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MIL-STD-1773 Users Handbook

RATIONALE

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To the MIL-STD-1773 User:

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We especially solicit contributions on application experiences and "lessons learned" for incorporation in planned future updates of this handbook. It is intended that this handbook become a forum for the exchange of information and experiences as fiber optics technology and MIL-STD-1773 applications evolve.

Please address your comments/contributions to the following:

Chairman, AS3A-4B Handbook Working Group
c/o SAE International
400 Commonwealth Drive
Warrendale, PA 15096-0001
(412) 776-4841

Thank you for your interest in the ongoing activities of the AS3 Committee.

The Editors

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PREFACE

This handbook was written to encourage and support the use of Fiber Optic Avionics data bus systems covered by MIL-STD-1773 and demonstrate the versatility MIL-STD-1773 offers for system implementation. The handbook fills in details that are necessarily not allowed within the rigid confines of a MIL standard and provides guidance for the preparation of a system detail specification under the standard.

Typical details include pertinent component types and their parameters, advantages and drawbacks of different implementation approaches, and a comparison to electrical bus systems.

Future editions will contain updated information based on changes and evolution within the fiber optics technology and 1773 applications experience. This handbook is intended as a forum for ideas and information exchange.

ACKNOWLEDGMENTS

This handbook is the product of the voluntary labors of a large number of people within the SAE Aeronautical Systems Division AS3 Committee. These people have expended, both singly and collectively, hundreds of hours preparing, editing, and reviewing the written material for the various Chapters and Appendices. The editors wish to thank everyone who has contributed their time and energy to the completion of this project over the past four years.

Handbook Participants:

AS3A Handbook Task Group Chairman:

Dwight Tabit, Naval Air Engineering Center, Lakehurst, NJ

HandBook Coordinator:

Jean Lagerquist Turner, Delco, Santa Barbara, CA

Editors:

Jean Lagerquist Turner, Delco, Santa Barbara, CA
Dwight Tabit, Naval Air Engineering Center, Lakehurst, NJ
John Kolling, Unisys, St. Paul, MN

Authors:

Robert Betts, IBM, Owego, NY
William Briscoe, SCI Technology, Huntsville, AL
David Daum, McDonnell Douglas, St. Louis, MO
Roger Greenwell, SEA Inc., San Diego, CA
Homer Heinzman, LTV, Dallas, TX
Charles Husbands, Mitre Corp., Bedford, MA
Rod Katz, Naval Avionics Center, Indianapolis, IN
John Kolling, Unisys, St. Paul, MN
Jean Lagerquist Turner, Delco, Santa Barbara, CA
Robert Lebduska, SAIC, San Diego, CA
K. W. Lee, IBM, Owego, NY
John Marcin, Douglas Aircraft Co., Long Beach, CA
Art Meixner, AT&T, Whippany, NJ
Owen Mulkey, Boeing, Seattle, WA
Don Shafferkoetter, McDonnell Douglas, Mesa, AZ
Dwight Tabit, Naval Air Engineering Center, Lakehurst, NJ
William Walsh, Veda Inc., Warminster, PA

Reviewers, in addition to the authors and editors:

Uldis Duselis, Naval Avionics Center, Indianapolis, IN
Leanne Eamon, Naval Avionics Center, Indianapolis, IN
David Griffith, Boeing, Seattle, WA
Mark Harrington, Smiths Industries, Gloucestershire, United Kingdom



Bruce Kline, Simmonds Precision, Vergennes, VT
Edward Mikoski, AMP Inc., Alexandria, VA
Randall Morton, Eldec Corp. Lynwood, WA
George Mullin, Amphenol Corp., Sidney, NJ
Francois Padovani, Texas Instruments, Attleboro, MA
Mark Setman, Seicor Corp., Hickory, NC
Pat Shuster, Fitel Corp., Peachtree City, GA
Ben Sitler, Raychem Corp., Sherman Oaks, CA
Susan Smith, Naval Air Development Center, Warminster, PA
Kauser Talat, Boeing, Seattle, WA
Aki Tomita, Raychem, Menlo Park, CA
John Verschoor, Northrop, Pico Rivera, CA

The Editors.

INTRODUCTION

This handbook has been prepared to support the applications of MIL-STD-1773 systems. It has been written to promote good design procedures and provide technical guidance for implementing, installing, and maintaining a MIL-STD-1773 system.

To meet MIL-STD-1773 Users' needs, the following topics are covered in the handbooks chapters:

Chapter 1. Background.

- o A short history of the development of fiber optic technology and an overview of MIL-STD-1773.

Chapter 2. Components for Media Implementation.

- o Brief descriptions of components that may be used in MIL-STD-1773 bus media implementation.
- o Relevant properties and features that should be considered to optimize a design for its intended purpose.

Chapter 3. Media Design.

- o Parameters that must be specified to make bus terminals interoperable.
- o Various topology choices.
- o System performance criteria such as Optical Power Budget bit error rate (BER), and dynamic range.
- o Describes how 1773 fiber optic systems may be integrated into electrical 1553 systems to produce a hybrid system.
- o Technical issues and available options are discussed.

Chapter 4. Electrical/Optical Interface Considerations.

- o Basic elements of fiber optic transmitter and receiver design.
- o Descriptions of active components.
- o Tests that measure circuit performance.

Chapter 5. Environmental and Performance Testing.

- o Table of environmental and performance tests compiled from military standards and Fiber Optic Test Procedures (FOTPs). These standards and FOTPs have been listed to show the MIL-STD-1773 system user and designer the types of adverse environments and conditions which the overall system and fiber optic components must withstand.

Chapter 6. Testing and Diagnostics.

- o Measurement methods that establish system performance limits.
- o Troubleshooting methods.

Chapter 7. Media Installation Considerations.

- o Fiber Cable Assembly and Installation Considerations.
- o Lessons learned on the AV8B Harrier program.
- o Lessons learned during installation of a Fiber Optic position sensing system on a commercial aircraft.

Chapter 8. Radiation Effects.

- o Provides pointers on the application of MIL-STD-1773 in a nuclear radiation environment.
- o Overviews the effect of radiation on individual components.

Chapter 9. Terms and Definitions.

- o Definition of terms important to MIL-STD-1773.

References.

- o Bibliography. The bibliography gives references used to compile the information given in this document's chapters.

Appendix A. MIL-STD-1773.

- o The annotation describes the rationale used to arrive at the standards requirements.
- o A copy of MIL-STD-1773 is attached for reference.

Appendix B. Example Fiber Optic Transmitter and Receiver Development/Procurement Detail Specification.

- o Example detail specifications for modules appropriate for either standard or enhanced Dual-Speed 1773 applications.

Appendix C. Design Example - A Missile Application.

- o An example of a detailed 1773 system design, based on a missile application.

Appendix D. Implementing Multiple Speed Data Rate Transmission.

- o Further discussion of MSDRT.
- o Inclusion D-1. Presentation of a Proposed General Specification Document for the implementation of a 1 Mb/S - 8 Mb/S "Dual Speed" version of MSDRT.
- o Inclusion D-2. Presentation of a Proposed General Specification Document for a "Distributed Switch Network Using 100 Mb/S Fiber Optic Collateral Data Pipelines Under Control of a MIL-STD-1773 Bus".

Appendix E. Static Fatigue Failure and Service Life of Large Core Fibers in Avionic Platforms.

- o A discussion of the fiber quality issues and installation parameters which affect the service life of fibers most likely to be used in Avionics applications.

Appendix F. Reliability and Wearout of Light Emitting Diodes in High Temperature Environments.

- o A discussion of the fabrication quality and test issues that are critical to the determination and verification of LED service life in a severe environment.

CHAPTER 1. BACKGROUND.



CHAPTER 1. BACKGROUND.

1.0. Background.

The goals of fiber optic communications development in the military have been to reduce system costs as well as to provide increased bandwidth, flexibility, reliability, immunity to EMI and simplicity.

In the military environment, the immunity of fiber optics to external electro-magnetic interference is an important adjunct to its wide bandwidth capacity, providing the following advantages:

- o signals can be transmitted through electrically noisy areas with extremely high integrity/quality.
- o data security is enhanced because the fiber does not radiate extraneous emissions.
- o electronics enclosure penetrations are immune to Electromagnetic Pulse conducted energy damage.
- o elimination of shielding requirements means cables with smaller size and weight.

1.1. An Overview of Military Fiber Optics Applications.

The military services first began using fiber in relatively simple telecommunications applications as a one-for-one replacement for copper cable. The initial goal was to save weight. Enhanced performance at first was just a bonus, but it opened eyes of system designers to the possibilities of building entirely new systems around the fiber's unique properties. All three services have found applications for fiber optic technology.

The Army began replacing twin-coaxial cable systems with 10 Km optical fiber cable under its Fiber Optic Transmission System - Long Haul (FOTS-LH) program and built a 667 Km tactical communications network from Seoul to Pusan under the Korea Backbone program.

The Navy at first stressed intrasystem data communications applications of fiber optic technology with internal cabling of the Marine Corps AV-8B V/STOL (Vertical/Short Takeoff and Landing) attack aircraft (about 6 m/aircraft) and the Aegis cruisers (about 2-3 Km each).

In 1983, the Airforce/JCMPO deployed the first production tactical Fiber Optic data communications system in the mobile Ground Launched Cruise Missile, Common Weapons Control System. A multi-channel point-to-point system connecting redundant Launch Control Center vehicles to multiple Transporter Erector Launcher vehicles over 300 meter radiatio hardened fiber cables.

The Air Force installed a 147 Km fiber optic cable at its Missile Test Center, Vandenberg AFB, Calif., to serve as the primary communications link for controlling ground and flight tests of the MX (Peacekeeper) ICBM.

Some other programs where the military is applying fiber optic technology include the Army's fly-by-light helicopter control systems under its Advanced Digital Optical Control System (ADOCS) program and the follow on Fiber Optic Control System Integration (FOCSI) program, jointly with the other services and delivery of tactical missiles with pinpoint precision under the Fiber Optic Guided Missile (FOG-M) program.

The Navy has done studies of undersea fiber networks to link acoustic sensors and shore-based computers for antisubmarine warfare as part of the Ariadne program while the Air Force has shown a growing interest in the use of fiber to maintain secure communications among the system components of the proposed Strategic Defense Initiative (SDI) antiballistic missile system.

The future of Fiber Optics for Military Avionics lies in the areas of evolutionary growth and enhancement of MIL-STD-1553 based Command and Control Systems with MIL-STD-1773 technology; the development of entirely new Avionic System architecture and integration concepts through the application of High Speed Fiber Optic Data Busses, Video Distribution and Sensor Fusion Networks and eventually a revolution in Flight Management, Safety and Damage Assessment through the application of Fiber Optic Sensors and "Smart" skins/structures.

