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To	Fiber Optic Subcommittee	**Date**	February 14, 2023
From	Scott L. Smith email: smitty@sae-itc.org tel +1 443.221.8372	**Reference**	23-008/FOWG-191 jlg

Subject

Circulation prior to Adoption Action
Draft 1 of Supplement 5 to ARINC Report 803: *Fiber Optic System Design Guidelines*

Summary

The ARINC Industry Activities staff prepared this draft based on Fiber Optic Subcommittee (FOS) meetings held virtually in 2022.

This supplement adds guidance to fiber optic system designers and implementers by defining wavelengths for use in airborne avionics components to ensure interoperability.

This draft is produced through industry consensus in response to ARINC Project Initiation/Modification (APIM) 21-006.

All technical changes are shown in **blue bold**. Text that has been deleted may or may not be shown in ~~strikethrough~~ depending on the extent of the deletions.

Action

If no adverse technical comments are received by March 22, 2023, Draft 1 of Supplement 5 to ARINC Report 803 will be submitted to the AEEC Executive Committee for adoption consideration at the AEEC General Session, to be held May 8-10, 2023.

Preamble:

When this Supplement has been completed, adopted and published, Sections A, B and C will be affixed to the end of the published Specification. These pages, currently numbered a, b, c…, are used to explain the changes that will be made by this draft Supplement. The content of Sections A, B and C is under development in parallel with the changes to the body of the existing standard. Therefore, changes to their content are shown in blue bold in the same manner as changes to the body of the document.

Section A is written as it is expected to read when the Supplement is mature.

When the changes developed in this Supplement are integrated into the existing standard, they will be identified by blue bold.

Section C contains a cumulative list of entries describing the changes to be incorporated by this Supplement. Typically, Section C expands in size with each draft.

DRAFT 1 OF

SUPPLEMENT 5
TO
ARINC REPORT 803

FIBER OPTIC DESIGN GUIDELINES

Published: Month Day, Year

Prepared by the AEEC

Report 803-5 Adopted by the AEEC Executive Committee: TBD

A. PURPOSE OF THIS DOCUMENT

This supplement adds guidance to fiber optic system designers and implementers by defining wavelengths for use in airborne avionics components to ensure interoperability.

- 155 Mbp/s or less
- 1 Gbp/s but less than 10 Gbp/s
- 10Gbp/s or higher speeds

These design requirements are intended for new system designs and improved retrofit applications.

B. ORGANIZATION OF THIS SUPPLEMENT

In this document **blue bold** text is used to indicate those areas of text changed by the current supplement only.

C. CHANGES TO ARINC REPORT 803 INTRODUCED BY THIS SUPPLEMENT

This section presents a complete listing of the changes to the document introduced by this supplement. Each change is identified by the section number and the title as it will appear in the complete document. Where necessary, a brief description of the change is included.

APPENDIX F End User Level Wavelength Designation for Interoperability

This Attachment was added to provide guidance for airlines and end users to improve interoperability in airborne avionics and cabin components utilizing fiber optic networks.

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DRAFT 1 OF

SUPPLEMENT 5
TO
ARINC REPORT 803

FIBER OPTIC DESIGN GUIDELINES

This draft dated: February 14, 2023

TABLE OF CONTENTS

APPENDICES

1.0 INTRODUCTION

1.1 Purpose of this Document

The purpose of ARINC Report 803 is to provide design and implementation guidelines together with a selection guide, providing a fiber optic system design engineer with documentation to assess the design requirements for an aerospace fiber optic installation.

The purpose of these guidelines is to assist in the identification and implementation of design requirements for aerospace fiber optic-based systems. The specification also includes recommendations for good practice and aspects of system testing.

Appendices to this standard cover the particular case of system design for ARINC Specification 664-compliant networks over a fiber optic physical layer, including an equipment interface specification to ensure interoperability of ARINC Specification 664 equipment.

1.2 Related Documents

ARINC Specification 628*: Cabin Equipment Interfaces Part 6, Fiber Optic Cable Assembly General Specification*

ARINC Specification 664: *Aircraft Data Network, Part 2, Ethernet Physical and Data Link Layer Specifications*

ARINC Specification 801: *Fiber Optic Connectors*

ARINC Specification 802: *Fiber Optic Cables*

ARINC Report 804: *Fiber Optic Active Device Specification*

ARINC Report 805: *Fiber Optic Test Procedures*

ARINC Report 806: *Fiber Optic Installation and Maintenance Procedures*

ARINC Report 807: *Fiber Optic Training Requirements*

ARINC Specification 845: *Fiber Optic Expanded Beam Termini*

ARINC Specification 846: *Fiber Optic Ferrule, Mechanical Transfer (MT)*

ASSC/120/2/81: *Guide to Avionic Fiber Optic Systems Design*

EN 4533-001: *Aerospace Series, Fiber Optic Systems Handbook, Part 001: Termination Methods and Tools*

EN 4533-002: *Aerospace Series, Fiber Optic Systems Handbook, Part 002: Test and Measurement*

EN 4533-003: *Aerospace Series, Fiber Optic Systems Handbook, Part 003: Looming and Installation Practices*

EN 4533-004: *Aerospace Series, Fiber Optic Systems Handbook, Part 004: Repair, Maintenance and Inspection*

IEEE Std 802.3-2002: *Part 3, Carrier Sense Multiple Access With Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*

2.0 SCOPE

2.1 System Design

The fundamental element of a reliable, functional aerospace fiber optic application is the system design. It is the system designers' task to define the most efficient and cost-effective methods of transmitting the optical signal, while providing a physical layer with sufficient performance, reliability, and availability for the application.

This document provides guidance on key areas of system design to achieve this goal:

- Section 3.0, System Definition, describes the system requirements information that is necessary to begin the process and the topology options available to a system designer.
- Section 4.0, System Design, describes the process that a system designer should go through when deciding on a network design or topology for a particular application, including the procedure of power budgeting.
- Section 5.0, Component Selection, covers the actual hardware options that the designer will need to select.

Topology design, power budgeting, and component selection are discussed in that order, but in reality, system design is an iterative process and all three topics should be considered in parallel.

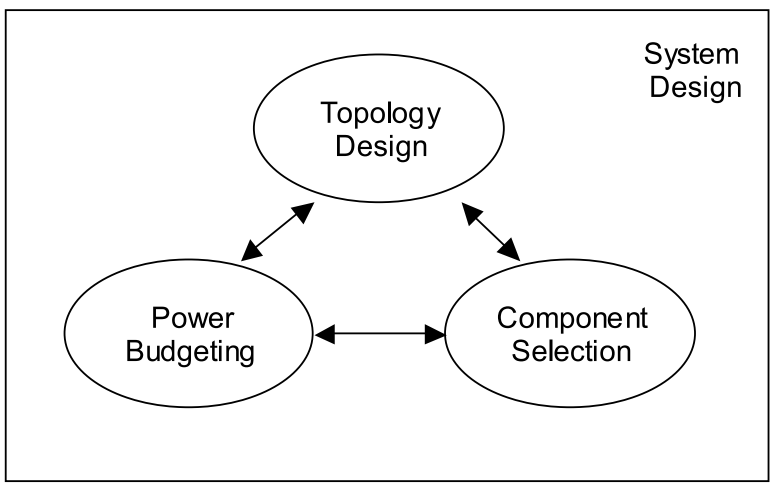


Figure 2-1 – Basic System Design

Additional sections provide guidance on system design considerations for aircraft installation and safety.

Information defined in the **ASSC/120/2/81:** *Guide to Avionic Fiber Optic System Design* document and European Norm **EN 4533:** *Fiber Optics Handbook* has been used extensively in the preparation of this document.

3.0 SYSTEM DEFINITION

The system definition provides the reader with general information applicable to the initial design requirements for a fiber optic system. It provides overviews of the typical topologies available and information that should be considered during a review of the system requirements.

3.1 System Requirements

To begin the process of system design, it is necessary to capture system requirements information for the application. All of the following information is important:

1. Topology
    a. Number of nodes (pieces of equipment) on the network
    b. Physical location and separation of the nodes
    c. Connectivity requirements of each node
    d. Installation breaks (connectors) between nodes
    e. Constraints on routing of the links between nodes (practical installation)
    f. Specific network protocols in use (protocols can constrain the physical layer topology)
2. Data Flows
    a. Bandwidth requirements
    b. Criticality of the data (and required link redundancy)
    c. Specific network protocols in use (can influence selection of active devices)
3. Future Proofing
    a. Design of the system to allow for predictable upgrades

With these requirements identified, the designer can then begin the process of system design, i.e., defining the best way to transmit the data while maintaining a cost effective, reliable, and robust network.

3.2 Introduction to Network Topologies

A topology defines the method in which the physical elements of the network (e.g., cable, connectors, and equipment nodes) are connected together.

There are a number of physical fiber optic topologies that are available to the system designer. The choice is driven by the characteristics required of the resulting network and is linked to the communication protocol to be used, component performance, and physical distribution of the system elements within the airframe.

3.2.1 Link Configurations

Fiber optic links can be divided into two distinct classes: those that provide a "dedicated" connection between two systems and those that offer the use of a shared medium.

3.2.1.1 Point-to-Point

The simplest topology involves a direct connection between a source or transmitter and a receiver or sinks (Figure 3-1) over which private communications can occur in one direction. To provide two-way communication, a second, separate link is required (Figure 3-2).

Figure 3-1 – Basic Point-to-Point Topology

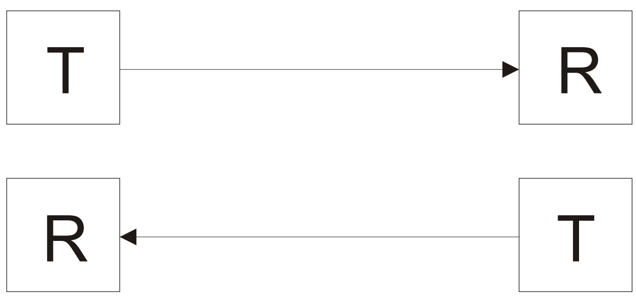


Figure 3-2 – Two-Way Communication Using Point-to-Point Links

3.2.1.2 Point-to-Multi-Point (Splitter)

It may be advantageous in a system to provide additional connectivity from a single source to two or more sinks. This can be accomplished by providing a device to split the signal according to a defined ratio, as shown in Figure 3-3. In a fiber optic system, splitting can be achieved using bulk optics, fiber-based splitters, or integrated optics. Additional receivers can be linked into the system without causing problems to the existing terminals other than the reduced power due to additional splitting. Communication still occurs in one direction.

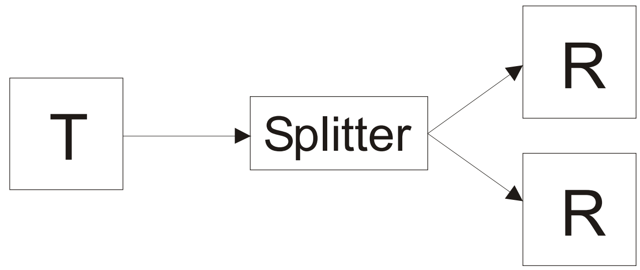


Figure 3-3 – Splitter Used to Distribute Signal to Two Receivers

3.2.1.3 Bidirectional Point-to-Point Link

Splitters can also be used to provide two-way communications over a single fiber optic cable between two terminals by incorporating a splitter in or near each terminal equipment, as shown in Figure 3-4. Each transmission is private because the reflections from the terminal equipment's own transmitter into its receiver created by the splitter are designed to be overcome by the power level from the transmitter in the other equipment. This particular arrangement is only possible when two transmitters are present within the system, as further transmitters would require a shared medium protocol to be established. Additional receivers can be linked into the system at either splitter, without causing problems to the terminals undertaking two-way communication, but they will only see the transmission arriving at this splitter from the other equipment.

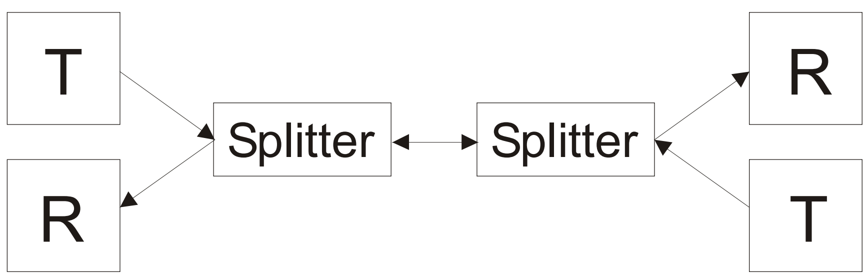


Figure 3-4 – Two-Way Communication Using Splitters

3.2.2 Basic Topologies

Basic topologies can be broken down into four distinct types: Star, Bus, Ring, and Tree.

3.2.2.1 Star

Star topologies provide a technique for providing communications between numbers of nodes via a "hub" (Figure 3-5).

In fiber optic applications, a passive device can be used as a hub and is capable of splitting one or more input signals and output them to one or more receivers.

This passive device is commonly known as a star coupler and can provide a shared broadcast medium for all of the terminal equipment connected to it.

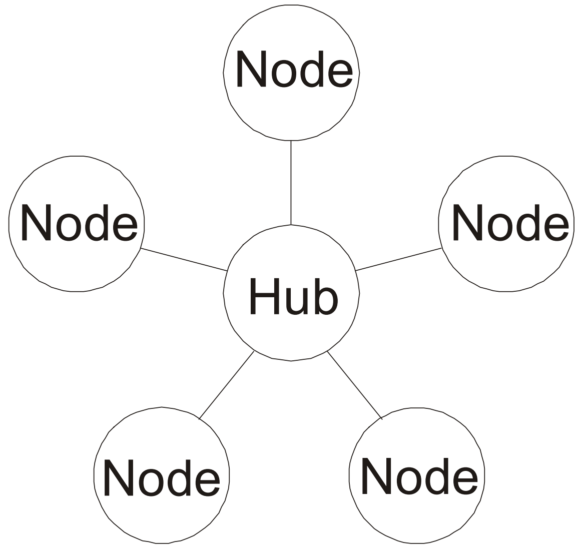


Figure 3-5 – Star

A star coupler consists of a mixing element to which input and output fibers are connected; therefore, a simple single star coupled topology will produce a system with path losses very similar to each other.

Stars may be either active or passive, and two types of passive fiber optic stars are transmissive and reflective.

3.2.2.1.1 Transmissive Star

A transmissive star, see Figure 3-6, incorporates separate input and output fibers connected to opposite ends of the mixing element. Inputs from each piece of equipment use half the fibers; these inputs are mixed and returned along separate fibers. Thus, each piece of connected equipment does not need a splitter, as the transmitter and receiver are connected to separate fibers. It is also worth noting that with careful design, this star coupler can be operated in a bi-directional manner, i.e., signals can be transmitted in either direction through the device.

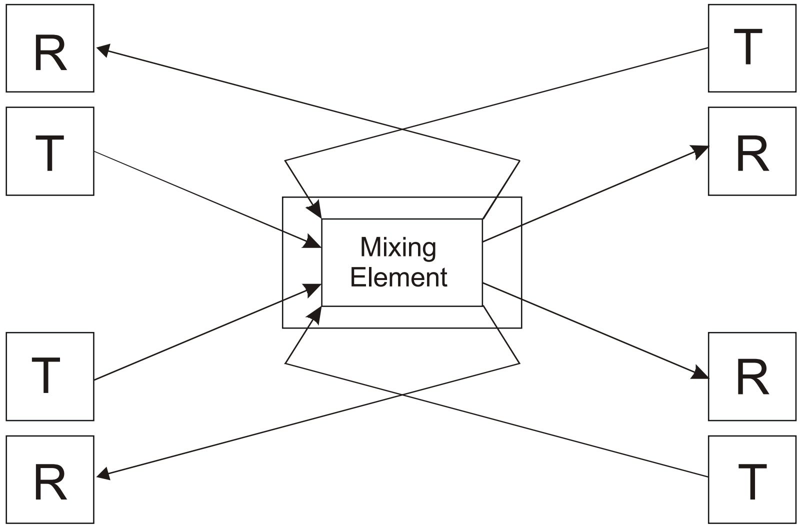


Figure 3-6 – Single Transmissive Star

3.2.2.1.2 Reflective Star

A reflective star coupled topology is similar to a transmissive star except that a reflecting device is attached to one end of the mixing element and the optical signal travels in both directions along the optical fibers. Inputs on all fibers are mixed and reflected back to the fibers to return along all the same fibers. This arrangement requires a splitter at each of the terminals (as in the bi-directional point-to-point link) if they are to both transmit and receive data, as shown in Figure 3-7. Alternatively, the fibers may be used individually for transmission and reception, as shown in Figure 3-8, or a combination of both.

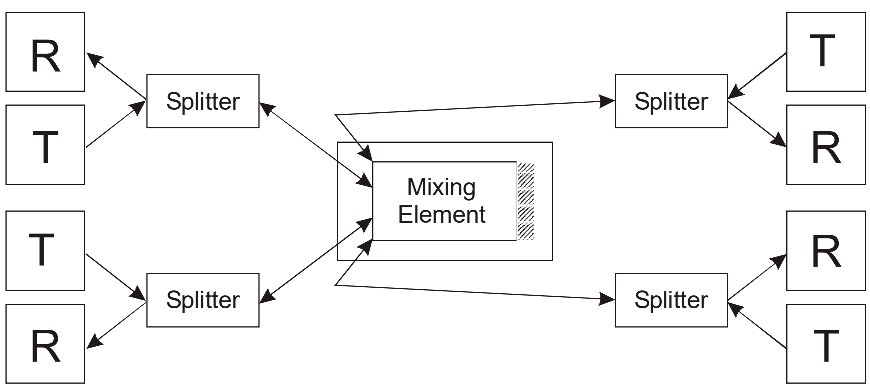


Figure 3-7 – Reflective Star Coupled Topology with Bidirectional Links

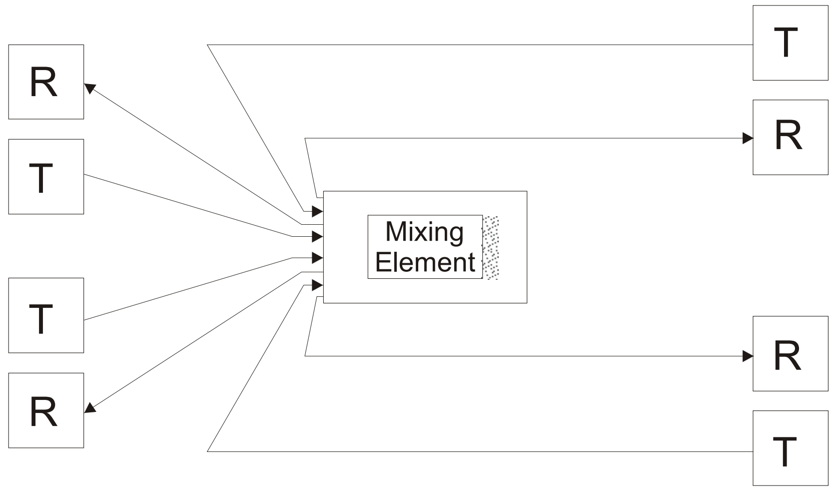


Figure 3-8 – Reflective Star Coupled Topology with Unidirectional Links

3.2.2.1.3 Multi-Local Star

A multi-local star topology can be constructed by interconnecting either transmissive or reflective star couplers. Careful consideration of multi-path effects must be considered in the reflective system. It is also important to consider the path loss differences that are created when a signal arrives at a receiver having traversed one-star coupler or having traversed multiple star couplers. The topology also requires receivers with sufficient dynamic range to cope with the extremes of received optical power. Transmissive star couplers may be used in several multi-star configurations.

3.2.2.1.4 Distributed

The principal of distributed multi-star topologies is that the stars interconnect with a number of other stars (Figure 3-9).

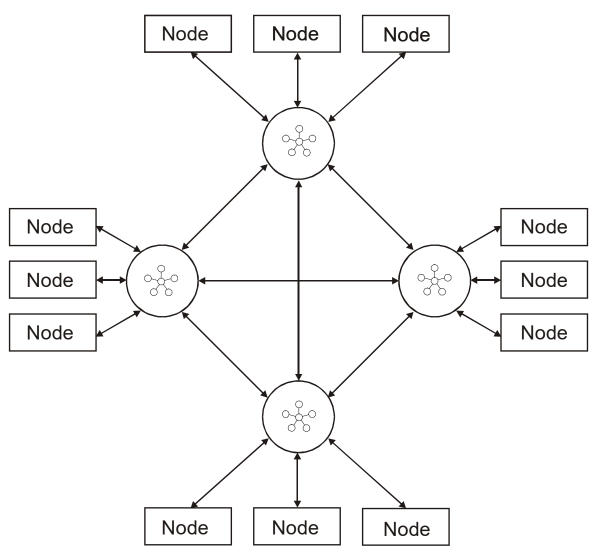


Figure 3-9 – Multi-Local Distributed Star Topology

3.2.2.1.5 Local-Central

The principal of local-central topologies is that one star is used to interconnect the other stars (Figure 3-10).

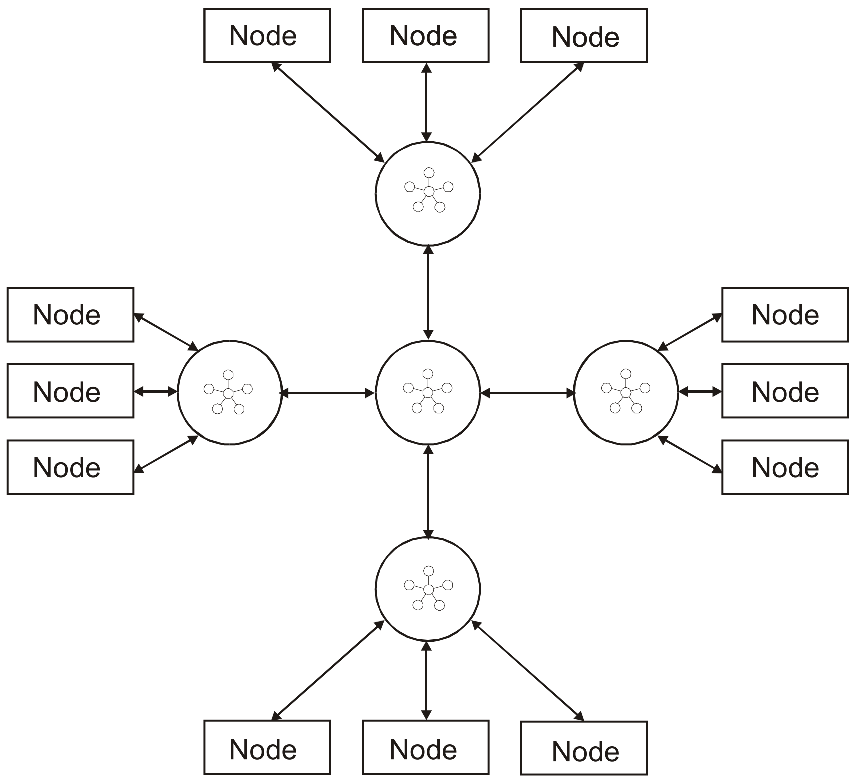


Figure 3-10 – Basic Multi-Local/Central Star Topology

3.2.2.2 Bus Topology

A bus topology connects each node to an optical backbone (bus) that accepts the transmitted signals and broadcasts to all other nodes. Only one node can “talk” to the bus at any one time.

A bus topology can be designed as a regular bus (Figure 3-11) where the nodes connect directly to the bus or local bus where each node is “daisy chained” to the next node (Figure 3-12).

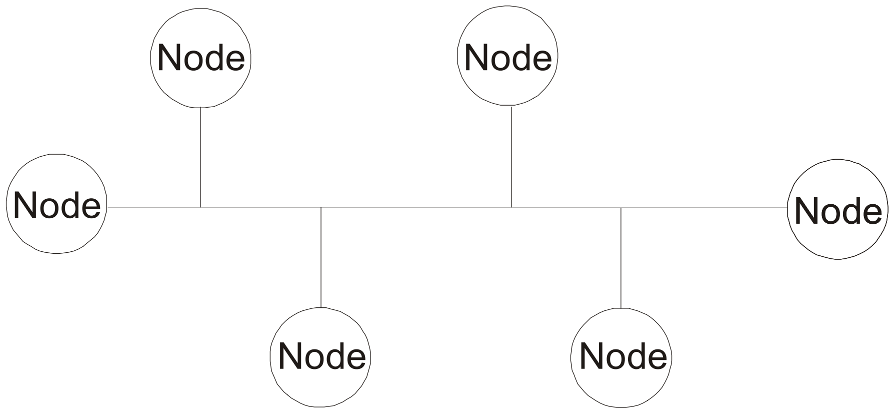


Figure 3-11 – Regular Bus

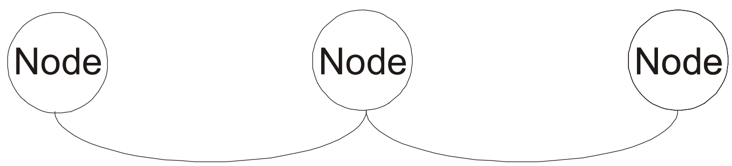


Figure 3-12 – Local Bus

The main advantages of a bus topology include:

- Failure of a single node does not affect other nodes (regular bus).
- Shared media reduces amount of cabling.

Disadvantages of a bus topology include:

- Limited number of nodes and cable length.
- Performance degrades with an increase in nodes: optical signal needs to be split between more receivers and inter-transmission dynamic range increases.
- A break in the backbone can disable the network.
- Bus couplers (regular bus) not simple to implement optically.
- Requires protocol to control access to shared media physical layer.
- Redundancy requires a duplicate network.

