CHAPTER

28

Mobile Fiber-Optic Communications

About This Chapter

The past few chapters have described the many applications of fiber optics in fixed telecommunication systems. Fibers also are used in a variety of mobile systems for civilian and military systems. Fiber cables can be used for remote control of robotic vehicles and guidance of tactical missiles. Fiber cables also are used inside vehicles ranging from battleships to private automobiles. This chapter briefly surveys these diverse applications, explaining how and why fibers are used.

Mobile Systems

Mobile systems differ in important ways from fixed systems, with the details depending on the application. This leads to some constraints on system design.

Some fiber-optic cables are used as tethers or connections for transmitting signals to and from moving objects. An example is a cable connected to a remotely operated vehicle that may venture into extreme environments where humans can't go. These cables have to survive whatever environment they pass through, so they are specially designed for that environment. The requirements can vary widely. Cables that tether a robotic mini-submarine to its human operators in a ship have to be strong and rugged. In contrast, the single fiber that connects to a fiber-guided missile during its brief flight must be light and flexible as well as strong, and is used only once.

Connections inside vehicles generally are short, with the exception of those in ships. Links inside a plane or car run no more than tens of meters, and often only meters, so plastic or graded-index fibers are often used, although single-mode fibers are used in some places. Often these are miniature dedicated local-area networks that interconnect

Connections in vehicles generally are short.

Vehicles are more hostile environments than offices.

Military equipment must be rugged and repairable in the field.

the growing variety of electronic systems in the vehicle. Copper cables often can carry data the required distances, but fiber cables are lighter and smaller. The immunity of fiber to electromagnetic interference is a big plus in vehicles where electrical, electronic, and mechanical systems are packed tightly together.

Environmental requirements generally are much more stringent for equipment installed in a vehicle than in an office. Connections to your desktop computer don't have to withstand the constant vibration of a moving car or flying airplane. Some common fiber connectors that work perfectly well in an office building or telecommunications switching center can work loose in moving vehicles that are exposed to outdoor temperature extremes.

Military equipment must meet special requirements for ruggedness and field repairability, and some must meet radiation-hardening specifications. Recent changes allow the use of some off-the-shelf commercial components that meet most military requirements.

Military systems share some other common features with civilian aircraft and automotive systems. They tend not to adapt cutting-edge optical and electronic technologies. Design cycles and production cycles are usually much longer than for telecommunications or computer equipment. Many systems are critical for safety and have to pass stringent testing requirements. You can survive a system error on your personal computer, but you might not survive if your car's computerized braking system froze when you stomped on the brakes in an emergency. The auto industry has different standards for entertainment systems and for safety-critical components. Military and civilian aircraft are designed to operate for a dozen years or more, so their control systems have to meet the same requirements. Automotive systems are supposed to last for many years, but also must be mass producible at low cost, which leads to long design lead times.

This chapter will give you a brief overview of these special fiber systems, emphasizing how they resemble and differ from other fiber communications equipment.

Remotely Controlled Robotic Vehicles

When we think of remotely controlled vehicles, most of us think first of radio-controlled toys that zip across the floor until the batteries run down. Radio controls are cheap and simple, but limited. You can command your radio-controlled car to go faster, slower, forward, backward, or turn right or left—but not much more.

Fiber-optic cables carry signals to control robotic vehicles.

Control of advanced robotic vehicles is a far more demanding job. The operator needs video transmission from a camera in the robot to see the local environment. Other environmental sensing information may also be needed, such as temperature and pressure readings. Signals must flow in the opposite direction so the operator can control the vehicle. Fiber-optic cables carry signals in both directions in a variety of remotely controlled vehicles, often sending two signals in opposite directions through a single fiber at different wavelengths. Although care must be taken to protect them, fiber-optic cables can work in places where radio signals cannot, including underwater and in electromagnetically noisy environments. Fiber cables can also be made quite rugged and special ruggedized connectors are made for military systems. Other fiber advantages include their ability to carry high-bandwidth signals over greater distances and their light weight.

Remotely controlled robots can go into places unsafe for humans. Robots can probe the radioactive parts of nuclear reactors to take measurements or make repairs, or to disassemble old reactors at the ends of their operating lifetimes. Robots can descend deep into the ocean or explore the surface of the moon or Mars. Robots can be scouts for armies, and they can even deliver weapons to their target (we call them guided missiles).