1.2. MIL-STD-1773, Where Did It Come From ?

In May, 1976, the SAE-A2K Subcommittee formed a Fiber Optics Task Group to generate a fiber optics version of MIL-STD-1553B. DOD-STD-XXFO (unapproved) became the prevailing document for MIL-STD-1553B data buses with fiber optics. In March, 1982, the Air Force made a request for a new draft standard for fiber optics, to be called MIL-STD-1773, that would establish a single modulation technique. Selection of the modulation technique was essentially to meet the latest organizational requirements. The solution was to adopt a unipolar two state (on-off) form of Manchester II biphase level encoding. This technique had been demonstrated in industry using various receiver detection schemes, i.e.; Adaptive Threshold, Fast Attack Automatic Gain Control, Edge Detection, and Symmetrical Clamp. The current version of the standard, MIL-STD-1773, was circulated for review in 1987 under the auspices of the Naval Air Engineering Center, Lakehurst, NJ, and gained final approval and release on 20 May, 1988.

1.3. What is MIL-STD-1773 ?

MIL-STD-1773 is (to quote the title) a "Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus". It's objective is to provide the option of using fiber optics in military avionics systems designed for MIL-STD-1553B. The fiber optic bus does not affect any system level factors such as protocol, data

rate, word formats and message formats. Response times, number of terminals and bus length are unchanged by MIL-STD-1773. The only basic difference between the two standards occurs in the transmission media and modulation technique used to transmit the Manchester II biphasic level encoded messages.

The primary purpose of this standard is to preserve the multiplex bus architecture and protocol which have been standardized in MIL-STD-1553B while providing guidelines for the application of fiber optic transmission techniques to the MIL-STD-1553B interconnect media. The application of the standard by itself will not ensure total compatibility of transmission characteristics between different systems that employ a fiber optic interconnect; however it will ensure general compatibility of transmission techniques to the MIL-STD-1553B interconnect. The optical power levels, optical wavelength and the media topology for distributing optical power in any avionics implementation must be contained in a system specification which references the standard.

1.4. A Growth Path for MIL-STD-1773.

MIL-STD-1553 (and 1773) was designed for Command and Control functions with little capacity for data exchange. However, for avionics data bus applications, it was "the only game in town". It becomes bound at an average data rate of 200 to 300 kilobits/sec. and cannot support terminals that require peak data rates above 800 kilobits/sec. The result has been the development of platforms with as many as 5 dual redundant 1553 buses on board.

A system that could replace the multiple 1553 installations with a single 1773 bus and also provide means to incorporate new system elements that require much higher peak transfer rates without modification of terminals supporting existing functions would make application of 1773 more cost effective and extend the useful life of the present investment in 1553 based hardware.

Multi-speed data rate transmission (MSDRT) is a technique which promises to provide these enhancements to MIL-STD-1773. In this concept, the standard 1 Mbit/Sec. data rate is employed between all terminals for Command/Status traffic and between unenhanced terminals for data, exactly as specified in MIL-STD-1773. However, when the bus controller initiates data exchange between enhanced terminals, the data itself is exchanged at a second higher rate, in a manner that is transparent to the unenhanced terminals. This multi-speed concept implements the transmission of large blocks of data and high peak rates within the system without affecting the time critical exchange requirements imposed on the system network.

A second enhancement concept utilizes the command and control capabilities of a 1773 bus to provide network supervision for very high data rate exchanges (as a video distribution network for example) on a collateral Fiber Optic distributed switching network. This concept makes use of media level hardware developed for the ANSI Fiber

Data Interface (FDDI) to implement multiple packet and circuit switched channels, of 100 Mbits/sec. capacity each, all under the supervision of the 1773 Bus Controller.

These enhancements are discussed in further detail and proposed general implementation specifications to be referenced from MIL-STD-1773 are presented in Appendix D of this handbook.

NOTES



CHAPTER 2. COMPONENTS FOR MEDIA IMPLEMENTATION.



CHAPTER 2. COMPONENTS FOR MEDIA IMPLEMENTATION.

2.0. Media Components.

The technology of data transmission on optical waveguides requires the understanding of some new components by the system designer. Some, such as the waveguide or "fiber" itself, the optical detector and optical source are unique to this technology. Others, like connectors, couplers and switches are familiar functions but with new and unique requirements and problems.

2.1. Fiber.

The optical fiber waveguide is, of course, the heart of "fiber optics". It's capacity to guide light from point a to point b with extremely wide bandwidth and low losses while offering nearly total immunity to external electromagnetic influences opens new possibilities for avionics systems architecture, but also presents many challenges.

2.1.1. Types.

Optical fiber communication systems contain two basic fiber types, single mode and multimode. Single mode fiber designs are characterized by small (typically 5 to 10 microns) core diameters, while multimode fibers have large (typically 50 to 400 microns) core diameters and may be of either "step" or "graded" index of refraction profile.

Single mode fiber provides maximum bandwidth. This type of fiber is the clear choice for long distance, high bandwidth systems. In contrast, multimode fiber designs minimize connector loss and loss coupling to optical sources; they are preferred for short distance, lower bandwidth systems.

2.1.2. Function.

The fiber provides a low loss electrical noise immune optical signal path from the transmitter to the receiver.

2.1.3. Profiles.

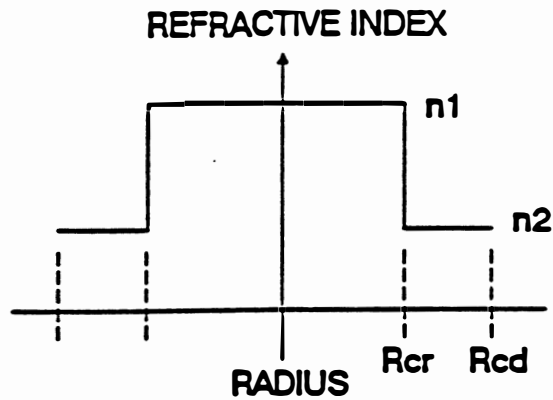
The fiber profile refers to how the refractive index varies as a function of radial distance from the fiber's center.

2.1.3.1. Step Index.

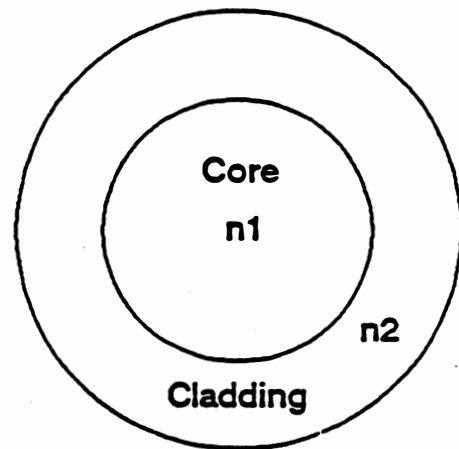
The step index profile steps downward at the core radius, Figure 2-1(a). This step divides the fiber's cross section, given in Figure 2-1(b), into a central core with index n_1 and a surrounding cladding with index n_2 .

2.1.3.2. Graded Index.

The graded index profile of Figure 2-2(a), tapers off parabolically with radius from its central axis value n_1 to a lower value n_2 at the core radius R_{cr} .

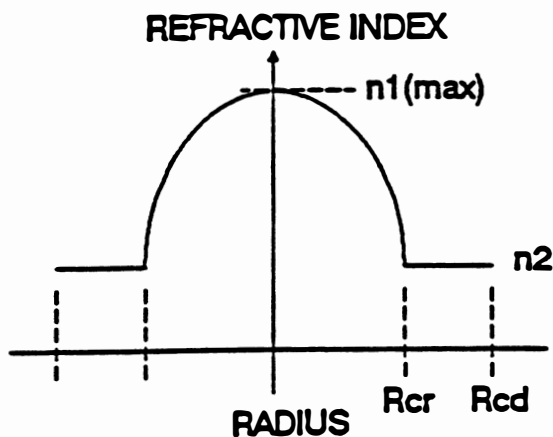


(a)

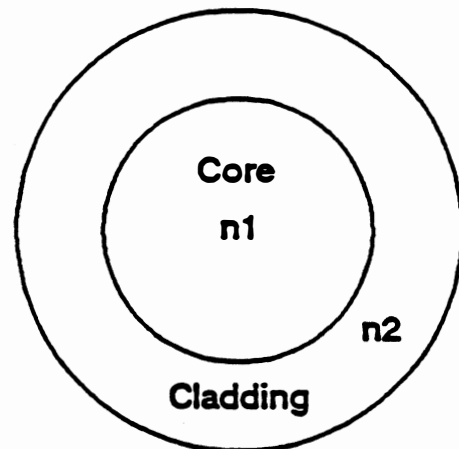


(b)

Figure 2-1. Step Index Profile.



(a)



(b)

Figure 2-2. Graded Index Profile.

2.1.3.3. Single Mode.

In a single mode fiber the core diameter (2-10 microns) has been reduced to allow only one primary mode (an axial ray) to propagate.

2.1.4. Light Propagation.

Light propagation in three most common fibers is shown in Fig. 2-3.

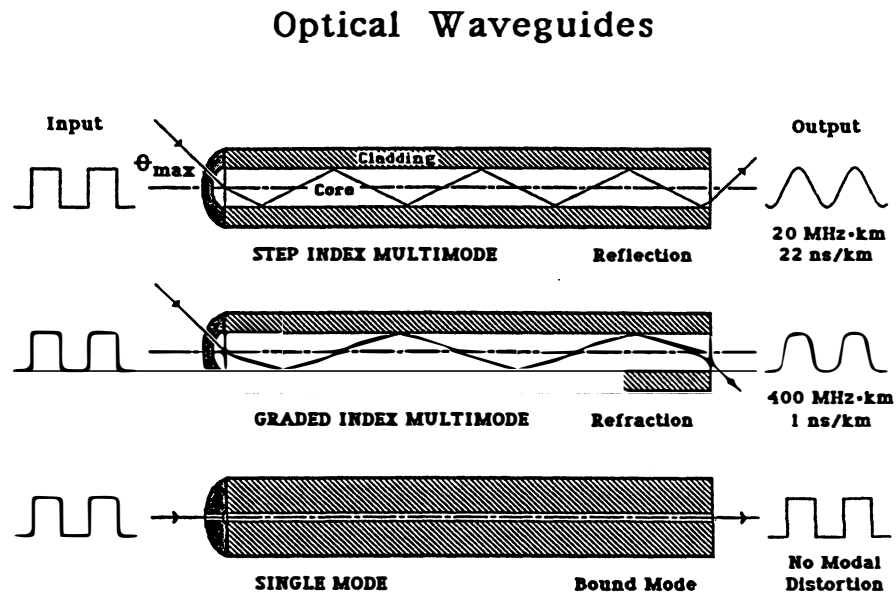


Figure 2-3. Light Propagation For Three Common Fiber Types.

