Transceiver 1

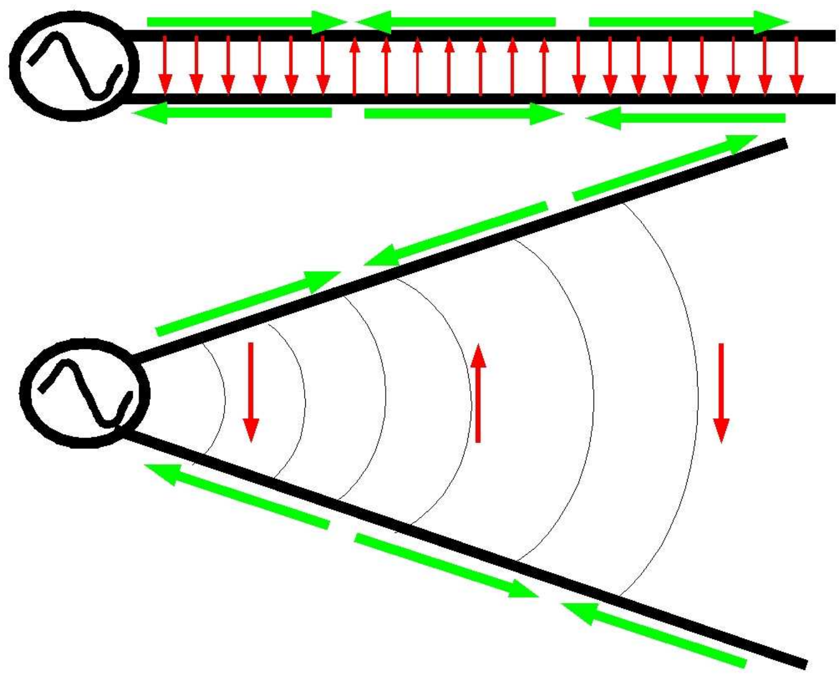
- Worth 40% of mark.
- Mark of 80% of this for the report describing all.
- Mark of 20% of this for the logbook, scrap book and description and dead bug results for the frequency synthesiser.
- $\approx 15 - 20\%$ within this for the PCB layout design and description (Eagle files).
- 0% for the working circuit.

Lecture #20 Overview

- Antennas – Radiation pattern, Gain, Friis transmission, Impedance, Radiated power, Aperture, Received power.
- Satellites
- Link budgets

