

AEROSPACE INFORMATION REPORT

AIR5667™

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Fiber Optic Wavelength Division Multiplexed (WDM) Singlemode
Interconnect and Component Standards Mapping for Aerospace
Platform Applications – Device Level Specification

RATIONALE

As aerospace fiber optics engineers turn to wavelength division multiplexed fiber optic technology for advanced network implementations, it is important that any standards produced agree and build on standards that already exist. This document seeks to leverage the standardization effort made by the telecommunication industry and identify how their efforts apply to aerospace applications.

AIR5667 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

The purpose of this document is to serve as a resource to aerospace designers who are planning to utilize Wavelength Division Multiplexed (WDM) interconnects and components. Many WDM commercial systems exist and they incorporate a number of existing, commercially supported, standards that define the critical parameters to guide the development of these systems. These standards ensure interoperability between the elements within these systems. The commercial industry is motivated to utilize these standards to minimize the amount of tailored development.

However, since some of the aerospace parameters are not satisfied by the commercial devices, this document will also try to extend the commercial parameters to those that are necessary for aerospace systems. The document provides cross-references to existing or emerging optical component and subsystem standards. These parameter definitions, test methods, and procedures typically apply to telecommunications application and in some cases may require refining to adapt them to aerospace optical network and system applications.

2. REFERENCES

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

- a. 86B/1708/CD USNC Comment Attachment 1, "A Position Paper On The Harmonization Of North American Fiber Optic Connector Performance Requirements With Those Contained In The IEC General And Guidance For Performance Standards (IEC 61753-1)."
- b. LaBel, K., et al., "On the Suitability of Fiber Optic Data Links in the Space Radiation Environment: A Historical and Scaling Technology Perspective," IEEE Proceeding, Aerospace Conference, Vol. 4, 21-28 March 1998.
- c. Marshall, P., et al., "Space Radiation Effects in High Performance Fiber Optic Data Links for Satellite Data Management," Aerospace Applications Conference, IEEE Proceedings, Vol. 4, 3-10 February 1996.
- d. Crain, S., et al., "Analog and Digital Single-Event Effects Experiments in Space," IEEE Transactions on Nuclear Science, Vol. 48, No. 6, December, 2001.

NOTE: Individual citations to the referenced International Electrotechnical Commission (IEC), Telecommunications Industry Association (TIA), International Telecommunications Union (ITU) and Telcordia Generic Requirements (GR) documents are provided within the text of Sections 1 through 7 in the main body of this document.

2.1 Applicable Documents

2.1.1 Commercial Standards

The requirements and parameters identified in Section 7 of this document were selected from a number of international commercial standards, including the IEC, ITU, TIA, and Telcordia GR documents.

2.1.1.1 IEC documents

Available from International Electrotechnical Commission, 3 rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +44-22-919-02-11, www.iec.ch.

IEC61753-081-2	Fiber optic interconnecting devices and passive components performance standard – Part 3-1: Single-mode fiber optic medium-scale 1 x N DWDM devices for category C – Controlled environment
IEC/PAS 61300-3-29	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 3-29: Examinations and Measurements-Measurement Techniques for Characterizing the Amplitude of the Spectral Transfer Function of DWDM Components
IEC/PAS 61300-3-20	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 3-20: Examinations and Measurements – Directivity of Fiber Optic Branching Devices
IEC/PAS 61300-3-2	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 3-2: Examinations and Measurements – Polarization Dependence of Attenuation in a Single-Mode Fiber Optic Device
IEC/PAS 61300-3-32	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 3-32
IEC/PAS 61300-3-6	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 3-6: Examinations and Measurements – Return Loss
IEC61753-081-2	Fiber optic interconnecting devices and passive components performance standard – Part 3-1: Single-mode fiber optic medium-scale 1 x N DWDM devices for category C – Controlled environment
IEC/PAS 61300-2-17	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-17: Tests – Cold
IEC/PAS 61300-2-18	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-18: Tests – Dry Heat – High Temperature Endurance
IEC/PAS 61300-2-19	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-19: Tests – Damp Heat (steady state)
IEC/PAS 61300-2-22	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-22: Tests – Change of Temperature
IEC/PAS 61300-2-1	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-1: Tests – Vibration (sinusoidal)
IEC/PAS 61300-2-4	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-4: Tests – Fiber/cable Retention
IEC/PAS 61300-2-9	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-9: Tests – Shock

