Data and Computer Communications

Transmission Media

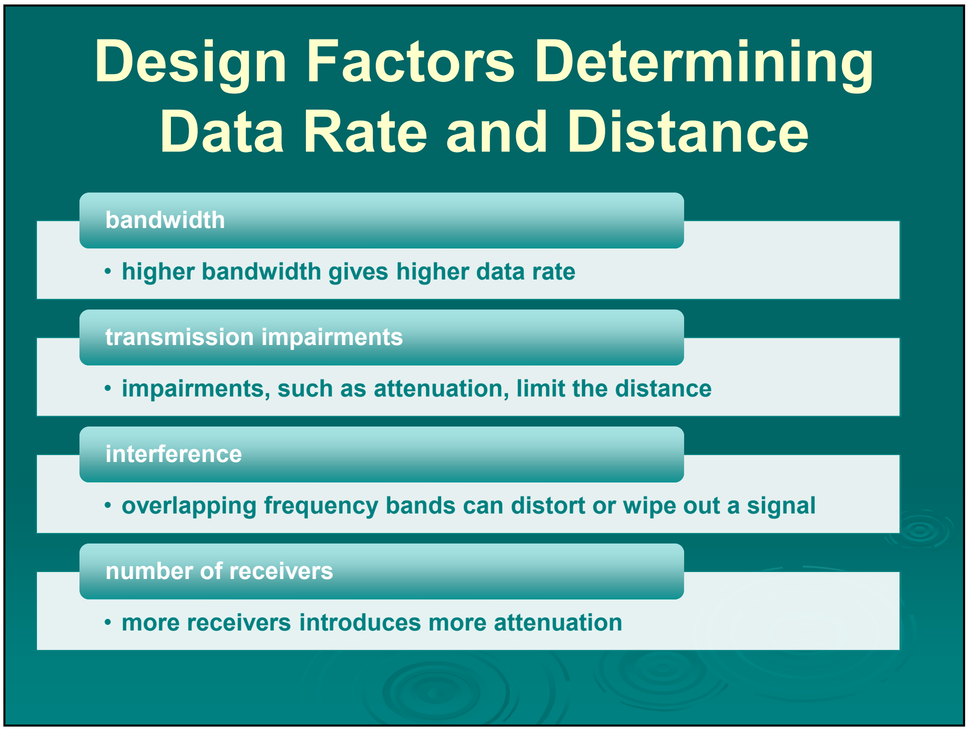
Overview

- transmission medium is the physical path between transmitter and receiver
- guided media – guided along a solid medium
- unguided media – atmosphere, space, water
- characteristics and quality determined by medium and signal
  - guided media - medium is more important
  - unguided media - bandwidth produced by the antenna is more important
- key concerns are data rate and distance

In a data transmission system, the **transmission medium** is the physical path between transmitter and receiver. Recall from Chapter 3 that for **guided media**, electromagnetic waves are guided along a solid medium, such as copper twisted pair, copper coaxial cable, and optical fiber. For **unguided media**, wireless transmission occurs through the atmosphere, outer space, or water.

The characteristics and quality of a data transmission are determined both by the characteristics of the medium and the characteristics of the signal. In the case of guided media, the medium itself is more important in determining the limitations of transmission.

For unguided media, the bandwidth of the signal produced by the transmitting antenna is more important than the medium in determining transmission characteristics. One key property of signals transmitted by antenna is directionality. In general, signals at lower frequencies are omnidirectional; that is, the signal propagates in all directions from the antenna. At higher frequencies, it is possible to focus the signal into a directional beam.



Data rate and distance are the key considerations in data transmission system design; with emphasis placed on achieving the highest data rates over the longest distances. A number of design factors relating to the transmission medium and the signal determine the data rate and distance:

Bandwidth: All other factors remaining constant, the greater the bandwidth of a signal, the higher the data rate that can be achieved.

Transmission impairments: Impairments, such as attenuation, limit the distance. For guided media, twisted pair generally suffers more impairment than coaxial cable, which in turn suffers more than optical fiber.

Interference: Interference from competing signals in overlapping frequency bands can distort or cancels out a signal. Interference is of particular concern for unguided media, but is also a problem with guided media. For guided media, interference can be caused by emanations coupling from nearby cables (alien crosstalk) or adjacent conductors under the same cable sheath (internal crosstalk). For example, twisted pairs are often bundled together and conduits often carry multiple cables. Interference can also be caused by electromagnetic coupling from unguided transmissions. Proper shielding of a guided medium can minimize this problem.

Number of receivers: A guided medium can be used to construct a point-to-point link or a shared link with multiple attachments. In the latter case, each attachment introduces some attenuation and distortion on the line, limiting distance and/or data rate.