Fiber-Optic Guided Missiles

Guided missiles are essentially simple robots with deadly missions—to deliver bombs to their targets. One type of guided missile uses a ruggedized optical fiber to carry control signals to and from the launch site on the ground or a ship. The original version, called *FOG-M* for *fiber-optic guided missile*, was developed by the Pentagon, and gives a good idea how remote control through optical fibers works.

A fiber carries video images back to a soldier who guides the missile.

As shown in Figure 28.1, a video camera in the missile sends images to a soldier who guides the missile to its target by sending control signals in the opposite direction. The missile is preprogrammed to aim at the target, but the soldier provides fine guidance to make sure it hits the target. Images and control signals travel through a single bare ruggedized optical fiber that trails from the missile to the launcher. The soldier monitors the video image throughout the missile's flight to home the missile in on its target, following it all the way to impact. This system enables the soldier to stay hidden out of sight because it does not require a line of sight to the target, unlike laser-guided bombs that require that the soldier be able to see the target. The fiber-guided missile is similar to a wire-guided missile, but the fiber has much greater bandwidth, so it can carry video signals or span longer distances.

The components of the U.S. FOG-M system is shown in Figure 28.2. The missile contains a video camera, a fiber-optic video transmitter, a low-bandwidth receiver for control signals, and a special reel of fiber. One end of the fiber is fixed to the launcher, and remains behind when the missile is fired. As the missile flies toward its target, the fiber unwinds rapidly from the reel, forming a long arc over the battlefield. The reel is a critical component because it must deploy the fiber at the right rate so as not to tangle or break the fiber. The

Up to 60 km of fiber can be deployed from the missile.

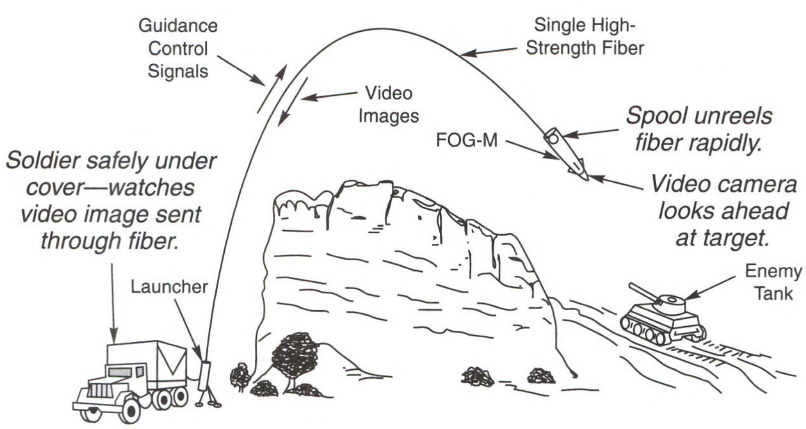
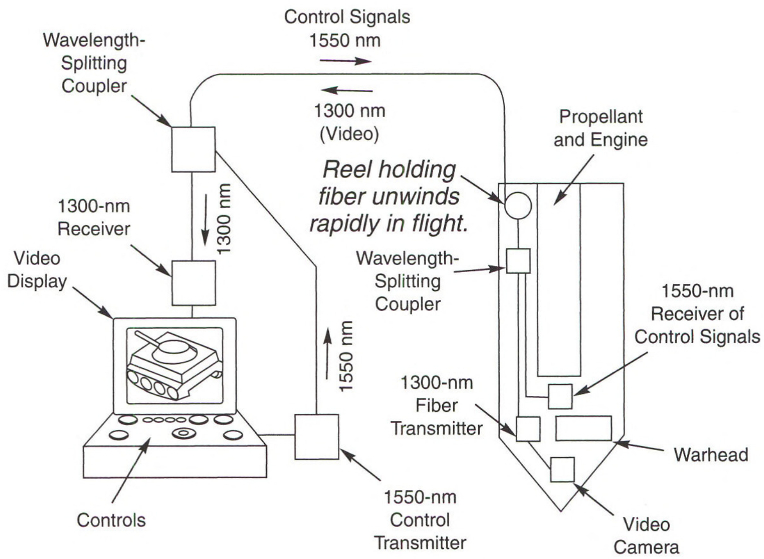


FIGURE 28.1
A concealed soldier guides a FOG-M missile to its target.

