William Stallings
Data and Computer Communications

Chapter 4

Transmission Media

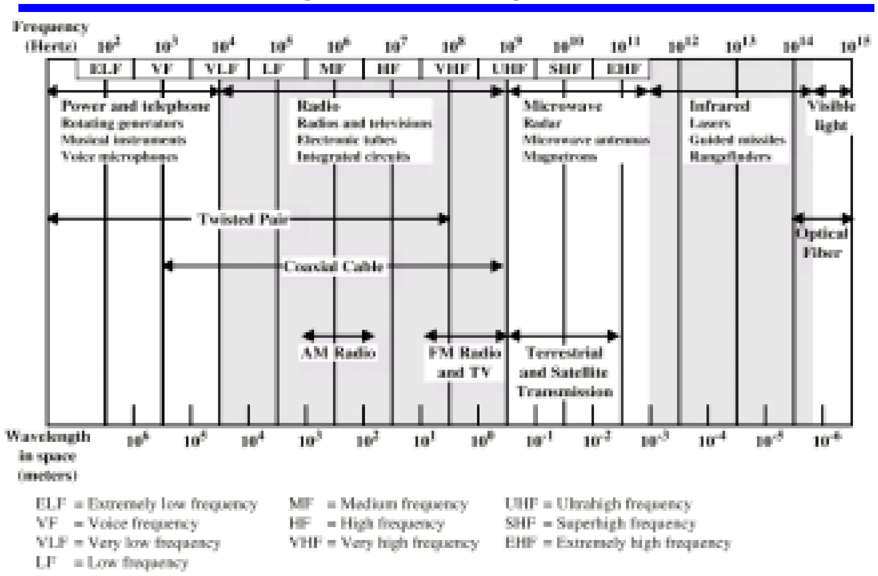
Transmission Medium

- Physical path between transmitter & receiver
  - Guided - wire
  - Unguided - wireless
- Characteristics and quality of data transmission determined by medium and signal
- For guided transmission, the medium is more important
- For unguided transmission, the bandwidth produced by the antenna is more important
- Signal directionality
  - Lower frequency signals are omnidirectional
  - Higher frequency signals can be focused in a directional beam

Transmission System Design Factors

- Key concerns are data rate and distance
- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
  - Can be minimized by proper shielding in guided media
- Number of receivers
  - In guided media, more receivers (multi-point) introduce more attenuation and distortion

Electromagnetic Spectrum



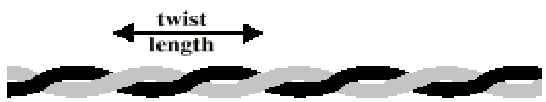
Guided Transmission Media

- Transmission capacity depends on distance and type of network (point-to-point or multipoint)
- Types of guided transmission media
  - Twisted Pair
  - Coaxial cable
  - Optical fiber

Twisted Pair

- Least expensive and most widely used
- Two insulated copper wires arranged in regular spiral pattern
- Number of pairs bundled together in a cable
- Twisting decreases crosstalk interference between adjacent pairs in cables
  - Using different twist length for neighboring pairs

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction



(a) Twisted pair

Twisted Pair - Applications

- Most common transmission medium for both analog & digital signals
- Telephone network
  - Between house and local exchange (subscriber loop)
- Within buildings
  - Telephones connected to private branch exchange (PBX) for voice traffic
  - Connections to digital switch or digital PBX (64kbps)
- For local area networks (LAN)
  - 10Mbps or 100Mbps

Twisted Pair - Pros and Cons

- Advantages
  - Cheap
  - Easy to work with
- Disadvantages
  - Low data rate
  - Short range

Twisted Pair - Transmission Characteristics

- Analog transmission
  - Amplifiers every 5km to 6km
- Digital transmission
  - Use either analog or digital signals
  - repeater every 2km or 3km
- Attenuation is a strong function of frequency
- Susceptible to interference and noise
  - Easy coupling with electromagnetic fields
  - A wire run parallel to power line picks up 60-Hz energy
  - Impulse noise easily intrudes into twisted pairs