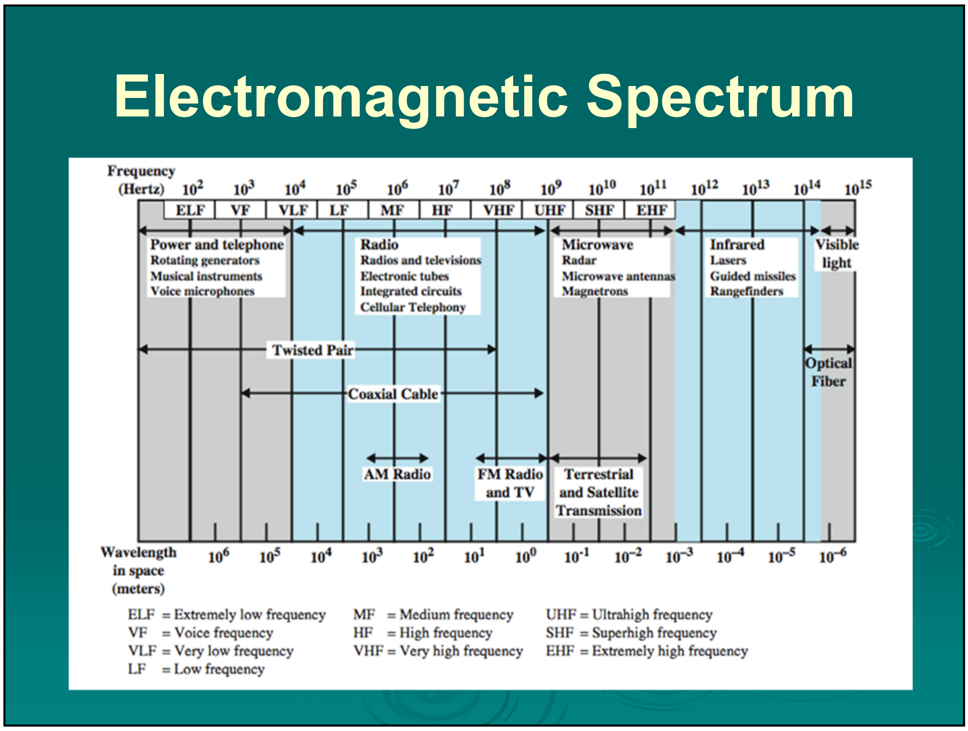


Figure 4.1 depicts the electromagnetic spectrum and indicates the frequencies at which various guided media and unguided transmission techniques operate. In this chapter we examine these guided and unguided alternatives. In all cases, we describe the systems physically, briefly discuss applications, and summarize key transmission characteristics.

Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

For guided transmission media, the transmission capacity, in terms of either data rate or bandwidth, depends critically on the distance and on whether the medium is point-to-point or multipoint. Table 4.1(shown above) indicates the characteristics typical for the common guided media for long-distance point-to-point applications; we defer a discussion of the use of these media for LANs to Part Four. The three guided media commonly used for data transmission are twisted pair, coaxial cable, and optical fiber. We examine each of these in turn.

Guided Transmission Media

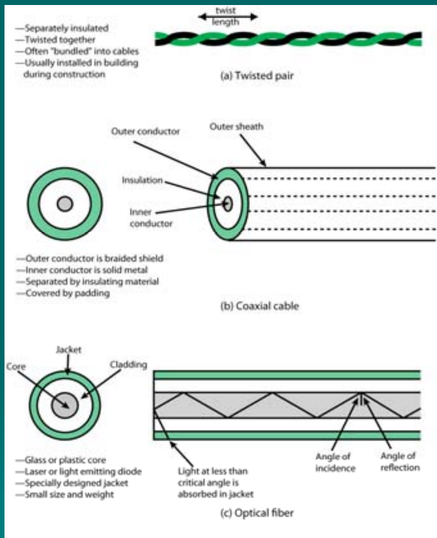
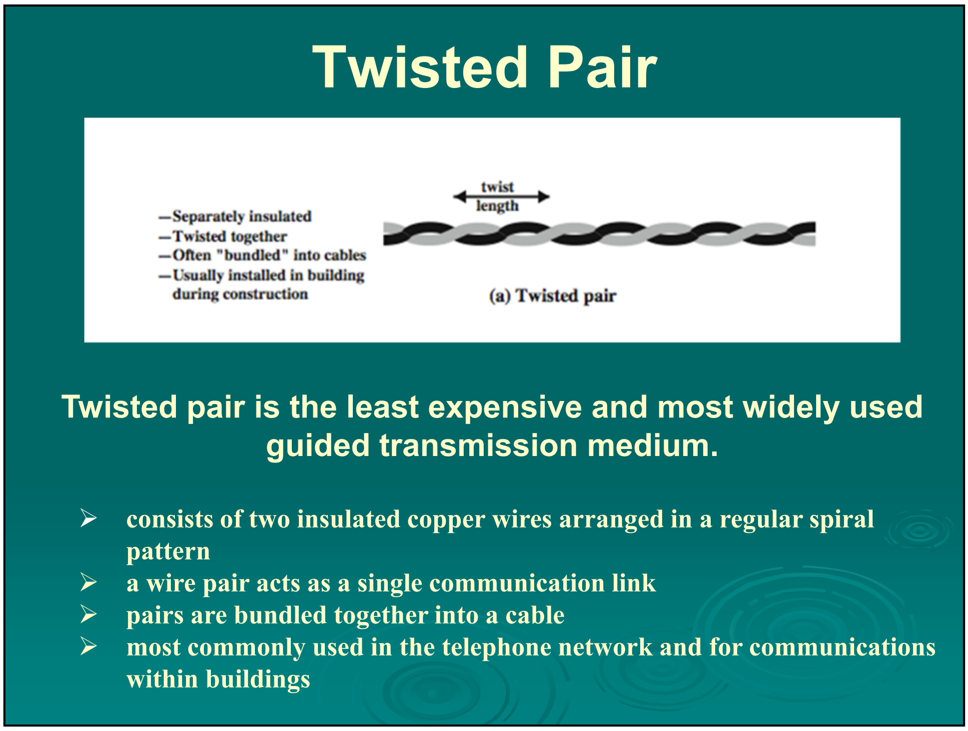


Figure 4.2 Guided Transmission Media

The three guided media commonly used for data transmission are twisted pair, coaxial cable, and optical fiber (Figure 4.2). We examine each of these in turn.



The least expensive and most widely used guided transmission medium is twisted pair.

Physical Description

A twisted pair consists of two insulated copper wires arranged in a regular spiral pattern. A wire pair acts as a single communication link. Typically, a number of these pairs are bundled together into a cable by wrapping them in a tough protective sheath, or jacket. Over longer distances, cables may contain hundreds of pairs. The twisting tends to decrease the crosstalk interference between adjacent pairs in a cable. Neighboring pairs in a bundle typically have somewhat different twist lengths to reduce the crosstalk interference. On long-distance links, the twist length typically varies from 5 to 15 cm. The wires in a pair have thicknesses of from 0.4 to 0.9 mm.