FIGURE 28.2
FOG-M components.



single fiber carries signals in both directions: a video signal from the missile at 1300 nm and a control signal to the missile at 1550 nm.

Raytheon developed an enhanced version of FOG-M with a range of 15 km, which could fly at altitudes to 300 meters. This design enabled it to hit the tops of armored vehicles, which are more vulnerable than the sides. Although test flights were successful, the Army cancelled the program in 2002.

In a parallel program, the governments of Germany, France, and Italy sponsored development of their own fiber-guided missile called *Polyphem.* Designed to be fired from ships or the ground, it has a range to 60 km and uses infrared cameras, which were optional on FOG-M. Data from the missile reportedly can be transmitted at rates above 200 Mbit/s.

Robotic Vehicles on Land

Fiber cables can control robotic land vehicles.

Fiber-optic cables also can guide robotic vehicles on land. Military agencies have done extensive testing of unmanned ground vehicles that are remotely controlled in various ways, including by fiber. Radio signals have the obvious advantage of not requiring a physical connection to the vehicle. Cables have to be ruggedized because the robots are likely to run over them. However, fiber cables are immune to electromagnetic interference, electromagnetic pulse effects, and jamming that could block radio communications. Fibers also offer high bandwidth, so operators can obtain detailed information from the vehicle.

The robots are intended for hazardous duty. For example, the Naval Sea Systems Command has developed the Remote Ordnance Neutralization System, which runs on pivoting tracks and has a robotic arm that can defuse explosives. A soldier can control the robot over a radio link or fiber cable, staying safely out of harm's reach in case anything goes wrong. Similar robots could be used to detect and remove land mines, which continue to take a heavy toll on civilians long after the wars are over. Other robots might fire weapons at dangerous targets.

The high bandwidth of fiber cables makes it possible to consider using virtual reality techniques to remotely operate robotic vehicles. Sensors on the vehicle would scan the area, serving as the operator's "eyes," while other sensors would listen for sounds and "feel" the terrain. The sights, sounds, and feel would be conveyed to the operator—far from the vehicle—using screens, speakers, and perhaps virtual-reality gloves. The goal would be to keep the operator safe while feeling as if he or she were driving the vehicle.

Remote-controlled robots could also serve many nonmilitary purposes in dangerous environments. Robots could inspect the "hot" interiors of nuclear power plants or perform needed repairs inside the reactor. The robots could be left inside the reactor permanently if they became contaminated. Specialized robots could be used to dismantle old reactors, without exposing people to the highly radioactive materials inside. Likewise, remotely controlled robots could clean up hazardous wastes. Scientists used a fiber-optic cable to control a multilegged robot as it climbed into a hazardous Antarctic volcano to collect data.

Remotely controlled robots could clean up hazardous wastes and dismantle old nuclear reactors.

Submersible Robots

Radio links can substitute for cables in many land applications, but most radio waves don't penetrate far into water. Cables or acoustic signaling are required to maintain contact with submerged vessels. Although crewed submersibles can operate without a continuous link to the surface, only cables can provide the transmission capacity needed to remotely operate a sophisticated submerged vessel. Fiber cables are preferred because of their high bandwidth and durability.

Hybrid fiber-electrical cables carry signals and power to remotely operated submersibles.

Hybrid fiber and electrical cables carry the signals and power needed to steer and accelerate submerged vessels, as well as bring video signals and telemetry to the surface, where shipboard operators can monitor them.

Fiber cables also allow operators aboard a submersible to control robotic vehicles that can be sent into small spaces or dangerous areas. The most famous example came when Robert Ballard's team from the Woods Hole Oceanographic Institution discovered the sunken wreck of the *Titanic* in 1985. The scientists discovered the wreck with *Alvin*, a submersible that carried three people. However, they did not dare to explore the inside of the deteriorating wreck. Instead, they used a 250-lb robot, tethered to *Alvin* with a fiber-optic cable that carried control signals. It was this fiber-controlled robot that photographed details of the dark interior of the wreck. Ballard remains enthusiastic about the use of fiber-controlled robot submarines.

Fibers in Aircraft

It was not too long ago that most aircraft were controlled by hydraulic systems. When the pilot moved a lever, it would cause hydraulic fluid to move a control surface (e.g., a wing flap), much as hydraulic brakes work in an automobile. Newer planes have fly-by-wire electronic controls that send electronic signals to motors that move control surfaces. Modern aircraft—particularly military planes—also use many electronic systems and sensors,

Fibers can serve as the control networks for aircraft.

adding to signal transmission requirements. These include radars, navigation and guidance systems, and—in military planes—weapons systems with automatic targeting capabilities and electronic countermeasure equipment.