2.1.4.1. Multimode Step Index.

Light is propagated along a step index fiber by the principle of total internal reflection, in which, light entering the fiber acceptance cone is repeatedly reflected from one core-cladding interface through the core to the other core-cladding interface along the fiber length.

2.1.4.2. Multimode Graded Index.

In graded index fiber, light is propagated by the continual bending of the light rays toward the fiber's optical axis, rather than by total internal reflection.

2.1.4.3. Single Mode.

In single mode fiber, only the lowest order mode (the bound mode) can propagate. This mode is most like propagation in RF waveguides.

2.1.5. Design Parameters.

Basic design parameters and performance issues are core diameter, cladding diameter, numerical aperture, attenuation, transit time and bandwidth.

2.1.5.1. Core Diameter.

The core diameter (D_{cr}), usually given in micrometers (microns), is the diameter of the higher refractive index center section of the fiber. The optical energy launched into the fiber travels primarily within this region.

2.1.5.2. Cladding Diameter.

In most silica based optical fibers, the core is surrounded concentrically by a cladding of lower refractive index glass. The cladding diameter (D_{cd}) is the outside diameter of this two-glass structure. Large core plastic clad silica (PCS) fibers have a glass core and a plastic cladding.

2.1.5.3. Numerical Aperture.

Numerical Aperture (NA), as described in Figure 2-4., is a fiber's "light gathering" ability and defines the fiber's acceptance cone half angle (Θ). Light waves injected at angles within this cone will be propagated along the fiber.

Numerical Aperture (NA) is calculated:

$$NA = \sin(\Theta) = [n_1^2 - n_2^2]^{0.5}$$

Where:

n_1 = core refractive index

n_2 = cladding refractive index

and Θ = the maximum off axis angle for the acceptance of optical energy.

Typical silica-based multimode fiber designs which one might consider for a MIL-STD-1773 system are listed in Table 2-1.

Table 2-1. Parameter Values for Typical Step index Silica on Silica Fibers.

Core Diameter (d) microns	Cladding Diameter (D), microns	Numerical Aperture (NA)
200	240	0.29
125	200	0.25
100	140	0.29
85	125	0.26
62.5	125	0.22, 0.275
50	125	0.20, 0.23

It should be noted that measurement techniques vary among fiber manufacturers. These differences (launch cone, exit cone and refraction index profile methods) yield slightly different values for NA.

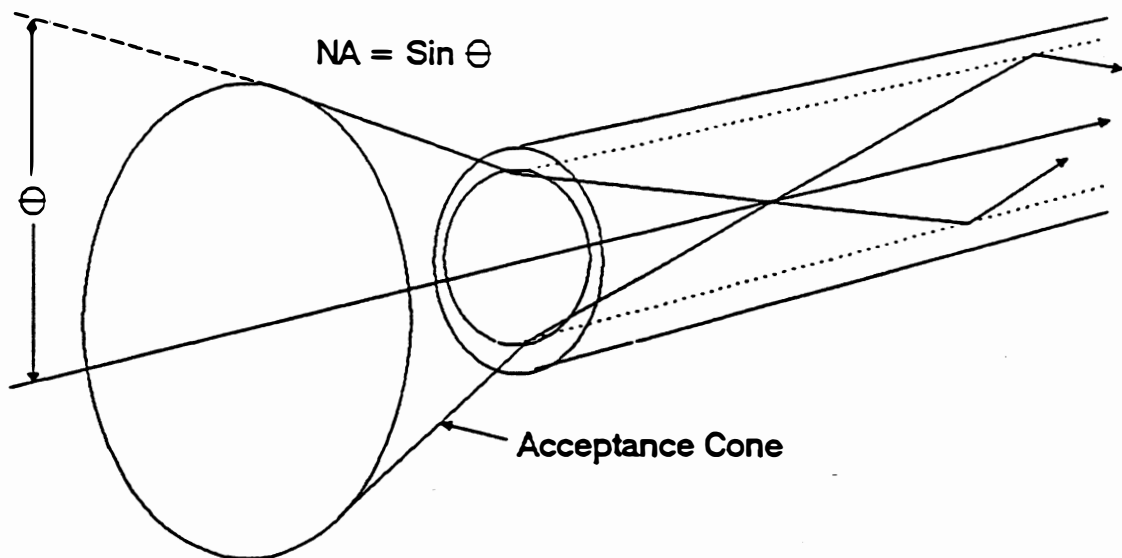


Figure 2-4. Numerical Aperture/Acceptance Cone Relationship.

2.1.5.4. Spectral Attenuation.

Spectral Attenuation is optical power loss due to intrinsic fiber loss (Rayleigh scattering and absorption), macrobending, microbending and radiation induced losses within a fiber. This quantity is expressed in dB/km at a specific wavelength, usually 850, 1300, or 1500 nanometers. Figure 2-5. shows the spectral attenuation plot for a typical fiber.

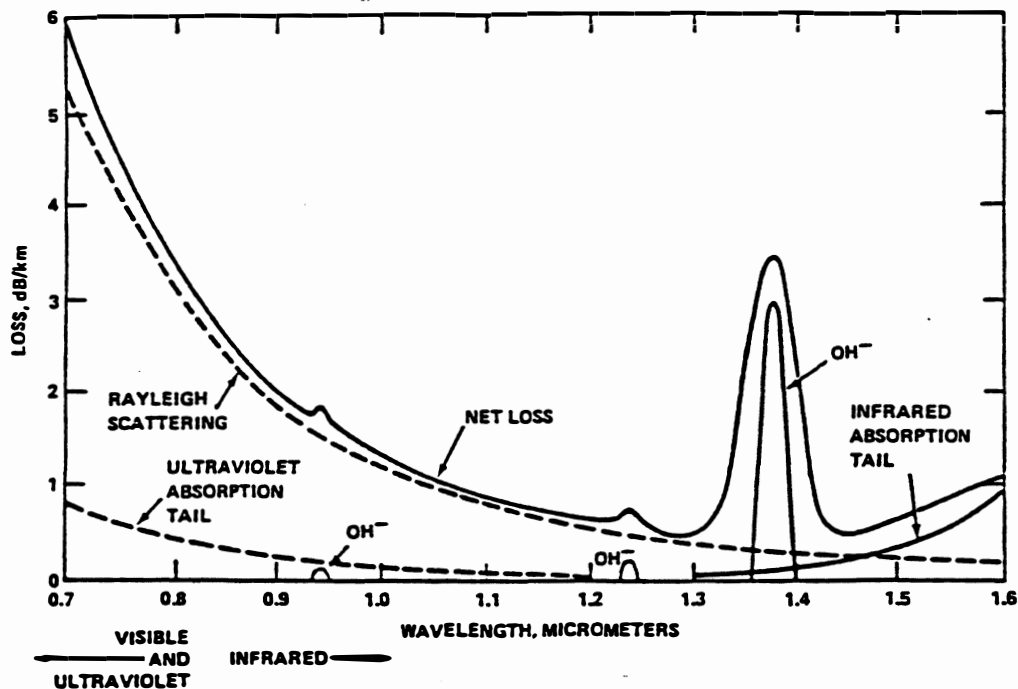


Figure 2-5. Optical Fiber Attenuation vs. Wavelength.

Attenuation is directly proportional to the cable length after steady state equilibrium conditions are attained. Attenuation is determined by:

$$\text{Attenuation (dB/km)} = [10 \log (P_o/P_i)]/L$$

Where:

P_i = Input Power

P_o = Output Power

L = Measured length in km.

Typical attenuation ranges for three common fiber types as described in section 1.1.2.1 before degradation by radiation and other effects are listed in Table 2-2.

Table 2-2. Typical Attenuation Ranges.

Fiber Type	Attenuation
Step Index	5 dB/km to 20 dB/km @ 850 nm
Graded Index	2 dB/km to 10 dB/km @ 850 nm
Single mode	0.2 dB/km to 1 dB/km @ 1300 nm

2.1.5.5. Transit Time.

Light propagates in an optical fiber at the speed of light in the core material, which is proportional to the square root of the core dielectric constant (or the index of refraction, n_2), which is a function of the wavelength of the propagating light. For example, the refraction index of fused silica ranges from about 1.452 at 850 nm. to about 1.450 at 1.3 μm .

The optical signal transit time is then the core index of refraction, at the wavelength of interest, times the transit time of light in a vacuum (3.336 ns/m. or 1.017 ns/ft.). A typical useful value for transit time estimation in a silica fiber is 4.84 nanoseconds/meter or 1.48 nanoseconds/foot.

2.1.5.6. Bandwidth.

A fiber's capacity to carry information is generally expressed in terms of its bandwidth-length product. The value is normalized to 1 km and expressed in MHz-km, this allows a length independent fiber comparison. Some typical bandwidth values for the three common fiber types are listed in Table 2-3.

Modulation Bandwidth limitations are produced by multimode and chromatic (optical wavelength) dispersion. For example, in a step index multimode fiber, each of up to a 1000 spatial modes from the zero-angle mode to the highest order modes, sees a different path length within the fiber. The multimode dispersion for a step index fiber (ΔT_{mod}) is given:

$$\Delta T_{\text{mod}} = L \left(\text{NA}^2 / (2 \times n_2 \times C) \right), \text{ seconds.}$$

where:

NA = fiber Numeric Aperture.

n_2 = core refractive index.

L = fiber length, meters or feet

C = speed of light in a vacuum, meters or feet per second.

and the optical 3 dB cutoff frequency ($F_{3\text{db}}$) is:

$$F_{3\text{db}} = 0.44 / \Delta T_{\text{mod}}, \text{ Hertz. (modulation bandwidth)}$$



Figure 2-6. depicts how modulation bandwidth is typically determined. Multimode dispersion limits the bandwidth-length product of step index multimode fiber designs to about 20 MHz-km.

In a graded index multimode fiber, transit times for the various propagation modes are equalized by the index grading. This reduces the multimode dispersion to the point where chromatic dispersion may be the limiting factor. Chromatic dispersion is produced when a broad optical spectrum source is used, as the different wavelengths travel at different velocities in an optical fiber. Total dispersion is the RMS sum of multimode and chromatic dispersion. Graded index multimode fibers have bandwidth-length products in the range of 100 MHz-km to 2 GHz-km.

Table 2-3. Typical Bandwidth Values.

