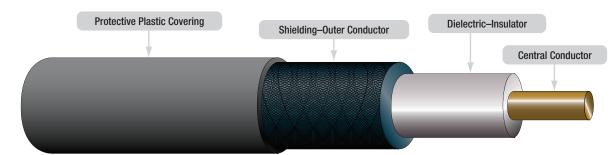# FIBER OPTICS

Figure 10-1. Coaxial cable typically used for data rates of 2Mbps to 50Mbps.

Sub-Module 04 discussed various digital data buses, such as MIL-STD-1553B and ARINC 629, which use shielded twisted-pair copper wires for transmitting information at data rates of one to two millions bits per second (Mbps). From 2 Mbps to 50 Mbps, coaxial cable is the preferred transmission medium. Coaxial cable, also known as coax, consists of a center wire conductor surrounded by a semi-rigid insulator. Surrounding the wire and the insulator material is a conductive, braided cover that runs the length of the cable. Finally, a waterproof covering is set around the braided shield to protect the entire assembly from the elements. The braided cover in the coax shields the inner conductor from any external electro-magnetic fields. It also prevents the fields generated by the internal conductor from radiating. (**Figure 10-1**)

Aircraft networks, such as AFDX and Firewire, with data rates running as high as 1000 Mbps, or one gigabit per second (Gbps), require the use of fiber optic cables to reliably transmit large bandwidths of information. As shown in **Figure 10-2**, a fiber optic cable consists of the core, which is a thin glass or plastic center where the light travels, surrounded by an outer optical material, called a cladding, which reflects the light back into the core, and a black polyurethane outer jacket over the cladding to protect the cable from damage and moisture. If the fibers in the core are made from glass there will also be a plastic coating applied to the cladding, called a buffer jacket, to provide additional protection. Materials made from fiberglass or Kevlar add mechanical strength to the cable.

ADVANTAGES AND DISADVANTAGES

Besides having a high data-rate capability and a wide bandwidth to carry more information, optical buses exhibit extremely low loss and low crosstalk since there
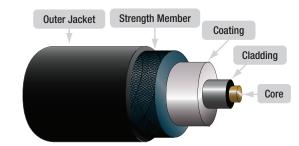

Figure 10-2. Fiber optic cable used for data rates as high as 1Gbps.

is no line capacitance or mutual coupling. The reason why optical cables exhibit such low loss is because there is very little attenuation, or reduction in signal strength, over long distances as compared to copper wire. Cables made from silica glass fibers have the lowest attenuation, and as such, are widely used in the telecommunications industry for large bandwidths and long distances. Plastic fibers are less expensive, extremely rugged and have a tight bend radius, but exhibit a higher loss.

Tensile strength is the ability of a fiber or wire to be stretched without breaking. Copper wire must have twice the diameter to have the same tensile strength as a glass fiber. When installing fiber cable, care must be taken not to exceed its recommended bend radius since a sharp bend will decrease the tensile strength and may snap the glass. Sharp bends will also increase attenuation since the bends change the angle of incidence and reflection of the light. The chief advantage of optical cables are that they are immune from electro-magnetic interference (EMI). Copper conductors will act like antennas, either transmitting or receiving energy. Copper wires connecting avionics equipment can be one of the main sources of EMI, which can cause errors to occur during digital data transmissions. Optical cables can also withstand nuclear radiation in that the fibers will not short out if their jackets melt.
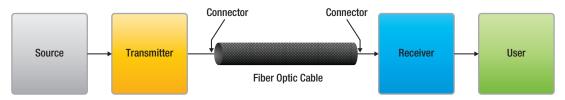
Figure 10-3. Basic fiber optic link.

All though optical cables are lighter than copper cables, they are generally more expensive and require the use of optical transmitters and receivers. In addition, fibers are more difficult and expensive to splice than copper wires. However, the advantages of fiber optic networks far outweigh the disadvantages of electrical data buses for the reasons stated above.

FIBER OPTIC DATA BUS

A fiber optic data bus operates basically the same as an electrical data bus except that the fiber carries light instead of electricity. As shown in *Figure 10-3*, a basic fiber optic link connects two electrical circuits from the data source to the data sink (user) using a light source, transmitter, fiber optic cable, and receiver to provide information to the user. The light source can be either a Light Emitting Diode (LED) or a laser diode. The laser diode has a higher output power and faster speed than an LED, but it is more expensive. The transmitter converts electrical signals into light pulses and sends the pulses over the fiber optic cable to the receiver.