Like many other users faced with increasing communications requirements, the aerospace industry and the Air Force began investigating fiber optics. Pentagon research programs date back to the 1970s. Aircraft performance depends on weight, and military engineers wanted to reduce the load of heavy, metal cables. They also wanted to protect their avionic systems from electromagnetic interference, electromagnetic pulse effects, and potential enemy countermeasures.

New tactical aircraft use fiber-optic links.

Fiber is used extensively in the latest generation of tactical aircraft, such as the U.S. Air Force F-22 Raptor and the Eurofighter. Multimode fibers transmit signals for radars, weapons control systems, and electronic warfare systems. The use of fiber greatly reduces vulnerability to enemy countermeasures.

Some older military aircraft have been retrofit with fiber for high-bandwidth applications. An example is the modernization of computer systems in the Air Force's AWACS (Airborne Warning and Communications System) fleet. Fiber systems transmitting 1 Gbit/s using the Fibre Channel standard are replacing communications equipment developed in the 1970s.

Another addition to existing airborne systems is the Fiber Optic Towed Decoy, which helps protect aircraft from enemy missiles. When instruments detect a potential threat, the aircraft releases the radar-emitting decoy and tows it behind the plane on a fiber-optic cable. The system identifies the type of threat, and commands the decoy to emit a radio signal designed to fool that particular enemy weapon system. The commands go through the fiber cable, which emits no radio waves, and the aircraft's radio emissions are limited, so the enemy weapon is fooled by the decoy's emissions and homes in on it. The decoy is part of a new countermeasure system being integrated into F-15 and F-18 fighter planes.

Fiber-optic aircraft links use multimode fiber.

Military systems have long development times, and most military aircraft use multimode fibers to transmit no more than a few hundred megabits per second over the short distances inside a plane. However, some new systems use advanced fiber technology. The towed decoy borrows techniques developed to transmit analog microwave signals in cable television and microwave antenna systems. High-speed detectors convert the analog signal from an externally modulated laser back to microwaves, which the decoy then emits. The special towing cable is built around single-mode fiber designed to be particularly insensitive to bending, which is hard to control in a cable hanging from a fast-moving jet.

Civilian airliners also use fibers in control systems. After testing "fly-by-light" controls in eight 757 jets, Boeing included a 100-Mbit/s fiber-optic local-area network in the control system of its 777 airliners. Boeing engineers calculated that they could have saved over 1300 kg if they used only fiber instead of copper wiring for the communication system in the plane, but they did not go that far. Airlines are looking to fiber for higher bandwidth as they upgrade in-flight entertainment systems.

Fiber-optic systems must meet some special requirements for aircraft use. Temperatures can vary widely, and planes suffer continual vibrations in flight. Many connectors that work fine in ground-based equipment, such as the FC, ST, and SC, are not recommended for aircraft use. However, suitable connectors are available, including some designed to meet military environmental requirements.

