MODULE II

TRANSMISSION MEDIA

A **transmission medium** can be broadly defined as anything that can carry information from a source to a destination.
Example: For a written message, the transmission medium might be a mail carrier, a truck, or an airplane.

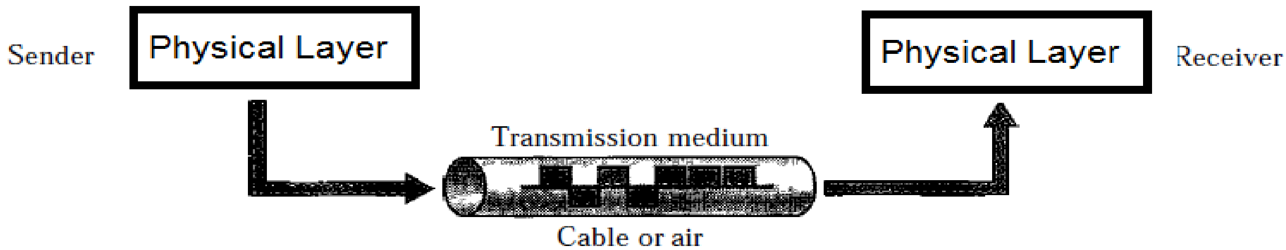


Fig: Transmission Medium and physical layer

In considering the design of data transmission systems, key concerns are **data rate and distance**: the greater the data rate and distance the better. 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.
- **Interference**: Interference from competing signals in overlapping frequency bands can distort or wipe out a signal.
- **Number of receivers**: A guided medium can be used to construct a point- to- point link or a shared link with multiple attachments.

Classes of transmission media:

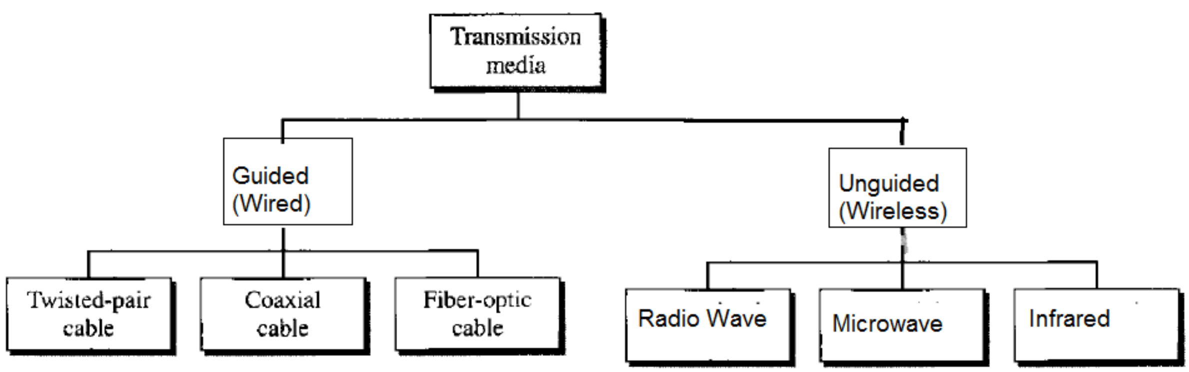


Fig: Classes of transmission media

GUIDED TRANSMISSION MEDIA

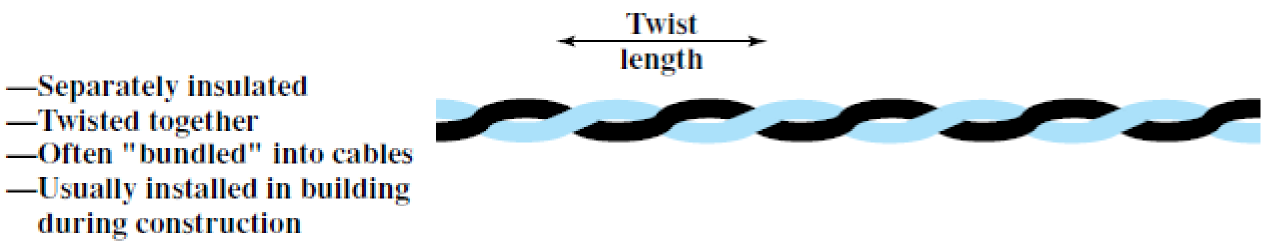
- For guided transmission media, the transmission capacity, in terms of either data rate or bandwidth, depends critically on the distance and on whether the medium is point-to-point or multipoint.
- Table 1 indicates the characteristics typical for the common guided media for long-distance point-to-point applications.