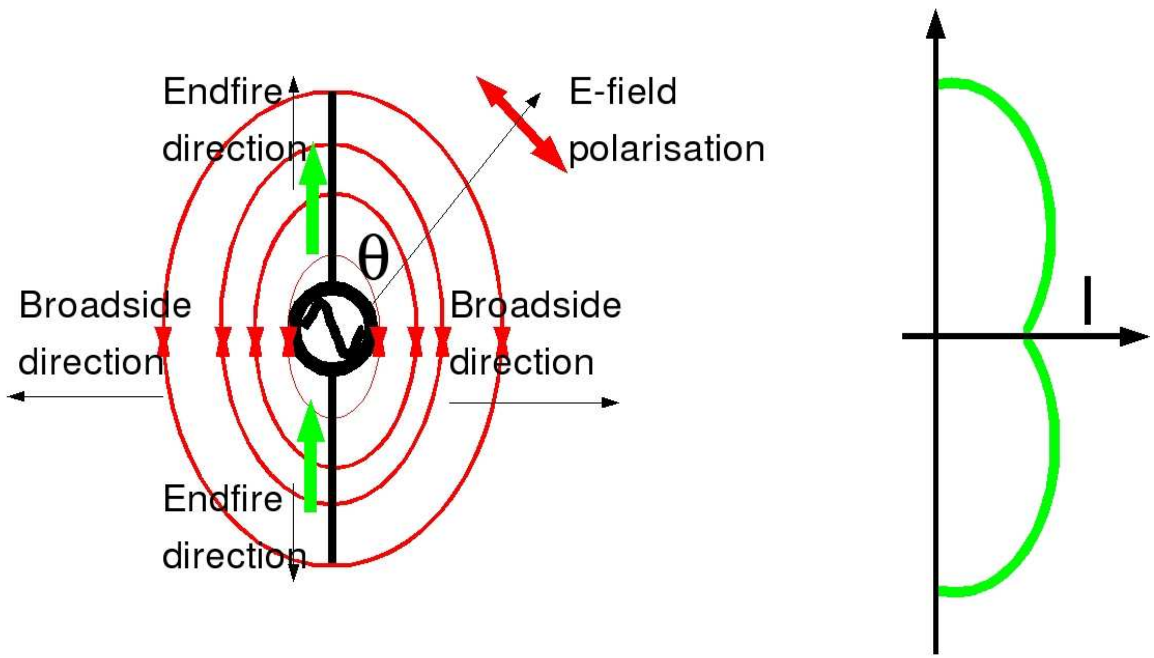
Antennas

♣ Can be thought of as an opened out transmission line.



Dipole Antennas

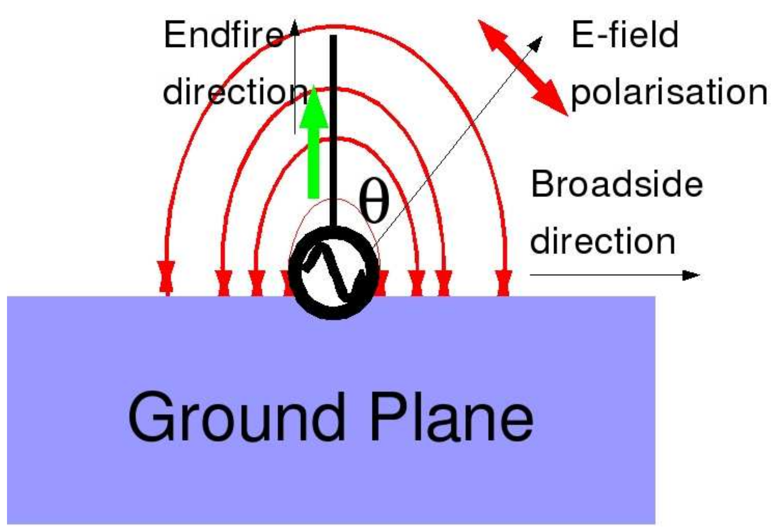
- The dipole antenna is the fully opened out symmetric twin wire transmission line.

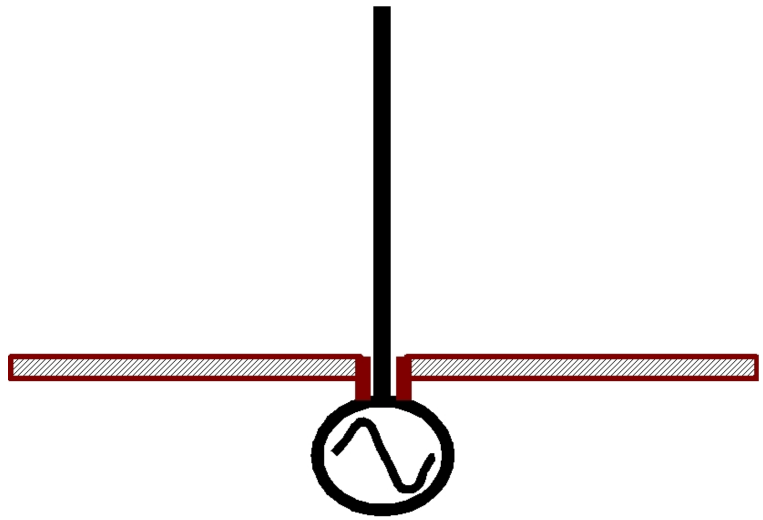


The Monopole Antenna

- The monopole antenna is a half a dipole antenna that protrudes from an earth plane.

