William Stallings
Data and Computer Communications

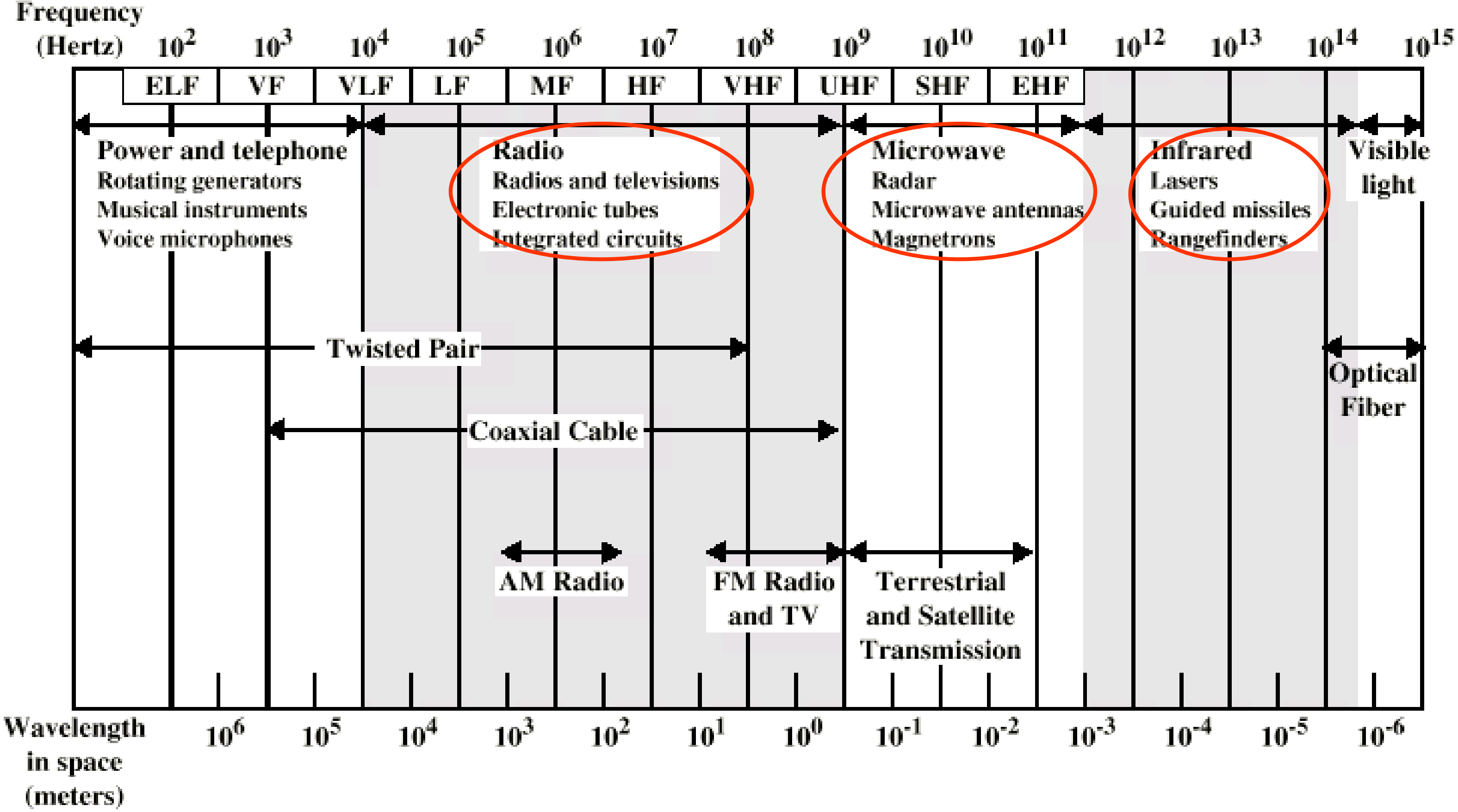
Chapter 4
Transmission Media

Part II: Wireless Transmission

Wireless Transmission

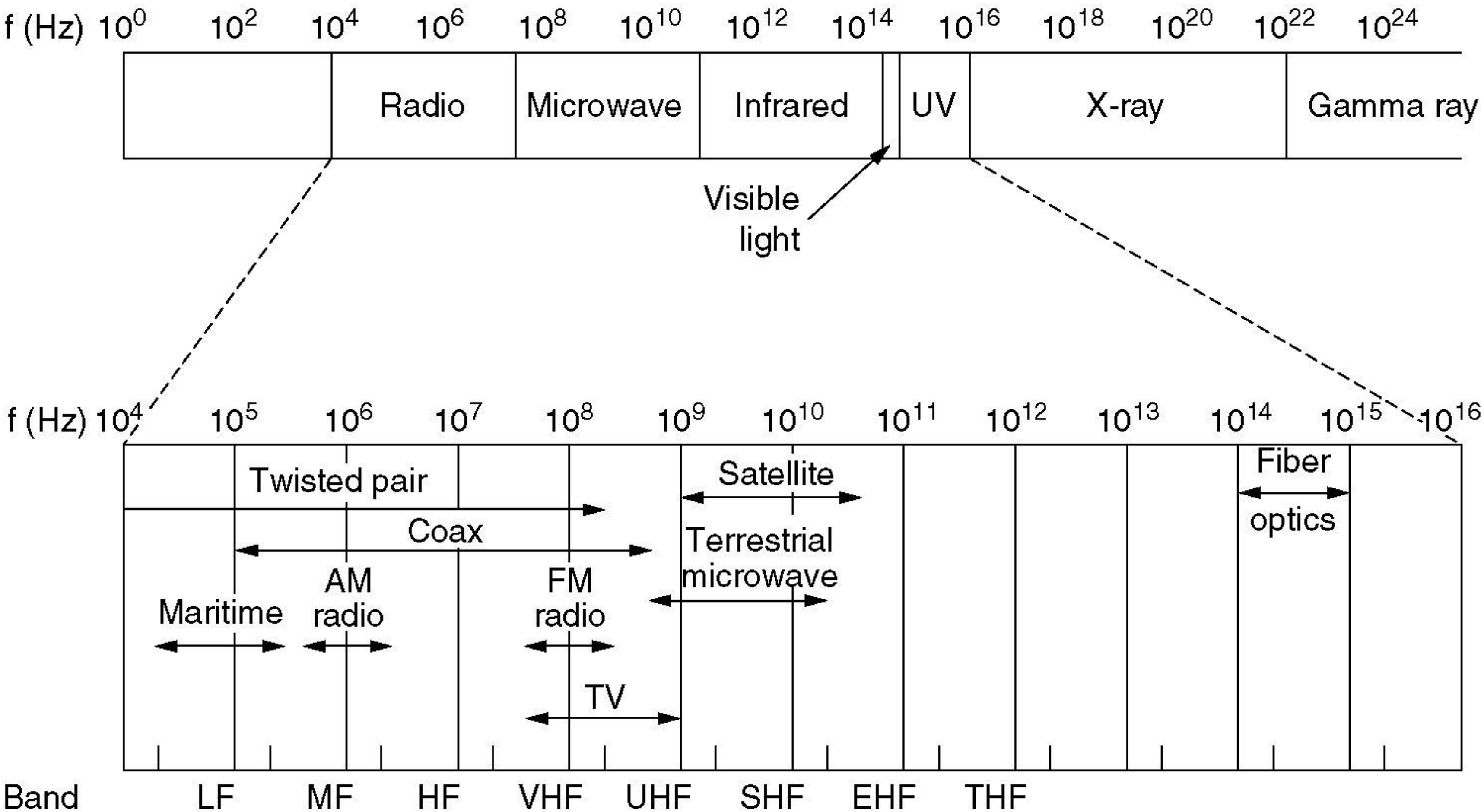
- Antennas
- Terrestrial Microwave
- Satellite Microwave
- Broadcast Radio
- Infrared

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

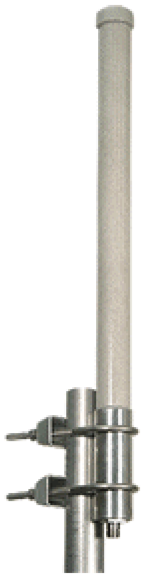
Three general ranges of frequencies:

- **Microwave frequencies**
  - Frequencies in the range of 1GHz to 40GHz
  - Highly directional
  - Point to point
  - Microwave is also used for satellite communications
- **Broadcast Radio**
  - 30MHz to 1GHz
  - 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

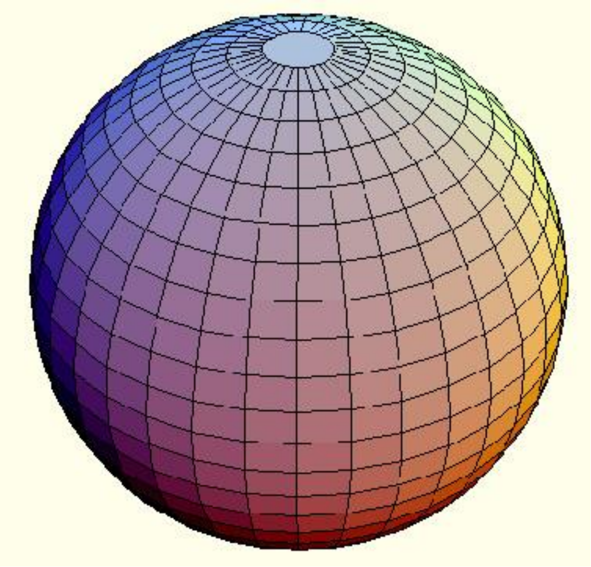
Directional:
Focused Coverage

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.

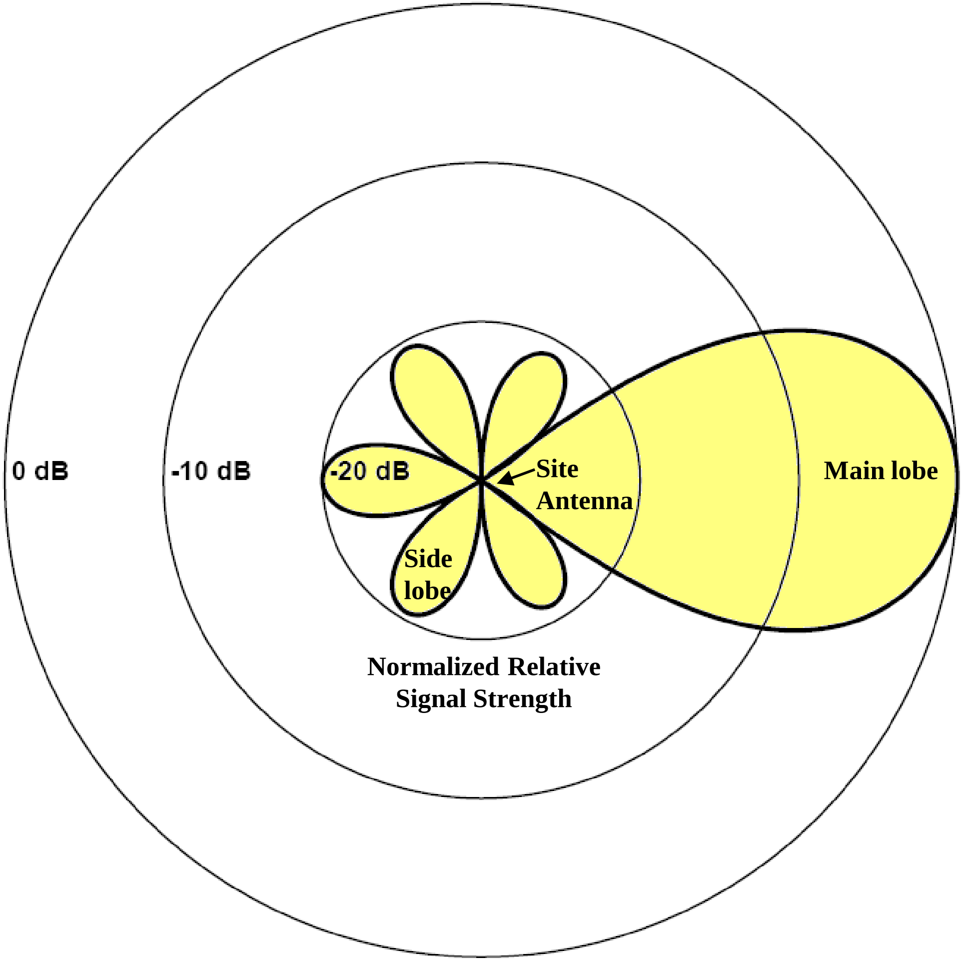
Isotropic Antenna

- 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

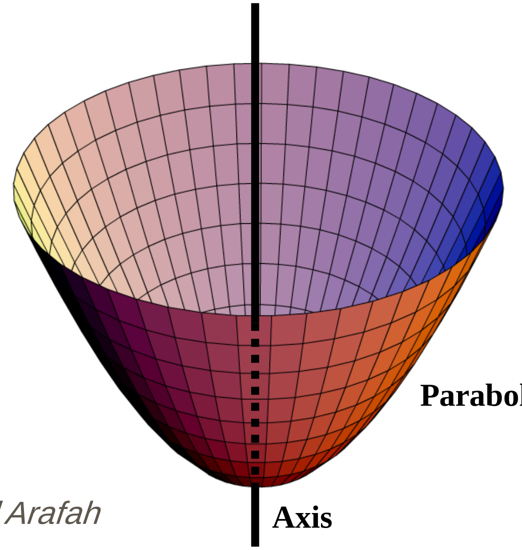
- No antenna is able to radiate all the energy in one preferred direction
- Often there are small peaks in different directions
- The peaks are referred to as **sidelobes**
- Commonly specified in dB down from the **main lobe**, or **preferred direction**

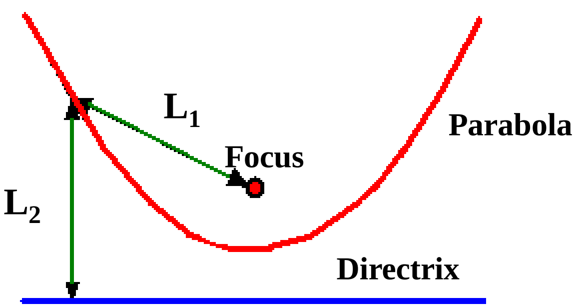


Parabolic Reflective Antenna

Paraboloid

- Parabola revolved about its axis
- Cross section parallel axis → parabola
- Cross section perpendicular to axis → 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





