Satellite Signals
and
Communications Principles

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Principle of Satellite Signals

- In essence, satellite signals are electromagnetic waves that travel from the satellite all the way onto Earth.

- Either a tracking station or a simple VSAT terminal is needed to have a two way satellite signal between the satellite and the Earth

- If only unidirectional signal is there, then a simple satellite dish to converge the signal is enough

Electromagnetic Signals

THE ELECTROMAGNETIC SPECTRUM
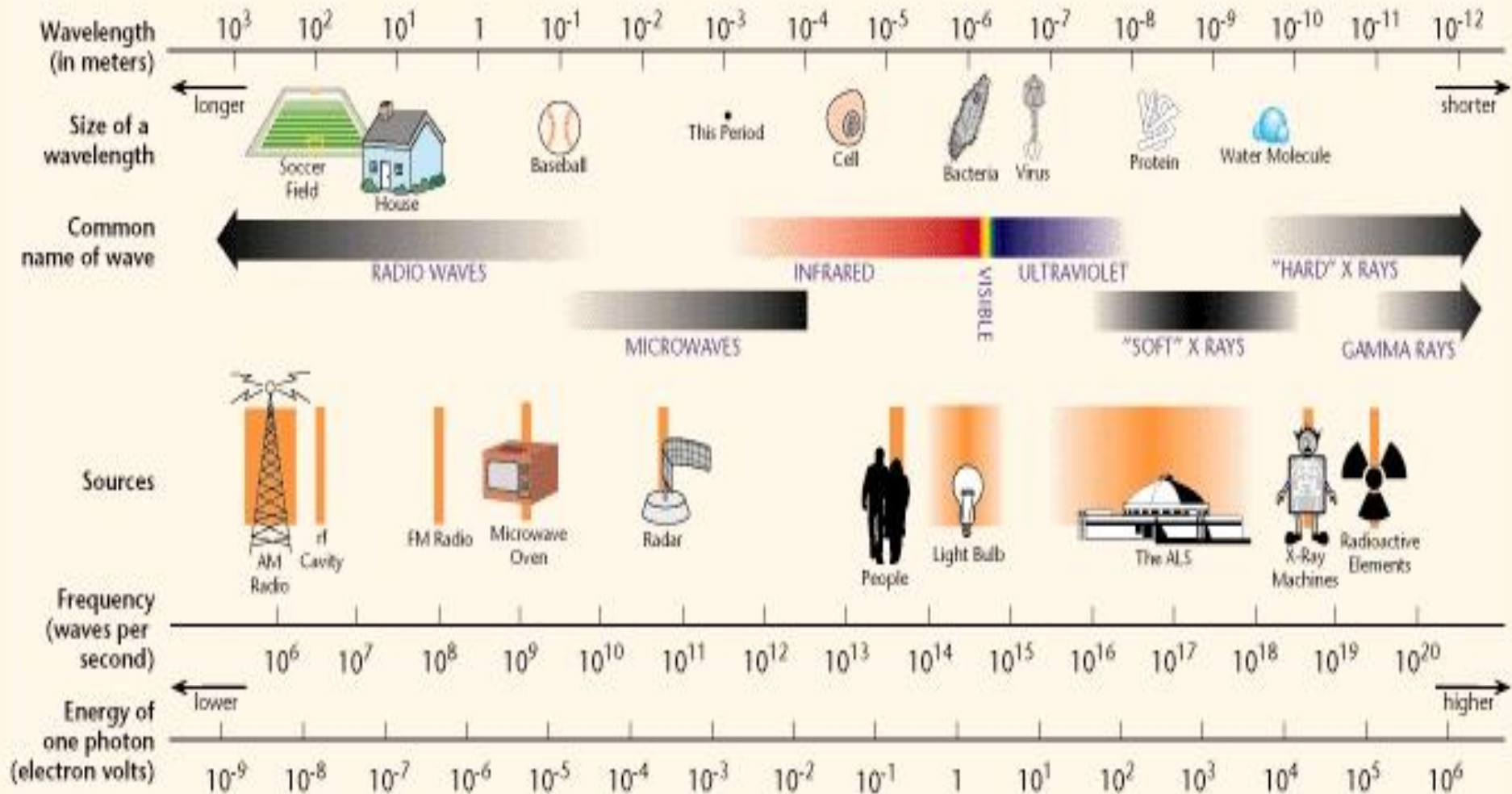
Electromagnetic Energy Source

Isotropic source
EIRP = P_t watts

Distance R m

Area A m^2

Flux density F watts/m^2
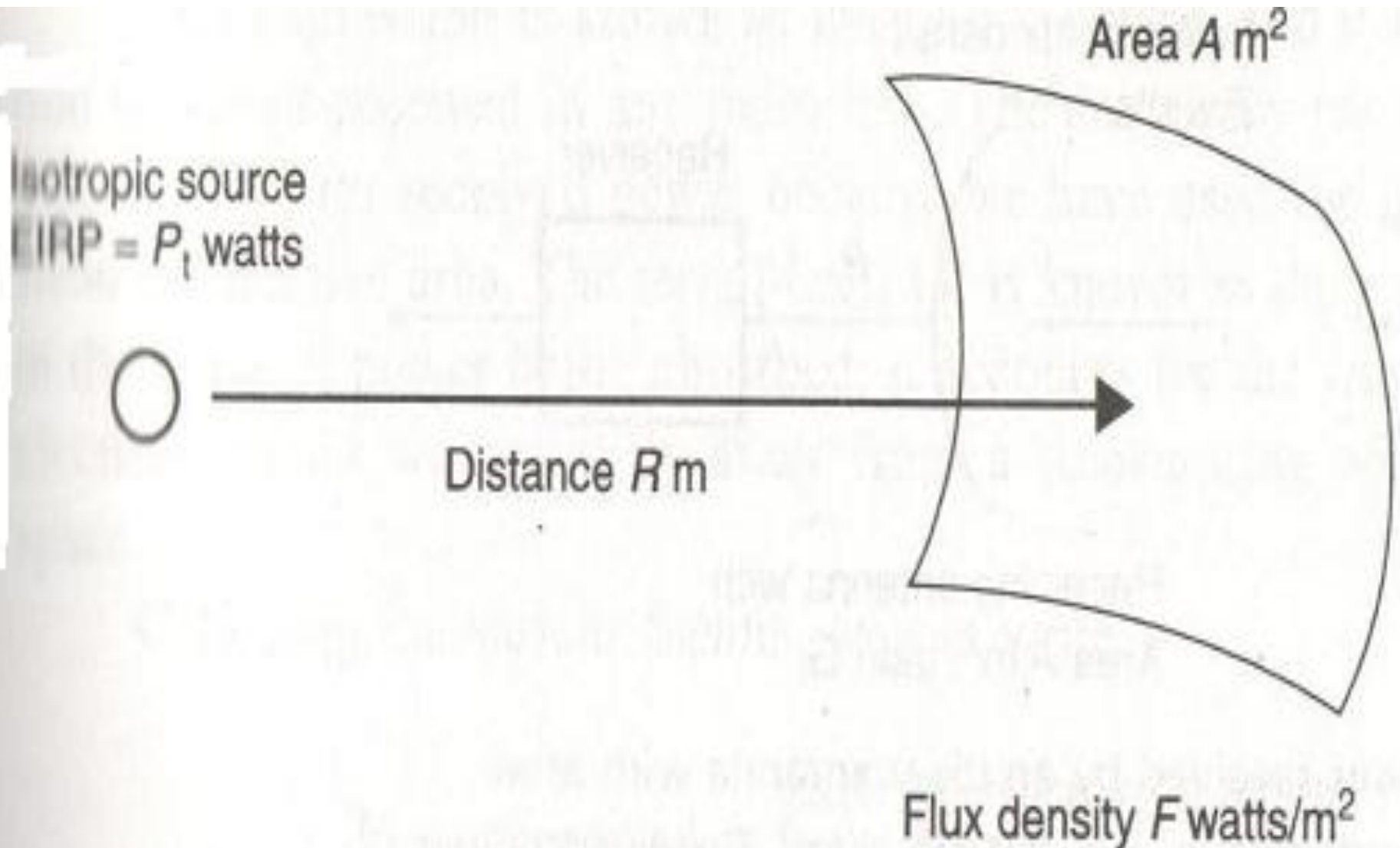
Equivalent Isotropic Radiated Power

- Equivalent Isotropic Radiated Power is shown as EIRP
- EIRP = 10log(powerwatts)+Antenna Gain
- **<u>EXAMPLE</u>**
- A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. Calculate EIRP in dBW.