Fiber Type	Bandwidth
Step Index	20 MHz-km
Graded Index	100 to 1500 MHz-km
Single Mode	a few hundredths of a nanosecond pulse spreading

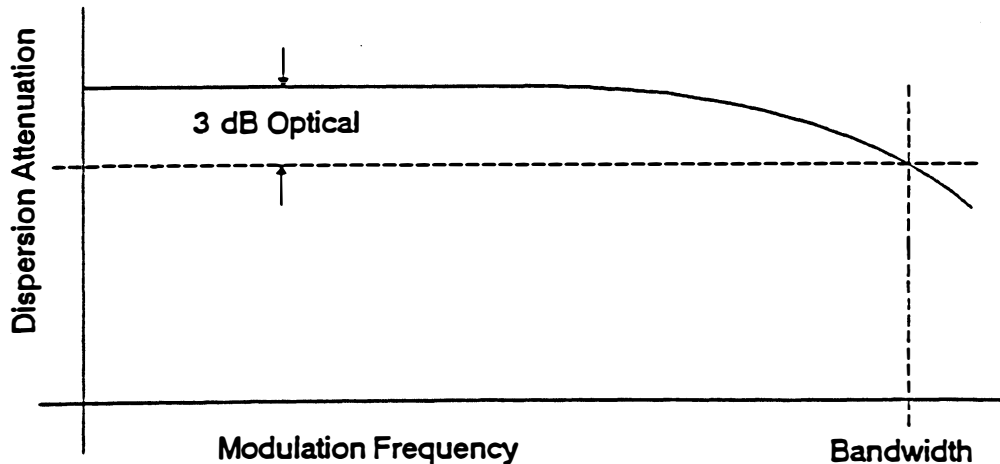


Figure 2-6. Attenuation versus Frequency of an Optical Fiber.

2.1.6. Materials.

The materials used to manufacture fibers are glass or plastic. The core/cladding combinations are glass/glass, glass/plastic or plastic/plastic.

Optical fibers are coated to afford protection against abrasion, mechanical abuse, and contamination. Buffer coatings are normally applied during the fiber drawing process.

2.1.6.1.1. Types.

Types of coatings include lacquers, blocked urethanes, silicone rubbers, acrylates, ceramics and metals. Sometimes a two layer coating is employed, a soft inner coating is used to reduce microbending losses by shielding the fiber from some external forces and a tough outer coating to protect the fiber from abrasion and handling. These losses are due to the existence of lateral pressures or forces which can cause microscopic departures from straightness in the waveguide axis.

Buffer coating is also required to protect the glass fiber from moisture to improve the fiber's long-term strength retention. This reduces the susceptibility to fatigue failure caused by moisture attacking the fiber's surface. The moisture causes the growth of microcracks on the glass surface and a gradual reduction in fiber strength. Fatigue failure is addressed in detail in Appendix E.

2.1.7. Selection.

Characteristics that are usually considered when selecting a fiber are source power coupling efficiency, bandwidth, attenuation, and operating wavelength.

2.1.7.1. Source Coupling.

The amount of optical energy coupled into a given fiber design is determined by two source characteristics, the source diameter (near field coupling, Cnf) and the numerical aperture (far field coupling, Cff). The total power coupled into a fiber is proportional to the product of these two factors. For an LED source without lense enhancement, the far field is a cosine angular distribution ($NA = 1$) and the near field is the diameter of the uniformly illuminated source area when the plane of the fiber end is very near to the source. In this case, the LED to fiber coupled power (P_c) is related to the ratio of the fiber NA (NA_f) squared to the source NA (NA_s) squared and the fiber core area (D_f squared) to the source area (D_s squared):

$$P_c \text{ (watts)} = P_o \text{ (total output, watts)} \times [C_{ff} \times C_{nf}], \text{ watts.}$$

where:

$$\begin{aligned} C_{ff} &= \text{farfield factor} = NA_f^2 / NA_s^2 = NA_f^2 / 1 \\ &= NA_f^2, \leq 1. \end{aligned}$$

$$C_{nf} = \text{nearfield factor} = D_f^2 / D_s^2, \leq 1.$$

Lense enhancement is often used to partially collimate the emission cone of the source to better match the acceptance cone of the fiber. Optical reciprocity however, results in the apparent near field diameter of the source being increased by the same ratio as the sine of the far field emission half angle (its Numeric Aperture) is reduced. So a net increase in coupling is achieved only when fiber with a core diameter larger than the physical diameter of the source is used. As the source diameter magnification exceeds the fiber core diameter, the increase in far field coupling is offset by the reduction in near field coupling and no further coupling increase can be achieved. This is the primary reason to choose large core fiber in avionics applications where the need for more launched power outweighs the need for bandwidth.

For a lense enhanced LED (or where the fiber is not located in very close proximity to the source), estimating the LED to fiber coupling becomes more complex than described in the equations above. We must first characterize the near field and far field patterns of the device.

The near field can be measured with a scanning optical microscope. The intensity of the LED output is plotted as the optical probe, with a diameter small compared to the source diameter and an NA larger than the sources emission half angle, is traced across the plane where the fiber end is to be located in at least two orthogonal directions (with the measurements averaged to ensure that the near field is rotationally symmetrical). The measured intensity (I) and distance from the aperture center (d) is measured at (m) points and the d[n], I[n] values from n = 0 to m are recorded. The near field coupling factor is the integral of the near field intensity over the area of a circle, centered on the axis of symmetry, as the circle radius is increased from zero to infinity. The near field coupling coefficient (Cnf%) is calculated by numeric integration:

$$\text{delta}[I] = I[n-1] + I[n] / 2 \text{ (average intensity over annulus)} \times \pi (d[n]^2 - d[n-1]^2) \text{ (area of annulus)}$$

$$\text{Cnf\% (for fiber with core radius, } D_{\text{cr}}/2 = d[n] \text{)} = \frac{100 \left(\text{summation of delta}[I] \text{ from } d = 0 \text{ to } d[n] \right)}{\text{summation of delta}[I] \text{ from } d = 0 \text{ to } d[m]}$$

Figure 2-6. shows the result of the near field intensity plot and the near field coupling co-efficient (Cnf) integration for a typical lensed surface emitter with a 50 micron source diameter and a 16 mil diameter spherical sapphire lense nearly in contact with the emitter.

The far field can be measured by placing the source at the pivot point of a swing arm Goniometer with a detector of small diameter and small acceptance angle at the end of the arm. For at least two orthogonal axis (again, average the measurements to ensure that the far field is rotationally symmetrical), the measured intensity of the LED output (I) is plotted as a function of the angle of the arm from the perpendicular to the plane of the emitter (Theta). The farfield coupling factor is the integral of the measured radiant intensity over the surface area of the intersection of a hemisphere of a radius equal to

the swing arm length and a cone (solid angle) whose half angle is increased from zero to 90 degrees.

The measured intensity (I) and the angle from the perpendicular (Theta) is measured at (m) points and the Theta[n], I[n] values from n = 0 to m are recorded. The far field coupling coefficient (Cff%) is calculated by numeric integration:

$$\Delta I = I[n-1] + I[n] / 2 \text{ (average intensity solid angle)} \times 2 \pi (\cos(\Theta[n]) - \cos(\Theta[n-1])) \text{ (area of annulus)}$$

$$Cff\% \text{ (for fiber with } NA = \sin(\Theta[n]) \text{)} = \frac{100 \text{ (summation of } \Delta I \text{ from } \Theta = 0 \text{ to } \Theta[n] \text{)}}{\text{summation of } \Delta I \text{ from } \Theta = 0 \text{ to } \Theta[m]}$$

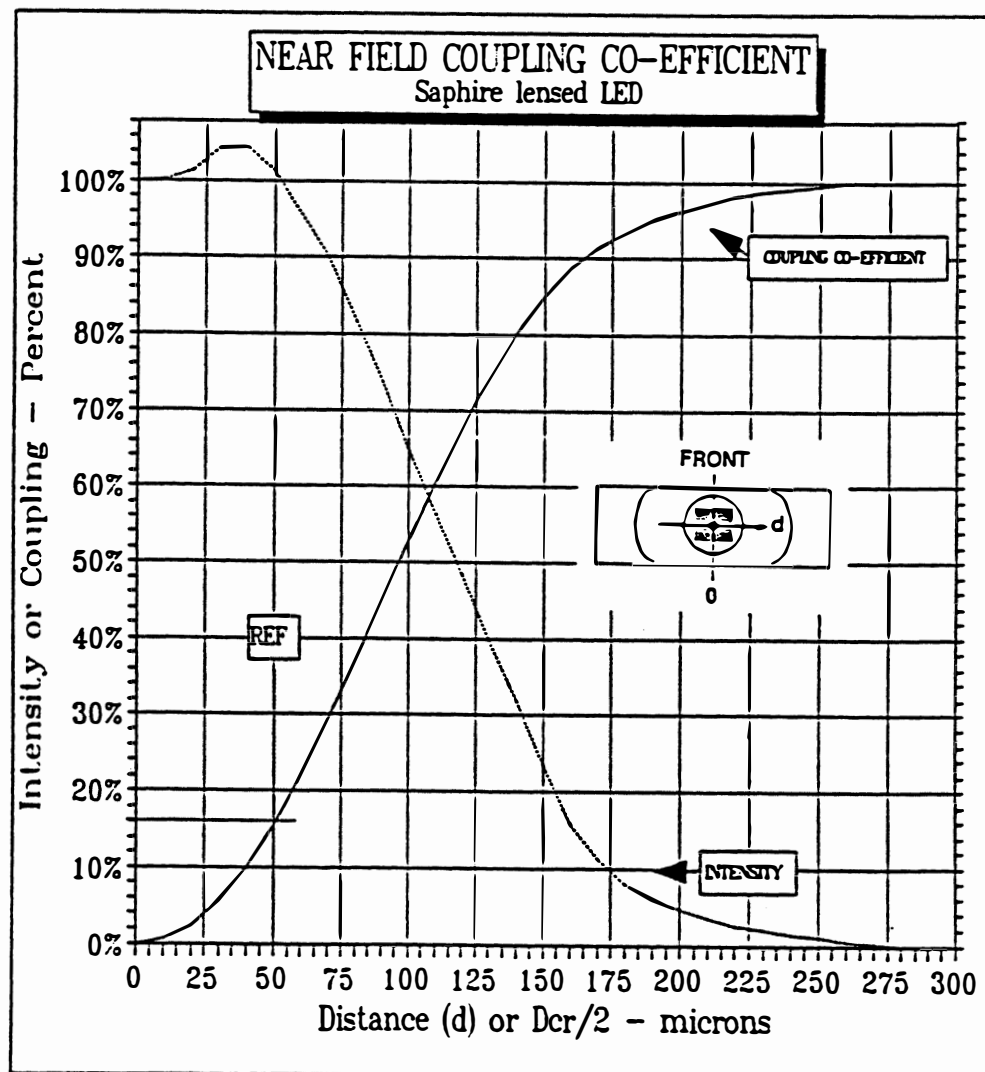


Figure 2-6. Normalized Near Field Intensity vs d and Coupling Co-efficient vs Fiber Core Radius Example.

