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MIL-STD-1773 USERS HANDBOOK

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To the MIL-STD-1773 User:

This is the first release of the Society of Automotive Engineers (SAE) AIR4508, MIL-STD-1773 USERS HANDBOOK. Your comments and constructive criticism are welcomed.

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

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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, Indanapolis, 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, Gloustershire, United Kingdom

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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.

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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.

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Chapter 5. Environmental and Performance Testing.

- 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.

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

Chapter 7. Media Installation Considerations.

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

Chapter 8. Radiation Effects.

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

Chapter 9. Terms and Definitions.

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

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References.

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

Appendix A. MIL-STD-1773.

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

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

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

Appendix C. Design Example - A Missile Application.

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

Appendix D. Implementing Multiple Speed Data Rate Transmission.

- Further discussion of MSDRT.
- 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.
- 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.

- 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.

- 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.

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CHAPTER 1. BACKGROUND.

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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.

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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.

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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 Symetrical 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 biphase 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 Distributed

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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.

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NOTES

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CHAPTER 2. COMPONENTS FOR MEDIA IMPLEMENTATION.

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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 n1 and a surrounding cladding with index n2.

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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 n1 to a lower value n2 at the core radius Rcr.

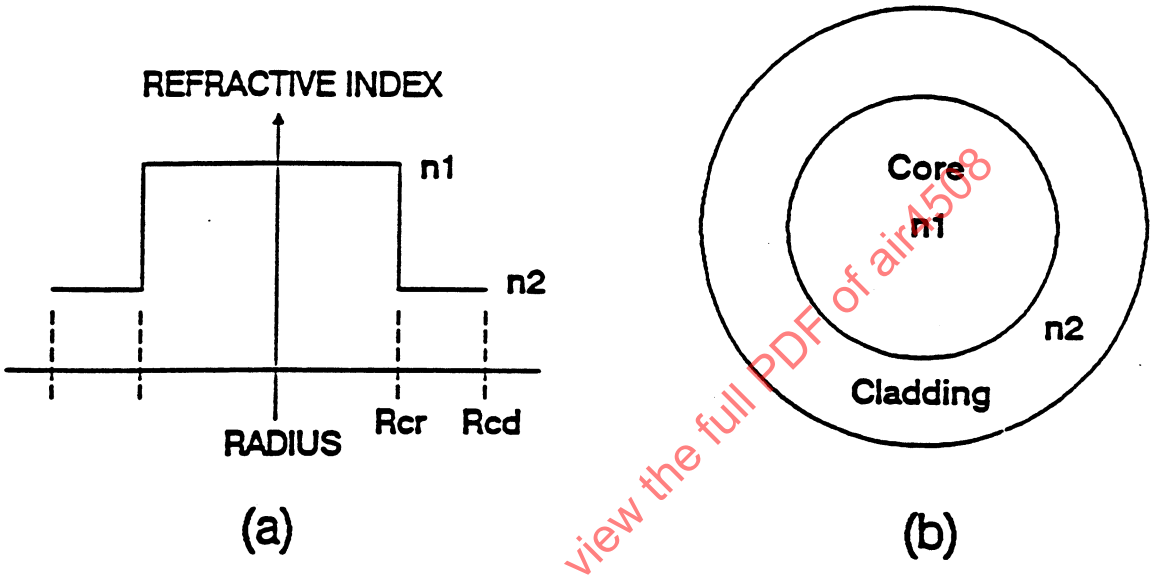

Figure 2-1. Step Index Profile.

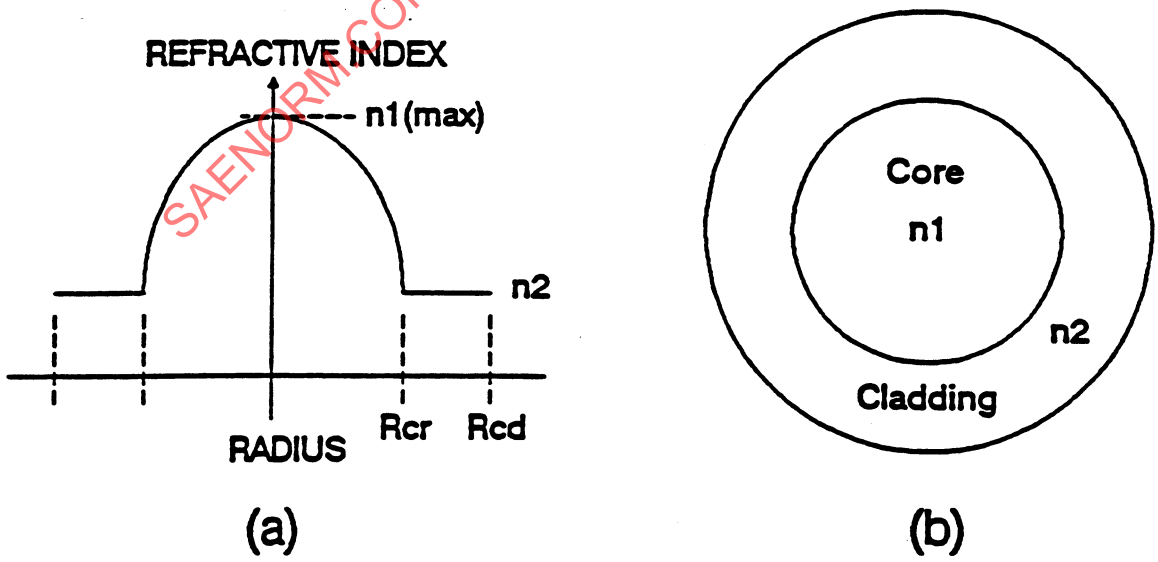

Figure 2-2. Graded Index Profile.

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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.

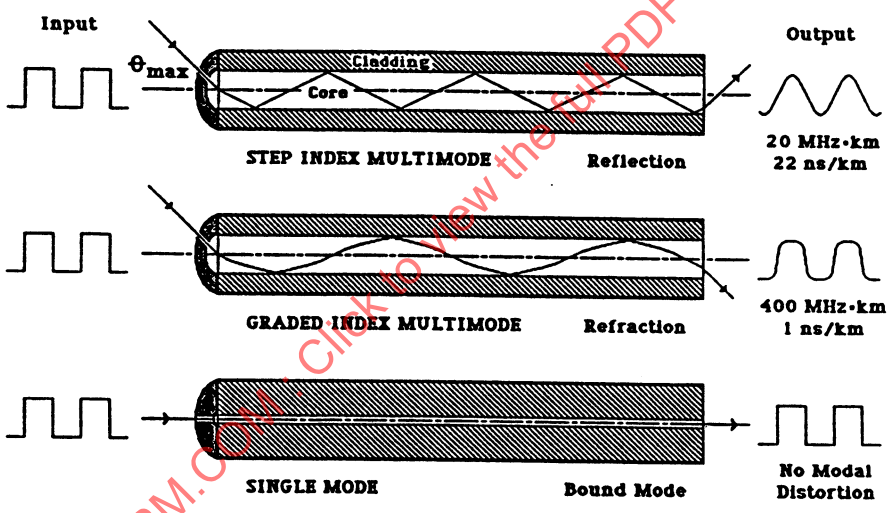

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Figure 2-3. Light Propagation For Three Common Fiber Types.

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 (Dcr), 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 (Dcd) 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 (Theta). Light waves injected at angles within this cone will be propagated along the fiber.

Numerical Aperture (NA) is calculated:

NA = Sin(Theta) = [n1 exp2 - n2 exp2] exp.5

Where:
n1 = core refractive index
n2 = cladding refractive index

and Theta = 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.

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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.

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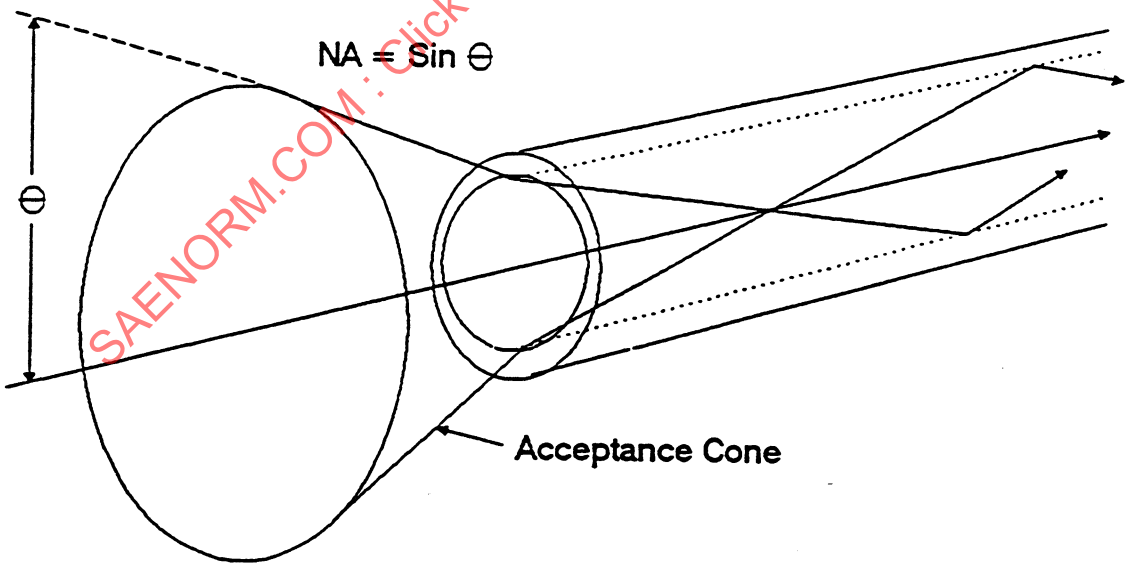

Figure 2-4. Numerical Aperture/Acceptance Cone Relationship.

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.

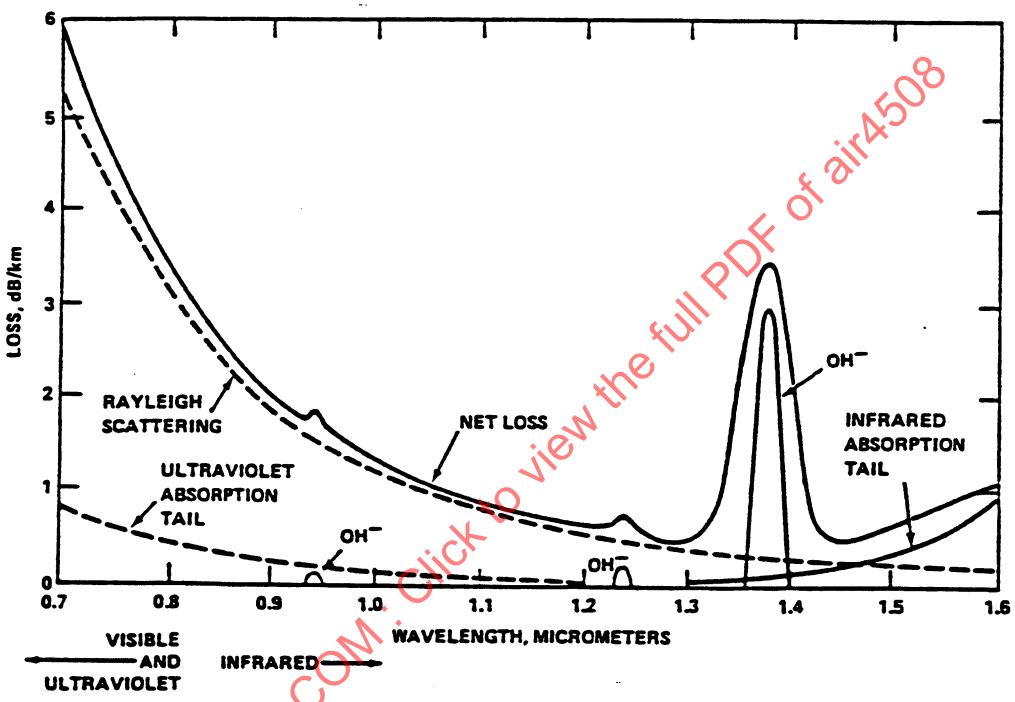

Figure 2-5. Optical Fiber Attenuation vs. Wavelength.

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

$$\text{Attenuation (dB/km)} = [10 \text{ Log } (Po/Pi)]/L$$

Where:
- Pi = Input Power
- Po = 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, n2), 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 um.

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 (delta Tmod) is given:

delta Tmod = L (NA exp2 / (2 x n2 x C)), seconds.

where:
NA = fiber Numeric Aperture.
n2 = 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 (F3db) is:

F3db = 0.44 / delta Tmod, Hertz. (modulation bandwidth)

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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 were 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 Graded Index Single Mode	20 MHz-km 100 to 1500 MHz-km a few hundredths of a nanosecond pulse spreading

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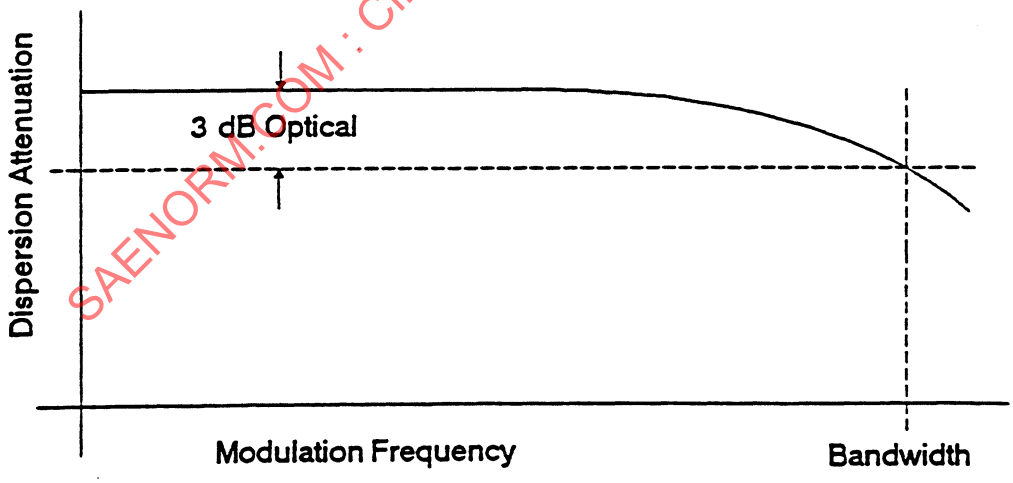

Figure 2-6. Attenuation versus Frequency of an Optical Fiber.

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 (Pc) is related to the ratio of the fiber NA (NAf) squared to the source NA (NAs) squared and the fiber core area (Df squared) to the source area (Ds squared):

Pc (watts) = Po (total output, watts) x [Cff x Cnf], watts.

where:
Cff = farfield factor = NAf exp2 / NAs exp2 = NAf exp2 / 1
= NAf exp2, <= 1.

Cnf = nearfield factor = Df exp2 / Ds exp2, <= 1.

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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 orthoginal directions (with the measurements averaged to ensure that the near field is rotationaly 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:

delta[I] = I[n-1] + I[n] / 2 (average intensity over annulus) x
Pi (d[n] exp2 - d[n-1] exp2) (area of annulus)

Cnf% (for fiber with core radius, Dcr/2 = d[n]) =
100 (summation of delta[I] from d = 0 to d[n]
/ summation of delta[I] from d = 0 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 saphire 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 symetrical), 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

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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 (average intensity solid angle) x
2 Pi (Cos(Theta[n]) - Cos(Theta[n-1])) (area of annulus)

Cff% (for fiber with NA = Sin(Theta[n])) =
100 (summation of delta[I] from Theta = 0 to Theta[n]
/ summation of delta[I] from Theta = 0 to Theta[m])

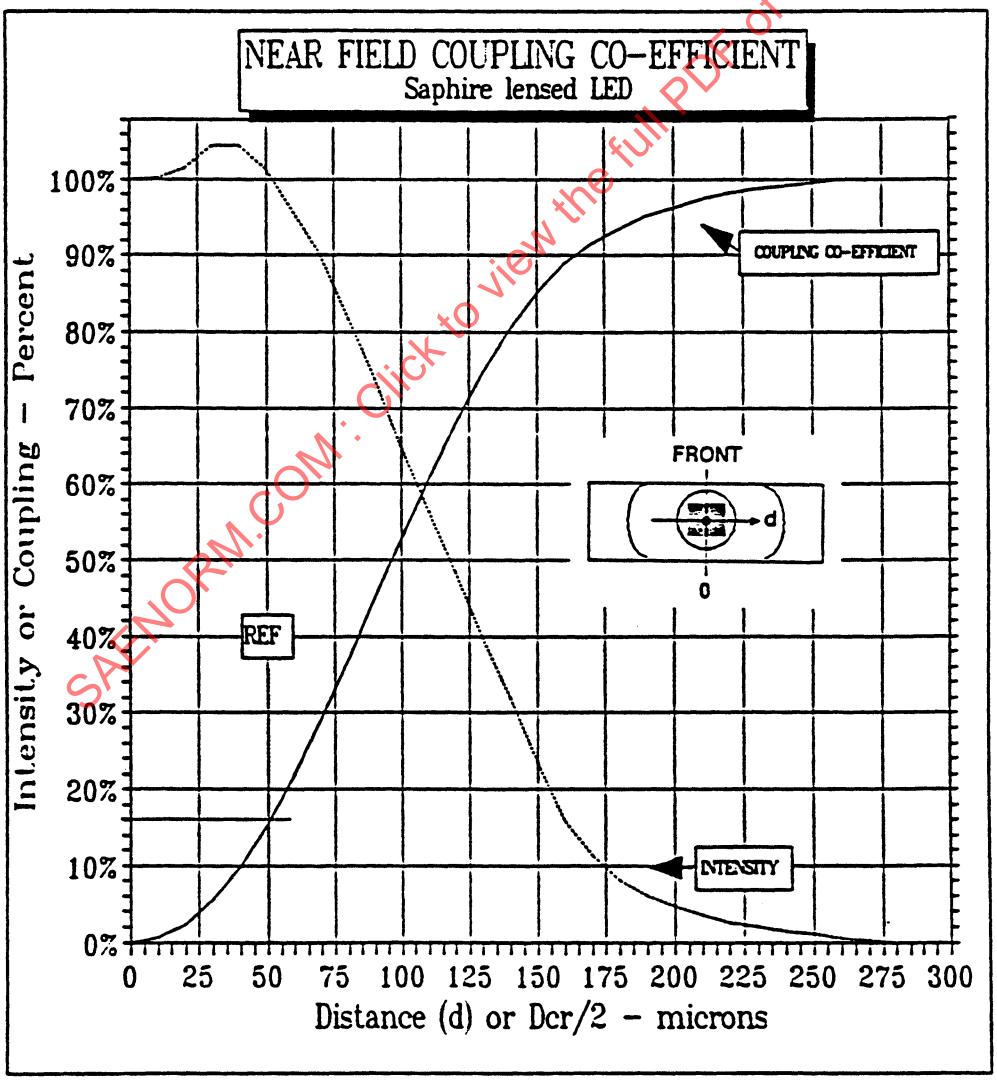

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Figure 2-6. Normalized Near Field Intensity vs d and Coupling Co-efficient vs Fiber Core Radius Example.

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):

$$Pc2 = Pc1(watts)\ [(Cnf2 / Cnf1) \times (Cff2 / Cff1)],\ watts;$$

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.

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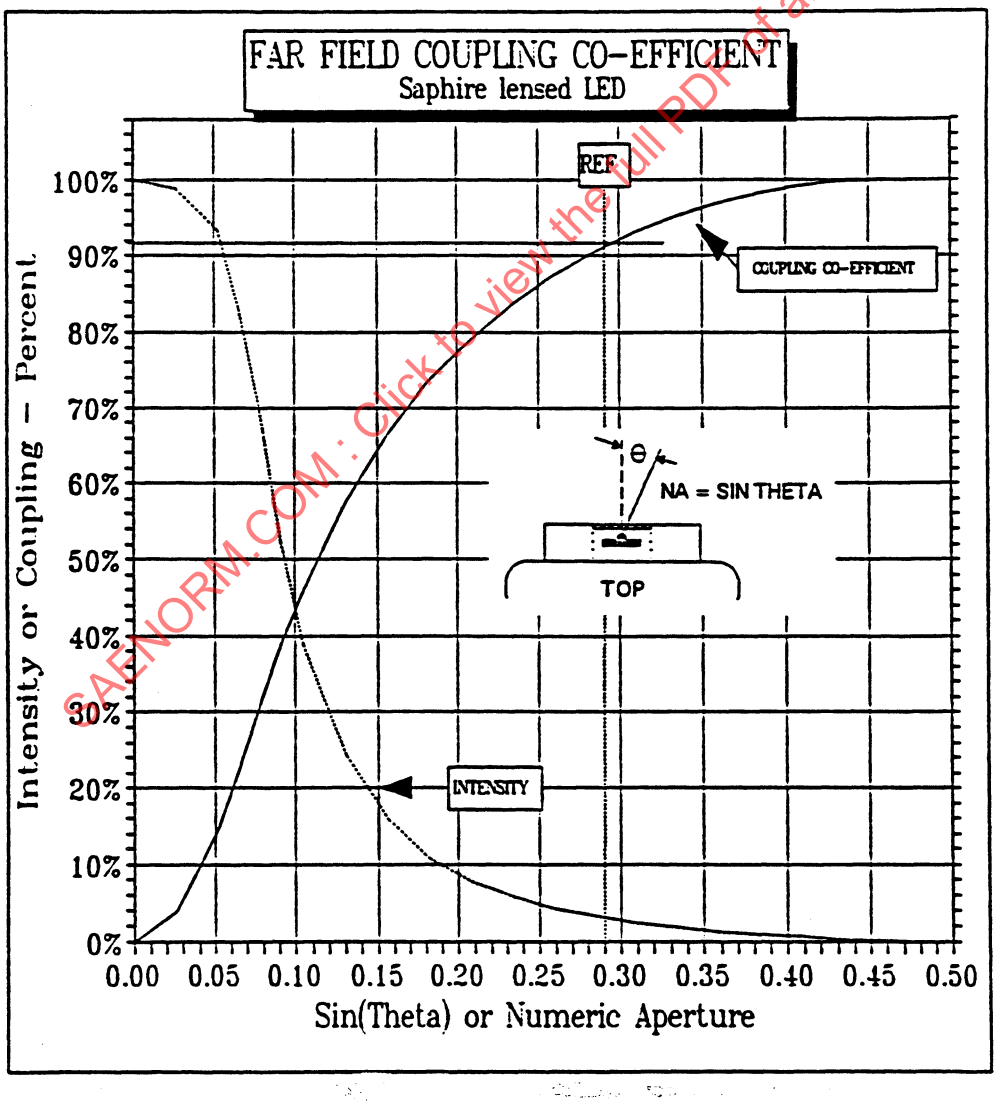

Figure 2-7. Normalized Far Field Intensity vs Sin(Theta) and Coupling Co-efficient vs Fiber NA Example.

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) x 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 Log(P2 / Pref), 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

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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

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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 discused in the following paragraphs. Insertion loss is minimized by using a connector that has proper axial,

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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).

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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 b considered:

Optical Properties

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

Physical Properties

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

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- 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.

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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, P12 = P21 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 P11, P22, and P33 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.

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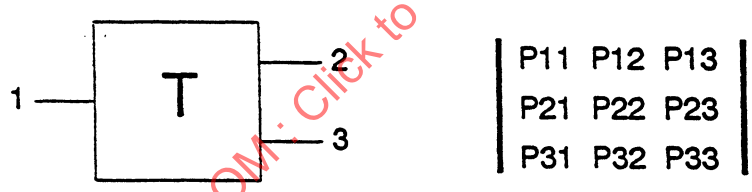

Figure 2-9. Tee Coupler with Transfer Matrix.

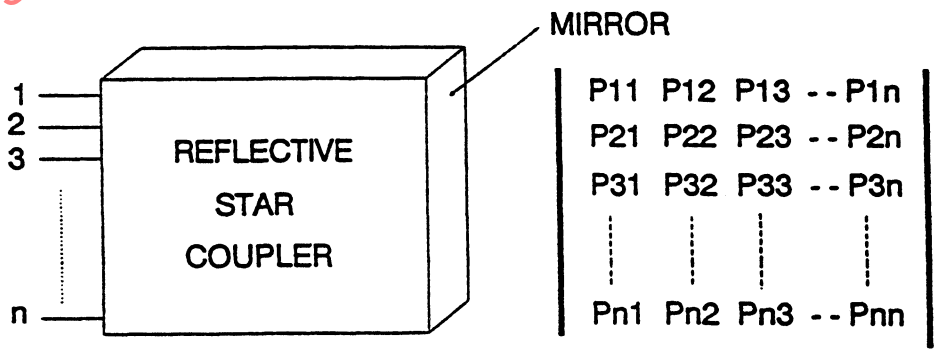

Figure 2-10. Reflective Star Coupler with Transfer Matrix.

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 x 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, P11, P22 --- Pnn coupling coefficients are self-induced power levels reflected back into their respective input arms. Cross-coupling terms (Pxy) are as noted previously for the tee coupler.

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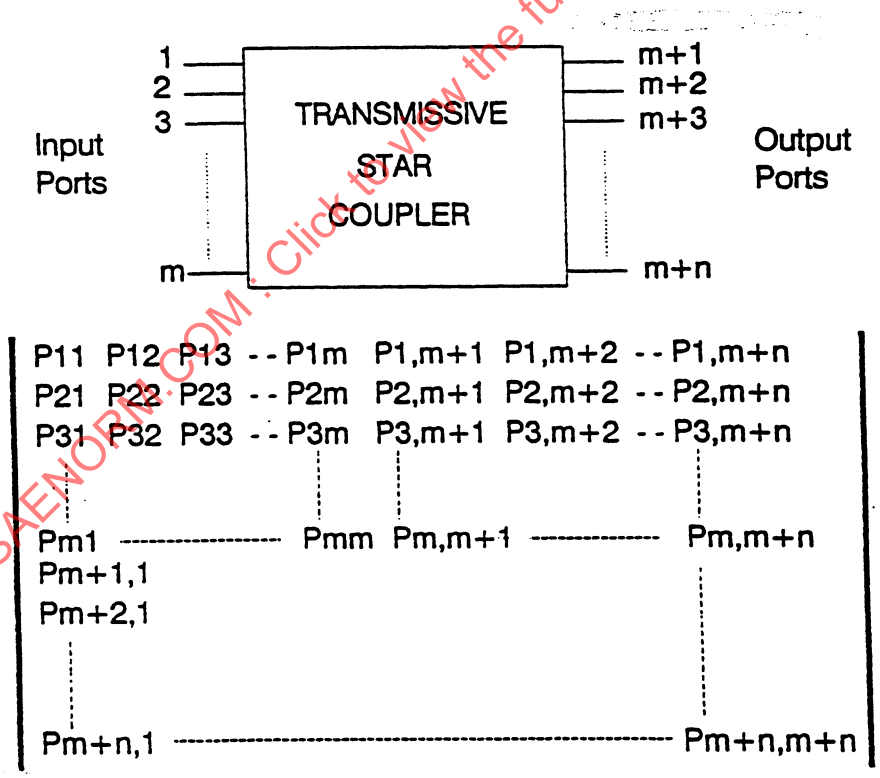

Figure 2-11. Transmissive Star Coupler with Transfer Matrix.

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) x (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 Pxy 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 Pxy notation (x = input port, y = output port), the insertion loss (iLxy) across ports Pxy is as follows. The port-to-port (channel) insertion loss (iLxy) is equal to the sum of the channel splitting loss (sLxy) and the channel excess loss (eLxy). That is,

$$iLxy = 10 \log [Py / Px] \text{ dB and } iLxy = sLxy + eLxy \text{ dB.}$$

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:

$$sLxy = 10 \log [Pxy] \text{ dB.}$$

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

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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, P2 + P3 + P4 = P1) power splitting. Now the individual channel splitting losses are:

$$sL12 = 10 \log [P12] = 10 \log [0.5] = -3.01 \text{ dB}$$

$$sL13 = 10 \log [P13] = 10 \log [0.3] = -5.22 \text{ dB}$$

$$sL14 = 10 \log [P14] = 10 \log [0.2] = -6.99 \text{ dB}.$$

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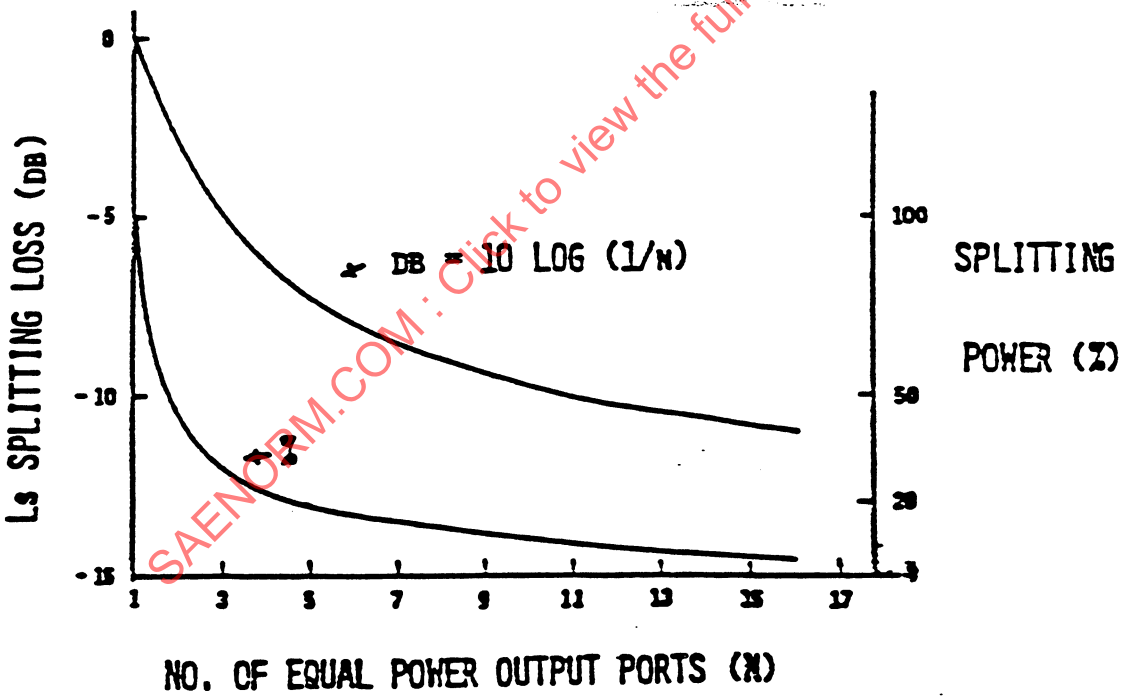

Figure 2-12. Splitting Loss for n Equal Power Output Ports.

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 Pxy and Pyx matrix output ports. That is, if P12 = P21, the port-to-port directivity is equal for signals propagating in both directions between ports and is called bidirectional. When Pxy is unequal to Pyx, a preferred signal transfer direction is established and an improved unidirectional coupling sense is obtained. Directivity (Dxy) may be expressed as a factor or decibel relation; that is, Pxy / Pyx or 10 log [Pxy / Pyx] respectively. When Pxy = Pyx, the directivity is 1.0 or 0 dB. If Pxy = 4Pyx, Dxy = 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

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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 difraction

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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 t 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

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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 (Lc) is:

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

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 +/-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 (Lc) 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.

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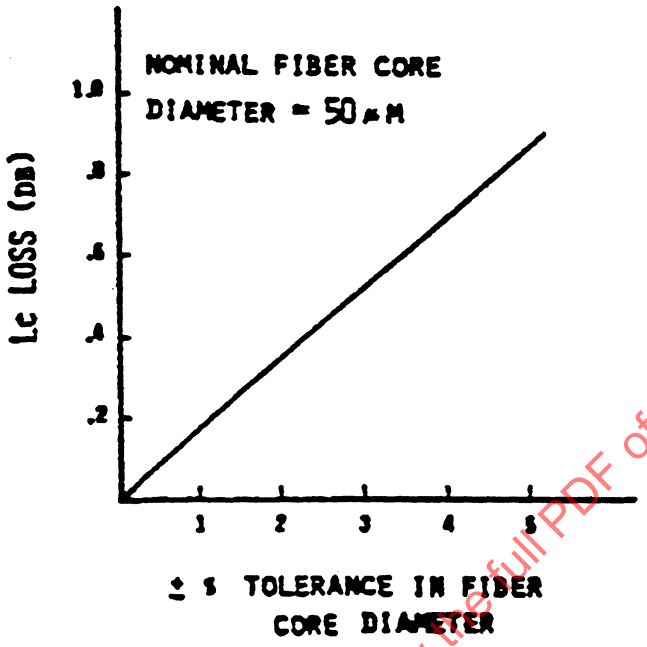

Figure 2-13. Coupling Loss as a Function of Diameter Variation

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 were only one interface exists, Fresnel loss (sLf) may be approximated in terms of the fiber numerical apertures as follows:

$$sLf = 10 \log \{[1 - [NA1 \exp 2 - NA2 \exp 2] / [NA1 \exp 2 + NA2 \exp 2]\} \exp 2 \quad dB.$$

where NA1 and NA2 are the spliced fibers numerical apertures. It should be noted that sLf 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.

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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

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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.

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CHAPTER 3. MEDIA DESIGN.

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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.

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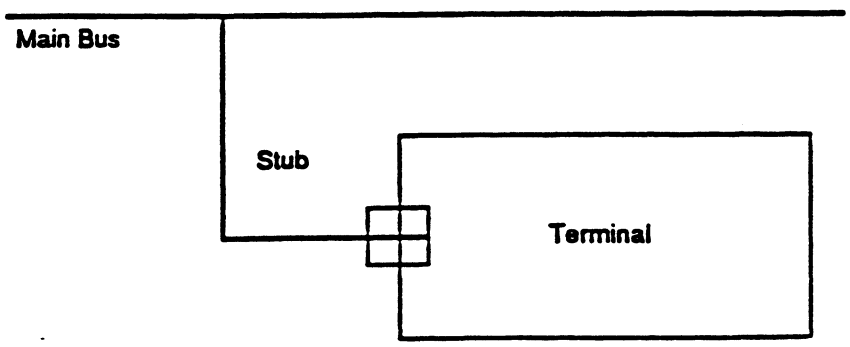

Figure 3-1. Bidirectional Wire Bus with Stub.

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.

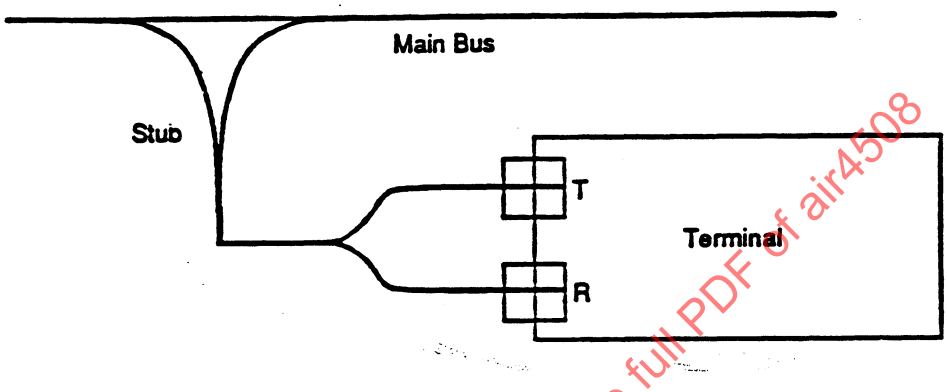

Figure 3-2. Bidirectional Optical Bus with Stub.

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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

networks will introduce pulse width distortion and jitter in addition to that inserted by the sender and destination transmitters/receivers. This distortion could be considerable in the case where the message must pass through several active stages en route from sender to destination. The system designer must analyze the overall system timing margins and/or do breadboard testing to determine whether this pulse shifting would cause the system to fail the 1773 word error rate test. (Remember, neither output nor input waveform distortion limits are specified in 1773 as they are in 1553, but the word error rate test still applies!) If repeaters are needed but pulse distortion is a problem, retiming repeaters may be used. Retiming repeaters will cause additional transmission delay but will restore pulses to nominal width as determined by the retransmit clock. Keep in mind, when introducing transmission delays, that the 12 microsecond 1773 response time requirement still applies. So delays in the 100 nanosecond range are probably insignificant, but microsecond or more delays may require modification of the 1773 response timeout value. MIL-STD-1773 allows for 2 microseconds total media delay, as a 14 microsecond minimum controller time-out is specified.

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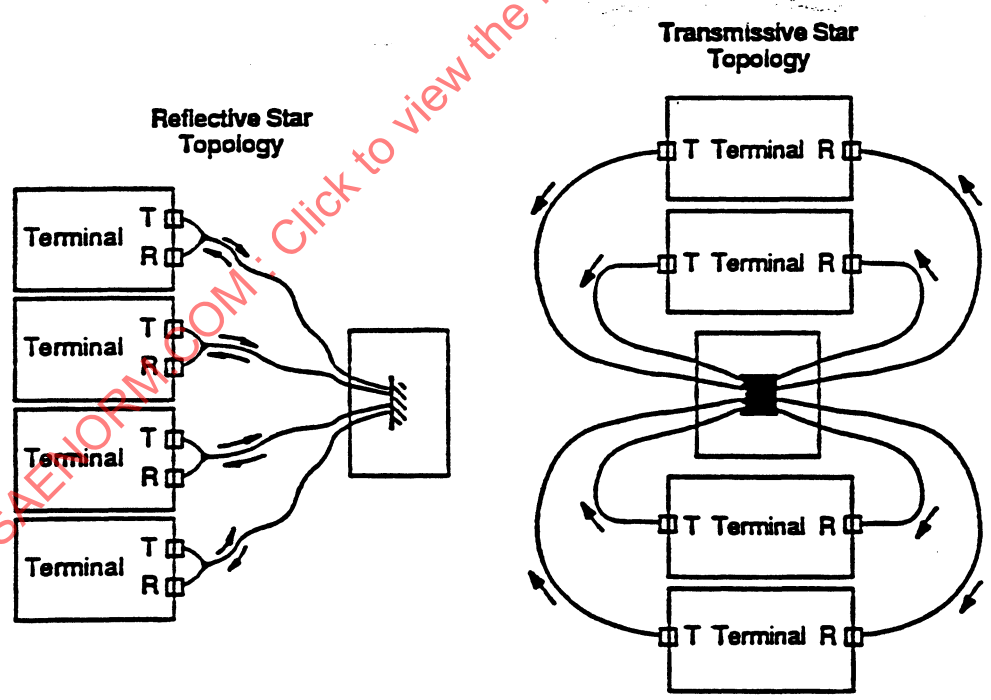

Figure 3-3. Reflective Star and Transmissive Star Topologies.

3.2. Power Budgeting.

Compared to electrical bus systems, fiber optics designs are very lossy. The task of calculating maximum and minimum accumulated losses from transmitter to receiver, known as power budgeting, is very important for deriving component specifications in fiber optic systems.

Power levels in fiber optics systems are usually expressed in dBm. The dB unit expresses a logarithmic power ratio between two absolute values, such as optical output power compared to optical input power. The dBm unit means dB relative to one milliwatt reference level, hence it is effectively an absolute power measurement (Loss in dB = 10 log [Pout/Pin] while power in dBm = 10 log [P(in mW) / 1 mW]. For example, 100 microwatts = -10 dBm and 10 microwatts = -20 dBm. An ideal equal division of power in a 2x splitter would result in a 3 dB loss.

Power budgets are more easily computed in dB rather than Watts because losses can be computed as the sum of all individual dB losses between transmitter output and receiver input, rather than as the product of the ratios. Each loss in the signal path must be accounted for; these will include insertion losses, connector losses, splitter losses, "excess" losses, fiber losses, etc. Additional losses due to connector contamination and misalignment, transmitter aging, fiber darkening due to radiation, etc., can occur, and should also be accounted for in what is called the "power margin". A power margin of 3 dB for source ageing should be provided as a minimum. Losses must be tabulated for "worst-case" and "best-case" attenuation values for each signal path from transmitter to receiver. Worst-case and best-case values, plus the transmitter output variation, determines the dynamic operating range requirement of the receiver.

Consider the system segment shown in Figure 3-5., for the case of an eight terminal, passive, unidirectional, star topology. Maximum and minimum attenuation values are assigned and tabulated in Table 3-1. For this example, the same path is used for both cases. (For the case of a passive linear topology, there is usually a much bigger loss differential due to signal path differences.)

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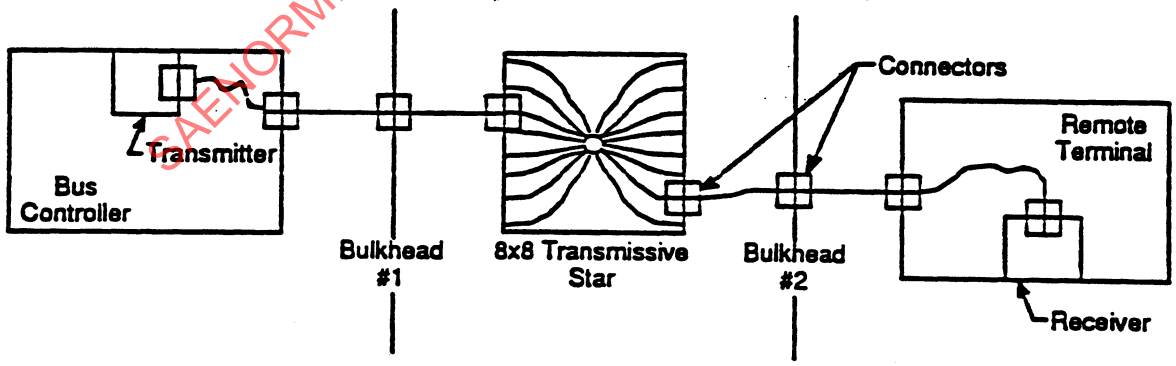

Figure 3-4. Passive Terminal System Example.

Table 3-1. Power Budget Calculations.

Component	Max Loss	Min Loss
Transmitter Output Variance (temp. etc)	3 dB	0 dB
Transmitter or Board Internal Connection	2	0.5
Bus Controller Output Connector	2	0.5
1st Bulkhead Connector	2	0.5
Star Input Connector	2	0.5
1:8 Splitting Loss (9 dB ideal)	11	7
Star Output Connector	2	0.5
2nd Bulkhead Connector	2	0.5
Remote Terminal Input Connector	2	0.5
Receiver or Board Internal Connection	2	0.5
Overall Cable Loss	-	-
Power Margin	6	0
Total Loss	36 dB	11 dB

Hence the difference between the strongest and weakest signal seen by the receiver, or its dynamic range requirement, is 36 dB - 11 dB or 25 dB. If transmitter maximum output power is -5 dBm, the receiver sensitivity requirement becomes -5 dBm - 36 dB = -41 dBm. The values given in the table above are for example only. Except for the 1:8 ideal splitting loss, all values shown are subject to some judgement calls by the system designer. For example, replacing all 2 dB connector maximum loss values in the table above with 1.5 dB would improve the total maximum loss by 4.ϕ dB to 32.ϕ dB. Receiver dynamic range requirements would be reduced to 21.ϕ dB, and receiver sensitivity is now -37.ϕ dBm. The system engineer must assign a value for connector losses based upon considerations which affect these losses. Included are fiber core size, connector alignment, keying, contamination, the number of mate/demate cycles, etc. These attributes are discussed in paragraph 2.3. When figuring connector losses, note that connections may be required at the transmitter or receiver, at a motherboard/daughterboard connector in a card cage, and at the back of a box. Some transmitters and receivers come with "pigtails" and as such require no device connector. Usually, platform cable lengths are too short for significant losses. (This may not be true for plastic-core fiber or radiation-darkened fiber). Sharp bends in the cable and pinching from cable ties may produce additional losses but proper installation procedures should not allow this to happen.

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3.3. System Element Selection.

3.3.1. Fiber Optic Cable.

Most 1773 networks will not have bandwidth or fiber attenuation problems. Instead, fiber optic cable is more likely to be chosen based upon its mechanical properties as dictated by system requirements. Tensile strength, flexibility, temperature, etc. are some important parameters (a complete cable description is supplied in section 2.2). Will the fiber optic cable be in a harness assembly or cable bundle with electrical wires? If so, it probably will get the same type of rough handling as a wire, so it must be protected from tensile stress. Considerations for installing fiber optic cable in a harness assembly are included in chapter 7. The mandrel wrap test can be used to specify a bending radius that the fiber must tolerate without breakage or severe loss. The selection of fiber core/cladding material (i.e., glass or plastic), strength member material, and jacket construction can affect fiber flexibility and temperature range. Cable jacket and strength member design can improve tensile strength and make the fiber less vulnerable to breakage caused by pinching, kinks, knots, etc. Fiber and cable size must also be compatible with available connector termini in multi-contact connectors, if used. Larger core diameter allows more power to be captured from the transmitter, and reduces misalignment losses at connectors. However, larger core fiber may not meet system bend-radius requirements. The three fibers available for use in fiber optic systems are step index, graded index and single mode. The later is not recommended for MIL-STD-1773 applications since it requires an injection laser diode source to couple adequate optical power.

Step-index fiber has better coupling efficiency than graded-index fiber for the same given NA. Graded-index fiber has better bandwidth but this is not significant for 1 MHz (or even 20 MHz) systems over short distances (Step-index fiber typical bandwidth is 20 MHz Km). The system engineer must weigh all these considerations, and probably others, as well as the current state of the art, before specifying fiber size and construction.

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3.3.2. Connectors.

A number of connector decisions also confront the fiber optic system designer. Probably one of the first decisions is whether each fiber optic cable will have its own dedicated connector, or if cables will be combined, possibly even with electrical wires, in a multichannel connector. For example, a dual-redundant, bidirectional system requires four optical fibers per terminal. Four separate Single-channel connectors (see section 2.2.5) could be used, or the signals could be connectorized using individual termini within multichannel connector, possibly containing other signals as well. (Redundancy requirements would likely dictate two separate multichannel connectors).

Some factors affecting the choice of connector hardware are:

- o Number of anticipated mating cycles
- o Enviromental extremes
- o Degree of handling abuse
- o Ease of installation
- o Use of standard components
- o Choice of fiber optic cable
- o Importance of fiber end face alignment and connector losses

Options to consider in meeting the connector requirement include:

- o Single channel (dedicated) vs multichannel connectors
- o Keyed or non-keyed
- o Lens-coupled vs butt-coupled connectors
- o Epoxy vs crimp assembly
- o Polished vs cleaved end face
- o Field-installable
- o Transfer of tensile stress from cable strength member to connector body
- o Positive mating interlock with backoff prevention
- o Choice of interconnect harness type

3.3.3. Transmitters/Receivers.

The most basic decision to be made involving transmitters and receivers is which type of optical source to use. For transmitters, Injection Laser Diodes (ILDs) and Light Emitting Diodes (LEDs) are available (see section 4). ILDs output more power and can operate at higher data rates than LEDs but are rather sensitive devices. They must generally be temperature-stabilized with Peltier coolers and must be operated at a bias. All this requires much control circuitry and power. LEDs can operate two orders of magnitude above the basic 1773 data rate, so speed advantages are moot for ILDs. ILDs are usually much more expensive then LEDs. Available LED types include edge emitters, surface emitters and etched well (Burrus) emitters. A discussion of wearout and service life of optical sources in the high temperature avionics environment is given in Appendix F.

There are two types of detectors used in receivers - PIN diodes and Avalanche Photo Detectors (APD's). The PIN diode, the most basic device, has high bandwidth, good temperature stability, but only moderate sensitivity, typically about .5 amps/watt of incident optical power. APDs are more sensitive, as they provide internal power gain, but require temperature compensated bias voltages of 200 to 500 volts. The 1553-type burst message format used in 1773 poses some potential problems for the receiver, clock recovery and data extraction design. Many receivers have a minimum modulation rate limitation and also require a long stabilization period after a silent period on the bus. Certain sync/data character combinations in 1773 can create frequencies of 250 KHz and silent periods occur between messages. Message preamble which allow time for gain stabilization and clock synchronization, are not used in 1773. The designer of the data decoding circuitry must

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ensure the design will work for the 1773 protocol, where silence is followed by the single sync character and then the information bits. Worst-case conditions will probably occur when a receiver is detecting a strong message from a near terminal, followed by a 4 microsecond gap, followed by a weak message. Section 4.2 contains additional information.

3.3.4. Noise Margins, SNR and BER.

For digital systems such as 1773, the bottom line on signal/noise performance is the Bit Error Rate (BER). For 1773 this is specified as a word error rate of 10 exp-7 over the conditions specified in 1773, paragraph 3.5.3.3 (basically, message-level I/O, alternating strong and weak signals). Receiver performance parameters (sensitivity, dynamic range) are often given at a specified BER, but the system word error rate test is the final arbitrator. The system engineer, who may not have control over RT component selection, must, however, come up with a set of input and output waveform specs, which if met by the terminal designer, will result in the RT passing the word error rate test. Waveform specifications can be expressed as a waveform envelope as shown in Figure 3-5. Transmitter noise, receiver noise, jitter, rise/fall time, pulse lengthening/shortening, attenuation, bandwidth limitations, clock recovery and bit sampling timing, etc. all affect the bit and word error rate.

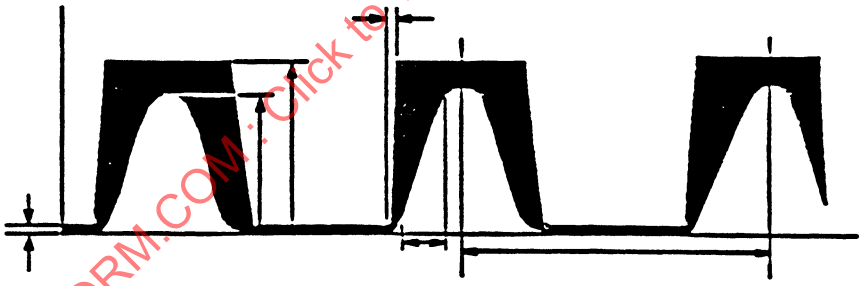

Figure 3-5. Waveform Envelope.

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3.4. System Integration Tests.

The 1773 system integrator should follow traditional good system engineering practice by adhering to system build-up test sequence. Remote terminals and bus controllers should be first tested in a stand-alone environment for optical and message-level requirements, and the word error rate test. A BC/RT simulator will be needed to perform these tests. The BC and RTs should then be integrated into the actual system configuration, one terminal at a time, and run functional I/O at operating message rates. The system integration engineer may not have direct control over selection of RT components such as transmitters and receivers, but still needs to be aware of the state-of-the-art so specifications compatible with his requirement and existing technology can be written. It is important that the overall system integration tests use the type and lengths of fiber optic cable, and the type, configuration, and number and type of connectors employed in the actual

system.

3.5. Considerations For Implementation of Hybrid Systems.

A hybrid bus system uses MIL-STD-1553B transmission on wire cable as well as MIL-STD-1773 transmission on fiber optic cable. MIL-STD-1773 terminals can communicate with MIL-STD-1553B terminals because the transmission bit rate, modulation code and protocol specified by the two standards are the same. The hybrid bus uses MIL-STD-1553B components in the electrical part of the bus, MIL-STD-1773 components in the optical part of the bus and an electrical/ optical interface unit at the transition between the two bus types. The electrical/optical interface converts input optical signals to output electrical signals and also converts input electrical signals to output optical signals.

The following section describes a few of the many possible hybrid bus configurations. The second section describes the electrical/optical interface and the final section covers the deviations of hybrid systems from MIL-STD-1773 and MIL-STD-1553B.

3.5.1. Hybrid Bus Configurations.

Four different hybrid bus configurations are given in Figures 3-6 through 3-9. Many other configurations are obviously possible and the number of terminals on the hybrid buses can be increased to 31 remote terminals plus one controller terminal as specified by MIL-STD-1553B.

Figure 3-6. shows a bus configuration wherein a MIL-STD-1553B bus and a MIL-STD-1773 bus are connected through an electrical/optical interface to form a single hybrid bus. The bus controller is shown on the 1553B bus but one of the 1773 terminals could function as the bus controller if desired. Communication between the bus controller and remote terminals on the 1553B bus is unchanged from a normal 1553B bus. A command from the bus controller to a 1773 remote terminal is coupled from the main bus cable through a bus coupler into the electrical/ optical interface and converted to optical form. The optical command signal then propagates through a fiber optic cable to the transmissive star coupler where the signal is split out to all the 1773 remote terminals. (The arrows on Figure 3-6. indicate the direction of signal propagation). The remote terminals respond back on a separate cable to the transmissive star coupler. An input from any of the 1773 remote terminals is coupled to the electrical/optical interface, converted to electrical form and transmitted on the 1553B bus cable. The electrical/ optical interface should reclock the signal transmitted to the 1553B bus in order to meet the waveform timing requirements of MIL-STD-1553B and should meet the input impedance specified for a 1553B bus. One potential problem is that additional delays are introduced by the electrical/ optical interface which will violate timing requirements. This delay and its effect on operation of the hybrid bus are discussed in sections 3.5.2 and 3.5.3.

A second hybrid bus configuration, given in Figure 3-7, is basically a 1773 bus with electrical/optical interfaces added so that

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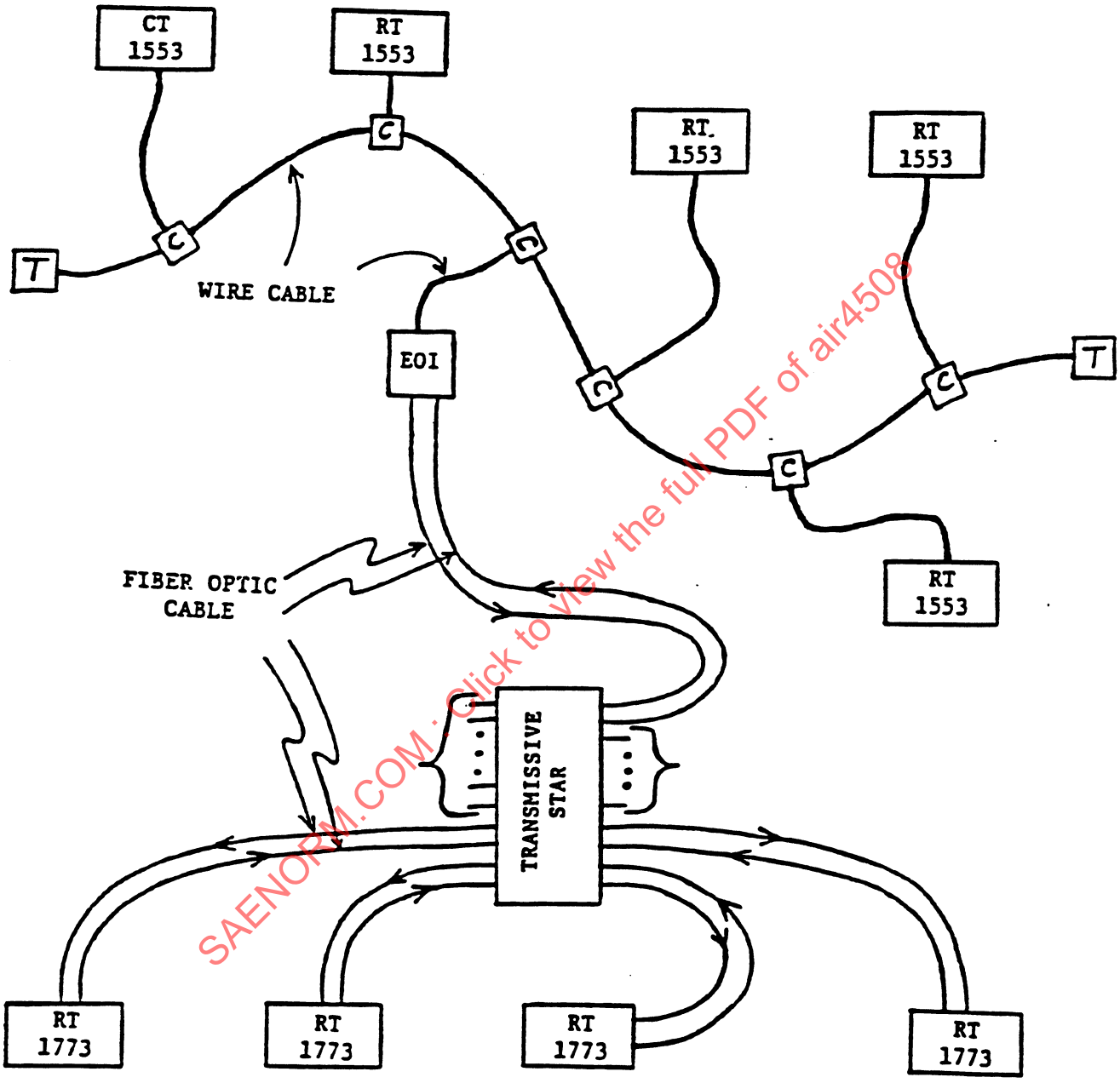
1553B remote terminals can be connected to the bus. The maximum number



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CT - CONTROLLER TERMINAL
RT - REMOTE TERMINAL
EOI - ELECTRICAL/OPTICAL INTERFACE
C - BUS COUPLER
T - BUS TERMINATION

Figure 32-6. Coupled MIL-STD-1553B and MIL-STD-1773 Buses.

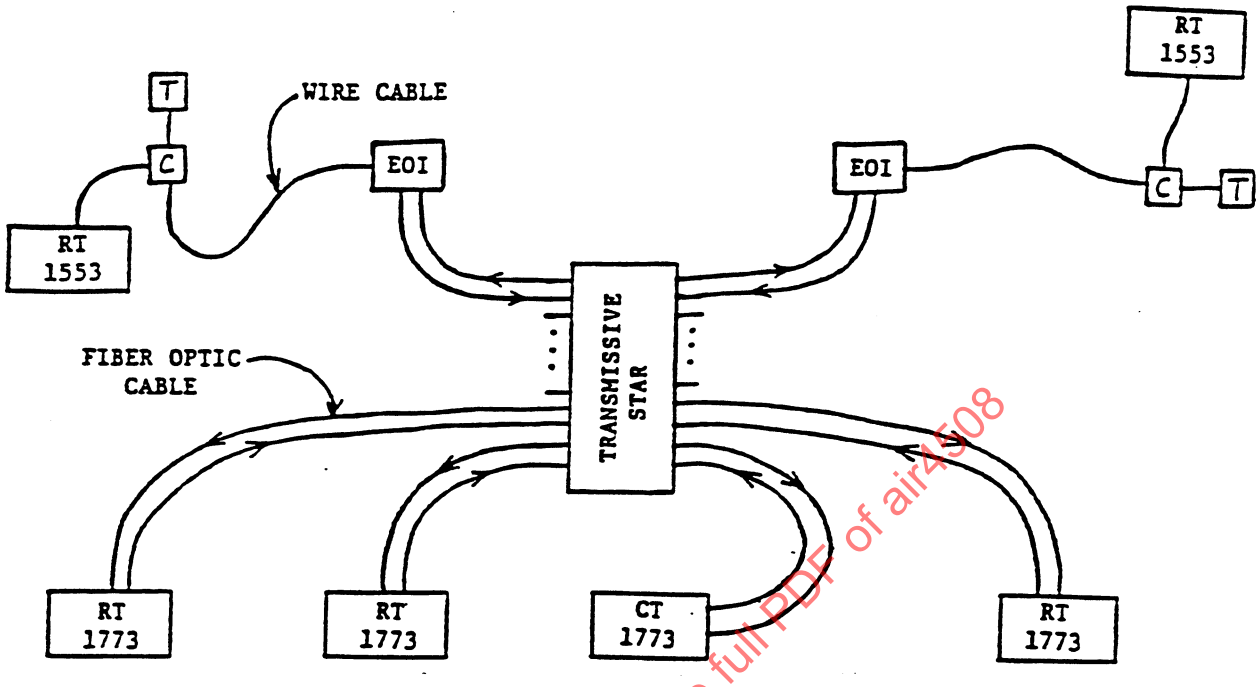

Figure 3-7. MIL-STD-1773 Bus With 1553 Remote Terminals.

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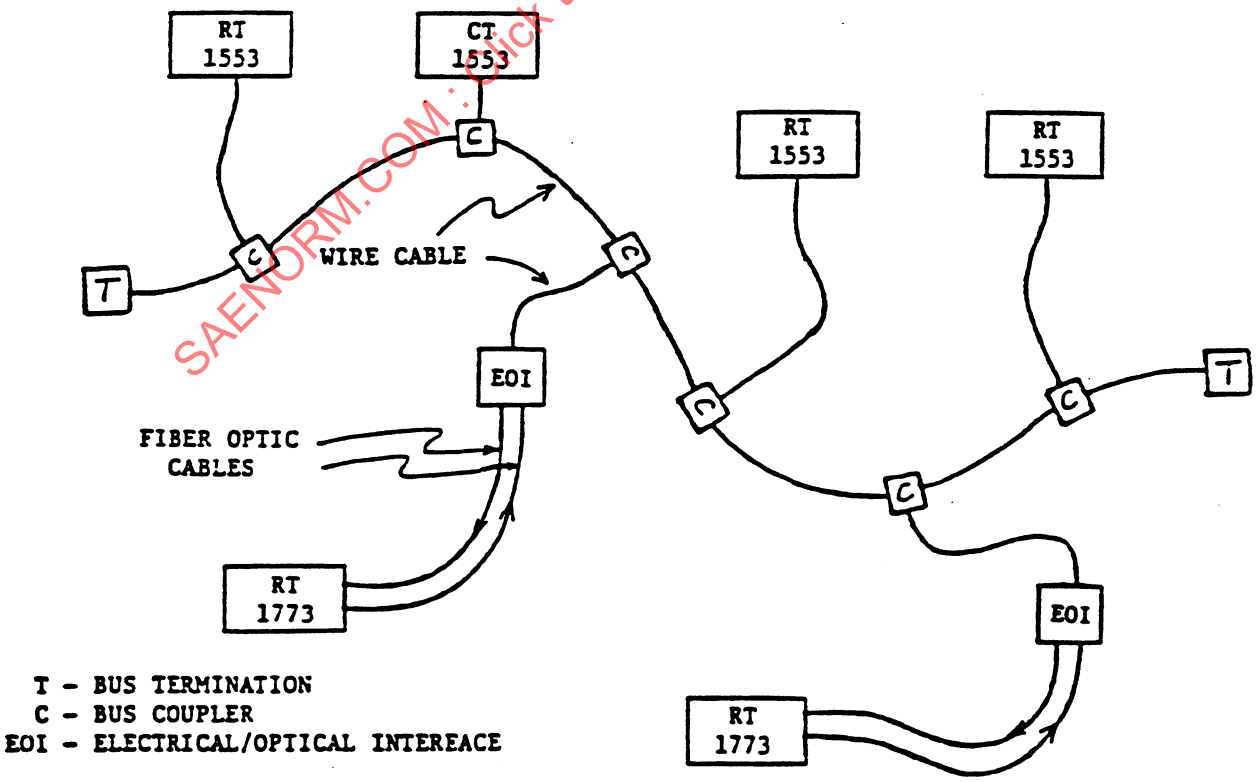

Figure 3-8. MIL-STD-1553B Bus With 1773 Remote Terminals.

of terminals is probably limited to 16 by loss in the transmissive star coupler, connectors and cables. Operation of the bus is essentially the same as described for the hybrid bus in Figure 3-6.

Another hybrid bus configuration is given in Figure 3-8. This bus is basically a 1553B bus with electrical/optical interfaces added so that 1773 remote terminals can be connected to the bus. Either 1773 or 1553B remote terminals can be added to the bus up to a total of 31 remote terminals. Total length of the wire cable and fiber parts of the bus is limited to about 300 feet by the standard, but the fiber optic stubs could be longer, as long as the 2 microsecond maximum two way delay is observed. The fiber cable does not load the main 1553B bus cable and waveform distortion is low on the fiber optic cable.

Another possible hybrid bus configuration is two or more 1553B bus cables which are linked together via electrical/optical interfaces and fiber optic cables as shown in Figure 3-9. Again, the total number of remote terminals is limited to 31 by the 1553B protocol. This bus configuration keeps the daisy chain connection advantage of 1553B but allows much greater distance separation of 1553B bus terminals.

3.5.2. Electrical/Optical Interface.

The electrical/optical interface (EOI) is a circuit which accepts MIL-STD-1553B bus signals, performs the required conversions and transmits the message to a fiber optic cable or receives MIL-STD-1773 messages, performs the required conversions and couples the message in electrical form to the MIL-STD-1553B bus cable. A pulse of light is transmitted by the 1773 transmitter when the received 1553B signal is positive and no light is transmitted when the 1553B signal is zero or negative. Electrical 1553B signals and corresponding optical 1773 signals are illustrated in Figure 3-10.

When an optical signal is received, a bipolar 1553B signal must be reconstructed from the optical unipolar input signal. The EOI must accurately determine the time "T2", in the reconstructed 1553B signal when the 1773 message ends at "T1". A further requirement is that "T1" be distinguished from "T3". "T3" is not the end of a message because a data sync follows the command word. (T1, T2, and T3 are shown in Figure 3-10.) Since the circuit must look ahead in time to determine whether a data word follows the end of the previous word, the re-transmitted 1553B message must be delayed by at least 1.5 microseconds.

The simplified block diagram of an electrical/optical interface (EOI) is given in Figure 3-11. An input optical signal from the 1773 cable is converted to a unipolar electrical signal by the 1773 receiver. The clock synchronizer senses input sync patterns and generates a clock which is synchronized with the input biphase signal. The delayed biphase generator provides a reclocked, delayed biphase signal with input waveform distortion removed. A counter and data sync detection circuit are used to generate the transmit enable signal. The delayed biphase signal and transmit enable are fed to the 1553B bus cable. Signals are

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also coupled from the 1553B bus cable transceiver. The received signal is converted to a unipolar signal which is fed to the 1773 fiber optic cable. A signal from the transmit enable generator also inhibits the 1773 transmitter when the 1553B transceiver is transmitting.

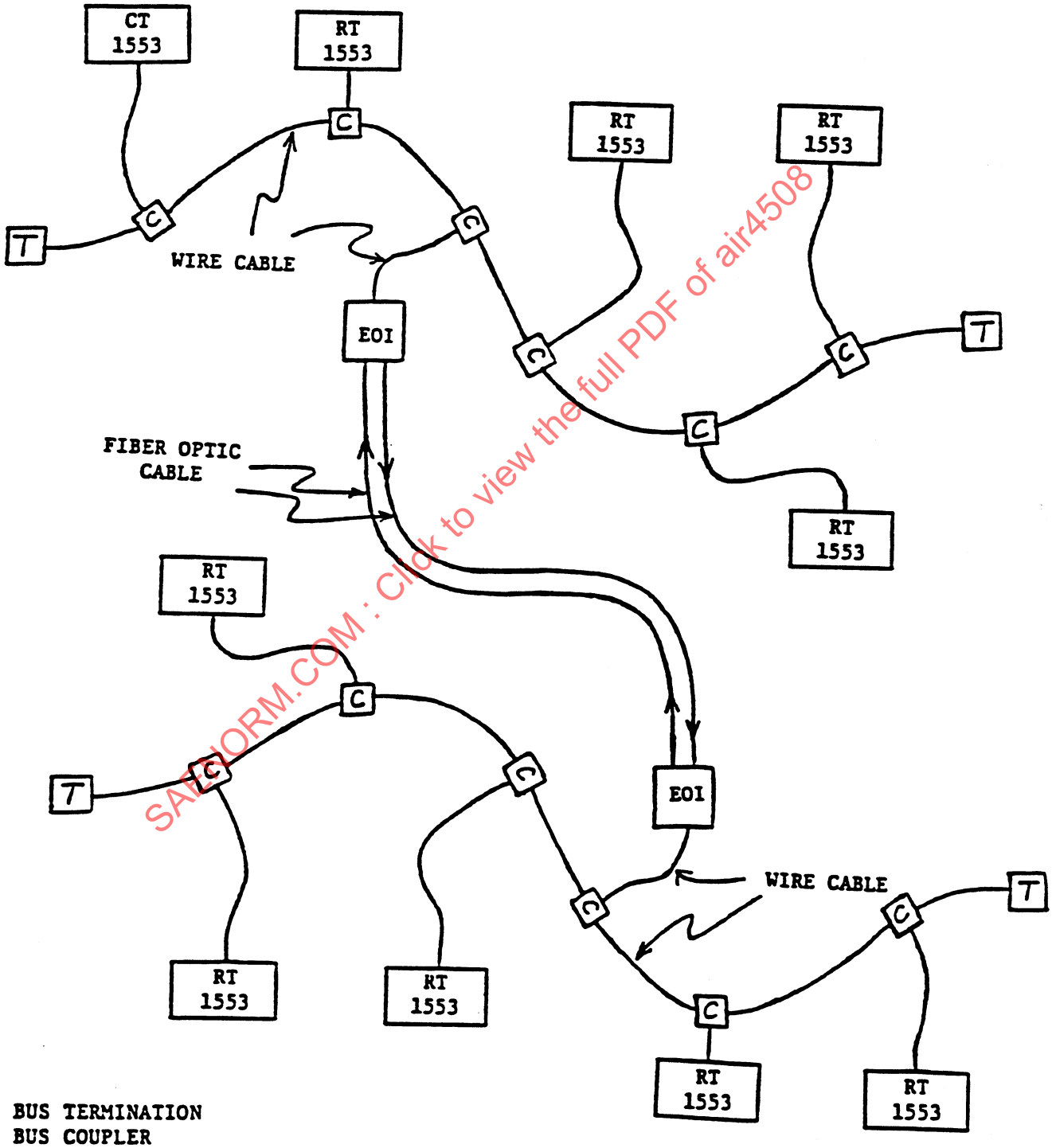

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Figure 3-9. Hybrid Bus With Fiber Optic Linked MIL-STD-1553B Cables.

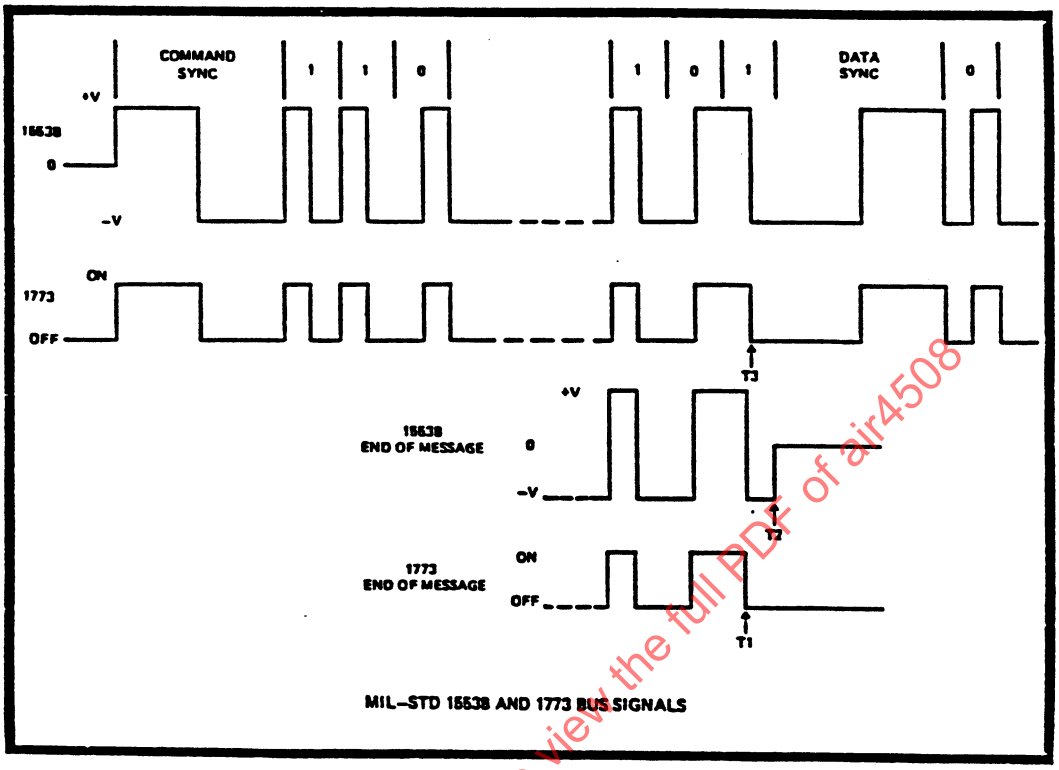

Figure 3-10. MIL-STD-1553B and 1773 Bus Signals.

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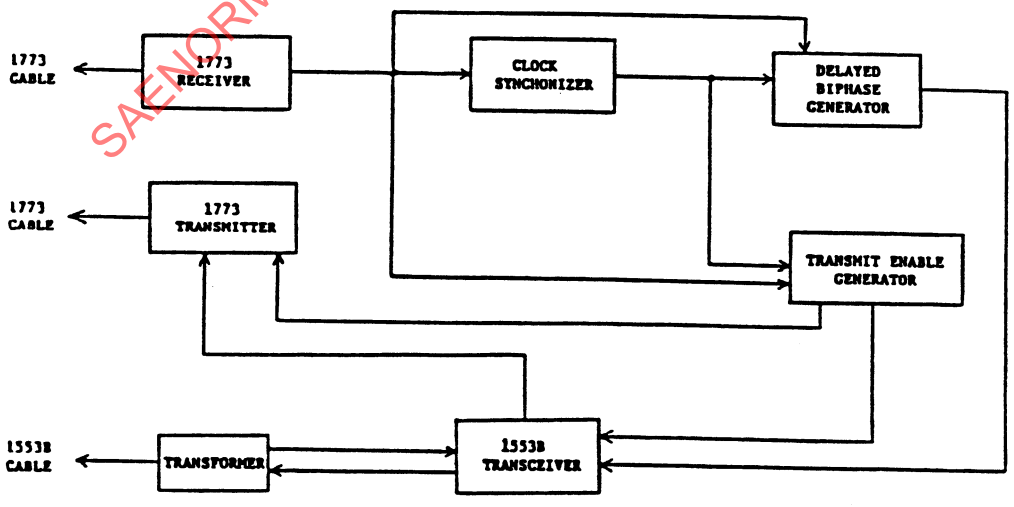

Figure 3-11. Block Diagram of Electrical/Optical Interface.

3.5.3. Deviations from MIL-STD-1773 and MIL-STD-1553B.

Any hybrid bus does not fully comply with either standard because one standard specifies only electrical transmission and the other standard specifies only optical transmission; however, the electrical part of the bus fully complies with MIL-STD-1553B and the optical part of the bus fully complies with MIL-STD-1773. As a result, any terminal which complies with MIL-STD-1553B can be used in the electrical part of the bus and any terminal which complies with MIL-STD-1773 can be used in the optical part of the bus.

Neither standard includes the use of an electrical/optical interface but the only standard requirement that the interface affects is the "minimum no-response time-out". Because the typical two microsecond two-way delay of the electrical/optical interface adds to the apparent response time of a terminal, the "Minimum no-response time-out" should be increased by two microseconds for each electrical/optical interface that the bus signal passes through. The time-out should be further increased if the fiber optic cable lengths exceed 300 feet in length. The approximate two-way delay of a fiber optic cable is 1.5 nanoseconds per foot. Use of a no-response time-out longer than the 14.0 microseconds minimum required by MIL-STD-1553B will only delay messages if there is no response or if the hybrid bus introduces the extra delays described above. These delays will slightly reduce the effective data transfer rate of the bus.

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CHAPTER 4. ELECTRO/OPTIC INTERFACE CONSIDERATIONS.

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CHAPTER 4. ELECTRO/OPTIC INTERFACE CONSIDERATIONS.

4.0. Electro/Optical Interface Considerations.

As was stated in section 3.0, the terminal input and output characteristics of a MIL-STD-1773 system must be specified by the system designer. Therefore, it is important to understand the design characteristics and system trade-off considerations that are required when developing the electrical/optical interface for a MIL-STD-1773 system application.

For most aircraft applications of MIL-STD-1773, the Fiber Optic data bus is a loss-limited system. Interface considerations for such a system must therefore concentrate on addressing the optical power loss budget and related optical output parameters of transmitters and the achievable sensitivity/dynamic range capabilities of practical receivers.

4.1. Bus Network and Terminal Interface.

The bus/user interface is provided by means of a Bus Interface Unit (BIU) which provides the hardware and software needed to interface the terminal Host (CRT, teletype, microcomputer, memory and storage devices, etc.) with the data bus. A generalized functional diagram showing this interface appears in Figure 4-1. below.