  EIRP = 10 log (6W) + 48.2

  As a result, we get EIRP = 56 dBW

White Noise

- There is a certain background radiation that is always present in the universe.

- The background radiation which interferes with the EM spectrum is white noise

- The universe has a 3K-4K radiation that also acts as a white noise in every direction
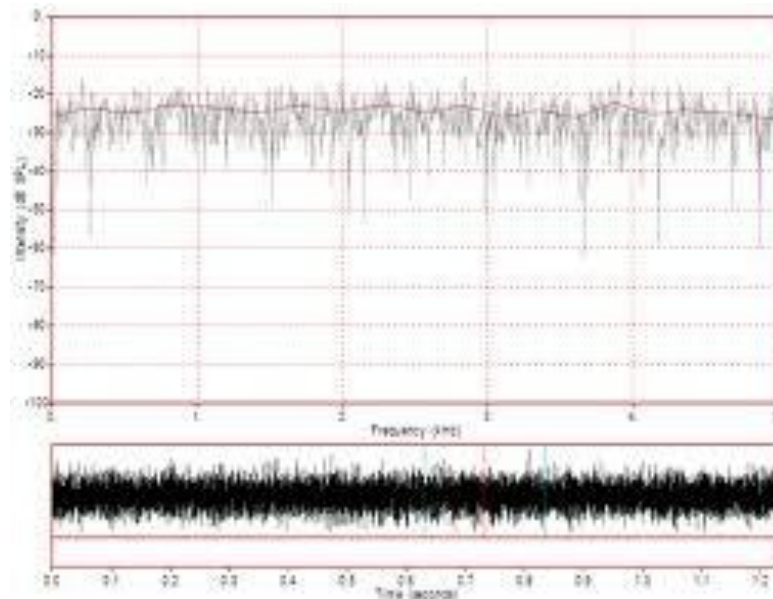
Freespace Loss

- As the distance between the satellite and the Earth increases, the amount of freespace loss increases.

- Radiation strength decreases with distance
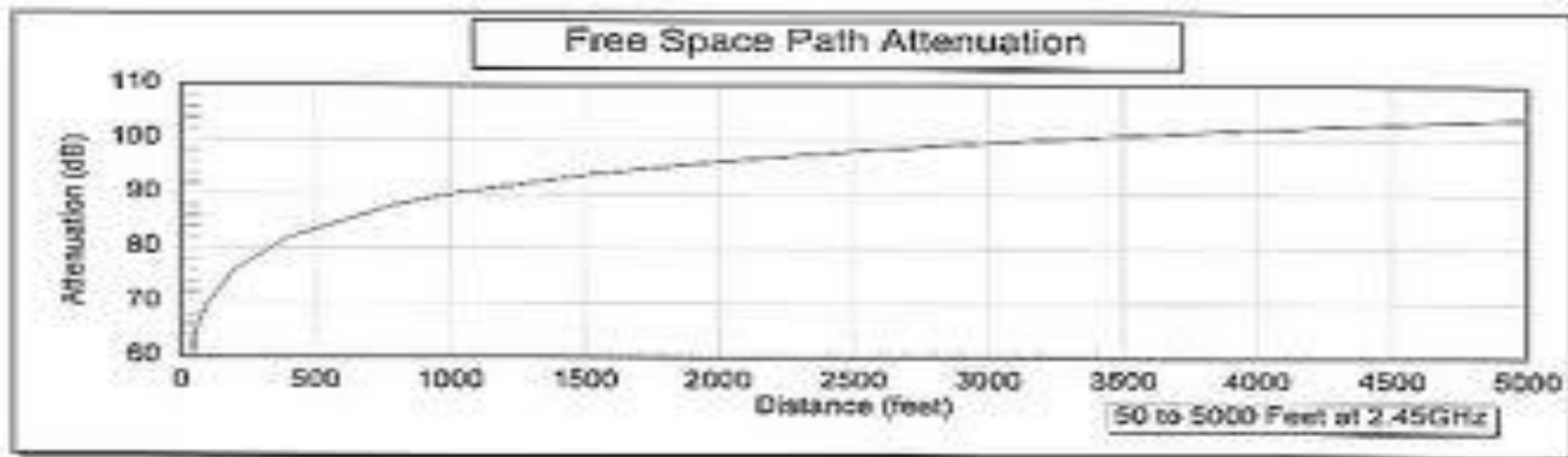
$$FSL = 10\log(\frac{4\pi r}{\lambda})^2 = 32.4 + 20\log r + 20\log f$$

Freespace Loss Example

- The range between a ground station and a satellite is at 42,000 km of altitude. Calculate the free space loss at a frequency of 6 GHz

$$FSL = 10\log(\frac{4\pi r}{\lambda})^2 = 32.4 + 20\log r + 20\log f$$

- FSL = 32.4 + 20 log 42,000 + 20 log 6000 = 200.4 dB
- Hence the freespace loss is 200.4 dB
- The frequency has to be taken at KHz

Atmospheric Loss

- The signal between the satellite and the tracking station is effected as atmospheric losses takes place.

- Atmospheric attenuation is the weather related loss of the signal.

- Atmospheric absorption is the loss of the signal due to energy absorption of the gases in Earth's atmosphere
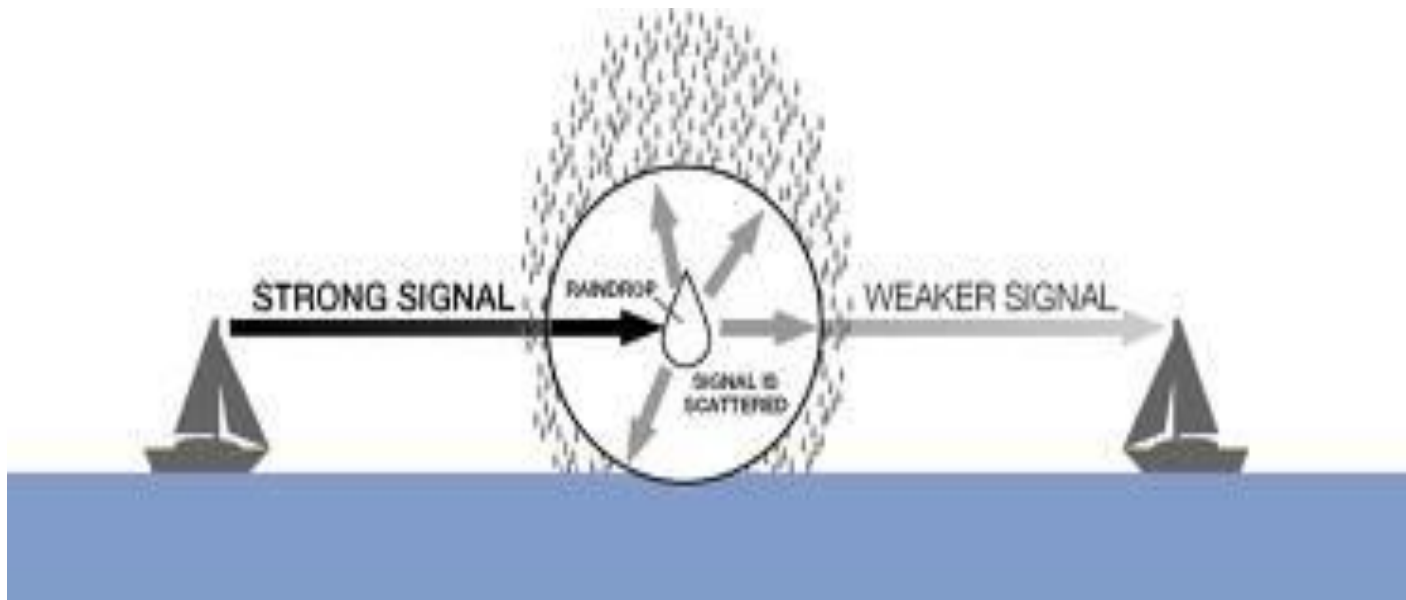
Atmospheric Loss Frequency

- Atmospheric absorption loss varies with frequency.

