THREE LOOPS

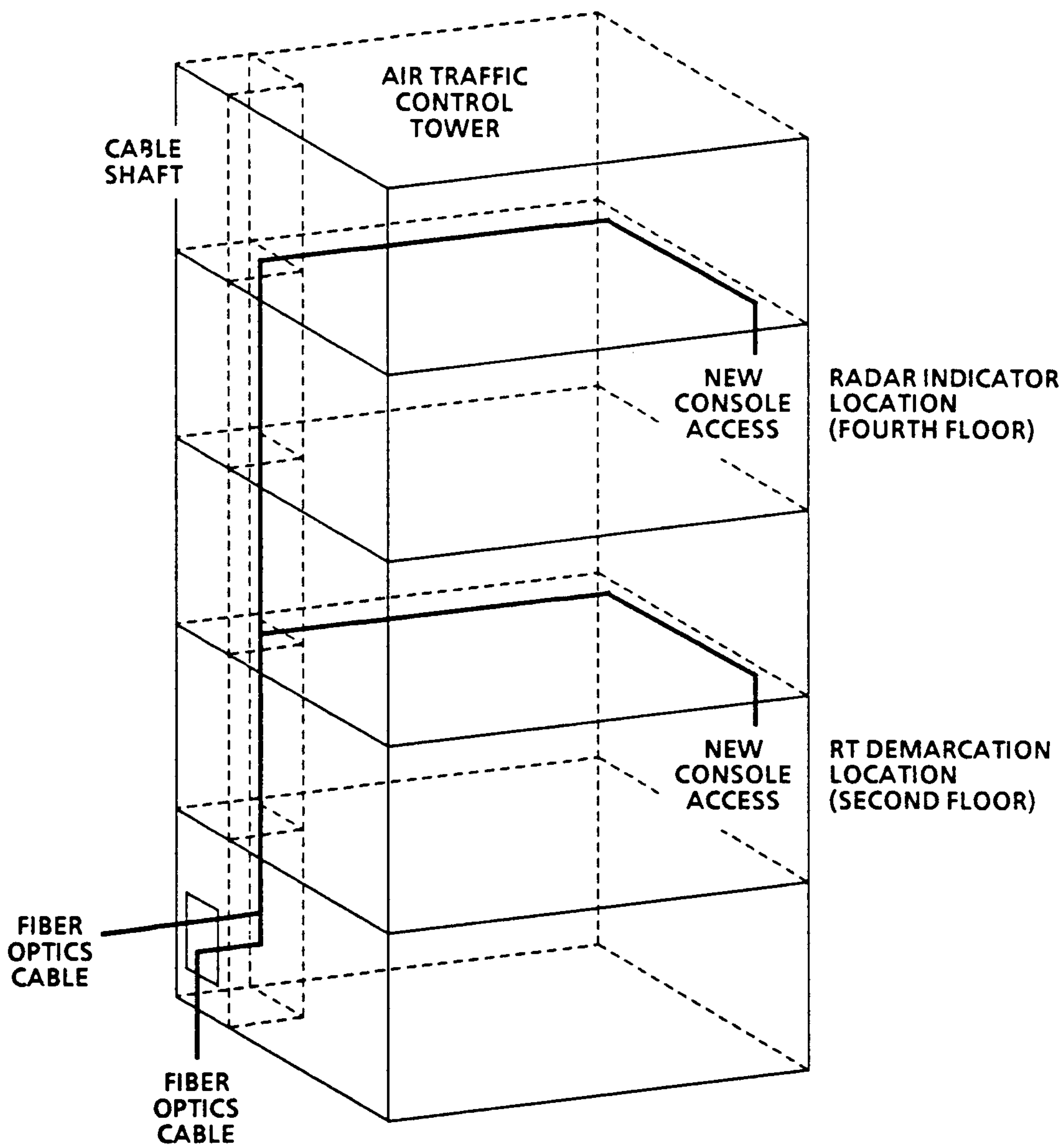
Loop	From	To	Distance (feet)	No. MH/HH	dB Losses @ 850nm	dB Losses @ 1300nm
1	ATCT	ASR	3750	3	4.2	1.2
	ASR	ATCT	3750	3	4.2	1.2
					8.4	2.4
2	ATCT	RT	1590	3	1.75	0.5
	RT	LOC(1)	2085	3	2.3	0.65
	LOC(1)	MALSR(1)	1335	2	1.5	0.45
	MALSR(1)	RVR	2000	3	2.2	0.65
	RVR	ATCT	2166	4	2.4	0.70
					10.15	2.95
3	ATCT	GS	1750	2	1.95	0.55
	GS	MALSR(2)	1000	3	1.1	0.35
	MALSR(2)	LOC(2)	835	2	0.95	0.30
	LOC(2)	ATCT	3583	3	3.95	1.15
					7.95	2.35

* For duct installation, manholes/handholes (MH/HH) are required at each facility where a building does not exist and/or every 600 feet.

** Loss = 1.1 dB/1000 feet

*** Loss = 0.31 dB/1000 feet

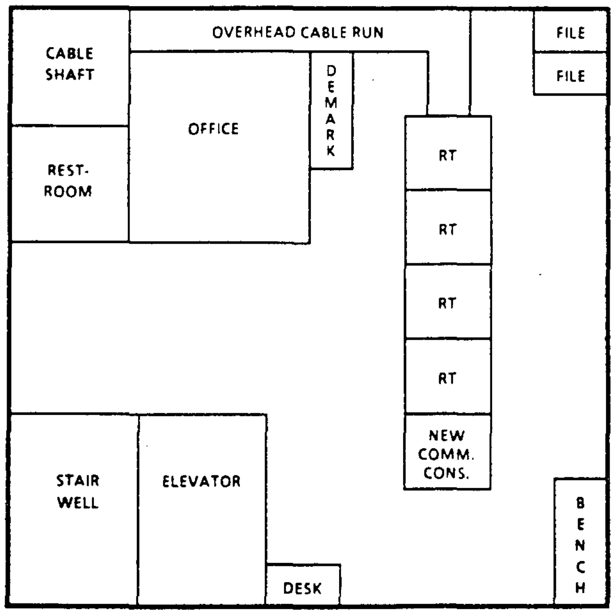
FIGURE 3-10. CABLE ROUTING WITHIN THE ATCT



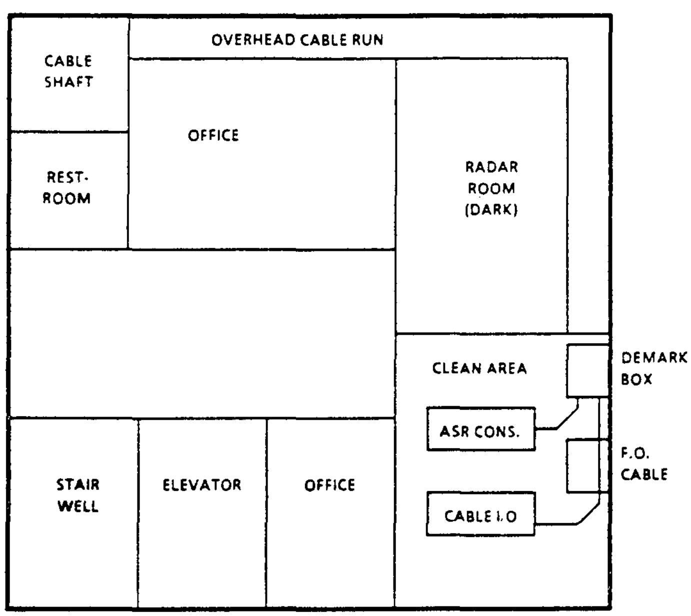
SECOND FLOOR RUN 95 FEET FROM ENTRY

FOURTH FLOOR RUN 125 FEET FROM ENTRY

FIGURE 3-11. ATCT FACILITY TYPICAL EQUIPMENT LAYOUT



SECOND FLOOR



FOURTH FLOOR

e. Choices When Planning an Installation. There are some site-dependent decisions to be made when planning a fiber optic cable installation. These decisions are concerned with the various physical types of fiber optic cable available, the type of programmable logic controller to be used, and the planned use of a channel bank for voice channel linkage with the loop.

(1) Physical Types of Fiber Optic Cable. There are several types of fiber optic cable available, the use of each is site dependent upon various physical requirements. Fiber optic cable is available armored, unarmored, and with or without a jet fuel resistant sheath. The six type classifications and respective characteristics is shown in table 3-2. Refer to FAA-E-2761a, Multimode, Multifiber, Fiber Optic Cable for recommendations on the use of each type. A flow chart to be used as an aid in planning is given in figure 3-15. It provides decision points about proper cable types, and conditions where cost savings may be realized when planning a cable loop. For example, it may not be cost effective to use Type D cable in areas of a loop where jet fuel is not likely to be spilled, use Type A instead.

TABLE 3-2. CLASSIFICATIONS OF FIBER OPTIC CABLE

Fiber Type	No. of Fibers	Mode of Installation	Armored	Resistant to		
				Rodents	Fuel Spill	Lightning
A	6	Exterior-Duct	No	No	No	Yes
B	6	Exterior-DEB	Yes*	Yes	No	No*
C/F	2	Interior only	No	No	No	Yes
D	6	Exterior-Duct	No	No	Yes	Yes
E	6	Exterior-DEB	Yes*	Yes	Yes	No*

* Use of copper counterpoise system recommended in high lightning areas.

(2) Programmable Logic Controller. A programmable controller (PLC), hereafter called a programmable logic controller or PLC, provides, monitor and control functions, multiplexing and demultiplexing, and fault isolation capability for a communications network comprised of counter-rotating rings. There are three types of PLCs, the choice of which is dependent upon capacity and processing requirements, most notably whether the PLC is to be used to reconfigure and control power where speed and interrupt capabilities are important. A brief description of each is given below, and a decision tree shown in figure 3-16 can aid in selecting the proper PLC. Additional guidance is available in FAA-E-2789, Monitor and Control, Programmable Controllers.

FIGURE 3-12. DEMARCATION BOX SUMMARY

LOCATION: ATCT BOX NO. ___________ DATE: _________ BY: ________________

Term	Signal	Input	Output	L	M	H	1	2	3	Description
1	Normal video	ASR	-	-	-	X	X	-	-	Normal video
2	Pulse	ASR	-	-	-	X	X	-	-	ASR antenna change pulse (ACP)
3	Pulse	ASR	-	-	-	X	X	-	-	ASR antenna reference pulse (ARP)
4	MTI	ASR	-	-	-	X	X	-	-	Target indicator
5	Beacon	ASR	-	-	-	X	X	-	-	Beacon
6	Tone	GS	-	-	X	-	-	X	-	Tone signal for glide slope
7	MM	ASR	-	X	-	-	X	-	-	Meter movement (1 of 6)
8	MM	ASR	-	X	-	-	X	-	-	Meter movement (2 of 6)
9	MM	ASR	-	X	-	-	X	-	-	Meter movement (3 of 6)
10	MM	ASR	-	X	-	-	X	-	-	Meter movement (4 of 6)
11	+48 VDC	-	RT	-	-	-	X	-	-	Transmitter keying (1 of 24)
12	+48 VDC	-	RT	-	-	-	X	-	-	Transmitter keying (2 of 24)

(3) Channel Bank Usage. A channel bank unit is a commercially available telephone multiplexing system. A standard configuration of a channel bank is shown on figure 3-17. Given that data modules such as EIA-232, are available, and further assuming that all signals to be transmitted are either compatible or could be made compatible to EIA-232 or voice, all general and voice communication could be transmitted using a channel bank unit. For those airports that have ASR-9 radars, there is no need for ASR video equipment, and all signals could be transmitted using the channel bank. The decision to do so should be evaluated on a site-specific basis by determining the most cost effective design with special regard for overall system reliability and performance.

46.-59. RESERVED.