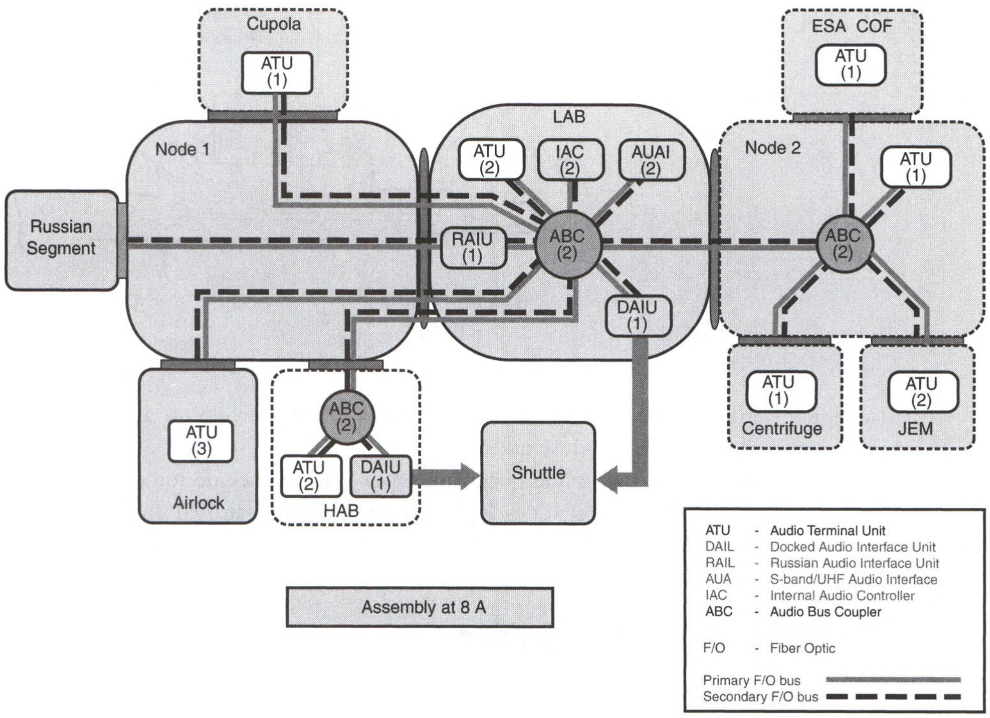


FIGURE 28.3

Fiber-optic audio network in the International Space Station. (From NASA "International Space Station Familiarization" government work not subject to copyright)

Light weight also tips the balance toward fiber in spacecraft, and the International Space Station includes fiber-optic networks for audio and video transmission. Figure 28.3 shows the layout of the station's fiber-optic audio network.

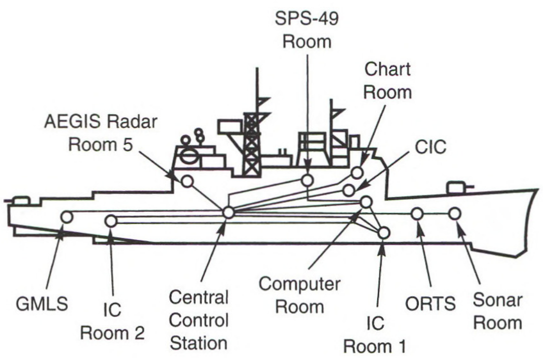
Shipboard Fiber-Optic Networks

The communication requirements of a big ship rival those of an office building. Ships have their own telephone networks to keep officers and crew in contact, as well as communication systems that link them to the outside world. Military ships carry a variety of weapon systems, as well as radars, sonar systems and other sensors. Modern military ships have computer rooms, both to control on-board weapon systems and to analyze incoming information. Computers have become so important to naval operations that many ships in the U.S. Navy are now equipped with fiber-optic local-area networks. Figure 28.4 shows one example of how fiber optics can interconnect shipboard systems.

Big ships have massive communication requirements.

Radars and other imaging and sensing systems often collect large volumes of data, requiring the high transmission capacity of fiber links. Weight is not as critical on ships as it is on aircraft, but scrapping metal cables can save valuable space. Fibers are immune to

FIGURE 28.4
Cabling in a large ship. (Courtesy of AT&T)



electromagnetic interference, which can be a problem when mechanical and electronic systems are packed tightly in the close quarters of ships.

Early naval systems used multimode fiber, but newer systems include some single-mode fibers for high-capacity systems. Recent developments include a standardized ship-to-shore cable for in-port connections, which includes eight multimode fibers and four single-mode fibers.

Automotive Fiber Optics

Automotive engineering, like military system design, involves an odd mix of conservative and advanced design. Some innovations appear surprisingly quickly in luxury cars, such as navigation systems based on the Global Positioning System. Yet fiber optics have appeared only recently, and only in a limited range of luxury cars.

Automotive design faces stringent requirements.

Automotive engineers are not hopelessly conservative about using fiber. They are cautious because car designers face very stringent requirements. Modern automotive equipment must survive hostile conditions ranging from freezing in Alaskan winters to baking in south Texas parking lots in mid-summer. Cars must be repairable by technicians with a wide range of skills and equipment, and able to withstand the efforts of amateur mechanics. Safety-critical systems such as steering, brakes, and wipers must withstand minor failures, so new technology for those applications requires very stringent testing. Planning cycles are long, with major changes often requiring five years to reach full-scale production. In addition, unit costs must be kept low so manufacturers can make profits.

