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CEN 534 Review of Data Transmission

Wireless Transmission

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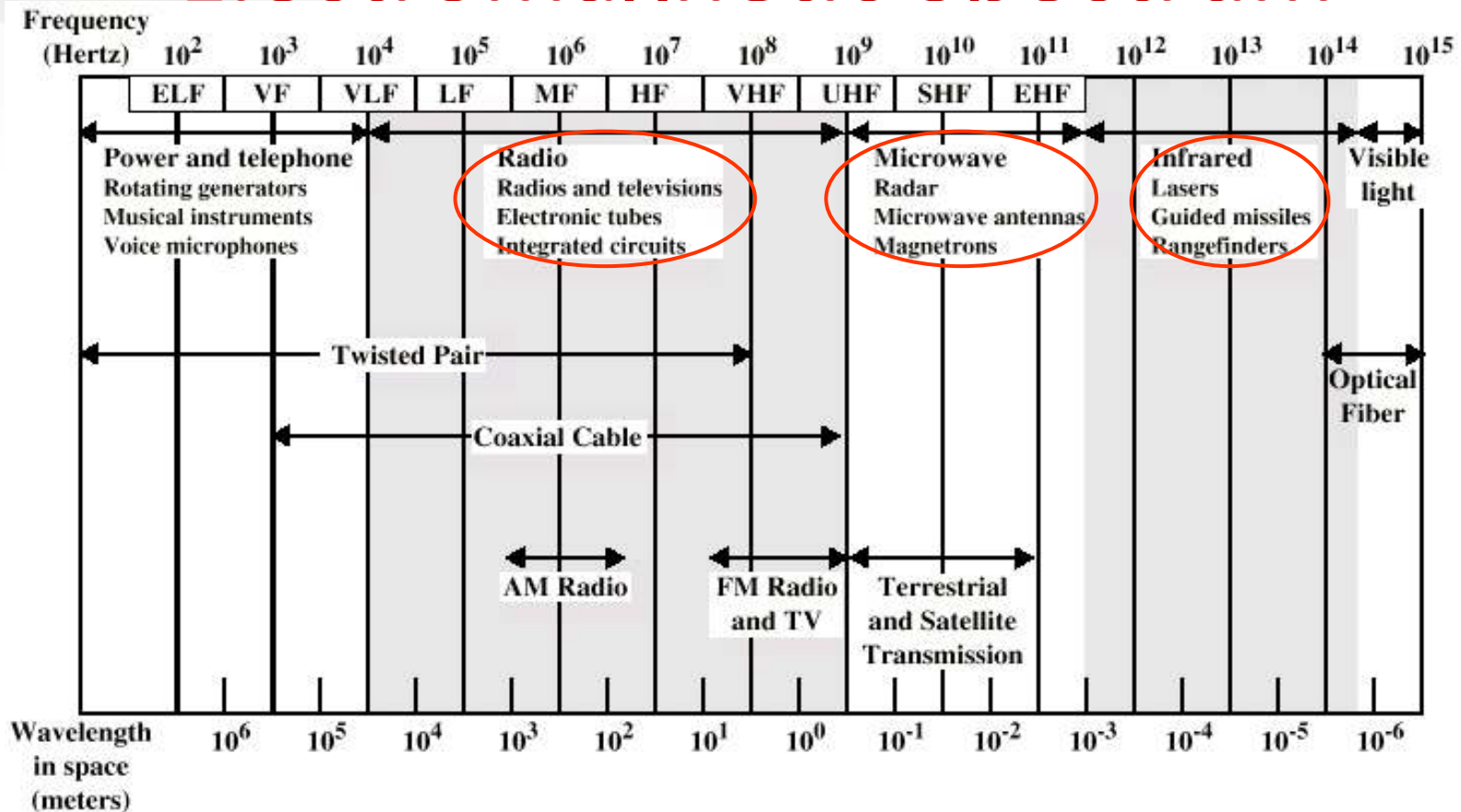
Wireless Transmission



- Antennas
- Terrestrial Microwave
- Satellite Microwave
- Broadcast Radio
- Infrared



Electromagnetic Spectrum

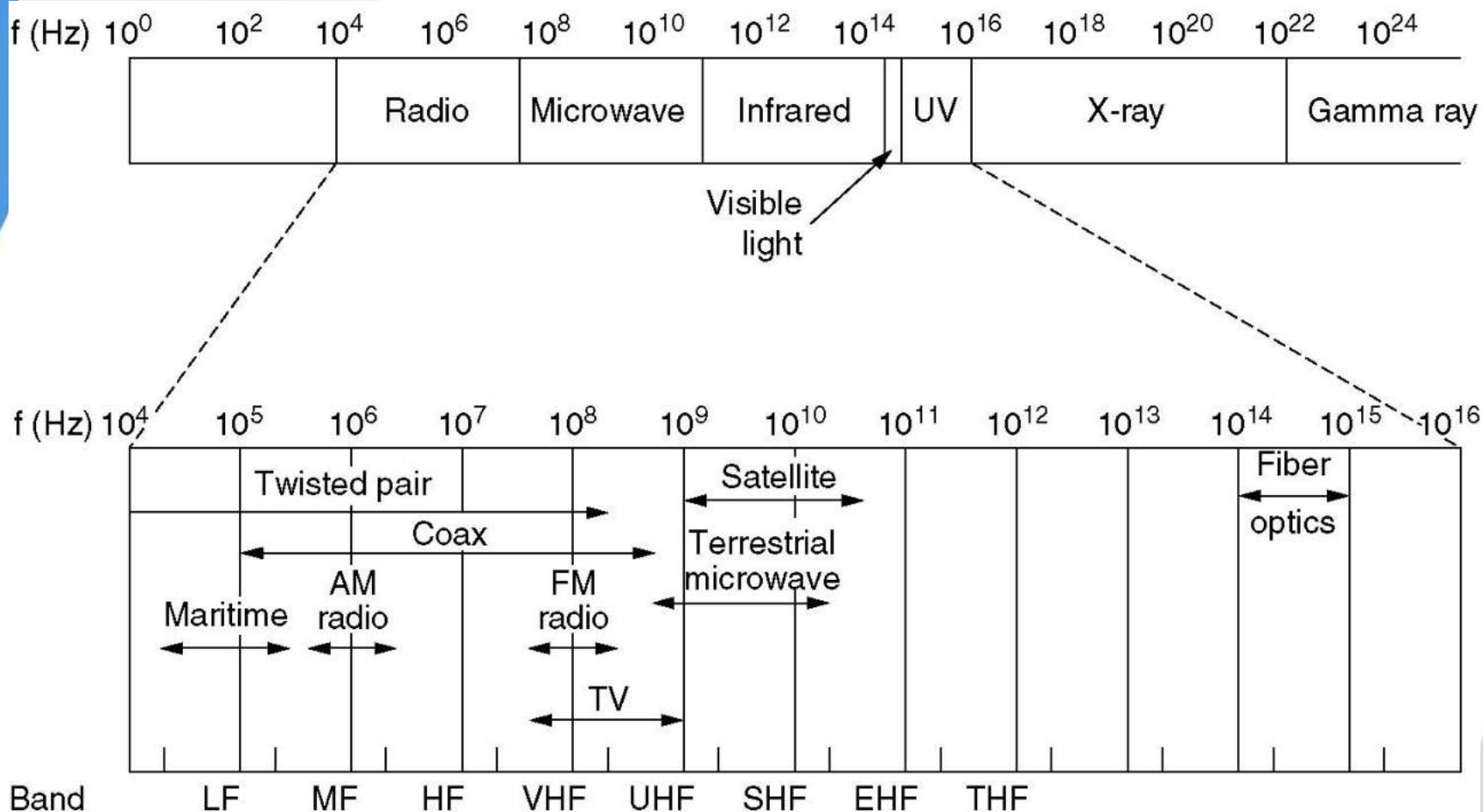


ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency

MF = Medium frequency
HF = High frequency
VHF = Very high frequency

UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Wireless Spectrum





Wireless Transmission Frequencies

Three general ranges of frequencies:

- **Microwave frequencies**
 - Frequencies in the range of 300 MHz to 40GHz
 - Highly directional
 - Point to point
 - Microwave is also used for satellite communications
- **Broadcast Radio**
 - 300KHz to 300 MHz
 - FM radio
 - UHF and VHF television
- **Infrared**
 - 3×10^{11} to 2×10^{14} Hz
 - Local applications

Antennas



- Transmission and reception are achieved by means of an **antenna**.
- An antenna is an electrical conductor used to:
 - radiating electromagnetic energy
 - collecting electromagnetic energy
- **Transmission antenna**
 - Electrical energy converted to electromagnetic
 - Radiated to surrounding environment
- **Reception antenna**
 - electromagnetic energy impinge on antenna
 - electromagnetic energy converted to electrical
- Same antenna is often used for both purposes



Omnidirectional vs. Directional



**Omnidirectional:
360° Coverage**



**Directional:
Focused Coverage**



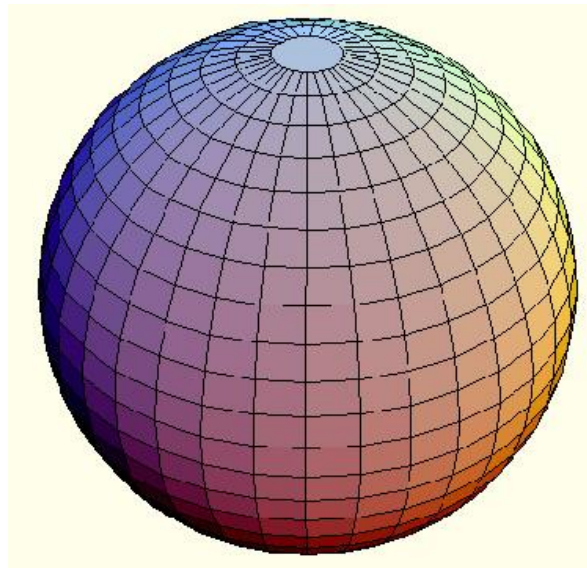
Radiation Pattern

- Power radiated in all directions
- Not same performance in all directions
- The simplest pattern is produced by an idealized antenna known as the **isotropic antenna**
- An isotropic antenna is a point in space that *radiates in all directions equally*
- The actual radiation pattern for the isotropic antenna is a *sphere* with the antenna at the center.



Isotropic Antenna

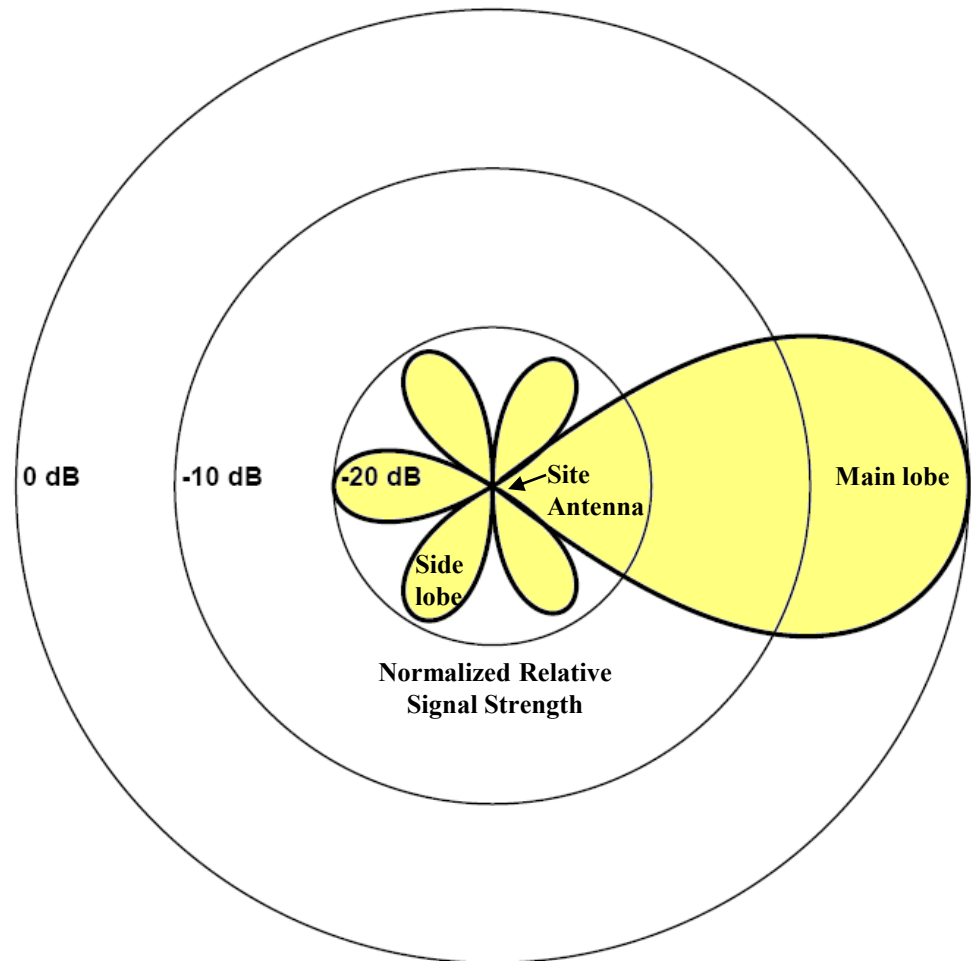
- A theoretical Antenna with a uniform spherical radiation pattern
- An **isotropic antenna** is said to have a **0db** gain when compared to itself.
- **Gain relative to an isotropic antenna** is denoted with **dBi**.