FIGURE 3-13. SOURCE/DESTINATION SUMMARY FOR LOOP 1

Number of Channels		Input or Output	Type	Frequency Band	Interface Module Required	Mode of Transmission		
ATCT	ASR					ASR Video[1]	PLC[2]	Channel Bank[3]
47	31	In	+28 VDC	Low	No	-	X	-
0	1	In	+48 VDC	Low	No	-	X	-
1	7	In	AC	Low	No	-	X	-
0	6	In	Meter movement	Low	Yes	-	X	-
2	2	In	Voice	Medium	Yes	X	-	-
1	3	In	Video/triggers	High	Yes	X	-	-
0	4	In	Intermediate frequency pulse	Medium	No	X	-	-
32	39	Out	+28 VDC	Low	No	-	X	-
7	0	Out	AC	Low	No	-	X	-
6	0	Out	Meter movement	Low	Yes	-	X	-
2	2	Out	Voice	Medium	Yes	X	-	-
3	1	Out	Video triggers	High	Yes	X	-	-
4	0	Out	Intermediate frequency pulse	Medium	No	X	-	-
6	9	Out	Relay	Low	No	-	X	-

Notes:

1. Refer to ASR Video specification, FAA-E-2790.
2. Refer to Programmable Logic Controller specification, FAA-E-2789 and FAA-E-2788.
3. Refer to Channel Bank specification, FAA-E-2810 and FAA-E-2820

FIGURE 3-14. DETERMINATION OF FIBER REQUIREMENTS

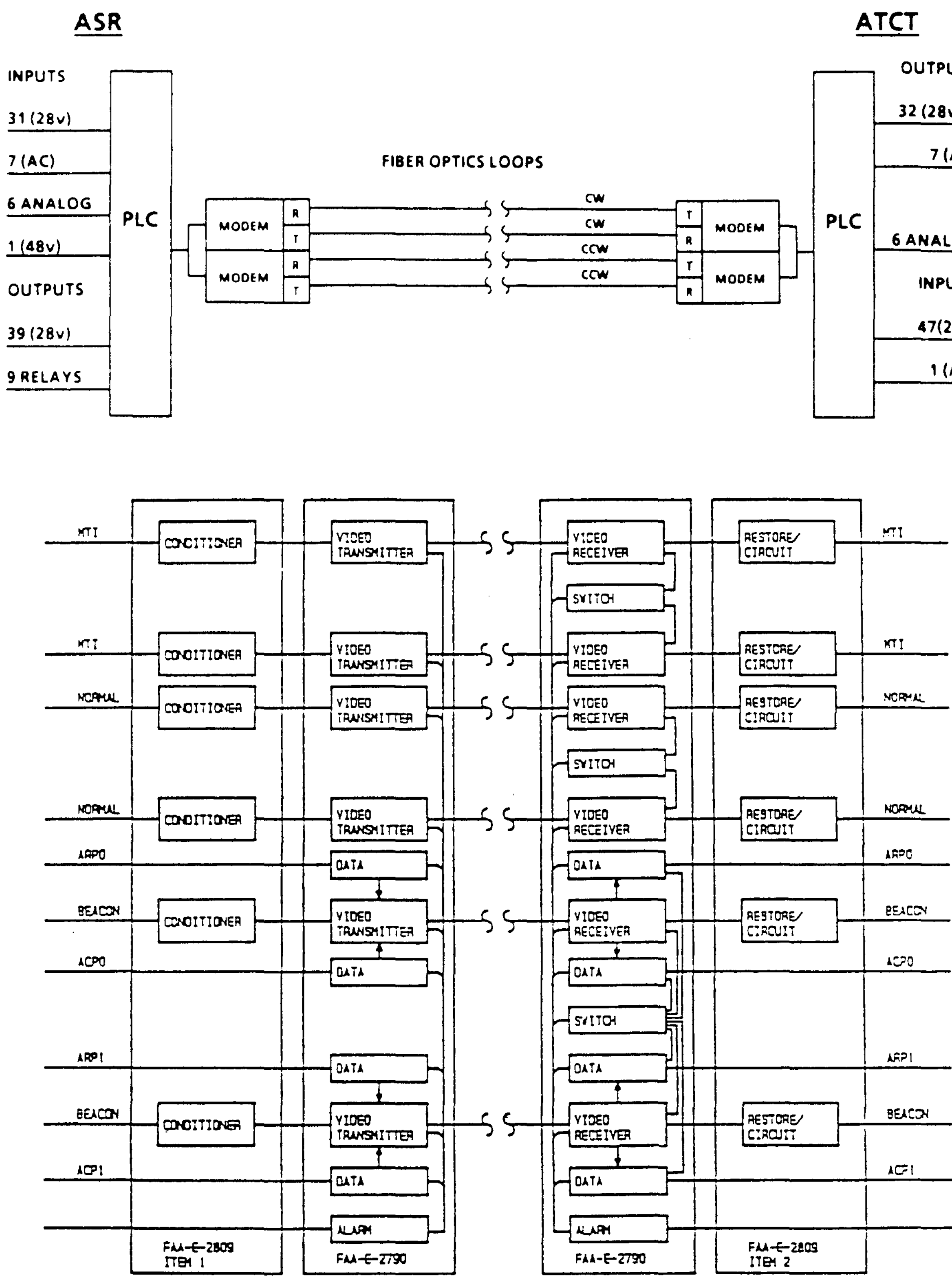
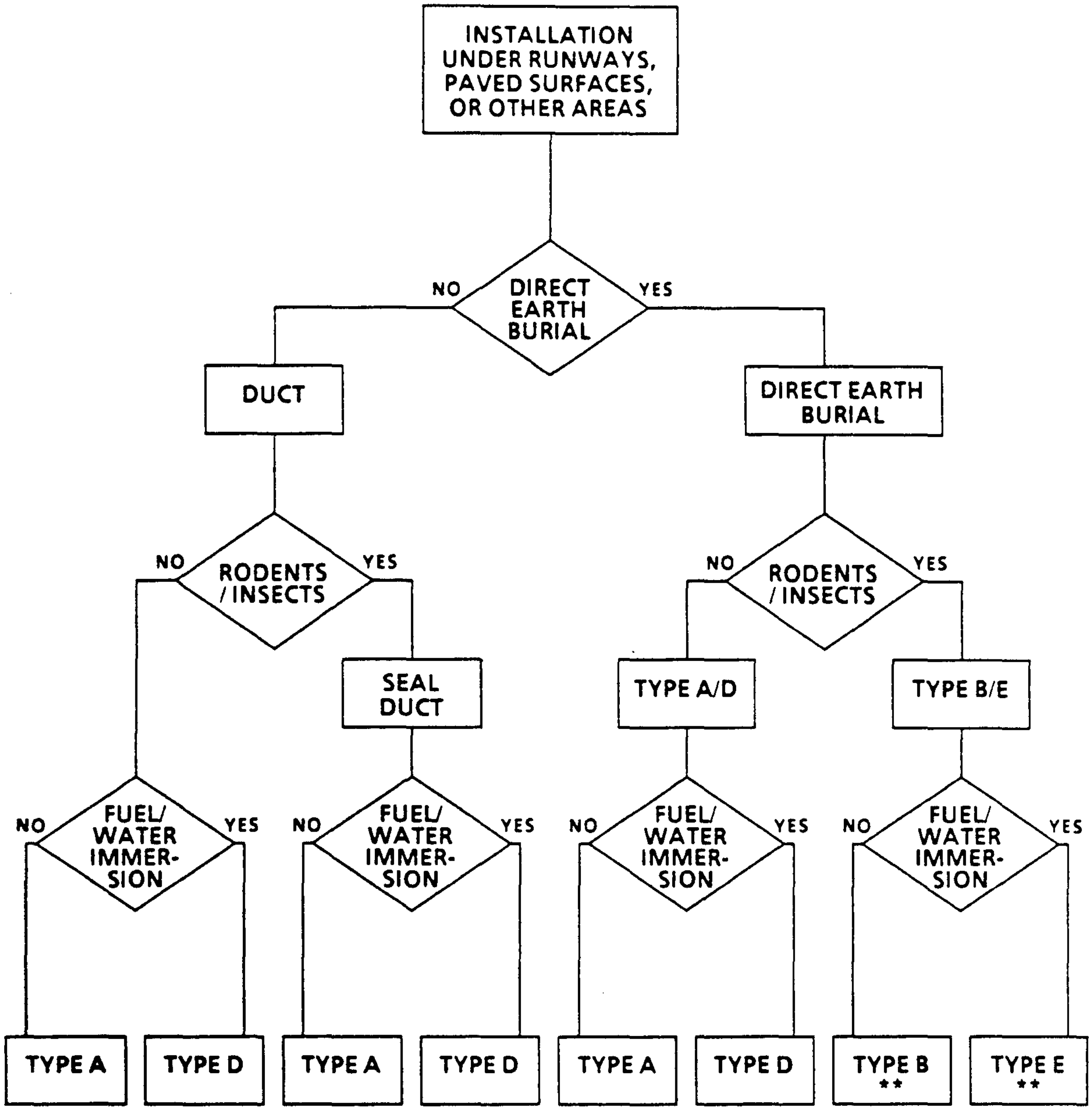


FIGURE 3-15. TYPE OF FIBER OPTIC CABLE AND RECOMMENDED INSTALLATION METHOD

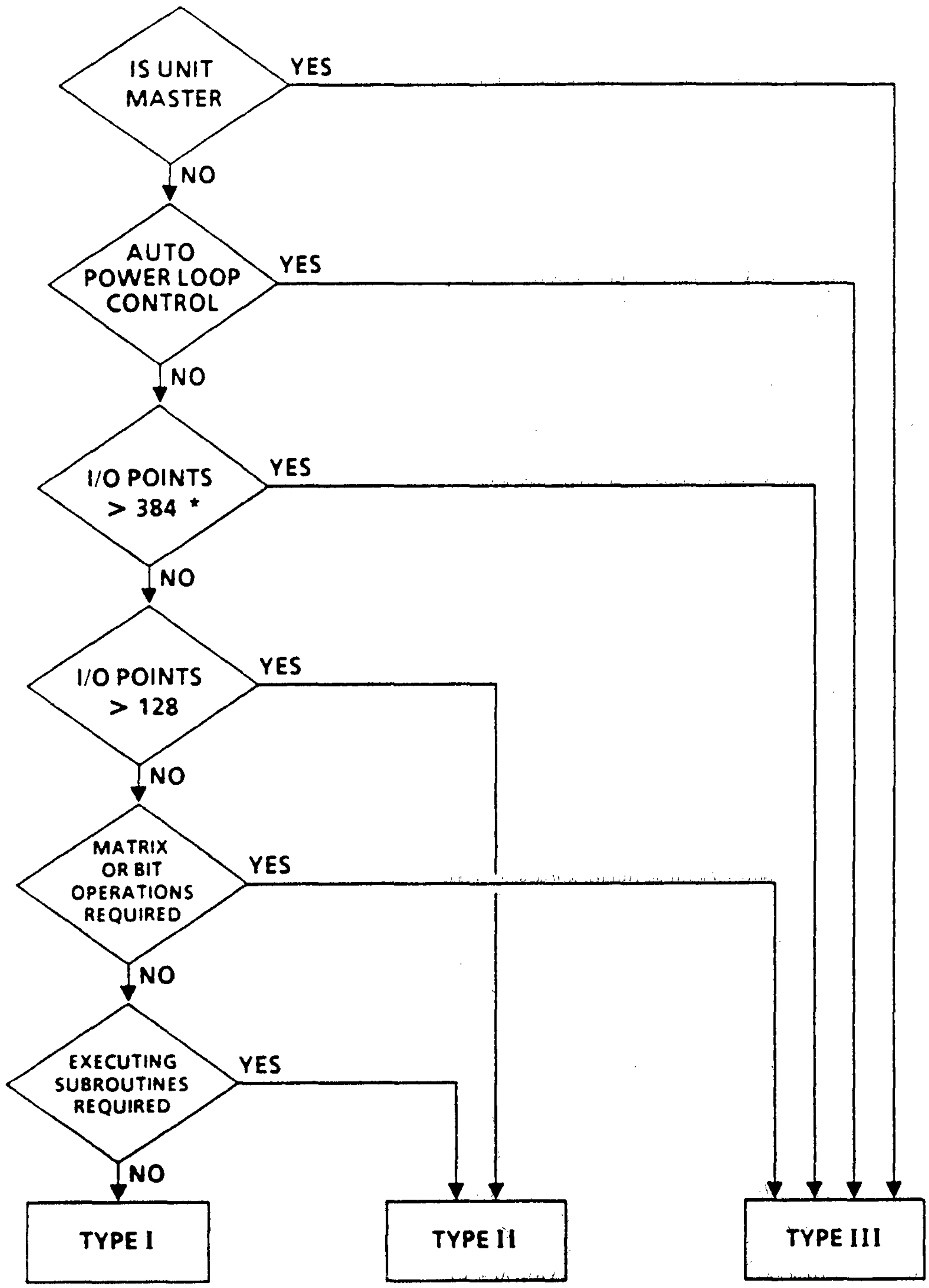


* For description of fiber optic types, see specification FAA-E-2761A.

** In areas of high-lightning activity, a copper counterpoise system shall be installed per FAA practices.

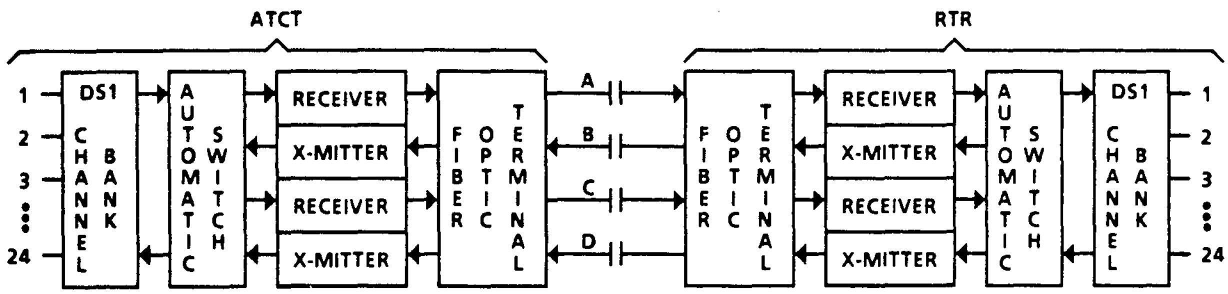
Fiber optic cable runs inside a building should use Type C or F cable.