Figure 2-7. shows the results of the farfield intensity plot and the farfield coupling factor (Cff) resulting from the integration for the LED mentioned above.

The power coupled to a fiber of any description (Pc2) can then be determined, relative to the measured power coupled to a reference test fiber (Pc1):

$$Pc2 = Pc1(\text{watts}) \left[\left(\frac{Cnf2}{Cnf1} \right) \times \left(\frac{Cff2}{Cff1} \right) \right], \text{ watts};$$

where:

the Cnf's and Cff's are determined from the coupling co-efficient plots as a function of the fibers core radius (Dcr/2) and NA.

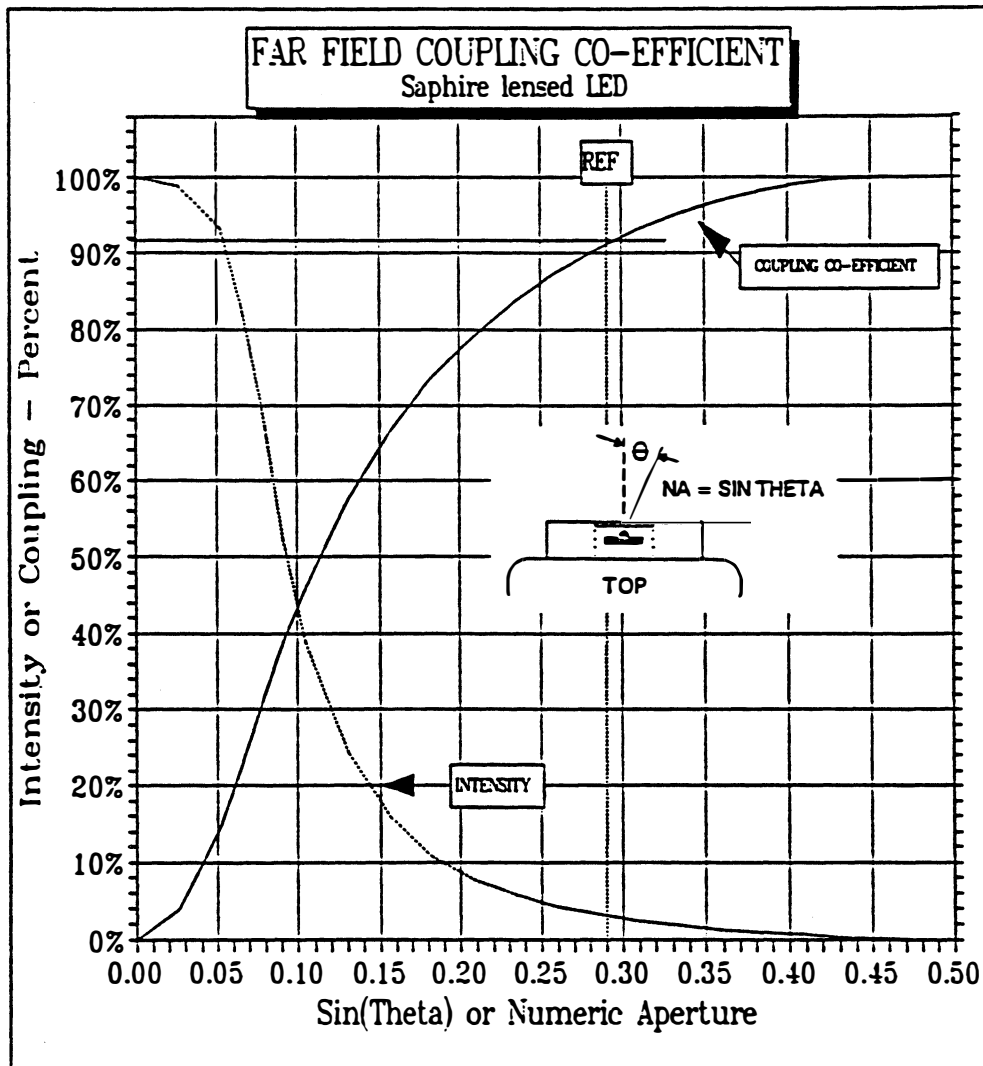


Figure 2-7. Normalized Far Field Intensity vs Sin(Theta) and Coupling Co-efficient vs Fiber NA Example.

The near field coupling factor (Cnf) for a 100 micron core diameter (50 micron radius) and .29 NA reference fiber is seen to be 16.0% from the plot of Figure 2-6. and the far field coupling co-efficient, Cff is seen to be 91.5% from Figure 2-7. The total coupling for this fiber is then $16.0\%(Cnf) \times 91.5\%(Cff) = 14.64\%$ of the total radiant power emitted from this source. The coefficients of typical step index fibers, as determined from the plots, are summarized in Table 2-4., below. The relative coupling as $10 \text{ Log}(P_2 / P_{ref})$, dB, with the 100 um, .29 NA fiber as the reference is shown in the last column.

Table 2-4. Relative Fiber to LED Coupling.

Fiber Parameters		Coupling			
Dcr um	NA	Cnf	Cff	Product	dB rel
62.5	.22	6.5%	81.2%	5.28%	-4.43
85	.26	11.5%	87.7%	10.09%	-1.62
100	.29	16.0%	91.5%	14.64%	0 (ref)
125	.25	22.0%	86.0%	18.92%	+1.11
200	.29	52.8%	91.5%	48.31%	+5.18

2.2. Cable.

2.2.1. Function.

The cable's primary function is to survive in its environment and protect the fiber's optical transmission properties. Key issues include durability, tolerance to fluids and environmental conditions.

2.2.2. Durability.

The cable must be able to withstand the rigors of manufacture, installation, and the military environment. Anticipated cable lifetimes are on the order of 2 to 20 years, dependent on the environment.

2.2.3. Tolerance to Fluids.

The cable must be immune to the fluids commonly found in a military manufacturing and operating environment. Of particular concern are petrochemicals that are not compatible with many standard cables. A list of these fluids can be found in MIL-C-85045/7.

2.2.4. Tolerance to the Environment.

Optical fiber normally requires protection from the environment. This includes protection from crushing or impact, tensile loading, repeated cable flexing and temperature related effects. The test criteria for these parameters are defined in MIL-STD-1678, and can be



tailored to the specific environment in which the cable is used.

2.2.5. Adverse Effects of Cabling on Fiber.

When a fiber is cabled, the fiber's optical attenuation may increase. This increase is due to fiber surface deformation which causes light to escape (microbending). The relative magnitude of this attenuation can be computed in terms of the fiber parameters which were defined in Section 1.1.3.

2.2.6. Fiber Protection Aspects of Cabling.

The "cable" encloses one or more optical fibers with one or more material layers to combine the fibers into a contiguous assembly for handling and installation while providing the necessary mechanical and environmental protection to preserve the optical integrity of the fiber waveguides. Unlike electrical cable, the optical cable does not need to provide "insulation" as generally no electrically conducting materials are included in the cable assembly and neither must it include any electrical shielding properties.

2.2.6.1. Inner Jacket.

The inner jacket, if one exists, is primarily to augment the buffer in cushioning the fiber from mechanical stresses. There are two inner jacket types; loose tube and tight tube. Typical tube materials are nylon, Hytrel, PVC, or rubber.

2.2.6.1.1. Loose Tube.

The loose tube places the fiber in a tube that allows it to move. This construction isolates the fiber from temperature induced differential expansion and tensile strain. It is used for long distance runs where an increase in attenuation cannot be tolerated.

2.2.6.1.2. Tight Tube.

The tight tube buffer is in intimate contact with the fiber. This construction is more crush resistant and more flexible than the loose tube buffer. It is usually used for short distance runs where an increase in attenuation can be tolerated.

2.2.6.2. Strength Members.

Strength members protect fibers by absorbing tensile loads so that the fiber can withstand the strain induced at installation and throughout its lifetime, especially during installation.

2.2.6.2.1. Materials.

Typical materials include Aramid, Kevlar (Aramid Yarn 1/), Epoxy Rod, Steel and Fiberglass. Kevlar is the material used in most single



fiber cables, while epoxy rods or Kevlar are used for multifiber cables. The individual fibers in most cases will have their own Kevlar strength members that are used as a strain relief when crimped onto a connector terminus.

2.2.6.2.2. Antibuckling Elements.

Strength members may be used in tandem with antibuckling elements. In these applications, the antibuckling elements offer resistance to contraction forces experienced when low temperatures shrink the plastics faster than the glass fibers and prevent buckling when the cable is bent.

2.2.6.3. Outer Jacket.

Fiber optic cables are jacketed to provide abrasion and environmental protection to the entire cable assembly, and to protect the fiber from sharp bends.

The outer jacket of a fiber optic cable is the outermost element of the cable which provides environmental protection. It can surround a single fiber, a fiber bundle, or multiple individually jacketed fibers.

The commonly used materials are polyvinyl chloride (PVC), polyethylene (PE), polyurethane (PUR), and a number of fluoropolymers. Some examples of fluoropolymers presently used in the industry are Kynar, Halar, Nylon and Teflons - fluorinated ethylene propylene (FEP), perfluoroalboxy (PFA), and Tefzel.

2.3. Connectors.

The connector in the MIL-STD-1773 system provides optical continuity between the various components of the overall system and allows disassembly and reassembly without damage. Because of the large number of connector devices required on a typical bus system, it is imperative that these devices introduce as little loss as possible. Losses are minimized to maintain system specifications such as bit error rate, signal to noise ratio, and system power margin.

The connector must protect the optical interface from the environment and provide the necessary mechanical stability to insure the reliability and system performance requirements. Connector performance can be the limiting factor in system performance. The most important connector performance parameter is insertion loss. Typical connectors generally exhibit insertion losses on the average of 1.0 dB with a 3 Sigma spread of up to 1 dB. Current design practice is to allow 1.5 dB to 2.0 dB per connector. Using more conservative numbers can lead to over-specifying the system so that more expensive sources and detectors are required. Other major performance parameters include resistance to vibration induced optical discontinuity (microphonics), ambient light pickup, and freedom from signal distortion. Major functions and performance characteristics are discussed in the following paragraphs. Insertion loss is minimized by using a connector that has proper axial



lateral, and angular alignment of its mating termini. The rest of the connectorizing loss equation is attributable to fiber mechanical tolerances and termination procedures.

2.3.1. Terminus Selection Considerations.

Termini are metal or ceramic tubes with axial holes which concentrically locate the optical fiber. Tight mechanical tolerances are required to minimize lateral misalignment in the plane of the end-face, longitudinal end-face separation (gapping), and angular misalignment.