Typical Antenna Pattern

- ❑ No antenna is able to radiate all the energy in one preferred direction
- ❑ Often there are small peaks in different directions
- ❑ The peaks are referred to as **sidelobes**
- ❑ Commonly specified in dB down from the **main lobe**, or **preferred direction**

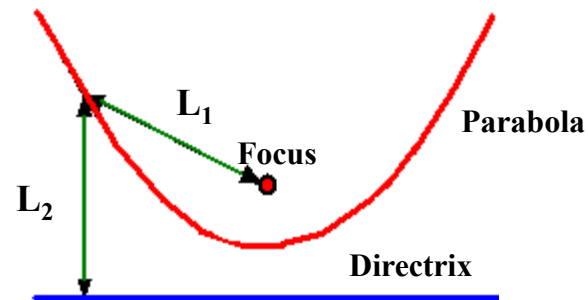
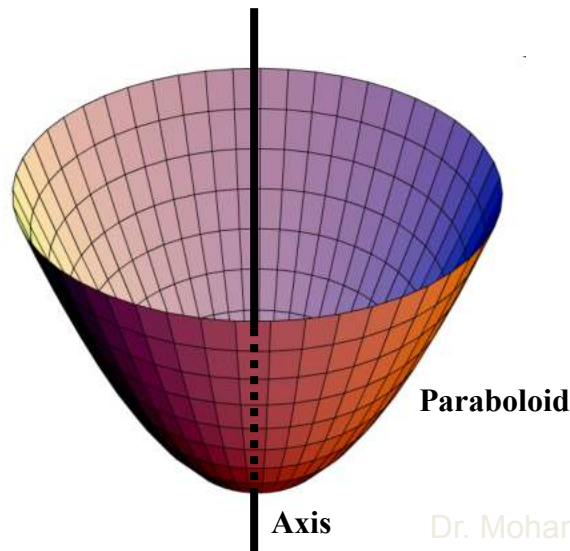




Parabolic Reflective Antenna

Paraboloid

- Parabola revolved about its axis
- Cross section **parallel** axis $\rightarrow$ **parabola**
- Cross section **perpendicular** to axis $\rightarrow$ **circle**
- A parabola is the locus of all points equidistant from a fixed line (**Directrix**) and a fixed point (**Focus**) not on the line.
- Used in microwave antennas



Parabola with Focus and Directrix

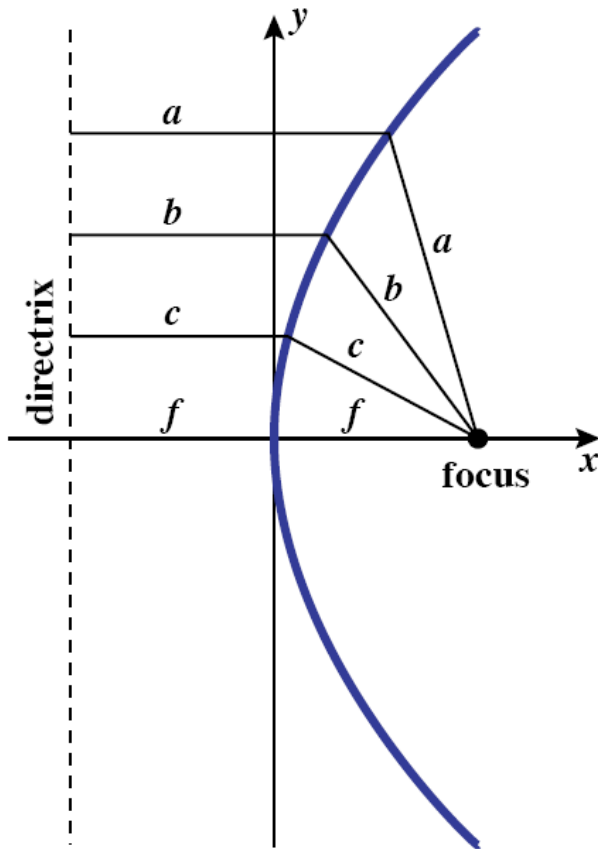
The distances L_1 and L_2 are equal



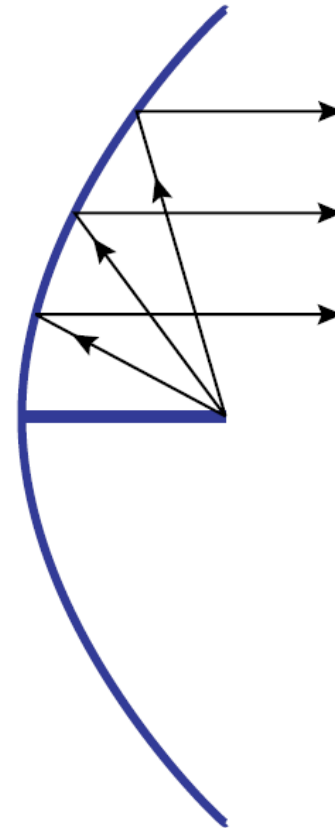
Parabolic Reflective Antenna

- **Transmission**
 - source placed at **focus of paraboloid**
 - wave bound parallel to axis
- **Reception**
 - incoming waves parallel to axis
 - concentrated at the **focus**

Parabolic Reflective Antenna



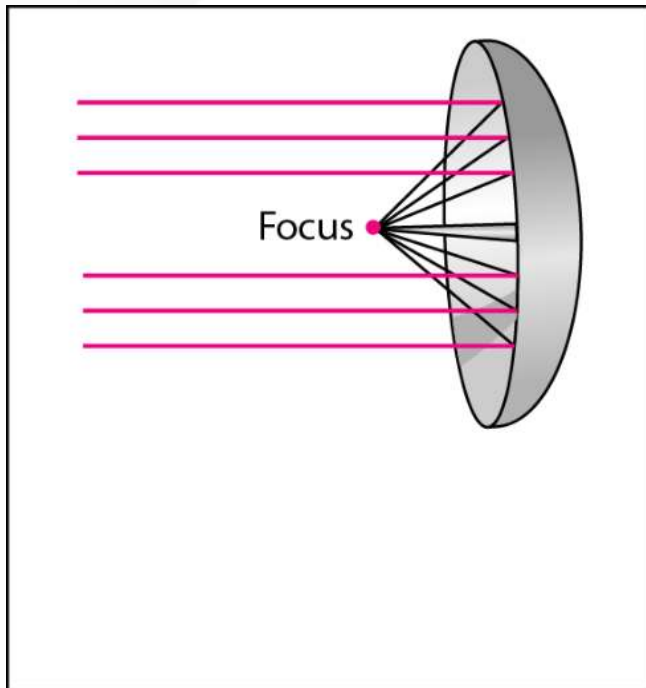
(a) Parabola



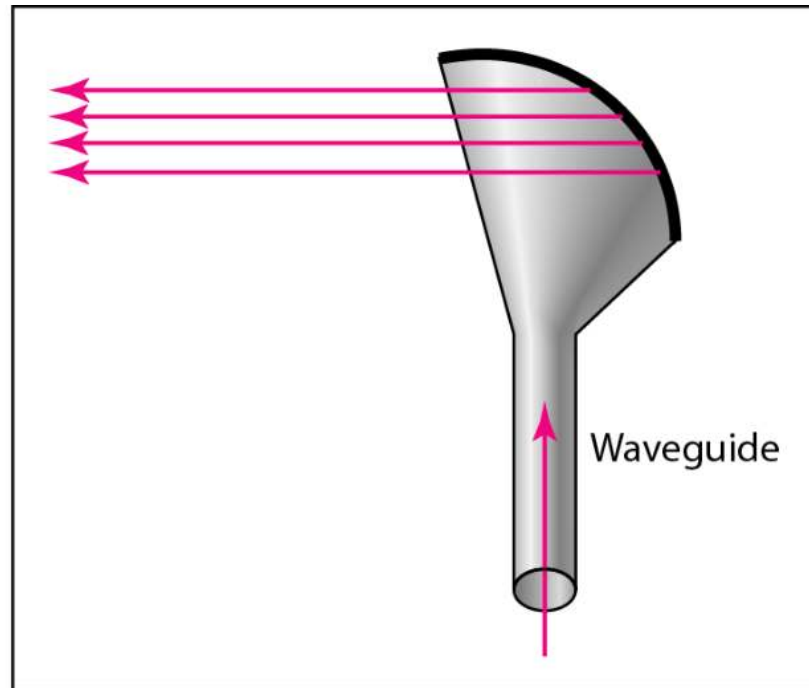
(b) Cross-section of parabolic antenna showing reflective property



Parabolic Reflective Antenna



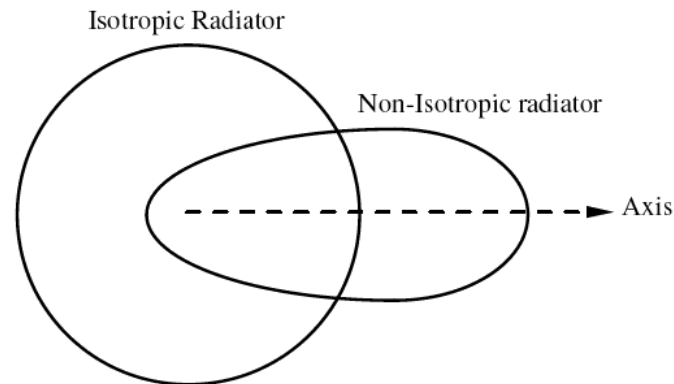
a. Dish antenna



b. Horn antenna

Antenna Gain

- A measure of **directionality of antenna**
- **Antenna gain is usually defined as the ratio of the power produced by the antenna to the power produced by an isotropic antenna**



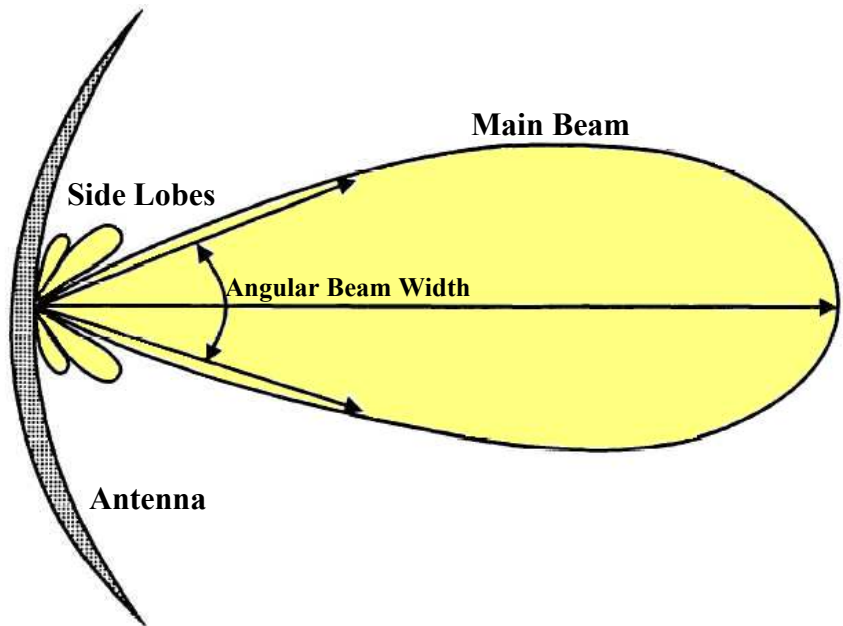
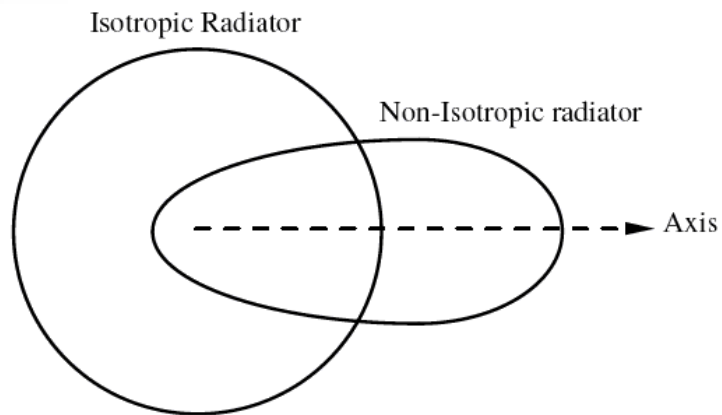
- When we talk about antenna gain (G), we use it as a multiplier compared to an ideal isotropic antenna.
- **Where are we getting the extra power to get antenna gain?**
- **We cannot change the total power of the antenna, we are just redistributing it. We reduce the power in directions we do not want an antenna beam, and increase it greatly in areas in which we do want high antenna power.**



Antenna Gain

- **Increased power in one direction means reduced power in other directions**
- Antenna gain does not refer to obtaining more output power than input power **but rather to directionality**.
- **Antenna gain** measured in **decibels (dB)**
- **Antenna Gain:** A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern. The measurement is typically measured in **dB_i** (Decibels relative to an isotropic radiator).
- Power output in particular direction compared to that produced by a perfect omnidirectional antenna (isotropic antenna)

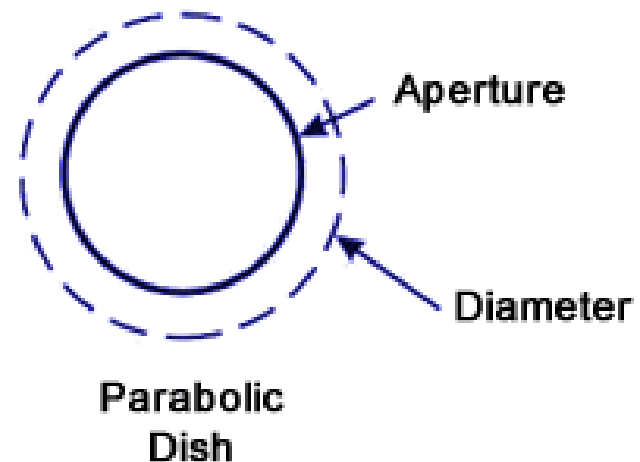
Antenna Gain





Effective Area of Antenna

- Effective area is the area of the incoming wavefront which is captured by the receiving antenna and fed to its load circuit.
- Related to **physical size** and **shape**
- For **parabolic antenna**
 - Face area $A = \pi r^2$
 - Effective area $A_e = 0.56 A$





Antenna Gain & Effective Area

- Relationship between G and A_e is

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

- G = antenna gain
- A_e = effective area
- f = carrier frequency
- c = speed of light ($\approx 3 \times 10^8$ m/s)
- λ = carrier wavelength



Example

- For **isotropic antenna**, $G=1$
 $1 = 4\pi A_e / \lambda^2$
 $A_e = \lambda^2 / 4\pi$
- For **parabolic antenna** with face area A
 $A_e = 0.56 A$
 $G = 4\pi A_e / \lambda^2 = 4\pi 0.56 A / \lambda^2$
 $= 7A / \lambda^2$





Example

- **Parabolic reflective antenna** has diameter 2 m operating at 12 GHz. Calculate A_e , G
- Answer
 - Radius = $r = 1$
 - $A = \pi r^2 = \pi \times 1 = \pi$
 - $A_e = 0.56 A = 0.56 \pi = 1.76$
 - $\lambda = c/f = (3 \times 10^8)/(12 \times 10^9) = 0.025 \text{ m}$
 - $G = 7A/\lambda^2 = (7 \pi / 0.025^2) = 35186$
 - $G_{\text{dB}} = 10 \log_{10}(35186) = 45.46 \text{ dB}$

Antennas



- Three basic types of antennas.