FIGURE 3-16. PROGRAMMABLE LOGIC CONTROLLER SELECTION CRITERIA



* TYPICALLY, ANALOG I/O REQUIRES 32 POINTS PER CHANNEL

FIGURE 3-17. STANDARD INPUT/OUTPUT CONFIGURATION OF CHANNEL BANK UNIT



- FULL DUPLEX VOICE (INCLUDING SIGNALLING) CHANNELS
- DIGITAL COMMUNICATION CAPABILITY IS AVAILABLE
- EITHER, A AND B ARE ROUTED CLOCKWISE ON THE LOOP, AND, C AND D ARE ROUTED COUNTER-CLOCKWISE, OR, VICE VERSA

APPENDIX 1. CONFIGURATION GUIDELINES

1. GENERAL. This appendix presents configuration information and guidance for planning implementation of airport fiber optic cable loops. The rationale for the four configurations presented herein is discussed in detail in Chapters 2 and 3 of the Airport Fiber Optic Communications Loop Guideline. The four configurations discussed herein assume that certain equipment common to a given configuration is either available or is planned for. Each configuration identifies the basic generic components required, the number required, and the FAA specification that describes the performance requirements for the component.

2. COUNTER-ROTATING RING CONFIGURATION. The counter-rotating ring configuration is comprised of the following components at each node:

Quantity	Component	Specification
2 (1 for each loop)	Fiber Optic Transceiver	FAA-E-2788
1	Chassis and Power Supplies (+5, +15, -15, +24[b] Vdc)	FAA-E-2809, Item 6[a]
1	Modem Interface and Adjustable Delay Lines	FAA-E-2809, Item 12
1	Power Control Unit Module	FAA-E-2809, Item 5
1	Programmable Logic Controller[c]	FAA-E-2789
1	Analog Input[d] (PLC I/O)	FAA-E-2789
1	VDC Input[d] (PLC I/O)	FAA-E-2789
1	Relay Output[d] (PLC I/O)	FAA-E-2789

a At the ASR or TRACON, the chassis is specified by FAA-E-2809, Item 7.

b At the TRACON, the +24 Vdc power supply is replaced by a +35 Vdc power supply.

c At the master station (usually located at the ATCT), the PLC will be a type III. At the slave stations, the PLC will be a type I, II, or III. Generally, it will be a type I at all remote facilities except at the ASR where it will be a type II. Automatic monitor and control of a power loop may require a type III at each of the affected nodes.

d For monitor and fault isolation.

3. POINT-TO-POINT CONFIGURATION. The point-to-point configuration requires a transceiver at each site, and will require two fibers if both send and receive functions are required.

Quantity	Component	Specification
1 (at each site)	Fiber Optic Transceiver	FAA-E-2788

4. T-CARRIER WITH CHANNEL BANK CONFIGURATION. A T-carrier with channel bank capability can be configured in any of three ways; point-to-point, simple drop and insert, or a ring. When used in a network with three or more nodes, the recommended approach is to provide a redundant system which transmits in the opposite direction. The following components are required at each node.

Quantity[e]	Component	Specification
1	Multiplexer[f]	FAA-E-2810
1	T-Carrier	FAA-E-2810
1	Common Equipment	FAA-E-2810

5. MULTIPLEXING MODEM CONFIGURATION. A multiplexing modem configuration can be either a ring or a point-to-point configuration. See footnote "f" at the bottom of page 2 of this appendix. It requires the following at each node.

Quantity	Component	Specification
1 (at each node)	Multiplexing Modem with "Common" Equipment	FAA-E-2788

---

e In as much as the primary application of T-carrier channel bank equipment is for RTs, RRs or RTRs, completely independent equipment will be provided for main and standby modes irrespective of the configuration and any redundancy that it may inherently imply.

f A multiplexer, if one is required, will be an M13 (DS1 to DS3 multiplexer). The choice of M13 will ultimately be predicated upon cost considerations. In general, if the number of nodes equals, or exceeds four, M13s configured for either "drop and insert" or a ring may be justified. The numbers of fibers required to implement multiple T-1 systems is one of two principle deciding factors. The other factor is the cost differential for the additional number of lower level T-carrier fiber optic transceivers which would be required.

As in the selection of an M13 multiplexer, the selection of M12 is ultimately predicated upon cost considerations, the deciding factors for which are the same as for the M13. For example, the cost of two T-1 carrier systems may be less than one T-2 carrier system.

6. HYBRID CONFIGURATIONS. Two or more of the configurations described in paragraphs 2 through 5 can be integrated into networks. The basis of an integrated network, depending on complexity, would be either the T-carrier with drop and insert and/or the multiplexing modem with drop and insert. Figure 1 depicts a network comprised of multiplexing modems with counter-rotating ring and point-to-point elements. Figure 2 shows the use of T-carrier with drop and insert to integrate voice and systems of the type shown in Figure 1-1. With the exception of the counter-rotating rings comprised of the transceivers, the discussion and diagrams for the purpose of simplicity, do not include redundancy.

FIGURE 1-1. MULTIPLEXING MODEMS NETWORK w/Counter-Rotating Rings and Point-to-Point Elements

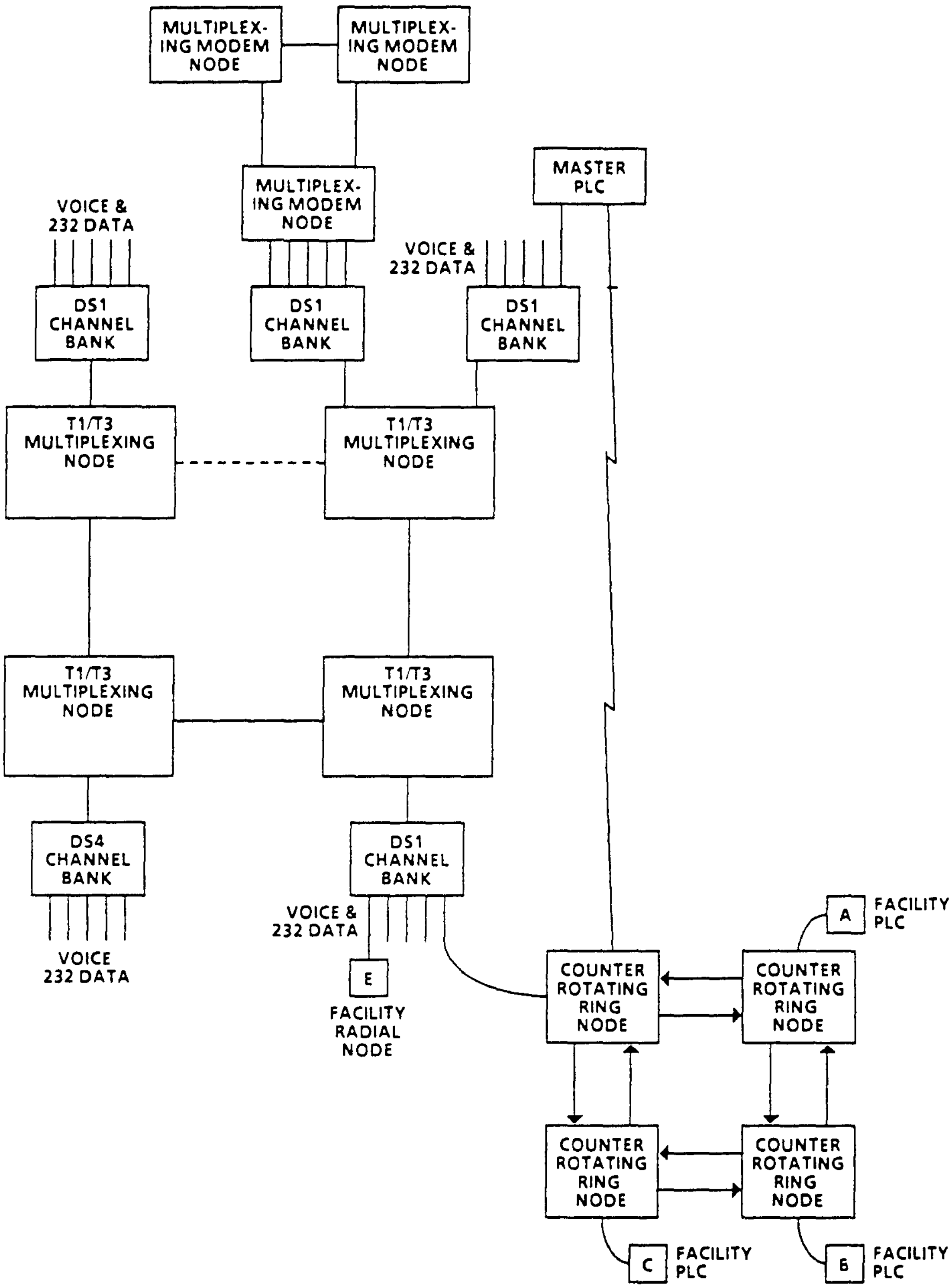


FIGURE 1-2. T-CARRIER NETWORK w/Counter-Rotating Rings and Point-to-Point Elements

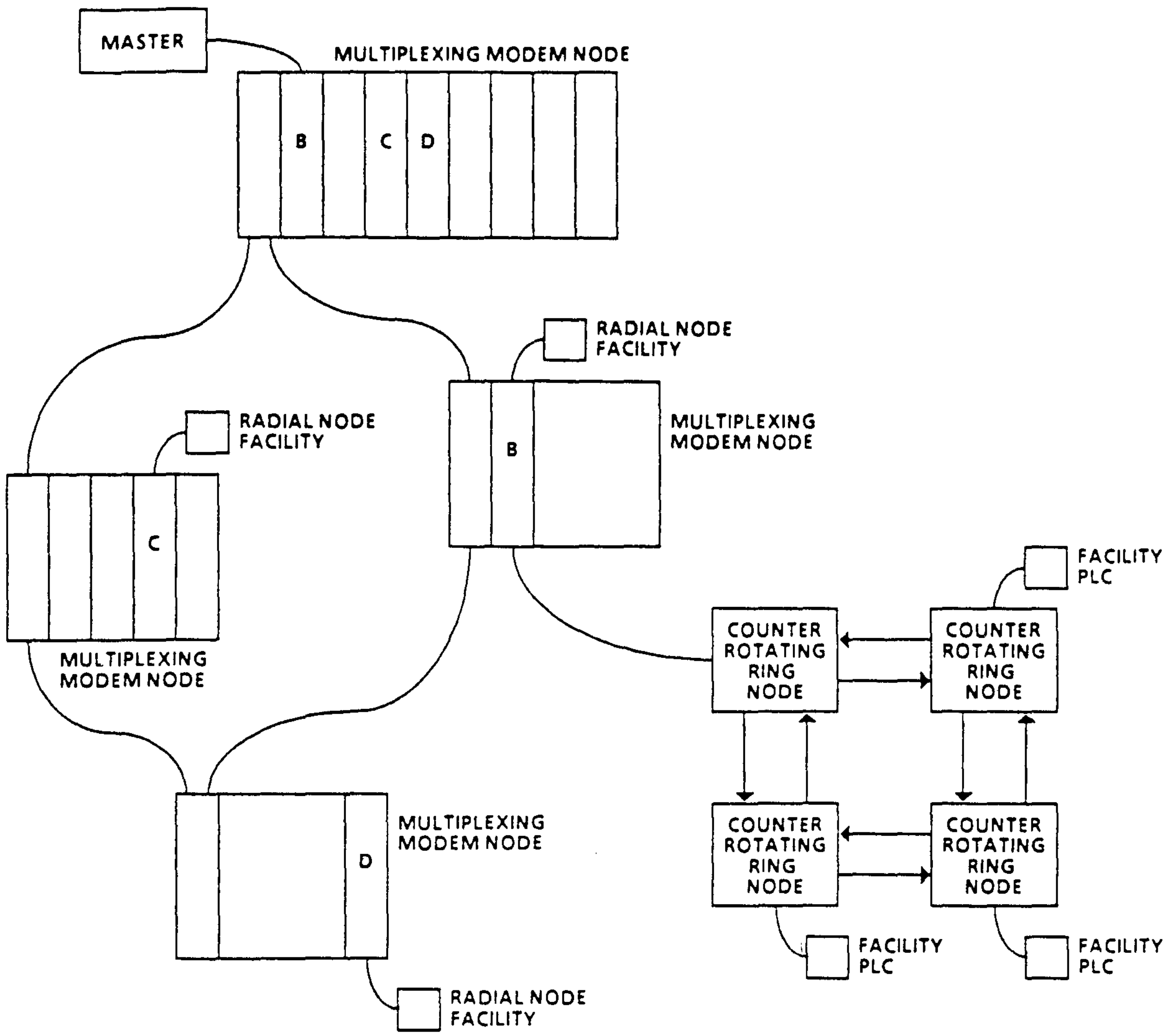


TABLE 1-1. AIRPORT SURVEILLANCE RADAR VIDEO ARP/ACP

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	Point-to-point/Loop						
		X	X	FM fiber optic video transmission system chassis with alarm control unit	2	FAA-E-2790	
		X		Video carrier transmitter module	3	FAA-E-2790	
		X		Subcarrier transmitter module	2	FAA-E-2790	
			X	Video carrier receiver module	3	FAA-E-2790	
			X	Subcarrier receiver module	2	FAA-E-2790	
		X		Video signal attenuator and pulse height limiter	2	FAA-E-2809	Item 1 (0120-board)
			X	Video amplifier and pulse height restorer module	2	FAA-E-2809	Item 2 (0119-board)
		X	X	Power control unit with power supplies (+5, +15 -15, and +35 Vdc)	2	FAA-E-2809	Item 5 (0123-board)
		X	X	Chassis	2	FAA-E-2809	Item 7 (0125-board)