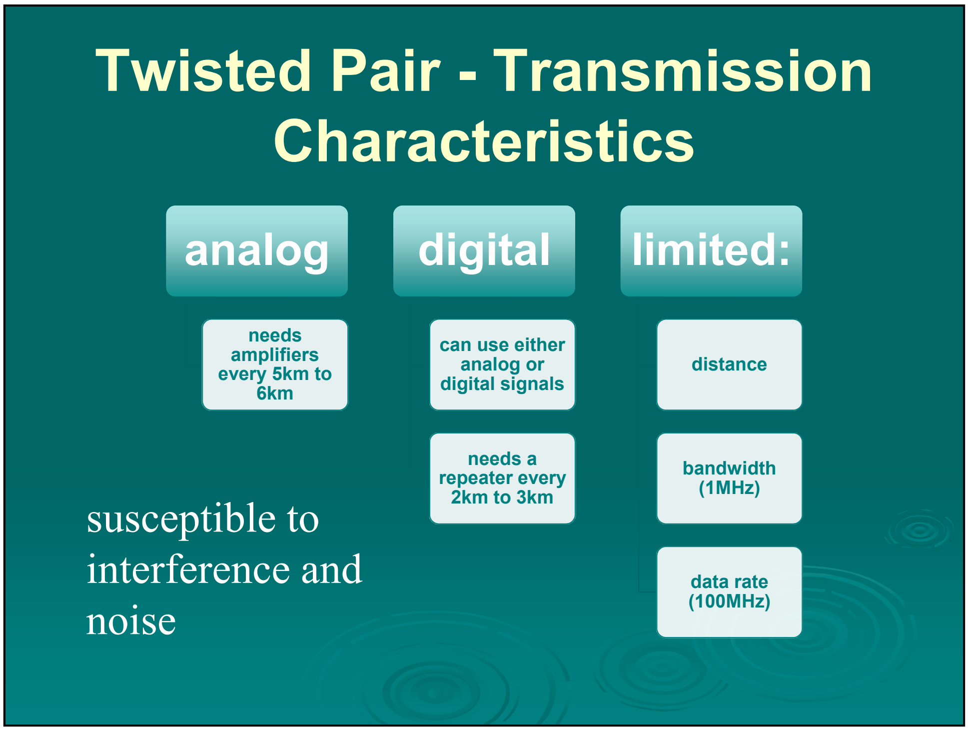
Applications

By far the most common guided transmission medium for both analog and digital signals is twisted pair. It is the most commonly used medium in the telephone network and is the workhorse for communications within buildings.

In the telephone system, individual residential telephone sets are connected to the local telephone exchange, or "end office," by twisted-pair wire. These are referred to as **subscriber loops**. Within an office building, each telephone is also connected to a twisted pair, which goes to the in-house private branch exchange (PBX) system or to a Centrex facility at the end office. These twisted-pair installations were designed to support voice traffic using analog signaling. However, by means of a modem, these facilities can handle digital data traffic at modest data rates.

Twisted pair is also the most common medium used for digital signaling. For connections to a digital data switch or digital PBX within a building, a data rate of 64 kbps is common. Ethernet operating over twisted-pair cabling is commonly used within a building for local area networks supporting personal computers. Data rates for Ethernet products are typically in the neighborhood of 100 Mbps to 1 Gbps. Emerging twisted-pair cabling Ethernet technology can support data rates of 10Gbps. For long-distance applications, twisted pair can be used at data rates of 4 Mbps or more.

Twisted pair is much less expensive than the other commonly used guided transmission media (coaxial cable, optical fiber) and is easier to work with.

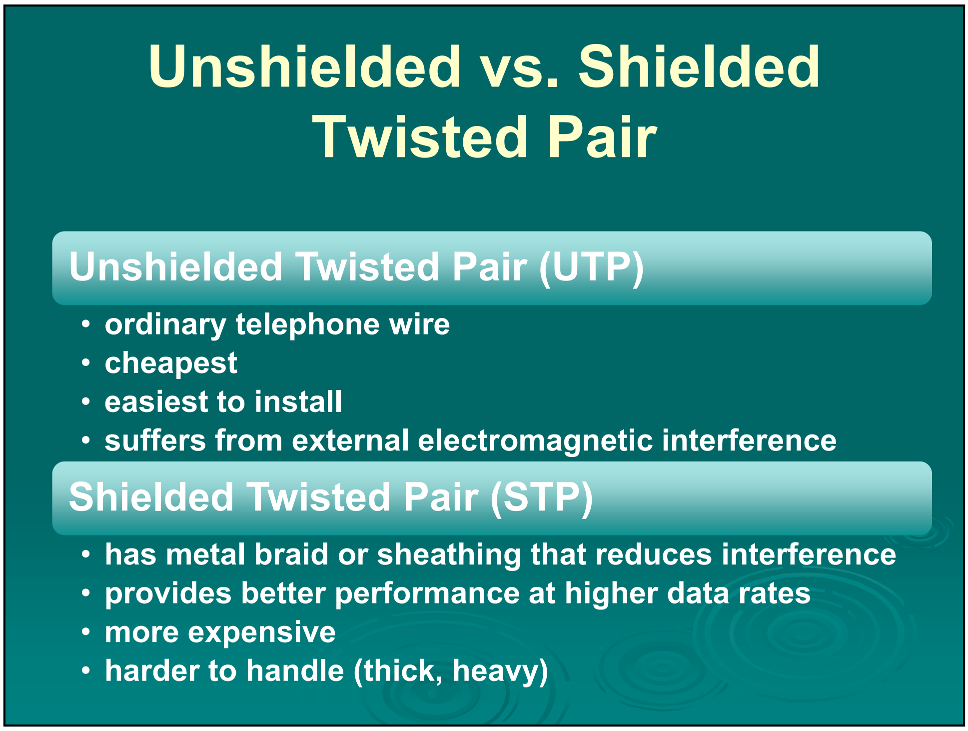


TRANSMISSION CHARACTERISTICS

Twisted pair may be used to transmit both analog and digital transmission. For analog signals, amplifiers are required about every 5 to 6 km. For digital transmission (using either analog or digital signals), repeaters are required every 2 or 3 km.