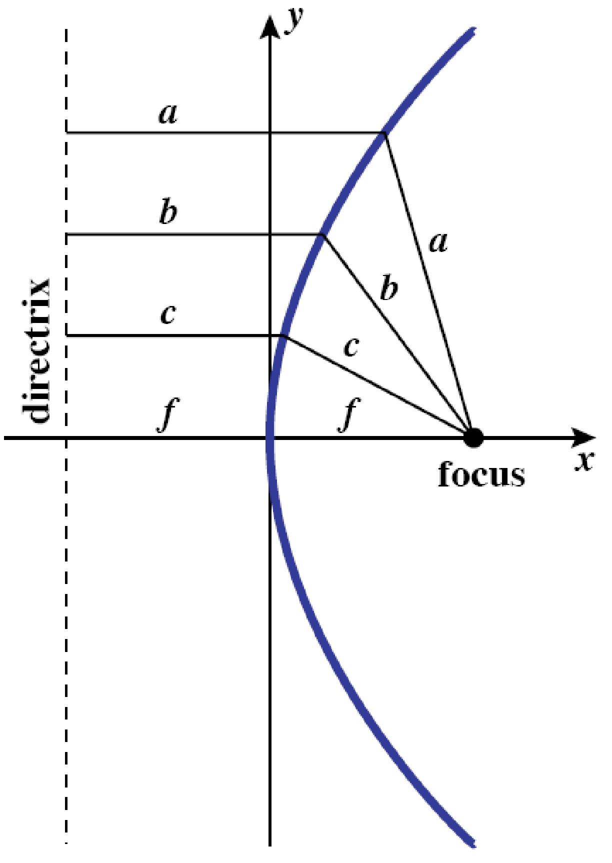
Parabola with Focus and Directrix

The distances L_1 and L_2 are equal

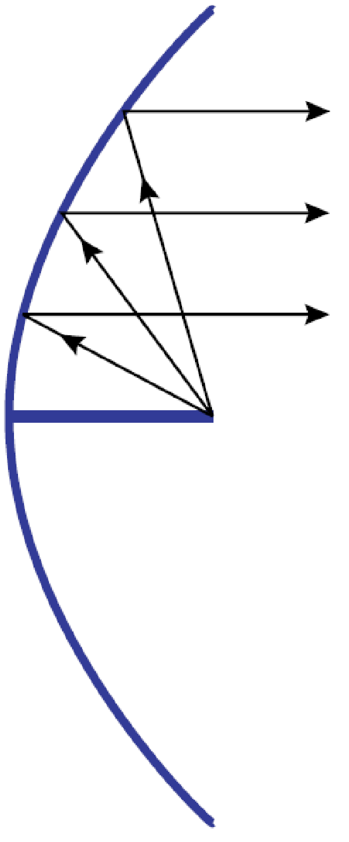
Parabolic Reflective Antenna

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

Parabolic Reflective Antenna

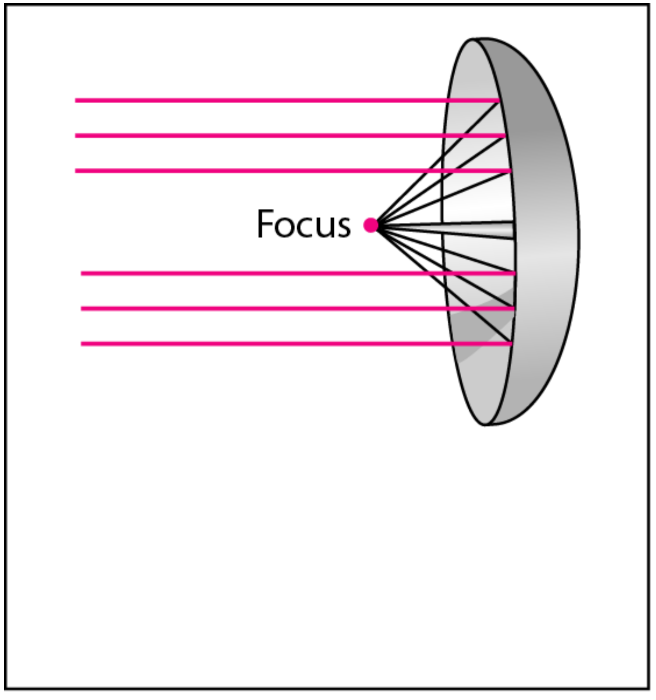


(a) Parabola

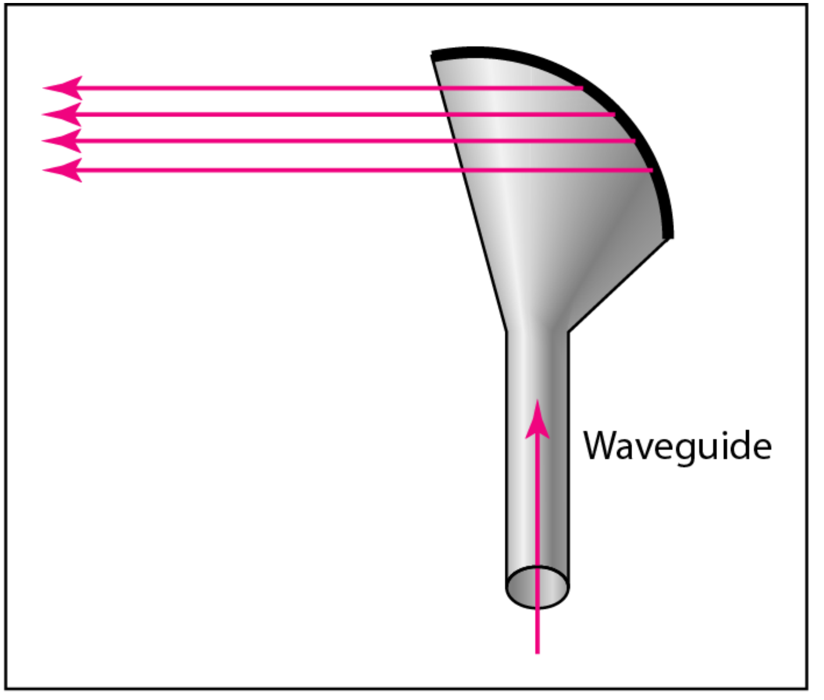


(b) Cross-section of parabolic antenna showing reflective property

Parabolic Reflective Antenna



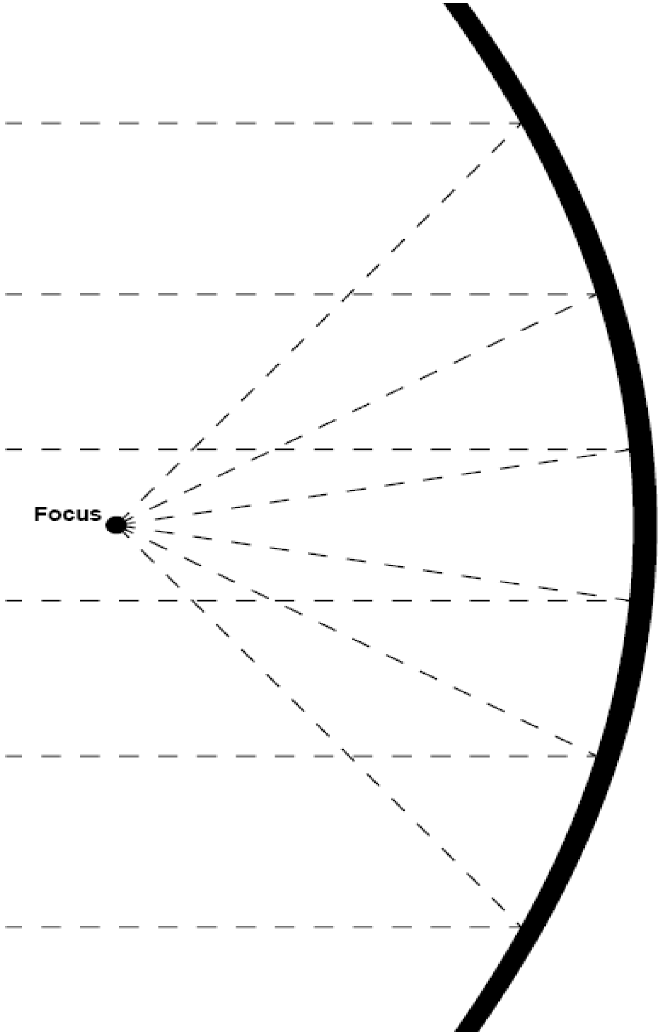
a. Dish antenna



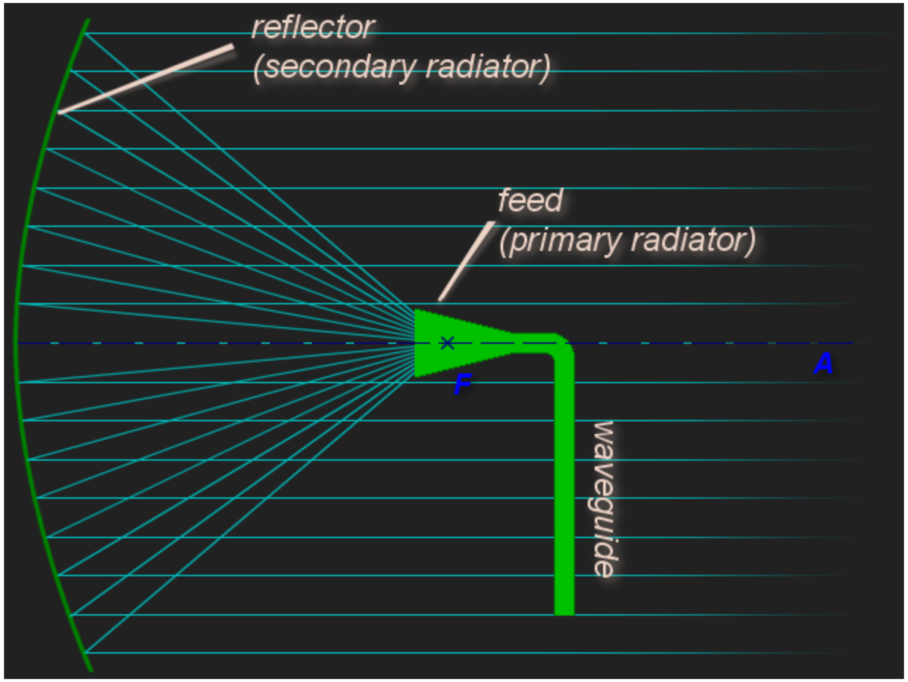
b. Horn antenna

Parabolic Reflective Antenna

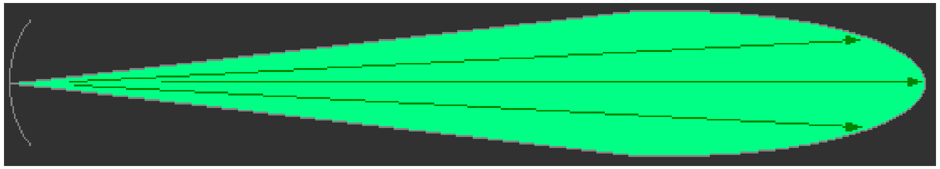
- If a source of electromagnetic energy is placed at the focus of the paraboloid, and if the paraboloid is reflecting surface, then the wave will bounce back in lines parallel to the axis of the paraboloid.
- **On reception**, if the incoming waves are parallel to the axis of the reflecting paraboloid, the resulting signal will be concentrated at the focus.



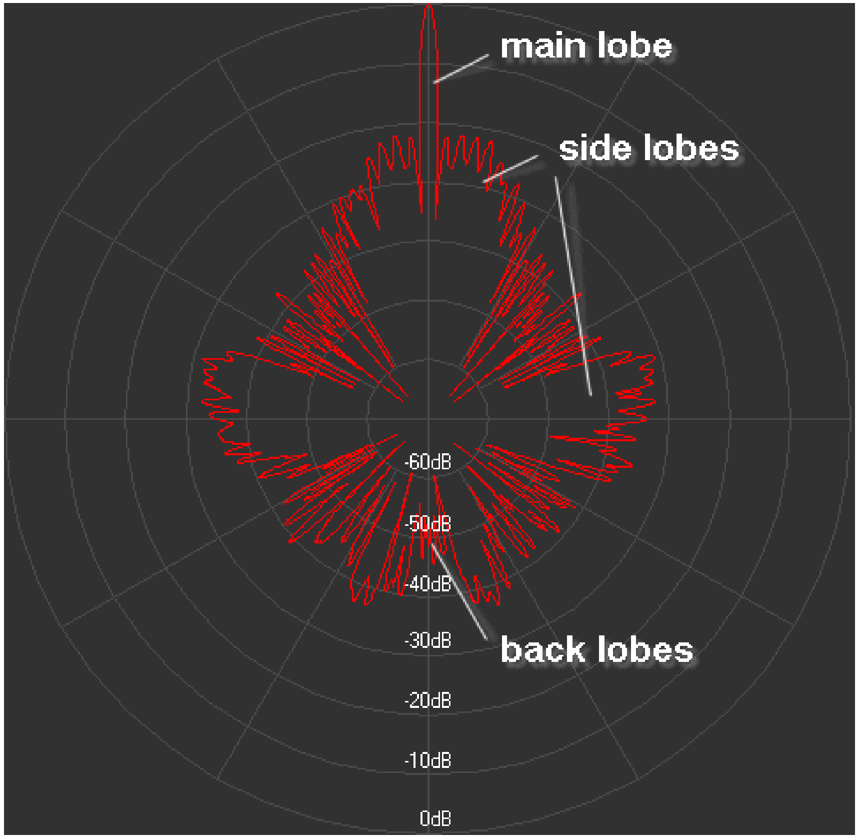
Parabolic Reflective Antenna



Parabolic Antenna



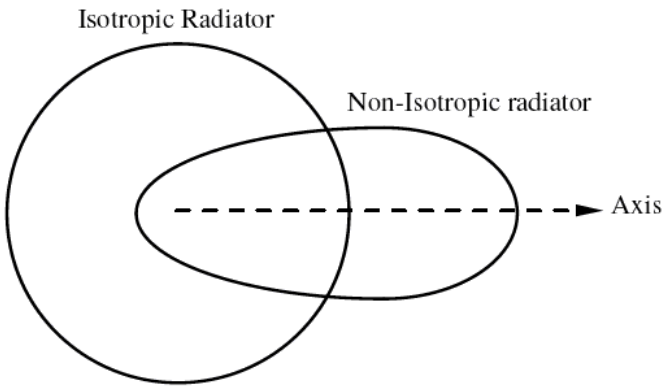
Parabolic Radiation Pattern



Horizontal Cross Section of a real measured radiation pattern of a parabolic pattern

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**

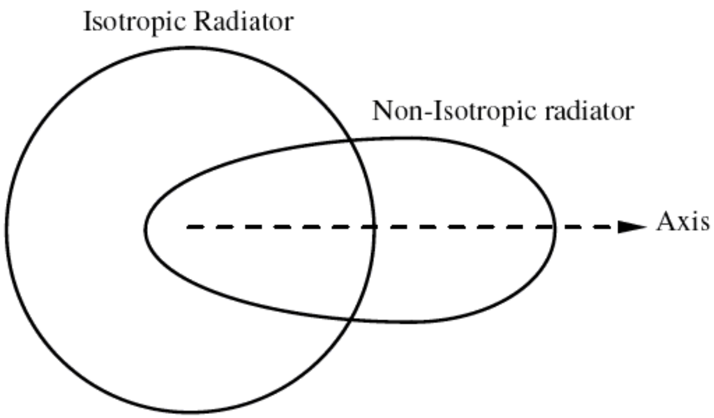


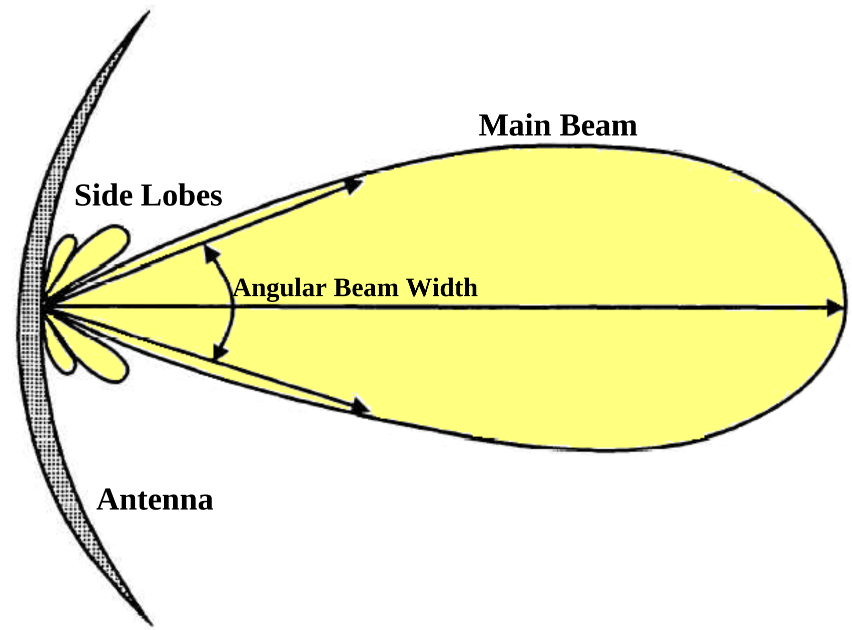
- When we talk about antenna gain (G), we use it as a multiplier compared to an ideal isotropic antenna.
- **Where are we getting the extra power to get antenna gain**?
- **We cannot change the total power of the antenna, we are just redistributing it. We reduce the power in directions we do not want 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 **dBi** (Decibels relative to an isotropic radiator).
- Power output in particular direction compared to that produced by a perfect omnidirectional antenna (isotropic antenna)

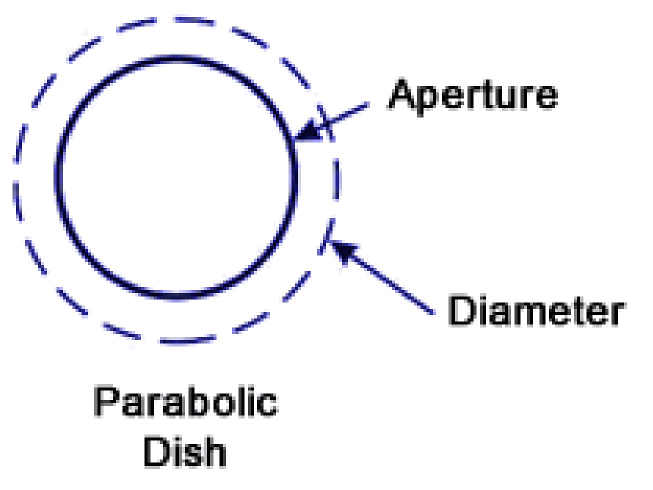
Antenna Gain





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 ($\approx 3\times10^8$ 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
  - $A = \pi r^2 = \pi \times 1 = \pi$
  - $A_e = 0.56\ A = 0.56\ \pi = 1.76$
  - $\lambda = c/f = (3\times10^8)/(12\times10^9) = 0.025$ m
  - $G = 7A/\lambda^2 = (7\ \pi/0.025^2) = 35186$
  - $G_{dB} = 10 \log_{10}(35186) = 45.46$ dB

Antennas

- Three basic types of antennas.
  - **Omnidirectional**
    - Common type used for wireless LANs is called a **dipole antenna**
  - **Semi-directional**
    - **Patch**
    - **Yagi** (pronounced yah-gee)
  - **Directional**
    - **Parabolic dishes**
    - **Grid antennas**