Table .1 Point-to-Point Transmission Characteristics of Guided Media [GLOV98]

	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 (multipair 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

THz = TeraHertz = 10^{12} Hz

1.TWISTED PAIR CABLE



(a) Twisted pair

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

Physical Description:

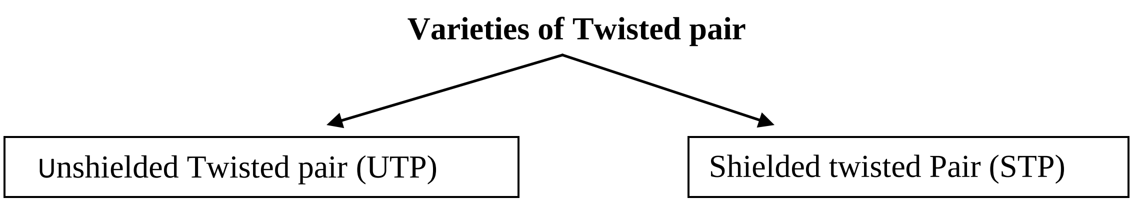
- A twisted pair consists of **two insulated copper wires** arranged in a regular **spiral** pattern.
- A wire pair acts as a single communication link.
- Typically, a number of these pairs are bundled together into a cable by wrapping them in a tough protective sheath.
- Over longer distances, cables 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:

- 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**.
- Twisted pair is also the most common medium used for **digital signaling**.

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 (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.
- The **attenuation** for twisted pair is a very strong function of frequency.
- Twisted-pair cabling used for data transmission is **highly immune to interference** from low frequency (60Hz) distributer due to
  (a) 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
  (b) The media's differential mode transmission scheme.
- 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 upto **10Gbps** can be achieved over **100 m** of twisted- pair cabling.

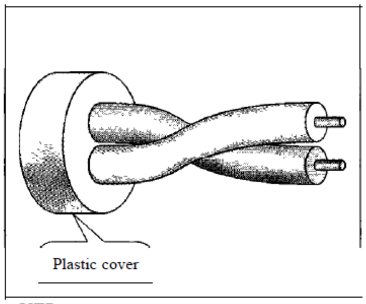


Unshielded Twisted pair (UTP):

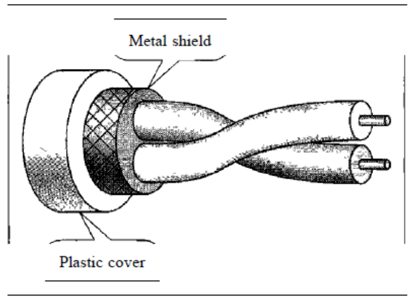
- Consists of one or more twisted-pair cables, enclosed within an overall thermoplastic jacket, which provides **no electromagnetic shielding.**
- The most common form of UTP is ordinary **voice-grade telephone wire**, which is pre-wired in residential and office buildings.
- For high speed LAN, UTP typically has 4 pairs of wires inside the jacket, with each pair twisted with a different number of twists per centimeter to help eliminate the interference between adjacent pairs.
- The tighter the twisting, the higher the supported transmission rate, and 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.

Shielded Twisted pair (STP):

- In an environment with a number of sources of potential interference (eg: electric motors, wireless devices and RF transmitters) STP may be a preferred solution.
- STP can be manufactured in three different configurations:
  (a) Each pair of wires is individually shielded with metallic foil, generally referred to as **foil twisted pair (FTP).**
  (b) There is a foil or braid shield inside the jacket covering all wires as a group. This is **screened twisted pair (F/UTP).**
  (c) There is a shield around each individual pair, as well as around the entire group of wires. This is **fully shielded twisted pair or shielded/foil twisted pair (S/FTP).**
- The shielding reduces interference and provides better performance at higher data rates.



a.UTP



b.STP

Categories of Twisted Pair for data transmission:

The Electronic Industries Association published standard ANSI/EIA/TIA-568, *Commercial Building Telecommunications Cabling Standard*, which specifies the use of voice-grade UTP and F/UTP cabling for in-building data applications.

Category	Features
ANSI/EIA/TIA-568-C.0 Generic Telecommunications Cabling for Customer Premises	Planning & installation of a structured cabling system for Customer Premises
ANSI/EIA/TIA-568-C.1 Commercial Building Telecommunications Cabling Standard	Planning & installation of a structured cabling system for Commercial Building
ANSI/EIA/TIA-568-C.2 Balanced Twisted PairTelecommunications Cabling and Components Standards	Specifies minimun requirements for Balanced Twisted PairTelecommunications Cabling (eg: channels & permanent links) and componenets (eg; cable, connectors, connecting H/W, patch cords, equipment cords, work cords & jumpers)
ANSI/EIA/TIA-568-C.3 Optical FiberCabling Components Standards	Specifies cables and component transmission performance requirements for premises optical fibre cabling.
Category 5e/Class D	Address the transmission performance characterization required by applications such as 1-Gbps Ethernet
Category 6/Class E	Structured cabling for new buildings. Provides gretaer performance than category 5e. Supports 1 Gbps Ethernet.
Category 6A/Class E_A	10Gbps Ethernet applications
Category 7/Class F	Uses Fully S/FTP. Decreases pair to pair cross talk & external alien cross talk. Beyond 10Gbps applications.
Category 7A/Class F_A	Extend the frequency bandwidth to 1GHz.