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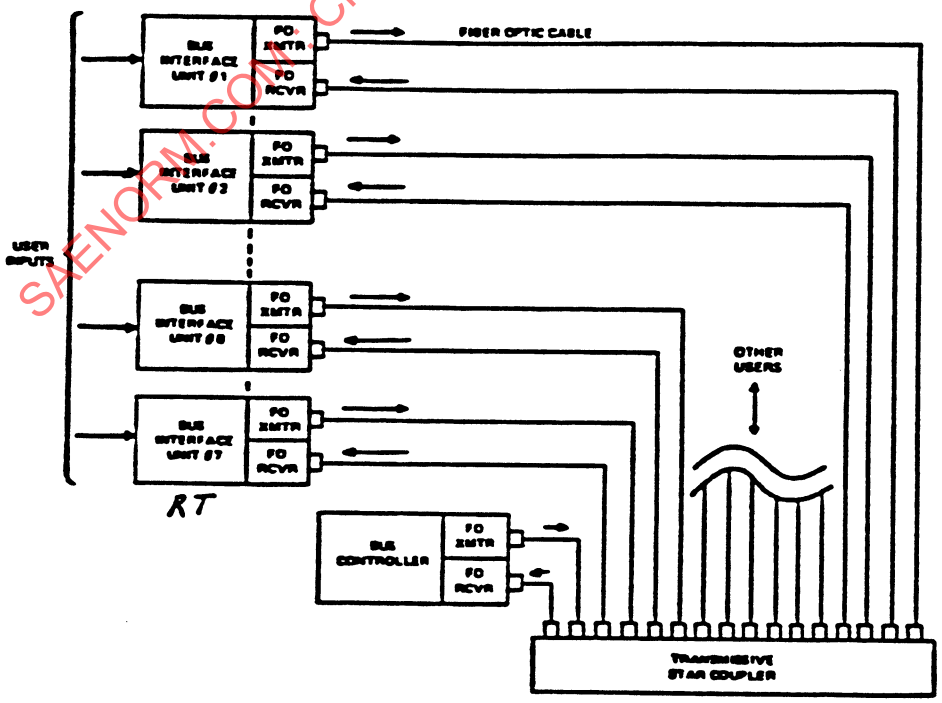

Figure 4-1. Bus Network Interface.

In this example, an 8-port (16 terminal) transmissive star coupler is seen to interconnect the bus controller with 7 remote terminals (RT) sites. Each RT is interfaced by a BIU of characteristics specific to its host's requirement. The BIU accepts the user inputs, serializes the data for transmission, when necessary, and provides Manchester data encoding (for transmitter inputs) or decoding (for receiver outputs) Data synchronization, word organization, clocking and parity are also provided by the BIU. Since BIU functions are varied and may be implemented in numerous ways, suffice it to say that this is a key function for the 1773 data bus, but it is no different than for a 1553 bus. The same hardware would suit either purpose.

4.2. Receiver Design Considerations.

4.2.1. Purpose.

The basic purpose of the receiver in the terminal is to detect the light incident upon it and to convert that light to an electrical signal that contains the information impressed on the light at the transmitting end. The receiver is thus an optical to electrical converter or O/E transducer.

4.2.2. Function.

The fundamental goal in the design of an optical receiver is to detect a range of optical power levels (Optical Signal Range, OSR) at or below a given bit error rate (BER). The minimum power level, commonly referred to as the sensitivity, depends upon the detector type and characteristics as well as the design of the amplifier. Sensitivity is usually measured in dBm (dB relative to 1 milliwatt) of optical power. For MIL-STD-1773 applications, burst mode data transmission is required. That is, all messages start from the quiet line state after an indefinite period since the previous message and the two messages may differ in amplitude by the total allowed OSR. The minimum time allowed for recovery of the receiver from a maximum amplitude signal in order to detect the first transition of a subsequent minimum amplitude signal is only 2 microseconds.

In a fiber optic data bus application the receiver's most important elements are the photodetector and low-noise preamplifier. These elements determine the responsivity, bandwidth and noise characteristics of the total receiver function. The photodetectors, PIN and avalanche photodiodes (APDs), are square law devices in that input optical power in watts is converted directly to electrical current in amperes. The photodetector, therefore, directly accomplishes the optical to electrical conversion. Since temperature and reverse bias voltage variations have strong impacts on the performance of APD photodetectors,provision must be made (either within or external to the diode package) to compensate for these effects, if an APD is used.

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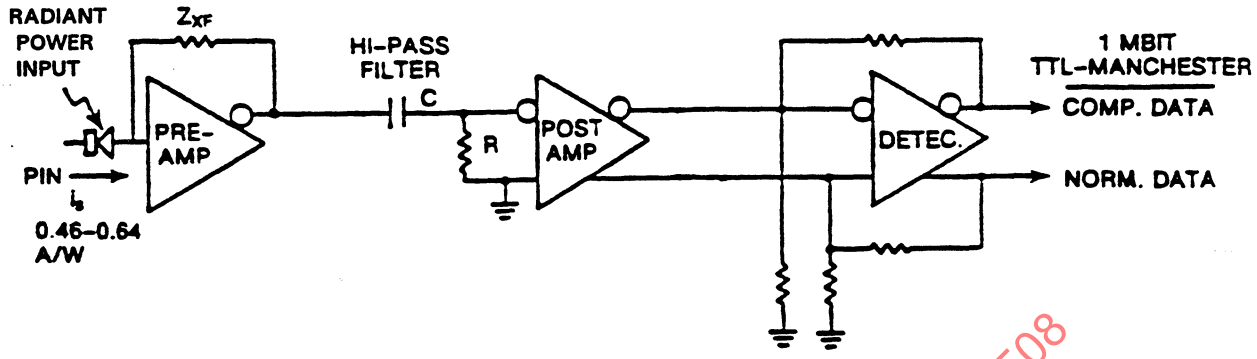

Figure 4-2. Receiver Block Diagram.

Additional amplification and threshold detection is needed to complete the optical signal to logic signal conversion process. Due to the very low level input signals generally received, AC coupling, electrical shielding and extensive power supply decoupling are required to preserve the signal sensitivity of the receiver.

A typical 1773 receiver may operate with a minimum optical input signal of 200 nanowatts peak (or 100 nanoamps peak photo current) and require a one volt or greater peak signal at the threshold detector. This results in an overall voltage gain requirement of 20,000 or more. It is impractical to build a DC coupled amplifier to operate over the MIL temperature range at these gain levels. In this example, a one microvolt drift in bias level at the input would result in 20 millivolts drift at the threshold detector. For this reason, AC coupling is required within the signal path of the amplifier to reduce the amplification of temperature induced offsets. The presence of AC coupling introduces complications to the implementation of burst mode operation. Even though the signal modulation (Manchester coding) has a limited duty cycle range, the Message duty cycle does not. Coupling time constants must be short enough to allow baseline recovery at the beginning and end of a message within the minimum allowed time yet not droop out significantly within in the maximum duration of a "high" level input in the data stream and multiple time constants may result in the recovering baseline crossing the detection threshold one or more times to generate false extra bits. These requirements are nearly mutually exclusive with out the application of circuit techniques and "tricks" that are not necessarily obvious. Some of the approaches that have proven successful are DC restoration with adaptive thresholding or fast attack AGC, symmetrical non-linear amplitude limiting and edge detection (differentiation).

Other special circuits may be employed in the receiver to provide signal conditioning, comparators for digital signal level decisions, operational amplifiers for current to voltage conversion, signal gain-bandwidth control and for other purposes. A block diagram of a typical MIL-STD-1773 terminal receiver, useing edge detection, is shown in Figure 4-2.

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4.2.2.1. Preamplifier.

A usable signal must be obtained from the current generated by the photodetector. This is accomplished in the amplification stages of the receiver. The preamplifier is very important because it is the predominant noise source in the signal path. The preamplifier self noise determines the sensitivity (the minimum signal for a required maximum BER) of the receiver.

At present, the preamplifier design that has emerged as the predominant one for use in 1773 fiber optic receivers is the transimpedance amplifier. The transimpedance amplifier is finding widespread use because it is capable of wide bandwidths, wide dynamic range, and low noise performance over wide temperature range. Various circuitry versions of this amplifier exist but basically it is a current-to-voltage converter providing gain stabilization by inverse (negative) feedback. For the transimpedance amplifier, the output voltage (Vo) = the input current (Ii) x the Transfer Impedance (Zf).

A primary consideration in receiver design is its Optical Signal Range. Having a wide OSR available is important since it allows flexibility and convenience in system configuration. The saturation level of the preamplifier sets the upper limit of the OSR, while the preamplifier noise level referred to the input sets the lower limit. The system designer must develop a receiver with the lowest noise possible for the greatest sensitivity but also with a high saturation level and that recovers quickly from a maximum level input (for burst mode operation).

4.2.2.2. Other Receiver Components.

The remaining sections of a fiber optic receiver include a post amplifier circuit and a comparator (threshold detector).

The post amplifier amplifies the preamp output to a peak level adequate for threshold detection (about one volt or so). In most cases, the postamp noise contribution is insignificant in the calculation of the overall sensitivity of the receiver. It does however affect OSR. The postamplifier must be capable of handling signal levels up to 1000 times higher than the minimum level (30 dB OSR) with out adding pulse distortion that will cause bit errors. Fast Automatic Gain Control and symmetrical non-linear limiting of differentiated signals (edge detection) are two approaches that have proven successful.

The threshold detector compares the amplified signal to a reference level that is higher than the receiver noise level by an appropriate ratio to insure the desired BER is achieved. A threshold to noise ratio of about 6:1 is required for a 1 x 10 exp-9 BER and about 7:1 for a 1 x 10 exp-12 BER. In a baseband receiver, the threshold detector indicates logical "true" when the signal level is above the decision threshold and "false" otherwise. In an "edge detector", the threshold detector is toggled to "true" when the differentiated positive edge pulse exceeds a positive threshold level and toggled back to "false"

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when the negative edge pulse exceeds a negative threshold level. The detector thus restores the low frequency content of the data modulation that was removed by the differentiation process.

All things considered, the design of the receiver is the most technically demanding task and the most critical task of the overall design of the MIL-STD-1773 terminal. It is an area were there is just no substitute for experience in achieving a successful and produceable design.

4.3. Transmitter Design Considerations.

4.3.1. Purpose.

As the receiver is the optical/electrical transducer in a MIL-STD-1773 fiber optic terminal, the transmitter is the electric to optic transducer. The transmitters that are presently used in today's fiber optic networks utilize either an LED, for high reliability, low drive circuit complexity, high optical extinction ratio, and low cost, or a laser. Lasers are typically used where high speed and high optical power requirements are critical. They are also quite expensive and require extensive support circuitry and auxiliary cooling for MIL environment applications. As was implied in section 3.3.3, an LED source is the logical choice for a 1 Megabit MIL-STD-1773 system.

4.3.2. Function.

In general, optical transmitters will provide the means for converting logical data inputs to optical source drive currents /voltages, optical output level control and electrical bias for source operation and controlled geometry to couple the output to the fiber. A block diagram of an example transmitter function is shown in Figure 4-3.

4.3.2.1. The LED Driver.

The driver switches the optical source on and off in response to an input logic signal, generally, the logic true state results in the LED being in the ON state and the logic false state turns the LED OFF. The driver must provide drive current of 100 milliamps or more for full output and excess current to charge and discharge the junction capacitance of the LED rapidly. Drive current compensation and/or LED prebias may be used to speed up the rise and fall time of the optical output signal.

LED drivers normally provide the means to forward bias the device at a low current level. This bias level will reduce the diode voltage swing from off to on to a few tenths of a volt and hence reduce the amount of junction capacitance charge that must be transferred to switch between on and off. Care must be exercised to select a bias level that is below the LED threshold (LEDs output almost no optical power at drive current levels from 2 to 10 ma., dependant on the device). If significant "Off" optical power is emitted by the source, the photocurrent resulting from the summation of this optical pedestal signal from all the system

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transmitters in a receiver input can generate shot noise that is greater than the receiver self noise and therefore reduces the sensitivity of the system receivers. An on to off ratio (extinction ratio) of 30 dB is desirable.

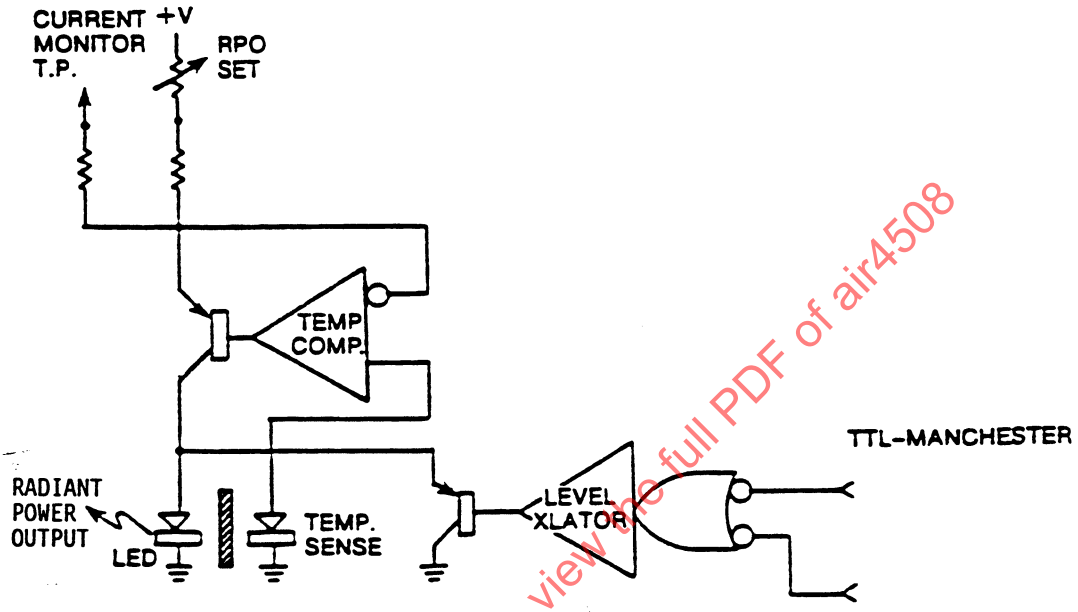

Figure 4-3. Transmitter Block Diagram.

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4.3.2.2. Temperature Compensation.

If an LED is driven with a constant current (during the steady state "on" period) the resulting optical output will vary with ambient temperature. The output decreases with increasing junction temperature. From -55C to 125C, this decrease will be typically 3 to 5 dB or about .01 dB per degree Celcius. This variation can be reduced by temperature compensation that increases drive current in response to an increase in device temperature. Temperature compensation adds complexity to the transmitter circuitry, but if compensation is not provided, the entire output variance must be absorbed within the OSR capability of the receiver. This is the approximate equivalent of having to eliminate two to three connectors from the maximum number allowed in line in the system topology and is equal to or greater than the "End of Life" degradation of the LED.

4.3.2.3. Optical Coupling Geometry.

Providing uniform and repeatable coupling geometry to the fiber waveguide is a non-trivial task of the transmitter. Close mechanical location tolerances of all optical components and lense enhancement of the sources emission cone to alter the near and far field parameters to

more closely match the core diameter and Numeric Aperture of the optical fiber is generally required. This requirement applies to both connectorized and pigtailed modules. Active alignment of source to connector or source to pigtail fiber is usually the only practical method of overcoming mechanical tolerance runout that accumulates during device fabrication and transmitter module assembly.

4.4. Radiation Effects on Optical Transmitters and Receivers.

Both the transmitter and the receiver are transistor amplifiers, even though their basic functions are different. Since the transistor is the only active component in the interface circuitry, any changes in the transistor performance induced by ionizing radiation or neutrons will be reflected in degraded operation of the transmitter and receiver.

If a nuclear environment is specified, this may become a limiting factor in the interface circuit design and at the least will require that much more ample margins be provided. A detailed discussion of radiation effects is given in Chapter 8. of this handbook.

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CHAPTER 5. ENVIRONMENTAL AND PERFORMANCE TESTING.

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CHAPTER 5. ENVIRONMENTAL AND PERFORMANCE TESTING.

5.0. Environmental and Performance Testing.

Environmental and performance test methods for the fiber optic cable, connectors, couplers, detectors, sources splices, termini and optical fibers are given in Tables 5-1. through 5-10. Because of the adverse conditions in the military avionic environment it may be necessary to generate application specific specification sheets from the applicable basic specifications to meet the given system requirements.

5.1. Fiber Optic Cable.

DOD-C-85045 is a specification for a fiber optic cable approved for military applications. Test parameters, applicable test methods and the corresponding test paragraph in MIL-C-85045 are listed in Table 5-1. For specific test conditions and procedures the user should see DOD-C-85045, any applicable DOD-C-85045 specification sheets and the appropriate test methods.

Table 5-1. DOD-C-85045 Fiber Optic Cable Test Methods.

Parameter	Test Method	DOD-C-85045 Paragraph
Attenuation Rate	EIA-455-46	4.7.2
Induced Attenuation	EIA-455-20	4.7.3
Blocking (Jacket Self-Adhesion)	EIA-455-84	4.7.21
Optical Fiber Bandwidth	EIA-455-51	4.7.4
Finished Cable Diameter	FED-STD-228 Method 1441	4.7.1.4
Cable Element Removability	DOD-C-85045 Para. 4.7.28	4.7.28
Finished Cable Mass	FED-STD-228 Method 8311	4.7.1.5
Cable Jacket Opacity	DOD-C-85045 Para. 4.7.23	4.7.23
Cable Twist Bending	DOD-STD-1678 Method 2060	4.7.19
Concentricity	DOD-C-85045 Para. 4.7.1.3	4.7.1.3
Cold Working	DOD-C-85045 Para.4.7.36	4.7.36
Corner Bend	DOD-C-85045 Para 4.7.25	4.7.25
Crosstalk	DOD-STD-1678 Method 6060	4.7.5
Crush	EIA-455-41	4.5.1.9

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Table 5-1. DOD-C-85045 Fiber Optic Cable Test Methods (cont.).

Parameter	Test Method	DOD-C-85045 Paragraph
Cycling Flexing	DOD-STD-1678 Method 2010	4.7.17
Dripping	FED-STD-228 Method 5141	4.7.32
Durability of Identification Marking	DOD-C-85045 Para. 4.7.29	4.7.29
Elevated Temperature Life	MIL-STD-202 Method 108	4.7.12
Fiber and Buffer Geometry	EIA 455-29, 44, 45, 55, 58	4.7.1.1
Flamability	DOD-C-85045 Para. 4.7.30	4.7.30
Fluid Immersion	DOD-STD-1678 Method 8030	4.7.24
Freezing Water Immersion	DOD-STD-1678 Method 4050	4.7.14
Fungus	MIL-STD-810 Method 508	4.7.15
Gas Flame	EIA-455-99	4.7.34
Hosing	DOD-C-85045 Para. 4.7.31	4.7.31
Humidty	DOD-STD-1678 Method 4030	4.7.9
Impact	DOD-STD-1678 Method 2030	4.7.20
Knot	DOD-C-85045 Para.4.7.26	4.7.26
Numerical Aperature	EIA-455-47	4.7.6
Operating Tensile Load	EIA FOTP 455-33	4.7.13.1
Potective Layer and Jacket Thickness	FED-STD-228 Method 1018	4.7.1.2
Pressure Cycling	DOD-C-85045 Para. 4.7.35	4.7.35
Reduced Barometric Pressure	MIL-STD-202 Method 105 Test Condition C	4.7.11
Low Temperature Flexability	DOD-STD-1678 Method 2020	4.7.16
Oxygen Pressure Cycling	DOD-C-85045 Para. 4.7.35	4.7.33

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Table 5-1. DOD-C-85045 Fiber Optic Cable Test Methods (cont.).

Parameter	Test Method	DOD-C-85045 Paragraph
Pressure Cycling	DOD-C-85045 Para. 4.7.35	4.7.35
Stuffing Tube Compression	DOD-C-85045 Para 4.7.37	4.7.37
Temperature Cycling	DOD-STD-1678 Method 4010	4.7.7
Tensile Loading and Elongation	EIA FOTP 455-33	4.7.13
Thermal Shock	DOD-STD-1678 Method 4020	4.7.8
Ultraviolet Radiation	MIL-STD-810 Method 505	4.7.27
Visual and Mechanical Inspection	EIA-455-13	4.7.1
Wicking	EIA-455-39	4.7.22

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5.2. Fiber Optic Connectors.

MIL-C-28876, MIL-C-83522 and MIL-C-83526 are specifications for fiber optic connectors approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in MIL-C-28876, MIL-C-83522 and MIL-C-83526 are listed in Tables 5-2, 5-3 and 5-4. For specific test conditions and procedures the user should see MIL-C-28876, MIL-C-83522 or MIL-C-83526 any applicable specification sheets and the appropriate test methods.

Table 5-2. MIL-C-28876 Fiber Optic Connector Test Methods.

Parameter	Test Method	MIL-C-28876 Paragraph
Analog Modulation	MIL-C-28876 Para. 4.7.3	4.7.3
Backshells and Accessory Attachments	MIL-C-28876 Para. 4.8.15	4.8.15
Cable End Flexing	MIL-STD-1344 Method 2017	4.8.13
Cable Pullout Force	MIL-STD-1344 Method 2009	4.8.6
Connector Engagement and Disengagement Forces	MIL-STD-1344 Method 2013	4.8.8
Coupling Torques	MIL-STD-1344 Method 2013	4.8.9

Table 5-2. MIL-C-28876 Fiber Optic Connector Test Methods (cont.).

Parameter	Test Method	DOD-C-28776 Paragraph
Crosstalk	MIL-C-28876 Para. 4.7.4	4.7.4
Crush Resistance	MIL-STD-1344 Method 2008	4.9.8
Discontinuity	MIL-C-28876 Para. 4.7.2	4.7.2
External Bending Moment	MIL-C-28876 Para. 4.8.7	4.8.7
Flammability	MIL-STD-1344 Method 1012	4.9.13
Fluid Immersion	DOD-STD-1678 Method 8030	4.9.1
Humidty	MIL-STD-1344 Method 1002	4.9.9
Impact	MIL-C-28876 Para. 4.9.7	4.9.7
Identification Marking	MIL-C-28876 Para. 4.6.3	4.6.3
Insertion Loss	MIL-C-28876 Para. 4.7.1	4.7.1
Insertion Retention Axial Stength	MIL-STD-1344 Method 2010	4.8.4
Insertion Retention Radial Stength	MIL-C-28876 Para. 4.8.5	4.8.5
Maintenance Aging	MIL-STD-1344 Method 2002	4.8.11
Mass	MIL-C-28876 Para. 4.6.2	4.6.2
Mating Durability	MIL-STD-1344 Method 2016	4.8.14
Mechanical Shock	MIL-S-901	4.9.3
Optical Conformance	MIL-C-28876 Para. 4.7	4.7
Ozone Exposure	MIL-STD-1344 Method 1007	4.9.5
Salt Spray	MIL-STD-1344 Method 1001	4.9.10
Sand and Dust	MIL-STD-202 Method 110	4.9.11
Size	MIL-C-28876 Para. 4.6.1	4.6.1
Temperature Life	MIL-STD-1344 Method 1005	4.8.10
Terminus Cleaning	MIL-C-28876 Para. 4.9.12	4.9.12
Terminus Retention Force	MIL-STD-1344 Method 2007	4.8.3

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Table 5-2. MIL-C-28876 Fiber Optic Connector Test Methods (cont.).

Parameter	Test Method	DOD-C-28776 Paragraph
Thermal Shock	MIL-STD-1344 Method 1008	4.9.2
Twist	MIL-C-28876 Para. 4.8.12	4.8.12
Vibration	MIL-STD-1344 Method 2005	4.9.4
Water Pressure	MIL-C-83526 Para. 4.9.6	4.9.6
Workmanship Inspection	MIL-C-28876 Para. 4.6.4	4.6.4

Table 5-3. MIL-C-83522 Fiber Optic Connector Test Methods.

Parameter	Test Method	DOD-C-83522 Paragraph
Coupling Loss	EIA-455-20, -34	4.7.4
Coupling Mechanism Retention Forces	MIL-C-83522 Para. 4.7.9	4.7.9
Coupling Proof Torque	MIL-C-83522 Para. 4.7.8	4.7.8
Dust	MIL-STD-202 Method 110	4.7.11.9
Flex Life	MIL-C-83522 Para. 4.7.6.3	4.7.6.3
Fluid Immersion	MIL-STD-1344 Method 1016	4.7.11.11
Force to Engage/Disenguage	MIL-C-83522 Para. 4.7.7.	4.7.7
Humidity	MIL-STD-202 Method 106	4.7.11.6
Mating Durability	MIL-C-83522 Para. 4.7.10	4.7.10
Ozone Exposure	MIL-STD-1344 Method 1007	4.7.11.10
Pressure Altitude	MIL-STD-202 Method 105	4.7.11.1
Room Temperature Tests	MIL-C-83522 Par. 4.7.6.3.1	4.7.6.3.1
Salt Fog	MIL-C-1344 Method 1001	4.7.11.8
Shock	MIL-STD-202 Method 213	4.7.11.5
Size	MIL-C-83522 Para. 4.7.3	4.7.3
Signal Discontinuities	MIL-C-83522 Para. 4.7.5	4.7.5

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Table 5-3. MIL-C-83522 Fiber Optic Connector Test Methods (cont.).

Parameter	Test Method	DOD-C-83522 Paragraph
Submersion	MIL-C-83522 Para. 4.7.11.7	4.7.11.7
Temperature (High)	MIL-C-83522 Pr. 4.7.11.2.1	4.7.11.2.1
Temperature (Low)	MIL-C-83522 Pr. 4.7.11.2.2	4.7.11.2.2
Temperature Shock	MIL-STD-202 Method 107	4.7.11.3
Cable Strain Relief	MIL-C-83522 Para. 4.7.6.2	4.7.6.2
Tensile Loading	MIL-C-83522 Para. 4.7.6.1	4.7.6.1
Twist	MIL-C-83522 Para. 4.7.6.4	4.7.6.4
Vibration	MIL-STD-202 Method 204	4.7.11.4
Inspection	MIL-C-83522 Para. 4.7.1	4.7.1
Weight	MIL-C-83522 Para. 4.7.2	4.7.2

Table 5-4. MIL-C-83526 Fiber Optic Connector Test Methods.

Parameter	Test Method	DOD-C-83526 Paragraph
Analog Modulation	MIL-C-83526 Para. 4.6.3	4.6.3
Altitude	MIL-STD-1344 Method 1004	4.7.26
Ambient Optical Pick-up	MIL-STD-810 Method 505	4.6.5
Cable Seal Flexing	MIL-STD-1344 Method 2017	4.7.16
Cable Retention	MIL-STD-1344 Method 2009	4.7.17
Color	MIL-C-83526 Para. 4.7.3	4.7.3
Coupling Forces	MIL-STD-1344 Method 2013	4.7.11
Coupling Torques	MIL-STD-1344 Method 2013	4.7.12
Crosstalk	MIL-C-83526 Para. 4.6.4	4.6.4
Crush Resistance	MIL-STD-1344 Method 2008	4.7.18
Discontinuity	MIL-C-83526 Para. 4.6.2	4.7.6.2

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Table 5-4. MIL-C-83526 Fiber Optic Connector Test Methods (cont.).

Parameter	Test Method	DOD-C-83526 Paragraph
External Bending Moment	MIL-C-83526 Para. 4.7.19	4.7.19
Flammability	MIL-STD-1344 Method 1012	4.7.31
Fluid Immersion	MIL-STD-1344 Method 1016	4.7.27
Humidty	MIL-STD-1344 Method 1002	4.7.24
Impact	MIL-STD-1344 Method 2015	4.7.14
Identification Marking	MIL-C-83526 Para. 4.7.4	4.7.4
Insertion Loss	MIL-C-83526 Para. 4.6.1	4.6.1
Insertion Retention Axial Stength	MIL-STD-1344 Method 2010	4.7.6
Insertion Retention Radial Stength	MIL-C-83526 Para. 4.7.7	4.7.7
Maintenance Aging	MIL-STD-1344 Method 2002	4.7.10
Mating Durability	MIL-STD-1344 Method 2016	4.7.13
Optical Conformance	MIL-C-83526 Para. 4.6	4.6
Ozone Exposure	MIL-STD-1344 Method 1007	4.7.30
Sand and Dust	MIL-STD-202 Method 110	4.7.29
Shock	MIL-STD-1344 Method 2004	4.7.22
Size	MIL-C-83526 Para. 4.7.1	4.7.1
Temperature Life	MIL-STD-1344 Method 1005	4.7.20
Terminus Cleaning	MIL-C-83526 Para. 4.7.5	4.7.5
Terminus Retention Force	MIL-STD-1344 Method 2007	4.7.8
Terminus Insertion and Removal Forces	MIL-STD-1344 Method 2012	4.7.9
Thermal Shock	MIL-STD-1344 Method 1003	4.7.21
Vibration	MIL-STD-202 Method 204	4.7.23

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Table 5-4. MIL-C-83526 Fiber Optic Connector Test Methods (cont.).

Parameter	Test Method	DOD-C-83526 Paragraph
Water Pressure/Freezing	MIL-C-83526 Para. 4.7.28	4.7.28
Weight	MIL-C-83526 Para. 4.7.2	4.7.2
Workmanship Inspection	MIL-C-83526 Para. 4.8	4.8

5.3. Fiber Optic Couplers.

DOD-C-24621 is a specification for fiber optic coupler approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in DOD-C-24621 are listed in Tables 5-5. For specific test conditions and procedures the user should see DOD-C-24621, any applicable specification sheets and the appropriate test methods

Table 5-5. DOD-C-24621 Fiber Optic Coupler Test Methods.

Parameter	Test Method	DOD-C-24621 Paragraph
Accelerated Aging	MIL-STD-1344 Method 1005	4.7.1
Ambient Optical Pickup	DOD-C-24621 Para. 4.6.5	4.6.5
Analog Modulation	DOD-C-24621 Para. 4.6.3	4.6.3
Axial Loading (Tension)	DOD-C-24621 Para. 4.7.8.1	4.7.8.1
Axial Loading (Compression)	DOD-C-24621 Para. 4.7.8.2	4.7.8.2
Cable Seal Flexing	MIL-STD-1344 Method 2017	4.7.11
Cable Twist	DOD-C-24621 4.7.10	4.7.10
Coupler Radiation Pattern Measurement	MIL-STD-1678 Method 6030	4.6.7.2
Discontinuity	DOD-C-24621 Para. 4.6.2	4.6.2
Enclosure Bending Moment	DOD-C-24621 Para. 4.7.9	4.7.9
Flammability	MIL-STD-1678 Method 1012	4.7.17
Fluid Immersion	MIL-STD-1344 Method 1016	4.7.3

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Table 5-5. DOD-C-24621 Fiber Optic Coupler Test Methods. (cont.)

Parameter	Test Method	DOD-C-24621 Paragraph
Humidty	MIL-STD-1344 Method 1002	4.7.4
Impact Resistence	DOD-C-24621 Para. 4.7.7	4.7.7
Input Power Measurements	MIL-STD-1678 Method 6030	4.6.7.1
Identification Marking	DOD-C-24621 Para. 4.7.6	4.7.6
Insertion Loss	DOD-C-24621 Para. 4.6.1	4.6.1
Mechanical Shock	MIL-S-901	4.7.12
Operating Temperature	DOD-C-24621 Para. 4.7.14	4.7.14
Optical Power Angular Distibution	DOD-C-24621 Para. 4.6.7	4.6.7
Ozone Exposure	DOD-STD-1344 Method 1007	4.7.2
Pulse Distortion	DOD-C-24621 Para. 4.6.4	4.6.4
Salt Spray	MIL-STD-1344 Method 1001	4.7.16
Thermal Shock	DOD-STD-1678 Method 4020	4.7.13
Vibration	MIL-STD-1344 Method 2005	4.7.15
Water Pressure	DOD-C-24621 Para. 4.7.5	4.7.5

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5.4. Fiber Optic Detector.

DOD-C-24620 is a specification for fiber optic detectors approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in DOD-C-24620 are listed in Tables 5-6. For specific test conditions and procedures the user should see DOD-C-24620, any applicable specification sheets and the appropriate test methods.

Table 5-6. DOD-D-24620 Fiber Optic Detector Test Methods.

Parameter	Test Method	DOD-C-24620 Paragraph
Analog Bandwidth	DOD-C-24620 Para. 4.6.2.7	4.6.2.7
Bond Strength	MIL-STD-750 Method 2037	4.6.3.9

Table 5-6. DOD-D-24620 Fiber Optic Detector Test Methods (cont.).

Parameter	Test Method	DOD-C-24620 Paragraph
Burn-in	MIL-STD-750 Method 1038	4.6.3.4
Dark Current	MIL-STD-750 Method 3061	4.6.2.4
Decap Internal Visual Design Verification	MIL-STD-750 Method 2075	4.6.3.8
Fine Leakage Rate	MIL-STD 750 Method 1071	4.6.3.5.1
Gross Leakage Rate	MIL-STD 750 Method 1071	4.6.3.5.2
Junction Capacitance	MIL-STD-750 Method 4001	4.6.2.2
Moisture Resistance	MIL-STD-750 Method 1021	4.6.3.12
Noise Equivalent Power	DOD-D-24620 Para. 4.6.2.8	4.6.2.8
Physical Dimensions	MIL-STD-750 Method 2066	4.6.1.2
Responsivity Linearity	DOD-D-24620 Para. 4.6.2.5	4.6.2.5
Resistence to Solvents	MIL-STD-750 Method 1022	4.6.3.7
Reverse Current Leakage and Breakdown Voltage	MIL-STD-750 Method 3061	4.6.2.3
Shock	MIL-STD-750 Method 2016	4.6.3.13
Solderability	MIL-STD-202 Method 208	4.6.3.6
Spectral Responsivity and Quantum Efficiency	DOD-D-24620 Para. 4.6.2.1	4.6.2.1
High Temperature (Nonoperating Life)	MIL-STD-750 Method 1032	4.6.3.1
Terminal Strength (Tension)	MIL-STD-750 Method 2036	4.6.3.11.1
Terminal Strength (Torque)	MIL-STD-750 Method 2038	4.6.3.11.2
Thermal Shock (Strain)	MIL-STD-750 Method 1056	4.6.3.10
Variable Frequency Vibration	MIL-STD-750 Method 2056	4.6.3.14
Visual and Mechanical Inspection	MIL-STD-750 Method 2071	4.6.1.1

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5.5. Optical Fiber.

DOD-F-49291 is a specification for optical fiber approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in DOD-F-49291 are listed in Table 5-7. For specific test conditions and procedures the user should see DOD-F-49291, any applicable specification sheets and the appropriate test methods.

Table 5-7. DOD-F-49291 Optical Fiber Test Methods.

Parameter	Test Method	DOD-F-49291 Paragraph
Induced Attenuation	EIA-455-20	4.7.2.1
Attenuation Rate	EIA-455-46, -50	4.7.2.2
Bandwidth (Freq. Domain)	RS-455-5, FOTP 30 & 54	4.7.2.5.1
Bandwidth (Time Domain)	RS-455-51, RS-455-5, FOTP 64	4.7.2.5.2
Core Diameter	EIA-455-58	4.7.2.4
Dimensional Stability	MIL-STD-1678 Method 4060	4.7.2.7
Fiber and Coating Geometry	EIA-455-45, -55	4.7.1.1
Fluid Immersion	MIL-STD 1678 Method 8030	4.7.2.11
Fungus	EIA-455-56	4.7.2.13
Life	MIL-STD 202 Method 108	4.7.2.10
Mechanical Stripability	DOD-F-49291 Para. 4.7.1.3	4.7.1.3
Nucear Radiation Resistence	DOD-F-49291 Para. 4.7.2.12	4.7.2.12
Numerical Aperature	RS-455-47	4.7.2.3
Proof Test	EIA-455-31	4.7.1.2
Temperature Cycling	RS-455-1, FOTP-3	4.7.2.9
Temperature Shock	MIL-STD-1678 Method 4020	4.7.2.6
Temperature Humidity Cycling	MIL-STD-1678 Method 4030	4.7.2.8
Visual and Mechanical Inspection	EIA-455-13	4.7.1

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5.6. LED Source.

DOD-S-24622 is a specification for LED sources approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in DOD-S-24622 are listed in Table 5-8. For specific test conditions and procedures the user should see DOD-S-24622, any applicable specification sheets and the appropriate test methods.

Table 5-8. DOD-S-24622 LED Fiber Optic Source Test Methods.

Parameter	Test Method	DOD-S-24622 Paragraph
Bond Strength	MIL-STD-750 Method 2037	4.7.3.13
Breakdown Voltage	MIL-STD-750 Method 4021	4.7.2.9
Constant Acceleration	MIL-STD-750 Method 2006	4.7.3.4
Visual Design Verification	MIL-STD-750 Method 2075	4.7.3.12
Forward Voltage	MIL-STD 750 Method 4011	4.7.2.7
Frequency Response	DOD-S-24622 Para. 4.7.2.12	4.7.2.12
Hermetic Seal Fine Leakage Rate	MIL-STD 750 Method 1071	4.3.7.3.1
Hermetic Seal Gross Leakage Rate	MIL-STD 750 Method 1071	4.3.7.3.2
Intermittent Operation Life	MIL-STD-750 Method 1037	4.7.3.21
Moisture Resistance	MIL-STD-750 Method 1021	4.7.3.16
Optical Power Amplitude	MIL-STD-1678 Method 6010	4.7.2.4
Optical Power Amplitude Stability	DOD-S-24622 Para. 4.7.2.5	4.7.2.5
Optical Power Angular Distribution	MIL-STD-1678 Method 6030	4.7.2.6
Peak Optical Wavelength	DOD-S-24622 Para. 4.7.2.1	4.7.2.1
Peak Optical Wavelength Drift	DOD-S-24622 Para. 4.7.2.2	4.7.2.2
Physical Dimensions	MIL-STD-750 Method 2066	4.7.1.2
Pulse Rise and Fall Times	DOD-S-24622 Para. 4.7.2.11	4.7.1.2
Reverse Current Leakage	MIL-STD-750 Method 4016	4.7.2.8

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Table 5-8. DOD-S-24622 LED Fiber Optic Source Test Methods (cont.).

Parameter	Test Method	DOD-S-24622 Paragraph
Resistence to Solvents	MIL-STD-750 Method 1022	4.7.3.9
Salt Atmosphere (Corrosion)	MIL-STD-750 Method 1041	4.7.3.19
Shock	MIL-STD-750 Method 2016	4.7.3.17
Signal Linearity	DOD-S-24622 Para. 4.7.13	4.7.2.13
Solderability	MIL-STD-202 Method 208	4.7.3.8
Steady State Reverse Bias Burn-in	MIL-STD-750 Method 1038	4.7.3.5
Steady State Power Burn-in	MIL-STD-750 Method 1038	4.7.3.6
Steady State Operation Life	MIL-STD-750 Method 1026	4.7.3.20
Temperature Cycling (Thermal Shock)	MIL-STD-202 Method 107	4.7.3.3
Elevated Temperature Life	DOD-S-24622 Para. 4.7.3.1	4.7.3.1
High Temperature (Nonoperating Life)	MIL-STD-750 Method 1032	4.7.3.2
Thermal Shock (Strain)	MIL-STD-750 Method 1056	4.7.3.14
Terminal Strength (Tension)	MIL-STD-750 Method 2036	4.7.3.15.1
Terminal Strength (Torque)	MIL-STD-750 Method 2038	4.7.15.2
Thermal Resistance	MIL-STD-750 Method 4081	4.7.2.10
Variable Frequency Vibration	MIL-STD-750 Method 2056	4.7.3.18
Visual and Mechanical Inspection	MIL-STD-750 Method 2071	4.7.1.1

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5.7. Fiber Optic Splice.

DOD-S-24623 is a specification for fiber optic splices approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in DOD-S-24623 are listed in Table 16. For specific test conditions and procedures the user should see DOD-S-24623, any applicable specification sheets and the appropriate test methods

Table 5-9. DOD-S-24623 Fiber Optic Splice Test Methods.

Parameter	Test Method	DOD-S-24623 Paragraph
Ambient Optical Pickup	DOD-STD-810 Method 505	4.5.2.6
Analog Modulation	DOD-S-24623 Para. 4.5.2.3	4.5.2.3
Axial Loading (Compression)	DOD-S-24623 Para. 4.5.1.8	4.5.1.8
Cable Seal Flexing	MIL-STD-1344 Method 2017	4.5.1.6
Cable Tensile Loading	DOD-S-24621 4.5.1.7	4.5.1.7
Color	MIL-STD-104	4.5.1.3
Crosstalk	DOD-S-24623 Para. 4.5.2.4	4.5.2.4
Crush	DOD-STD-1678 Method 2040	4.5.1.9
Discontinuity	DOD-S-24623 Para. 4.5.2.2	4.5.2.2
Fiber Tensile Loading	DOD-S-24623 Para. 4.5.1.13	4.1.5.13
Flammability	DOD-STD-1678 Method 5010	4.5.3.7
Fluid Immersion	MIL-STD-1344 Method 1016	4.5.3.6
Humidty	MIL-STD-1344 Method 1002	4.5.3.3
Impact	DOD-STD-1678 Method 2030	4.5.1.10
Identification Marking	DOD-S-24621 Para. 4.5.1.4	4.5.1.4
Insertion Loss	DOD-S-24623 Para. 4.5.2.1	4.5.2.1
Mass	DOD-S-24623 Para. 4.5.1.2	4.5.1.2
Mechanical Shock	MIL-S-901	4.5.1.12
Operating Temperature	DOD-S-24621 Para. 4.5.3.9	4.5.3.9
Optical Conformance	DOD-S-24623 Para. 4.5.2	4.5.2
Ozone Resistance	MIL-STD-1344 Method 1007	4.5.3.8
Personel Safety Labeling	DOD-S-24623 Para. 4.7	4.7
Pulse Distortion	DOD-S-24623 Para. 4.5.2.4	4.5.2.4
Salt Spray	MIL-STD-1344 Method 1001	4.5.3.4
Size	DOD-S-24623 Para.4.5.1.1	4.5.1.1
Temperature Life	MIL-STD-1678 Method 4010	4.5.3.1

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Table 5-9. DOD-S-24623 Fiber Optic Splice Test Methods (cont.).

Parameter	Test Method	DOD-S-24623 Paragraph
Thermal Shock	MIL-STD-1344 Method 1003	4.5.3.2
Twist	DOD-S-24623 Para.4.5.1.6	4.5.1.6
Vibration	MIL-STD-1344 Method 2005	4.5.1.11
Water Pressure	DOD-S-24623 Para. 4.5.3.5	4.5.3.5

5.8. Fiber Optic Termini.

MIL-T-29504 is a specification for fiber optic termini approved for military applications. Test parameters, applicable test methods and the corresponding test paragraphs in MIL-T-29504 are listed in Table 5-10. For specific test conditions and procedures the user should see MIL-T-29504, any applicable specification sheets and the appropriate test methods.

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Table 5-10. MIL-T-29504 Fiber Optic Splice Test Methods.

Parameter	Test Method	MIL-T-29504 Paragraph
Axial Concentricity	MIL-T-29504 Para. 4.7.5	4.7.5
Identification Marking	MIL-T-29504 Para. 4.7.3	4.7.3
Insertion Loss	EIA-455-34 (FOTP-34)	4.6.1
Marking Inspection	MIL-T-29504 Para. 4.8	4.8
Mating Durability	MIL-STD-1344 Method 2016	4.7.11
Optical Conformance	MIL-T-29504 Para. 4.6	4.6
Salt Spray	MIL-STD-1344 Method 1001	4.7.14
Shock	EIA-455-14 (FOTP-14)	4.7.12
Size	MIL-T-29504 Para. 4.7	4.7
Temperature Life	MIL-STD-1344 Method 1004	4.7.8
Terminus Cleaning	MIL-T-29504 Para. 4.7.4	4.7.4
Terminus Engagement and Separation Force	MIL-STD-1344 Method 2014	4.7.7

Table 5-10. MIL-T-29504 Fiber Optic Termini Test Methods (cont.).

Parameter	Test Method	MIL-T-29504 Paragraph
Terminus Retention Force	MIL-STD-1344 Method 2007	4.7.6
Thermal Shock	DOD-STD-1344 Method 2003	4.7.10
Vibration	EIA-455-11 (FOTP-11)	4.7.13
Weight	MIL-T-29504 Para. 4.7.2	4.7.2

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CHAPTER 6. SYSTEM TESTING AND DIAGNOSTICS.

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CHAPTER 6. SYSTEM TESTING AND DIAGNOSTICS.

6.0. System Testing and Diagnostics.

The purpose of the testing described in this section is to verify that the bus system complies with the requirements of MIL-STD-1773 multiplexing system specification and to provide data for use in diagnostic testing which may be required.

Diagnostic procedures are used to identify the cause of a system malfunction. Once the cause of the system malfunction has been identified, faulty components can be isolated and replaced. Specific diagnostic procedures discussed include network loss measurements, bit error rate measurements, waveform measurements, timing measurements and optical time domain reflectometry.

6.1. Bus Network Loss Measurements.

Loss measurements are the best technique available for the verification of proper installation of cables, connectors, and couplers in a bus network. Two significant problems in making loss measurements are that results may not be as accurate as desired and the data obtained is not consistently repeatable. All light signal paths should be tested by connecting a test source to the transmitter input ports of the bus network and measuring output power at the receiver ports of the bus network. These loss measurements will identify damaged components, dirty connectors, and poorly mated connectors. If cleaning and adjustment of connectors does not correct a problem, optical domain reflectometry measurements may be required to locate a fault in a cable.

Accuracy and repeatability of optical attenuation measurements is a problem because of errors due to distribution of modes in the fiber core and cladding mode propagation. Fiber modes are illustrated in Figure 6-1. Hundreds of different modes (propagation paths) exist in a multimode optical fiber and the amount of power carried by the various modes is different for different lengths of cable and different amounts of cable bending.

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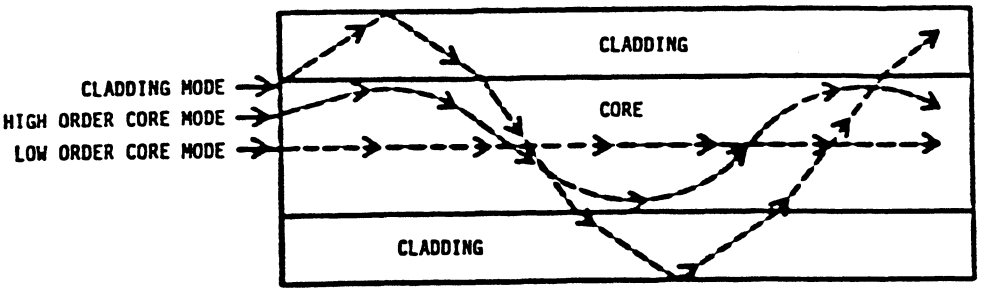

Figure 6-1. Propagation Modes in a Graded Index Fiber.

Cladding modes are launched into the fiber cladding by LED's that have a numerical aperture and spot diameter which are larger than the numerical aperture and core diameter of the fiber. Received cladding mode energy is also dependent upon cable length and bending. Mode distribution and cladding modes can cause apparent measured attenuation to change by a significant amount. The repeatability of measurements can be improved by the use of mode scramblers and cladding mode strippers to yield reproducible modal distribution.

Lateral misalignment of fiber cores at an SMA connector can cause increased loss which varies when the connector is mated and unmated or rotated. This loss is caused by the eccentricity (out of roundness) and core/cladding concentricity error of the fibers. For example, an axial displacement equal to 10% of the core diameter will cause a 0.6 dB loss.

Typical loss measurement variations and are summarized in Table 18. These optical attenuation measurement problems make the identification of damaged connectors or cables more difficult, but satisfactory results can be obtained. An important way to obtain good results include using a source that is geometrical and spectrally the same as the system source, to make loss measurements, to ensure that the core mode distribution and cladding modes will be similar to their condition during system operation. In addition, cables should be moved as little as possible and connectors should remain connected after these measurements. If a fault in the cable network is suspected, loss measurements can be repeated a compared to the initial measurement values. Under these conditions the measurements should be repeatable to within a few tenths of a dB. If cables were moved by a significant amount and SMA style connectors were disconnected and reconnected, the diagnostic measurement could change by as much as 1.0 dB.

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Table 6-1. Typical Loss Measurement Variation.

Core Mode Distribution	0.2 - 0.6 dB
Cladding Modes	0.0 - ?
Connector (SMA)	0.3 - 0.6 dB
Meter Repeatability	1% (0.1 dB)

It should be noted that the cladding mode energy may not be significant if an epoxy having an index of refraction which is higher than the cladding index is used inside the fiber optic connectors. The epoxy provide cladding mode stripping.

6.2. Word Error Rate Measurements.

Overall performance of a MIL-STD-1773 bus terminal is determined b making word error measurements at maximum and minimum light signal levels. A bus tester which functions as a bus controller is required for these measurements. MIL-STD-1553B bus testers can easily be modified for

MIL-STD-1773 testing because the standards are very similar except for the change from electrical to optical transmission.

The word error rate of a MIL-STD-1773 bus is limited at both high received optical power levels as well as at low received optical power levels as shown in Figure 6-2. These two boundaries establish an optical signal range (OSR) at a given word error rate. At high signal levels, the amplifier in the receiver saturates and produces wide pulses or other pulse distortion, which leads to higher word error rates. At low signal levels, the signal-to-noise ratio decreases, which causes the bit and word error rates to increase. The best operating region is to the left side of Figure 6-2. between the two boundary curves. An optical power budget analysis of a particular bus is required to determine the theoretical minimum received power and the lower boundary curve in Figure 6-2. A method for measurement of the boundary curves is described in paragraphs 6.2 through 6.5. The operating minimum received power should be between 3 dB and 6 dB above the lower boundary curve to provide a loss margin to cover temperature effects, component aging, and increased connector loss with use in a system application.

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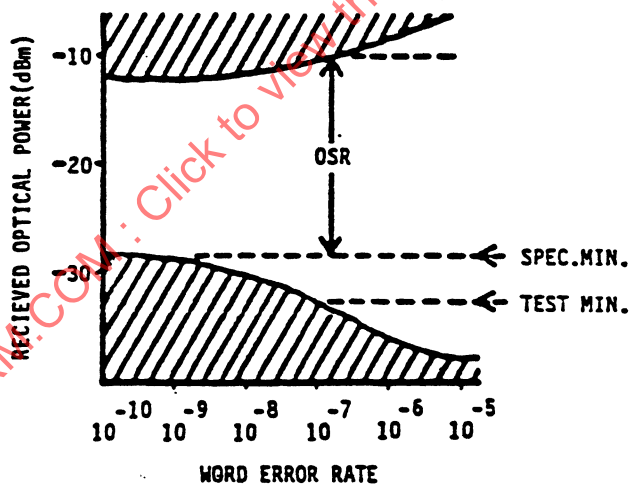

Figure 6-2. Typical Relationship Between Received Optical Power and Word Error Rate.

The word error rate of a bus terminal is required by MIL-STD-1773 to be measured when "receiving two successive messages which differ in optical power by the maximum OSR in accordance with the system specification(s) for messages separated in time by the intermessage gap (4.0 us min.)". The block diagram of a bus setup for this test is given in Figure 6-3. Variable optical attenuator #1 (VOA1) is adjusted to give the maximum optical signal level to the RT under test when RT1 transmits and VOA2 is adjusted to give the minimum optical signal level to the RT under test when the controller terminal transmits. Points on the boundary curves of Figure 6-2. are measured by measuring word error rate for different attenuator positions.

The transfer of data in the error rate measurement takes place in a three stage process as shown on Figure 6-4. First, a set of random data words is transferred from the controller to remote terminal number one which responds with a status word to the controller. Next, the controller sends a broadcast receive command to all remote terminals followed contiguously by a transmit command to remote terminal number one. Remote terminal number one then issues a status word followed by the random data words. The remote terminal under test receives and stores the data words. After the minimum intermessage gap time, the controller issues a transmit command to the remote terminal under test (RTUT) and the RTUT responds by transmitting a status word followed by the random data words. Finally, the random data words are received back at the controller and compared to the data words that were originally sent to the remote terminal number one. This test sequence runs continuously for the time required to complete the word error rate test.

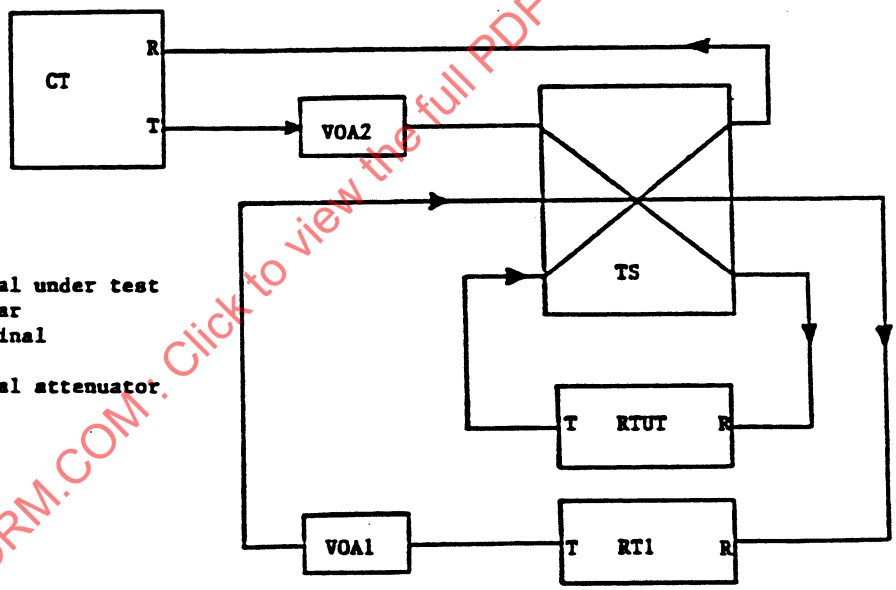

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Figure 6-3. Error Rate Test Setup Block Diagram.

6.3. Waveform Measurements.

Waveform measurements are needed in the testing of MIL-STD- 1773 systems to verify a proper transmitted waveform and proper received waveform after signal propagation through a fiber optic bus network. The output waveform and input waveform compatibility specifications of 1773, 1553B, and a suggested 1773 signal system specification are given on Figure 6-5. Although 1773 does not specify waveform accuracy, a 1.0 megabit per second, Manchester II coded signal is specified. The suggested 1773 system specification is consistent with this requirement and is necessary in order to use encoder-decoder LSI chips which were developed for 1553B use. An overshoot and ringing specification is probably not necessary for a fiber optic bus. Because of the low

distortion and the absence of large reflected signals on a fiber optic cable, the input waveform ON/OFF time deviation will generally be much better than specified on Figure 6-5.

Waveform can be measured by using an optical-to-electrical transducer such as the Hewlett-Packard HP 81519A Optical Receiver or the Photodyne 1500XP Optical Waveform Analyzer. Both of these instruments can accurately reproduce the MIL-STD-1773 waveforms because their frequency response extends from DC to 200 MHz or higher.

6.4. Timing Measurements.

Times which must be measured to verify compliance with MIL-STD-1773 requirements are intermessage gap time, response time, and minimum no-response time-out. Signal times cannot be directly measured at point A on Figure 9 and Figure 10 of MIL-STD-1773, as called for in paragraphs 4.3.3.7, 4.3.3.8, and 4.3.3.9, because the signal is in the form of pulses of light in a fiber optic cable at point A. The light signal must be coupled from the fiber and converted to electrical form to be observed, with the detector delays considered.

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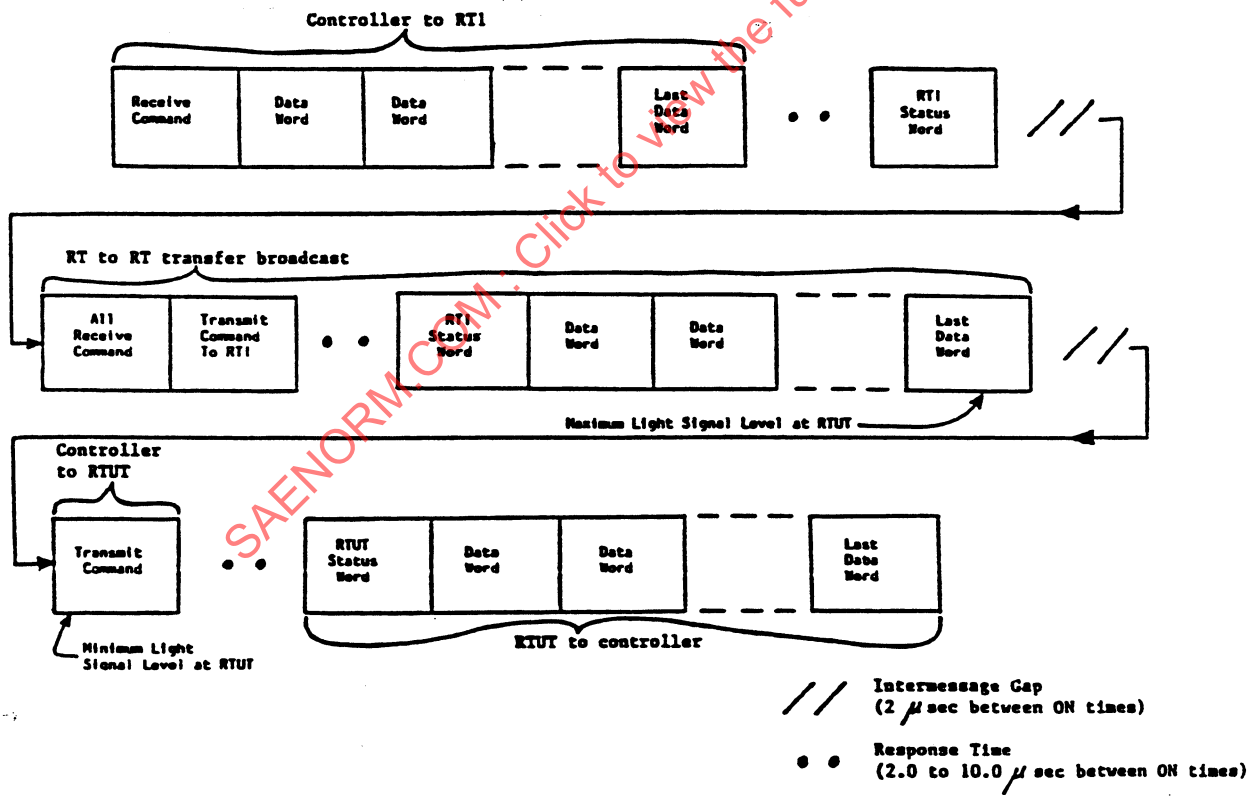

Figure 6-4. Message Sequence For Error Rate Test.

MIL-STD-1773	MIL-STD-1553B	SUGGESTED 1773 SYSTEM SPECIFICATION
Output Waveform (4.5.2.2) "in accordance with the system specification"	Output Waveform (4.5.2.1.1.2) zero crossing deviation ≤ 25ns 100 ns < Tr,f < 300ns; overshoot and ringing ≤ ±900mv	Output Waveform ON/OFF time deviation ≤25ns Tr,f < 100ns
Input Waveform Compatibility (4.5.3.1) "in accordance with the system specification"	Input Waveform Compatibility (4.5.2.1.2.1) Maximum zero crossing deviation of ±150ns Vpp = 0.86 to 14V	Input Waveform Compatibility ON/OFF time deviation ±150ns max.

Figure 6-5. Waveform Specifications.

Note: IMG is defined as 4 uS. minimum, but will include only 2 to 2.5 uS. of quiet time since the next message will always start with Command/Status Synch.

A practical way to measure timing is to observe the electrical waveform at the amplified output of the photodetector and at the electrical input to the electroluminescent device (LED or LASER diode) in the bus terminal using a dual trace oscilloscope. The typical delay through a LED, PIN diode, and transimpedance amplifier is only about 0.05 microseconds which is an insignificant fraction of the times being measured.

6.4.1 Inter-message Recovery.

The optical signal power level of successive messages received at a bus terminal will be different when the messages are transmitted by different bus terminals. Even a star bus topology, which has less signal level variation than most topologies, will have a range of signal power levels because of transmitter power variations, the variable number of connectors and range of connector losses and non-uniformity of coupling to different ports of the star coupler.

The inter-message dynamic signal range of a receiver is defined as the range from the maximum signal power level to the minimum signal power that the receiver will detect with a bit error rate less than or equal to the allowed system maximum, when a message at the minimum level is preceded by a message at the maximum level and the messages are separated by the minimum inter-message gap (IMG) time. MIL-STD-1773 specifies a minimum IMG of four microseconds, measured from the mid-bit transition of the parity bit of the last word of the preceding message to the mid-bit of the synch character of the Command/Status word at the beginning of the following message. Of this 4 microsecond period, as

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little as 2 microseconds may be signal "off" for the receiver to recover before it must detect the positive transition of a minimum level Command/Status synch character.

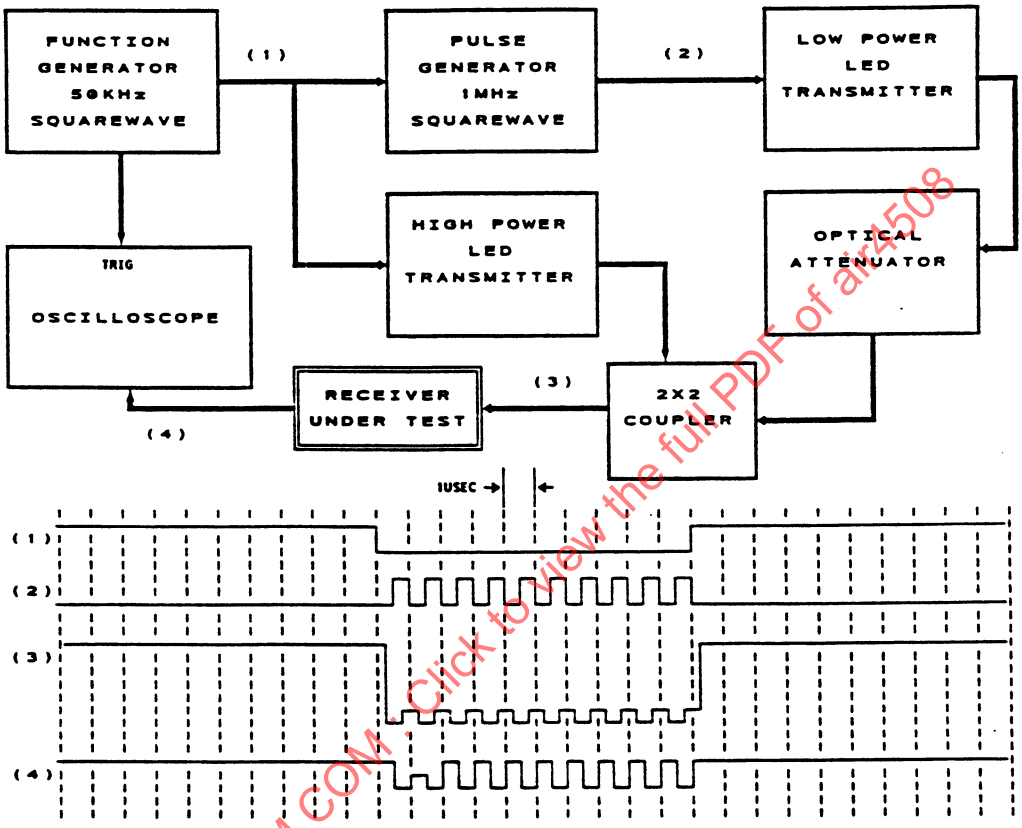

Figure 6-6. Inter-Message Recovery Measurement.

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A block diagram of a test setup and the reference waveforms for the measurement of inter-message recovery are shown in Figure 6-6. The numbers on the block diagram identify where each of the waveforms is measured. the output of the 50 KHz function generator switches the high-power LED transmitter and also gates the 1 MHz square wave pulse generator ON for 10 microsecond periods, as shown in waveform #2. The output of the pulse generator switches the low-power transmitter ON and OFF. The output of the high-power transmitter and the optical attenuator is adjusted so that the high and low signals are at the specified levels at the output of the 2x2 coupler. Waveform #3 represents the combined signal sequence at this point. The "high" power level generates the maximum amount of baseline shift in the receiver under test and the "low" power level square wave provides a measure of the receiver recovery from this condition.

Waveform #4 is the oscilloscope display of the receiver output

during the test. Pulse Width Distortion of the first pulses of the low level square wave will be observed. The width of both the high and low levels of the receiver output pulse train must be within the allowed distortion limits, following the second positive pulse, in order for the receiver to meet the inter-message recovery requirements.

6.5. Optical Time Domain Reflectometry.

The optical time domain reflectometer (OTDR) is a basic fiber optic instrument which is used to measure the reflection from and loss of splices, connectors, couplers, and cables. The position of faults on a line can also be determined. A simplified block diagram of an OTDR is given in Figure 6-7.

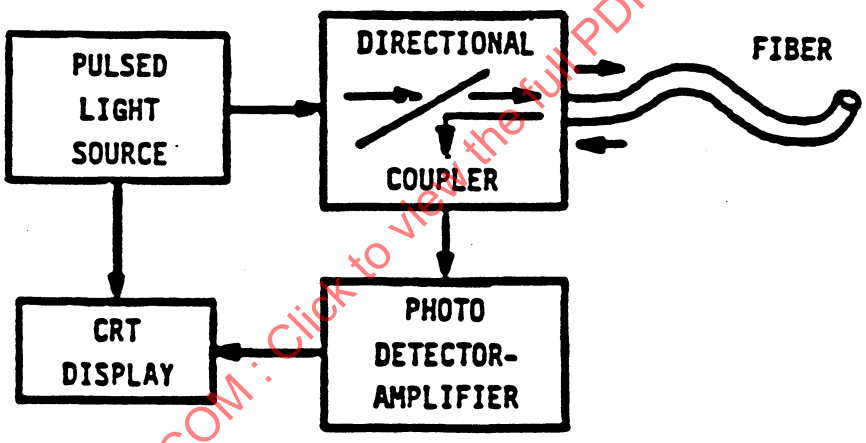

Figure 6-7. Simplified Block Diagram of an Optical Time Domain Reflectometer.

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The pulsed light source emits a short pulse of light which passes through the directional coupler and is injected into the fiber optic cable. The light pulse propagates down the fiber and light is reflected back to the directional coupler by flaws in the cable and by Rayleigh back-scatter reflections in the fiber. The directional coupler directs the reflected light into the photodetector. Amplitude and time of arrival of the reflected light are used to generate the CRT display of reflected signal amplitudes versus distance (time) along the cable.

Two characteristics of a typical MIL-STD-1773 bus which limit the usefulness of an OTDR are the relatively short cable lengths and the use of star couplers. The shorter lengths of cable in a MIL-STD-1773 bus and possibly close spacing of couplers, connectors, and fault points requires that the OTDR have good distance resolution and be able to resolve the Fresnel reflections that occur at a fiber break.

A sketch of the theoretical display of a short range-high resolution

OTDR is given in Figure 6-8. Typical signal levels are shown for a 1.0 mW light source and a graded index multimode fiber. The sketch illustrates the OTDR problems of resolving both low and high level signals with high position resolution. The dashed line shows that the backscatter signal becomes even smaller when the OTDR is designed for better resolution. Signal averaging is required to increase the signal-to-noise ratio of the backscatter signal.

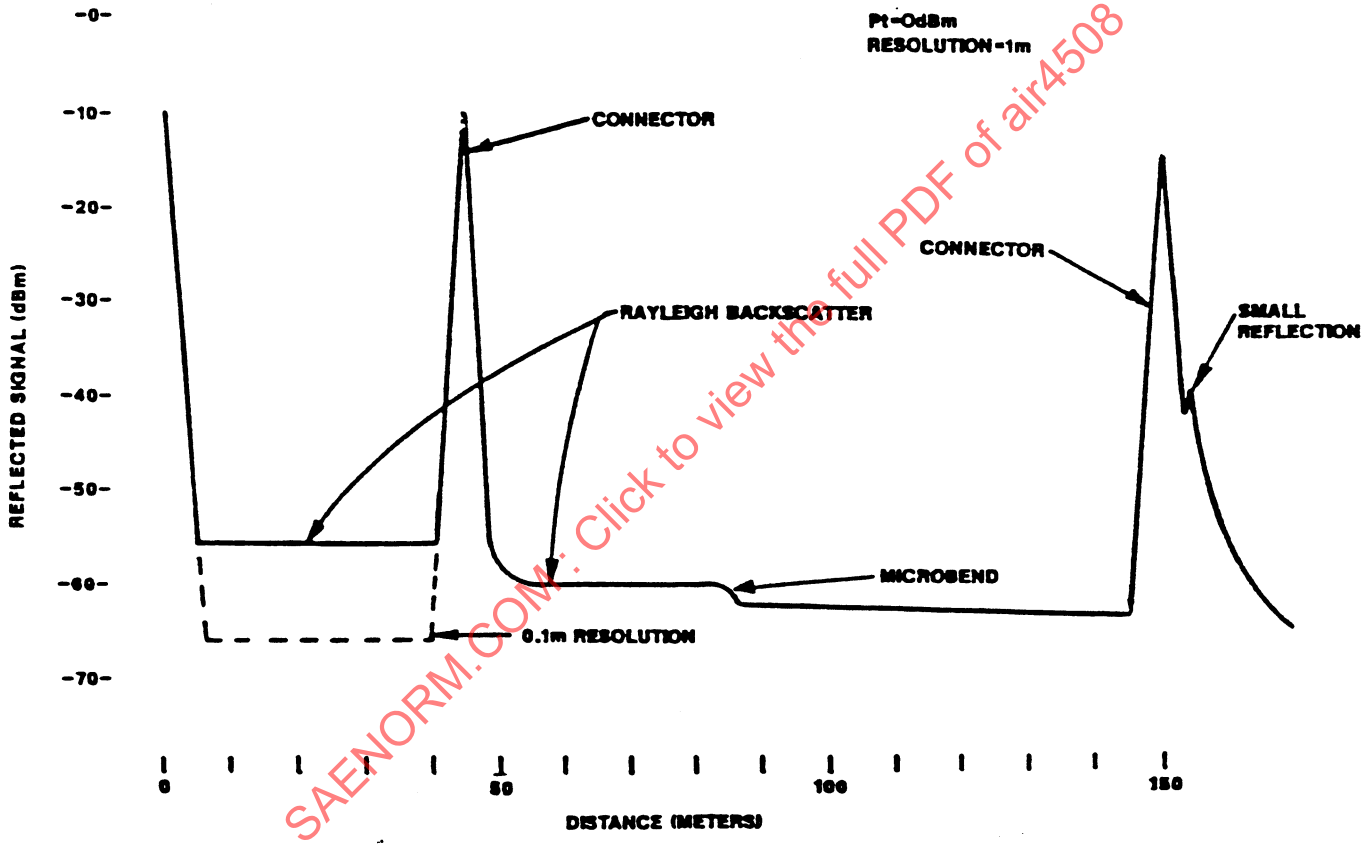

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Figure 6-8. Theoretical OTDR Display.

OTDR testing is most used for diagnostic testing to find the location of a damaged connector or a break in a cable. The OTDR will also indicate which connector or splice in a cable is faulty. Loss measurements give no indication of which connector may be faulty or which splice of a cable may be damaged.

6.6. Optical Power Measurements.

In order to check the performance of fiber optic transmitters and receivers it is necessary to measure the optical power. Many optical power meters are available. When using optical power meters,

consideration must be given to the wavelength of operation and spectral calibration of the meter. For repeatable power measurements, it may be necessary to use mode scramblers and cladding mode stripping in order to achieve a consistent modal distribution. When measuring the power level of a non-steady state optical signal, the AC response of the meter becomes important, since many optical power meters do not read true average power.

6.7. Optical Wavelength Measurement.

The optical spectrum of the transmitter needs to be measured to check compliance with the standard and specification. Wavelength meters are available and are satisfactory as test equipment for MIL-STD-1773 systems.

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CHAPTER 7. MEDIA INSTALLATION CONSIDERATIONS.

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CHAPTER 7. MEDIA INSTALLATION CONSIDERATIONS.

7.0. Media Installation Considerations.

The extensive use of fiber optic interconnects in military aircraft, whether in point-to-point links, a MIL-STD-1773 bus, or any other bus implementation, requires that the fiber optic cable be at least as rugged as the electrical cable it will be replacing. Therefore, the fiber optic cables must pass all of the environmental and mechanical tests that electrical cables are required to pass. Other considerations, some of which are unique to fiber optics, are described in the following paragraphs.

7.1. Cable Assembly.

Installation and maintenance of fiber optic cables requires that extra care be taken during the following procedures: fiber cleaning, epoxy preparation and application, and the polishing of the fiber face.

Successful termination of fiber optic cables requires that the user carefully apply the following cable fabrication steps to ensure that cable/connector assemble will not fail during normal use.

7.1.1. Cable Stripping.

The stripping dimensions for a particular cable will vary with the terminus to be attached. The following paragraphs will describe the termination procedure for the fiber optic cable being used in the AV-8B, terminated with an ITT Cannon fiber optical terminus, part number 031-9600-003, however, the manufacturers suggested procedure should be rigorously followed for a specific terminus.

7.1.1.1. Dimensions.

The cable should be stripped to the dimensions given in Figure 7-1. Many common tools, such as razor blades, X-ACTO knives, and NO-NIK strippers are adequate for the job.

7.1.2. Fiber/Connector Cleanliness.

Fiber optic components must be free of contamination so that the integrity of the adhesive will not be compromised. A clean environment (but not a cleanroom) is required. Clean the portions of the cable and connector parts to be epoxied by dipping them in an ultrasonic cleaning tank containing liquid Freon TF or wipe with an alcohol swab. Wipe the components clean with tissue, and allow them to dry.

7.1.3. Epoxy Adhesive.

Epoxy is used to secure the terminus to the optical fiber and cab The epoxy used in the AV-8B interconnect is described below.

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7.1.3.1. Temperature Stability.

The continuous operating range of the cured epoxy is -55 C to +160 C. The epoxy properties must not deteriorate over this temperature range.

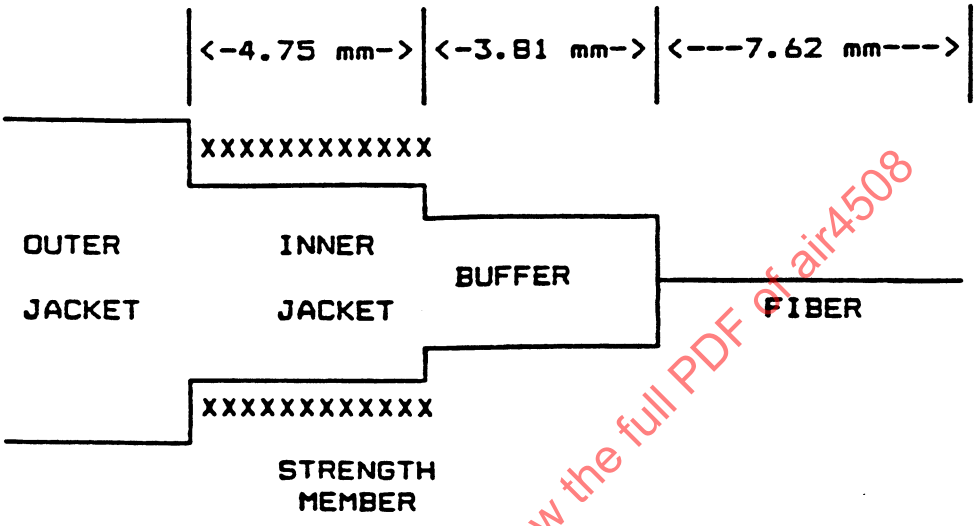

Figure 7-1. Cable Strip Dimensions.7.1.2. Fiber/Connector Cleanliness.

Fiber optic components must be free of contamination so that the integrity of the adhesive will not be compromised. A clean environment (but not a cleanroom) is required. Clean the portions of the cable and connector parts to be epoxied by dipping them in an ultrasonic cleaning tank containing liquid Freon TF or wipe with an alcohol swab. Wipe the components clean with tissue, and allow them to dry.

7.1.3.2. Application.

Epoxy is applied to the inside of the terminus by filling a syringe with epoxy (making sure all air bubbles have been expelled), inserting the syringe needle into the rear of the terminus, and injecting sufficient epoxy to half-fill the terminus. Be sure that no air bubbles get into the epoxy during this operation. Epoxy should come through the fiber opening at the end of the terminus.

Install the terminus onto the stripped portion of the cable, ensuring that the bare fiber protrudes through the hole in the end of the terminus, and that the terminus is properly seated on the cable. Apply a drop of epoxy at the fiber/terminus junction, and clean any excess epoxy from the body of the terminus with a tissue. The assembly can now be cured at 300 F. for thirty minutes, with the fiber longitudinal axis oriented horizontally.

7.1.4. Polishing.

The fiber face must be polished to provide maximum light transfer in

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and out of the fiber and to ensure proper longitudinal positioning within the mated connector. Polishing fixtures and polishing sheets of varying grit sizes can be obtained. The polishing sheets used in the AV-8B are Blue (40 micron grit size), Yellow (12 micron), Pink (3 micron), and Violet (1 micron). These are commercially available from 3M.

7.1.4.1. Amount of Material Removed.

After Epoxy cure, cut or break off the excess fiber at the surface of the epoxy bead, leaving approximately 2 mm to be ground off. When the terminus is inserted into the polishing fixture, the epoxy bead will protrude past the plane of the fixture surface. The end of the terminus will be flush with the plane of the fixture surface. Using the various polishing sheets in turn, from coarse to fine, grind off the epoxy/fiber material until no material protrudes beyond the polishing fixture surface. Clean the fiber face with liquid Freon TF in an ultrasonic bath; dry with heat or tissue.

