

# William Stallings

## Data and Computer Communications

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### Chapter 4 Transmission Media

These slides are originally for W. Stallings.

## Overview

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- Guided - wire
- Unguided - wireless
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance

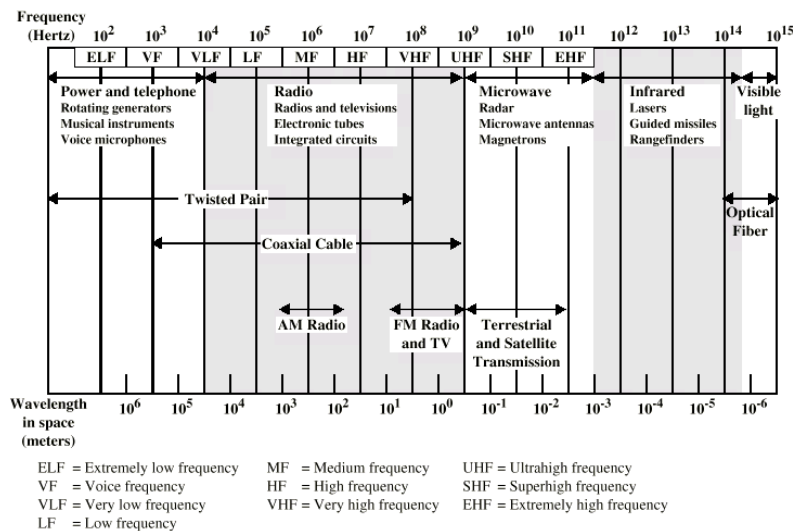
# Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
- Number of receivers
  - In guided media
  - More receivers (multi-point) introduce more attenuation

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# Electromagnetic Spectrum



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## Guided Transmission Media

- Twisted Pair
- Coaxial cable
- Optical fiber

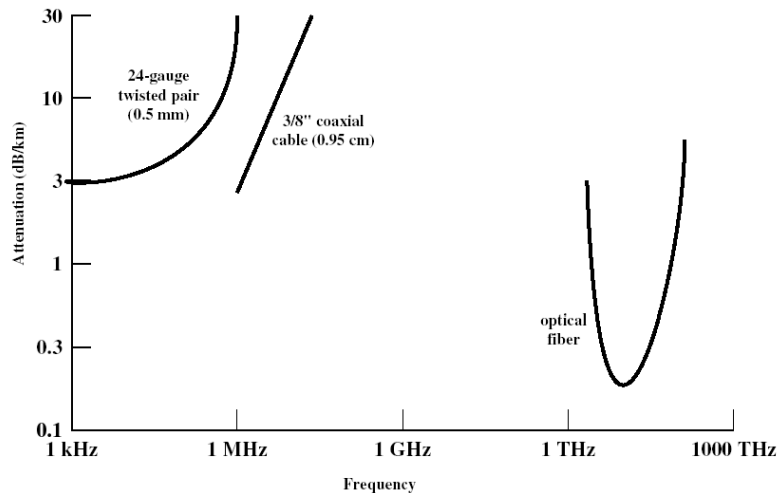
Table 4.1 Point-to-Point Transmission Characteristics of Guided Media [GLOV98]

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 $\mu$ s/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	3 dB/km @ 1 kHz	5 $\mu$ s/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 $\mu$ s/km	1 to 9 km
Optical fiber	180 to 370 THz	0.2 to 0.5 dB/km	5 $\mu$ s/km	40 km

THz = TeraHerz =  $10^{12}$  Hz

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## Attenuation of Typical Guided Media



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## Twisted Pair

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



(a) Twisted pair

- Usually more than one pair bundled together
- Nearby pairs have different twist length to reduce crosstalk
- Twist length 5 cm to 15cm
- Wire thickness 0.4 to 0.9 mm

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## Twisted Pair - Applications