- Two absorption peaks are observed. The first one is at 22.3 GHz range due to resonance absorption of the water vapor

- The second absorption peak is at 60 GHz sue to the absorption of oxygen

Atmospheric Loss
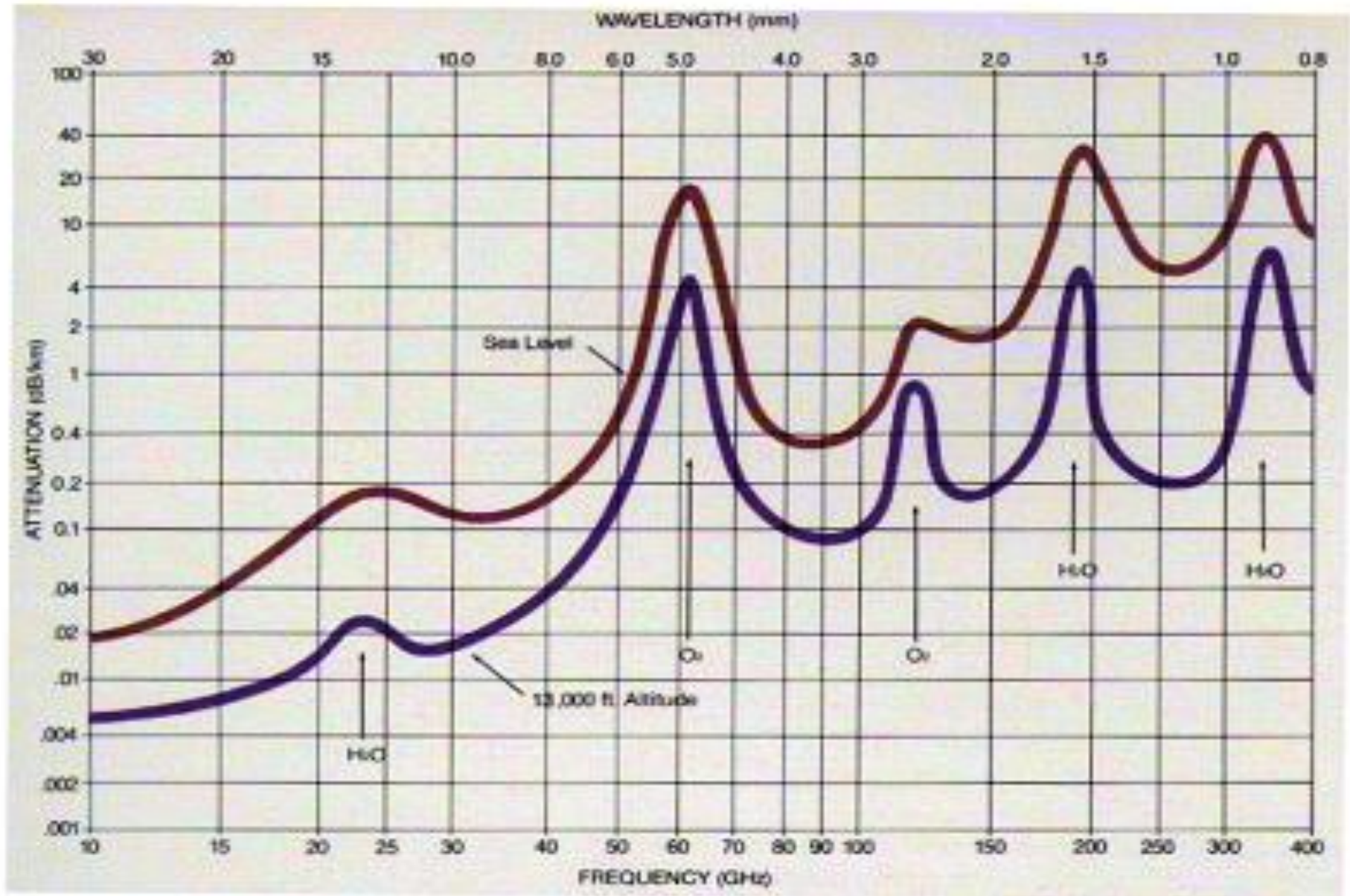
Atmospheric Scintillation

- Differences in the atmospheric refractive index results in focusing and the defocusing of the radio waves which follow different ray paths in the atmosphere.

- It is a fading phenomena in the order of several seconds
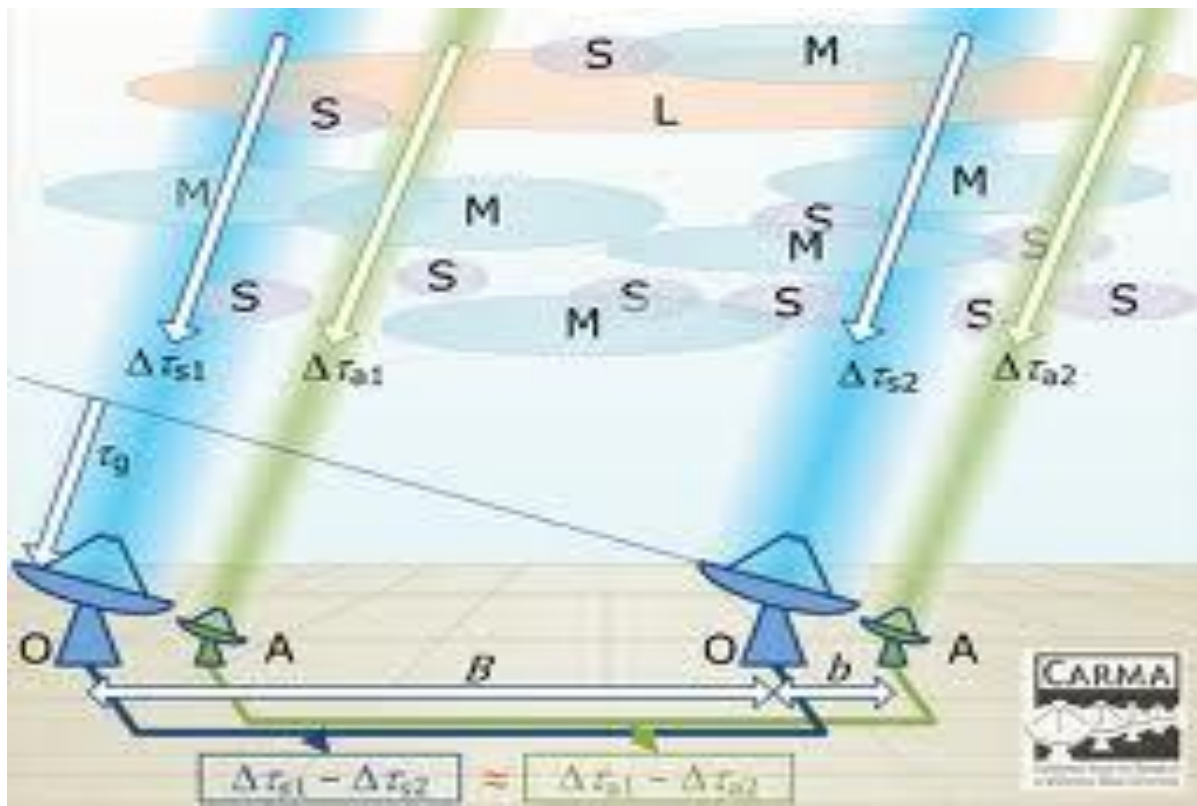
Ionosphere Effects

- From 90 km to 400 km, the layer of the atmosphere is called the ionosphere.