7.1.4.2. Angle of the Fiber Face.

The finished fiber face should lie in exactly the same plane as the polishing fixture surface. This will make the angle of the fiber face 90 degrees to the longitudinal axis of the fiber.

7.1.4.3. Smoothness of Fiber Face.

The fiber end must be microscopically inspected for a highly polished surface free of scratches, digs, chips or epoxy smears. Additional polishing can be used to remedy an imperfection. The fiber end should be even or slightly recessed with the terminus end.

7.1.5. Cable Harness Assembly Installation.

Fiber optic cables can be routed in harnesses containing only fiber optics, or in harnesses containing both wire and fiber optics. The harnesses (of either type) must meet the requirements of MIL-W-5088.

Harnesses containing fiber optics must be capable of withstanding the installation environment as though they were wire only harnesses. Cable clamps must be tight enough to properly secure the harness, but not so tight that microbending losses are incurred in the fiber(s). The harness bend radius should be as large as is practicable, and never less than 10 times the outside diameter of the largest diameter cable in the harness. The harness should require no special routing considerations due to the presence of fiber optics.

7.1.6. Preventing Connector Contamination.

Fiber optic connectors must be protected from contamination to prevent excessive signal strength loss within a mated connector. Connectors should be mounted in drip free areas and horizontally as much

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as possible to prevent exposure to dust, moisture, or other debris. Unmated connectors should be capped or otherwise protected from the environment.

7.2. Miscellaneous Lessons Learned with the AV-8B.

The design and development of fiber optics for production military aircraft has provided many lessons, some of which are not necessarily obvious. These include problems encountered in the area of cable design, harness break-outs and connector location.

7.2.1. Cable Design.

Fibers of smaller than 140 micron diameter in tight jacket avionics cable are subject to breakage due to the differential temperature expansion of silica fibers and Kevlar strength members, under thermal shock conditions.

7.2.2. Harness Break-outs.

When individual fiber optic cables are broken out of the main harness, do not allow much slack from the break-out point to the terminal point of the cable. Production personnel have a tendency to want things to "look neat", and may fold a cable back upon itself to be clamped. This can cause excessive static fatigue in the fiber, which can cause premature breakage.

7.2.3. Connector Location.

Avoid placing SMA or other single channel connectors in locations where equipment removal/installation or maintenance personnel can cause accidental damage.

7.3. Lessons Learned During Installation of a Fiber Optic Position Sensing System on a Commercial Transport Airplane.

7.3.1. Training.

It is absolutely essential that production personnel be trained in proper handling procedures. During our installation we had five cable segments break because of rough handling. Examples of mistreatment that resulted in cable breakage:

a. Coiling a cable into a tight loop to fit through lightening holes in structure.

b. Improper use of fiber optic contact insertion tools.

c. Pulling slack out of a cable resulted in too sharp a bend radius at a string tie.

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d. Stowing excess cable in a bundle by bending it back on itself and string tying the excess onto the harness.

e. Improper bonding of fiber at a connector.

7.3.2. Harness Assembly Techniques.

Care should be exercised when using string ties or nylon ties on a fiber optic cable harness in a manner that would be used for a harness of copper wires. Each tie can result in microbending losses, and increase cable attenuation. On some long runs of approximately sixty feet, we found that a string tie or nylon tie every four inches will double the attenuation in the cable. Loose, or semi-loose tube construction is less susceptible to losses of this type than tight tube construction.

7.3.3. Connector Losses.

New, low loss, low reflection fiber optic connectors are needed. A typical cable run on a large transport aircraft will have from four to six production breaks. With current connector technology, this represents one-way attenuation of 7 to 12 dB, and the signal level reflected back from the connector often exceeds the level reflected from the primary sensor. These problems make it difficult to apply the advantages of passive, reflective sensors.

7.3.4. Index Matching Gels.

Unless components are environmentally sealed, and will not be opened during normal maintenance activities, index matching gels should not be used. They are easily contaminated and difficult to remove if cleaning is necessary.

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CHAPTER 8. RADIATION EFFECTS.

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CHAPTER 8. RADIATION EFFECTS.

8.0. Radiation Effects.

In the recent years, the development of fiber optic technology has been accelerated mainly by the widespread use of the technology in the telecommunication industry. Fiber optics is an attractive technology for military applications because of its many advantages such as lightweight, small size, large bandwidth capacity, immunity to electromagnetic interference, and immunity to ground loop and cross talk effects.

Military systems operate in much more demanding environments, including nuclear radiation. Therefore, a thorough understanding of the nuclear radiation effects on fiber optic components is essential to the successful implementation of fiber optics into military systems. This assessment consolidates the vast amount of currently available data and provides a comprehensive summary to familiarize the readers with the problems of fiber optic technology in a nuclear radiation environment.

Due to the wide variety of components in the fiber optic technology, the following types of components will be addressed:

- o Transmitter - Discrete bipolar circuitry
- o Light Emitting Diode (LED) - AlGaAs [0.8-0.9 micron (um)], InGaAs and InGaAsP (1.06-1.3 um)
- o Laser diode - AlGaAs (0.8-1.3 um)
- o Optical fiber - Multimode (step and graded index), pure silica and doped silica core, polymer, silica or doped silica cladding
- o Photodiode - Silicon PIN (0.8-1.1 um), AlGaAs, AlGaSb, InGaAsP (0.7-1.6 um)
- o Receiver - Discrete bipolar circuitry

The discussions in this report include the following:

- o Summary of the nuclear environment and transient radiation effects (TRE)
- o Details of nuclear radiation effects and failure mechanism on each element of the fiber optic transmission system (FOTS) as obtained through currently available data and visits to Naval Research Laboratory, Harry Diamond Laboratories, Air Force Weapons Laboratory, Rome Air Development Center, Naval Ocean Systems Center, and Sandia National Laboratory

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- o Listings of the definition of failure criteria and the radiation hardness levels of each element of the FOTS
- o An assessment of fiber optics vulnerability to nuclear radiation based on the preceding information
- o A radiation design guideline formulated according to hardening techniques and approaches learned through technical discussions and literature
- o A Discussion of Radiation Effects Test Methods for Fiber

8.1. Background.

8.1.1. Nuclear Environment.

A nuclear weapon burst creates an environment which consists of blast wave, thermal, electromagnetic pulse (EMP), and nuclear radiation. Blast wave causes physical damage such as crushing and deforming. Thermal effects produce charring, flaming, melting, and vaporizing of materials. EMP induces current on or in a system, which causes upset or damage to the components of the system. Nuclear radiation induces ionization, which causes device or component failures. The approximate pulse shape and time history of a nuclear weapon burst are shown in Figure 8-1.

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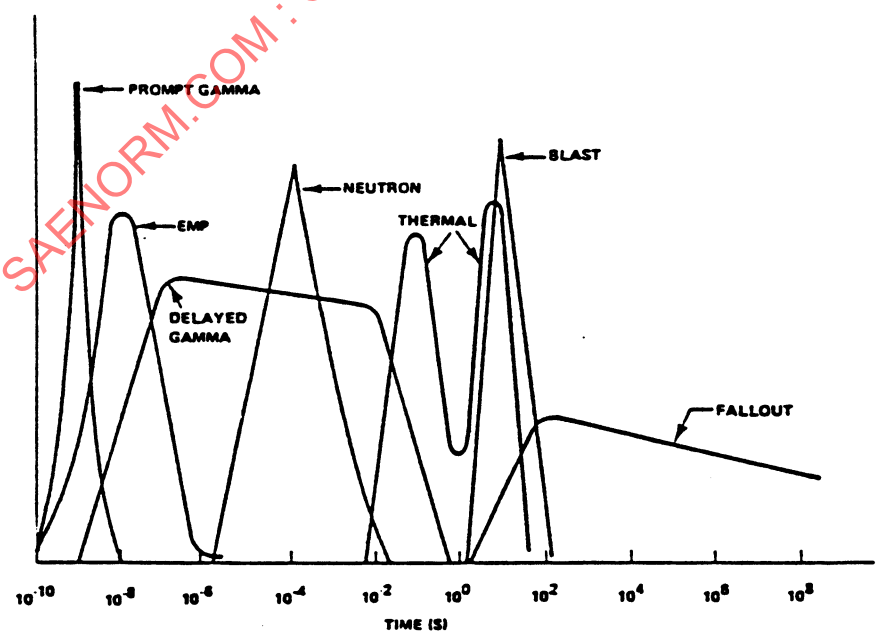

Figure 8-1. Approximate pulse shape and radiation time history of a nuclear weapon burst. [40]

The components of a burst do not arrive simultaneously at a system. The arrival time and the duration of the various components are quite different. Prompt gamma and EMP travel at the speed of light. Neutrons have a finite travel time, depending on their individual energy. Thermal radiation as emitted from the fireball also travels at the speed of light. Blast wave interacts with the air molecules and arrives at a later time with some finite speed related to the speed of sound in air. Table 8-1. lists the arrival time and the pulse duration of the various components of a 40 kiloton, near-surface burst at a range of 1300 meters.

8.1.2. Transient Radiation Effects.

The effects produced by the gamma rays and neutrons of the nuclear radiation component of the weapon burst are commonly referred to as "Transient Radiation Effects (TRE)." TRE occurs in electronic systems, particularly in semiconductor and optical material which can be permanent and/or transient. TRE consists of total dose, dose rate, and neutron effects.

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Table 8-1. Pulses produced at 1300 m from 40 kiloton weapon burst (near surface). [41]

Type of Pulse	Time of Arrival of Pulse Maximum (S)	Pulsewidth (S)
Prompt Gamma	~5 x 10 exp-6	~3 x 10 exp-8
Electromagnetic	~5 x 10 exp-6	~1 x 10 exp-3
Neutron and delayed Gamma radiation	~5 x 10 exp-5	~1 x 10 exp-3 (50% -) ~10 (90% of total dose)
Thermal	~0.2	~2
Blast	2	1

Total dose effects are due to the buildup of trapped charges within the insulating layers on a semiconductor device. These trapped charges cause an increase in leakage current in bipolar devices. Both gamma rays and neutrons interact with materials and contribute to total ionizing dose effects. Dose rate effects are due to the creation of excess electron-hole pairs as a result of the interaction between the prompt gamma pulse and the material. These electron-hole pairs generate photocurrent under bias, which in turn causes component latchup and/or burnout.

Neutron effects are the result of the collision between the neutron particle and an atom. The collision displaces atom from its normal lattice site and creates defects in the material. This displacement damage decreases the minority-carrier lifetime and increases the material resistivity.

A brief definition and the units of measurement for both types of radiation are given below:

- o Gamma rays are high energy photons, with a wavelength of 0.5 to 0.005 angstrom, and an energy range that overlaps that of X-rays. They are, in effect, electromagnetic waves which have no electrical charge and, therefore, can penetrate the nucleus of an atom because the electric field about the atom exerts no influence on the ray.

- o Total dose is expressed in rad (radiation absorbed dose). Dose rate is expressed in rad/s. Rad and rad/s are the units of the absorbed dose and absorbed dose rate of any material. One rad is equal to an absorbed energy of 100 ergs per gram of material.

- o Neutrons have no electrical charge. The mass of a neutron is 1.67 x 10 exp-4 gram, which is approximately 1836 times that of an electron. Neutrons can penetrate several millimeters of lead since there is no electrical interaction with the electrons and nuclei in matter. However, neutrons can do considerable damage to the nucleus of an atom, including the splitting of nuclei to cause fission and a huge release of energy.

- o Neutron radiation is expressed in fluence (neutrons/cm exp2). Neutrons/cm exp2 is the unit of integrated neutron flux density or the total number of neutrons traversing an area in a given time.

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8.1.3. FOTS - TRE and Failure Mechanism.

TRE are detrimental to the performance and operation of the FOTS (fiber optic transmission system). In general, the effects can be either permanent or transient. Permanent damages are caused by total ionizing dose or neutron radiation, while transient damages are caused by ionizing dose rate radiation. TRE and failure mechanism for each element of the FOTS are identified discussed in the following sections. The most dominant effects on the elements of a FOTS are summarized in Table 8-2.

8.2. Transmitter and Receiver.

Both the transmitter and the receiver are discrete transistor amplifiers, even though their basic functions are different. The transmitter is basically a current source. Its function is to convert input voltage into output current in order to drive the light source.

The receiver amplifies the low level current from the photodiode and generates an output signal which contains all of the original information being transmitted within a given tolerance. Since the transistor is the only active component in the circuit, any changes in the transistor will be reflected in the operation of the transmitter and receiver.

Table 8-2. Summary of the Most Dominant Nuclear Radiation Effects on Elements of the Fiber Optic System.

Elements of Fiber Optic System	Nuclear Environment		
	Total Dose	Dose Rate	Neutron
Transmitter	Circuit noise increases	Circuit upset/ burnout	Circuit gain decreases
LED	No significant effect	No significant effect	Light output decreases
Laser Diode	No significant effect	No significant effect	Quantum effic. decreases, Thresh. cur. increases
Optical fiber	Attenuation increases	Attenuation increases, luminescence	No significant effect
Photodiode	Leakage cur. increases, responsivity decreases	Induced photocurrent	Leakage cur. increases
Receiver	Circuit noise increases, sensitivty decreases	Circuit upset/ burnout	Circuit gain decreases

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The two most noticeable radiation-induced effects in transistors are current gain degradation and photocurrent generation. Both total ionizing dose and neutron radiation cause current gain degradation. The buildup of space charge within the oxide or insulating layers in the transistor is the major contributor of current gain degradation due to total dose radiation. Reduction of minority carrier lifetime is the damage mechanism for current gain degradation in a transistor under neutron radiation.

The resultant effects due to gain degradation in the transistor circuit is insufficient current to turn on or modulate the light source, and in the receiver circuit, it is the loss of information due to distortion in the output signal. Leakage current also increases due to total dose in a transistor, but the effect is not as significant.

The Transient ionizing dose creates free electron-hole pairs which can result in photocurrent crossing the reverse biased junction of the transistor. Photocurrent causes the transmitter and the receiver to either upset, latchup or burn out.

8.3. Light Source.

The semiconductors used as light-emitters for FOTS are LEDs and laser diodes. They convert electrical signals into optical signals for transmission in the optical fiber cable. A LED emits light due to a radiative recombination process. Excess carriers injected across a p-n junction recombine with their opposite charge when an external voltage is applied. During normal operation, the majority of the recombinations are radiative.

A laser diode operates by a spontaneous emission of multiple photons of the same wavelength. This emission requires a population inversion in the laser diode. With population inversion, more electrons reside metastably in a high energy level than in a low energy level, to which they migrate.

LEDs in general have a lower optical power output, a wider spectral width, and a slower rise time than a laser diode. Their advantages are less complicated transmitter circuitry, lower cost, and higher reliability. Laser diodes are more suitable for long-distance and wide bandwidth applications because of high speed, high power, and narrow spectral width. Table 8-3. compares LED and laser diode characteristics.

The major concern on radiation damage in LEDs and laser diodes is neutron fluence. Total ionizing radiation dose and dose rate effects are insignificant in comparison.

Neutron irradiation favors the increase of nonradiative recombination and reduces the light output of the LEDs and laser diodes. The failure mechanism in these devices is the decrease in minority carrier concentration. The reduction in the concentration of minority carriers due to neutron-induced defects leads to an increase in the nonradiative recombination process. When this process predominates, radiative recombination decreases and light output goes down.

A more serious effect in laser diodes is the increase in threshold current. Threshold current may move beyond the maximum operating current and terminate laser action. The shift in threshold current is interpreted as a decrease in quantum efficiency brought on by the reduction of radiative recombination. Quantum efficiency is defined as the ratio between the optical power out to the electrical power in.

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Table 8-3. A Comparison of LED and Laser Diode Characteristics. [42]

Characteristic	LED	Laser Diode
Optical power output (mW)	0.5-1.5	3-10
Spectral range (nm)	25-40	2-5
Rise time (ns)	3-20	1-2
Bias current range (mA)	50-150	100-500
Coupling efficiency	Low to Fair	High

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8.3.1. Temperature Effect.

LEDs and laser diodes react differently to temperature variation. Degradation in light output of LEDs is greater at higher temperature (87 C) than at lower temperature (-55 C), but it is not significant. One could conclude that temperature has no appreciable effect on the neutron radiation response of LEDs.

Neutron damage becomes more severe in laser diodes as temperature increases. More current is required to generate the same amount of light output as a result of current threshold shift due to the reduction in quantum efficiency. Figure 8-2. shows the temperature dependence of the threshold current before and after neutron irradiation of the least-radiation-sensitive AlGaAs CW laser.

8.3.2. Long Wavelength LEDs.

Up to now, the discussion has been concentrated on AlGaAs LED operation at 0.82 um. LEDs operating at long wavelengths (>1.0um) are being employed in state-of-the-art FOTS because of inherent lower attenuation characteristics and less sensitive radiation response of fibers. In GaAs and InGaAsP devices operating at 1.06 and 1.3 um exhibit equal or less sensitivity to nuclear radiation than the shorter wavelength devices.

8.4. Optical Fiber.

Optical fiber is basically a dielectric transmission medium for light energy which consists of a cylindrical core with a high index of refraction and a concentric cladding with a lower index of refraction. Light propagates by internal reflection at the core-cladding interface. The most common optical fibers are either pure silica (SiO) core or doped silica core; cladded with pure silica, doped silica, or polymer. Present generation optical fibers are fabricated with silica and polymers which permit transmission of light signals for a long distance with very little loss. However, exposure to ionizing radiation produces defects such as broken and dangling bonds, which function as charge

trapping sites in the glass matrix. Lower energy transitions to and from these defect energy levels result in optical attenuation and emission in the irradiated fibers. The loss of signal transmission can be either permanent or temporary. The unit of measurement for induced loss is dB/Km.

Total ionizing dose radiation produces permanent attenuation in optical fibers, even at very low dose [<10 rad(Si)]. In general, all fibers exhibit a nearly linear growth versus dose response characteristic for total dose up to a few kilorads. But for higher doses, a saturation effect was observed for pure silica core fibers. Figure 8-3. shows the induced attenuation growth curves for a variety of fibers at 0.82 mm. Some of the curves are nearly linear while others show saturation effects. (In the curves of Figure 8-3. for doses less than 100 rad the dose rate was 25 rad/min and for doses greater than 100 rad the dose rate was 1.8 X 10 exp4 rad/min. In addition, it should be noted that some of the curves are nearly linear while others show saturation effects.)

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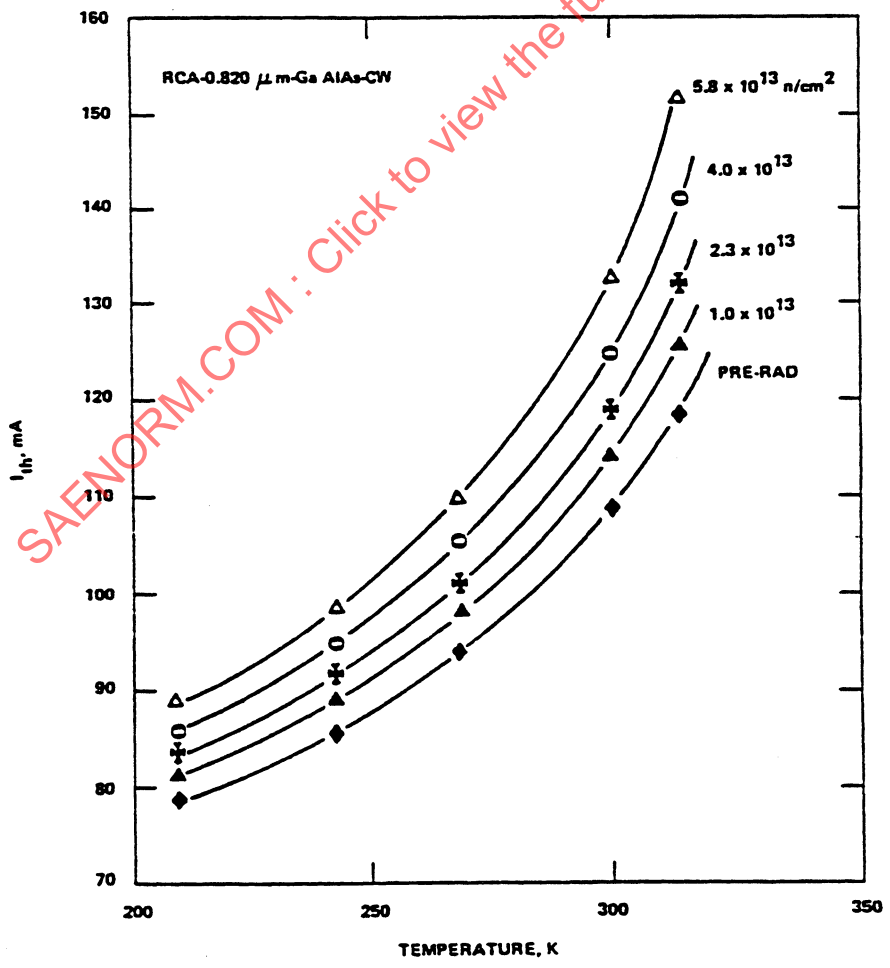

Figure 8-2. Neutron Radiation Response of Current Threshold as a Function of Temperature of an AlGaAs CW Laser Diode. [43]

Transient ionizing dose radiation produces luminescence and attenuation. Both effects are undesirable because luminescence generates false signals, while attenuation interrupts intended signal transmission. Figure 8-4. shows a typical optical fiber response to transient ionizing radiation.

Luminescence occurs during the ionizing pulse and decays rapidly. Its emission spectrum lies between 0.45 to 0.65 mm. This band of emissions should not cause a problem since most systems operate at wavelengths of 0.82 mm or greater. A band filter could be used to minimize the emission light output if more protection is required.

The induced attenuation due to transient radiation may far exceed the attenuation levels produced by an equivalent dose due to total radiation dose It peaks right at the conclusion from the transient ionizing pulse and starts to decay to some permanent value with time. The recovery process to the residual permanent value is slow, usually in terms of seconds. The effect of transient attenuation on a system will be detrimental if the system is required to operate during or a short time after the transient ionizing pulse. Neutron radiation has very little effect on the transmission properties of the optical fiber.

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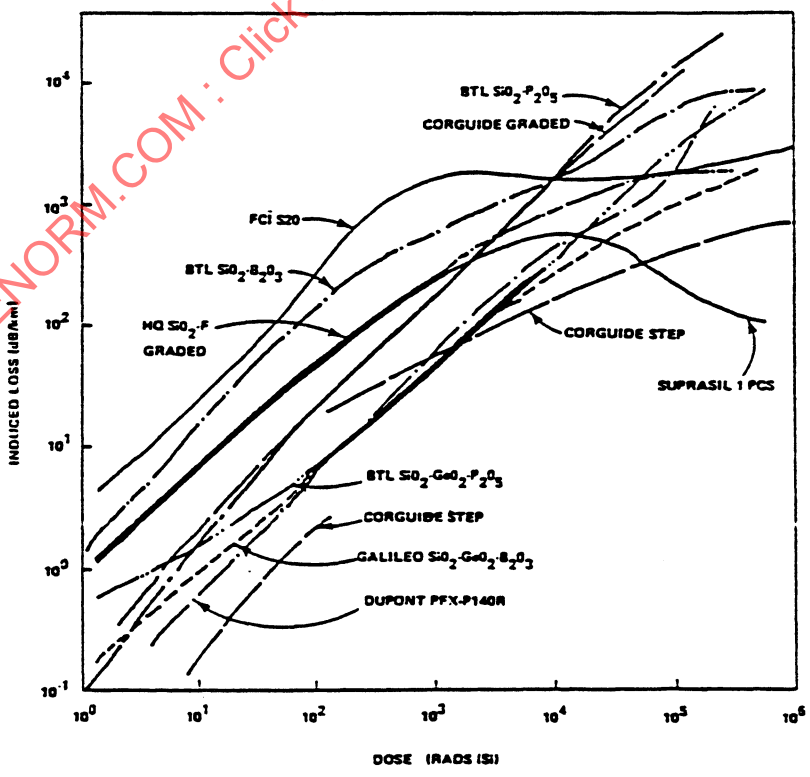

Figure 8-3. Co-60 Induced-Attenuation Growth Curves for a Variety of Fibers at .820 mm. [44]

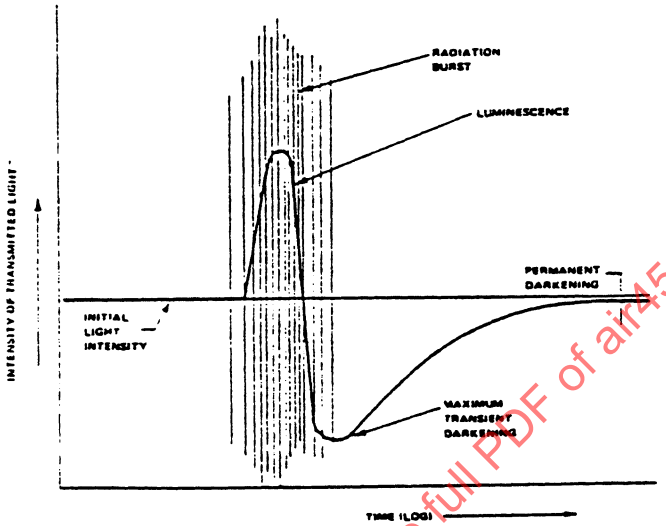

Figure 8-4. Optical Fiber Response to Transient Ionizing Radiation. [45]

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8.4.1. Factors Affecting Radiation Response.

Radiation characteristics of optical fibers are affected by several factors. These factors include fiber composition, OH content, wavelength of operation, temperature and photobleaching.

8.4.1.1. Fiber Composition.

During the manufacturing of optical fibers, various materials can be added to the basic silica to change the refraction index for more efficient waveguide action. Germanium (Ge) and phosphorus (P) are the most commonly used index lowering dopants. The introduction of index modifying dopants into silica may strongly modify bonding strengths and configuration and can also strongly affect production defects and the charge trapping process. As the failure mechanism changes, so does the radiation response of the optical fiber.

Ge dopant increases both the permanent and transient radiation responses of the optical fiber. Permanent attenuation is generally lower at low radiation doses but often higher at high radiation doses as compared to the pure silica core fiber. Pure silica core fibers saturate at high doses but Ge-doped fibers do not.

A very strong transient response is observed in Ge-doped fibers. An attenuation increase of 5 times was measured at 10 ms after irradiation. Figures 8-5. and 8-6. show the transient response of pure silica core fibers and Ge-doped silica fibers.

The addition of Phosphorus (P) to pure silica core fibers changes both the permanent and transient attenuation dramatically. Permanent attenuation increases by a factor of 100 at 0.82 mm, as shown in Figure 8-7. Transient attenuation is greatly reduced due to the addition of P, but residual attenuation increases due to minimal recovery after irradiation. Figure 8-8. shows the effect of P on fiber transient response as a function of time.

Another important aspect of the Phosphorus (P) dopant is the stabilization of fiber radiation response as a function of temperature. The temperature effect will be detailed later in this section. Boron (B) dopant has been used as an index lowering modifier in the core of the fiber. Measurement shows B has a detrimental effect on both the permanent and transient radiation responses of the fiber. B doped fibers should not be used in a radiation environment. Figures 8-6., 8-7., and 8-8. illustrate this effect.

In Figure 8-5. the radiation pulse was a 3 ns wide electron pulse from a Febetron 706.

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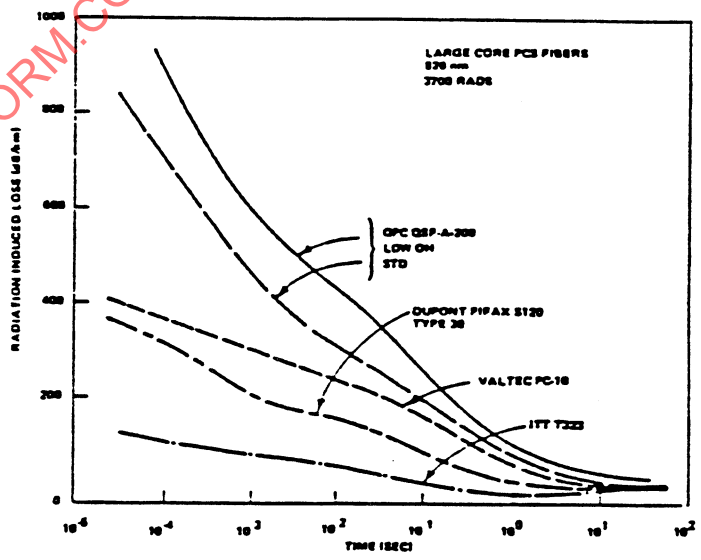

Figure 8-5. Recovery of Transient Attenuation at Room Temperature and 0.82 mm in a Variety of PCS Fibers All With Large Diameter Cres. [46]

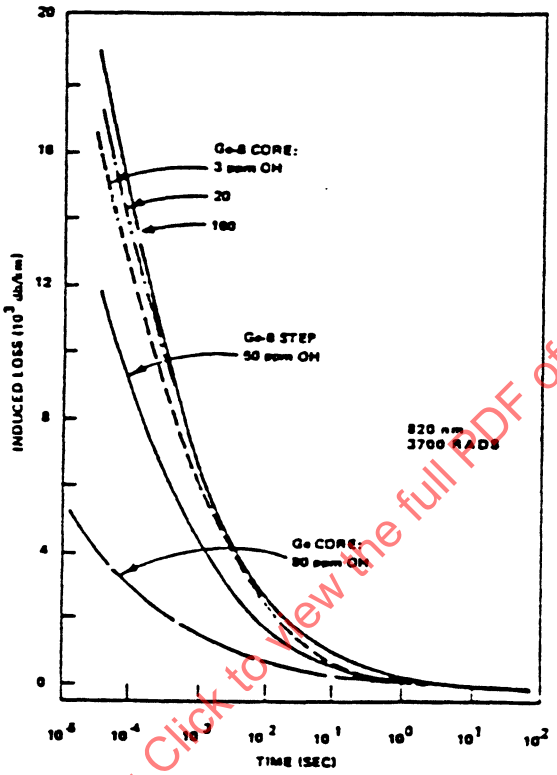

Figure 8-6. Recovery of Room Temperature Transient Attenuation at 0.82 mm Induced in Ge and B Doped Core Fibers by a 3 ns Wide, 3.7 Krad Electron Pulse. [47]

It should be noted that in Figure 8-6. the OH content does not significantly influence the attenuation.

Flourine (F) is used mainly in the cladding material of the fiber to lower the refraction index. Doping the cladding material usually does not affect radiation response. A well controlled fabrication process will ensure the purity and doping concentration in the core and in the cladding of the fiber.

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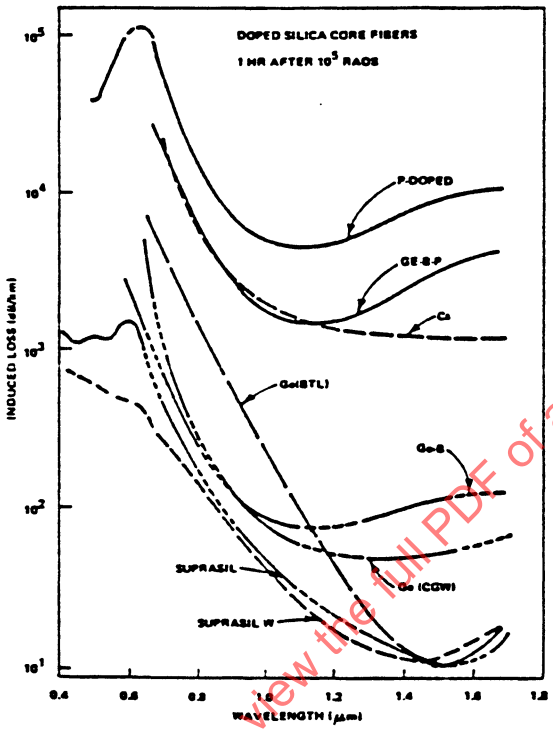

Figure 8-7. Induced Attenuation Spectra for a Variety of Pure Silica Core and Doped Silica Core Fibers at Room Temperature 1 Hour After a Co-60 Irradiation of 10 rads. [48]

Figure 8-7. shows that both B and P doping strongly increase the IR attenuation.

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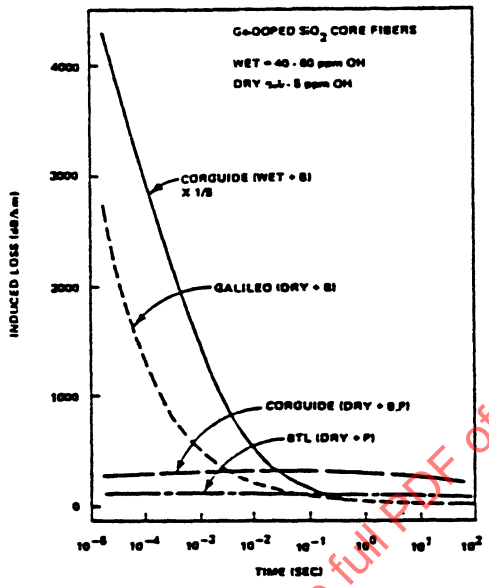

Figure 8-8. Effect of P and B on Transient Radiation Response of Ge-Doped Fibers. [ibid Figure 8-3.]

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8.4.1.2. OH Concentration.

OH concentration affects the radiation response of pure silica core optical fibers. Higher OH content reduces radiation sensitivity, enhances saturation effect at high dose, and exhibits quicker recovery after transient radiation.

Radiation response measurements of optical fibers operating at long wavelengths such as 1.3 mm show substantial increase in radiation hardness. Both permanent and transient radiation induced attenuations at 1.3 mm are generally lower by a factor of 5 to 10 as compared to 0.82mm.

Also, less attenuation is observed in high OH fibers than in low OH fibers over the temperature range of -50 C to 70 C. High OH content is defined to be greater than 1000 ppm while low OH content is less than 10 ppm. High OH fibers have greater intrinsic attenuation than low OH fibers. Therefore, one must compromise between radiation sensitivity and intrinsic attenuation. No significant radiation effect due to OH concentration is observed in doped silica fibers.

Figure 8-9. shows the permanent radiation induced attenuation of Ge doped silica fibers at 1.3 mm. A comparison can be made with data shown in Figure 8-2., which is measured at 0.82 mm. Figure 8-10. shows the transient attenuation of some of the fibers in Figure 8-9. at 1.3 mm. State-of-the-art multimode fibers have intrinsic loss approaching 1 dB/km at 1.3 mm and between 4 to 10 dB/km at 0.82 mm.

Radiation induced attenuation and the rate of recovery after irradiation of an optical fiber exhibit a strong dependency on temperature. The lowest temperature of interest represents the worst-case situation, both with respect to the magnitude of the induced loss and rate of recovery.

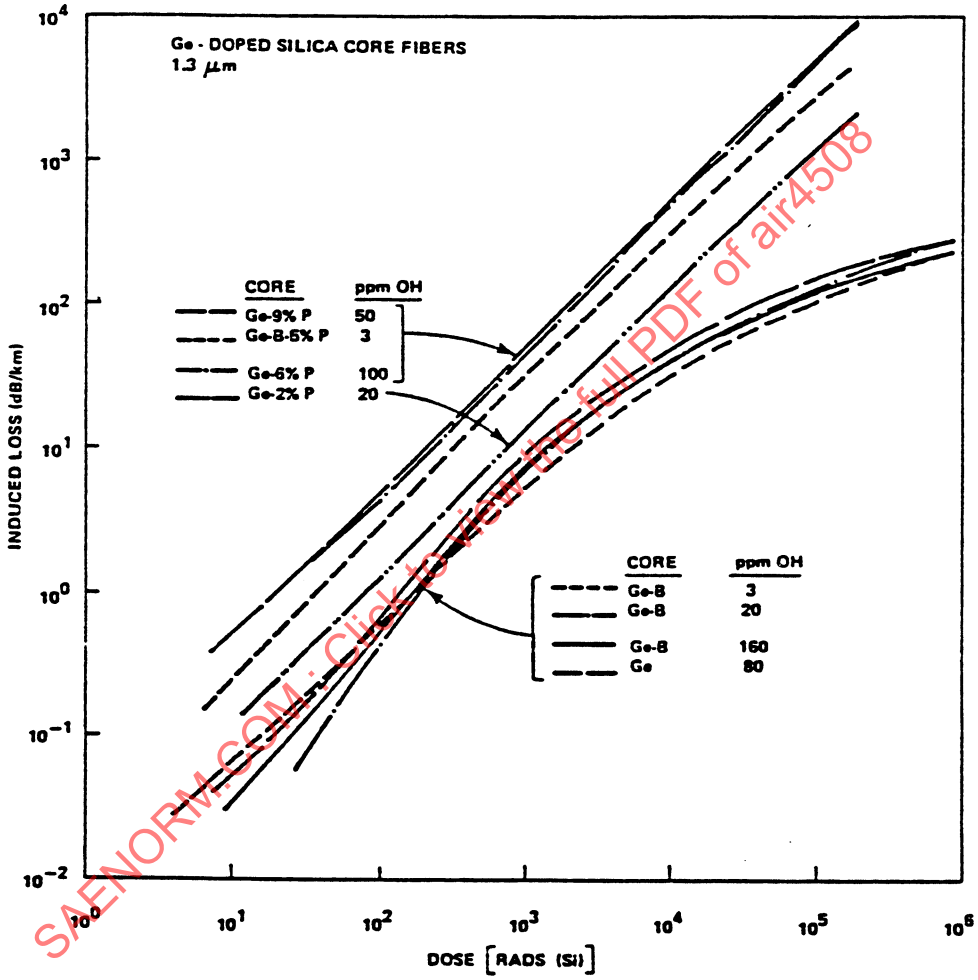

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Figure 8-9. The Radiation-Induce Attenuation of Ge-Doped Silica Core Optical Fiber Waveguides at 1.3 mm Measured at Room Temperature During Steady-State Irradiation. (Dose Rate = 1.8 x 104 rad/min). [ibid Figure 8-7.]

Figure 8-10. shows some typical data of a doped silica fiber over a temperature range of -77 to 100°C. The increase in attenuation at low temperature is approximately 5 to 15 times that of the room temperature response.

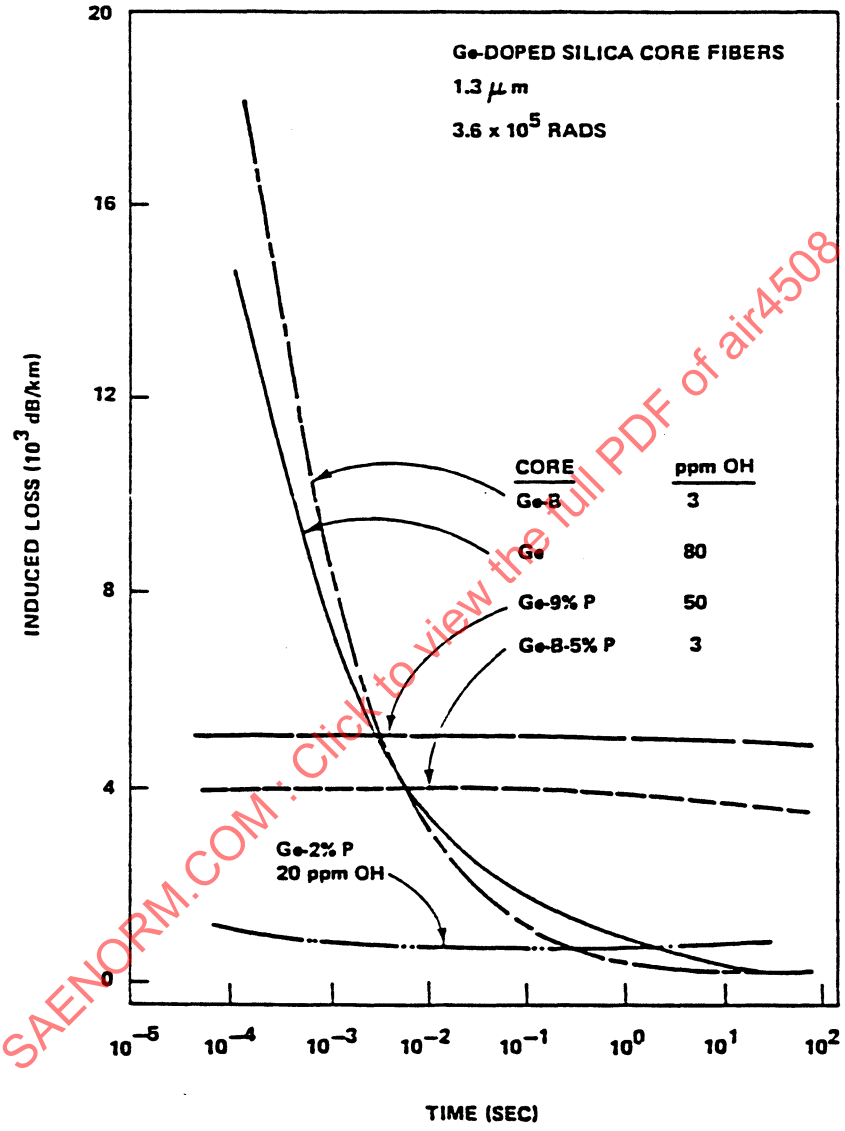

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Figure 8-10. Recovery of the Radiation-Induced Attenuation of Ge Doped Silica Core Waveguides at 1.3 mm Following a 3 ns, 0.5 MeV Pulsed Electron Irradiation of 3.6 X 10 exp5 rads. [Ibid Figure 8-7.]

Figure 8-12. shows the rate of recovery of the same fiber as in Figure 8-11. after 2000 rad(Si) of total dose radiation. The intrinsic loss of this fiber is 5 dB/km. Figure 8-11. indicated that even after 100 seconds, the induced attenuation at 22 C is still 3 or 4 times the intrinsic loss.

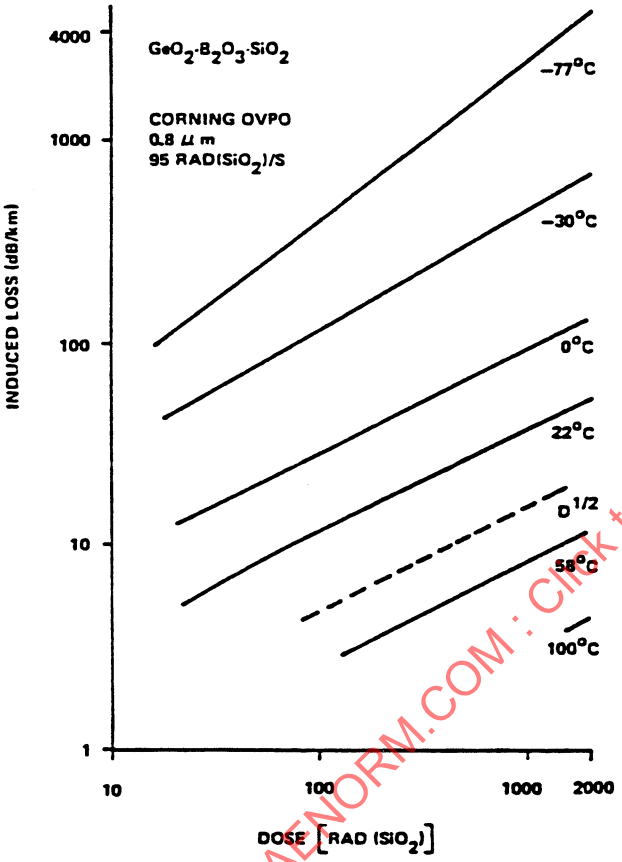

Figure 8-11. Induced loss at .8 mm in Corning GeO-Bo-SiO OVPO fiber from in-situ Co irradiation at various temperatures. The Co 60 dose rate was 95 rad (SiO)/s. [47]

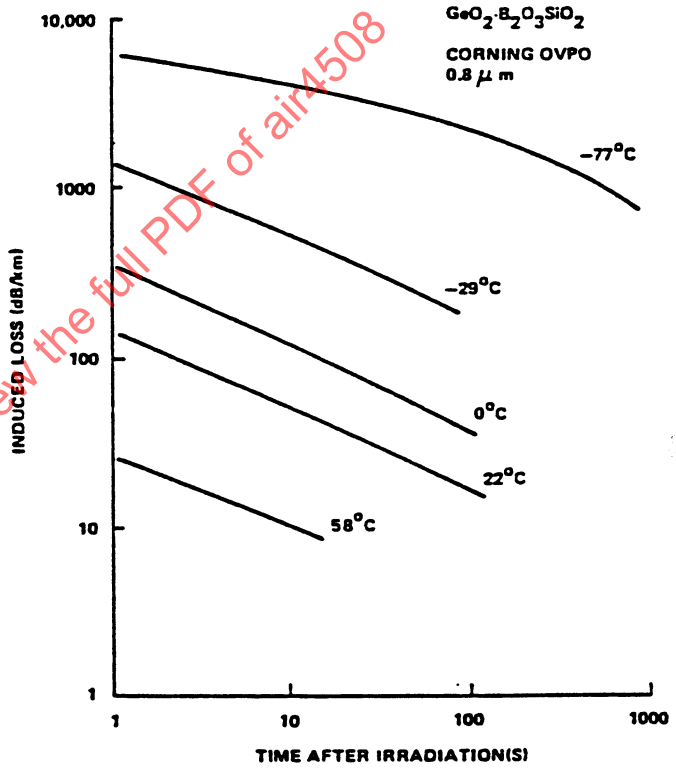

Figure 8-12. Induced loss at .8 mm in Corning GeO-Bo-SiO OVPO fiber plotted versus time after a 21 ns, 1900 rad(Si). 2 Mev X-ray pulse from a high intensity flash X-ray. [48]]

Polymer clad silica (PCS), pure silica core fibers are tested to be the most radiation resistant fiber at room temperature. But they exhibit significant transmission loss at low temperature due to the rapid increase in the cladding refraction index, which eventually approaches or equals the silica core refraction index. Under this condition, the waveguiding effect of the fiber degrades rapidly. Fortunately, glass-on-glass fibers such as fluorosilicate clad, pure silica core fiber are available which do not have this low temperature problem.

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With the introduction of P to Ge-doped fibers, the fiber response as a function of temperature is stabilized. The induced attenuation is actually less at low temperature, but is greater at high temperature as compared to other non P-containing fibers. Figure 8-13. shows the response of various fibers as a function of temperature.

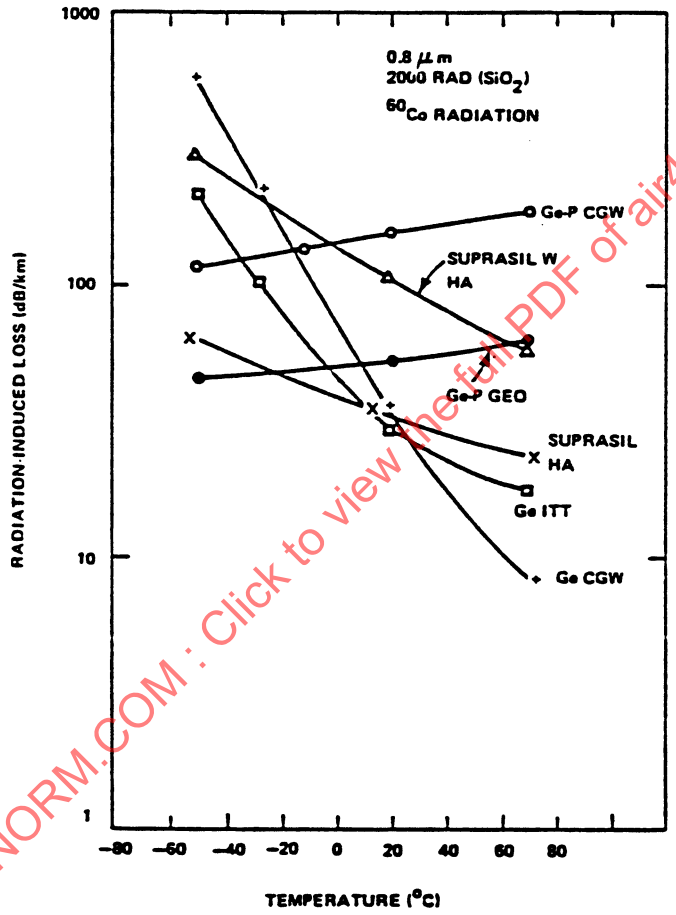

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Figure 8-13. Co-60 Induced Attenuation at 0.80 mm in a Variety of Fibers for a 2.0 Krad Irradiation at 95 rad/s. (Irradiations and Measurements were Performed as a Function of Temperature). [49]

Figure 8-13. shows the significant effect of P-doping on the temperature dependence.

In a continuing effort to find ways to minimize the radiation induced attenuation in fibers, a process called photobleaching was discovered. This process involves the application of a high intensity light to optical fiber after irradiation to expedite the rate of recovery. Photobleaching is very important at low temperature operation, since thermal recovery is very slow and radiation induced attenuation is at the worst.

The most sensitive optical fibers to photobleaching are pure silica core fiber with high OH content. Photobleaching removes nearly all the induced attenuation from high OH fibers. Significant effects are also observed in Ge-doped fibers. Figure 8-14. illustrates the effect of photobleaching for a PCS, a Ge-doped, and a P containing fiber. Figure 8-15. shows the photobleaching effect on super dry and standard OH PCS

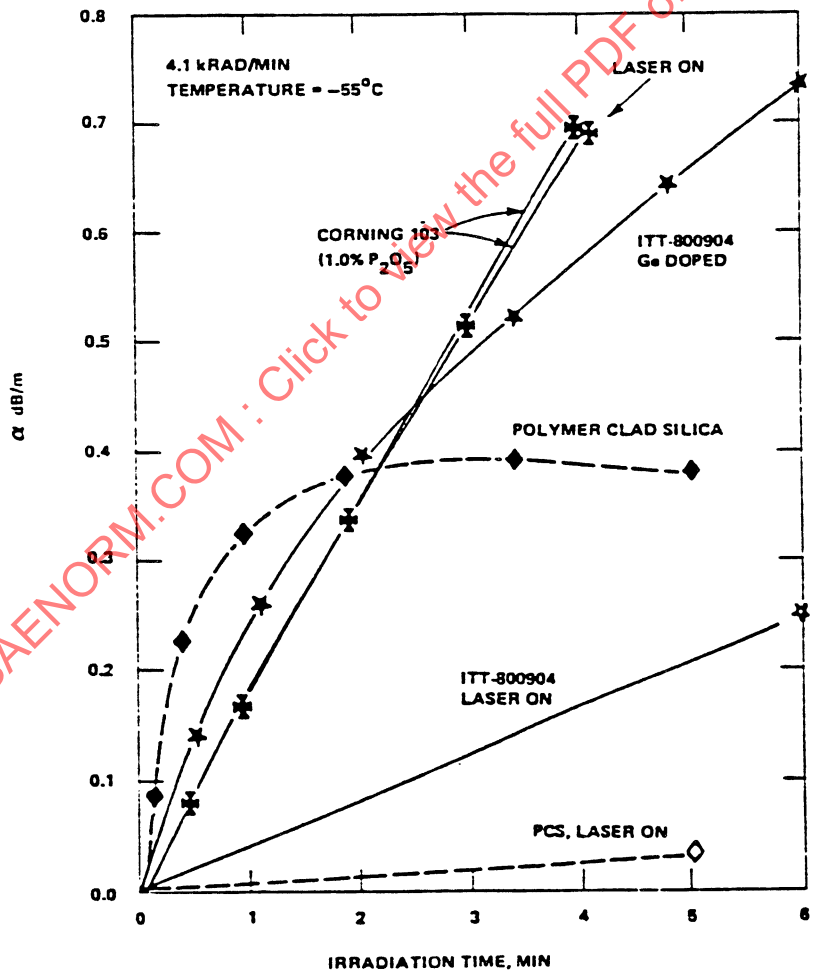

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Figure 8-14. Induced Attenuation at -55°C in Various Fibers With and Without the AlGaAs Laser Diode 0.82 mm Photobleaching Light Present During Co-60 Irradiation. [50]

fibers. Note in Figures 8-14. and 8-15. that the light source employed for photobleaching is operating at 0.82 mm. This suggests the same light source employed for photobleaching can also be used for signal transmission.

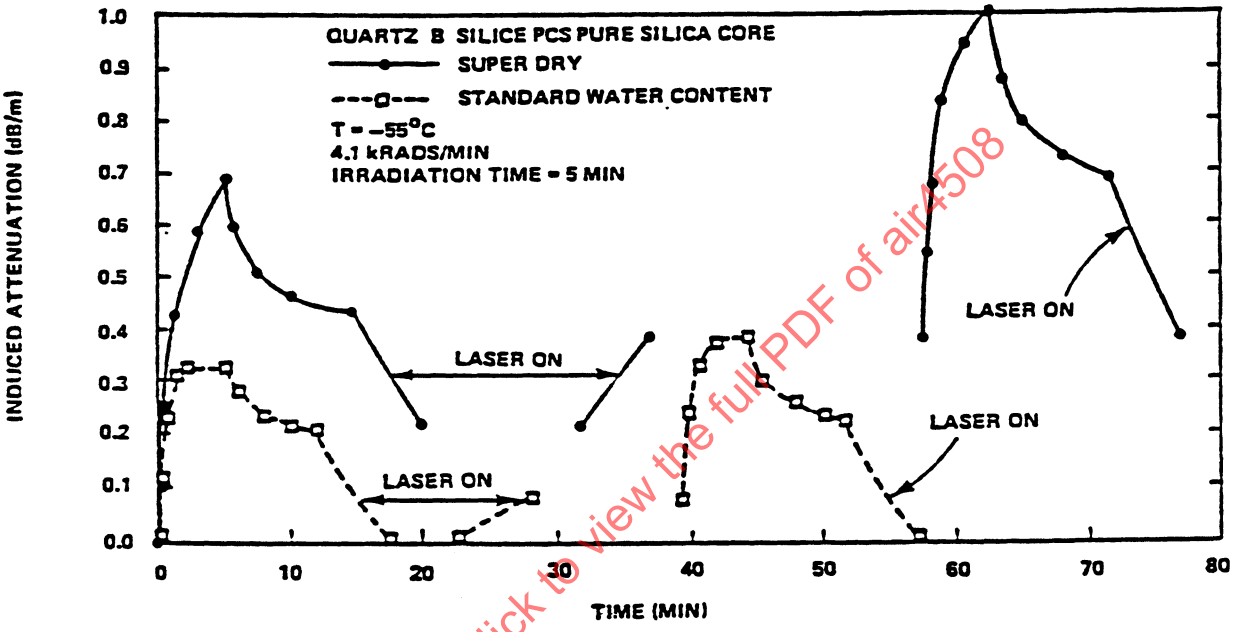

Figure 8-15. A Sequence of Irradiation and Photobleaching Steps at -55°C for Two PCS Fibers With Differing OH Content. Measurement and Bleaching Were Accomplished With 0.82 mm AlGaAs Laser Light. [51]

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8.4.1.3. Fabrication Process.

Doped silica fibers manufactured with the modified chemical vapor deposition (MCVD) process were the least sensitive to radiation. But this result is not conclusive because the sensitivity varies with different manufacturers.

8.4.1.4. Sheathing Technique.

The optical fiber sheathed by the loose tube technique were less sensitive to radiation than the conformal technique. No definitive explanation is available for this result.

8.4.1.5. Cladding Thickness.

Thinly clad PCS fibers were less radiation sensitive and recovered faster than more thickly clad fibers of identical composition. Very limited data is available on this subject.

8.4.1.6. Preirradiation.

The preirradiation of fibers seemed to increase fiber hardness only under special conditions and for selected fibers. The mechanism for this increase is not well understood.

8.5. Photodiode.

Photodiodes are solid-state devices designed to exhibit maximum sensitivity to electromagnetic radiation of a certain wavelength. They operate in a photoconductive mode with an external reverse bias. They detect light and convert it to electric current for subsequent processing by the receiver.

Silicon PIN photodiodes are most commonly used detectors in a FOTS. Silicon material had a low optical absorption coefficient and long minority carrier diffusion length. The low absorption coefficient necessitates a thick active region to provide sufficient optical sensitivity. The active region is generally tens to hundreds of microns thick.

Long minority carrier diffusion length improves optical efficiency by increasing the collection of excess minority carriers. These excess minority carriers also contribute to the noise level of the device. Most of the signal current created in the photodiode are generated in the space charge (depletion) region. Under reverse bias, the intrinsic region in a PIN structure becomes a fully depleted part of the space charge region and enhances current generation.

When operated at the recommended reverse bias voltage, the silicon PIN photodiodes are generally characterized by good optical responsivity, fast response time, and low dark current. Their wavelength range of operation is 0.3 to 1.1 mm.

Recent interest in long wavelength operation between 1.1 to 1.6 mm has prompted the development of photodiode made with III-V semiconductor materials. The term III-V describes semiconductor materials composed of elements from column III (Al, Ga, In) and column V (P, As, Sb) of the periodic table of elements. These materials have a relatively large optical absorption coefficient and short minority carrier diffusion length.

Photodiodes fabricated from these materials have a very thin active layer (1 mm thick), very small active volume, faster response than silicon devices with similar structure, and require lower bias than silicon devices. The drawback is the III-V devices have higher capacitance per unit area and less mature in the areas of materials and production fabrication processes.

Both total dose and neutron radiation cause a substantial increase in photodiode leakage current due to the radiation-induced recombinati centers in the depletion region and the surface of the photodiode. As

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the leakage current increases, the system's signal-to-noise ratio degrades, and the minimum detectable signal also increases. Another effect of total dose and neutron radiation is a moderate decrease in optical reponsivity due to the radiation-induced degradation of minority carrier lifetime.

Both optical radiation and transient ionizing radiation generate current in a photodiode. As a result, the photodiode is very sensitive to transient ionizing radiation, with response typically about 4 microamps per Krad/Sec. of dose rate. Exposure to ionizing radiation creates minority carriers throughout the active volume of the photodiode. Radiation-induced photocurrent results when the carriers are collected and detected. The magnitude of this induced photocurrent can overwhelm the nanoamps or microamps of desired signal current and disrupt normal operation.

A more severe problem is device burnout, which seriously interrupts system operation. This induced photocurrent is directly related to the volume of the device; the smaller the physical size of a device, the smaller the photocurrent. Since a silicon photodiode depends on a large active area for current generation, a smaller device provides less optical responsivity, which is undesirable.

8.5.1 III-V Compound Semiconductor Photodiode.

Photodiodes designed and fabricated by Sandia National Laboratory using III-V materials such as AlGaAs, AlGaSb, and InGaAsP exhibit much less sensitivity to the effects of nuclear radiation. The relatively large optical absorption coefficient of these materials permits the design of an efficient photodiode with a very thin active region and small physical size. The small size is made possible by using the liquid phase epitaxy processing technique for fabrication. The short minority diffusion length of these materials allows the collection of excess carriers generated in the depletion region or within close proximity to the depletion region for low-noise operation. These two features provide inherent immunity to nuclear radiation.

Sandia also developed a double heterojunction structure to further enhance the immunity of these devices. This structure consists of the top window layer, the active region, the barrier layer, and the substrate. The p-n junction is at the window layer/active region interface. Only photons with the wavelengths of interest are allowed to pass through to the active region and the substrate. Carriers generated in the active region are collected as current by the p-n junction by the barrier layer to minimize noise current generation.

This double heterostructure configuration creates built-in electric fields which assist the collection of optically generated carriers and prevent the collection of extraneous carriers from the substrate during exposure to ionizing radiation. The built-in electric field results from

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the energy bandgap mismatch between physical adjacent semiconductor layers. Figure 8-16. is a diagram of the double heterostructure photodiode developed by Sandia National Laboratory.

Besides being more radiation resistant than silicon photodiodes, these III-V photodiodes can have varying wavelengths of operation by changing the alloy composition (such as aluminum in an AlGaAs photodiode). The range of wavelength can be selected to cover 0.4mm to over 9.0 mm.

8.5.2 Temperature Effect.

Very little data is available on radiation responses of photodiodes with varying temperature. Preliminary indications are that the radiation response of photodiodes is affected at high temperatures. Testing of photodiodes is continuing to determine the extent temperature variations effect photodiodes.

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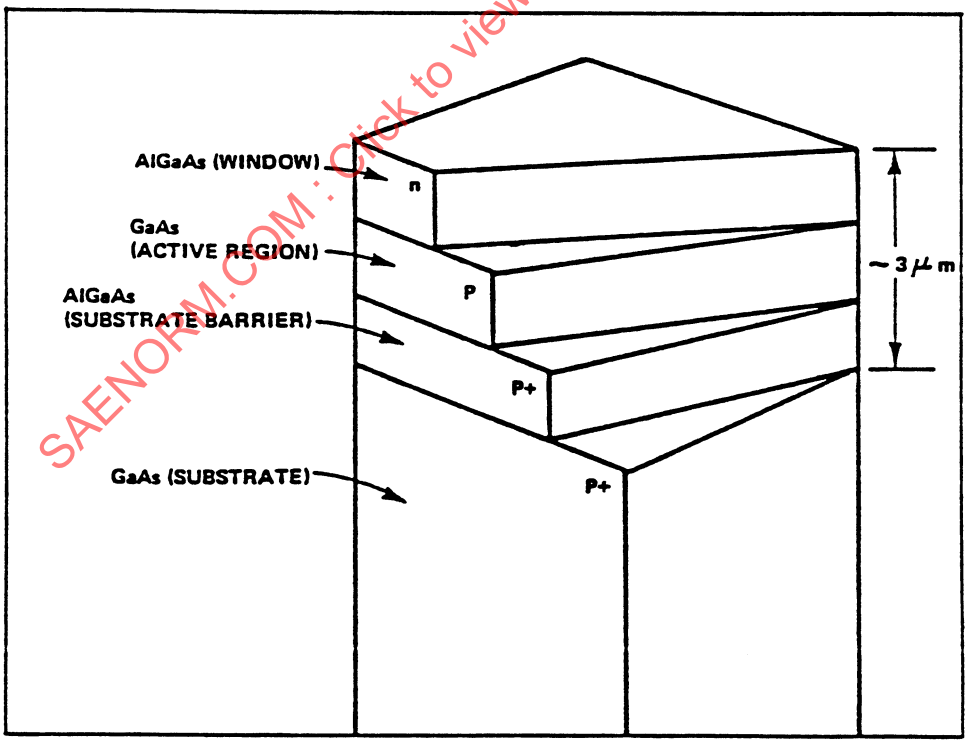

Figure 8-16. Sandia National Laboratory developed double heterostructure photodiode. [ibid Figure 8-4.]

8.6. FOTS - Failure Criteria and Hardness Level.

To establish the nuclear hardness levels for each element of the FOTS, one must determine the failure criteria. The failure criterion is defined as a given percentage change in the value of the parameter most sensitive to a given type of radiation. The nuclear hardness level is simply the threshold at which the failure parameter of the device moves beyond the failure criterion. Even though the failure criteria are highly design and application dependent, they define a boundary between a useful and a problem device.

8.6.1. Transmitter and Receiver.

Upset occurs when induced photocurrents change the operating point of an amplifier to the point that it no longer amplifies the desired optical signal acceptable. The dose rate at which this occurs is extremely sensitive to component selection and circuit design and can occur as low as a few hundred rads/Sec. The upset will only last for the duration of the prompt event, so the key consideration is that photo-current and amplified photocurrent be limited in amplitude by the design to a level below which permanent damage can be incurred by thermal heating effects.

Neutrons and ionizing dose can cause circuit damage by permanently increasing leakage currents or decreasing gain. A 50% decrease in circuit gain is defined as the failure criterion in the transmitter and receiver circuits. This corresponds to a hardness level of about10 exp12 neutrons/cm exp2 fluence and 10 exp5 to 10 exp6 rad(Si) total ionizing radiation dose. A 100% increase is defined as the failure criterion due to leakage current. The dose rate hardness level is about 10 exp4 to 10 exp6 rad(Si)/Sec. in an unhardened design and up to 10 exp10 rad(Si)/Sec. for a hardened design.

8.6.2. LED and Optical Fiber.

The failure criterion of an LED is defined to be a 50% decrease in light output. The neutron fluence level for short wavelength LEDs is 10 exp13 n/cm exp2 and for long wavelength LEDs is 10 exp14 n/cm exp2. The total dose hardness level is 10 exp6 rad(Si) (short wavelength) and 10 exp8 rad (Si) (long wavelength). No appreciable performance degradation is anticipated below these levels. The point where ionizing dose rate effects should be considered is 10 exp10 rad (Si)/s (short wavelength) and 10 exp10 to 10 exp11 rad (Si)/Sec. (long wavelength).

The failure criterion of a laser diode is defined to be a 50% decrease in quantum efficiency. The neutron fluence level is about 10 exp13 to 10 exp14 n/cm exp2. The hardness level is 10 exp6 rad(Si) due to ionizing total dose and 10 exp10 to 10 exp11 rad (Si)/Sec. due to ionizing dose rate.

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8.6.3. Optical Fiber.

No general failure criterion and hardness level can be established for the optical fiber because it is extremely application dependent. The radiation responses are both fiber composition and length dependent.

8.6.4. Photodiode.

The failure criterion of a photodiode is defined as the radiation required to cause a 100% increase in leakage current. The total dose and neutron hardness levels are approximately 10 exp6 rad (Si) and 10 exp13 n/cm exp2, respectively, for a silicon PIN photodiode. The hardness levels for the Sandia developed experimental photodiode are approximately 10 exp7 rad(Si) and 10 exp14 n/cm exp2. A 10 to 50% degradation in optical responsivity is also observed at the above levels for both types of devices.

No specific failure criterion can be defined for induced photocurrent since it is highly application dependent. High-level photocurrent causes long recovery and possible burnout, while low-level photocurrent causes transient upset. Device upset is expected at 10 exp4 rad (Si)/Sec. for silicon PIN photodiodes and 10 exp6 rad (Si)/Sec. for the Sandia experimental photodiodes.

Table 8-4. summarizes the failure criteria and Table 8-5. lists the nuclear hardness levels of the elements of the FOTS. Since no specific hardness level is determined for the optical fiber, the radiation responses of the most radiation resistant type of fiber are listed instead.

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Table 8-4. Summary of Failure Criteria for Elements of the Fiber Optic System.

Elements of Fiber Optic System	Failure Parameter or Condition	Percentage Change to Define Failure
Transmitter	Circuit current gain Output due to photocurrent	-50% +100%
LED	Output light intensity	-50%
Laser Diode	Quantum efficiency	-50%
Optical Fiber	Attenuation	Note 1.
Photodiode	Leakage current Photocurrent	+100% Note 2.
Receiver	Circuit current gain Output due to photocurrent	-50% +100%

Note 1: Increase in attenuation of optical fiber is composition and length dependant. Limit depends on margins designed in.
Note 2: Transient upset results at from low level. Long recovery and possible burnout occurs at high level.

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8.7. FOTS - Nuclear Vulnerability Assessment.

Based on the nuclear radiation effects, failure criteria and the hardness levels, a vulnerability assessment of the fiber optic technology to nuclear radiation has been made.

8.7.1. Optical Fiber.

The characteristics of the optical fiber present the greatest potential for problem when fiber optics is exposed to nuclear radiation because of the increase in attenuation and slow annealing in some fibers. One must analyze each case and consider all other factors before selecting a fiber. Some of the factors include the bandwidth, the wavelength of operation, the numerical aperture, the length of the link, the temperature range, the allowable downtime, the loss budget, including radiation effects, and the anticipated radiation environment.

Table 8-5. Summary of Nuclear Hardness Levels of Elements of Fiber Optic System and Radiation Responses of Optical Fiber.

Element of Fiber Optic System	Nuclear Hardness Level		
	Total Dose rads (Si)	Dose Rate rads (Si)/Sec	Neutrons
Transmitter	1 x 10 e5/e6	upset: 1 x 10 e4/e6	1 x 10 e12
Receiver		hardened: 1 x 10 e6/e8	
LED			
0.8 - 0.9 um	1 x 10 e6	1 x 10 e10	1 x 10 e13
1.06 - 1.3 um	1 x 10 e8	1 x 10 e10/e11	1 x 10 e14
Laser Diode	1 x 10 e6	1 x 10 e10/e11	1 x 10e13/e14
Photo Diode			
Silicon Pin 0.8 - 1.1 um	1 x 10 e6	1 x 10 e4	1 x 10 e13
AlGaAs * 0.7 - 1.6 um	1 x 10 e7	1 x 10 e6	1 x 10 e14

Optical Fiber			Recovery after 1 x 10 e12 rads (Si)/S dose rate	
	Total Dose rads (si)	Attenuation dB/Km	Time (S)	Attenuation dB/Km
pure silica	1 x 10 e2	23	1 x 10 e-5	120
polymer clad	1 x 10 e3	50	1 x 10 e-3	75
	1 x 10 e4	60	1 x 10 e-1	25
	1 x 10 e6	25	10	2

* Experimental device developed by Sandia National Laboratory.

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As a class, pure silica core fibers represent the most radiation-resistant optical fiber available today. In particular, polymer clad, pure silica core (PCS) fiber with high OH concentration exhibits a minimum transient attenuation under high dose rate conditions. This

fiber type also exhibits almost complete recovery following transient ionizing radiation. It also exhibits a minimum permanent degradation to total dose radiation and strong saturation effects after doses a few kilorads.

However, there are also some disadvantages in PCS fibers. These fibers have limited bandwidth due to their step index profile. Attaching connectors, coupling, and splicing is more difficult because of the smearing effect of the polymer cladding. In addition, PCS fibers lose waveguiding properties at low temperature because of the temperature dependency of the polymers index of refraction. Fortunately, glass-on-glass fibers such as fluorosilicate clad, pure silica core fiber are also available which exhibit radiation characteristics similar to PCS fibers without the low-temperature problem.

Figures 8-17. and 8-18. illustrate the radiation-induced attenuation and rate of recovery of PCS fibers from various manufacturers. Tables 8-6. and 8-7. summarize the results of Figures 8-17. and 8-18.

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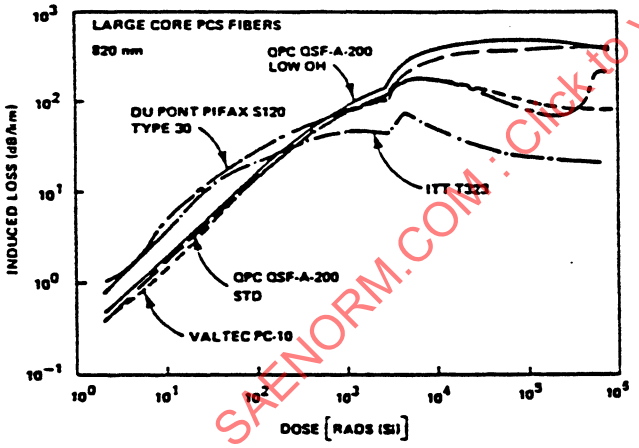

Figure 8-17. Induced optical loss measured during in-situ Co-60 gamma irradiation at an operational wavelength of 820 nm (.82 m) for the five selected large core PCS fibers. Measurements were conducted at room temperature. [ibid Figure 8-5.]

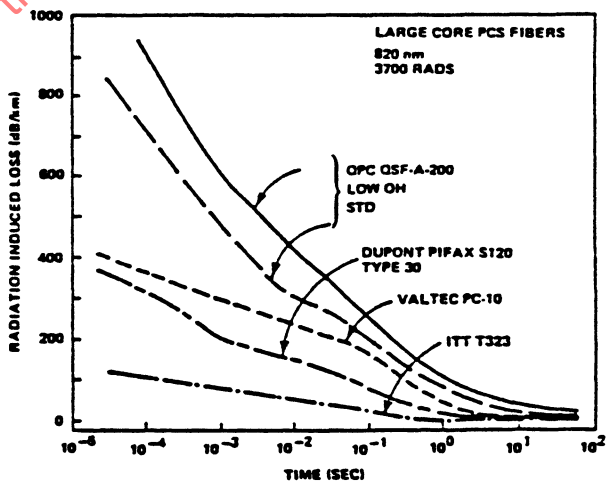

Figure 8-18. Induced optical loss measured at 820 nm (.82 mm) as a function of time following delivery of a 3 ns, 3700-rad(Si), 500 keV electron pulse from a Febetron 706 for 5 selected large core PCS fibers. (Measurements were conducted at Room Temp). [ibid Figure 8-5.]

Table 8-6. Summary of Total Dose Radiation-Induced Loss (dB/Km) of PCS Fibers. [ibid Figure 8-17.]

Fiber Manufacturer	For Lambda = 0.82 um Dose rads (Si)		
	100	1000	10000
Dupont (PIFAX S120-Type 30)	28	89	195
ITT (T-323)	23	50	60
Quartz Products (QSFA-200-STD)	15	77	300
Quartz Products (QSFA-200-Low OH)	16	90	400
Valtec (PC-10)	14	75	195
Galileo (TO-8)	250	2400	20000

Table 8-7. Summary of Transient Radiation-Induced Loss (dB/Km) of PCS Fibers. [ibid Figure 8-18.]

Fiber Manufacturer	For Lambda = 0.82 um Time after Pulse (S)		
	.001	.01	10
Dupont (PIFAX S120-Type 30)	210	90	5
ITT (T-323)	75	25	2
Quartz Products (QSFA-200-STD)	450	200	20
Quartz Products (QSFA-200-Low OH)	600	250	20
Valtec (PC-10)	280	170	15
Galileo (TO-8)	8400	7000	3350

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Generally speaking, the pure silica core fibers are less sensitive and most advantageous for use in the radiation environment. The saturation effects of pure silica core fibers make them attractive at high dose operation, even though their low dose loss is high. For low dose, a high dose rate environment with relatively long allowable downtime (seconds), Ge-doped fibers may be preferable. Whereas in a high dose, low does rate environment with minimum downtime, a Ge-P-doped fiber should be considered. For the worst possible case where both total dose and dose rate are high and the downtime is minimal, pure silica core fibers are probably the best choice. Also, nearly all types of fiber will have better radiation response if long wavelength (1.3 mm) operation is possible.

Low temperature increases radiation-induced attenuation and rate of recovery by approximately 5 to 15 times. High temperature decreases radiation-induced attenuation by approximately half and accelerates the rate of recovery. Long wavelength operation (1.3 mm) also lowers radiation-induced attenuation by a factor of 5 to 10 over temperature.

8.7.2. Transmitter and Receiver.

Hardened transmitter and receiver designs which include sufficient design margin, current limiting and good engineering design practices would be acceptable in a radiation environment. Temperature is not a problem for the transmitter and receiver since it is part of the design requirements.

8.7.3. LED.

Present commercial devices such as AlGaAs LEDs in the 0.8 to 0.9mm range and InGaAs and InGaAsP LEDs in the 1.06 to 1.3 mm range are acceptable in a radiation environment. Temperature has no significant effect on the radiation response of LEDs. Long wavelength devices exhibit slightly better radiation hardness.

8.7.4. Laser Diode.

Present commercial devices such as AlGaAs LEDs in the 0.8 to 0.9 mm range and InGaAs and InGaAsP LEDs in the 1.06 to 1.3 mm range are acceptable in a radiation environment. High temperature causes lasing current threshold to increase, which may inhibit normal laser operation.

8.7.5. Photodiode.

Silicon PIN devices in the 0.8 to 1.1 mm range manufactured by liquid phase epitaxy process are acceptable in a radiation environment if current limiting and circumvention (power supply turned off) techniques are employed.

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Experimental devices developed by Sandia National Laboratory exhibit better radiation hardness than silicon PIN devices. These devices are fabricated with III-V materials such as AlGaAs, AlGaSb, and InAlGaP. They are not yet commercially available.

Currently, temperature effects on radiation response of photodiode are unavailable.

8.8. FOTS Radiation Design Guideline.

A radiation design guideline for TRE on FOTS was formulated according to hardening techniques and approaches learned through literature and technical discussions. It is presented in outline format to provide a readily available reference listing for FOTS radiation design:

- o Transmitter and receiver
  - Use transistors with f >100 MHz
  - Bias transistors to operate near the peak current gain (hfe)
  - Select transistors with smallest physical size
  - Provide current limiting
  - Design with sufficient margin to accommodate temperature effects, part variations, and radiation effects.

- o Optical fiber
  - Consider all constraints of a particular application before selecting a fiber:
  - System requirements
  - Environmental conditions.

- o LED
  - Select device with the following characteristics:
  - High radiance
  - High speed
  - Small junction area.

- o Laser diode
  - Select device with the following characteristics:
  - Low threshold current
  - High maximum allowable operating current
  - Minimal temperature variation in threshold current.

- o Photodiode
  - Select device with the following characteristics:
  - Thin active layer
  - Small active volume.

A survey was performed to determine the effects of nuclear radiation on and the radiation tolerance of fiber optic technology. The conclusion is that the optical fiber presents the most difficult problem due to a significant increase in attenuation and slow annealing after exposure nuclear radiation. As of now, there is not a single, particular fiber

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which will satisfy all operational requirements in a nuclear radiation environment. Each application must be analyzed separately by considering all of the factors which restrict the selection of a fiber.