TABLE 1-2. AIRPORT SURVEILLANCE RADAR ASR-4 CONTROL/READBACK

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	Point-to-point						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[g]	1	FAA-E-2789	
		X		Analog input (PLC I/O)	1	FAA-E-2789	
			X	Analog output (PLC I/O)	2	FAA-E-2789	
		X		Meter indicator isolator/ Current convertors module	2	FAA-E-2809	Item 3 (0121-board)
			X	Meter driver module	2	FAA-E-2809	Item 4 (0122-board)
		X	X	Power control unit with power supplies (5, +15, -15, and +35 Vdc)	2	FAA-E-2809	Item 5 (0123-board)
		X	X	Chassis (Host board #2)	4	FAA-E-2809	Item 7 (0125-board)
		X	X	115 Vac input (PLC I/O)	2	FAA-E-2789	8 point modules
		X	X	115 Vac output (PLC I/O)	1	FAA-E-2789	8 point modules
		X	X	28 Vdc input (PLC I/O)	4	FAA-E-2789	32 point modules
		X	X	Relay (PLC I/O)	3	FAA-E-2789	4 point modules
		X	X	28 Vdc source output (PLC I/O)	4	FAA-E-2789	8 point modules
		X	X	28 Vdc sink output (PLC I/O)	8	FAA-E-2789	8 point modules

[g]. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-3. AIRPORT SURVEILLANCE RADAR ASR-4 CONTROL/READBACK

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	Counter-rotating rings						
		X		Analog input (PLC I/O)	1	FAA-E-2789	
			X	Analog output (PLC I/O)	2	FAA-E-2789	
		X		Meter indicator isolator/ Current convertors module	2	FAA-E-2809	Item 3 (0121-board)
			X	Meter driver module	2	FAA-E-2809	Item 4 (0122-board)
		X	X	115 Vac input (PLC I/O)	2	FAA-E-2789	8 point modules
		X	X	115 Vac output (PLC I/O)	1	FAA-E-2789	8 point modules
		X	X	28 Vdc input (PLC I/O)	4	FAA-E-2789	32 point modules
		X	X	Relay (PLC I/O)	3	FAA-E-2789	4 point modules
		X	X	28 Vdc Source output (PLC I/O)	4	FAA-E-2789	8 point modules
				28 Vdc sink output (PLC I/O)	8	FAA-E-2789	8 point modules

TABLE 1-4. AIRPORT SURVEILLANCE RADAR ASR-4 CONTROL/READBACK

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	T-carrier with channel bank						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[h]	1	FAA-E-2789	
		X		Analog input (PLC I/O)	1	FAA-E-2789	
			X	Analog output (PLC I/O)	2	FAA-E-2789	
		X		Meter indicator isolator/ Current convertors module	2	FAA-E-2809	Item 3 (0121-board)
			X	Meter driver module	2	FAA-E-2809	Item 4 (0122-board)
		X	X	Power control unit with power supplies (+5, +15 -15, and +35 Vdc)	2	FAA-E-2809	Item 5 (0123-board)
		X	X	Chassis (Host board #2)	2	FAA-E-2809	Item 7 (0125-board)
		X	X	115 Vac input (PLC I/O)	2	FAA-E-2789	8 point modules
		X	X	115 Vac output (PLC I/O)	1	FAA-E-2789	8 point modules
		X	X	28 Vdc input (PLC I/O)	4	FAA-E-2789	32 point modules
		X	X	Relay (PLC I/O)	3	FAA-E-2789	4 point modules
		X	X	28 Vdc source output (PLC I/O)	4	FAA-E-2789	8 point modules
		X	X	28 Vdc sink output (PLC I/O)	8	FAA-E-2789	8 point modules
		X	X	EIA-232 module	2	FAA-E-2810	

h. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-5. AIRPORT SURVEILLANCE RADAR ASR-4 CONTROL/READBACK

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	Multiplexing modems						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[i]	1	FAA-E-2789	
		X		Analog input (PLC I/O)	1	FAA-E-2789	
			X	Analog output (PLC I/O)	2	FAA-E-2789	
		X		Meter indicator isolator/ Current convertors module	2	FAA-E-2809	Item 3 (0121-board)
			X	Meter driver module	2	FAA-E-2809	Item 4 (0122-board)
		X	X	Power control unit with power supplies (+5, +15 -15, and +35 Vdc)	2	FAA-E-2809	Item 5 (0123-board)
		X	X	Chassis (Host board #2)	2	FAA-E-2809	Item 7 (0125-board)
		X	X	115 Vac input (PLC I/O)	2	FAA-E-2789	8 point modules
		X	X	115 Vac output (PLC I/O)	1	FAA-E-2789	8 point modules
		X	X	28 Vdc input (PLC I/O)	4	FAA-E-2789	32 point modules
		X	X	Relay (PLC I/O)	3	FAA-E-2789	4 point modules
		X	X	28 Vdc source output (PLC I/O)	4	FAA-E-2789	8 point modules
		X	X	28 Vdc sink output (PLC I/O)	8	FAA-E-2789	8 point modules
		X	X	EIA-232 module	2	FAA-E-2820	

[i]. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-6. AIRPORT SURVEILLANCE RADAR ASR-7/ASR-8[j] CONTROL/READBACK

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Radar	Point-to-point						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[k]	1	FAA-E-2789	
		X	X	Power control unit with power supplies (+5, +15 -15, and +35 Vdc)	2	FAA-E-2809	Item 5 (0123-board)
		X	X	Chassis (Host board #2)	2	FAA-E-2809	Item 7 (0125-board)
		X	X	5/28 Vdc input (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	5/28 Vdc output (PLC I/O)	5	FAA-E-2789	32 point modules
	Counter-rotating rings						
		X	X	5/28 Vdc input (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	5/28 Vdc output (PLC I/O)	5	FAA-E-2789	32 point modules
	Multiplexing modems						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[k]	1	FAA-E-2789	
		X	X	5/28 Vdc input (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	5/28 Vdc output (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	EIA-232 module	2	FAA-E-2810	
	T-carrier with channel bank						
		X		PLC type II	1	FAA-E-2789	
			X	PLC type III[k]	1	FAA-E-2789	
		X	X	5/28 Vdc input (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	5/28 Vdc output (PLC I/O)	5	FAA-E-2789	32 point modules
		X	X	EIA-232 module	2	FAA-E-2810	

[j] ATCBI Requirement can be accomodated using the same I/O module as the control and readback.

[k]. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-7. AIRPORT SURVEILLANCE RADAR ASR-9

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
4-wire voice	Multiplexing modem						
		X	X	Voice module	4	FAA-E-2820	
4-wire voice	T-carrier with channel bank						
		X	X	Voice module	22	FAA-E-2810	

TABLE 1-8. MODE S ASR-7/ASR-8/ASR-9

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
4-wire voice	Multiplexing modem						
		X	X	Voice module	4[l]	FAA-E-2820	
4-wire voice	T-carrier with channel bank						
		X	X	Voice module	26[m]	FAA-E-2810	
2-wire voice	Multiplexing modem						
		X	X	Voice module	2	FAA-E-2820	
2-wire voice	T-carrier with channel bank						
		X	X	Voice module	4	FAA-E-2810	

[l] ASR-9 requirement is 2.

[m] ASR requirement is 14.

TABLE 1-9. ATCBI WITH ASR-9

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
AC/DC Discrete I/O	Multiplexing modem						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2820	
			X	PLC type III	1	FAA-E-2789	
AC/DC Discrete I/O	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2810	
			X	PLC type III	1	FAA-E-2789	

TABLE 1-10. INSTRUMENT LANDING SYSTEM
No Voice Required, But With Identification Tone

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Tones	Counter-rotating rings						
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	Tone Detect/Generate[n]	4[o]	FAA-E-2809	Item 9 (0115-board)
Tones	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
Tones	T-carrier with channel bank						
		X	X	Voice module	4	FAA-E-2810	
EIA-232	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
		X	X	EIA-232 module	2	FAA-E-2820	
EIA-232	T-carrier with channel bank						
		X	X	Voice module	2	FAA-E-2810	
		X	X	EIA-232 module	2	FAA-E-2810	

[n]. Tone generate/detect will require a different crystal reference for identification tone.

[o]. Two tone generate/detect modules per site as defined in footnote k; the other as specified in FAA-E-2809.

TABLE 1-11. INSTRUMENT LANDING SYSTEM
(No Voice Required, But With Identification Tone)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
AC/DC Discrete I/O	Counter-rotating rings						
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vac output (PLC I/O)	2	FAA-E-2789	
		X	X	Tone Detect/Generate[p]	4[q]	FAA-E-2809	Item 9 (0115-board)
AC/DC Discrete I/O	Multiplexing modems						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[o]	1	FAA-E-2789	
		X	X	Voice module	2	FAA-E-2820	
		X	X	EIA-232 module	2	FAA-E-2820	
AC/DC Discrete I/O	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[o]	1	FAA-E-2789	
		X	X	Voice module	2	FAA-E-2810	
		X	X	EIA-232 module	2	FAA-E-2810	

p. Tone generate/detect will require a different crystal reference for identification tone.

q. Two tone generate/detect modules per site as defined in footnote m; the other as specified in FAA-E-2809.

o. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-12. INSTRUMENT LANDING SYSTEM
(Voice Required)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
AC/DC Discrete I/O	Multiplexing modem						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2820	
		X	X	Voice module	2	FAA-E-2820	
			X	PLC type III[p]	1	FAA-E-2789	
AC/DC Discrete I/O	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2810	
		X	X	Voice module	2	FAA-E-2810	
			X	PLC type III[p]	1	FAA-E-2789	

p. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-13. INSTRUMENT LANDING SYSTEM
(Voice Required)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Tones	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
Tones	T-carrier with channel bank						
		X	X	Voice module	4	FAA-E-2810	
EIA-232	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
		X	X	EIA-232 module	2	FAA-E-2820	
EIA-232	T-carrier with channel bank						
		X	X	Voice module	2	FAA-E-2810	
		X	X	EIA-232 module	2	FAA-E-2810	

TABLE 1-14. INSTRUMENT LANDING SYSTEM
(No Voice, No Identification Tone Required)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
AC/DC Discrete I/O	Counter-rotating rings						
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	Tone Detect/Generate	4	FAA-E-2809	Item 9 (0115-board)
AC/DC Discrete I/O	Multiplexing modem						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[q]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2820	
AC/DC Discrete I/O	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[q]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2810	

q. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-15. INSTRUMENT LANDING SYSTEM
(No Voice Required, But With Identification Tone)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
Tones	Counter-rotating rings						
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
		X	X	Tone Detect/Generate[r]	4[s]	FAA-E-2809	Item 9 (0115-board)
Tones	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
Tones	T-carrier with channel bank						
		X	X	Voice module	4	FAA-E-2810	
EIA-232	Multiplexing modems						
		X	X	Voice module	2	FAA-E-2820	
		X	X	EIA-232 module	2	FAA-E-2820	
EIA-232	T-carrier with channel bank						
		X	X	Voice module	2	FAA-E-2810	
		X	X	EIA-232 module	2	FAA-E-2810	

[r]. Tone generate/detect will require a different crystal reference for identification tone.

[s]. Two tone generate/detect modules per site as defined in footnote r; the other as specified in FAA-E-2809.