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- Most common medium
- Telephone network
  - Between house and local exchange or end-office (subscriber loop)
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)
  - 10Mbps or 100Mbps (for high rates – limited number of devices and distance)

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## Twisted Pair - Pros and Cons

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- Cheap
- Easy to work with
- Low data rate
- Short range: repeaters required every few hundred meters

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## Twisted Pair - Transmission Characteristics

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- Analog
  - Amplifiers every 5km to 6km
- Digital
  - Use either analog or digital signals
  - repeater every 2km or 3km (This may be wrong, few hundred meters is the answer)
- Limited distance: highest attenuation relative to other guided media
- Limited bandwidth (1MHz)
- Limited data rate (100MHz)
- Susceptible to interference and noise

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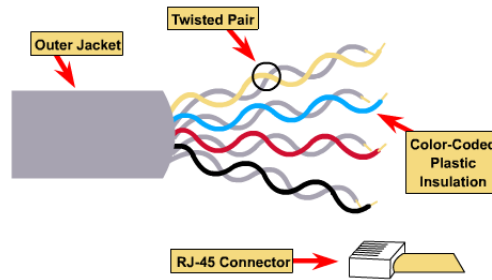
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## Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)

- Ordinary telephone wire
- Cheapest
- Easiest to install
- Suffers from external EM interference

### Unshielded Twisted Pair (UTP)



- Speed and throughput: 10 - 100 Mbps
- Average \$ per node: Least Expensive
- Media and connector size: Small
- Maximum cable length: 100m (short)

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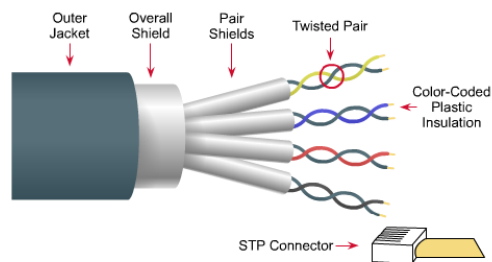
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## Unshielded and Shielded TP

- Shielded Twisted Pair (STP)

- Metal braid or sheathing that reduces interference
- More expensive
- Harder to handle (thick, heavy)

### STP (Shielded Twisted Pair)



- Speed and throughput: 10 - 100 Mbps
- Average \$ per node: Moderately Expensive
- Media and connector size: Medium to Large
- Maximum cable length: 100m (short)

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## UTP Categories (Recognized by EIA-568)

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- 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

Cat 3 and Cat 5 are ones mostly used for LAN applications:  
- Differ in number of twists

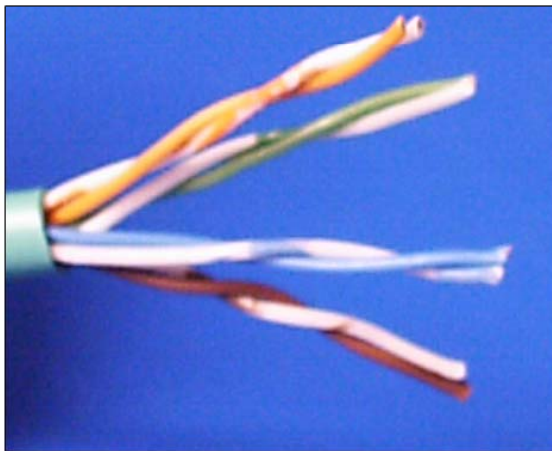
EIA = Electronic Industries Association

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## UTP Categories

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### CAT 5 Cable



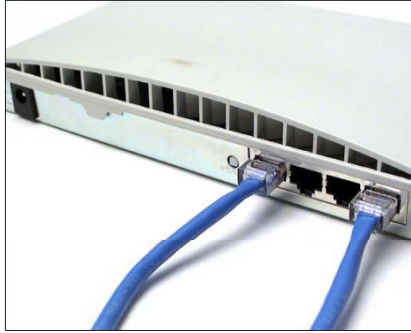
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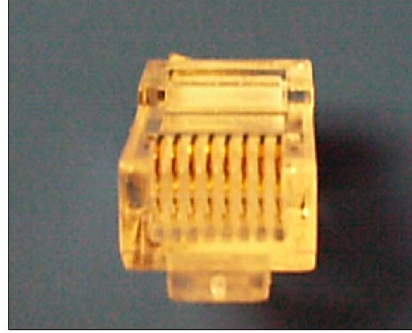
## RJ-45 Connector