- **Omnidirectional**

- Common type used for wireless LANs is called a **dipole antenna**



Dipole Antenna

- **Semi-directional**

- **Patch**
 - **Yagi** (pronounced yah-gee)



Patch Antenna



Yagi Antenna

- **Directional**

- **Parabolic dishes**
 - **Grid antennas**

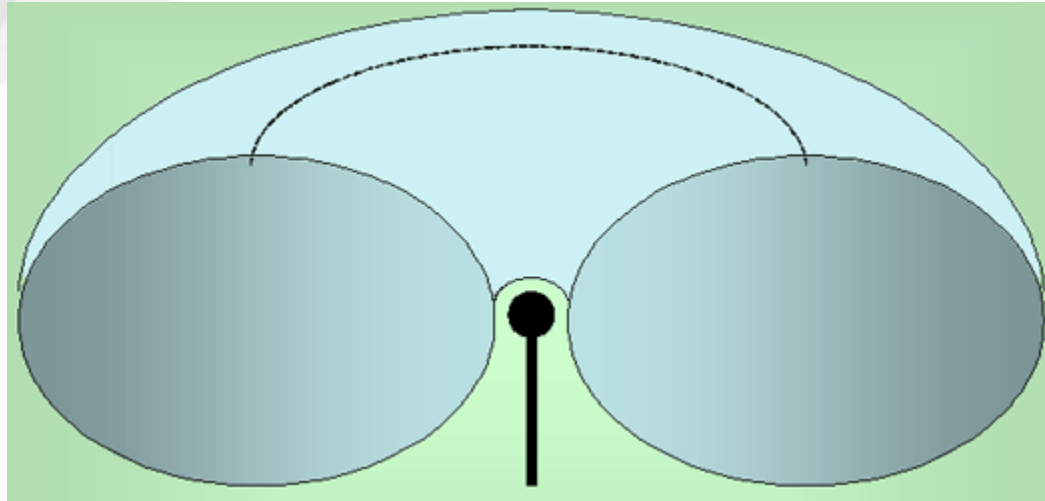


Parabolic Dishes

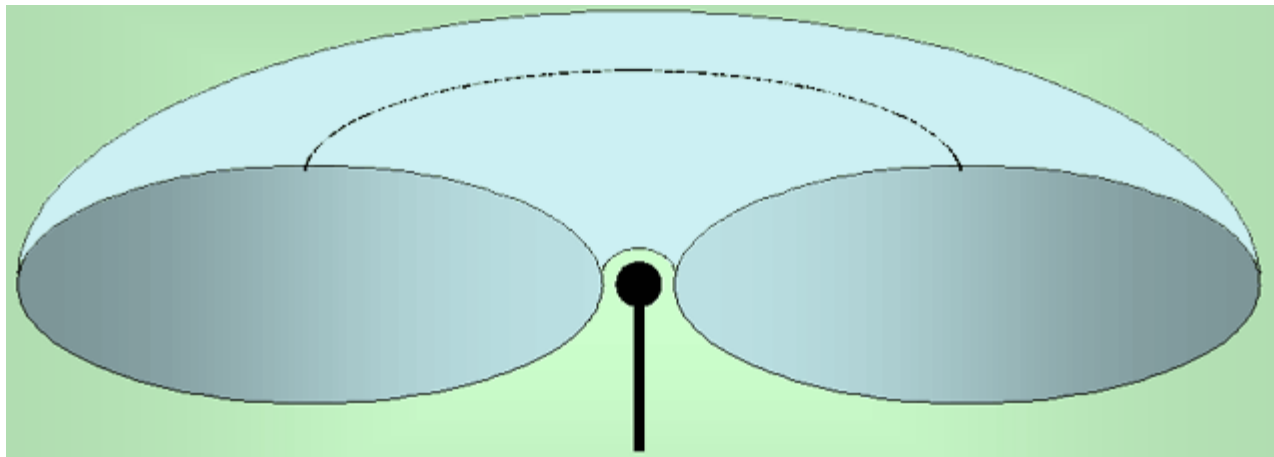


Grid Antenna

Omnidirectional- Dipole Antenna

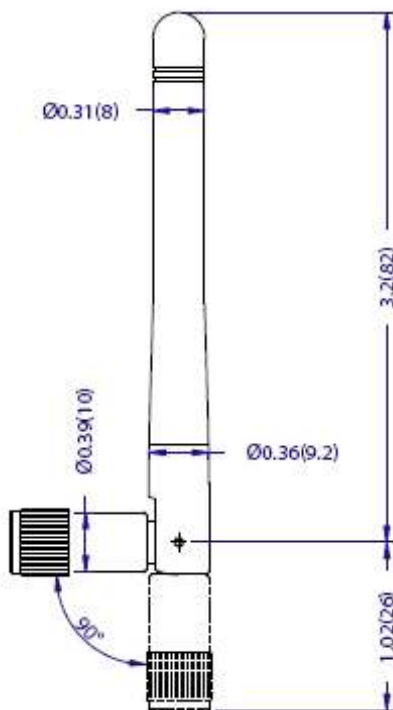


- As the gain increases the antenna's range decreases along the vertical axis and reaches out further on the horizontal.