TABLE 1-16. REMOTE MAINTENANCE MONITORING SYSTEM

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
EIA-232	Multiplexing modems						
		X	X	EIA-232 module	2	FAA-E-2820	
EIA-232	T-carrier with channel bank						
		X	X	EIA-232 module	2	FAA-E-2810	
*	Counter-rotating rings						
		X	X	Inputs[t] (PLC I/O)	x[t]	FAA-E-2789	
		X	X	Outputs[t] (PLC I/O)	x[t]	FAA-E-2789	
*	Multiplexing modem						
		X		PLC type I	1	FAA-E-2789	
		X	X	Inputs[t] (PLC I/O)	x[t]	FAA-E-2789	
		X	X	Outputs[t] (PLC I/O)	x[t]	FAA-E-2789	
			X	PLC type III[u]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2820	
*	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Inputs[t] (PLC I/O)	x[t]	FAA-E-2789	
		X	X	Outputs[t] (PLC I/O)	x[t]	FAA-E-2789	
			X	PLC type III[u]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2810	

t. Undefined.

u. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-17. RUNWAY LIGHTING SYSTEMS

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
AC/DC Discrete I/O	Counter-rotating rings						
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
AC/DC Discrete I/O	Multiplexing modem						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[V]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2820	
AC/DC Discrete I/O	Point-to-point						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[V]	1	FAA-E-2789	
AC/DC Discrete I/O	T-carrier with channel bank						
		X		PLC type I	1	FAA-E-2789	
		X	X	Vac or Vdc input (PLC I/O)	2	FAA-E-2789	
		X	X	Vac or Vdc output (PLC I/O)	2	FAA-E-2789	
			X	PLC type III[V]	1	FAA-E-2789	
		X	X	EIA-232 module	2	FAA-E-2810	

[V]. In general, a single type III PLC at the ATCT will serve all remote facilities.

TABLE 1-18. RUNWAY VISUAL RANGE
(Transmissometer)

Type of Interface	Communication System	Sensor Site	Indicator Site	Component	Qty	Reference Specification	Comments
	Counter-rotating rings						
		X		Runway visual range - Load simulator module	1	FAA-E-2809	Item 10 (0117-board)
		X		Relay output (PLC I/O)	1	FAA-E-2789	
		X	X	24 Vdc input (PLC I/O)	2	FAA-E-2789	
			X	Analog output (PLC I/O)	1	FAA-E-2789	
			X	Runway visual range - Pulse train generator module	1	FAA-E-2809	Item 11 (0118-board)
	Point-to-point						
		X		Runway visual range - Load simulator module	1	FAA-E-2809	Item 10 (0117-board)
			X	Runway visual range - Pulse train generator module	1	FAA-E-2809	Item 11 (0118-board)
	Multiplexing modem						
		X		Runway visual range - Load simulator module	1	FAA-E-2809	Item 10 (0117-board)
		X	X	EIA-232 module	2	FAA-E-2820	
			X	Runway visual range - Pulse train generator module	1	FAA-E-2809	Item 11 (0118-board)
	T-carrier with channel bank						
		X		Runway visual range - Load simulator module	1	FAA-E-2809	Item 10 (0117-board)
		X	X	EIA-232 module	2	FAA-E-2810	
			X	Runway visual range - Pulse train generator module	1	FAA-E-2809	Item 11 (0118-board)

APPENDIX 2. ACRONYMS, UNITS OF MEASURE AND RELATED DOCUMENTATION

1. PURPOSE. This appendix provides a list of acronyms, units of measure and a list of FAA and other documents that are related to the cable loop guideline.

2. ACRONYMS. The following is a list of acronyms for facilities, equipment and operations discussed in the guidelines.

ASR	Airport surveillance radar
ALSF	Approach lighting system with flashers
APD	Avalanche photodiode
ATCT	Air traffic control tower
BER	Bit error rate
ccw	Counterclockwise
cw	Clockwise
DEB	Direct earth burial
DME	Distance measuring equipment
EIA	Electronic Industries Association
GS	Glide slope
HH	Handholes
ILS	Instrument landing system
IM	Inner marker
LED	Light-emitting diode
LOC	Localizer
MALSR	Medium-intensity approach lighting system with runway alignment indicator lights
MH	Manholes
MM	Middle marker
MTI	Moving target indicator
NA	Numerical aperture
NAS	National airspace system
NRZ	Non-return-to-zero
OM	Outer marker
OTDR	Optical time domain reflectometry
PCM	Pulse-code modulation
PLC	Programmable controller
PPI	Plan position indicator
RCE	Radio control equipment
RF	Radio frequency
RMMS	Remote maintenance monitoring system
RTR	Remote transmitter/receiver
RVR	Runway visual range
SNR	Signal-to-noise ratio
TRACON	Terminal radar approach control
VOR	VHF omnidirectional range

3. UNITS OF MEASURE. The following units of measure are used in this guideline:

a. nm = 10^{-9} meter = one billionth of a meter

b. μm = 10^{-6} meter = one millionth of a meter

c. mm = 10^{-3} meter = one thousandth of a meter

d. km = 10^{3} meters = one thousand meters

e. MHz = 10^{6} hertz = one million hertz

f. dB = ten times the ratio of power levels expressed as a logarithm to the base 10.

4. RELATED DOCUMENTS. The following is a list of FAA specifications, standards and orders and other documents for equipment and procedures related to this guideline.

a. Specifications.

FAA-C-1217	Electrical Work, Interior,
FAA-C-1391	Installation and Splicing of Underground Cables
FAA-E-2761	Fiber Optic Cable, Multimode, Multifiber
FAA-E-2788	RS-232 Transceiver, Fiber Optic
FAA-E-2789	Programmable Controllers
FAA-E-2790	Airport Surveillance Radar Transmission System, Video, Fiber Optic
FAA-E-2809	Airport Facility Fiber Optic Interface
FAA-E-2810	T-Carrier w/Drop and Insert, Fiber Optics
FAA-E-2820	Modem, Fiber Optic, Multiplexing, Drop and Insert

b. Standards.

FAA-STD-020	Transient Protection, Grounding, Bonding and Shielding Requirements for Equipment

c. Orders.

FAA 6950.26	Airport Selection Criteria for Power and Signal Distribution

d. Other publications.- The following documents of the issue in effect form a part of this guideline and are applicable to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this guideline, the contents of this guideline shall be considered a superseding requirement.

NFPA-70 **National Electrical Code**, (NFPA Publications. National Fire Protection Association, Batterymarch Park, Quincy, MA 02269)

NFPA-78 Lightning Protection Code, (NFPA Publications. National Fire Protection Association, Batterymarch Park, Quincy, MA 02269)

APPENDIX 3. GLOSSARY

The following definitions describe operations, equipment functions or protocols pertinent to this guideline. Definitions for other terms not given in this glossary may be found in the latest release of the FAA Glossary, Order 1000.15.

Abrasive: Any of a number of materials, such as aluminum oxide, silicon carbide, etc., that are carefully graded according to particle size and are used to shape and/or finish optical elements, including optical fiber connectors and endfaces. Abrasive materials differ from polishing materials in both particle size and the action they have on the workpiece. Abrasive particles are much larger than polishing particles, and remove glass by a fracturing action. Polishing materials cause a molecular surface flow of workpiece material to produce the final optical finish. See Microfinishing Film.

Absorption: The conversion of radiant energy into other forms or wavelengths by interaction with matter.

Absorption Band: A spectral region in which the absorption coefficient reaches a maximum, by virtue of the physical properties of the matter in which the absorption process takes place.

Absorption Coefficient: The fraction of incident radiation absorbed by a material in a specified path length.

Acceptance Angle: Half the vertex angle of the largest cone within which optical power may be coupled into the bound modes of an optical waveguide.

Angstrom (symbol: Å): An obsolete unit of optical wavelength. One angstrom is equal to 10^{-10} meter.

Angular Misalignment Loss: Optical power loss that occurs when the longitudinal axes of two connecting fibers (or a fiber and optical source) are not coincident, but rather are at a slight angle with respect to each other.

APD: Avalanche Photodiode.

Aramid (yarn): Generic name for a tough synthetic yarn ("Kevlar," Du Pont trade name) often used for the protective braid in optical cable construction.

Area Loss. A loss of optical power at a splice or pair of mated connectors due to a mismatch in size (cross-sectional area) or shape, or lateral misalignment, of the cores of the mating fibers. See Gap Loss, Fresnel Loss.

Attenuation: A diminishing of optical power, usually expressed in decibels (dB). Often used as a synonym for attenuation coefficient.

Attenuation Coefficient: The rate of diminution of optical power with distance along an optical fiber. It is usually expressed in decibels (dB) per kilometer.

Attenuation-Limited Operation: The condition that prevails when fiber attenuation, rather than bandwidth, limits system operation. See Bandwidth-Limited Operation.

Avalanche Multiplication: A current-multiplying phenomenon that occurs in a semiconductor diode that is reverse-biased just below its breakdown voltage. Under such a condition, electrons (e.g., photocurrent) are swept across the junction with sufficient energy to ionize additional bonds, creating more electron-hole pairs in a regenerative action.

Avalanche Photodiode (APD): A solid-state photodiode that takes advantage of avalanche multiplication of the photocurrent. See Avalanche Multiplication.

Axial Ray: A ray that travels along the optical axis of a fiber. Also see Meridional Ray, Skew Ray.

Axis: A straight line about which an object or geometric figure is symmetrical or may be supposed to rotate.

Backscattering: Scattering of light in a direction having a component opposite from its original direction of propagation. See Scattering.

Bandwidth (of an electronic device): The lowest frequency at which the electrical transfer function of the device decreases to a specified fraction of the zero-frequency value. The specified fraction is usually one-half the zero-frequency (power) value (3-dB decrease).

Bandwidth (of an optical fiber): The lowest modulation frequency at which the fiber's transfer function decreases to a specified value of the zero-frequency value. The specified fraction is usually one-half the zero-frequency value. IMPORTANT NOTE: Optical detectors such as PIN diodes are square-law devices; i.e., the output photocurrent is proportional to the detected optical power. But because electrical power is proportional to the square of the current, when optical power drops by one-half (3 dB) the electrical power produced by the detected signal drops by 6 dB (One-half times one-half equals one-fourth, or 6 dB.)

Bandwidth-Limited Operation: The condition that prevails when fiber bandwidth, rather than loss (attenuation) limits performance.

Baseband Modulation: Modulation of an optical source (LED or ILD) directly, without first impressing (modulating) the signal of interest onto an RF (electrical) carrier.

Beam: A column of light. It may be parallel. diverging or converging.

Beamwidth (of light): The angle subtended by the extreme rays of a beam of light; the vertex angle of a cone defined by a nonparallel beam of light.

Bidirectional Transmission: Simultaneous transmission of optical signals in opposite directions over a single fiber.

Bound Mode: A mode of propagation in an optical fiber that is confined to the core of the fiber; a mode that propagates indefinitely. Strictly speaking, in single-mode fibers, the one bound mode does have a significant fraction of its total energy traveling in the cladding. A treatment of this may be found in advanced references.

Bound Ray: Synonym for Bound Mode, Guided Ray.

Buffer: See Fiber Buffer.

Cable: See Optical Cable.

Channel Bank: A group of voice-frequency communications channels multiplexed for simultaneous transmission over a single communications path. A modern digital carrier multiplexes 24 voice or data channels (with supervisory signals) onto a single 1.544-Mbit data stream. See DS-1 and Time Division Multiplexing.

Cladding: The dielectric material surrounding the core of an optical fiber. It is usually of glass, and has an index of refraction slightly lower than that of the core. It may also be of plastic (not to be confused with the polymer overcoat of a glass-clad fiber).

Cladding Mode: A mode of propagation that is confined to the cladding by virtue of the fact that the surrounding medium (air or polymer overcoat) has a lower index of refraction than the cladding. Cladding modes are undesirable in most applications. Modern fibers usually have a polymer overcoat with an index of refraction slightly higher, rather than lower, than that of the cladding, in order to strip off cladding modes after only a few centimeters of propagation. See Snell's Law, Total Internal Reflection.

Cladding Mode Stripper: Any device or material that encourages the radiation, and thus the loss, of cladding modes.

Cladding Ray: Synonym for Cladding mode.

Coherent Light: Light in which the phase relationship between points in a beam remains constant throughout the duration of the beam.

Concentricity Error: The distance between the center of the core and the center of the cladding. More specifically, when a tolerance field is used to define the boundaries of the core and the cladding, the distance between the center of the pair of circles defining the core and the center of the pair of circles defining the cladding. Also called Core-Cladding Offset. See Tolerance Field.

Connector: A demountable device for attaching an optical waveguide (fiber) to another fiber (or to an active device such as a transmitter). It is distinguished by the fact that it may be disconnected and reconnected, as opposed to a splice, which is generally considered a permanent joint between two fibers.

Convergence: In optics, an approach, or closing, of the rays of a beam of light as they propagate; e.g.; to a focus.