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**Multiport Repeaters (Hubs)**



**RJ-45 Front**



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## Near End Crosstalk

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- Coupling of signal from one pair to another
- Coupling takes place when transmit signal entering the link couples back to receiving pair
- i.e. near transmitted signal is picked up by near receiving pair

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# STP vs. UTP

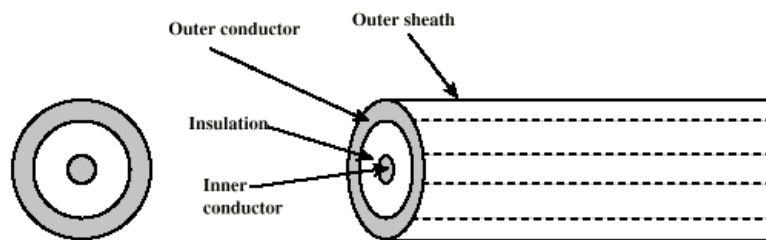
Table 4.2 Comparison of Shielded and Unshielded Twisted Pair

Frequency (MHz)	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
	Category 3 UTP	Category 5 UTP	150-ohm STP	Category 3 UTP	Category 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

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# Coaxial Cable



- Outer conductor is braided shield
- Inner conductor is solid metal
- Separated by insulating material
- Covered by padding

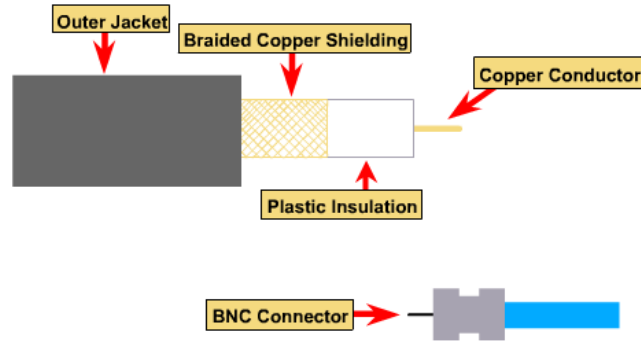
- To allow operation over wider range of frequencies
- Diameter of 1 to 2.5 cm
- Because of shielding, much less susceptible to interference and crosstalk

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# Coaxial Cable

## Coaxial Cable



- ◆ Speed and throughput: 10 - 100 Mbps
- ◆ Average \$ per node: Inexpensive
- ◆ Media and connector size: Medium
- ◆ Maximum cable length: 500m (medium)

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# Coaxial Cable Applications

- Most versatile medium
- Television distribution
  - Ariel to TV
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously (using FDM)
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks

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## Coaxial Cable - Transmission Characteristics

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- Analog
  - Amplifiers every few km
  - Closer if higher frequency
  - Up to 500MHz
- Digital
  - Repeater every 1km
  - Closer for higher data rates

Performance limited by attenuation, thermal noise, and intermodulation noise

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## Coaxial Cable - Transmission Characteristics

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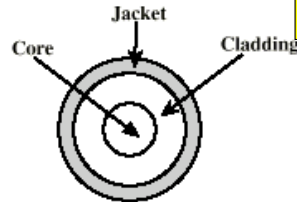
### 10BASE2 50 Ohm Coax Cable



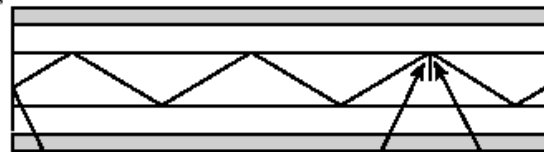
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# Optical Fiber

- Core: one or more thin strands or fibers (8 to 100  $\mu$ m)
- Cladding: glass or plastic coating with different optical properties than the core
- Core/Cladding interface: reflector – confine ray
- Jacket: protection against moisture, abrasion, crushing ...