3.2.2.2.1 Tee

Unlike electrical systems, an optical signal cannot be inserted via a stub on to a linear bus by simply attaching the stub to the bus. Each source and sink must have a bus coupler device, which incorporates three optical splitters, as shown in Figure 3-13. If optical power is to be launched on to the main bus to both the left and the right (as for an electrical bus), the stub must be split into two. One splitter output must be passed through a combiner to launch the power to the right, and likewise for the left. If a single stub is used to transmit and receive, another splitter/combiner is required at the terminal.

Whenever splitters are used, optical power is divided. In addition to this division, power is also lost at the splitters/combiner connectors and at any other connectors present along the signal path.

This power loss, together with the division of power, places a practical limitation on the number of nodes that can be connected to the linear bus; in addition, the lengths of the patch cords and number of interconnects also contribute to the overall losses. The maximum size of this topology is limited by the worst-case path loss between the transmitter at one end of the bus and the receiver at the other end. There is also a requirement for a large dynamic range for each receiver so that it can decode the weakest signal from the most distant transmitter followed by a signal from its own transmitter (inter-transmission dynamic range).

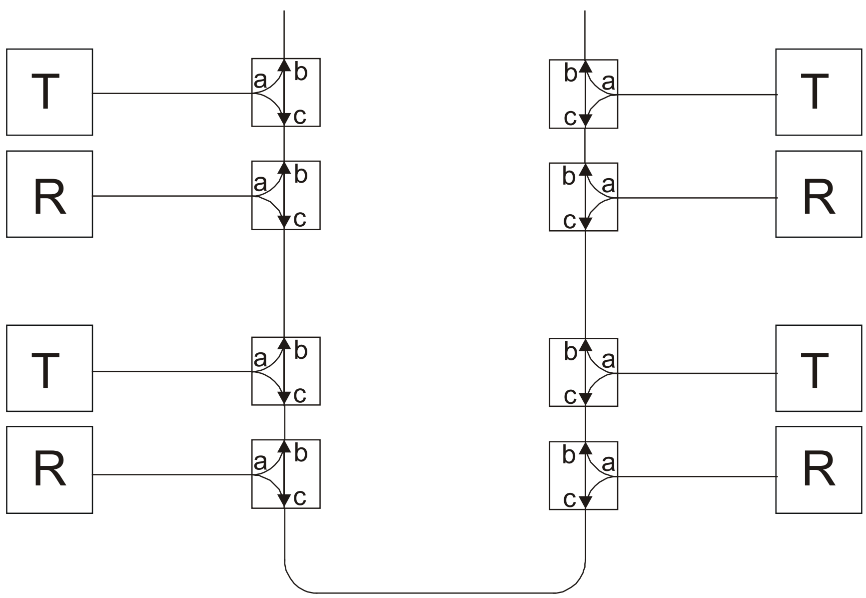


Figure 3-13 – Tee Bus Topology

3.2.2.2.2 Unidirectional

To overcome some of the drawbacks of the Tee bus, it is possible to form unidirectional buses with separate transmit and receive paths. See Figure 3-14. This also allows a hybrid approach to be adopted, where multiple transmit paths are connected to a transmissive star to mix their signals and output them to the receive paths. The advantage of this over the simple transmissive star is the reduced fiber required and reduced complexity of individual components (i.e., a smaller star). The disadvantage is increased losses due to more optical elements in the path. This topology is especially appropriate with the use of optical amplification between transmit and receive paths.

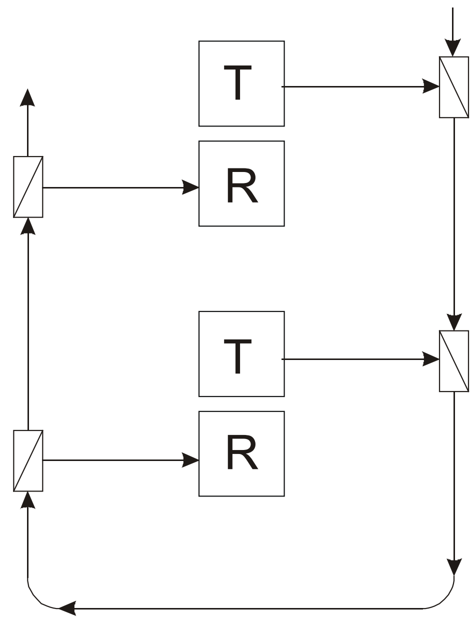


Figure 3-14 – Unidirectional Bus Topology

3.2.2.3 Ring

In a ring topology, all devices are connected to one another in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side of it. See Figure 3-15.

A ring topology can be formed from point-to-point links connecting the terminal equipment, where the optical signal is converted into an electronic format before passing the data into the terminal or relaunching it onto the next terminal equipment if the data is not for its own use. The terminal equipment could contain a bypass (either a switch or a passive splitter) to provide a fail-safe method to maintain the ring in the event of a failure of the terminal.

This approach requires the use of a protocol optimized for this topology (e.g., token passing or register insertion).

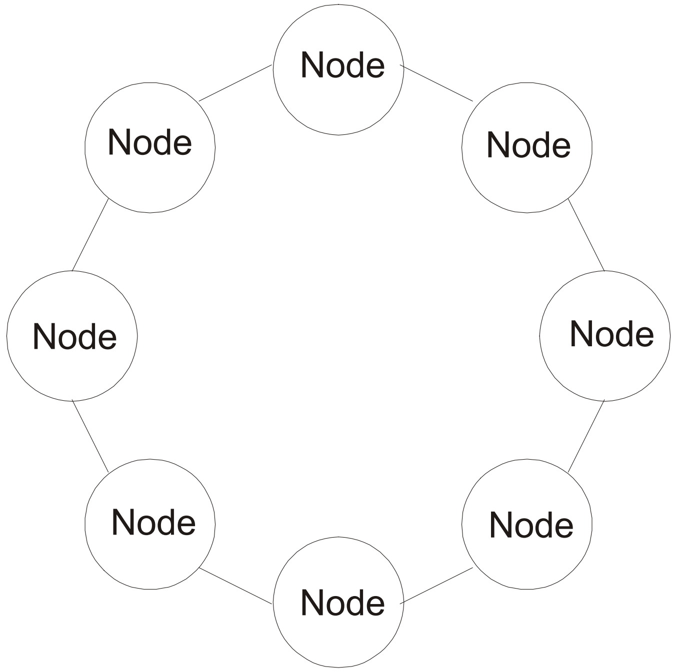


Figure 3-15 – Ring Topology

3.2.2.4 Tree

In a tree topology, not all nodes are the same. All communication between nodes must pass through the node at the base of the tree. All communication from the base node (downstream) is broadcast to the other nodes. A protocol is required to ensure that nodes communicating upstream do not access the shared media at the same time. This topology is useful when a large amount of information needs to be broadcast but the upstream data requirements are limited (asynchronous data flow).

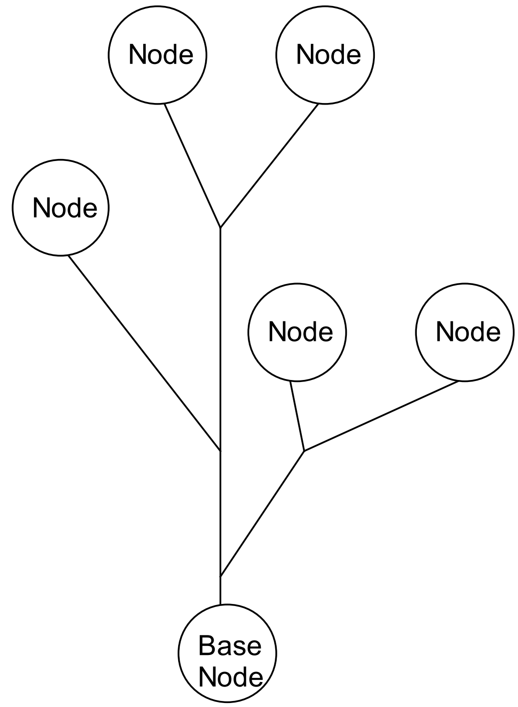


Figure 3-16 – Tree Topology

3.2.3 Expanded Topologies

3.2.3.1 Multiple Point-to-Point: Mesh

Using multiple basic point-to-point links (Figure 3-1), it is possible to define an extended topology where information is transferred between the links by the terminal in order to reach the final destination. This is called a mesh network (Figure 3-17), and routing decisions are made at each terminal traversed for which link should be used next. A protocol needs to be defined in order to route the information. This type of network usually works on a “store-and-forward” basis, where the terminal receives the whole message before passing it on to the next terminal. This provides a very resilient network, but at the cost of high connectivity requirements and increased node complexity.

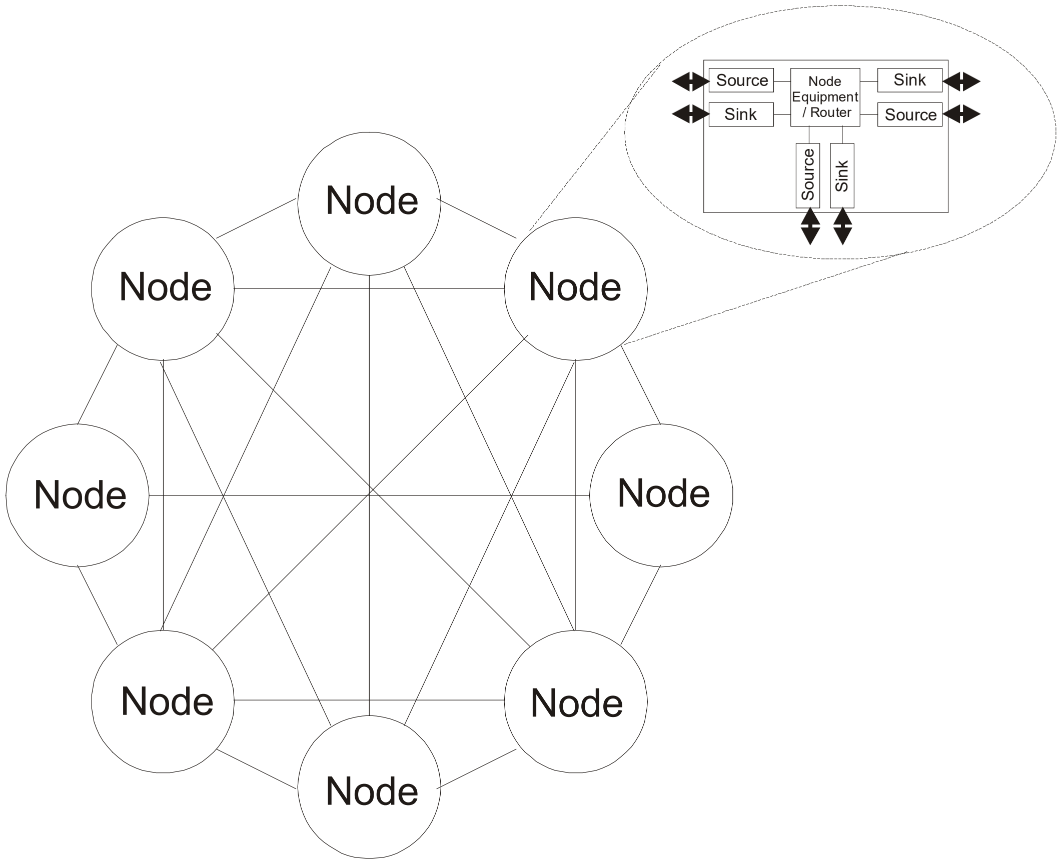


Figure 3-17 – Mesh Topology

3.2.3.2 Multiple Point-to-Point: Crosspoint Switched Links

An alternative topology is to provide re-arrangeable point-to-point links, Figure 3-18, provided by a switch physically connecting input and output pairs in a transparent manner. A number of optical technologies exist to provide switching of this kind, although the number of ports on the switch and/or the number of switches, which can be strung in series, is limited by the source-sink power budget and the losses through the switches. The rearrangement of the input-output pairs is carried out by external means. The time to switch the routing is, depending on the technology employed, in the region of 1μs to 10 ms.

An extension of this topology is to have the routing switched according to information contained in the header of the transferred data rather than by some external means, i.e., packet switching. The major drawback is handling of incoming transfers for which the required output is not currently free, i.e., optical buffering. Such switches are not normally constructed with passive optical paths (all-optical switching), but make use of hybrid electro-optical techniques (see Section 3.2.4.). All-optical packet switches have been under development for some time but their maturity is such that they would be unlikely to be considered for aircraft networks.

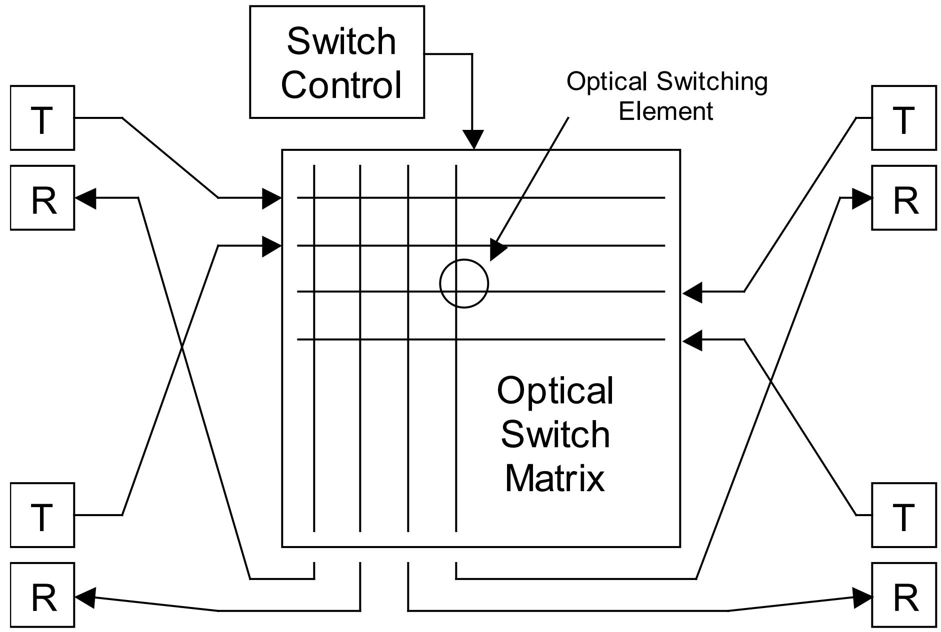


Figure 3-18 – Crosspoint Switched Optical Link

3.2.4 Active Element Topologies (Including Packet Switching)

Due to the power sharing and excess losses of splitters/combiners and passive stars, some configurations are quite demanding with respect to the path loss capability of the transmitter-receiver pair. These losses can be overcome through the use of active regenerative elements in the system, which may also provide retiming of the signals. The use of active elements can also reduce the dynamic range requirements of receivers, by balancing the signal strengths at each point in the system.

There are three basic types of active elements that can be used: optical amplification, signal regeneration, and regeneration/retiming. Each of these has particular uses in different topologies, as described below. Consideration must be made of the effect on the timing of the network, both absolute and differential (i.e., jitter) latency, when including regeneration and retiming.

3.2.4.1 Optical Amplifiers

Optical amplifiers are typically based around Erbium doped single mode fibers together with a 980 or 1480 nm pump laser and provide wideband amplification of optical signals through stimulated emission triggered by the incoming signal. They can be used in most topologies to simply increase signal levels or balance dynamic range, as appropriate. An example of its use in a unidirectional bus is shown in Figure 3-19.

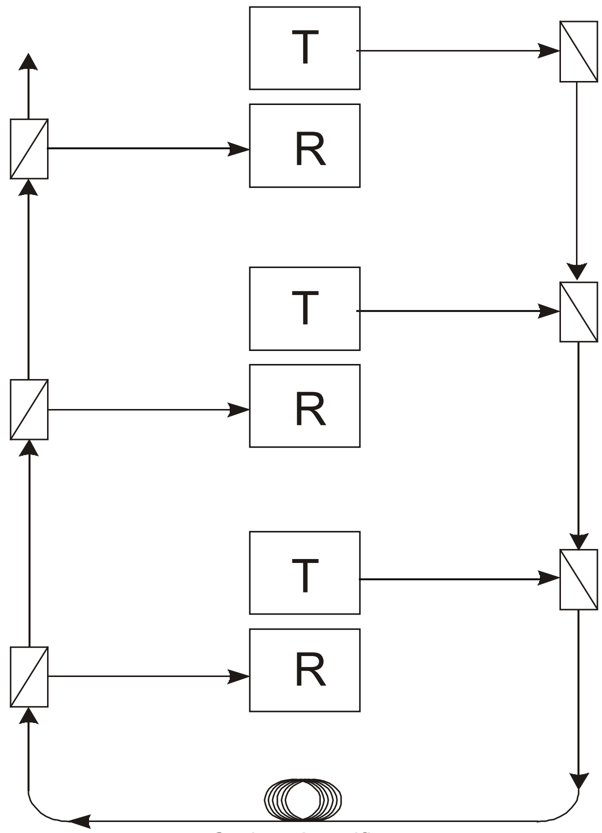


Figure 3-19 – Use of an Optical Amplifier in a Unidirectional Bus

3.2.4.2 Signal Regeneration

The received fiber optic signals are converted to electrical signals and input to fiber optic transmitters. It is typically used in transmissive star couplers (Figure 3-20), Tee buses, and for switched links. All electrical activity is internal to the device. The disadvantage of this approach is that the active star coupler contains active power elements that may be susceptible to EMI or “EMC problems” and present additional reliability problems (increased component count always leads to reduced reliability); system timing margins may be also affected. An advantage is that there are still many functions that can be performed more effectively in silicon. For example, Figure 3-21 shows signal regeneration in Crosspoint-switched links.

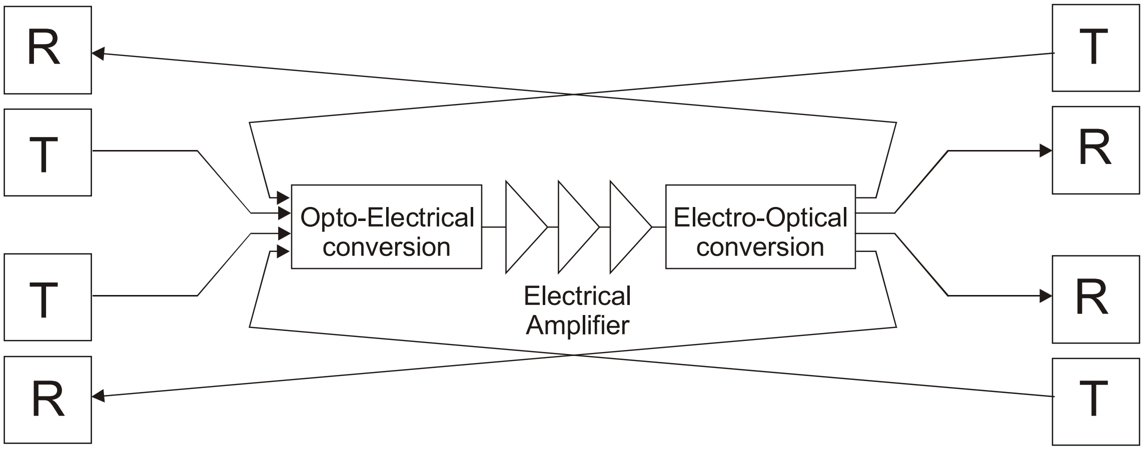


Figure 3-20 – Active Star Technology

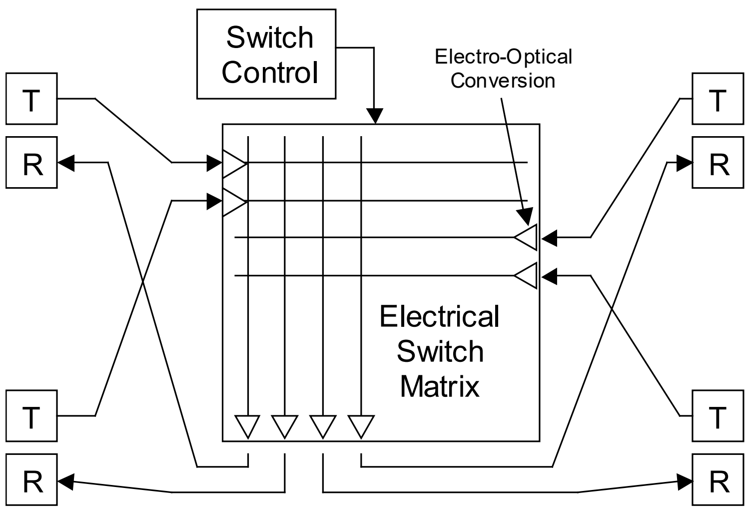


Figure 3-21 – Regenerative Crosspoint Switch Topology

3.2.4.3 Signal Regeneration and Retiming (Including Packet Switching)

In this approach, the protocol of the network is also involved to retime the signals for onward transmission. Although this can be applied to star couplers, it is most widely used when switching data transmission frames in a packet-switch (Figure 3-22). In fact, of all the topologies described above, the regenerative switch, or switched fabric network, is by far the most widely used in commercial networks with a huge installed base of switched Ethernet, Fiber Channel, and Asynchronous Transfer Mode (ATM) packet switched networks already employing them. In addition, the newer backplane and system area network technologies, (i.e., InfiniBand and PCI Express), will expand their use into other application areas.

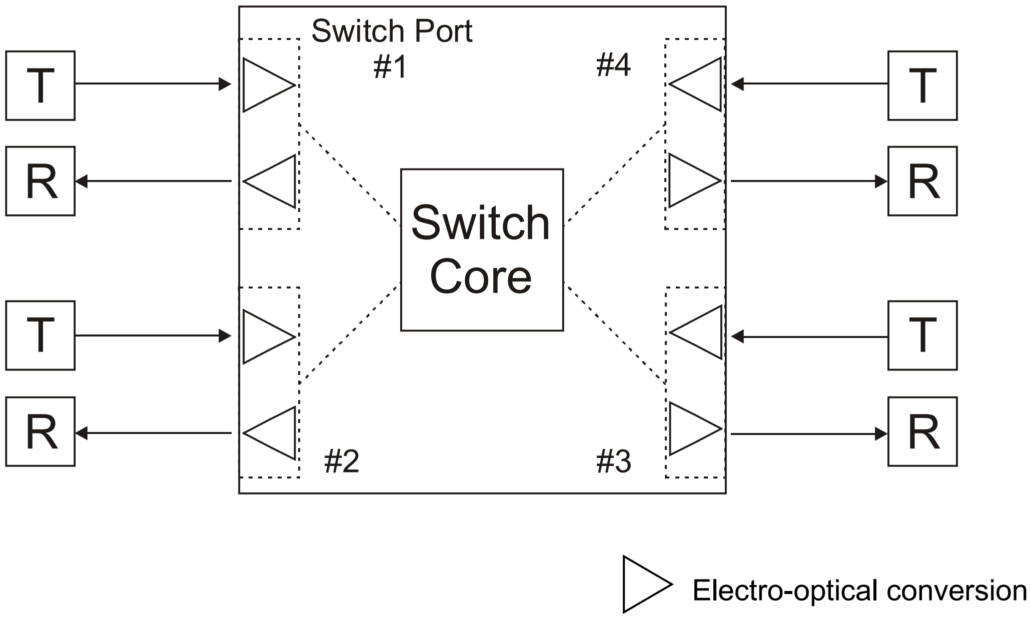


Figure 3-22 – Packet Switch Topology

The implementation and use of packet switched networks has been driven predominantly by the need for increased bandwidth and scalability. They allow aggregate bandwidth to be increased compared to shared-media networks, as multiple data paths can be operated through the switches simultaneously, and extensible networks can be deployed that allow the easy addition of end points and switches. The use of optical links also allows greater link distances to be achieved compared to electrical links. As each link is only point-to-point, the requirements (e.g., dynamic range) on the active components are also reduced, allowing faster devices to be produced.

4.0 SYSTEM DESIGN

4.1 Topology Selection

Fiber optic implementation places more responsibility on the system designer than their electrical equivalent. Terminal input/output characteristics, cable and connector definition, and bus topology are all the responsibility of the system designer. Topology refers to the overall physical geometric layout of the terminal interconnection scheme, and includes stars, rings, linear buses, and other options described in the previous section. A complete system may comprise of a mix of topologies.

A number of decisions and selections may have to be made with respect to the system design that will have an effect on a number of issues, such as manufacture, test, integration, repair, maintenance, expansion, and cost. The system designer should be aware that while a particular selection may be beneficial, it may impact on the system in other areas; therefore, careful consideration must be made when making design decisions.

In all applications, the topology must be compatible with the transmission protocol. A protocol is a formal set of conventions governing the formatting and relative timing of message exchange between two communicating systems, or network. The protocol ensures that each end understands the rules and can interpret the transmitted data while the logical element defines what the information flow is. Low-level protocols define physical standards to be observed, e.g., bit and byte-ordering, transmission, error detection, and correction of the bit stream. High-level protocols address data formatting, including the syntax of messages, terminal to computer dialogue, character sets, sequencing of messages, etc. In some situations, selection of the transmission protocol may be at the discretion of the system designer, but in others, it may be stipulated as a system requirement.

The key characteristics of the topologies discussed that could influence selection are summarized in Table 4-1.

Table 4-1 – Topology Characteristics

Topology	Advantages	Disadvantages	Notes
Point-to-point	Simple implementation	No multicast capability. No shared media – increased number/weight of physical layer components.	Use for dedicated, high-bandwidth links (e.g., video data to displays).
Passive Star	Immediate sharing of information – broadcast medium. Redundant bus increases availability.	Topology based on single star vulnerable to single point-of-failure (low probability for passive star component). No way to remove node from network.	All optical broadcast – useful if minimal latency is desired. Multi-star arrangement can be partially fault tolerant.