Core: The central part of an optical fiber, through which light is transmitted. (Strictly speaking, in certain cases a significant fraction of the energy in a bound mode does travel in the cladding. Discussion of this may be found in advanced reference material.)

Core Area: The cross-sectional area of the core, defined by the refraction boundary between the core and the cladding. In an ideal fiber it is usually perfectly circular. In a realizable fiber, it will not be, but rather will be an approximately circular area.

Core-Cladding Offset: See Concentricity Error.

Coupler: See Directional Coupler, Star Coupler.

Coupling Efficiency: The amount (percentage or fraction) of optical power transferred from one optical component (active or passive) to another.

Coupling Loss: The power loss, usually expressed in decibels, that occurs when light is transferred from one optical component (active or passive) to another.

Critical angle: The smallest angle of incidence, with respect to the normal at a refractive boundary, that will support total internal reflection. See Snell's Law.

Cutback Technique: A method of measuring the loss of an optical fiber by first measuring the level of optical power emerging from the full length of a long fiber, and then cutting the fiber near the optical source, and measuring the amount of optical power emerging from this short pigtail. The power lost in the cut-off length is determined by the difference between the two power readings.

In a related method of measuring fiber loss, used in field practice, the fiber under test is disconnected from the optical source, and a short length of fiber having the same optical characteristics (core size and numerical aperture) is substituted. A reference reading, representing the launched optical power level, is taken. The fiber under test is then reconnected, and a power reading taken at the distant end. The difference between this reading and the reference reading is the fiber loss.

These methods of measuring loss are straightforward and easy to perform, but suffer from inaccuracies that usually indicate a higher transmission loss than a more accurate technique would yield.

Cutoff Frequency: In any active or passive device, the frequency at which the transfer function falls below a specified level. In electronics practice, the specified level is usually taken to be the half-power, or 3 dB, point. Also see Bandwidth (of an electronic device) and Bandwidth (of an optical fiber).

Dark Current: The electrical current that flows, under given bias conditions, in a photosensitive device (detector) when there is no incident radiation.

Detection: In communications practice, the conversion of an electromagnetic wave into an electrical signal. Conventional radio waves are usually detected by heterodyning; that is, they are coherent waves that are mixed in some sort of nonlinear device with a signal from a local oscillator to produce an intermediate (beat) frequency, which is then detected. As of 1986, there is no commercially-available lightwave communications transceiver that operates by heterodyne detection, because of the inherent instabilities in available optical sources. Optical detection is always direct; that is, by the received signal impinging directly onto a detector. See Modulation.

Dichroic Mirror (Filter): A mirror, or filter, that reflects one or more optical bands or wavelengths and transmits others, while maintaining a nearly zero coefficient of absorption for all the wavelengths of interest.

Dielectric: An electrical insulator. Characteristic of substances in which an electric field can be maintained with zero or near-zero power consumption.

Direct Detection: See Detection.

Directional Coupler (Optical Directional Coupler): A three- or four-port passive optical coupler, in which a single optical input may be distributed to two outputs, or two inputs may be combined into a single output, or two outputs. Sometimes called a splitter, or optical splitter. See Star Coupler, Tee Coupler.

Dispersion: Temporal spreading of an optical signal in a fiber. There are two major dispersion mechanisms in an optical fiber: Chromatic (Material) Dispersion, and Waveguide Dispersion.

Another major mechanism that causes temporal spreading of the optical signal is intermodal distortion (intermodal delay distortion), sometimes improperly referred to as modal, or intermodal, dispersion.

Chromatic dispersion occurs by virtue of the fact that different wavelengths propagate at different velocities through the bulk material (glass) of which the fiber is made. Because the optical signal necessarily has a finite spectral width (line width), not all of its component wavelengths propagate along the fiber at precisely the same velocity, resulting in temporal spreading of the signal. In the first (850-nanometer) window, chromatic dispersion amounts to approximately 0.1 nanosecond, per nanometer of optical bandwidth, per kilometer of fiber length. In the second (1.3-micron) window, it approaches zero. See Index of Refraction, Zero-Dispersion Wavelength (Window).

Intermodal (delay) distortion occurs in multimode fibers because not all modes in a given multimode fiber (step-index or graded-index) propagate at precisely the same velocity. It limits the bandwidth of a typical 50-micron-core step-index fiber to approximately 20 megahertz for a one-kilometer length (i.e., a bandwidth of 20 megahertz-kilometer). It limits the bandwidth of a typical 50-micron core off-the-shelf graded-index fiber to approximately 1 gigahertz-kilometer, although multimode fibers having bandwidths approaching 3 gigahertz-kilometer have been produced.

Waveguide dispersion is extremely small compared to the preceding mechanisms and is of interest only in single-mode fibers. Because the velocity of the single propagating mode depends on the ratio a/λ, where a is the core radius and λ is the wavelength, a small spreading occurs in an optical signal of finite bandwidth even in the absence of chromatic dispersion. In a realizable fiber, chromatic dispersion is always present to some degree, but with proper fiber design and construction, waveguide dispersion and chromatic dispersion may be made to cancel one another over a very narrow band.

Dispersion-Shifted Fiber: An optical fiber that has its minimum-dispersion window shifted, by the addition of dopants, to coincide with its minimum-attenuation window. The engineering tradeoff is a slight increase in the minimum attenuation coefficient. This type of fiber is useful in very-long-distance, broadband telecommunications applications. See Minimum-Attenuation Window, Minimum-Dispersion Wavelength (Window).

Distortion: A change of shape of the signal waveform from one or more mechanisms. See Dispersion, Intermodal Distortion.

Divergence: In optics, a spreading of the rays of a beam away from one another as they propagate.

Dopant: An impurity added to an optical medium to change its optical properties.

Drop and Insert: As used herein, a multiplexer that can receive (drop) or add (insert) data from one or more channels in a multiplexed communications link without demodulating (demultiplexing) other channels.

DS-1: The basic North American and European data rate (1.544 Mb/s) for digital telephone carrier (T-Carrier). It is capable of transmitting twenty-four digitally multiplexed voice channels, with supervisory signals.

EIA-232-D: A commonly-used serial binary digital interface between data terminal equipment (DTE) and data communications equipment (DCE), for transmission at low data rates (under 20 kb/s). For a complete description, see Electronic Industries Association specification EIA-232-D.

EIA-422-A: A specification describing the electrical characteristics of balanced voltage digital interface circuits. For a complete description, see Electronic Industries Association specification EIA-422-A.

Electrical Bandwidth: See Bandwidth (electrical).

Electro-optic: Referring to the electro-optic effect, a change in refractive index of a material under the influence of an electric field. Sometimes erroneously used as a synonym for optoelectronic. See Optoelectronic.

EMD: Abbreviation for Equilibrium Mode Distribution.

Equilibrium Length: The length of (multimode) fiber necessary to establish equilibrium mode distribution (EMD). It varies from fiber to fiber and may range from a fraction of a kilometer to a kilometer and a half or more.

Equilibrium Mode Distribution (EMD): A condition in a multimode fiber wherein after propagation has taken place for a certain distance (equilibrium length), the outermost (highest order) modes in the fiber core are stripped off by such mechanisms as microbending, etc., and only the innermost (lowest order) modes continue to propagate. In a stricter sense, the condition wherein the input numerical aperture equals the output numerical aperture.

In a typical 50-micron core multimode fiber, light propagating under equilibrium conditions occupies approximately the middle seven-tenths of the core and has a numerical aperture approximately seven-tenths that of the full numerical aperture of the fiber.

Expanded-Beam Connector: A fiber optic connector that employs a miniature positive lens to collimate the diverging cone of light emitted by an optical fiber. A similar lens in the mating connector reconverges the collimated light to a focus at the core of the connecting fiber.

The expanded-beam connector has the advantage that because of the large cross-sectional area of the expanded beam, small lateral misalignments, including those from connector wear, are relatively insignificant. This connector may thus be remated many times without appreciable deterioration in performance. The engineering tradeoff of the expanded-beam connector is that the alignment of the fiber end, relative to the focal point of the miniature lens, is extremely critical.

Fiber: Optical fiber.

Fiber Buffer: A material (component) used to protect an optical fiber from mechanical and/or chemical damage. Not to be confused with the fiber's primary polymer overcoat, this protection takes one of two forms: an additional plastic coating in intimate contact with the overcoat, similar to electrical insulation on a wire ("Tight Buffering") or a miniature plastic tube, having an inside diameter several times the diameter of the fiber's polymer overcoat, in which the coated fiber lies ("Loose Buffering").

Fiber Optics: The branch of optics concerned with the transmission of light through thin fibers (filaments) of transparent dielectric materials such as glass or plastic.

f-Number (f/#, f-#): The ratio of the effective focal length of a lens to the diameter of the lens. See Numerical Aperture.

Frequency-Division Multiplexing: A process in which each signal modulates a separate subcarrier. Subcarriers are spaced in frequency, allowing the simultaneous transmission of two or more signals over a common communications channel; e.g., an optical fiber.

Fresnel (Reflection) Loss: A loss of optical power that takes place, especially at a pair of mated connectors, but also to a lesser degree at splices, due to Fresnel reflection. The effect is normally greatest at mated connectors because of the boundary conditions at the small air gap between the mating fibers. In some applications it is alleviated by the use of an index-matching gel to eliminate the air space. In splices, if the refractive indices of the mating fibers do not match perfectly, Fresnel reflection will also occur. When mechanical splices are secured by an adhesive, an optical adhesive having a refractive index approximating that of the mating fibers is used to minimize Fresnel loss. See Fresnel Reflection. Also see Area Loss, Gap Loss.

Fresnel Reflection: A reflection that takes place at the boundary between two optical media having different indices of refraction; e.g., a glass-air boundary such as the end of an optical fiber. For a normal ray, the Fresnel reflection coefficient is obtained from the following formula:

$$r = [(n_1 - n_2)/(n_1 + n_2)]^2, \text{ where}$$

n_1 is the index of the medium having the lower index of refraction and n_2 is the index of the medium having the higher index of refraction. For a glass-air in-terface, n_2 may be considered to equal 1.

Full-Width (Duration) Half Maximum (FWHM): One way of defining or measuring the extent of a function. It is expressed as the difference between the values of the independent variable at which the dependent variable is one-half its maximum value (e,g., the line width of an optical source).

Fusion Splice: A splice (permanent joint) made by carefully aligning the mating fibers under a microscope and fusing (melting) them together, usually with an electric arc. See Mechanical Splice.

FWHM: Abbreviation for Full Width Half Maximum.

Gap Loss: The loss that occurs when optical power is transferred from one fiber to another that is axially aligned with it but longitudinally separated from it. This allows light from the "transmitting" fiber to spread out, and enter the cladding of the "receiving" fiber, where it is quickly lost. See Area Loss, Fresnel (Reflection) Loss.

Geometric (Geometrical) Optics: The treatment of light propagation as rays perpendicular to the electromagnetic wavefront.

Germanium Photodiode: A germanium-based PN- or PIN-junction photodiode useful for direct detection of optical wavelengths from one micron to several tens of microns. It is usually doped with materials such as boron, indium, etc., to modify its properties. Germanium detectors are noisier than silicon detectors, which are preferred for wavelengths shorter than one micron. See Silicon Photodiode.

Giga- A prefix denoting one billion (10^9).

Glass: Technically, a state of matter. In fiber optics, any of a number of noncrystalline, amorphous inorganic substances, formed by heating, from metallic or semiconductor oxides or halides.

Graded-Index Optical Fiber (Waveguide): An optical fiber having a nonuniform refractive index within the core. See Graded Index Profile.

Graded Index Profile: Descriptor denoting an optical fiber having a core with an index of refraction that decreases as a function of distance from the fiber axis. It is obtained by plotting the refractive index (ordinate, or "y" direction) against the distance from the fiber axis (abscissa). In an ordinary multimode graded-index fiber, the ideal index profile is very nearly a perfect parabola. The graded profile partially compensates for intermodal distortion in multimode fibers. See Refractive Index, Intermodal Distortion.

Guided Wave (Ray, Mode): Synonyms for Bound Mode.

Hockey Puck: Colloquial term for a fixture used to manually polish the endface of certain types of optical connectors. It consists of the appropriate mating sleeve for the connector in question, mounted at right angles in the center of a disk of stainless steel or other hard material. When the unpolished connector, secured to the optical cable, is mounted in the fixture, excess material (fiber end, epoxy bead, excess connector length) protrudes from the opposite side of the disk. The excess is then ground away as the fixture is swept to and fro, usually in a figure-8 pattern, on a piece of microfinishing film supported by a substrate of plate glass. Three or four grades of microfinishing film, with abrasive particles ranging in size from 15 microns to 0.3 micron, are commonly used.

Hybrid Cable: See Optical Cable.

Incoherent Light: A beam of light that lacks a fixed, or constant, phase relationship between the various waves in the beam.