- Glass or plastic core
- Laser or light emitting diode
- Specially designed jacket
- Small size and weight

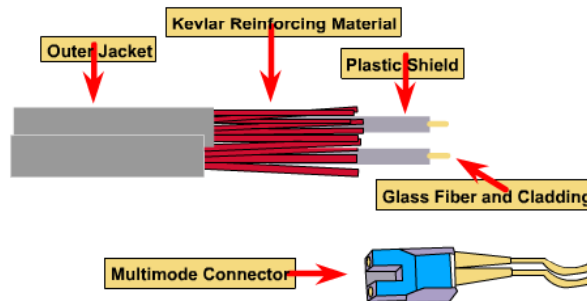


- Lowest losses using ultrapure fiber – difficult to manufacture
- Higher loss multicomponent glass fibers are more economical
- Plastic fiber is the cheapest used for short-haul links

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# Optical Fiber

## Fiber Optic Cable



- ◆ Speed and throughput: 100+ Mbps
- ◆ Average \$ per node: Most Expensive
- ◆ Media and connector size: Small
- ◆ Single mode, maximum cable length: Up to 3000m
- ◆ Multimode mode, maximum cable length: Up to 2000m
- ◆ Single mode: One stream of laser-generated light
- ◆ Multimode: Multiple streams of LED-generated light

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## Optical Fiber - Benefits

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- Greater capacity
  - Data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - 10s of km at least

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## Optical Fiber - Applications

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- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- LANs

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# Optical Fiber - Transmission Characteristics

- Act as wave guide for  $10^{14}$  to  $10^{15}$  Hz
  - Portions of infrared and visible spectrum
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate
- Wavelength Division Multiplexing

LED – ILD: semiconductor devices that emit a beam when voltage is applied

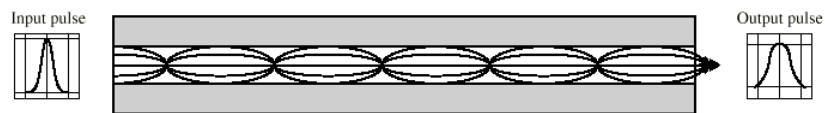
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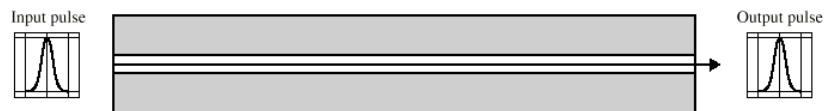
# Optical Fiber Transmission Modes



(a) Step-index multimode More than one path for signal – distortion  
Limits maximum data rate



(b) Graded-index multimode Intermediate mode

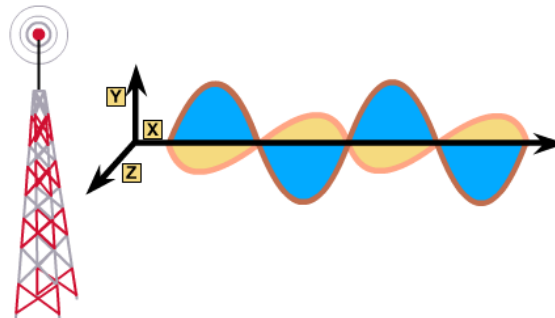


(c) Single mode One path for signal – superior signal quality  
Used for long-haul telephone and TV comm

# Wireless Transmission

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## Encoding Signals as Electromagnetic Waves



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# Wireless Transmission

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- Unguided media
- Transmission and reception via antenna
- Directional
  - Focused beam
  - Careful alignment required
- Omnidirectional
  - Signal spreads in all directions
  - Can be received by many antennae