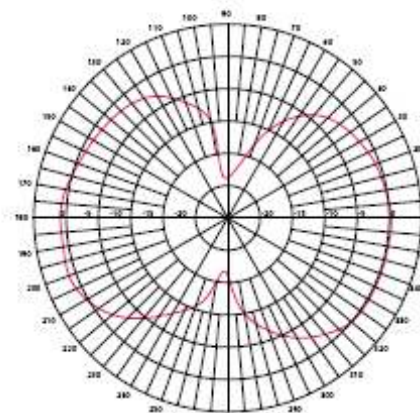




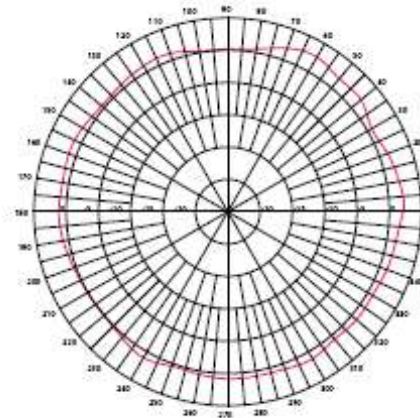
Omnidirectional- Dipole Antenna



E-Plane Pattern @ 2.45GHz

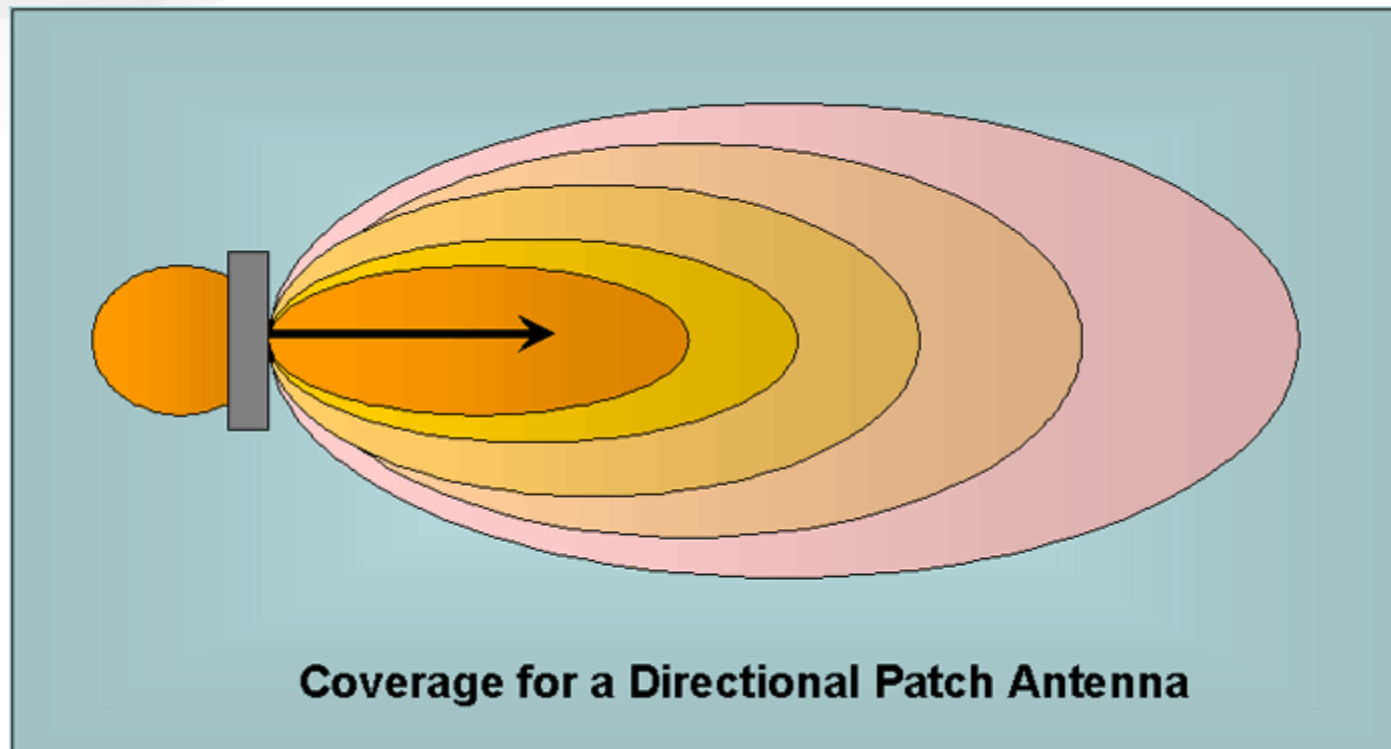


H-Plane Pattern @ 2.45GHz



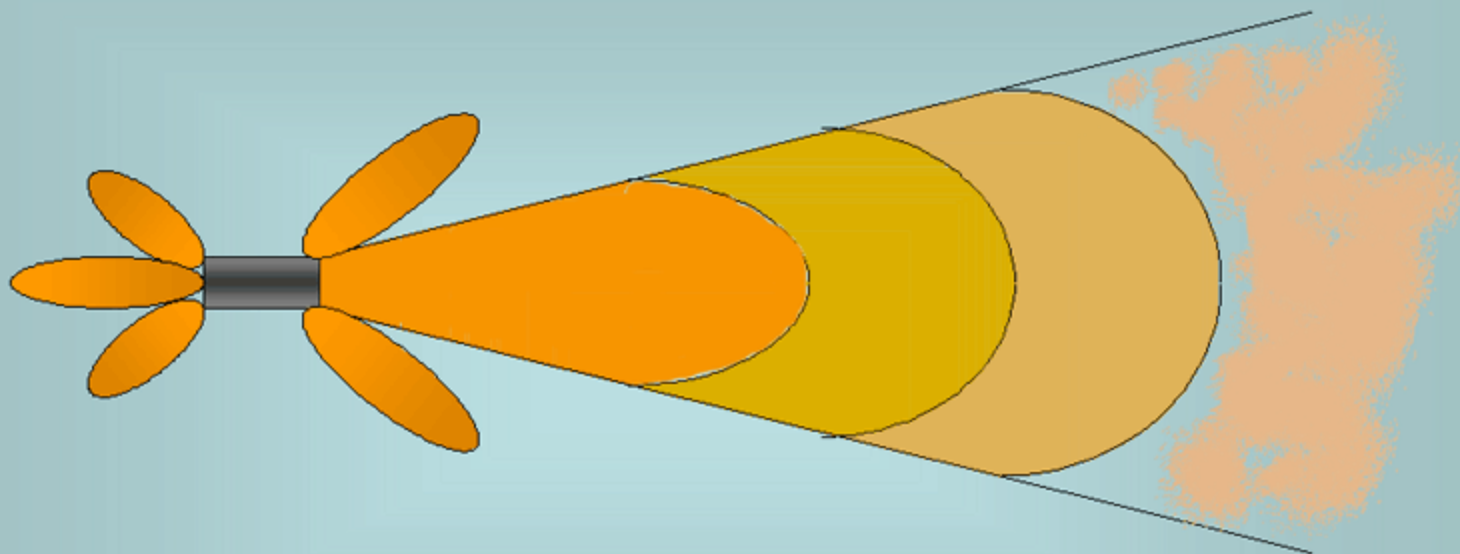


Semi-Directional - Patch Antenna



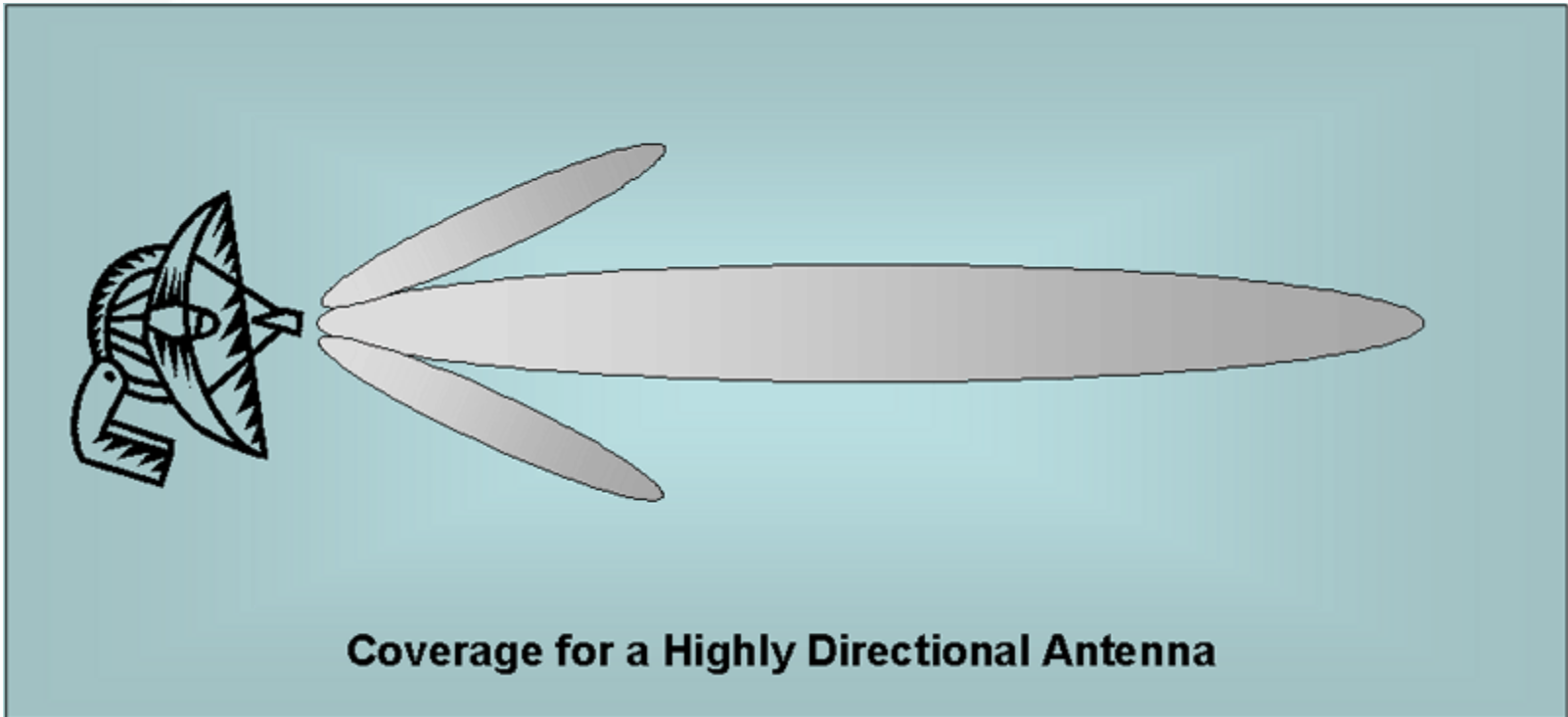


Semi-Directional - Yagi Antenna



Coverage for a Directional Yagi Antenna

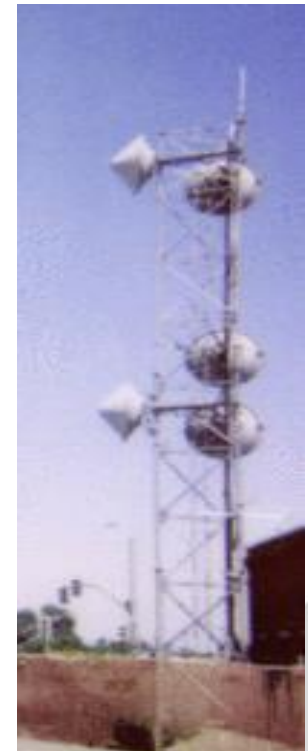
Directional Antenna





Terrestrial Microwave

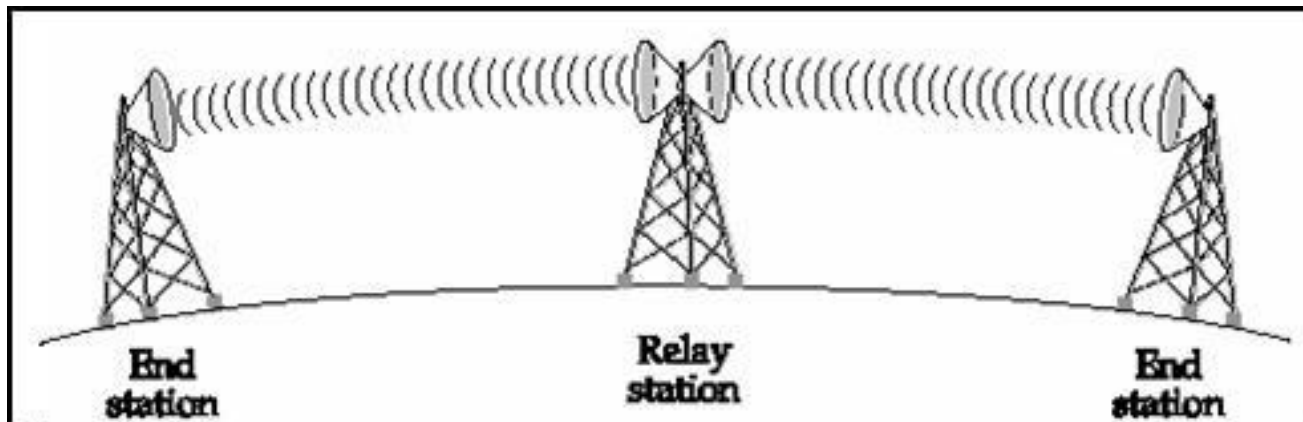
- Use **parabolic dish**, about 3 m diameter
- Antenna focuses signal in small beam
- **Line-of-sight transmission**
- Usually located at substantial **height**
 - extend range
 - avoid obstacles





Terrestrial Microwave

- A **series of microwave** relay towers used to extend range



Microwave

Transmission Characteristics



- Main source of loss is **attenuation**
- Loss can be expressed as:

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

- d = distance
- λ = wavelength

- Loss varies as **square of distance**
 - More repeater spacing for microwave systems - 10-100 km
- Other sources of impairments:
 - **Rainfall**: It is noticeable above 10 GHz
 - **Interference**: Assignment of frequency bands is strictly regulated

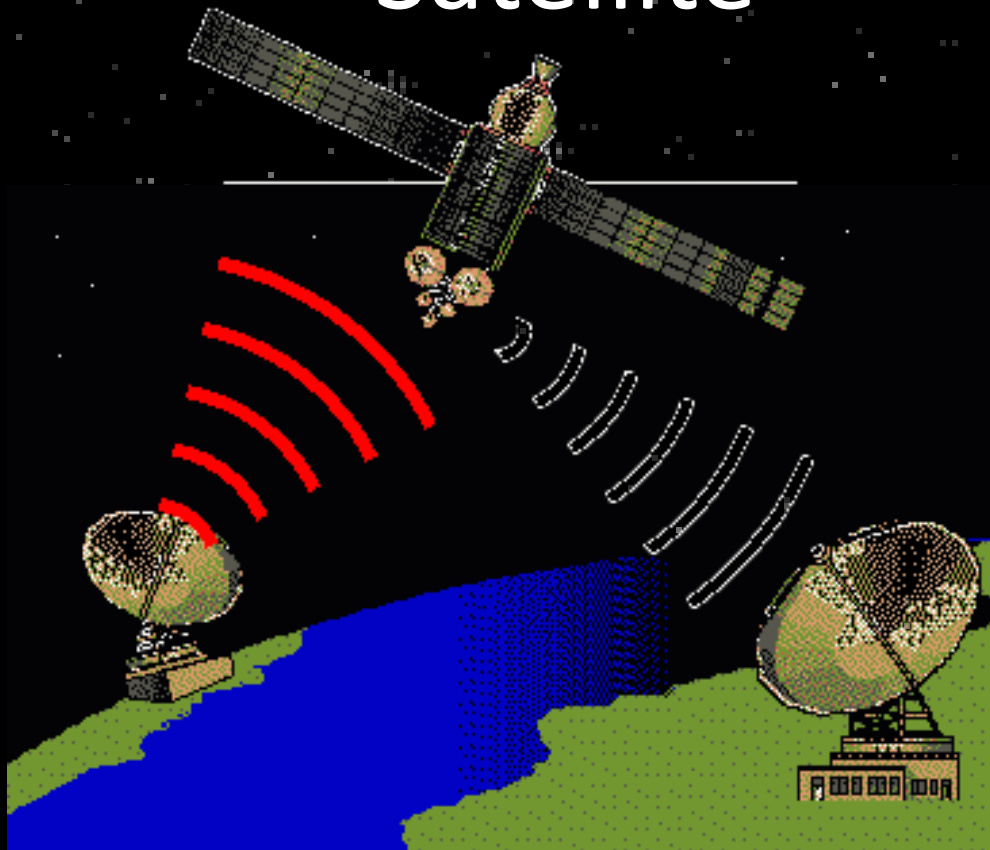


Terrestrial Microwave

Transmission Characteristics

- Common band for long-haul **4-6 GHz**
- Bands are increasingly congested
- More bands are now used: **11-12 GHz**
- **Higher frequencies** used for short p2p links
 - less useful in long distance due to attenuation
 - antennas are smaller and cheaper

Satellite



Satellite

Orbital Altitudes of many significant satellites of earth



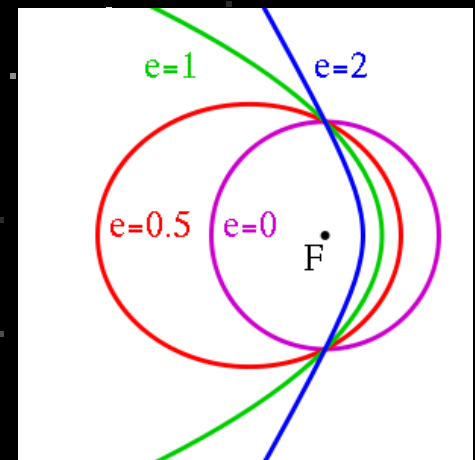
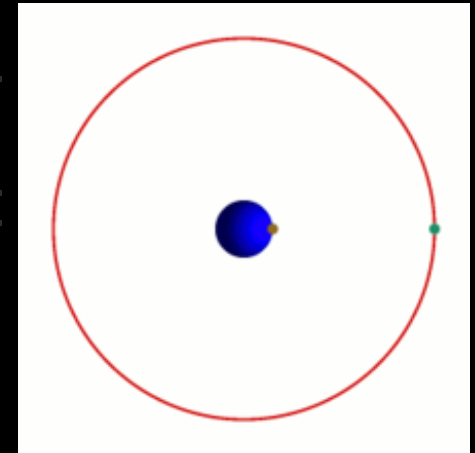
Earth