Attenuation of Guided Media

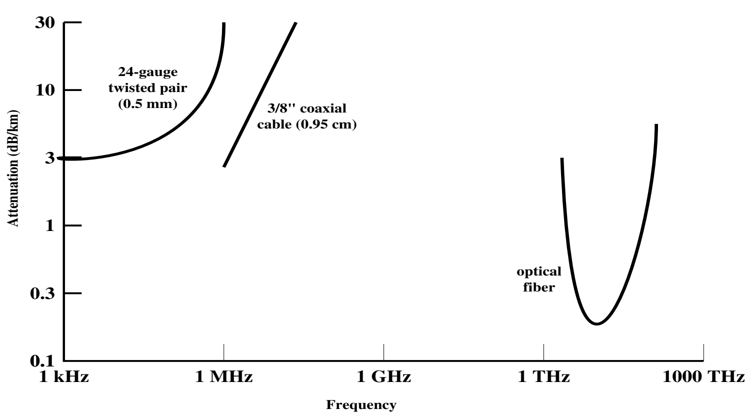


Figure 4.3 Attenuation of Typical Guided Media

Twisted Pair - Transmission Characteristics

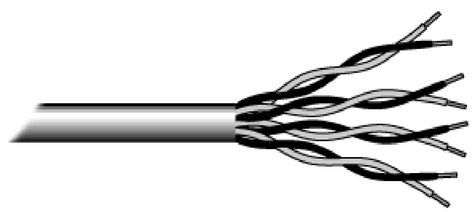
- Measures to reduce impairments
  - Shielding with metallic braids or sheathing reduces interference
  - Twisting reduces low frequency interference
  - Different twist length in adjacent pairs reduces crosstalk
- Limited distance
- Limited bandwidth
  - For point-to-point analog signaling, 1MHz
- Limited data rate
  - For long distance digital point-to-point signaling, 4 Mbps
  - For very short distances, 100Mbps-1Gbps

Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference
- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - Better performance at higher data rates
  - More expensive
  - Harder to handle (thick, heavy)

Unshielded Twisted-Pair (UTP)

- Quality of UTP vary from telephone-grade wire to extremely high-speed cable
- Cable has four pairs of wires inside the jacket
- Each pair is twisted with a different number of twists per inch to help eliminate interference
  - The tighter the twisting, the higher the supported transmission rate and the greater the cost per foot

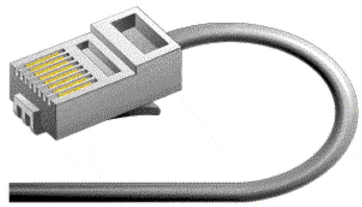


UTP Categories

- Cat 3
  - up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- Cat 4
  - up to 20 MHz
- Cat 5
  - up to 100MHz
  - Commonly pre-installed in new office buildings
  - Twist length 0.6 cm to 0.85 cm

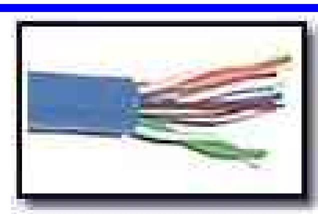
Unshielded Twisted Pair Connector

- The standard connector for unshielded twisted pair cabling is an RJ-45 connector.
  - A plastic connector that looks like a large telephone-style connector
  - RJ stands for Registered Jack; connector follows a standard borrowed from telephone industry.
  - Standard designates which wire goes with each pin inside the connector.

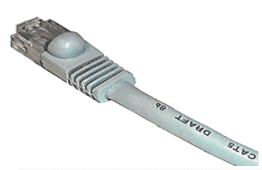


Cat 5 Network Cables

Category 5 Cable composed of 4 twisted pairs



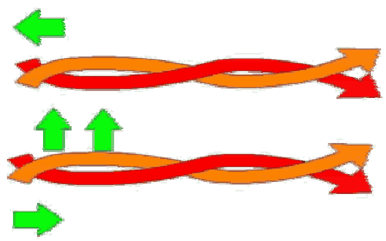
Cat 5Cable RJ45 composed of 4 twisted pairs



Shielded Cat 5 Network Cable RJ45

Near-End Cross Talk (NEXT)

- When current flows in a wire, an electromagnetic field is created which can interfere with signals on adjacent wires.
- As frequency increases, this effect becomes stronger



Near-End Cross Talk (NEXT)

- Each pair is twisted because this allows opposing fields in the wire pair to cancel each other.
  - The tighter the twist, the more effective the cancellation, and the higher the data rate supported by the cable.
  - *Maintaining this twist ratio is the single most important factor in any successful UTP installation*
  - If wires are not tightly twisted, the result is near end crosstalk (NEXT).
- NEXT is the portion of the transmitted signal that is electromagnetically coupled back into the received signal.