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## Frequencies

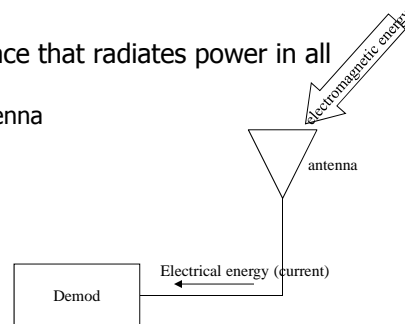
- 2GHz to 40GHz - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz - Radio
  - Omnidirectional
  - Broadcast radio
- $3 \times 10^{11}$  to  $2 \times 10^{14}$  - Infrared
  - Local point-to-point or point-to-multipoint in indoor applications

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## Antenna

- Definition: An electrical conductor or system of conductors used either for radiating electromagnetic energy or for collecting electromagnetic energy.
- General receiver/Transmitter structure
- Receiver/transmit characteristics of an antenna are the same
- Isotropic antenna – is a point in space that radiates power in all directions equally.
  - Referred to as omni-directional antenna



General Receiver Structure

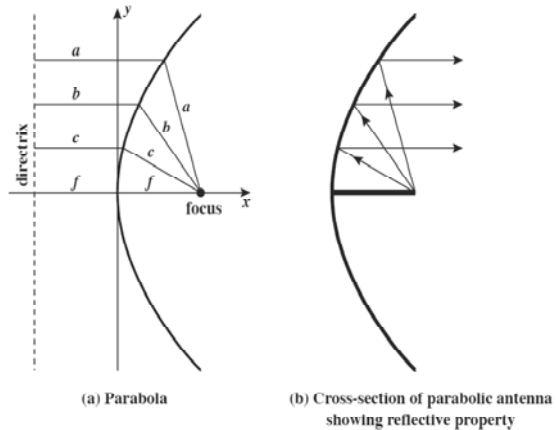
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## Parabolic Reflective Antenna

- Used in terrestrial microwave and satellite applications



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## Antenna Gain

- Definition: the power output, in a particular direction, compared to that produced in any direction by a perfect omni-directional antenna.
- It is a measure of directionality.
- Effective Area – a concept related to the physical size and shape of antenna
- Gain is given by

$$G = \frac{4 \pi A_e}{\lambda^2}$$

Where  $G$  – antenna gain  
 $A_e$  – effective antenna area  
 $\lambda$  – carrier wavelength

- For an ideal isotropic antenna –  $A_e = \lambda^2 / (4 \pi) \rightarrow G = 1$  or 0 dB
- For a parabolic antenna with face area of  $A$  –  $A_e = 0.56A \rightarrow G = 7A / \lambda^2$

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## Antenna Gain - Example

- Problem: Consider a parabolic reflective antenna with a diameter of 2 m operating at 12 GHz, what is the effective area and the antenna gain?
- Solution:  
face area,  $A = \pi r^2 \rightarrow \pi \text{ m}^2$   
effective area,  $A_e = 0.56 A = 0.56 \pi \text{ m}^2$   
wavelength,  $\lambda = c/f = 3 \times 10^8 / 12 \times 10^9 = 0.025 \text{ m}$   
then Gain,  $G = 4 \pi A_e / \lambda^2 = 35,180$ , or  
 $G_{\text{dB}} = 10 \log_{10}(35,180) = 45.46 \text{ dB}$

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## Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications (4-6 GHz and 11 GHz)
- Higher frequencies give higher data rates



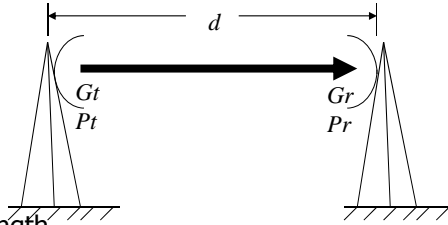
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## Transmission Characteristic