IEC/PAS 61300-2-42	Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures – Part 2-42: Tests – Tests – Static Side Load for Connectors
IEC 61281-1	Fiber optic communication subsystems – Part 1: Generic specification
IEC 61291-1	Optical fiber amplifiers – Part 1: Generic specification
IEC 61291-2	Optical fiber Amplifiers – Part 2: Digital applications – Performance specification template; also published as TIA/EIA-455-223-2001 (FOTP-223)
IEC 61291-4	Optical amplifiers; Part 4: Multichannel applications – Performance specification template
IEC 61291-5	Optical amplifiers; Part 5-2: Qualification specifications – Reliability qualification for optical fiber amplifiers
IEC 61290-2-1	Optical fiber amplifiers; Basic specification – Part 2-1: Test methods for optical power parameters; Optical spectrum analyzer.
IEC 61977	Fiber optic filters – Generic specification.

2.1.1.2 TIA documents

Available from Telecommunications Industry Association, 2500 Wilson Boulevard, Suite 300, Arlington, VA 22201, Tel: 703-907-7700, www.tiaonline.org/standards/.

TIA/EIA-455-223-2001 (FOTP-223) same as IEC 61291-2 above.

2.1.1.3 Telcordia Generic Requirements (GR) documents

GR-468	Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment
GR-1209	Generic Requirements for Passive Optical Components (Issue 3 includes GR-2882, GR-2883, GR-2884)
GR-1221	Generic Reliability Assurance Requirements for Passive Optical Components
GR-1312	Generic Requirements for Optical Fiber Amplifiers and Proprietary Dense Wavelength-Division Multiplexed Systems
GR-2918	DWDM Network Transport Systems with Digital Tributaries for Use in Metropolitan Area Applications: Common Generic Criteria.

2.1.1.4 ITU documents

G.957	(operating wavelength ranges, receiver & transmitter specifications)
G.651, G.652, G.655, G.657	(fiber characteristics – could be important for cable plant definition, with impact on component performance)
G.694.1, G.694.2	wavelength/frequency grid
G.671	passive and active components (e.g., filters reference in Section 7 of this document).

While the ITU recommendations generally pertain to WDM system requirements, the following documents contain portions that can be practical in determining component performance parameters. While the following ITU recommendations have not been extensively referenced in this document, they are listed here to point the reader to additional sources of WDM component specifications.

2.1.2 Military Standards

Available from the Document Automation and Production Service (DAPS), Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

The following is a list of the military standards documents that provide information associated with detailed requirements for insertion of components into aerospace platforms.

DOD-STD-1678

MIL-STD-202, Method 110

MIL-STD-202, Method 204

MIL-HDBK-310

MIL-HDBK-415A

MIL-STD-810

MIL-STD-883, Method 2026

MIL-STD-1344, Method 1001

MIL-STD-1344, Method 1002

MIL-STD-1344, Method 1003

MIL-STD-1344, Method 1012

MIL-STD-1344, Method 1016

MIL-STD-1344A, Method 2004

MIL-STD-1344, Method 2005

MIL-STD-1344, Method 2016

MIL-STD-1344 (see also EIA-364)

MIL-DTL-38999

3. WDM STANDARDIZATION OVERVIEW

3.1 WDM Architecture Approach

Commercial WDM systems have been initially constructed using a number of individual devices. These devices are assembled to create unique architectural solutions for specific applications. However, it is the use of these standard building block devices that enables the affordability of these systems. For aerospace systems, it would be beneficial for designs to also constrain their building block devices, when constructing a system, to the same set used by the commercial industry. Section 4.0 of this document will identify these building block devices and how they could be used in various types of system topologies. Over time, it is anticipated that further integration of these individual device functions will occur.