4.0 SYSTEM DESIGN

Topology	Advantages	Disadvantages	Notes
Bus (Shared Media)	Failed nodes can be isolated. Share media reduces amount of cabling.	Limited number of nodes and cable length. Performance degrades with increase in nodes. A break in the backbone can disable the network. Bus couplers (regular bus) not simple to implement optically. Requires protocol to control access to shared media physical layer.	Direct replacement for electrical bus. Consider passive star as alternative (requires greater total cable length but simpler to implement).
Ring	Effectively a broadcast medium. Dual rings can provide fault protection. Minimal physical components to interconnect nodes.	Requires node bypass else node becomes single point-of-failure.	Alternative to packet switch if amount of cabling is an issue.
Tree (Point-to-Multipoint)	Sections of shared media – reduces number/weight of physical layer components.	No way to remove faulty node from network. Not efficient for node-to-node communication.	Useful for asymmetric data or broadcast e.g., distribution of high bandwidth sensor information to multiple nodes.
Multiple Point-to-Point (Mesh or Crossbar)	Failure Resilient	Resilience at cost of increase number/weight of physical layer components.	Useful for highly critical applications or distributed processing. Not widely implemented.
Packet Switched	Data can be single destination, multicast or broadcast. Can isolate faulty nodes. Extend network with additional switches. Network control (routing and traffic policing) within switch.	Switch becomes single point-of-failure. Electro-optical conversion and packet buffering introduces latency.	Full-duplex packet switched networks can handle large amounts of data. Routing capability opens up new possibilities for network design.

The systems designer should decide whether to use active or passive couplers/stars, point-to-point transfers with bi-directional or unidirectional data paths, or multiplex buses. The decision will be based on system requirements, the state of fiber optic technology, power budget considerations, cost, and the physical location of equipment to be interconnected.

4.2 Power Budget

The task of compiling maximum and minimum accumulated losses from transmitter to receiver is known as power budgeting and is most easily calculated in dB.

The simplest method is the loss summation technique where the sum of all individual losses between transmitter output and receiver input are computed including connector losses, fiber losses, splitter division, “excess” losses, and power penalties. Worst-case connector losses include the effects of misalignment and a practical level of contamination. Additional losses from fiber ageing, installation, repair, etc., are also included under “other losses.” Contingencies for these effects are reviewed elsewhere in this report. Losses should be tabulated for “worst-case” and “best-case” attenuation values for each signal path element from transmitter to receiver, taking into account the intended optical source wavelength and launch profile (which will have a large effect on the losses through components). The difference between the worst-case and best-case values added to the likely differences in transmitter output power will determine the dynamic operating range requirement of the receiver.

Although relatively simple to undertake, the use of worst-case losses with this loss summation technique is likely to overestimate the loss for the short-haul harnesses or links typical of aircraft installations and could put unnecessary constraints on the system design. For example, components could be over-specified or the number of in-line connectors that can be used could be compromised. A number of other techniques exist that allow a more realistic link loss to be calculated. Instead of representing the optical loss by a single parameter (the insertion loss), a matrix representation of the optical power distribution can be used. Components in the link are then characterized by what effect they have on this distribution to measure how a component alters it or is influenced by it. This technique could also be used within a computer model to undertake ray tracing calculations through the optical components that comprise the installation, and predict the optical power distribution at any point. The Fiber Optic Systems Handbook – Part 2: Test and measurement (EN 4533-002) discusses these techniques in more detail.

A statistical approach to link loss calculation (using statistical distributions for connector loss rather than worst-case) can also give more realistic predicted link loss values.

4.2.1 Receiver Sensitivity

Perhaps the most important factor in the performance of an optical system is the characteristic of the optical detector and its associated pre-amplifier, since noise introduced at this point will limit receiver sensitivity.

Even for the hypothetical case of a noiseless optical receiver, a certain minimum power is required to achieve a low error rate. Due to the statistical uncertainty of electron generation at the detector from an incident optical field, this minimum power is greater than one photon per pulse. In order to achieve a BER of 10^{-9}, an ideal direct detection receiver requires a mean receiver power per pulse equivalent to about 21 photons. As a direct consequence of this “quantum limitation,” an ideal detector requires a mean receiver power proportional to the bit rate (21 photons x bit rate in bit/s x duty cycle expressed as a percentage). For a 50% duty cycle, the quantum limit may be expressed as about 10 photons per bit (note that half the bits are pulses). For peak power limited systems, this value cannot be bettered. As the energy per quantum is proportional to the carrier frequency of the carrier, longer wavelength systems have a lower quantum limit.

Direct detection receivers are limited by other sources of noise: thermal and FET noise in PIN-FET receivers and both thermal and multiplication noise in Avalanche photo detectors. At 1550 nm and at speeds between 50 Mbit/s and 500 Mbit/s, the very best receivers have a sensitivity of about 1000 photons per bit, i.e., 20 dB worse than the quantum limit. At lower bit rates, dark current in the photo detector becomes the dominant noise source: below 1 Mbit/s, the sensitivity is largely independent of bit rate. Figure 4-1, originally produced in the context of long haul telecommunications on single mode fiber at 1550 nm, is a graph whose axes are log bit-rate horizontally and log optical power vertically. The lower of the diagonal lines represents the quantum limit to sensitivity, the absolute minimum power required at the receiver to achieve one error in 10^{-9} bits.

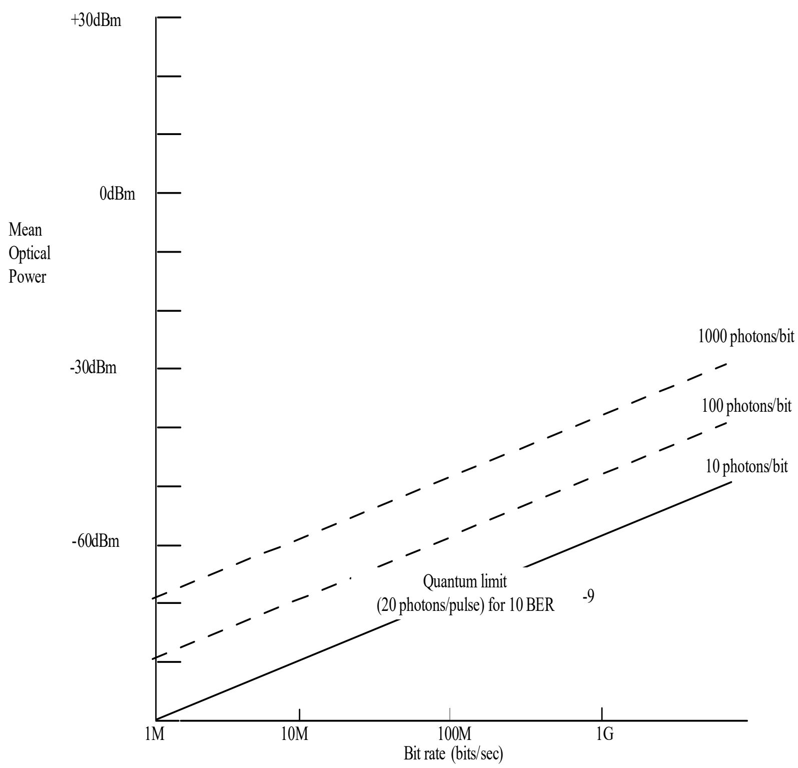


Figure 4-1 – Power Limits in Optical Systems at 1550 nm

Digital modulation is used because the error rate rapidly becomes negligible once the signal is significantly larger than the noise. This is demonstrated by the curve in Figure 4-2, which shows the bit error rate (or more correctly bit error ratio) versus electrical signal/rms noise ratio. Most telecommunications systems require a BER of 10^{-9} or better, which is produced from an electrical signal noise ratio of about 22 dB. It is to be noted that for only a 2-dB improvement in electrical signal/noise ratio (equivalent to a 1 dB increase in received optical power), there is a corresponding improvement in BER of more than three decades in the sensitivity region of 10^{-9}.

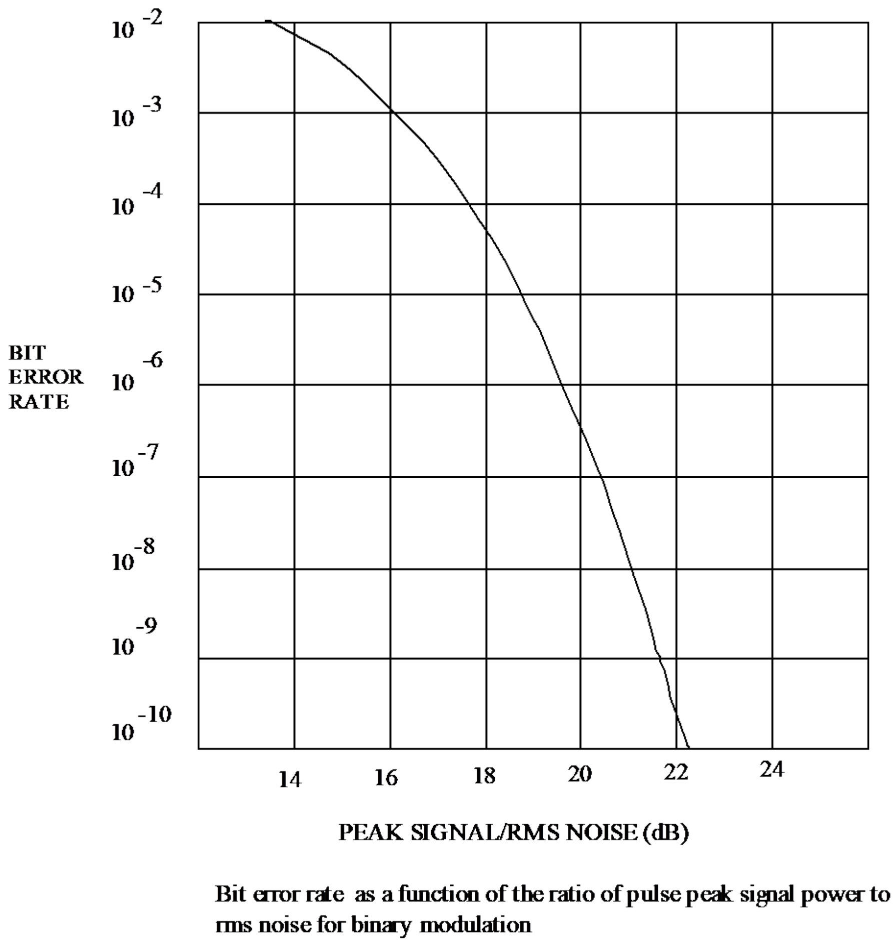


Figure 4-2 – Bit Error Rate versus Peak Signal/rms Noise (dB)

4.2.2 Receiver Operating Range

The operating range is based on the range of optical power likely to be experienced at the receiver input due to path loss differences, maximum permitted variation of transmitted power, etc., and should also include a margin. The operating range will usually extend upwards from the minimum input power necessary to achieve the required BER.

Consider the system segment based on a passive 8 x 8-way transmissive central star coupler, shown in Figure 4-3. Minimum and maximum attenuation values are assigned in Table 4-2. These will be used to assess operating range, sensitivity, and intertransmission dynamic range requirements of the receiver.

The operating range for this receiver would be:

Path loss difference (36 - 9.6) = 26.4 dB

Transmitter power range, e.g., 3.0 dB

Margin, e.g., 3.0 dB

32.4 dB

The 3-dB optical transmitter power range allows for temperature, ageing, and set-up.

Generally, a maximum “safe” power input will also be specified, above which damage may be caused to the receiver. The receiver should recover within a specified period of time from any saturation that exceeds the operating range but is less than or equal to the maximum safe power input. In most systems, this maximum safe power input would never be reached, as the transmitter power is limited to comply with eye safety regulations.

Note: Definitions of receiver operating range, sensitivity, etc., should accord with the glossary of terms.

4.2.3 Sensitivity

Assuming a value for minimum transmit power of -5 dBm, the minimum sensitivity required is:

- 5 dBm - 36 dBm = - 41 dBm

Note: This sensitivity requirement must be met over the entire temperature range and life of the receiver.

The values given in Table 4-2 are for example only. Except for the 1:8 ideal splitting reductions, all values shown are subject to some judgment 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 dB to 32 dB. Receiver minimum operating range requirements would be reduced to 27.4 dB, and receiver sensitivity would now be -37 dBm. Other passive topologies may have bigger loss differentials due to signal path differences.

COMMENTARY

The values for connector loss given in the above example are not representative of the current generation of connectors specified for aviation use that are defined in ARINC Specification 801.

The designer must assign a value for connector losses, which takes into consideration fiber core size, Numerical Aperture (NA), connector alignment, keying, contamination, the number of mate/demate cycles, etc. When calculating connector losses, it must be remembered that connections may be required at the transmitter or receiver, at a motherboard/daughterboard connector in a card cage, and at the back of an LRU. Refer to ARINC Report 804 for a detailed description of typical optical losses encountered internal to LRUs.

Often the ultimate limit is the receiver sensitivity, so the system designer may need to take the opposite approach and add the link budget to the receiver sensitivity to get a desired transmitter power.

Table 4-2 – Typical Path Loss Calculations for Central Star Topology

Component	Max loss (dB) [4]	Min loss (dB) [4]
Transmitter[1]	2 dB	0.2 dB
Output connector[1]	2 dB	0.2 dB
1st Bulkhead connector	2 dB	0.2 dB
Star Input Connector[2]	2 dB	0.2 dB
1:8 Splitting Loss (9 dB ideal)	11 dB	7 dB
Excess loss in 8x8 star	3 dB*	1 dB*
Star output coupler	2 dB*	0.2 dB*
2nd Bulkhead connector	2 dB*	0.2 dB*
Input connector[1]	2 dB*	0.2 dB*
Receiver	2 dB*	0.2 dB*
Overall cable loss	0 dB*	0 dB*
Other losses[3]	6 dB*	0 dB*
Total loss	36 dB	9.6 dB

Notes:

1. Normally included in the LRU specification.
2. In an ideal 1xN way coupler, the sum total power in the output fibers will equal the power in the input fiber. Therefore, the power in any individual output fiber will be $\frac{1}{N}$ of the input power. In practice, the total output power will be less than at the input; the ratio of $\frac{\text{input power}}{\text{total output power}}$ is termed the "Excess Loss."

   $$\text{Excess Loss} = 10\ \text{Log}_{10} \frac{P_{in}}{\sum P_{out}}$$

3. A practical coupler will also suffer an unequal division of power to all output fibers; this is referred to as port non-uniformity. Here, for example, the max/min splitting loss of the coupler is taken to be 11 dB and 7 dB, respectively.
4. "Other losses" are included to allow for such effects as ageing, temperature, repair, power penalties, and other contingencies.
5. Losses in the common path between the star coupler and any given receiver should, to all practical purposes, remain constant from one message to the next. These losses, shown *(17 dB and 1.8 dB) in Table 4-2, should be deducted from the maximum and minimum path loss when computing a figure for Intertransmission Dynamic Range (IDR).

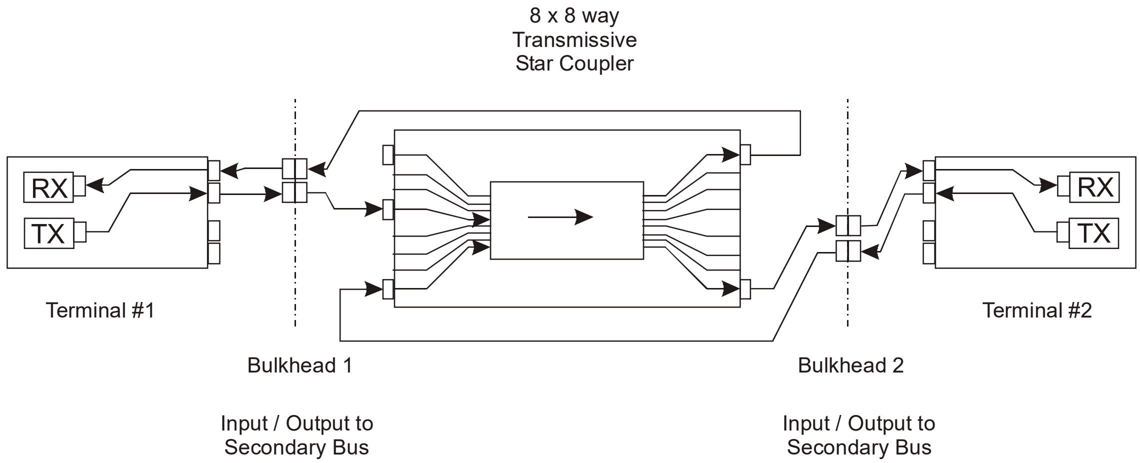


Figure 4-3 – Transmissive Central Star

4.2.4 Receiver Intertransmission Dynamic Range

IDR, as seen at the input to any given receiver, is the ratio of the largest-received signal to the smallest-received signal for adjacent messages from different terminals and occurs due to differences in path loss and transmitted power. It is necessary that the receiver should be capable of recovering full sensitivity following the largest expected signal within the minimum intertransmission time. Obviously, this IDR is not applicable in a point-to-point topology.

4.2.4.1 Single Star

Losses in the common path between the star coupler and any given receiver should, to all practical purposes, remain constant from one message to the next (see Table 4-2, Note 4). It will be noted that coupler excess loss has been included among the common losses, and for convenience, losses listed under the heading “other losses” are assumed to be in the common path between the star coupler and the receiver and have been bracketed in with the other common losses. Normally these “other losses” will be distributed throughout the interconnect and a more formal computation should allow for this. Assuming a value of 3 dB, as before, for the maximum difference in transmitter output powers, the IDR for the central star configuration example at the input to a given receiver will have a maximum value of:

(36 - 17) dB - (9.6 - 1.8) dB + 3 dB = 14.2 dB

Again, when specifying a value for receiver IDR, it is usual to add a margin, say about 2 dB; in this case, the required IDR capability of the receiver would be 16 dB.

It is to be noted that optical reflections, which occur at all fiber/air, air/fiber interfaces, will have a modifying effect on the above computations. The effect will be small for the transmissive central star configurations where separate transmit and receive fiber link each terminal to the star. However, a reflective star configuration employing a bi-directional link has a Y splitter at each transceiver and reflections at any connector or discontinuity in the bi-directional path will result in some of the transmitted power being reflected back into that terminal's receiver. This reflected power might increase the IDR requirement for receivers used in a "reflective" central star configuration compared with that for the corresponding "transmissive" central star arrangement.

4.2.5 Optical Power Penalties

All of the losses described above cause a loss of average optical power. However, there are other processes that cause losses in modulation of a signal, i.e., decrease the signal-to-noise ratio, for example, modal noise, and back-reflections. These factors become more important at higher data rates where a loss of modulation can increase the bit error rate. These processes can be overcome by increasing the optical power in the link so it can effectively be treated as an additional loss when calculating link budgets. They are cumulatively referred to as "power penalties."

4.3 Multiplexing Wavelengths

Currently, many aerospace applications utilize fiber optic technology for fairly simple point-to-point single wavelength systems; however, with the ever-increasing requirement for additional bandwidth, and in order to utilize fiber optic technology to its full capabilities, multiplexing of data signals down single fibers is being investigated.

Already in widespread use in the telecommunications industry, multiplexing of data is achieved by sending the data into a multiplexer and transmitting the data at different wavelengths through the single fiber to a de-multiplexer where the data signals are once again separated. The data is separated to ensure that crosstalk and channel separations are maintained. The term for this process is Wavelength Division Multiplexing (WDM) and can be broken down into three distinct categories:

- Wavelength Division Multiplexing
  - WDM consists of two to four wavelengths per fiber.
  - A basic WDM system could comprise data signals using 850 nm and 1300 nm wavelengths.
- Coarse Wavelength Division Multiplexing
  - Coarse Wavelength Division Multiplexing (CWDM) typically consists of four to eight wavelengths, but more can be accommodated; designed for short to medium haul networks.
  - Wavelength spacing in a CWDM system is approximately 10 to 20 nm.
- Dense Wavelength Division Multiplexing
  - Dense Wavelength Division Multiplexing (DWDM) supports eight or more wavelengths. The wavelengths are typically spaced at 1 to 2 nm. However, careful control of the laser temperature source is required to prevent wavelength drifting and causing crosstalk and data collision.

5.0 COMPONENT SELECTION

5.1 Passive Components

From a system designer's perspective, two important decisions need to be made before selecting a set of passive components. The first is whether the physical layer will be multimode or single mode. The second is at which wavelength(s) the system will operate.

Fiber optic cables, connectors, star couplers, and wavelength de-multiplexers form the basis of any data bus passive component set.

All of these components must be specified and tested for:

- Optical performance over a wide temperature and environmental range, typically -55 °C to 125 °C for aerospace use.
- Compatibility with normal airframe manufacturing, installation, in-service maintenance, and damage repair schemes.
- Operation for up to 25 years in an aerospace avionics environment.

5.1.1 Optical Fiber

Also known as optical fiber waveguides, aerospace optical fibers are typically small diameter, circularly symmetric silica fibers as used in many modern digital and analogue transmission networks. A central core is surrounded by a concentric coating of lower refractive index silica called cladding, which confines most of the transmitted light to the core.

For current and future applications, aerospace systems designers support standardization of a commercially sized multimode fibers of 62.5/125 μm or 50/125 μm Multimode Graded Index (GI) fibers, as used in the telecommunications arena, is in the best interest as this approach addresses the issues of obsolescence and reduces both cable and connector costs while providing the required bandwidths.

Some of the larger core fibers, e.g., 200/280 Step Index (SI), may be suitable for the transmission of "power by light," while single mode fibers typically 9/125 μm can be utilized within optical sensor systems and for very high bandwidth requirements.

5.1.1.1 Fiber Type

- Multimode (MM)

50/125 μm (GI)

Typical Bandwidth – 850 nm ≥ 510 MHz-km

Typical Bandwidth – 1310 nm ≥ 500 MHz-km

62.5/125 μm (GI)

Typical Bandwidth – 850 nm ≥ 160 MHz-km

Typical Bandwidth – 1310 nm ≥ 500 MHz-km

100/140, 200/230 μm (GI)

Typical Bandwidth – 850 nm ≥ 150 MHz-km

Typical Bandwidth – 1310 nm ≥ 150 MHz-km

- Single mode (SM)

Typically 9/125 µm

Typical bandwidth – 1310-1550 nm ≥ 1 GHz

5.1.1.2 Fiber Coatings

Bare optical fiber is extremely brittle by the very nature of the material. In order to utilize the fiber as a product, additional protection is needed to ruggedize and improve the capabilities of the fiber. An important element of these requirements is coatings applied during fiber draw and buffers, which may be extruded or wrapped on to the coated fiber.

5.1.1.2.1 Primary Coating

During draw, the bare fiber is coated with a soft primary coating, typically silicone and/or acrylate, to effectively limit micro-bending losses in the fiber and act as a shock absorber. It also provides an element of temperature and moisture protection.

5.1.1.2.2 Secondary Coating

A secondary coating of harder material may be added to enhance its temperature resilience and/or to protect the fiber during handling.

5.1.1.3 Coating Materials

5.1.1.3.1 Acrylates

High-temperature acrylates are available with various high-temperature limits and offer easy stripping. However, the thermal stability of the fiber should be carefully analyzed to assure reliability over long lifetimes encountered in avionics applications.

5.1.1.3.2 Silicones

Silicones offer operation at higher and lower temperatures than acrylates, are resistant to water vapor and chemicals, plus offer easy stripability. Silicone is generally applied to a greater thickness than acrylate and is usually up-buffered with a thermoplastic for abrasion protection. There are many types of silicone, some of which may leave a residue when stripped. Careful selection by the fiber manufacturer eliminates this potential problem. There are silicones used as coatings that can be prepared for termination using standard cleaning procedures used on acrylate-coated fibers.

5.1.1.3.3 Polyimides

Polyimide coating offers high strength, extreme high and low temperature performance, and abrasion and chemical resistance. It is also a thin coating that can be applied in varying thicknesses. Polyimide is difficult to strip and may require chemical or plasma stripping. Larger size ferrules are available to accommodate the polyimide without stripping.

5.1.1.3.4 Carbon

Carbon is a very thin layer applied to the bare glass during draw. It extends fiber lifetime by hermetically sealing the glass surface to impede moisture ingress and microscopic crack growth. This can improve the resistance to fatigue (n value) of a fiber from ~20 to as high as 200. Carbon is applied in such a thin layer that it is measured in hundreds of Angstroms and must always have a secondary coating applied over it. An adequate picture of primary coating types and the requirements for the selected fiber in relation to the mechanical and thermal aspects of operation is important for successful fiber cable definition.

5.1.1.4 Buffers

5.1.1.4.1 Function

The major function of the fiber buffer coating is to protect the coated fiber from abrasive and environmental damage, also limiting micro-bending losses in the fiber. Many materials have been used for the primary coating of optical fibers but the most widely known and used of these are acrylate, polyimide, and silicone. The pros and cons of each are briefly described below.

Most fibers use an acrylate-type material for the primary coating; other materials can be encountered, however, such as silicone, polyimide, nylon, proprietary polymers, and even metal such as Gold or Aluminum (although these are somewhat specialized and will not be considered here). Carbon is sometimes applied to special fibers to hermetically seal the fiber surface and prevent moisture reaching the glass surface (typically used on space applications).

5.1.1.4.2 Acrylate

This is perhaps the most common of optical fiber primary coating materials and is relatively easy to remove with hand tools. The coating is usually a UV cured acrylate that is translucent and typically is the same thickness as the fiber. Acrylates have a limited temperature performance of up to approximately 100 °C; therefore, for high temperature applications, other additional coatings are also applied.