- Free-Space loss model

$$P_r/P_t = G_t G_r * [\lambda / (4\pi d)]^2$$
  
where:  $P_t$  – transmitted power level  
 $P_r$  – received power level  
 $G_r$  – receive antenna gain  
 $G_t$  – transmit antenna gain  
 $\lambda$  – carrier frequency wavelength  
 $d$  – distance between transmitter and receiver



- **Path loss** is defined as  $L = P_t/P_r$  – usually measured in dBs (i.e.  $L_{dB} = 10\log_{10}(L) = 10\log_{10}(P_t/P_r)$ )
- If  $G_t$  and  $G_r$  are not given – assume  $G_t = G_r = 1$ .

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## Satellite Microwave

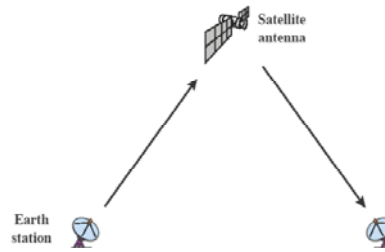
- Satellite is relay station
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Requires geo-stationary orbit
  - Height of 35,784km
- Television
- Long distance telephone
- Private business networks

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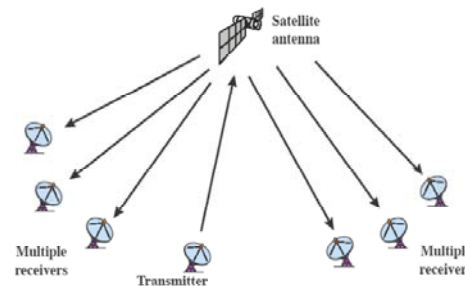
## Satellite Communication Configurations

- Point-to-point link (uplink: 5.925-6.425 GHz, downlink: 3.7-4.2 GHz) – 4/6 GHz band



(a) Point-to-point link

- Broadcast link
- Typical range 1-10GHz
  - Below 1 GHz – noise
  - Above 10GHz – atmospheric absorption
- 12/14 GHz and 20/30 GHz are also being used



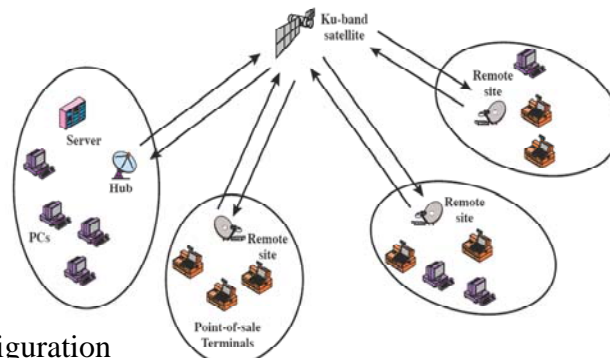
(b) Broadcast link

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## Applications

- Public Broadcasting services (PBS)
- Direct Broadcasting Satellite (DBS)
- Very Small Aperture Terminal (VSAT)



Typical VSAT Configuration

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## Broadcast Radio

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- Omnidirectional; 30 MHz ~ 1 GHz
- FM radio
- UHF and VHF television
- Line of sight
- Suffers from multipath interference
  - Reflections

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## Infrared

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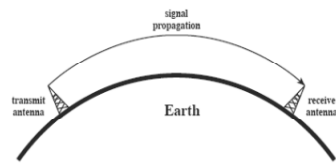
- Modulate noncoherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- e.g. TV remote control, IRD port

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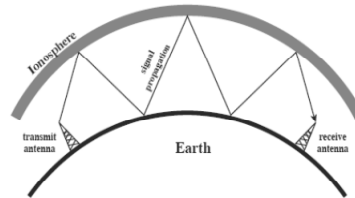
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## Wireless Propagation