3.2 Aerospace Environmental Consideration

Some WDM systems are sensitive to environmental conditions due to the need to maintain tight optical wavelength control. Typically, the wavelength of these WDM devices has been dependent on environmental changes. Aerospace environments are generally harsher than commercial environments. Careful consideration has to be given in the design process to the aerospace environment. This document will focus on the most important of these differences, which include:

- a. Temperature
- b. Vibration and shock
- c. Contamination (dust, fluids, etc.)

Combinations of these environmental conditions also need to be considered.

3.3 Telecommunication WDM Standards

Telecommunications standards for WDM systems have been developed both in U.S. national and international standards organizations since the early 1990s, including the ITU, Optical Internetworking Forum (OIF), IEC, TIA and through Telcordia GRs. Many of these standards have focused on system and networking aspects of commercial optical WDM networks, primarily intended for digital transport systems. Specifications and requirements for WDM applications using Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH) and gigabit rate networking solutions have been standardized in the ITU and the OIF standards organizations among others. While the standards developed by the ITU (and OIF) may be useful references for standardization of WDM components in avionics, this document draws on the ongoing WDM technology (components and subsystems) standardization that has been the focus of specific committees within the TIA and IEC standards organizations.

The IEC is an organization that prepares and publishes international standards for electrical, electronic and related technologies. Often the IEC standards serve as a basis for national standardization (such as for U.S. national standards development by the TIA). The relevant Technical Committees and Subcommittees of the IEC are SC 86B and SC 86C within Technical Committee 86 (TC 86). The scope of Subcommittee 86B, Fiber Optic Interconnecting Devices and Passive Components, includes preparing international standards and specifications for fiber optic interconnecting devices and passive components. The activity of SC 86B covers all interconnecting devices and all passive fiber optic components such as attenuators, switches, branching devices, wavelength multiplexers/demultiplexers, isolators, and the combination of such components. SC86B also has formal liaisons with Study Group 15 of the ITU-T standards organization.

The scope of Subcommittee 86C, Fiber Optic Systems and Active Devices, includes establishing and maintaining standards for fiber optic systems and active devices for use in the area of analog and digital communication equipment. The activity of SC 86C covers terminology, essential characteristics, tests and measurement methods and functional interfaces as well as mechanical, environmental, optical, and electrical requirements to ensure interoperability and reliable system performance. The active devices covered include optically amplified devices and amplified subsystems. The IEC has stated that system and active device standards shall be developed in harmony with ITU-T.

The TIA is accredited by the American National Standards Institute (ANSI) to develop voluntary industry standards for a wide variety of telecommunications products. The TIA Standards and Technology Department is composed of five divisions which sponsor more than 70 standards-setting formulating groups. The committees and subcommittees sponsored are organized into five divisions, Fiber Optics, User Premises Equipment, Network Equipment, Wireless Communications, and Satellite Communications. The standards pertaining to Fiber Optics are of particular relevance to this document.

The TR-42 Engineering Committee on Fiber Optics is responsible for the development and maintenance of fiber optic component, subsystem, system, and network technology standards. The TR-42 Engineering Committee primarily focuses on standards for testing methodologies, optical interface standards, performance and reliability standards, design guidelines, and the resulting product specifications, as well as the associated metrology and calibration requirements.

These standards are intended for users and suppliers of fiber optic communications technology to promote compatible and interoperable systems that support a wide variety of voice, data, video and telemetry applications for trade and commerce. The TR-42 Engineering Committee works closely with other national and international standards development organizations in promoting harmonization and ease of use for worldwide fiber optic technology deployment. In fact, in recent years the TIA TR-42 Committee has been committed to worldwide harmonization of fiber optic standards and continues to adopt IEC published standards where possible. Moving forward, the back-adoption of IEC standards will allow manufacturers to use the same standard worldwide. This enhances specification of product performance and reliability using uniform methods. IEC standards can be adopted nationally without any change or they can be adopted with some regional variations.

In this document (refer to Section 7) we reference several of the IEC documents (which in many cases have one-to-one correspondence with selected TIA documents) in the development of the templates for defining requirements for avionic optical network specifications.

In addition to the IEC and TIA standards, some of the Telcordia GRs contain relevant specifications for component level standardization, spanning performance, test methods and reliability/environmental requirements. Portions of specific WDM networking standards developed by the ITU are also relevant. In areas where the IEC (and TIA) specifications are incomplete or are currently under development we turn to the Telcordia GRs as sources of component performance and reliability specifications. Refer to Section 3.4 for a listing of the standards and recommendations used to generate the tables in Section 7.