Compared to other commonly used guided transmission media (coaxial cable, optical fiber), twisted pair is limited in distance, bandwidth, and data rate. As Figure 4.3a shows, the attenuation for twisted pair is a very strong function of frequency. Twisted-pair cabling is also susceptible to signal reflections, or return loss, caused by impedance mismatches along the length of the transmission line and crosstalk from adjacent twisted-pairs or twisted-pair cables. Due to the well-controlled geometry of the twisted-pair itself (pairs are manufactured with a unique and precise twist rate that varies from pair to pair within a cable) and the media's differential mode transmission scheme (discussed in Chapter 5), twisted-pair cabling used for data transmission is highly immune to interference from low frequency (i.e., 60 Hz) disturbers. Note that twisted-pair cabling is usually run separately from cables transmitting ac power in order to comply with local safety codes, which protect low voltage telecommunications installers from high voltage applications. The possibility of electromagnetic interference from high frequency (i.e., greater than 30 MHz) disturbers such as walkie-talkies and other wireless transmitters can be alleviated by using shielded twisted-pair cabling.

For point-to-point analog signaling, a bandwidth of up to about 1 MHz is possible. This accommodates a number of voice channels. For long-distance digital point-to-point signaling, data rates of up to a few Mbps are possible. Ethernet data rates of up to 10Gbps can be achieved over 100 meters of twisted-pair cabling.



Twisted pair comes in two varieties: unshielded and shielded. As the name implies, **unshielded twisted pair** (UTP) consists of one or more twisted-pair cables, typically enclosed within an overall thermoplastic jacket, which provides no electromagnetic shielding. The most common form of UTP is ordinary voice-grade telephone wire, which is pre-wired in residential and office buildings. For data transmission purposes, UTP may vary from voice-grade to very high-speed cable for local area networks (LANs). For high-speed LANs, UTP typically has four pairs of wires inside the jacket, with each pair twisted with a different number of twists per centimeter to help eliminate interference between adjacent pairs. The tighter the twisting, the higher the supported transmission rate and the greater the cost per meter.

Unshielded twisted pair is subject to external electromagnetic interference, including interference from nearby twisted pair and from noise generated in the environment. In an environment with a number of sources of potential interference (e.g., electric motors, wireless devices, and RF transmitters), **shielded twisted pair** (STP) may be a preferred solution. Shielded twisted pair cable is manufactured in three different configurations:

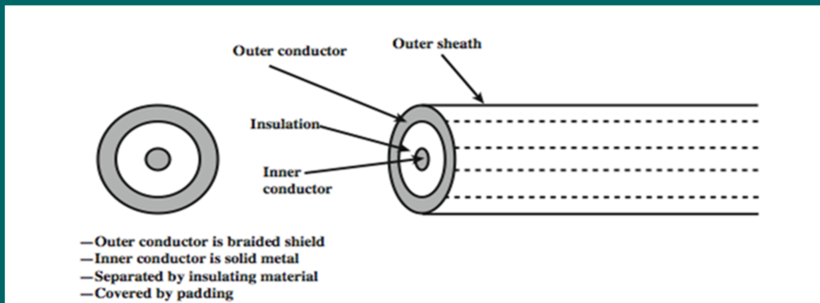
1. Each pair of wires is individually shielded with metallic foil, generally referred to as foil twisted pair (FTP).

2. There is a foil or braid shield inside the jacket covering all wires (as a group). This configuration is sometimes designated as screened twisted pair (F/UTP).

3. There is a shield around each individual pair, as well as around the entire group of wires. This is referred to as fully-shielded twisted pair or shielded/foil twisted pair (S/FTP).

The shielding reduces interference and provides better performance at higher data rates. However, it may be more expensive and installers familiar with UTP technology may be reluctant to work with a new media type.

Coaxial Cable



(b) Coaxial cable

Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

- consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- is a versatile transmission medium used in a wide variety of applications
- used for TV distribution, long distance telephone transmission and LANs

Coaxial Cable

Physical Description

Coaxial cable, like twisted pair, consists of two conductors, but is constructed differently to permit it to operate over a wider range of frequencies. It consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor (Figure 4.2b). The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material. The outer conductor is covered with a jacket or shield. A single coaxial cable has a diameter of from 1 to 2.5 cm. Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

Applications

Coaxial cable is a versatile transmission medium, used in a wide variety of applications. The most important of these are