Near-End Cross Talk (NEXT)

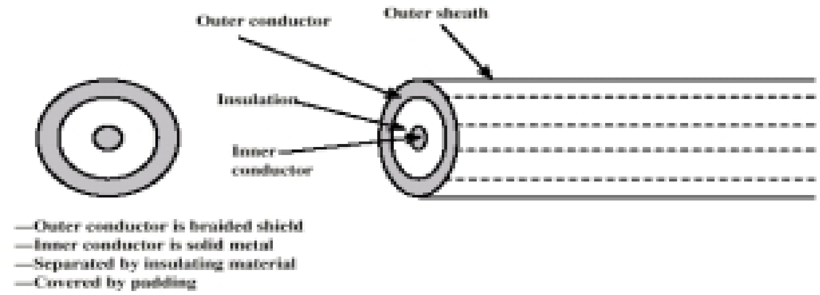
- NEXT is a measure of difference in signal strength between a disturbing pair and a disturbed pair.
- A larger number (less crosstalk) is more desirable than a smaller number (more crosstalk).
- Because NEXT varies significantly with frequency, it is important to measure it across a range of frequencies, typically 1 – 100 MHz.

Comparison of Shielded & Unshielded Twisted Pair

	Attenuation (dB per 100m)			Near-End Crosstalk (dB)		
Frequency (MHZ)	Cat. 3 UTP	Cat. 5 UTP	150-ohm STP	Cat. 3 UTP	Cat. 5 UTP	150-ohm STP
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25		10.4	6.2		41	47.5
100		22.0	12.3		32	38.5
300			21.4			31.3

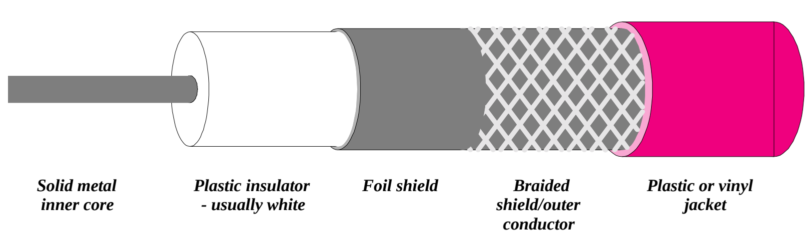
Coaxial Cable

- ⌘Hollow outer cylindrical conductor surrounding a single inner conductor
- ⌘Inner conductor held by regularly spaced insulating rings or solid dielectric material
- ⌘Operates at higher frequencies than twisted pair



Coaxial Cable

- ⌘Outer conductor covered with a jacket or shield
- ⌘Diameter from 1 to 2.5 cm
- ⌘Shielded concentric construction reduces interference & crosstalk
- ⌘Can be used over longer distances & supports more stations on a shard line than twisted pair



Coaxial Cable Applications

- ⌘ Most versatile medium
- ⌘ Television distribution
  - Ariel to TV
  - Cable TV
  - Can carry hundreds of TV channels for tens of kms
- ⌘ Long distance telephone transmission
  - Can carry 10,000 voice channels simultaneously
  - Being replaced by fiber optic
- ⌘ Short distance computer systems links
- ⌘ Local area networks

Coaxial Cable - Transmission Characteristics

- ⌘ Used to transmit both analog & digital signals
- ⌘ Superior frequency characteristics compared to twisted pair (1KHz-1GHz)
- ⌘ Less susceptible to interference & crosstalk
- ⌘ Constraints on performance are attenuation, thermal noise, intermodulation noise
- ⌘ Analog
  - Amplifiers every few km
  - Closer spacing if higher frequency
  - Up to 500MHz
- ⌘ Digital
  - Repeater every 1 to 9 km
  - Closer spacing for higher data rates

Cable Construction

components and abbreviation key

CommScope®

Center Conductor

Conductors in coaxial cable are either solid or stranded wire. Solid conductors are described by their diameter and material (i.e. 18 AWG Solid TC) while stranded conductors include their stranding (i.e. 20 AWG (19x32 AWG) Strand TC).

BC - Bare Copper
SC - Silvered Copper
TC - Tinned Copper
CCA - Copper Clad Aluminum
CCS - Copper Covered Steel

Dielectric

Most CommScope coaxial cables have foamed (or cellular) dielectrics for better velocity of propagation characteristics. Different materials are used to meet electrical and fire-safety performance.

Foam PE - Foamed Polyethylene
Solid PE - Solid Polyethylene
Foam FEP - Foamed Fluorinated Ethylene Propylene (generic or Teflon® brand)
Solid FEP - Solid Fluorinated Ethylene Propylene
AD/PE - Air Dielectric created with a Polyethylene filament

Shields

Coaxial shields (also called the outer conductor) come in several varieties. Two types of coverage are: **Foil**, where aluminum is bonded to both sides of a polypropylene or polyester tape to provide 100% coverage and **Braid** where flexible wire is woven around the dielectric. Braid coverage designation is given as a percentage followed by a two letter code representing the material of the braid (i.e. 96% TC braid would be 96% coverage of a Tin Copper braid).