Termini end faces may be shaped flat and orthogonal to the termini longitudinal axis (butt junction types) or they may contain a lensing manner to provide focusing capability (expanded beam types). In all cases, it is necessary that a high level of surface finish quality (polish) be present at the fiber or bundle mating end faces to prevent scattering of optical energy by surface imperfections. (scratches, bubbles, digs, etc.). Scattered energy is signal power which is lost and represents one source of attenuation in the connector. Single fiber termini may use fibers with end faces prepared by wet methods using grinding and polishing compounds and equipment arrangements common to the lapidary arts. Alternately, a scribe-and-break dry method can be used effectively whereby the fiber cladding is scratched at the desired location and application of simultaneous tensile and bending forces applied to the fiber placed over a suitable mandrel until fiber fracture occurs. Some skill or sophisticated tooling is involved to obtain repeatedly good results by this fracture method, but excellent surface finishes have been obtained. Recommended end-finishing methods and means for assessing the optical finish quality have been developed by the Electronic Industries Association (E.I.A.) standardizing groups for fiber optics and are part of the RS 455 Series of test methods. As a general guide, surface finishes with irregularities not exceeding sub-micrometer dimension are obtainable by these methods and are adequate to provide high transmission across the optical faces.

The final loss mechanism is due to Fresnel effects, The reflection that occurs whenever light passes through an interface which includes an abrupt change in index of refraction. Losses due to Fresnel effects are described in more detail in the section on splices, in paragraph 2.7.

2.3.2. Mechanical Performance.

Optical connector mechanical performance requirements will vary with the intended application. The high reliability and logistical impact of connectors used in military systems establishes the following common requirements for these parts:

Optical termini junctions must be individually sealed against the entry of all foreign agents (moisture and contaminants).

Termini and their termination procedures must be capable of preventing "pistoning" or extrusion of the fiber end out of the terminus during temperature cycling.

Termini must be capable of simple replacement (or repair) in the field environment within a specified maximum amount of time.

Connector materials used shall be nonmagnetic, non-toxic, non-nutrient to fungus, non-corrosive, and flame resistant.

Mechanical parts shall provide the specified coupling and mating force levels required for termini insertion, removal and retention and shell engagement and locking.

Cable/connector interfaces must preserve cable tensile and sealing properties across the boundary while not affecting the optical transfer characteristics.

2.3.3. Military Connector Specifications.

Since specific connector requirements for military use are application dependent, only the more general requirements are listed. Specific connector requirements, beyond those noted, should be specified by the system design engineer to satisfy the particular application. The following list contains some of the connector properties which should be considered:

Optical Properties

- o Insertion Loss
- o Signal interruption
- o Signal modulation
- o Multi-termini crosstalk
- o Ambient optical pick-up
- o Signal waveform distortion
- o Signal back-reflection

Physical Properties

- o Dimensional interchangeability
- o Marking durability
- o Temperature life
- o Thermal shock
- o Humidity
- o Fluid immersion/corrosion
- o Flammability
- o Termini maintenance aging
- o Termini insertion/removal forces
- o Termini and insert retention strengths
- o Termini repair and cleaning
- o Engagement/disengagement forces
- o Coupling torque forces
- o Mating durability



- o Twist
- o Impact
- o Vibration
- o Mechanical shock
- o Cable seal flexure
- o Cable pull-out force
- o External bending moment.

2.3.4. Types and Characteristics.

Connectors available for use in 1773 applications can be divided up into many categories. For the purposes of this discussion, the following definitions will be used:

Class - the class of fiber connected, i.e. single mode or multimode

Type - the type of junction used at optical interface, i.e. butt (dry or wet), lensed

Configuration - the connector configuration, e.g., rack and panel, circular, bulkhead, edge card, and rectangular

2.3.5. Testing.

Connectors are tested to verify the specified requirements. These requirements can be broken down into optical performance, mechanical performance, and environmental performance. The qualification tests are performed to ensure that the connectors meet all specification requirements. Lot acceptance tests are also conducted. Examples of common test methods are given in section 5.1.

2.4. Couplers

A coupler simultaneously distributes optical signals from one or more inputs to one or more outputs. This capability permits fiber optic technology to leave the realm of individual point-to-point transmission architecture and enter the area of linear bus topology with optical signal transfer.

2.4.1. Applications.

Coupling devices in 1773 systems find application in unidirectional and bidirectional optical signal transmissions. Couplers provide the additional capabilities of directional coupling, branching or splitting, and optical signal combining.

2.4.2. Coupler Types.

Optical coupler types are tee (or access), reflective star and transmissive star.

2.4.2.1. Tee Coupler.

The tee coupler is a 3-port device with input and output ports having properties selected as required for the application. The tee coupler ports are numbered as shown in Figure 2-9. with the port-to-port power transfer coefficients shown in the accompanying matrix. Notation on the coefficient numerical subscripts should be checked on all data sheets since consistency does not exist, but for our purpose the notation (Pxy) shall be the power level (defined in ratio, percent or dB) existing when x is selected as the input terminal and y as the output terminal. As an example, in an ideal and equal splitter operation with input port at 1 and output ports at 2 and 3, $P_{12} = P_{21}$ which will equal 0.5, 50% or -3 dB, depending upon the relation desired. All three terms may be used on data sheets and conversion between these is advised. Generally, dB will be the preferred units used. The matrix also shows that P_{11} , P_{22} , and P_{33} represent power levels reflected back out of ports used as input ports. Isolation considerations require these values to be small. The Pxy cross-coupling terms define the coupler properties of insertion loss, excess loss, splitting loss, and directivity.

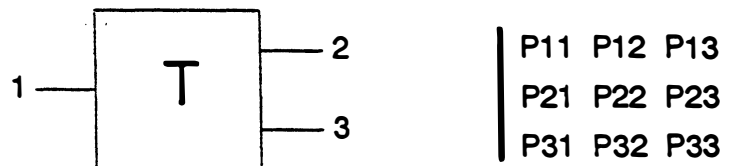


Figure 2-9. Tee Coupler with Transfer Matrix.

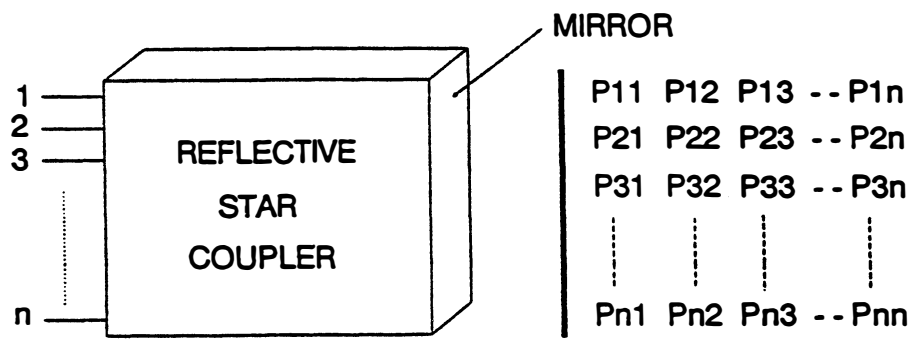


Figure 2-10. Reflective Star Coupler with Transfer Matrix.

2.4.2.2. Reflective Star Coupler.

In Figure 2-10., the reflective star coupler can be described by an extension of the tee coupler matrix principle to an $n \times n$ matrix for a coupler of (n) ports, where each port may act as an input or output.

The reflective star coupler derives its name from the fact that optical energy entering any port is reflected from a mirrored surface to uniformly and efficiently illuminate all coupler ports. The use of this coupler within the system topology is star-like in that all optical signals requiring coupler processing are brought to the central coupler location from various platform locations. As noted before for the tee coupler, P_{11} , P_{22} --- P_{nn} coupling coefficients are self-induced power levels reflected back into their respective input arms. Cross-coupling terms (P_{xy}) are as noted previously for the tee coupler.

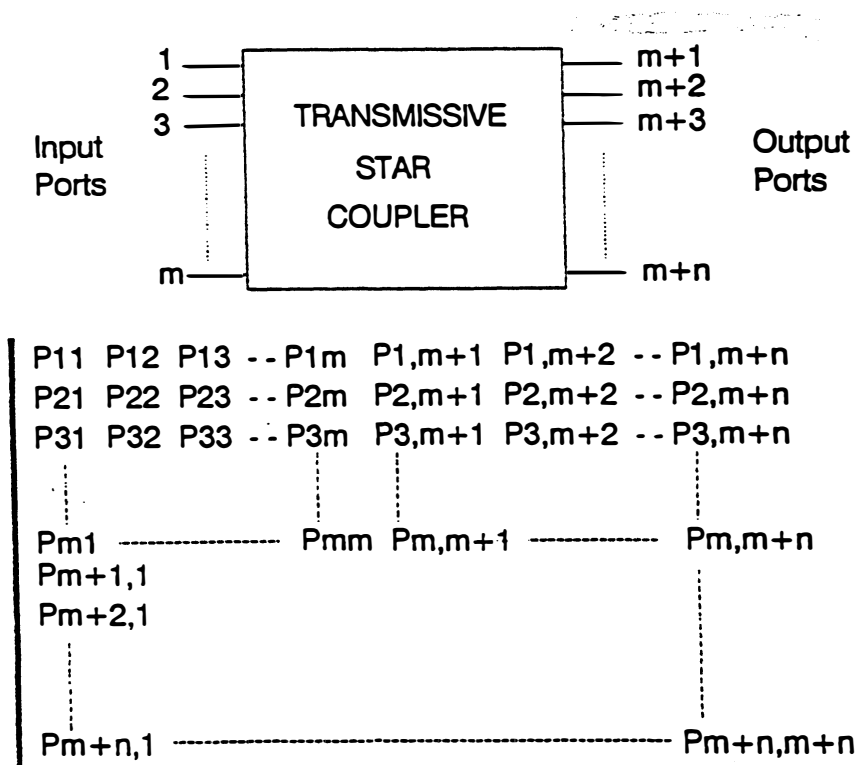


Figure 2-11. Transmissive Star Coupler with Transfer Matrix.

2.4.2.3. Transmissive Star Coupler.

In Figure 2-11., the transmissive star coupler provides m input ports and n output ports with an $(m+n) \times (m+n)$ coupling matrix. Each input port couples uniformly to each output port (in the ideal case) and only backscatter and reflections from the output ports are returned to the input ports. This arrangement provides better isolation between input and output ports and improved directivity over reflective stars.

All possible power linkages between terminals are expressed by suitable values inserted into the matrix with the P_{xy} notation.

2.4.2.4. Performance.

Couplers must be capable of withstanding the rigors of system installation and service while meeting specified optical, mechanical and environmental performance levels in accordance with the following definitions.