Forward-looking automotive engineers realized more than two decades ago that fiber optics could reduce the weight and complexity of wiring harnesses and prevent electromagnetic interference from jamming electronic systems. However, other options looked better, so fiber optics stayed on the shelf for many years. A new generation of sophisticated electronics, such as video systems with back-seat screens, has now revived interest in fiber links in autos.

Plastic fibers are easy to connect and splice.

The new systems use step-index multimode plastic fiber with 1000-micrometer PMMA (polymethyl methacrylate) cores. Although its attenuation is high and bandwidth low by telecommunication standards, this fiber has plenty of capacity to deliver signals throughout even the biggest sport-utility vehicles. Plastic fibers also are easy to install and repair, critical concerns in both manufacture and repair. The big challenges are temperature and vibration, with the auto industry wanting robust connectors and fibers able to withstand

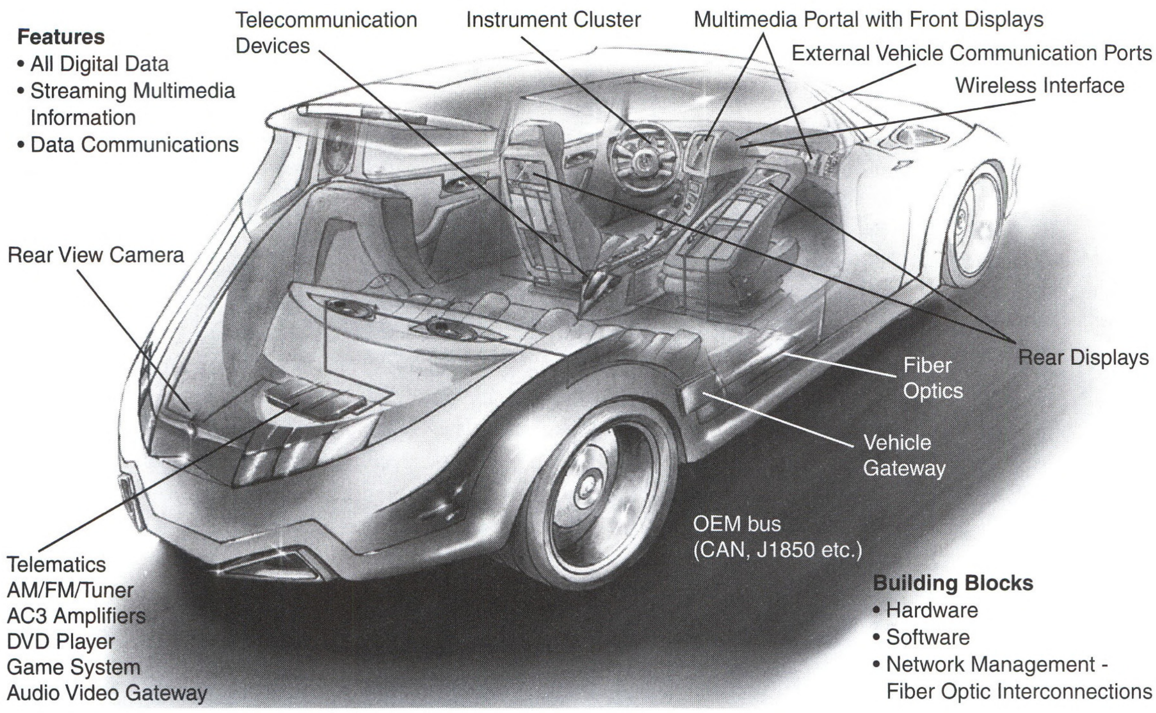


FIGURE 28.5

A MOST network links electronic equipment in a car. (Courtesy of MOST Cooperation)

temperatures as high as 85°C. Fiber networks are starting to appear as options on high-end luxury cars, where new automotive technology traditionally appears first. Separate networks have been developed for entertainment systems, where failures are annoying but not dangerous, and for systems critical to car safety.

Entertainment Networks

The first generation of fiber systems installed in cars provide multimedia interfaces that carry audio, video, and digital data for entertainment equipment and amenities such as stereos, DVD players, and navigation systems. Driving a car without music, GPS navigation, and back-seat movies may not be pleasant, but it certainly poses no danger. So automotive engineers feel freer to experiment with these systems than with networks that control safety-critical equipment such as turn signals, windshield wipers, and brakes. Two major standards have been developed for fiber entertainment networks: MOST and an automotive version of FireWire.