Television distribution

Long-distance telephone transmission

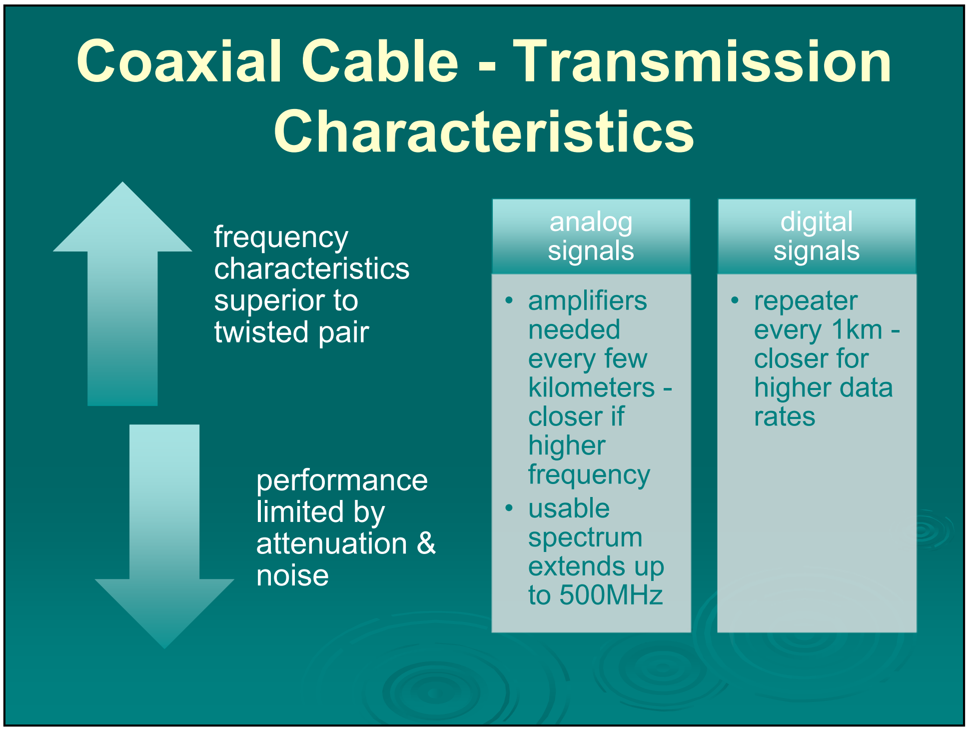
Short-run computer system links

Local area networks

Coaxial cable is widely used as a means of distributing TV signals to individual homes—cable TV. From its modest beginnings as Community Antenna Television (CATV), designed to provide service to remote areas, cable TV reaches almost as many homes and offices as the telephone. A cable TV system can carry dozens or even hundreds of TV channels at ranges up to a few tens of kilometers.

Coaxial cable has traditionally been an important part of the long-distance telephone network. Today, it faces increasing competition from optical fiber, terrestrial microwave, and satellite. Using frequency division multiplexing (FDM, see Chapter 8), a coaxial cable can carry over 10,000 voice channels simultaneously.

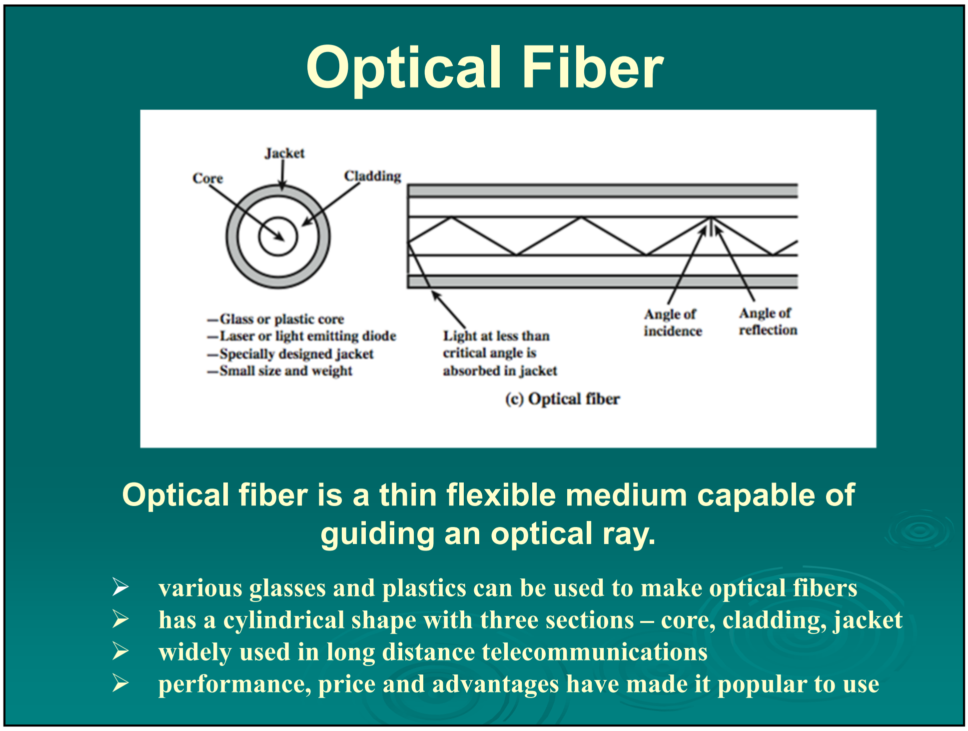
Coaxial cable is also commonly used for short-range connections between devices. Using digital signaling, coaxial cable can be used to provide high-speed I/O channels on computer systems.



TRANSMISSION CHARACTERISTICS

Coaxial cable is used to transmit both analog and digital signals. As can be seen from Figure 4.3b, coaxial cable has frequency characteristics that are superior to those of twisted pair and can hence be used effectively at higher frequencies and data rates. Because of its shielded, concentric construction, coaxial cable is much less susceptible to interference and crosstalk than twisted pair. The principal constraints on performance are attenuation, thermal noise, and intermodulation noise. The latter is present only when several channels (FDM) or frequency bands are in use on the cable.

For long-distance transmission of analog signals, amplifiers are needed every few kilometers, with closer spacing required if higher frequencies are used. The usable spectrum for analog signaling extends to about 500 MHz. For digital signaling, repeaters are needed every kilometer or so, with closer spacing needed for higher data rates.