Dipole Antenna

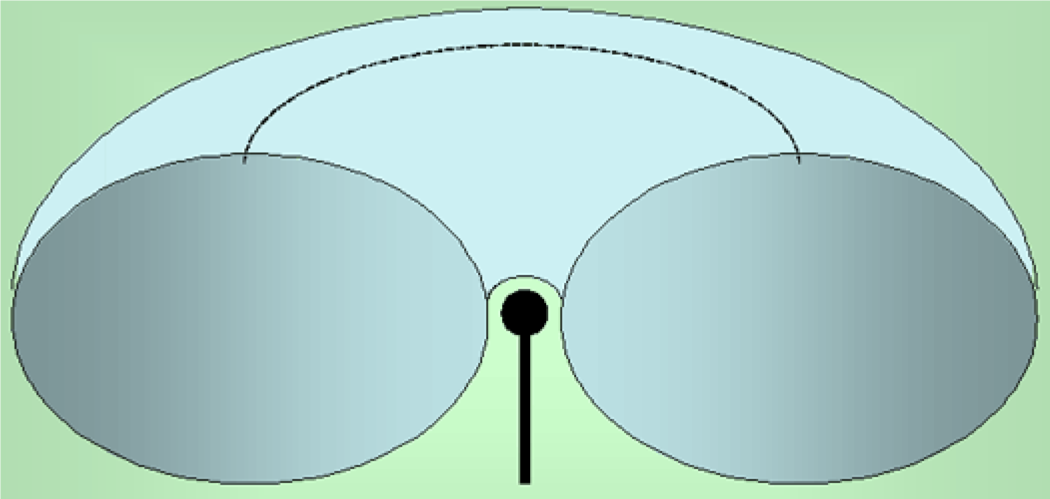
Patch Antenna

Yagi Antenna

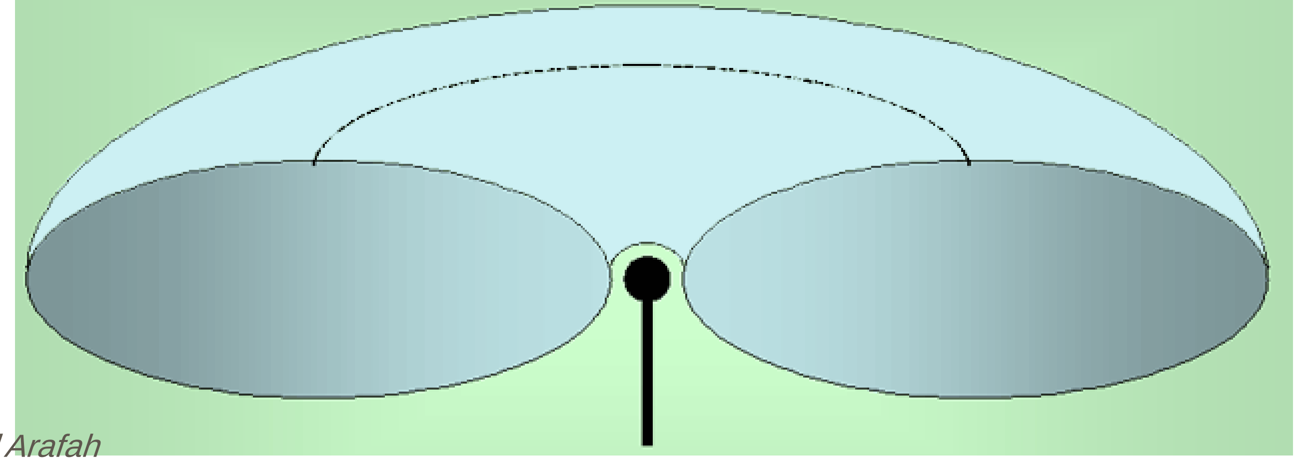
Parabolic Dishes

Grid Antenna

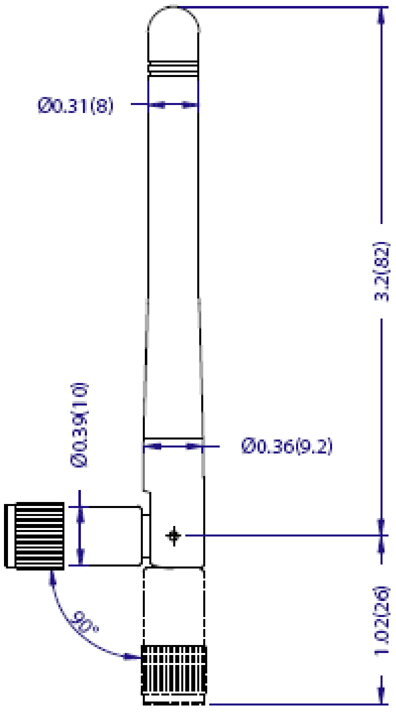
Omnidirectional- Dipole Antenna



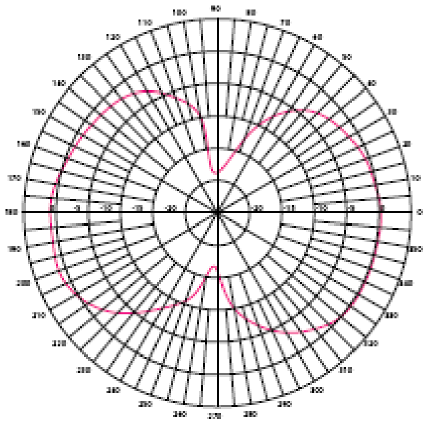
- As the gain increases the antenna's range decreases along the vertical axis and reaches out further on the horizontal.



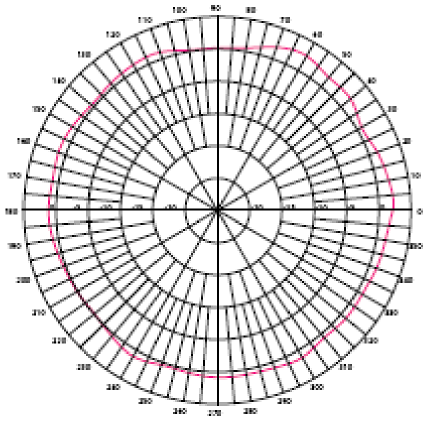
Omnidirectional- Dipole Antenna



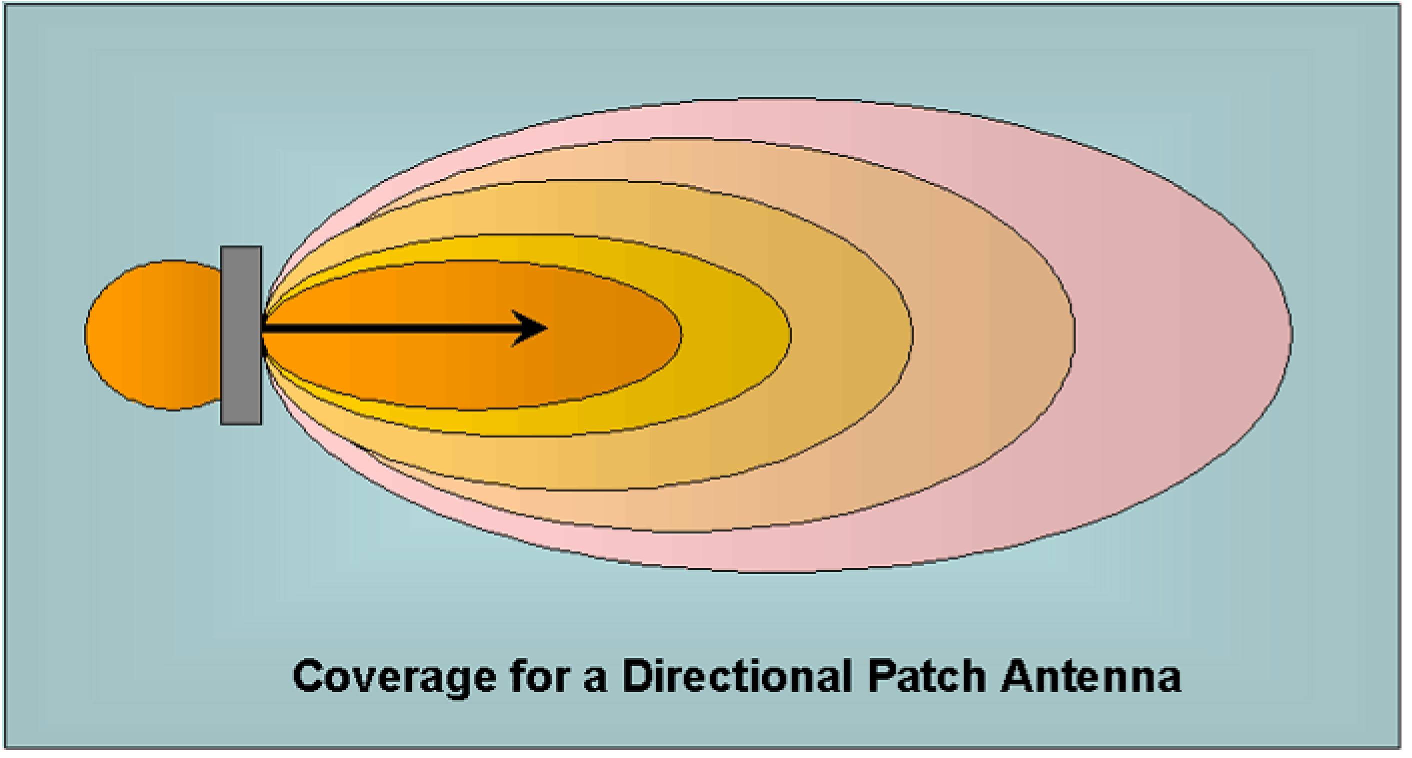
E-Plane Pattern @ 2.45GHz



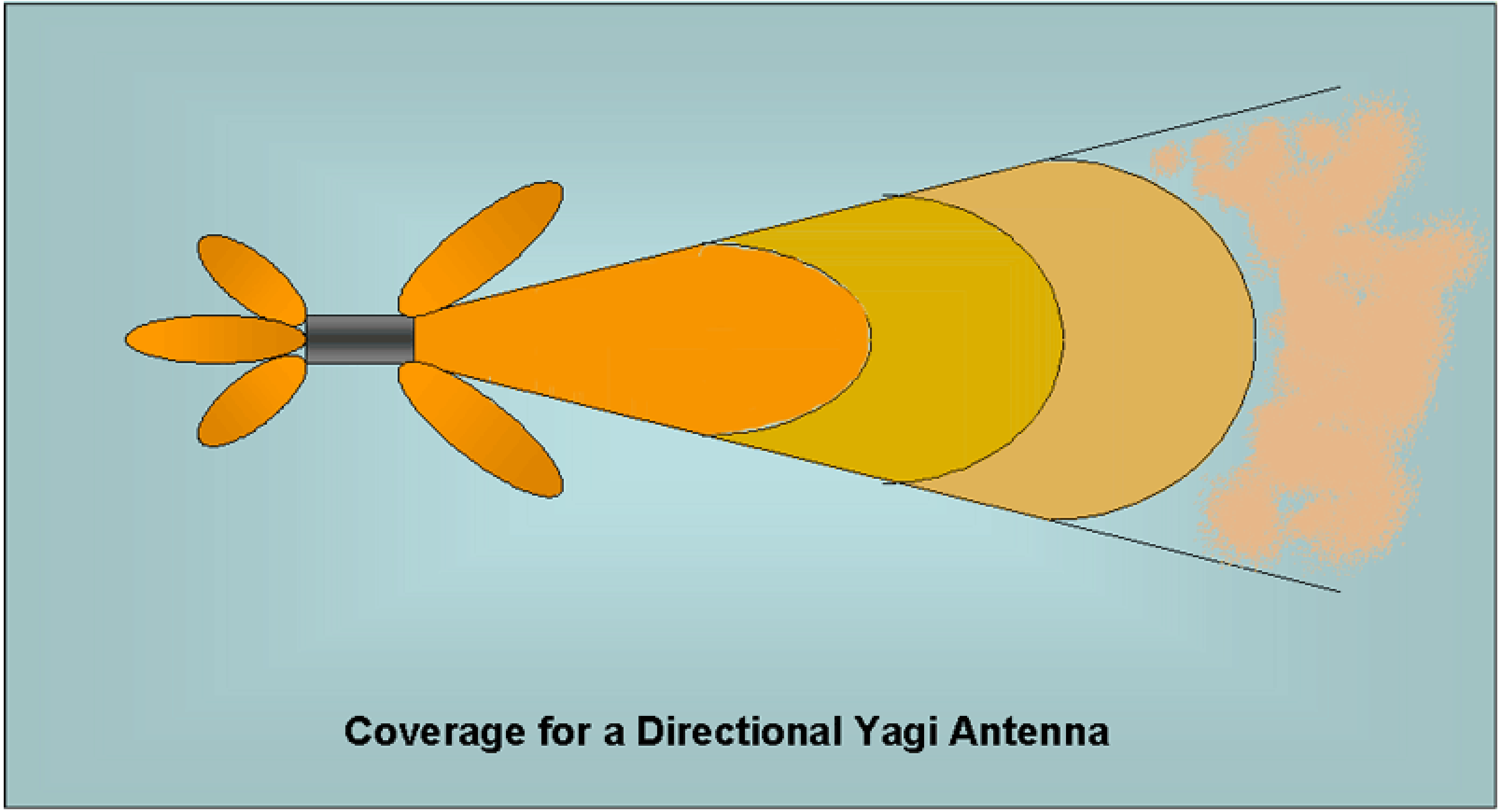
H-Plane Pattern @ 2.45GHz



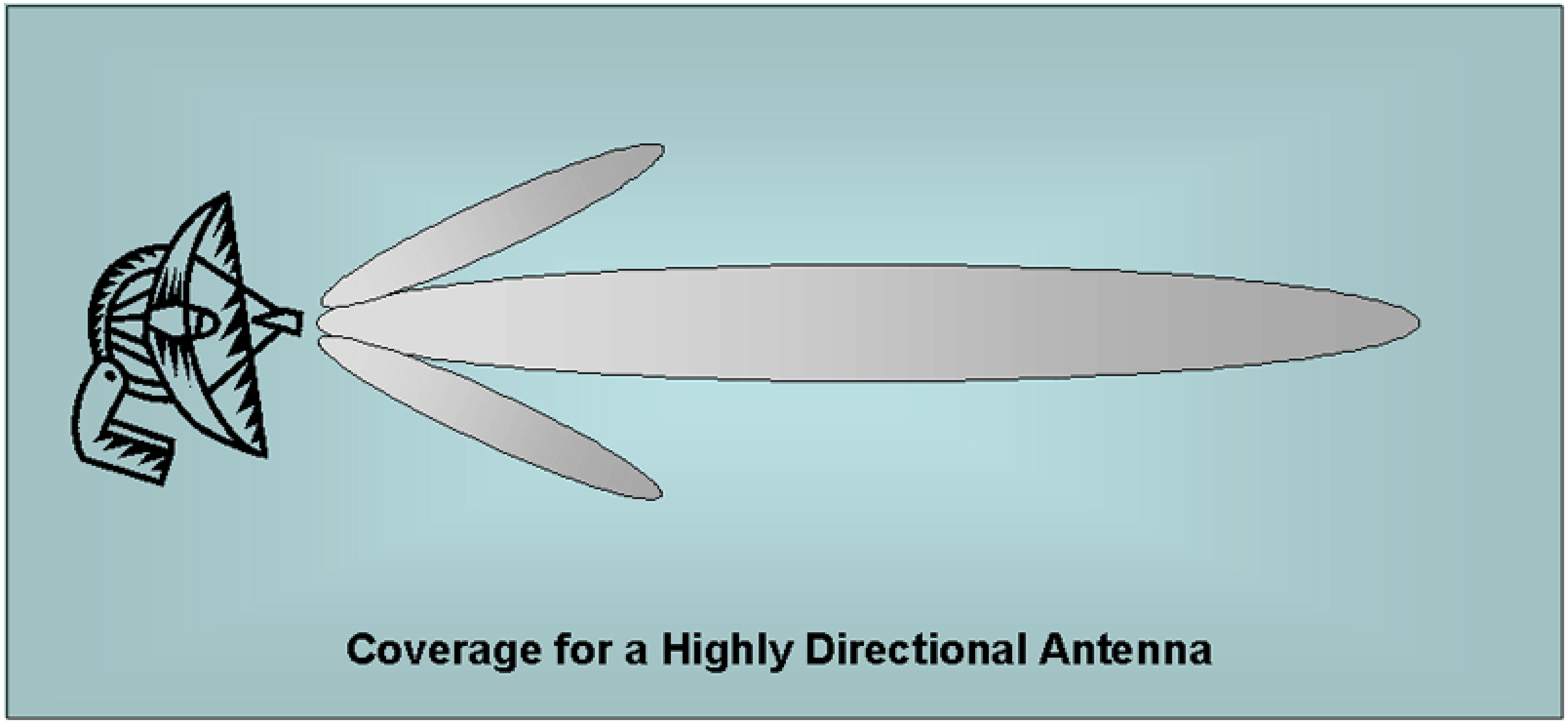
Semi-Directional - Patch Antenna



Semi-Directional - Yagi Antenna



Directional Antenna

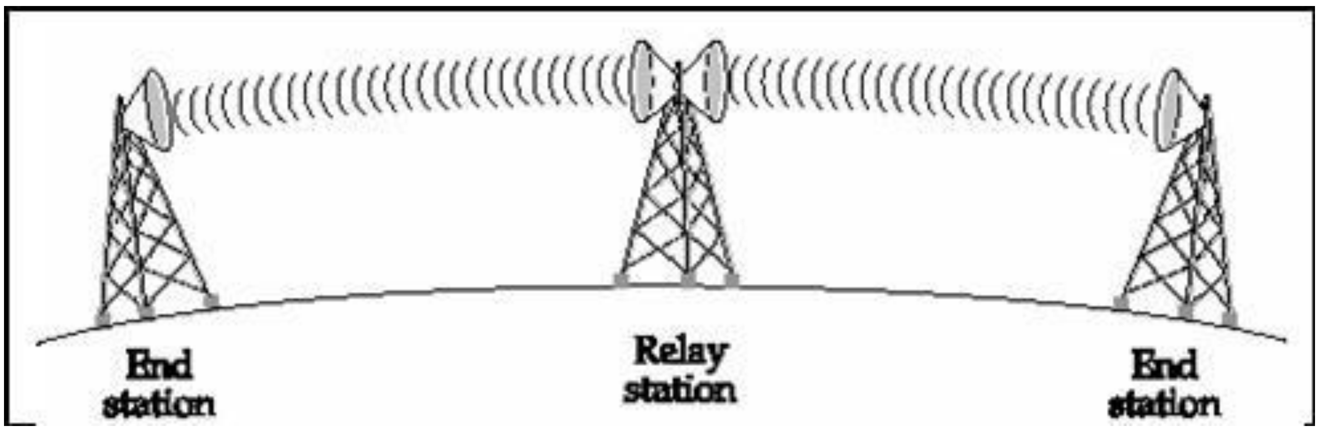


Terrestrial Microwave

- 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



Terrestrial Microwave - Applications

- **Long-haul telecommunications**
  - alternative to coaxial and optical fiber
  - require fewer amplifiers for same distance
  - require line-of-sight
- **Short point-to-point links between buildings**
  - closed-circuit TV
  - data link between local area networks
  - bypass local phone company to long-distance