- In the ionosphere, the gases are completely ionized due to solar as well as cosmic radiation

- Ionosphere can cause frequency change, dispersion, polarization, variation in the amplitude as well as the change in angle of arrival
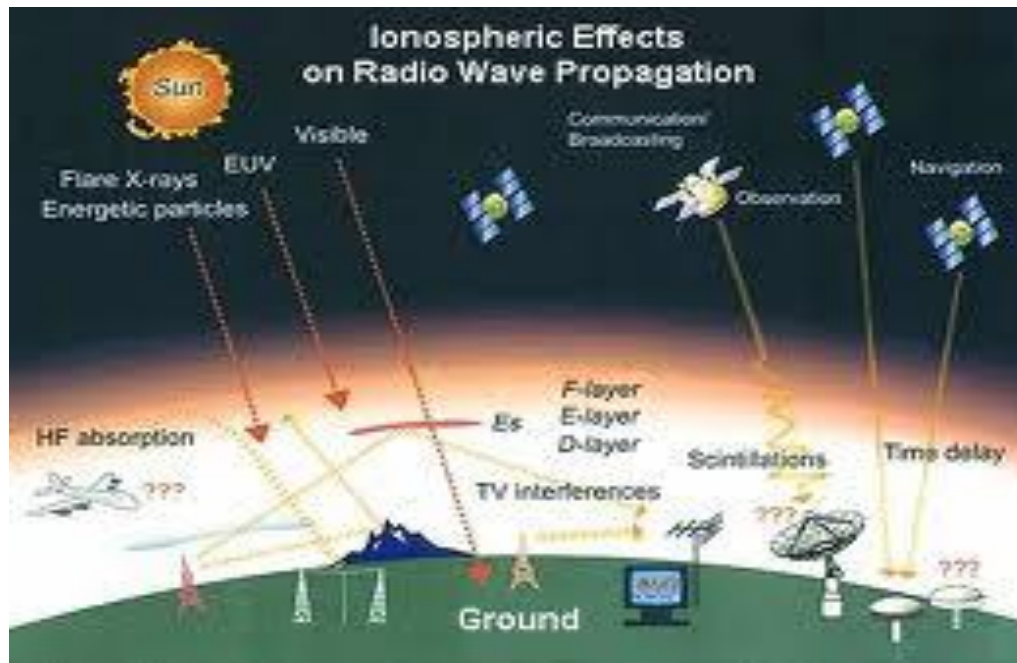
Ionosphere Effects

- The effects of the ionosphere decreases as the frequency of the signal increases.

- It is in inverse proportion to the frequency squared.

- The main effect of ionosphere scintillation is generally the fading of the signal

Rain Attenuation

- Rain attenuation is a function of rain rate
- Rain rate is measured in mm/hour
- Specific attenuation depends on the frequency of the signal as well too. In lower frequencies, attenuation is less
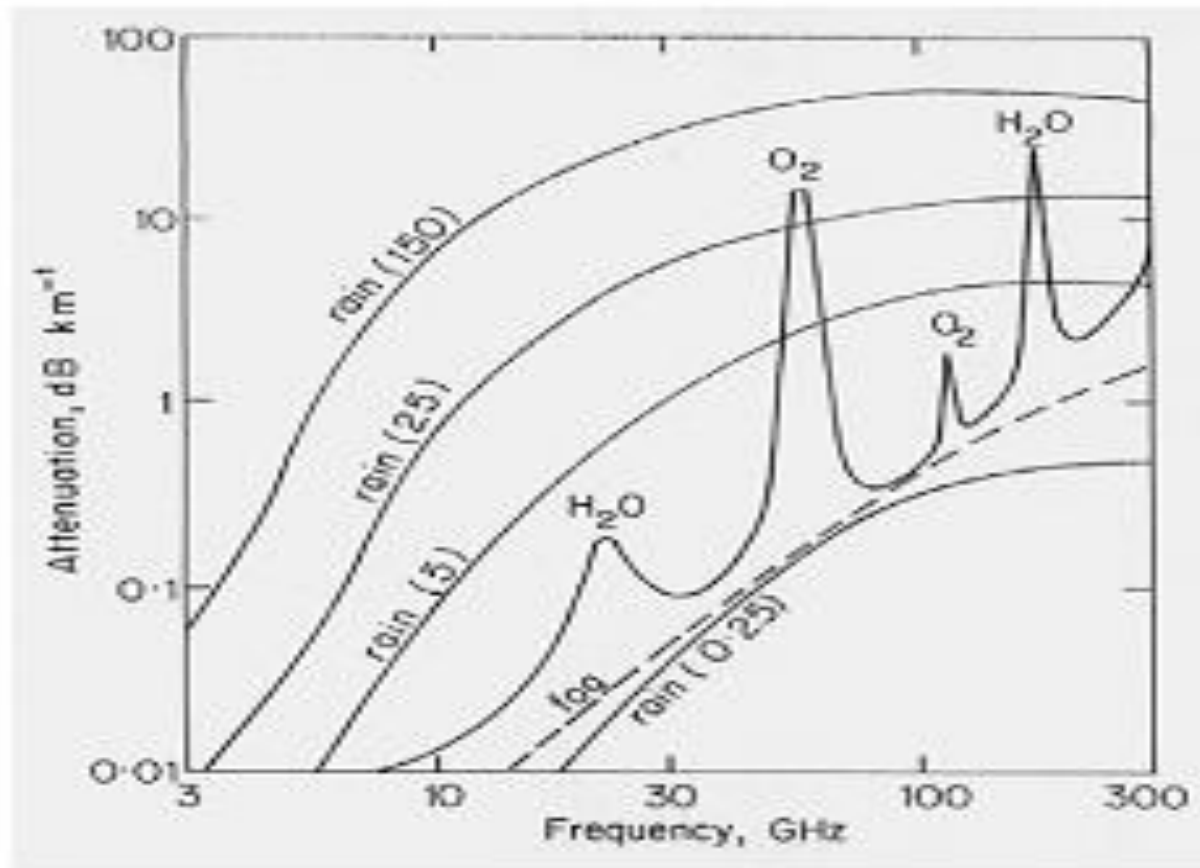
Total Losses

- The total losses in clear sky conditions is:
- **[LOSS] = [FSL] + [RFL] + [AML] + [AA] + [PL]**
- FSL = Free Space Spreading Loss dB
- RFL = Receiver Feeder Loss dB
- AML = antenna misalignment loss dB
- AA = atmospheric absorption loss dB
- PL = polarization mismatch loss dB

Satellite Loss Example

- A satellite link operating at 14 GHz has receiver feeder losses of 1.5 dB and a freespace loss of 207 dB. The atmospheric absorption loss is 0.5 dB and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total loss for clear sky conditions

- **[LOSS] = [FSL] + [RFL] + [AML] + [AA] + [PL]**

- Loss = 207 + 1.5 + 0.5 + 0.5

- Total Loss = 209.5 dB

Received Power (Final Equation)

- For the final received power, it is essential to write EIRP, Antenna gain as well as the losses, so that you can see the final value.

- Hence, the decibel equation for the received power is given by:

- **[PR] = [EIRP] + [G] - [LOSS]**

Uplink and Downlink

- An earth station transmits the signal up to the satellite. This is called the **<u>uplink</u>** and is transmitted on one frequency.