- The impedance of a monopole is a half of that of the same dipole antenna. **WHY?**



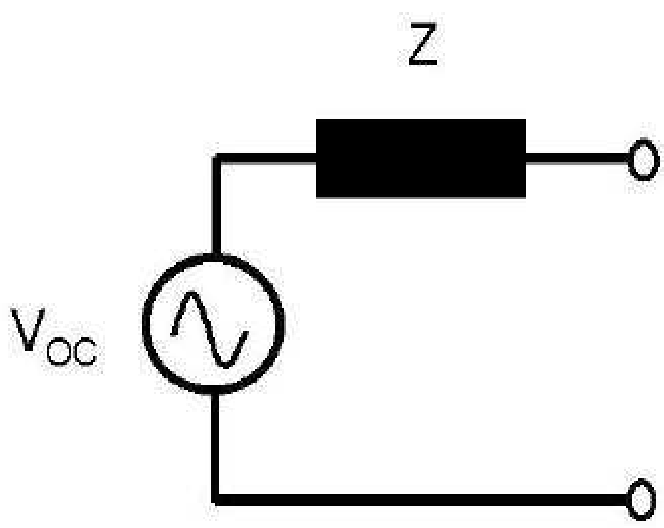


How to connect a monopole antenna?

Antennas

- Antennas look like a linear impedance to a transmitter - *Radiation impedance,* $Z = Z_{ANT}$ *(-same for reception)*

- Antennas look like a *Thevenin source* (or Norton) to a receiver. What is the O.C. voltage of the source? - Depends on many things.. local signal strength, antenna tuning and orientation.



Antenna Radiated Power

- Antennas look like a linear impedance to a transmitter - *Radiation impedance,* $Z = Z_{ANT}$ *(-same for reception)*

- Therefore the antenna radiated power is given by,

$$P_{rad} = \frac{1}{2} Re\left[\frac{|V_{ant}^2|}{Z_{ant}}\right] = \frac{1}{2} R_{ant} |I_{ant}|^2$$

Antenna Radiation Pattern

- Suppose we have a hypothetical point source radiator.

- Then the power radiated leads to a power flux S as follows

$$S = \frac{P_{rad}}{4\pi r^2}$$

- Recall the *Poynting flux*

$$\mathbf{S} = \frac{1}{2\mu_o}\mathbf{E} \times \mathbf{B}\ (\mathbf{Watts/m^2})$$

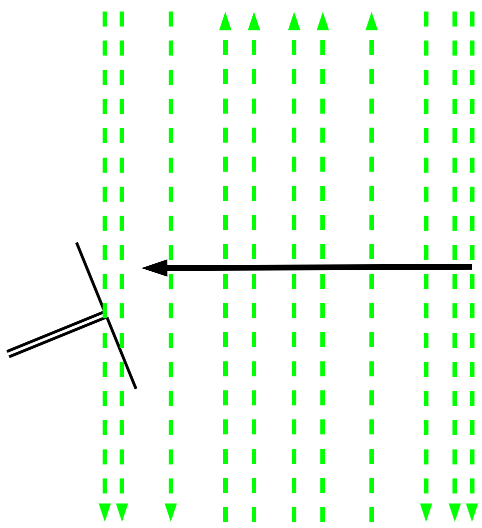
Antenna Radiation Pattern of a Transmitting Antenna

- **The form of the Poynting flux suggests that there is no such thing as an antenna with an isotropic radiation pattern.**
- Real antennas beam or focus electromagnetic energy. Thus there are preferred directions in which they radiate and receive their energy.
- *The radiation pattern of a transmitting antenna is the angular three dimensional plot of the normalised Poynting Flux*

$$R_P(\theta, \phi) = \frac{|\mathbf{S}|}{|max\,[\mathbf{S}|]}$$

Antenna Radiation Pattern of a Receiving Antenna

- *The radiation pattern of a receiving antenna is the angular three dimensional plot of the normalised received power when the antenna is rotated with respect to an incident plane electromagnetic wave*