PAGE 115 WS TABLE

The table includes three key performance parameters:

1. **Insertion Loss**: The amount of attenuation across the link from the transmitting system to the receiving system. Thus, lower dB values are better.

$$A_{dB} = 10 \log_{10} P_t/P_r$$

2. **Near-end Crosstalk (NEXT) loss**: The coupling of the signal from one pair of conductors to another pair. These conductors may be the metal pins in a connector or wire pairs in a cable**.**

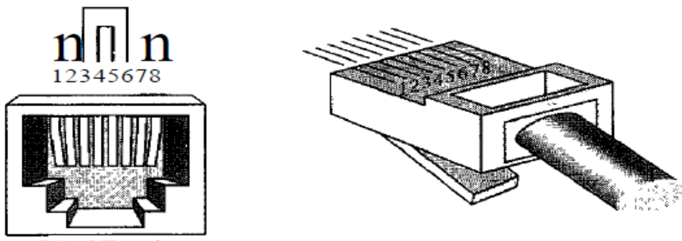
$$NEXT_{dB} = 10 \log_{10} P_t/Pc$$

3. **Attenuation to Cross-talk ratio (ACR): $ACR_{dB} = NEXT_{dB} - A_{dB}$**
   ACR is a measure of how much larger the received signal strength is compared to the crosstalk on the same pair. A positive value is required for successful operation.
   $NEXT_{dB} > A_{dB}$ implies **$P_r > P_c$**. This is the desired condition.

[P_t – transmitted signal power, P_r – reduced signal power, P_c –crosstalk signal]

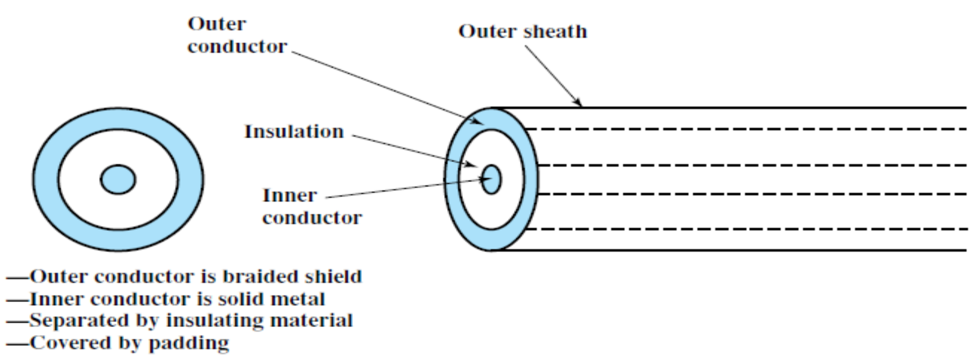
Connector:

Most common UTP connector is **RJ45**.It is a keyed connector, meaning the connector can be inserted only in one way.



RJ-45 Female RJ-45 Male

<u>2. COAXIAL CABLE</u>



(b) 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**.
- 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:

- Television distribution
- Long-distance telephone transmission
- Short-run computer system links
- Local area networks

Transmission Characteristics:

- Coaxial cable is used to transmit both analog and digital signals.
- 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.

Coaxial Cable Standards:

Coaxial cables are categorized by their radio government (RG) ratings.

Table *Categories of coaxial cables*

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

Coaxial cable Connectors:

To connect coaxial cable to devices, we need coaxial connectors. The most common type of connector used today is the Bayone-Neill-Concelman (BNe), connector.

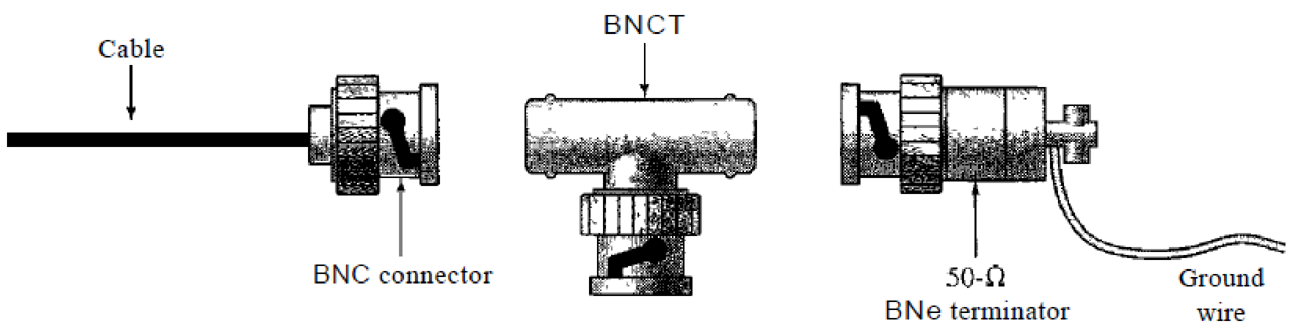
Three popular types of these connectors:

(a) **BNC connector** - used to connect the end of the cable to a device, such as a TV set.