- The satellite receives the signal and retransmits it on what is termed the **<u>downlink</u>** which is on another frequency
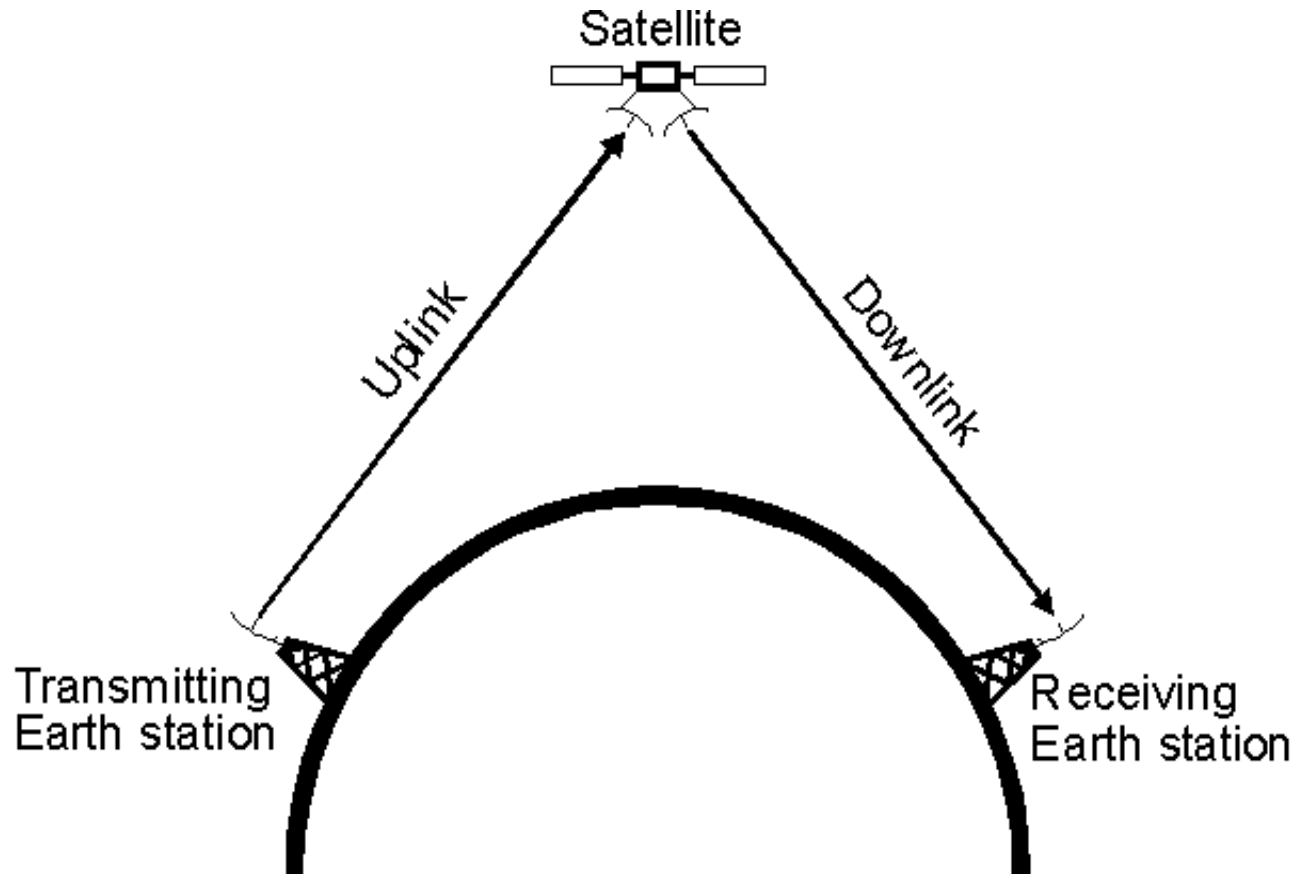
Satellite Communications Concept
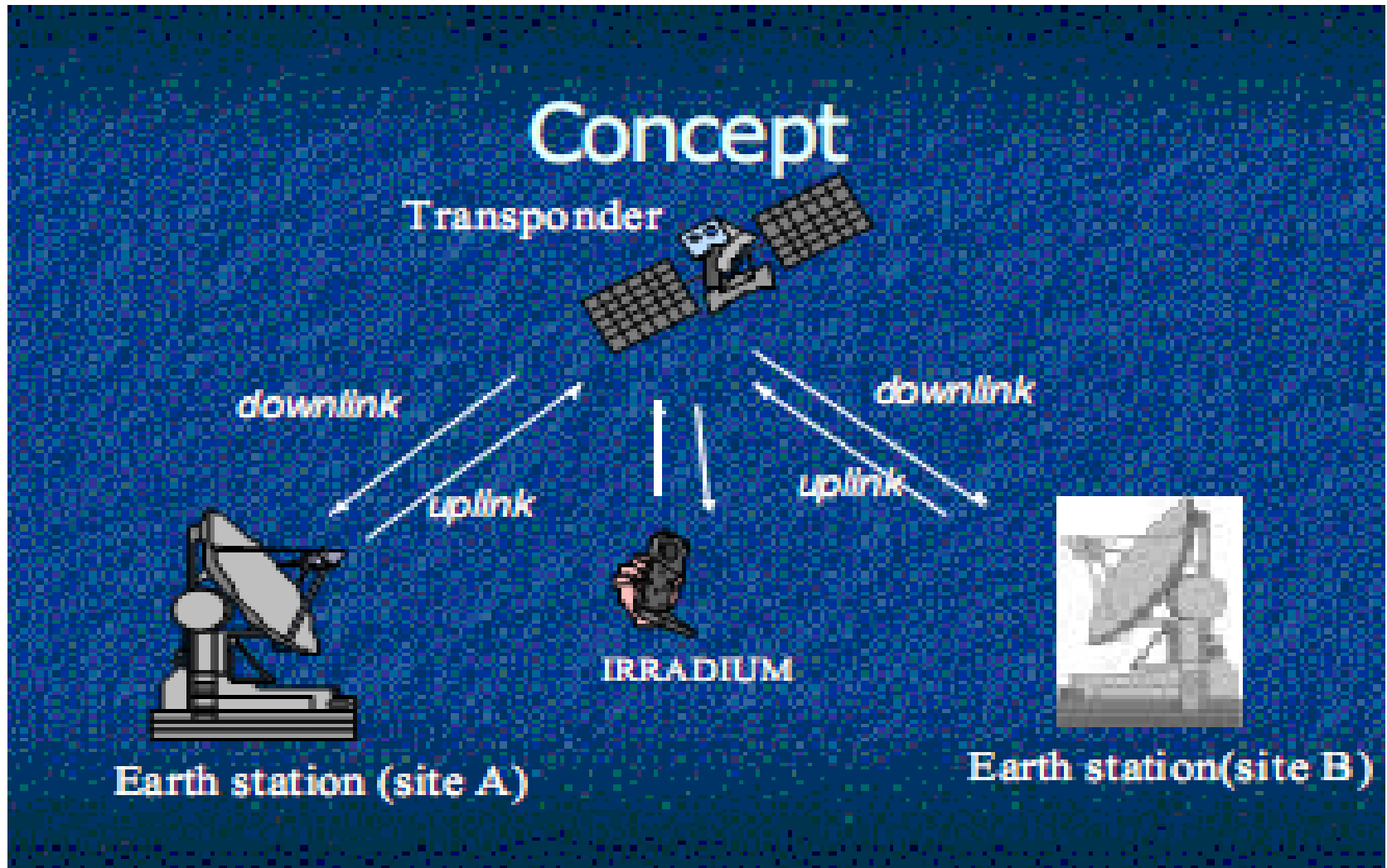
Transponder

- The circuitry in the satellite that acts as the receiver, frequency changer, and transmitter is called a **transponder.**
- This basically consists of a low noise amplifier, a frequency changer consisting a mixer and local oscillator, and then a high power amplifier.