The rest of the components of a FOTS such as transmitter, LED, laser diode, photodiode and receiver are either intrinsically hard or can be designed with hardening provisions to survive the anticipated nuclear radiation environment.

8.9. Radiation Effects Test Methods for Optical Fiber.

Total radiation sensitivity of optical fibers has been studied during the past few years and found to be one of the most significant design problems concerning fiber optic implementation. Depending on fiber composition and fabrication technique, significant optical losses can often be produced by rather low radiation doses which would have a degrading effect on long haul systems. Conversely, induced losses can be nearly insignificant in short-haul systems with low total dose requirements.

The effects of exposure from these high energy photons or particles on the physical properties of silica glass (the dominant optical fiber material) have to be considered, particularly its optical characteristics such as absorption, scattering, and index of refraction. Two principal interactions of nuclear radiation occurs within the glass matrix: (1) ionization of electrons, and (2) direct displacement of atoms by elastic scattering. Damage from these high energy photons depends upon the type of radiation, the total fluence or dose, the radiation flux or dose rate, environmental factors such as temperature, and of course glass composition. In glasses, the electrons and holes produced by the irradiation can subsequently be trapped at pre-existing flaws or dangling bonds in the glass matrix to produce a defect center. Pre-existing flaws arise because of the presence of both substitutional and interstitial impurities or dopants, the lack of stoichiometry in the glass matrix, multivalent cations present in the glass, and highly strained bonds; the latter item being of some interest for rapidly drawn optical waveguides. Ionizing radiation produces broken and dangling bonds which serve as charge trapping sites in the glass matrix. The introduction of foreign atoms into silica can strongly impact the defect center production and charge trapping processes, and pre-existing flaws and strains are common in glasses, making them more susceptible to radiation damage than their crystalline counterparts. (53)

Defects in silica glass typically possess ground state energy levels within the forbidden gap which results in the formation of both optical absorption and luminescence bands in the ultraviolet, visible, and near infrared spectral regions. In fact, radiation induced defect centers in transparent glasses and crystals have been traditionally referred to as "color centers" because of the strong absorption they can introduce. These defects are particularly of concern in the case of optical fibers since the optical path length may extend for many kilometers. A challenge to the research community is the correlation of the many

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defects present in irradiated silica and doped silica glasses and waveguides with the absorption spectra of color center bands. At any given wavelength, several different defect centers contribute to optical absorption.

The color centers produced within the silica matrix by ionizing radiation are not all permanent so that some recovery and annealing of absorption are observed in most materials at room temperature. Luminescence is normally observed only during and within a few microseconds following exposure. The maximum transient darkening will be a function of both radiation and test environmental conditions for any given fiber. The recovery process is strongly influenced by glass composition, residual impurities such as OH, internal stresses, ambient temperature, light level, and radiation history.

"In Situ" measurements are essential because of the dynamic and transient character of the damage process. Defects are being created and annihilated on a continuous basis as one irradiates a silica fiber. Since various defects generated in the glass may absorb in different spectral regions, the annealing process versus time is not spectrally uniform. High temperatures typically tend to accelerate the recovery process overall but strange temperature variations can occur in specific wavelength regions since defects may release electrons or holes which, in turn, are retrapped at another site. The lower temperatures are usually the worst case situation both in terms of peak transient darkening as well as rate of recovery. For complete characterization of fibers under radiation conditions, it is essential to have a variable temperature testing capability. It has also been discovered that the intensity of the light signal propagating down the fiber can dramatically impact the measured radiation induced loss. This phenomenon known as "photo-bleaching" appears to offer the opportunity to increase the radiation resistance of some optical data links, particularly at low temperatures were thermal assisted annealing is minimal. Finally, it should be noted that because the optical degradation process is governed by an ionizing process, the amount of damage (in this case optical loss) generated per "rad" is to first order approximation independent of radiation quality and type. Neutron testing of fibers has repeatedly demonstrated and confirmed this experimentally. (54)

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Luminescence during pulsed irradiation is indicated by a detectable light level increase in the fibers which exceeds the pre-irradiation value. For fiber optic data links operating in a pulsed irradiation environment, luminescence detected by broadband silicon photodetectors acts as a source of false signals if the wavelength of the emitted light falls into the photodetector region. Possible transient interference on the data communications may occur under this condition. Characteristics of the induced luminescence can be summarized as follows:

- o The intensity of luminescence is proportional to the instantaneous rate of dose deposition in the fiber.

- o Luminescence is caused primarily by Cerenkov radiation of electron energies greater than 200 keV.

- o Luminescence is observed only during the irradiation pulse. Long exponential decays have been observed for luminescence in certain glasses.

- o The intensity of luminescence is greater during electron irradiation then during x-ray excitation for the same dose. (X-rays must be converted into high-energy electrons by the Compton process, etc. in order to generate Cerenkov radiation.)

If researchers were to review past data to select their fiber optic components, they would be bombarded with a myriad of conflicting information and voids in the data. The Naval Research Laboratory (NRL) personnel have performed most of the radiation testing on optical fibers; they have the most reliable test procedure; and also have the most consistent set of data. Other government laboratories and industrial firms have also performed radiation tests on optical fibers on a limited scale, but most of these test results are not comparable to the NRL data. In fact, some facilities who have repeated the tests on the same product have recorded different findings. This problem is either a function of inconsistent test procedures or variations in the product development. However, it has been proved that in attempting to compare radiation test results from various laboratories, the test methods differ so much that no relationships in the data can be found. Table 8-8. lists test results from several laboratories who tested the same two products using their individual test methods. The tests were performed at room temperature to a total gamma dose of 3,000 rads (Si). The two products were step index fluorosilicate clad, pure fused silica core fibers drawn specifically for this research effort. In comparing the various test methods, many of the test parameters varied significantly. The operating wavelength varied between 800 and 850 nanometers, and the dose rate ranged from 75 rads (Si)/min. to 18,000 rads (Si)/min. Some of the test procedures did not include the recording of the optical power coupled into the fiber. The optical power coupled into the fiber ranged from 1 nanowatt to 5 microwatts from those facilities which did document their power readings. The lengths of the test samples also varied significantly from 6 meters to as long as 200 meters. A cobalt (Co60) sources was used in all these tests. Based on these findings, the researchers immediately decided to establish a test method and procedure which would allow more consistent results and provide for comparable test results among the labs. (55)

Three primary factors dictate the test methods and procedures for fiber optic components. Compatibility with electronic standards helps the design engineer to select his electronics and fiber optics with some degree of certainty that they will meet the same nuclear criteria. Defining the fiber optics test requirements to meet the systems needs will provide the necessary information to the systems engineer prior to accepting his system. Finally, given the above criteria, the test methods and procedures have to be developed to comply with the

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limitations of existing test facilities. This last factor may negate some of the desired requirements to comply with systems needs and to be compatible with electronic standards.

Two basic types of standards provide information about the radiation testing of electronic components. MIL-STD-883, Test Methods and Procedures for Micro-electronics, which identifies the Air Force as the cognizant agency, is approved for use by all departments and agencies of the Department of Defense. The American Society for Testing and Materials (ASTM) also publishes a number of national standards relating to radiation effects on electronics. MIL-STD-883 consists of five primary test categories which included environmental testing, mechanical testing, digital electrical tests, linear electrical tests, and test procedures. Of primary interest to this program are five environmental tests which require testing related to steady state total dose irradiation (method 1019.2), radiation induced latch up (method), dose rate threshold for upset (method 1021), dose response (method 1023), and neutron irradiation (method 1017.2). The ASTM documents basically support the MIL-STD-883 test methods by defining how to measure neutrons, gammas, and x-rays as well as determining their application for radiation hardness testing of electronics. (56)

Fiber optic components are tested in the same sources but seldom adhere to the same parameters as those test methods listed in MIL-STD-883. Consistent testing of optical fiber components with established guidelines similar to those in the microelectronics industry will assu the availability of qualified radiation hardened optical fiber components. Only through consistent test procedures can fiber optic components be qualified for incorporation into optical fiber systems.

In 1980, a fiber optic standards committee solicited ideas for the publication of a fiber specification to perform radiation testing. Two primary draft documents have evolved from this initial effort. The Defense Electronic Supply Center (DESC) established a fiber optic committee to work with the Electronic Industries Association (EIA) to produce Fiber Optic Test Procedure FOTP-49, also referenced as RS-455-49. FOTP-49 is a procedure to measure nuclear radiation effects in fiber optic components. This draft document addresses the test equipment, test sample, test procedure, and calculation methods.

In June 1984, the International Electrotechnical Committee (IEC) on Fiber Optics (#46E), published a different draft test procedure for "Nuclear Radiation Testing of Optical Fibers." This test procedure also addressed the test equipment (apparatus), test sample (specimen), test procedure, and calculations (results). It also gave further detail about the types of irradiation tests (i.e. continuous radiation versus pulse irradiation) and test conditions (i.e. photobleaching from optical power injection, and luminescence from flash x-ray). These draft standards either provide general elements of testing, which will vary results considerably, or provide specific elements of testing, which do not relate to operational system needs. Neither appear to meet the needs f qualifying optical fiber components for today's system needs.

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A comparison of losses induced at 850 nanometers in the most recent all glass, pure silica core optical fibers by "in situ" radiation exposures were made at five government research laboratories. Both the growth of the attenuation during irradiation and the recovery following an exposure of 3,000 rads (Si) were measured. A standard set of test conditions were specified for these tests and the measured total loss results from the various Laboratory's tests is summarized in Table 8-8.

It is obvious from the divergence of the results that even when every attempt is made to standardize procedures, obtaining consistent results is difficult.

Table 8-8. Induced Loss in Optical Fibers Tested at Room Temperature and at a Total Dose of 3,000 Rads (Si) 10/85 [14]

INDUCED LOSS (dB/Km)		
Laboratory	Vendor A's fiber	Vendor B's fiber
A	15	12
B	3	6
C	8	11
D	12	12
E	28	36

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CHAPTER 9. TERMS AND DEFINITIONS.

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CHAPTER 9. TERMS AND DEFINITIONS.

9.0. Terms and Definitions.

9.1. Fiber Optic Terms.

For all definitions of FIBER OPTIC terms, the recognized authority is:

NBS Handbook 140
Optical Waveguide Communications Glossary

This handbook is available from:

U.S. Department of Commerce
National Bureau of Standards
Washington D.C. 20234

9.2. MIL-STD-1773 Terms.

The following paragraphs give definitions of important terms in MIL-STD-1773.

1) Bit.

Contraction of binary digit: may be either zero or one. In information theory a binary digit is equal to one binary decision or the designation of one of two possible states of any thing used to store or convey information.

2) Bit Rate.

The number of bits transmitted per second.

3) Pulse Code Modulation (PCM).

The form of modulation in which the modulation signal is sampled, quantized and coded so that each element of information consists of different types or numbers of pulses and spaces.

4) Time Division Multiplex (TDM).

The transmission of information from several signal sources through one communication system with different signal samples staggered in time to form a composite pulse train.

5) Half Duplex.

Operation of a data transfer system in either direction over a single line, but not in both directions on that line at the same time.

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6) Word.

In this document, a word is a sequence of 16 Data bits, preceded by a synch code and followed by an odd parity bit. There are three types of words: Command, Status and Data.

7) Message.

A single message is the transmission of a Command word, Status word and Data words if they are specified. For the case of a remote terminal to remote terminal (RT to RT) transmission, the message shall include two Command words, two Status words and Data words.

8) Subsystem.

The device or functional unit receiving data transfer from the data bus.

9) Data Bus.

Whenever a data bus or bus is referred to in this document, it shall imply all hardware in the signal distribution network, including the harness assembly of fiber optic cables, access coupler(s), connectors, etc., required to provide a path between all terminals.

10) Terminal.

The electronic module necessary to interface the data bus with the subsystem and the subsystem with the data bus. Terminals may exist as separate line replaceable units (LRUs) or be contained within the elements of the subsystem.

11) Bus Controller (BC).

The terminal assigned the task of initiating information transfers on the bus.

12) Bus Monitor (BM).

The terminal assigned the task of receiving bus traffic and extracting selected information to be used at a later time.

13) Remote Terminal (RT).

All terminals not operating as the Bus Controller or as a Bus Monitor.

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14) Asynchronous Operation.

For the purposes of this handbook, asynchronous operation is the use of an independent clock source in each terminal for message transmission. Decoding is achieved in receiving terminals using clock information recovered from the Manchester coded message.

15) Dynamic Bus Control.

The operation of a data bus system in which designated terminals are offered control of the data bus.

16) Command/Response.

Operation of a data bus such that remote terminals receive and transmit data only when commanded to do so by the bus controller.

17) Redundant Data Bus.

The use of more than one data bus to provide more than one path between the subsystems (i.e., dual redundant bus, triple redundant bus, etc.).

18) Broadcast.

Operation of a data bus system such that information transmitted by the bus controller or a remote terminal is addressed to more than one the remote terminals connected to the data bus.

19) Mode Code.

A means by which the bus controller can communicate with the multiplex bus related hardware in order to assist in the management of information flow.

20) Access Coupler.

An access coupler is a device which distributes optical power among several ports. Star couplers and tee couplers are examples of access couplers.

21) Optical Signal Range (OSR).

Optical signal range is the ratio of a maximum optical signal power to a minimum optical signal power, expressed in deciBels. As a system specification, applied to an optical bus network, it describes the maximum range of signals that can be seen by a terminal's receiver over the operating conditions specified. Although OSR is expressed as a ratio, it is important that the maximum and/or minimum levels be specified as well.

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22) Mid-Bit Transition.

In MIL-STD-1773, this is the transition from one optical state (on or off) to the other that always occurs in the center of each bit period in the Manchester Biphase Level encoded data bit or synch symbol. This transition contains the clock timing information for the decoding process.

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CHAPTER 2.

A. Footnotes:

1/ Kevlar, Teflon, and Tefzel are all registered trademarks of E. I. DuPont DeNemours and Company.
2/ Kynar is a registered trademark of Penna. Corp.
3/ Halar is a registered trademark of Ausimont U.S.A. Inc.

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APPENDIX A.

MIL-STD-1773.

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A-1.0. Introduction.

In this appendix we discuss the differrences between MIL-STD-1773 and MIL-STD-1553B. For reference, a complete copy of MIL-STD-1773 is included in this appendix as Inclusion A-1.

A-2.0. Annotations to Paragraphs Added/Altered in MIL-STD-1773.

The paragraphs marked by an asterisk (*) in MIL-STD-1773 are added (or are altered from the corresponding paragraph in MIL-STD 1553) due to the differences in the two media implementations. The following paragraphs correspond to the same numbered paragraph in 1773 and present the rationale for the addition or modification.

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Body of the Standard.

1. SCOPE

1.1 SCOPE.

Mil-Std-1773 was written only as a guideline to the implementation of a 1553 bus in Fiber Optic media and only addresses issues related to this implementation. All protocol and performance issues not affected by the new media are carried forward without alteration in order to maintain backwards compatibility with 1553B terminal hardware.

1.3 PURPOSE.

This paragraph explains the difference in philosophy between the combined standard/general specification of MIL-STD-1553B and MIL-STD-1773. 1773 follows the proper form for a military standard which requires multi-level specifications, referencing the standard, to fully define an interoperable hardware implementation. The strict MIL Standard form was used so that choices made at the time of the writing of 1773 would not lock in the current technology and prevent the adoption of new technology that is evolving at a rapid pace.

2. REFERENCED DOCUMENTS

2.1 Issue of Document.

The MIL-STD-1553B reference to MIL-E-6051 in this paragraph is removed. MIL-E-6051 defines wiring and cable electromagnetic compatibility requirements that are not applicable to the non-susceptable optical media.

A reference to MIL-STD-1553B is added here because 1553 is the general guide line for all protocol and general performance requirements of 1773 and these will change as MIL-STD-1553 is modified.

3. DEFINITIONS

3.9 Data Bus.

This definition is changed to reflect the elements of a Fiber Optic implementation of the bus as opposed to a shielded twisted pair electrical implementation.

3.20 Access Coupler.

This definition is added to define optical bus couplers.

3.21 Optical Signal Range.

This definition is added to define a parameter that replaces signal voltage amplitude range parameter of MIL-STD-1553B.

3.22 Mid-Bit Transition.

This definition is added to reflect the change from bipolar electrical signaling to unipolar optical signaling.

4. GENERAL REQUIREMENTS

4.2 Data Bus Operation.

This paragraph alters a reference to "Figure 1." that does not apply to 1773 and was reworded to reflect optical bus topology, rather than electrical.

4.3.3.2 Data Code.

This paragraph defines the difference between tri-level electrical and bi-level optical representation of the Manchester II modulation format. As the tri-level electrical signal is the logical OR of data, clock and message envelope, the start and end of both words and messages are implicitly known. With bi-level optical the message envelope information is lost. As the start of a message always includes "Command Synch" with a positive first transition, the start of message is still implicit. However, end of word and end of message must now be detected thru the absence of mid-bit transitions, injecting a decision delay of about two microseconds. This difference is normally of no consequence, unless one is attempting to perform 1773 to 1553 conversions within the minimum response time limitations of 1553.

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4.3.3.5.1.1 Sync.

This paragraph defines the depiction of the Command Sync code as implemented in bi-level optical signaling as compared to tri-level electrical signaling.

4.3.3.5.2.1 Sync.

This paragraph defines the depiction of the Data Sync code as implemented in bi-level optical signaling as compared to tri-level electrical signaling. See Chapter 3. of Users Handbook.

4.3.3.7 Intermessage Gap.

4.3.3.8 Response Time.

4.3.3.9 Minimum NO-response Timeout.

These three paragraphs reflect the differences in measuring time to the mid-bit of a tri-level electrical signal and measuring to the mib-bit of a bi-level optical signal. To obtain comparable results to the electrical case, these measurements must be made with an electro/optical converter with a known propagation delay!

4.5 Hardware Characteristics.

4.5.1 Data Bus Characteristics.

4.5.1.1 Cable.

4.5.1.2 Cable Termination.

4.5.1.3 Connectors.

4.5.1.4 Bus Configuration.

4.5.1.5 Optical Signal Requirements.

The paragraphs of Section 4.5.1 shift the responsibility for the optical media detail definition to the system peculiar detail specification.

4.5.2 Terminal Output Characteristics.

4.5.2.1 Output Optical Power.

4.5.2.2 Output Waveform.

4.5.2.3 Output Noise.

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4.5.2.4 Output Spectral Characteristics.

The paragraphs of Section 4.5.2 shift the responsibility for definition of the characteristics of the optical signal imposed on the bus network to the system peculiar detail specification.

4.5.3 Terminal Input Characteristics.

This paragraph defines the point at which signal measurements are made, a point in the optical media. This essentially means that measurements must be made on power exiting a precision test fiber connected to the output port of the terminal or the power exiting a precision test fiber connected to the media fiber that will be connected to the terminal input port. See the note for Paragraph 4.3.3.9 for warning on optical measurements.

4.5.3.1 Input Waveform Compatibility.

4.5.3.2 Minimum Input Signal.

This paragraph leaves the responsability of defining minimum optical signal levels and waveforms to the system peculiar detail specification.

4.5.3.3 Error Rate.

This paragraph only modifies the definition of required maximum bus word error rate to require optical rather than electrical signals.

4.6 Redundant Data Bus Requirements.

4.6.1 Electrical/Optical Isolation.

This paragraph defines isolation between dual redundant busses to include optical as well as electrical coupling. The levels that must be achieved are left for the system peculiar detail specification to define.

5. DETAILED REQUIREMENTS

5.1 Specific Implementations.

This paragraph restates that a detail specification is required to design or procure a 1773 compliant data bus implementation in legal terminology.

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Appendix to the Standard.

10. GENERAL

The MIL-STD-1553 Appendix, contains general information and warnings that are NOT a requirement and therefore cannot be included in the body of the standard for which compliance is compulsory.

The 1773 Appendix, in addition to carrying forward the Appendix information of MIL-STD-1553, adds Section 20. to provide additional information for the 1773 bus implementation that should not properly be included in the compulsory body of the 1773 standard.

10.3 Multiplex Selection Criteria.

This paragraph should NOT be asterisked in 1773, it is NOT altered !

10.5 Use of Broadcast Option.

Paragraph 10.5 (Stubbing) of MIL-STD-1553B was deleted as not applicable to 1773, resulting in this paragraph being renumbered from 10.6 in 1553 to 10.5 in 1773. The modification simply adds a reference to MIL-STD-1553B as the parent standard.

20. OPTICAL BUS NETWORK CONSIDERATIONS

The material in Section 20. of this Appendix is unique to the Fiber Optic media implementation of MIL-STD-1773 and is an addition to the 1553 material.

20.1 Comparison with Wire Bus Networks.

This paragraph hilites the parameters of the implementation of a Fiber Optic media. For additional information, see Chapter 3 of the handbook.

20.2 Typical Fiber Optic Data Bus Configurations.

This paragraph hilites the media topology and the optical components to implement it. For further information see Chapter 2 and Chapter 3 of the handbook.

20.3 Optical Signal Power Reduction in Access Couplers.

This paragraph hilites the power division and loss characteristics of optical couplers and splitters. Further details are provided in Chapter 2, section 2.4. (Couplers) and Chapter 3, section 3.2. (Power Budgeting).

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APPENDIX A, INCLUSION A-1.

REFERENCE COPY OF MIL-STD-1773.

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MIL-STD-1773
20 MAY 1988

MILITARY STANDARD

FIBER OPTICS MECHANIZATION OF AN AIRCRAFT INTERNAL TIME DIVISION COMMAND/RESPONSE MULTIPLEX DATA BUS

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Fiber Optics Mechanization of an Aircraft Time Division Command/Response Multiple Data Bus

MIL-STD-1773

1. This Military Standard is proposed for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Engineering Center, Systems Engineering and Standardization Department (Code 5313), Lakehurst, NJ 08733, by using the self-addressed Standardization Document improvement Proposal (DD Form 1426) appearing at the end of this standard or by letter.

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FOREWORD

This Military Standard contains requirements for fiber optic mechanizations of an aircraft internal time division command/response multiplex data bus for use in systems integration of aircraft subsystems. The parent document for data bus protocol, bit assignment and related bus traffic management is MIL-STD-1553B. DOD-STD-1773 provides for the use of fiber optics as the transmission medium in a manner which is compatible with MIL-STD-1553B.

This document is structured to follow the organization of MIL-STD-1553B as closely as possible with additions and omissions to MIL-STD-1553B only where necessary to allow fiber optics. To assist the reader in identifying changes which have been made, an asterisk has been placed to the left of each paragraph, figure and table number which is not identical with MIL-STD-1553B. Paragraph numbers used in MIL-STD-1553B but omitted in DOD-STD-1773 include all subparagraph numbers of 4.5.1.5, 4.5.2.1 and 4.5.2.2.

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1. SCOPE

* 1.1 Scope. This standard defines requirements for digital, command/ response time division multiplexing (data bus) techniques on aircraft. It encompasses the fiber optic data bus transmission line, the electro-optical transmission and reception units, and the associated interface electronics. The concept of operation and information flow on the multiplex data bus and the optical, electrical and functional formats to be employed are also defined.

1.2 Application. When invoked in a specification or statement of work, these requirements shall apply to the multiplex data bus and associated equipment which is developed either alone or as a portion of an aircraft weapon system or subsystem development. The contractor is responsible for invoking all of the applicable requirements of this Military Standard on any and all subcontractors he may employ.

* 1.3 Purpose. The purpose of this standard is twofold: (a) it seeks to preserve the multiplex bus techniques which have been standardized in MIL-STD-1553B, and (b) it provides guidelines for the application of fiber optic transmission techniques to the MIL-STD-1553B interconnect. Use of this standard alone will not ensure total compatibility of transmission characteristics between different systems which employ a fiber optic interconnect; however, it will ensure general compatibility of the optical modulation technique. The optical power levels, optical wavelength and the means for distributing optical power in any specific implementation must be contained in a specification which references this standard.

2. REFERENCED DOCUMENTS

* 2.1 Issue of document. The following documents of the issue in effect on date of invitation for bid or request for proposal form a part of this standard to the extent specified herein.

SPECIFICATIONS

STANDARDS

MILITARY

MIL-STD-1553B	Aircraft Internal Time Division Command/Response Multiplex Data Bus

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

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3. DEFINITIONS

3.1 Bit. Contraction of binary digit: may be either zero or one. In information theory a binary digit is equal to one binary decision or the designation of one of two possible values or states of anything used to store or convey information.

3.2 Bit rate. The number of bits transmitted per second.

3.3 Pulse Code Modulation (PCM). The form of modulation in which the modulation signal is sampled, quantized and coded so that each element of information consists of different types or numbers of pulses and spaces.

3.4 Time Division Multiplexing (TDM). The transmission of information from several signal sources through one communication system with different signal samples staggered in time to form a composite pulse train.

3.5 Half duplex. Operation of a data transfer system in either direction over a single line, but not in both directions on that line simultaneously.

3.6 Word. In this document a word is a sequence of 16 bits plus sync and parity. There are three types of words: command, status and data.

3.7 Message. A single message is the transmission of a command word, status word and data words if they are specified. For the case of a remote terminal to remote terminal (RT to RT) transmission, the message shall include the two command words, the two status words and data words.

3.8 Subsystem. The device or functional unit receiving data transfer service from the data bus.

* 3.9 Data bus. Whenever a data bus or bus is referred to in this document, it shall imply all the hardware in the signal distribution network, including the harness assembly of fiber optic cables, access coupler(s), connectors, etc., required to provide a path between all terminals.

3.10 Terminal. The electronic module necessary to interface the data bus with the subsystem and the subsystem with the data bus. Terminals may exist as separate line replaceable units (LRUs) or be contained within the elements of the subsystem.

3.11 Bus controller (BC). The terminal assigned the task of initiating information transfers on the data bus.

3.12 Bus monitor (BM). The terminal assigned the task of receiving bus traffic and extracting selected information to be used at a later time.

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3.13 Remote Terminal (RT). All terminals not operating as the bus controller or as a bus monitor.

3.14 Asynchronous operation. For the purpose of this standard, asynchronous operation is the use of an independent clock source in each terminal for message transmission. Decoding is achieved in receiving terminals using clock information derived from the message.

3.15 Dynamic bus control. The operation of a data bus system in which designated terminals are offered control of the data bus.

3.16 Command/response. Operation of a data bus system such that remote terminals receive and transmit data only when commanded to do so by the bus controller.

3.17 Redundant data bus. The use of more than one data bus to provide more than one data path between the subsystems, i.e., dual redundant data bus, tri-redundant data bus, etc.

3.18 Broadcast. Operation of a data bus system such that information transmitted by the bus controller or a remote terminal is addressed to more than one of the remote terminals connected to the data bus.

3.19 Mode code. A means by which the bus controller can communicate with the multiplex bus related hardware in order to assist in the management of information flow.

* 3.20 Access coupler. An access coupler is a device which distributes optical power among several ports. Star couplers and tee couplers are examples of access couplers.

* 3.21 Optical Signal Range (OSR). Optical Signal Range is the ratio of the maximum optical signal power to the minimum optical signal power expressed in dBs. As a system specification applied to an optical bus network, it describes the maximum range of signals that can be seen by any terminal over the operating conditions specified. Although OSR is expressed as a ratio, it is important that the maximum and minimum optical signal power levels be specified as well.

* 3.22 Mid-Bit Transition. The position in the sync waveform where the optical pulse goes from a high state to a completely off or low state.

4. GENERAL REQUIREMENTS

4.1 Test and operating requirements. All requirements as specified herein shall be valid over the environmental conditions in which the multiplex data bus system shall he required to operate.

* 4.2 Data bus operation. The multiplex data bus system shall function asynchronously in a command/response mode, and transmission shall occur in a half duplex manner. Sole control of information

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transmission on the bus shall reside with the bus controller, which shall initiate all transmissions. The information flow on the data bus shall be comprised of messages which are, in turn, formed by three types of words (command, data and status) as defined in paragraph 4.3.3.5. A sample multiplex data bus system showing interconnection with a star configuration is illustrated on Figure 1. However, it is not the intent of this standard to dictate or recommend a specific configuration for distribution of optical power.

4.3 Characteristics.

4.3.1 Data form. Digital data may be transmitted in any desired form, provided that the chosen form shall be compatible with the message and word formats defined in this standard. Any unused bit positions in a word shall be transmitted as logic zeros.

4.3.2 Bit priority. The most significant bit shall be transmitted first with the less significant bits following in descending order of value in the data word. The number of bits required to define a quantity shall be consistent with the resolution or accuracy required. In the event that multiple precision quantities (information accuracy or resolution requiring more than 16 bits) are transmitted, the most significant bits shall be transmitted first, followed by the word(s) containing the lesser significant bits in numerical descending order. Sit packing of multiple quantities in a single data word is permitted.

4.3.3 Transmission method.

4.3.3.1 Modulation. The signal shall be transferred over the data bus in serial digital pulse code modulation form consistant with the resolution or accuracy required. In the event that multiple precision quantities (information accuracy or resolution requiring more than 16 bits) are transmitted, the most significant bits shall be transmitted first, followed by the word(s) containing the lesser significant bits in numerical descending order. Bit packing of multiple quantities in a single data word is permitted.

* 4.3.3.2 Data code. The data code shall be Manchester II bi-phase level. A logic one shall be transmitted as a coded signal I/O (i.e., an optical pulse followed by a low level or completely off condition). A logic zero shall be a coded signal O/1 (i.e., an optical pulse preceded by a low level or completely off condition). A transition occurs at the midpoint of each bit time (see Figure 2).

4.3.3.3 Transmission bit rate. The transmission bit rate on the bus shall be 1.0 megabit per second with a combined accuracy and long-term stability of. ±0.1 percent (i.e., +1000 bits per second). The short-term stability (i.e., stability over 1.0 second interval) shall be at least 0.01 percent (i.e., ±100 bits per second).

4.3.3.4 Word size. The word size shall be 16 bits plus the sync waveform and the parity bit for a total of 20 bit times as shown on Figure 3.

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4.3.3.5 Word formats. The word formats shall be as shown on Figure 3 for the command, data and status words.

4.3.3.5.1 Command word. A command word shall be comprised of a sync waveform, remote terminal address field, transmit/receive (T/R) bit, sub-address/mode field, word count/mode code field and a parity (P) bit (see Figure 3).

* 4.3.3.5.1.1 Sync. The command sync waveform shall be an invalid Manchester waveform as shown on Figure 4. The width of the sync waveform shall be three bit times, with an optical pulse for the first one and one-half bit times and then a low level or completely off condition for the following one and one-half bit times. If the next bit following the sync waveform is a logic zero, then the last half of the sync waveform will have an apparent width of two clock periods due to the Manchester encoding.

4.3.3.5.1.2 Remote terminal address. The next five bits following the sync shall be the RT address. Each RT shall be assigned a unique address. Decimal address 31 (11111) shall not be assigned as a unique address. In addition to its unique address, a RT shall be assigned decimal address 31 (11111) as the common address, if the broadcast option is used.

4.3.3.5.1.3 Transmit/receive. The next bit following the remote terminal address shall be the T/R bit, which shall indicate the action required of the RT. A logic zero shall indicate the RT is to receive, and a logic one shall indicate the RT is to transmit.

4.3.3.5.1.4 Subaddress/mode. The next five bits following the T/R bit shall be utilized to indicate an RT subaddress or use of mode control, as is dictated by the individual terminal requirements. The subaddress/mode values of 00000 and 11111 are reserved for special purposes, as specified in 4.3.3.5.1.7, and shall not be utilized for any other function.

4.3.3.5.1.5 Data word count/mode code. The next five bits following the subaddress/mode field shall be the quantity of data words to be either sent out or received by the RT or the optional mode code as specified in 4.3.3.5.1.7. A maximum of 32 data words may be transmitted or received in any one message block. All 1s shall indicate a decimal count of 31 and all 0s shall indicate a decimal count of 32.

4.3.3.5.1.6 Parity. The last bit in the word shall be used for parity over the preceding 16 bits. Odd parity shall be utilized.

4.3.3.5.1.7 Optional mode control. For RTs exercising this option a subaddress/mode code of 00000 or 11111 shall imply that the contents of the data word count/mode code field are to be decoded as a five bit mode command. The mode code shall only be used to communicate with the multiplex bus related hardware, and to assist in the management of information flow, and not to extract data from or feed data to a functional subsystem. Codes 00000 through 01111 shall only be used for

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mode codes which do not require transfer of a data word. For these codes, the T/R bit shall be set to 1. Codes 10000 through 11111 shall only be used for mode codes which require transfer of a single data word. For these mode codes, the T/R bit shall indicate the direction of data word flow as specified in 4.3.3.5.1.3. No multiple data word transfer shall be implemented with any mode code. The mode codes are reserved for the specific functions as specified in Table I and shall not be used for any other purpose. If the designer chooses to implement any of these functions, the specific codes, T/R bit assignments and use of a data word, shall be used as indicated. The use of the broadcast command option shall only be applied to particular mode codes as specified in Table I.

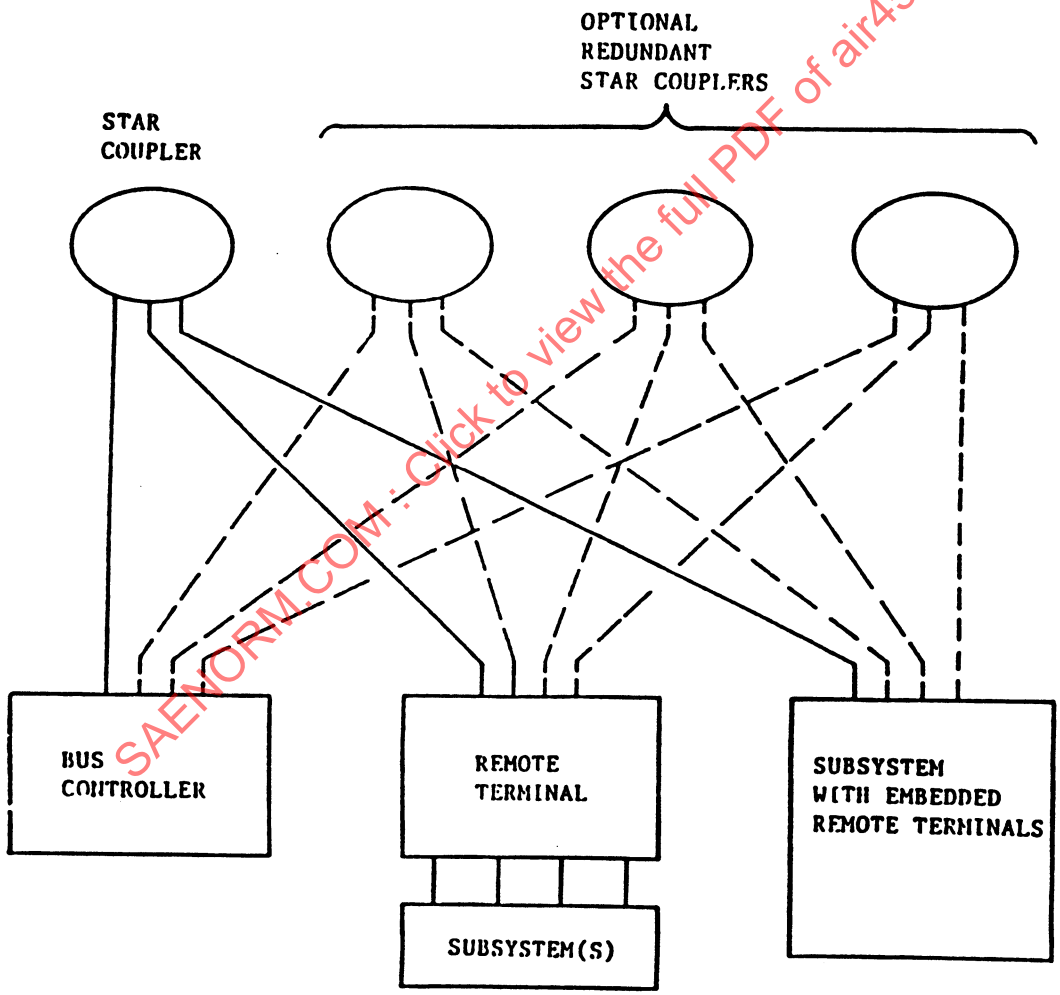

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*FIGURE 1. Sample multiplex data bus architecture.

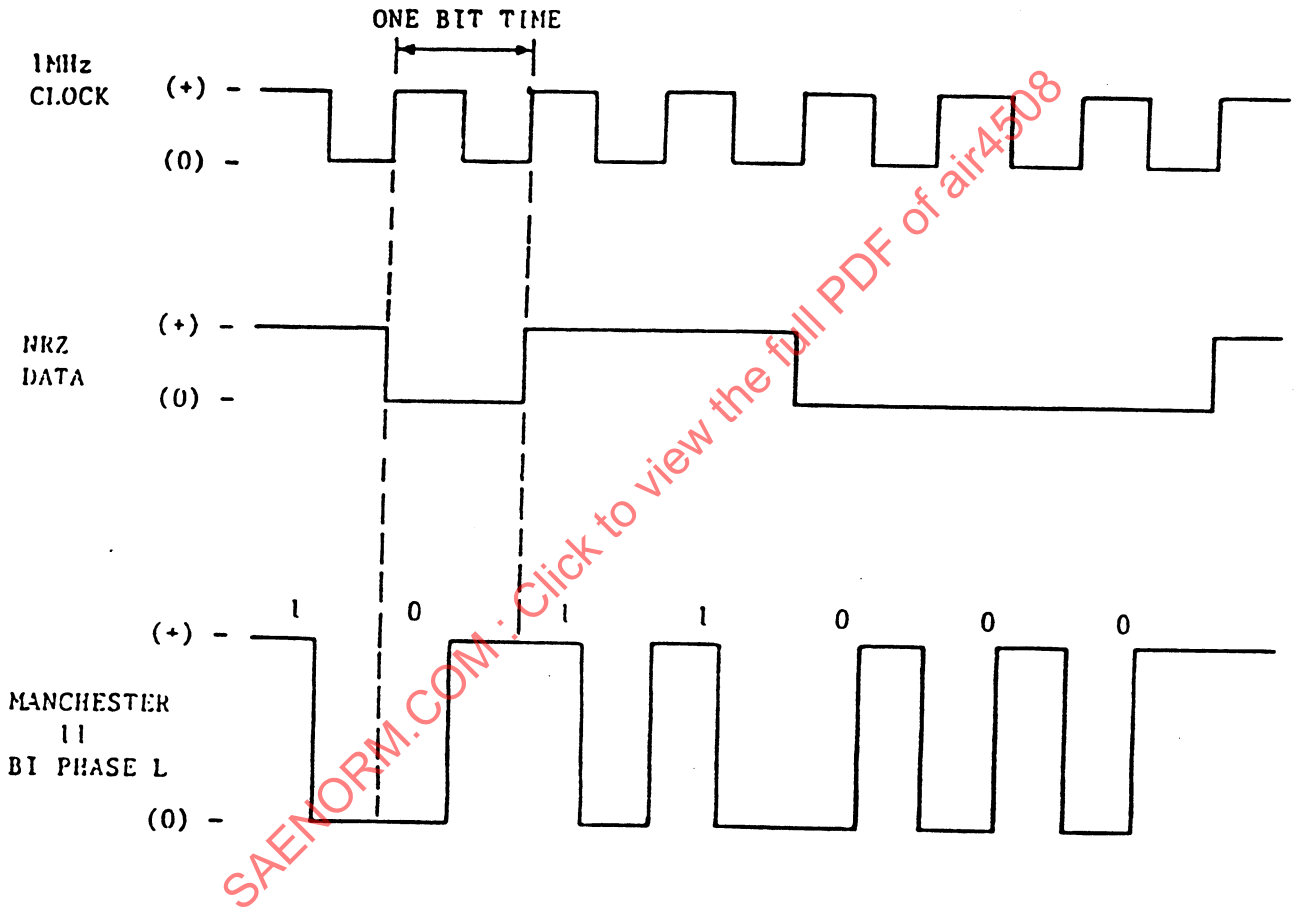

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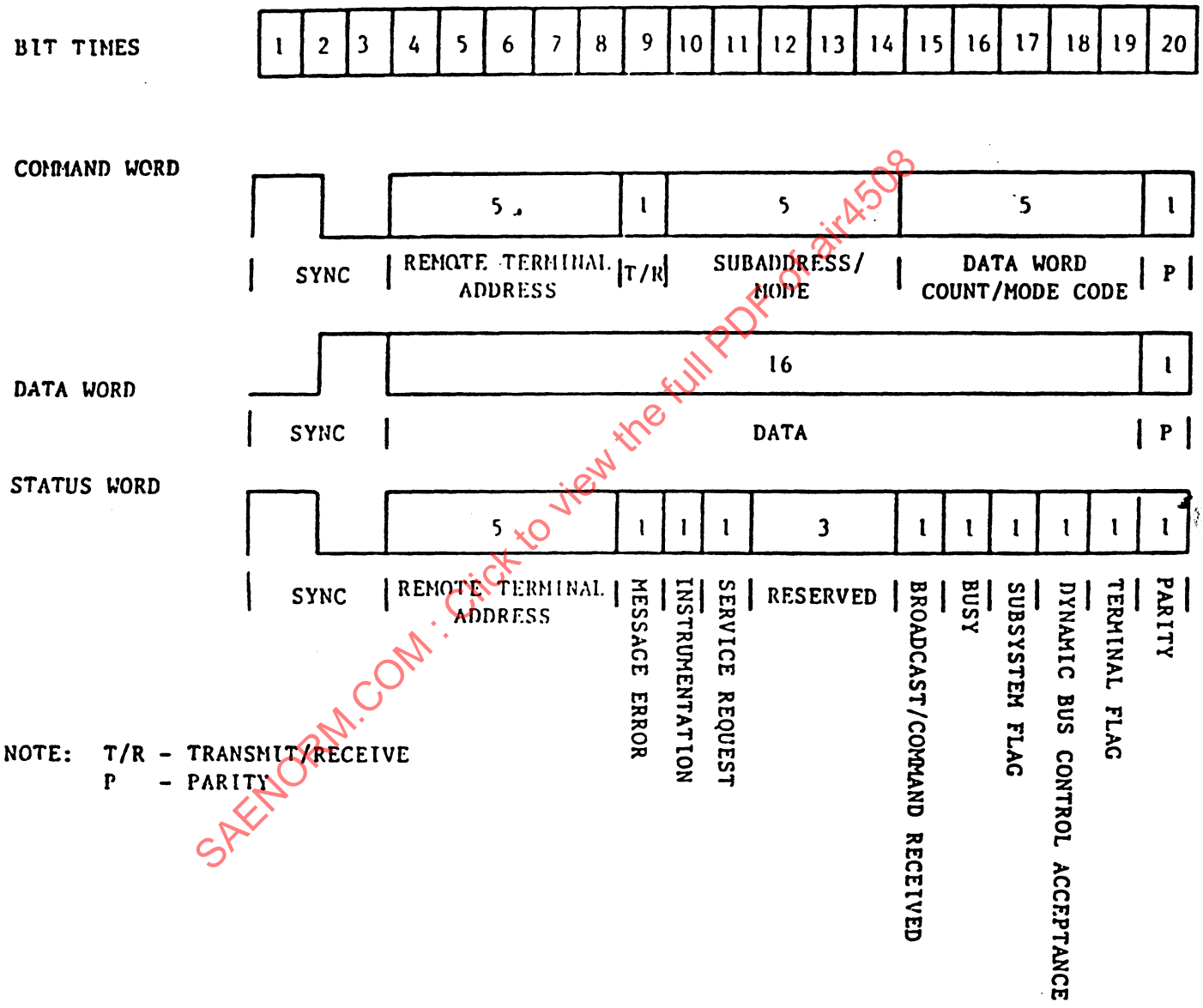
***FIGURE 2. Data encoding.**



NOTE: T/R - TRANSMIT/RECEIVE
P - PARITY

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*FIGURE 3. Word Formats.

4.3.3.5.1.7.1 Dynamic bus control. The controller shall issue a transmit command to an RT capable of performing the bus control function. This RT shall respond with a status word as specified in 4.3.3.5.3. Control of the data bus passes from the offering bus controller to the accepting RT upon completion of the transmission of the status word by the RT. If the RT rejects control of the data bus, the offering bus controller retains control of the data bus.

4.3.3.5.1.7.2 Synchronize (without data word). This command shall cause the RT to synchronize (e.g., to reset the internal timer, to start a sequence, etc.). The RT shall transmit the status word as specified in 4.3.3.5.3.

4.3.3.5.1.7.3 Transmit status word. This command shall cause the RT to transmit the status word associated with the last valid command word preceding this command. This mode command shall not alter the state of the status word.

4.3.3.5.1.7.4 Initiate self test. This command shall be used to initiate self test within the RT. The RT shall transmit the status word as specified in 4.3.3.5.3.

4.3.3.5.1.7.5 Transmitter shutdown. This command (to only be used with dual redundant bus systems) shall cause the RT to disable the transmitter associated with the redundant bus. The RT shall not comply with a command to shut down a transmitter on the bus from which this command is received. In all cases, the RT shall respond with a status word as specified in 4.3.3.5.3 after this command.

4.3.3.5.1.7.6 Override transmitter shutdown. This command (to only be used with dual redundant bus systems) shall cause the RT to enable a transmitter which was previously disabled. The RT shall not comply with a command to enable a transmitter on the bus from which this command is received. In all cases, the RT shall respond with a status word as specified in 4.3.3.5.3 after this command.

4.3.3.5.1.7.7 Inhibit terminal flag (T/F) bit. This command shall cause the RT to set the T/F bit in the status word specified in 4.3.3.5.3 to logic zero until otherwise commanded. The RT shall transmit the status word as specified in 4.3.3.5.3.

4.3.3.5.1.7.8 Override inhibit T/F bit. This command shall cause the RT to override the inhibit T/F bit specified in 4.3.3.5.1.7.7. The RT shall transmit the status word as specified in 4.3.3.5.3.

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TABLE I. Assigned mode codes.

T/R Bit	Mode Code	Function	Associated Data Word	Broadcast Command Allowed
1	00000	Dynamic Bus Control	No	No
1	00001	Synchronize	No	Yes
1	00010	Transmit Status Word	No	No
1	00011	Initiate Self Test	No	Yes
1	00100	Transmitter Shutdown	No	Yes
1	00101	Override Transmitter Shutdown	No	Yes
1	00110	Inhibit Terminal Flag Bit	No	Yes
1	00111	Override Inhibit Terminal Flag Bit	No	Yes
1	01000	Reset Remote Terminal	No	Yes
1	01001	Reserved	No	TBD
1	01111	Reserved	No	TBD
1	10000	Transmit Vector Word	Yes	No
1	10001	Synchronize	Yes	Yes
1	10010	Transmit Last Command	Yes	No
1	10011	Transmit BIT Word	Yes	No
1	10100	Selected Transmitter Shutdown	Yes	Yes

NOTE: To be determined (TBD)

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TABLE I. Assigned mode codes.

T/R Bit	Mode Code	Function	Associated Data Word	Broadcast Command Allowed
0	00000	Reserved	Yes	TBD
0	10001	Reserved	YES	TBD
0	10010	Synchronize	Yes	Yes
0	10011	Reserved	Yes	TDB
0	10100	Selected Transmitter Shutdown	Yes	Yes
0	10101	Override Selected Transmitter Shutdown	Yes	Yes
1 or 0	10110	Reserved	Yes	TDB
1 or 0	11111	Reserved	Yes	TDB

NOTE: To be determined (TBD)

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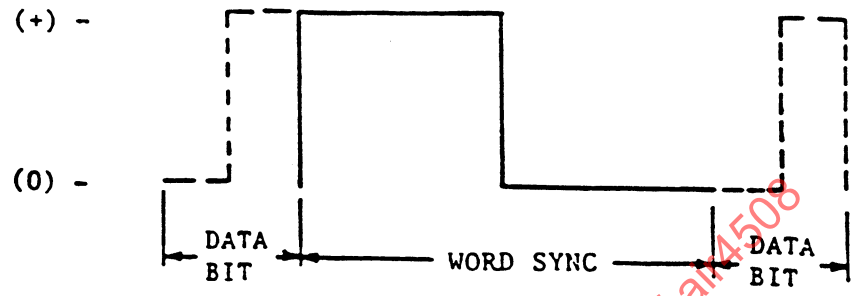

*FIGURE 4. Command and status sync.

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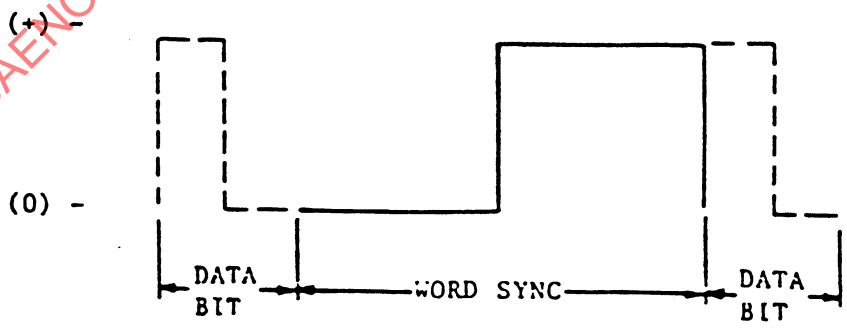

*FIGURE 5. Data Sync.

4.3.3.5.1.7.9 Reset remote terminal. This command shall be used to reset the RT to a power up initialized state. The RT shall first transmit its status word and then reset.

4.3.3.5.1.7.10 Reserved mode codes (01001 to 01111). These mode codes are reserved for future use and shall not be used.

4.3.3.5.1.7.11 Transmit vector word. This command shall cause the RT to transmit a status word as specified in 4.3.3.5.3 and a data word containing service request information.

4.3.3.5.1.7.12 Synchronize (with data word). The RT shall receive a command word followed by a data word as specified in 4.3.3.5.2. The data word shall contain synchronization information for the RT. After receiving the command and data word, the RT shall transmit the status word as specified in 4.3.3.5.3.

4.3.3.5.1.7.13 Transmit last command word. This command shall cause the RT to transmit its status word as specified in 4.3.3.5.3 followed by a single data word which contains bits 4-19 of the last command word, excluding a transmit last command word mode code received by the RT. This mode command shall not alter the state of the RT1s status word.

4.3.3.5.1.7.14 Transmit Built-In-Test (BIT) word. This command shall cause the RT to transmit its status word as specified in 4.3.3.5.3 followed by a single data word containing the RT BIT data. This function is intended to supplement the available bits in the status word when the RT hardware is sufficiently complex to warrant its use. The data word, containing the RT BIT data, shall not be altered by the reception of a transmit last command or a transmit status word mode code. This function shall not be used to convey BIT data from the associated subsystem(s).

4.3.3.5.1.7.15 Selected transmitter shutdown. This command shall cause the RT to disable the transmitter associated with a specified redundant data bus. The command is designed for use with systems employing more than two redundant buses. The transmitter that is to be disabled shall be identified in the data word following the command word in the format as specified in 4.3.3.5.2. The RT shall not comply with a command to shut down a transmitter on the bus from which this command is received. In all cases, the RT shall respond with a status word as specified in 4.3.3.5.3.

4.3.3.5.1.7.16 Override selected transmitter shutdown. This command shall cause the RT to enable a transmitter which was previously disabled. The command is designed for use with systems employing more than two redundant buses. The transmitter that is to be enabled shall be identified in the data word following the command word in the format as specified in 4.3.3.5.2. The RT shall not comply with a command to enable a transmitter on the bus from which this command is received. In all cases, the RT shall respond with a status word as specified in 4.3.3.5.3.

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4.3.3.5.1.7.17 Reserved mode codes (10110 to 11111). These mode codes are reserved for future use and shall not be used.

4.3.3.5.2 Data word. A data word shall be comprised of a sync waveform, data bits and a parity bit (see Figure 3).

4.3.3.5.2.1 The data sync waveform shall be an invalid Manchester waveform as shown on Figure 5. The width shall be three bit times, with the waveform being a low level or completely off condition for the first one and one-half bit times, and then an optical pulse for the following one and one-half bit times. Note that if the bits preceding and following the sync are logic ones, then the apparent width of the sync waveform will be increased to four bit times.

4.3.3.5.2.2 Data. The sixteen bits following the sync shall be utilized for data transmission as specified in 4.3.2.

4.3.3.5.2.3 Parity. The last bit shall be utilized for parity as specified in 4.3.3.5.1.6.

4.3.3.5.3 Status word. A status word shall be comprised of a sync waveform, RT address, message error bit, instrumentation bit, service request bit, three reserved bits, broadcast command received bit, busy bit, subsystem flag bit, dynamic bus control acceptance bit, terminal flag bit and a parity bit. For optional broadcast operation, transmission of the status word shall be suppressed as specified in 4.3.3.6.7.

4.3.3.5.3.1 Sync. The status sync waveform shall be as specified in 4.3.3.5.1.1.

4.3.3.5.3.2 RT address. The next five bits following the sync shall contain the address of the RT which is transmitting the status word as defined in 4.3.3.5.1.2.

4.3.3.5.3.3 Message error bit. The status word bit at bit time nine (see Figure 3) shall be utilized to indicate that one or more of the data words associated with the preceding receive command word from the bus controller has failed to pass the RT's validity tests as specified in 4.4.1.1. This bit shall also be set under the conditions specified in 4.4.1.2, 4.4.3.4 and 4.4.3.6. A logic one shall indicate the presence of a message error and a logic zero shall show its absence. All RTs shall implement the message error bit.

4.3.3.5.3.4 Instrumentation bit. The status word at bit time ten (see Figure 3) shall be reserved for the instrumentation bit and shall always be a logic zero. This bit is intended to be used in conjunction with a logic one in bit time ten of the command word to distinguish between a command word and a status word. The use of the instrumentation bit is optional.

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4.3.3.5.3.5 Service request bit. The status word bit at bit time eleven (see Figure 3) shall be reserved for the service request bit. The use of this bit is optional. This bit, when used, shall indicate the need for the bus controller to take specific predefined actions relative to either the RT or associated subsystem. Multiple subsystems, interfaced to a single RT, which individually require a service request signal, shall logically OR their individual signals into the single status word bit. In the event this logical OR is performed, then the designer must make provisions in a separate data word to identify the specific requesting subsystem. The service request bit is intended to be used only to trigger data transfer operations which take place on an exception rather than periodic basis. A logic one shall indicate the presence of a service request, and a logic zero its absence. If this function is not implemented, the bit shall be set to zero.

4.3.3.5.3.6 Reserved status bits. The status word bits at bit times twelve through fourteen are reserved for future use and shall not be used. These bits shall be set to a logic zero.

4.3,3.5.3.7 Broadcast command received bit. The status word at bit time fifteen shall be set to a logic one to indicate that the preceding valid command word was a broadcast command and a logic zero shall show it was not a broadcast command. If the broadcast command option is not used, this bit shall be set to a logic zero.

4.3.3.5.3.8 Busy bit. The status word bit at bit time sixteen (see Figure 3) shall be reserved for the busy bit. The use of this bit is optional. This bit, when used, shall indicate that the RT or subsystem is unable to move data to or from the subsystem in compliance with the bus controller's command. A logic one shall indicate the presence of a busy condition, and a logic zero its absence. In the event the busy bit is set in response to a transmit command, then the RT shall transmit its status word only. If this function is not implemented, the bit shall be set to logic zero.

4.3.3.5.3.9 Subsystem flag bit. The status word bit at bit time seventeen (see Figure 3) shall be reserved for the subsystem flag bit. The use of this bit is optional. This bit, when used, shall flag a subsystem fault condition, and alert the bus controller to potentially invalid data. Multiple subsystems, interfaced to a single RT, which individually require a subsystem flag bit signal, shall logically OR their individual signals into the single status word bit. In the event this logical OR is performed, then the designer must make provisions in a separate data word to identify the specific reporting subsystem. A logic one shall indicate the presence of the flag, and a logic zero its absence. If not used, this bit shall be set to logic zero.

4.3.3.5.3.10 Dynamic bus control acceptance bit. The status word bit at bit time eighteen (see Figure 3) shall be reserved for the acceptance of dynamic bus control. This bit shall be used if the RT implements the optional dynamic bus control function. This bit, when used, shall indicate acceptance or rejection of a dynamic bus control offer as specified in 4.3.3.5.1.7.1. A logic one shall indicate

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acceptance of control, and a logic zero shall indicate rejection of control. If this function is not used, this bit shall be set to logic zero.

4.3.3.5.3.11 Terminal flag bit. The status word bit at bit time nineteen (see Figure 3) shall be reserved for the terminal flag function. The use of this bit is optional. This bit, when used, shall flag a RT fault condition. A logic one shall indicate the presence of the flag, and a logic zero, its absence. If not used, this bit shall be set to logic zero.

4.3.3.5.3.12 Parity bit. The least significant bit in the status word shall be utilized for parity as specified in 4.3.3.5.1.6.

4.3.3.5.4 Status word reset. The status word bit, with the exception of the address, shall be set to logic zero after a valid command word is received by the RT with the exception as specified in 4.3.3.5.1.7. If the conditions which caused bits in the status word to be set (e.g., terminal flag) continue after the bits are reset to logic zero, then the affected status word bit shall be again set, and then transmitted on the bus as required.

4.3.3.6 Message formats. The messages transmitted on the data bus shall be in accordance with the formats on Figure 6 and Figure 7. The maximum and minimum response times shall be as stated in 4.3.3.7 and 4.3.3.8. Ho message formats, other than those defined herein, shall be used on the bus.

4.3.3.6.1 Bus controller to remote terminal transfers. The bus controller shall issue a receive command followed by the specified number of data words. The RT shall, after message validation, transmit a status word back to the controller. The command and data words shall be transmitted to a contiguous fashion with no interword gaps.

4.3.3.6.2 Remote terminal to bus controller transfers. The bus controller shall issue a transmit command to the RT. The RT shall, after command word validation, transmit a status word back to the bus controller, followed by the specified number of data words. The status and data words shall be transmitted in a contiguous fashion with no interword gaps.

4.3.3.6.3 Remote terminal to remote terminal transfers. The bus controller shall issue a receive command to RT A followed continuously by a transmit command to RT B. RT B shall, after command validation, transmit a status word followed by the specified number of data words. The status and data words shall be transmitted in a contiguous fashion with no gap. At the conclusion of the data transmission by RT B, RT A shall transmit a status word within the specified time period.

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4.3.3.6.4 Mode command without data word. The bus controller shall issue a transmit command to the RT using a mode code specified in Table I. The RT shall, after command word validation, transmit a status word.

4.3.3.6.5 Mode command with data word (transmit). The bus controller shall issue a transmit command to the RT using a mode code specified in Table I. The RT shall, after command word validation, transmit a status word followed by one data word. The status word and data word shall be transmitted in a contiguous fashion with no gap.

4.3.3.6.6 Mode command with data word (receive). The bus controller shall issue a receive command to the RT using a mode code specified in Table I, followed by one data word. The command word and data word shall be transmitted in a contiguous fashion with no gap. The RT shall, after command and data word validation, transmit a status word back to the controller.

4.3.3.6.7 Optional broadcast command. See 10.5 for additional information on the use of the broadcast command.

4.3.3.6.7.1 Bus controller to remote terminal(s) transfer (broadcast). The bus controller shall issue a receive command word with 11111 in the RT address field followed by the specified number of data words. The command word and data words shall be transmitted in a contiguous fashion with no gap. The RT(s) with the broadcast option shall, after message validation, set the broadcast command received bit in the status word as specified in 4.3.3.5.3.7 and shall not transmit the status word.

4.3.3.6.7.2 Remote terminal to remote terminal(s) transfers (broadcast). The bus controller shall issue a receive command word with 11111 in the RT address field followed by a transmit command to RT A using the RT's address. RT A shall, after command word validation, transmit a status word followed by the specified number of data words. The status and data words shall be transmitted in a contiguous fashion with no gap. The RT(s) with the broadcast option, excluding RT A, shall after message validation, set the broadcast received bit in the status word as specified in 4.3.3.5.3.7 and shall not transmit the status word.

4.3.3.6.7.3 Mode command without data word (broadcast). The bus controller shall issue a transmit command word with 11111 in the RT address field, and a mode code specified in Table I. The RT(s) with the broadcast option shall, after command word validation, set the broadcast received bit in the status word as specified in 4.3.3.5.3.7 and shall not transmit the status word.

4.3.3.6.7.4 Mode command with data word (broadcast). The bus controller shall issue a receive command word with 11111 in the RT address field and a mode code specified in Table I, followed by one data word. The command word and data word shall be transmitted in a contiguous fashion with no gap. The RT(s) with the broadcast option shall, after message validation, set the broadcast received bit in the

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status word as specified in 4.3.3.5.3.7 and shall not transmit the status word.

* 4.3.3.7 Intermessage gap. The bus controller shall provide a minimum gap time of 4.0 microseconds (μs) between messages as shown on Figure 6 and Figure 7. This time period, shown as T on Figure 8, is measured at point A of the bus controller as shown on Figure 9 or Figure 10. The time is measured from the mid-bit transition of the last bit of the preceding message to midsync transition of the next command word sync.

* 4.3.3.8 Response time. The RT shall respond, in accordance with 4.3.3.6, to a valid command word within the time period of 4.0 to 12.0 μs. This time period, shown as T on Figure 8, is measured at point A of the RT as shown on Figure 9 or Figure 10. The time is measured from the mid-bit transition of the last word as specified in 4.3.3.6 and as shown on Figure 6 and Figure 7 to the mid-sync transition of the status word sync.

* 4.3.3.9 Minimum no-response time-out. The minimum time that a terminal shall wait before considering that a response as specified in 4.3.3.8 has not occurred shall be 14.0 μs. The time is measured from the mid-bit transition of the last bit of the last word to the mid-sync transition of the expected status word sync at point A of the terminal as shown on Figure 9 or Figure 10.

4.4 Terminal operation.

4.4.1 Common operation. Terminals shall have common operating capabilities as specified in the following paragraphs.

4.4.1.1 Word validation. The terminal shall insure that each word conforms to the following minimum criteria:

a. The word begins with a valid sync field.

b. The bits are in a valid Manchester II code.

c. The information field has 16 bits plus parity.

d. The word parity is odd.

When a word fails to conform to the preceding criteria, the word shall be considered invalid.

4.4.1.2 Transmission continuity. The terminal shall verify that the message is contiguous as defined in 4.3.3.6. Improperly timed data syncs shall be considered a message error.

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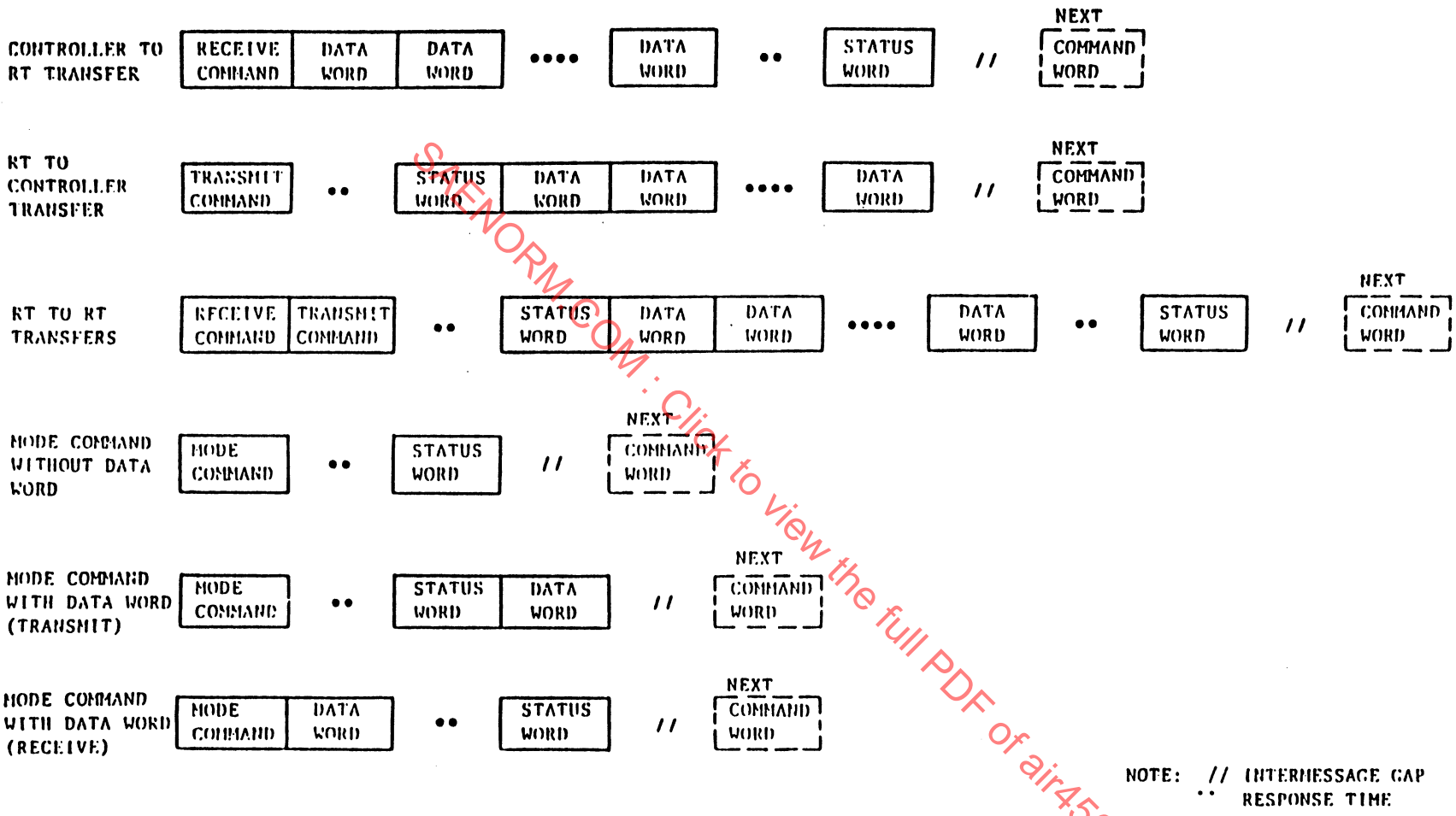

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FIGURE 6. Information transfer formats.

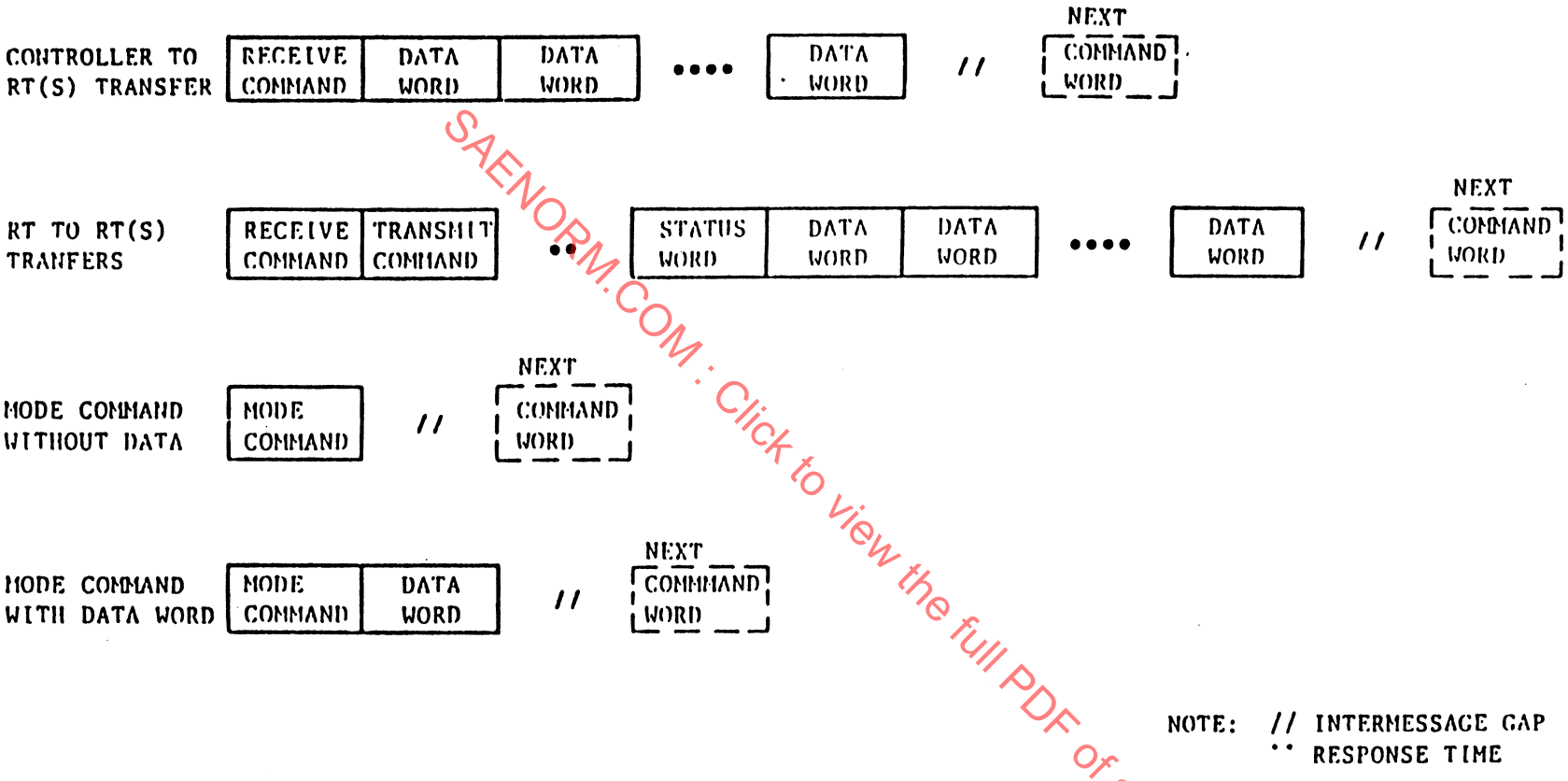

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FIGURE 7. Broadcast information transfer formats.

4.4.1.3 Terminal fail-safe. The terminal shall contain a hardware implemented time-out to preclude a signal transmission of greater than 800.0 μs. This hardware shall not preclude a correct transmission in response to a command. Reset of this time-out function shall be performed by the reception of a valid command on the bus on which the time-out has occurred.

4.4.2 Bus controller operation. A terminal operating as a bus controller shall be responsible for sending data bus commands, participating in data transfers, receiving status responses, and monitoring system status as defined in this standard. The bus controller function may be embodied as either a stand-alone terminal, whose sole function is to control the data bus(s), or contained within a subsystem. Only one terminal shall be in active control of a data bus at any one time.

4.4.3 Remote terminal.

4.4.3.1 Operation. A remote terminal (RT) shall operate in response to valid commands received from the bus controller. The RT shall accept a command word as valid when the command word meets the criteria of 4.4.1.1, and the command word contains a terminal address which matches the RT address or an address of 11111, if the RT has the broadcast option. No combination of RT address bits, T/R bit, subaddress/mode bits and data word count/mode code bits of a command word shall result in invalid transmission by the RT. Subsequent valid commands shall be properly responded to by the RT.

4.4.3.2 Superseding valid commands. The RT shall be capable of receiving a command word on the data bus after the minimum intermessage gap time as specified in 4.3.3.7 has been exceeded, when the RT is not in the time period T as specified in 4.3.3.8 prior to the transmission of a status word, and when it is not transmitting on that data bus. A second valid command word sent to an RT shall take precedence over the previous command. The RT shall respond to the second valid command as specified in 4.3.3.8.

4.4.3.3 Invalid commands. A remote terminal shall not respond to a command word, which fails to meet the criteria specified in 4.4.3.1.

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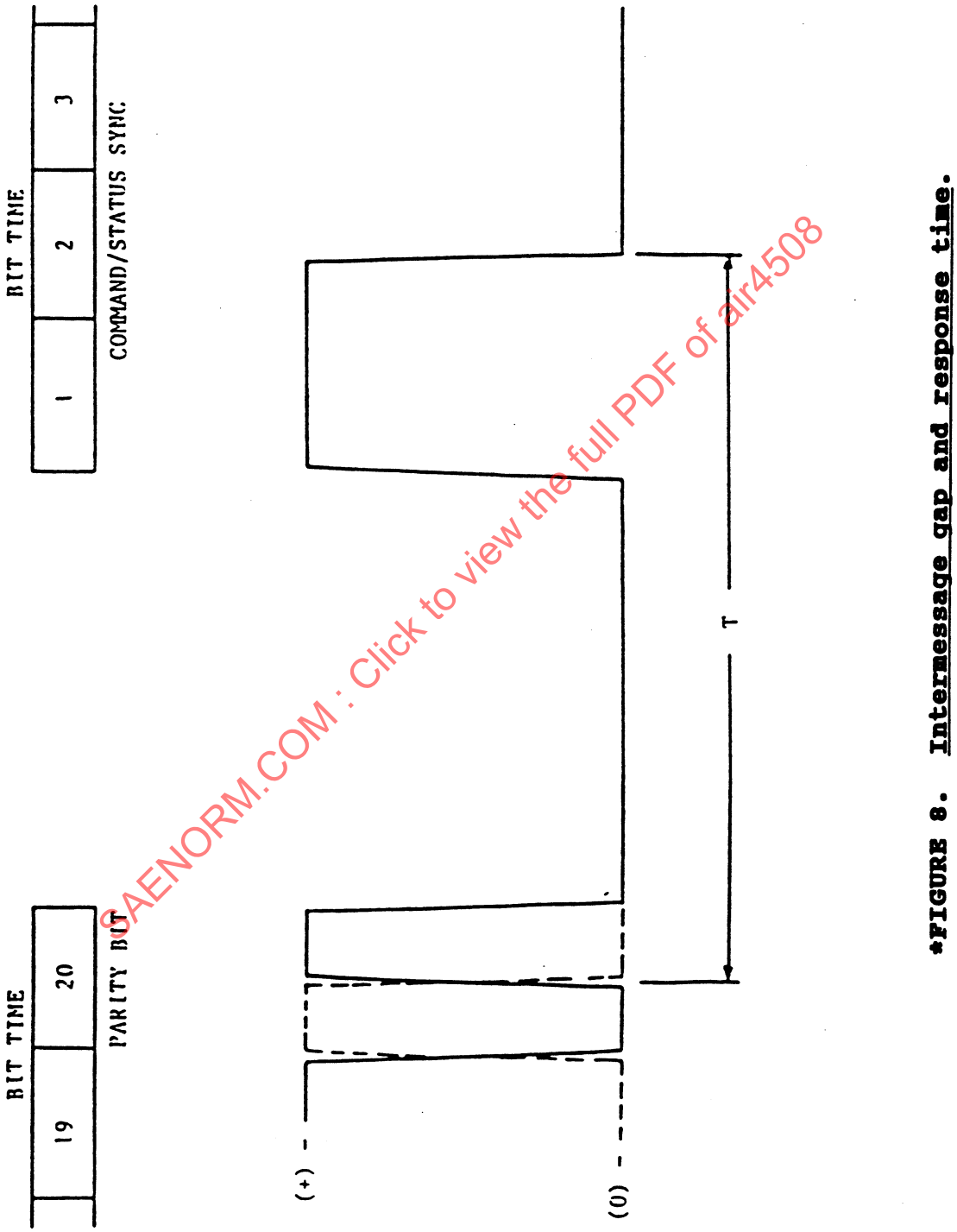

*FIGURE 8. Intermessage gap and response time.

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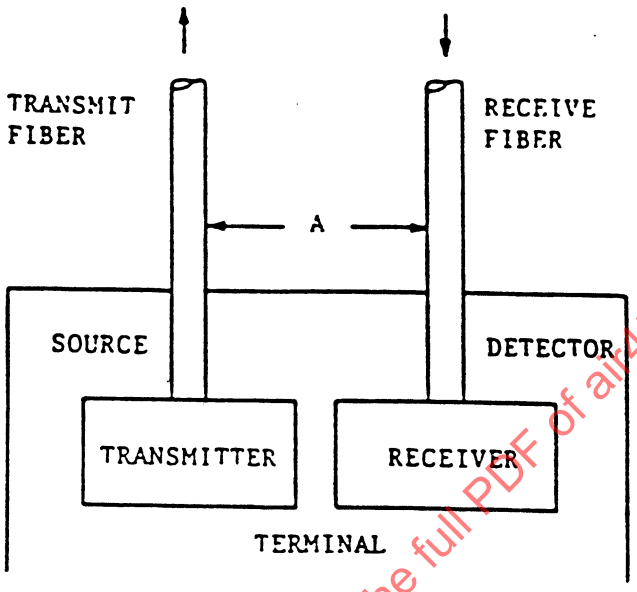

Figure 9. Data bus interface using separate trensmit and receive fibers.