The purpose of the receiver is to rebuild the signals back to their original state as they were presented to the transmitter. The two basic parts of the receiver are the photocell, also called a photodiode detector, which converts the light back into an electrical signal; and the output circuit, which amplifies and reshapes the signal back into its original digital data stream. Clock information is either contained in the transmitted signal or the receiver may provide its own timing information to decode and reshape the digital pulse train. The following paragraphs will compare and contrast various fiber optic transmitter and receiver circuits.

TRANSMITTERS

To reiterate, fiber optic transmitters consist of a driver and a source. The input to the driver is the binary code used to turn the current on and off to the light source, whether it be an LED or a laser diode. The op-amp driver accepts either TTL or CMOS logic levels and provides the output current to drive the source. For

example, the drive circuit would convert 0.5v (bit "0") and 5v (bit "1") of TTL binary logic into 0 ma and 50 ma respectively to modulate the light source off and on. A modulation code is used as a method of encoding digital data such that turning the source on and off forms Pulse-Coded Modulation (PCM) waveforms that correspond to binary number equivalents, as shown in *Figure 10-4*.

Each bit of data must occur within its bit period, which is defined by the transmitter clock. The clock provides a steady string of pulses for basic system timing. Some codes are self-clocking, meaning that the clock information is contained within the modulation code. However, a receiver may provide its own timing, and not rely on clock signals from the transmitter, if it designed to receive non-self-clocking code.

DECIMAL NUMBER	BINARY EQUIVALENT				PULSE – CODE WAVE FORMS
	2^3	2^2	2^1	2^0	2^3 2^2 2^1 2^0
0	0	0	0	0	
1	0	0	0	1	
2	0	0	1	0	
3	0	0	1	1	
4	0	1	0	0	
5	0	1	0	1	
6	0	1	1	0	
7	0	1	1	1	
8	1	0	0	0	
9	1	0	0	1	
10	1	0	1	0	
11	1	0	1	1	
12	1	1	0	0	
13	1	1	0	1	
14	1	1	1	0	
15	1	1	1	1	

Figure 10-4. Binary number to pulse-coded modulation translation table.

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NRZ (non-return-to-zero) is a non-self-clocking code whereby the signal remains high during a string of 1s and remains low for a sting of 0s. (*Figure 10-5*) However, there are many different types of modulation codes that are in use today. For example, MIL-STD-1553B uses what is called Manchester Code, whereby there is a transition in the middle of each bit period. Manchester, which is a self-clocking code, is generated by placing an Exclusive OR gate between the clock pulse and the data pulse. As such, for a binary 1, the first half of the period is high, and the second half is low. For a binary 0, the first half is low and the second half is high. As a result, Manchester code has two symbols per bit, instead of one as in NRZ code. Therefore, to transmit a 1 Mbps data stream requires a bandwidth of 2 MBaud. Baud rate is the number of symbols or pulses per second.

LIGHT-EMITTING DIODES

LEDs operate on the principle of electroluminescence, which is a term used to describe a phenomenon whereby light emission is caused by the application of an electric current. Light contains electromagnetic energy that is carried by photons. The amount of energy depends on the frequency of light of the photon. In a forward biased diode, electrons cross the junction and fall into holes.

As the electrons fall into the valence band, they radiate energy. In a rectifier diode, this energy is dissipated as heat. However, in a LED, the energy is dissipated as light. By using elements, such as gallium, arsenic, and phosphorous, an LED can be designed to radiate colors, such as red, green, yellow, blue and infrared light. *Figure 10-6* illustrates the anatomy of a single LED, the symbol of an LED, and a graphic depiction of the LED process. Note that when the diode is reversed biased, no light is given off. However, when the diode is forward biased, the energy given off is visible in the color characteristic for the material being used.