ALS - Aluminum sheath
AL - Aluminum braid
BC - Bare Copper braid
SC - Silver Copper braid
TC - Tin Copper braid

Jackets

Jacket material may vary depending on application. Plenum-rated cables provide superior fire safety, while flame-retardant PVC are used in riser, general purpose and residential situations. Outdoor cables (especially those meant for burial) are usually sheathed in polyethylene.

K - Kynar™ Polyvinylidene Fluoride (PVDF - used in plenum cables)
V - CommFlex, our proprietary jacketing compound (used in plenum cables)
PE - Polyethylene
PVC - Polyvinylchloride

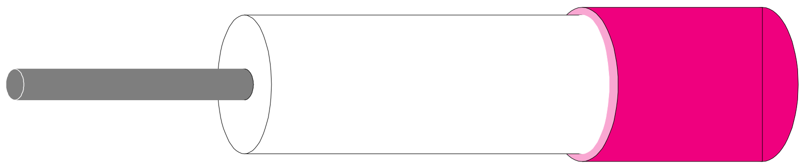
Teflon is a registered trademark of E.I. Dupont de Nemours and Co.

Optical Fiber

- Thin, flexible material to guide optical rays
- Cylindrical cross-section with three concentric links
- Core
  - Innermost section of fiber
  - One or more very thin (diameter 8-100 μm) strands or fibers
- Cladding
  - Surrounds each strand
  - Plastic or glass coating with optical properties different from core

Optical Fiber

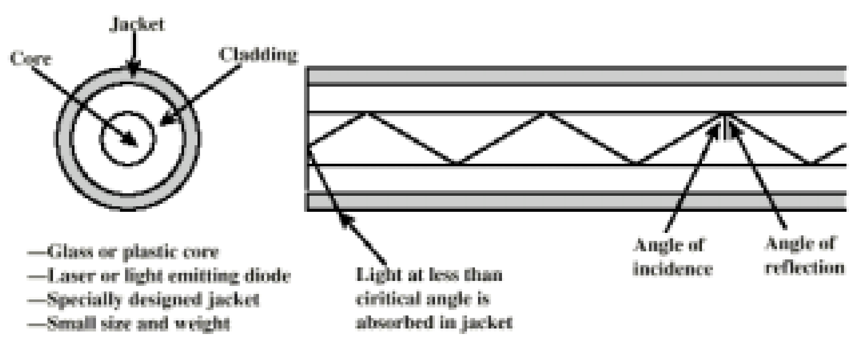
- Jacket
  - Outermost layer, surrounding one or more claddings
  - Made of plastic and other materials
  - Protects from environmental elements like moisture, abrasions and crushing



diameters	*Glass core*		*Glass cladding*
	50 microns 62 microns 100 microns	Multimode	125 microns 125 microns 140 microns
	2-8 microns	Singlemode	

Note: A micron is a millionth of a meter

Optical Fiber



Optical Fiber - Benefits

- ⌘ Greater capacity
  - Data rates of hundreds of Gbps over tens of Kms
- ⌘ Smaller size & weight
- ⌘ Significantly lower attenuation
- ⌘ Electromagnetic isolation
  - Not affected by external EM fields
  - Not vulnerable to interference, impulse noise, or crosstalk
  - No energy radiation; little interference with other devices; security from eavesdropping
- ⌘ Greater repeater spacing
  - 10s of km at least
  - Lower cost and fewer error sources

Optical Fiber - Applications

- ⌘ Long-haul trunks
  - Increasingly common in telephone networks
  - About 1500 km in length with high capacity (20,000-60,000 voice channels)
- ⌘ Metropolitan trunks
  - Average length of about 12 km with capacity of 100,000 voice channels
  - Mostly, repeaters not required
- ⌘ Rural exchange trunks
  - Lengths from 40 to 160 km with fewer than 5000 voice channels
- ⌘ Subscriber loops
  - Handle image, video, voice, data
- ⌘ LANs
  - 100 Mbps to 1 Gbps, support hundreds of stations on campus