3.4 Aerospace to WDM Standards Mapping

The mapping of aerospace optical networks to existing WDM standards involves multiple steps. Given a set of technologies that constitute the WDM architecture building blocks (refer to Section 4.0), we can then follow the process described here to arrive at either preliminary specifications that apply to telecommunications-driven applications or a methodology for determining the needed Aerospace network standards.

The first step is to identify the relevant existing national or international standards, such as the IEC, ITU or Telcordia GRs. The next step is to identify specific sections of the standard (e.g., specification tables, reliability requirements, etc.) that are applicable to the devices considered for the Aerospace standard. Finally, we reference the specifications from the corresponding standards document where applicable, providing a template for indicating the parameter ranges suitable for Aerospace applications. In many cases additional analysis of the parameter under consideration is necessary to determine a specification range that is applicable to the Aerospace platforms (some of which is beyond the scope of this document). We leave that analysis to the platform design engineers. Table 1 summarizes some of the relevant IEC, ITU, and Telcordia standards that have been reviewed and/or referenced.

TABLE 1 – SUMMARY OF WDM COMPONENTS STANDARDS RESOURCES CONSULTED

Component	Sec.	Optical Performance		Test Methods		Reliability/Environmental	
		Standard Source	Table in Section 7	Standard Source	Table in Section 7	Standard Source	Table in Section 7
Receiver	7.1	IEC61281-1 (Sec. 5.2.4)	7.1.1.1-1	IEC61281-1 (Sec. 5.2.4)	7.1.1.1-1	GR-468	7.1.2.1-1 and 7.1.2.1-2
Transmitter	7.2	IEC61281-1 (Sec. 5.2.3)	7.2.1.1-1	IEC61281-1 (Sec. 5.2.3)	7.2.1.1-1	GR-468	7.2.2.1-1 and 7.2.2.1-2
Mux/Dmux	7.4	IEC61753-081-2; Tables 2, 3	7.4.1.1-1	IEC61753-081-2 and IEC61300-series & related docs	7.4.1.2-1	IEC61753-081-2; Tables 2, 3	7.4.2.1-1
Optical Amplifier	7.6	GR-1209	7.4.1.1-2	IEC61300-series & related docs	7.4.2.2-1	GR-1221	7.4.2.2-2
		IEC61291-4	7.6.1.1-1	IEC61291-1	7.6.1.2-1	IEC61291-4	7.6.2.1-1
Filters	7.7	IEC61281-1	7.6.1.1-2	GR-1221 ITU G.671	7.4.2.2-2 7.1.1.1-1	GR-1221	7.4.2.2-2
		GR-1312	7.6.1.1-3				
Couplers/Splitters	7.8	GR-1209	7.7.1.1-1	61753-2-3 and IEC 61300 series	7.8.2.1-1	61753-2-3 and IEC 61300 series	7.8.2.1-1
		61753-2-3 and IEC 61300 series	7.8.1.1-1				
		GR-1209	7.8.1.1-2				

4. WDM ARCHITECTURES

The primary building blocks of a WDM system are:

Fiber Optic Receiver – used to convert optical signals into electrical signals.

Fiber Optic Transmitter – used to convert electrical signals into optical signals.

Fiber Optic Transceiver – used to convert both optical signals into electrical and electrical signals into optical.

Demultiplexer – used to separate different wavelengths of light out of a transmission.

Multiplexer – used to combine different wavelengths of light into a transmission.

NOTE: Generally, but not exclusively, the demultiplexer and multiplexer are the same device operated in different directions.

Optical Amplifier – used to amplify an optical transmission.

Optical Add Filter – used to add a specific wavelength of light onto a transmission.

Optical Drop Filter – used to drop a specific wavelength of light from a transmission.

NOTE: Generally, but not exclusively, the optical add filter and optical drop filter are the same device operated in different directions.

Optical Coupler – used to couple two or more optical transmissions into one using a nonwavelength specific method.