5.1.1.4.3 Polyimide

This coating has a higher temperature range than UV cured acrylates and can be used in temperatures up to approximately 350 °C. Polyimide coatings, although useful for high temperature applications, are difficult to remove and are not amenable to tool stripping. Typically, to remove polyimide effectively, hot sulfuric acid is required. This method of stripping is not recommended for use on aerospace platforms, but if deemed necessary, all safety precautions should be strictly followed in accordance with the supplier’s instructions. Polyimide-coated fibers are widely used on a number of aerospace programs in the United States.

5.1.1.4.4 Silicone

The main benefits of silicone as a primary coating are the reduction of fiber micro-bend effects due to the “cushioning” effect of the soft primary coating layer, its high temperature (up to 200 °C) capability, its resilience to water absorption, and its low flammability. However, as with acrylate, this material needs to be stripped prior to inserting optical fibers into fiber optic connectors. The removal of the coating (if not of the proper formulation) will leave a silicon residue on the fiber cladding; without the proper material selection, this may lead to a compromise of the epoxy adhesive/fiber bonding process.

5.1.2 Fiber Optic Cable

A fiber optic cable describes the primary coated optical fiber enclosed within the supporting outer structure. It is this structure that provides the ruggedized characteristics of a typical aerospace fiber optic cable.

In addition to the primary jacket coating described in Section 5.1.1.2.2, a strength member is added, typically an Aramid yarn, fiberglass braid, or a mix of both materials to provide longitudinal strength and relieve any direct stress on the fiber. Finally, an outer jacket, typically a fluoropolymer material, enables the whole package to be capable of withstanding temperatures as wide ranging as -65 °C to +155 °C, resistant to numerous fluids and chemicals and with low smoke and toxicity emissions. In addition, this construction protects the fiber against the mechanical and environmental rigors experienced on aerospace applications.

5.1.3 Fiber Characteristics

Some key fiber characteristics and parameters that impact the performance of avionic networks are:

- Fiber material
- Spectral loss
- Fiber diameter
- Cladding and overall diameter
- Numerical aperture
- Refractive index profile
- Cable construction

- Cable strength
- Nuclear radiation hardness

Network designers should have a top-level awareness of these characteristics, and their general significance for avionic cable design for good long-term performance within the hostile airborne environment.

5.1.3.1 Fiber Material

All-silica fibers (core and cladding) are currently seen to be most suitable for aerospace applications. The refractive index of the cladding is reduced relative to the core, or that of the core is raised relative to the cladding. In both cases, the effect is to ensure effective guidance of the signal power by the optical waveguide.

Some specialty fibers are required to be capable of being immune to the effects of radiation darkening, a phenomenon that causes a silica fiber to darken momentarily when subjected to high level pulses of radiation. This type of fiber is commonly called “radiation hardened.”

5.1.3.2 Spectral Loss

Figure 5-1 shows schematically the loss spectrum examples of 2 silica fibers. They differ only in the water impurity level in each case. So-called “wet” fibers have a general loss curve as illustrated. The hydroxyl absorption bands present very high loss beyond about 820 nm, and such fibers can be called First Window in that transmission is limited to the spectral region around 800 nm – 830 nm. By contrast, “dry” fibers allow operation in all 3 low-loss windows simultaneously using wavelength multiplexing, and can be called “Multi-window Fibers.” These windows are indicated in Figure 5-1 as W1, W2, and W3. The centers of these windows are indicated as W1, W2, and W3.

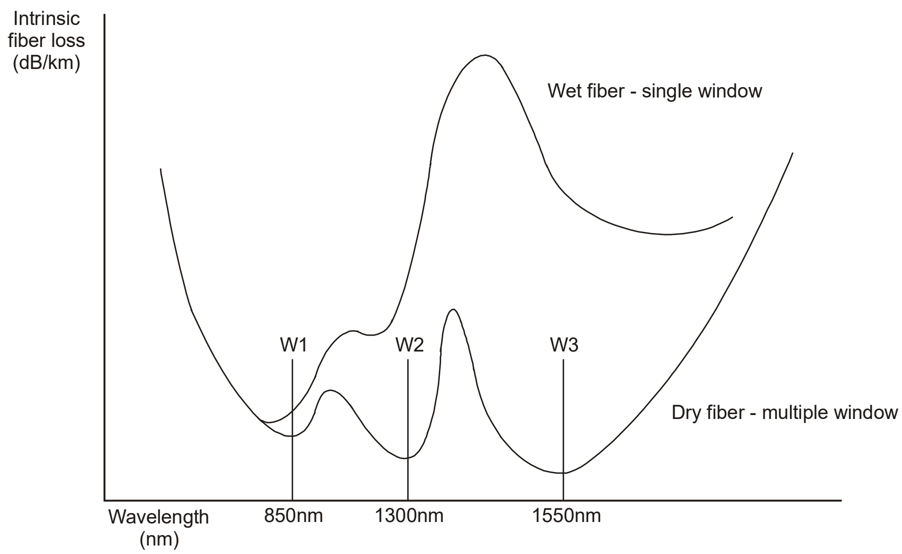


Figure 5-1 – Spectral Loss Schematic for Optical Fiber

5.1.3.3 Fiber Diameter

There have been a number of fiber sizes used on a number of aerospace platforms, mainly military and space, and typically driven by technology availability and requirements. Presently, the commercial market has settled around 50/125 µm and 62.5/125 µm for multimode applications and 9/125 µm for single mode applications.

- Multimode
  - 50/125 µm
  - 62.5/125 µm
  - 100/140 µm
  - 200/230 µm
  - 200/280 µm
- Single mode
  - 9/125 µm

A number of specialty fibers have been incorporated for application-specific military programs. However, these will not be discussed within this document.

5.1.3.4 Refractive Index Profile

The Refractive Index is the ratio of the speed of light in a material to the speed of light in a vacuum.

The variation of the fiber refractive index across the core depends on fundamental fabrication as well as data transmission performance issues. However, at the macroscopic level, 2 extreme profiles exist. The step index profile fiber has a constant index across the core. In reality, all-silica fibers do not meet this ideal, and various Quasi-Step Index (QSI) profiles exist. At the opposite extreme is the pure graded index profile, which is parabolic in form.

The bandwidth of the graded index fiber is much greater than that of the step index variant. Typical bandwidths approaching or equal to 20 MHz/km are found with LED sources in silica fibers. For GI fibers where laser sources are used, there is increasing evidence that bandwidths well into the GHz/km region are achievable. If the maximum length of a single fiber optic cable on an aircraft is generally assumed to be 200 meters, this would mean that signaling rates in excess of 10 Gbps are entirely feasible. Nearly all commercial multimode fiber is now graded index.

Control of the index profile is key for producing high bandwidth fibers as anomalies in the profile (sometimes found at the center of the core or at the core-cladding boundary) can introduce extra modal dispersion and reduce the bandwidth of the fiber.

5.1.3.5 Cable Construction

The commercial aerospace industry has concentrated on a common size (62.5/125 μm) multimode GI fiber for aerospace applications. However, different packaging solutions are used for individual design requirements. Currently, two types of cable construction have been selected for in-service use: these are defined in ARINC Specification 802 as tight jacket (type MGT) and semi-loose construction (type MGL).

Avionic fiber optic cables are usually single way (single fiber), and are designed to protect the secondary coated fiber package. In a tight jacket construction, the secondary coated fiber is surrounded by a tightly-wound strength member, itself extruded over by the cable sheath. In such a structure, fiber movement is closely constrained by the interactions within the total package. In the semi-loose structure, the secondary coated fiber is not significantly laterally constrained, providing protection to the fiber while allowing fiber an element of free movement. The fluoropolymer sheath, of typical diameter in avionics between 1.8 and 2.5 mm, surrounds very high tensile modulus strength members often made from Aramid yarn, fiberglass, or a mix of both in braided or stranded form. When terminated with fiber optic connectors, the strength member should be fixed in such a way that any cable tensile loads present no significant tensile force onto the fiber. Note that a well-developed fiber optic cable termination technique, compatible with the fiber, cable, connector, and the operational mechanical/environmental envelope, is assumed.

Any aerospace fiber optic cable specification will include a wide range of optical, mechanical, and environmental tests appropriate to the type of airborne application.

5.1.3.6 Mechanical Behavior

The nature of the mechanical strain experienced by a fiber will vary widely depending on its application. For aerospace applications, the major source of strain is localized at cable bends and installation mounting points. In order to significantly reduce strain effect caused by routing bends, fiber optic cables must not exceed their designed minimum bend radius, as defined by the product, manufacturer. It must be noted that typical bend radii are defined for short term, e.g., during installation, and long-term durations. In the case of cable retention, the use of recognized and designated mounting brackets and clips must be followed.

5.1.3.7 Cable Strength

The cable strength is the figure identified by the manufacturer and specified by a designer as the maximum achievable longitudinal load before breakage of the fiber. It is an important requirement that this figure is never exceeded during the installation process or during the life of the installation.

5.1.3.8 Numerical Aperture

The Numerical Aperture (NA) describes the ability of a fiber to accept light; only light injected into the fiber at angles within the acceptance cone will be propagated. At greater angles, the light cannot be propagated through the fiber as the angle of incidence at the core-cladding boundary is less than the critical angle and total internal reflection does not occur.

The NA of a fiber is important to the designer because it indicates how a fiber will accept and propagate light, e.g., a large NA fiber will have a large acceptance angle whereas a low NA fiber only captures a narrower cone of light. Different optical sources have different beam characteristics so matching the NA of the fiber with the source properties can optimize the amount of light coupled into the fiber.

The angles at which the rays will be propagated can be calculated. These angles form a cone known as the “acceptance cone,” indicating the maximum angle of light acceptance.

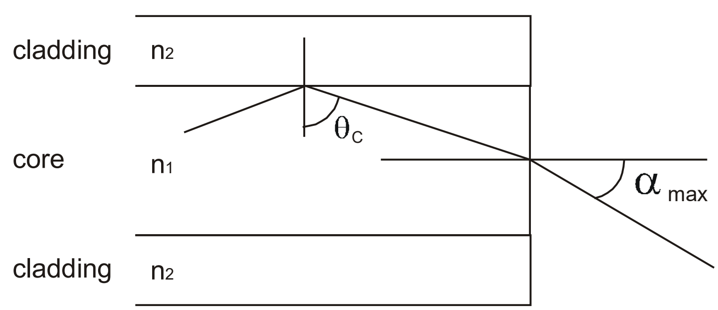


Figure 5-2 – Maximum Acceptance Angle for Light Propagation in Fiber

Where: α = acceptance angle

α_{max} = limiting case for propagation of light in fiber

θ_c = critical angle at core/cladding boundary

n_1 = refractive index of core

n_2 = refractive index of cladding

NA = numerical aperture

The acceptance cone is related to the NA by

$$NA = \sin\alpha$$

and for a step index fiber it can be shown that

$$NA = \sqrt{\left(n_1^2 - n_2^2\right)}$$

Analysis of the propagation of light in a fiber shows that only certain "modes" are supported by a fiber, i.e., the light can only take a certain number of routes. Over long distances, it becomes desirable for the light to take as few routes as possible as each route will have a different journey time leading to dispersion of the signal. The number of modes that the fiber supports is controlled by the diameter of the core (for a given wavelength of transmission) – reducing the core size reduces the number of modes. There comes a point where the fiber can only support one mode – single mode fiber.

Generally, high bandwidth fibers have a lower NA, therefore allowing fewer modes. Fewer modes equal less modal dispersion, therefore higher bandwidth. Typically, NAs range from approximately 0.50 for POF to 0.27 for GI fibers.

A mode can be described as the stable transverse interference pattern of the waveguide.

Single mode fiber is not normally allocated a NA as it is not a significant parameter for the designer due to the light not being reflected or refracted.

The NA of a fiber changes with distance as high order modes, e.g., those traveling near the critical angle, can be lost. As a GI fiber reaches Equilibrium Mode Dispersion (EMD) the NA can be reduced by up to 50%. This reduction results in the propagated light emerging at lower angles than the defined acceptance cones. Additionally, the spot diameter of the emerging light can also be reduced.

Sources and detectors also have a NA: the source NA defines the angle of the exiting light whereas the detector NA defines the light operating angle. Therefore, it is important that the source NA is matched to the NA of the fiber in order to attain the maximum propagation. A mismatch of NAs will result in additional losses.

5.2 Fiber Optic Connectors

It is recommended that 1.25 mm ferrule type connectors, specified by ARINC Specification 801, be used for new designs. A number of connector decisions 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 routed via a multiway connector, possibly even with electrical wires, in a hybrid connector. For example, a dual-redundant, bi-directional system may require up to four fiber optic cables per terminal, four single way connectors could be used, or the signals could be combined into a multiway connector, possibly with other signals as well. Redundancy and damage survivability requirements might dictate the inclusion of two separate connectors, depending on specific applications.

The choice of connector will also be influenced by factors such as fiber size and type and the compatibility between connector and cable, particularly in the area of the backshell. Certain system wide factors also have to be considered such as the number of connectors in the signal path, etc.

The most common ferrule diameter sizes used in aerospace fiber optic connectors are 1.25 mm and 2.5 mm. Their selection is a matter of choice for the designer; however, a number of requirements will have to be taken into account when selecting a particular size.

For example, terminus density – if large numbers of fibers are required to be routed through a single connector, then 1.25 mm termini may provide the additional density requirements. However, an increase in ferrule count increases the mating forces exerted on the connector body. See Section 5.2.3.3 for more information.

Information on ARINC compliant 1.25 mm ferruled termini and connectors can be found in ARINC Specification 801 and EN 4639, 4640, and 4644.

Information on 2.5 mm ferruled termini and connectors detailed in Appendix C of ARINC Specification 801 can be found in EN 4531.

Expanded Beam connectors should be considered for applications where connectors mate/demate cycles are by their nature high such as is the case with maintenance or data loading ports. For these applications, Expanded Beam connectors are more resilient to contamination and damage to the optical interface. Information on Expanded Beam termini and connectors can be found in ARINC Specification 845.

Mechanical Transfer (MT) support applications where a large quantity of fibers (channels) is needed in a high-density environment. Specially designed multifiber cables are required when using MT termini. Information on MT termini can be found in ARINC Specification 846.

5.2.1 Purpose of a Connector

The purpose of any fiber optic connector is to align two optical fibers and to keep the fibers positioned within tight physical constraints such that a good optical interface is maintained. This can be achieved in a number of ways.

5.2.1.1 Number of Fiber Channels

The fiber optic system designer has a choice when deciding how to join multiple optical fibers to equipment and to other optical fibers; whether to use multiple single-way connectors or a multi-way connector. However, if using Physical Contact (PC) type termini in multiway connectors, the effects of increased connector mating forces with an increase in termini density must be taken into account. See Section 5.2.3.3.

5.2.1.2 General

There are a large variety of connectors available, ranging from single way “crimp and cleave” to complex multi-way “pot and polish” devices. It is, therefore, necessary to understand the differences between these connector types and their associated features. When specifying a fiber optic connector, it will be necessary to define the optical interfacing method, the fiber attachment method, and the number of fibers to be accommodated.

5.2.1.3 Optical Interface

Fiber optic system designers have the option of using optical connectors with one of two types of interfaces, these being “butt-coupled” or “Expanded Beam.” A typical butt-coupled arrangement is shown in Figure 5-3. The fibers physically “butt” together at the connection.

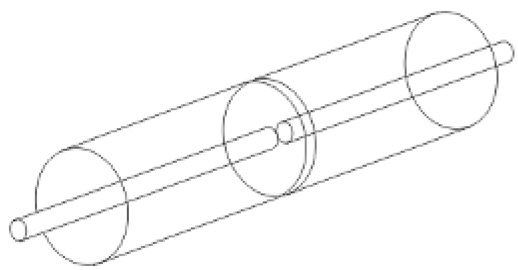


Figure 5-3 – Butt Coupled Interface

This is the simpler of the two in terms of the number of elements in the optical path. However, the performance of this interface is highly dependent upon the quality of the fiber end-face. This implies stringent requirements in terms of cleanliness and polishing (or cleaving).

An alternative to the butt-coupled interface is to place lenses between the two fiber ends (see Figure 5-4). Connectors employing such lenses are referred to as “Expanded Beam” connectors. The purpose of the lens is to take the small diameter, diverging output of the fiber and convert it into a larger diameter, collimated (parallel) beam of light. This has advantages in terms of enhanced tolerance to particulate contamination. The inclusion of lenses, however, can increase connector insertion loss compared to butt-coupled interfaces as well as adding cost and complexity to the termination process. See Section 5.2.2.5.

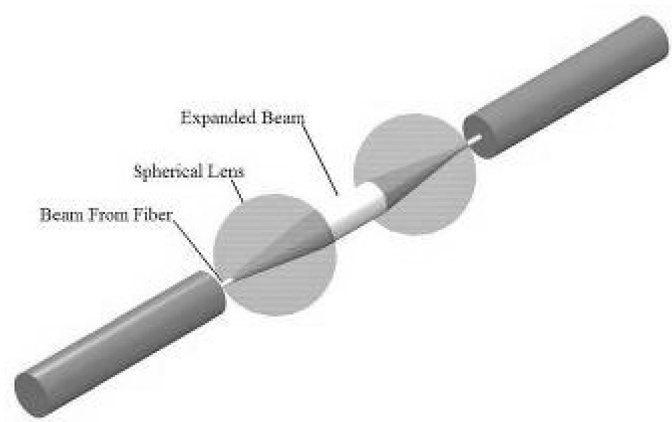


Figure 5-4 – Example of Expanded Beam Channel

5.2.2 Connector Types

5.2.2.1 Single-Way Connectors

The simplest fiber optic connector is the single-way connector. This connector terminates a single cable to another with integral strain relief and (generally) some form of environmental sealing. The fiber end-face is usually easily accessible for cleaning and inspection in such connectors, either by disassembly or by virtue of using exposed ferrules and a separate guide tube or adapter. Since it is designed to handle individual fiber optic cables, it is not very space efficient when used for multiple fiber optic cables. Single-way connectors may be plug/receptacle type, male/female, or hermaphroditic (same design on both mating connectors). Spring loading will probably be supplied on at least one side of the single-way connection to keep the fibers in intimate contact.

5.2.2.2 Circular Multi-Way Connectors

As the name suggests, this type of connector is designed to join two or more optical fibers simultaneously. Since the connector coupling hardware is common for a number of optical ferrules (or termini), this arrangement is fairly space efficient. Cleaning and inspection can be difficult with this type of connector unless a provision is made for a removable ferrule alignment assembly or the design incorporates features to alleviate the need for removable inserts while allowing access to the end face of the ferrule. Figure 5-5 shows an example of an aerospace multi-way fiber optic connector with removable alignment insert. Figure 5-6 is an example of an aerospace multi-way fiber optic connector with designed access to the ferrule end face.

Figure 5-5 – Example of an Aerospace Multi-Way Fiber Optic Connector with Removable Insert Assembly

Figure 5-6 – Example of an Aerospace Multi-Way Fiber Optic Connector with Accessible Ferrule End Face

5.2.2.3 Rectangular Multi-Way Connectors

Avionics rectangular connectors typically form part of rack applications in which Line Replacement Items (LRI) or Line Replacement Units (LRU) incorporating plug housings are mated with rack-mounted receptacles. This avionics rack configuration allows for controlled utilization and positioning of avionics equipment.

New designs of aerospace fiber optic termini can also be used in a range of rectangular and modular connectors such as:

- ARINC 404A
- ARINC 600
- DMC-MO (EN 4165)
- EPX

The use of these connectors provides increased pin density subject to mating force limitations. See Section 5.2.3.3.

5.2.2.4 Hybrid Connectors

A hybrid connector comprises of a mix of optical and electrical technologies, allowing the transfer of data and power signals through a common interconnect.

The design of a hybrid connector should incorporate separated termini inserts designed to prevent the cross-contamination of the optical termini end faces with particles from the electrical contacts. An example is shown in Figure 5- 7.

The use of hybrid connectors could reduce the number of interconnects on applications or components that require separate power and data paths, e.g., surveillance camera.

It must be recognized that a system of connector polarization must be identified to ensure that cross-connection of “all-electrical” and hybrid connectors cannot take place to prevent damage to either connector contacts or termini.

Figure 5-7 – Example of an Optical/Electrical Hybrid Connector

5.2.2.5 Expanded Beam Connectors

Expanded Beam connectors use lenses to expand and then refocus light from the transmitting fiber optic termini into the receiving termini. Fiber separation and lateral misalignment are less significant in an Expanded-Beam coupling than in physical contact ferrules. The same amount of fiber separation and lateral misalignment in Expanded-Beam coupling produces a lower coupling loss than in a physical contact solution; however, angular misalignment is more significant. The same amount of angular misalignment in Expanded-Beam coupling tends to produce a higher loss than in a physical contact ferrules unless tight tolerance designs are incorporated.

Information on Expanded Beam termini and connectors utilizing standard electrical inserts with size 16 contact cavities can be found in ARINC Specification 845.

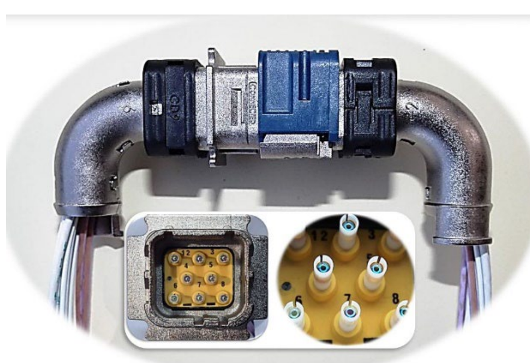


Figure 5-8a – Example of ARINC 845 Expanded Beam Contacts in an EN 4165 Connector

5.2.2.6 Mechanical Transfer

Mechanical Transfer (MT) termini provide multiple channels for higher density installation requirements. The MT ferrules typically use PC connections for low insertion loss.

5.2.2.6.1 Standard MT Termini

Mechanical Transfer connectors use specially-designed cavities to accept the MT ferrule. MT termini are used in inserts designed to accept a copper quadrax, or potentially in a hybrid/copper insert.

5.2.2.6.2 Quadrax MT Termini

An ARINC 846 MT quadrax termini is used in a Size 8 cavity in a conventional insert with provisions for a quadrax, or potentially in a hybrid copper/fiber insert.

Figure 5-8b – Example of an MT Contact in a Quadrax Cavity

System designers should consider the benefit of cable and connector maintenance when using an ARINC 846 MT Quadrax in a connector. The component or LRU shall have pin termini, and cables will have socket termini.

It is important to note that in an MT Quadrax mated pair, the pin quadrax contain the pin side of the MT. Conversely, the socket quadrax contains the socket side of the MT. MT alignment pins are quadrax pin side. During mating, the quadrax body engages before the MT mating.

See ARINC Specification 846 for the MT Quadrax termini design.

5.2.3 Connector Requirements

5.2.3.1 Termini Arrangement

The termini arrangement of a connector details the number, spacing, and arrangement of the optical termini. Termini arrangement selections are chosen on the basis of the system requirements.

5.2.3.2 Environmental Sealing

This defines the capability of the connector assembly (mated plug and receptacle, plus accessories) to withstand the effects of fluids, and dust particles from contaminating the end face of the optical termini, causing degradation of the optical signal. Methods for environmental sealing include the utilization of gaskets, inter-facial seals, fluorosilicone inserts, and O-ring seals.

5.2.3.3 Mating Force

This is the force required to fully interface and lock mated pairs of connectors. This is the sum of the termini mating forces plus the force required to displace the termini against their spring retention, together with any mechanical forces present between the connector housings.

The higher the number of termini in the connector or connector module, the higher the mating force required to fully mate the connector halves. This is because of the spring forces being exerted on the fiber optic termini to ensure the ferrule end faces remain in contact with each other in all operating conditions. As the number of termini in a connector increase, the multiplication of the spring pressure is also increased until a situation arises where the mating forces needed to fully mate the interconnect exceed the connector body strength, leading to failure of the connector body or associated locking mechanism.

5.2.3.4 Guide Pins

Guide pins can be used to assist in the correct alignment of the connector plug and receptacle optical termini. The guide stands proud of the optical contact end face and interfaces with a corresponding guide hole in the mating connector half before any mating of the optical end faces occurs.

5.2.3.5 Connector Insert

This can be manufactured in various materials including molded material, e.g., peek or metal, and provides support to the optical termini assembly. Elements of the insert can be removable to assist in the cleaning of the optical end faces. In some designs, the insert can also house the optical termini alignment sleeve.

Some connector designs incorporate a “floating” insert that allows an element of movement of the optical termini that assists in the alignment of the optical contacts during connector mating. However, this may lead to fretting of the inserts when subjected to high vibration conditions with the effect that particles may be formed that could contaminate the end face of the optical contact.

5.2.3.6 Alignment Sleeve

An alignment sleeve provides a method of accurately aligning the optical contact ferrules which, in turn, aligns the cores of the fiber optic end faces. This is achieved by using a sleeve made of ceramic, or in some cases, metal.

5.2.3.7 Fiber Attachment Method

There are two main types of fiber-to-connector attachment processes. The first is “pot and polish,” where a fiber is bonded into a ferrule using adhesive and subsequently polished. This process generally uses adhesive, a source of heat for curing the adhesive, and various grades of polishing film and tools to achieve a good fiber end finish.

Although the pot and polish process is achievable in an aircraft environment, it has notable differences to a conventional electrical wire termination process. This has led to significant effort being invested into the search for a mechanical based, dry termination process that does not require a heat source for attaching fibers to connectors. Some adhesive terminations can be performed with specialist adhesives, e.g., anaerobic adhesives, without the need for a heat source. However, the performance of these adhesives is inferior over temperature to that of heat-cured epoxies.