Networks carrying safety-critical data must be more reliable than entertainment networks.

MOST stands for *Media Oriented Systems Transport*, a network with a "plug and play" interface that can transmit data at up to 24.8 Mbit/s. It's targeted at automotive applications. Devices that follow the MOST standard can be used in any car network that complies with it. Figure 28.5 shows how the devices might be installed in a car.

A MOST network consists of point-to-point plastic-fiber links. The transmitters are 650-nm LEDs emitting 0.1 to 0.75 mW, which are directly modulated with an extinction ratio of at least 10 dB; the receivers are PIN photodiodes. Each device contains two ports, for input and output, and the links are arranged in a loop or ring. Each device converts the input optical signals to electronic form, then converts them back into optical form for retransmission to the next device. The loop can support up to 64 devices, including stereos, DVD players, video displays, speakers, mobile phones, computers, game centers, and navigation equipment.

MOST and FireWire are entertainment networks.

Devices automatically initialize when plugged into the network, and all analog signals are converted into digital format before transmission. A master clock synchronizes data transmission from all devices, which allows the use of simple transmitters and receivers and avoids the need for data buffering. A control channel carries 700 kbit/s, and the network can carry asynchronous data at up to 14.4 Mbit/s and synchronous data, like video, up to 24.8 Mbit/s. The MOST network is already used in some high-end luxury cars, including the Audi A-8, the BMW 7 Series, the Mercedes E class, the Porsche Cayenne, the Saab 9-3, and the Volvo XC-90. Developers have talked about extending network speed to as fast as 1 Gbit/s and about developing a version for use in home entertainment networks. Above 100 Mbit/s, hard-clad silica fibers and VCSEL transmitters would replace plastic fibers and red LEDs in MOST networks.

Like MOST, the automotive version of the FireWire standard developed by the 1394 Trade Association has point-to-point fiber links that connect plug-and-play devices. However, the links contain two fibers and do not have to form a complete ring. The standard does not specify transmission wavelength, but normally it uses 650-nm LEDs with plastic fiber. Alternatives include glass fibers and Category 5 twisted pairs. The original 1394 FireWire standard transmitted at 100, 200, or 400 Mbit/s, but an updated version adds 800 and 1200 Mbit/s. Current versions can link up to 63 devices. Although FireWire is common on computers, it is not yet widely used in cars.

Safety-Critical Networks

Byteflight carries 10 Mbit/s for safety-critical devices.

Different considerations apply to safety-critical networks, which shaped the Byteflight protocol developed by BMW and several electronics companies. Byteflight transmits at 10 Mbit/s through plastic fibers, picked for their immunity to electromagnetic interference. The network is arranged in an active star configuration, with fibers linking individual devices to the central active node, which regenerates input signals for transmission to other nodes. Transceivers consist of a red LED mounted on top of a photodiode, so both couple to the same fiber.

The transmission protocol is designed to meet safety needs, with transmission arranged in 250-microsecond blocks for sending urgent messages. The active node generates the clock signals. Byteflight was first used in BMW 7 Series cars to connect 13 electronic modules that controlled air bag deployment, transmission gear shifting, and other critical functions.

What Have You Learned?

1. Mobile systems must operate in different environments than fixed systems. Vehicle systems face more difficult conditions than those used in offices.
2. Vehicle communication systems generally span short distances.

3. Military equipment must meet special requirements for ruggedness and field repairability. New military systems can use some commercial equipment that meets their requirements.
4. Military systems have long design cycles. Military and aerospace systems typically have lifetimes of over a dozen years.
5. Optical fibers can carry signals to control robotic vehicles on land, in air, or in the water. Fibers' advantages are their small size, light weight, immunity to EMI, and high bandwidth. Ruggedization of cables is critical for vehicle applications.
6. A fiber can transmit images from a television camera in a missile back to a soldier guiding the missile to its target. Fiber unwinds from a special reel on the missile.
7. Remotely controlled robots could defuse bombs. In civilian applications, remotely controlled robots could clean up hazardous wastes and dismantle old nuclear reactors.
8. Fibers can be used for signal transmission in aircraft because of EMI immunity, small size, and light weight.
9. Fiber-optic communication networks are used on military ships, which have large communication needs.
10. Automotive fiber-optic links use plastic fiber to control production and repair costs.
11. MOST is a 25-Mbit/s network that carries entertainment and convenience signals in cars. A version of FireWire also has been developed for automotive entertainment; it operates at higher speeds.
12. Safety-critical automotive networks require different protocols than entertainment networks to reliably deliver signals such as those that trigger air-bag deployment.