By modulating the bias of the LED, light pulses are formed to be sent over a fiber optic cable to a photodiode receiver. Different color LEDs can be employed in the transmitter to signify which receiver the signal is intended. This is known as Wavelength-Division Multiplexing (WDM). Light that is emitted by a semiconductor can be absorbed by the same semiconductor material in the receiver. WDM is used in some fiber optic data bus systems whereby the selection of the color of light passing through a fiber cable denotes the source and destination address
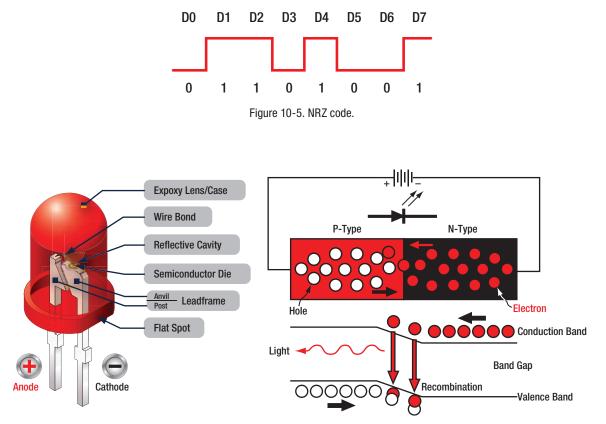

Figure 10-5. NRZ code.

Figure 10-6. An LED producing light by electrons dropping into holes and giving off energy.
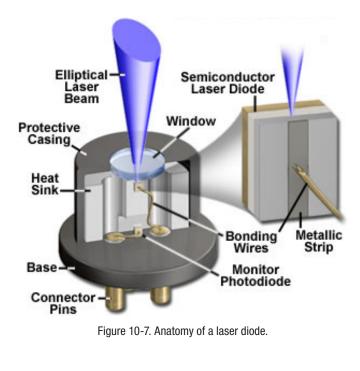
LASER DIODES

Laser is an acronym standing for Light Amplification by Simulated Emission of Radiation. The main difference between an LED and a laser diode (*Figure 10-7*) is that the laser diode has an optical cavity required to produce a laser beam. In general, laser diodes have higher modulation bandwidth, greater optical output power, and higher coupling efficiency to the fiber cable, and therefore, are widely used for high-speed digital applications. The reason why a laser diode has a higher coupling efficiency is due to its narrow spatial beam width. The amount of bias current applied to the laser diode controls the gain, and thus the light intensity. Photodiodes are often installed on the rear face of the cavity to monitor the light output to adjust the drive current to maintain a constant optical power level.

As shown in *Figure 10-8*, the semiconductor material used for a laser diode consists of an alloy of aluminum (Al) and gallium arsenide (GaN). Lasing is achieved through optical resonance whereby photons are generated due to a high current being applied across the semiconductor material. At low drive currents, the laser diode acts much like an LED in that it emits light spontaneously resulting in photon emission with random phase and direction. However, as the drive current increases, stimulated emission occurs, whereby electrons are injected into the laser diode and combine with holes forming photons. If one of these photons comes in contact with an electron, the electron immediately recombines and gives off another photon.

The photon that has been created is a duplicate of the first proton in that it has the same wavelength, phase and direction of travel. These photons interact with more incoming electrons, helping to produce more photons, and so on in a self-perpetuating process called optical resonance. The emitted photons will resonate in the optical cavity, which is lined with reflective material, and will travel in the same direction with the same frequency and phase emitting an amplified beam of light from the open end of the cavity.

Fiber optic sources, such as high-radiance LEDs and lasers, emit intense infrared light invisible to the human eye. Such radiation can cause permanent damage to the retina of the eye and produce blindness. Never look directly into a source or into a fiber energized by a source!
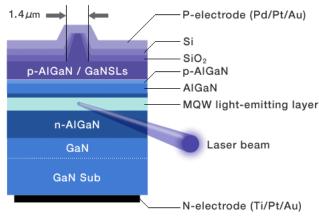

Figure 10-7. Anatomy of a laser diode.

Figure 10-8. AlGaN semiconductor material
is used to produce a laser beam.