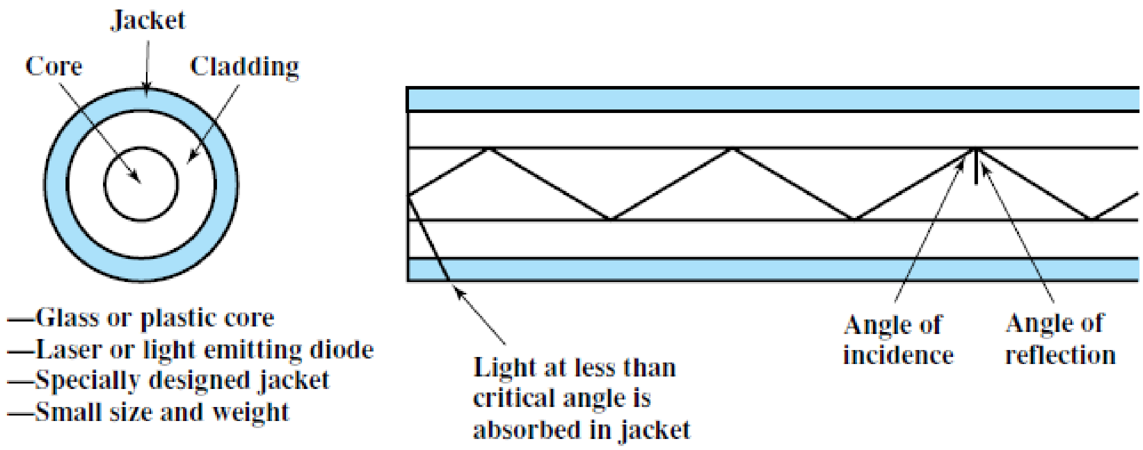
(b) **BNC T connector**- used in Ethernet networks to branch out to a connection to a computer or other device.

(c) **BNC terminator**- used at the end of the cable to prevent the reflection of the signal.

Figure *BNC connectors*



3. OPTICAL FIBER



(c) 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.
- An optical fiber cable has a cylindrical shape and consists of three concentric sections: **the core, the cladding, and the jacket.**
- 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 I 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:

- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- Local area networks

Advantages of Optical Fiber:

Fiber-optic cable has several advantages over metallic cable (twisted pair or coaxial).

- **Higher bandwidth -** Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.

- **Less signal attenuation -** Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
- **Immunity to electromagnetic interference** - Electromagnetic noise cannot affect fiber optic cables.
- **Resistance to corrosive materials -** Glass is more resistant to corrosive materials than copper.
- **Light weight** - Fiber-optic cables are much lighter than copper cables.
- **Greater immunity to tapping** -Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages of Optical Fiber:

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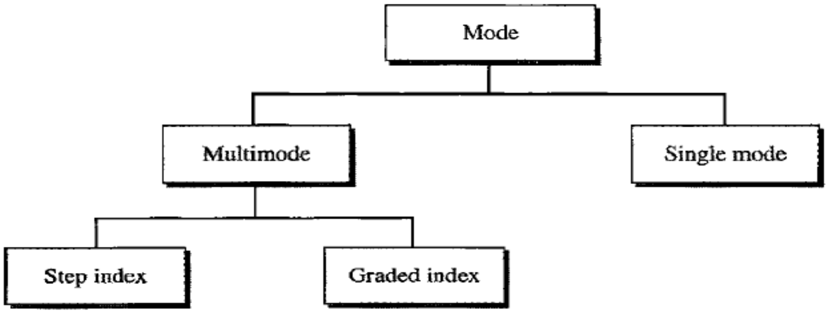
- **Installation and maintenance -** Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation -** Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.
- **Cost -** The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

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 10^{14} to 10^{15} Hertz; this covers portions of the infrared and visible spectra.

Propogation Modes:



1. Multimode:

Multimode is so named because multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core.

(a) Multimode step – index fiber:

In multimode step-index fiber, the density of the core remains constant from the center to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. At the interface, there is an abrupt change due to a lower density; this alters the angle of the beam's motion. The term **step index** refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber.

(b)Multimode graded – index fiber:

In multimode graded-index fiber, decreases this distortion of the signal through the cable. The word *index* here refers to the index of refraction. As we saw above, the index of refraction is related to density. A graded-index fiber, therefore, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge.

2.Single mode:

Single-mode uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The single mode fiber itself is manufactured with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction). The decrease in density results in a critical angle that is close enough to 90° to make the propagation of beams almost horizontal. In this case, propagation of different beams is almost identical, and delays are negligible. All the beams arrive at the destination "together" and can be recombined with little distortion to the signal

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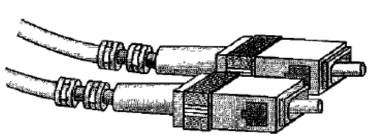
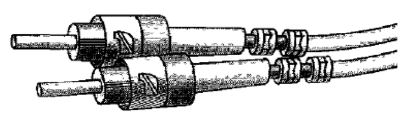
Two different types of light source are used in fiber optic systems: the **light emitting diode (LED)** and the **injection laser diode (ILD).** Both are semiconductor devices that emit a beam of light when a voltage is applied.The LED is less costly, operates over a greater temperature range, and has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

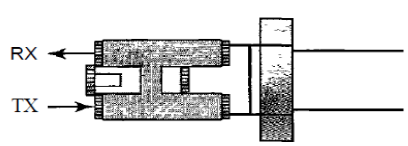
Fiber Optic cable Connectors:



SC connector



ST connector



MT-RJ connector

Three types:

(a) The **subscriber channel** (SC) **connector** is used for cable TV. It uses a push/pull locking system.