The second process, referred to as "crimp and cleave" is an attempt to satisfy the need for an electrical wire equivalent process. This is where a connector ferrule is crimped down onto the fiber or some other element of the fiber's jacketing layers, with the fiber end being prepared by cleaving rather than polishing.

This technology is inferior to an optimized "pot and polish" process and will not perform as well in an avionics environment.

There are, of course, other connector termination processes; however, they tend to be variants or hybrids of the above two techniques. The one notable exception is a variation on fusion splicing (a fiber repair process designed to permanently join two fibers). In this technique, a cleaved fiber is inserted into a connector and fused by an electric arc to a pre-installed, pre-polished fiber. This is not a widely used technique and has significant safety implications for on-aircraft use.

Fiber attachment is predominantly achieved by use of adhesive in the aerospace community, while crimping is more widespread in the telecommunications community. No aerospace suitable mechanical-based termination process is presently available for silica fibers. Terminations using adhesive are thus the only ones considered in detail in this document. This is not to say that all mechanical crimp and cleave terminations will not become available in the future. See ARINC Report 806 for termination processes.

5.2.3.8 Termination Issues

Section 5.2.3.7 describes fiber attachment to optical termini using the "pot and polish" method. There are a number of technical issues that should be addressed when using this method:

- Epoxy insertion
    - An element of the termination process requires that a controlled amount of epoxy adhesive should be injected into the termini assembly. In the case of the ARINC 801 1.25mm terminus, the preferred method is to inject the epoxy through the front-end face of the ferrule via the fiber bore. In the case of the EN4531 2.5mm terminus, the preferred method is to inject the epoxy adhesive directly into the rear of the contact body.
    - In both cases, care should be taken to ensure that the correct amount of epoxy is injected and that no air cavities remain that could lead to open voids around the fiber after curing. This could lead to fiber breakage or introduction of microbending and increased attenuation.
- Ferrule end face contamination
    - It is important to control the injecting of the epoxy to ensure that the adhesive does not contaminate the end face or body of the ferrule. If

not controlled or removed, a ring of cured epoxy could be retained on the ferrule (Figures 5-9 and 5-10). This epoxy ring could come away during service life and cause contamination issues.

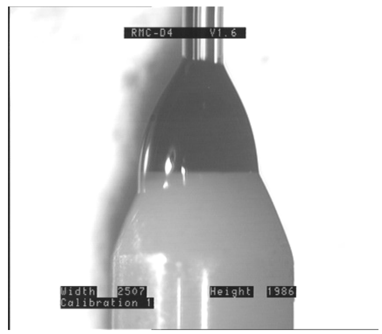


Figure 5-9 – Excessive Epoxy on Ferrule End Face

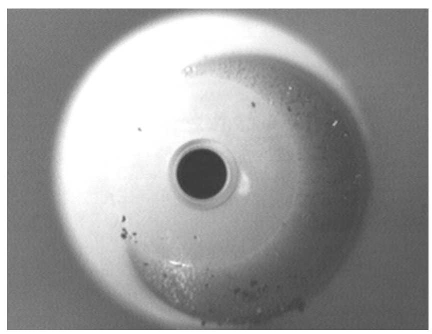


Figure 5-10 – Ring of Epoxy Remaining After Polishing

- Internal spring contamination
  - When injecting epoxy adhesive into termini assemblies containing internal springs, care should be taken to ensure contamination of the spring with epoxy does not occur. If contamination occurs and curing is carried out, the termini will not be able to compress and will have to be removed and replaced.
- Wicking of epoxy in strength member
  - Care should be taken when inserting the fiber optic cable into the rear of the termini to prevent wicking of the epoxy adhesive into the cable strength member. If wicking occurs, the cable assembly may become rigid for a number of millimeters behind the termini assembly and cause issues with fiber push back when using LM, LS, or LSA style termini. See ARINC Specification 801.

5.2.4 Passive Couplers

A coupler is a multiport bi-directional device that accepts light via an input port and divides or combines light and outputs it via the output ports.

There are typically three types of passive star coupler: reflective, transmissive, and Y-coupler.

5.2.4.1 Reflective

A reflective star coupler comprises of *N* number of ports where any port can serve as an input or output. An optical signal injected into one port will be equally reflected to all of the remaining ports, as shown in Figure 5-11.

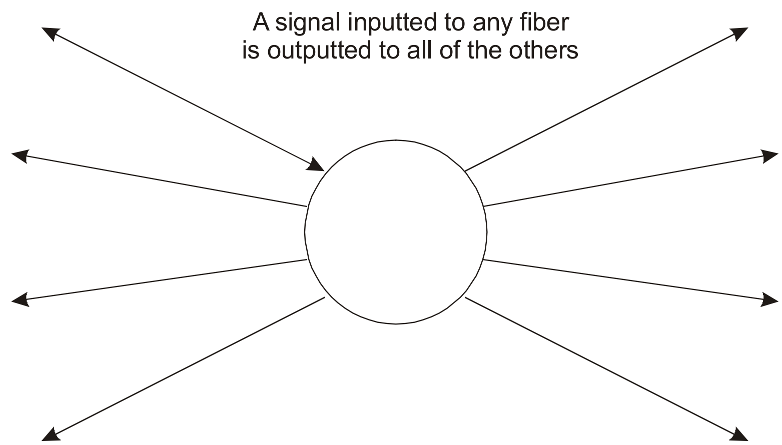


Figure 5-11 – Reflective Star Coupler

5.2.4.2 Transmissive

Transmissive star couplers provide an equal number of inputs and outputs as shown in Figure 5-12. Typically, transmissive star couplers are manufactured by fusing wrapped fibers causing the glass to melt into a unified mass. This means that an optical signal inputted into a single input port will only be reflected to the output ports. However, it is more typical for larger aerospace couplers to be manufactured using mixer rods.

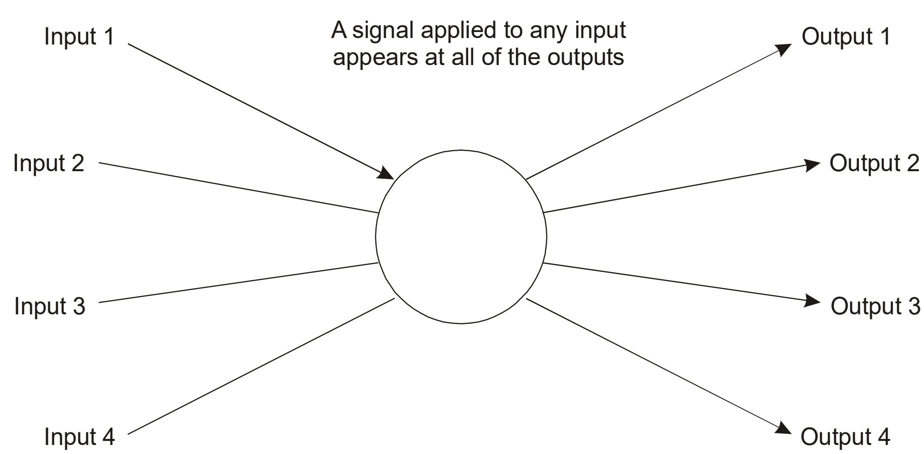


Figure 5-12 – Example of a Transmissive Star Coupler

5.2.4.3 Coupler Selection

The choice between these two types of coupler and the number of ports depends upon the requirement and limitations imposed by the system, e.g., a reflective star coupler will have a lower cabling interconnect requirement providing mass and cost benefits. However, reflections from the interconnect system can upset the data traffic flow and may affect the transmitter performance.

Transmissive couplers require more cabling within the network, but the port-to-port losses are reduced. The choice of coupler type therefore requires careful consideration at the system design stage.

Y-couplers are small dimension couplers (typically 1x2 or 2x2), both of which are similar to reflective star couplers in that light may be inputted and outputted on the same port, and to transmissive star couplers in that incident light is not passed back to the same port. This is achieved through asymmetric coupling where incident light is not equally mixed to all the ports but is directed to specific ports. This is particularly useful in reflective star systems where a single fiber used to connect the node to the star (as an input or output port) is connected to the node's transmitter and receiver (i.e., separate output and input ports).

The following clause describes technologies and key parameters that must be specified by the systems engineer and is relevant to both transmissive and reflective star couplers.

5.2.4.4 Passive Star Couplers

The use of passive star couplers in avionic systems allows information to be distributed to a number of items of equipment around a data network. As previously mentioned, there are two types of passive fiber optic star couplers, reflective and transmissive. Reflective couplers can range from three to currently forty ports and transmissive couplers from three to currently sixty-four ports. Coupling of the optical power may be performed in one of two ways:

1. Symmetrical – where the coupling ratio is a proportion of input to output fibers, e.g., for a 16-way star coupler the power loss will be 1/16th of input power or 12 dB (power loss in dB = 10 log Pout/Pin).
2. Asymmetrical and non-reciprocal – where the coupling ratio is determined by the application. Asymmetrical couplers are briefly discussed in Section 5.2.6, but are different to Y-couplers in their use. The key parameter considerations will be the same as those for symmetrical couplers.

5.2.5 Coupler Technologies

There are a number of technologies available for multimode coupler design and manufacture:

- Fused bi-conical taper
- Ion exchange waveguide
- Micro-optic techniques
- Mixer rod
- Optical tap
- Polished fibers

Although each of these technologies may have individual benefits over the others, the choice of coupler is not largely dependent on them. More importantly, it is the overall performance of the coupler that is of importance to the system designer.

5.2.6 Key Performance Parameters

5.2.6.1 Insertion Loss

This is the optical attenuation caused by adding the coupler component into the system. Insertion loss of a coupler can be split into two categories:

1. Theoretical or splitting loss – The power that is lost in a signal due to the number of output fibers (e.g., taking a 1 x 2 coupler, the splitting loss is equal to 50%, this will account for a splitting loss of 3 dB. For a 16-way coupler, the input optical power is split 16 ways, resulting in 1/16 of the power into each output fiber, equivalent to 12 dB). This loss is unavoidable in any passive star coupler.
2. Excess loss – Possible loss mechanisms in the coupler, based on mixer rod technology, for example, are:
    a. Packing fraction loss, where power is lost due to the area of the output end of the mixer-rod, which is not coupled directly into the output fibers.
    b. Misalignment of fibers and mixer-rod.
    c. Scattering and reflections at the fiber/mixer interface.
    d. Absorption.
    e. Connections.

These losses are largely due to imperfections in manufacture and are additional to the theoretical power splitting loss. Excess losses, therefore, should be minimized. Excess losses for a 32-way reflective star are typically 2 to 3 dB and 3 to 4 dB for a transmissive 32-way coupler.

5.2.6.2 Port Uniformity

Port to port uniformity is where the power at the output fibers is not evenly split. These variations in optical signal strength are very important as they may put too great a demand on receiver Intertransmission Dynamic Range (IDR). Ideally the port-to-port uniformity should be ±0 dB. Typically, a coupler has a port-to-port uniformity of ±1 to ±2 dB.

5.2.6.3 Modal Dependence

In multimode couplers, there is often a highly mode dependent power splitting action. This can potentially create problems in both the characterization of the devices and in the uncontrolled way in which power is distributed in a real system (e.g., two closely connected couplers may not perform as their individual testing suggested they might). However, there is often enough mode mixing, either inherent in the particular coupler design or the interconnect between couplers, to eliminate this problem.

5.2.6.4 Environmental Requirements

The couplers should all withstand their specified avionic environmental requirements.

5.2.6.5 Packaging

There is a tradeoff to be made between the various packaging options. This will depend largely on the system configuration but consideration should be given to the following options:

- Cost
- Ease of manufacture
- Repair
- Reliability
- Optical performance
- Mass
- Size

The purpose of packaging is to protect a coupler and to provide a mechanism for strain relief. There are two options of coupler packaging to consider with respect to interfacing with the network:

- Pigtailed coupler – where a length of fiber cable exits the coupler housing.
- Connectorized coupler – where the connector is attached to the coupler housing.

A pigtailed coupler may be a lighter and smaller package than an equivalent connectorized coupler, although it will still have a requirement for the pigtails to be terminated at some point before its installation. Installation of a pigtailed coupler is likely to be more difficult due to the looming and adding connectors to the pigtails; this will also have an adverse effect on repair or replacement of such.

Connectorized couplers trade off their size and weight requirements against ease of installation, removal, and replacement.

5.3 Active Devices

This section is included to provide the user with an overview of some of the most common technologies incorporated in photonics active devices. It is not the intention of this section to fully describe the relevant technologies. This information is detailed in **ARINC Report 804:** *Fiber Optic Active Device Specification.*

5.3.1 Optical Sources

The key element in any optically based system is the availability of an easily modulated light source. The source should produce energy concentrated in a narrow band around an appropriate wavelength. The source should also emit light in such a way that the light can be easily coupled into an optical fiber.

Sources can be broadly split into two classes: non-lasing (e.g., LED) and lasing (e.g., Fabry-Perot laser, DFB laser, and VCSEL).

5.3.1.1 Light Emitting Diode

Light Emitting Diodes (LEDs) offer a low-cost, effective source option for data rates up to around 100 Mb/s. They are used exclusively with multimode fibers, and they are available over a broad spectrum of wavelengths covering all of the common multimode fiber transmission windows.

They are not lasers and the light that they produce is non-coherent. They produce significantly lower levels of light than lasers but have longer lifetimes and reliability due to their simpler structure. Control drive circuitry can be simpler than that for lasers and LEDs are also less susceptible to temperature variation as they have no lasing cavity.

5.3.1.2 Laser Diode

Laser Diodes (LDs) are semiconductor junction devices that contain substrates that are etched, or cleaved, to act as reflecting facets for field reinforcements over the junctions. They therefore combine the properties of an LED and a cavity reflector, producing an external light radiation that is higher in power and better focused than a simple LED.

Unlike an LED, a laser diode is a semiconductor device that generates coherent light through the stimulated emission process. The coherent light emitted by laser diodes provides many advantages for optical-fiber communication systems:

- A relatively higher directivity of the output beam permits higher coupling efficiency (approximately 50%) into single mode fibers.
- A narrower spectral width makes it possible to push the fiber dispersion limit towards higher bit rate-distance products.

Laser diodes can be broken down into different categories; the ones included here are those that could typically be used for aerospace applications.

5.3.1.2.1 Fabry-Perot

Fabry-Perot (FP) laser sources are available as communication sources at all common wavelengths from the visible through to the long-haul telecommunications band at 1550 nm. They are more expensive than LEDs, but offer narrow line widths, high power, and greatly improved modulation rates needed for high data rate transmission over long distances.

Fabry-Perot refers to the design of the laser cavity that is created by etching or cleaving the semiconductor material to create reflecting surfaces.

The relatively higher directivity of the output beam (compared to LEDs) permits higher coupling efficiency (approximately 50%) into single mode fibers. Light emission is perpendicular to the semiconductor layer structure.

An FP laser emits multiple narrowly spaced wavelengths either side of the central wavelength as several longitudinal modes are supported within the cavity.

5.3.1.2.2 Distributed Feedback Lasers

Distributed Feedback (DFB) lasers emit a single wavelength with a spectral width of less than 1 nm. This is achieved by the use of an internal grating construction that only allows a single wavelength to be amplified, while suppressing the others. The emitted wavelength is dependent on the length of the cavity and spacing of the grating.

DFBs are available for both 1300 and 1550 nm transmission windows and are also capable of higher outputs and can couple mW of power into a single mode fiber. Their main drawbacks are the requirement to tightly control the output and very high cost.

5.3.1.2.3 Vertical Cavity Surface Emitting Laser

Vertical Cavity Surface Emitting Lasers (VCSEL) are semiconductor lasers diodes that emit a circular cross-section, low divergence beam of light vertically from the surface of a fabricated wafer allowing passive fiber alignment and high coupling efficiency.

Mature devices at 850 nm are only slightly more expensive than LEDs and they can be modulated at speeds of over 10 Gb/s. Longer wavelength devices for use in long-haul communication links have been on the brink of commercialization for some time but are still overcoming technical problems.

The main benefits of VCSEL technology are their cost, their low threshold current (enabling low power consumption), their good thermal stability, and the ability to arrange them in arrays providing parallel transmission.

Table 5-4 summarizes relevant characteristics of LEDs, laser diodes, and VCSELs.

Table 5-4 – Comparison of Typical Parameters of Interest for Light Emitting Diodes, Laser Diodes, and VCSELs

Attribute/Parameter	LED	Laser Diode (Edge Emitting)	VCSEL
Radiative Recombination	Spontaneous Emission	Stimulated Emission	Stimulated Emission
Particle Phase	Incoherent	Coherent	Coherent
Direction	Random	Linear	Linear
λ = 850 nm	Yes	Yes	Yes
λ = 1300 nm	Yes	Yes	No[1]
λ = 1550 nm	Yes	Yes	No[1]
Spectral Width	~100 nm	~1 nm (FP) <1 nm (DFB)	<1 nm
Reliability Lifetimes (MTTF)	10^5 to 10^8 hrs.	>10^5 hrs at 85 ºC	>10^5 hrs at 85 ºC
Fiber Coupled Output Power (max)	<<1 mW	>>1 mW	~1 mW
Modulation Rate (max)	~200 MHz	~10 GHz	>10 GHz
Threshold Current[2]	-	~50 mA	<2 mA
Wavelength Temperature Dependence[3]	-	~0.1 nm/K (DFB)	<0.1 nm/K

Notes:

1. Under development
2. Drive current above which lasing occurs
3. Not usually specified for LEDs due to large spectral width

6.0 INSTALLATION

6.1 Installation Considerations

It is not the intention of this document to provide specific installation requirements for fiber optic installations. It is aimed at providing the designer with an overview of the basic elements of the installation requirements that will need to be addressed during the system design phase.

6.1.1 Areas for Consideration

Optical fiber installation may be considered within the aircraft and within a Line Replaceable Unit (LRU).

Fiber cabling within the aircraft requires strength members and protective jacketing to prevent or mitigate damage over relatively long distances in widely varying environments (e.g., temperature, exposure to elements, etc.).

Optical fiber may be installed inside of an LRU or within an avionics rack. Different designs of cables can be used, such as buffered fiber that does not include jacketing. Protection from chafing and temperature must be considered in these situations.

6.1.2 Harnesses between LRUs and within Aircraft

During the design phase, it is important to identify and examine potential technical issues that may arise. This is particularly important when designing the harness and its subsequent routing.

Harnesses should be designed to incorporate suitable production breaks to allow ease of through-life support without impacting on the power budget of the system.

Additional production breaks can be implemented to allow easier repair and maintenance particularly where harnesses are routed in maintenance intensive areas. For equipment positioned in high maintenance areas, i.e., the cockpit, the use of short, accessible harnesses from the bulkhead to the equipment should be considered to allow ease of replacement of a damaged harness (without the need for a full system harness replacement).

6.1.2.1 Positioning of Equipment and Interconnects

The positioning of equipment should allow easy access to the fiber optic interconnects and not introduce the possibility of damage to harnesses or interconnects during maintenance, removal, and installation.

Interconnects should be positioned so as not to introduce excessive bending to harnesses, or force on the cables exiting interconnects.

Wherever possible, interconnects should not be positioned in Severe Weather and Moisture Prone (SWAMP) areas.

6.1.2.2 Harness Routing

Routing of harnesses should take into account:

- High maintenance areas.
- Areas where additional protection to the harness can be afforded.
- Ease of access.

An installation can be broken down into two specific main elements: Line Replacement Units (LRU) and the aircraft platform. The installation and routing of fiber optic harnesses can greatly influence the integrity and performance of the physical layer. For guidelines on harness installation considerations, the reader should refer to **ARINC Report 806:** *Fiber Optic Installation and Maintenance Procedures.*

6.1.2.3 Fiber Optic Harness Composition

To determine the composition of the fiber optic harness, the designer should take into account any sparing accommodation that may be designed into each LRU in the link. For example, some LRUs may be designed to accommodate spare fiber conductors in unused connector cavities, therefore providing for the quick restoration of a failed link. To accommodate this feature, the aircraft cable harnesses that comprise the link need to include the spare fibers as well.

Conversely, even though an LRU that is being integrated into the aircraft may have this sparing feature, it may not be compatible with the airframe manufacturer's overall fiber optic maintenance philosophy.

6.1.3 Fiber Routing Considerations within LRUs

Routing fiber optic cables internally should take into account:

- Minimum bend radius of the cable
- Sharp edges or moving objects
- Termini to be used
- Ease of access
- Ample tolerance in harness designs (e.g., 1 or 2 inches)
- Fiber management (retention, straps, etc.)

Considerations for internal routing within LRUs are similar in many ways to the external cable routing considerations.

CAUTION

Routing cabling about moving objects or heat sources should be avoided whenever possible.

Do not exceed the bend radius limits found in the recommendations of the fiber or fiber cable manufacturer. Early planning and consideration during mechanical layout of other internal components is a must.

Care must be taken during assembly to prevent kinking of the fiber optic cabling. While the cable may appear to be intact after final installation, severe performance losses may become evident during testing.

Many connections route from the I/O connectors to an internal physical board. It is important to consider the required space to attach or remove the termini.

As defined in Section 5.0 of this document, there are jacketed and buffered fibers. Since the LRUs must be qualified, installation options that meet the functionality and overall requirements for the specific application must be considered.

For applications where there is a need for denser packaging, a buffered fiber of 900 μm can be utilized as an option to a fully jacketed fiber. Packaging approaches include the following:

- Buffered fiber with board hold downs that assist in the guidance/routing of the buffered fibers. These can serve as a “racetrack” for the fiber and also accommodate additional fiber for routing purposes.
- Fiber Circuits where a flat flex auto routed buffer is employed to consolidate the routings.
- Trays with lids for manufacturing modularity.

7.0 SAFETY

7.1 Personal Safety

This series of guidelines details the use of substances and procedures that could be injurious to health and safety of individuals if all adequate precautions are not taken. They refer only to technical suitability and in no way absolve the designer, the producer, the supplier, or the user from statutory and all other legal obligations relating to personal safety during any stage of use.

While the information below is not specific to this document, safety issues must be adhered to.

7.2 Hazards

Specific attention is drawn to Section 7.2.1, Safety, which details a number of hazards that may not be exhaustive. Detailed specifications should also provide the following information in a prominent position in the document under the heading WARNING.

7.2.1 Safety

7.2.1.1 Fiber Optic Connectors

When used as an integral part of optical fiber systems, fiber optic connectors may emit potentially hazardous light waves. Injury or damage to the eyes may be caused by infrared, ultraviolet, high intensity visible, and coherent light.

7.2.1.2 Optical Fiber

Special care should be taken when handling optical fiber. Injury can be caused by skin puncture, particularly in the area of the eyes. Small pieces of optical fiber can be inhaled. Every precaution should be taken to restrict the possibilities of injury by the use of protective equipment and clothing.

7.2.1.3 Eye Safety

Terminated and un-terminated fiber optic cables may emit potentially hazardous light waves by infrared, ultraviolet, high intensity, visible, and coherent light. This light may be injurious to the individual and cause injury or permanent eye damage; for this reason, it is prohibited to directly view the end of an optical fiber, terminated optical fiber, or connector when it is transmitting or propagating energy.

When handling fiber optic cables or bare fibers, particularly during termination processes, eyeglasses should be worn to prevent accidental ingress of glass shards into the eyes and reduce the chance of eye damage.

The regulations for eye safety during research, development, production, or testing of Laser-based systems are the main focus of the regulations and control criteria contained in CFR Title 21, Part 1040, and ANSI Z136.1. The reason that eye safety is so important in the field of Lasers and Laser-based systems is that they produce concentrated light energy, and the functions of the human eye are light amplification, beam or image focusing, and absorption of light energy. Any amplification of an already collimated (concentrated) beam of light energy could reasonably be expected to create a higher classification of light energy at the beam focal point. In the human eye, that focal point is the retina. Any further focusing of a collimated beam of light energy will increase the density of the optical energy of that beam. The sensitive tissue, vitreous fluid, and light detection cells of the human eye are not meant to absorb any energy (much less light energy) that can be measured in watts. As a result, serious and permanent eye damage can occur if this concentrated light is viewed directly.

All equipment housing laser light sources should be marked with the recognized symbol for lasers and include a warning label detailing the safety requirements to be taken. Figure 7-1 shows an example of the international symbol for laser sources, while Figures 7-2 through 7-4 show examples of laser type warning labels.

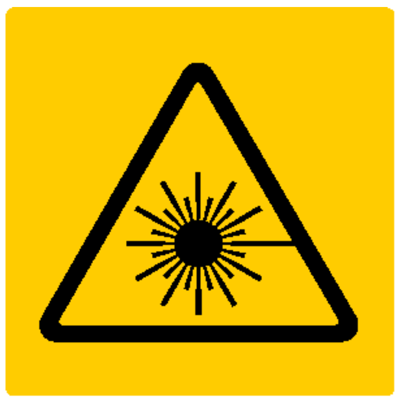


Figure 7-1 – International Laser Warning Label

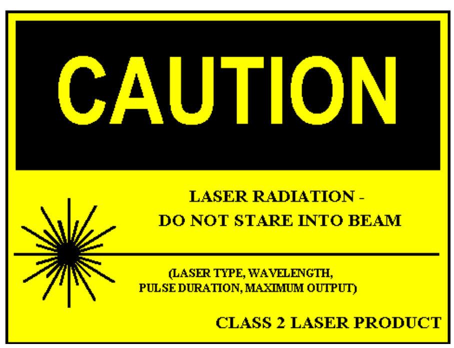


Figure 7-2 – Class 2 Laser Warning Label

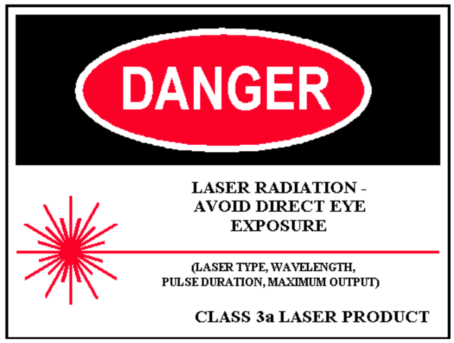


Figure 7-3 – Class 3a Laser Warning Label

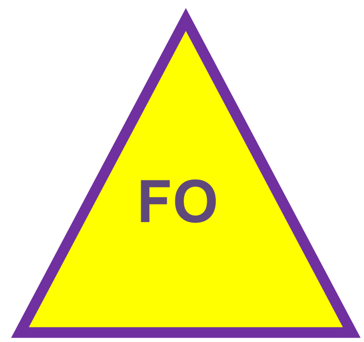
Method of Attachment: Adhesive Triangle Frame: Violet, 1/32-inch line width Triangle Dimensions: 1/2 in x 1/2 inch (HxW) Triangle Background Color: Yellow Font: Arial Font Size 2.5 mm (0.10 in)	

Figure 7-4 – Fiber Optic Label

7.2.1.4 Chemical Safety

Certain chemicals used to prepare and clean optical fiber may be considered hazardous if inhaled, ingested by mouth, or contact with the skin. The use of non-hazardous liquids is preferred. If the use of hazardous chemicals is deemed necessary, all safety precautions should be strictly followed in accordance with the supplier's instructions.