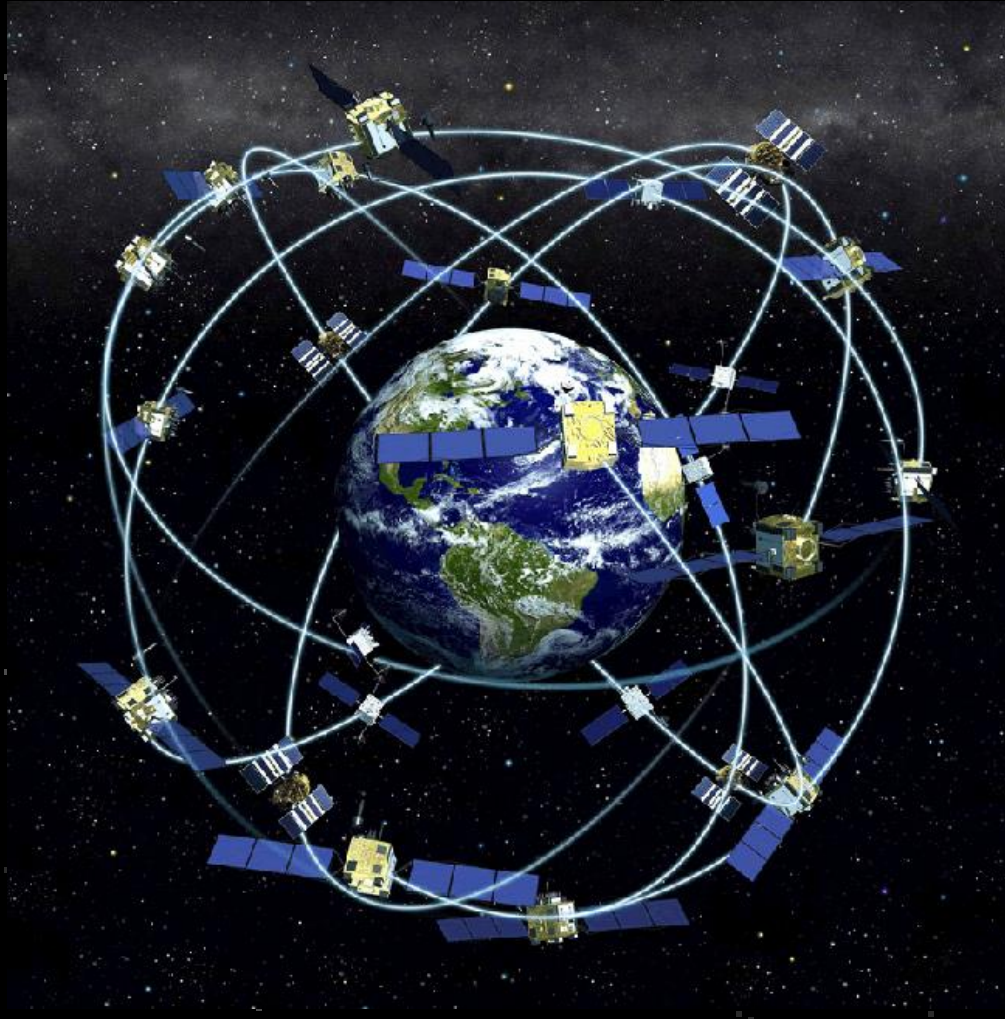
Moon
384,392 km

Satellite - GEO

- A geostationary orbit (or Geostationary Earth Orbit - GEO) is a geosynchronous orbit
 - directly above the Earth's equator (0° latitude)
 - with a period equal to the Earth's rotational period
 - an orbital eccentricity of approximately zero.
- An object in a geostationary orbit appears motionless, at a fixed position in the sky, to ground observers.
- Communications satellites and weather satellites are often given geostationary orbits
- Due to the constant 0° latitude and circularity of geostationary orbits, **satellites in GEO differ in location by longitude only.**



Satellite – GPS

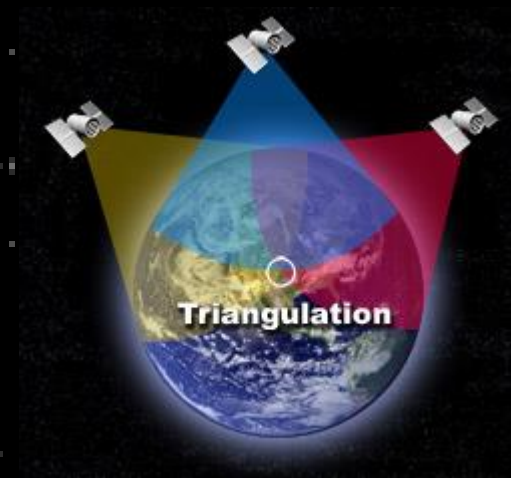
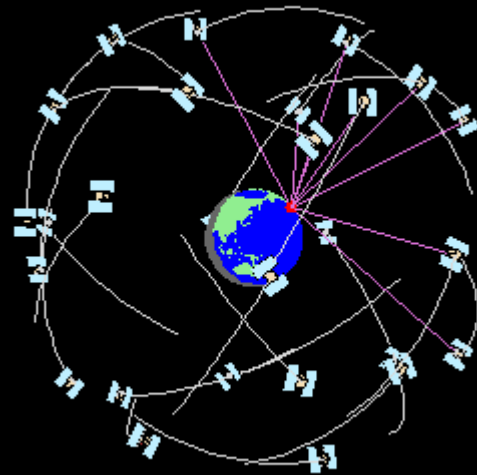


Satellite -

In order to use the GPS system, you need **at least three GPS satellites**. That means that the GPS system is designed in such a way that three satellites can be seen from anyway on the planet at any time.

Each of the three satellites will transmit information that is received by the GPS receiver.

The GPS receiver uses this information to calculate where you are (**longitude and latitude**) and **sometimes even your altitude (height about sea-level)**. The mathematical method the system uses to do this is called 'triangulation'.





Satellite Microwave

- Satellite is effectively relay station
- Used to link two or more ground stations
 - satellite **receives** tx at frequency band (uplink)
 - **amplifies** or repeat signal
 - **transmits** it on another band (downlink)
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
 - eg. **uplink 5.925-6.425 GHz** & **downlink 3.7-4.2 GHz**
- Satellite operates on multiple frequency bands (transponders)



Satellite Microwave - GEO

Advantages of a geostationary orbits include:

- **Large spatial coverage** (five geostationary satellites are enough to cover all of the non-polar regions of the Earth).
- **Permanent visibility of the satellite** allowing continuous telecommunications
- **one ground segment** is enough for the **satellite monitoring**.

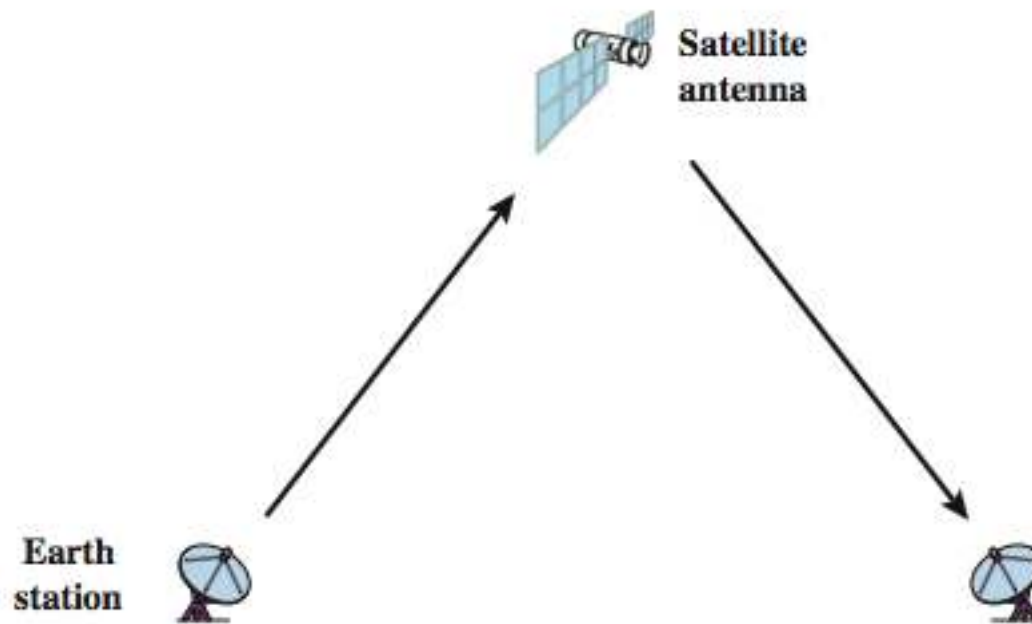


Limitations of geostationary satellites include:

- **Polar regions** are not observed.
- Some perturbations of the **solar electricity power supply** to the satellite occur during **eclipse phenomena**.



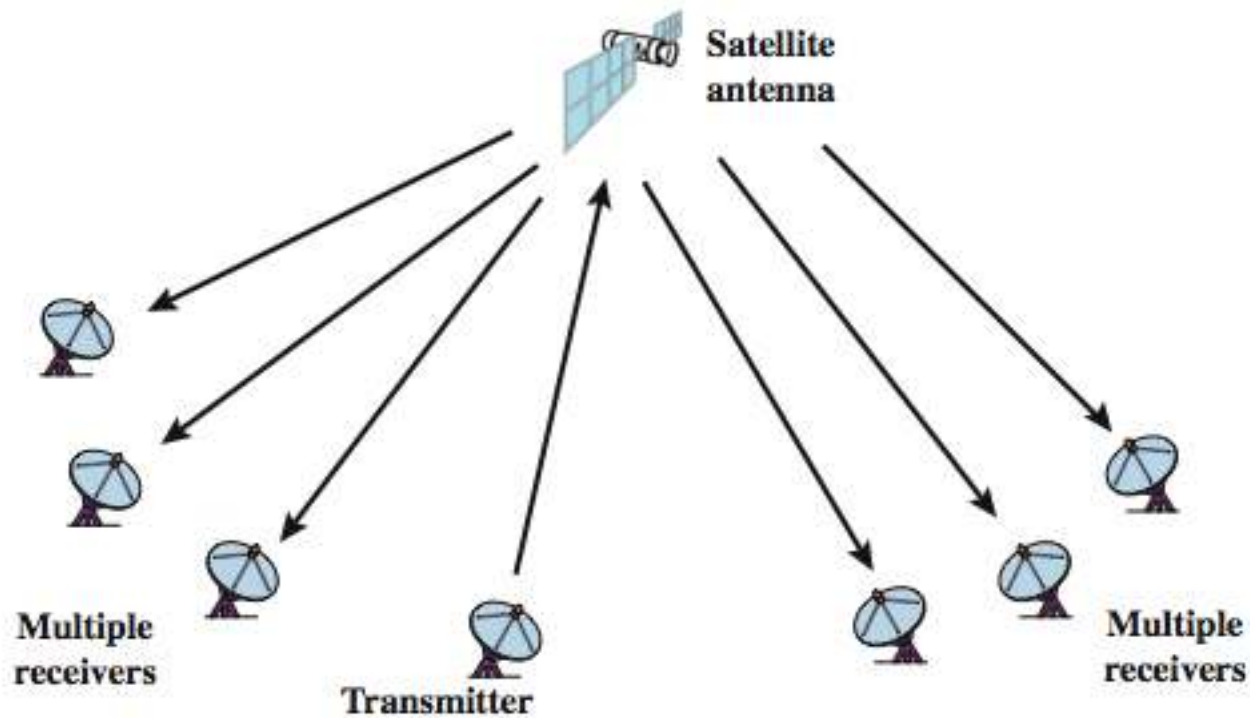
Satellite Point to Point Link



(a) Point-to-point link



Satellite Broadcast Link

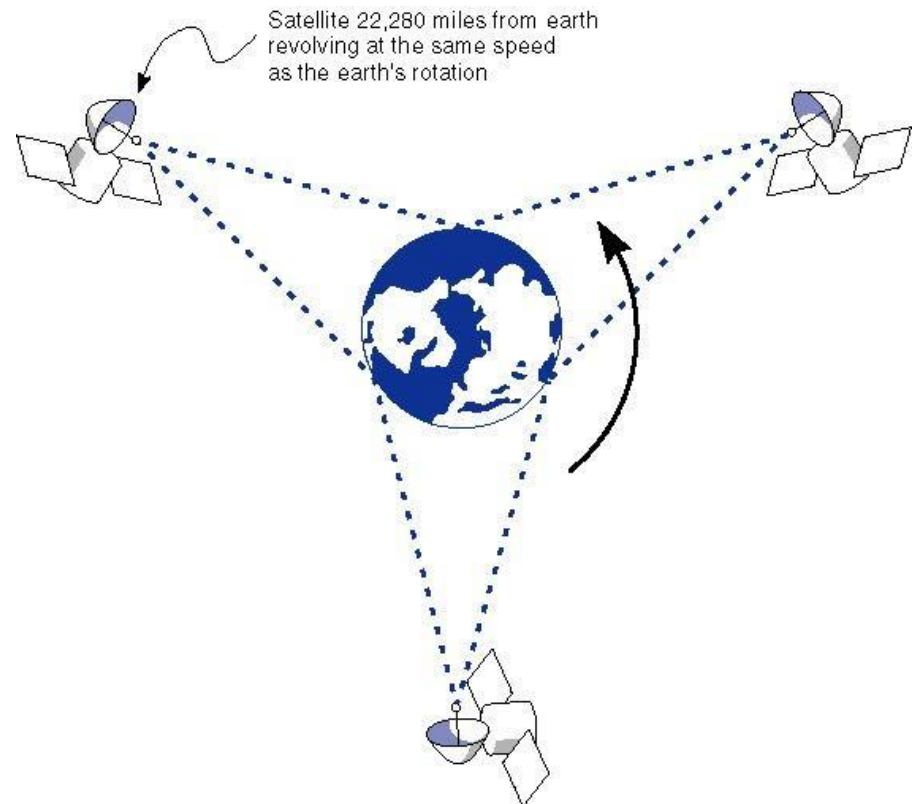


(b) Broadcast link



Satellite Position

- Communication satellite should remain in **stationary position over earth**
- Otherwise, it will not be within line-of-sight of its earth stations
- **Period of rotation = earth's rotation period**
- Match occurs at height of 35,786 km at the **equator**
- Satellite locations may differ by longitude only as geostationary orbits must have a latitude that is zero.