(b) The **straight-tip** (ST) **connector** is used for connecting cable to networking devices. It uses a bayonet locking system and is more reliable than SC.

(c) The **MT-RJ** is a connector that is the same size as RJ45.

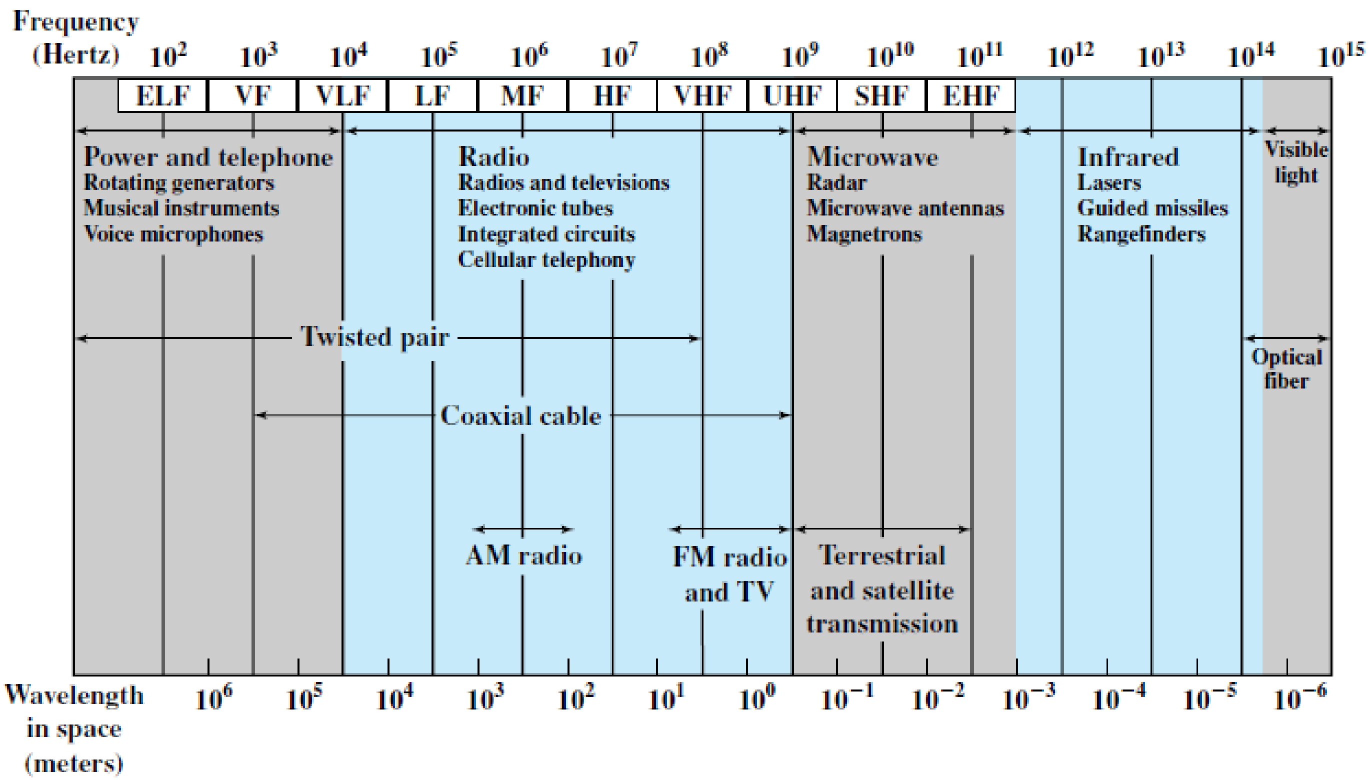
Fiber Sizes:

Optical fibers are defined by the ratio of the diameter of their core to the diameter of their cladding, both expressed in micrometers.

Table *Fiber types*

Type	*Core (μm)*	*Cladding (μm)*	*Mode*
501125	50.0	125	Multimode, graded index
62.51125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

<u>ELECTROMAGNETIC SPECTRUM INDICATING FREQUENCIES AT WHICH GUIDED & UNGUIDED TRANSMISSION TECHNIQUES OPERATE</u>



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultra high frequency
SHF = Super high frequency
EHF = Extremely high frequency

Figure 4 Electromagnetic Spectrum for Telecommunications

WIRELESS TRANSMISSION

- Frequencies in the range of about 1 GHz 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.
- This range is the **radio range**.

1.Antennas:

- An antenna can be defined as an electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.
- For transmission of a signal, radio-frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment (atmosphere, space, water).
- For reception of a signal, electromagnetic energy impinging on the antenna is converted into radio-frequency electrical energy and fed into the receiver.
- An **isotropic antenna** is a point in space that radiates power in all directions equally. The actual radiation pattern for the isotropic antenna is a sphere with the antenna at the center.