2.4.2.4.1. Optical.

Coupling parameters of importance to the design engineer are insertion loss, splitting loss, excess loss, directivity, isolation and output uniformity.

2.4.2.4.1.1. Insertion Loss.

Insertion loss is the port-to-port or channel-related optical power loss which occurs in a signal path by insertion of a device. Using the P_{xy} notation (x = input port, y = output port), the insertion loss (iL_{xy}) across ports P_{xy} is as follows. The port-to-port (channel) insertion loss (iL_{xy}) is equal to the sum of the channel splitting loss (sL_{xy}) and the channel excess loss (eL_{xy}). That is,

$$iL_{xy} = 10 \log [P_y / P_x] \text{ dB and } iL_{xy} = sL_{xy} + eL_{xy} \text{ dB.}$$

2.4.2.4.1.2. Splitting Loss.

The nominal splitting loss for couplers requiring equal outputs can be expressed as:

$$sL = 10 \log [1 / n] \text{ dB.}$$

where:

n is the number of output terminals

When unequal power splitting is desired at the output ports, L may be calculated individually for each output channel from:

$$sL_{xy} = 10 \log [P_{xy}] \text{ dB.}$$

For reference convenience, the splitting percents and dB losses are plotted in Figure 2-12., for couplers requiring equal powers at a



varying number of output ports for a given input port.

In the example of the 4-port coupler of Figure 2-12., let the chosen output channels, P2, P3, and P4 have required splitting ratios of 0.5, 0.3 and 0.2 respectively. The sum of these decimal ratios must equal unity (ideally, $P_2 + P_3 + P_4 = P_1$) power splitting. Now the individual channel splitting losses are:

$$sL_{12} = 10 \log [P_{12}] = 10 \log [0.5] = -3.01 \text{ dB}$$

$$sL_{13} = 10 \log [P_{13}] = 10 \log [0.3] = -5.22 \text{ dB}$$

$$sL_{14} = 10 \log [P_{14}] = 10 \log [0.2] = -6.99 \text{ dB}.$$

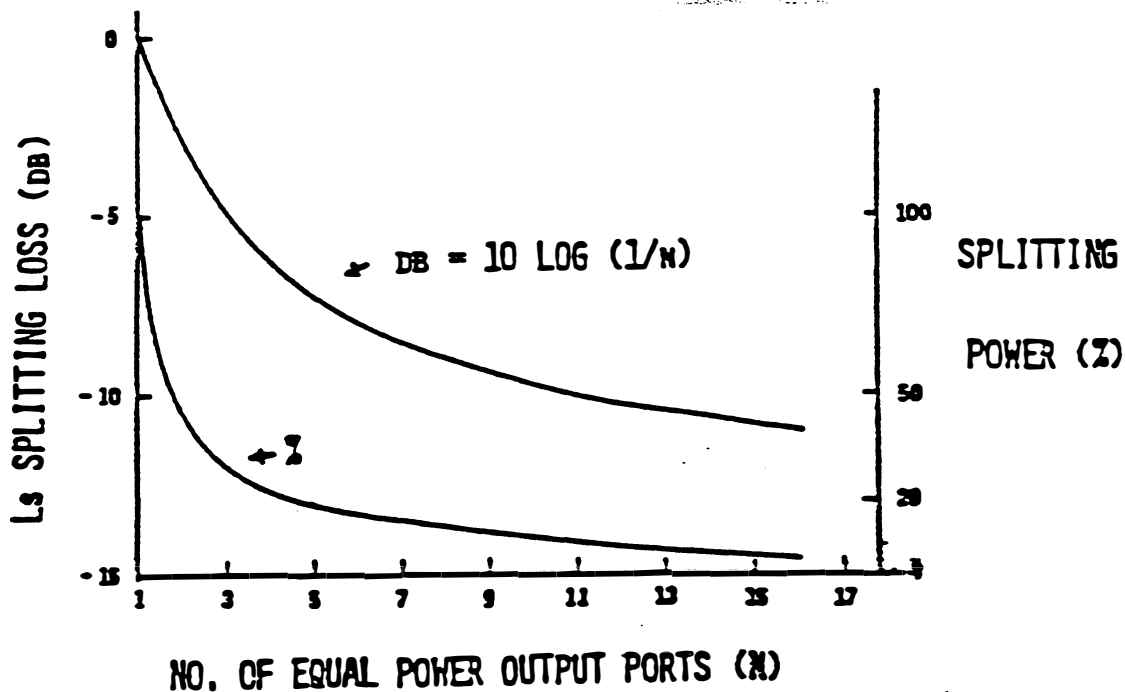


Figure 2-12. Splitting Loss for n Equal Power Output Ports.

2.4.2.4.1.3. Excess Loss.

Excess loss is the additional loss which occurs between an input and an output port in excess of the expected splitting loss and is the difference between the input power and the sum of all the power at the output ports. These additional losses are due to manufacturing techniques, materials, etc.

2.4.2.4.1.4. Directivity.

Directivity is the directional ease with which optical signal propagation may take place between two ports used alternately as input and output. From the transfer matrix shown previously, this represents a comparison between the P_{xy} and P_{yx} matrix output ports. That is, if $P_{12} = P_{21}$, the port-to-port directivity is equal for signals propagating in both directions between ports and is called bidirectional. When P_{xy} is unequal to P_{yx} , a preferred signal transfer direction is established and an improved unidirectional coupling sense is obtained. Directivity (D_{xy}) may be expressed as a factor or decibel relation; that is, P_{xy} / P_{yx} or $10 \log [P_{xy} / P_{yx}]$ respectively. When $P_{xy} = P_{yx}$, the directivity is 1.0 or 0 dB. If $P_{xy} = 4P_{yx}$, $D_{xy} = 4$ or +6 dB. Directivity is an important parameter for data busing applications, control monitors, directional coupling, and other operations requiring the transfer of optical energy in preferred directions.

2.4.2.4.1.5. Isolation.

Isolation is the ratio of optical power delivered from an input port to an undesired port. This is equivalent to crosstalk between cabled fibers within a common jacket and is usually given in decibel notation.

2.4.2.4.1.6. Output Uniformity.

Port-to-port output uniformity is an important consideration for couplers which are intended to provide equal energy splitting between output ports. Output uniformity is usually expressed on coupler data sheets as a positive decibel variation in output level. Maintaining a small output tolerance range may be an important feature of a coupler used over a wide operating temperature range.

2.4.2.4.1.7. External Interface Losses.

Couplers normally interface with optical circuits through connectors. Coupler data may be given on manufacturers' data sheets, exclusive of the input or output (or both) connector interface loss(es). The design engineer should interpret the data presented with regard to interface loss.

2.4.2.4.2. Mechanical.

Couplers are affected by mechanical and environmental extremes. Since each coupler port will normally be connectorized, port connector performance variations will be additive to the internal coupler



performance effects. Mechanical tests which may affect the internal coupler structure (dimensionally and mechanically) are vibration, mechanical shock and impact.

2.4.2.4.3. Environmental.

Environments such as fluids, radiation, humidity, and temperature may degrade coupler performance.

2.4.2.5. Testing.

Couplers are tested to verify the specified requirements. These requirements can be broken down into optical performance, mechanical performance, and environmental performance. The qualification tests are performed to ensure that the couplers meet all specification requirements. Lot acceptance tests are also conducted. For specific tests see Chapter 5.

2.5. Fiber Optic Switches.

Fiber optic switches are the optical counterpart to electrical relays but called switches to avoid confusion with repeaters. They switch the optical signal from one port to another on command from an electrical control signal. They are available in latching and non-latching types with many of the switching combinations popular in relay contacts: normally open, normally closed, transfer, and exchange.

Fiber optic "switches" are commonly used in ring bus and LAN (Local Area Network) applications but may also be used in 1773 bus systems to:

- o Improve optical efficiency by reducing the number of ports required at a Star Coupler if different terminals are used in different modes (i.e. redundant system).
- o Improve security by automatically disconnecting unused branches or switching to a test system to detect unauthorized taps.

Fiber optic switching can be implemented by electromechanical, solid state, or optoelectronic technologies. Electromechanical technologies include systems to physically move a fiber to align it with a different port or to move a mirror or prism to deflect light beam(s) to different port(s). Switching time is typically 5-10 milliseconds. Some electromechanical switches are sensitive to shock, vibration, humidity, salt spray, and may have limited life.

2.5.1. Solid State Switches.

Solid state technologies provide much faster operation (microsec.) but devices are not as readily available. Solid state approaches utilize principles of change of reflectivity such as liquid crystals (1, 2), polarization rotation, beam deflection by variable spacing diffraction



gratings formed by stripe domain magnetic Garnet films or interferometric technologies (3). Many of these require Laser light sources and monomode fibers which are more expensive and not currently included in 1773.

2.5.2. Optoelectronic switches.

Optoelectronic switch matrices use broadband photodetectors to detect the signal, switch electronically, then retransmit with LEDs. Switching times below 1 ns have been reported (4). When fiber optic "switches" are used, the system designer must carefully evaluate the possibility of loss of electrical power to the switch control circuit.

2.6. Optical Slip Rings.

The 1773 data bus can be carried across a rotary joint by using a fiber optic slip ring. An optical slip ring has several advantages over the electrical counterpart: no friction, no wear, no brush noise, no radiated EMI, and communication can be carried in both directions through the slip ring simultaneously.

Optical slip rings are available in three types: on-axis, off-axis, and in combination with electrical, hydraulic, or pneumatic slip rings.

On-axis optical slip rings have the lowest losses but are limited to one optical path and must occupy the center of the axis of rotation. One slip ring can carry a large number of independent channels by using a variety of multiplexing techniques. For example, a 1773 bus can share the same slip ring with several audio, video, and discrete channels by using different colors (optical frequencies) for each channel.

Off-axis optical slip rings allow the center of the axis of rotation to be used for hydraulic, pneumatic or structural functions. However, They have much higher optical losses. Optical slip rings are more sensitive to contamination because they do not have the wiping action inherent in electrical slip rings. Various types of o-rings can be used to protect the optical slip ring depending on what contaminants, speeds, friction, and alignment accuracies are required in the application.

Misalignment of the optical path or vibration in the optical slip ring can cause modulation of the optical signal which is a function of speed of rotation. The effects of these can be minimized in the design of the slip ring by using "expanded beam" techniques.

2.7. Splices.

Optical fiber/cable splices are permanent connections between their respective counterparts with losses typically lower than those achievable with mechanical connectors. They may be used for repair purposes or for extension of fibers and cables. Ideally, the incorporation of a splice into a fiber or cable link should have no influence upon the optical or mechanical properties of the link. This

ideal is only partially achieved in practical splice fabrications. Fiber splice parameters of interest are the optical loss and modal continuity achieved across the splice junction. Cable splice parameters of interest are tensile strength and environmental sealing of the fiber junction.