Index-Matching Material: A substance, usually a liquid, cement (adhesive), or gel, that has an index of refraction that closely approximates that of the fiber, and is used to reduce Fresnel reflection at a fiber endface.

Index of Refraction: Synonym for Refractive Index.

Index Profile: Refractive index profile. See Graded Index Profile.

Infrared: The region of the electromagnetic spectrum that lies between the longest visible waves (approximately 700 nanometers) and the shortest microwaves (approximately 1 millimeter).

Injection Laser Diode (ILD): A laser that uses a forward-biased semiconductor junction as the active (lasing) medium.

Integrated Optical Circuit (IOC): A hybrid or monolithic optical circuit having both active and passive components and performing the dual functions of the electrical-optical interface and signal processor.

Intermodal Dispersion: A term incorrectly used for Intermodal Distortion, Intermodal Delay Distortion.

Intermodal Distortion: Intermodal delay distortion. A distortion mechanism, similar to dispersion in its effect on the optical signal, that occurs in multimode optical fibers. Because different modes have slightly different propagation times, the signal undergoes a temporal spreading that ultimately limits fiber bandwidth performance. Sometimes incorrectly referred to as intermodal dispersion. See Dispersion.

IOC: Abbreviation for Integrated Optical Circuit.

Laser: Acronym for Light Amplification by Stimulated Emission of Radiation. A device that produces highly coherent optical radiation by means of population inversion and an optical cavity to produce positive feedback.

Laser Diode: Synonym for Injection Laser Diode.

Lateral Offset Loss: A loss of optical power at a splice or connector caused by a lateral offset of the mating fiber cores. This allows some of the light from the "transmitting" fiber to enter the cladding of the "receiving" fiber, where it is quickly lost.

Lay Length: In a communications cable (optical or metallic) having the conducting media wrapped helically around a central member, the longitudinal distance along the cable required for one complete helical turn; conversely, the total cable length divided by the total number of turns. In optical cables, the lay length is usually shorter than in metallic cables, to avoid overstressing the fibers during installation (pulling).

LED: Abbreviation for Light-Emitting Diode.

Light: In the strictest sense, the portion of the electromagnetic spectrum that is visible to the normal human eye (approximately 400 nanometers to 700 nanometers). Now customarily held to include the infrared spectrum to a wavelength of tens of microns.

Light-Emitting Diode (LED): A solid-state diode employing a forward-biased PN junction that emits incoherent light.

Line Width: See Spectral Width.

Loose Buffer: A protective plastic tube, having an outside diameter of approximately 2 to 3 millimeters and an inside diameter much larger than the primary coating of the optical fiber, which lies loosely inside it. The loose buffer tube often is filled with a gel, resembling petroleum jelly in consistency, that lubricates and tends to float the fiber. It also prevents water intrusion in the event the buffer tube is breached. The loose buffer tube is commonly, but not exclusively, used in trunk cables. In such cables a number of loose buffer tubes, with their fibers enclosed, are spun around a central strength member, and protected by a braid of aramid yarn and an outer jacket.

Macrobend: A Large-radius bend in an optical fiber. It will result in no significant radiation loss if it is of sufficiently large radius. The definition of "sufficiently large" depends on the type of fiber. Single-mode fibers, which have low numerical apertures, are more sensitive than other types and may require a minimum bend radius (e.g., in a splice tray) of not less than 2 1/2 to 3 inches (6 1/2 to 7 1/2 centimeters). A fiber of the type specified for FAA applications (50/125, 0.20 NA) will typically require a minimum bend radius of not less than 1 1/2 inches (4 centimeters).

Maxwell's Equations: A set of four partial differential equations developed by James Clerk Maxwell (ca. 1873) which expand upon and unify the laws of Ampere, Faraday, and Gauss, and which form the foundation of modern electromagnetic theory. They describe and predict the behavior of electromagnetic waves in free space, in dielectrics, and at conductor-dielectric boundaries. See Mode.

Mechanical Splice: A splice (permanent joint) accomplished by aligning the mating fibers in some kind of mechanical fixture, and (usually) securing them in it with an adhesive. See Fusion Splice.

Meridional Ray: A ray that passes through the fiber axis, as opposed to a skew ray, which does not. See Axial Ray, Skew Ray.

Micro-: Prefix denoting one-millionth (10^{-6}).

Microbends: Very small, sharp curves imparted to a fiber by the processes of coating, cabling, etc., and which cause radiative losses and mode coupling.

Microbend Loss: See Microbends.

Microfinishing Film: A thin film of dimensionally stable plastic, coated with carefully graded abrasive powders having dimensions in the micron and submicron range, used commercially to produce an extremely high polish on machined parts. Also used to grind and polish the endfaces of certain types of optical connectors.

Micrometer (pronounced micro-meter, sometimes abbreviated um): A unit of length equal to one-millionth of a meter (10^{-9} meter), and commonly used to express optical wavelengths greater than 1000 nanometers.

Micron (μ, um): Micrometer (micrometer).

Millimicron: Obsolete name for the nanometer.

Minimum-Dispersion Window: The transmission window of an optical fiber at which the chromatic (material) dispersion is essentially zero. More precisely, the window (in a single-mode fiber) at which chromatic and waveguide dispersion cancel one another, resulting in extremely wide bandwidth. For ordinary silica-based fibers, this window occurs at a wavelength of approximately 1.3 microns, but it may be shifted by dopants to coincide with the minimum-loss window. See Dispersion, Dispersion-Shifted Fiber, Minimum-Loss Window, Refractive Index.

Minimum-Loss Window: The transmission window of an optical fiber at which the attenuation coefficient is at a theoretical (quantum-limited) minimum. It is the point at which the Rayleigh-scattering attenuation curve and the infrared phonon-absorption curve intersect. For ordinary silica-based fibers, this wavelength is approximately 1.55 microns. See Rayleigh Scattering, Phonon Absorption.

Mode: In any cavity comprised of conductor-dielectric boundaries (e.g., a conventional microwave cavity) or dielectric-dielectric boundaries (e.g., an optical fiber), any electromagnetic field distribution that satisfies the wave equation derived from Maxwell's equations and the given boundary conditions; i.e., an allowed path of propagation, represented mathematically by the eigenvalues of the solutions of the wave equation for the given boundary conditions. See Maxwell's Equations.

Modal Dispersion: A term sometimes improperly applied to modal distortion (i.e., intermodal distortion). See Dispersion, Intermodal Distortion.

Mode Coupling: In a multimode optical fiber, a power exchange between propagating modes due to perturbations in the fiber. In graded-index fibers, this phenomenon reaches a statistical equilibrium (equilibrium mode distribution) after propagation over some finite distance (equilibrium length). See Equilibrium Mode Distribution, Equilibrium Length.

Mode Scrambler: Any device used to induce mode coupling in an optical fiber. One practical use for such a device is to obtain an even distribution of propagating modes from an optical source, for making transmission loss measurements.

Modulation: A controlled variation with time of any property of an electromagnetic wave, for the purpose of transmitting information. At the present time (1986) there is no practical, commercially-available means of coherently modulating a lightwave in the same sense that radio waves are modulated. Light is always modulated by what may be called "amplitude intensity modulation;" that is, no matter what the form, if any, of modulation of the electrical signal being transmitted by the lightwave, it is the intensity of the lightwave that convey the information. There are no sidebands in the normally-understood sense of the word, because optical sources, even "monochromatic" ones, are too unstable to permit ordinary sideband generation and heterodyne detection.

Monochromatic: Consisting of only one wavelength or color. In practice, no lightwave is ever perfectly monochromatic. There is always a band of frequencies (wavelengths), however narrow. When used, the term is understood to mean an extremely narrow band of optical wavelengths, on the order of a fraction of a nanometer.

Multifiber Cable: An optical cable having two or more fibers, each of which is capable of serving as an independent optical transmission channel.

Multimode Distortion: See Intermodal Distortion.

Multimode Optical Fiber: An optical fiber that allows more than one bound mode of propagation.

Multiplexing: Any process for combining and simultaneously transmitting multiple communications channels over a common medium, and separating them at the received end. See Frequency-Division Multiplexing, Time-Division Multiplexing, Wavelength-Division Multiplexing.

NA: Abbreviation for Numerical Aperture.

Nano-: A prefix denoting one-billionth (10^{-9}).

Nanometer: A unit of length equal to one-billionth part of a meter, and commonly used to express optical wavelengths of less than one micron (micrometer).

Noncircularity: A term used to specify or describe the cross section of an optical fiber. It is sometimes referred to as Ovality. It refers to the degree of deviation from a perfect circle, of the cladding or the core-cladding boundary. If the cross section is assumed to be elliptical, noncircularity is defined as:

$$2\frac{\{(\text{Major axis})-(\text{Minor axis})\}}{\{(\text{Major axis})+(\text{Minor axis})\}}$$

The above fraction is usually multiplied by 100, to express noncircularity as a percentage.

Numerical Aperture: (1) In an imprecise but commonly-used expression, numerical aperture is the sine of the acceptance angle (one-half of the acceptance cone) of an optical fiber. (2) The sine of the vertex angle of the largest cone of meridional rays that can enter or leave an optical element (including an optical fiber), multiplied by the index of refraction of the medium in which the cone is located. (3) In a graded-index optical fiber, numerical aperture is defined as the square root of the difference between the square of the axial refractive index of the core and the square of the refractive index of the cladding.

Optical Cable: A communications cable containing one or more optical fibers (waveguides). It may be an all-fiber cable or contain both optical fibers and metallic conductors (hybrid cable).

Optical Coupler: See Directional Coupler, Star Coupler.

Optical Fiber: In a broad sense, any dielectric filament that guides light. In a stricter sense, a dielectric filament of carefully controlled design, composition and construction intended for use as an electromagnetic waveguide at optical frequencies.

Optical Heterodyning: See Optical Mixing.

Optical Link: An optical transmission channel designed to connect two end terminals. Sometimes held to include the end terminals.

Optical Mixing (Heterodyning): Optical beating. The mixing (heterodyning) of two lightwaves (incoming signal and local oscillator) in a nonlinear device to produce a beat frequency low enough to be further processed by conventional electronic circuitry. The optical analog of superheterodyne reception of radio signals. As of 1986, a technique still being explored in the laboratory, with no commercial application.

Optical Receiver: An apparatus that receives an optical signal, detects it, and processes the resulting electrical signal as required.

Optical Time-Domain Reflectometer (OTDR): An optoelectronic instrument used to characterize an optical fiber. It works by first injecting short (a few tens of nanoseconds) optical pulses into the fiber and then measuring the intensity of the backscattered signal as a function of time. From this information a plot is made of optical power level versus distance along the fiber, giving a transmission loss profile of the fiber, and an estimate of its total length. It is a useful tool for estimating (and only estimating) the fiber attenuation coefficient and overall loss, and losses caused by local defects, splices and connectors, and the distance to such defects or to a fiber break.

Optical Transceiver: An apparatus that combines the functions of an optical transmitter and optical receiver.

Optical Transmitter: An apparatus that accepts an electrical signal as its input, processes this signal, and uses it to modulate an optoelectronic device (LED or laser diode) to produce an optical signal capable of being transmitted via an optical fiber.

Optical Waveguide: Optical Fiber.

Optoelectronic: Pertaining to a device that functions an electrical-optical or optical-electrical transducer.

Ovality: A term used to specify or describe the cross section of an optical fiber. It refers to the degree of deviation from a perfect circle, of the cladding or the core-cladding boundary. See Noncircularity.

PCS (Fiber): Abbreviation for Plastic Clad Silica (Fiber).

Peak Spectral Emission: See Peak Wavelength.

Peak Wavelength: The wavelength at which the radiant intensity of an optical source is at a maximum.

Phonon: A quantum of vibrational energy.

Phonon Absorption: Absorption of light by its conversion to vibrational energy. Phonon absorption determines the fundamental (quantum) limit of attenuation of silica-based glasses in the far infrared region. Also see Rayleigh Scattering.

Photoconductivity: An increase in electrical conductivity, exhibited by some materials, which results when free carriers are generated by the electronic transitions caused by the absorption of photons.

Photocurrent: The electrical current that flows in a photosensitive device due to exposure to radiant energy. See Dark Current.

Photodiode: A (solid-state) diode in which the flow of electrical current is produced or enhanced by the absorption of light. See Avalanche Photodiode (APD), Positive-Intrinsic-Negative (PIN) Diode, Germanium Photodiode, Silicon Photodiode.

Photon: A quantum of electromagnetic energy.

Photon Noise: See Quantum Noise.

Pico-: Prefix for one-trillionth (10^{-12}).

Pigtail: A short length of optical cable or fiber that is permanently affixed to an active or passive device (e.g, an LED or connector), and used to couple the device to a longer fiber (e.g., in a trunk cable), usually by a splice.