Parabolic Reflective Antenna:

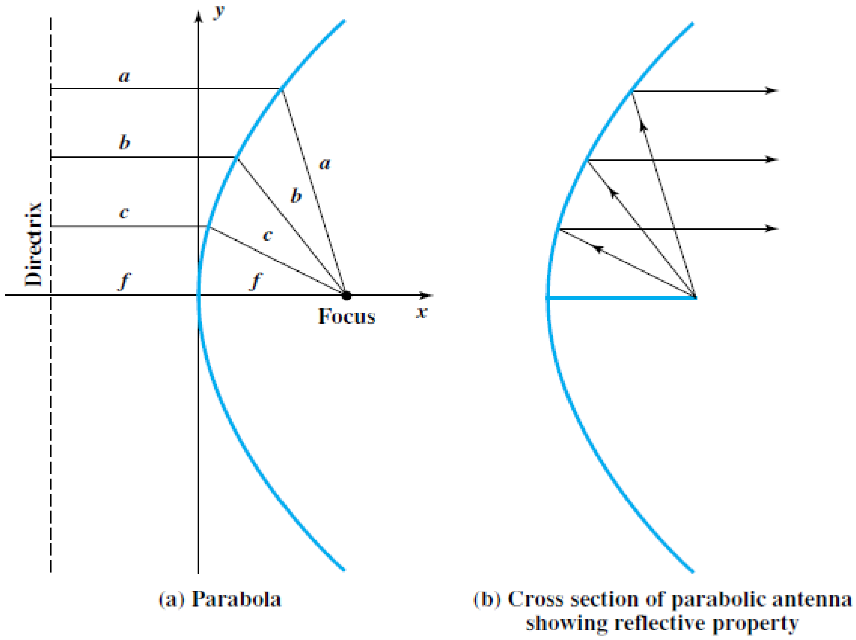


Figure Parabolic Reflective Antenna

An important type of antenna is the parabolic reflective antenna, which is used in **terrestrial microwave and satellite applications**. A **parabola** is the locus of all points equidistant from a fixed line and a fixed point not on the line. The fixed point is called the **focus** and the fixed line is called the **directrix**. If a parabola is revolved about its axis, the surface generated is called a **paraboloid**. A cross section through the paraboloid parallel to its axis forms a parabola and a cross section perpendicular to the axis forms a circle. Such surfaces are used in headlights, optical and radio telescopes, and microwave antennas because of the following property: If a source of electromagnetic energy (or sound) is placed at the focus of the paraboloid, and if the paraboloid is a reflecting surface, then the wave will bounce back in lines parallel to the axis of the paraboloid.

Antenna Gain:

Antenna gain is a measure of the directionality of an antenna. Antenna gain is defined as the power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna).

$\mathbf{G_{dB} = 10 \log (P_2/P_1)}$, where G is the antenna gain, P_1 is the radiated power of the directional antenna and P_2 is the radiated power from the reference antenna.

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2.Terrestrial Microwave:

Physical Description:

- The most common type of microwave antenna is the parabolic "dish."
- A typical size is about 3 m in diameter.
- The antenna is fixed rigidly and focuses a narrow beam to achieve line-of-sight transmission to the receiving antenna.
- Microwave antennas are usually located at substantial heights above ground level to extend the range between antennas and to be able to transmit over intervening obstacles.
- To achieve long distance transmission, a series of microwave relay towers is used, and point-to-point microwave links are strung together over the desired distance.

Applications:

- Long-haul telecommunications service, as an alternative to coaxial cable or optical fiber.
- Microwave is commonly used for both voice and television transmission.
- Short point-to-point links between buildings.

Transmission Characteristics:

Common frequencies used for transmission are in the range 1 to 40 GHz. The higher the frequency used, the higher the potential bandwidth and therefore the higher the potential data rate.
As with any transmission system, a main source of loss is attenuation. For microwave (and radio frequencies), the loss can be expressed as,

$$L = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \text{ dB}$$

where d is the distance and is the wavelength, in the same units. Thus, loss varies as the square of the distance.

Table 4. Typical Digital Microwave Performance

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

3.Satellite Microwave:

Physical description:

- A communication satellite is, in effect, a microwave relay station.
- It is used to link two or more ground based microwave transmitter/receivers, known as earth stations, or ground stations.
- The satellite receives transmissions on one frequency band (**uplink**), amplifies or repeats the signal, and transmits it on another frequency (**downlink**).
- A single orbiting satellite will operate on a number of frequency bands, called **transponder channels**, or simply **transponders**.

Fig 127 ws

For a communication satellite to function effectively, it is generally required that it remain stationary with respect to its position over the earth. To remain stationary, the satellite must have a period of rotation equal to the earth's period of rotation. This match occurs at a height of 35,863 km at the equator.

Applications:

1. Television distribution
2. Long-distance telephone transmission
3. Private business networks
4. Global positioning

1. A network provides programming from a central location. Programs are transmitted to the satellite and the broadcast down to a number of stations, which then distribute the programs to individual viewers.