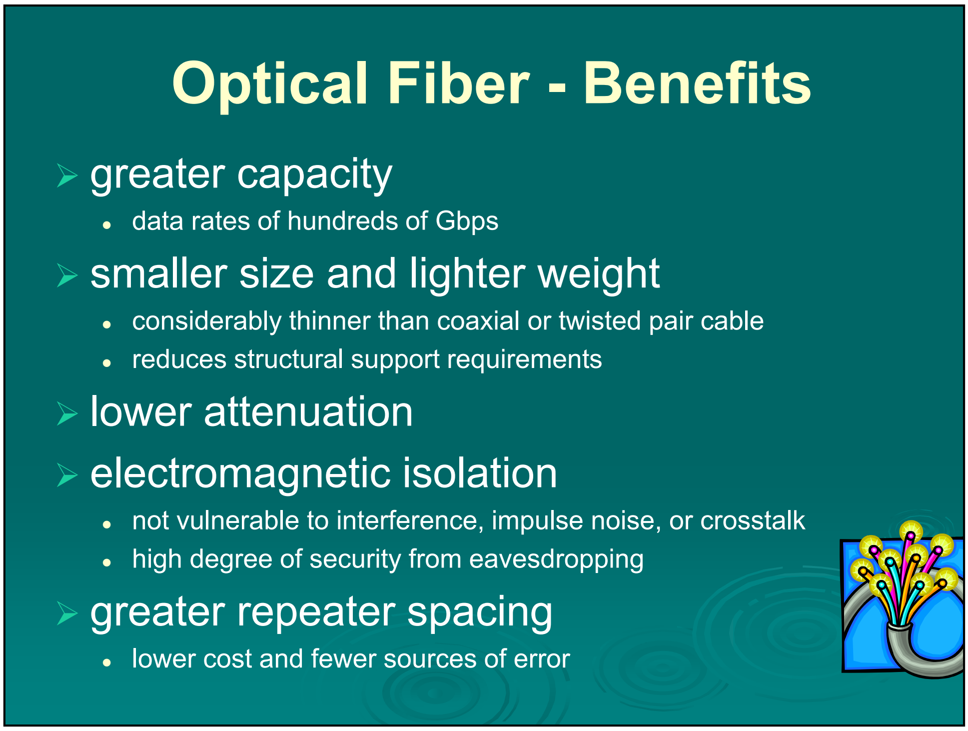


Optical Fiber

PHYSICAL DESCRIPTION

An optical fiber is a thin (2 to 125 µm), flexible medium capable of guiding an optical ray. Various glasses and plastics can be used to make optical fibers. The lowest losses have been obtained using fibers of ultrapure fused silica. Ultrapure fiber is difficult to manufacture; higher-loss multicomponent glass fibers are more economical and still provide good performance. Plastic fiber is even less costly and can be used for short-haul links, for which moderately high losses are acceptable.

An optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding, and the jacket (StallingsDCC9e Figure 4.2c). The **core** is the innermost section and consists of one or more very thin strands, or fibers, made of glass or plastic; the core has a diameter in the range of 8 to 50 µm. Each fiber is surrounded by its own **cladding**, a glass or plastic coating that has optical properties different from those of the core and a diameter of 125 µm. The interface between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer, surrounding one or a bundle of cladded fibers, is the **jacket**. The jacket is composed of plastic and other material layered to protect against moisture, abrasion, crushing, and other environmental dangers.



APPLICATIONS

Optical fiber already enjoys considerable use in long-distance telecommunications, and its use in military applications is growing. The continuing improvements in performance and decline in prices, together with the inherent advantages of optical fiber, have made it increasingly attractive for local area networking. The following characteristics distinguish optical fiber from twisted pair or coaxial cable:

Greater capacity: The potential bandwidth, and hence data rate, of optical fiber is immense; data rates of hundreds of Gbps over tens of kilometers have been demonstrated. Compare this to the practical maximum of hundreds of Mbps over about 1 km for coaxial cable and just a few Mbps over 1 km or up to 100 Mbps to 10 Gbps over a few tens of meters for twisted pair.

Smaller size and lighter weight: Optical fibers are considerably thinner than coaxial cable or bundled twisted-pair cable—at least an order of magnitude thinner for comparable information transmission capacity. For cramped conduits in buildings and underground along public rights-of-way, the advantage of small size is considerable. The corresponding reduction in weight reduces structural support requirements.

Lower attenuation: Attenuation is significantly lower for optical fiber than for coaxial cable or twisted pair (Figure 4.3c) and is constant over a wide range.

Electromagnetic isolation: Optical fiber systems are not affected by external electromagnetic fields. Thus the system is not vulnerable to interference, impulse noise, or crosstalk. By the same token, fibers do not radiate energy, so there is little interference with other equipment and there is a high degree of security from eavesdropping. In addition, fiber is inherently difficult to tap.

Greater repeater spacing: Fewer repeaters mean lower cost and fewer sources of error. The performance of optical fiber systems from this point of view has been steadily improving. Repeater spacing in the tens of kilometers for optical fiber is common, and repeater spacings of hundreds of kilometers have been demonstrated. Coaxial and twisted-pair systems generally have repeaters every few kilometers.

Five basic categories of application have become important for optical fiber:

Long-haul trunks

Metropolitan trunks

Rural exchange trunks

Subscriber loops

Local area networks

Long-haul fiber transmission is becoming increasingly common in the telephone network. Long-haul routes average about 1500 km in length and offer high capacity (typically 20,000 to 60,000 voice channels). These systems compete economically with microwave and have so underpriced coaxial cable in many developed countries that coaxial cable is rapidly being phased out of the telephone network in such countries. Undersea optical fiber cables have also enjoyed increasing use.