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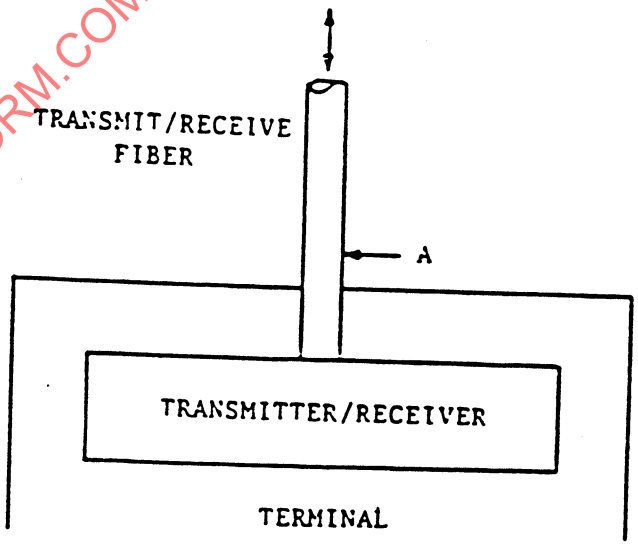

FIGURE 10. Data bus interface suing a single transmit and and receive fiber.

4.4.3.4 Illegal command. An illegal command is a valid command as specified in 4.4.3.1, where the bits in the subaddress/mode field, data word count/mode code field and the T/R bit indicate a mode command, subaddress or word count that has not been implemented in the RT. It is the responsibility of the bus controller to assure that no illegal commands are sent out. The RT designer has the option of monitoring for illegal commands. If an RT that is designed with this option detects an illegal command and the proper number of contiguous valid data words as specified by the illegal command word, it shall respond with a status word only, setting the message error bit, and not use the information received.

4.4.3.5 Valid data reception. The remote terminal shall respond with a status word when a valid command word and the proper number of contiguous valid data words are received, or a single valid word associated with a mode code is received. Each data word shall meet the criteria specified in 4.4.1.1.

4.4.3.6 Invalid data reception. Any data word(s) associated with a valid receive command that does not meet the criteria specified in 4.4.1.1 and 4.4.1.2 or an error in the data word count shall cause the remote terminal to set the message error bit in the status word to a logic one and suppress the transmission of the status word. If a message error has occurred, then the entire message shall be considered invalid.

4.4.4 Bus monitor operation. A terminal operating as a bus monitor shall receive bus traffic and extract selected information. While operating as a bus monitor, the terminal shall not respond to any message except one containing its own unique address if one is assigned. All information obtained while acting as a bus monitor shall be strictly used for off-line applications (e.g., flight test recording, maintenance recording or mission analysis) or to provide the back-up bus controller sufficient information to take over as the bus controller.

4.5 Hardware characteristics.

4.5.1 Data bus characteristics.

* 4.5.1.1 Cable. The mechanical and optical characteristics of the fiber optic cable shall be in accordance with the system specification. The bus network cable fibers shall be compatible with the 1/0 fiber(s) of the bus terminal, in accordance with the system specification(s).

* 4.5.1.2 Cable termination. The fiber optic cable termination characteristics (connection losses, environmental characteristics, etc.) shall be in accordance with the system specification(s).

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* 4.5.1.3 Connectors. The fiber optic connectors shall be in accordance with the system specification(s).

* 4.5.1.4 Bus configuration. The selection of bus configuration and access technique shall be as specified by the system designer but shall be compatible with the terminal input/output characteristics in accordance with the system specification(s).

* 4.5.1.5 Optical signal requirements. The data bus shall be designed such that the optical signal received at every terminal receiver port from any terminal on the data bus shall be greater than the minimum level and within the optical signal range (OSR) specified in the system specification(s).

* 4.5.2 Terminal output characteristics.

4.5.2.1 Output optical power. Output optical power shall be in accordance with the system specification(s).

* 4.5.2.2 Output waveform. The output optical waveform shall be in accordance with the system specification(s).

* 4.5.2.3 Output noise. The output noise shall be in accordance with the system specification(s).

* 4.5.2.4 Output spectral characteristics. The output spectral characteristics shall be in accordance with the system specification(s).

* 4.5.3 Terminal input characteristics. The terminal shall have the specified input characteristics at the optical bus interface at point A shown on Figure 9 or Figure 10.

* 4.5.3.1 Input waveform compatibility. The terminal shall be capable of receiving and operating with the incoming signals in accordance with the system specification(s).

* 4.5.3.2 Minimum input signal. The terminal shall achieve an error rate not greater than that specified in 4.5.3.3 when operated with the minimum input optical signal level and the environmental conditions in accordance with the system specification(s).

* 4.5.3.3 Error rate. The terminal shall exhibit a maximum word error rate of one part in 10^7 on all words received by the terminal after validation checks as specified in 4.4. A word error shall include any fault which causes the message error bit to be set in the terminal's status word or one which causes a terminal to not respond to a valid command. The terminal shall achieve this error rate when receiving two successive messages which differ in optical power by the maximum OSR in accordance with the system specification(s) for messages separated in time by the intermessage gap as specified in 4.3.3.7 (i.e., 4.0 μs), irrespective of order. The error test shall be run continuously until, for a particular number of failures, the number of words received by the

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terminal, including both command and data words, exceeds the required number for acceptance of the terminal or is less than the required number for rejection of the terminal in accordance with Table II. All data words used in the test shall contain random bit patterns. These bit patterns shall be unique for each data word in a message and shall change randomly from message to message.

4.6 Redundant data bus requirements. If redundant data buses are used, the requirements specified in Table II shall apply.

*TABLE II. Criteria for acceptance or rejection of a terminal for the error rate test.

TOTAL WORDS RECEIVED BY THE TERMINAL
(in multiples of 10^7)

No. of Errors	Reject (Equal or Less)	Accept (Equal or More)
0	N/A	4.40
1	N/A	5.21
2	N/A	6.02
3	N/A	6.83
4	N/A	7.64
5	N/A	8.45
6	0.45	9.27
7	1.26	10.08
8	2.07	10.89
9	2.88	11.70
10	3.69	12.51
11	4.50	13.32
12	5.31	14.13
13	6.12	14.94
14	6.93	15.75

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*TABLE II. Criteria for acceptance or rejection of a terminal for the error rate test.

TOTAL WORDS RECEIVED BY THE TERMINAL
(in multiples of 10^7)

No. of Errors	Reject (Equal or Less)	Accept (Equal or More)
15	7.74	16.56
16	8.55	17.37
17	9.37	18.19
18	10.18	19.00
19	10.99	19.81
20	11.80	20.62
21	12.61	21.43
22	13.42	22.24
23	14.23	23.05
24	15.04	23.86
25	15.85	24.67
26	16.66	25.48
27	17.47	26.29
28	18.29	27.11
29	19.10	27.92
30	19.90	28.73
31	20.72	29.54
32	21.53	30.35
33	22.34	31.16
34	23.15	31.97
35	23.96	32.78
36	24.77	33.00
37	25.58	33.00
38	26.39	33.00
39	27.21	33.00
40	28.02	33.00
41	33.00	N/A

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* 4.6.1 Electrical/optical isolation. Electrical and/or optical isolation between multiple-redundant data buses shall be as specified in the system specification(s).

4.6.2 Single event failures. All data buses shall be routed to minimize the possibility that a single event failure to a data bus shall cause the loss of more than that particular data bus.

4.6.3 Dual standby redundant data bus. If a dual redundant data bus is used, then it shall be a dual standby redundant data bus as specified in the following paragraphs.

4.6.3.1 Data bus activity. Only one data bus can be active at any given time except as specified in 4.6.3.2.

4.6.3.2 Reset data bus transmitter. If while operating on a command, a terminal receives another valid command, from the other data bus, it shall reset and respond to the new command on the data bus on which the new command is received. The terminal shall respond to the new command as specified in 4.3.3.8.

5. DETAILED REQUIREMENTS

* 5.1 Specific implementations. Specific fiber optic bus implementation, based on this standard, involving specifications of parameters such as optical transmitter output power, optical receiver minimum signal level (sensitivity), optical interfaces and optical cable configuration, shall be in accordance with system specifications which reference this standard, as required by the invitation for bid or request for proposal.

6. NOTES

6.1 Intended use. Multiplex data buses conforming to the requirements of this standard are intended for use in general military fiber optic applications.

6.2 Subject term (key word) listing.

Access coupler
Bit
Bit rate
Bus controller
Bus monitor
Cable Connectors
Data bus
Detector
Error rate
Fiber optics
Mode code
Modulation
Optical signal power
Optical signal terminal
Parity
Remote terminal
Source
Terminal
Time division multiplexing
Word

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Custodians:
Navy-AS
Air Force-11
Army-AV

Preparing Activity:
Navy-AS
Project Number MCCR-0025

APPENDIX

*10. GENERAL. The following paragraphs in this appendix are presented in order to discuss certain aspects of the standard in a general sense. They are intended to provide a user of the standard with more insight into the aspects discussed.

10.1 Redundancy. It is intended that this standard be used to support rather than to supplant the system design process. However, it has been found, through application experience in various aircraft, that the use of a dual standby redundancy technique is very desirable for use in integrating mission avionics. For this reason, this redundancy scheme is defined in 4.6 of this standard. Nonetheless, the system designer should utilize this standard as the needs of a particular application dictate. The use of redundancy, the degree to which it is implemented, and the form which it takes must be determined on an individual application basis. Figures 11 and 12 illustrate some possible approaches to dual redundancy. These illustrations are not intended to be inclusive, but rather representative. It should be noted that analogous approaches exist for the triple and quad redundant cases.

10.2 Bus controller. The bus controller is a key part of the data bus system. The functions of the bus controller, in addition to the issuance of commands, must include the constant monitoring of data bus and the traffic on the bus. It is envisioned that most of the routine minute details of bus monitoring (e.g., parity checking, terminal non-response time-out, etc.) will be embodied in hardware, while the algorithms for bus control and decision making will reside in software. It is also envisioned that, in general, the bus controller will be the general purpose airborne computer with a special input/output (I/O) to interface with the data bus. It is of extreme importance in bus controller design that the bus controller be readily able to accommodate terminals of differing protocols and status word bits used. Equipment designed to MIL-STD-1553A will be in use for a considerable period of time; thus, bus controllers must be capable of adjusting to their differing needs. It is also important to remember that the bus controller will be the focal point for modification and growth within the multiplex system and thus the software must be written in such a manner as to permit modification with relative ease.

*10.3 Multiplex selection criteria. The selection of candidate signals for multiplexlng is a function of the particular application involved, and criteria will in general vary from system to system. Obviously, those signals which have bandwidths of 400 Hz or less are prime candidates for inclusion on the bus. It is also obvious that video, audio, and high speed parallel digital signals should be excluded. The area of questionable application is usually between 400 Hz and 3 kHz bandwidth. The transfer of these signals on the data bus will depend heavily upon the loading of the bus in a particular application. The decision must be based on projected future bus needs as well as the current loading. Another class of

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in general are not suitable for multiplexing are those which can be typified by a low rate (over a mission) but possessing a high priority or urgency. Examples of such signals might be a nuclear event detector output or a missile launch alarm

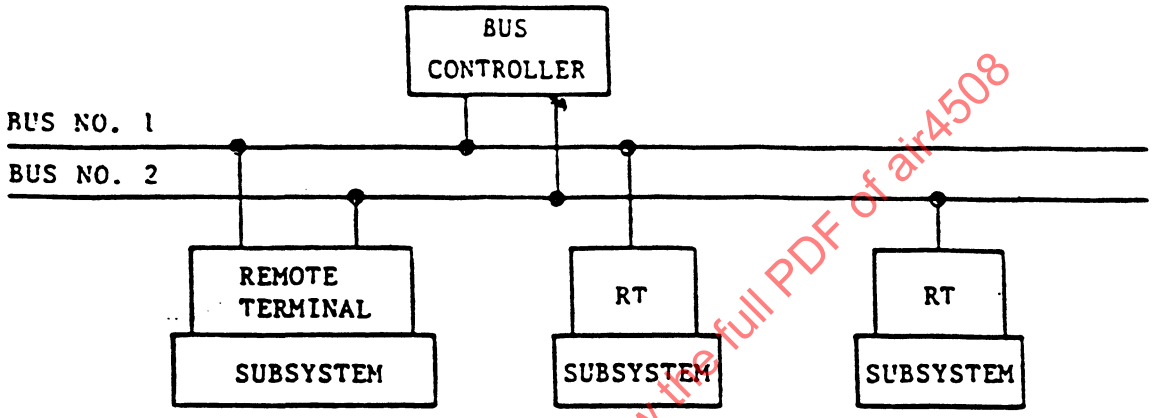
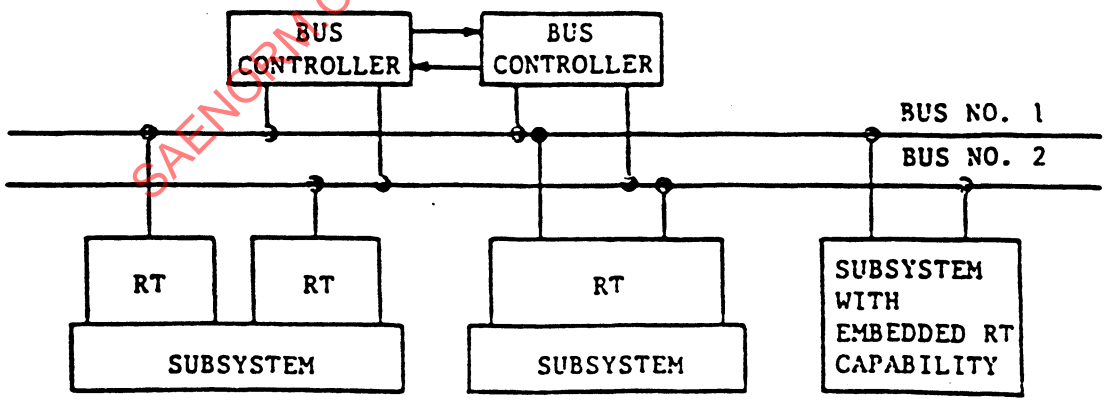


FIGURE 11. Illustration of possible redundancy



RT - REMOTE TERMINAL

FIGURE 12. Illustrations of possible redundancy.

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from a warning receiver. Such signals are usually better left hardwired, but they may be accommodated by the multiplex system if a direct connection to the bus controller's interrupt hardware is used to trigger a software action in response to the signal.

10.4 High reliability requirements. The use of simple parity for error detection within the multiplex bus system was dictated by a compromise between the need for reliable data transmission, system overhead and remote terminal simplicity. Theoretical and emperical evidence indicates that an undetected bit error rate of 10-12 can be expected from a practical multiplex system built to MIL-STD-1553B. It is expected that a MIL-STD-1553B bus implemented in Fiber Optics (DOD-STD-1773) will achieve a comparable undetected error rate. If a particular signal requires a bit error rate which is better than that provided by the parity checking, then it is incumbent upon the system designer to provide the reliability within the constraints of the standard or to not include this signal within the multiplex bus system. A possible approach in this case would be to have the signal source and sink extra data words to transfer the information. Another approach would be to partition the message, transmit a portion at a time, and then verify (by interrogation) the proper transfer of each segment.

*10.5 Use of broadcast option. The use of a broadcast message as defined in 4.3.3.6.7 of this standard represents a significant departure from the basic philosophy of this standard in that it is a message format which does not provide positive closed-loop control of bus traffic. The system designer is strongly encouraged to solve any design problems through the use of the three basic message formats without resorting to use of the broadcast. If system designers do choose to use the broadcast command, they should carefully consider the potential effects of a missed broadcast message, and the subsequent implications for fault or error recovery design in the remote terminals and bus controllers, which corresponds to paragraph number 10.5 of MIL-STD-1553B.

*20. OPTICAL BUS NETWORK CONSIDERATIONS

*20.1 Comparison with wire bus networks. An optical data bus network is more analogous to a constant current electrical network than to a constant voltage network, such as the wire bus network described in MIL-STD-1553B. Thus, the effective distribution of optical power from a bus terminal to N other terminals on the bus calls for the consideration of bus network configurations considerably different from the tee-tap daisy chain method of MIL-STD-1553B. Worst-case optical losses for line replaceable unit (LRU) connectors, in-line bulkhead connectors, access couplers, cable, etc., must be combined with available optical power and receiver unit sensitivity to derive optical power budget and optical signal range (OSR) figures for any proposed bus configuration. The power budget

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must also be computed taking into account applications factors such as temperature, altitude, humidity, statistical component variations, age and radiation effects over the ranges detailed in the applicable system and item specifications. Reliability, installation, maintainability and related life cycle cost factors must also be considered, especially with regard to use of active (repeater) access coupling devices.

20.2 Typical fiber optic data bus configurations. Fiber optic data bus configuration is determined by selection of the coupling elements which provide the terminals with access to the bus. Tee couplers will allow a single transmission line to be tapped at selected locations. Depending upon the mode of operation of the tee couplers, either a one dimension, bidirectional data bus or a looped, unidirectional data bus can be constructed. Of the basic fiber optic data bus configurations, the bidirectional tee-coupled configuration is closest in form to the MIL-STD-1553B wire bus. Use of a star coupler required that each terminal be provided with a transmission path to and from the coupler. The path can consist of either one or two fiber optic transmission lines depending upon the type of star coupler chosen. Figure 13 illustrates some of the fundamental fiber optic data bus configurations.

*20.3 Optical signal power reduction in access couplers. Access couplers exhibit three optical power reduction mechanisms. The first is power division. Unlike data bus systems which utilize a wire interconnection, a fiber optic system divides signal power among all terminals having access to the bus. This division of power is accomplished by one or more access couplers. Thus, for a N port transmissive star coupler in which input power P_{in} is evenly distributed, the power available from any port due to this mechanism will equal P_{in}/N. This division loss, L_D, can be expressed as:

$$L_D = 10 \log N \text{ dB}$$

The second reduction mechanism results from the inefficiency of the coupler itself and is called excess loss, L_E. Excess loss can be described by:

$$L_E = 10 \log \left[1 - \frac{\sum_{i=1}^{N} Pout_i}{P_{in}} \right] dB$$

where P_{in} is the optical power into the coupler and $Pout_i$ is the

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optical power out of the ith output port. These losses are attributable primarily to optomechanical factors, such as packing fraction, numerical aperture mismatch, scattering and assembly tolerance losses.

Finally, power is reduced by interface losses, L_i, at the cable-to-coupler and coupler-to-cable interfaces. These losses may be due to either connectors or splices, depending on the system assembly technique adopted, but each interface will have a characteristic loss, L_i.

30. GENERAL REQUIREMENTS

30.1 Option selection. This section of the appendix shall select those options required to further define portions of the standard to enhance tri-service interoperabillty. References in parenthesis are to paragraphs in standard which are affected.

30.2 Application. Section 30 of this appendix shall apply to all dual redundant applications for the Army, Navy, and Air Force. All Air Force aircraft internal avionics applications shall be dual standby redundant, except where safety critical or flight critical requirements dictate a higher level of redundancy.

30.3 Unique address (4.3.3.5.1.2). All remote terminals shall be capable of being assigned any unique address from decimal address 0 (00000) through decimal address 30 (11110). The address shall be established through an external connector which is part of the system wiring and connects to the remote terminal. Changing the unique address of a remote terminal shall not require the physical modification or manipulation of any part of the remote terminal. The remote terminal shall, as a minimum, determine and validate its address during power-up conditions. No single point failure shall cause a terminal to validate a false address. The remote terminal shall not respond to any messages if it has determined its unique address is not valid.

30.4 Mode codes (4.3.3.5.1.7).

30.4.1 Subaddress/mode (4.3.3.5.1.4). An RT shall have the capability to respond to mode codes with both subaddress/mode of 00000 and 11111. Bus controllers shall have the capability to issue mode commands with both subaddress/mode of 00000 and 11111. The subaddress/mode of 00000 and 11111 shall not convey different information.

30.4.2 Required mode codes (4.3.3.5.1.7).

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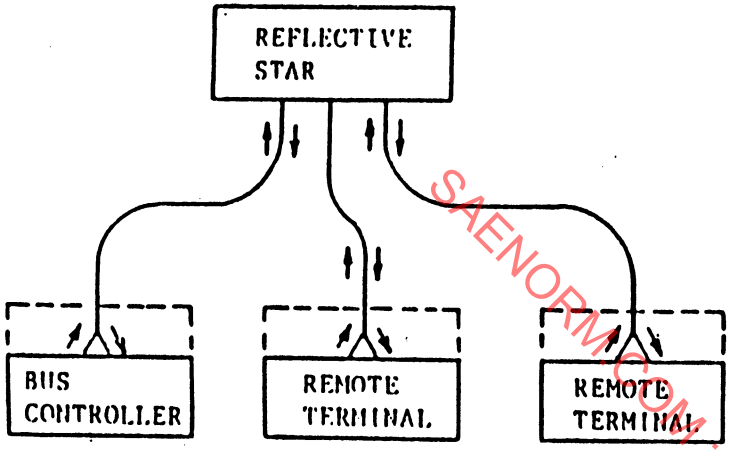
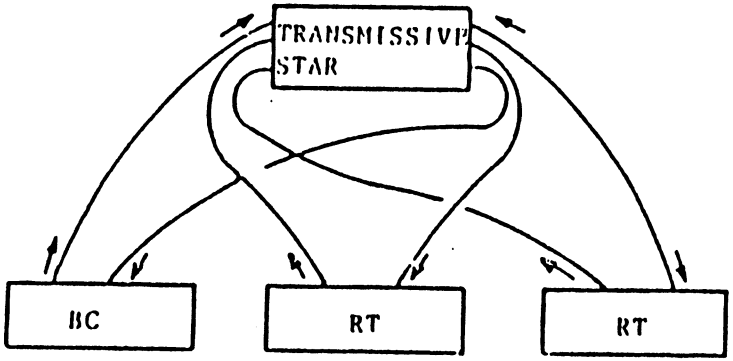
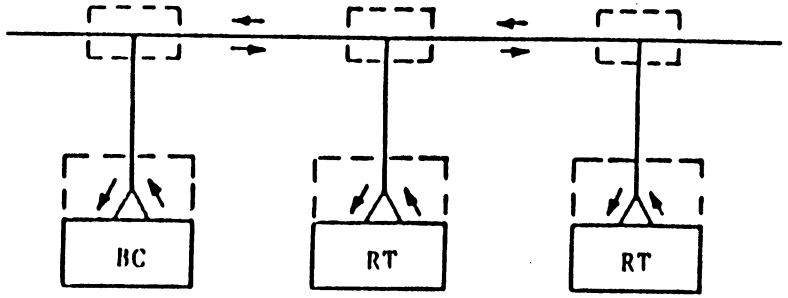


a. REFLECTIVE STAR COUPLED BUS

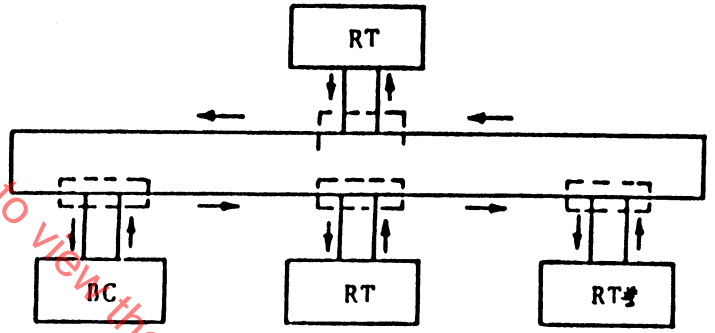


b. TRANSMISSIVE STAR COUPLED BUS

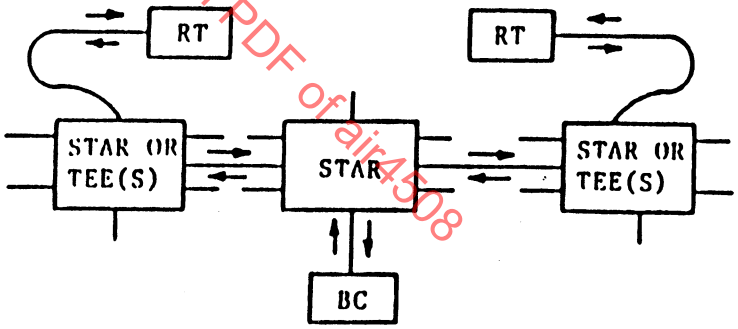
NOTE: STAR AND TEE ACCESS COUPLERS MAY BE PASSIVE OR ACTIVE AND MAY RESIDE WITHIN OR EXTERNAL TO THE LRUs.



c. BI-DIRECTIONAL T-COUPLED BUS



d. UNI-DIRECTIONAL T-COUPLED BUS



e. BI-DIRECTIONAL HYBRID COUPLED BUS

FIGURE 13. Typical fiber optic data bus system configurations.

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30.4.2.1 Remote terminal required mode codes. An RT shall implement the following mode codes as a minimum:

Mode Code	Function
00010	Transmit status word
00100	Transmitter shutdown
00101	Override transmitter shutdown
01000	Reset remote terminal

30.4.2.2 Bus controller required mode codes. The bus controller shall have the capability to implement all of the mode codes as defined in 4.3.3.5.1.7. For Air Force applications, the dynamic bus control mode command shall never be issued by the bus controller.

30.4.3 Reset remote terminal (4.3.3.5.1.7.9). An RT receiving the reset remote terminal mode code shall respond with a status word as specified in 4.3.3.5.1.7.9 and then reset. While the RT is being reset, the RT shall respond to a valid command with any of the following: No response on either data bus, status word transmitted with the busy bit set, or normal response. If any data is transmitted from the RT while it is being reset, the information content of the data shall be valid. An RT receiving this mode code shall complete the reset function within 5.0 milliseconds following transmission of the status word specified in 4.3.3.5.1.7.9. The time shall be measured from the mid-bit zero crossing of the parity bit of the status word to the mid-sync zero crossing of the command word at point A on Figures 9 and 10.

30.4.4 Initiate RT self-test (4.3.3.5.1.7.4). If the initiate self-test mode command is implemented in the RT, then the RT receiving the initiate self-test mode code shall respond with a status word as specified in 4.3.3.5.1.7.4 and then initiate the RT self-test function. Subsequent valid commands may terminate the self-test function. While the RT self-test is in progress, the RT shall respond to a valid command with any of the following: No response on either data bus, status word transmitted with the busy bit set, or normal response. If any data is transmitted from the RT while it is in self-test, the information content of the data shall be valid. An RT receiving this mode code shall complete the self-test function and have the results of the self-test available within 100.0 milliseconds following transmission of the status word specified in 4.3.3.5.1.7.4. The time shall be measured from the mid-bit zero crossing of the parity bit of the status word to the mid-sync zero crossing of the command word at point A on Figures 9 and 10.

30.5 Status word bits (4.3.3.5.3).

30.5.1 Information content. The status word transmitted by an RT shall contain valid information at all times, e.g., following RT power-up, during initialization and during normal operation.

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30.5.2 Status bit requirements (4.3.3.5.3). An RT shall implement the status bits as follows:

Message error bit (4.3.3.5.3) - Required.

Instrumentation bit (4.3.3.5.3.4) - Always logic zero.
Service request bit (4.3.3.5.3.5) - Optional.

Reserved status bits (4.3.3.5.3.6) - Always logic zero.

Broadcast command received bit (4.3.3.5.3.7) - If the RT implements the broadcast option, then this bit shall be required.

Busy bit (4.3.3.5.3.8) - As required by 30.5.3.

Subsystem flag bit (4.3.3.5.3.9) - If an associated subsystem as the capability for self-test, then this bit shall be required.

Dynamic bus control acceptance bit (4.3.3.5.1.10) - If the RT implements the dynamic bus control function, then this bit shall be required.

Terminal flag bit (4.3.3.5.3.11) - If an RT has the capability for self-test, then this bit shall be required.

30.5.3 Busy bit (4.3.3.5.3.8). The existence of busy conditions is discouraged. However, any busy condition, in the RT or the subsystem interface that would affect communication over the bus shall be conveyed via the busy bit. Busy conditions, and thus the setting of the busy bit, shall occur only as a result of particular commands/messages sent to an RT. Thus for a non-failed RT, the bus controller can, with prior knowledge of the remote terminal characteristics, determine when the remote terminal can become busy and when it will not be busy. However, the RT may also set the busy bit (in addition to setting the terminal flag bit or subsystem flag bit) as a result of failure/fault conditions within the RT/subsystem.

30.6 Broadcast (4.3.3.6.7). All hardware implementatlons shall include both command/response and broadcast capability. If the broadcast option is implemented the RT shall be capable of distinguishing between a broadcast and a non-broadcast message to the same subaddress for non-mode command messages. The RT address of 11111 is reserved for broadcast and shall not be used for any other purpose.

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30.7 Data wraparound (4.3.3.5.1.4). Remote terminals shall provide a receive subaddress to which one to N data words of any bit pattern can be received. Remote terminals shall provide a transmit subaddress from which a minimum of N data words can be transmitted. N is equal to the maximum word count from the set of all messages defined for the RT. A valid receive message to the data wraparound receive address followed by a valid transmit command to the data wraparound transmit subaddress, with the same word count and without any intervening valid commands to the RT, shall cause the RT to respond with each data word having the same bit pattern corresponding to the received data word.

30.8 Message formats (4.3.3.6). Remote terminals shall, as a minimum, implement the following non-broadcast message formats as defined in 4.3.3.6: RT to BC transfers, BC to RT transfers, RT to RT transfers (receive and transmit), and mode code command without data word transfers. For non-broadcast messages, the RT shall not distinguish between data received during a BC to RT transfer or data received during a RT to RT transfer (receive) to the same address. The RT shall not distinguish between data to be transmitted during an RT to BC transfer or data to be transmitted during an RT to RT transfer (transmit) from the same subaddress. Bus controllers shall have the capability to issue all message formats defined in 4.3.3.6.

30.9 RT to RT validation (4.3.3.9). For RT to RT transfers, in addition to the validation criteria specified in 4.4.3.6, if a valid receive command is received by the RT and the first data word is received after 57.0 ± 3.0 microseconds, the RT shall consider the message invalid and respond as specified in 4.3.3.6. The time shall be measured from the mid-bit zero crossing of the parity bit of the receive command to the mid-sync zero crossing of the expected data word at point A as shown on Figures 9 and 10. It is recommended that the receiving RT of an RT to RT transfer verify the proper occurrence of the transmit command word and status word as specified in 4.3.3.6.3.

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APPENDIX B.

SAMPLE FIBER OPTIC TRANSMITTER AND RECEIVER DEVELOPMENT/PROCUREMENT DETAIL SPECIFICATIONS.

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APPENDIX B.

SAMPLE FIBER OPTIC TRANSMITTER AND RECEIVER DEVELOPMENT/PROCUREMENT DETAIL SPECIFICATIONS.

B-1.0. Sample Fiber Optic Transmitter and Receiver Development/General Specification and Procurement Detail Specifications.

B-1.1. Purpose of The Specification Documents.

These sample specifications provide examples of a general development specification for the transmit/receive unit under MIL-STD-1773 (inclusion B-1.) and the detail level of a development/procurement specification necessary to define Fiber Optic Hybrid Microcircuit transmitter (inclusion B-2.) and receiver (inclusion B-3.) modules suitable for use in either an unenhanced standard MIL-STD-1773 terminal hardware set or an enhanced 1 Mb/S. - 8 Mb/S. Dual-Speed 1773 terminal hardware set. The Dual-Speed application is defined by the Preliminary General Specification in inclusion D-1. of Appendix D.

The module specifications typically define the following parameters:

- A listing of higher level standards and specifications and a listing of the lower level assembly specification documents that are included by reference.

  Complete documentation for these modules will additionally include schematic diagram, assembly drawings, purchased component and materials specifications and baselined fabrication/assembly/test process specifications.

- A definition of the mechanical configuration of the modules.

- Functional electrical/optical performance limits required by the application.

- The environmental test conditions and operating environment reflecting the application requirements.

- Quality Assurance provisions, inspection and test procedures/methods required to guarantee conformance.

The functional requirements defined in these sample documents represent a compromise that will meet all requirements defined in MIL-STD-1773 for a Remote Terminal or Bus Controller (including Intermessage Recovery and better than 1 exp-7 word error rate) as well as all additional requirements to implement the Dual-Speed enhancement of Appendix D.

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APPENDIX B, INCLUSION B-1

PROPOSED DEVELOPMENT SPECIFICATION, GENERAL FIBER OPTIC TRANSMIT/RECEIVE UNIT, BI LEVEL MANCHESTER MODULATION

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MIL-S-1773

PROPOSED DEVELOPMENT SPECIFICATION, GENERAL, FIBER OPTIC TRANSMIT/RECEIVE UNIT, BILEVEL MANCHESTER MODULATION.

NOTE: This draft, dated 15 April, 1990, was prepared by the SAE-AS3A Fiber Optics Committee, has not been approved and is subject to modification.

DO NOT USE FOR PROCUREMENT PURPOSES.

1.0. SCOPE.

This specification establishes the general performance and test requirements for a fiber optics data bus interface developed in accordance with MIL-STD-1773. Specifically, this implementation shall utilize a Manchester II Biphase Level encoded, bilevel signal modulation format on the optical media. Required performance levels shall be in accordance with detail specifications which reference this general specification.

1.1 CLASSIFICATION.

Fiber Optic data bus mechanizations based on MIL-STD-1773 (which specifies MIL-STD-1553 compatibility and the sub-system interface) and this specification (which delineates general provisions and requirements for bilevel (on/off) Manchester encoded modulation on the optical bus) can further be sub-divided into Types, which have application specific hardware configuration and performance requirements. Type characteristics and requirements will be specified in detail specifications which reference the general specification. Optical data bus hardware built to a given Type specification should be compatible and capable of data communications.

1.1.1 DEFINED TYPES.

Bus Mechanization Types will be defined based on major characteristics which will be specified in the application detail specification. Some of the characteristics that may define Type are: optical fiber utilized, optical wavelength of signal, optical power budget requirement, operating environment.

2.0. APPLICABLE DOCUMENTS.

2.1. ISSUE OF DOCUMENTS.

The following documents of the issue in effect on the date of invitation for bids or request for proposal, unless otherwise indicated, form a part of this specification to the extent specified herein.

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MILITARY SPECIFICATIONS

MIL-B-5087 - Bonding, Electrical and Lightning Protection for Aerospace Systems.
DOD-C-85045C - Cables, Fiber Optic, General Specifications for.
MIL-E-5400 - Electronic Equipment, Aircraft, General Specification for.
MIL-T-18303 - Test Procedures; Preproduction and Acceptance for Aircraft Electronic Equipment, Format for.
MIL-T-29504 - Termini, Connector, Fiber Optic, General.

MILITARY STANDARDS

MIL-STD-1773 - Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus.
DOD-STD-1678 - Fiber Optics Test Methods and Instrumentation.
MIL-STD-415 - Test Provisions for Electronic Systems and Associated Equipment Design, Criteria for.
MIL-STD-454 - Electronic Equipment, General Requirements for.
MIL-STD-461 - Electromagnetic Interference Characteristics, Requirements for Equipment.
MIL-STD-462 - Electromagnetic Interference Characteristics, Measurement of.
MIL-STD-704 - Electric Power, Aircraft, Characteristics and Utilization of.
MIL-STD-781 - Reliability Tests, Exponential Distribution.
MIL-STD-810 - Environmental Test Methods for Aerospace and Ground Equipment.
MIL-STD-882 - System Safety Program for Systems, Associated Subsystems and Equipment, Requirements for.

HANDBOOKS AND PAMPHLETS

MIL-HDBK-217 - Reliability Prediction of Electronic Equipment.
DH 1-4 - AFSC Design Handbook, Electromagnetic Compatibility.
DH 1-6 - AFSC Design Handbook, System Safety.

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2. OTHER PUBLICATIONS.

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bid or request for proposal shall apply.

Society of Automotive Engineers (SAE)
AIR 4508, MIL-STD-1773 Users Handbook.

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Electronic Industries Association (EIA)
Fiber Optic Test Procedures:

EIA-455-27A-86 (FOTP-27).	- Methods for Measuring Outside (uncoated) Diameter of Optical Waveguide Fibers.
EIA-455-29A-89 (FOTP-29).	- Refractive Index Profile, Transverse Interference Method.
EIA-455-44A-86 (FOTP-44).	- Refractive Index Profile, Refracted Ray Method.
EIA-455-45A-88 (FOTP-45).	- Microscope Method for Measuring Fiber Geometry of Optical Waveguide Fibers.
EIA-455-S1-83 (FOTP-51).	- Pulse Distortion Measurement of Multimode Glass Optical Fiber Information Transmission Capacity.
TIA-4 55-55B-90 (FOTP-55).	- End View Method for Measuring Coating and Buffer Geometry of Optical Fibers.
EIA- 455-58-84 (FOTP-58).	- Core Diameter Measurement of Graded Index Optical Fibers.

National Burenu of Standards

NBS Handbook 140, Optical Waveguide Communications Glossary.

3.0. REQUIREMENTS.

3.1. ITEM DEFINITION.

The Fiber Optic Transmitter/Receiver Unit (FOTRU) equipment, described herein, provides a bidirectional interface between an optical bus network (the media) and the host subsystem Bus Interface Unit (BIU). The equipment is intended to be incorporated within an avionics subsystem and to provide the interface between optical and electrical domains. The equipment is comprised of two elements: (a) an optical interface for connecting the equipment to the media, which may be comprised of optical fiber(s) from the bus connector to the optoelectronic modules or optical connector(s) integrally mounted on the modules and (b) optoelectronic modules which perform the bidirectional optical/electrical conversions. The BIU, which provides functions such as clock recovery, bit detection, etc., is involved in this specification only in that the FOTRU electrical interface must be fully compatible with the BIU interface. Both the BIU and the FOTRU shall be fully characterized in their respective detail specifications.

3.1.1. TERMINAL DIAGRAM.

The fiber optic data bus system terminal is shown in Figure 1.

3.1.2. INTERFACE DEFINITION.

The FOTRU/BIU and optical bus interface are shown in Figure 2.

3.1.2.1. FOTRU/BIU INTERFACE.

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The interface between the Fiber Optic Transmitter/Receiver Unit and the Bus Interface Unit shall be as specified in MIL-STD-1773 and the detail application specification.

3.1.2.2. FOTRU OPTICAL INTERFACE.

The FOTRU and media optical interface shall be as described below.

3.1.2.2.1. FIBER CABLE I/O INTERFACE.

For the purposes of this specification, all optical power levels and insertion losses are defined as at or between the ports defined in

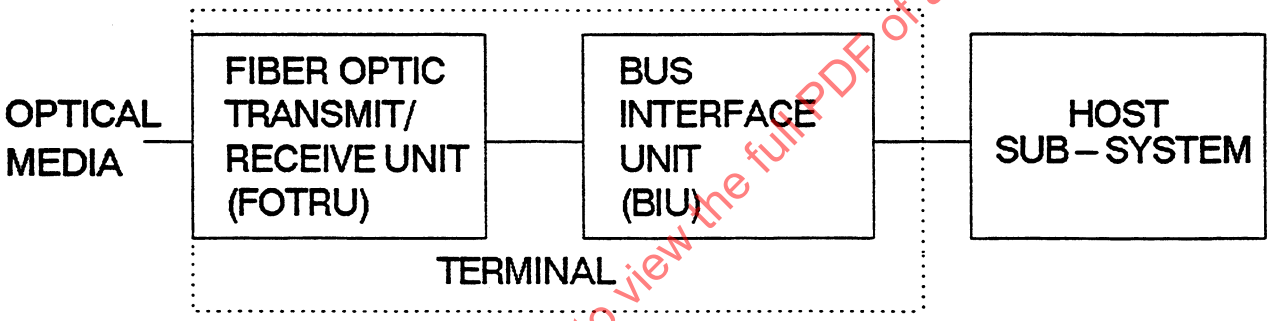

Figure 1. Block Diagram of Fiber Optic Bus System Terminal.

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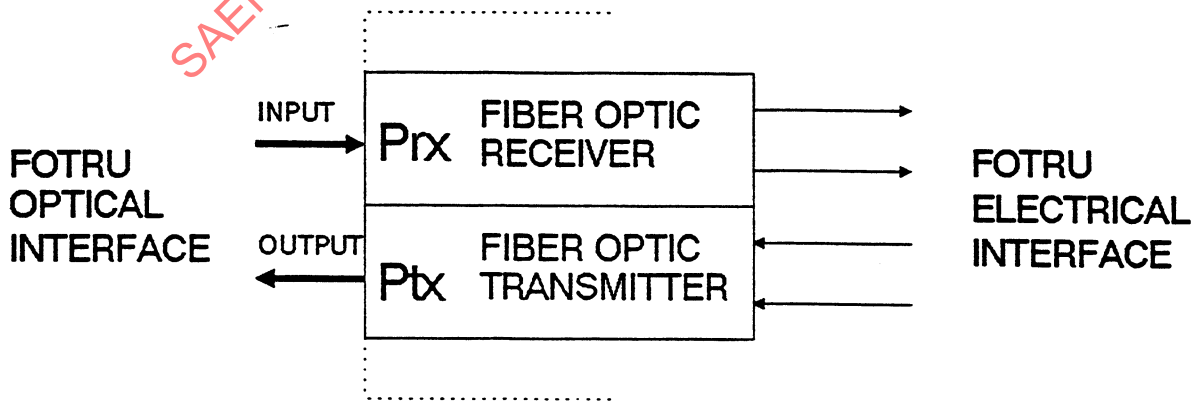

Figure 2. FOTRU Interfaces.

the following paragraphs and shown in Figure 2. The connectors constituting the defined ports DO NOT accrue a connector loss, as these losses are incorporated in the defined optical power levels. The losses of any other connectors used in the system and fiber media attenuation must fall between the limits of the optical power budget defined in respect to these ports and are the responsibility of the system design activity to define. For access to the bus media, optical connections to these ports shall be accomplished with connector types and termini selected by the system design activity, utilizing the optical fiber defined below.

Each station shall have a receiver input port (Prx) and a transmitter output port (Ptx). These ports are defined as either:

(a) The connector on the Transmitter or Receiver Module, if they are equipped with connectors, OR

(b) The connector on the end of the integral "pigtail" fiber on a Transmitter or Receiver Module if so equipped.

The optical losses between these points and the optical media external to the terminal enclosure (which will include any optical connectors internal to the terminal enclosure and the loss accrued at the terminal enclosure bulkhead connector) must be included in the overall system power budget by the terminal design activity.

This method of specifying the transmit and receive ports is necessary to enable the specification and test of the transmitter and receiver functions as "components" for design or procurement purposes. The specification does NOT define or control the internal configuration of the terminal, so it cannot anticipate what losses may be incurred. It is therefor incumbent upon the terminal design activity to make these decisions.

The FOTRU optical source and optical detector devices shall be connected to the optical media via individual fibers for transmit and receive functions. These optical fibers shall have the detail characteristics as described below and enumerated in the application detail specification (parameters (d) - (h) are described further by Figure 3.):

Fiber Characteristics:

(a) Fiber construction/materials. (may be satisfied by specifying one or more equally acceptable manufacturers/part numbers.)

(b) PS: Proof Test Stress level, kilopounds/square inch (Kpsi).

(c) RI: Refraction Index Type, step or graded.

(d) Dcd: Fiber cladding (outside) diameter and tolerance, microns. This parameter shall be measured per EIA-455-27A-86 (FOTP-27) and Figure 3.

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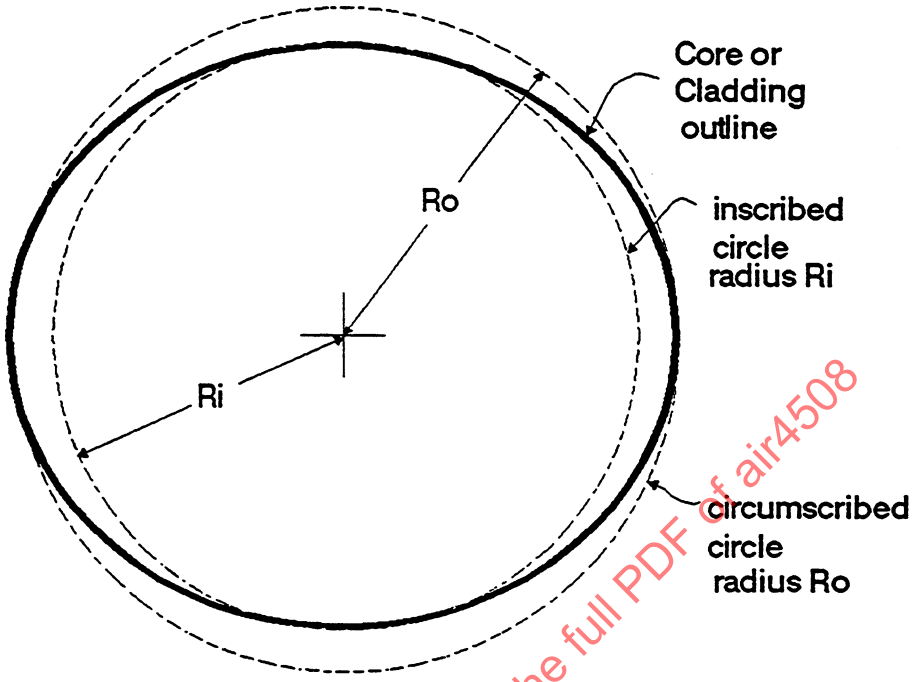
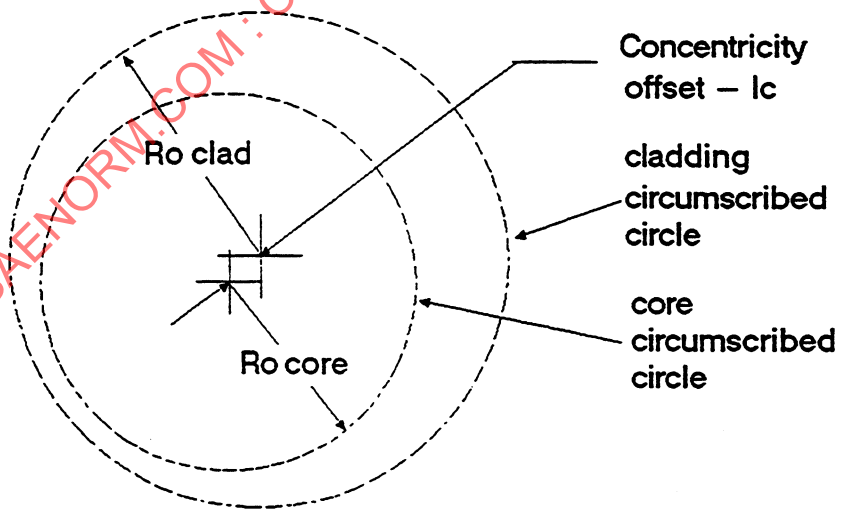


Diameter of Core (Dcr) or Diameter of Clad (Dcd) = 2 x Ro.

Eccentricity = [(Ro − Ri) / 2 Ro] x 100%

Ecr = core Eccentricity, Ecd = cladding Eccentricity.



Concentricity = [Ic / 2 x Ro clad] x 100% = [Ic / Dcd] x 100%

Figure 3. Fiber Geometry Parameters.

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(e) Dcr: Fiber core diameter and tolerance, microns. If graded index, This parameter shall be measured per EIA-455-58-84 (FOTP-58), else per EIA-455-45A-88 (FOTP-45) and Figure 3.

(f) C: Fiber core/cladding concentricity, variance maximum.

(g) Ecr: Fiber core Eccentricity, variance maximum.

(h) Ecd: Fiber Cladding Eccentricity, variance maximum. Parameters (f) - (h) shall be measured per EIA-455-45A-88 (FOTP-45) and Figure 3.

(i) Buffer coating material/construction.

(j) Db: Buffer diameter and tolerance, microns. This parameter shall be measured per TIA-455-55B-90 (FOTP-55).

(k) NA: calculated Numerical Aperture and tolerance, (the sine of the maximum Launch Acceptance Half Angle).

NA = [n1 expl - n2 exp2] expo.5, dimensionless.

were: n1,n2 = refraction indices of the core (the central axis, if graded index) and cladding, respectively.

The refractive index profile shall be measured per TIA455-44A-89 (FOTP-44) or TIA-455-29A (FOTP-29).

(l) BWo: Minimum Optical bandwidth (at the -3 dB optical or -6 dB post-detection electrical levels) as limited by multimode and chromatic dispersion, at the specified wavelength W0nom, MHz Km.

BWo = 0.44 / delta Tf, nanosec/Km and
delta Tf = [w2 exp2 - w1 exp2] exp0.5

where: w1 = the full width at half maximum of the pulse at the transmitter end and w2 = the maximum allowable full width at half maximum of the pulse at the receiver end.

The pulse dispersion shall be measured per EIA-455-51-83 (FOTP-51).

Cable Characteristics:

(m) Lo: Optical attenuation and tolerance of the fully cabled fiber, at wave length W0 and over the operating temperature range, dB/Km. The attenuation of the fully

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cabled fiber is specified because of the possibility of excessive "microbending" loss, in some fiber types, induced by cabling of the fiber.

(n) Inner jacket (if any) material/construction.

(o) Dij: Inner jacket (if any) diameter and tolerance, millimeters.

(p) Strength members (if any) material and configuration.

(q) Outer jacket material/construction.

(r) Doj: Outer jacket diameter and tolerance, millimeters.

(s) FLmax: Maximum total fiber length allowed in the system between communicating terminals.

The specification of parameters (d), (j), (o), (p) and (r) are critically related to the selection of a suitable terminus or vice versa. Parameters (c) - (h) and (k) are critical to the determination of connectorization and splice losses (in addition to terminus mechanical tolerances). Parameters (a), (b) and (i) are critical to static fatigue failure/service life prediction for the optical cable after installation in the aircraft/platform. Parameters (a) and (m) are especially affected by a nuclear radiation environment. See Chapter 8. of the MIL-STD-1773 USERS HANDBOOK for a discussion of nuclear effects. If a nuclear environment or other special environmental requirements are specified, documentation beyond the scope of this specification will be required to define the special environment and the effect on the Lo parameter.

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3.1.2.2.2. FOTRU OPTICAL SIGNAL FORMAT.

The optical signal transmitted and received by the FOTRU shall be unipolar Manchester II Biphase Level encoding as defined in MIL-STD-1773. The signal shall be bilevel, ie, have two optical power states. A Manchester logical one shall be encoded as an ON optical state of one half bit period duration followed by an OFF optical state of one half bit period duration. A logical zero shall be a one half bit period OFF state followed by a one half bit period ON state.

3.1.2.2.3. MEASUREMENT OF LAUNCHED AND RECEIVED OPTICAL POWER LEVELS.

Both the ON and OFF state power levels shall be between the maximum and minimum levels defined in the application detail specification at either the transmit or the receive end of the media. At the transmit end, the power level shall be defined as that launched in a standard test fiber of the type specified for

the system media. This test fiber shall be as close to nominal in all parameters of 3.1.2.2.1. (a) - (j) as is possible to obtain and shall be one meter +/-5 cm. in length with provisions for cladding mode stripping. The output of the test fiber shall be measured when connectorized as required to either join to the output connector of a connectorized transmitter or couple to the pigtail of a pigtailed transmitter (port Ptx). If the connection devices utilized do not contain anti-rotation keying mechanisms, the test fiber shall be rotated to achieve maximum coupling. Test fiber termini shall be premium versions that are selected for close fit with the measured fiber diameter at the time of termination.

The receiver input power related to a performance parameter (such as Bit Error Rate, Distortion, etc.) shall be defined as the power measured at the output of the above standard test fiber that was or will be coupled to the receiver input connector or pigtail (port Prx) for the measurement of the performance parameter of interest.

All optical power levels shall be stated as "PEAK values" and must either be measured as peak or measured as average with correction for the duty cycle applied to convert to peak. This method forces the activity making the measurements to apply the proper correction factor for duty cycle, rather than leave a potential ambiguity for the later observer of the test data. **Caution, average measurements without a known duty cycle are MEANINGLESS.**

3.1.2.2.4. OPERATING WAVELENGTH.

The transmitter optical source spectrum shall have a wavelength of peak radiance between the limits of 820 and 850 nanometers and spectral full width at half maximum power of less than/equal 60 nanometers. The receiver detector shall have a wavelength dependant responsivity of no less than 90% of its maximum value between the limits of 720 and 950 nanometers. The upper limit on source spectrum is dictated by the possible necessity of using "wet" fiber to meet a radiation environment requirement. These "wet" fibers have an effective spectral cutoff at 850 nanometers due to an exceedingly high hydroxyl absorption band.

3.1.2.3. HOST SUBSYSTEM/TERMINAL INTERFACE DEFINITION.

The Host/Terminal interface shall be as defined in the detail application specification.

3.1.2.4. ELECTRICAL POWER.

The FOTRU shall operate from power supplied by the host avionics subsystem. The hosts internal power supplies shall in

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compliance with MIL-STD-704 and provide the level of regulation and noise suppression required by the FOTRU functions as enumerated in the application detail specification. DC power distribution and filtering within the FOTRU shall follow good engineering practice for high gain noise sensitive circuitry. The power supplies will meet all the requirements when energized from prime sources having characteristics and limits as defined in MIL-STD-704 for Category B equipment. No equipment damage shall result from power interrupts on a single supply or any on one or more of multiple supplies. Operation shall return to normal upon resumption of electrical power. The maximum allowable power consumption of the FOTRU shall be defined by the application detail specification.

3.1.2.5.COOLING REQUIREMENTS.

The FOTRU shall be designed to operate in the environments specified in 3.2.5. with only the cooling provisions supplied by the host system and defined in the application detail specification.

3.1.3. MAJOR COMPONENT LIST.

Not Applicable.

3.1.4. GOVERHENT-FURNISHED PROPERTY LIST.

None.

3.2. ITEM CHARACTERISTICS.

The functional, performance, physical and operability characteristics of the Fiber Optic Transmit/Receive Unit shall be in accordance with the requirements below as a minimum and as enumerated /modified by the application detail specification. The use of optical fiber as a transmission medium in lieu of wire as in MIL-STD-1553, shall be totally transparent to the host avionics system.

3.2.1. PERFORMANCE.

3.2.1.1.OPTICAL BUS TRANSMISSION DATA RATE.

BRT: Bit Rate Transmitted, Megabits/Second.

The data rate transmitted on the bus shall be 1.0 Megabits/Second, with a combined accuracy and long term stability in accordance with MIL-STD-1773, paragraph 4.3.3.3., titled "Transmission Bit Rate".

3.2.1.2. OPTICAL OUTPUT CHARACTERISTICS OF THE TRANSMIT FUNCTION.

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3.2.1.2.1. OUTPUT OPTICAL POWER.

(a) RPOon: Radiant Power Output On, microwatts.

(b) RPOoff: Radiant Power Output Off, nanowatts.

The optical power coupled into the standard test fiber by the transmitter in both the logical ON and the logical OFF state, as measured by the method described in 3.1.2.2.3., shall comply with the maximum and minimum limits stated in the application detail specification over the entire specified environmental and power supply variance.

(c) RPOi: Radiant Power Output Inactive, nanowatts.

An inactive (non-transmitting) terminal shall launch a power level no greater than 30 dB below the maximum ON level as measured anywhere in the media. The cumulative power launched by all inactive transmitters connected to the media, as measured at any receiver input, shall not generate RMS Shot noise current (In) greater than 50% of the RMS self noise current of the receiver (Ir). The RMS Shot noise is calculated as:

Id = [measured total receiver optical pedestal power input (watts) x detector responsivity (amps/watt)], amps.

In = ([(2 x q x Id) exp0.5] x BWn exp0.5), amps RMS.

where: Id = induced detector photo current due to the optical pedestal, amps.
In = the resultant Shot noise current, amps RMS.
q = charge on an electron = 1.602 exp-19 coulombs.

BWn = Noise bandwidth of the receiver = full width at half maximum (-3 dB) receiver signal bandwidth (BWs) x Pi/2, Hertz.

Receiver RMS self noise (Ir) is defined as the receiver Noise Equivalent Optical Power (NEP, watts referred to the input) multiplied by the detector responsivity (R, amps/watt), Ir = NEP x R, amps RMS.

3.2.1.2.2. TRANSMITTER OUTPUT OPTICAL WAVEFORM.

(a) PW: Pulse Width (distortion + jitter), nanoseconds.

The full width at half amplitude of either the ON or OFF optical periods, exclusive of the inactive Intermessage Gap period, shall be 500, 1000, 1500 or 2000 nanosecs +/-25 nanoseconds as measured at the transmitter output. This width tolerance range shall include the total algebraic sum of all distortion plus intersymbol interference jitter introduced by the

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transmitter and the logic driving it.

Transmitter pulse width distortion is the broadening or shrinking of the width of either high or low level pulses, relative to the nominal width of the signaling Baud. The total observed distortion consists of two components, Distortion and Intersymbol Interference.

Distortion is a long term (slowly varying) parameter produced by the effect of power supply and temperature variations on the operation of the circuit. Distortion shall be +/-10 nanoseconds maximum, when measured by the method shown in Figure 4.A., as the time between the rising and falling edges of the pulses in an "eye" diagram display at the 50% amplitude level. PLUS distortion is defined as broadening of the width of the High level pulses (or the crossover of the rising edge and falling edge shown in the "eye" diagram in the figure occurs above the 50% amplitude level). MINUS distortion results from broadening of the Low level pulse (or the crossover occurring below the 50% level in the diagram). This test shall be performed with a square wave input with a period of 1000, 2000, 3000 or 4000 nanoseconds, whichever gives the largest value. The duty cycle of the logic input to the transmitter shall be adjusted to exactly 50%, as measured at the threshold level of the logic waveform, before the measurement is made on the optical output wave form.

The second component is Intersymbol Interference jitter, produced by the upper and lower frequency cutoff (bandwidth) limitation of the circuitry, when successive pulses of different widths are transmitted.

D+J is measured as the time between when the earliest pulse edge crosses the 50% level until the latest pulse edge crosses the 50% level, as shown in the "eye" diagram of Figure 4.B. and stated as +/-(the total divided by 2). This test shall be performed with a worstcase pulse pattern driving the transmitter. The worstcase pulse pattern shall include the full range of duty cycle variations possible in the normal message traffic, including Intermessage Gaps.

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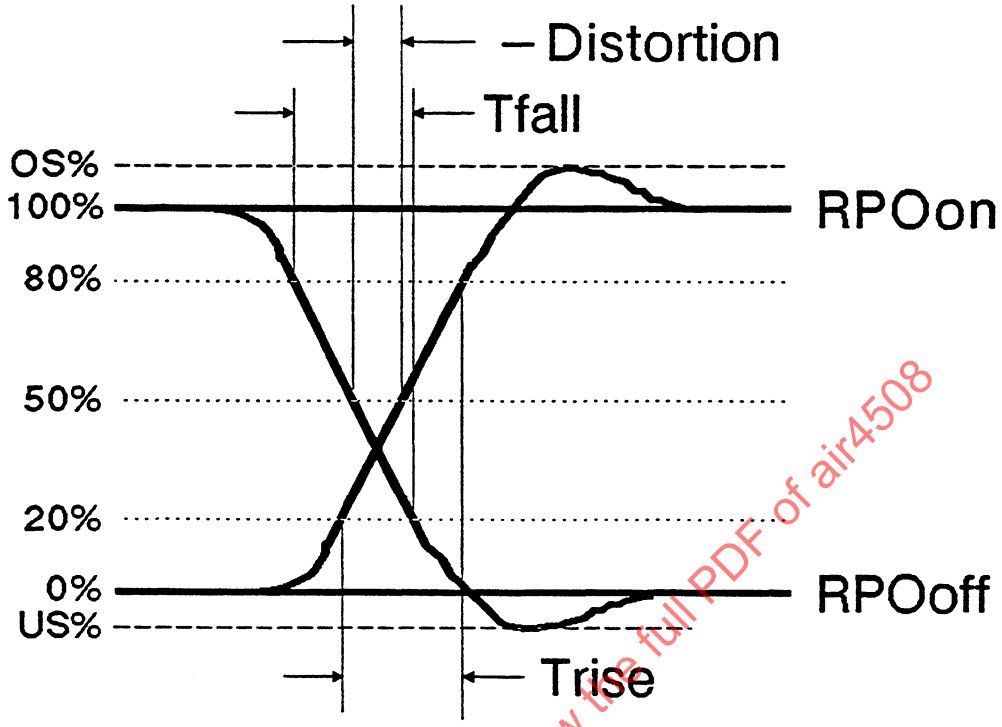
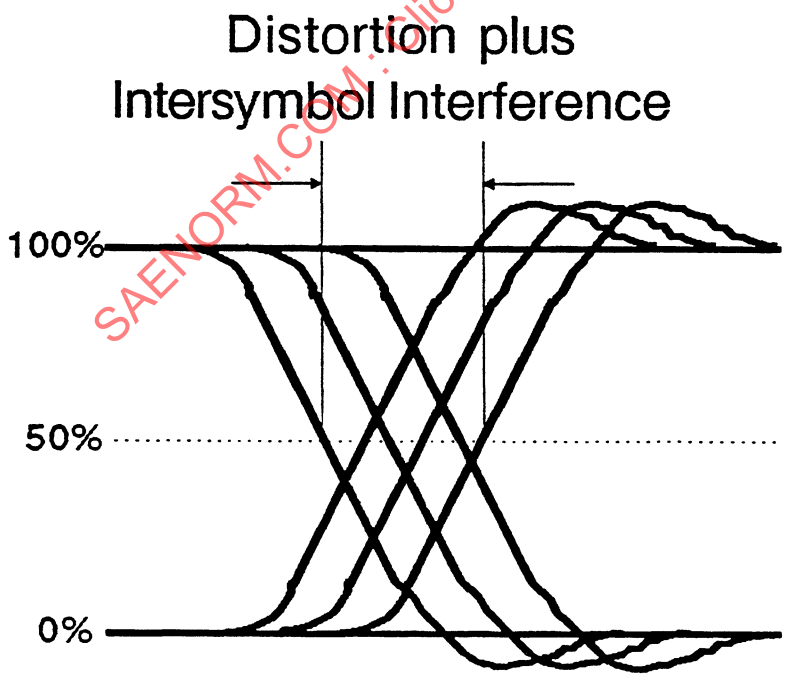


A. With Square Wave Input.



B. With Worstcase Pattern Input.

Figure 4. Transmitter Optical Waveform Parameters.

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(b) OS: Overshoot, US: Undershoot, percent.

As shown in Figure 4.A., the peak amplitude of On level of the transmitted waveform shall not exceed 105% of the steady state level of the ON optical level (5% overshoot) and the peak level of the OFF level shall not be less than 5% below the steady state OFF optical level. This overshoot/undershoot limitation is for the benefit of edge detector (differentiating) receivers.

OS% = ([OS peak - RPOon] / [RPOon - RPOoff]) x 100%
US% = ([RPOoff - US peak] / [RPOon - RPOoff] x 100%

where: RPOon and RPOoff = steady state high and low levels of the pulse waveform, respectively.

(c) Tr, Tf: Time Rise, Time Fall, nanoseconds.

As shown in Figure 4.A., the rise time and fall time of the transmitted optical waveform shall not exceed 20 nanoseconds when measured as the time between the points that are 20% and 80% of the range between the steady state ON and OFF levels for all of the pulsewidths of (a) above. The slope of the optical waveform shall exhibit no inflections (steps) or reversals (sign changes) between the 20% and 80% levels during the rising or falling edges.

3.2.1.3. OPTICAL INPUT CHARACTERISTICS OF THE RECEIVE FUNCTION.

3.2.1.3.1. RECEIVER WAVEFORM COMPATIBILITY.

The receive function of the FOTRU shall be compatible with the Manchester II Biphase Level encoding scheme, including the Command /Status, Data Synch codes and minimum Intermessage Gap period as defined in MIL-STD-1773. The receiver must also be capable of detecting the first pulse occurring after an indeterminately long quiet period, equal to or greater than the minimum Intermessage Gap period.

The receiver must meet all of the requirements of 3.2.1.3.x., for all power supply and environmental variations specified in the application detail specification, when the received waveform is within the parameter limits of 3.2.1.2.2. (other than attenuation, there should be no measurable degradation of the waveform introduced by the optical media between what is specified at the transmit end and what is measured at the receive end on a 1773 bus).

3.2.1.3.2. ERROR RATE.

(a) WER: Word Error Rate, errors per word.

The receive function, in combination with the Manchester Decoder utilized in the system, shall have a WER no greater than 1

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x 10 exp-7 as defined in MIL-STD-1773. The WER must be achieved for all conditions specified in 3.2.1.3.1. and for all optical power levels defined in 3.2.1.3.3. below.

(b) BER: Bit Error Rate, errors per bit.

BER is undefined by 1773, but a spec limit is useful for testing the receive unit before installation in the system to provide confidence that the WER requirement will be achieved. IF the receive function is tested in a manner identical to its use in the system, including using the system decoder for error detection, then a BER of less than/equal 5 x 10 exp-9 is equivalent to the required WER. If standard laboratory BER test equipment is used for the receiver test, then the maximum acceptable BER at the specified power levels or the power levels for 5 x 10 exp-9 BER must be modified to accommodate the fact that laboratory BER test gear tolerates much greater distortion and jitter than the typical system Manchester decoder. As an example, the Hewlett Packard data generator /BER detector test set will accommodate nearly +/-100% Baudwidth distortion plus jitter when the clock phasing is properly adjusted, while the Harris 15530 Manchester decoder tolerates only 160 nanoseconds (+/-32% of the minimum Baudwidth). This will not make a great deal of difference at the maximum signal end were pulse width stretching due to amplifier overdrive is the limiting factor but at the low signal end were noise induced jitter is the limitation, the Manchester decoder would require nearly 5 dB greater optical power to achieve the same BER as measured by the lab BER test set.

3.2.1.3.3. INPUT OPTICAL POWER LEVELS.

The optical input power parameters, specified below, shall be measured with the standard test fiber procedure described in 3.1.2.2.3. This test shall be performed with a worstcase pulse pattern driving the receiver. The worstcase pulse pattern shall include the full range of duty cycle variations possible in the normal message traffic, including Intermessage Gaps.

(a) RPImin: Radiant Power Input minimum, nanowatts.

The receiver/decoder function shall operate at less than/equal WER/BER specified above for the RPImin specified in the application detail specification.

(b) OSR: Optical Signal Range, dB.

The receiver/decoder function shall operate at less than/equal WER/BER specified above for any optical input power between RPImin and a level OSR dB higher, as enumerated in the application detail specification. This is a static parameter, in that it is measured with a continuous bit pattern or a continuous 1773 message pattern in which the optical power level is constant. OSR essentially

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defines the range between the minimum optical signal at any receiver input due to an output from any of the transmitters and the maximum optical signal level at that receiver input due to an output from any of the other transmitters. This range includes the allowed variance in transmitter output due to all causes (including ageing) and the maximum/minimum range of attenuation allowed within the bus media between any two terminals.

(c) DSR: Dynamic Signal Range, dB.

The receiver/decoder function shall operate at less than/equal WER/BER specified above with a 1773 message format consisting of a Data word transmitted at a power level of RPImin, preceded by a Command word with an even parity bit, transmitted at an optical power level DSR dB (as enumerated in the application detail specification) higher when the successive words are separated by the four microsecond minimum Intermessage Gap specified by MIL-STD-1773.

3.2.2. PHYSICAL CONFIGURATION.

3.2.2.1. FOTRU CONFIGURATION.

The FOTRU physical configuration shall be specified in the application detail specification.

3.2.2.2. FOTRU OPTICAL CONNECTOR(S).

The FOTRU shall connect to the bus media through LRU and/or Bulkhead connectors as specified by the application detail specification.

3.2.3. RELIABILITY.

MTBF: Mean Time Between Failure, hours. The FOTRU MTBF shall be enumerated, under the environmental conditions specified, by the application detail specification.

3.2.4. MAINTAINABILITY.

The requirements shall be per MIL-STD-454; Requirement 54 and as specified in the application detail specification.

3.2.5. ENVIRONMENTAL CONDITIONS.

The FOTRU shall withstand any of the operating or non-operating conditions of MIL-E-5400 Class II as a minimum and any additional requirements of the application detail specification.

3.2.6. TRANSPORTABILITY. N/A

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3.3. DESIGN AND CONSTRUCTION.

The FOTRU design and construction shall meet the requirements of MIL-E-5400 and any additional requirements imposed by the application detail specification.

3.3.1. PARTS AND MATERIALS.

Parts, materials and processes selected for use in the FOTRU design shall be of sufficient quality to meet the equipment's performance and reliability requirements in the operational environment. The contractor is encouraged to maximize the use of standard parts and materials, consistent with reasonable cost constraints. Unless waived by the procuring activity, microcircuit components shall be MIL-STD-883/MIL-M-38510 Class B or equivalent. Discrete semiconductors shall be MIL-STD-750/MIL-S-19500 JANTX or equivalent. Passive components shall be of comparable quality. All semiconductors devices shall be hermetically sealed. Waivers for use of non-standard/non-compliant parts and materials may be granted by the procuring activity if adequately justified by the contractor.

3.3.2. ELECTROMAGNETIC RADIATION.

When properly contained within the next level assembly, the FOTRU shall comply with the EMI control requirements cited in MIL-STD-461 for Class A1 equipment. Electrical bonding, grounding and lightning protection provisions shall be in accordance with requirements of MIL-B-5087. Design guidance is provided in AFSC design handbook DH 1-4.

3.3.3 IDENTIFICATION AND MARKING.

As required by the application detail specification.

3.3.4. WORKMANSHIP.

The workmanship requirements of MIL-E-5400 shall be employed.

3.3.5. INTERCHANGEABILITY.

Data Bus subsystems employing FOTRU's in compliance with this specification, if interconnected with appropriate fiber optic media and a host with a compatible FOTRU/BIU interface, shall be capable of data communications over the performance parameter ranges as specified in the application detail specification(s). Mechanical interchangeability (form, fit) is not required.

3.3.6. SAFETY.

Operation of the FOTRU equipment within avionics systems shall present no safety hazard to the system equipment or to operational or repair personnel. Design requirements of MIL-STD-882 shall apply.

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3.3.7. HUMAN PERFORMANCE/HUMAN ENGINEERING.

Shall be as required by the application detail specification.

3.4. DOCUMENTATION.

Shall be as required by the application detail specification.

3.5. QUALIFICATION.

Shall be as required by the application detail specification.

4.0. QUALITY ASSURANCE PROVISIONS.

4.1. GENERAL.

This section contains the requirements for formal verification of the performance, design and construction requirements of the provisions of MIL-E-5400 and the requirements specified herein shall be applicable to this section unless otherwise specified in the application detail specification(s).

4.1.1. RESPONSIBILITY FOR TESTS.

The contractor shall be responsible for all inspection and test requirements specified herein. The procuring activity reserves the right to perform any tests or inspections deemed necessary to assure conformance to contractual requirements. The contractor shall perform all tests in contractor facilities or in commercial laboratories acceptable to the procuring activity.

4.1.2 SPECIAL TESTS AND EXAMINATIONS.

The following special tests shall be accomplished prior to Government-conducted flight tests to assure that the equipment does not create a flight safety hazard. the tests shall be conducted in accordance with MIL-STD-810.

(a) Explosive atmosphere (Method 511, Procedure 1).

(b) Shock (method 516, Procedure III, Figure 516-1).

4.2. QUALITY CONFORMANCE INSPECTIONS AND TESTS.

4.2.1. CONFORMANCE TESTS.

The following paragraphs specify the inspections, analyses, demonstrations and tests for verifying that each Section 3. requirement has been satisfied. FOTRU testing shall be conducted by the contractor in accordance with contractor-prepared and government-approved Test Plan and Procedures Document, herein called the Test Plan.

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4.2.1.1. INSPECTION.

Inspections shall be conducted to verify that materials, construction, physical characteristics and workmanship comply with the requirements of this specification and the applicable detail specification(s).

4.2.1.2. ANALYSES.

Analyses shall be conducted to verify that the FOTRU complies with the requirements for:

(a) Performance.
(b) ReliabilitY.
(c) Maintainability.
(d) Safety.
(e) Interchageability.
(f) Interoperability.
(g) EMIcontrol compatibility.

4.2.1.3. QUALIFICATION TESTS.

4.2.1.3.1. ENVIRONMENTAL TESTS.

Environmental tests as specified below shall be conducted in accordance with MIL-STD-810, DOD-STD-1678 or other referenced documents. examination of product as specified in 4.2.3.1. shall be accomplished prior to initiation of environmental tests. Performance testing as specified in 4.2.3.2. shall be accomplished prior to, during and subsequent to the exposure to each test environment, as specified in the approved test plan. For purposes of stand alone testing the FOTRU may be installed in a typical avionics LRU case and instrumented such that the host avionics subsystem is simulated sufficiently that unambiguous error rate testing can be performed. The contractor is responsible for proving that the FOTRU test setup accurately simulates actual operational conditions.

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4.2.1.3.1.1. DUST.

In accordance with MIL-STD-810, Method 510. Equipment non-operating during 6 hour test period.

4.2.1.3.1.2. ACCELERATION.

In accordance with MIL-STD-810, Method 513, Procedure II. Forward acceleration level 2 G's.

4.2.1.3.1.3. EXPLOSIVE ATMOSPHERE.

In accordance with MIL-STD-810, Method 511, Procedure I.

4.2.1.3.1.4. SHOCK.

In accordance with MIL-STD-810, Method 516, Procedure I, II, III, V; Procedures I, III, Figure 516-1. Equipment operating during Procedure I.

4.2.1.3.1.5. SALT FOG.

In accordance with MIL-STD-810, Method 509.

4.2.1.3.1.6. TEMPERATURE SHOCK.

In accordance with MIL-STD-810, Method 503.

4.2.1.3.1.7. HIGH TEMPERATURE.

In accordance with MIL-STD-810, Method 501, Procedure I. Maximum temperature in accordance with the application detail specification.

4.2.1.3.1.8. LOW TEMPERATURE.

In accordance with MIL-STD-810, Method 502, Procedure I.

4.2.1.3.1.9.TEMPERATURE CHARACTERIZATIONS.

Functional performance parameters, as specified in 4.2.3.2., shall be measured at Tmin, -25C, 0C, +25C, +71C and Tmax, as a minimum. Tmin and Tmax are the minimum and maximum system operating temperature as specified in the application detail specification.

4.2.1.3.2. COMBINED STRESSES.

Combined environmental tests as specified below, shall be conducted under the same general provisions of paragraph 4.2.1.3.1. and in accordance with the approved test plan.

4.2.1.3.2.1. TEMPERATURE/ALTITUDE.

In accordance with the requirements of the application detail specification.

4.2.1.3.2.2. TEMPERATURE/VIBRATION.

In accordance with the requirements of the application detail specification.

4.2.1.3.2.3. TEMPERATURE/HUMIDITY.

In accordance with the requirements of the application detail specification.

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4.2.1.3.3. ELECTROMAGNETIC INTERFERENCE TESTS.

The FOTRU shall be tested in accordance with MIL-STD-462 to demonstrate compliance with the requirements of MIL-STD-461 for Class A1 equipment.

4.2.1.3.4. POWER VARIATION TESTS.

The FOTRU shall be tested to demonstrate compliance with the requirements of MIL-STD-704.

4.2.2. RELIABILITY AND MAINTAINABILITY.

In accordance with the requirements of the application detail specification.

4.2.3. ACCEPTANCE TESTS.

Each FOTRU submitted for acceptance (within an avionics LRU) shall be subjected to acceptance tests adequate to determine compliance with the requirements of performance, materials and workmanship. As a minimum, each FOTRU accepted shall pass the following:

(a) Examination of product.
(b) Performance tests.
(c) Product reliability verification.

4.2.3.1. EXAMINATION OF PRODUCT.

Each FOTRU (within an LRU) shall be given a thorough visual and mechanical inspection to determine that the quality of material, workmanship, design and construction complies with the following specified requirements:

(a) Completeness.
(b) Mechanical fit.
(c) Dimensions and part locations.
(d) Heat removal design.
(e) Fastening and securing devices or parts.

4.2.3.2. PERFORMANCE TESTS.

Each FOTRU shall be subjected to functional tests which assure compliance with the specified performance requirements. These tests shall be conducted both prior to and following the product reliability verification test. The following tests shall be included in the Test Plan and Procedures Document as a minimum.

4.2.3.2.1. OPTICAL OUTPUT POWER.

The optical output parameters of paragraph 3.2.1.2.1., RPOon,

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RPOoff and RPOi, shall be measured per the approved test plan, using the standard test fiber described in 3.1.2.2.3., with instrumentation having 5% absolute accuracy or better.

4.2.3.2.2. TRANSMITTER OPTICAL WAVEFORM.

The optical output wave form parameters of paragraph 3.2.1.2.2., PW, OS, US, Tr and Tf, shall be measured with an optical detector system having 10% to 90% rise and fall times no greater than 5 nanoseconds and amplitude linearity of 2% or better. These measurements are ratio measurements, so absolute accuracy is not required.

4.2.3.2.3. SPECTRAL CHARACTERISTICS.

The output spectral parameters of paragraph 3.1.2.2.4. shall be measured in accordance with the test plan.

4.2.3.2.4. WORD ERROR RATE.

The intent of the WER test is to assure that a terminal consisting of the FOTRU coupled with the BIU will meet the WER requirements of MIL-STD-1773. The test will be performed to the method and limits described in paragraph 3.2.1.3.2. with a Manchester decoder that is identical to that of the host system.