RECEIVERS

A fiber optic receiver consists of a detector, amplifier, and output circuit. The output circuit is used to separate the clock signals from the data, reshape the data pulses back into their original format, and provide gain control to maintain constant output levels once the signal from the photo-diode detector is amplified. As shown in *Figure 10-9*, light striking the photodiode causes current to flow in the circuit whereas the diode would have otherwise blocked it. The result is that the data pulse is allowed to pass through the receiver to be amplified and filtered.
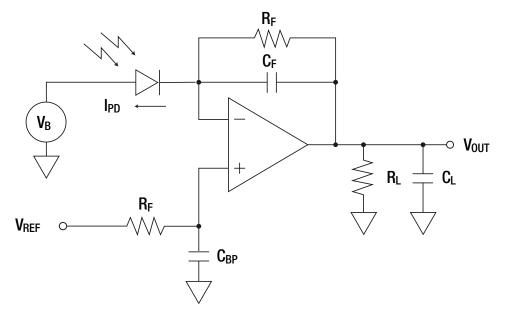
Figure 10-9. Fiber optic receiver with detector, Op-amp, and output circuit.

Receivers are classified based on their sensitivity and dynamic range. Sensitivity specifies the weakest optical signal that can be detected while rejecting noise. Dynamic range is the difference between the minimum and the maximum power levels. The minimum level is determined by receiver sensitivity and the maximum level is determined by the gain setting on the amplifier. Excessive power levels can saturate the receiver and distort the output signal.

PHOTO-DIODE DETECTORS

Light contains electromagnetic energy that is carried by photons. The amount of energy depends on the frequency of light of the photon. This energy can be very useful in the operation of fiber optic data buses since all semiconductors are affected by light energy. When a photon strikes a semiconductor atom, it raises the energy level above what is needed to hold its electrons in orbit. The extra energy frees an electron enabling it to flow as current. The vacated position of the electron becomes a hole. In photodiodes, this occurs in the depletion area of the reversed biased PN (positive-negative) junction turning on the device and allowing current to flow. (*Figure 10-10*)

Thermal energy produces minority carriers in a diode. The higher the temperature, the greater the current in a reverse current diode. Light energy can also produce minority carriers. By using a small window to expose the PN junction, a photodiode can be built. When light fall upon the junction of a reverse-biased photodiode, electrons-hole pairs are created inside the depletion layer. The stronger the light, the greater the number of light-produced carriers, which in turn causes a greater magnitude of reverse-current. Because of this characteristic, photodiodes are used in light detecting circuits, such as fiber optic data bus receivers.
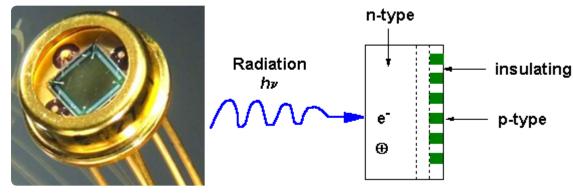

Figure 10-10. Photodiode detector.

RELATED TERMS

There are two types of fiber-optic cable that are available, single mode and multimode. As shown in *Figure 10-11*, many beams of light travel through the multimode cable bouncing off of the cable walls. Attenuation is caused by the scattering and absorption of light as it travels down the fiber core. Light is reflected off the cladding, which acts like a mirror so that light can bend along its length. Scattering re-directs light out of the core to the cladding and absorption occurs when the light is not reflected back into the core, but instead is absorbed by the coating due to imperfections in the optical material. Single-mode fiber uses a single direct beam of light, thus allowing for greater distances and increased transfer speeds. Common types of fiber optic cable include the 62.5 micron core with 125 micron cladding multimode cable, 50 micron core with 125 micron cladding multimode cable, and the 9 micron core with 125 micron cladding single mode cable.

TERMINATIONS

Unlike copper wire, fiber optic cables can't be soldered or crimped to make a low resistance connection; however, it is equally important that fiber optic terminations couple light from one component to another with as little loss of optical power as possible. The key to low loss is precise alignment of the mated fiber cores so that nearly all the light is coupled from one fiber across the junction to the other fiber. Fibers must be checked for precise perpendicularity and end finish prior to termination. Mismatches can occur due to variations in tolerances between the diameter and concentricity of the core and cladding. In addition, connectors and splices can contribute to insertion losses due to variations in lateral displacement, end separation, angular misalignment and surface roughness.

The scribe-and-break method is commonly used to prepare fibers for termination. A cutting tool scribes a small nick across the cladding. The blade is then pulled across the stationary fiber. After scribing, pressure is increased on the cable by pulling it resulting in a clean break with a mirror-like finish. Once the fiber is prepared, splices can be made either by fusion or by using elastomeric inserts held within a glass sleeve. A fusion splice is accomplished by placing the two fibers on the V-grove of a splicing tool alignment block. The alignment is adjusted while viewing it though a microscope. Once aligned, an electric arc is applied.