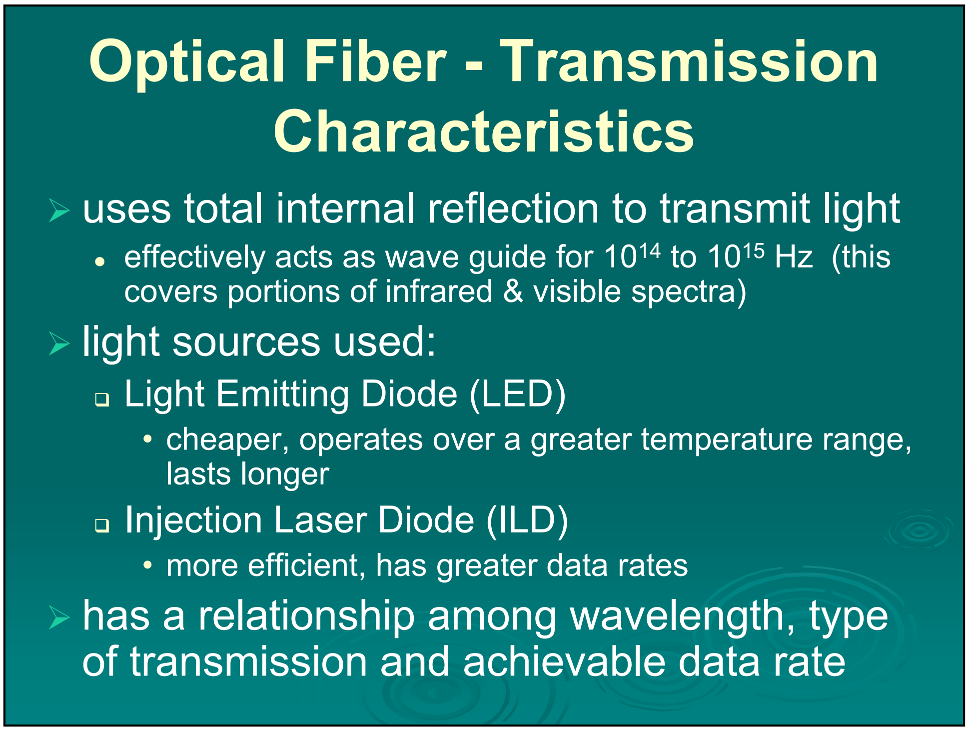
Metropolitan trunking circuits have an average length of 12 km and may have as many as 100,000 voice channels in a trunk group. Most facilities are installed in underground conduits and are repeaterless, joining telephone exchanges in a metropolitan or city area. Included in this category are routes that link long-haul microwave facilities that terminate at a city perimeter to the main telephone exchange building downtown.

Rural exchange trunks have circuit lengths ranging from 40 to 160 km and link towns and villages. In the United States, they often connect the exchanges of different telephone companies. Most of these systems have fewer than 5000 voice channels. The technology used in these applications competes with microwave facilities.

Subscriber loop circuits are fibers that run directly from the central exchange to a subscriber. These facilities are beginning to displace twisted pair and coaxial cable links as the telephone networks evolve into full-service networks capable of handling not only voice and data, but also image and video. The initial penetration of optical fiber in this application has been for the business subscriber, but fiber transmission into the home is now a significant presence in many areas.

A final important application of optical fiber is for local area networks. Standards have been developed and products introduced for optical fiber networks that have a total capacity of 100 Mbps to 10 Gbps and can support hundreds or even thousands of stations in a large office building or a complex of buildings.

The advantages of optical fiber over twisted pair and coaxial cable become more compelling as the demand for all types of information (voice, data, image, video) increases.



TRANSMISSION CHARACTERISTICS

Optical fiber transmits a signal-encoded beam of light by means of **total internal reflection**. Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium. In effect, the optical fiber acts as a waveguide for frequencies in the range of about 1014 to 1015 hertz; this covers portions of the infrared and visible spectra.

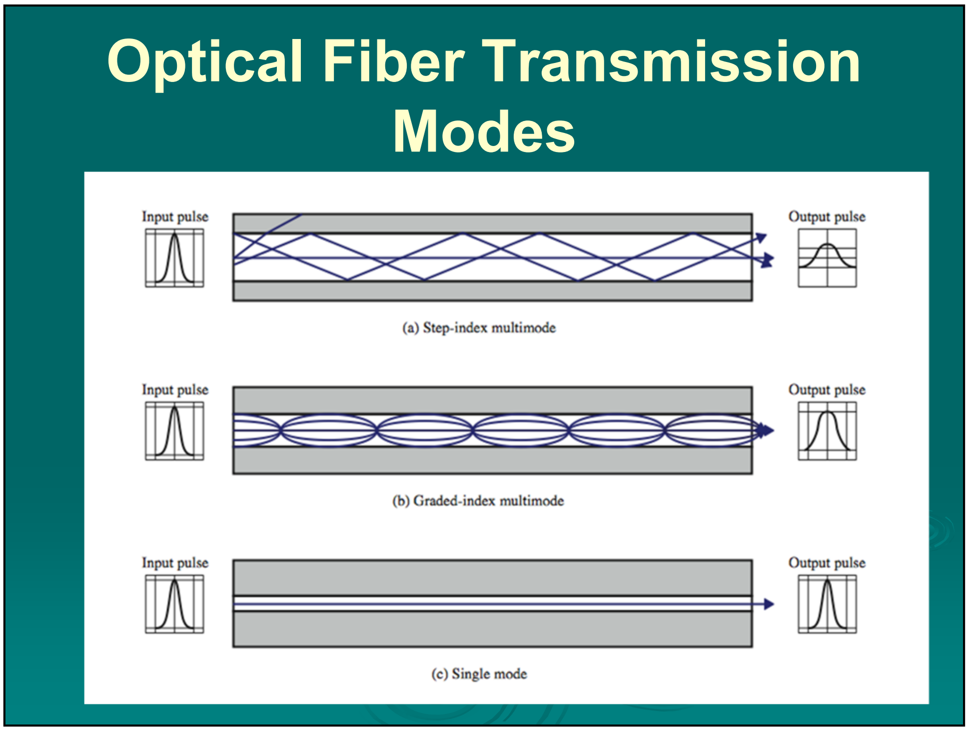


Figure 4.6 shows the principle of optical fiber transmission. Light from a source enters the cylindrical glass or plastic core. Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material. This form of propagation is called **step-index multimode**, referring to the variety of angles that reflect. With multimode transmission, multiple propagation paths exist, each with a different path length and hence time to traverse the fiber. This causes signal elements (light pulses) to spread out in time, which limits the rate at which data can be accurately received. Put another way, the need to leave spacing between the pulses limits data rate. This type of fiber is best suited for transmission over very short distances. When the fiber core radius is reduced, fewer angles will reflect. By reducing the radius of the core to the order of a wavelength, only a single angle or mode can pass: the axial ray. This **single-mode** propagation provides superior performance for the following reason. Because there is a single transmission path with single-mode transmission, the distortion found in multimode cannot occur. Single-mode is typically used for long-distance applications, including telephone and cable television. Finally, by varying the index of refraction of the core, a third type of transmission, known as **graded-index multimode**, is possible. This type is intermediate between the other two in characteristics. The higher refractive index (discussed subsequently) at the center makes the light rays moving down the axis advance more slowly than