Satellite Spacing

- Satellites using same frequency band must be spaced far enough to **avoid interference**
- 4° spacing for **4/6 GHz** band
- 3° spacing for **12/14 GHz** band
- **Angular displacement measured from earth**
- **Number of possible satellites is limited**



Transmission Characteristics

- Optimum frequency range is 1-10 GHz
 - <1 GHz: noise from natural sources, atmosphere, interference with electronics
 - >10 GHz: signal attenuation, absorption
- Most satellites providing p2p service use
 - 5.925 – 6.425 GHz for uplink
 - 3.7 – 4.2 GHz for downlink
 - different frequency band to allow continuous operation without interference

} known as 4/6 GHz band



Transmission Characteristics

- **4/6 GHz** band within optimum
- Has become **saturated**
- **12/14 GHz** band has been developed
 - attenuation problems must be considered
 - will also **saturate**
- Use is projected for **20/30 GHz** band
 - greater attenuation but allows more bandwidth

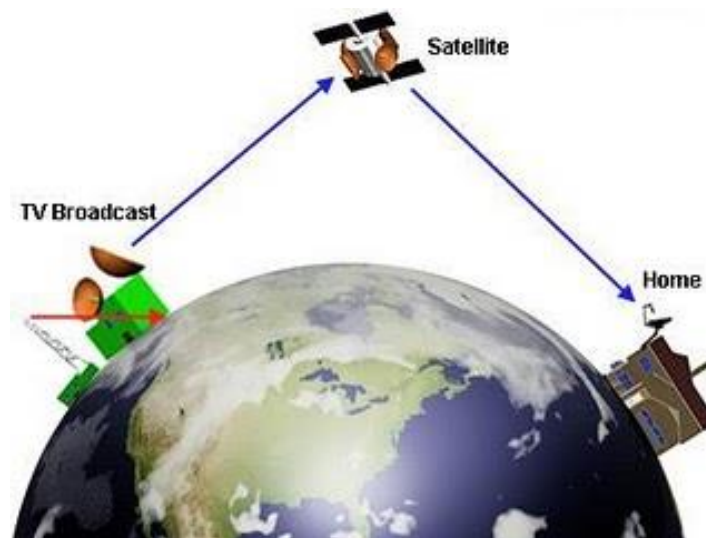


Commercial Communications Satellites - Example

Name of Satellite	Operator/Owner	Purpose	Class of Orbit	Longitude of GEO (degrees)	Perigee (km)	Apogee (km)	Eccentricity	Inclination (degrees)	Period (minutes)	Launch Mass (kg.)
Badr 3 (Arabsat 3A)	Arab Satellite Communications Org. (ASCO)	Communications	GEO	+30.30	35,769	35,801	3.80E-04	0.19	1436.94	2,700
Badr 4 (Arabsat 4B)	Arab Satellite Communications Org. (ASCO)	Communications	GEO	+26.02	35,780	35,791	1.30E-04	0.07	1436.06	3,304
Badr 5 (Arabsat 5B)	Arab Satellite Communications Org. (ASCO)	Communications	GEO	+26.00	35,834	35,883	5.80E-04	0.06	1439.76	5,420
Badr 5A (Arabsat 5A)	Arab Satellite Communications Org. (ASCO)	Communications	GEO	+30.50	35,605	35,623	2.14E-04	0.03	1427.27	4,940
Badr 6 (Arabsat 4AR)	Arab Satellite Communications Org. (ASCO)	Communications	GEO	+26.08	35,768	35,805	4.39E-04	0.05	1436.1	3,400

Satellite Comm. Considerations

- Long distance implies **propagation delay**
 - about **0.25 end-to-end**
- Satellite microwave is inherently **broadcast**
 - many stations can transmit to satellite
 - transmission received by many stations



Broadcast Radio

- radio is 3kHz to 300GHz
- Use broadcast radio, 30MHz – 300 MHz, for:
 - FM radio
 - UHF and VHF television

- Line of sight

- Loss can be expressed as:

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

- d = distance
 - λ = wavelength
- Suffers from multipath interference
 - reflections from land, water, other objects



Infrared

- Line of sight (or reflection)
- Blocked by walls
- no licenses required
- typical uses
 - TV remote control
 - IRD port



Wireless Propagation

Three modes:

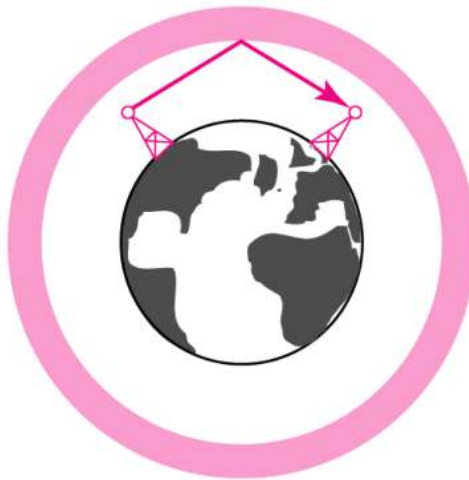
- Ground wave (GW) propagation
- Sky wave (SW) propagation
- Line of sight (LOS) propagation

Ionosphere



Ground propagation
(below 2 MHz)

Ionosphere



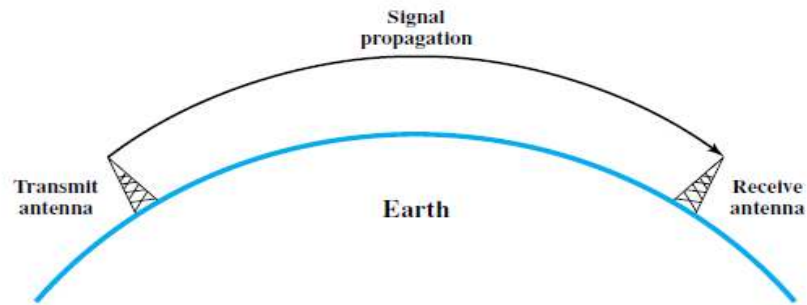
Sky propagation
(2–30 MHz)

Ionosphere

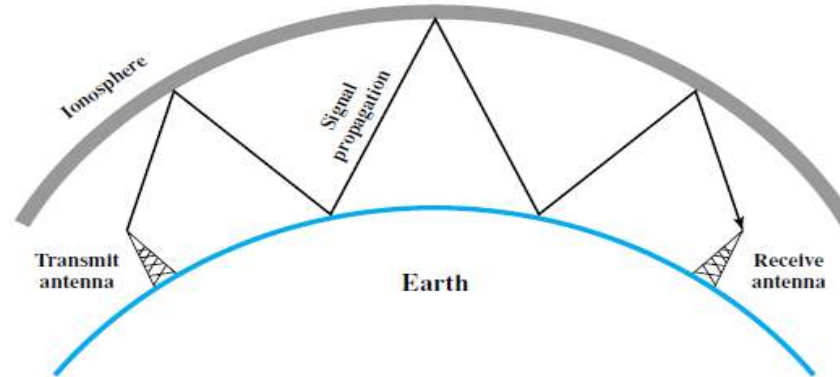


Line-of-sight propagation
(above 30 MHz)

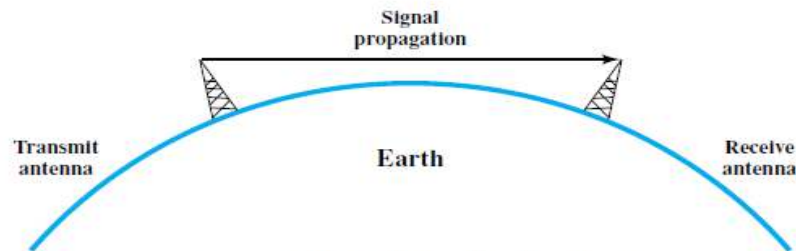
Wireless Propagation



(a) Ground wave propagation (below 2 MHz)



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



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



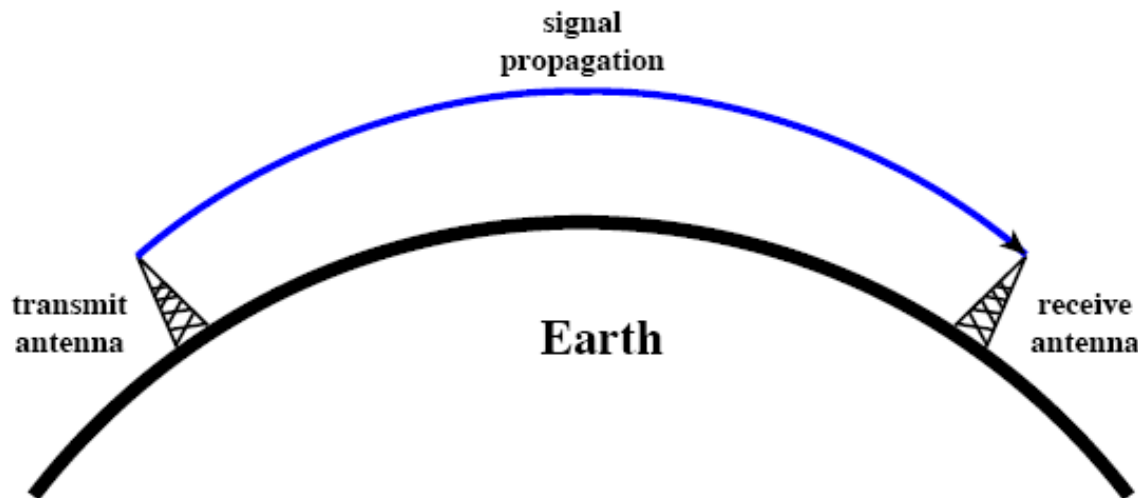
Frequency Bands

Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; international broadcasting, military communication; long-distance aircraft and ship communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

GW = Ground Wave SW = Sky Wave

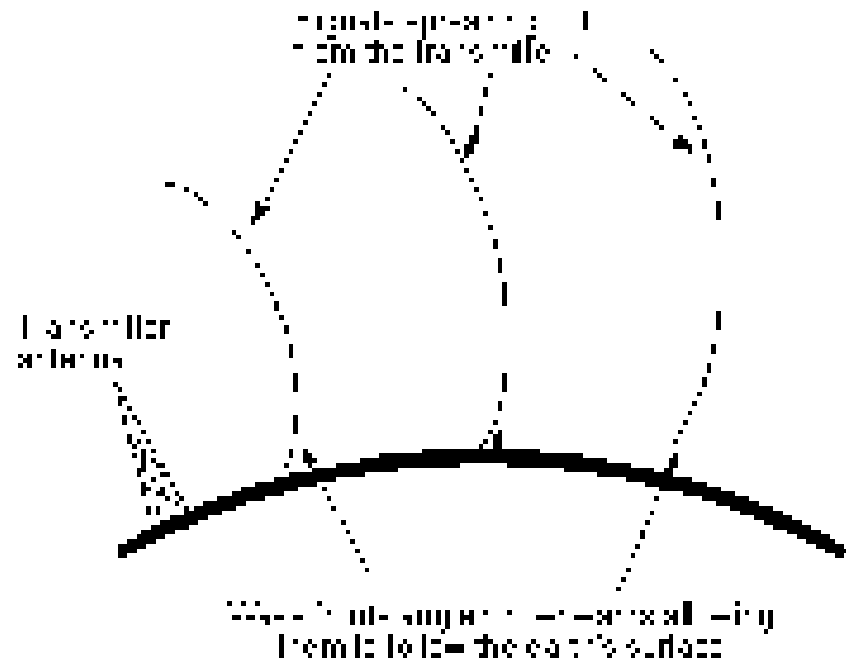
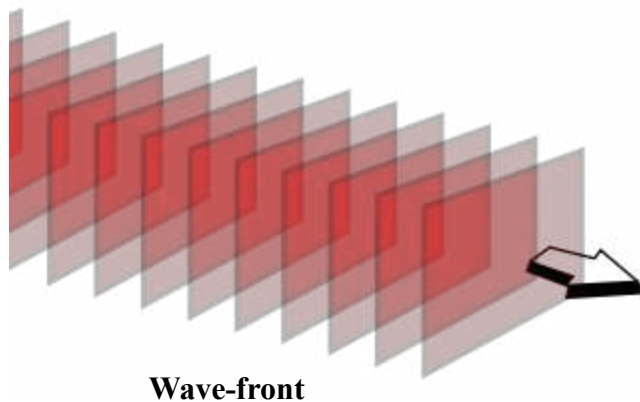
Ground Wave Propagation

- Follows curvature of the earth
- Can propagate to large distance, over the visual horizon
- Frequency range up to **2 MHz**
- Do not penetrate upper atmosphere
- Best known example: **AM radio**



Ground Wave Propagation

- The radio signal spreads out from the transmitter along the surface of the Earth.
- Instead of just travelling in a straight line the radio signals **tend to follow the curvature of the Earth**.
- This is because **currents are induced in the surface of the earth** and this action slows down the wave-front in this region, causing the wave-front of the **radio communications signal to tilt downwards towards the Earth**.
- With the wave-front tilted in this direction it is able to curve around the Earth and be received well beyond the horizon.





Ground Wave Propagation

- Factors for the tendency of electromagnetic wave for the frequencies up to 2MHz to follow the earth's curvature:

1. As a surface wave passes over the ground, the wave induces a voltage in the Earth. **The induced voltage takes energy away from the surface wave**, thereby attenuating, the wave as it moves away from the transmitting antenna, **causing the signal to tilt downwards towards the Earth**.