Input frequency

Output frequency

Low noise amplifier → Mixer → Power amplifier

Frequency coverage limited to bandwidth required to be received

Local oscillator
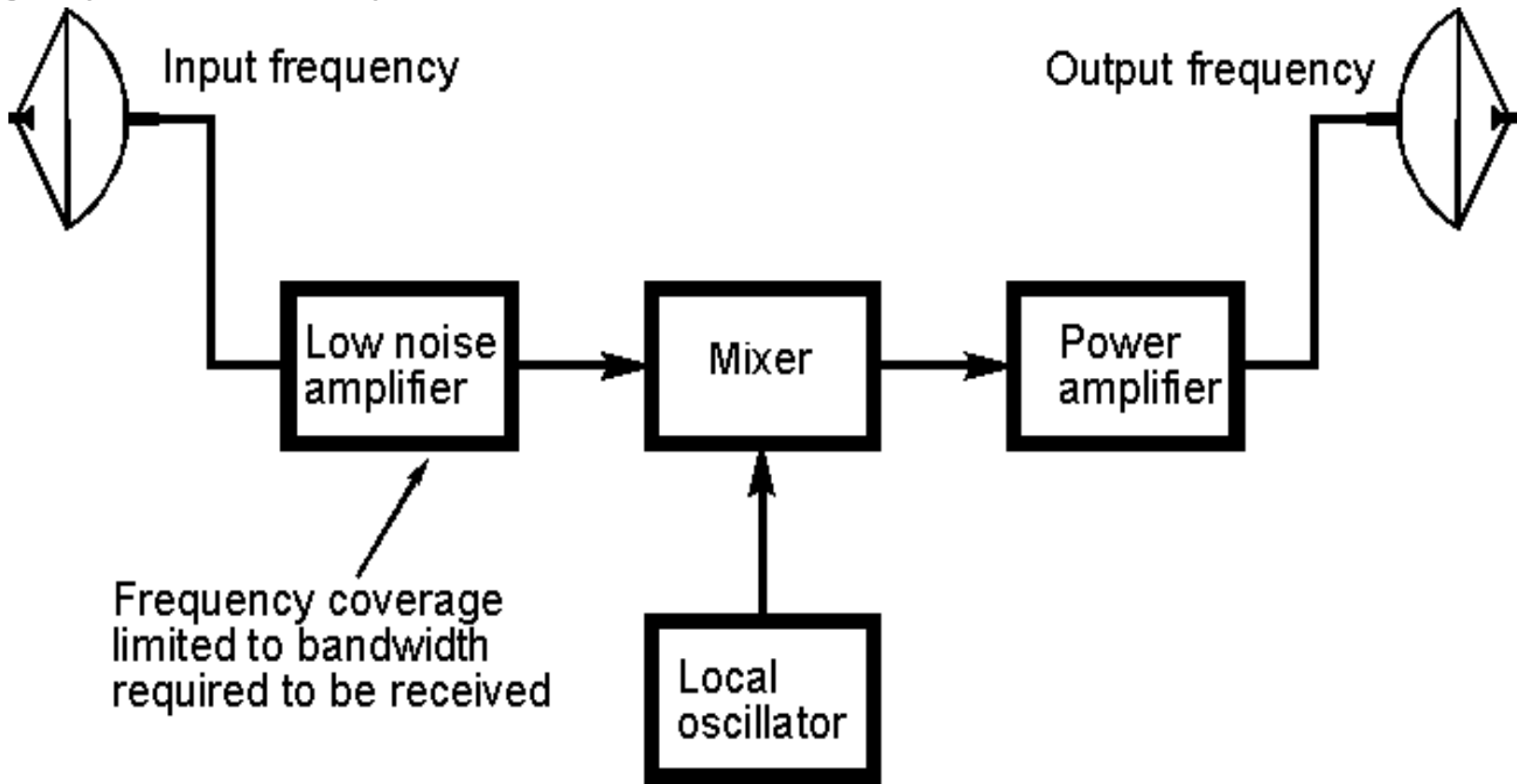
Satellite Signals

- Signals transmitted to satellites usually consist of a large number of signals multiplexed onto a main transmission. In this way one transmission from the ground can carry a large number of telephone circuits or even a number of television signals. This approach is operationally far more effective than having a large number of individual transmitters
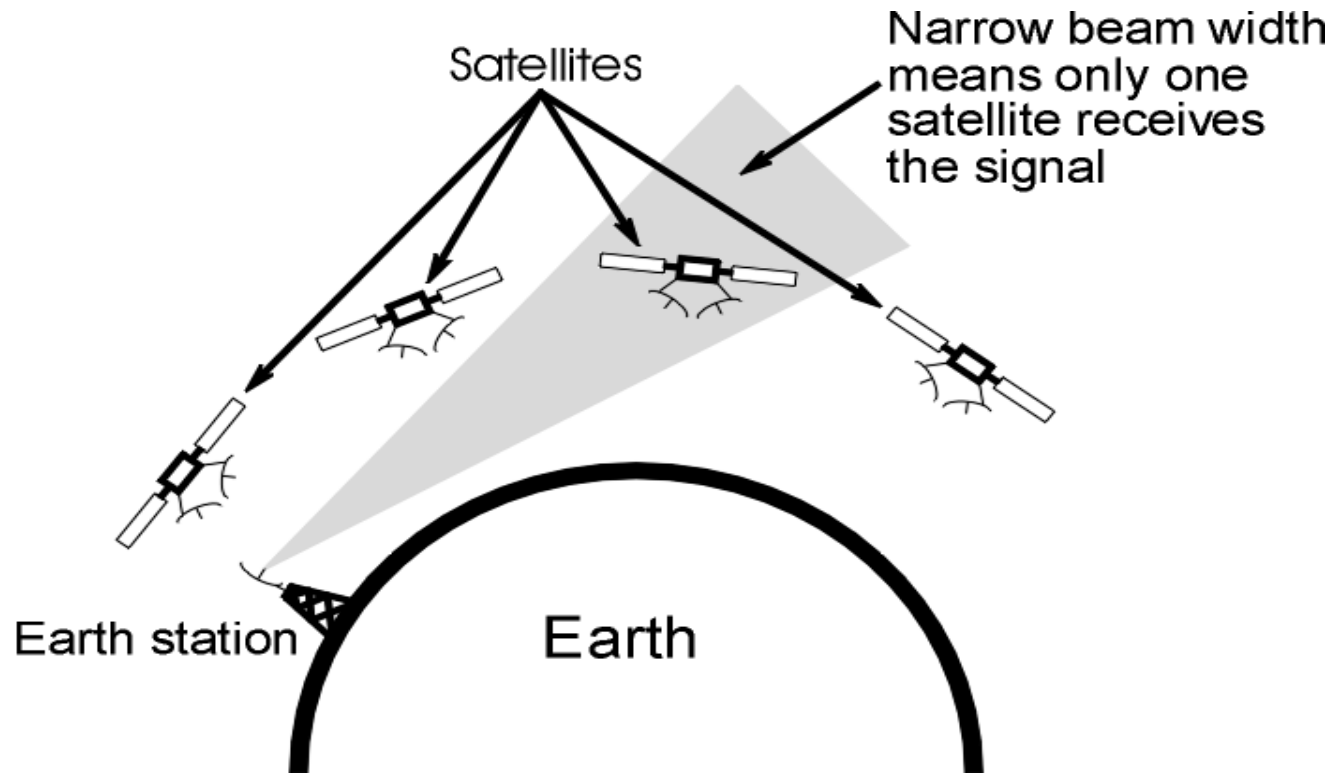
Satellite Signals

- Further capacity can be achieved using several satellites on different bands, or by physically separating them apart from one another. In this way the beamwidth of the antenna can be used to distinguish between different satellites. Normally antennas with very high gains are used, and these have very narrow beamwidths, allowing satellites to be separated by just a few degree

Satellites

Narrow beam width means only one satellite receives the signal

Earth station

Earth

Satellite Frequency Bands

-
  C Band is the oldest and most frequently used frequency for sending signals to satellite dishes. The C band consumes 3.7 to 4.2 GHz for sending the signals to earth stations (known as downlink) and 5.9 to 6.4 GHz for vice versa (known as uplink). This frequency band has been found to operate under extreme weather conditions as well.

- Ku Band or Kurtz Under band is used to transmit signals at high frequencies. The downlink frequency of the band ranges from 11.7 to 12.7 GHz while uplink frequency ranges from 14 to 14.5 GHz

- Kurtz Above or Ka Band requires more power to transmit signals. The downlink frequency range is 18.3 to 20.2 GHz while uplink frequency range is 27.5 to 31 GHz.

Satellite Frequency Bands

| Letter designation for satellite frequency band	Frequency Range (GHz)
L	1 -2
S	2 - 4
C	4 - 8
X	8 - 12 (8 - 12.5 in North America)
Ku	12 - 18 (12.5 - 18 in North America)
K	18 - 27 (18 - 25.5 in North America)
Ka	27 - 40 (26.5 - 40 in North America)
O	40 - 50
V	50 - 75

FDMA

- Satellite frequency is already broken into bands, and is broken in to smaller channels in Frequency Division Multiple Access (FDMA)

- Overall bandwidth within a frequency band is increased due to frequency reuse (a frequency is used by two carriers with orthogonal polarization)

- The number of sub-channels is limited by three factors:
  - Thermal noise (too weak a signal will be effected by background noise)
  - Intermodulation noise (too strong a signal will cause noise)
  - Crosstalk (cause by excessive frequency reusing).