those near the cladding. Rather than zig-zagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis. Graded-index fibers are often used in local area networks.

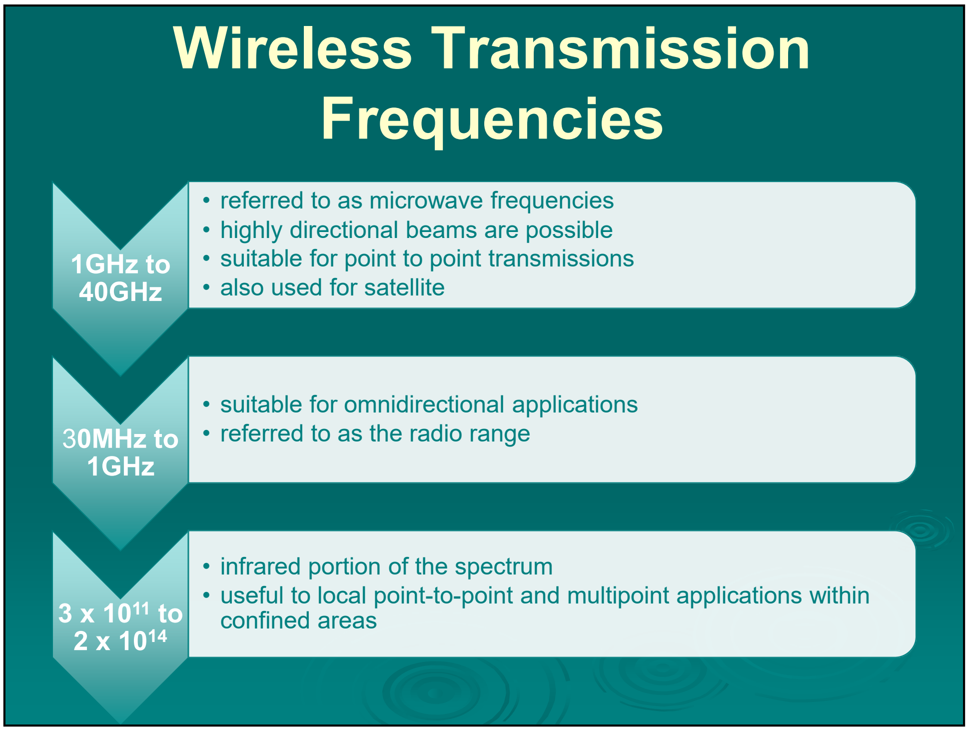
Two different types of light source are used in fiber optic systems: the light-emitting diode (LED) and the injection laser diode (ILD). Both are semiconductor devices that emit a beam of light when a voltage is applied. The LED is less costly, operates over a greater temperature range, and has a longer operational life. The ILD, which operates on the laser principle, is more efficient and can sustain greater data rates.

There is a relationship among the wavelength employed, the type of transmission, and the achievable data rate. Both single mode and multimode can support several different wavelengths of light and can employ laser or LED light sources. In optical fiber, based on the attenuation characteristics of the medium and on properties of light sources and receivers, four transmission windows are appropriate, shown in Table 4.3.

Note the tremendous bandwidths available. For the four windows, the respective bandwidths are 33 THz, 12 THz, 4 THz, and 7 THz. This is several orders of magnitude greater than the bandwidth available in the radio-frequency spectrum.

One confusing aspect of reported attenuation figures for fiber optic transmission is that, invariably, fiber optic performance is specified in terms of wavelength rather than frequency. The wavelengths that appear in graphs and tables are the wavelengths corresponding to transmission in a vacuum. However, on the fiber, the velocity of propagation is less than the speed of light in a vacuum (c); the result is that although the frequency of the signal is unchanged, the wavelength is changed.

1 THz = 1012 Hz. For a definition of numerical prefixes in common use, see the supporting document at William Stallings.com.



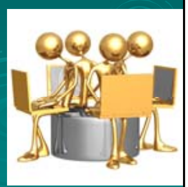
Three general ranges of frequencies are of interest in our discussion of wireless transmission. Frequencies in the range of about 1 GHz (gigahertz = 109 hertz) to 40 GHz are referred to as **microwave frequencies**. At these frequencies, highly directional beams are possible, and microwave is quite suitable for point-to-point transmission. Microwave is also used for satellite communications. Frequencies in the range of 30 MHz to 1 GHz are suitable for omnidirectional applications. We refer to this range as the **radio** range.

Another important frequency range, for local applications, is the infrared portion of the spectrum. This covers, roughly, from 3 ´ 1011 to 2 ´ 1014 Hz. Infrared is useful to local point-to-point and multipoint applications within confined areas, such as a single room.

For unguided media, transmission and reception are achieved by means of an antenna. Before looking at specific categories of wireless transmission, we provide a brief introduction to antennas.

Summary

- transmission Media
  - physical path between transmitter and receiver
  - bandwidth, transmission impairments, interference, number of receivers
- guided Media
  - twisted pair, coaxial cable, optical fiber
- wireless Transmission
  - microwave frequencies



Chapter 4 summary.