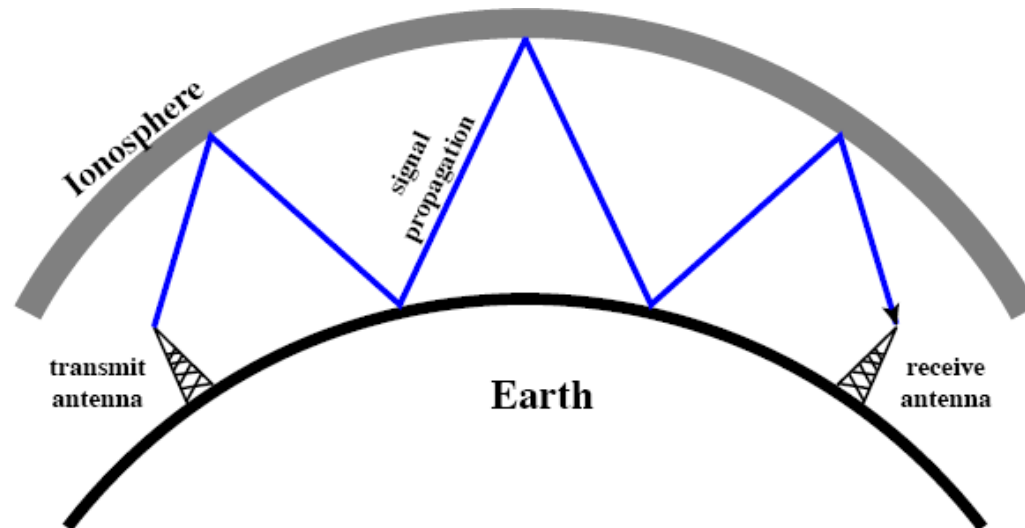
2. **Diffraction by obstacles:**

When a surface wave meets an object, the **wave tends to curve or bend around the object**.

3. Electromagnetic waves in the frequencies up to 2 MHz are **scattered by the atmosphere**.

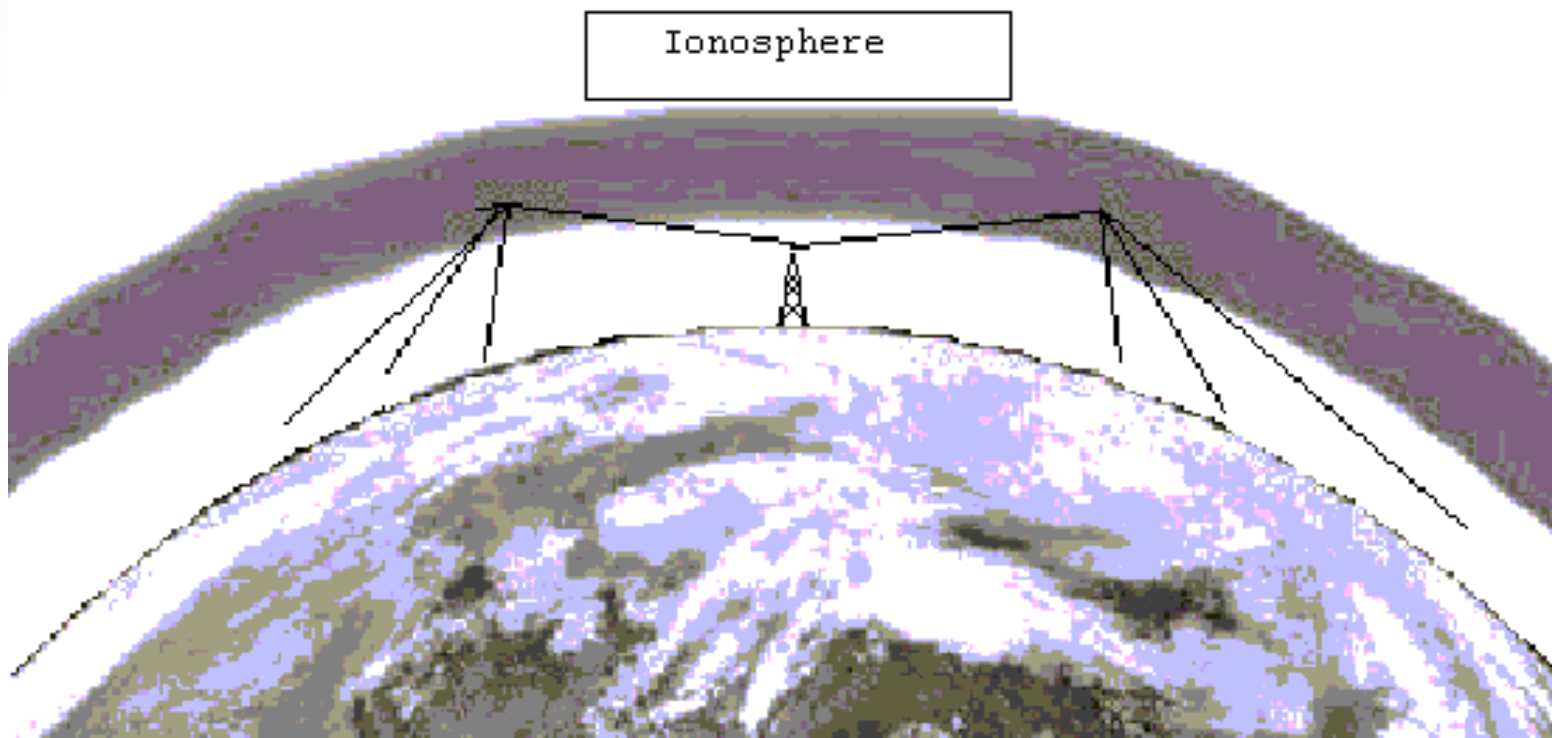
Sky Wave Propagation

- Signal from earth station reflected by ionosphere to earth
- Can travel through number of hops
- Frequency range **2 – 30MHz**
- Can be picked up **1000s of kilometers away from transmitter**
- Used for amateur radio, international radio



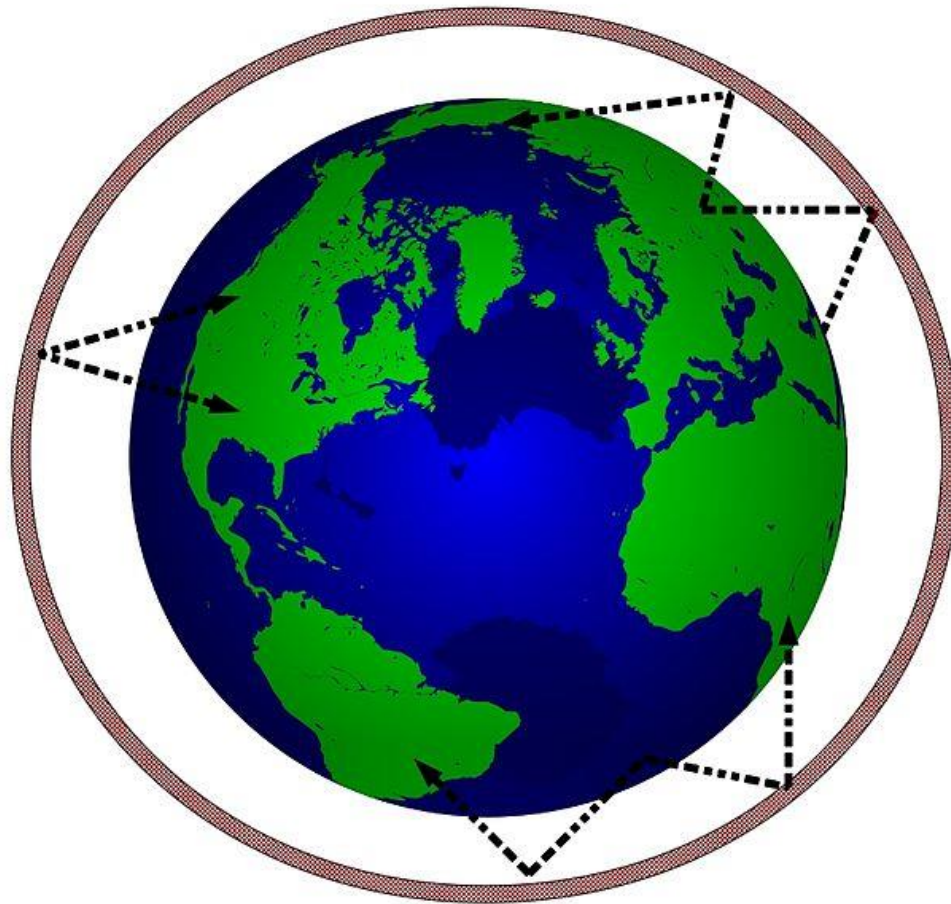


Sky Wave Propagation



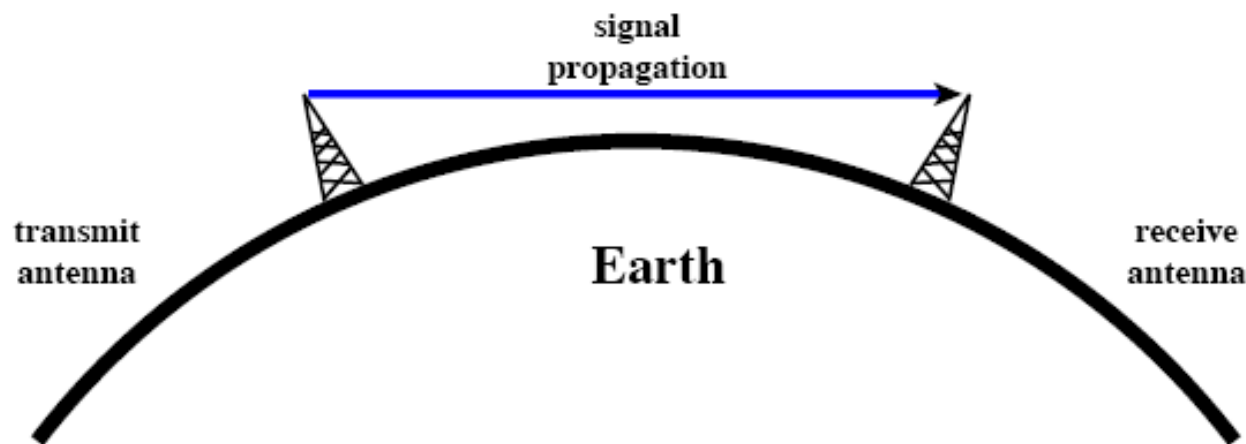


Sky Wave Propagation



Line-of-Sight Propagation

- Above 30 MHz neither GW nor SW operate
- Effective LOS is longer than optical LOS
 - Microwaves are **refracted by atmosphere**





Refraction

- velocity of electromagnetic wave is a function of density of material
 - $\sim 3 \times 10^8$ m/s in vacuum, less in anything else
- speed changes as move between media
- Index of refraction (refractive index) is
 - $\sin(\text{incidence}) / \sin(\text{refraction})$
 - varies with wavelength
- **have gradual bending if medium density varies**
 - **density of atmosphere decreases with height**
 - results in **bending towards earth** of radio waves
 - **hence optical and radio horizons differ**

Optical and Radio LOS

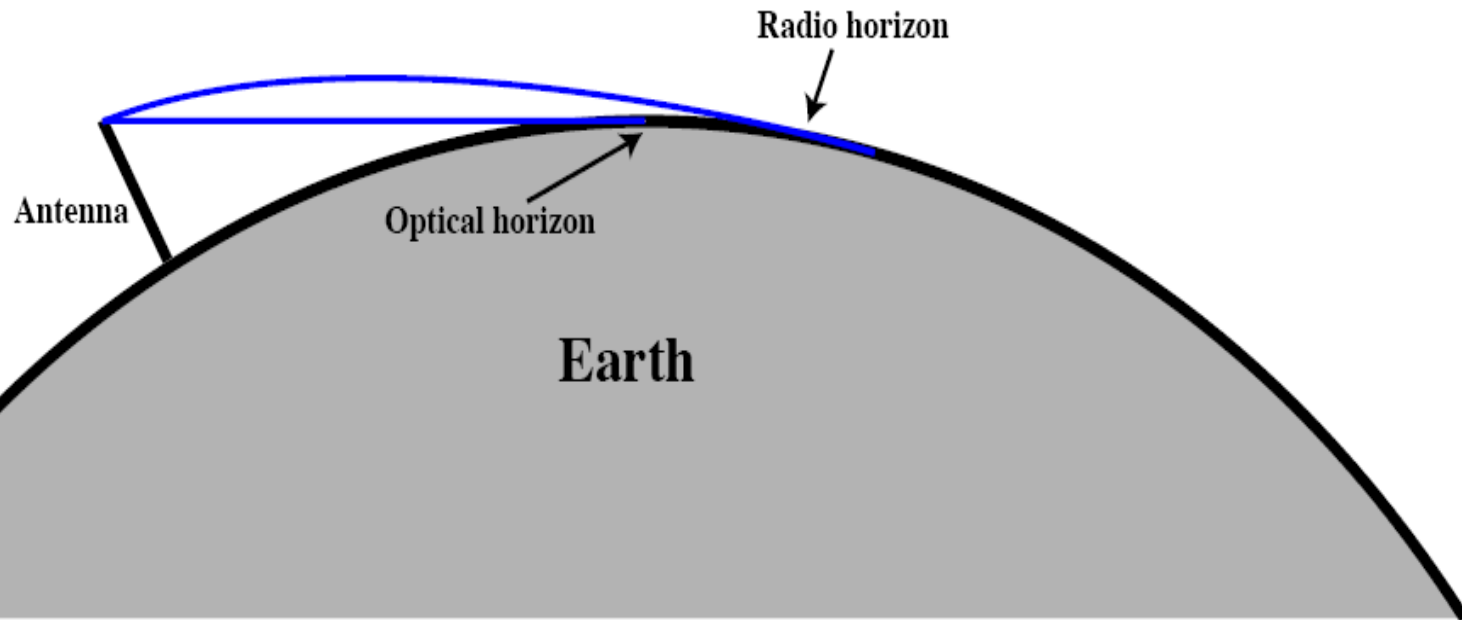
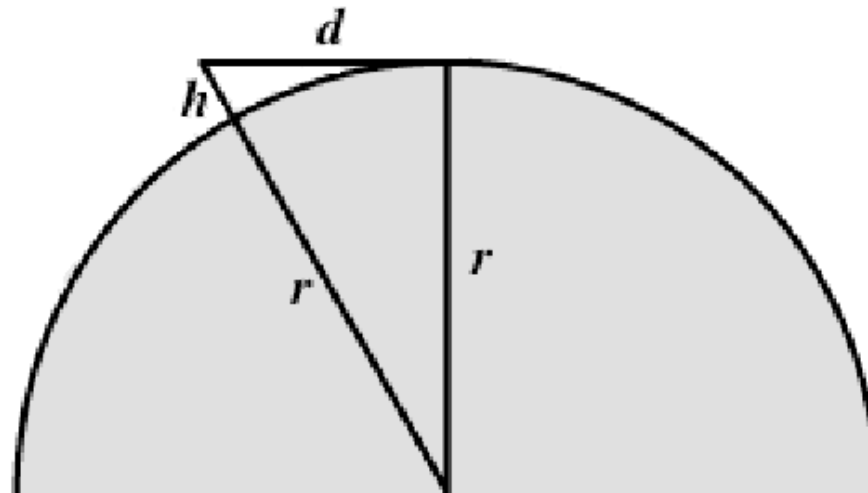