2.7.1. Types.

Splice types are mechanical, fused and adhesive bonded. In all splice types, the mechanical requirements for fiber-to-fiber alignment (axial, lateral, gapping and angular) and fiber end-face finishing are very stringent. Alignment of splices is often achieved by illuminating the input segment and aligning for maximum output.

2.7.2. Performance.

2.7.2.1. Optical.

Primary optical losses associated with single fiber splices are due to lateral axial misalignment loss, differences in the mating fiber core diameters, and Fresnel effects from splicing fibers with different core indices of refraction.

2.7.2.1.1. Fiber Core Dimensional Loss.

This loss occurs when optical energy passes from a larger fiber core area to a smaller fiber core area. Assuming negligible gapping loss and perfectly circular and aligned fiber cores, the core dimensional loss (L_c) is:

$$L_c = 20 \log [100 - \%d / 100 + \%d] \text{ dB.}$$

where:

$\%d$ is the percent tolerance in core diameter.

For a nominal fiber core diameter of 50 microns, the plot of Figure 2-13. shows the coupling loss associated with percent core diameter variation.

As an example, if a $\pm 1\%$ manufacturing tolerance is assumed, the respective worst case fiber core diameters being joined will be 49.5 and 50.5 micrometers. If energy passes from the core of larger diameter into the core of smaller diameter, a core loss (L_c) of 0.17 dB will result. Energy passing through the junction in the opposite direction (from smaller to larger) will not exhibit this loss. This loss will also be prevalent in splices using fibers of different core size with similar rationale for the loss criteria.

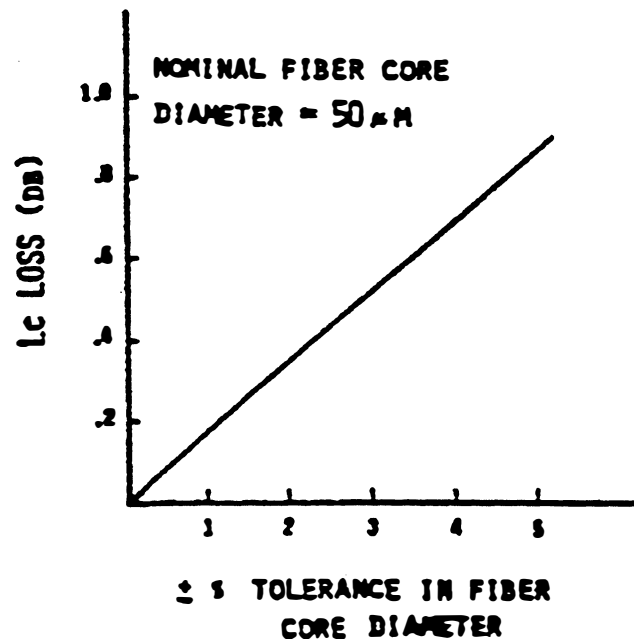


Figure 2-13. Coupling Loss as a Function of Diameter Variation

2.7.2.1.2. Fresnel Reflections.

When fiber cores of different refractive indexes are spliced (joined), then Fresnel loss(es) will be developed at each interface at which a change in index of refraction occurs. For thermally spliced fibers where only one interface exists, Fresnel loss (sL_f) may be approximated in terms of the fiber numerical apertures as follows:

$$sL_f = 10 \log \left\{ \frac{1 - [NA_1^2 - NA_2^2]}{1 + [NA_1^2 + NA_2^2]} \right\} \text{ dB.}$$

where NA_1 and NA_2 are the spliced fibers numerical apertures. It should be noted that sL_f occurs regardless of the energy propagation direction through the splice. Mechanical or adhesive Splices coupling fibers with an intermediate layer of adhesive, index matching gel or air of different refractive indices will include two Fresnel losses. This loss can be found by calculating the loss at each boundary and by summing the loss values.

2.7.2.2. Mechanical.

Unprotected optical fiber splices are quite fragile and easily broken if subjected to bending and tensile stresses. Therefore, splicing operations must be conducted with great care and spliced fibers should be afforded protection as soon after splicing as possible. Mechanical parameters which should be considered include tensile strength preservation across the splice and resistance to crush, impact, vibration, and mechanical shock exposures.

2.7.2.3. Environmental.

Environmental considerations include differential expansion during temperature excursions and sealing against intrusion of water and other external contaminants.

2.7.2.4. Splice Military Specification Requirements.

Since specific splice requirements for military use are application dependent, only the more general requirements are listed. Specific splice requirements, beyond those noted, should be specified by the system design engineer to satisfy the particular application. The following list contains some of the splice properties which should be considered:

Optical Properties

- o Insertion loss
- o Multi-splice crosstalk
- o Ambient optical pick-up
- o Signal waveform distortion (mode stripping/mixing)

Physical Properties

- o Tensile strength
- o Compressive strength
- o External bending moment
- o Torsional strength
- o Abrasion resistance
- o Vibration
- o Mechanical shock
- o Impact
- o Cable seal flexure
- o Flammability
- o Thermal life
- o Thermal shock
- o Humidity
- o Fluid immersion
- o Fungus resistance

2.7.3. Testing.

Splices are tested to verify the specified requirements. These requirements can be broken down into optical performance, mechanical performance, and environmental performance. The qualification tests are performed to ensure that the splices meet all specification requirements. Lot acceptance tests are also conducted. Specific test methods are given in chapter 5.



CHAPTER 3. MEDIA DESIGN.



CHAPTER 3. MEDIA DESIGN.

3.0. Media Design.

MIL-STD-1773 puts more responsibility on the individual system designer than MIL-STD-1553 (which includes some aspects of a specification). Terminal input and output characteristics, cable and connector definition, and bus topology are all left to the discretion of the system engineer; this is not the case for 1553. It is important that potential users of 1773 understand that they cannot avoid these design responsibilities by merely invoking MIL-STD-1773 in a master specification. This handbook, the system specification, and MIL-STD-1773 are all required for implementation.

3.1. Media Implementation Considerations.

Topology refers to the overall physical geometric layout of the terminal interconnection scheme. Typical topologies or topology features include stars, rings, and linear buses. A system can be comprised of a mix of topology features. The specified electrical layout in MIL-STD-1553 is a bidirectional linear bus with terminals attached at stubs. For 1773, however, the topology is not specified. The 1773 topology selection process, as complicated by the unique problems associated with fiber optic networks, can be a potential mine field. Below are some considerations for the system engineer to keep in mind.

A fiber optic signal cannot be inserted via a stub onto a linear bus by simply attaching the stub to the bus as is done in wire applications (Figure 3-1.). If optical power is to be launched onto the main bus to both the left and the right, the stub must be split into two. One splitter output must be passed through the combiner to launch the power to the right, and likewise for the left. If the stub is used to receive as well as transmit, another splitter/combiner device is required at the terminal. (See Figure 3-2.) Whenever splitters are used, the optical power is divided. The division need not be designed as an even split.

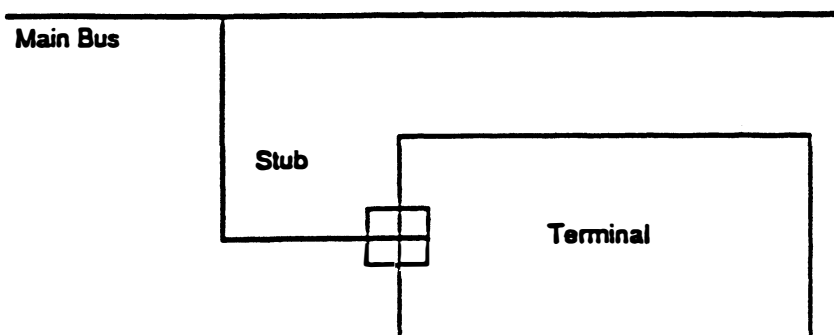


Figure 3-1. Bidirectional Wire Bus with Stub.

In Figure 3-2, it would probably be best for the stub taps to remove only a small fraction of power from the main bus. In addition to the division of power, power is lost at the splitter/combiners, connectors and at any other connectors present along the signal path. Another method of distributing power is the star coupler. There are two types of passive fiber optic stars, reflective and transmissive, as shown in Figure 3-4.

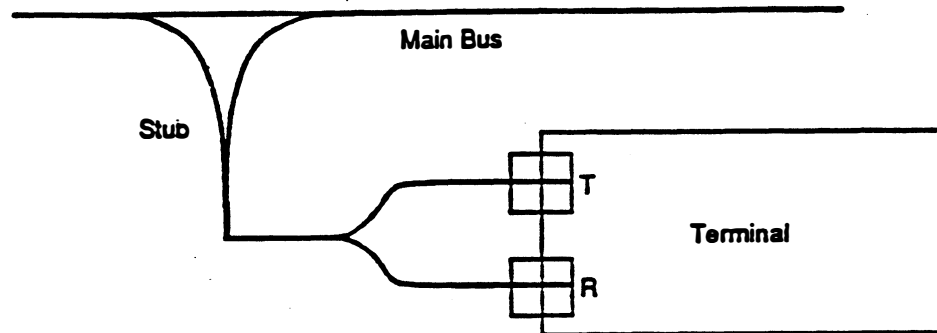


Figure 3-2. Bidirectional Optical Bus with Stub.

Reflective stars utilize bidirectional data transfer and require splitters/combiners at the terminals. Transmissive stars use separate input and output links from each terminal to the star. Because of the power losses and the difficulty of protecting splitter/combiner structures in the avionics environment, some systems are designed utilizing only point-to-point, unidirectional, fiber optic links. One way to accomplish this is to make all "tees" and stars active. In this approach, received fiber optic signals are converted to electrical signals, combined/amplified and retimed electrically, and input to fiber optic transmitters, generally with one transmitter for each branch out of the tee or star. All electrical activity is internal to the tee or star. The disadvantage of this approach is that the topology contains active, powered elements and pulse width distortion will be added by the threshold detection if retiming is not performed. Another approach is to use a protocol and topology optimized for point-to-point data transfer; this is the case with token-ring bus concepts. 1773 is required to use the command-response protocol of 1553, regardless of the topology selected. Because 1773 requires a broadcast medium, ring topologies are not appropriate. Hence for 1773, a linear or a star topology, or a mixture of the two, is recommended. The system designer should decide whether to use active or passive couplers/stars, point-to-point transfer, and bidirectional vs. unidirectional data paths based on system requirements, the current state of fiber optic technology, and power budget considerations (paragraph 3.2). A topology based on a single, central star is vulnerable to total failure due to battle damage or failure of the star itself. Risks are reduced by the utilization of redundant media structures with the second star located elsewhere.

As briefly mentioned earlier, active elements (repeaters) in