Terrestrial Microwave
Transmission Characteristics

- Cover substantial range of electromagnetic spectrum
- Common frequencies 1-40 GHz
- Higher frequencies → higher potential bandwidth → higher data rate

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

Terrestrial Microwave
Transmission Characteristics

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

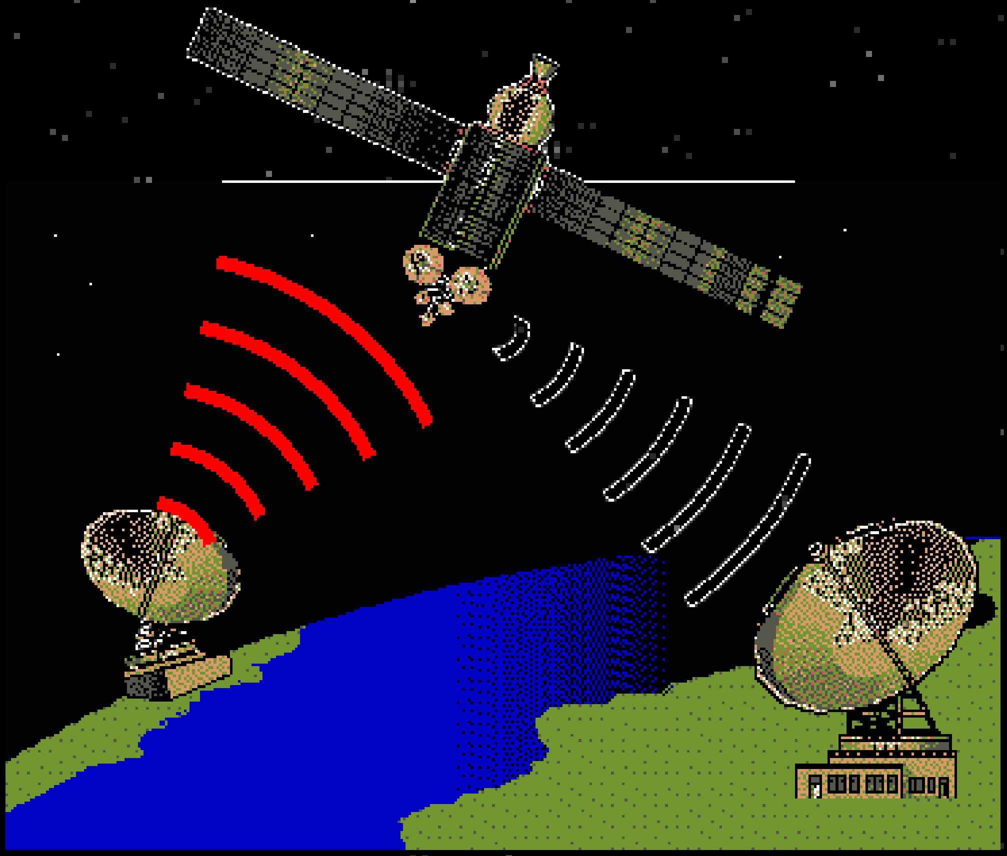
$$L = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 \quad \text{dB}$$

  - 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

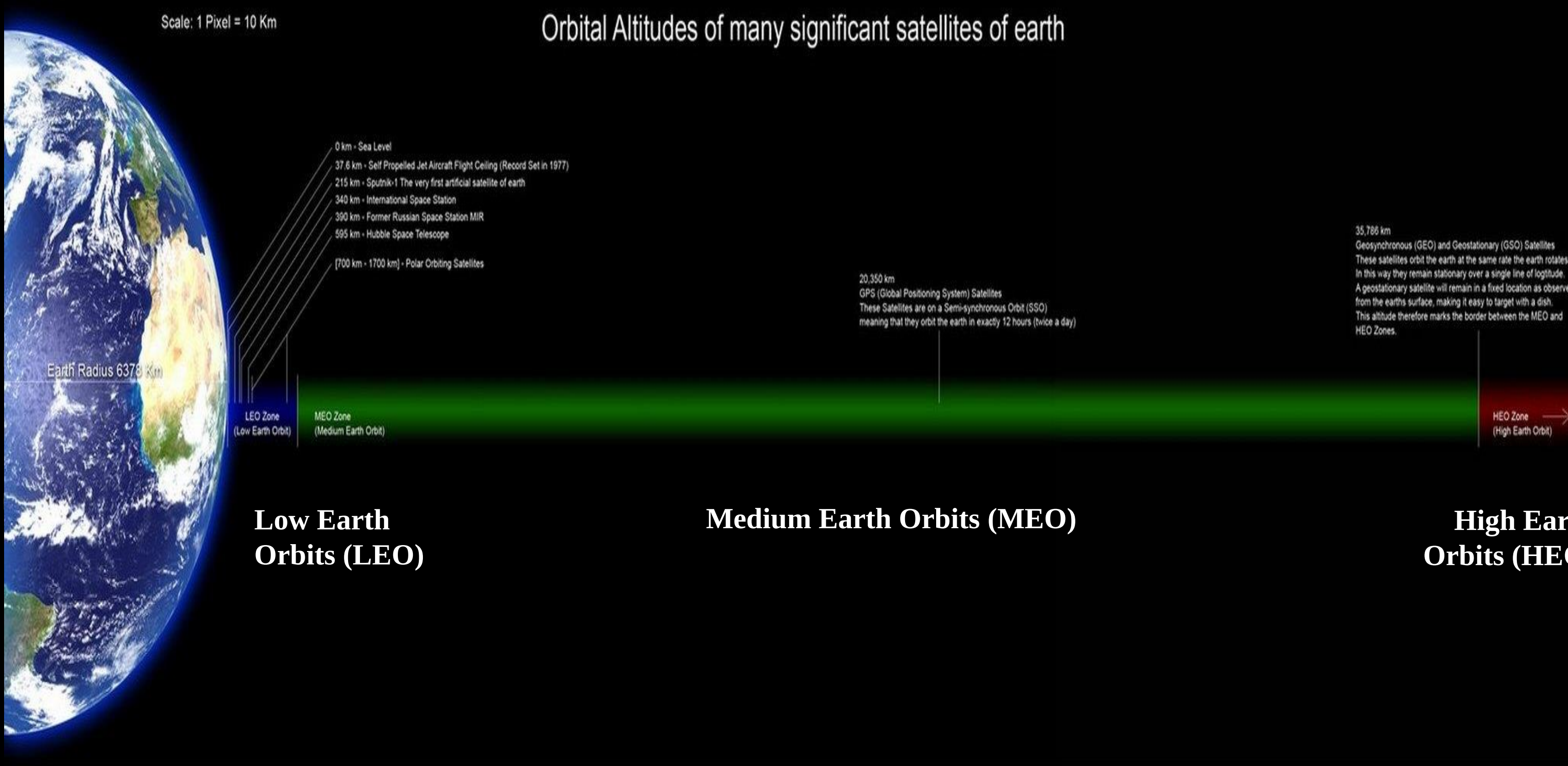
- Common band for long-haul **4-6 GHz**
- Bands are increasingly congested
- More bands are now used: **11-12 GHz**
- Higher frequencies used for short p2p links
  - less useful in long distance due to attenuation
  - antennas are smaller and cheaper

Satellite



Satellite Microwave

Satellite



Low Earth Orbits (LEO)

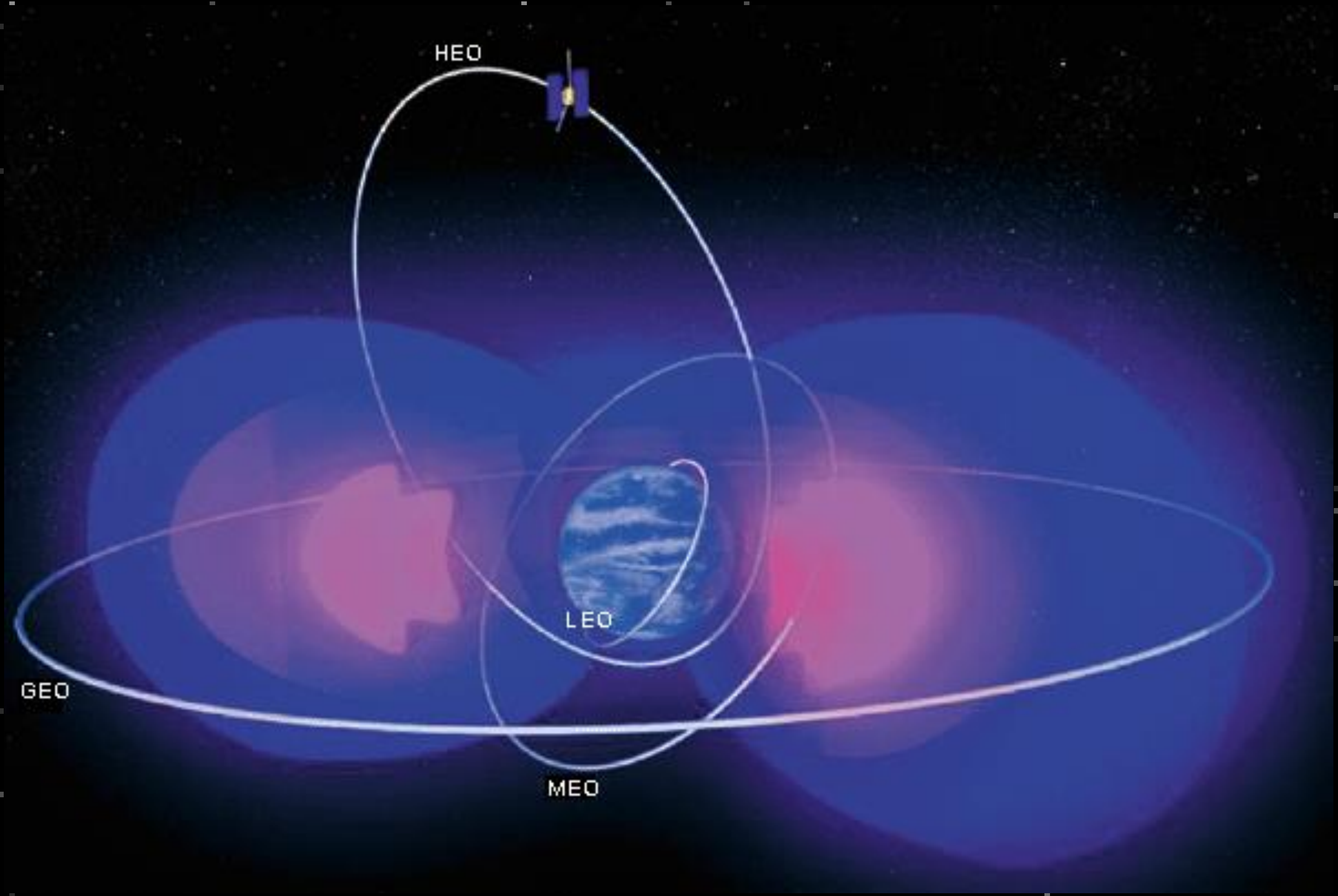
Medium Earth Orbits (MEO)

High Earth Orbits (HEO)

Earth

Moon
384,392 km

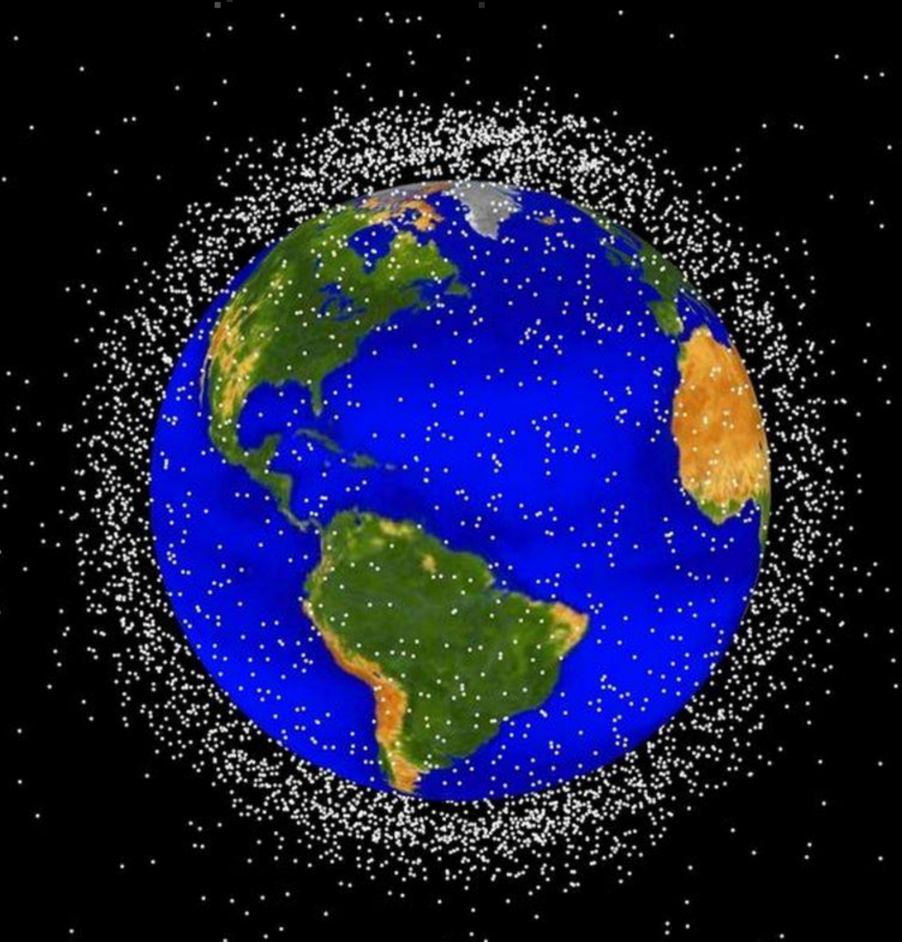
Satellite - Orbits



Satellite - LEO

Satellites in LEO are typically **160 - 2000 km** above the Earth's surface. Because it is close to the earth, it must travel **very fast to avoid being pulled out of orbit by gravity** and crashing into the earth.

For example, a LEO satellite orbiting at 340 km above the Earth, like the Space Shuttle, will take about 90 minutes to circle the Planet at a speed or about 27,400 km/h, or 8 km/s.



Satellite - MEO

Satellites in MEO are at about **2,000 km to 35,786 km** up.

The orbital period for MEO satellites can be anywhere between 2 to 24 hours.