Optical Splitter – used to split a single optical transmission into two or more using a nonwavelength specific method.

NOTE: Generally the optical coupler and optical splitter are the same device operated in different directions.

Optical Switch – used to reconfigure or select optical pathways.

NOTE: This component will be addressed in future versions of this document.

These building blocks can be used to create a large number of unique topologies. Note that many topologies as well as other devices may be generated from these basic building blocks. The categories described in this document include bus, ring, star, switched, and mesh topologies. The paragraphs within this section will briefly describe these topologies and the building block devices used in each. This is intended to provide a basic understanding of these different topologies to support the aerospace designers' system architecture development.

4.1 Bus

A bus topology creates a linear tap communication system. Each node is connected to a single backbone where every node has an equal access capability. Each node can transmit on any wavelength(s) and receive on any wavelength(s). Implementing a bus topology using WDM devices can be done in two basic ways, using two unidirectional fiber optic links or a single bidirectional fiber optic link.

Figure 1 shows the bus topology using unidirectional links. In this particular example each node transmits a single information stream onto the bus using a single fiber optic transmitter which could be fixed wavelength or tunable. This transmitted information is coupled at each node and after the final node contains a composite of all transmitted information. At this final node the composite signals that were transmitted are routed back to each of the nodes using another unidirectional link. Each node will split off a portion of the composite such that any transmission can be received by any node. This unidirectional bus utilizes a number of the building blocks, namely Fiber Optic Receiver, Fiber Optic Transmitter, Optical Amplifier, Demultiplexer, Optical Coupler, and Optical Splitter.

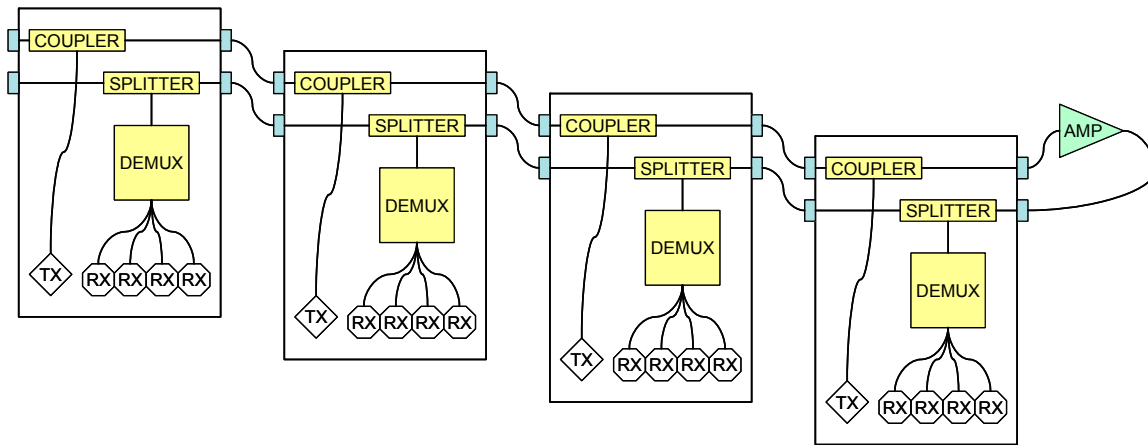


FIGURE 1 – BUS TOPOLOGY USING UNIDIRECTIONAL LINKS

Figure 2 shows the bus topology using bidirectional links. In this particular example each node transmits a single information stream onto the bus in both directions simultaneously using a single fiber optic transmitter which could be fixed wavelength or tunable. This transmitted information is coupled at each node onto the composite transmission in each direction. Each node will split off a portion of the composite from each direction and combine this to be received by each node. This bidirectional bus utilizes a number of the building blocks, namely Fiber Optic Receiver, Fiber Optic Transmitter, Optical Amplifier, Demultiplexer, Optical Coupler, and Optical Splitter.