Optical Fiber - Transmission Characteristics

- Single-encoded beam of light transmitted by total internal reflection
- Fiber has two basic types, multimode and singlemode
- Multimode fiber means that light can travel many different paths (called modes) through the core of the fiber, which enter and leave the fiber at various angles.
  - highest angle that light is accepted into the core of the fiber defines the numerical aperture (NA).
- Transparent medium should have higher refractive index than surrounding medium
  - Refractive index: ratio of speed of light in vacuum to speed of light in medium
- Act as wave guide for frequency 10^{14} to 10^{15} Hz
  - Portions of infrared and visible spectrum

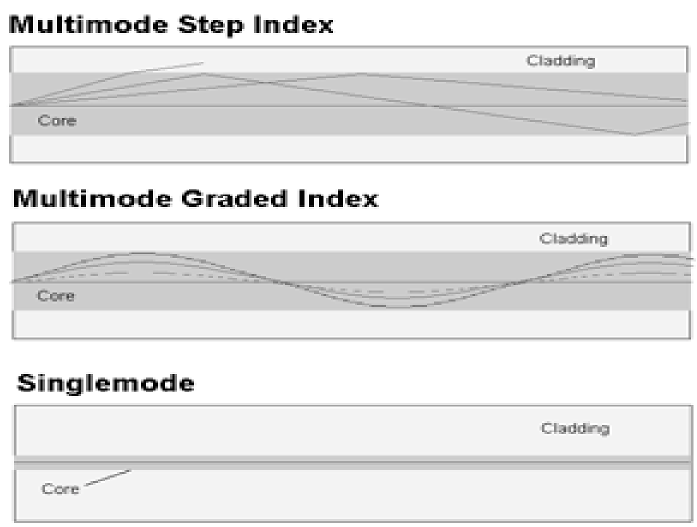
Optical Fiber – Light Sources

- Semiconductor devices that emit light when voltage applied
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Longer operational life
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate
- Wavelength Division Multiplexing (WDM)
  - Multiple beams of light at different frequencies transmitted simultaneously
  - 100 beams operating at 10 Gbps, for a total of 1 trillion bps

Optical Fiber Transmission Modes

- Step-index multimode
  - Core made of one type of glass
  - Light traveling in fiber travels in straight lines, reflecting off the core/cladding interface
  - Rays at shallow edges reflected and propagated along fiber
  - Other rays absorbed by surrounding material
  - Allows for multiple propagation paths with different path lengths and time to traverse fiber
  - A pulse of light is dispersed while traveling through the fiber
  - Limits rate at which data can be accurately received
  - Best suited for transmission over very short distances

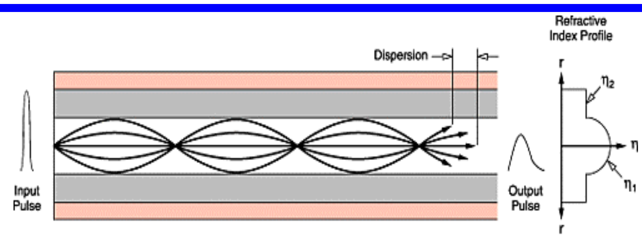
Optical Fiber Transmission Modes



Graded Multimode Fiber

- Core is composed of many different layers of glass, with indices of refraction producing a parabola index profile
- A properly constructed index profile will compensate for the different path lengths of each mode
- Bandwidth capacity of graded fiber 100 times larger than step index fiber
- Normally uses inexpensive LED laser transmitter and receiver
- Maximum distance up to 2 km
- Most common type is 62.5/125μm
- Uses wavelengths of 850nm and 1300nm
- Often used for building backbones and short inter-building communications

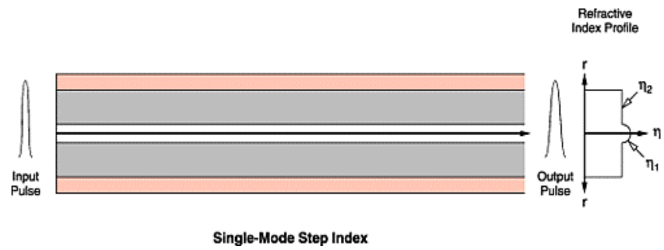
Graded Multimode Fiber



Multimode Graded Index

- Higher refractive index at center makes rays close to axis advance slower than rays close to cladding
- Light in core curves helically reducing traveling distance (does not zigzag off cladding)
- Shorter path & higher speed makes light at periphery as well as axis travel at same speed

Single-Mode Fiber



- Shrinks core size to a dimension about 6 times the wavelength of the fiber, causing all the light to travel in only one mode
- Modal dispersion disappears and bandwidth of the fiber increases by at least a factor of 100 over graded index fiber
- Can be used for distances of 30 km or when high data rates are required