2.Satellite transmission is also used for point-to-point trunks between telephone exchange offices in public telephone networks. It is the optimum medium for high usage international trunks and is competitive with terrestrial systems for many long distance intranational links.

3.There are a number of business data applications for satellite. The satellite provider can divide the total capacity into a number of channels and lease these channels to individual business users. A user equipped with the antennas at a number of sites can use a satellite channel for a private network. Figure depicts a typical VSAT configuration. A number of subscriber stations are equipped with low-cost VSAT antennas. Using some discipline, these stations share a satellite transmission capacity for transmission to a hub station. The hub station can exchange messages with each of the subscribers and can relay messages between subscribers.

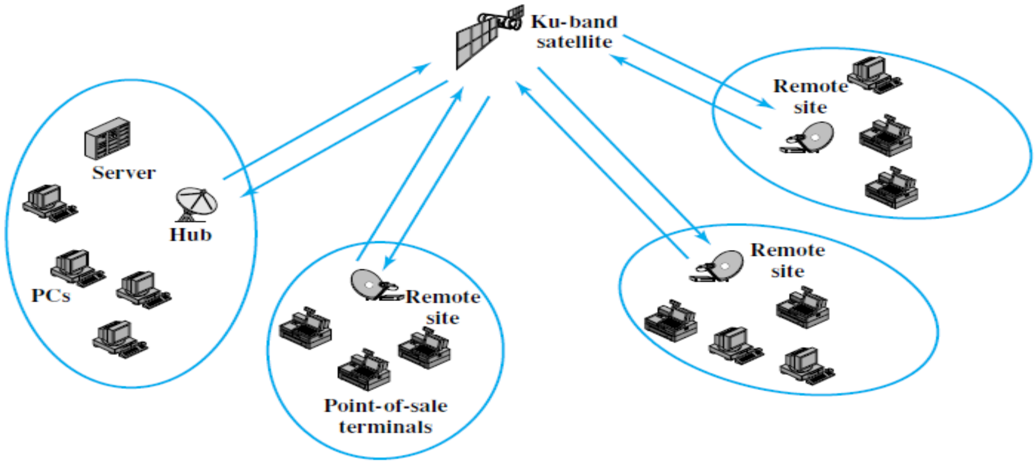


Figure Typical VSAT Configuration

4.The Navstar Global Positioning System, or GPS for short, consists of three segments or components:

- A constellation of satellites (currently 27) orbiting about 20,000 km above the earth's surface, which transmit ranging signals on two frequencies in the microwave part of the radio spectrum.
- A control segment which maintains GPS through a system of ground monitor stations and satellite upload facilities.
- The user receivers—both civil and military.

Each satellite transmits a unique digital code sequence of 1s and 0s, precisely timed by an atomic clock, which is picked up by a GPS receiver's antenna and matched with the same code sequence generated inside the receiver. By lining up or matching the signals, the receiver determines how long it takes the signals to travel from the satellite to the receiver. These timing measurements are converted to distances using the speed of light. Measuring distances to four or more satellites simultaneously and knowing the exact locations of the satellites (included in the signals transmitted by the satellites), the receiver can determine its latitude, longitude, and height while at the same time synchronizing its clock with the GPS time standard which also makes the receiver a precise time piece.

Transmission Characteristics:

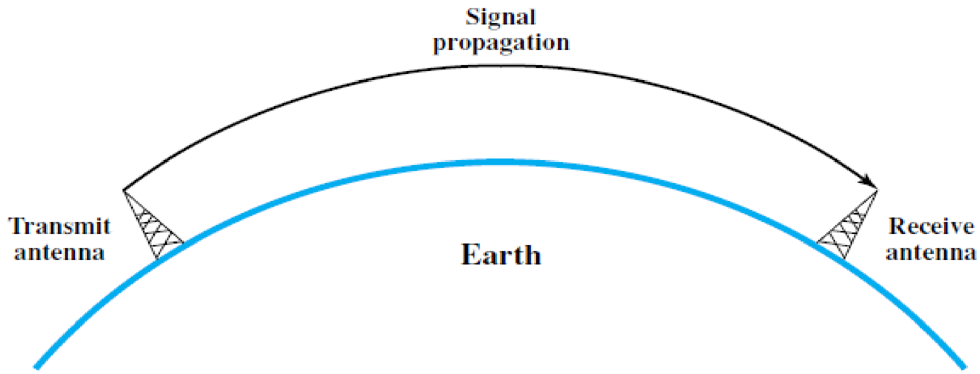
- The optimum frequency range for satellite transmission is in the range 1 to 10 GHz.
- Below 1 GHz, there is significant noise from natural sources, including galactic, solar, and atmospheric noise, and humanmade interference from various electronic devices.
- Above 10 GHz, the signal is severely attenuated by atmospheric absorption and precipitation.
- Most satellites providing point-to-point service today use a frequency bandwidth in the range 5.925 to 6.425 GHz for transmission from earth to satellite (uplink) and a bandwidth in the range 3.7 to 4.2 GHz for transmission from satellite to earth (downlink). This combination is referred to as the 4/6-GHz band.