7.2.1.5 Epoxies

Materials, such as epoxy resins or adhesives used in the assembly of fiber optic terminations, may contain hazardous components that may cause allergic reactions or other symptoms. The manufacturer's usage instructions should be followed at all times and, where stipulated, suitable hand protection, i.e., surgical gloves, should be worn.

7.2.1.6 Test Equipment

When using test equipment, the manufacturer's instructions, particularly those relating to eye safety, should be closely followed.

7.0 SAFETY

While manufacturers information may indicate that equipment, such as microscopes, may have protective filters the user should never use the equipment to examine the end face of a fiber optic terminus while it is transmitting or propagating energy.

Fault location equipment such as visual fault locators uses a high intensity light to check the integrity of a fiber optic cable. This light is typically produced by Class 2 lasers. Therefore, under no circumstance should the beam be looked at directly when connected or disconnected from the fiber under test.

For detailed information on fiber optic safety precautions, refer to **ARINC Report 805:** *Fiber Optic Test Procedures* and **ARINC Report 806:** *Fiber Optic Installation and Maintenance Procedures.*

8.0 TESTING

8.1 Testing

During the life cycle of a fiber optic installation elements of testing will be required to ascertain the integrity of the passive components, active devices, and associated system components. The test philosophy is applicable from the manufacture of the individual fiber optic cables through to the in-service support of the application. This section aims to provide a brief résumé of the various test requirements expected to be seen for a fiber optic installation plus an overview of the pieces of test equipment and their purpose. A full breakdown of test requirements can be found in **ARINC Report 805:** *Fiber Optic Test Procedures.*

8.2 Test Equipment

There are a number of different types of test equipment available to carry out the various aspects of testing fiber optic applications; brief descriptions of the types of equipment and their use are detailed below. It must be noted that test equipment holdings are dependent on the required levels of test defined for a specific work area; therefore, any area involved in the manufacture, installation, or support of a fiber optic application must review their testing regime and allocate the relevant equipment to match their needs.

8.2.1 White Light Source

A simple white light source can be used for continuity testing and end-to-end fiber identification. The source can comprise of a flashlight (torch) incorporating an adaptor to efficiently couple the light into the fiber under test. This method of testing is well suited to larger core fibers; however, it may not be adequate for use on single mode fibers, and for this a visual fault locator would be better suited.

8.2.2 Visual Fault Locator

A Visual Fault Locator (VFL) is typically used for fiber optic cable continuity testing, end to end fiber identification, identifying microbends, or areas where fiber has exceeded its minimum bend radius. It is also useful for identifying the location of broken fibers within a cable where the light fluoresces through the buffer and outer jacket of the cable.

The VFL is designed for attachment directly to the connector ferrule and the visible red LED (Class II laser light) is coupled into the fiber using a steady or pulsed beam. Use caution when viewing the emitted visible laser light; try to project the emitted light onto a suitable surface. Never directly view the emitted light.

Figure 8-1 shows an example of a broken fiber within a fiber optic cable assembly. It must be noted that the degree of light emitted through the outer jacket is directly dependent on the cable construction and lower levels of light may be emitted where different materials are used in the cable construction.

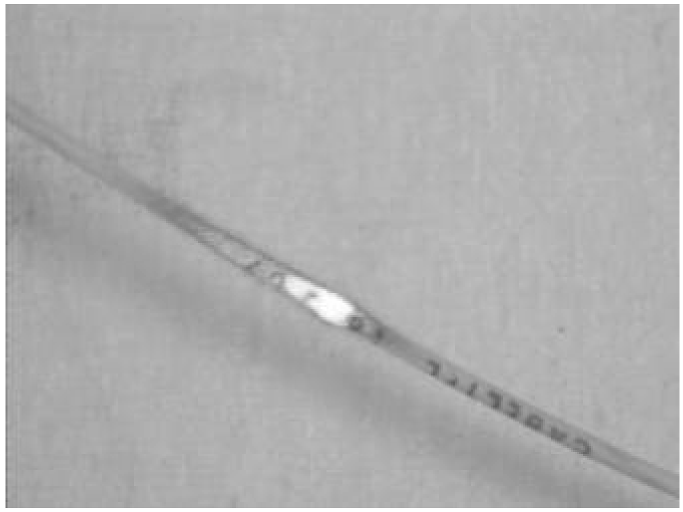


Figure 8-1 – Example of a VFL Locating a Break in a Fiber within a Cable

8.2.3 Inspection Microscopes

Inspection microscopes are used to examine the end face of an optical ferrule to ascertain the quality of finish of a polished fiber and check for scratches, chips, pits, cracks, etc., or to inspect for end face contamination. They are available as bench mounted products or, as is more likely for aerospace operators, hand held.

Typical magnification levels of hand-held microscopes are x200 and x400. The x200 magnification is recommended for use when examining multimode fibers and x400 magnification for single mode fibers.

Hand-held inspection microscopes are usually fitted with protective filters for eye safety; however, the user should never use the equipment to examine the end face of fiber optic termini while the fiber is transmitting or propagating energy.

8.2.4 Light Source

A light source is usually an LED or laser diode used to inject an optical signal into a fiber to test the performance of the fiber optic system. LED sources have relatively large emitting areas and are typically used for larger core multimode fibers; a laser optical source is usually used to test single mode fiber.

Light sources are available at a single wavelength, i.e., 850 nm for multimode fibers, or dual wavelength, i.e., 1310/1550 nm for single mode fibers.

It is important that high-quality jumpers, also known as launch cables or test leads, be used to ensure repeatable accurate measurements. See Section 8.2.8.

8.2.5 Power Meter

Power meters are optical testing instruments designed to measure the average power of the continuous light beam produced by the light source and are used to measure the signal power through the fiber.

8.2.6 Optical Time Domain Reflectometer

An Optical Time Domain Reflectometer (OTDR) is an instrument that analyzes light loss in an optical fiber by injecting a laser pulse into the fiber and measuring the backscatter (Rayleigh) and reflection (Fresnel) of light as a function of time. By comparing the amount of light scattered back at different times, the OTDR analyzes the light characteristics to determine the location of any events in the fiber such as interconnects splices, fiber breaks, etc. These events are then displayed as occurrences at indicated lengths along the fiber on a visual display screen. The accuracy of these lengths is controlled by the resolution of the OTDR and, depending on the type of OTDR, can be measured down to millimeter resolution. Figure 8-2 shows an example of a trace with a nominally square laser pulse launched into an optical fiber at the instrument bulkhead and a reflective event, such as a connector, at some distance along the fiber.

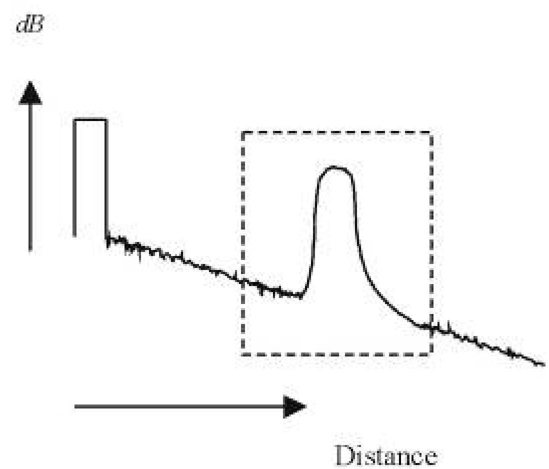


Figure 8-2 – OTDR Trace with Event

Originally designed for long haul telecommunications installations, OTDRs suffer from a phenomenon known as “event dead zone.” This dead zone is a limit of the OTDR to discriminate between closely spaced events, including the instrument’s bulkhead connector. This dead zone can be many meters in length and requires suitable jumpers between the equipment and the cable under test to remove the event dead zone. OTDRs with millimeter resolution have been developed for the aerospace industry resulting in a zero dead zone, which allows the use of short jumpers; however, these OTDRs are extremely expensive compared with the normal telecommunication versions.

8.2.7 Interferometer

Interferometry is a method of measuring the topography of a surface by the use of light waves. This technique can be utilized to measure the end face of a fiber optic ferrule. The resultant measurements can provide a variety of information including:

- Radius of curvature.
- Fiber apex.

- Fiber protrudence or cut-back.
- End face profile.

Until recently, interferometers have been items of bench-mounted laboratory equipment, and as a consequence, very expensive. However, new measuring techniques and utilizing software to analyze data and provide pass/fail criteria have produced small, portable interferometers outputting data onto laptop computers.

This move towards portable, affordable equipment allows the interferometer to be considered for use as a quality inspection tool in areas such as a cable/harness manufacturing shop where testing a percentage of produced products to ensure the same level of quality is being achieved. The portability of the equipment may also allow end face interferometry measurements to be taken on installed cables, as long as access is available to the termini.

8.2.8 Jumpers

For accurate and reproducible measurement of Insertion Loss (IL) and Return Loss (RL) of fiber optic assemblies, it is important to use Aerospace-Certified Measurement Quality Jumpers (AMQJ) in conjunction with an optical loss test set. By definition, an AMQJ is a jumper that is of high optical quality, is highly repeatable in successive connections, and is consistent with other measurement quality jumpers in connections.

8.3 Test Requirements

This section aims to provide a breakdown of where fiber optic testing may be required, together with information of what testing may be required. A full description of test methods can be found in **ARINC Report 805:** *Fiber Optic Test Procedures.*

8.3.1 Cable Delivery

On receipt of bulk fiber, an OTDR measurement may be taken to ascertain the amount of cable delivered, together with indication of any events that may be present in the fiber. If an OTDR is not available, an insertion loss measurement may be taken to ensure the correct figures can be achieved in accordance with the product quality sheet.

8.3.2 Cable Assembly

During cable assembly and contact termination, inspection will take place as part of the polishing process. When completed, the assembled cable will then be subjected to additional inspection an insertion loss measurement and, if specified, a return loss measurement. In addition, end face geometry measurements may be taken using an interferometer to provide a record for auditing records. In all cases, a test report should be included with the completed assembly.

8.3.3 Harness Assembly

Following harness assembly, an inspection, insertion loss, and return loss may be specified before the assembly is released for issue.

8.3.4 Harness Installation

8.3.4.1 Pre-Installation

Upon receipt of a completed harness assembly and before installation, additional tests may be specified to ensure integrity of the assembly and pre-installation loss figures. Typical tests may include VFL and insertion loss.

8.3.4.2 Post-Installation

Post-installation tests may comprise of insertion loss and return loss, if deemed necessary, or limited to a system Built-In-Test Equipment (BITE). If harness end points are not easily accessible, i.e., fin tip installation, then the use of an OTDR may be required to ensure system integrity.

8.3.5 In-Service

8.3.5.1 Rectification

In-service testing may only be deemed necessary when rectification work is required and may be broken down into specific test requirements for different maintenance activities; for example:

- Identification of fiber location: VFL or white light source.
- Replacement of fiber optic cable: Inspection, insertion loss, and return loss.
- Replacement of LRU: BITE.
- Un-mating and mating of connectors: Inspection, BITE.

8.3.5.2 Scheduled Maintenance

This element of test will be directly linked to the requirements raised within the breakdown of the scheduled maintenance and may involve elements of all the identified test methods.

APPENDIX A OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664, PART 2 – 100BASE-FX FULL DUPLEX ETHERNET OPERATING AT 1300NM OVER MULTIMODE FIBER

A-1 Scope

This appendix defines an optical interface specification for aircraft equipment (LRUs) complying to ARINC Specification 664P2 100BASE-FX implemented with an optical physical layer at a nominal wavelength of 1300 nm.

The basis of this specification is IEEE 802.3. Where possible, the same optical parameter values have been adopted. However, this specification does take into account the additional optical losses involved in implementing aircraft optical links and also the particular constraints imposed by aircraft equipment (in terms of defining test points).

A-1.1 Relationship to ARINC Specification 664

ARINC Specification 664 refers to this appendix for equipment optical interface specifications.

A-1.2 Relationship to ARINC Report 804

ARINC Report 804 appendices refer to this appendix to complete the optical interface specifications for optical transceivers. This specification assumes the use of ARINC 804-compliant active devices within the equipment.

A-1.3 Relationship to ARINC Specifications 801/802

This appendix refers to ARINC Specification 801 and 802 for connectors and cable for use when testing equipment. Link budgets are calculated using data representative of ARINC Specifications 801 and 802 connectors and cables.

A-2 Background (Including Wavelength Selection)

Ethernet networks and their derivatives are an increasingly popular choice for data communication on aircraft. The data rate at which aircraft manufacturers begin to consider optical fiber physical layer in preference to copper is 100 Mbps. In IEEE 802.3, the 100 Mbps-over-fiber standards is called 100BASE-FX (commonly called Fast Ethernet). The baud rate at which 100BASE-FX runs, i.e., the rate at which the transceiver needs to operate, is 125 MBaud. IEEE 802.3 defines the nominal operating wavelength of 100BASE-FX to be 1300 nm.

COMMENTARY

A non-IEEE 802.3 compliant variation of 100BASE-FX may select operation at a nominal wavelength of 850 nm (short wavelength) as opposed to 1300 nm (long wavelength). There are arguments for utilizing either wavelength, so appendices covering both alternatives exist under ARINC Report 803. This appendix considers the 1300 nm option as currently mandated in the 100BASE-FX standard. The short wavelength option is covered in Appendix B.

There are components available for implementing an optical physical layer for ARINC Specification 664 at both 850 nm and 1300 nm. The system designer should select a single wavelength for the network to ensure that all equipment is interoperable.

A-3 Test Points and Interoperability Point

The objective of these specifications is to ensure interoperability between equipment: the interoperability point is at the box connector.

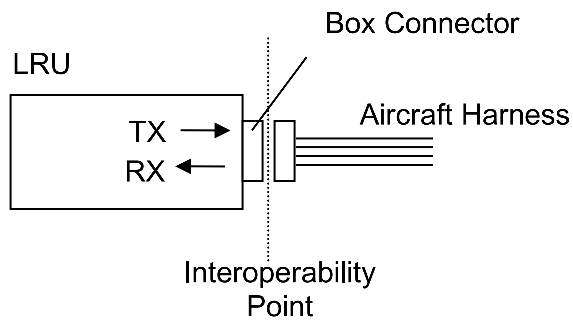


Figure A-1 – Definition of Interoperability Point

However, it is not possible to access the equipment connector to measure optical parameters directly at the interoperability point, so it is necessary to define test points at which measurements are made to confirm compliance of the equipment at the interoperability point. These test points should be used during acceptance test procedures and qualification testing.

A-3.1 Test Point for Measuring Optical Transmit Signal (TP1)

Parameters measured at TP1: Wavelength (λ), spectral width ($\Delta\lambda$), average launch power (P_0), rise/fall time (T_r/T_f), extinction ratio (E_r), overshoot, undershoot, transmit signal jitter, transmit signal eye pattern.

TP1 is defined as immediately after a test cable assembly comprising the mating half of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly is connected to the transmitting equipment (at the interoperability point).

APPENDIX A
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664, PART.2 - 100BASE-FX FULL DUPLEX ETHERNET OPERATING AT 1300nm OVER MULTIMODE FIBER

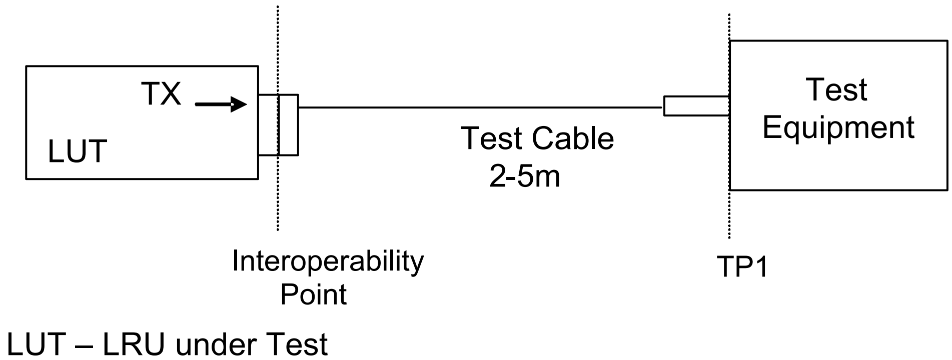


Figure A-2 – Definition of Test Point 1 (TP1)

A-3.2 Test Point for Measuring Optical Receive Signal (TP2)

Parameters measure at TP2: equipment receiver sensitivity (S), receiver saturation input power (P_{sat}), receive signal jitter.

TP2 is defined as immediately after a test cable assembly comprising of a duplicate of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly replaces the receiving equipment (at the interoperability point).

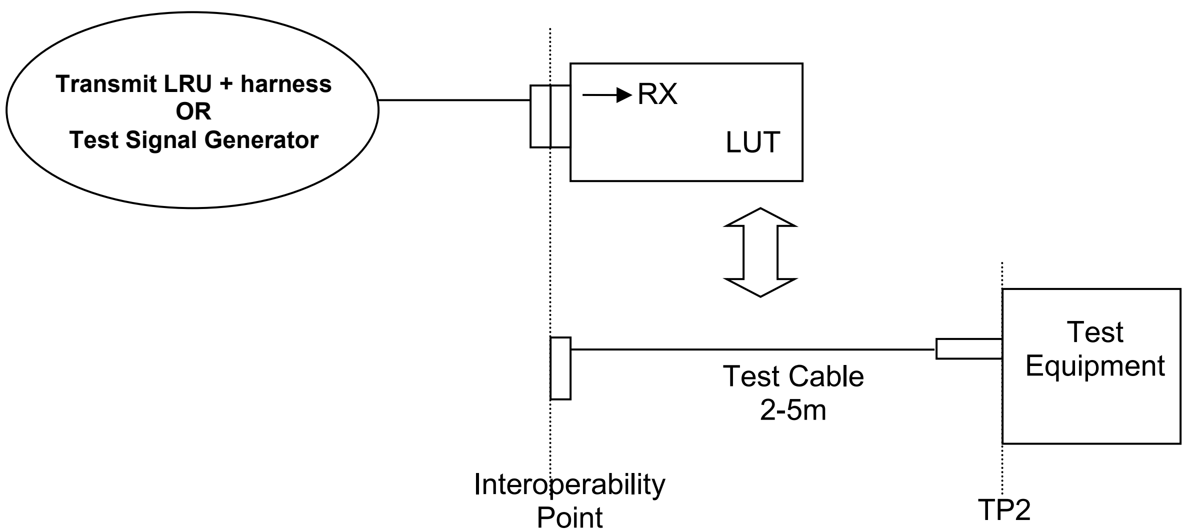


Figure A-3 – Definition of Test Point 2 (TP2)

Measuring the receiver sensitivity of the LUT requires a test signal generator that outputs ARINC Specification 664 compliant data and an attenuator to reduce the average optical power. It also requires that the LUT can be monitored in some way to indicate that it is receiving valid data. It is not possible to perform an actual bit error rate test without a test point inside the box – this specification relies on the use of compliant active devices as described in ARINC Report 804.

A-4 Optical Interface Definition

Optical interface parameters are defined for operation at a nominal wavelength of 1300 nm (long wavelength) over multimode fiber.

All parameters are defined at the equipment interface – these are not specifications for optoelectronic transceivers. For information on transceiver specifications, see ARINC Report 804.

A-4.1 Transmit Characteristics

The transmit channels of compliant equipment should meet the specification defined in Table A-1, as measured at TP1.

Table A-1 – Transmit Characteristics at 1300 nm

Parameter	Min	Max
Wavelength (λ)	1270 nm	1380 nm
FWHM Spectral Width ($\Delta\lambda$)	N/A	200 nm
Line rate	125 MBaud	
Ave Launch Power[1,2] (P_o)	- 19.5 dBm	-14 dBm
Rise/Fall-time (T_r/T_f)	0.6 ns (10-90%)	3.5 ns (10-90%)
Overshoot	N/A	25%
Undershoot	N/A	3%
Extinction Ratio (E_r)	10dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Dictates the use of an Option B (increased link budget) transmitter as defined in ARINC Report 804.

A-4.2 Receive Characteristics

The receive channels of compliant equipment should meet the specification defined in Table A-2, as measured at TP2.

APPENDIX A
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664, PART.2 - 100BASE-FX FULL DUPLEX ETHERNET OPERATING AT 1300nm OVER MULTIMODE FIBER

Table A-2 – Receive Characteristics at 1300 nm

Parameter	Min	Max
Receiver Sensitivity[1, 2](S)	N/A	- 29.5 dBm
Receiver Saturation Input Power[2] (P_{sat})	-14 dBm	N/A
BER[2,3]	10^{-12}	
Return Loss	12 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Measured with a 125 Mbps, PRBS 2^7-1, NRZ test pattern.
3. BER value used to measure receiver sensitivity.

A-4.3 Link Power Budget

The optical power figures in Tables A-1 and A-2 are based on a worst-case link power budget calculated using the figures in Table A-3 and the 100BASE-FX worst-case receiver sensitivity (S) value of –31 dBm.

Table A-3 – Link Power Budget at 1300 nm

Link Power Budget	10 dB
Operating Distance	200 m
Number of Connectors (excluding LRU connector)	6
Channel Insertion Loss	2 dB[1]
Aircraft Installation Loss[2]	2 dB
Repair Budget[3]	2 dB
Link Power Penalties and Unallocated Margin	4 dB[4]

Notes:

1. Based on 0.3 dB worst-case loss per connector and 3 dB/km of fiber attenuation (at 1300 nm).
2. Aircraft Installation Loss is an estimated worst-case figure that takes into account losses due to cable fixing and bending when installed on an aircraft.
3. Repair Budget is an estimated worst-case figure that takes into account losses due to fiber splices or other post-installation repair procedures.
4. This value is an estimated figure that takes into account several factors, including connectorization, etc. The value has not been confirmed.

An LRU that exceeds the operational distance requirement while meeting all other optical specifications is considered compliant.

A-4.4 Jitter Specification

Jitter specifications are shown in Table A-4.

Table A-4 – Jitter Specification at TP1 and TP2

Test Point	Total Jitter [1] (ns)	Deterministic Jitter (ns)
TP1	2.36	1.6
TP2	2.96	2.2

Note:

5. Total Jitter = Deterministic Jitter + Random Jitter

COMMENTARY

Deterministic jitter is the sum of duty cycle jitter and data-dependent jitter.

A-4.5 Transmitter Optical Waveform (Transmit Eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye pattern as shown in Figure A-4. The transmit mask is not used for response time or jitter specification. The eye diagram axes are both normalized so they can be applied to patterns of any optical power amplitude or data rate.

The mask is defined in conjunction with a filter, which is used in the reference receiver when testing the device. The filter reduces the effects of overshoot and noise, producing a more consistent result, and ensures similar measurements across different pieces of test equipment. The filter is a fourth-order, Bessel-Thomson, low-pass filter as defined in ITU-T G.957 and as called in IEEE 802.3 Clause 38 (1000BASE-SX/LX standard).

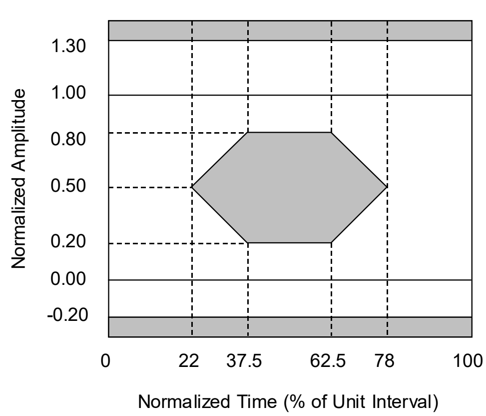


Figure A-4 – Transmit Eye

APPENDIX B OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664P2 – 100BASE-FX FULL DUPLEX ETHERNET OPERATING AT 850NM OVER MULTIMODE FIBER

B-1 Scope

This appendix defines an optical interface specification for aircraft equipment (LRUs) complying with ARINC Specification 664, Part 2, 100BASE-FX implemented with an optical physical layer at a nominal wavelength of 850 nm.

The basis of this specification is IEEE 802.3. Where possible, the same optical parameter values have been adopted. However, this specification does take into account the additional optical losses involved in implementing aircraft optical links and also the particular constraints imposed by aircraft equipment (in terms of defining test points).

B-1.1 Relationship to ARINC Specification 664

ARINC Specification 664 refers to this appendix for equipment optical interface specifications.

B-1.2 Relationship to ARINC Report 804

ARINC Report 804 appendices refer to this appendix to complete the optical interface specifications for optical transceivers. This specification assumes the use of ARINC 804-compliant active devices within the equipment.