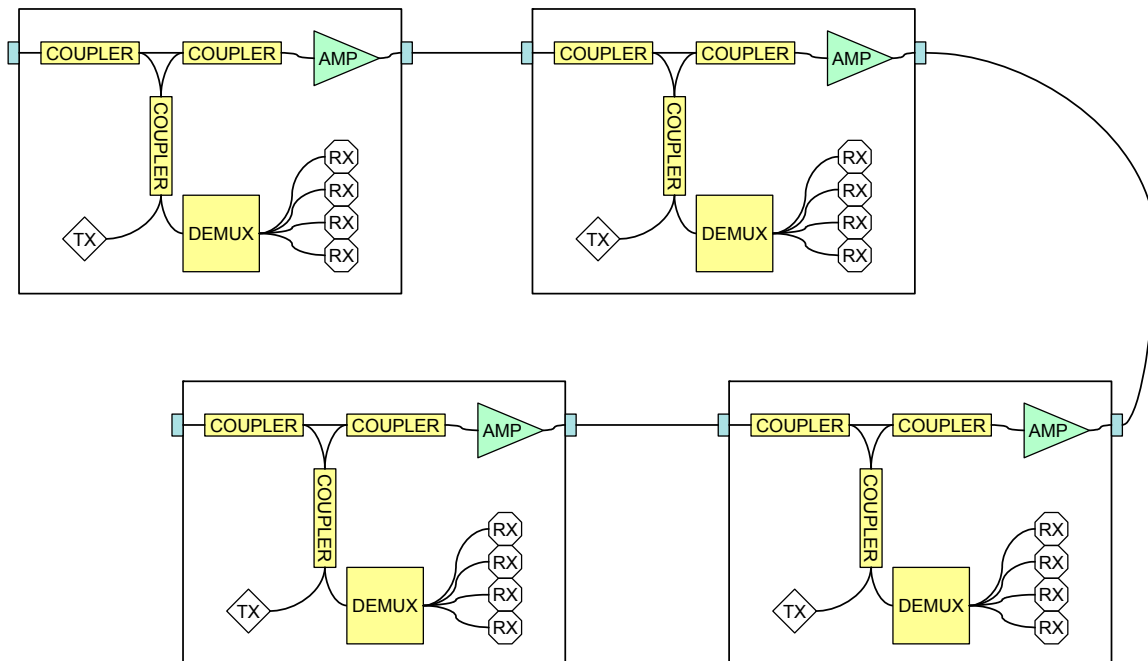


FIGURE 2 – BUS TOPOLOGY USING BIDIRECTIONAL LINKS

4.2 Ring

A ring topology connects all of the nodes in a continuous loop. Each node is connected to its predecessor and successor using a unidirectional link. Each node can transmit on any wavelength(s) and receive on any wavelength(s). Implementing a ring topology, unlike the bus, requires the node transmitting to remove its transmission when it has traveled around the ring.

Figure 3 shows the ring topology using unidirectional links. In this particular example each node transmits a single information stream onto the bus using a single fiber optic transmitter which could be fixed wavelength or tunable. This transmitted information is coupled at each node and circulated around the ring clockwise until the originating node removes it. This unidirectional bus utilizes a number of the building blocks, namely Fiber Optic Receiver, Fiber Optic Transmitter, Optical Amplifier, Demultiplexer, Optical Splitter, and Optical Drop Filter.