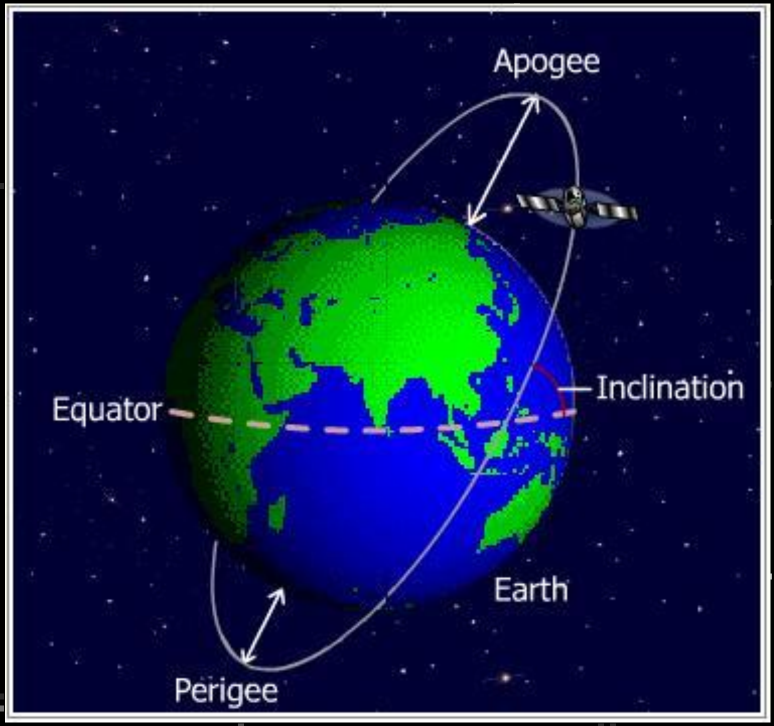
Special orbit within the MEO is at about 20,350 km above the Earth's surface. At this location, the orbital period of satellites is exactly 12 hours. The most common use for satellites in this region is for navigation, such as the GPS (Global Positioning System).

Satellite - HEO

High Earth Orbit is a geocentric orbit whose apogee lies above that **of a geosynchronous orbit (35,786 kilometers).**

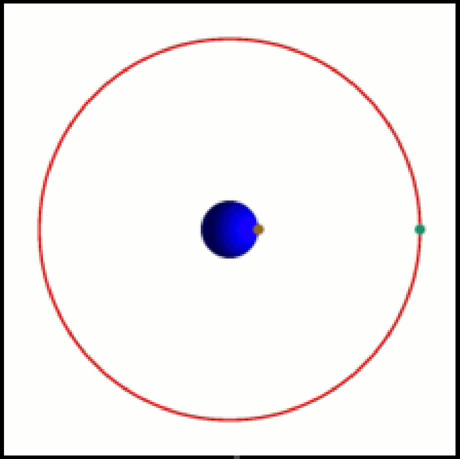
Highly elliptical orbit: an orbit with a perigee (low point) below 3,000 km and an apogee (high point) above 30,000 km.

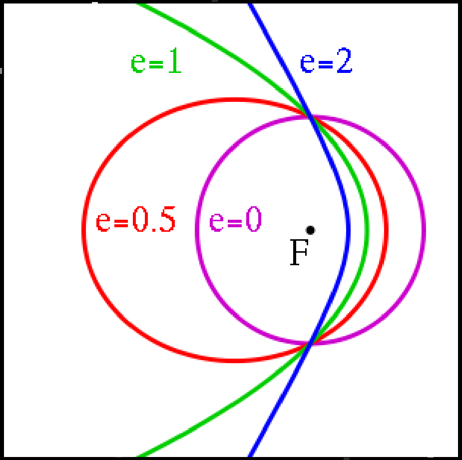
HEO satellites orbit the Earth in an elliptical path rather than the circular paths of LEOs and GEOs.



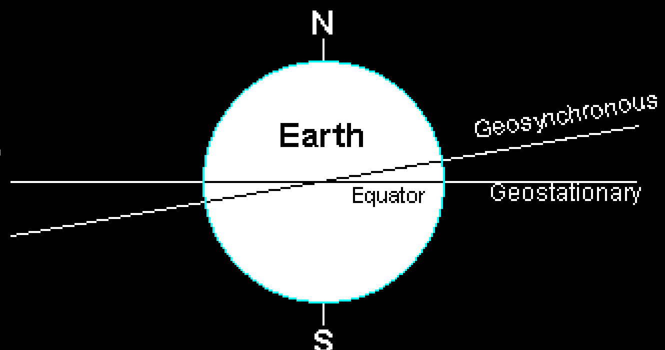
Satellite - GEO

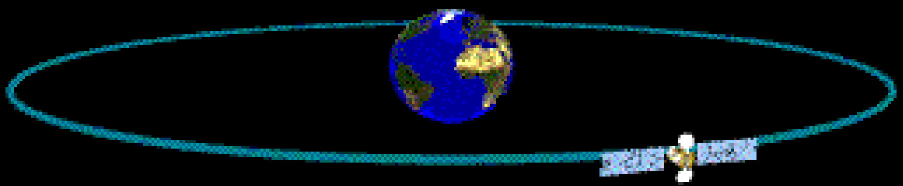
- A geostationary orbit (or Geostationary Earth Orbit - GEO) is a geosynchronous orbit
  - directly above the Earth's equator (0° latitude)
  - with a period equal to the Earth's rotational period
  - an orbital eccentricity of approximately zero.
- An object in a geostationary orbit appears motionless, 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**.



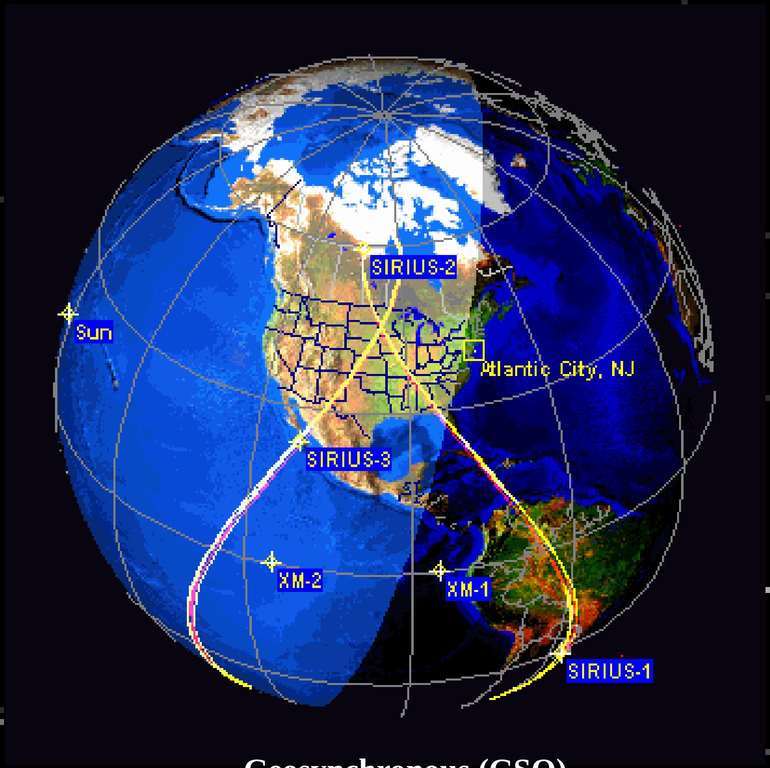


Satellite – GEO versus GSO



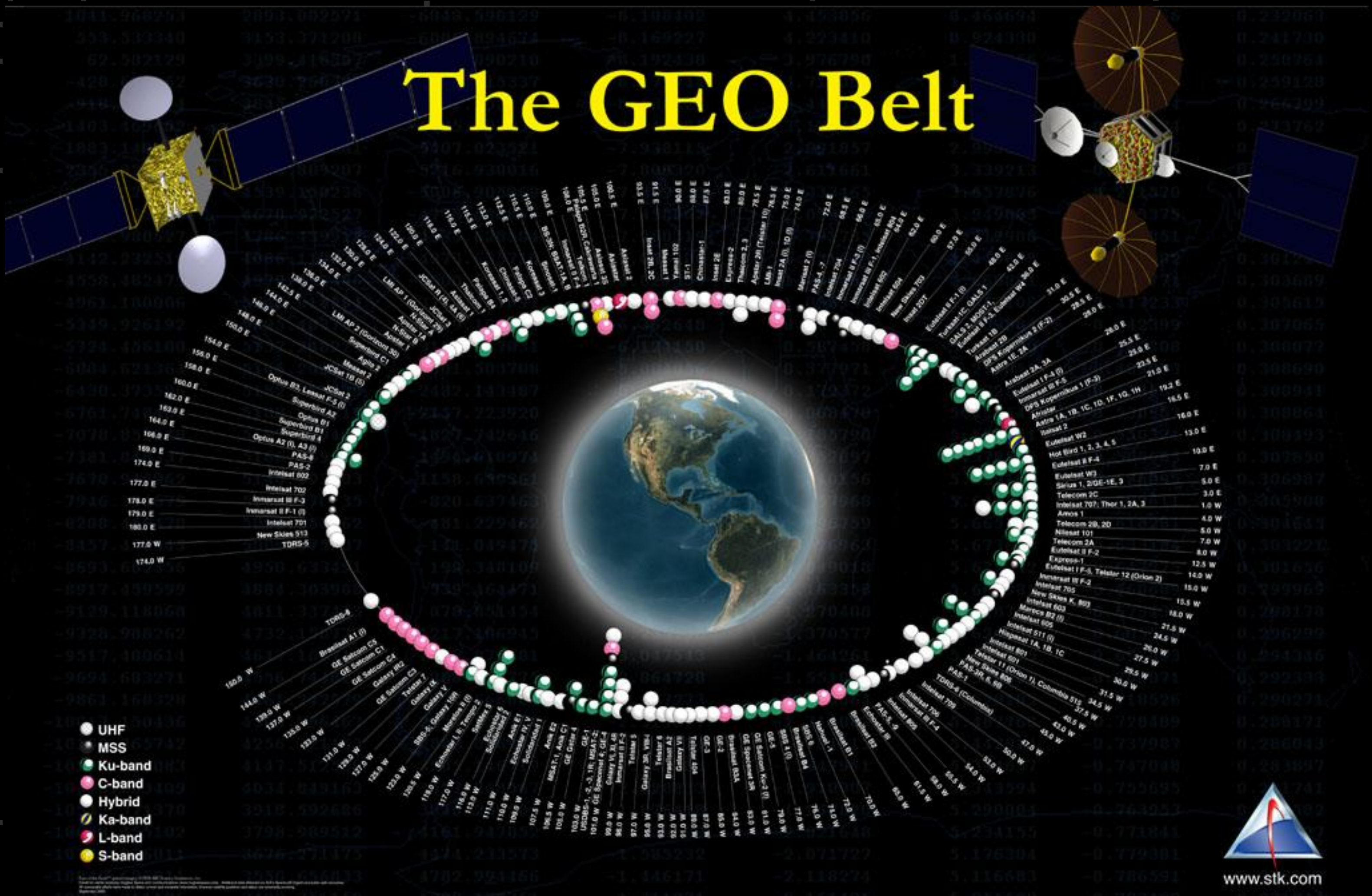


Geostationary (GEO)
Directly above the Earth's equator
(0° latitude)

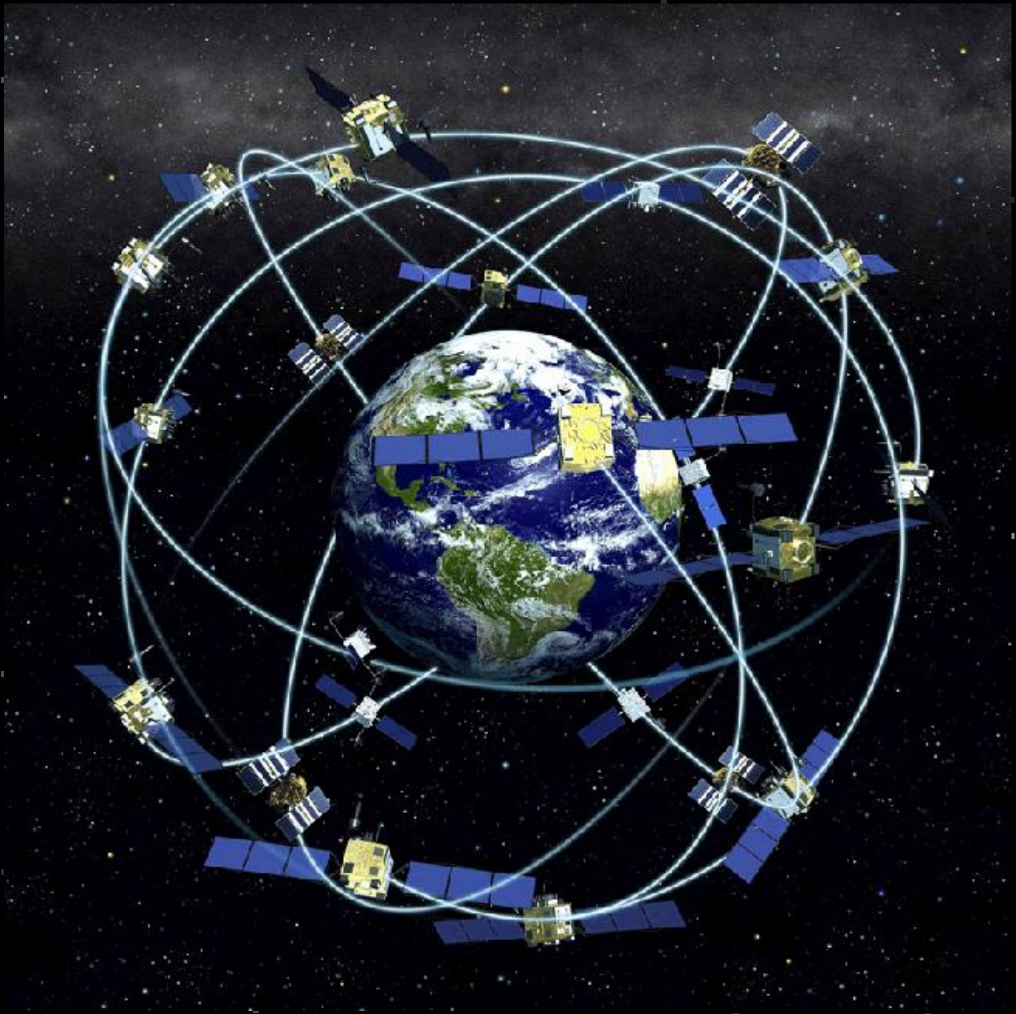


Geosynchronous (GSO)
This is not the actual path of the satellites in space, but rather their positions in the sky as seen from the surface of the Earth

Satellite – GEO

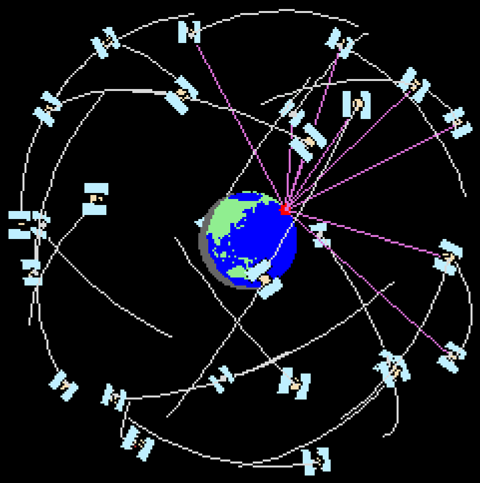


Satellite – GPS



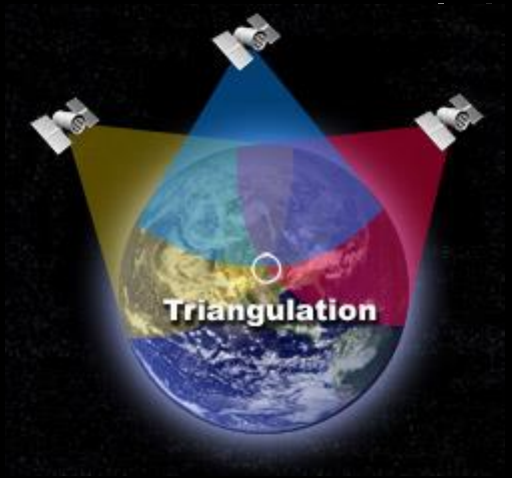
Satellite – GPS

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.