TDMA

- TDMA (Time Division Multiple Access) breaks a transmission into multiple time slots, each one dedicated to a different transmitter.
- TDMA is increasingly becoming more widespread in satellite communication.
- Advantages of TDMA over FDMA.
    - Digital equipment used in time division multiplexing is increasingly becoming cheaper.
    - There are advantages in digital transmission techniques. Ex: error correction.
    - Lack of intermodulation noise means increased efficiency.
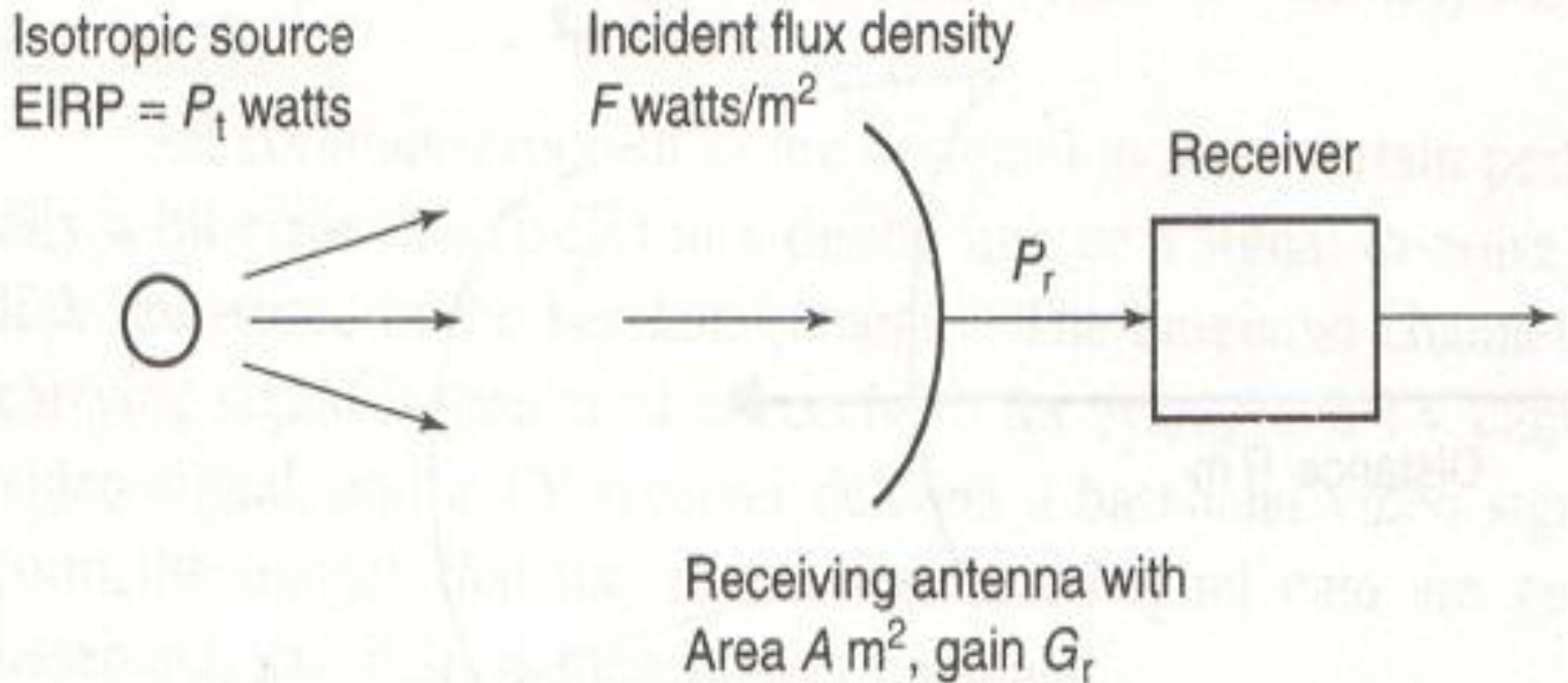
Propagation Delay

- Due to the high distances involved between a ground station and the satellite, there will be some propagation delay which is unavoidable.
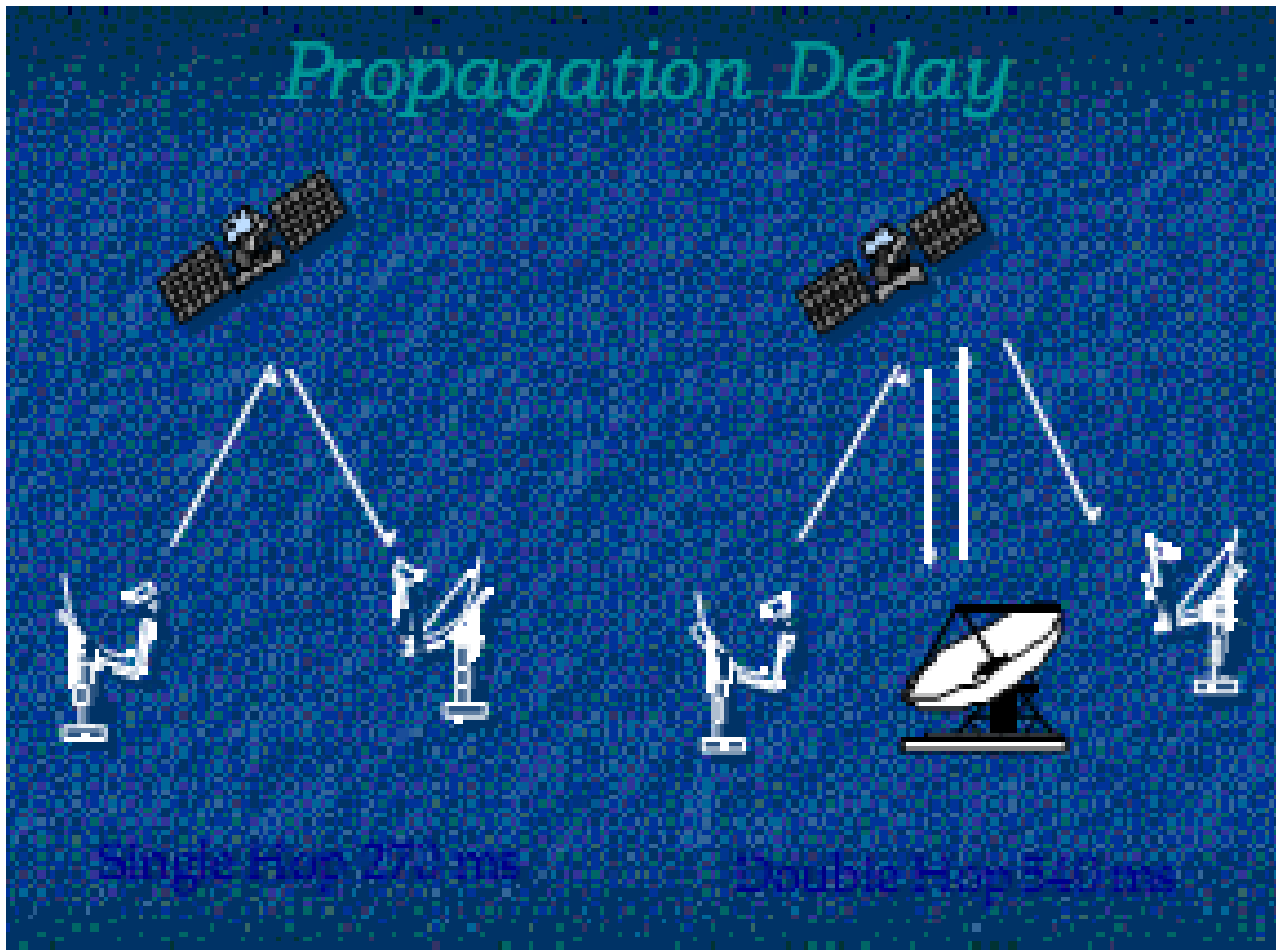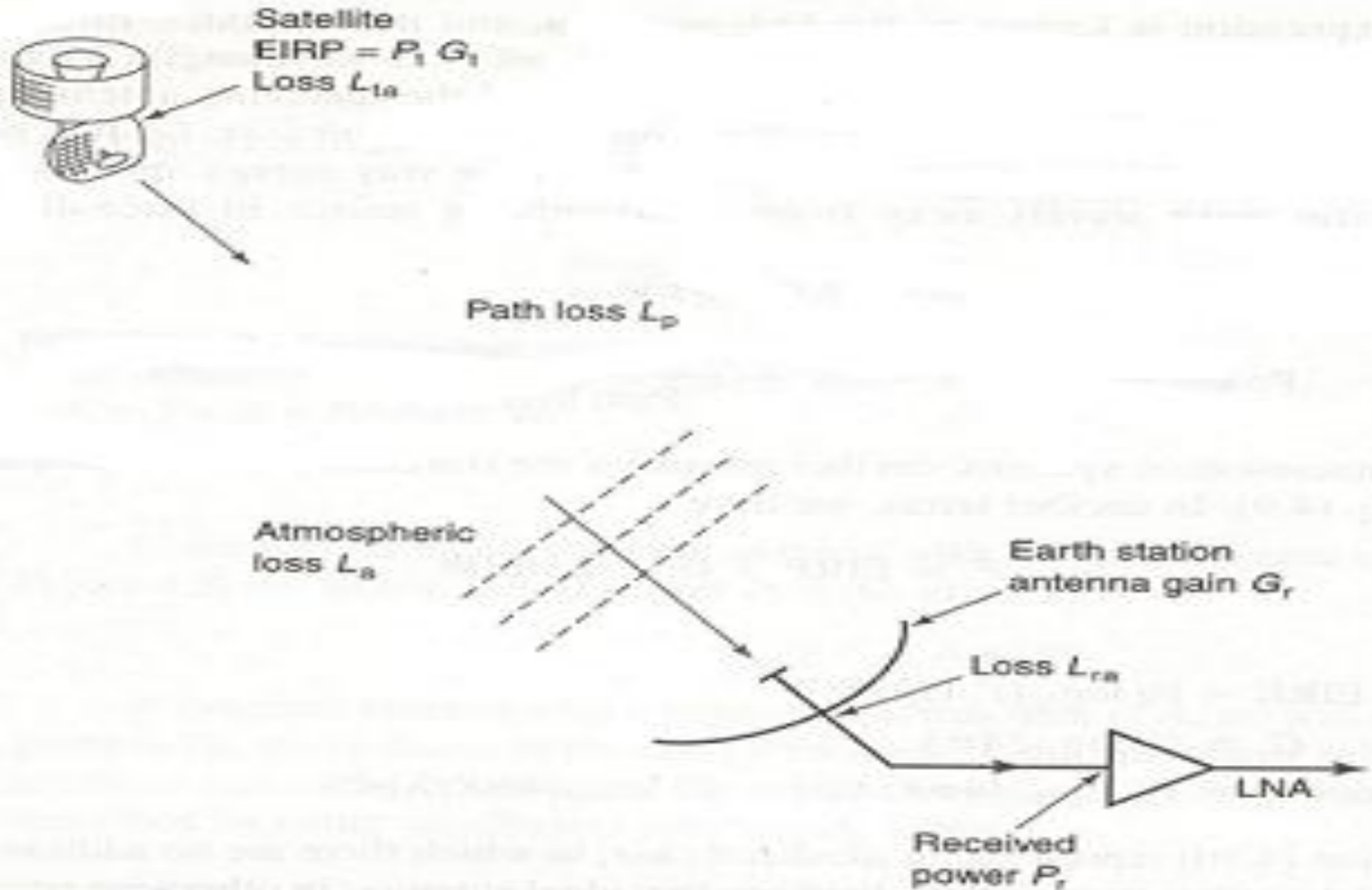
Antenna Gain