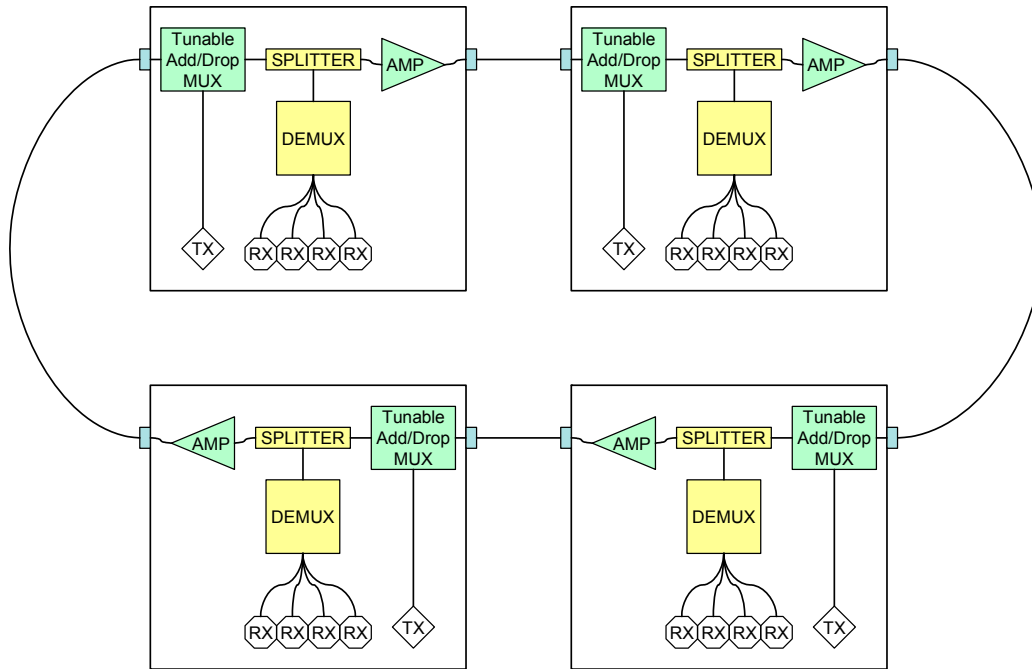


FIGURE 3 – RING TOPOLOGY

4.3 Star

In a star topology each node transmits into a central star coupler which then distributes the composite transmission back to each of the nodes using the receive interface. In Figure 4 each of the nodes attached to the 4x4 coupler are the same as those used the unidirectional bus shown in Figure 4. What is unique about the star topology is that since each node has its own transmit and receive links it enables a level of fault tolerance that doesn't exist in the bus topologies. For example, if any of the nodes or node links fail, there is no impact on the connectivity of the remaining nodes; whereas for the bus topologies if a node or link fails, it impacts the connectivity of the remaining nodes. However, the cabling required to implement a star topology can be burdensome since each node has to be cabled to a centrally located star.

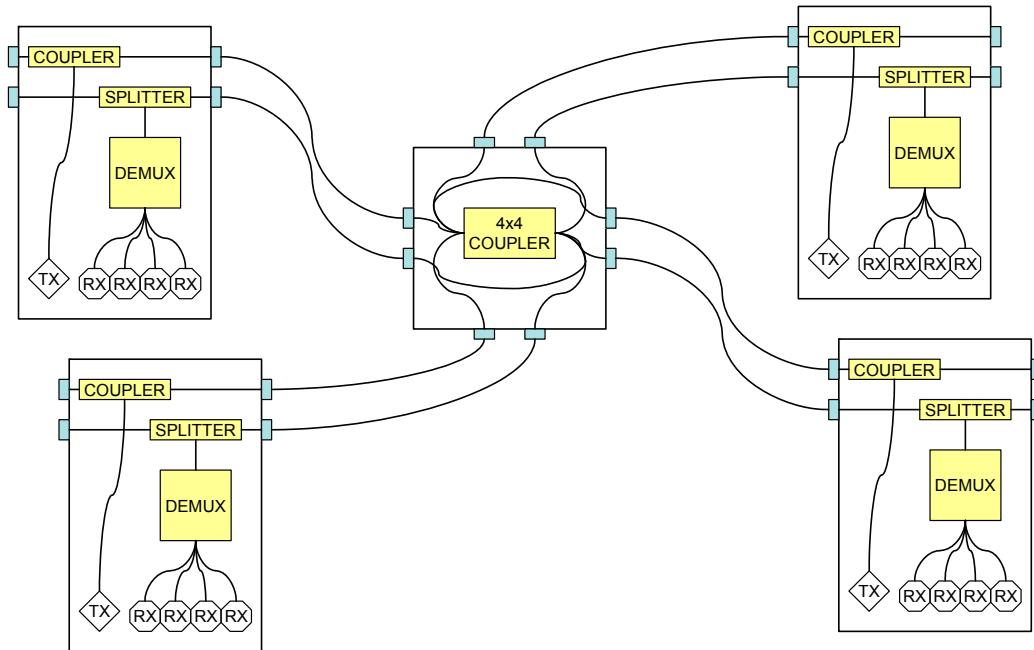


FIGURE 4 – STAR TOPOLOGY