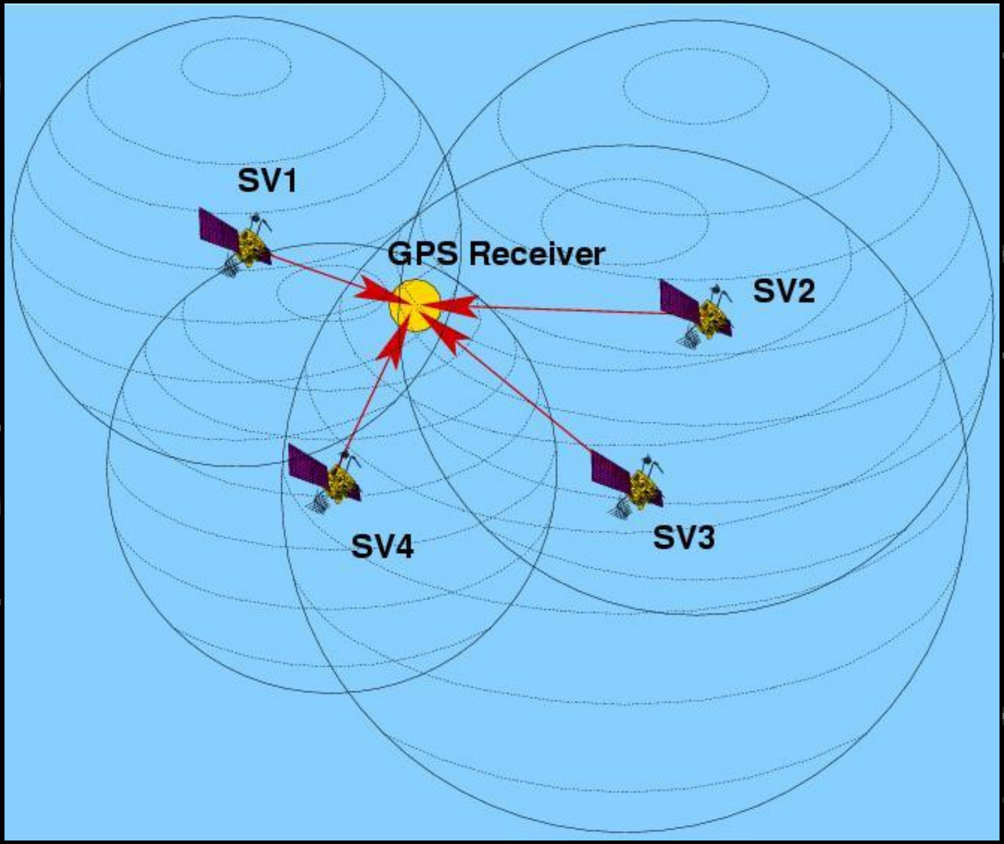


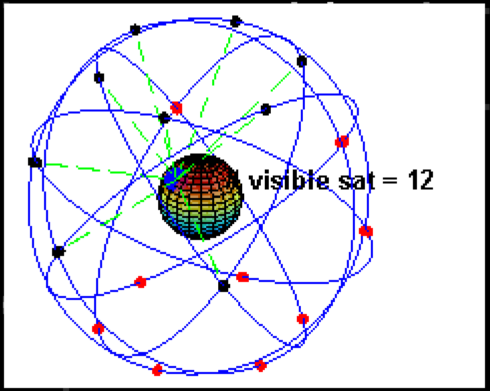
Each of the three satellites will transmit information that is received by the GPS receiver.

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 – GPS



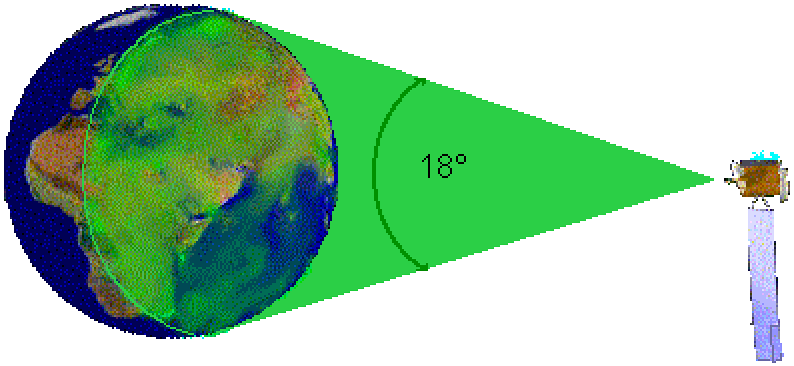


Satellite Microwave

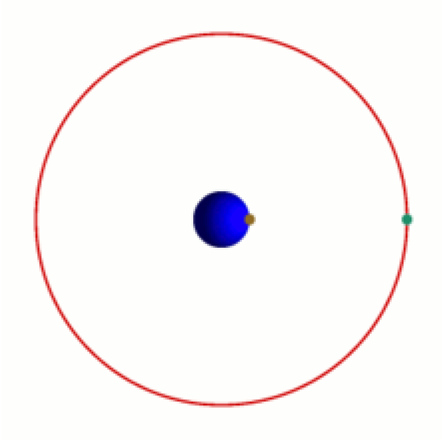
- Satellite is effectively relay station
- Used to link two or more ground stations
  - satellite **receives** tx at frequency band (uplink)
  - **amplifies** or repeat signal
  - **transmits** it on another band (downlink)
- receives on one frequency, amplifies or repeats signal and transmits on another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

Satellite Microwave

- Satellite requires geo-stationary orbit
  - height of 35,786km
  - spaced at least 3-4° apart



- Typical uses:
  - television
  - long distance telephone
  - private business networks
  - global positioning
  - army: detection of rocket launches
  - meteorology:
    - cloud systems
    - sea and land surface temperatures



Derivation of geostationary Altitude

In any circular orbit, the centripetal acceleration required to maintain the orbit is provided by the gravitational force on the satellite. To calculate the geostationary orbit altitude, one begins with this equivalence, and uses the fact that the orbital period is one sidereal day.

$$\mathbf{F}_c = \mathbf{F}_g$$

By Newton's second law of motion, we can replace the forces **F** with the mass *m* of the object multiplied by the acceleration felt by the object due to that force:

$$m\mathbf{a}_c = m\mathbf{g}$$

We note that the mass of the satellite *m* appears on both sides — geostationary orbit is independent of the mass of the satellite.[4] So calculating the altitude simplifies into calculating the point where the magnitudes of the centripetal acceleration required for orbital motion and the gravitational acceleration provided by Earth's gravity are equal.

The centripetal acceleration's magnitude is:

$$|\mathbf{a}_c| = \omega^2 r$$

where ω is the angular speed, and r is the orbital radius as measured from the Earth's center of mass.

The magnitude of the gravitational acceleration is:

$$|\mathbf{g}| = \frac{GM}{r^2}$$

where M is the mass of Earth, 5.9736×10^{24} kg, and G is the gravitational constant, $6.67428 \pm 0.00067 \times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$.

Equating the two accelerations gives:

$$r^3 = \frac{GM}{\omega^2} \to r = \sqrt[3]{\frac{GM}{\omega^2}}$$

The product GM is known with much greater accuracy than either factor; it is known as the geocentric gravitational constant μ = $398{,}600.4418 \pm 0.0008\ \mathrm{km^3\ s^{-2}}$:

$$r = \sqrt[3]{\frac{\mu}{\omega^2}}$$

The angular speed ω is found by dividing the angle travelled in one revolution (360° = 2π rad) by the orbital period (the time it takes to make one full revolution: one sidereal day, or 86,164.09054 seconds).[5] This gives:

$$\omega \approx \frac{2\pi\ \mathrm{rad}}{86\,164\ \mathrm{s}} \approx 7.2921 \times 10^{-5}\ \mathrm{rad/s}$$

The resulting orbital radius is 42,164 kilometres (26,199 mi). Subtracting the Earth's equatorial radius, 6,378 kilometres (3,963 mi), gives the altitude of **35,786 kilometres (22,236 mi)**.

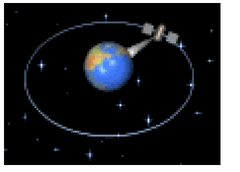
Orbital speed (how fast the satellite is moving through space) is calculated by multiplying the angular speed by the orbital radius:

$$v = \omega r \approx 3.0746\ \mathrm{km/s} \approx 11068\ \mathrm{km/h} \approx 6877.8\ \mathrm{mph}.$$

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).

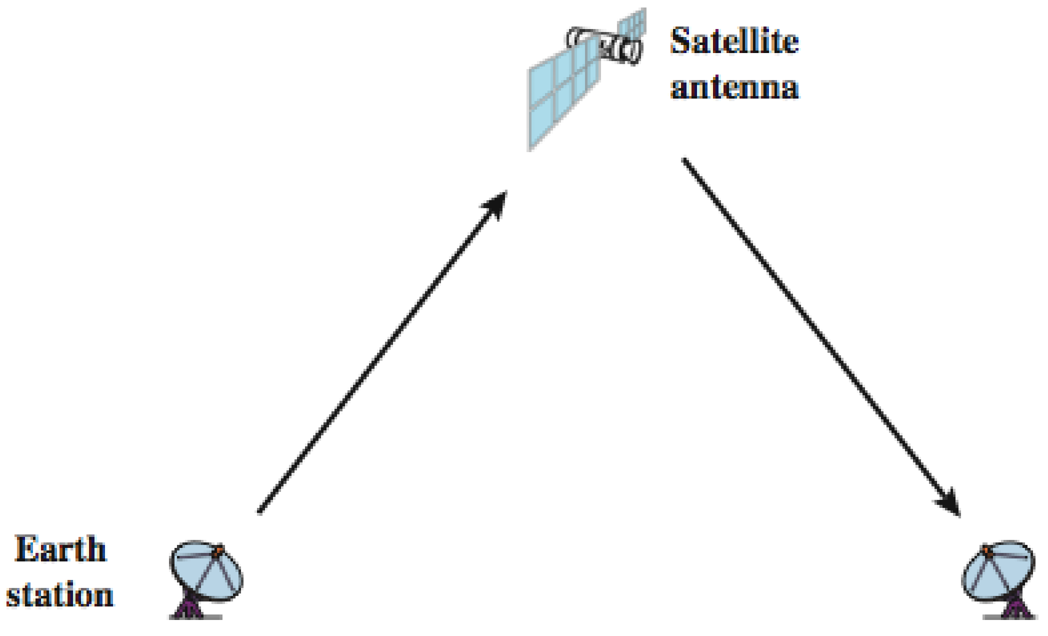


- Permanent visibility of the satellite allowing continuous telecommunications
- one ground segment is enough for the satellite monitoring.

Limitations of geostationary satellites include:

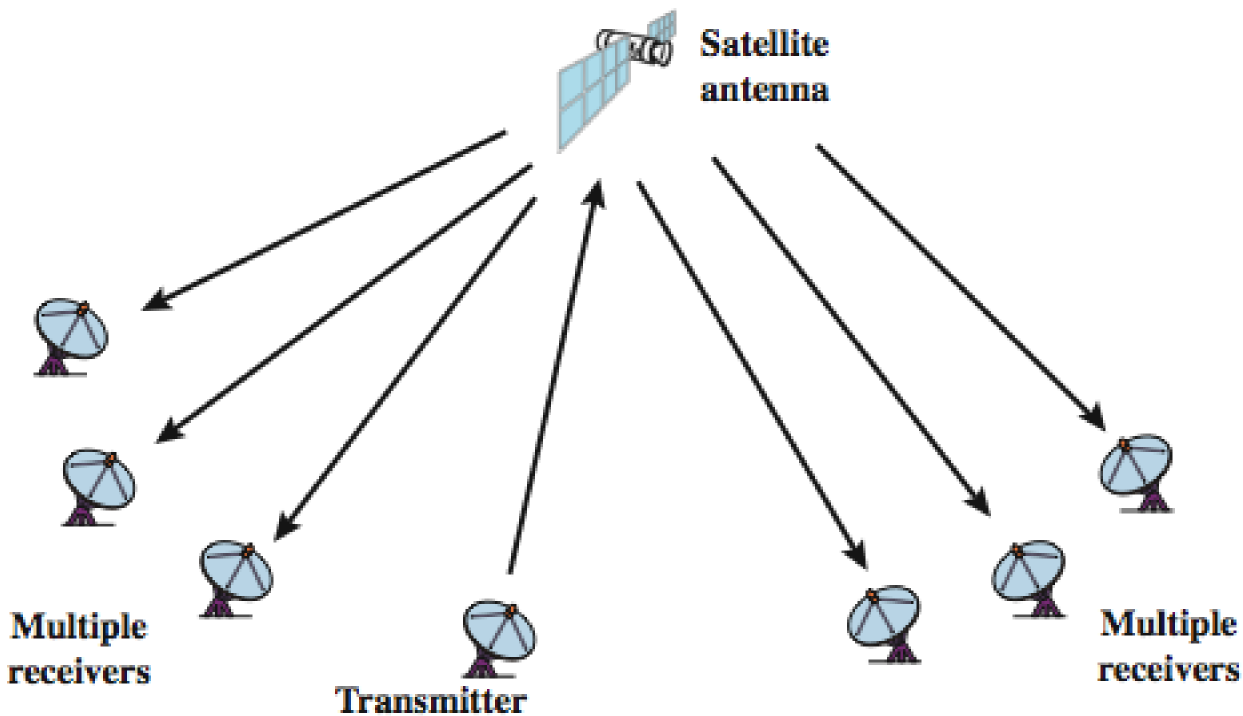
- Polar regions are not observed.
- Some perturbations of the solar electricity power supply to the satellite occur during eclipse phenomena.

Satellite Point to Point Link



(a) Point-to-point link

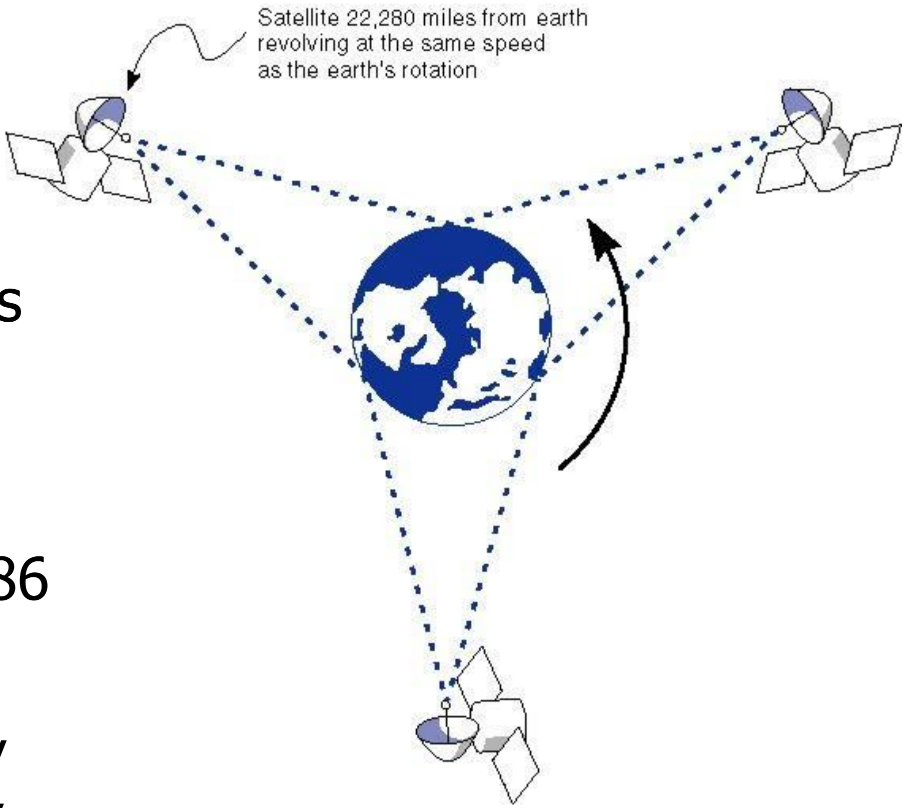
Satellite Broadcast Link



(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 f or 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

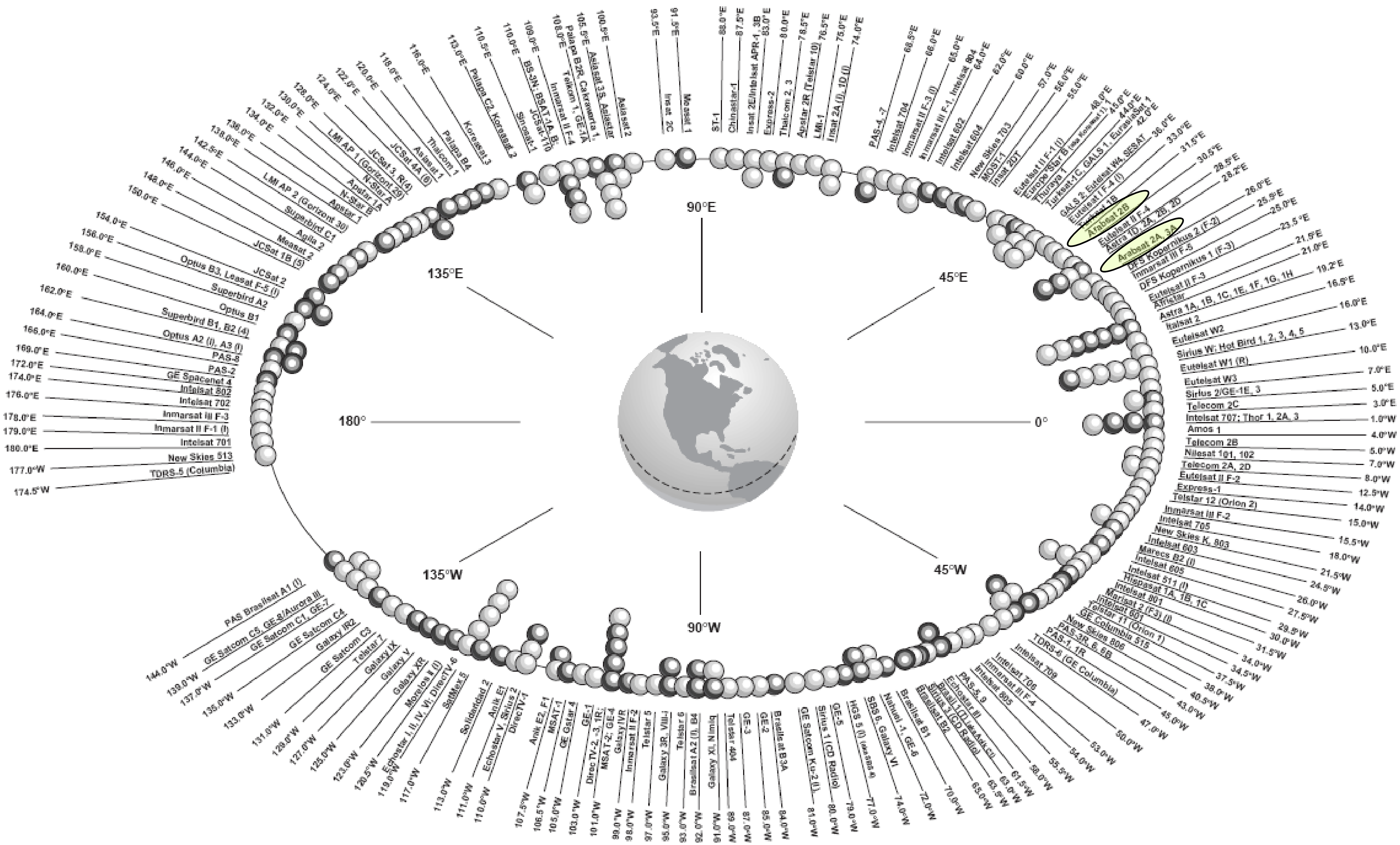
- Most satellites providing p2p service use
  - 5.925 – 6.425 GHz for uplink
  - 3.7 – 4.2 GHz for downlink