PIN Diode (Photodiode): Abbreviation for Positive-Intrinsic-Negative Diode (Photodiode).

Plastic-Clad Silica Fiber: An optical fiber that has a silica-based core and a plastic cladding (not to be confused with the primary polymer overcoat of an all-silica-based fiber). Not normally used for telecommunications purposes.

Polling: A communications control procedure in which a master station queries slave stations.

Positive-Intrinsic-Negative (PIN) Diode (Photodiode): A semiconductor diode that has a relatively large intrinsic (i.e., undoped or neutral) region between the P- and N-doped regions. Photons are absorbed in the intrinsic region and create electron-hole pairs that are separated by the applied bias voltage, thus generating a current in the load circuit.

Preform: A large glass rod, approximately 4 centimeters in diameter by two meters long, from which an optical fiber is drawn. The refractive index profile of the preform determines the profile of the fiber that is drawn from it.

Primary Coating: The polymer overcoat is deposited onto the cladding of an optical fiber immediately after drawing as part of the drawing process. This coating typically has an outside diameter of approximately 250 to 500 microns, and serves to protect the fiber from mechanical damage and chemical attack. It also enhances its optical properties by stripping off cladding modes, and in the case where multiple fibers are used inside a single buffer tube, it prevents cross-coupling of optical signals from one fiber to another. This coating should not be confused with a tight buffer or the plastic cladding of a plastic-clad-silica (PCS) fiber. See Loose Buffer, Plastic-Clad-Silica (PCS) Fiber, Tight Buffer.

Profile: Refractive index profile (of an optical fiber). See Graded Index Profile.

Quantum-Limited Operation: In an optical communications system, operation in which the minimum detectable signal is limited by quantum (photon) noise. An ideal condition not realized in practice. See Quantum Noise.

Quantum Noise: In optical communications, the noise attributable to the particle nature of light. It represents the fundamental limit to the signal-to-noise ratio of an optical communications system. A synonym for photon noise.

Radiation Angle: Half the vertex angle of the cone of light emitted by an optical fiber, or by an optical source such as an LED.

Radiative Mode: An unbound mode; any mode that is not confined to the core of the fiber, and thus does not propagate indefinitely.

Rayleigh Scattering: Scattering of light that is caused by refractive index inhomogeneities that are small compared to the wavelength. The amount of scattering is inversely proportional to the fourth power of the wavelength. Rayleigh scattering represents the dominant fundamental limitation on fiber transparency at short (ultraviolet, violet) wavelengths.

Ray: A geometric representation of a lightwave by a line normal to the electromagnetic wavefront. See Geometric Optics.

Refraction: The bending of a non-normal beam of light as it passes through the boundary (interface) between two media having different indices of refraction, or through a medium whose index of refraction is a continuous function of position (e.g., the core of a multimode graded-index fiber). See Refractive Index (of an optical medium).

Refractive Index (of an optical medium; symbol, n): The ratio of the speed of light in a vacuum, to the speed of light in the medium. Synonym for index of refraction. The refractive index varies with different materials, and also varies with wavelength in a given material. For example, in ordinary silica-based glasses, the refractive index is highest for violet light. It decreases in a nearly linear fashion (linear slope) through the visible red and into the infrared region just beyond. This phenomenon gives rise to chromatic, (material) dispersion of the optical signal. Further in the infrared region, however, the slope (rate of change of refractive index with wavelength) becomes less and less. The slope becomes essentially zero at a wavelength of approximately 1.3 microns (the so-called "zero-dispersion," or "minimum-dispersion," wavelength), where it exhibits a point of inflection and again begins to slowly increase. Still further in the infrared, it increases more rapidly. See Dispersion, Dispersion-Shifted Fiber, Minimum-dispersion Window, Velocity of Light.

Refractive Index Profile: In an optical fiber, a plot of refractive index (ordinate, or "y" direction) versus distance from the center (axis) of the fiber (abscissa, or "x" direction). See Graded Index Profile.

Scattering: As applied to light propagation in an optical fiber, a change in direction or polarization through interaction with refractive microinhomogeneities in the fiber material. See Rayleigh Scattering.

Selection: A communications process in which a master station (facility) contacts a specific slave facility for the purpose of sending it a message.

Semiconductor Laser: Synonym for Laser Diode, Injection Laser Diode.

Shot Noise: Quantum noise caused by current fluctuations attributable to the discrete nature of charge carriers.

Silica: Silicon dioxide (SiO_2). It may occur in crystalline or amorphous form, and occurs naturally in impure forms (quartz, sand, etc.)

Silicon Diode (Photodiode): A silicon-based PN- or PIN-junction photodiode. Because of their greater bandgap, they are quieter than germanium-based photodiodes, but are effective only for wavelengths up to approximately 1 micron.

Single-Mode Fiber: An optical fiber that supports only one mode of propagation. See Maxwell's Equations, Mode.

Skew Ray: In a multimode optical fiber, a bound ray that in propagating does not at any time pass through the fiber axis. See Axial Ray, Meridional Ray.

Snell's Law: A law of geometric optics that defines the amount of bending that takes place when a light ray strikes a refractive boundary (e.g., an air-glass interface) at a non-normal angle. The law states that

$$n_i(\mathrm{Sin}\ -\Theta_i) = n_r(\mathrm{Sin}\ -\Theta_r)$$

where n_i is the index of refraction of the medium in which the incident ray travels, $-\Theta_i$ is the angle (with respect to the normal at the refractive boundary) at which the incident ray strikes the boundary, n_r is the index of refraction of the medium in which the refracted ray travels, and $-\Theta_r$ is the angle (with respect to the normal at the refractive boundary) at which the refracted ray travels. The incident ray and refracted ray travel in the same plane, on opposite sides of the normal.

If a ray travels from a medium of lower refractive index into a medium of higher refractive index, it is bent toward the normal; if it travels from a medium of higher refractive index to a medium of lower index, it is bent away from the normal.

If the incident ray travels in a medium of higher refractive index toward a medium of lower refractive index at such an angle that Snell's Law would call for the sine of the refracted ray to be greater than unity (a mathematical impossibility); i.e.,

$$\text{Sin } \Theta_r = [n_i/n_r]\text{Sin } \Theta_i, \text{ and Sin } \Theta_r > 1$$

then the "refracted" ray in reality becomes a reflected ray and is totally reflected back into the medium of higher refractive index, at an angle equal to the incident angle (and thus still "obeys" Snell's Law). This reflection occurs even in the absence of a metallic reflective coating (e.g., aluminum or silver) on the glass. This phenomenon is called Total Internal Reflection. The smallest angle of incidence with respect to the normal at the refractive boundary that will support total internal reflection is called the Critical Angle.

Spectral Bandwidth: See Spectral Width.

Spectral Width: A measure of the wavelength extent of a spectrum. See Full Width Half Maximum (FWHM). Sometimes expressed as Relative Spectral Width, δ/λ, where δ is the bandwidth in nanometers, and λ is the (center) wavelength in nanometers.

Spectral Window: See Window.

Splitter: A three-port optical directional coupler (one input port, two output ports). See Directional Coupler.

Splice: A permanent joining of optical fibers, either by fusing (melting, or welding) them together, or by aligning them in a mechanical fixture and securing them, usually with some kind of adhesive. See Connector.

Splice Loss: A loss of optical power at a splice, attributable to one or mechanisms, some of which are intrinsic to the fiber, and some of which are intrinsic to the method or fixture being used to join them.

Star Coupler: A passive optical coupler having a number of input and output ports, used in network applications. An optical signal introduced into any input port is distributed to all output ports. Because of the nature of their construction, the number of ports in a star coupler is normally a power of 2; i.e., two input and two output ports (a "two-port" coupler, or directional coupler), four input and four output ports (a "four-port" coupler), eight input ports and eight output ports (an "eight-port" coupler), etc.

Steady-State Distribution (Condition): Synonym for Equilibrium Mode Distribution.

Step-Index Fiber: An optical fiber having a uniform refractive index throughout its core. Also see Graded Index Fiber.

Strength Member: A component of a communications cable (optical or metallic) whose function is to protect the conducting (transmission) medium from tensile and bending stresses during installation and (e.g., in an aerial installation) while in service.

Surface Reflection: See Fresnel Reflection.

T-1: Synonym for the DS-1 digital carrier format.

Tap: A device used to extract a portion of the optical power from a fiber.

T-Carrier: A telephone carrier system for digitally multiplexing (time-division multiplexing) voice, data, and supervisory (signalling) information. See DS-1.

T-Coupler: See Tee Coupler.

Tee ("T") Coupler: A passive optical coupler having three ports.

Tight Buffer: A protective coating applied to an optical fiber, in intimate contact with the primary polymer overcoat. It typically has an outside diameter of approximately 1 millimeter. Tight buffering is commonly, but not exclusively, used for optical patch cords or for short indoor runs of one- or two-fiber cable. Such cables normally would have an aramid braid over the tight buffer, with an outer jacket extruded over the braid.

Time-Division Multiplexing: Any communications technique whereby digital signals (digitized analog signals or digital communications) are interleaved in time (i.e., assigned time slots in a digital signal of higher rate) and in effect simultaneously transmitted over a single communications medium, and separated and restored to their original form at the receiving end.

Token Ring: A technique for controlling data communications in a logical ring network. A freely-circulating token (packet of binary information) acts as a supervisory key (control signal) to ensure that only one station transmits at a time. A station wishing to transmit first determines that the network is idle, by monitoring the status of the token. It then takes control by altering the token to signify to other stations that the network has become busy. After the station having control transmits its packet of information, the token is restored to idle state. If the receiving station does not receive an error-free message, it will, when it gains access to the network, request retransmission of the message.

Tolerance Field: When used to specify the diameter of either the core or cladding of an optical fiber, an annular region between two concentric circles of diameter D+ΔD and D-ΔD, where D is the nominal diameter (usually expressed in microns), and ΔD is the diameter tolerance.

When specifying or characterizing the ovality and core-cladding offset of a fiber, two such pairs of circles are used; one pair for the core and the other pair for the cladding. The larger circle of each pair is the smallest that circumscribes the outside of the core (cladding) cross section, and the smallest of each pair is the largest that fits within the core (cladding) cross section. The distance between the centers of the two concentric pairs (core pair and cladding pair) defines the core-cladding offset. The width of the annulus defined by the core (cladding) circles defines the ovality of the core (cladding). See Concentricity Error.

Total Internal Reflection: The total reflection of a lightwave that occurs under certain conditions at a refractive boundary; e.g., a glass-air interface. See Critical Angle, Snell's Law.

Transfer Function: The complex mathematical function that is equal to the ratio of the output of a device (active or passive) to the input, as a function of frequency. For an optical fiber, this function is taken to be the ratio of the output optical power to the input optical power as a function of the modulation frequency.

Trapped Mode (Ray): Synonym for Bound Mode (Ray), Guided Mode (Ray).

Ultraviolet: The region of the electromagnetic spectrum consisting of wavelengths shorter than the shortest visible light (approximately 400 nanometers), but longer than X-rays.

Unbound Mode: A radiative or leaky mode; one that does not propagate indefinitely.

Velocity of Light (symbol: c): The velocity of an electromagnetic wave in free space (299,792,438 meters per second; authority, International Bureau of Weights and Measures, Paris, 1983). It is equal to the product of the wavelength and the frequency. In an optical medium, the velocity will be lower. Since the frequency is not changed, wavelength is also decreased. See Refractive Index (of an optical medium).

Vertex Angle: As applied to fiber optics, the angle between the longitudinal axis of a fiber and the cone of bound meridional rays accepted by it or emerging from it. See Numerical Aperture.

Video: Adjective describing the bandwidth necessary for the transmission of real-time television pictures; i.e., on the order of several megahertz. In the United States, a commercial television channel has a bandwidth of 6 megahertz, including audio carrier and guard bands. The actual video channel is approximately 4.2 megahertz wide, and is transmitted over a band approximately 5 megahertz wide, including the vestigial sideband.

Waveguide Dispersion: The temporal spreading of an optical signal as a function of wavelength due to factors related to the geometry of the optical waveguide (fiber). See Dispersion.

Wavelength Division Multiplexing. Any technique by which two or more optical signals of different wavelength may be simultaneously transmitted in the same direction over the same fiber.

Window: A band of wavelengths at which an optical fiber is sufficiently transparent for practical use in communications applications. A wavelength or band at which the fiber is sufficiently free from undesired impurities that cause attenuation substantially in excess of the quantum-limited mechanisms of Rayleigh Scattering (predominates at shorter wavelengths) and phonon absorption (predominated at longer wavelengths). See Rayleigh Scattering, Phonon Absorption, Zero-Dispersion Window).

Zero-Dispersion Window. The window of an optical fiber in which material dispersion is essentially zero. In single-mode fibers, the window where chromatic dispersion and waveguide dispersion cancel one another. See Dispersion.

APPENDIX 4. ALPHABETICAL INDEX