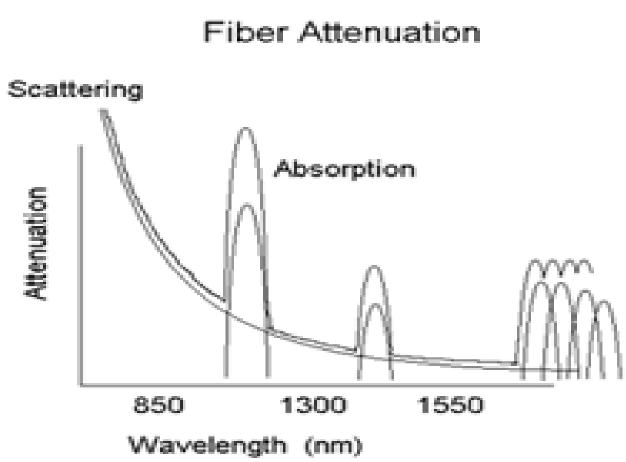
Fiber Optic Attenuation

- Attenuation of optical fiber is a result of two factors, absorption and scattering
- Absorption is caused by absorption of light and conversion to heat by molecules in the glass.
- Absorption occurs at discrete wavelengths, and occurs most strongly around 1000 nm, 1400 nm and above 1600 nm.
- Scattering occurs when light collides with individual atoms in the glass
- Light scattered at angles outside the numerical aperture of fiber will be absorbed into the cladding or transmitted back toward the source.

Fiber Optic Attenuation

- Scattering is a function of wavelength, proportional to inverse fourth power of wavelength of light
  - doubling wavelength of light, reduces scattering losses 16 times
- For long distance transmission, use longest practical wavelength for minimal attenuation and maximum distance between repeaters
- Fiber optic systems transmit in the "windows" created between the absorption bands at 850 nm, 1300 nm and 1550 nm
- Plastic fiber has a more limited wavelength band, that limits practical use to 660 nm LED sources

Fiber Optic Attenuation

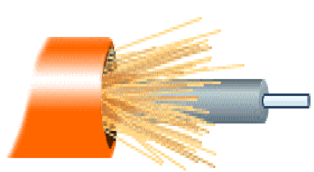


Fiber Types and Typical Specifications

Fiber Type	Core/Cladding Diameter	Attenuation Coefficient (dBkm)			Bandwidth @ 1300 nm
.	(microns)	850 nm	1300 nm	1550 nm	(MHz-km)
Step Index	200/240	6	NA	NA	50@850
Multimode	50/125	3	1	NA	600
Graded Index	62.5/125	3	1	NA	500
.	85/125*	3	1	NA	500
.	100/140*	3	1	NA	300
Singlemode	8-9/125	NA	0.5	0.3	high
Plastic	1 mm	(1 dB/m @665 nm)			Low

Fiber Optic Cables

Fiber optic cable



Duplex Multimode 62.5/125 µm

Duplex Singlemode 9/125 µm

Point-to-Point 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 @1kHz	50 us/km	2 km
Twisted Pair (multiple pair cable)	0 to 1 MHz	3 dB/km @1kHz	5 us/km	2 km
Coaxial Cable	0 to 500 MHZ	7 dB/km @10MHz	4 us/km	1 to 9 km
Optical fiber	180 t0 370 THZ	0.2 to 0.5 dB/km	5 us/km	40 km

Wireless Transmission

- Unguided media
- Transmission and reception via antenna
- Directional
  - Transmitter send a focused EM beam
  - Transmitter & receiver antennae must be carefully aligned
  - Suitable for higher frequency signals
- Omnidirectional
  - Transmitted signal spreads in all directions
  - Can be received by many antenna