4.2.3.2.5. RADIANT INPUT POWER MINIMUM, RPImin.

The FOTRU/Decoder combination shall meet the WER requirement of 4.2.3.2.4. with the input to the receiver (via the standard test fiber of 3.1.2.2.3.) adjusted to the level RPImin as specified in paragraph 3.2.1.3.3. (a).

4.2.3.2.6. OPTICAL SIGNAL RANGE, OSR: DYNAMIC SIGNAL RANGE, DSR.

The FOTRU/Decoder combination shall meet the WER requirement of 4.2.3.2.4. with the input to the receiver (via the standard test fiber of 3.1.2.2.3.) to a level OSR dB greater than RPImin (as defined in 3.2.1.3.3.(b)) and with the message format and levels of RPImin and DSR dB greater as described in paragraph 3.2.1.3.3.(c). If the levels of OSR and DSR required by the application detail specification are identical, then only the DSR (dynamic range) test need be performed.

4.2.3.3. PRODUCT RELIABILITY VERIFICATION, PRV.

Each FOTRU shall be tested in accordance with MIL-STD-781, Test Level E. the minimum required PRV shall be fifteen (15) cycles with the final six (6) cycles and the final performance test as specified in paragraph 4.2.3.2. immediately following, to be error free. Compliance with MIL-STD-781B, paragraphs 5.1.5. and 5.1.6. are required prior to initiation of PRV. During

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equipment operating time in the PRV, selected critical parameters shall be continuously monitored per the approved test plan.

4.2.3.3.1. BURN-IN RELIABILITY ASSESSMENT.

One qualification model FOTRU shall undergo powered burn-in at a temperature, proposed by the contractor and approved by the government, that represents the maximum operating temperature capability of the device. The unit shall be operated continuously for 1000 hours or until the unit fails to meet performance requirements. A reliability forecast shall be made based on the time to failure and the general procedures of MIL-HDBK-217.

4.2.4. TEST FAILURE REQUIREMENTS.

4.2.4.1. FAILURE DEFINITION.

A failure shall be defined as the occurrence of any of the following conditions:

(a) Equipment not meeting it's specified performance requirements.

(b) Mechanical deformation or breakage of any component or module.

(c) The need for electrical or mechanical adjustment in order to meet the specified performance requirements.

4.2.4.2. FAILURE DURING CONTRACTOR CONDUCTED TESTS.

When a failure occurs during a contractor conducted test, the following procedure shall be implemented:

(a) The procuring activity shall be notified within 48 hours.

(b) A failure summary report shall be submitted to the procuring activity within one month, covering the previous test history (including previous test failures), the cause of the failure and the corrective action.

(c) Any other action required by the contract.

5.0. PREPARATION FOR DELIVERY.

Completed FOTRU's shall be packed in Electrostatic protective materials and prepared for delivery per good commercial practise.

6.0. NOTES.

None.

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6.1. PREPARATION REFERENCE.

This draft specification is based on the provisions of MIL-STD-490, Critical Item Development Specification, type B2. Reference documents used in preparation of this draft are listed below.

STANDARDS.

MIL-STD-490 Specification Practises, 30 Oct 68.

MIL-STD-961 Outline of Forms and Instructions for the Preparation of Specifications and Associated Documents, 22 Sep 75.

MIL-STD-962 Outline of Forms and Instructions for the Preparation of Military Standards and Military Handbooks, 22 Sep 75.

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APPENDIX B, INCLUSION B-2.

PRELIMINARY DEVICE PERFORMANCE SPECIFICATION:
MICRO CIRCUIT, HYBRID -- LIGHT WAVE TRANSMITTER.

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SPECIFICATION NUMBER xxxxxTX

PRELIMINARY DEVICE PERFORMANCE SPECIFICATION:
MICRO CIRCUIT, HYBRID -- LIGHT WAVE TRANSMITTER.

1. SCOPE. THIS SPECIFICATION DEFINES THE REQUIREMENTS FOR A HYBRID LIGHT WAVE TRANSMITTER MICROCIRCUIT CAPABLE OF TRANSMITTING AT MODULATION RATES FROM "DC" UP TO 40 MEGABAUD MAXIMUM (25 NANOSECONDS ON, 25 NANOSECONDS OFF), AND OPERATING AT A CASE TEMPERATURE ENVIRONMENT OF -55°C TO +85°C.

1.1 SYSTEM REQUIREMENTS. THIS DOCUMENT REPRESENTS THE SYSTEM FUNCTIONAL AND TEST REQUIREMENTS OF THIS DEVICE AS USED IN THE 1 AND 8 MEGABITS/SEC. MANCHESTER ENCODED DATA TRANSMISSION OF A "DUAL SPEED" ENHANCEMENT OF A MIL STD 1773 TERMINAL HARDWARE OR IN AN UNENHANCED 1 MEGABIT/SEC. ONLY 1773 TERMINAL WHICH IS COMPATIBLE WITH AND MAY CO-EXIST WITH ENHANCED TERMINALS ON A DUAL SPEED FIBER OPTIC BUS.

2. APPLICABLE DOCUMENTS. THE FOLLOWING DOCUMENTS, OF THE ISSUE IN EFFECT ON THE DATE OF INVITATION FOR BIDS, FORM A PART OF THIS DRAWING TO THE EXTENT SPECIFIED HEREIN.

MIL-STD-883C NOTICE 4	TEST METHODS AND PROCEDURES FOR MICROCIRCUITS
MIL-M-38510	MICROCIRCUITS, GENERAL SPECIFICATION FOR
MIL-STD-1772	CERTIFICATION REQUIREMENTS FOR HYBRID MICROCIRCUIT FACILITIES AND LINES
xxxxxHA	HYBRID ASSEMBLY -- FIBER OPTIC RECEIVER
xxxxxES	ELECTRICAL SCHEMATIC -- FIBER OPTIC RECEIVER
xxxxLA	HYBRID ASSEMBLY -- OPTICAL SIGNAL SOURCE,LED, GaAlAs, SAPHIRE LENSED
xxxxxPD	PACKAGE, FIBER OPTIC -- MIL HERMETIC
xxxxxCA	CONNECTOR ADAPTOR, FIBER OPTIC -- SMA
xxxxxOR	O-RING, NITRILE RUBBER
xxxxxSC	SCREW, MACHINE -- PAN HEAD, PHILLIPS DRIVE CRES 2-56, UNC-2A

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3. REQUIREMENTS. THE REQUIREMENTS SHALL BE AS SPECIFIED HEREIN.

3.1 MECHANICAL.

3.1.1 DESIGN AND DIMENSIONS. DESIGN AND CONSTRUCTION SHALL BE AS SPECIFIED HEREIN. DIMENSIONS SHALL BE IN ACCORDANCE WITH FIGURE 7 FOR REFERENCE ONLY.

3.1.2 LEAD MATERIAL AND FINISH. THE LEAD MATERIAL AND FINISH SHALL BE IN ACCORDANCE WITH MIL-M-38510, PARA. 3.5.6.

3.1.3 SERIAL NUMBER. PRIOR TO THE FIRST RECORDED ELECTRICAL MEASUREMENT IN SCREENING, EACH HYBRID SHALL BE MARKED WITH A UNIQUE SERIAL NUMBER.

3.1.4 MARKINGS, MINIMUM. MANUFACTURER'S IDENTIFICATION, PART NUMBER IDENTIFICATION AND DASH NUMBER, SERIAL NUMBER, COUNTRY OF ORIGIN, ESD IDENTIFIER, PIN 1 INDEX MARK AND DATE CODE OF MANUFACTURE SHALL BE MARKED ON THE COVER PLATE OF EACH DEVICE. NOTE: THE ESD IDENTIFIER (SEE MIL-M-38510, PARA.3.6.9.2) MAY BE USED AS THE PIN 1 INDEX MARK.

3.1.4.1 RELIDDED DEVICE MARKINGS. RELIDDED DEVICES SHALL HAVE THE LETTER "R" STAMPED AFTER THE NEW DATE CODE.

3.1.5 TEST TOOLING. ANY DEVIATION FROM THE TEST TOOLING DESCRIBED IN 3.1.5.1 AND FIGURES 2, 3, AND 4 MUST BE APPROVED BY THE PROCURING ACTIVITY PRIOR TO IMPLEMENTATION.

3.1.5.1 FIBER OPTIC TEST CABLE ASSEMBLY. THE CABLE ASSEMBLY SHALL BE AN APPROPRIATELY JACKETED 200 MICRON CLAD DIAMETER, 125 MICRON CORE DIAMETER SILICA ON SILICA OPTICAL FIBER WITH A NUMERIC APERTURE OF .25 ± .01. THE END TO ATTACH TO THE UNIT UNDER TEST SHALL BE APPROPRIATELY TERMINATED IN AN AMPHENOL SERIES TYPE 906-110-5013 SMA STYLE OPTICAL CONNECTOR OR EQUIVALENT. THE OTHER END MAY BE TERMINATED AS APPROPRIATE FOR THE TEST EQUIPMENT.

3.1.6 STANDARD CONFIGURATION. THE STANDARD CONFIGURATION CONSISTS OF THE HYBRID ASSEMBLY (xxxxxHA) COUPLED WITH THE SMA CONNECTOR ADAPTOR (xxxxxCA) BY SCREWS (xxxxxSC) AND WITH O-RING (xxxxxOR) INSTALLED IN THE CONNECTOR ADAPTOR RECESS. SEE FIGURES 5, 6, 7, 8, 9, AND 10.

3.1.6.1 OPTICAL CONNECTOR ADAPTOR. THE OPTICAL CONNECTOR ADAPTOR SHALL BE OF BRASS WITH 50 MICROINCHES MINIMUM OF GOLD, PLATED OVER 200 MICRO INCHES MINIMUM OF NICKEL PLATING.

3.1.6.2 OUTPUT TERMINATION. THE EXTERNAL THREAD AND INSIDE DIAMETER OF THE CONNECTOR ADAPTOR SHALL BE CAPABLE OF MATING WITH AN AMPHENOL 906-110-5013 TYPE SMA FIBER OPTIC CABLE CONNECTOR OR EQUIVALENT.

3.1.6.3 WEIGHT. 35 GRAMS, MAXIMUM.

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3.2 ELECTRICAL.

3.2.1 ABSOLUTE MAXIMUM RATINGS.

(a)	VEE	-15.0 VOLTS
(b)	VCC	7.0 VOLTS
(c)	DISSIPATION	1.8 WATTS MAX
(d)	LOGIC INPUTS	5.5 VOLTS MAX -0.4 VOLTS MIN
(e)	SOLDERING HEAT	EACH LEAD SHALL BE CAPABLE OF WITHSTANDING +300°C MAX FOR 12 SECONDS MINIMUM AS MEASURED AT A POINT .020 INCH FROM UNIT BODY.
(f)	STORAGE TEMPERATURE (AMBIENT)..	-65°C TO +150°C AMBIENT
(g)	OPERATING TEMPERATURE (CASE)...	UNIT SHALL NOT BE PHYSICALLY DAMAGED BY OPERATION WITH CASE TEMPERATURE OF -55°C TO +85°C.

WARNING: THE MEAN TIME TO FAILURE (MTTF) FOR AGEING OF THE TRANSMITTING LIGHT EMITTING DIODE (LED) BECOMES THE DOMINANT RELIABILITY FACTOR IF THE TRANSMITTER IS OPERATED BEYOND THE +85°C CASE TEMPERATURE AND OPERATION BEYOND THAT TEMPERATURE MAY RESULT IN SIGNIFICANT LED JUNCTION DEGRADATION. AS TEMPERATURE INCREASES, MORE CURRENT IS REQUIRED TO MAINTAIN A CONSTANT LIGHT OUTPUT LEVEL AND IS PROVIDED BY THE DESIGNED TEMPERATURE COMPENSATION CIRCUITRY AND THE AGEING RATE IS ACCELERATED.

(h)	THERMAL IMPEDANCE	
	(1) LED JUNCTION TO CASE.....	50°C/WATT MAX
	(2) HYBRID SUBSTRATE TO CASE.....	30°C/WATT MAX
	(3) CASE TO FREE AIR.....	30°C/WATT MAX

3.2.2 ELECTRICAL CHARACTERISTICS. UNLESS OTHERWISE SPECIFIED, THE ELECTRICAL PERFORMANCE CHARACTERISTICS ARE AS SPECIFIED IN TABLE 1 OVER THE MAXIMUM OPERATING CASE TEMPERATURE.

3.2.3 OPTICAL SIGNAL SOURCE.

3.2.3.1 LED ASSEMBLY. THE LED ASSEMBLY USED IN THIS TRANSMITTER SHALL BE PER xxxxxLA OR AN OPTICAL AND FUNCTIONAL EQUIVALENT. SEE FIGURE 6.

3.2.3.2 LED LIGHT OUTPUT. THE PERCENTAGE OF RATED LED CURRENT (HENCE THE APPROXIMATE RADIATED POWER OUTPUT (RPO) SHALL BE DETERMINED BY THE DRIVE CONTROL INPUTS A, B, AND C IN ACCORDANCE WITH FIGURE 1.

3.2.3.3 RADIATED POWER OUTPUT. THE RADIATED POWER OUTPUT (RPO) SHALL BE SPECIFIED AT PEAK LEVEL.

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3.2.4 ELECTRICAL SCHEMATIC. PER FIGURE 1. COMPONENT DATA (TYPES AND VALUES) IS FOR INFORMATION ONLY. THE DEVICE MUST MEET ALL THE REQUIREMENTS OF THIS DRAWING REGARDLESS OF ACTUAL CIRCUIT CONFIGURATION. THE SCHEMATIC (xxxxxES) HAS PRECEDENCE OVER THIS SPECIFICATION.

3.2.5 MECHANICAL CONFIGURATION. PER FIGURE 7. CONFIGURATION IS FOR INFORMATION ONLY. THE PACKAGE MUST MEET ALL THE REQUIREMENTS OF THIS DRAWING REGARDLESS OF ACTUAL CIRCUIT CONFIGURATION. THE PACKAGE DRAWING (xxxxxPD) HAS PRECEDENCE OVER THIS SPECIFICATION.

3.3 ENVIRONMENTAL.

3.3.1 OPERATING TEMPERATURE RANGE. -55°C TO +85°C CASE TEMPERATURE.

4. QUALITY ASSURANCE PROVISIONS. PARTS SUPPLIED TO THIS DOCUMENT SHALL MEET THE REQUIREMENTS OF THIS DOCUMENT. QUALITY CONFORMANCE SHALL BE AS SPECIFIED HEREIN. CONFORMANCE INCLUDES ELEMENT EVALUATION, PROCESS CONTROL, DEVICE SCREENING AND QUALITY CONFORMANCE EVALUATION, ALL AS DEFINED IN THIS DOCUMENT AS A MINIMUM ACCEPTANCE CRITERIA, ALL PARTS SHIPPED SHALL HAVE SUCCESSFULLY COMPLIED WITH THE SCREENING AND ELECTRICAL TEST REQUIREMENTS AS DEFINED IN THIS SECTION.

4.1 ELEMENT EVALUATION. ALL ELEMENTS UTILIZED IN THE MANUFACTURE OF HYBRIDS TO THIS DOCUMENT SHALL BE EVALUATED PER THE REQUIREMENTS OF THE PROCURING ACTIVITY. ELEMENTS ARE DEFINED AS 'MATERIALS' FOR DEVICE ASSEMBLY AND INCLUDE ACTIVE AND PASSIVE PARTS, THE PACKAGE AND ADHESIVES.

4.2 PROCESS CONTROL. PROCESS CONTROL PERTAINING TO WIRE BONDING SHALL BE MACHINE PROCESS QUALIFICATION CONSISTING OF SAMPLE WIRE BOND TESTING PRIOR TO PROCESSING AND A 100% DESTRUCTIVE TEST OF ALL INPUT/OUTPUT WIRES OF ONE SAMPLE PACKAGE PER ASSEMBLY LOT.

4.3 DEVICE SCREENING. DEVICE SCREENING SHALL BE AS SPECIFIED IN TABLE II WHEN REQUIRED BY THE PROCURING ACTIVITY. SCREENING SHALL BE CONDUCTED ON ALL DEVICES PRIOR TO QUALITY CONFORMANCE INSPECTION. ELECTRICAL TESTS SHALL BE PER TABLE I. DEVICES SHALL BE CONFIGURED PER PARAGRAPH 3.1.6 FOR ALL ELECTRICAL TESTS.

I. ADDITIONAL TEST AND INSPECTIONS MAY PERFORMED WHERE EXPERIENCE INDICATES CONCERN FOR SPECIFIC QUALITY CHARACTERISTICS.

II. ANY DEVICES THAT FAIL ANY TEST CRITERIA SHALL BE REMOVED FROM THAT LOT AT THE TIME OF OBSERVATION OR IMMEDIATELY AT THE CONCLUSION OF THE TEST IN WHICH THE FAILURE OCCURRED.

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4.3.1 PRESEAL BURN-IN. PRESEAL BURN-IN IS OPTIONAL AND REQUIRES THE APPROVAL OF THE PROCURING ACTIVITY. IF PERFORMED, CASE TEMPERATURE OF THE DEVICE SHALL NOT EXCEED +125°C.

4.3.2 INTERNAL VISUAL AND MECHANICAL. FAILURE CRITERIA SHALL BE PER MIL-STD-883C, METHOD 2017, AND THIS DOCUMENT. THE SUPPLIER WILL FURNISH A TOPOGRAPHICAL LAYOUT OF ELEMENTS ON THE METALIZED SUBSTRATE IN THE PACKAGE INITIALLY AND WHENEVER A DESIGN CHANGE REQUIRES AN UPDATE.

4.3.3 STABILIZATION BAKE. THE STABILIZATION BAKE SHALL BE PER MIL-STD-883C, METHOD 1008, FOR 24 HOURS AT +125°C.

4.3.4 TEMPERATURE CYCLING. TEMP CYCLING SHALL BE PER MIL-STD- 883, METHOD 1010, TEST CONDITION B (15 CYCLES FROM -55°C to +125°C).

4.3.5 CONSTANT ACCELERATION. CONSTANT ACCELERATION SHALL BE PER MIL-STD-883C, METHOD 2001, TEST CONDITION A (5000 G's IN THE "Y1" DIRECTION ONLY).

4.3.6 PREBURN-IN ELECTRICAL. INTERIM ELECTRICAL TESTING PRIOR TO BURN-IN IS OPTIONAL, BUT IF PERFORMED, SHALL BE PER TABLE I. CASE TEMPERATURE SHALL NOT EXCEED 85°C.

4.3.7 BURN-IN. TESTING SHALL BE FOR 160 HOURS MINIMUM PER MIL-STD-883C, METHOD 1015, TEST CONDITION B (STEADY STATE, FORWARD BIAS). CASE TEMPERATURE SHALL BE 85°C AND PDA SHALL BE 10% OR 1 DEVICE, WHICHEVER IS GREATER. SEE BURN-IN CONNECTIONS, FIGURE 1.

4.3.8 PACKAGE SEAL. PRIOR TO FINAL ELECTRICAL TESTING, GROSS AND FINE LEAK SEAL TESTS ARE PERFORMED. GROSS LEAK SHALL BE PER MIL-STD-883C, METHOD C (HEATED PERFLUOROCARBON IMMERSION). FINE LEAK RATE SHALL NOT EXCEED 1 x 10 exp-7 ATM CC/SEC. PER MIL-STD-883C, METHOD 1014.5, TEST CONDITION A2.

4.3.9 FINAL ELECTRICAL. FINAL ELECTRICAL SHALL BE THOSE TESTS OUTLINED IN TABLE I.

4.3.10 EXTERNAL VISUAL. EXTERNAL VISUAL SHALL BE PER MIL-STD- 883C, METHOD 2009.

4.4 QUALITY CONFORMANCE PROVISIONS. QUALITY CONFORMANCE INSPECTIONS SHALL BE PERFORMED AS SPECIFIED HEREIN. AN INSPECTION LOT SHALL BE AS DEFINED IN MIL-M-38510, PARA. 3.1.3.8.

4.4.1 GROUP A INSPECTION. 100% SCREENING WILL BE DONE IN LIEU OF GROUP A SAMPLING INSPECTION. GROUP A ELECTRICAL TEST SHALL BE PER TABLE I. GROUP A TESTING BY SUBGROUP OR WITHIN SUBGROUPS MAY BE PERFORMED IN ANY SEQUENCE. SEE TABLE I AND III FOR PARAMETERS AND SUBGROUPS. EACH SERIALIZED DEVICE WILL HAVE A DATA SHEET WHICH WILL INCLUDE PART NUMBER, SERIAL NUMBER, TEST DATE, LED SERIAL NUMBER, JOB OR LOT NUMBER AND A TABULATION WHICH PERMITS LOGGING OF TEST DATA AT -40°C ROOM AMBIENT AND +85°C. THE COMPLETED DATA SHEETS WILL BECOME PART OF THE JOB PACKET AND A COPY WILL BE DELIVERED WITH THE DEVICE.

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4.4.2 GROUP B INSPECTION. GROUP B INSPECTION SHALL BE PERFORMED ON EACH INSPECTION LOT AS SPECIFIED HEREIN AND DESCRIBED IN TABLE IV.

4.4.2.1 PHYSICAL DIMENSIONS. PACKAGES ARE MEASURED AT INCOMING INSPECTION. A SINGLE SEALED DEVICE FROM EACH LOT SHALL BE MEASURED FOR ACCURATE HEIGHT DIMENSIONS.

4.4.2.2 SOLVENT RESISTANCE. FOUR LIDS (COVERS) WILL PASS THROUGH ALL PROCESS STEPS WITH A DEVICE LOT EVERY 90 DAYS. THE INK MARKING ON THE FOUR LIDS WILL BE SOLVENT RESISTANCE TESTED PER MIL-STD-883C, METHOD 2015.

4.4.2.3 SOLDERABILITY. SOLDERABILITY TEST SHALL BE PERFORMED ON ONE SAMPLE PER LOT. IT MAY BE PERFORMED ON A FUNCTIONAL FAILURE THAT IS UNUSABLE OTHERWISE OR ON A DELIVERABLE PART, IF NO SOLDER RESIDUE IS PRESENT ON THE LEADS WITHIN .5 INCHES OF THE PACKAGE WALL.

4.4.2.4 INTERNAL VISUAL AND MECHANICAL. THIS IS NOT NECESSARY FOR DELIVERABLE PARTS, DUE TO PRECAP VISUAL (SEE 4.3.2). THIS TEST WILL BE PERFORMED, PER MIL-STD-883C, METHOD 2014, ON FUNCTIONAL FAILED UNITS AFTER REWORK.

4.4.2.5 WIRE BOND STRENGTH. A SINGLE TEST PACKAGE WILL BE ASSEMBLED FOR EACH ASSEMBLY LOT, IT WILL HAVE WIRE BONDED ELEMENTS (DIE) WHICH WILL BE SUBJECTED TO ALL PROCESS AND SCREENING STEPS. BOND STRENGTH TESTING WILL BE PERFORMED MIL-STD-883C, METHOD 2011.

4.4.2.6 DIE SHEAR STRENGTH. THE DESTRUCTIVE DIE SHEAR TEST WILL BE PER MIL-STD-883C, METHOD 2019. IT WILL BE PERFORMED ON THE DEVICES OF THE TEST PACKAGE (SEE 4.4.2.6).

4.4.2.7 SEAL. FINE AND GROSS SEAL TESTS ARE PERFORMED DURING DEVICE SCREENING (SEE 4.3.8).

4.4.2.8 ELECTROSTATIC DISCHARGE SENSITIVITY. THIS TEST SHALL BE PERFORMED FOR INITIAL QUALIFICATION AND PRODUCT REDESIGN AS A MINIMUM AND ESD MARKING SHALL BE A TRIANGLE INDICATING CLASS 1 UNTIL FORMAL TESTING HAS BEEN COMPLETED FOR FINAL CLASSIFICATION DETERMINATION.

4.4.3 GROUP C INSPECTION. THERE SHALL BE NO GROUP C TESTING.

4.4.4 GROUP D INSPECTION. THERE SHALL BE NO GROUP D TESTING.

4.5 REWORK. REWORK SHALL BE PERFORMED IN ACCORDANCE WITH MIL-M- 38510.

4.6 QUALIFICATION. WHEN REQUIRED, QUALIFICATION SHALL BE PERFORMED PER THE REQUIREMENTS OF THE PROCURING ACTIVITY.

4.7 HYBRID PRODUCTION FACILITY. THIS PRODUCT MAY BE PRODUCED IN ANY FACILITY APPROVED BY THE PROCURING ACTIVITY, WHICH NEED NOT BE A MIL-STD-1772 QUALIFIED FACILITY UNLESS SPECIFIED. IT MUST BE EQUIPPED FOR ESD (ELECTROSTATIC DISCHARGE) REQUIREMENTS, WITH ALL WORK STATIONS GROUNDED AND ANTI-STATIC HANDLING DEVICES, CLOTHING,

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AND WRIST STRAPS USED. ALL ASSEMBLY AND OPEN PACKAGE TESTING SHALL BE PERFORMED IN A CONTROLLED ATMOSPHERE.

5. PREPARATION FOR DELIVERY. THE ITEMS SHALL BE AFFORDED PRESERVATION AND PACKAGING TO ASSURE ADEQUATE PROTECTION DURING NORMAL COMMERCIAL HANDLING. THE ESD PROVISIONS WILL INCLUDE ENCLOSING IN STATIC PROTECTIVE BAG, AND SECURING IN AN ESD SHIELDED CONTAINER.

6. NOTES. NONE

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TABLE I --- NOTES 1/, 2/, 3/, 4/

ITEM	SYMBOL	CHARACTERISTICS	TEST PIN	TERMINAL CONDITIONS								GROUP A SUBGRPS	LIMITS		UNITS	TEST CONDITIONS
				PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN8		MIN	MAX		
A	Iee	POWER SUPPLY CURRENT	5	5.25V	0.0V	5.25V	5.25V	-12.6V	10/	0.0V	0.0V	1-3	--	-15	mA	
B	Icc	POWER SUPPLY CURRENT	1	5.25V	0.0V	5.25V	5.25V	-12.6V	10/	0.0V	0.0V	1-3	--	250	mA	
C1	Iil	INPUT CURRENT	3	5.25V	0.0V	0.40V	5.25V	-12.0V	10/	0.0V	0.0V	1-3	--	-0.3	mA	
C2	Iil	INPUT CURRENT	4	5.25V	0.0V	5.25V	0.40V	-12.0V	10/	0.0V	0.0V	1-3	--	-0.3	mA	
D1	Iih	INPUT CURRENT	3	5.25V	0.0V	5.25V	0.40V	-12.0V	10/	0.0V	0.0V	1-3	--	+10	uA	
D2	Iih	INPUT CURRENT	4	5.25V	0.0V	0.40V	5.25V	-12.0V	10/	0.0V	0.0V	1-3	--	+10	uA	
E1	RPO	COUPLED RADIANT POWER OUTPUT	OUTPUT	4.75V	0.0V	5/	LO 7/	-11.4V	10/	0.0V	0.0V	4-6	240	--	uW	FIG. 2 8/
E2	RPO(var)	COUPLED RADIANT POWER OUTPUT (VARIANCE)	OUTPUT	4.75V	0.0V	5/	LO 7/	-11.4V	10/	0.0V	0.0V	4-6	--	?10	%	FIG. 2 8/, 11/
F1	RPO(off)	COUPLED RADIANT POWER OUTPUT (OFF STATE)	OUTPUT	5.25V	0.0V	HI 7/	LO 7/	-11.4V	10/	0.0V	0.0V	1-3	--	100	nW	FIG. 2 9/
F2	RPO(off)	COUPLED RADIANT POWER OUTPUT (OFF STATE)	OUTPUT	5.25V	0.0V	LO 7/	HI 7/	-11.4V	10/	0.0V	0.0V	1-3	--	100	nW	FIG. 2 9/
G1	DPW	PULSE WIDTH DISTORTION	OUTPUT	5.25V	0.0V	6/	HI 7/	-12.6V	10/	0.0V	0.0V	9-11	--	?6.0	nS	FIG. 3
G2	DPW	PULSE WIDTH DISTORTION	OUTPUT	4.75V	0.0V	6/	HI 7/	-11.4V	10/	0.0V	0.0V	9-11	--	?6.0	nS	FIG. 3
H1	JN/JP	EDGE JITTER	OUTPUT	5.25V	0.0V	6/	HI 7/	-12.6V	10/	0.0V	0.0V	9-11	--	1.0	nS	FIG. 3
H2	JN/JP	EDGE JITTER	OUTPUT	4.75V	0.0V	6/	HI 7/	-11.4V	10/	0.0V	0.0V	9-11	--	1.0	nS	FIG. 3
I	Tor	OPTICAL RISE TIME	OUTPUT	4.75V	0.0V	5/	HI 7/	-11.4V	OPEN	OPEN	0.0V	9-11	--	10.0	nS	FIG. 4
J	Tof	OPTICAL FALL TIME	OUTPUT	4.75V	0.0V	5/	HI 7/	-11.4V	OPEN	OPEN	0.0V	9-11	--	10.0	nS	FIG. 4
K	OVR	SIGNAL OVERSHOOT, %	OUTPUT	5.25V	0.0V	5/	HI 7/	-12.6V	OPEN	OPEN	0.0V	9-11	--	10.0	%	FIG. 4

NOTES:

1/ CURRENTS LEAVING THE CIRCUIT ARE INDICATED BY A MINUS (-) SIGN.
2/ LIMITS APPLY OVER THE TEMPERATURE RANGE OF -55?C TO +85?C CASE.
3/ THE PEAK SPECTRAL OUTPUT SHALL BE BETWEEN 810 AND 850 nM WITH A HALF POWER SPECTRAL BANDWIDTH OF ? 50 nM.
4/ SEE FIGURE 5. FOR LOGIC BLOCK DIAGRAM.
5/ THE INPUT SIGNAL IS A STANDARD TTL LOGIC SIGNAL OF A REPEATING "1010101010101010" PATTERN WITH 62.5 nS WIDE PULSES.
6/ THE INPUT SIGNAL IS A STANDARD TTL LOGIC SIGNAL OF A REPEATING "1010001110100000" PATTERN WITH 62.5 nS WIDE PULSES.
7/ THE INPUT SIGNAL IS A CONSTANT TTL HI OR LO LEVEL.
8/ PEAK RPO OR 2 TIMES AVG. READING.
9/ RECORD RADIOMETER READING.
10/ PIN 6 HAS A 29.4 OHM, 0.1 WATT FILM RESISTOR CONNECTED TO GROUND.
11/ COOL TO -55 ?C. DURING WARM UP TO 85 ?C OVER A PERIOD OF ABOUT 10 MIN., RECORD MAX AND MIN RPO READINGS OBSERVED.
RPO(var)% = 100((MAX-(MAX + MIN / 2)) / (MAX + MIN / 2)).

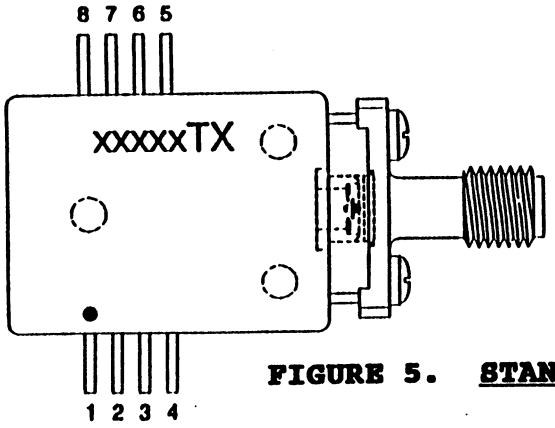

FIGURE 5. STANDARD CONFIGURATION

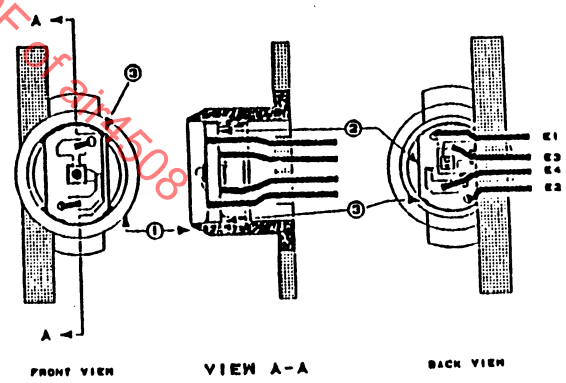

FIGURE 6. OPTICAL SOURCE ASSEMBLY.

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TABLE II. Device Screening

Test Inspection	Mil-Std-883		Requirement
	Method	Condition	
Pre-seal Burn-in	1030		Optional
Internal Visual	2017		100%
Stabilization Bake	1008	C	100%
Temperature Cycling or Thermal Shock	1010 1011	C A, min	100% or 100%
Mechanical Shock or Constant Acceleration	2002 B (Y1 only) 2001 A (Y1 only)		100% or 100%
Interim Electrical			Optional
Burn-in	1015	125°C	100%
Final Electrical Test	Per Table I		100%
Seal a) Fine b) Gross	1014		100%
External Visual	2009		100%

TABLE III. Group A Electrical Test

Subgroup	Parameters	LTPD
1	Static tests at 25°C	2
2	Static tests at maximum rated operating temp	3
3	Static tests at minimum rated operating temp	5
4	Dynamic tests at 25°C	2
5	Dynamic tests at maximum rated operating temp	3
6	Dynamic tests at minimum rated operating temp	5
7	Functional tests at 25°C	2
8	Functional tests at maximum and minimum rated operating temperatures	5
9	Switching tests at 25°C	2
10	Switching tests at maximum rated operating temp	3
11	Switching tests at minimum rated operating temp	5

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TABLE IV. Group B Test

Subgroup	Test	Mil-Std-883		Quantity (Accept No.) or LPTD
		Method	Condition	
1	Physical Dimensions	2016		2 (0)
3	Resistance to Solvents	2015		4 (0)
4	Internal Visual & Mech.	2014		1 (0)
5	Bond Strength 1. Thermocompression 2. Ultrasonic or Wedge 3. Flip-Chip 4. Beam Lead	2011	 C or D C or D F H	2 (0)
6	Die Shear Strength	2019		2 (0)
7	Solderability	2003	Solder Temperature 245 ±5°C	
8	Seal 1. Fine 2. Gross	1014		15
9	1. Electrical Parameters 2. Electrostatic Discharge 3. Electrical Parameters	3015	Group A-1 Group A-1	15 (0)

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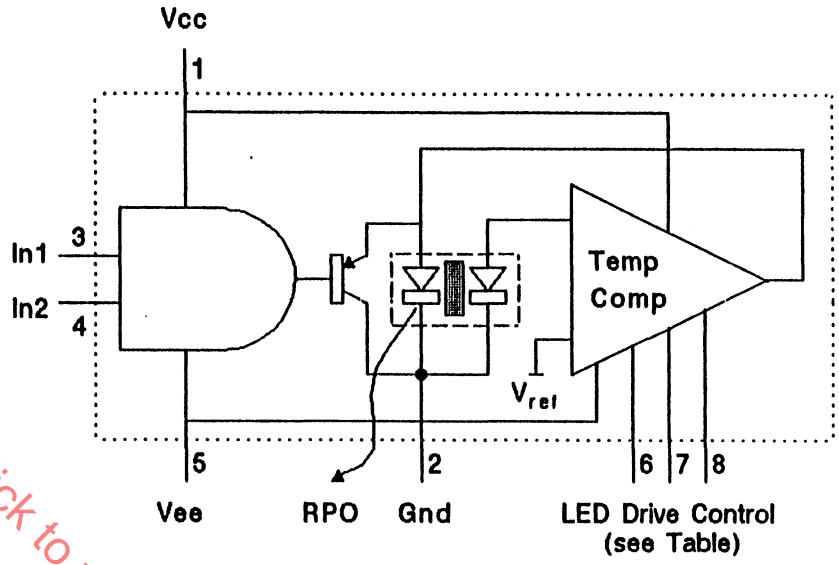
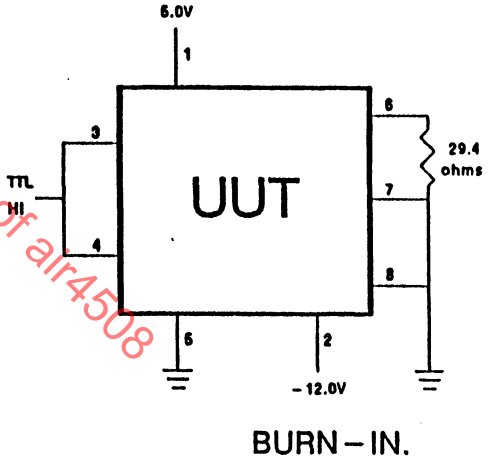
APPLICATION INFORMATION TABLE

DRIVE CONTROL INPUTS			%ILED (MAX)
PIN 8	PIN 7	PIN 6 ohms	
S	S	402-29.4	85.7%-100%
S	O	402-10.0	57.2%-84.3%
O	S	402-10.0	26.6%-55.8%
O	O	402-10.0	1.43%-27.2%

NOTES:
Only those combinations shown are allowed.
"O" means Open Circuit, "S" means Short to ground.
Connect Pin 6 to gnd thru R in range shown or leave open.

XMTR INPUT TRUTH TABLE		
PIN 3	PIN 4	OPTICAL OUT
TTL LO	TTL LO	OFF
TTL LO	TTL HI	OFF
TTL HI	TTL LO	OFF
TTL HI	TTL HI	ON





BURN-IN.

FIGURE 1. ELECTRICAL SCHEMATIC, DUAL SPEED FIBER OPTIC RECEIVER.

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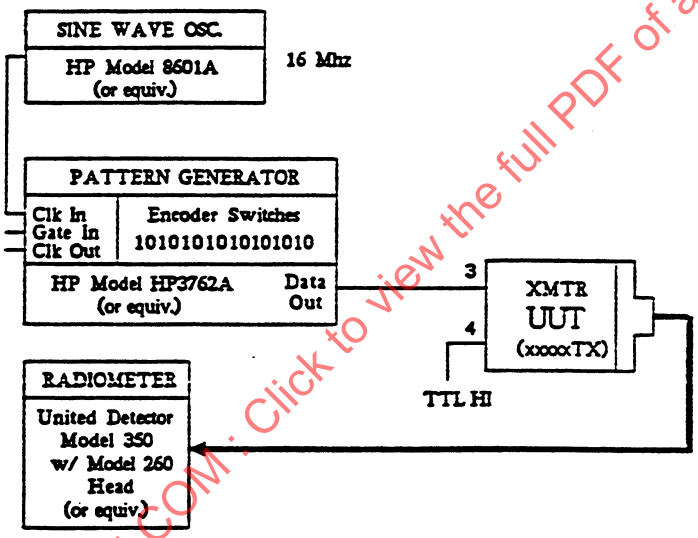

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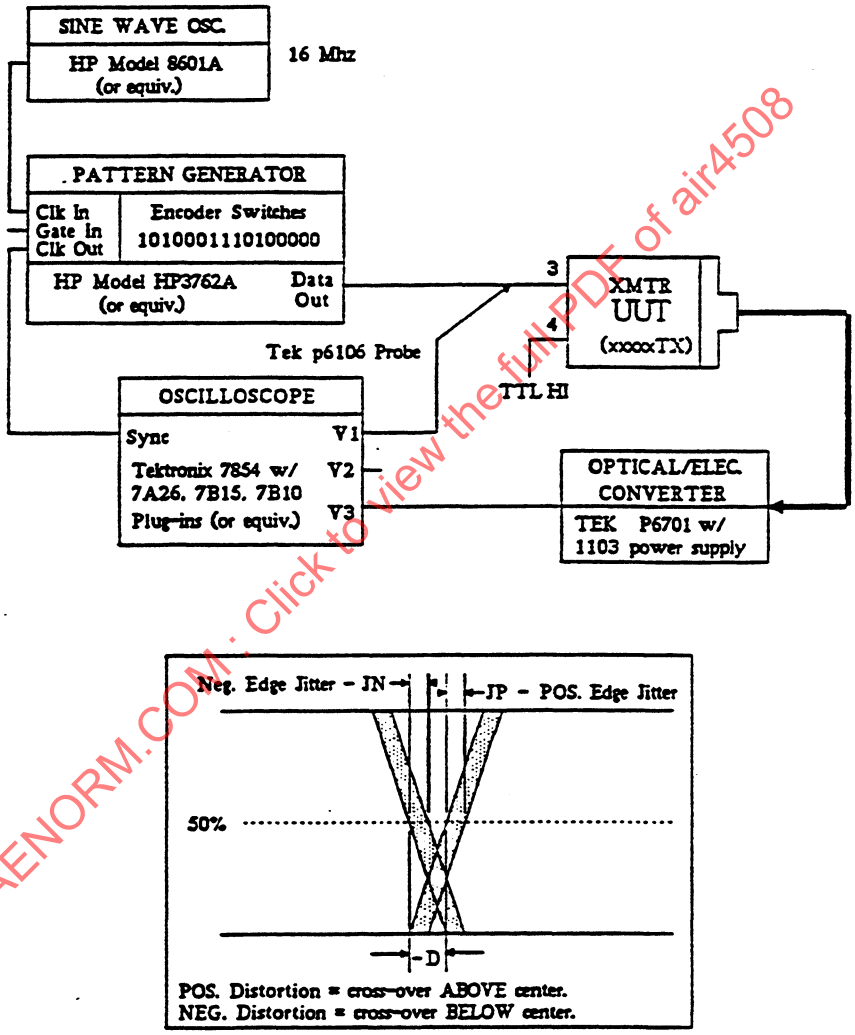
NOTES: 1. With test fiber connected, loosen Connector Adapter mounting screws. Align Connector Adapter to maximise Radiometer reading. Re-tighten screws.
2. Record RPO Peak = Radiometer reading x 2.
3. Remove test fiber and plug UUT Optical Input. Record Radiometer reading as RPOoff.

FIGURE 2. TEST CIRCUIT TO MEASURE RADIANT POWER OUTPUT.



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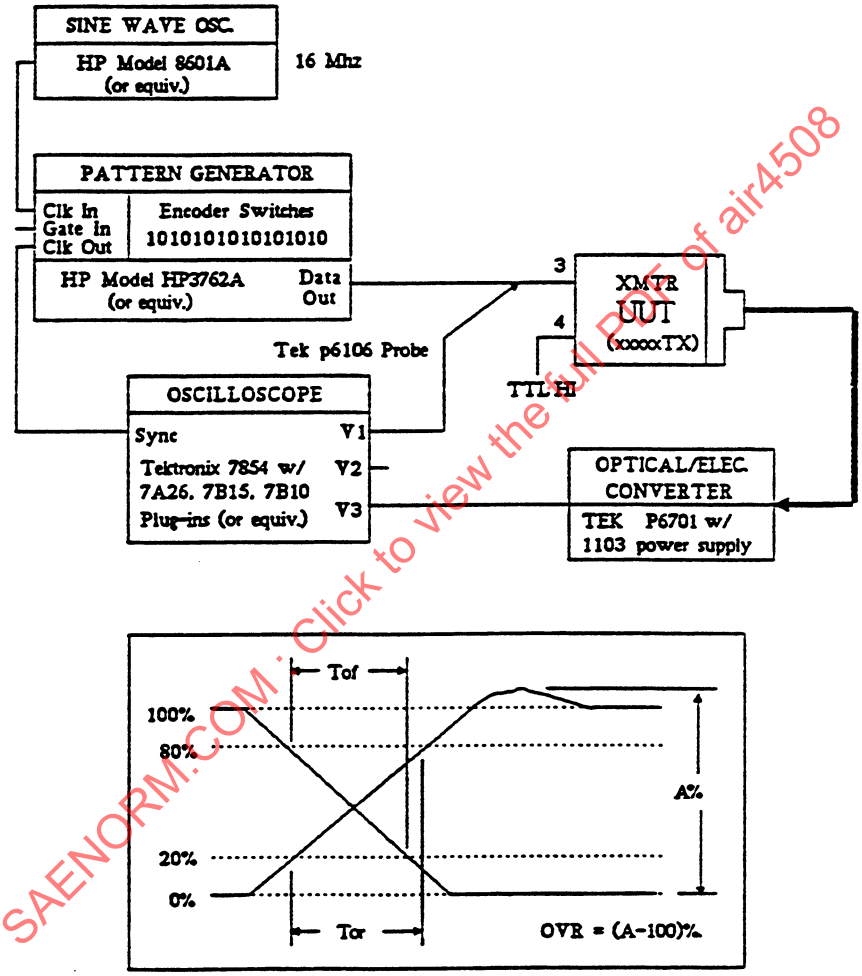
NOTES: 1. Adjust Generator output level for zero distortion at the +1.25V threshold level BEFORE making JN, JP and Pulse Width Distortion measurements at UUT Optical Output.

FIGURE 3. TEST CIRCUIT TO MEASURE DISTORTION AND EDGE JITTER.



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NOTES: 1. Adjust Generator output level for zero distortion at the +1.25V threshold level. BEFORE making Rise time. Fall time and Overshoot measurements at UUT Optical Output.

FIGURE 4. TEST CIRCUIT TO MEASURE RISE/FALL TIME AND OVERSHOOT.

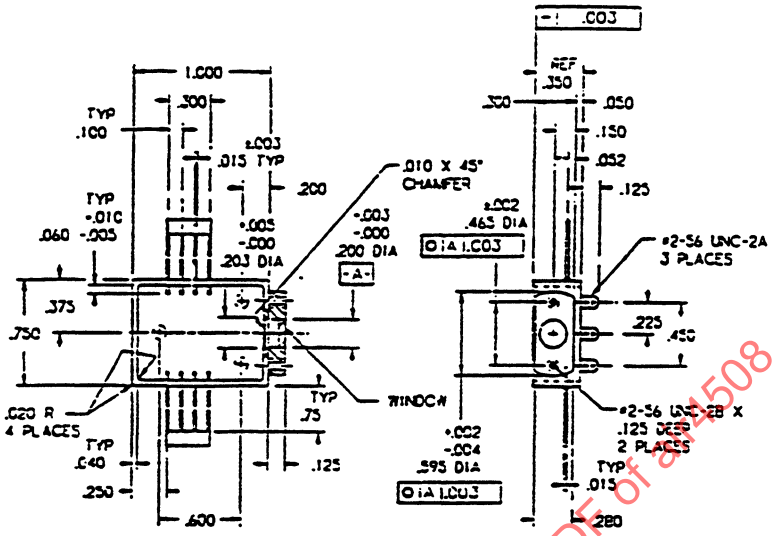

FIGURE 7. PACKAGE DIMENSIONS.

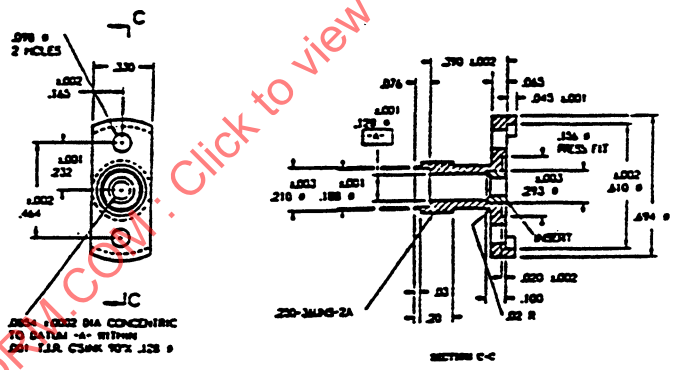

FIGURE 8. CONNECTOR ADAPTER.

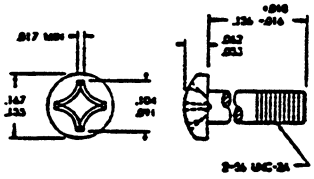

FIGURE 9. MOUNTING SCREW

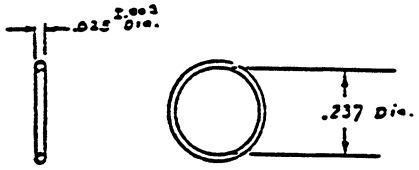

FIGURE 10. O-RING SEAL

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APPENDIX B, INCLUSION B-3.

PRELIMINARY DEVICE PERFORMANCE SPECIFICATION:
MICRO CIRCUIT, HYBRID -- LIGHT WAVE RECEIVER.

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SPECIFICATION NUMBER xxxxxRX

**PRELIMINARY DEVICE PERFORMANCE SPECIFICATION:
MICRO CIRCUIT, HYBRID -- LIGHT WAVE RECEIVER.**

1. **SCOPE.** THIS SPECIFICATION DEFINES THE REQUIREMENTS FOR A HYBRID LIGHT WAVE BURST MODE RECEIVER MICROCIRCUIT CAPABLE OF RECEIVING 500 KILOBAUD TO 20.0 MEGABAUD DATA RATES (.05 TO 4.0 MICROSECONDS ON, .05 MICROSECONDS TO CONTINUOUS OFF) DUTY CYCLE VARIATION DURING THE MESSAGE MODULATION; IS CAPABLE OF DETECTING ERROR FREE, A MINIMUM OPTICAL SIGNAL LEVEL MESSAGE STARTING FROM THE FIRST PULSE FOLLOWING A MESSAGE AT THE MAXIMUM OPTICAL SIGNAL LEVEL, WITH AN INTERMESSAGE GAP OF .5 MICROSECONDS OR MORE WHILE OPERATING AT A CASE TEMPERATURE ENVIRONMENT OF - 55°C TO +85°C.

1.1 **SYSTEM REQUIREMENTS.** THIS DOCUMENT REPRESENTS THE SYSTEM FUNCTIONAL AND TEST REQUIREMENTS OF THIS DEVICE AS USED IN THE 1 AND 8 MEGABITS/SEC. MANCHESTER ENCODED DATA TRANSMISSION OF A "DUAL SPEED" ENHANCEMENT OF A MIL STD 1773 TERMINAL HARDWARE OR IN AN UNENHANCED 1 MEGABIT/SEC. ONLY 1773 TERMINAL WHICH IS COMPATIBLE WITH AND MAY CO-EXIST WITH ENHANCED TERMINALS ON A DUAL SPEED FIBER OPTIC BUS.

2. **APPLICABLE DOCUMENTS.** THE FOLLOWING DOCUMENTS, OF THE ISSUE IN EFFECT ON THE DATE OF INVITATION FOR BIDS, FORM A PART OF THIS DRAWING TO THE EXTENT SPECIFIED HEREIN.

MIL-STD-883C NOTICE 4	TEST METHODS AND PROCEDURES FOR MICROCIRCUITS
MIL-M-38510	MICROCIRCUITS, GENERAL SPECIFICATION FOR
MIL-STD-1772	CERTIFICATION REQUIREMENTS FOR HYBRID MICROCIRCUIT FACILITIES AND LINES
xxxxxHA	HYBRID ASSEMBLY -- FIBER OPTIC RECEIVER
xxxxxES	ELECTRICAL SCHEMATIC -- FIBER OPTIC RECEIVER
xxxxxPA	HYBRID ASSEMBLY -- OPTICAL SIGNAL DETECTOR, SILICON, PIN
xxxxxPD	PACKAGE, FIBER OPTIC -- MIL HERMETIC
xxxxxCA	CONNECTOR ADAPTOR, FIBER OPTIC -- SMA
xxxxxOR	O-RING, NITRILE RUBBER
xxxxxSC	SCREW, MACHINE -- PAN HEAD, PHILLIPS DRIVE CRES 2-56, UNC-2A

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3. REQUIREMENTS. THE REQUIREMENTS SHALL BE AS SPECIFIED HEREIN.

3.1 MECHANICAL.

3.1.1 DESIGN AND DIMENSIONS. DESIGN AND CONSTRUCTION SHALL BE AS SPECIFIED HEREIN. DIMENSIONS SHALL BE IN ACCORDANCE WITH FIGURE 8 FOR REFERENCE ONLY.

3.1.2 LEAD MATERIAL AND FINISH. THE LEAD MATERIAL AND FINISH SHALL BE IN ACCORDANCE WITH MIL-M-38510, PARA. 3.5.6.

3.1.3 SERIAL NUMBER. PRIOR TO THE FIRST RECORDED ELECTRICAL MEASUREMENT IN SCREENING, EACH HYBRID SHALL BE MARKED WITH A UNIQUE SERIAL NUMBER.

3.1.4 MARKINGS, MINIMUM. MANUFACTURER'S IDENTIFICATION, PART NUMBER IDENTIFICATION AND DASH NUMBER, SERIAL NUMBER, COUNTRY OF ORIGIN, ESD IDENTIFIER, PIN 1 INDEX MARK AND DATE CODE OF MANUFACTURE SHALL BE MARKED ON THE COVER PLATE OF EACH DEVICE. NOTE: THE ESD IDENTIFIER (SEE MIL-M-38510, PARA.3.6.9.2) MAY BE USED AS THE PIN 1 INDEX MARK.

3.1.4.1 RELIDDED DEVICE MARKINGS. RELIDDED DEVICES SHALL HAVE THE LETTER "R" STAMPED AFTER THE NEW DATE CODE.

3.1.5 TEST TOOLING. ANY DEVIATION FROM THE TEST TOOLING DESCRIBED IN 3.1.5.1 AND FIGURES 2, 3, 4 AND 5 MUST BE APPROVED BY THE PROCURING ACTIVITY PRIOR TO IMPLEMENTATION. THE STANDARD TEST TRANSMITTER (xxxxxTX) IS ADJUSTED FOR ZERO (0) DISTORTION AT THE TEST EQUIPMENT OPERATING TEMPERATURE.

3.1.5.1 FIBER OPTIC TEST CABLE ASSEMBLY. THE CABLE ASSEMBLY SHALL BE AN APPROPRIATELY JACKETED 200 MICRON CLAD DIAMETER, 125 MICRON CORE DIAMETER SILICA ON SILICA OPTICAL FIBER WITH A NUMERIC APERTURE OF .25 ± .01. THE END TO ATTACH TO THE UNIT UNDER TEST SHALL BE APPROPRIATELY TERMINATED IN AN AMPHENOL SERIES TYPE 906-110-5013 SMA STYLE OPTICAL CONNECTOR OR EQUIVALENT. THE OTHER END MAY BE TERMINATED AS APPROPRIATE FOR THE TEST EQUIPMENT.

3.1.6 STANDARD CONFIGURATION. THE STANDARD CONFIGURATION CONSISTS OF THE HYBRID ASSEMBLY (xxxxxHA) COUPLED WITH THE SMA CONNECTOR ADAPTER (xxxxxCA) BY SCREWS (xxxxxSC) AND WITH O-RING (xxxxxOR) INSTALLED IN THE CONNECTOR ADAPTER RECESS. SEE FIGURES 6, 7, 8, 9, 10 AND 11.

3.1.6.1 OPTICAL CONNECTOR ADAPTER. THE OPTICAL CONNECTOR ADAPTER SHALL BE OF BRASS WITH 50 MICROINCHES MINIMUM OF GOLD, PLATED OVER 200 MICRO INCHES MINIMUM OF NICKEL PLATING.

3.1.6.2 INPUT TERMINATION. THE EXTERNAL THREAD AND INSIDE DIAMETER OF THE CONNECTOR ADAPTER SHALL BE CAPABLE OF MATING WITH AN AMPHENOL 906-110-5013 TYPE SMA FIBER OPTIC CABLE CONNECTOR OR EQUIVALENT.

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3.1.6.3 **WEIGHT.** 40 GRAMS, MAXIMUM.

3.2 **ELECTRICAL.**

3.2.1 **ABSOLUTE MAXIMUM RATINGS.**

(a)	VEE	-15.0 VOLTS
(b)	VCC	7.0 VOLTS
(c)	VBB	+90.0 VOLTS
(d)	DISSIPATION	1.0 WATTS MAX
(e)	RADIANT POWER INPUT.....	10.0 MILLIWATTS MAX
(f)	LOGIC OUTPUTS.....	1 STANDARD TTL LOGIC LOAD EACH.
(g)	SOLDERING HEAT	EACH LEAD SHALL BE CAPABLE OF WITHSTANDING +300°C MAX FOR 12 SECONDS MINIMUM AS MEASURED AT A POINT .020 INCH FROM UNIT BODY.
(h)	STORAGE TEMPERATURE (AMBIENT)...	-65°C TO +150°C AMBIENT
(i)	OPERATING TEMPERATURE (CASE)....	UNIT SHALL NOT BE PHYSICALLY DAMAGED BY OPERATION WITH CASE TEMPERATURES OF -55°C TO +85°C.

WARNING: ABOVE 85°C, THE SENSITIVITY OF THE RECEIVER AND THE BIT ERROR RATE MAY BE ADVERSELY EFFECTED BY THE SHOT NOISE OF THE THERMAL LEAKAGE OF THE PIN PHOTO DIODE. THIS SHOT NOISE DOUBLES ABOUT EVERY 20°C.

(j)	THERMAL IMPEDANCE	
	(1) HYBRID SUBSTRATE TO CASE.....	30°C/WATT MAX
	(2) CASE TO FREE AIR.....	30°C/WATT MAX

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3.2.2 **ELECTRICAL CHARACTERISTICS.** UNLESS OTHERWISE SPECIFIED, THE ELECTRICAL PERFORMANCE CHARACTERISTICS ARE AS SPECIFIED IN TABLE 1 OVER THE MAXIMUM OPERATING CASE TEMPERATURE.

3.2.3 **OPTICAL SIGNAL DETECTOR.**

3.2.3.1 **PIN PHOTO DETECTOR ASSEMBLY.** THE PIN ASSEMBLY USED IN THIS RECEIVER SHALL BE PER xxxxxPA OR AN OPTICAL AND FUNCTIONAL EQUIVALENT. SEE FIGURE 7.

3.2.3.2 **PIN PHOTO DETECTOR CONVERSION EFFICIENCY.** THE MEASURED EFFICIENCY OF THE PIN PHOTO DETECTOR, BEFORE ASSEMBLY xxxxxPA IS INSTALLED IN THE RECEIVER MODULE, SHALL BE .46 AMPS/WATT MINIMUM AT 30°C.

3.2.3.3 **RADIANT POWER INPUT.** THE RADIANT POWER INPUT (RPI) SHALL

BE SPECIFIED AT PEAK LEVEL.

3.2.4 **ELECTRICAL SCHEMATIC.** PER FIGURE 1. COMPONENT DATA (TYPES AND VALUES) IS FOR INFORMATION ONLY. THE DEVICE MUST MEET ALL THE REQUIREMENTS OF THIS DRAWING REGARDLESS OF ACTUAL CIRCUIT CONFIGURATION. THE SCHEMATIC (xxxxxES) HAS PRECEDENCE OVER THIS SPECIFICATION.

3.2.5 **MECHANICAL CONFIGURATION.** PER FIGURE 8. CONFIGURATION IS FOR INFORMATION ONLY. THE PACKAGE MUST MEET ALL THE REQUIREMENTS OF THIS DRAWING REGARDLESS OF ACTUAL CIRCUIT CONFIGURATION. THE PACKAGE DRAWING (xxxxxPD) HAS PRECEDENCE OVER THIS SPECIFICATION.

3.3 ENVIRONMENTAL.

3.3.1 **OPERATING TEMPERATURE RANGE.** -55°C TO +85°C CASE TEMPERATURE.

4. QUALITY ASSURANCE PROVISIONS. PARTS SUPPLIED TO THIS DOCUMENT SHALL MEET THE REQUIREMENTS OF THIS DOCUMENT. QUALITY CONFORMANCE SHALL BE AS SPECIFIED HEREIN. CONFORMANCE INCLUDES ELEMENT EVALUATION, PROCESS CONTROL, DEVICE SCREENING AND QUALITY CONFORMANCE EVALUATION, ALL AS DEFINED IN THIS DOCUMENT AS A MINIMUM ACCEPTANCE CRITERIA, ALL PARTS SHIPPED SHALL HAVE SUCCESSFULLY COMPLIED WITH THE SCREENING AND ELECTRICAL TEST REQUIREMENTS AS DEFINED IN THIS SECTION.

4.1 ELEMENT EVALUATION. ALL ELEMENTS UTILIZED IN THE MANUFACTURE OF HYBRIDS TO THIS DOCUMENT SHALL BE EVALUATED PER THE REQUIREMENTS OF THE PROCURING ACTIVITY. ELEMENTS ARE DEFINED AS 'MATERIALS' FOR DEVICE ASSEMBLY AND INCLUDE ACTIVE AND PASSIVE PARTS, THE PACKAGE AND ADHESIVES.

4.2 PROCESS CONTROL. PROCESS CONTROL PERTAINING TO WIRE BONDING SHALL BE MACHINE PROCESS QUALIFICATION CONSISTING OF SAMPLE WIRE BOND TESTING PRIOR TO PROCESSING AND A 100% DESTRUCTIVE TEST OF ALL INPUT/OUTPUT WIRES OF ONE SAMPLE PACKAGE PER ASSEMBLY LOT.

4.3 DEVICE SCREENING. DEVICE SCREENING SHALL BE AS SPECIFIED IN TABLE II WHEN REQUIRED BY THE PROCURING ACTIVITY. SCREENING SHALL BE CONDUCTED ON ALL DEVICES PRIOR TO QUALITY CONFORMANCE INSPECTION. ELECTRICAL TESTS SHALL BE PER TABLE I. DEVICES SHALL BE CONFIGURED PER PARAGRAPH 3.1.6 FOR ALL ELECTRICAL TESTS.

I. ADDITIONAL TEST AND INSPECTIONS MAY PERFORMED WHERE EXPERIENCE INDICATES CONCERN FOR SPECIFIC QUALITY CHARACTERISTICS.

II. ANY DEVICES THAT FAIL ANY TEST CRITERIA SHALL BE REMOVED FROM THAT LOT AT THE TIME OF OBSERVATION OR IMMEDIATELY AT THE CONCLUSION OF THE TEST IN WHICH THE FAILURE OCCURRED.

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4.3.1 **PRESEAL BURN-IN.** PRESEAL BURN-IN IS OPTIONAL AND REQUIRES THE APPROVAL OF THE PROCURING ACTIVITY. IF PERFORMED, CASE TEMPERATURE OF THE DEVICE SHALL NOT EXCEED +125°C.

4.3.2 **INTERNAL VISUAL AND MECHANICAL.** FAILURE CRITERIA SHALL BE PER MIL-STD-883C, METHOD 2017, AND THIS DOCUMENT. THE SUPPLIER WILL FURNISH A TOPOGRAPHICAL LAYOUT OF ELEMENTS ON THE METALIZED SUBSTRATE IN THE PACKAGE INITIALLY AND WHENEVER A DESIGN CHANGE REQUIRES AN UPDATE.

4.3.3 **STABILIZATION BAKE.** THE STABILIZATION BAKE SHALL BE PER MIL-STD-883C, METHOD 1008, FOR 24 HOURS AT +125°C.

4.3.4 **TEMPERATURE CYCLING.** TEMP CYCLING SHALL BE PER MIL-STD- 883, METHOD 1010, TEST CONDITION B (15 CYCLES FROM -55°C to +125°C).

4.3.5 **CONSTANT ACCELERATION.** CONSTANT ACCELERATION SHALL BE PER MIL-STD-883C, METHOD 2001, TEST CONDITION A (5000 G's IN THE "Y1" DIRECTION ONLY).

4.3.6 **PREBURN-IN ELECTRICAL.** INTERIM ELECTRICAL TESTING PRIOR TO BURN-IN IS OPTIONAL, BUT IF PERFORMED, SHALL BE PER TABLE I. CASE TEMPERATURE SHALL NOT EXCEED 85°C.

4.3.7 **BURN-IN.** TESTING SHALL BE FOR 160 HOURS MINIMUM PER MIL-STD-883C, METHOD 1015, TEST CONDITION B (STEADY STATE, FORWARD BIAS). CASE TEMPERATURE SHALL BE 125°C AND PDA SHALL BE 10% OR 1 DEVICE, WHICHEVER IS GREATER. SEE BURN-IN CONNECTIONS, FIGURE 1.

4.3.8 **PACKAGE SEAL.** PRIOR TO FINAL ELECTRICAL TESTING, GROSS AND FINE LEAK SEAL TESTS ARE PERFORMED. GROSS LEAK SHALL BE PER MIL-STD-883C, METHOD C (HEATED PERFLUOROCARBON IMMERSION). FINE LEAK RATE SHALL NOT EXCEED 1 x 10 exp-7 ATM CC/SEC. PER MIL-STD-883C, METHOD 1014.5, TEST CONDITION A2.

WARNING: DO NOT USE CONDITION B (RADIOISOTOPE FINE LEAK TEST) LEAK RATE TEST. THIS MAY CAUSE MALFUNCTION OF THE PHOTO DETECTING DEVICE IN THIS CIRCUIT, IF TRACER GAS RESIDUE IS TRAPPED WITHIN THE PACKAGE.

4.3.9 **FINAL ELECTRICAL.** FINAL ELECTRICAL SHALL BE THOSE TESTS OUTLINED IN TABLE I.

4.3.10 **EXTERNAL VISUAL.** EXTERNAL VISUAL SHALL BE PER MIL-STD-883C, METHOD 2009.

4.4 **QUALITY CONFORMANCE PROVISIONS.** QUALITY CONFORMANCE INSPECTIONS SHALL BE PERFORMED AS SPECIFIED HEREIN. AN INSPECTION LOT SHALL BE AS DEFINED IN MIL-M-38510, PARA. 3.1.3.8.

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4.4.1 **GROUP A INSPECTION.** 100% SCREENING WILL BE DONE IN LIEU OF GROUP A SAMPLING INSPECTION. GROUP A ELECTRICAL TEST SHALL BE PER TABLE I. GROUP A TESTING BY SUBGROUP OR WITHIN SUBGROUPS MAY BE PERFORMED IN ANY SEQUENCE. SEE TABLE I AND III FOR PARAMETERS AND SUBGROUPS. EACH SERIALIZED DEVICE WILL HAVE A DATA SHEET WHICH WILL INCLUDE PART NUMBER, SERIAL NUMBER, TEST DATE, LED SERIAL NUMBER, JOB OR LOT NUMBER AND A TABULATION WHICH PERMITS LOGGING OF TEST DATA AT -40°C, ROOM AMBIENT AND +85°C. THE COMPLETED DATA SHEETS WILL BECOME PART OF THE JOB PACKET AND A COPY WILL BE DELIVERED WITH THE DEVICE.

4.4.2 **GROUP B INSPECTION.** GROUP B INSPECTION SHALL BE PERFORMED ON EACH INSPECTION LOT AS SPECIFIED HEREIN AND DESCRIBED IN TABLE IV.

4.4.2.1 **PHYSICAL DIMENSIONS.** PACKAGES ARE MEASURED AT INCOMING INSPECTION. A SINGLE SEALED DEVICE FROM EACH LOT SHALL BE MEASURED FOR ACCURATE HEIGHT DIMENSIONS.

4.4.2.2 **SOLVENT RESISTANCE.** FOUR LIDS (COVERS) WILL PASS THROUGH ALL PROCESS STEPS WITH A DEVICE LOT EVERY 90 DAYS. THE INK MARKING ON THE FOUR LIDS WILL BE SOLVENT RESISTANCE TESTED PER MIL-STD-883C, METHOD 2015.

4.4.2.3 **SOLDERABILITY.** SOLDERABILITY TEST SHALL BE PERFORMED ON ONE SAMPLE PER LOT. IT MAY BE PERFORMED ON A FUNCTIONAL FAILURE THAT IS UNUSABLE OTHERWISE OR ON A DELIVERABLE PART, IF NO SOLDER RESIDUE IS PRESENT ON THE LEADS WITHIN .5 INCHES OF THE PACKAGE WALL.

4.4.2.4 **INTERNAL VISUAL AND MECHANICAL.** THIS IS NOT NECESSARY FOR DELIVERABLE PARTS, DUE TO PRECAP VISUAL (SEE 4.3.2). THIS TEST WILL BE PERFORMED, PER MIL-STD-883C, METHOD 2014, ON FUNCTIONAL FAILED UNITS AFTER REWORK.

4.4.2.5 **WIRE BOND STRENGTH.** A SINGLE TEST PACKAGE WILL BE ASSEMBLED FOR EACH ASSEMBLY LOT, IT WILL HAVE WIRE BONDED ELEMENTS (DIE) WHICH WILL BE SUBJECTED TO ALL PROCESS AND SCREENING STEPS. BOND STRENGTH TESTING WILL BE PERFORMED MIL-STD-883C, METHOD 2011.

4.4.2.6 **DIE SHEAR STRENGTH.** THE DESTRUCTIVE DIE SHEAR TEST WILL BE PER MIL-STD-883C, METHOD 2019. IT WILL BE PERFORMED ON THE DEVICES OF THE TEST PACKAGE (SEE 4.4.2.6).

4.4.2.7 **SEAL.** FINE AND GROSS SEAL TESTS ARE PERFORMED DURING DEVICE SCREENING (SEE 4.3.8).

4.4.2.8 **ELECTROSTATIC DISCHARGE SENSITIVITY.** THIS TEST SHALL BE PERFORMED FOR INITIAL QUALIFICATION AND PRODUCT REDESIGN AS A MINIMUM AND ESD MARKING SHALL BE A TRIANGLE INDICATING CLASS 1 UNTIL FORMAL TESTING HAS BEEN COMPLETED FOR FINAL CLASSIFICATION DETERMINATION.

4.4.3 **GROUP C INSPECTION.** THERE SHALL BE NO GROUP C TESTING.

4.4.4 **GROUP D INSPECTION.** THERE SHALL BE NO GROUP D TESTING.

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4.5 REWORK. REWORK SHALL BE PERFORMED IN ACCORDANCE WITH MIL-M-38510.

4.6 QUALIFICATION. WHEN REQUIRED, QUALIFICATION SHALL BE PERFORMED PER THE REQUIREMENTS OF THE PROCURING ACTIVITY.

4.7 HYBRID PRODUCTION FACILITY. THIS PRODUCT MAY BE PRODUCED IN ANY FACILITY APPROVED BY THE PROCURING ACTIVITY, WHICH NEED NOT BE A MIL-STD-1772 QUALIFIED FACILITY UNLESS SPECIFIED. IT MUST BE EQUIPPED FOR ESD (ELECTROSTATIC DISCHARGE) REQUIREMENTS, WITH ALL WORK STATIONS GROUNDED AND ANTI-STATIC HANDLING DEVICES, CLOTHING, AND WRIST STRAPS USED. ALL ASSEMBLY AND OPEN PACKAGE TESTING SHALL BE PERFORMED IN A CONTROLLED ATMOSPHERE.

5. PREPARATION FOR DELIVERY. THE ITEMS SHALL BE AFFORDED PRESERVATION AND PACKAGING TO ASSURE ADEQUATE PROTECTION DURING NORMAL COMMERCIAL HANDLING. THE ESD PROVISIONS WILL INCLUDE ENCLOSING IN STATIC PROTECTIVE BAG, AND SECURING IN AN ESD SHIELDED CONTAINER.

6. NOTES. NONE

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TABLE I --- NOTES 1/, 2/, 3/, 4/, 5/

ITEM	SYMBOL	CHARACTERISTICS	TEST PIN	TERMINAL CONDITIONS								GROUP A SUBGRPS	LIMITS		UNITS	TEST CONDITIONS
				PIN 1	PIN 2	PIN 3	PIN 4	PIN 5,7 11,12	PIN 6,10	PIN 8	PIN 9		MIN	MAX		
A	Iee	POWER SUPPLY CURRENT	6, 10	NC	5.25V	--	--	0.0V	-12.6V	55.0V	NC	1-3	--	-40	mA	
B	Icc	POWER SUPPLY CURRENT	2	NC	5.25V	--	--	0.0V	-12.6V	55.0V	NC	1-3	--	25	mA	
C	Idd	POWER SUPPLY CURRENT	8	NC	5.25V	--	--	0.0V	-12.6V	55.0V	NC	1-3	--	235	uA	
D1	Voh	OUTPUT VOLTAGE, HIGH	3	TTL LO	4.75V	--	--	0.0V	-11.4V	50.0V	NC	1-3	2.5V	--	V	
D2	Voh	OUTPUT VOLTAGE, HIGH	4	TTL LO	4.75V	--	--	0.0V	-11.4V	50.0V	NC	1-3	2.5V	--	V	
E1	Vol	OUTPUT VOLTAGE, LOW	3	NC	5.25V	--	--	0.0V	-11.4V	50.0V	NC	1-3	--	0.5V	V	
E2	Vol	OUTPUT VOLTAGE, LOW	4	NC	5.25V	--	--	0.0V	-11.4V	50.0V	NC	1-3	--	0.5V	V	
F1	Idark	DIODE DARK CURRENT	8, 9	NC	5.0V	--	--	0.0V	-12.0V	55.0V	7/	2	--	320	nA	FIG. 2, 8/
F2	Iresp	DIODE RESPONSIVITY	8, 9	NC	5.0V	--	--	0.0V	-12.0V	45.0V	7/	1	22.5	--	uA	FIG. 2, 9/
G1	RPImn, HR	RADIANT POWER INPUT HI RATE, BER e-9/e-12	INPUT	NC	5.25V	6/	6/	0.0V	-11.4V	45.0V	NC	4-6	--	200	nW	FIG. 3, 10/
														225	nW	(1 e-9/1 e-12)
G2	RPImn, LR	RADIANT POWER INPUT LO RATE, BER e-9/e-12	INPUT	NC	5.25V	6/	6/	0.0V	-11.4V	45.0V	NC	4-6	--	200	nW	FIG. 3, 11/
														225	nW	(1 e-9/1 e-12)
H	RPImx	RADIANT POWER INPUT	INPUT	NC	4.75V	6/	6/	0.0V	-11.4V	45.0V	NC	9-11	235	--	uW	FIG. 4, 12/
I	Timr	INTERMESSAGE RECOVERY	INPUT	NC	4.75V	6/	6/	0.0V	-11.4V	45.0V	NC	4-6	--	750	nS	FIG. 5, 13/

NOTES:

1/ CURRENTS LEAVING THE CIRCUIT ARE INDICATED BY A MINUS (-) SIGN.
2/ LIMITS APPLY OVER THE TEMPERATURE RANGE OF -55C TO +85C CASE.
3/ THE PEAK SPECTRAL INPUT SHALL BE BETWEEN 810 AND 850 nM WITH A HALF POWER SPECTRAL BANDWIDTH OF < or = 50 nM.
4/ ALL RPI MEASUREMENTS ARE PEAK (OR AVG. READING DIVIDED BY THE DUTY CYCLE).
5/ SEE FIGURE 5. FOR LOGIC BLOCK DIAGRAM.
6/ LOADED WITH ONE STANDARD TTL LOGIC INPUT LOAD.
7/ CONNECT A DVM BETWEEN PINS 8 (+) AND 9 (-). Id = VOLTAGE MEASURED DIVIDED BY 50 Kohms.
8/ AT TEMPERATURE OF +85?C CASE WITH OPTICAL INPUT PLUGGED.
9/ MEASURED WITH A 100% DUTY CYCLE, 100 uw, OPTICAL INPUT.
10/ RPI FOR BAUD ERROR RATES OF 1 exp-9 AND 1 exp-12. REPEATING "1011010010100000" PATTERN OF 62.5 nS BAUDS.
11/ RPI FOR BAUD ERROR RATES OF 1 exp-9 AND 1 exp-12. REPEATING "1011110100110000" PATTERN OF 500 nS BAUDS.
12/ RPI FOR PULSE WIDTH DISTORTION OF +/-20 nSEC. REPEATING "1011010010100000" PATERN OF 62.5 nS BAUDS.
13/ RECOVER FROM A HI LEVEL MESSAGE TO DETECT A LO LEVEL MESSAGE. SEE NOTES, FIGURE 5.

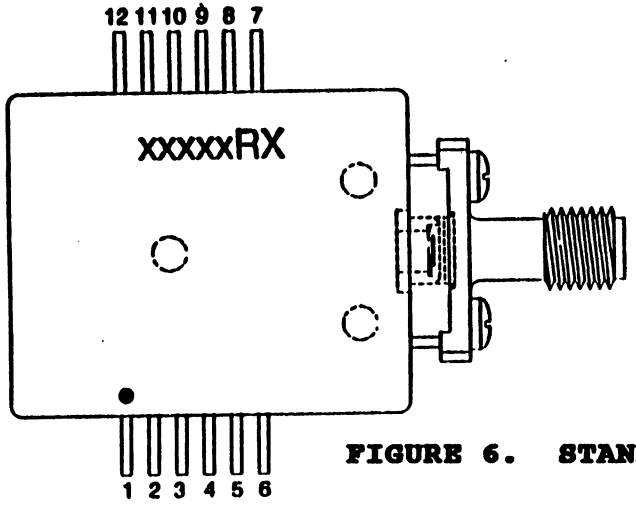

FIGURE 6. STANDARD CONFIGURATION.

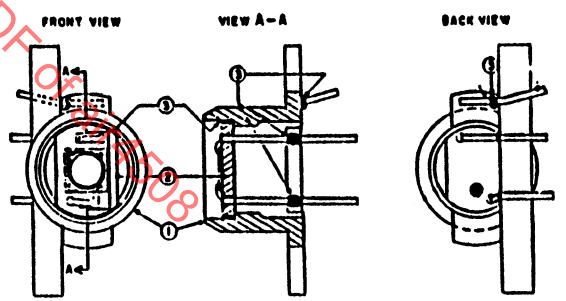

FIGURE 7. OPTICAL DETECTOR ASSEMBLY.