  } known as 4/6 GHz band
  - different frequency band to allow continuous operation without interference

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 in GEO



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 - 1GHz, 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

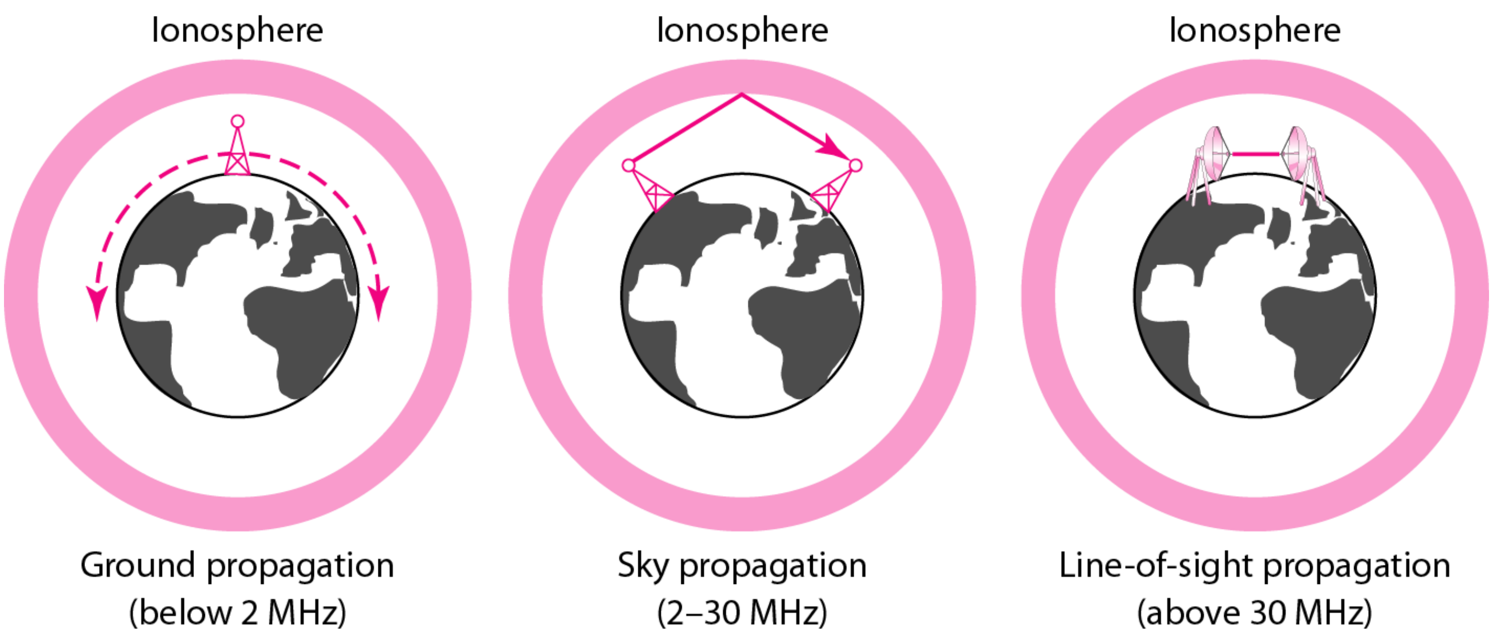
Infrared

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

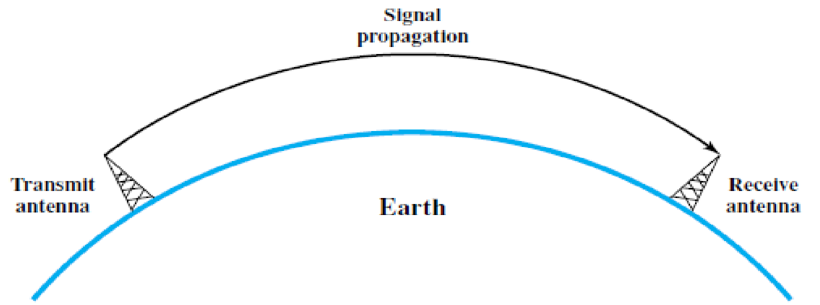
Wireless Propagation

Three modes:

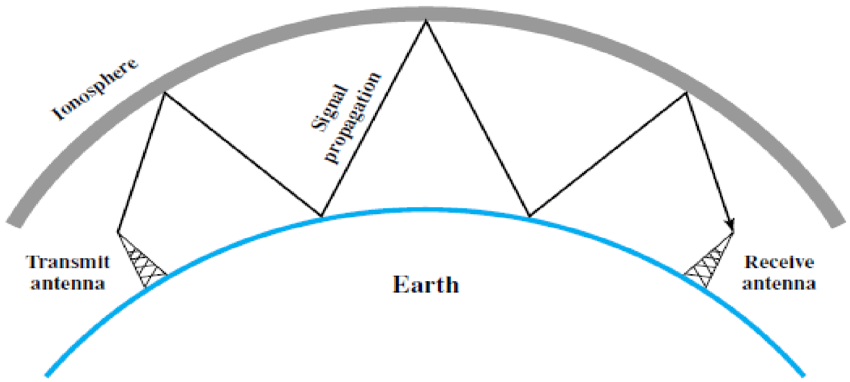
- Ground wave (GW) propagation
- Sky wave (SW) propagation
- Line of sight (LOS) propagation



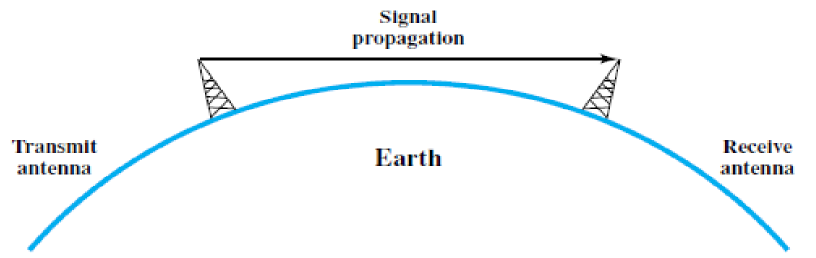
Wireless Propagation



(a) Ground wave propagation (below 2 MHz)



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



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

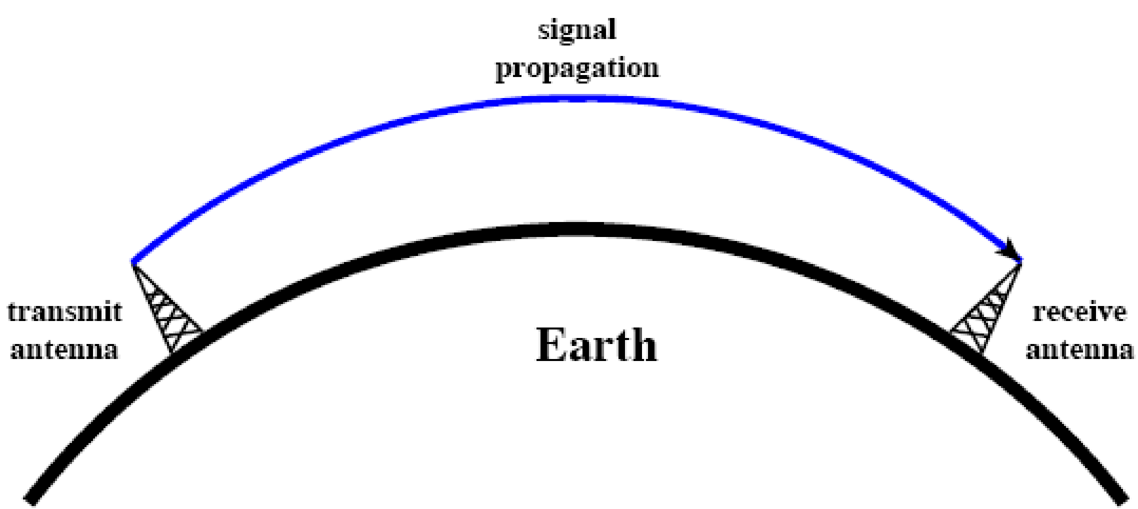
Frequency Bands

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

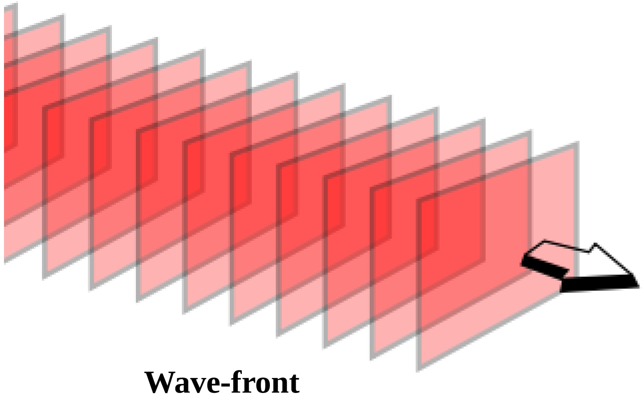
Ground Wave Propagation

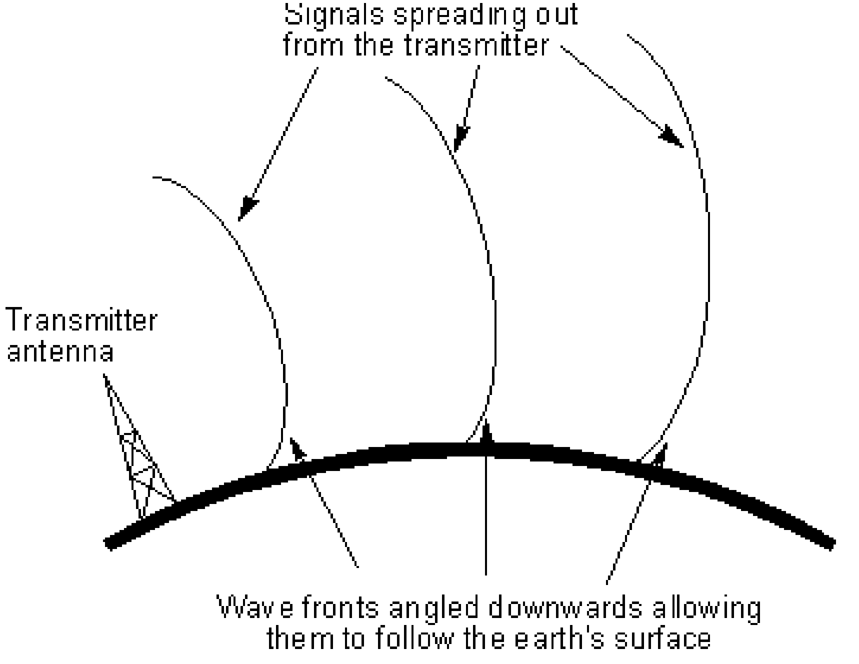
- **Follows curvature of the earth**
- Can propagate to large distance, over the visual horizon
- Frequency range up to **2 MHz**
- **Do not penetrate upper atmosphere**
- Best known example: **AM radio**



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**.

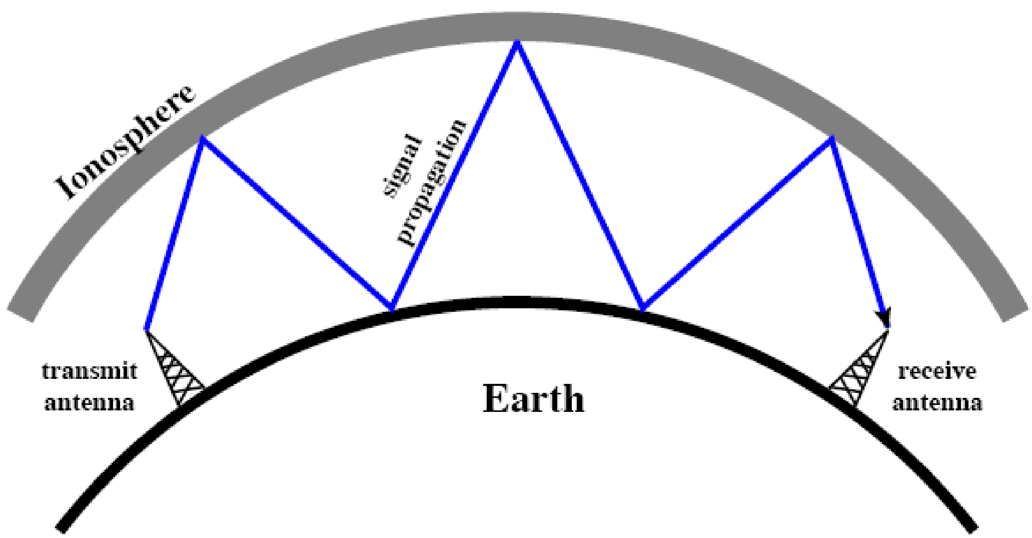
2. Diffraction by obstacles:

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

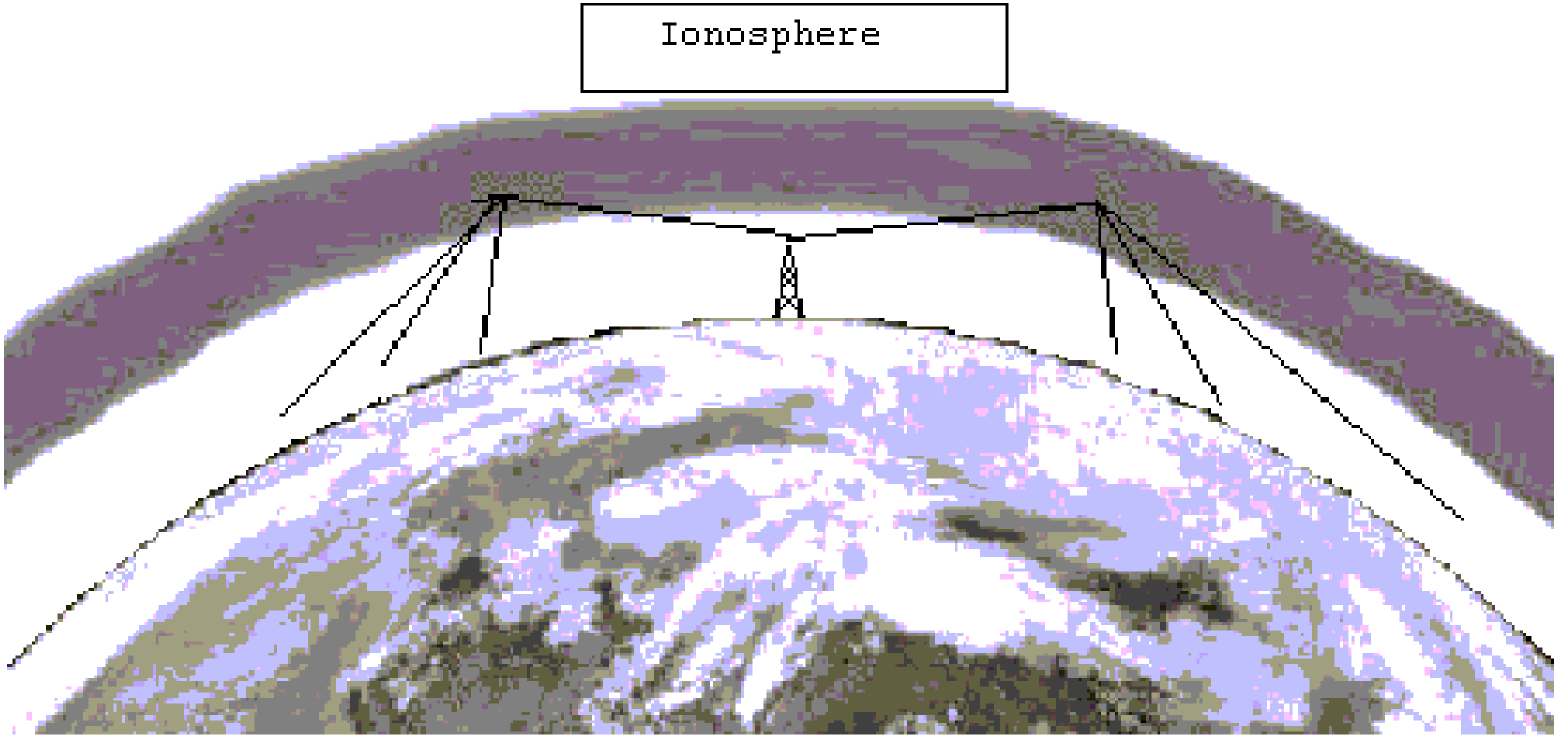
3. Electromagnetic waves in the frequencies up to 2 MHz are **scattered by the atmosphere**.