The localized heating softens the butted fiber ends and surface tension is applied during the fusion process. The finished splice is then encased in epoxy and heat-shrink tubing for protection.

Aircraft applications commonly use SMA (sub-miniature version A) fiber optic connectors due to their ruggedness. An SMA connector consists of a metal body assembly with a precision hole in the tip. (*Figure 10-12*) A stripped fiber, held within the alignment ferrule, is inserted into the body assembly and secured with epoxy. Strength members in the cable are then crimped between the body assembly and the eyelet to provide rigidity. The excess fiber is removed and then polished to the desired length and optical finish. The connector mates in a sleeve bushing with a screw-type coupling mechanism which provides a secure and aligned fit.
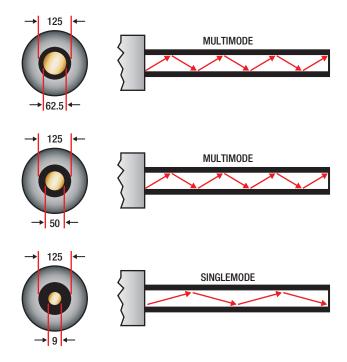

Figure 10-11. Multimode versus single mode fiber.

Figure 10-12. Standard SMA fiber optic cable connector.

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COUPLERS AND TERMINALS

A coupler is a device that has multiple input or output ports for light to travel. *Figure 10-13* shows a four-port directional coupler. Such a device is fabricated by fusing together two single mode fibers so that their cores come close together, allowing light to leak from one core to the other. Light entering port 1 will be split and will exit ports 3 and 4. Ideally, no light will appear at port 2. Likewise, light entering port 2 should only exit ports 3 and 4. Losses will naturally occur within the coupler due to scattering, absorption, reflections and cable misalignment. Another type of coupler is the tee coupler, shaped as a "T", and used in the MIL-STD-1773 fiber optic data bus equivalent of MIL-STD-1553B.

A tee coupler at each remote terminal splits off a portion of the light from the data bus and carries it to the fiber optic transceiver in each terminal. The disadvantage of the tee coupler is that the optical power loss increases proportionally to the number of terminal nodes on the bus.

A star coupler, as shown in *Figure 10-14*, has multiple ports to distribute the optical power point-to-point to multiple terminals. Unlike, the tee coupler, the insertion loss does not increase directly with the number of terminals; and therefore, it is well suited for connecting a large number of terminals to the fiber optic network. Directional couplers, tee couplers, and star couplers are called passive couplers because they allow the equal division of light between all the terminal nodes that are connected to them. However, an optical switch, such as used in the Avionics Full-Duplex Switched Network (AFDX) only allows light to be coupled from one fiber to another but not to both. As shown in *Figure 10-15*, the AFDX optical switch permits one of two circuit

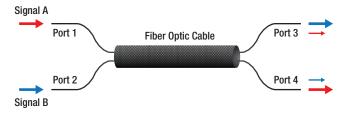Figure 10-13. Four-port directional coupler.
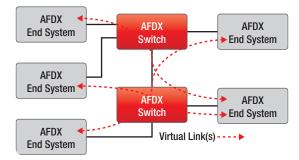

Figure 10-14. A six-port star coupler.

Figure 10-15. AFDX fiber optic network with active switches.

paths to be chosen depending on the switch setting. This active switch uses a relay to physically move the fiber between two or more positions.

APPLICATIONS IN AIRCRAFT SYSTEMS

All though fiber optic networks are beginning to appear in some modern flight and engine control systems, they are more prevalent in In-Flight Entertainment (IFE) systems due to their high bandwidth characteristics. (*Figure 10-16*) Currently in development is a Fourth Generation Cabin Distribution System standard, which locates an active fiber optic data switch below the floor panels with fiber optic cabling routed to each of the passenger seats. Cabin systems are covered in much more detail in *Sub-Module 15*.

A fiber network failure may be observed as an increase in the bit error rate or a total failure in data transmission, which could be the result of a broken fiber, a source with no optical output, or circuit failure where there is a loss of modulation. No optical output could be caused by a laser that no longer reaches its threshold where stimulated emission occurs. It is important to note that fiber optic cable breakages do not cause intermittent failures, unlike copper wire.