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TABLE II. Device Screening

Test Inspection	Mil-Std-883		Requirement
	Method	Condition	
Pre-seal Burn-in	1030		Optional
Internal Visual	2017		100%
Stabilization Bake	1008	C	100%
Temperature Cycling or Thermal Shock	1010 1011	C A, min	100% or 100%
Mechanical Shock or Constant Acceleration	2002 2001	B (Y1 only) A (Y1 only)	100% or 100%
Interim Electrical			Optional
Burn-in	1015	125·C	100%
Final Electrical Test	Per Table I		100%
Seal a) Fine b) Gross	1014		100%
External Visual	2009		100%

TABLE III. Group A electrical Test

Subgroup	Parameters	LTPD
1	Static tests at 25·C	2
2	Static tests at maximum rated operating temp	3
3	Static tests at minimum rated operating temp	5
4	Dynamic tests at 25·C	2
5	Dynamic tests at maximum rated operating temp	3
6	Dynamic tests at minimum rated operating temp	5
7	Functional tests at 25·C	2
8	Functional tests at maximum and minimum rated operating temperatures	5
9	Switching tests at 25·C	2
10	Switching tests at maximum rated operating temp	3
11	Switching tests at minimum rated operating temp	5

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TABLE IV. Group B Test

Subgroup	Test	Mil-Std-883		Quantity (Accept No.) or LPTD
		Method	Condition	
1	Physical Dimensions	2016		2 (0)
3	Resistance to Solvents	2015		4 (0)
4	Internal Visual & Mech.	2014		1 (0)
5	Bond Strength 1. Thermocompression 2. Ultrasonic or Wedge 3. Flip-Chip 4. Beam Lead	2011	 C or D C or D F H	2 (0)
6	Die Shear Strength	2019		2 (0)
7	Solderability	2003	Solder Temperature 245 ±5°C	
8	Seal 1. Fine 2. Gross	1014		15
9	1. Electrical Parameters 2. Electrostatic Discharge 3. Electrical Parameters	3015	Group A-1 Group A-1	15 (0)

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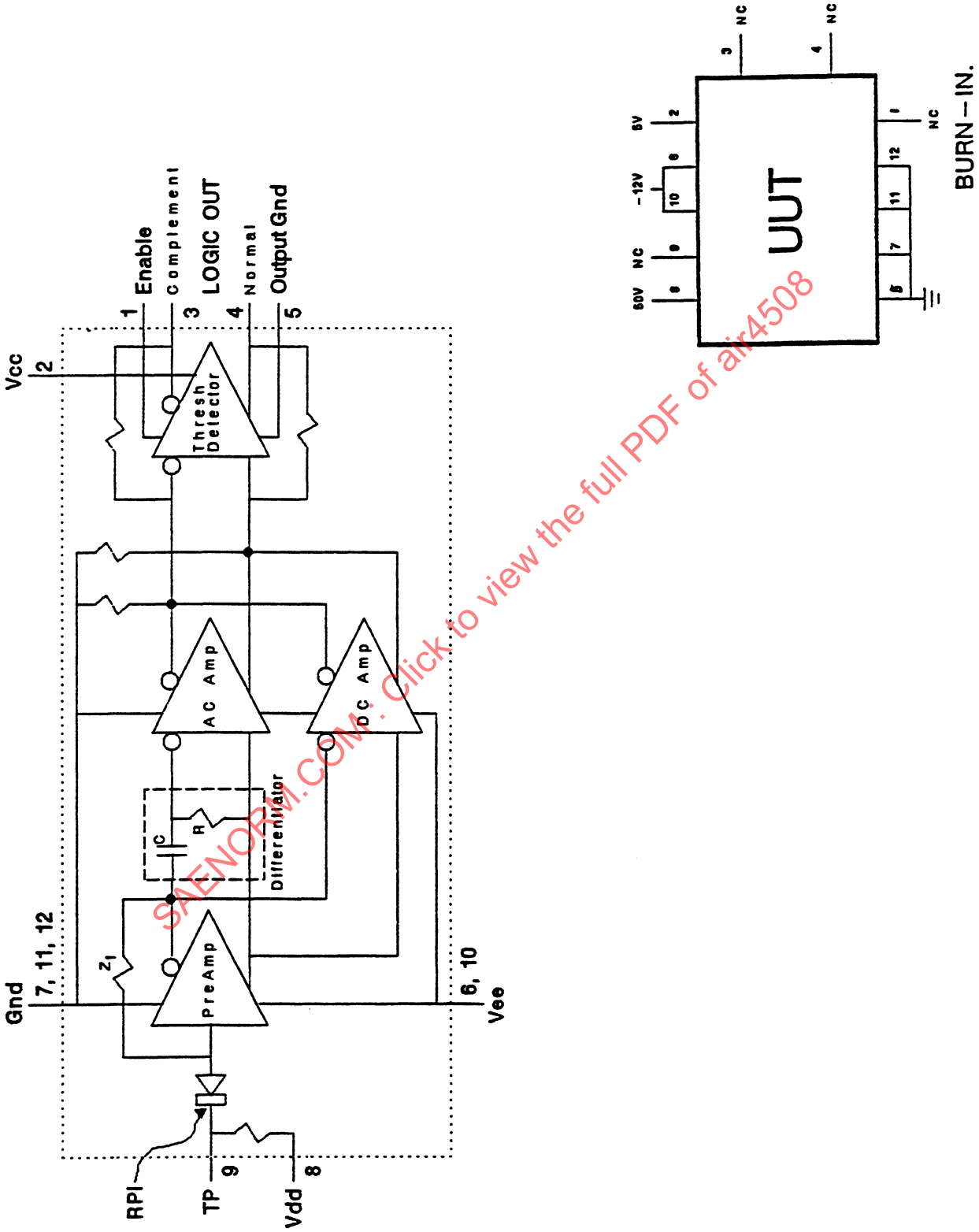

FIGURE 1. ELECTRICAL SCHEMATIC, DUAL SPEED FIBER OPTIC RECEIVER.

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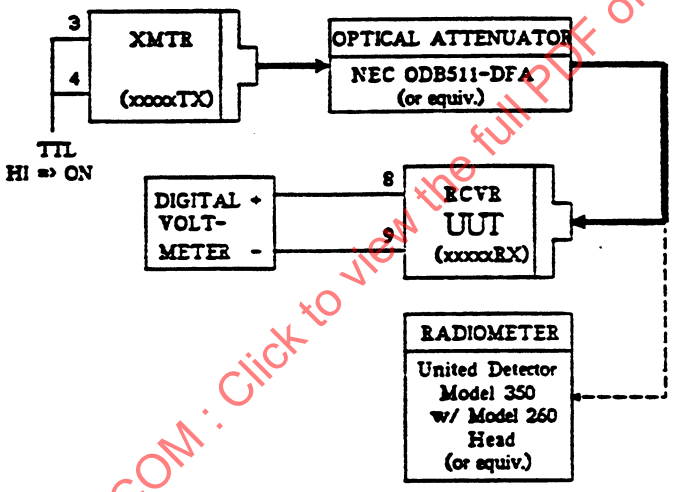

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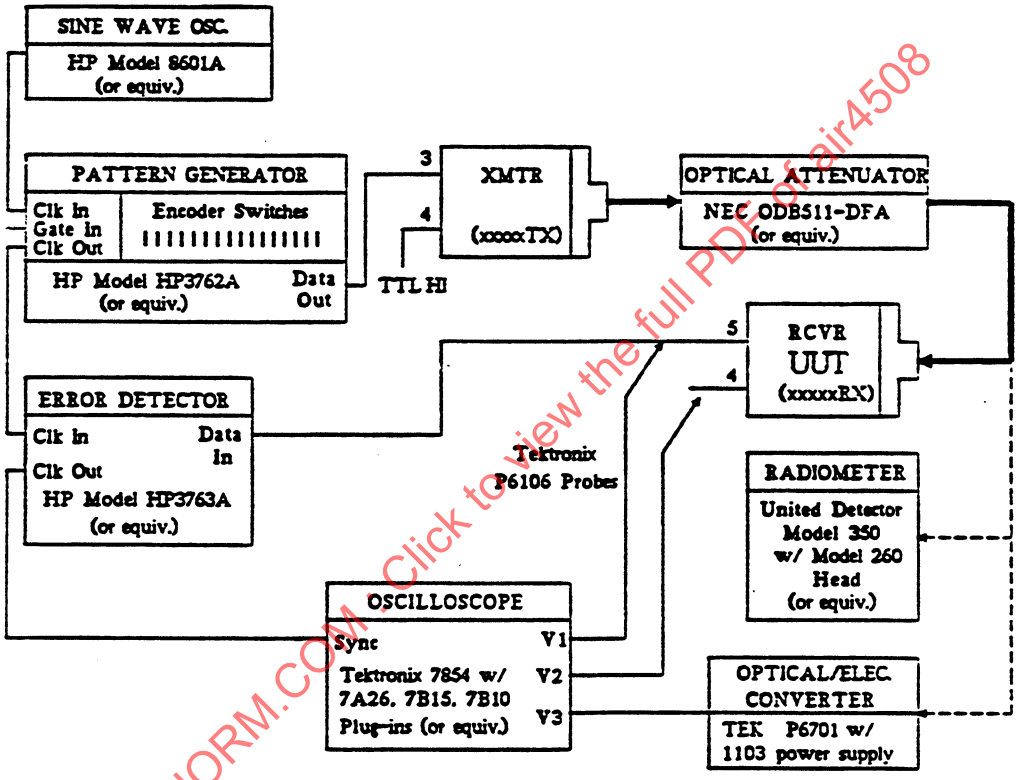
NOTES: 1. With transmitter ON:
Set attenuator for 100 uW power on the Radiometer.
Place test fiber in the UUT Optical Port and measure voltage from pin 8 to pin 9.
Iresp = V89 / 50 exp3.
2. With test fiber removed from UUT and input plugged -
Idark = V89 / 50 exp3.

FIGURE 2. PHOTO DIODE CURRENT MEASUREMENT TEST CIRCUIT.



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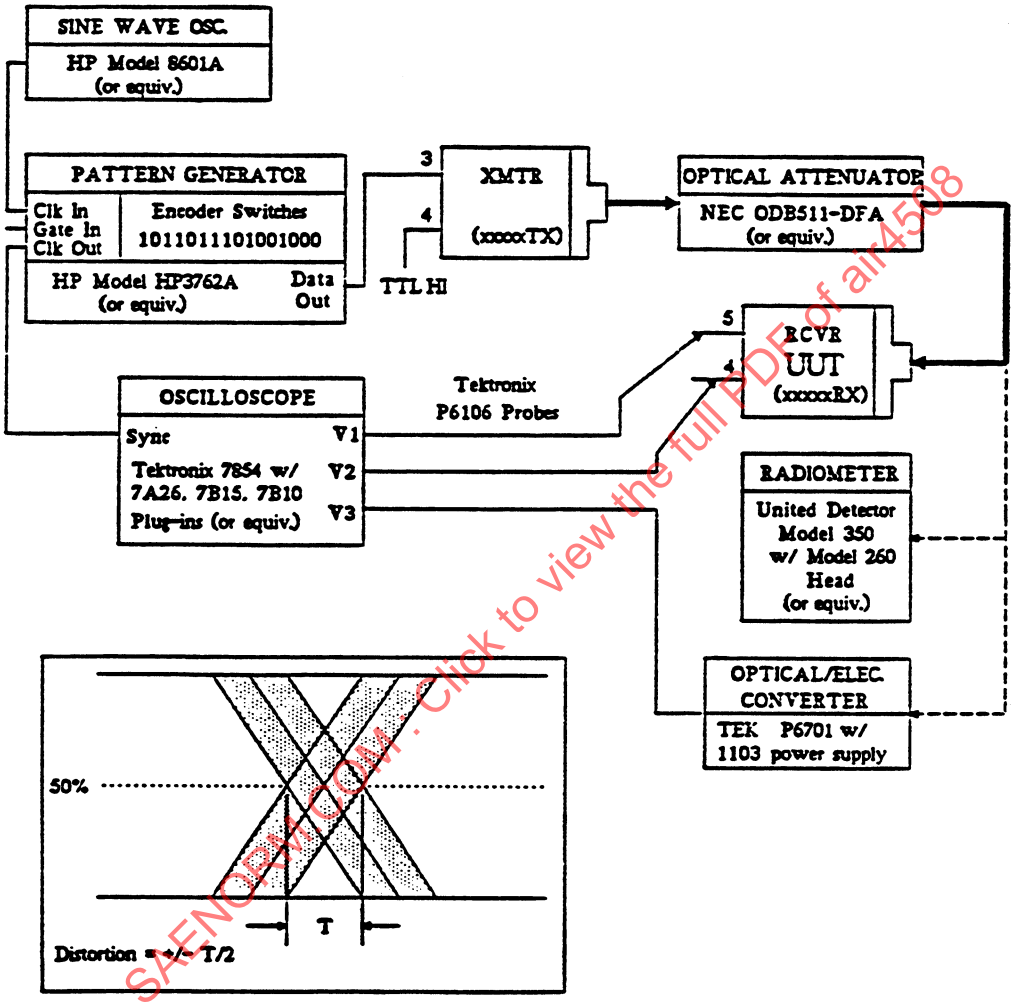
NOTES: 1. Adjust Generator output level for zero pulse width distortion of Transmitter Optical Output (at the 50% amplitude level) with a "1010..." repeating pattern, before starting measurements.

2. For test G1: Set Oscillator to 16 Mhz (62.5 nS pulses). Sey Encoder Switch pattern to "1011010010100000". Record PEAK (2 x Radiometer reading) optical power level and exact BER reading of the error Detector at approximate BERs of 10 exp-4, 10 exp-6 and 10 exp-9. Use linear regression to calculate RPImin at 10 exp-9 and 10 exp-12 Baud Error Rates.

3. For test G2: Set Oscillator to 2 Mhz (500 nS pulses). Set Encoder Switch Pattern to "1011110100110000". Repeat the procedure of 2. (above) for approximate BERs of -4, -6 and -8. Again, use Linear Regression to calculate RPImin at 10 exp-9 and 10 exp-12 Baud Error Rates.

FIGURE 3. TEST CIRCUIT TO MEASURE RPImin (Baud Error Rate).



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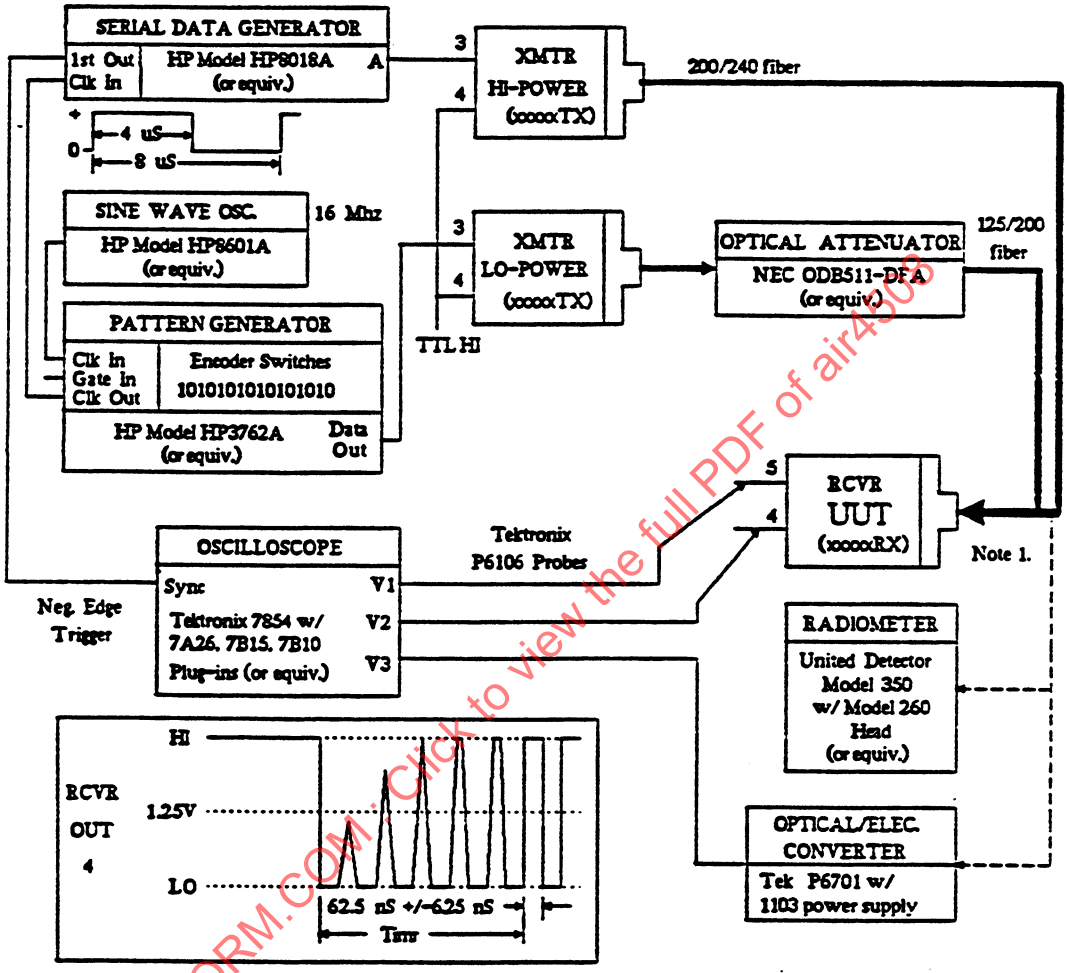
NOTES: 1. Adjust Generator output level for zero pulse width distortion of Transmitter Optical Output (at the 50% amplitude level) with a "1010..." repeating pattern, before starting measurements.

2. Set pattern indicated and increase receiver RPI by decreasing attenuation, until Pulse Width Distortion = 20 nS (+/- 16.7%). RPImax = 2 x Radiometer reading.

FIGURE 4. TEST CIRCUIT TO MEASURE RPImax (Distortion).



NOTES: 1. Both fibers are terminated in a common series 906 SMA ferrule. Bore size is not critical (<800 microns).

2. With HI-POWER transmitter DISABLED:
Adjust Pattern Gen Out levels for zero Pulse Width Distortion of LO-POWER transmitter output at the 50% amplitude level with a repeating "1010" pattern. Set Attenuator for a reading of 100 nW (200 nW Peak).

3. With LO-POWER transmitter DISABLED:
Set HI-POWER transmitter output for a Radiometer reading of 100 uW (200uW Peak).

4. With BOTH transmitters ENABLED:
Timr is the time from the end of the last POSITIVE pulse from the HI-POWER transmitter until the Distortion of the output pulses of the UUT is < or = to +/-6.25 nS at the 1.25V threshold level.

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FIGURE 5. TEST CIRCUIT TO MEASURE INTER-MESSAGE RECOVERY TIME.

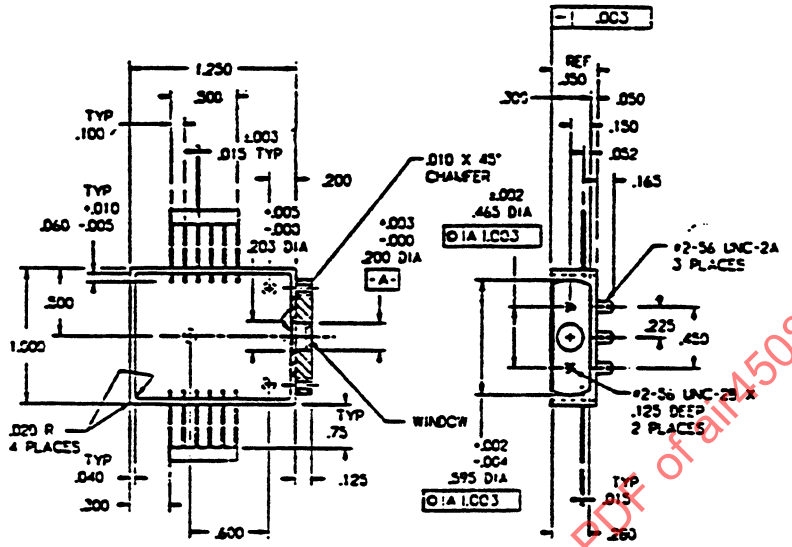

FIGURE 8. PACKAGE DIMENSIONS.

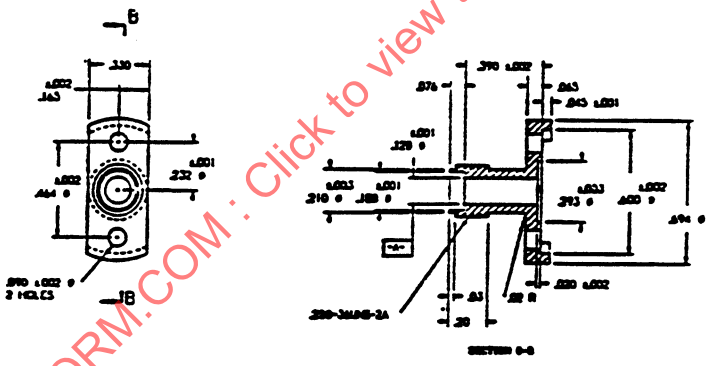

FIGURE 9. CONNECTOR ADAPTER.

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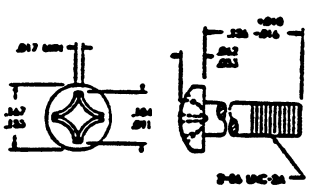

FIGURE 10. MOUNTING SCREW.

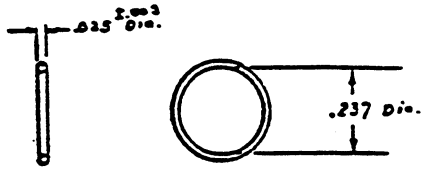

FIGURE 11. O-RING SEAL

APPENDIX C.

DESIGN EXAMPLE - A MISSILE APPLICATION.

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DESIGN EXAMPLE - A MISSILE APPLICATION.

C-1.0. Introduction.

The following discussion describes a data bus system of the MIL-STD-1773 type which was proposed for a missile system which was not developed. Although it does not demonstrate a full 32- station capability, it illustrates that the 1773 mechanization using fiber optics is a viable and satisfactory solution to transmission of data on systems which can make use of this standard with somewhat reduced port requirements.

C-2.0. Requirements.

The missile internal data bus must be capable of operating upon demand, under all conditions of environmental exposure, whether benign or hostile. Exposures may consist of temperatures ranging from 0 to 125C, acceleration, altitude, vibration, blast, overpressure conditions, radiation exposure to neutrons, x-rays and gamma rays, EMP, and other agents harmful to proper bus operation. It is important that the bus selection be made with system survivability and operability held uppermost in mind. The missile hostile environment created by exposure to a nuclear blast has promoted interest in employment of fiber optics as a medium for data transmission. The totally dielelctric nature of the optical fiber cable provides immunity to EMP, EMI, and electrical ground loop effects. Fiber optics provides complete electrical isolation between missile stage components located along the optical communication path. The number and location of data terminals within this missile makes a fiber optic data bus a prime candidate for the transfer of information between units.

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C-3.0. Bus Design.

Functionally, the missile data bus provides the two-way communication means between the four missile stage controllers (SC) (one on each of the four missile stages), the ordnance initiation unit (OIU), the reentry system electronics (RSE), the telemetry (TLM), and the guidance control computer (GCC); see Figure 1. The GCC operates as bus control unit (BCU) while the other bus terminals function as remote terminal units (RTUs). The protocol established for the 1773 type bus is command/response such that the BCU initiates, directs, and monitors all traffic that flows on the bus. As seen in Figure 1., the GCC also acts as a RTU on the hard mobile launcher (HML) missile data link providing the launcher/missile communication interface. Missile data traffic considerations indicate that the 1 megabit per second speed of a 1773 type bus is more than adequate to meet this missile's data transfer requirement.

Figure 2. shows the interconnection of a typical 1773 bus terminal arrangement. The 1773 bus design chosen here uses individual cable fibers between all receiver (R) and transmitter (T) units and an optical transmissive star coupler to accomplish the terminal-to-terminal

interconnection. This bus was chosen since it represents a candidate design for a fully passive (no optical repeater) bus which satisfies certain optical power level conditions to be described later herein. Cutting of the optical cables at the time of stage separation is accomplished by either explosive charge or sharp cutting devices for both cable types. No signal disruption will be seen on the remaining (upstage) portion of the bus due to the severance of the cable when this process is properly done. Bus operation is unaffected by open-ended or unterminated bus lines. The bus implementations shown route the signal cable exterior to the missile skin, within a protective cableway channel, along stages 1, 2, and 3 permitting access-port entry by the cables between stages for coupling to the electronic units of each stage. This arrangement eliminates the need for interstage connectors, saves weight, improves the data bus and missile performance, and facilitates the bus cabling installation.

The fiber optical cable selected contains a single glass optical fiber within a buffer, inner plastic jacket, Kevlar strength member, and outer plastic jacket. No electrical shielding is required due to the fully dielectric nature of the cable. Also, this cable has been ruggedized to provide resistance to moisture penetration and possesses high tensile strength to assist in its installation.

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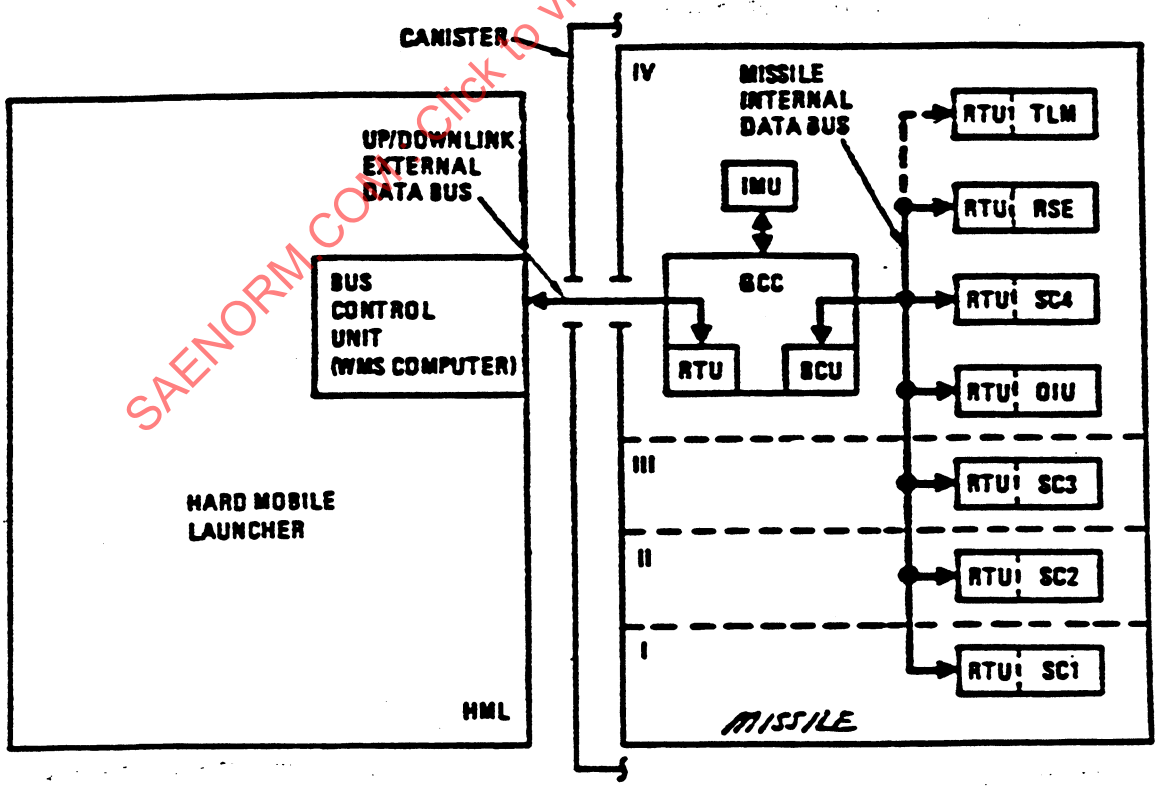

Figure 1. HML Missile Data Bus Communication Links.

C-3.1. Design Component Selection.

The nature of this bus design is to provide sufficient options and flexibility to permit capitalizing on future state-of-the-art performance and cost factors which become prudent. Certain choices made in the selection of components for the fiber optic bus design reflect this consideration. Uppermost among these is the selection of an operating optical wavelength, type of optical source and detector and optical fiber size for the bus mechanization. These design elements are discussed in the following paragraphs.

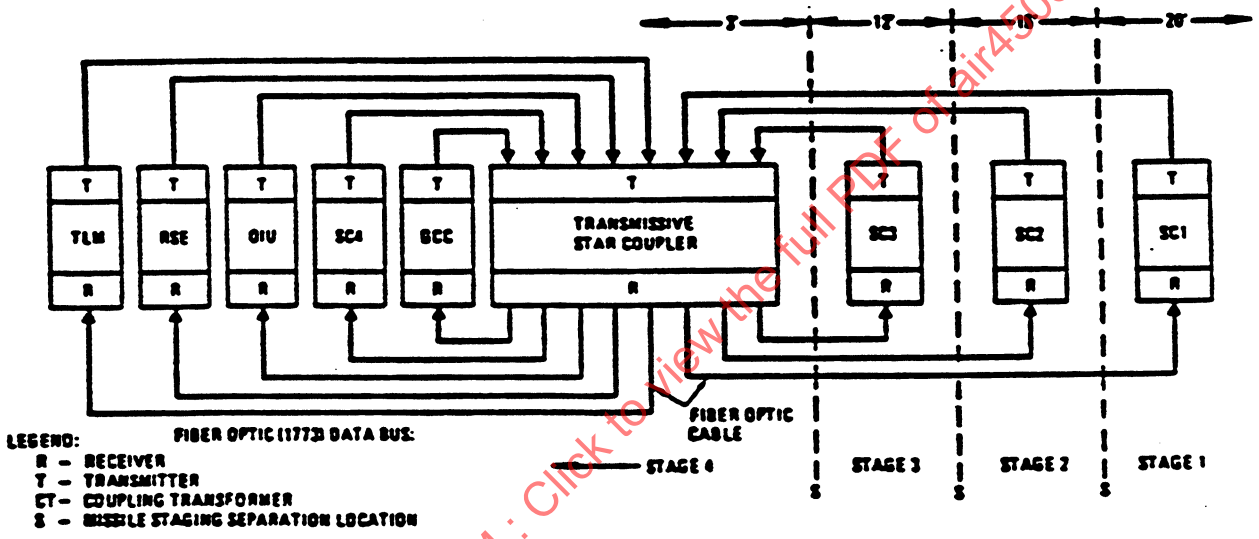

Figure 2. MIL-STD-1773 Bus Design.

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C-3.1.1. Optical Wavelength.

Historically, the initial development of fiber optic componentry was based upon (and limited to) the optical wavelength band suitable for optical detectors using silicon semiconductor technology. This places an upper wavelength limit for signal detection at about 1100 nanometers (in the near infrared region of the electromagnetic spectrum). Numerous optical sources of the light-emitting diode (LED) and injection laser diode (ILD) types have been developed to operate in the 800 to 950 nanometer wavelength region to take advantage of the silicon detection capability. Sufficient test data exists on these devices (sources and detectors) to provide high confidence in their durability and extended lifetime characteristics. Contemporary with the source and detector development effort optical fiber technology has produced glass fiber (fused silica) compositions with purity levels lower than 10 parts per million of foreign material and optical loss levels approaching 1 decibel per kilometer (dB/Km) of fiber length in this optical wavelength region. More recently (within the last 3 to 5 years) a major emphasis was made in the fiber optic industry to develop a long-wavelength

capability. Two wavelength bands are suggested, centered about 1300 nanometers and 1550 nanometers, respectively. This emphasis was created by the desire to reduce the signal distortion in long distance, high data rate transmissions and to further reduce the optical loss in the transmission line. Detectors operating in these spectral regions use germanium or indium gallium arsenide phosphide materials with band gaps which extend their detection capability to these longer wavelengths. Sources (of the LED and ILD types) are also operational in these long wavelength regions. Also, it should be noted that both positive-intrinsic-negative (PIN) diode and avalanche photodiode (APD) detectors are available at all wavelength bands discussed. This missile application, with its short cable path lengths (50 feet maximum) has little need for lower optical loss in the fiber cable than that provided by the shorter (800-950) nanometer wavelength cable type. Also, the 1773 bus data rate of 1 megabit per second is so low that negligible signal distortion will occur at the shorter wavelength. The newness of the longer wavelength technology also reflects on the reliability of the components and their availability to support this program within its timeframe. The primary feature of long wavelength operation that appears attractive from this missile standpoint relates to the radiation darkening effect in glass fiber due to exposure to gamma rays and neutron flux created by a nuclear event. Test data has confirmed that, for a given radiation exposure (a certain darkening level in the fiber, the propagation of longer wavelength signals is accomplished with less signal loss. The data presented is somewhat sketchy and even contradictory, but the evidence of radiation insensitivity for longer operating wavelength is irrefutable present. For this reason, the fiber type selected for use in this missile bus will provide essentially a "two window" capability.

That is, it provides low loss in both the 800 to 950 and 1300 nanometer regions. This provision permits the probable eventual use of 1300 nanometer source and detector components after the technology matures sufficiently to warrant that change, and does not penalize the performance of the presently selected shorter wavelength components. It is seen that fiber/cable optical loss (without radiation effects) is an insignificant parameter in bus design. If a 10dB/Km cable loss is assumed (a much higher loss than in cables available today), the loss in a 50 foot section of cable is only 0.15 dB. This loss value is very small compared to the losses associated with other bus coupling elements and may be generally omitted from the bus design loss budget calculations. Preliminary test data indicates that for radiation total dose and dose rate levels corresponding to the MX missile radiation environment, losses range from 2 to 6 dB lower (50 foot cable length) using the longer 1300 nanometer wavelength for bus transmission. This factor is important to the allocation of optical power loss (power budget) between the bus coupling elements and the selection of suitable sources and detectors.

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C-3.1.2. Optical Source and Detector.

But LED and ILD optical sources are available for use in the 800 to 950 nanometer wavelength region. In general, the ILDs are capable of injecting higher optical signal powers into a given fiber core size than are LEDs. Power advantages range from about 4 to 10 times more power or 6 to 10 dB. ILDs can be modulated at much higher pulse rates than LEDs and produce pulses with much shorter rise and fall times. The spectral (wavelength) width of the pulses is also much less, being about 1 to 2 nanometers for the ILD compared to 40 nanometers for the LED. The input/output linearity of the ILD is much less than for the LED. The necessity for laseing operation of the ILD requires diode operation at higher potential levels with an increase in electrical power consumption. Also, this process is very temperature-dependent and some means of thermal control is mandatory. For this missile application, high pulse rate and transient response capability are clearly not needed. Also, at 1 megabit per second data rate for the 50 foot maximum cable lengths, the increased signal distortion created by the greater spectral width of the LED is insignificant. Linearity is of primary importance to the transmission of analog modulation and plays only a very minor role, here, for digital signal transfer. The meaningful tradeoff between source types then becomes one of comparing the importance of providing increased optical power to the bus vs. the increased weight, electrical power, and control complexity required by the ILD. LEDs are now available which provide fiber-coupled power levels of -6 to -3 dBm (decible reference to 1 milliwatt) or powers of 250 to 500 microwatts. ILDs have produced fiber signal levels of 0 to +3 dBm or 1 to 2 milliwatts. The effect of radiation exposure is more severe for ILDs in that the power output is reduced and the signal noise is increased proportionally more than for LEDs when exposed to given radiation levels. Due to these effects, plus the reduced reliability associated with the refined control and shorter lifetimes for ILDs, the source type selected for this application is the LED.

C-3.1.3. Optical Fiber Size and Type.

Considerations important to the selection of the optical fiber to be used are 1) sensitivity to radiation (both total dose and dose rate), 2) the intrinsic fiber length loss level, such that transfer of adequate optical power is assured to all points on the bus, and 3) its various compositions of plastic and glass-like materials. Plastic fibers have been rejected for this application due to high loss levels experienced in the infrared wavelength region and poor high temperature properties. Glass fibers fall into two structural classes: glass cores with glass cladding layers and glass cores with plastic cladding layers (PCS). Also, the PCS types have two classes, ie , where the cladding layer is removable for fiber connectorization, and where the cladding layer remains with the fiber and becomes an inherent part of the connector assembly. This latter fiber type is called "hard plastic clad fiber" and exhibits low power-loss characteristics at cold temperatures. Optical fiber cables are presently available in both structural fiber types with good radiation characteristics. Test data indicates that at gamma and neutron dose levels corresponding to MX missile requirements, the

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induced optical loss due to fiber radiation darkening can be held to less than 200 dB/Km at 850 nanometers wavelength for a number of fiber types and constructions. Operation at 1300 nanometer wavelength further reduces the optical loss to levels of about 60 dB/Km. These loss levels correspond to about 3 dB and 1 dB, respectively for a 50 foot length of fiber optic cable in this missile. Optical fibers are also categorized as being of the "step" or "graded" index type. This refers to the refractive index profile exhibited by the fiber cross-section. Step index fiber is a fiber of constant refractive index core material cladded with a layer of a second material of constant and lower index of refraction. Step index fibers are generally confined to signal bandwidth levels of about 30 megahertz kilometer. Graded index fiber is a fiber with variable index of refraction across the core diameter, with maximum index of refraction at the core center. These fibers possess bandwidths into the hundreds of megahertz kilometer. This missile application with a signal data rate bandwidth of 1 megahertz @ 50 feet can easily be handled by the step index fiber so the choice of fiber-index-type is based upon other factors such as cost, radiation insensitivity, and wavelength characteristics. Since the grading process requires the successive addition of increased dopant to the glass mixture to provide the required change in index, the fiber cores are not as "pure" as step index cores and the radiation darkening effect is enhanced. Therefore, step index fiber is selected for this missile application. A recently adopted fiber size standard by the Military Tri-services and the Electronic Industries Association (EIA) is the 100/140 micrometer diameters for core and cladding for step index, glass-on-glass optical fibers. The 140 micrometer dimension is particularly important in that it sizes a critical dimension for insertability of a fiber into an optical connector ferrule for termination purposes. Numerous connector manufacturers are producing optical connectors sized to accommodate the 140 micrometer overall diameter fiber size and to do so with a minimum power loss at the optical connector junction. For this reason, the fiber selected for this application is one with a cladding diameter of 140 micrometers. Both the glass-on-glass and hard-plastic-on-glass fiber constructions provide 140 micrometer cladding diameters. Since the loss characteristics of these types are comparably low, the selection is based upon environmental considerations. During blast-off, the missile outer surface will reach temperatures exceeding 550 degrees centigrade. The bus cable(s) within their cableway channel on stages 1, 2, and 3 are protected by thermal insulation, such as a thin layer of cork or Vamac, to assure that the cable surface temperature does not rise to more than 130 degrees centigrade. Exposure at this temperature does not exceed 3 minutes due to Stage #1 separation at about this time. Optical cables of both types discussed can easily survive this thermal exposure. The choice between optical fiber type then becomes one of the long duration aging characteristics of glass vs. plastic. When discontinuity in the cladding layer of an optical fiber occurs, energy normally bound within the optical core is permitted to escape through the cladding discontinuity. No aging mechanism is known which separates the core and cladding boundary for glass-on-glass fiber structures. Plastic on glass, however, does not represent the same intimate fusion of like materials that favor the glass-on-glass construction. Also, insufficient test data exists on PCS (hard or soft) as to its extended

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lifetime characteristics. Therefore, a double window, step index, glass core/glass cladded fiber of 100/140 micrometer size is selected for this missile application. Also, these fiber types with very pure fused silica cores are among the most radiation resistant to fiber darkening available.

C-3.2. Design Component Performance.

It is important to set realistic, attainable performance levels for the discrete optical bus components to be used in the bus analysis. The values specified here for the optical loss properties of the passive components (slices, connectors, couplers, and cables) represent maximum values not to be exceeded under all combinations of environment, manufacturing tolerance, aging or other degrading effects. Certainly, components can be expected to perform better under a limited regime of degrading exposure, but realistically, the loss levels imposed must represent a worst case loss condition. Similarly, the optical power specified for the LED source (the power level injected into the fiber core at the source location) is representative of current optical source power capabilities. Sensitivity levels specified for minimum acceptable signal power for the optical detectors are also achievable at the present time.

C-3.2.1. Passive Component Losses.

Passive bus components consist of cables, splices, connectors, and couplers. Couplers are subdivided into the categories of directional, star and "tee" types. Star couplers may be either of a reflective or transmissive style. Optical loss values for these passive elements, as shown in Table 1, have been selected as appropriate for this bus design.

These coupler elements are shown diagramatically below with the port-to-port loss levels and locations identified. The loss values shown are for unconnectorized units (pigtailed). The addition of connectors at each of two ports increases the overall path loss by 3dB.

Table 1. Loss Levels for Fiber Optic Bus Components.

COMPONENT	OPTICAL LOSS
Cable	6 dB/Km
Connector	1.5 dB
Splice	0.3 dB
Coupler:	(Port-to-Port Losses)
Directional	4 dB for 1:1 Coupling Ratio
Tee	4 dB
Reflective Star	10 dB for 8- Port Unit
Transmissive Star	10 dB for 8 x 8 Port Unit

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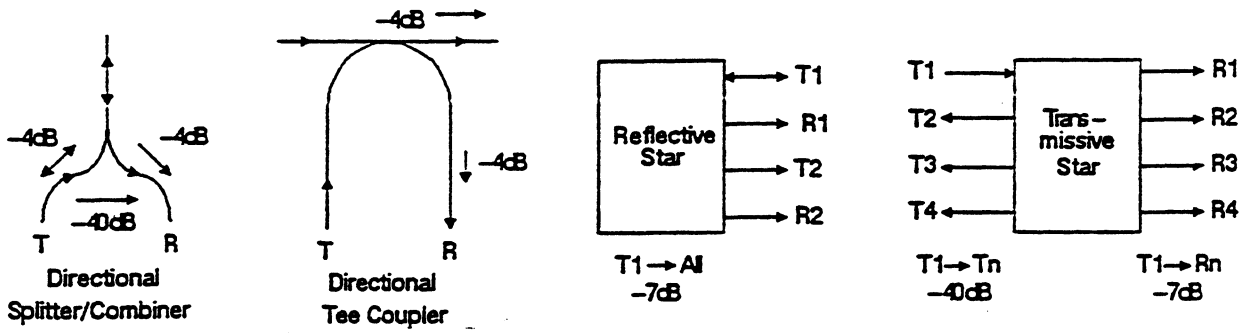

Figure 3. Bus Coupler Elements.

As seen, some of the couplers are bidirectional. The transmissive star coupler, however is not. Transmitter (T) and Receiver (R) locations are shown here for simplicity, it is interesting to note that increasing the terminal count to 8 only increases the star coupler port-to-port loss by 3 dB, as seen by reference to the previous table. Therefore, the signal power level received by each receiver from any transmitter is reduced to 1/2 by doubling the number of bus terminals from 4 to 8 - a fairly nominal power penalty to pay. These basic coupler "building blocks" are used to implement the following designs.

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C-3.2.2. Active Component Power Levels.

Active components consist of transmitters, receivers, and signal regeneration devices. The optical sources used for the terminal transmitters are LEDs and are assigned optical output powers of -5 dBm (316 microwatts). The optical detectors used for the terminal receivers are PIN detectors and are assigned signal sensitivity power levels of -35 dBm (0.316 microwatts) for a 10 bit error rate (BER) at a signal data rate of 1 megahertz per second. These power levels and sensitivities are fully available today and represent no technical risk to the fiber optic bus development. It is seen that an overall bus power level range of -5 - (-35) or 30 dB is available for power loss allocation between the terminal elements of the data bus. The source power level noted represents the power coupled into a fiber optic pigtail cemented to the source's active radiating element. Two packaging configurations exist:

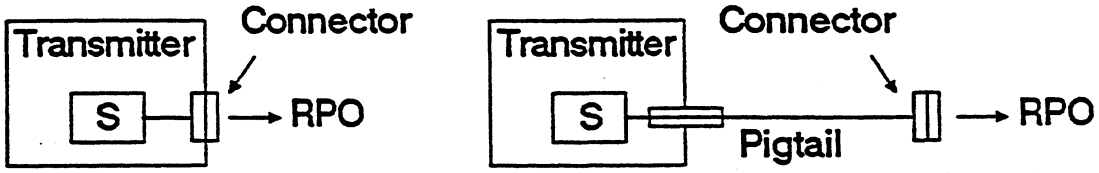

Figure 4. Two Packaging Configuration Types.

As seen, the source(s) is located within the transmitter (T) and ma terminate its pigtail fiber (P) either in a panel-mounted connector (C) or in a connector located some distance from T. In either case, the

optical loss associated with 1 connector junction occurs. Sometimes the extended pigtail arrangement, however, can save 1 connector loss if the design allows this arrangement. Similarly, the specified detector sensitivity level represents the minimum acceptable power level at the detecting element. Therefore, the power incident upon the detector is equal to the bus fiber output power reduced by the loss in the receiver input connector.

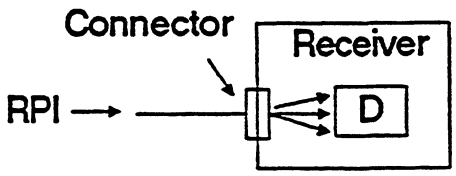

Figure 5. Incident Power Calculation.

That is, where Pd is the power incident on the detecting element (D), Pf is the power emitted by the bus fiber into connector C, and Lc is the optical loss of connector C. The understanding of these mechanizations is of value to properly assign loss values to the subsequent bus design.

C-3.3. Design Considerations.

The selection of an optimum bus configuration for this missile must consider the following design parameters as prime drivers:

1. Weight and weight/stage distribution of the bus components.
2. Volume of bus components and number of independent fiber/cable channels needed for intraterminal communication.
3. Electrical power requirements for active bus components.
4. Provide adequate optical signal power from all optical transmitters to all optical receiver terminals to overcome all bus optical degradations which may occur over the operational lifetime of the missile system. 5. Maintain the required dynamic range of the optical receivers to levels below those currently being achieved.
6. Resolve that only passive components shall be used to interconnect the terminal transmitters and receivers, i.e., signal boosting repeaters are not to be used.

C-3.3.1. General.

To select an optimum design for this application, a number of bus configurations were evaluated which interconnected the terminal unit

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using multidrop "T", reflective star, and transmissive star coupling methods for bus signal control and communication. The results of this evaluation indicated positively that the transmissive star coupler arrangement is the only coupling configuration which meets the power level requirements for proper operation.

C-3.3.2. Design Configuration and Parameters.

Parameters of primary interest for the bus assessment are the allocation of available optical power (power budget) along the bus transmission paths and the dynamic range requirement of the terminal receivers. Available excess bus power is important to provide an operating power margin to overcome radiation darkening of the optical fibers, aging of the optical source, losses due to environmental effects, and other bus power degradations. The receiver dynamic range requirement is important in that the receiver automatic gain control (AGC) circuitry or amplitude limiting must cover this complete range, and design complexities arise if this range of signal level control becomes too large. To determine the available optical reserve power (P_R) and the required receiver dynamic range (DR), it is first necessary to calculate the maximum and minimum bus path losses which correspond to the highest loss path and the lowest loss path between communicating bus transmitters and receivers. To illustrate the calculations of these optical performance parameters, consider the simple data bus shown in Figure 6.

This bus consists of the bus controller (BC) and 4 remote terminals (RT). A 5x5 port transmissive star coupler is used to interconnect the bus terminals, and optical connectors (C) are shown to provide signal transmission out of the optical transmitters (T) and into the optical receivers (R). Also, connectors are shown at locations simulating bulkhead feed-thru connectors between terminal stations. This bus is a simplified version of the final missile bus design described in 1.3.4. Using the component loss and power levels stated in 1.3.2.1 and 1.3.3.2, i.e., a connector loss of 1.5 dB, a cable loss of 6 dB/Km or 0.0019 dB /foot, a transmitter output of -5 dBm into the fiber, a receiver sensitivity of -35 dBm and a 5x5 port transmissive star coupler loss of 8 dB, the maximum and minimum path losses from BC to any RT may be determined. Assuming a maximum cable length of 50 feet between most distant terminals, the cable loss is less than 0.1 dB and may be neglected in these calculations. The maximum path loss is encountered by transmission from the BC transmitter to the RT1 receiver. Assuming the power and loss levels noted above, the optical power levels are shown in Figure 6. at various points along the transmission path. It is seen that the -5 dBm level signal transmitted by the BC has been reduced by 5 connector losses of 7.5 dB plus a coupler loss of 8 dB or by a total of 15.5 dB to provide a received power at RT1 of -20.5 dBm. A minimum optical path loss is encountered by transmission from the BC transmitter to the RT4 receiver. In this case, the received signal level is -16 dBm, as shown. To determine P and DR for this bus, Figure 7. is helpful.

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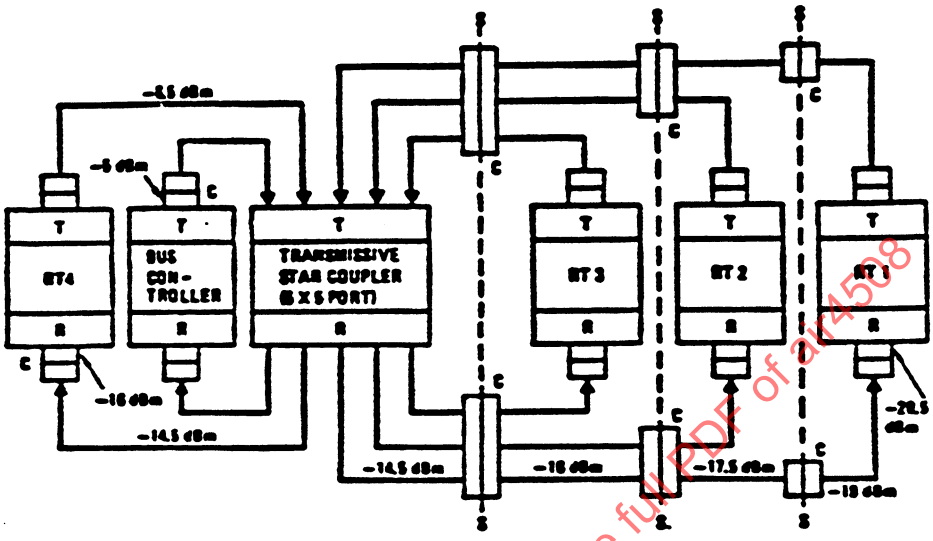

Figure 6. Transmissive Star Bus.

The receiver DR of 19 dB represents the overall range of signal power level incident at the PIN detector. The largest signal power is present at the receiver terminal with lowest path loss (-16 dB at RT4) and the minimum acceptable signal power is the receiver sensitivity level of -35 dBm. Therefore, the DR is 19 dB as shown. The reserve power (Pr), reserved here to counter optical loss due to fiber darkening, is seen to equal the difference between the overall power budget of the bus (here 5 dBm - (-35 dBm) or 30 dB and the sum of the maximum path loss plus the power margin. With a margin of 6 dB selected to overcome systematic and operational degradations to the bus, a Pr level of 8.5 dB or 7 times minimum satisfactory operating power is obtained. Values for DR and Pr are determined for the following missile bus design.

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C-3.4. Missile Bus Design.

The missile transmissive star bus design is shown in Figure 8. This design uses a 16-port transmissive star coupler to distribute optical power between bus terminal transmitters and receivers. This design is penalized in loss by the addition of connectorized inputs and outputs (c) at the coupler interface. This provides a convenience in cabling connectorization for the stage I, II, and II controllers (SC1, SC2, and SC3). Another possibility is to use optical fusion cable/fiber splices between the coupler pigtail fibers and the bus fibers of the downstage terminals. Since the splicing loss is specified as 0.3 dB per splice, the path loss between a stage IV transmitter and any downstage receiver will be reduced by [2 x (1.5) - 2 x (0.3)] dB or 2.4 dB. This example, however, uses the connectorized coupler for simplicity of cable installation and test.

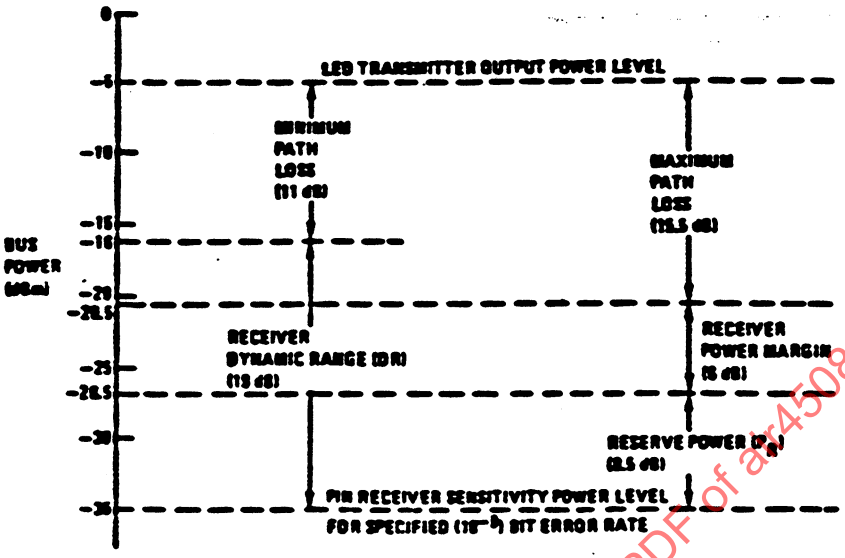

Figure 7. Fiber Optic Data Bus Pr and DR Levels.

Following the loss path from the GCC transmitter to the SC1 receiver yields the loss equation:

$$4\ Lc + Ls = 4\ (1.5) + 10 = 16\ dB$$

Where: Lc is the connector loss of 1.5 dB and Ls is the port-to-port transmissive star coupler loss of 10 dB.

The -5 dBm transmitted power then results in a received power at SC1 of -21 dBm as shown. The reserve power (Pr) is then:

$$Pr = 35 - (21+6) = 8\ dB$$

Again, using 6 dB for the receiver power margin, this bus design provides an 8 dB (7 times minimum operating power level) reserve in optical power to counter the loss due to fiber darkening from radiation exposure. It is seen that the minimum path loss (GCC transmitter to SC4 receiver) is the same as the maximum path loss (16 dB) for this design and the dynamic range (DR) for the terminal receivers is :

$$DR = 35 - 21 = 14\ dB$$

This DR level is easily accommodated by optical receivers. Normally, DR levels exceeding about 27 dB require special techniques to accomplish the signal processing. Since all receiver input signal levels tend to be the same in this design, this feature is attractive for commonality in receiver design.

It is seen that this design, however, requires 2 fiber/cables to interconnect each terminal to the coupler, and a total of 6 cables are needed to service the 3 downstage bus terminals.

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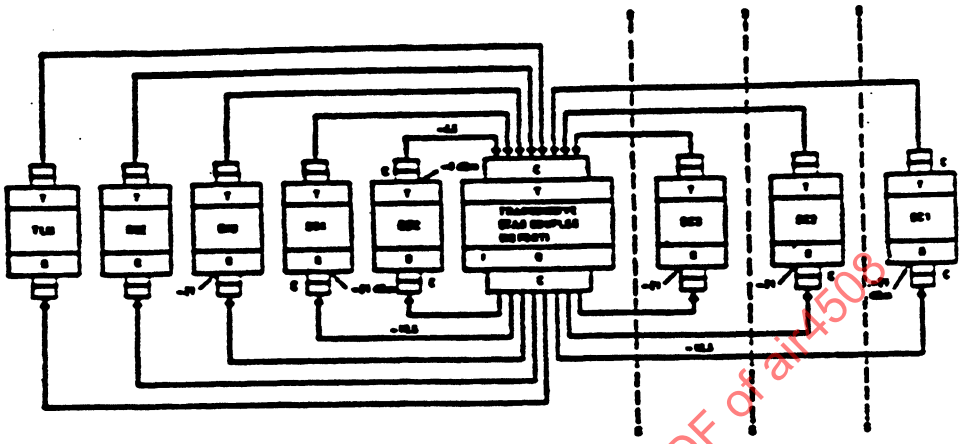

Figure 8. Fiber Optic Transmissive Star Bus Configuration.

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C-4.0. Conclusions and Recommendations.

From the data and arguments presented in the previous sections, it is evident that the fiber optic bus approach to data communication is a superior bus technology for this missile application. Fiber optic bus implementation provides the following advantages:

1. Lightweight system resulting in an extended missile range capability.

2. Complete electrical isolation between both missile stages and bus terminals eliminating the harmful effects of EMP, EMC, and ground loop currents.

3. Secure, interference-free communication between bus terminals.

4. Simplified installation and check-out procedure.

5. No electrical shock hazard to maintenance or operating personnel.

6. Increased system reliability due to graceful degradation nature of fiber optic components and their inherent long lifetime aging characteristics.

The choice of optimum bus configuration for this missile weighs heavily upon the necessity to provide adequate optical power at each receiver terminal for satisfactory bus operation. As seen, the passive (nonregenerative) transmissive star bus design provides 8 dB of excess power to cover transmission losses due exclusively to the fiber radiation darkening effect. Radiation data on existing fiber optic cable types exhibits considerable variability in optical loss test results,

but a large reduction in radiation sensitivity is generally noted for those newer cables designed for this purpose. Small compositional changes in the optical fibers and other material variations have yielded cables with much improved radiation insensitivity. This trend is expected to continue at an increasing rate as additional test data on fibers produced by innovative processing techniques becomes available. Although data on a few existing fiber types indicates that the 8 dB power allowance for the transmissive star bus is adequate to counter the 50 foot radiation induced power loss, it is reassuring to expect that future (near term) fibers developed will provide even lower radiation loss effects. In addition, the future holds promise of developing long wavelength (1300 nanometer) sources and detectors with improved output powers and sensitivities, respectively, to permit operation in this radiation insensitive region of the spectrum. Additionally, the availability of optical sources with increased output powers may be utilized to photobleach (purge) the optical fiber of some of its loss due to radiation darkening. It is not unreasonable to expect that prior to this missile's operational status, the above combination of effects will provide an additional net 10 dB of power advantage to the bus design.

For the above considerations, it is recommended at this time to use a passive transmissive star fiber optic data bus for this missile application with performance characteristics as stated herein, or better, as the future development of fiber optics technology dictates.

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APPENDIX D.

APPLICATION OF MULTIPLE SPEED DATA RATE TRANSMISSION.

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APPLICATION OF MULTIPLE SPEED DATA RATE TRANSMISSION.

D-1.0. Multiple Speed Data Rate Operation.

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.

Because of the early on Airforce request to make MIL-STD-1773 only a "Fiber Optic 1553" it makes little use of the available bandwidth in the media and media access level hardware. With a little thought, it immediately becomes apparent that this excess bandwidth can be utilized to provide an interesting growth path for systems currently based on and limited by the capabilities of MIL-STD-1553.

An approach that can 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 huge investment in 1553 based hardware.

There are many possible solutions to the implementation of this system with varying degrees of efficiency and/or complexity. What is considered in this appendix is an approach with the express purpose of developing a baseline architecture and hardware set which can be built with existing, or modified versions of existing Fiber Optic Modules and off the shelf terminal logic chip sets. The approach uses "Dual-Speed" operation of a 1773 bus, in which all Command/Status words (and data to unenhanced terminals) are transmitted in the standard 1 Mb/S. format while data transmission to Enhanced Remote Terminals (ERT's) is transmitted at 8 Mb/S. with a transmitter and receiver that are common to both data rates. The second speed data is transparent to the unenhanced RT's resident on the bus. One need only replace the low speed transmitter/receiver with the "Dual-Speed" transmitter/receiver and add an encoder/decoder for the high data rate, separate from the standard encoder/decoder used for the 1 Mb/s. data, to enhance the 1773 terminal for Dual-Speed operation.

In Addition, multiple 100 Mb/S. "Collateral Fiber Optic Data Pipelines" are utilized, under control of the 1773 Bus Controller (BC) as the network supervisor. The Pipelines have no protocol of their own, but are rather a set of distributed switch networks, with all users of the 1773 bus able to share the resources, in both the equivalent of "Packet Switch" and "Circuit Switch" operation. The collateral pipelines are designed to use media identical to the 1773 bus (or even share the same media through wavelength multiplexing) and the media access level hardware developed for the ANSI Fiber Distributed Data Interface (FDDI)

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Local Area Network.

This multi-speed combined Dual-Speed bus/distributed switch architecture was developed, top down, from the following application strategy:

1. Use existing 1553/1773 protocol, formats and data rate to continue to handle existing Command/Response Bus Functions, consisting mainly of short messages requiring sustained real data rates up to a few hundred Kilobits/Sec.

2. Use a "Time Division Multiplex" Second-Speed (transparent to existing or future 1 Megabit only Terminals) to handle Inter-computer and other System Integration data transfer tasks, that severely impact BUS availability or require additional dedicated 1553 Busses in current systems, to provide real data thruputs of a few 100's of Kilobits to a few Megabits/Second.

3. Use multiple "Collateral Data Pipelines", running at 100 Megabits /Sec. under control of the 1773 Bus Controller, to integrate system functions not currently possible with 1553. These functions will typically include; digitized Video, Sonar or Display Frames, Global Memory access, Block Program relocations (reconfiguration, initialization), data intensive inter-computer transfers, etc.

Assuming long messages, each of the multiple Pipelines can provide thruput in excess of 80 Megabits/Sec. with under 10% utilization of the 1773 Bus Controller's time. The Pipeline concept provides multi-level priorities; physical, functional, and broadcast addressed transmission; with identification and/or isolation of Classified Data.

The Bus/Pipeline Terminal configuration may include unenhanced Terminals that only operate at the current standard 1 Megabit data rate and enhanced Dual-Speed Terminals. Any terminal need not be connected to the Pipelines, but may be connected to 1 or more of the Pipelines as transmit only, receive only or transmit/receive. Each Terminal must connect to the 1773 bus but need only contain Pipeline hardware modules for connections and functions it needs. In the generalized terminal, the 1773 portion will utilize existing 1553 Terminal chipsets with no modification, except for substitution of Fiber Optic for electrical transmitters and receivers. The Pipeline hardware will "add on" to the 1553/1773 Terminal hardware. Any of the Terminal types may be the Bus Controller. The multiple Pipelines are inherently "multi-redundant" to the extent that all terminals are connected to all Pipelines, with graceful degradation capability. The total length of each Pipeline is limited to the same maximum as the 1773 Bus by the necessity of each terminal being connected to the 1773 Bus.

A proposed general specification for the architecture and hardware

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implementation for Dual-speed 1773 operation is presented in inclusion D-1. of this appendix and a proposed general specification for control of Collateral Fiber Optic Data Pipelines under 1773 is presented in inclusion D-2. It is hoped these proposals can become a baseline for an Extension to MIL-STD-1773. These enhancements can make the 1773 bus cost effective in a far greater range of applications than the basic 1553 compatible 1 Megabit version that now exists and preserve the investment in 1553 compatible hardware and experience into the next generation of Avionics Systems.

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APPENDIX D, INCLUSION D-1.

PROPOSED GENERAL SPECIFICATION FOR A DUAL SPEED ENHANCEMENT TO THE MIL-STD-1773 AVIONICS INTEGRATION BUS.

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John A. Kolling	Fiber Optic Engineering
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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This General Specification defines an Enhancement to MIL STD 1773 which implements the capability to transmit data between bus controller and remote terminals or between remote terminals at 8 MBits/Sec instead of 1 MBit/Sec. while retaining the standard 1 MBit format for command and status words and compatibility with unenhanced 1773 terminals on the same bus. This dual speed enhancement to MIL STD 1773 provides an evolutionary growth path for MIL STD 1553 or 1773 Avionics Bus Systems for inclusion of users which need much higher peak data rates available or to replace multiple 1553/1773 Busses on a platform with a single dual speed 1773 Bus System.

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MIL STD 1773, Fiber Optic Dual Speed Data Transmission, Avionics Command and Control Bus, Evolutionary Growth Enhancement.	

19. SECURITY CLASSIF.(OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified.			

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PROPOSED GENERAL SPECIFICATION FOR A DUAL SPEED ENHANCEMENT TO THE MIL STD 1773 AVIONICS MULTIPLEX BUS

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Figure 4.2. Dual Speed 1773 Bus, Effective Data Rate versus Words/Message.

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1.0. PURPOSE OF THIS SPECIFICATION.

MIL STD 1773 provides a general standard for a Fiber Optic implementation of a MIL STD 1553 wire bus and maintains exact compatibility with the original standard, including the 1 Megabit/sec. Manchester modulation format.

The purpose of this specification is to define the system and hardware implementation of an enhancement to MIL STD 1773 that will allow for the use of a second higher data rate for the transmission of Data Words between two Remote Terminals (RT) or the Bus Controller (BC) and an RT in a manner that in no way will impact the established and proven protocol of MIL STD 1773 (MIL STD 1553) or require the modification of existing Terminal chip sets. Only additions to the existing hardware and modifications to system operating software are required.

The replacement of the shielded twisted pair media and its associated transmit/ receive hardware with optical media as defined by MIL STD 1773, clearly adds the potential for reduction of system integration problems through EMI/RFI immunity and emanation control, but for the immediate future, does so at higher cost than the wire media. While some current or new applications exist in which this may be a cost effective addition, the Dual Speed enhancement of 1773 is designed as a means of making utilization of 1773 obviously cost effective in a wide variety of applications.

The 1553/1773 Protocol was designed primarily to provide integration of Avionics systems Command and Control functions through a centralized authority (the Bus Controller) with deterministic latency periods and absolute verification of the integrity of the transmissions. Short message structures and command/response protocol do not provide an efficient means for "data" transfer, and in the case of 1553/1773, the bus becomes bound at a thruput rate of a few hundred Kilobits/sec. Never the less, as no other proven bus standard has existed for Military Avionics applications, the use of 1553 for data transmissions has resulted in the inclusion of multiple dual-redundant 1553 busses in aircraft to provide the required capacity. The Dual Speed enhancement of MIL STD 1773 as defined by this specification achieves cost effectiveness by making use of the high data rate capability of optical transmission to replace the data transfer capacity of up to seven 1 Mbit 1553/1773 bus installations with a single bus.

The Dual Speed 1773 implementation can also handle peak data rates of eight Mbits/Sec., thereby providing for an evolutionary upgrade route for the incorporation of new avionics functions onto the 1773 bus that require peak data rates far greater than was formerly possible.

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2.0. IMPLEMENTATION SUMMARY.

The Dual Speed implementation defined by this specification is based on the following requirements list:

1. A single Fiber Optic Transmitter in a Dual Speed terminal will transmit the data at both normal and second rates.

2. A single Fiber Optic Receiver in a Dual Speed terminal will be capable of receiving data at both rates, with a common connection to separate decoders for each rate. The 1 Mbit decoder can be any existing or future design that is approved for use with 1773. The second speed decoder will be a new design, but the use of a simple valid Manchester Synch code (word delimiter) for the second speed will allow the mechanization of this decoder in a less complex manner than the existing 1 Mbit designs. As only Data Synch need be indicated for the second speed transmissions, this code will be a valid Manchester sequence consisting of two blank bit periods followed by a Manchester "zero" bit.

3. Only Data Words may be transmitted at the higher rate, all Command and Status Words will continue to be transmitted at the standard 1 MBit/S data rate (with no modification to the coding or format) to retain backwards compatibility with non-Dual Speed terminals that may be included on the same bus. Unipolar Manchester Biphase Level coding format will be utilized for the second speed transmissions with a 3 bit long delimiter, 16 data bits and an odd parity bit for a total 20 bit word format.

4. The data word count (1 to 32) in commands supporting second speed transfers are interpreted as a "block count" were the first n-1 blocks contain eight words each. The last transmitted block may contain less than 8 words if the actual number of words to be transmitted is not an integral multiple of 8. The total number of words in a message may be any number from 1 to 256.

5. These 8 Mbit/S rate data transmissions will be transparent to terminals that can only receive at the standard 1 Mbit rate.

6. The Bus Controller operating software will contain a listing of the addresses of those terminals that are equipped to transfer data at the higher data rate and automatically command all data messages, containing a number of words equal to or greater than a system level determined number, to be transmitted between those terminals at the higher data rate. If the Bus Controller is a Dual Speed enhanced terminal, then BC to/from Dual Speed RT's will be handled by the same criteria.

7. The Command Words initiating a Dual Speed transfer (command-transmit, command-receive) are identified by setting the command word's sub-address field to a number (30 decimal) reserved for this purpose.

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8. A nonenhanced 1773 terminal attached to a 1773 bus which includes Dual Speed enhanced terminals as users, will utilize F/O transmitters and receivers which meet the same performance specifications as required for the Dual speed terminals but need NOT meet any of the other special requirements or contain any of the other supplemental hardware of the enhanced terminals. This is necessary because the optical signal levels and rise/fall times of the Dual Speed Fiber Optics are dictated by the requirements of the higher Second data rate and a 1 Mbit only terminal must adhere to the same specifications to communicate with a Dual Speed terminal, even at the standard 1 Mbit rate.

9. If a Bus Monitor function is included in the Dual Speed architecture, then if the monitor is a Dual Speed terminal it will function in the same manner as does this function on an unenhanced 1773 bus. Otherwise the bus monitor will be able to identify Second speed commands by noting the sub-address field set to the reserved value. It will then only look for the transmitting and receiving terminals Status Word responses as indications of successful completion of the transfer.

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3.0. DETAIL SPECIFICATION.

A Dual Speed 1773 terminal equipment will meet all requirements of the current version of MIL STD 1773, all requirements of the current version of MIL STD 1553 as referenced by MIL STD 1773, all applicable requirements of any standards or specifications included in MIL STD 1773 by reference, as well as the following detail specifications which define the unique requirements of Dual Speed operation.

3.1. SECOND SPEED DATA RATE AND FORMAT.

3.1.1. DATA RATE.

The Second Speed transmission data rate shall be 8 Megabits/second with Unipolar Manchester Biphase Level modulation as described in section 4.3.3.2. and Figure 2. of MIL STD 1773, resulting in a modulation rate of 16 MegaBaud. Manchester code was selected to provide self clocking data decoding and retain compatibility with the 1773 standard 1 Mbit data format.

Although other priorities might suggest a different choice, 8 Megabits/second data rate was selected as providing maximum value added at least cost in a compromise between the following considerations:

1. Maximize usable Optical Signal Range.

   As the receiver must handle both data rates, it will have a bandwidth determined by the higher second modulation rate and also work at the lower 2 Mbaud rate. As the receiver is scaled up in data rate, the sensitivity is reduced by at least 3 dB/octave over that available for operation at the lower level only. Limitations in the power launched from LED optical sources into the fiber diameter one wishes to use will result in a loss of allowable Optical Signal Range in the bus media as the upper limit of the receiver dynamic range shifts above the maximum optical signal level available in the bus media. These factors severely limit the options available to configured the bus media topology as the data rate is increased. This limitation is illustrated in Figure 3.1.

2. Diminishing returns in thruput versus data rate with Command/Response protocols.

   With a Command/Response protocol such as defined by 1553/1773, increasing the data rate does not result in a directly proportionate increase in thruput. Overhead consisting of transmission delays, response times and required inter-message gaps remain constant and eventually result in very little improvement in thruput in return for considerable additional expense involved in implementing ever higher raw modulation rates in the bus physical media dependent hardware.

3. Selection of a Second Speed which is an integral binary multiple

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of the primary rate results in simplification and cost savings, in Dual Speed Terminal hardware implementation providing for non-impact on the existing protocol.

A ratio of Second Speed data rate to primary rate of 2, 4, 8, 16, etc. allows efficient implementation of message multiplex logic and the use of a common clock frequency source that is a binary multiple of both data rates. This simplifies retaining the integrity of time periods defined by the standard and guarantees synchronous timing between the two data rates.

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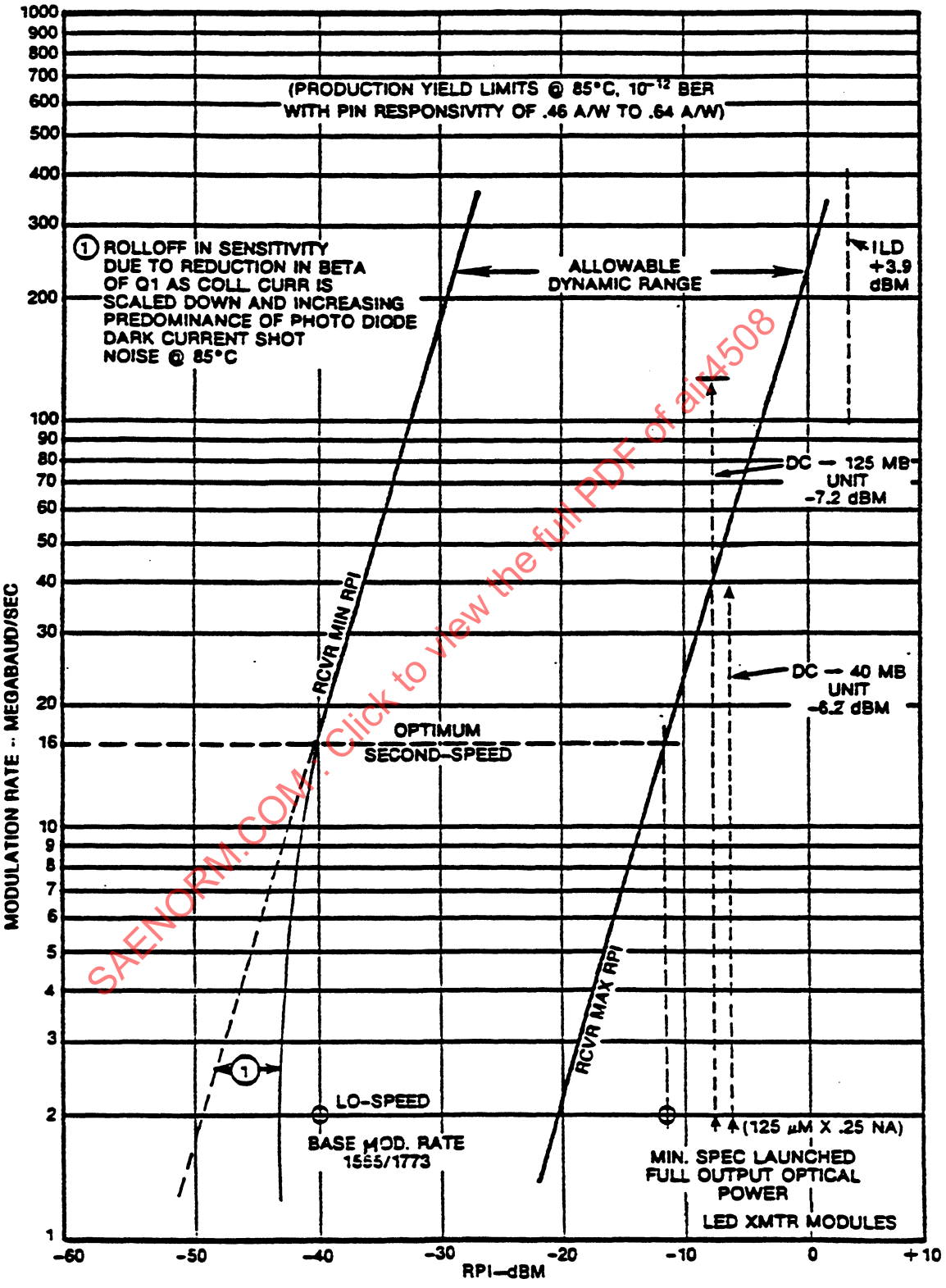

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Figure 3.1. Scaling the Fiber Optic Receiver.

3.1.2. WORD AND MESSAGE FORMAT.

The information transfer formats for Second Speed Data transfers shall be as shown in Figure 3.2. and shall include Data words consisting of 20 each, 125 nanosecond bit periods, or 2.5 microseconds per word and be synchronous with the edge times of 1 MBit words transmitted by the same terminal, ie, will be generated from a common time base.

3.1.2.1. WORD FORMAT.

As shown in Figure 3.3, Bit periods 1 thru 3 shall comprise a word delimiter or Synch Code consisting of two blank bit periods followed by a Unipolar Manchester Biphase Level "zero" bit. The Second Speed decoder shall interpret one or more blank bit periods following a valid bit as an End of Word indication and shall interpret a valid "zero" bit proceeded by one or more "blank" bit periods as a Start of Word indication. Consequently, data clocking will synchronize to the first transition of a word (the first edge of the Synch Code "zero") as the reference mid-bit transition of the following data field.

Bit periods 4 thru 19 shall comprise the 16 bit data field of the transmitted word.

Bit period 20 shall comprise an Odd Parity sum of the preceding 16 data bits.

Except for the exact format of the word delimiter, these format definitions are identical to those of 1553/1773.