Frequency Ranges for Wireless Transmission

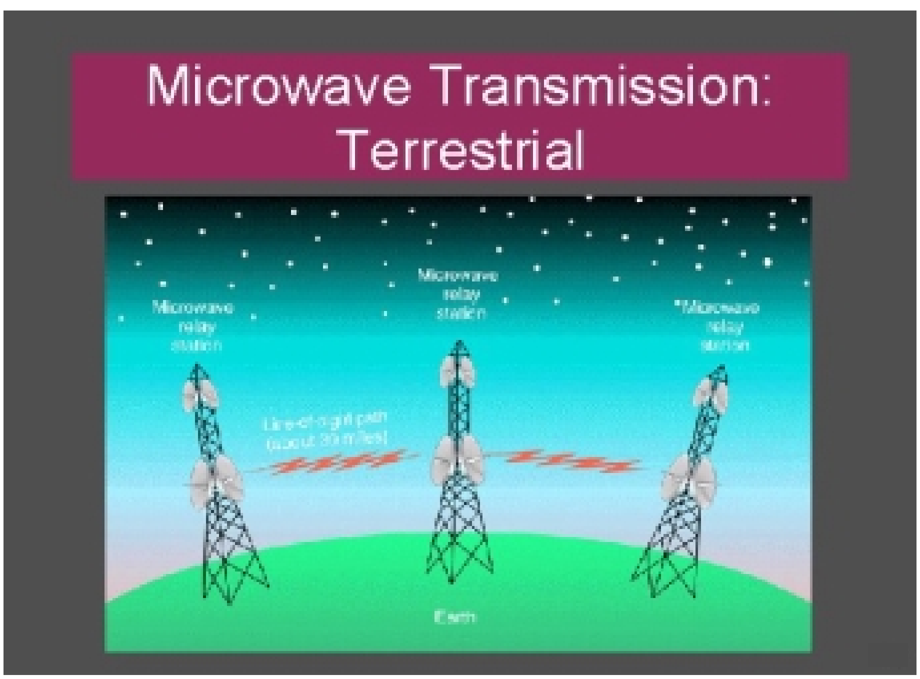
- 2GHz to 40GHz
  - Microwave frequencies
  - Highly directional beams for point to point communication
  - Used for satellite communications
- 30MHz to 1GHz
  - Broadcast radio range
  - Suitable for omnidirectional purposes
- 3×10^{11} to 2×10^{14}
  - Infrared
  - Local point-to-point & multipoint applications with confined areas
  - TV remote control

Terrestrial Microwave

- Parabolic dish antenna, 3m in diameter
- Focused beam along line of sight to receiving antenna
- With no obstacles, maximum distance (km) between antenna can be $d = 7.14\sqrt{Kh}$
  - H is antenna height
  - K is adjustment factor to account for bend in microwave due to earth's curvature; (K=4/3)
- Two microwave antenna at height of 100m may be as far as $7.14\sqrt{133} = 82km$

Terrestrial Microwave

- Long distance microwave transmission achieved by a series of microwave relay towers
- Long haul telecommunications
- Frequencies in the range of 2-40 GHz
- Higher frequencies give higher data rates
- Fewer repeaters than coaxial cable but needs line of sight



Terrestrial Microwave Attenuation

- Loss L due to attenuation over distance d at wavelength λ is expressed as

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

  - Loss varies as square of distance
  - For twisted pair and coaxial cable, loss varies logarithmically with distance (linear in decibels)
  - Repeaters placed farther apart for microwave systems 10 to 100 Km
- Attenuation may increase with rainfall, especially above 10 GHz
- Interference is a problem, leading to regulated assignment of frequencies