WIRELESS PROPOGATION

A signal radiated from an antenna travels along one of three routes: **ground wave, sky wave, or line of sight (LOS).** Table shows in which frequency range each predominates.

TABLE 131 WS

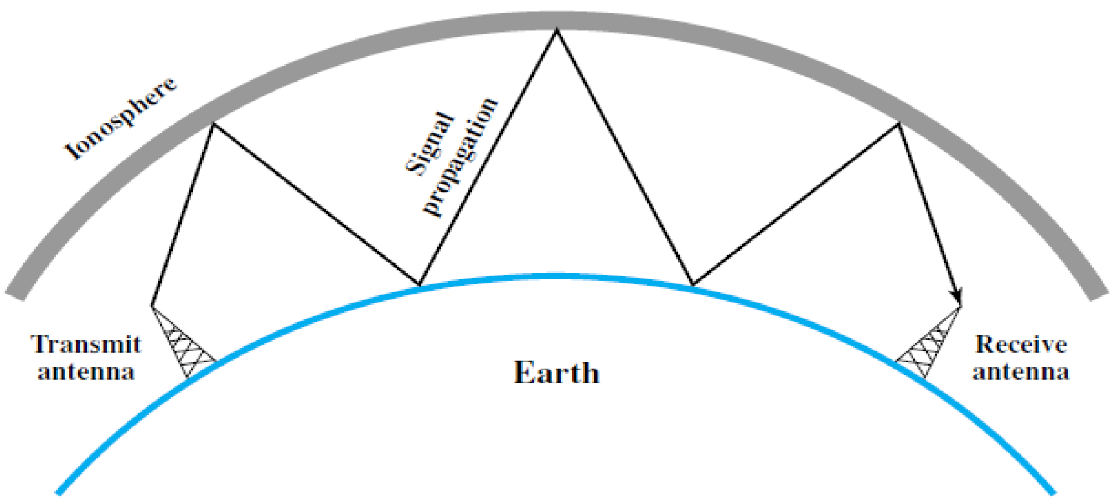
1.Ground Wave Propagation:



(a) Ground wave propagation (below 2 MHz)

Ground wave propagation is more or less follows the contour of the earth and can propagate considerable distances, well over the visual horizon. This effect is found in frequencies up to about 2 MHz. Several factors account for the tendency of electromagnetic wave in this frequency band to follow the earth's curvature. One factor is that the electromagnetic wave induces a current in the earth's surface, the result of which is to slow the wavefront near the earth, causing the wavefront to tilt downward and hence follow the earth's curvature. Another factor is diffraction, which is a phenomenon having to do with the behavior of electromagnetic waves in the presence of obstacles. Electromagnetic waves in this frequency range are scattered by the atmosphere in such a way that they do not penetrate the upper atmosphere. The best-known **example** of ground wave communication is AM radio.

2.Sky Wave Propagation:



(b) Sky wave propagation (2 to 30 MHz)

Sky wave propagation is used for amateur radio, CB radio, and international broadcasts such as BBC and Voice of America.With sky wave propagation, a signal from an earth-based antenna is reflected from the ionized layer of the upper atmosphere (ionosphere) back down to earth.Although it appears the wave is reflected from the ionosphere as if the ionosphere were a hard reflecting surface, the effect is in fact caused by refraction. Refraction is described subsequently. A sky wave signal can travel through a number of hops, bouncing back and forth between the ionosphere and the earth's surface.With this propagation mode, a signal can be picked up thousands of kilometers from the transmitter.

3.Line-of-Sight Propogation:

Above 30 MHz, neither ground wave nor sky wave propagation modes operate, and communication must be by line of sight. For satellite communication, a signal above 30 MHz is not reflected by the ionosphere and therefore a signal can be transmitted between an earth station and a satellite overhead that is not beyond the horizon. For ground-based communication, the transmitting and receiving antennas must be within an effective line of sight of each other. The term effective is used because microwaves are bent or refracted by the atmosphere. The amount and even the direction of the bend depends on conditions, but generally microwaves are bent with the curvature of the earth and will therefore propagate farther than the optical line of sight.

Refraction:

Refraction occurs because the velocity of an electromagnetic wave is a function of the density of the medium through which it travels. In a vacuum, an electromagnetic wave (such as light or a radio wave) travels at approximately 3×10^8 m/s. This is the constant, c, commonly referred to as the speed of light. In air, water, glass, and other transparent or partially transparent media, electromagnetic waves travel at speeds less than c. When an electromagnetic wave moves from a medium of one density to a medium of another density, its speed changes. Moving from a less dense to a more dense medium, the wave will bend toward the more dense medium. This phenomenon is easily observed by partially immersing a stick in water.

The **index of refraction**, or **refractive index**, of one medium relative to another is the sine of the angle of incidence divided by the sine of the angle of refraction. The index of refraction is also equal to the ratio of the respective velocities in the two media.

Under normal propagation conditions, the refractive index of the atmosphere decreases with height so that radio waves travel more slowly near the ground than at higher altitudes. The result is a slight bending of the radio waves toward the earth.