What's Next?

Chapter 29 covers sensing applications of fiber optics.

Further Reading

Automotive Multimedia Interface Collaboration: *http://www.ami-c.org*

Byteflight: *http://www.byteflight.com*

Firewire/1394 Trade Association: *http://www.1394ta.com*

MOST Cooperation: *http://www.mostcooperation.com*

Questions to Think About

1. Military research agencies in Britain and the United States were among the first sponsors of fiber-optic development. Yet military equipment has lagged far behind civilian telecommunications in deploying fiber-optic systems. Why?

2. One of the first fiber-optic systems deployed by the military was a portable battlefield communications network. The lightweight fiber cables replaced thick copper cables, which had proved very vulnerable to damage in handling. Recently, wireless systems have replaced the fiber network. Why do you think fiber optics were deployed earlier in battlefield networks than in other systems?
3. Why can't radio-controlled vehicles be used underwater?
4. A Nimitz-class nuclear aircraft carrier is 1092 ft (333 m) long and requires a crew of 3300 people to sail. Could you run a gigabit Ethernet link the length of the ship with 62.5/125-μm graded-index fiber at 850 nm? If not, could you use other types of multimode fiber?
5. A new car is 20 ft (6 m) long. A step-index plastic fiber has bandwidth of 10 MHz/km. Can you use this fiber to run a 25-Mbit/s MOST link the length of the car?
6. How far can you transmit a 25-Mbit/s NRZ signal through the step-index fiber of Question 5, considering only bandwidth? If attenuation is 200 dB/km, and the link margin is 20 dB, what is the limit imposed by distance, neglecting connector and coupling losses?

Chapter Quiz

1. What kinds of remotely operated vehicles cannot be controlled by operators through fiber optics?
    a. guided missiles
    b. submersibles
    c. munition-defusing robots
    d. robots for nuclear waste cleanup
    e. satellites
2. What signals are transmitted from fiber-guided missiles to the operator?
    a. video images of the target
    b. control commands
    c. data on temperature and pressure
    d. data on fiber attenuation
3. How are signals transmitted to and from a fiber-guided missile?
    a. separately through two fibers in a single cable
    b. bidirectionally through one fiber by time-division multiplexing
    c. bidirectionally through one fiber by wavelength-division multiplexing
    d. only one way
    e. from the missile through the fiber; to the missile via radio

4. Which of the following attributes of fiber optics are important for remote control of land vehicles?

a. secure data transmission
b. lightweight, durable cable
c. EMI immunity
d. b and c
e. a, b, and c

5. Which of the following reasons do not influence the use of fibers for signal transmission in aircraft?

a. Optical fibers are immune to EMI.
b. Optical fibers are lighter than wires.
c. Aircraft lack adequate power supplies for wire-based communications.
d. Military aircraft must be hardened against enemy electronic countermeasures.
e. Fiber optics can help reduce aircraft visibility to radar.

6. What were the most serious problems in developing fiber-optic networks for automobiles?

a. reducing the attenuation of plastic fibers
b. temperature and vibration in vehicles
c. designing high-bandwidth transmitters for plastic fibers
d. developing glass fibers usable in automobiles
e. greater interest in designing tail fins than data links

7. Aircraft fly-by-light systems use optical fibers

a. to illuminate cockpit instruments.
b. in high-strength cables to pull mechanical actuators.
c. to carry control signals to motors that move mechanical parts.
d. only to transmit data from sensors to cockpit instruments.
e. to deliver bright flashes of light that ignite fuel in the engines.

8. Single-mode fibers are used

a. to transmit radio-frequency signals to radar decoys towed by aircraft.
b. in local-area networks on submarines.
c. in cables controlling mobile ground robots.
d. in data links on board aircraft.
e. in automotive systems.

9. What type of system uses plastic fibers for data transmission?

a. fiber-guided missiles
b. radar decoys towed by aircraft

c. local-area networks on board ships
d. data links on board aircraft
e. automotive data links

10. The MOST standard for automotive data networks specifies what data rate?

a. 25 Mbit/s
b. 100 Mbit/s
c. 155 Mbit/s
d. 622 Mbit/s
e. 1 Gbit/s