Sky Wave Propagation

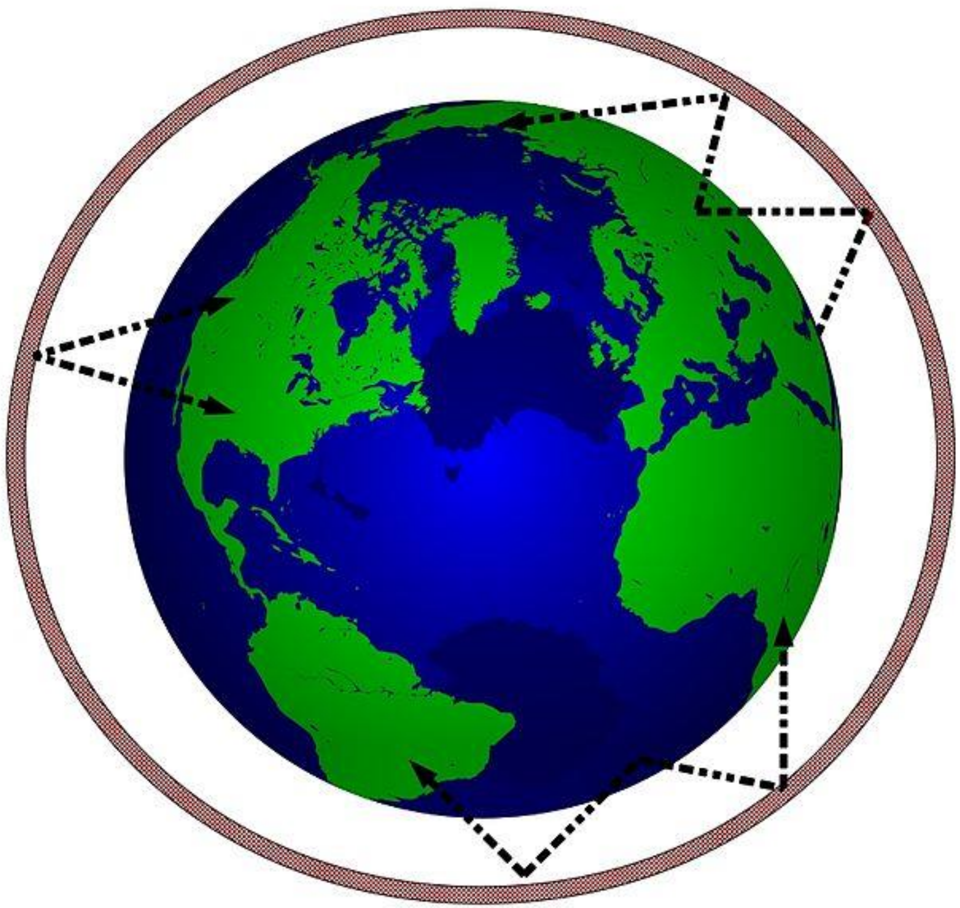
- **Signal from earth station reflected by ionosphere to earth**
- Can travel through number of hops
- Frequency range **2 – 30MHz**
- Can be picked up **1000s of kilometers away from transmitter**
- Used for amateur radio, international radio



Sky Wave Propagation

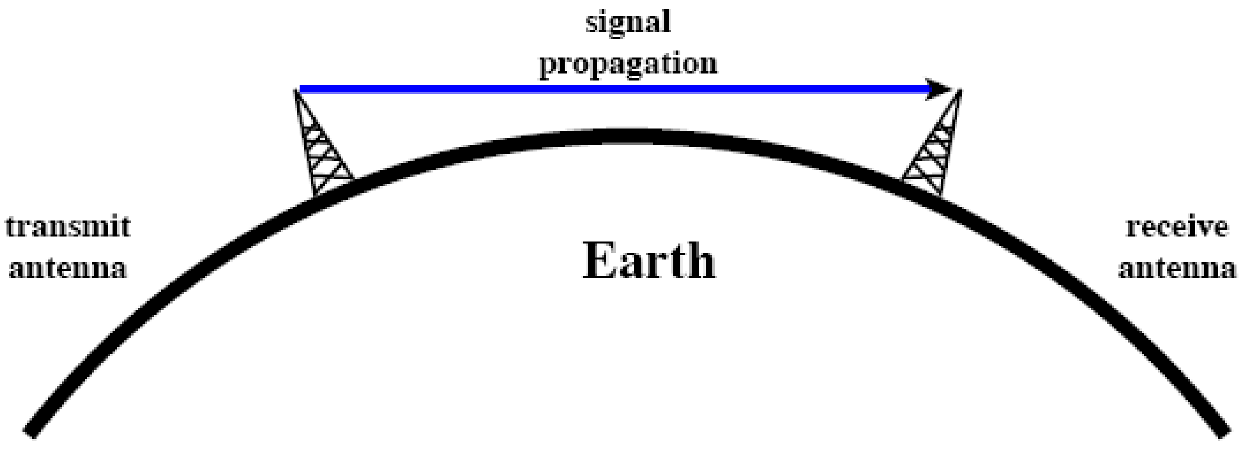


Sky Wave Propagation



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
  - ~3 x 10^8 m/s in vacuum, less in anything else
- speed changes as move between media
- Index of refraction (refractive index) is
  - sin(incidence)/sin(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

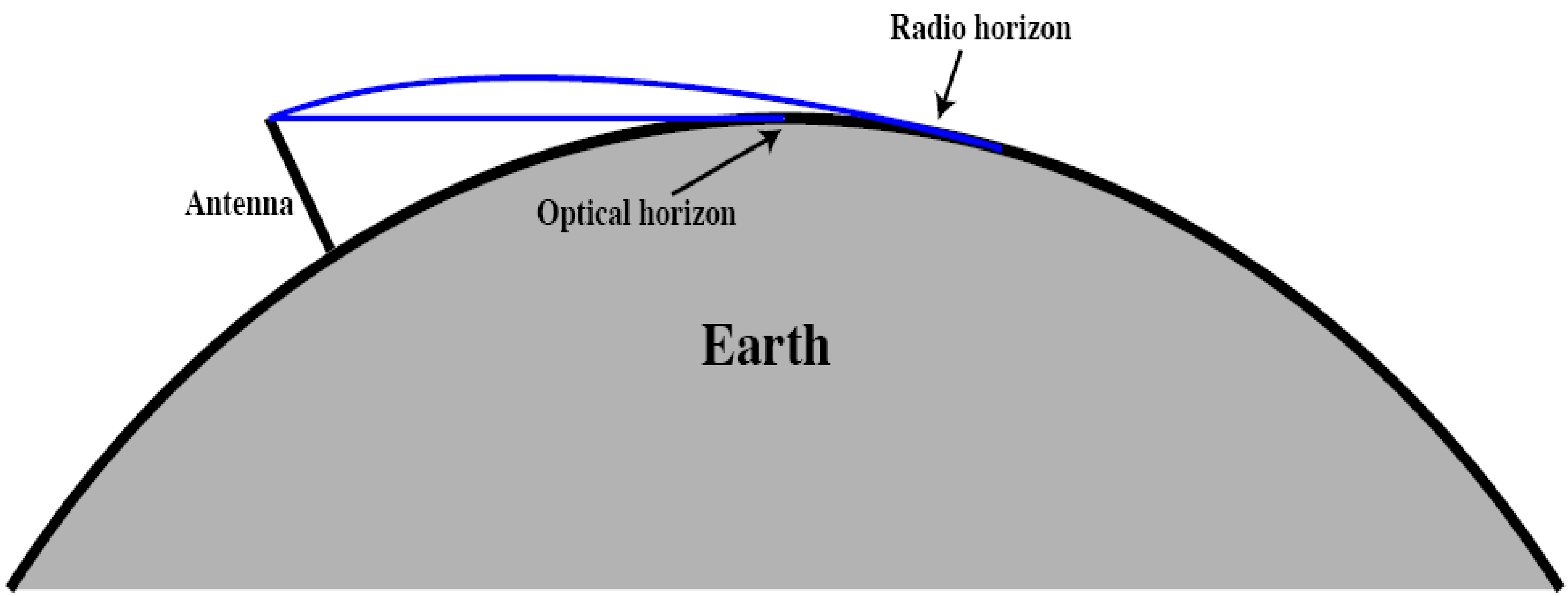
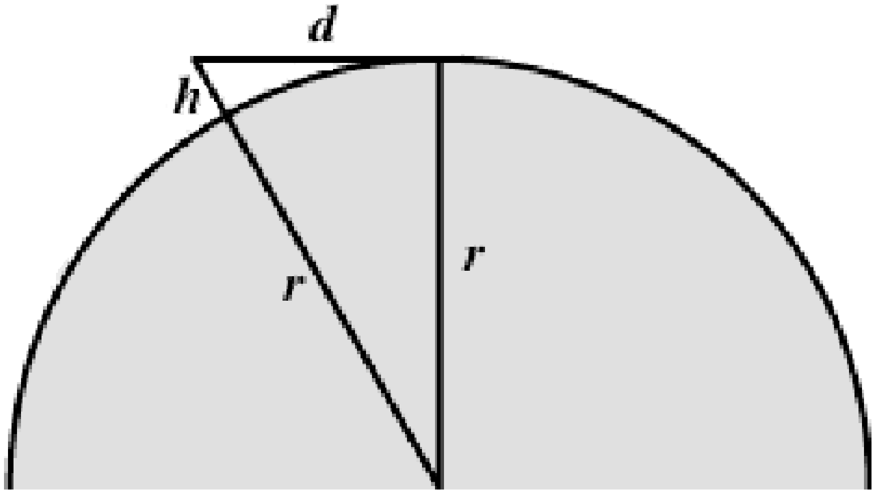


Figure 4.9 Optical and Radio Horizons

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 $d^2 = 2rh$.

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

$$d = 3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

$$= 3.57\left(\sqrt{133} + 0\right) = 41\text{km}$$

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

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

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

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

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:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 10\log\frac{(4\pi d)^2}{\lambda^2} = 10\log\frac{(4\pi d f)^2}{c^2}$$

- This can be recast as:

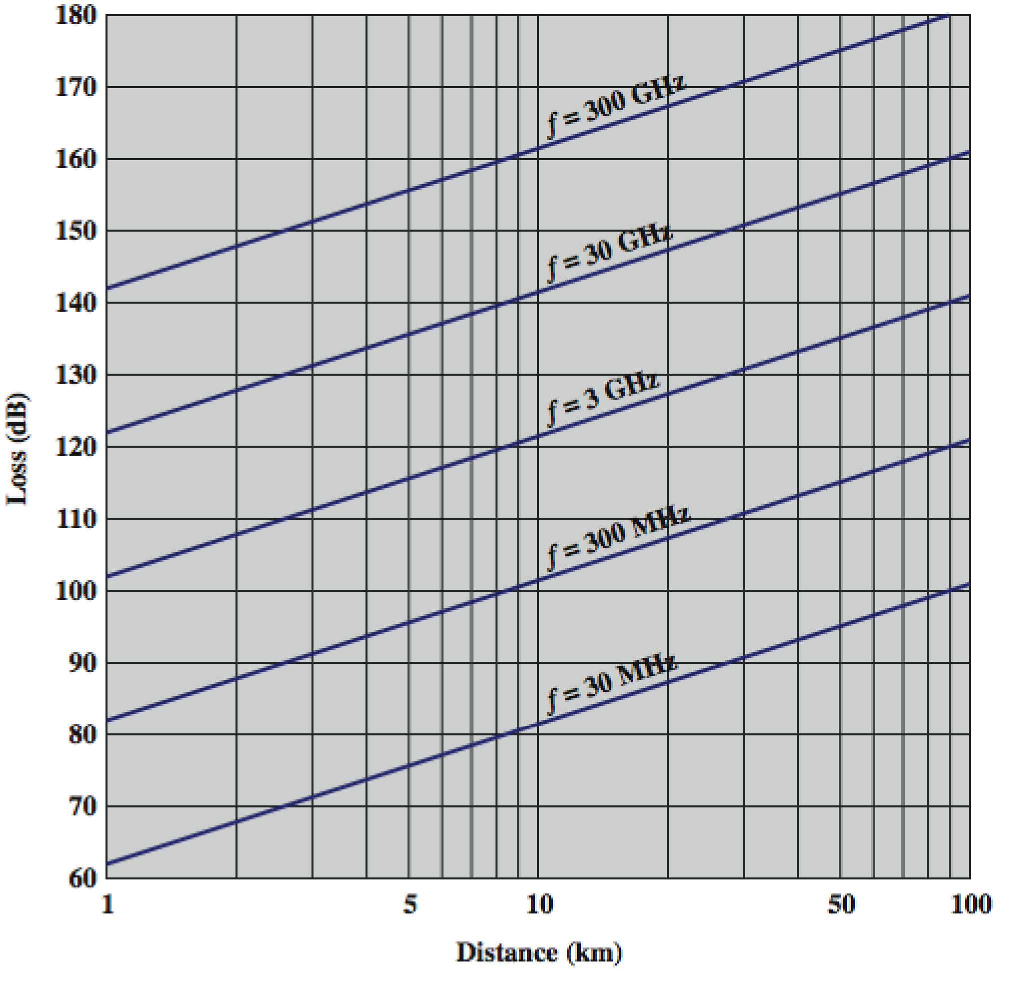
$$\boldsymbol{L_{dB} = 21.98 + 20\log(d) - 20\log(\lambda)}$$

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

Free Space Loss

- For non-isotropic antenna, gain must be considered
- $L_{dB} = 10 \log \frac{P_t}{P_r} = 10 \log \frac{(4\pi d)^2}{G_t G_r \lambda^2}$
- $L_{dB} = 21.98 + 20 \log(d) - 20 \log(\lambda) - G_{t\,dB} - G_{r\,dB}$
- $L_{dB} = -147.56 + 20 \log(d) + 20 \log(f) - G_{t\,dB} - G_{r\,dB}$
  - 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* = $3\times10^8/ 4\times10^9 = 0.075$m

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

$$L_{dB} = -20\log(0.075) + 20\log(35.863\times10^6) + 21.98 = 195.6 \quad \text{dB}$$

  - 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:

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

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

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

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

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

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.

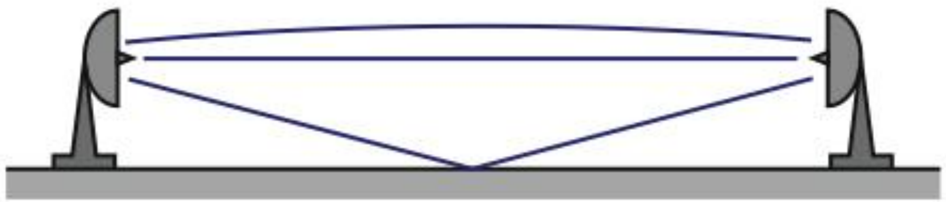
Atmospheric Absorption

- **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**

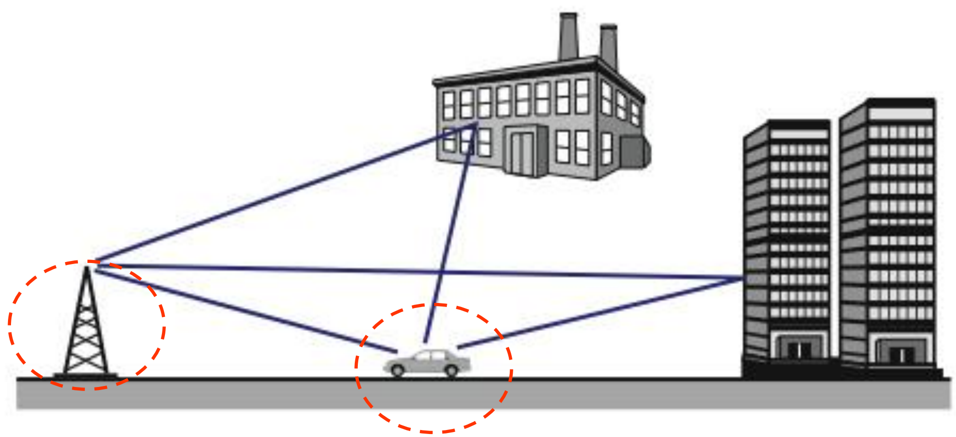
Multipath

- **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. Andew 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