B-1.3 Relationship to ARINC Specifications 801/802

This appendix refers to ARINC Specification 801 and 802 for connectors and cable for use when testing equipment. Link budgets are calculated using data representative of ARINC Specification 801 and 802 connectors and cables.

B-2 Background (Including Wavelength Selection)

Ethernet networks and their derivatives are an increasingly popular choice for data communication on aircraft. The data rate at which aircraft manufacturers begin to consider optical fiber physical layer in preference to copper is 100 Mbps. In IEEE 802.3, the 100 Mbps-over-fiber standard is called 100BASE-FX (commonly called Fast Ethernet). The baud rate at which 100BASE-FX runs, i.e., the rate at which the transceiver needs to operate, is 125 MBaud. IEEE 802.3 defines the nominal operating wavelength of 100BASE-FX to be 1300 nm.

In addition to 100BASE-FX, IEEE 802.3 also defines communications at 1000 Mbps (Gigabit Ethernet) that has a baud rate of 1250 Mbaud. For short wavelength (850 nm) communication over multimode fiber, the IEEE 802.3 specification identifies the Gigabit Ethernet option called 1000BASE-SX. Devices that are compliant with 1000BASE-SX can potentially also be run at 125 Mbaud.

COMMENTARY

A non-IEEE 802.3 compliant variation of 100BASE-FX may select operation at a nominal wavelength of 850 nm (short wavelength) as opposed to 1300 nm (long wavelength). There are arguments for utilizing either wavelength, so appendices covering both alternatives exist under ARINC Report 803. This appendix considers the 850-nm option and uses the 1000BASE-SX standard as its basis (albeit at a different baud rate). The long wavelength option is covered in Appendix A.

There are components available for implementing an optical physical layer for ARINC Specification 664 at both 850 nm and 1300 nm. The system designer should select a single wavelength for the network to ensure that all equipment is interoperable.

B-3 Test Points and Interoperability Point

The objective of these specifications is to ensure interoperability between equipment: the interoperability point is at the box connector.

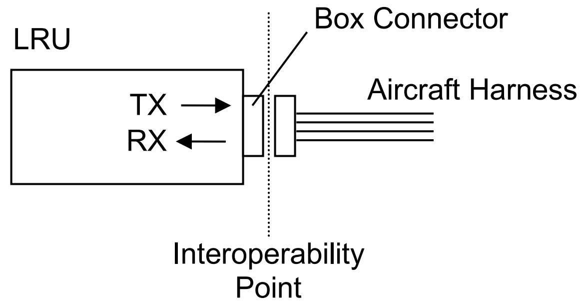


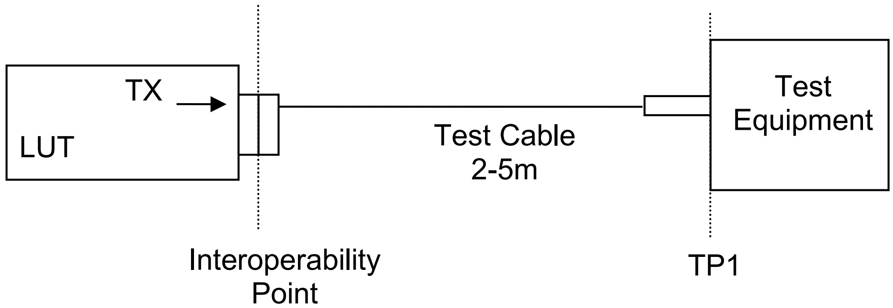
Figure B-1 – Definition of Interoperability Point

However, it is not possible to access the equipment connector to measure optical parameters directly at the interoperability point so it is necessary to define test points at which measurements are made to confirm compliance of the equipment at the interoperability point. These test points should be used during acceptance test procedures and qualification testing.

B-3.1 Test Point for Measuring Optical Transmit Signal (TP1)

Parameters measured at TP1: Wavelength (λ), spectral width ($\Delta\lambda$), average launch power (P_0), rise/fall time (T_r/T_f), extinction ratio (E_r), overshoot, undershoot, transmit signal jitter, transmit signal eye pattern.

TP1 is defined as immediately after a test cable assembly comprising the mating half of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly is connected to the transmitting equipment (at the interoperability point).



LUT – LRU Under Test

Figure B-2 – Definition of Test Point 1 (TP1)

B-3.2 Test Point for Measuring Optical Receive Signal (TP2)

Parameters measure at TP2: Equipment receiver sensitivity (S), receiver saturation input power (P_{sat}), receive signal jitter.

TP2 is defined as immediately after a test cable assembly comprising of a duplicate of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly replaces the receiving equipment (at the interoperability point).

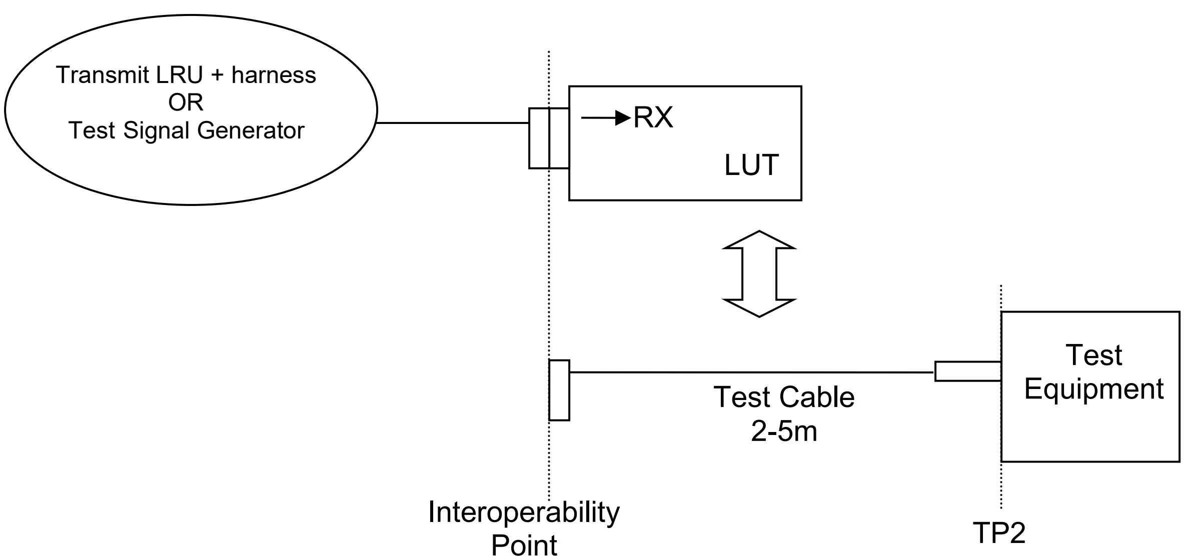


Figure B-3 – Definition of Test Point 2 (TP2)

Measuring the receiver sensitivity of the LUT requires a test signal generator that outputs ARINC Specification 664 compliant data and an attenuator to reduce the average optical power. It also requires that the LUT can be monitored in some way to indicate that it is receiving valid data. It is not possible to perform an actual bit error rate test without a test point inside the box. This specification relies on the use of compliant active devices as described in ARINC Report 804.

B-4 Optical Interface Definition

Optical interface parameters are defined for operation at nominal wavelength of 850 nm (short wavelength) over multimode fiber.

All parameters are defined at the equipment interface – these are not specifications for optoelectronic transceivers. For information on transceiver specifications, see ARINC Report 804.

B-4.1 Transmit Characteristics

The transmit channels of compliant equipment should meet the specification defined in Table B-1, as measured at TP1.

Table B-1 – Transmit Characteristics at 850 nm

Parameter	Min	Max
Wavelength (λ)	770 nm	860 nm
RMS Spectral Width ($\Delta\lambda$)	N/A	0.85 nm
Line rate	125 MBaud	
Ave Launch Power[1,2] (P_o)	- 6.5 dBm	1.0 dBm
Rise/Fall-time (T_r/T_f)	0 ns	3.5 ns (10-90%)
Extinction Ratio (E_r)	9 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Dictates the use of an Option B (increased link budget) transmitter as defined in ARINC 804.

B-4.2 Receive Characteristics

The receive channels of compliant equipment should meet the specification defined in Table B-2, as measured at TP2.

Table B-2 – Receive Characteristics at 850 nm

Parameter	Min	Max
Receiver Sensitivity[1, 2] (S)	N/A	-15.5 dBm
Receiver Saturation Input Power[2] (P_{sat})	1.0 dBm	N/A
BER[3]	10^{-12}	
Return Loss	12 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Measured with a 125 Mbps, PRBS 2^7-1, and NRZ test pattern.
3. BER value used to measure receiver sensitivity.

B-4.3 Link Power Budget

The optical power figures in the Tables B-1 and B-2 are based on a worst-case link power budget calculated using the figures in Table B-3 and the 1000BASE-SX worst-case receiver sensitivity (S) value of -17 dBm.

Table B-3 – Link Power Budget at 850 nm

Link Power Budget	9dB
Operating Distance	200 m
Number of Connectors (excluding LRU connector)	6
Channel Insertion Loss	3 dB[1]
Aircraft Installation Loss[2]	2 dB
Repair Budget[3]	2 dB
Link Power Penalties and Unallocated Margin	2 dB[4]

Notes:

1. Based on 0.3 dB worst-case loss per connector and 6dB/km of fiber attenuation (at 850 nm).
2. Aircraft Installation Loss is an estimated worst-case figure that takes into account losses due to cable fixing and bending when installed on an aircraft.
3. Repair Budget is an estimated worst-case figure that takes into account losses due to fiber splices or other post-installation repair procedures.
4. This value is an estimated figure that takes into account several factors including connectorization, etc. The value has not been confirmed.

An LRU that exceeds the operational distance requirement while meeting all other optical specifications is considered compliant.

B-4.4 Jitter Specification

Jitter specifications are shown in Table B-4.

Table B-4 – Jitter Specification at TP1 and TP2

Test Point	Total Jitter [1] (ns)	Deterministic Jitter (ns)
TP1	2.36	1.6
TP2	2.96	2.2

Note:

5. Total Jitter = Deterministic Jitter + Random Jitter

COMMENTARY

Deterministic jitter is the sum of duty cycle jitter and data-dependent jitter.

B-4.5 Transmitter Optical Waveform (Transmit Eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye pattern as shown in Figure B-4. The transmit mask is not used for response time or jitter specification. The eye diagram axes are both normalized so can be applied to patterns of any optical power amplitude or data rate.

The mask is defined in conjunction with a filter, which is used in the reference receiver when testing the device. The filter reduces the effects of overshoot and noise, producing a more consistent result, and ensures similar measurements across different pieces of test equipment. The filter is a fourth-order, Bessel-Thomson, low-pass filter as defined in ITU-T G.957 and as called in IEEE 802.3 Clause 38 (1000BASE-SX/LX standard).

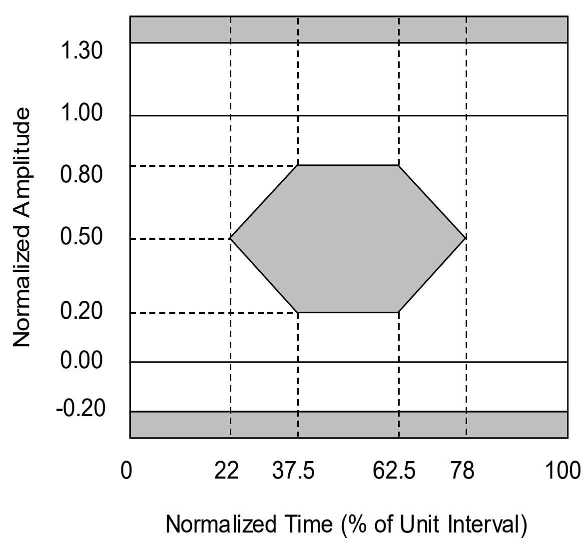


Figure B-4 – Transmit Eye

APPENDIX C OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664P2 – 1000BASE-SX FULL DUPLEX ETHERNET OVER MULTIMODE FIBER

C-1 Scope

This appendix defines an optical interface specification for aircraft equipment (LRUs) complying to ARINC Specification 664, Part 2, 1000BASE-SX implemented with an optical physical layer at a nominal wavelength of 850 nm.

The basis of this specification is IEEE 802.3. Where possible, the same optical parameter values have been adopted. However, this specification does take into account the additional optical losses involved in implementing aircraft optical links and also the particular constraints imposed by aircraft equipment (in terms of defining test points).

C-1.1 Relationship to ARINC Specification 664

ARINC Specification 664 refers to this appendix for equipment optical interface specifications.

C-1.2 Relationship to ARINC Report 804

ARINC Report 804 appendices refer to this appendix to complete the optical interface specifications for optical transceivers. This specification assumes the use of 804-compliant active devices within the equipment.

C-1.3 Relationship to ARINC Specifications 801/802

This appendix refers to ARINC Specifications 801 and 802 for connectors and cable for use when testing equipment. Link budgets are calculated using data representative of ARINC Specifications 801 and 802 connectors and cables.

C-2 Background (Including Wavelength Selection)

Ethernet networks and their derivatives are an increasingly popular choice for data communication on aircraft, particularly at data rates of a gigabit/s and above. In IEEE 802.3, the 1000 Mbps-over-multimode-fiber standard is called 1000BASE-SX. The baud rate, at which 1000BASE-SX runs, i.e., the rate at which the transceiver needs to operate, is 1250 MBaud. IEEE 802.3 defines the nominal operating wavelength of 1000BASE-SX to be 850 nm.

C-3 Test Points and Interoperability Point

The objective of these specifications is to ensure interoperability between equipment; the interoperability point is at the box connector.

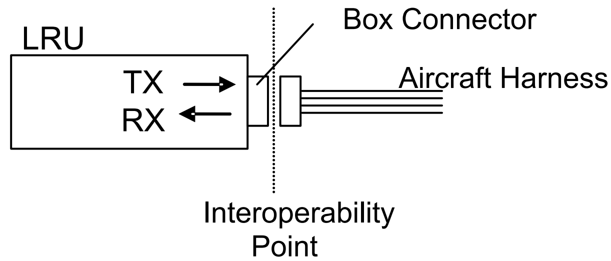


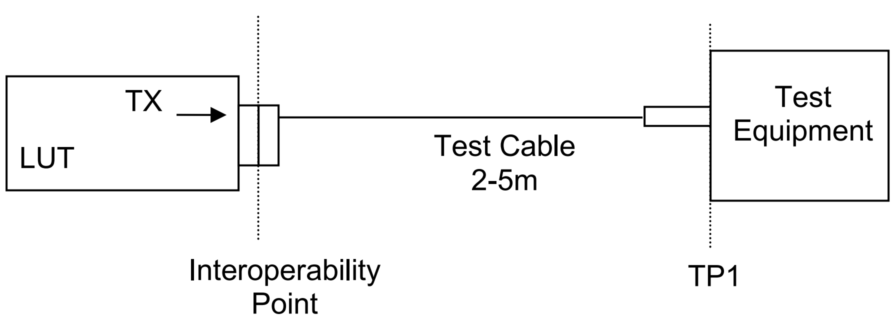
Figure C-1 – Definition of Interoperability Point

However, it is not possible to access the equipment connector to measure optical parameters directly at the interoperability point so it is necessary to define test points at which measurements are made to confirm compliance of the equipment at the interoperability point. These test points should be used during acceptance test procedures and qualification testing.

C-3.1 Test Point for Measuring Optical Transmit Signal (TP1)

Parameters measured at TP1: Wavelength (λ), spectral width ($\Delta\lambda$), average launch power (P_0), rise/fall time (T_r/T_f), extinction ratio (E_r), overshoot, undershoot, transmit signal jitter, transmit signal eye pattern.

TP1 is defined as immediately after a test cable assembly comprising the mating half of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly is connected to the transmitting equipment (at the interoperability point).



LUT – LRU Under Test

Figure C-2 – Definition of Test Point 1 (TP1)

C-3.2 Test Point for Measuring Optical Receive Signal (TP2)

Parameters measure at TP2: Equipment receiver sensitivity (S), receiver saturation input power (P_{sat}), receive signal jitter.

TP2 is defined as immediately after a test cable assembly comprising of a duplicate of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly replaces the receiving equipment (at the interoperability point).

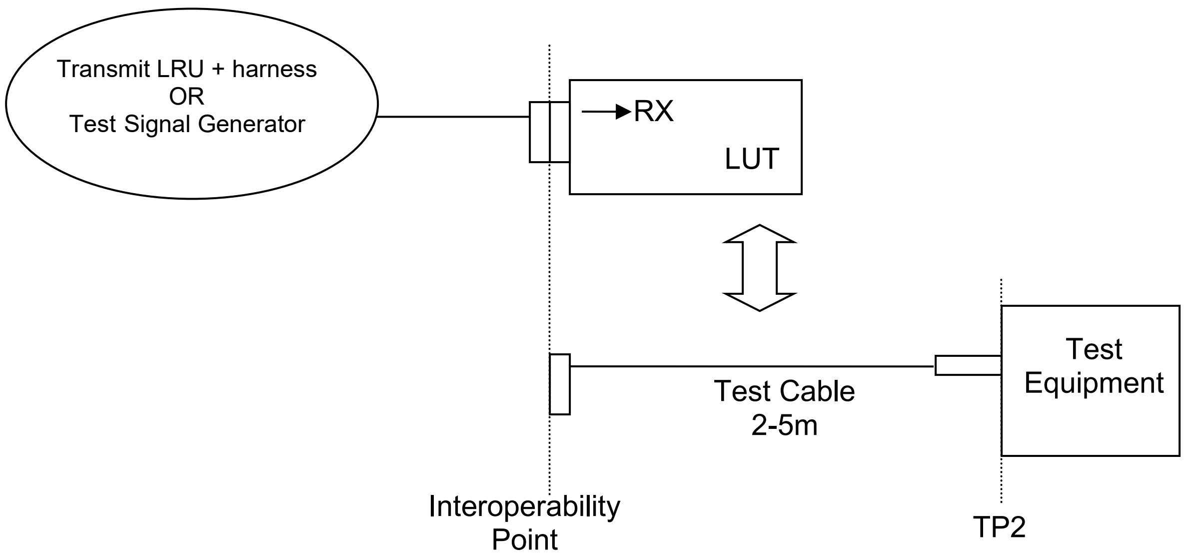


Figure C-3 – Definition of Test Point 2 (TP2)

Measuring the receiver sensitivity of the LUT requires a test signal generator that outputs ARINC 664 compliant data and an attenuator to reduce the average optical power. It also requires that the LUT can be monitored in some way to indicate that it is receiving valid data. It is not possible to perform an actual bit error rate test without a test point inside the box. This specification relies on the use of compliant active devices as described in ARINC Report 804.

C-4 Optical Interface Definition

Optical interface parameters are defined for operation at nominal wavelength of 850 nm (short wavelength) over multimode fiber.

All parameters are defined at the equipment interface – these are not specifications for optoelectronic transceivers. For information on transceiver specifications see ARINC Report 804.

C-4.1 Transmit Characteristics

The transmit channels of compliant equipment should meet the specification defined in Table C-1, as measured at TP1.

APPENDIX C
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664, PART.2 - 1000BASE-SX FULL DUPLEX ETHERNET OVER MULTIMODE FIBER

Table C-1 – Transmit Characteristics at 850 nm

Parameter	Min	Max
Wavelength (λ)	770 nm	860 nm
RMS Spectral Width ($\Delta\lambda$)	N/A	0.85 nm
Line rate	1250 MBaud	
Ave Launch Power[1,2] (P_o)	- 6.5 dBm	1 dBm
Rise/Fall-time (T_r/T_f)	0 ns	0.26 ns (20-80%)
Extinction Ratio (E_r)	9 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Dictates the use of an Option B (increased link budget) transmitter as defined in ARINC Report 804.

C-4.2 Receive Characteristics

The receive channels of compliant equipment should meet the specification defined in Table C-2, as measured at TP2.

Table C-2 – Receive Characteristics at 850 nm

Parameter	Min	Max
Receiver Sensitivity[1, 2] (S)	N/A	-15.5 dBm
Receiver Saturation Input Power[2] (P_{sat})	1.0 dBm	N/A
BER[3]	10^{-12}	
Return Loss	12 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Measured with a 1250 Mbps, PRBS 2^7-1, NRZ test pattern.
3. BER value used to measure receiver sensitivity.

APPENDIX C
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664, PART.2 - 1000BASE-SX FULL DUPLEX ETHERNET OVER MULTIMODE FIBER

C-4.3 Link Power Budget

The optical power figures in the Tables C-1 and C-2 are based on a worst-case link power budget calculated using the figures in Table C-3 and the 1000BASE-SX worst-case receiver sensitivity (S) value of -17 dBm.

Table C-3 – Link Power Budget at 850 nm

Link Power Budget	9dB
Operating Distance	200 m
Number of Connectors (excluding LRU connector)	6
Channel Insertion Loss	3 dB[1]
Aircraft Installation Loss[2]	2 dB
Repair Budget[3]	2 dB
Link Power Penalties and Unallocated Margin	2 dB[4]

Notes:

1. Based on 0.3 dB worst-case loss per connector and 6 dB/km of fiber attenuation (at 850 nm).
2. Aircraft Installation Loss is an estimated worst-case figure that takes into account losses due to cable fixing and bending when installed on an aircraft.
3. Repair Budget is an estimated worst-case figure that takes into account losses due to fiber splices or other post-installation repair procedures.
4. This value is an estimated figure that takes into account several factors including connectorization, etc. The value has not been confirmed.

An LRU that exceeds the operational distance requirement while meeting all other optical specifications is considered compliant.

C-4.4 Jitter Specification

Jitter specifications are shown in Table C-4.

Table C-4 – Jitter Specification at TP1 and TP2

Test Point	Total Jitter [1] (ps)	Deterministic Jitter (ps)
TP1	345	160
TP2	408	200

Note:

5. Total Jitter = Deterministic Jitter + Random Jitter

COMMENTARY

Deterministic jitter is the sum of duty cycle jitter and data-dependent jitter.

C-4.5 Transmitter Optical Waveform (Transmit Eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye pattern as shown in Figure C-4. The transmit mask is not used for response time or jitter specification. The eye diagram axes are both normalized so they can be applied to patterns of any optical power amplitude or data rate.

The mask is defined in conjunction with a filter, which is used in the reference receiver when testing the device. The filter reduces the effects of overshoot and noise, producing a more consistent result, and ensures similar measurements across different pieces of test equipment. The filter is a fourth-order, Bessel-Thomson, low-pass filter as defined in ITU-T G.957, and as called in IEEE 802.3 Clause 38 (1000BASE-SX/LX standard).

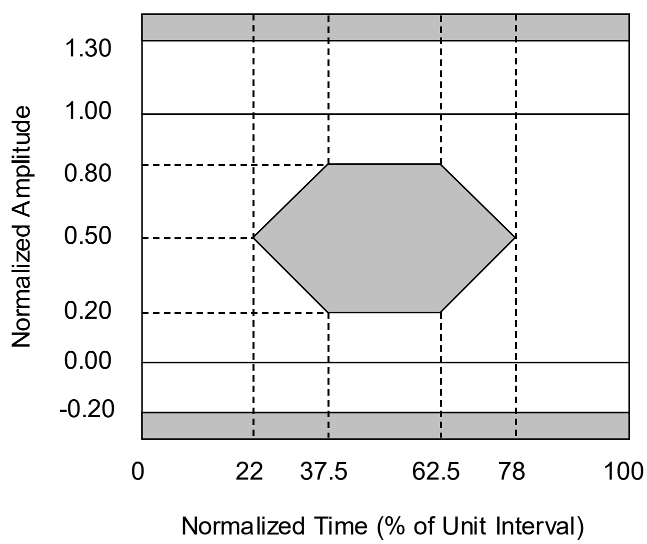


Figure C-4 – Transmit Eye

APPENDIX D OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 817 LOW DATA RATE VIDEO OVER MULTIMODE FIBER

D-1 Scope

This appendix defines an optical interface specification for aircraft equipment (LRUs) complying with ARINC Specification 817 implemented with an optical physical layer.

This specification takes into account the additional optical losses involved in implementing aircraft optical links and also the particular constraints imposed by aircraft equipment (in terms of defining test points).

D-1.1 Relationship to ARINC Specification 817

ARINC Specification 817 refers to this appendix for equipment optical interface specifications.

D-1.2 Relationship to ARINC Report 804

ARINC Report 804 appendices refer to this appendix to complete the optical interface specifications for optical transmitters and receivers. This specification assumes the use of ARINC 804 compliant active devices within the equipment.

D-1.3 Relationship to ARINC Specification 801/802

This appendix refers to ARINC Specifications 801 and 802 for connectors and cable for use when testing equipment. Link budgets are calculated using data representative of ARINC 801 and 802 connectors and cables.

D-2 Background (including Wavelength Selection)

For low data rate video, it is possible to use low-cost optical transmitter technology. To achieve the best link budget (dependent on receiver sensitivity) with low-cost technology, a nominal operating wavelength of 1310nm has been selected. This selection also allows for commonality with commercial low data-rate video test equipment.

D-3 Test Points and Interoperability Point

The objective of these specifications is to ensure interoperability between equipment: the interoperability point is at the box connector.