- The gain of an antenna is a measure of the antenna's capability to direct energy in one direction rather than all around.

- Reciprocity is the concept that an antenna has the same gain and pattern at any frequency whether it transmits or receives

- Satellite antennas often use paraboloidal reflector profiles to tailor the beam pattern to a particular coverage zone.

Power Received by the Antenna

Isotropic source
EIRP $= P_t$ watts

Incident flux density
F watts/m^2

Receiver

P_r

Receiving antenna with
Area A m^2, gain G_r

Power received by an ideal antenna with area A m^2. Incident flux density is $F = P_t/4\pi R^2$ W/m^2. Received power is $P_r = F \times A = P_t A/4\pi R^2$ W.

Low Noise Amplifier for Receiving

Satellite
EIRP = $P_s G_s$
Loss L_{ta}

Path loss L_p

Atmospheric
loss L_a

Earth station
antenna gain G_r

Loss L_{ra}

LNA

Received
power P_r

A satellite link. LNA, low noise amplifier.

Antenna Calculations

- If we had an ideal receiving antenna with an aperture area of A, then the power collected is:

- $P = F \times A$ (watts)

- In a real antenna, some of the energy incident on the aperture is reflected away from the antenna and some absorbed by the components. This reduction in efficiency is the effective aperture area

- $A_e = \eta_A A_r$

- η_A is the aperture efficiency with all the losses

Power Received by Antenna

- The power received by an antenna with the effective aperture receiving area would be:

$$P_r = \frac{P_t G_t A_e}{4\pi R^2}$$

Antenna Gain Calculations

- The gain of an antenna of a communications satellite is given as:

$$G = \eta_A 4\pi a / \lambda^2$$

- Where A is the area of the antenna, gamma is the operating wavelength in meters and nu is the efficiency of the antenna.

- In case of circular aperture antenna the equation is:

$$G = \eta_A (\pi D / \lambda)^2$$

Antenna Gain Example

- For a paraboloidal antenna, the isotropic power gain is given in terms of frequency is:

- $G = \eta(10.472fD)^2$

- **<u>EXAMPLE</u>**

- Calculate the gain in decibels of a 3m paraboloidal antenna operating at a frequency of 12 Ghz. Assume aperture efficiency of 0.55

    $G = 0.55 \times (10.472 \times 12 \times 3)^2 = 78168$

    From Watts to dB [G] = 10 log 78168 = 48.9 dB

System Noise Temperature

- Noise temperature is the thermal noise generated by active and passive devices in the receiving system.

- At microwave frequencies, a black body with a physical temperature of T_p degrees Kelvin will generate electrical noise over a wide bandwidth

$$P_n = k T_p B_n$$

- k = Boltzmann constant 1.39 x 10^-23 J/K=-226.6 DBW/K/Hz

- T_p= physical temperature of source in Kelvin

- B_n = noise bandwidth in which the noise power is measured in hertz

Example – Noise Temperature

- An antenna has a noise temperature of 35K and it is matched into a receiver which has a noise temperature of 100 K. Calculate the noise power for a bandwidth of 36 Mhz

$$P_n = kT_pB_n$$

- P = 1.38 x 10^-23 x (35+100) x 36 x 10^6
- P = 0.067 pW

Carrier to Noise Ratio

- Carrier to Noise Ratio C/N is used to determine the power efficiency of your broadcasting signal.

- The total C/N ratio will depend on the uplink as well as the downlink of the system.

- In satellite communication systems, we are always working with weak signals (because of large distances involved) and must make the noise level as low as possible to meet the C/N ratio requirements.

$$\frac{N}{C} = 10^{-Cu} + 10^{-Cd} + 10^{-Cim}$$

- u=uplink, d=downlink, im=intermodulation

C/N Example

- For a satellite circuit, the carrier to noise ratios are uplink 23dB, downlink 20dB, and the intermodulation is 24dB. Calculate the overall carrier to noise ratio in decibels

$$\frac{N}{C} = 10^{-Cu} + 10^{-Cd} + 10^{-Cim}$$

$$\frac{N}{C} = 10^{-2.4} + 10^{-2.3} + 10^{-2} = 0.0019$$

$$\left[\frac{C}{N}\right] = -10\log(0.0019) = 17.2 dBHz$$

THANK YOU

For further help consult Satellite Communications Textbook by Dennis Roddy

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