Figure 4.9 Optical and Radio Horizons

Optical LOS



By the Pythagorean theorem: $d^2 + r^2 = (r + h)^2$

Or, $d^2 = 2rh + h^2$. The h^2 term is negligible with respect to $2rh$, so we use $d^2 = 2rh$.

$$\text{Then, } d_{km} = \sqrt{2r_{km}h_{km}} = \sqrt{2r_{km}h_m/1000} = \sqrt{2 \times 6.37 \times h_m} = 3.57\sqrt{h_m}$$

$$d_{km} = 3.57\sqrt{h_m}$$

Optical and Radio LOS

- **Optical LOS** with no obstacles $d = 3.57\sqrt{h}$
- **Effective or radio LOS** is $d = 3.57\sqrt{Kh}$
 - d = distance between antenna and horizon (km)
 - h = height of antenna (m)
 - K = adjustment factor to account for **refraction**
 - A good rule of thumb is $K = 4/3$
- Maximum distance between two antennas $d = 3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$

Optical and Radio LOS Example



- Two antennas, one is 100m high. Other is **ground level**, calculate max distance

- Answer

$$\begin{aligned}d &= 3.57 \left(\sqrt{Kh_1} + \sqrt{Kh_2} \right) \\ &= 3.57 \left(\sqrt{133} + 0 \right) = 41 \text{ km}\end{aligned}$$



Optical and Radio LOS

Example

- Suppose receiving antenna is **10m high**. Calculate transmitting antenna height to achieve same distance

- Answer
$$41 = 3.57 \left(\sqrt{Kh_1} + \sqrt{13.3} \right)$$

$$\sqrt{Kh_1} = \frac{41}{3.57} - \sqrt{13.3} = 7.84$$

$$h_1 = 7.84^2 / 1.33 = 46.2 \text{ m}$$

– > 50 m saving; better to increase receiver's h

Optical and Radio LOS Example



EXAMPLE 4.3 The maximum distance between two antennas for LOS transmission if one antenna is 100 m high and the other is at ground level is

$$d = 3.57\sqrt{Kh} = 3.57\sqrt{133} = 41 \text{ km}$$

Now suppose that the receiving antenna is 10 m high. To achieve the same distance, how high must the transmitting antenna be? The result is

$$41 = 3.57(\sqrt{Kh_1} + \sqrt{13.3})$$

$$\sqrt{Kh_1} = \frac{41}{3.57} - \sqrt{13.3} = 7.84$$

$$h_1 = 7.84^2/1.33 = 46.2 \text{ m}$$

This is a savings of over 50 m in the height of the transmitting antenna. This example illustrates the benefit of raising receiving antennas above ground level to reduce the necessary height of the transmitter.



Line of Sight Transmission

- Free space loss
 - loss of signal with **distance**
- Atmospheric Absorption
 - from **water vapour and oxygen absorption**
- Multipath
 - **multiple interfering signals from reflections**
- Refraction
 - **bending signal away from receiver**

Free Space Loss



- Regardless of other impairment, a transmitted signal **attenuates over distance** because the signal is being spread over larger and larger area
- For ideal **isotropic** antenna, **free space loss** is:

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

- P_t = transmitted signal power
- P_r = received signal power
- d = propagation distance between antennas



Free Space Loss

- For ideal **isotropic** antenna, **free space loss** is:

$$L_{dB} = 10 \log \frac{P_t}{P_r}$$

- This can be recast as:

$$L_{dB} = 21.98 + 20 \log(d) - 20 \log(\lambda)$$

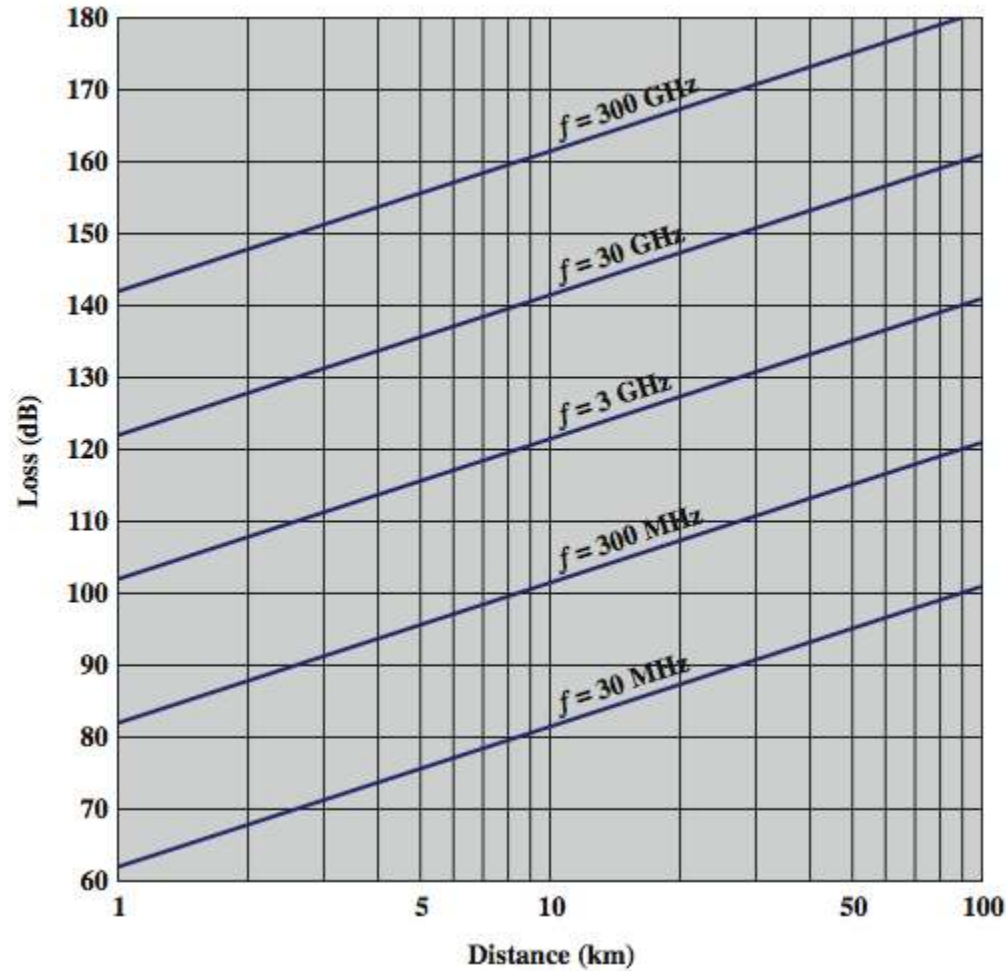
$$L_{dB} = -147.56 + 20 \log(d) + 20 \log(f)$$

Free Space Loss

- For **non-isotropic** antenna, gain must be considered
- $L_{dB} = 10 \log \frac{P_t}{P_r} = 10 \log \frac{(4\pi d)^2}{G_t G_r \lambda^2}$
- $L_{dB} = 21.98 + 20 \log(d) - 20 \log(\lambda) - G_t \text{ dB} - G_r \text{ dB}$
- $L_{dB} = -147.56 + 20 \log(d) + 20 \log(f) - G_t \text{ dB} - G_r \text{ dB}$
 - G_t = gain of transmitting antenna
 - G_r = gain of receiving antenna



Free Space Loss





Free Space Loss

- **Example:**

- **Determine the isotropic free space loss at 4 GHz for the shortest path to a synchronous satellite from earth (35863 Km).**

- At 4 GHz, the wavelength (λ) = $c/f = 3 \times 10^8 / 4 \times 10^9 = 0.075\text{m}$

$$L_{dB} = -20 \log(\lambda) + 20 \log(d) + 21.98$$

$$L_{dB} = -20 \log(0.075) + 20 \log(35.863 \times 10^6) + 21.98 = 195.6 \text{ dB}$$

- Now consider the antenna gain of both the satellite and ground-based antennas. Typical values are 44 dB and 48 dB, respectively. The free space loss is:

$$L_{dB} = 195.6 - 44 - 48 = 103.6 \text{ dB}$$

Free Space Loss



EXAMPLE 4.4 Determine the isotropic free space loss at 4 GHz for the shortest path to a synchronous satellite from earth (35,863 km). At 4 GHz, the wavelength is $(3 \times 10^8)/(4 \times 10^9) = 0.075$ m. Then

$$L_{\text{dB}} = -20 \log(0.075) + 20 \log(35.853 \times 10^6) + 21.98 = 195.6 \text{ dB}$$

Now consider the antenna gain of both the satellite- and ground-based antennas. Typical values are 44 dB and 48 dB, respectively. The free space loss is

$$L_{\text{dB}} = 195.6 - 44 - 48 = 103.6 \text{ dB}$$

Now assume a transmit power of 250 W at the earth station. What is the power received at the satellite antenna? A power of 250 W translates into 24 dBW, so the power at the receiving antenna is $24 - 103.6 = -79.6$ dBW.



Atmospheric Absorption

- **Water vapor**
 - peak attenuation near 22 GHz
- **Oxygen**
 - absorption peak near 60 GHz
- **Rain and fog**
 - cause **scattering** of radio waves → **attenuation**
 - **Scattering** refers to the production of waves of changed direction or frequency when radio waves encounter matter.
 - In areas with **significant rainfall**, either **path lengths have to be kept short or lower-frequency bands should be used**

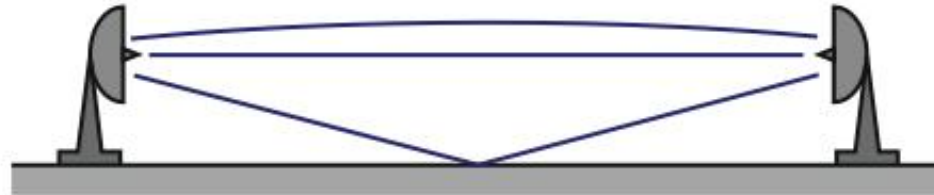


Multipath

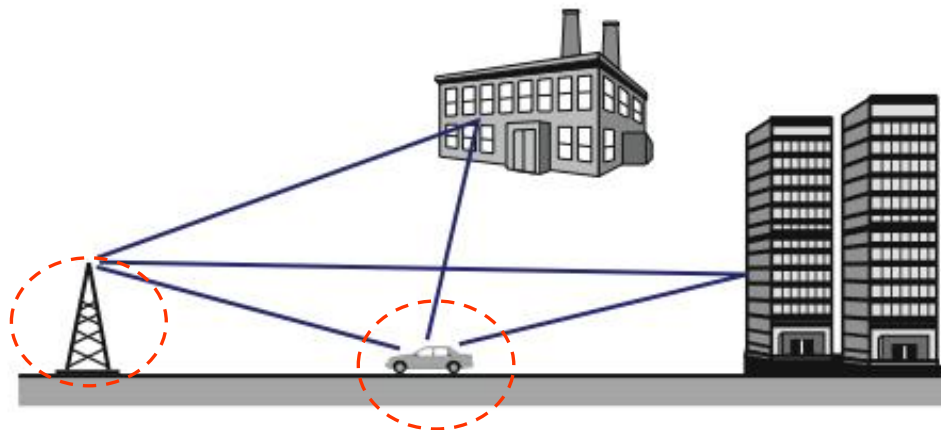
- Obstacles cause signals to reflect
- Receiver might get multiple copies of the signal with different delays
- Might reinforce or cancel each other
- Can be controlled for fixed well-suited antennas
- Hard to control for mobile antennas



Multipath Interference



(a) Microwave line of sight



(b) Mobile radio



Summary

- looked at data transmission issues
- frequency, spectrum & bandwidth
- analog vs digital signals
- transmission impairments



Required Reading

- Stallings Chapter 4
- **Additional References:**
 1. Andrew Tanenbaum, "*Computer Networks*," Prentice-Hall, 4th Edition, 2003
 2. Michael Palmer, "*Hands-On Networking Fundamentals*," Thomson Course Technology, 2006
 3. Wikipedia
 4. Richard Fitzpatrick, "Antenna directivity and effective area," farside.ph.utexas.edu/teaching/jk1/lectures/node83.html