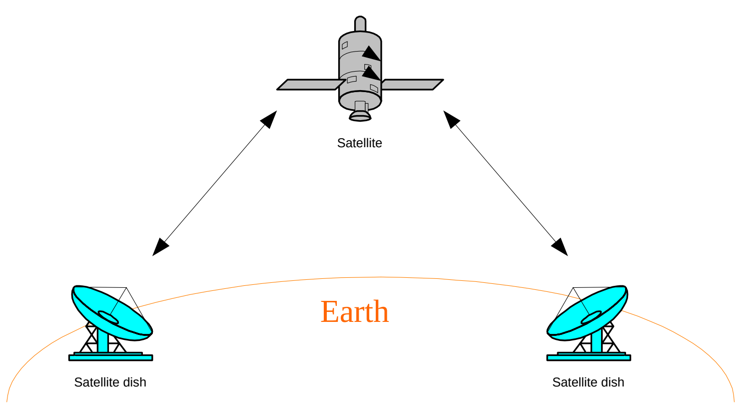
Typical Digital Microwave Performance

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

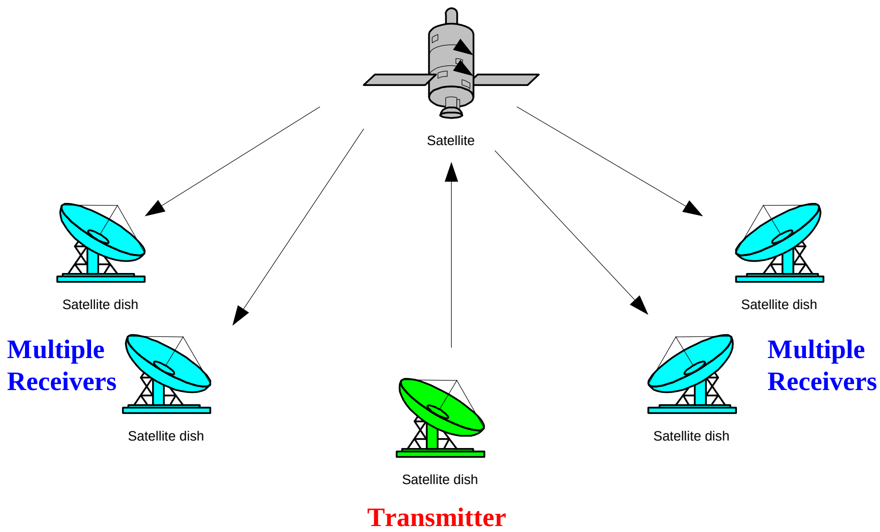
Satellite Microwave

- Satellite is microwave relay station between two or more ground stations
- Satellite receives on one frequency (uplink), amplifies or repeats signal and transmits on another frequency (downlink)
- Requires geo-stationary orbit
  - Remains in a fixed position relative to ground station
  - Period of rotation equal to earth's period of rotation
  - Height of 35,784 km
- A single satellite can operate on a number of frequency bands, known as *transponder channels* or *transponders*

Point-to-Point Link via Satellite Microwave



Broadcast Link via Satellite Microwave



Satellite Microwave

- Satellites cannot be too close to each other to avoid interference
  - Current standard requires a 4º displacement in the 4/6 GHz band and 3º displacement at 12/14 GHz
  - Limits number of available satellites
- Applications
  - Television, telephone, private business networks
  - VSAT – Very small aperture terminals
    - Used to share a satellite capacity for data transmission

VSAT System

- ⌘ Small fixed earth station.
- ⌘ VSATs provide the vital communication link required to set up a satellite based communication network.
- ⌘ VSATs can support any communication requirement be it voice, data, or video conferencing.
- ⌘ The VSAT comprises of two modules – an outdoor unit and an indoor unit.
- ⌘ The outdoor unit consists of an Antenna and Radio Frequency Transceiver. (RFT).
  - The antenna size is typically 1.8 meter or 2.4 meter in diameter.
- ⌘ The indoor unit functions as a modem and also interfaces with the end user equipment like stand alone PCs, LANs, Telephones.

VSAT System

- ⌘ A VSAT system consists of
  - a satellite transponder,
  - central hub or a master earth station,
  - remote VSATs.
- ⌘ The VSAT terminal can receive as well as transmit signals via the satellite to other VSATs in the network.
- ⌘ Depending on the access technology used the signals are either sent
  - via satellite to a central hub, which is also a monitoring center, or
  - directly to VSATs with the hub being used for monitoring and control

Satellite Microwave Transmission Characteristics

- ⌘ Optimum frequency range in 1-10 GHz
- ⌘ Below 1 GHz, significant noise from galactic, solar, atmospheric noise, terrestrial electronic devices
- ⌘ Above 10 GHZ, signal attenuated by atmospheric absorption and precipitation
- ⌘ Most satellites use 5.925-6.425 GHz for uplink and 3.7-4.2 GHz for downlink (4/6 band)
- ⌘ Propagation delay of about a quarter second due to long distance
  - Problems in error control and flow control
  - Inherently broadcast, leading to security problems

Satellite Bands

Frequency	Band	Uplink	Downlink	Use
4/6	**C**	**5.925-6.425**	**3.7-4.2**	**commercial**
7/8	**X**	**7.9-8.4**	**7.9-8.4**	**military**
11/14	**Ku**	**14.0-14.5**	**11.7-12.2**	**commercial**
20/30	**Ka**	**27.5-30.5**	**17.7-21.2**	**military**
20/44	**Q**	**43.5-45.5**	**20.2-21.32**	**military**

Broadcast Radio

- Omnidirectional
- 30 MHZ to 1 GHZ for broadcast copmmunications
- Covers FM radio, UHF and VHF television
- Line of sight transmission
- Maximum distance between transmitter & receiver and attenuation same as microwave
- Less sensitive to attenuation from rainfall
- Suffers from multipath interference
  - Reflections from land, water, natural, man-made objects

Infrared

- Modulate noncoherent infrared light
- Limited to short distances and highly directional
- Line of sight (or reflection)
- Blocked by walls
- e.g. TV remote control
- No licensing, no frequency allocation issues