APPENDIX D
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 817 LOW DATA RATE VIDEO OVER MULTIMODE FIBER

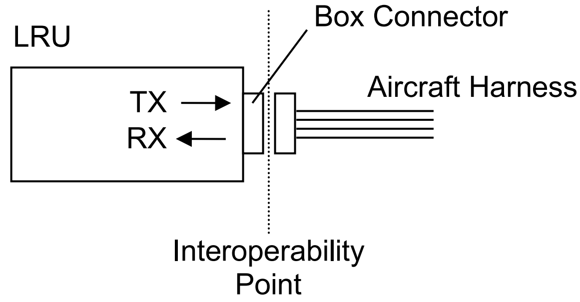


Figure D-1 – Definition of Interoperability Point

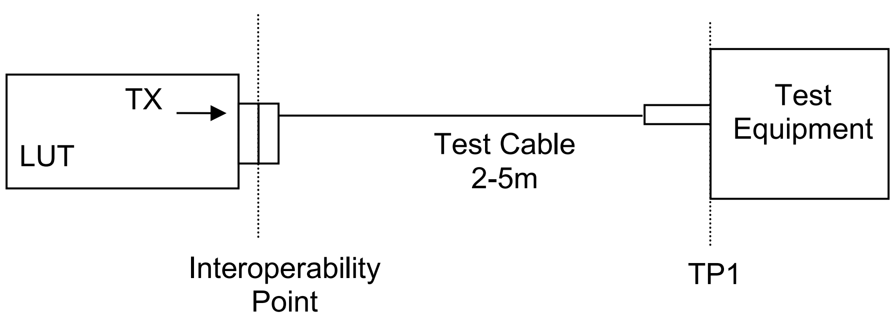
However, it is not possible to access the equipment connector to measure optical parameters directly at the interoperability point so it is necessary to define test points at which measurements are made to confirm compliance of the equipment at the interoperability point. These test points should be used during acceptance test procedures and qualification testing.

D-3.1 Test Point for Measuring Optical Transmit Signal (TP1)

Parameters measured at TP1: Wavelength (λ), spectral width ($\Delta\lambda$), average launch power (P_0), rise/fall time (T_r/T_f), extinction ratio (E_r), overshoot, undershoot, transmit signal jitter, transmit signal eye pattern.

TP1 is defined as the point immediately after the test cable assembly. This test cable assembly is connected to the transmitting equipment (at the interoperability point).

The test cable is an AMQJ between 2 and 5 meters in length, of type consistent with the application. One end is terminated at the mating half of the LUT connector and the other end is terminated with a connector that is compatible with the test equipment. Refer to Section 4.2 in ARINC Report 805.



LUT – LRU Under Test

Figure D-2 – Definition of Test Point 1 (TP1)

APPENDIX D
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 817 LOW DATA RATE VIDEO OVER MULTIMODE FIBER

D-3.2 Test Point for Measuring Optical Receive Signal (TP2)

Parameters measure at TP2: Equipment receiver sensitivity (S), receiver saturation input power (P_{sat}), receive signal jitter.

TP2 is defined as the point immediately after a test cable assembly. This test cable assembly replaces the receiving equipment (at the interoperability point).

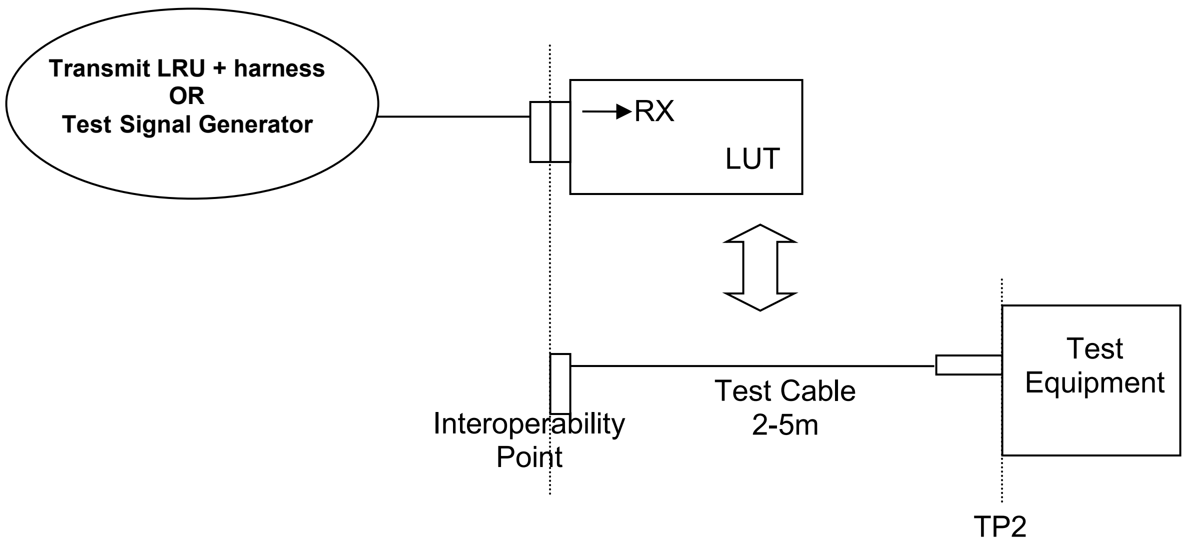


Figure D-3 – Definition of Test Point 2 (TP2)

Measuring the receiver sensitivity of the LUT requires a test signal generator that outputs ARINC 817 compliant data and an attenuator to reduce the average optical power. It also requires that the LUT can be monitored in some way to indicate that it is receiving valid data. It is not possible to perform an actual bit error rate test without a test point inside the box. This specification relies on the use of compliant active devices as described in ARINC Report 804.

D-4 Optical Interface Definition

Optical interface parameters are defined for operation at a nominal wavelength of 1310nm over multimode fiber.

All parameters are defined at the equipment interface – these are not specifications for optoelectronic transmitters and receivers. For information on transmitter and receiver specifications, see ARINC Report 804.

D-4.1 Transmit Characteristics

The transmit channels of compliant equipment should meet the specification defined in Table D-1, as measured at TP1.

Table D-1 – Transmit Characteristics at 1310nm

Parameter	Min	Max
Wavelength (λ)	1270 nm	1350 nm
RMS Spectral Width ($\Delta\lambda$)	N/A	170 nm
Line rate	270 MBaud	
Ave Launch Power[1] (P_o)	-12 dBm	-7.5 dBm
Rise/Fall-time (T_r/T_f)	0.6 ns (10-90%)	3.5 ns (10-90%)
Overshoot	N/A	10%
Undershoot	N/A	3%
Extinction Ratio (E_r)	7 dB	N/A

Note: Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).

D-4.2 Receive Characteristics

The receive channels of compliant equipment should meet the specification defined in Table D-2, as measured at TP2.

Table D-2 – Receive Characteristics at 1310 nm

Parameter	Min	Max
Receiver Sensitivity[1, 2] (S)	N/A	-28 dBm
Receiver Saturation Input Power[2] (P_{sat})	-7.5 dBm	N/A
BER[3]	10^{-10}	
Return Loss	20 dB	N/A

Notes:

1. Allows for 3 dB of additional loss within the equipment (1.5 dB within transmitting equipment and 1.5 dB within receiving equipment).
2. Measured with a 270 Mbps, PRBS, NRZ test pattern, including pathological data sequences representative of SMPTE 259.
3. BER value used to measure receiver sensitivity.

D-4.3 Link Power Budget

The optical power figures in the Tables D-1 and D-2 are based on a worst-case link power budget calculated using the figures in Table D-3 and the worst-case receiver sensitivity (S) value of -28 dBm.

APPENDIX D
OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 817 LOW DATA RATE VIDEO OVER MULTIMODE FIBER

Table D-3 – Link Power Budget at 1310 nm

Link Power Budget	16 dB
Operating Distance	200 m
Number of Connectors (excluding LRU connector)	8
Channel Insertion Loss	6 dB[1]
Aircraft Installation Loss[2]	2 dB
Repair Budget[3]	2 dB
Link Power Penalties and Unallocated Margin	6 dB[4]

Notes:

1. Based on 0.7 dB worst-case loss per connector and 3.0 dB/km of fiber attenuation. Connector loss is greater than described in ARINC Specification 801 to support a variety of other termination possibilities.
2. Aircraft Installation Loss is an estimated worst-case figure that takes into account losses due to cable fixing and bending when installed on an aircraft.
3. Repair Budget is an estimated worst-case figure that takes into account losses due to fiber splices or other post-installation repair procedures.
4. This value is an estimated figure that takes into account several factors, including connectorization, etc. The value has not been confirmed.

An LRU that exceeds the operational distance requirement while meeting all other optical specifications is considered compliant.

D-4.4 Jitter Specification

Jitter specifications are shown in Table D-4.

Table D-4 – Jitter Specification at TP1 and TP2

Test Point	Total Jitter (ns)
TP1	1.00
TP2	1.25

Note: Total Jitter = Deterministic Jitter + Random Jitter

COMMENTARY

Deterministic jitter is the sum of duty cycle jitter and data-dependent jitter.

D-4.5 Transmitter Optical Waveform (Transmit Eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye pattern as shown in Figure D-4. The transmit mask is not used for response time or jitter specification. The eye diagram axes are both normalized so they can be applied to patterns of any optical power amplitude or data rate.

The mask is defined in conjunction with a linear-phase, low-pass filter, which is used in the reference receiver when testing the device. The filter reduces the effects of overshoot and noise, producing a more consistent result, and ensures similar measurements across different pieces of test equipment. The suggested filter is a fourth-order, Bessel-Thomson, low-pass filter as defined in ITU-T G.957 with the pass frequency matched to the frequency of interest. This type of filter is commonly included with optical eye pattern test equipment.

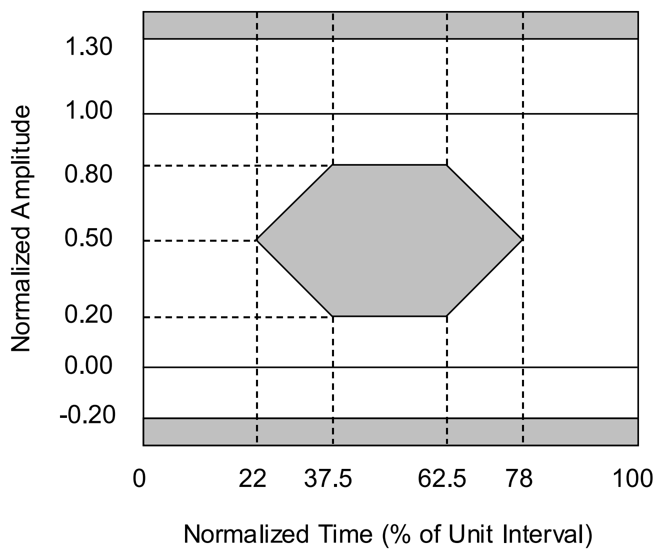


Figure D-4 – Transmit Eye

APPENDIX E OPTICAL INTERFACE FOR AVIONICS EQUIPMENT COMPLYING TO ARINC 664P2 – 10GBASE-SR FULL DUPLEX ETHERNET OVER MULTIMODE FIBER

E-1 Scope

This appendix defines an optical interface specification for aircraft equipment (LRUs) complying to ARINC Specification 664, Part 2, 10GBASE-SR implemented with an optical physical layer at a nominal wavelength of 850 nm.

The basis of this specification is IEEE 802.3. Where possible, the same optical parameter values have been adopted. However, this specification does take into account the additional optical losses involved in implementing aircraft optical links and also the particular constraints imposed by aircraft equipment (in terms of defining test points).

E-1.1 Relationship to ARINC Specification 664

ARINC Specification 664 refers to this appendix for equipment optical interface specifications.

E-1.2 Relationship to ARINC Report 804

ARINC Report 804 appendices refer to this appendix to complete the optical interface specifications for optical transceivers. This specification assumes the use of ARINC 804 compliant active devices within the equipment. Additionally, parallel channel transceivers (including transmitters and/or receivers) can be considered applicable to this standard and shall conform to specifications for **each individual channel**.

E-1.3 Relationship to ARINC Specifications 801 and 802

This appendix refers to ARINC Specifications 801 and 802 for connectors and cable for use when testing equipment. Link budgets are calculated using data representative of ARINC 801 and 802 connectors and cables.

E-2 Background (Including Wavelength Selection)

Ethernet networks and their derivatives are an increasingly popular choice for data communication on aircraft, particularly at data rates of 1 Gbps and above. In IEEE 802.3, the 10 Gbps-over-multimode-fiber standard is called 10GBASE-SR. IEEE 802.3 defines the nominal operating wavelength of 10GBASE-SR to be 850 nm.

E-3 Test Points and Interoperability Point

The objective of these specifications is to ensure interoperability between equipment; the interoperability point is at the box connector.

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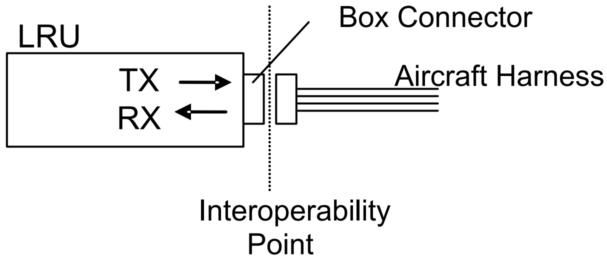

Figure E-1 – Definition of Interoperability Point

In some cases, it is not possible to access the equipment connector to measure optical parameters directly at the interoperability point so it is necessary to define test points at which measurements are made to confirm compliance of the equipment at the interoperability point. These test points should be used during acceptance test procedures and qualification testing.

E-3.1 Test Point for Measuring Optical Transmit Signal (TP1)

Parameters measured at TP1: Wavelength (λ), spectral width (Δλ), average launch power (P_0), rise/fall time (T_r/T_f), extinction ratio (E_r), overshoot, undershoot, transmit signal jitter, transmit signal eye pattern.

TP1 is defined as immediately after a test cable assembly comprising the mating half of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly is connected to the transmitting equipment (at the interoperability point).

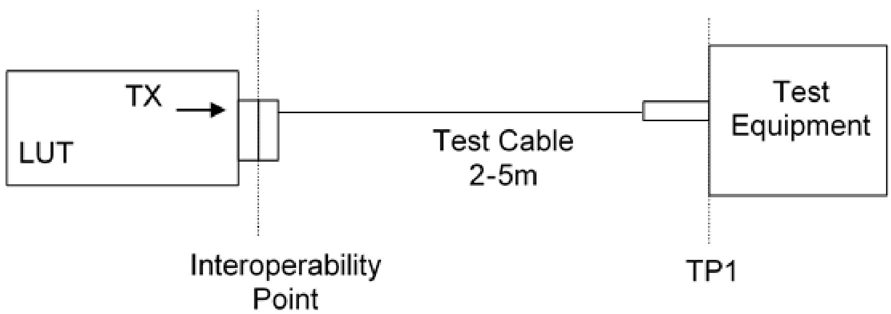

Figure E-2 – Definition of Test Point 1 (TP1)

E-3.2 Test Point for Measuring Optical Receive Signal (TP2)

Parameters measure at TP2: Equipment receiver sensitivity (S), receiver saturation input power (P_{sat}), receive signal jitter.

TP2 is defined as immediately after a test cable assembly comprising of a duplicate of the box connector, between 2 and 5 meters of fiber optic cable (of type consistent with the application) and connectors at the other end compatible with the test equipment. This test cable assembly replaces the receiving equipment (at the interoperability point).

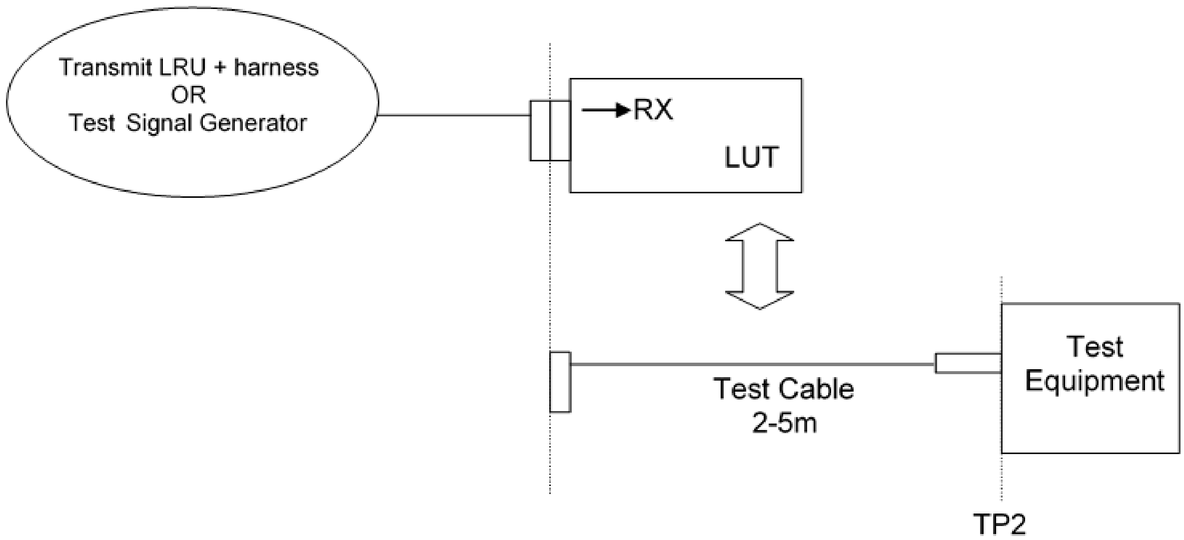

Figure E-3 – Definition of Test Point 2 (TP2)

Measuring the receiver sensitivity of the LUT requires a test signal generator that outputs ARINC 664 compliant data and an attenuator to reduce the average optical power. It also requires that the LUT can be monitored in some way to indicate that it is receiving valid data. It is not possible to perform an actual bit error rate test without a test point inside the box. This specification relies on the use of compliant active devices as described in ARINC Report 804.

E-4 Optical Interface Definition

Optical interface parameters are defined for operation at nominal wavelength of 850 nm (short wavelength) over multimode fiber.

All parameters are defined at the equipment interface – these are not specifications for optoelectronic transceivers. For information on transceiver specifications, see ARINC Report 804.

E-4.1 Transmit Characteristics

The transmit channels of compliant equipment should meet the specification as measured at TP1. Refer to ARINC 804, Appendix E,
Table E-2 for requirements.

E-4.2 Receive Characteristics

The receive channels of compliant equipment should meet the specification as measured at TP2. Refer to ARINC 804, Appendix E,
Table E-3 for requirements.

E-4.3 Link Power Budget

The following is an example of calculating required Link Power Budgets. Final values will vary based on system design, cable and connector type, reliability requirements, and other factors.

a. Channel Insertion Loss = Cable Loss[1] + Connector Loss
   Cable Loss[1] = Length x Attenuation Per Distance (i.e., 200m at 6db/km = **1.2dB**)
   Connector Loss = # of Conn. x Loss Per Conn. (6 conn. x 0.3db per conn. = **1.8dB**)
b. Aircraft Installation Loss[2] (i.e., **2dB**)
c. Repair Budget[3] (i.e., **2dB**)
d. Link Power Penalties and Unallocated Margin (i.e., **2dB**)

Link Power Budget = a + b + c + d = **9dB**

Notes:

1. Operating distance and fiber attenuation (at 850 nm) are dependent on OMx fiber optic cable type.
2. Aircraft Installation Loss is an estimated worst-case figure that takes into account losses due to cable fixing and bending when installed on an aircraft.
3. Repair Budget is an estimated worst-case figure that takes into account losses due to fiber splices or other post-installation repair procedures.

An LRU that exceeds the operational distance requirement while meeting all other optical specifications is considered compliant.

E-4.4 Jitter Specification

Jitter specifications are shown in Table E-4.

Table E-4 – Jitter Specification at TP1 and TP2

Test Point	Total Jitter (UIpp)
TP2 (worse case)	0.35 UIpp

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Note:

Total Jitter = Deterministic Jitter + Random Jitter

Jitter in terms of percentage of Unit Interval peak-to-peak (UIpp)

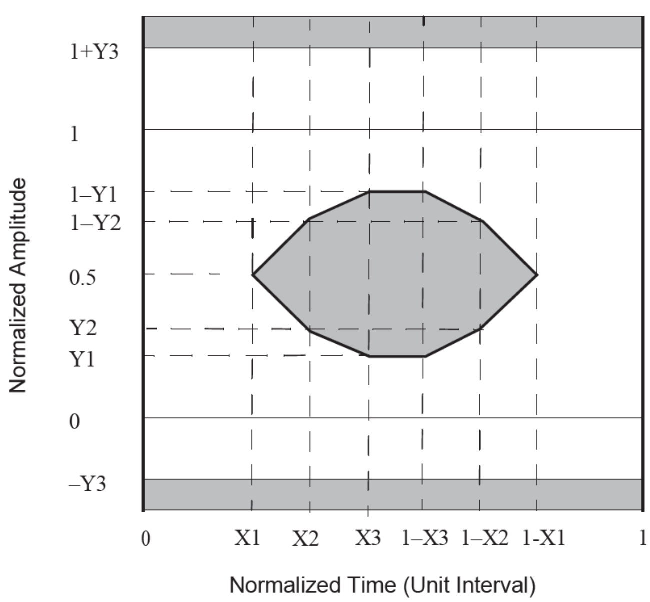
COMMENTARY

Deterministic jitter is the sum of duty cycle jitter and data-dependent jitter. Deterministic jitter is measured with 64b/66b Ethernet encoding.

E-4.5 Transmitter Optical Waveform (Transmit Eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye pattern as shown in Figure E-4. The transmit mask is not used for response time or jitter specification. The eye diagram axes are both normalized so they can be applied to patterns of any optical power amplitude or data rate.

The mask is defined in conjunction with a filter, which is used in the reference receiver when testing the device. The filter reduces the effects of overshoot and noise, producing a more consistent result, and ensures similar measurements across different pieces of test equipment. The filter is a fourth-order, Bessel-Thomson, low-pass filter as defined in ITU-T G.691 and as called in IEEE 802.3 Clause 52 (10GBASE-SR standard).



Transmitter Eye Mask Definition	
{X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.40, 0.45, 0.25, 0.28, 0.40}

Figure E-4 – Transmit Eye

APPENDIX F END USER LEVEL WAVELENGTH DESIGNATION FOR SYSTEM INTEROPERABILITY

F-1 Scope

This appendix defines the wavelengths to be used for fiber optic systems in aircraft equipment (LRUs) for the purposes of interoperability. This appendix is not applicable to legacy systems and is only applicable to new designs only.

F-2 Background

Fiber optic transceivers in aircraft equipment must operate on matched wavelengths to be interchangeable and/or intermixable. Avionics manufacturers need to know which operating wavelengths that equipment made by other manufacturers use.

F-2.1 Avionics System Hierarchy

For the purposes of this appendix a hierarchy of avionics units and fiber optic links is needed.

Avionic units will be described in relationship to their role within the system management unit vs. support unit/sensor.

Fiber optic links will be described in relationship to their redundancy using the terms primary and secondary.

F-3 Unidirectional Fiber Links

There are legacy components available for implementing an optical physical layer for ARINC Specification 664 at both 850 nm and 1300 nm.

Future system implementations should use 850 nm transmitters and receivers.

To achieve the best link budget (dependent on receiver sensitivity) with low-cost technology, a nominal operating wavelength of 1310 nm has been selected. This selection also allows for commonality with commercial low data-rate video test equipment. For new designs, 850 nm is preferred. For legacy systems, 1310 nm can be used.

F-4 Bidirectional Fiber Optic Transceivers

F-4.1 Guidance For 155 Mbps or Less

The primary bidirectional fiber optic transceiver in the system management unit will transmit at 1310 nm and receive at 1550 nm while the primary fiber optic transceiver in the support units will transmit at 1550 nm and receive at 1310 nm.

APPENDIX F
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The secondary bidirectional fiber optic transceiver in the management unit will transmit at 1550 nm and receive at 1310 nm while the secondary fiber optic transceiver will transmit at 1310 nm and receive at 1550 nm.

F-4.2 Guidance for 1 Gbps but Less than 10 Gbps

The primary bidirectional fiber optic transceiver in the system management unit will transmit at 1310 nm and receive at 1490 nm while the primary fiber optic transceiver in the support units will transmit at 1490 nm and receive at 1310 nm.

The secondary bidirectional fiber optic transceiver in the management unit will transmit at 1490 nm and receive at 1310 nm while the secondary fiber optic transceiver will transmit at 1310 nm and receive at 1490 nm.

F-4.3 Guidance for 10 Gbps or Higher

The primary bidirectional fiber optic transceiver in the system management unit will transmit at 1270 nm and receive at 1330 nm while the primary fiber optic transceiver in the support units will transmit at 1330 nm and receive at 1270 nm.

The secondary bidirectional fiber optic transceiver in the management unit will transmit at 1330 nm and receive at 1270 nm while the secondary fiber optic transceiver will transmit at 1270 nm and receive at 1330 nm.

Any additional bidirectional transceivers required should be based on the type of unit whose data is being received.

F-5 Coarse Wavelength Division Multiplexing (CWDM) Fiber Optic Transceivers

The CWDM fiber optic transceivers will utilize a wavelength range of 1270 nm to 1610 nm divided into 18 channels (odd ITU Channels numbers 27 thru 61) with a separation of 20 nm between each of the channels center wavelengths.

The channel usage is defined in the table below.

Table 1 - CWDM Channel Usage Specifications

Primary Link		Secondary Link	
Transmit	Receive	Transmit	Receive
1270 nm	1290 nm	1290 nm	1270 nm
1310 nm	1330 nm	1330 nm	1310 nm
1350 nm	1370 nm	1370 nm	1350 nm
1390 nm	1410 nm	1410 nm	1390 nm
1430 nm	1450 nm	1450 nm	1430 nm
1470 nm	1490 nm	1490 nm	1470 nm
1510 nm	1530 nm	1530 nm	1510 nm
1550 nm	1570 nm	1570 nm	1550 nm

Any additional CWDM transceivers required should be based on the type of unit whose data is being received.