3.1.2.2. MESSAGE FORMAT.

For Second Speed Data messages, the Word Count field of the Bus Controllers transmit command or receive command shall contain a value of 0 to 31 and shall be interpreted as 1 to 32 BLOCKS of 8 data words each, rather than 1 to 32 WORDS as in the primary speed data transmissions. If the actual number of words to be transmitted is not an integral multiple of 8, the last block transmitted shall contain the balance (1 to 7) of the total data words. The second speed decoder shall provide a Valid Block indication, as well as the Valid Word indication, to the terminal control for comparison to the command-receive block count. Each group of 8 words received and a final partial block will set the Valid Block indication if all the words in the block are valid. The Valid Block signal will be True, coincidentally with the Valid Word signal for the last word of the block. The Valid Word and Valid Block indications are discussed in more detail in the Encoder and Decoder sections and Figure 3.6.

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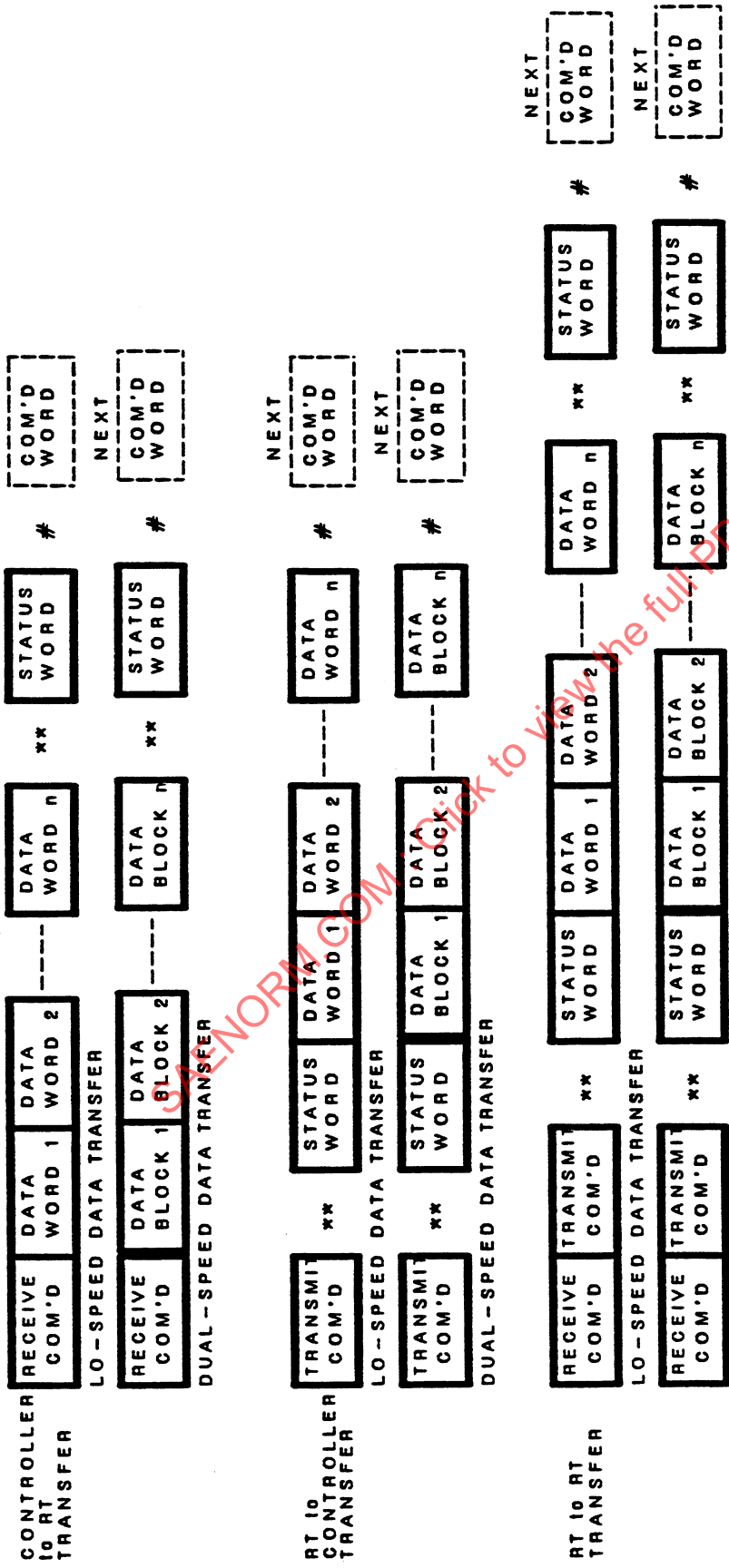

Figure 3.2. Information Transfer Formats (adapted from Fig. 6 of 1553B)

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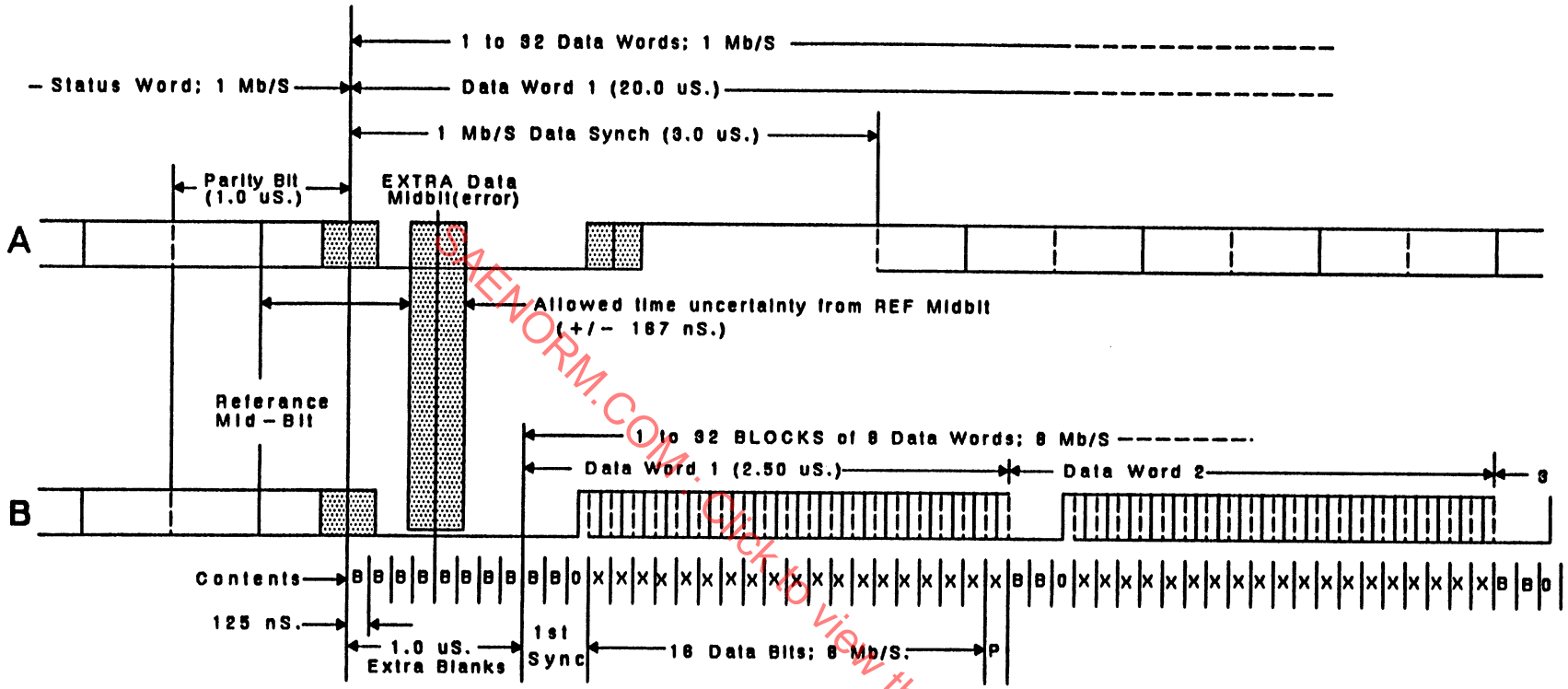

A = Standard 1 Mbit/S 1553/1773 Rt to RT Transfer B = 1 Mbit / 8 Mbit Dual-Speed RT to RT Transfer
(the two data rates are generated from a common clock)

P = Parity Bit; ▒ = Transition time uncertainty

Note: The 8 Mbit SYNC CODE consists of two blank bit periods followed by a Manchester 0. Eight extra Blank bit periods are at the beginning of the Second Speed data to prevent the first transition from ocurring within the period that the Midbit of an extra bit (ERROR) might occur in the preceeding Status Word and to allow for the detection of the END of the Status word by an Active Repeater.

Figure 3.3. Data Transmission Format Between Dual-Speed Terminals Compared to Standard 1553/1773

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The words as defined in 3.1.2.1. above shall be combined into a message format as depicted in Figure 3.2. This format shall include the insertion of 8 blank bit periods following the transmission of a Status Word and preceding the transmission of the Synch Code of the first word of the commanded message data field, in all cases of a Dual Speed RT to (RT or BC) data transfer.

A Bus Controller to Remote Terminal Second Speed Data transmission is initiated by a Receive Command from the BC to the target RT followed immediately by the transmission of the indicated number of data blocks.

For the other cases, in which an RT transmits to the BC or another RT, the standard requires the transmitting RT to precede its data message by a Status Word transmission to the BC followed immediately by the transmission of the indicated number of data blocks.

If the Sync code of the first word of Second Speed data were to be transmitted immediately following the low speed Command or Status word of the preceding examples, two problems are created which are addressed by the insertion of the extra blank bits in the Second Speed data message format as depicted in waveform (B). of Figure 3.3.

A 1 MBit unipolar Manchester decoder cannot detect an "end of word" until the occurrence of a missing mid-bit transition (which will occur at 1 microsecond +/- the tolerance allowed by the decoder following the preceding mid-bit transition). If a transition occurs within this time band, whether it is a real error in a 1 MBit word or a transition that is part of the 8 MBit data, the low speed decoder will probably assume it is an extra mid-bit transition in the preceding Status Word and indicate it in error. It is therefore necessary that the onset of Second Speed Data transmission, following a Status Word be delayed beyond this critical period.

Further more, in the implementation of a media topology for the Dual Speed bus (or for the standard unenhanced 1773 bus for that matter), it may be desirable or even necessary to include ACTIVE REPEATERS to achieve the necessary system margins. A Dual Speed Active Repeater will need to reclock data per the 1 Mbit or 8 Mbit Data rates, based on a decision that the low rate word is finished, and have time following that decision to renormalize and prepare to reclock at either rate commencing with the next transition. An Active Repeater design for Dual Speed has been accomplished that performs this conditional rate edge reclocking within the time allowed by the 8 blank bit period insertion with a latency of one quarter bit period of the 1 Mbit rate plus one quarter bit period of the 8 MBit rate or 281.25 nanoseconds.

3.2. DUAL SPEED TERMINAL HARDWARE.

A block diagram in Figure 3.4. shows the Dual Speed Terminal front end hardware including Fiber Optic Transmitter and Receiver common to both data rate transmissions and separate encoder/decoders to separate the two data rates. A transmit clock reference oscillator frequency of

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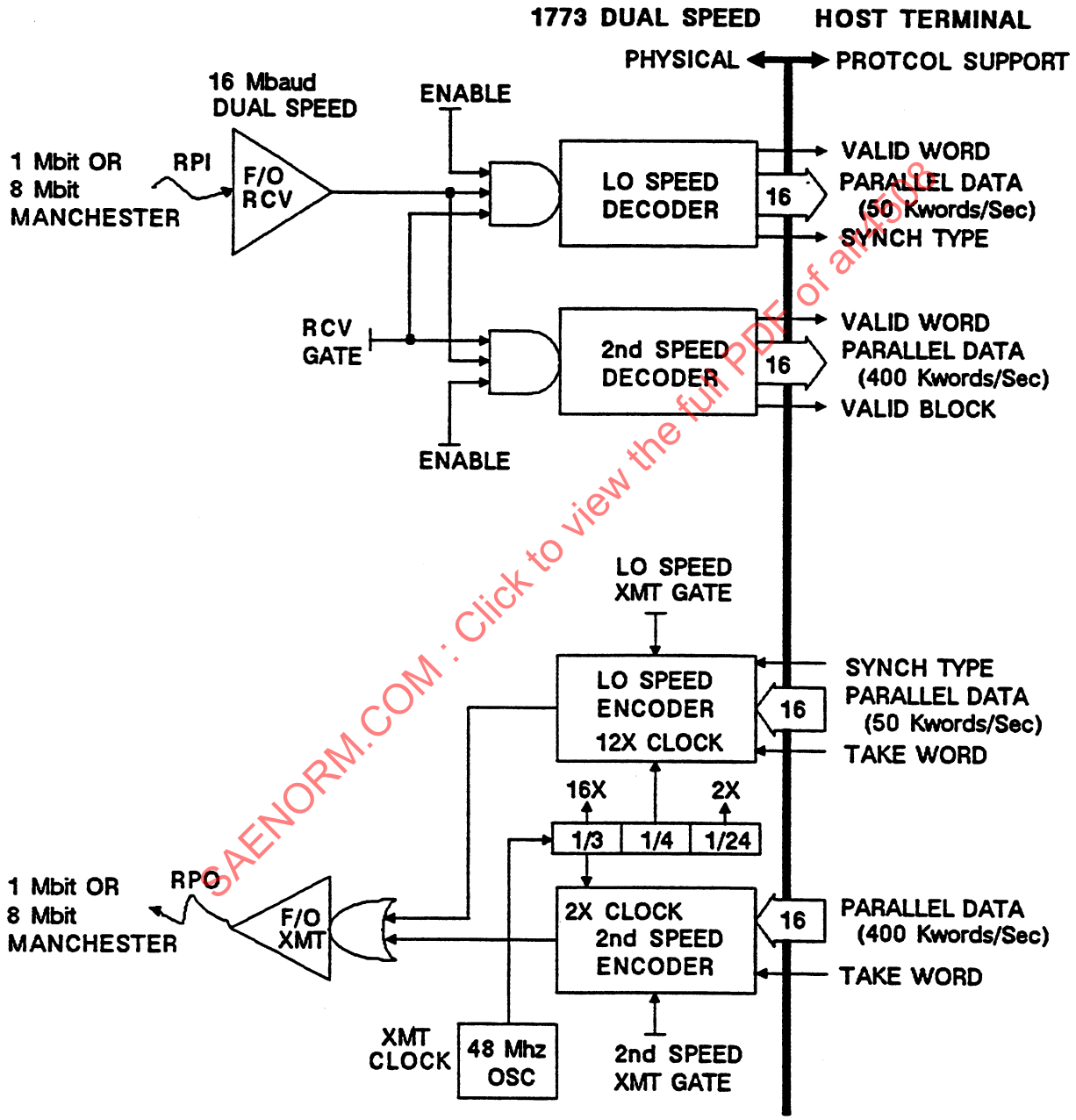

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Figure 3.4. Block Diagram, Basic Dual Speed Terminal Hardware

48 MegaHertz is used so that with appropriate division it will supply a 2 X Data Rate Clock for the Second Speed encoder and a 2 X, 12 X or 16 X Data Rate clock for the low speed encoder/decoder as may be required for existing chips such as the Harris 15530 or other alternatives. The protocol support hardware function is not defined here. These functions are defined by the 1553/1773 Standards, application specific specifications and as implemented in various available chip sets. Nor are details of the local control requirements defined, as they will depend on the encoder/decoder design and the protocol support logic implementation. The only purpose here is to define the minimum requirements for dual speed operation in a manor that is compatible with the existing 1553 hardware.

The following specifications are minimal system level functional performance requirements. They are preliminary and are meant to be examples of what can be achieved with current technology. These performance values will allow the system designer to define the required media topology, fiber parameters and environmental conditions for any given application.

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3.2.1. FIBER OPTIC TRANSMITTER.

The Dual Speed transmitter will contain a LED optical source capable of operating over the required system operating temperature without special cooling requirements and shall interface with TTL logic levels at its input while meeting the following performance limits. Some degree of drive current temperature compensation is desirable to minimize the variation of output over the temperature range and thereby preserve as much of the receiver dynamic range as possible for less easily controlled system variables.

3.2.1.1. LAUNCHED OPTICAL POWER.

Fiber Characteristics			
core diameter	100 micron	125 micron	200 micron
numeric aperture	.28	.25	.30
peak launched power at 25 degrees Cent.	- 7.9 dBm 160 μW	- 6.2 dBm 240 μW	- 2.4 dBm 570 μW

TABLE 3.1. Sample Transmitter Output Set Points

The optical transmitter shall provide a means of setting the LED drive current between 100% and 10% of rated maximum in such a manner as to allow the adjustment of the peak "on" optical output into a standard test fiber, of the type to be used in the bus media, to within +/-5% of a level dictated by the application system level specification.

Table 3.1. provides example peak optical power levels launched in the specified fiber, based on a lensed Burris type emitter with a wavelength

of peak emission of 840 +/-20 nanometers and a half power full spectral bandwidth of 80 nanometers max. These power levels represent the expected minimum parameter limit at 25 °C. and maximum rated drive current. A distribution maximum output of 3 to 4 times this level should be anticipated, which makes the an initialization adjustment of the transmitter output necessary in order to normalize all system transmitters to the same specified level. The specified level will normally be the maximum allowable input level to the receiver minus the minimum loss within the media from any transmitter to any receiver plus a margin for tolerances. If the transmitter does not contain temperature compensation, then the set output must take into consideration the variation in transmitter output over the operating temperature range. The normalization is performed to guarantee that no receiver can be over driven over the full range of system operating conditions.

The optical power launched into the media by an "off" transmitter shall be less than -40 dBm and shall also be 30 dB or more below the "on" peak level from the same transmitter, when measured at any point in the fiber media.

A separate input to the transmitter shall be provided to shut down the transmitter to the above indicated "off" state even should a "stuck true" condition at the normal data input or a failure in the internal normal data input path result in the optical output being "stuck on". It shall be the responsibility of the Bus Controller, through use of the "Transmitter Shutdown" and "Override Transmitter Shutdown" Mode Commands, to provide control to this function per the requirements of MIL STD 1773.

3.2.1.2. OPTICAL WAVEFORM.

Over the full specified system operating temperature range, over the range of specified high and low voltage signal levels for TTL logic and over a range of "on" optical pulse widths varying from 62.5 nanoseconds to 2 microseconds preceded by an "off" period of 125 nanoseconds to milliseconds:

The transmitter shall have a rise and fall time, as measured between the 10% and 90% points on the optical output, of 20 nanoseconds or less.

The optical output shall exhibit peak overshoot of no more than 2% of the steady state output "on" level.

The optical output shall exhibit no droop in the steady state output level during an "on" period of the maximum length.

The pulse width distortion plus jitter introduced by the transmitter as measured by comparing the 1.25 volt level pulse width at the electrical input to the 50% amplitude width at the optical output shall be no more than +/-5 nanoseconds.

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3.2.2. FIBER OPTIC RECEIVER.

Over the full specified system operating temperature range and a range of "on" optical pulse widths varying from 62.5 nanoseconds to 2 microseconds preceded by an "off" period of 62.5 nanoseconds to milliseconds:

The receiver electrical output shall meet all specifications for TTL logic waveforms, be at a level within the range for TTL "high" when the peak optical input level is between the limits of -39 dBm and -12 dBm and be at a level within the range for TTL "low" when the peak optical input level is no more than -42 dBm within the scope of the above mentioned duty cycle variations.

The receiver, in combination with the appropriate decoder, will handle data at either data rate with a word error rate no greater than 1 in 10 exp 7 words for optical inputs meeting the jitter and distortion limits specified for the transmitter output and with peak levels between the limits of -39 dBm and -12 dBm. These limits are set by receiver noise at the low signal end and by inter-symbol interference (input exceeding the dynamic range of the receiver) at the high signal end. No noise is coupled externally into the optical media, therefore, NO "injected noise" testing is required.

The word error rate limits, as above, shall be met when a 1 Mbit format word, at the -39 dBm peak input level, is preceded by an 8 MBit block of words, at the -12 dBm peak input level, separated by an Inter-message Gap of down to 4 microseconds. The IMG is measured as the period from the mid-bit transition of the Parity Bit of the preceding word to the mid-bit transition of the Synch Code of the following word. This guarantees that the receiver is capable of recovering from the baseline shift introduced by allowed maximum amplitude optical signal levels to properly detect allowed minimum optical signal levels within the time provided by the minimum Inter-message Gap.

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An example of a receiver design approach that is known to meet all the requirements stated above from its use in the "proof of concept" hardware is shown in the functional block diagram of Figure 3.5.

1. Preamplifier.

Low noise transimpedance amplifier with matched filter bandwidth and critically damped response converts the current output of the photo detector to a voltage signal.

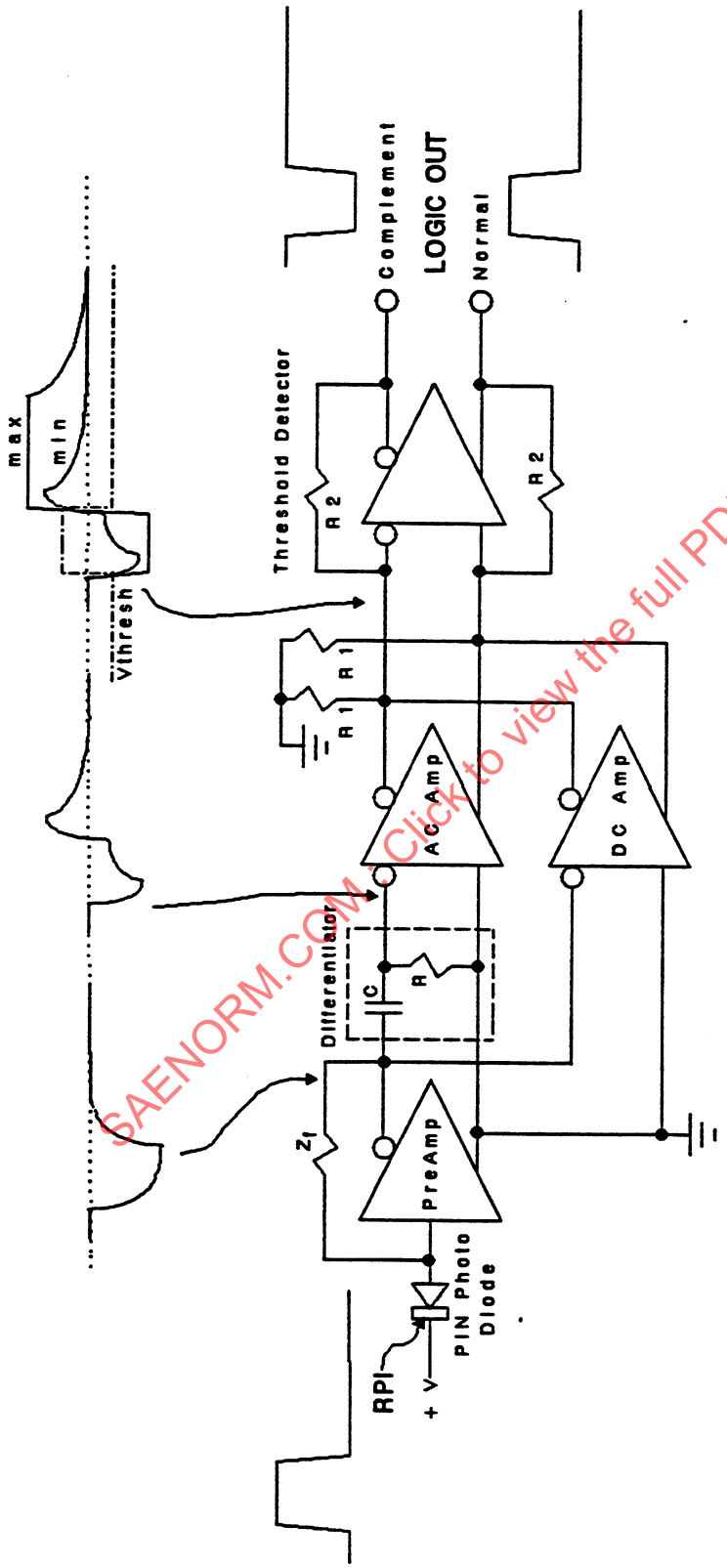

Figure 3.5. Functional Block Diagram of Dual Speed Receiver

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2. Differentiator (hi-pass filter).

   Converts the amplifier from a low pass to a band pass characteristic. This eliminates the baseline shift of the AC coupled Post Amplifier that is introduced by the message duty cycle and attenuates the low frequency 1/f noise in the preamplifier noise spectrum.

3. AC coupled post amplifier.

   Amplifies and limits the output of the preamp, presenting a normalized signal to the threshold detector over approximately a 60 dB dynamic range. The minimum signal is limited by the noise of the preamplifier and the maximum by pulse width distortion as the input signal exceeds the linear range of the preamp.

4. DC coupled post amplifier.

   Feeds a small fraction of the preamp DC output around the AC coupled amplifier to shift the detection threshold in a manner that maintains the threshold voltage to RMS noise voltage ratio constant as the Shot noise of the photo current from very large optical inputs begins to exceed the noise of the preamplifier. As the differentiator decays out during the long duration of the 1 Mbit Manchester code (up to 2 MicroSec. duration "high" levels exist) the photo current Shot noise is amplified by the full gai of the AC coupled post amp. Without this threshold shift, the threshold detector would switch randomly on the noise during the maximum signal periods of the 1 Mbit modulation format. It is this proportional threshold adjustment that allows the amplifier to handle modulation of both the 1 Mbits/S. and 8 Mbits/S. rates.

5. Symmetrical "Schmidt Trigger" threshold detector.

   Detects the "pips" generated by the differentiator at the edges of the input waveforms as they cross a threshold voltage that is shifted from positive to negative or back at each successive edge and restores the DC levels that were extracted. The output of this detector provides TTL logic level outputs that are a reproduction of the input to the optical transmitter.

The fundamental criteria for this (or any other circuit configuration that might be used) is that it must NOT require any recovery time to accurately reproduce modulation at either data rate starting with the first pulse from a quiet line state.

3.2.3. ONE MBIT/S ENCODER/DECODER.

The low speed encoder/decoder may be any circuit meeting the requirements of MIL STD 1773, such as the Harris 15530 chip or an integrated or discrete equivalent, that is capable of recognizing eithe Data or Command Synch and End of Word conditions, with unipolar Manchester Biphase Level input signals.

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The decoder must recognize any pair of transitions that have a nominal separation of .5, 1, 1.5 or 2 microseconds +/- a time uncertainty of at least 160 nanoseconds as a portion of a valid Manchester waveform. That is, it must tolerate distortion plus jitter of +/-160 nanoseconds or more.

As a minimum the decoder outputs shall provide an indication of Synch Type (Data or Command), the 16 data bits and a Valid Word indication that is the logical combination of the occurrence of a valid Synch Code, the proper number (16) of valid Manchester Data bits and valid Odd Parity.

NOTE: Any of the word validation criteria above, is sufficient to prevent a high speed word from generating a valid low speed word indication.

The encoder inputs, similarly will consist of a 16 bit parallel word, Synch Type indication and a Take Word indication for initiation of encoding and transmission of a word.

The encoder/decoder used may handle the data input/output in serial form, however for purposes of this specification, the data interface is defined as parallel and the serial/parallel conversion is functionally included in the encoder/decoder function where ever it is physically located.

3.2.4. EIGHT MBIT/S ENCODER/DECODER.

The Second Speed encoder/decoder may be a discrete logic circuit or a yet to be developed integrated version with the following minimum requirements:

> The decoder must recognize any pair of transitions that have a nominal separation of 62.5 or 125 nanoseconds +/- a time uncertainty of at least 12.5 nanoseconds as a portion of a valid Manchester waveform. That is, it must tolerate distortion plus jitter of +/- 12.5 nanoseconds or more.

As a minimum the decoder shall provide the 16 data bits from a word as a stable parallel register output coincidentally with a Valid Word indication. As shown in Figure 3.6., the Valid Word indication is the logical combination of the occurrence of a valid Synch Code, the proper number (16) of valid Manchester Data bits and valid Odd Parity.

The second speed decoder shall also provide a Valid Block indication, as defined in Figure 3.6., at the end of each contiguous group of eight words or at the end of the final block. The last block transmitted shall be counted as valid if all words in the block are valid, irregardless of the number (ie, 1 to 8). The Valid Block indication will be available to the terminal control logic for comparison to the Command-receive word

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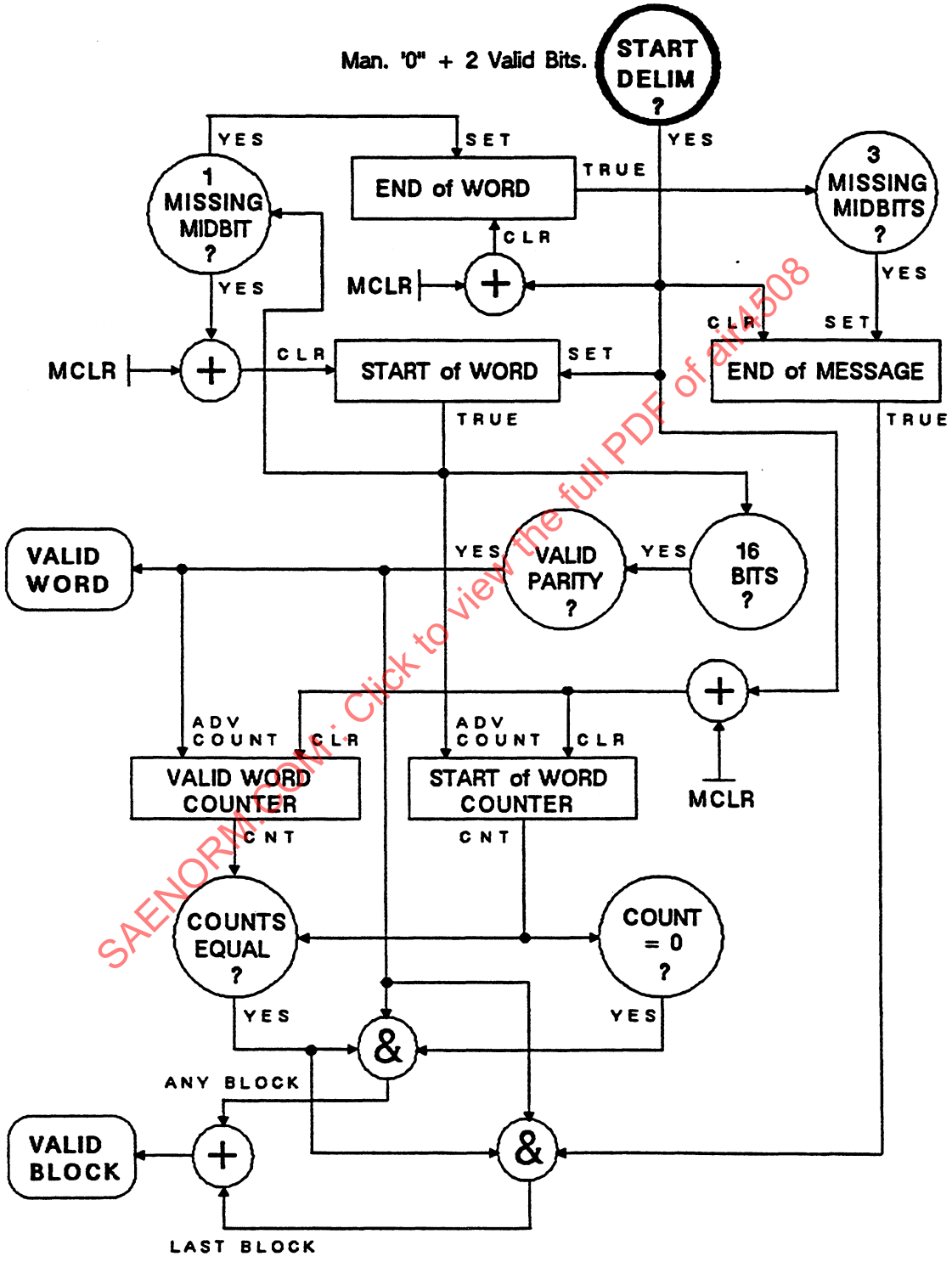

Figure 3.6. State Diagram of Second Speed Valid Word and Valid Block Indications

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(block) count field and have the same timing and duration as the Valid Word indication of the last word of a block. An improper Valid Block count shall make the entire message invalid.

NOTE: Any of the word validation criteria above, is sufficient to prevent a low speed word from generating a valid second speed word indication.

The second speed encoder will accept a 16 bit parallel word coincidentally with a Take Word indication to initiate the encoding and transmission of a second speed data word.

The separate word streams of the two data rates may be transferred to the host by separate paths or combined into a single path, depending on the capabilities of the host hardware.

Remember that the low rate data will transfer at 1 word every 20 microseconds while the high rate data will appear at 1 word every 2.5 microseconds. Depending on the capabilities of the host interface, it may be necessary to provide a buffer in the terminal logic to store and forward received second speed message data to the host at a lower data rate.

3.2.5. ENCODER OUTPUT TIMING.

Figure 3.7. describes the timing relationships between the Dual Speed data message and the two decoder's outputs as defined in the preceding sections. The message will consist of a low speed Status Word followed by 1 to 32 blocks of second speed data words in the format described in section 3.1.2.2. The low speed decoder data output will be stable and the Valid Word indication set within about two microseconds after the end of the serial status word and remain set until another low speed word arrives in a succeeding message. The results with the second speed words are, however, somewhat different.

The second speed decoders output is stable in less than 100 nanoseconds after the last serial bit and will remain stable until a succeeding second speed word OR low speed word is received. The difference derives from the fact that the low speed decoder does not recognize the high speed modulation as anything except noise and never detects the start of a word. The second speed decoder, however, recognizes the first transition of a low speed word as a possible word delimiter (a Manchester "zero" preceded by one or more blank bit periods) and immediately determines it to be an invalid word and drops the Valid Word indication of the previous word. This cannot happen sooner than 2.5 microseconds after the last second speed word is set, even with the minimum four microsecond inter-message gap.

The Valid Word indication is a take word signal in the second speed data interface, but the total number does not correspond to the "Block Count" set in the Command-receive sent by the bus controller, so a Valid Block indication must be generated that the protocol support logic can count

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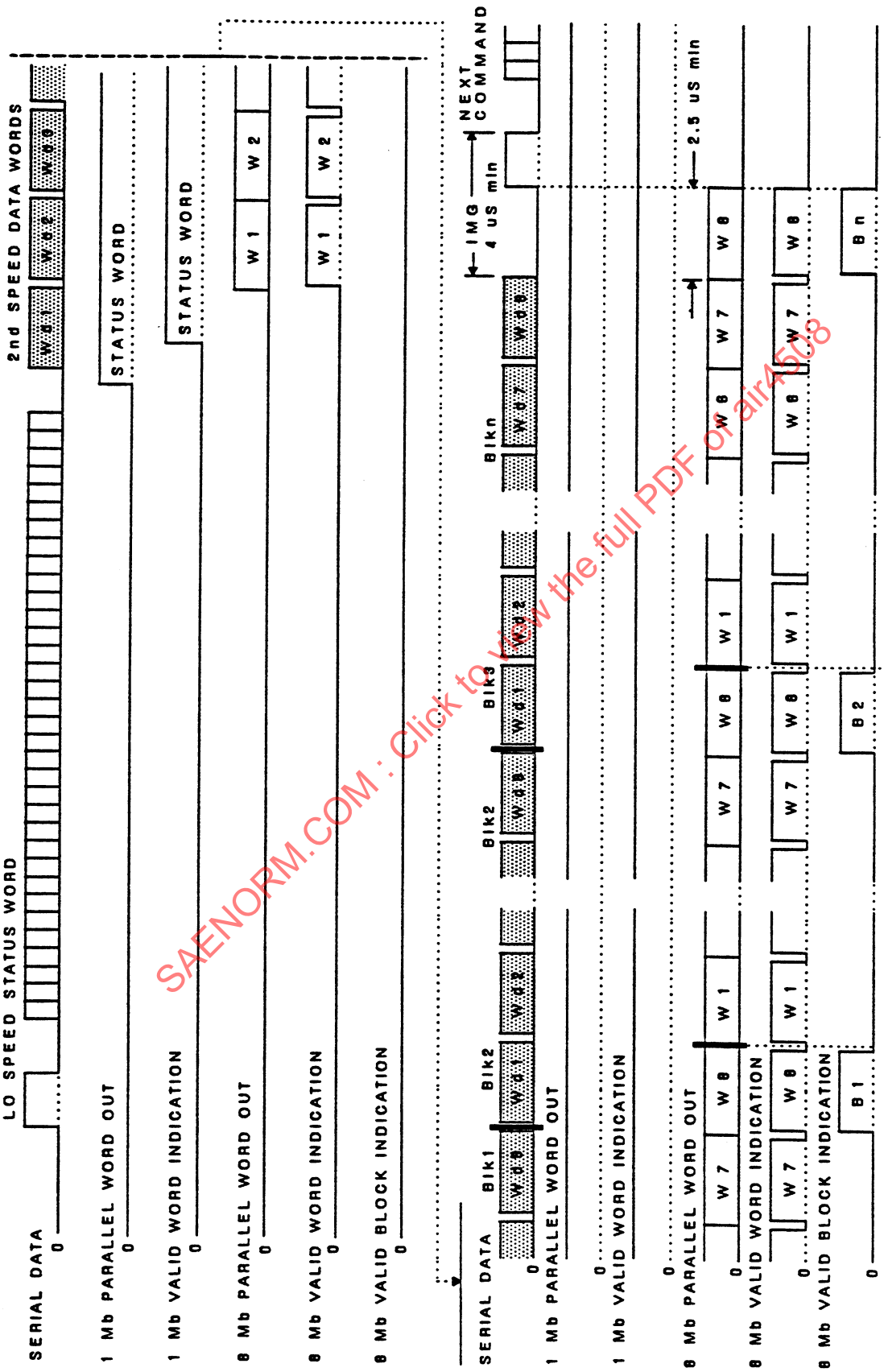

Figure 3.7. Timing of Valid Word and Valid Block Indications.

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and compare to the "Block Count" to decide whether or not the message is valid. The second speed Valid Block indication is generated in the following manner:

Each "Start of Word" and each "Valid Word" are summed in a separate counter.

When the "Start of Word" count reaches seven and the valid word count is also equal to seven, then the "Valid Block" indication is a "Valid Word" indication of the next word. Whether or not the next word is valid, the counters are cleared and the cycle starts over again.

3.2.6. MEDIA TOPOLOGY.

The media topology for a Dual Speed MIL STD 1773 bus shall generally be as the alternatives described in MIL STD 1773.

For the transmitter and receiver described above a media loss range of 4.1 dB to 31.1 dB is supported with the 100 micron fiber, 5.8 dB to 32.8 dB with the 125 micron core fiber and 9.6 dB to 36.6 dB for the 200 micron fiber. Assigning some of this loss budget for LED ageing and system margin will of course reduce the allowable loss range for the media. Active repeatering is possible with the Dual Speed media signals to provide additional loss budget or margins if necessary.

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4.0. SECOND SPEED DATA TRANSFER CONTROL SEQUENCES AND THRUPUT.

The Control sequences to initiate a Second Speed Data Transfer between the Bus Controller and a Remote Terminal or between two Remote Terminals shall be identical to those required for the initiation of Data Transfers on MIL STD 1553 or unenhanced MIL STD 1773 busses with the following provisions in the system operational software:

The Bus Controllers operating program shall include a lookup table listing those terminals that are Dual Speed enhanced, which may include itself, but probably will not include all terminals on the bus.

A transfer may be initiated by the Bus controllers operating program (the normal manner) or by the extraordinary means of a Remote Terminal setting the Request bit in any Status Word it has occasion to send to the Bus Controller. Under either of these circumstances, the Transmit or Receive Command Words that the Bus Controller sends to the Remote Terminals shall have the sub-address field set to decimal 30 to indicate that the transfer shall be Dual Speed, if both transmitting and receiving terminals are listed as Dual Speed terminals and the number of words to be transmitted is equal to or greater than a minimum number determined by the system level detail specification.

For the case of a Service Request initiated RT to RT data transfer, the BC responds with a Mode Command - Transmit Vector Word (see Fig. 4.1.). Two Vector Words shall be defined to enable a Remote Terminal to respond with a request to transmit to or receive from another terminal or the Bus Controller, N blocks (= 1 to 32) of Second Speed data words.

A diagram of the possible control sequences is provided as Figure 4.1. for reference. Table 4.1 and the graph of Figure 4.2. contain an analytical estimate of the second speed transfer real data thruput versus number of words per message compared to the thruput of low speed data transfers.

real data thruput (bits/sec) = the number of Data words per message X 16 bits/word divided by the Total Time for the transfer sequence (including command words, status words, and response times as shown in Figure 4.1.)

Command and Status words are not included as data.

As can be noted from the graph and table, even one word messages sent at the second speed significantly improves data thruput rate over the low speed case.

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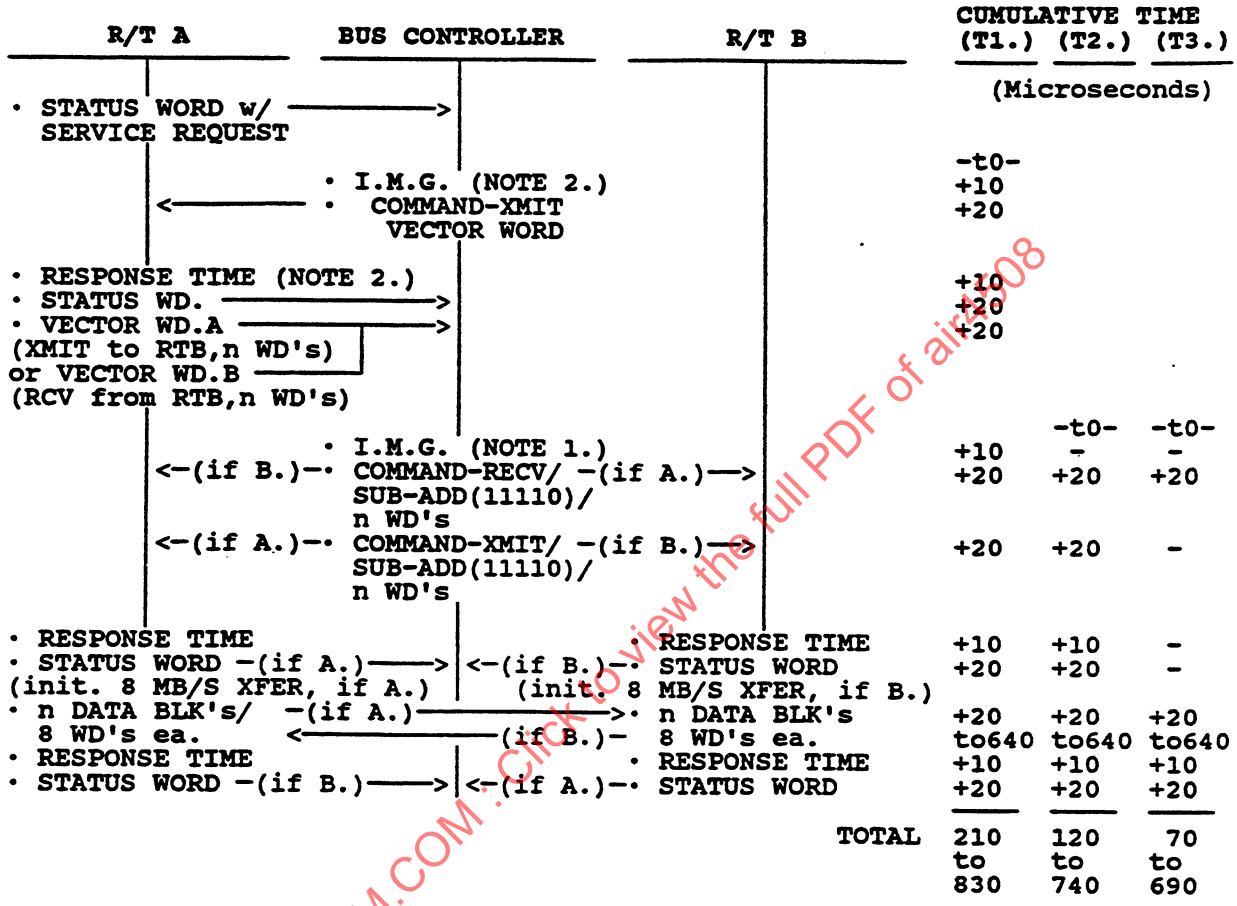

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CUMULATIVE TIME:

(T1.) SERVICE REQUEST initiated R/T->R/T XFER at SECOND SPEED.

(T2.) PRE-PROGRAMED or QUEUED R/T->R/T XFER at SECOND SPEED.

(T3.) BC->R/T XFER at SECOND SPEED.

NOTES:

(1.) BUS CONTROLLER SETS SUB-ADDRESS (11110), INDICATING A SECOND SPEED TRANSFER REQUEST, IN RECV AND XMIT COMMANDS ONLY IF BOTH TERMINALS ARE LISTED AS DUAL SPEED IN LOOK-UP TABLE.

(2.) ALL I.M.G.'s AND RESPONSE TIMES ARE ASSUMED TO BE 10 uS. AND INCLUDE MEDIA TRANSIT TIMES.

Figure 4.1. Second Speed Data Transfer Control Sequence

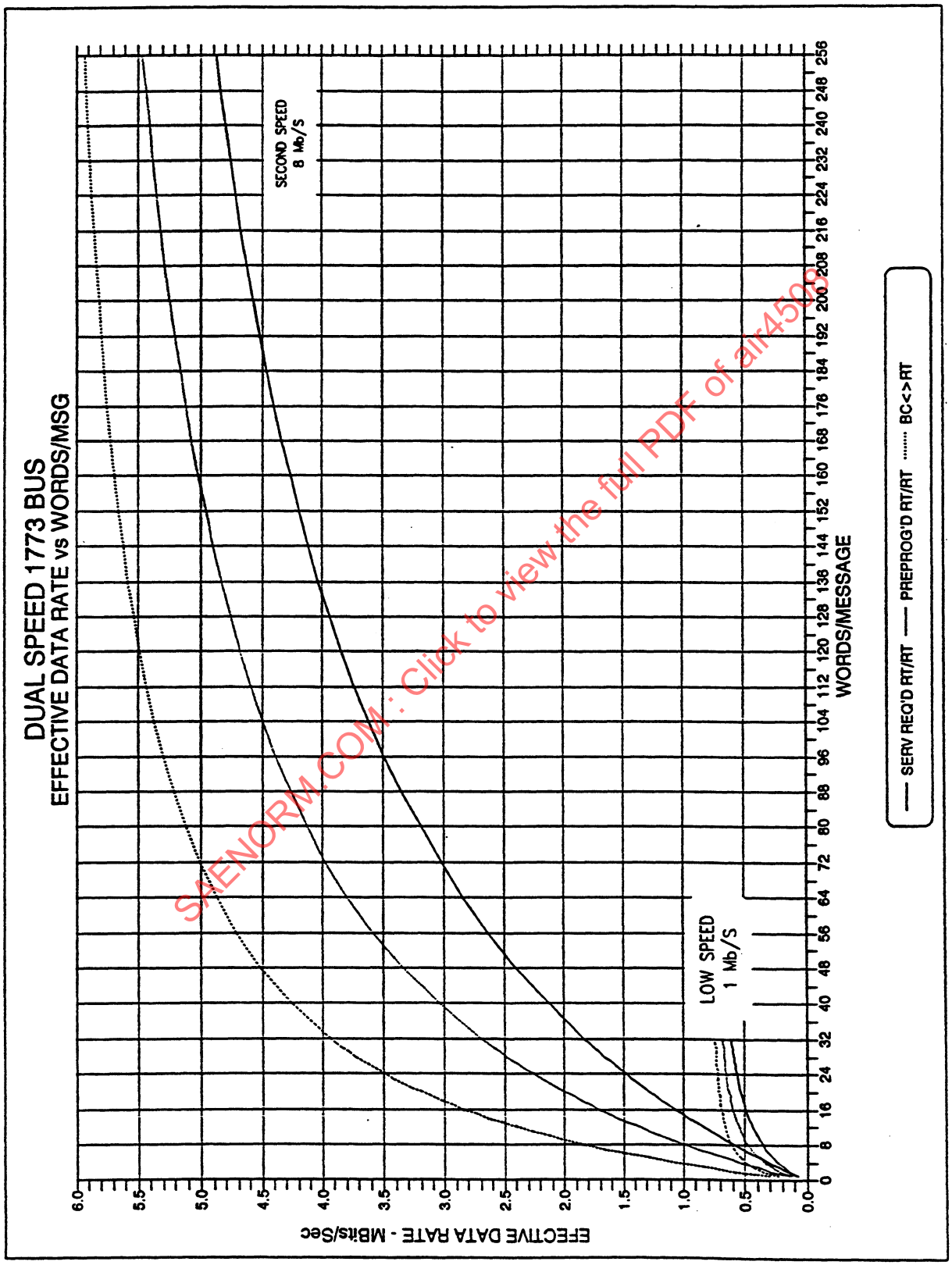

Figure 4.2. Dual Speed 1773 Bus, Effective Data Rate versus Words/Messages

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	LOW SPEED EFFEC DATA RATE – Mb/S			SECOND SPEED EFFEC DATA RATE – Mb/S		
	RT–RT TRANSFER		BC–RT XFER	RT–RT TRANSFER		BC–RT XFER
WORDS/MSG	SERVICE REQ	PRE–PROGD		SERVICE REQ	PRE–PROGD	
1	0.072727	0.123077	0.228571	0.079012	0.142222	0.304762
2	0.133333	0.213333	0.355556	0.156098	0.278261	0.581818
3	0.184615	0.282353	0.436364	0.231325	0.408511	0.834783
4	0.228571	0.336842	0.492308	0.304762	0.533333	1.066667
5	0.266667	0.380952	0.533333	0.376471	0.653061	1.280000
6	0.300000	0.417391	0.564706	0.446512	0.768000	1.476923
7	0.329412	0.448000	0.589474	0.514943	0.878431	1.659259
8	0.355556	0.474074	0.609524	0.581818	0.984615	1.828571
9	0.378947	0.496552	0.626087	0.647191	1.086792	1.986207
10	0.400000	0.516129	0.640000	0.711111	1.185185	2.133333
11	0.419048	0.533333	0.651852	0.773626	1.280000	2.270968
12	0.436364	0.548571	0.662069	0.834783	1.371429	2.400000
13	0.452174	0.562162	0.670968	0.894624	1.459649	2.521212
14	0.466667	0.574359	0.678788	0.953191	1.544828	2.635294
15	0.480000	0.585366	0.685714	1.010526	1.627119	2.742857
16	0.492308	0.595349	0.691892	1.066667	1.706667	2.844444
17	0.503704	0.604444	0.697436	1.121649	1.783607	2.940541
18	0.514286	0.612766	0.702439	1.175510	1.858065	3.031579
19	0.524138	0.620408	0.706977	1.228283	1.930159	3.117949
20	0.533333	0.627451	0.711111	1.280000	2.000000	3.200000
21	0.541935	0.633962	0.714894	1.330693	2.067692	3.278049
23	0.557576	0.645614	0.721569	1.429126	2.197015	3.423256
24	0.564706	0.650847	0.724528	1.476923	2.258824	3.490909
25	0.571429	0.655738	0.727273	1.523810	2.318841	3.555556
26	0.577778	0.660317	0.729825	1.569811	2.377143	3.617391
27	0.583784	0.664615	0.732203	1.614953	2.433803	3.676596
28	0.589474	0.668657	0.734426	1.659259	2.488889	3.733333
29	0.594872	0.672464	0.736508	1.702752	2.542466	3.787755
30	0.600000	0.676056	0.738462	1.745455	2.594595	3.840000
31	0.604878	0.679452	0.740299	1.787387	2.645333	3.890196
32	0.609524	0.682667	0.742029	1.828571	2.694737	3.938462
40				2.133333	3.047619	4.266667
48				2.400000	3.339130	4.517647
56				2.635294	3.584000	4.715789
64				2.844444	3.792593	4.876190
72				3.031579	3.972414	5.008696
80				3.200000	4.129032	5.120000
88				3.352381	4.266667	5.214815
96				3.490909	4.388571	5.296552
104				3.617391	4.497297	5.367742
112				3.733333	4.594872	5.430303
120				3.840000	4.682927	5.485714
128				3.938462	4.762791	5.535135
136				4.029630	4.835556	5.579487
144				4.114286	4.902128	5.619512
152				4.193103	4.963265	5.655814
160				4.266667	5.019608	5.688889
168				4.335484	5.071698	5.719149
176				4.400000	5.120000	5.746939
184				4.460606	5.164912	5.772549
192				4.517647	5.206780	5.796226
200				4.571429	5.245902	5.818182
208				4.622222	5.282540	5.838596
216				4.670270	5.316923	5.857627
224				4.715789	5.349254	5.875410
232				4.758974	5.379710	5.892063
240				4.800000	5.408451	5.907692
248				4.839024	5.435616	5.922388
256				4.876190	5.461333	5.936232

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Table 4.1. Data for Figure 4.2.

APPENDIX D, INCLUSION D-2.

PROPOSED GENERAL SPECIFICATION FOR A DISTRIBUTED SWITCH NETWORK USING 100 MEGABIT/SECOND FIBER OPTIC COLLATERAL DATA PIPELINES UNDER CONTROL OF A MIL-STD-1773 BUS.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This General Specification defines the architecture and hardware implementation of a Fiber Optic distributed Switch Network under control of a MIL STD 1773 Bus. Up to 16 100 MBit/sec collateral data pipelines are controlled as a sub-system under the 1773 protocol to implement the distributed switch array.

The pipelines utilize physical layer hardware as developed for the ANSI X3T9.5 FDDI standard and media identical to the 1773 Bus. The pipeline capacity may be used in packet (burst) mode or circuit switch (continuous) mode based on message priority level.

Any user connected to the 1773 bus may also be connected to any or all of the 1 to 16 pipelines implemented in the system.

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PRELIMINARY GENERAL SPECIFICATION FOR A DISTRIBUTED SWITCH NETWORK USING 100 MEGABIT/SEC FIBER OPTIC COLLATERAL DATA PIPELINES UNDER CONTROL OF A MIL STD 1773 BUS

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1.0. PURPOSE OF THIS SPECIFICATION.

The purpose of this specification is to define a system and hardware implementation for the use of high data rate Fiber Optic Data Pipelines, under control of a MIL STD 1773 Bus. The Pipelines have no protocol of their own, but are rather a distributed switch network, with multiple users sharing the same or identical media topology as the 1773 Bus, in both the equivalent of "Packet Switch" and "Circuit Switch" operation. The Pipelines are utilized as a collateral resource to the 1773 bus and are controlled by the 1773 Bus Controller as a sub-system, through Requests or Commands transmitted over the 1773 bus.

Figure 1.1. shows the Pipeline Terminal configuration. The Terminal blocks are representative of the basic types anticipated. Pipeline Terminals are MIL STD 1773 or enhanced Dual Speed Terminals connected to 1 or more of the possible complement of 16 collateral Pipelines as transmit only, receive only or transmit and receive users. Each Terminal must connect to the 1773 bus but only needs to contain Pipeline hardware for connections and functions it uses. The terminals resident on the 1773 Bus may also include unenhanced or enhanced Dual Speed Terminals with NO connection to the Pipelines.

- The Pipeline hardware will "add on" to the 1773 Terminal hardware and be controlled by it.

- To the degree that terminals are connected to the full set or a sub-set of the total Pipeline complement, the Pipelines are inherently "multi-redundant" with graceful degradation.

- The total extent of the Pipelines are limited to the maximums (length, number of terminals) as defined by the 1773 Bus Standard due to the necessity of each Pipeline terminal being connected to the 1773 Bus.

- Four message priority levels are provided, the highest level is dedicated or "Circuit Switch" mode, the remaining 3 designate undedicated burst or "Packet Switch" mode messages of descending order of time criticality.

- When a terminal is given dedicated access to a Pipeline, it may continue to transmit sequential messages for as long as desired or until usurped by the 1773 Bus Controller in it's role as network supervisor. Only one message may be transmitted per authorization in packet mode.

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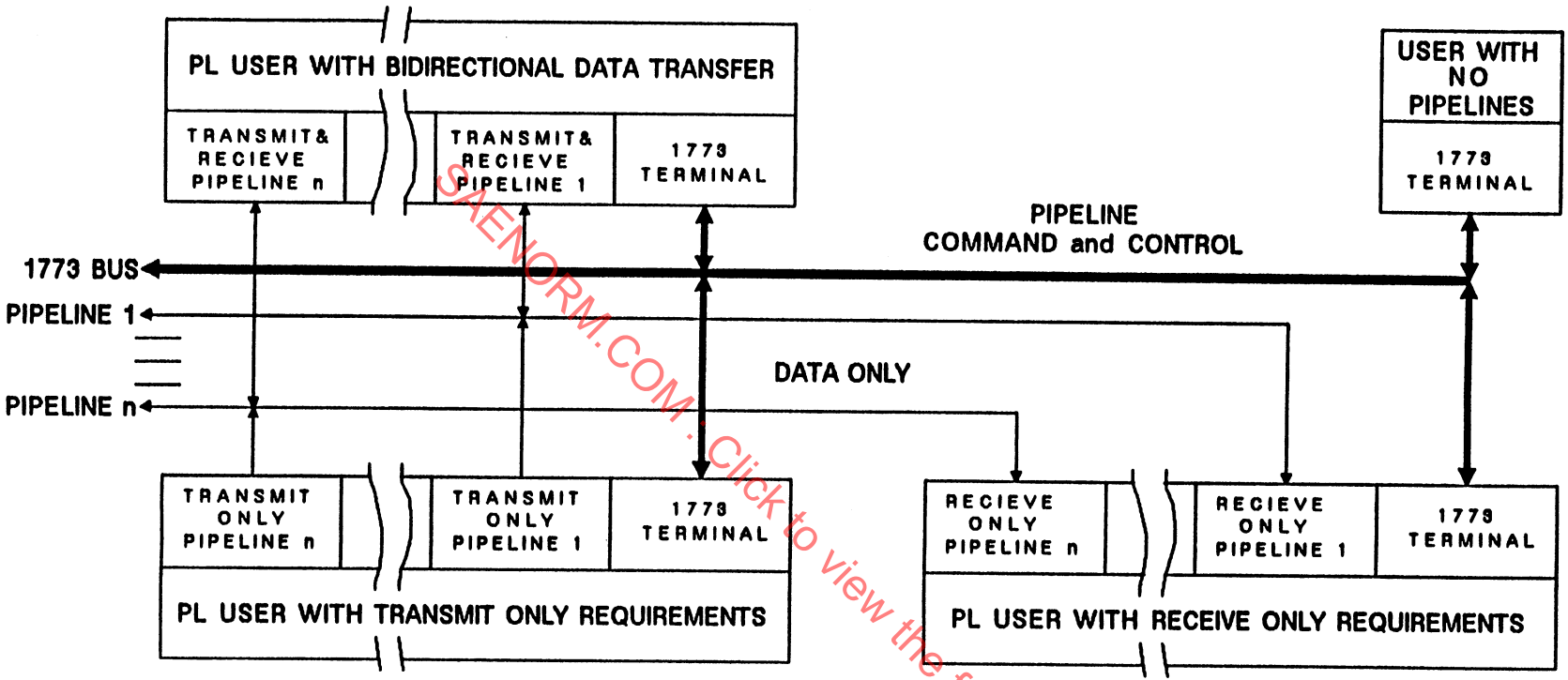

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COLLATERAL. ADJECTIVE; ACCOMPANYING AS SECONDARY, SERVING TO SUPPORT OR REINFORCE. (WEBSTERS NEW COLLEGIATE DICTIONARY, 7th EDITION)

Figure 1.1. Dual Speed 1773 bus with One or More Collateral Fiber Optic Data Pipelines.

- Each message, whether "Circuit Switch" or "Packet Switch" priority level contains terminal and sub-system physical source address, functional source address and sequence number identification to allow terminals, other than the designated receiving terminal, to also receive the message in "Broadcast" mode. It is the responsibility only of the transmitting terminal to notify the 1773 Bus Controller of the completion of a packet mode message.

- Provisions for Data security in Pipeline transmissions include flagging of classified data by a unique label designation in the Functional Address field or reservation of a sub-set of the Pipelines, connected only to secure terminals, for transmission of "Red" data. The latter is possible because ONLY data is transmitted on the Pipelines.

The 1773 Bus controlled, distributed switch architecture defined by this specification is meant to be utilized as an adjunct for the established 1553/1773 protocol to allow it to undertake new Avionics Systems integration tasks that are currently not possible. These primary tasks are:

1. Implement reconfigurability into high data rate interconnects, that are currently hardwired. This capability will typically be implemented with a sub-set of the total Pipeline complement, in "circuit switch" mode, to allow reconfiguration between identical redundant sub-systems or software definable common sub-systems as failures, battle damage or mission requirements dictate. This task will typically require only a minimal amount of service from the 1773 Bus Controller, and therefore has little impact on it's availability for other tasks.

2. Add the capability, in "circuit switch" or "packet switch" modes, to transmit very high data rate messages beyond the capacity of the 1773 bus. These will typically be long messages, NOT requiring frequent servicing by the 1773 Bus Controller. Likely candidates include loading of software blocks during system initialization or reconfiguration, transmission of digitized video or display frame updates, time critical sensor data, data base references to global memory and so forth.

   In this type of service, each Pipeline can provide sustained data rates in excess of 80 Mbits/s while using less than 10% of the 1773 Bus Controllers available time.

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2.0. IMPLEMENTATION SUMMARY.

2.1. FEATURE OVERVIEW.

The implementation defined by this specification is based on the following features:

1. More than ONE pipeline (up to 16 allowed in this BASELINE) may be associated with a 1773 BUS.

2. Pipeline(s) will share 1773 media, via Wavelength Division Multiplex, or be separate identical media(s). That is, the same fiber, connectors, couplers and topology will be used for both.

3. The Pipeline architecture will make use of the Physical Layer features of the ANSI X3T9.5 Fiber Distributed Data Interface (FDDI), to the maximum extent possible. Relating the Pipeline modulation, coding and message formats to the FDDI Standard presents the possibility of utilizing hardware developed for this international commercial standard for Pipeline implementation, with perhaps, only the neccesity of addressing "Militarization". FDDI is a Token Ring, in which each terminal is connected to it's immediate neighbors by "point to point" links and specifies long wave (1.3 micron) wavelength LED sources. For the Pipeline implementation, using the linear bus topology of 1773 with power division between multiple users, Light Emitting Diode (LED) transmitters will only provide an adequate optical power budget with 200 micron or larger core fibers. Therefore, this specification allows the use of 1.3 micron Injection Laser Diode (ILD) Transmitters (if the BIAS CURRENT is turned OFF during the Inter-message Gap in "Packet Switch" mode) when the media includes smaller core fiber.

4. The Pipeline MESSAGE FORMAT is similar to the FDDI message format and includes the FDDI 5 bit/4 bit substitution code set and NRZI modulation at a 125 MBAUD modulation rate. (100 MBIT/s data rate).

5. A 62.5 MHz squarewave pattern of 80 bit times duration (16 "IDLE" symbols, NRZI modulated "ones") provides a Message Preamble, to allow Receive Clock synchronization and stabilization of a receiver with Automatic Gain Control or A.C. coupling from the quiet line IMG period of Packet Switched (burst) mode operation. AGC Recovery delay time and ILD bias turn on/off time is provided by the minimum Inter Message Gap interjected by 1773 Bus Controller service time. AGC Recovery or ILD bias turn off is NOT required between messages on a Pipeline during Circuit Switch mode operation. Therefore, there is NO quiet line IMG between messages in this mode, but rather preamble "Idle" symbols are transmitted from the end of one message until the transmitting terminal is ready to send the next message.

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6. An unused FDDI code symbol (00101, Dec. 5), which meets all use criteria, is re-defined from "INVALID" to "WORD DELIMITER". This word delimiter and a "Bytes per Word Count" parameter in the message header field allow use of variable word length messages and automatic data compression. The delimiter is passed thru the CRC registers as Hex. 5, and is included in the Check Sum but ignored as Data.

7. A repeated "HALT" (forced break) symbol is used to interrupt Messages temporarily if the USER cannot supply the required data to continue the current message for up to a predetermined maximum time period. An "End Delimiter" is used to terminate a Message if this time period is exceeded. A "Halt - End Delimiter - Preamble - Start Delimiter" is used to terminate and start over if the Source finds an ERROR in the "TRANSMIT VERIFIED" Mode. The availability of forced break and early termination means that it is not necessary for the terminal to store a complete message before commencing transmission, and thereby eliminating the considerable message latency that would be introduced if "store and forward" operation were required.

8. A reserved SUB-ADDRESS (29 dec.) will be used to identify SYNCH, VECTOR and COMMAND WORDS for Pipeline transfer initiation actions on the 1773 Bus.

9. The 1773 BUS CONTROLLER need NOT be (but MAY also be) a PIPELINE TERMINAL. (Terminal address 31, which is the BROADCAST address on 1773, is reserved for the BUS CONTROLLER on the PIPELINE. All other Pipeline terminals have the same address as on the 1773 BUS).

2.2. HARDWARE OVERVIEW.

Figure 2.1. shows a block diagram of how the Pipeline hardware is appended to the 1773 terminal hardware and the interface of the embedment into a Host function. The hardware within the dashed line is that which is added to implement the Pipeline terminal functions and is discussed in this General Specification.

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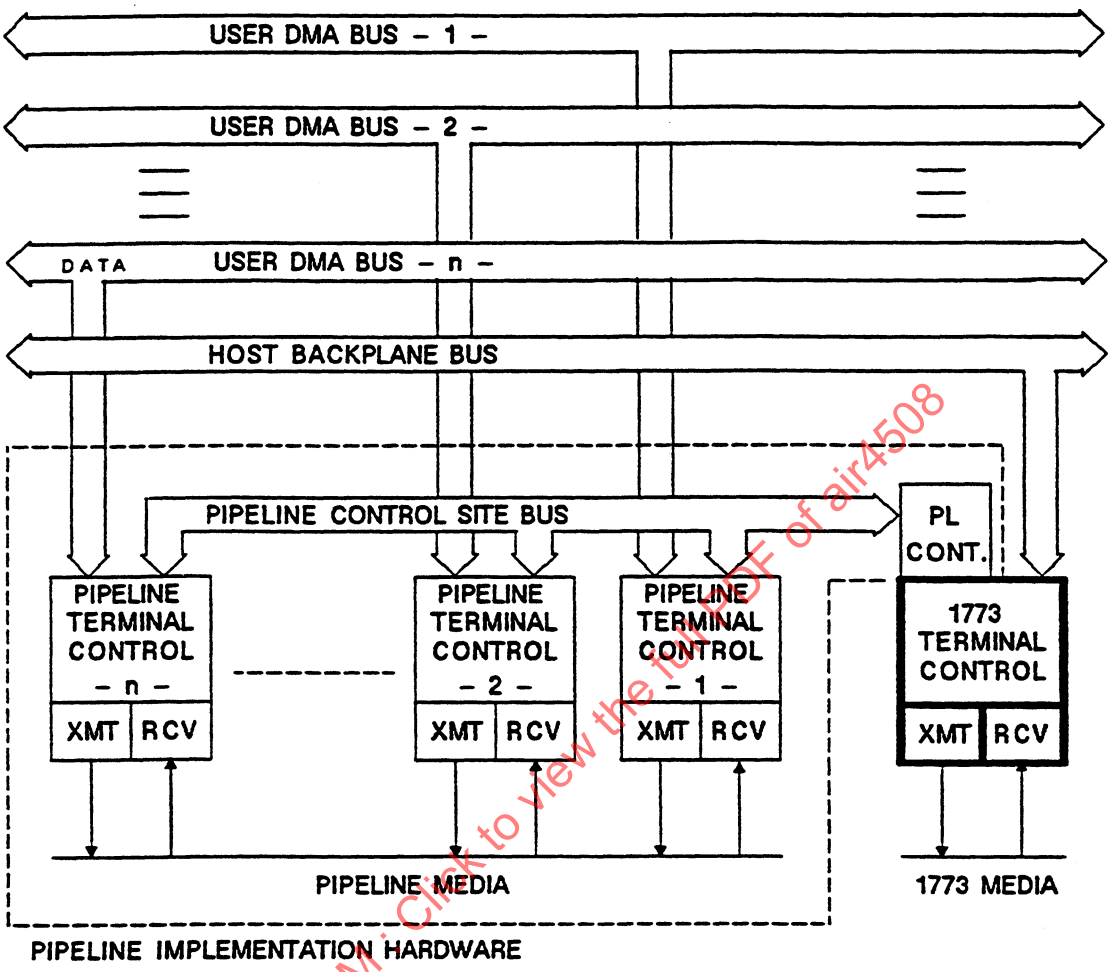

Figure 2.1. Pipeline Terminal Embedment in Host

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The Pipeline site bus is a backplane sub-bus into which the full complement of Pipeline terminal cards is connected. It functions to carry the signals for the "Message_Header" and "Terminal_Control" portion of the user interface to and from the "Pipeline Control" function. "Pipeline Control" is the additional hardware which must be added to the existing 1773 terminal control logic to interpret the commands received from the 1773 Bus Controller and generate the proper control indications for the "Pipeline Terminal Control" and conversely to interpret control indications from the Pipeline terminal and generate the proper responses to the Bus Controller. The Command, Vector and Synch words which implement the Bus Controller / Pipeline Controller exchange are defined in section 4.1.

The Pipeline "Message_Data" will interface through Direct Memory Access channels to Host memory. This interface in the Pipeline hardware will be implemented to 64 bit width but can be configured under program control for any width from 8 to 64 bits in multiples of 8 as required. The Host interface is described in section 3.2.6.

3.0. DETAIL SPECIFICATION.

A Pipeline terminal equipment shall meet all requirements of the following detail specifications within the full range of environmental conditions to be determined by the system requirements.

3.1. PIPELINE DATA TRANSMISSION FORMAT.

The Pipeline data transmission format shall use 5 bit/4 bit substitution code with NRZI modulation to transmit variable length messages containing variable length words. Messages shall contain a synchronizing preamble, an identifying header block, the data field and a CRC check sum. Messages shall be sent in "Packet Switched" mode or "Circuit Switched" mode based on assigned priority.

3.1.1. ANSI X3T9.5 FDDI 5B/4B SUBSTITUTION CODE SET.

Pipeline transmissions shall use a slightly modified version of the 5 bit/4 bit substitution code used in the ANSI X3T9.5 Standard Committee's Fiber Distributed Data Interface Token Ring standard, and the 5 bit code symbols shall be transmitted using Non Return to Zero Inversion (NRZI or "Change on One") 125 MegaBaud modulation rate. The 5b/4b code has a coding efficiency of 80% (5 Bauds are transmitted to represent 4 bits of data) resulting in a 100 MegaBits/second data rate. With NRZI modulation, the state of a bit is designated by a transition at the start of a bit period if it is a "one" and no transition if it is a "Zero".

From the 32 possible states of a five bit symbol, 25 are selected to represent the 16 states of a 4 bit data quad (hexadecimal number representation) and a group of 9 control codes which can be uniquely identified when embedded in the message stream.
In Figure 3.1., the first three columns show the decimal designation of each of the 32 symbol states, their Binary representation and the resulting waveform when this symbol is transmitted with NRZI modulation. The waveforms are depicted for the condition of the line state being "low" at the beginning of the symbol period, but except for the "Quiet" symbol, the beginning line state could as well be "high" which would result in a waveform that is the complement of that shown.

Examination of the wave forms for each of the symbols show that the selected symbols generate a set that is run length limited (the code stream can run for no more than 4 bit periods without a transition) and have a duty cycle of 50 +/-10% within the span of the symbol. The remaining possible symbols are declared "Invalid". Invalid symbols are never transmitted, and if they are detected at the Decoder, they are the result of the modification of a valid symbol by a bit error. This property provides a first order check on message integrity.

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CODE SYMBOL		NRZI WAVEFORM (NOTE 1)	MERIT(2)				CODE SYMBOL DEFINITION	
DEC.	BINARY	T- 5 4 3 2 1 +	C	D	T	Z	MNEMONIC	DECODED DATA QUAD
00	00000						Q (Quiet) -"HI" NOT ALLOWED!	
01	00001		*				V (Violation - Illegal Sym.)	
02	00010		*	*			V	
03	00011				*		V	
04	00100		*	*		*	T (½ of End of Mes.- TT) (3)	
05	00101			*	*	*	W (Word Delimiter) (NOTE 4)	
06	00110				*	*	V	
07	00111		*	*	*	*	R (Reset - Logical ZERO)	
08	01000		*				V	
09	01001			*	*	*	HEX 1	(0001+G)
10	01010			*	*	*	HEX 4	(0100+G)
11	01011		*	*	*	*	HEX 5	(0101+G)
12	01100				*	*	V	
13	01101		*	*	*	*	H (Halt - Forced Break) (3)	
14	01110		*	*	*	*	HEX 6	(0110+G)
15	01111			*	*	*	HEX 7	(0111+G)
16	10000		*				V	
17	10001				*		K (2nd ½ Start Mes. Delim.)	
18	10010			*	*	*	HEX 8	(1000+G)
19	10011		*	P	*	*	HEX 9	(1001+G)
20	10100			*	*	*	HEX 2	(0010+G)
21	10101		*	*	*	*	HEX 3	(0011+G)
22	10110		*	P	*	*	HEX A	(1010+G)
23	10111			*	*	*	HEX B	(1011+G)
24	11000				*		J (1st ½ Start Mes. Delim.)	
25	11001		*	*	*	*	S (Set - Logical ONE)	
26	11010		*	*	*	*	HEX C	(1100+G)
27	11011			*	*	*	HEX D	(1101+G)
28	11100		*	P	*	*	HEX E	(1110+G)
29	11101			*	*	*	HEX F	(1111+G)
30	11110			*	*	*	HEX 0	(0000+G)
31	11111		*	*	*	*	I (Idle - Synchronization)	

NOTE 1: Order of Xmission = 5(MSB), 4, 3, 2, 1(LSB)

NOTE 2: SYMBOL MERIT: (* = TRUE for this Symbol.)
C - Self COMPLEMENTING (has 50% duty cycle when repeated).
D - DUTY Cycle within 50 % ± 10, over Symbol width.
(P = TRUE for this Symbol, when PAIRED with itself or ANY other legal Symbol.)
T - Two or More TRANSITIONS within Symbol width.
Z - Less than 3 consecutive ZEROES in Symbol.

NOTE 3: The "H" and "T" Symbols Definitions HERE, are the REVERSE of their Definitions in the ANSII set.

NOTE 4: This "W" Symbol is NOT defined in ANSI X3T9.5 Set.
Treat as "HEX 5" in CRC Sum, with Data Gate (G)==>"LO"

Figure 3.1. Adaptation of the ANSI X3T9.5 4 Bit/5 Bit Substitution Code Symbol Set for Collateral Pipeline Transmissions.

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3.1.1.1. SYMBOL DEFINITIONS.

The valid symbols for this code set shall be as shown in Figure 3.1. and described here. Decoding of the symbols shall result in a "Violation" signal in the "False" state for these symbols and in the "True" state for all others. A Truth table for the Symbol Decoder function is shown

in Figure 3.5.

1. The 16 possible states of a group of 4 data bits shall be represented by the code symbols labeled "Hex 0" through "Hex F" inclusive. They shall be decoded as 0000 to 1111 inclusive with a "Data Gate" signal in the "True" state to indicate they are data rather than control symbols. For all other valid symbols decoded, the "Date Gate" signal shall be "False".

2. The symbol labeled "Q" (Quiet) shall exist only as a "Low" period of 5 bits duration, ie, the transmitter in the "Off" state, and shall be repeated indefinitely to indicate the Inter-message Gap period between messages in "Packet" mode.

3. The symbol labeled "I" (Idle) shall be transmitted as a synchronization aid, as defined in Section 3.1.2.

4. The symbols labeled "J" and "K" shall be used only as a pair (in that order) to designate the start of a message.

5. The symbol labeled "T" (End delimiter) shall be used alone or as a pair to indicate the end of a message, as defined in Section 3.1.2.

6. The symbol labeled "H" (HALT or forced break) may be interjected anywhere in the message Data Field to suspend the message transmission. The "Halt" symbols may be repeated for a maximum period of time to be determined at the system level. Repeating the "Halt" symbol will suspend message decoding/validity checking operations while maintaining receive clock synchronization and receiver normalization while the transmitting terminals host is temporarily unable to supply data to continue the message. This capability replaces requiring the terminal to store ahead the entire message before commencing transmission, to avoid a system crash.

   A sequence of "Halts" shall be followed by resuming the message at the point of suspension (Figure 3.2.B.) if data becomes available before the required time out. IF not, "T or TT" symbols shall be sent (Figure 3.2.C.) to terminate the message.

   A "Halt - T - 16 Idle's - J - K" sequence (Figure 3.2.D.) shall be used to terminate and restart or a "Halt - T or TT" sequence (Figure 3.2.E.) shall be used to terminate a message when the transmitting terminal detects an error in it's own transmission in the "Transmit Verified" mode.

7. The symbols labeled "S" (set or logical "one") and "R" (reset or

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