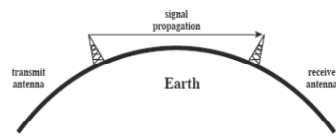
- Ground Wave propagation
  - Freq < 2 MHz
  - Signal tends to follow earth's curvature – scattered by atmosphere
  - Application - AM radio
- Sky Wave propagation
  - 2 MHz < Freq < 30 MHz
  - Signal from earth is reflected by Ionsphere – perhaps several hops
  - Application: armature radio, CB, and international broadcasts
- Line of Sight (LOS) propagation
  - Freq > 30 MHz
  - Optical versus Effective LOS



(a) Ground-wave propagation (below 2 MHz)



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

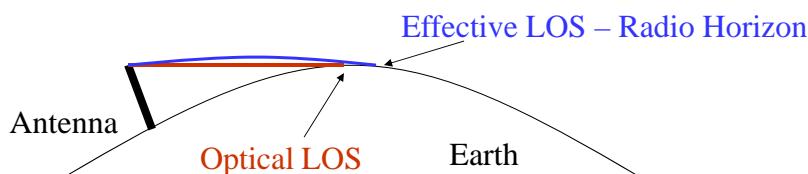


(c) Line-of-sight (LOS) propagation (above 30 MHz)

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## Line Of Sight Propagation

- The optical LOS distance in kilometers,  $d$ , is given by
 
$$d = 3.57\sqrt{h}$$
 where  $h$  is the antenna height in meters.
- The effective LOS distance in kilometers,  $d$ , is given by
 
$$d = 3.57\sqrt{Kh}$$
 where  $K$  is an adjustment factor  $\sim 4/3$
- The maximum distance between two towers for LOS is given by
 
$$d_{\max} = 3.57[\sqrt{Kh_1} + \sqrt{Kh_2}]$$



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## Example

- Problem: Assume an earth station is transmitting 250 Watts directed to an asynchronous satellite at the height of 35,863 km. If the carrier frequency is 4 GHz, calculate:
  - a) the path loss assuming isotropic antennas
  - b) the path loss assuming the antenna gain for satellite and ground station to be 44 dB and 48 dB, respectively.
  - c) what is the power level received at the satellite?

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## Example – cont'd

- Solution:

Path Loss,  $L = P_t/P_r = 1/\{G_t G_r * [\lambda / (4\pi d)]^2\}$   
 wavelength,  $\lambda = c/f = 3 \times 10^8 / 4 \times 10^9 = 0.075$  m

a) for isotropic antennas  $\rightarrow G_t = G_r = 1$ ;  
 $L = 1/\{1 \times 1 \times [0.075 / (4\pi \times 35853 \times 10^3)]^2\}$   
 $= 3.6087 \times 10^{19}$

$L_{dB} = 10 \times \log_{10}(L) = 195.6$  dB

b) for  $G_r = 44$  dB (or  $1044/10 = 25,119$ ) and  $G_t = 48$  dB (or  $63,096$ )

Therefore,

$L = 1/\{25119 \times 63096 \times [0.075 / (4\pi \times 35853 \times 10^3)]^2\}$   
 $= 2.2769 \times 10^{10}$

$L_{dB} = 10 \times \log_{10}(L) = 103.6$  dB

c) Power received at satellite:

$L = P_t/P_r \rightarrow P_r = P_t/L = 250 / 2.2769 \times 10^{10}$   
 $= 1.0980 \times 10^{-8}$  Watts

$P_{r,dBW} = 10 \times \log_{10}(P_r) = -79.6$  dBW

Another way for

b)  $L_{dB} = L_{dB, \text{isotropic}} - G_{t,dB} - G_{r,dB}$   
 $= 195.6 - 44 - 48$   
 $= 103.6$  dB

Another way for

c)  $P_t = 250$  Watts  $\rightarrow P_{t,dBW} = 10 \times \log_{10}(250) = 24$  dBW  
 $P_{r,dBW} = P_{t,dBW} - L_{dB} = 24 - 103.6 = -79.6$  dBW

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## Required Reading

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- Stallings Chapter 4

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