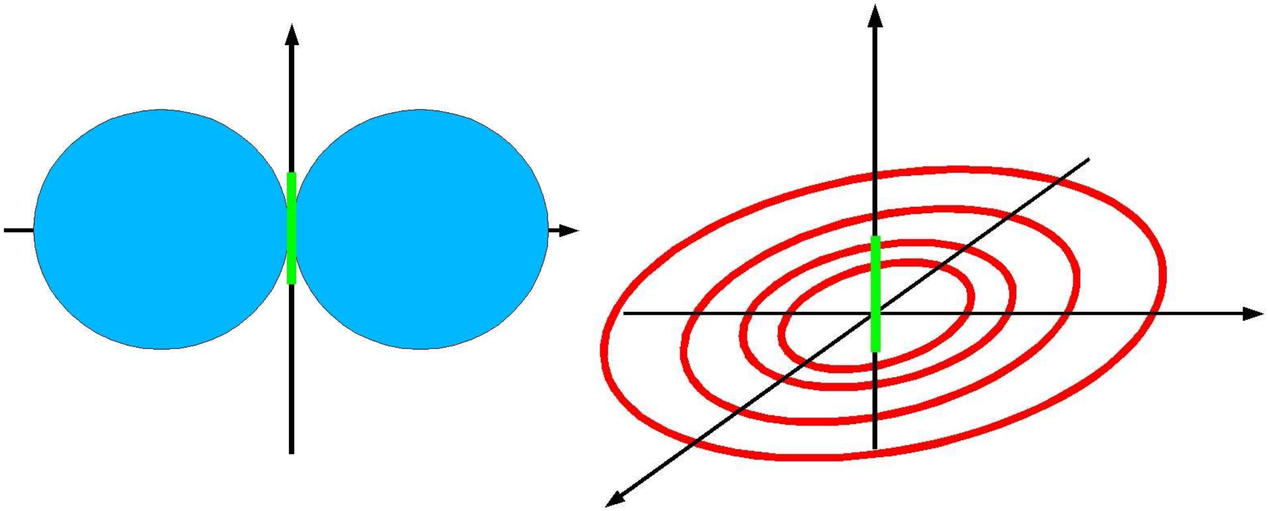


Theorem about Radiation Patterns of Antennas

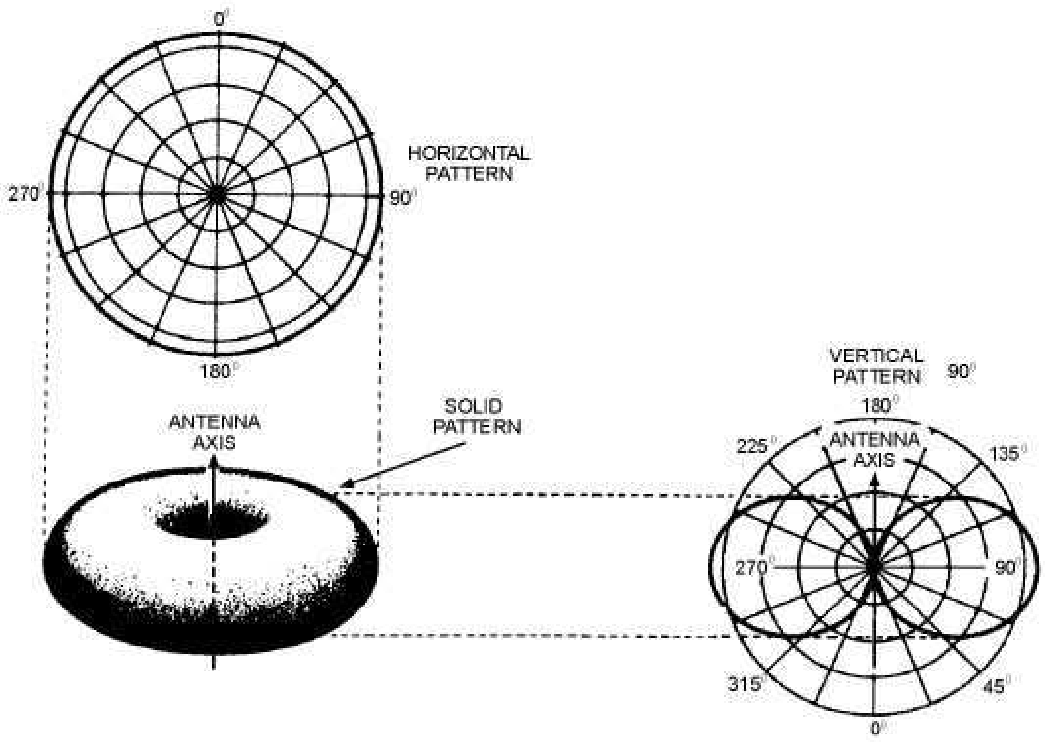
- *For any given antenna, the radiation pattern for transmission is the same as that for reception*

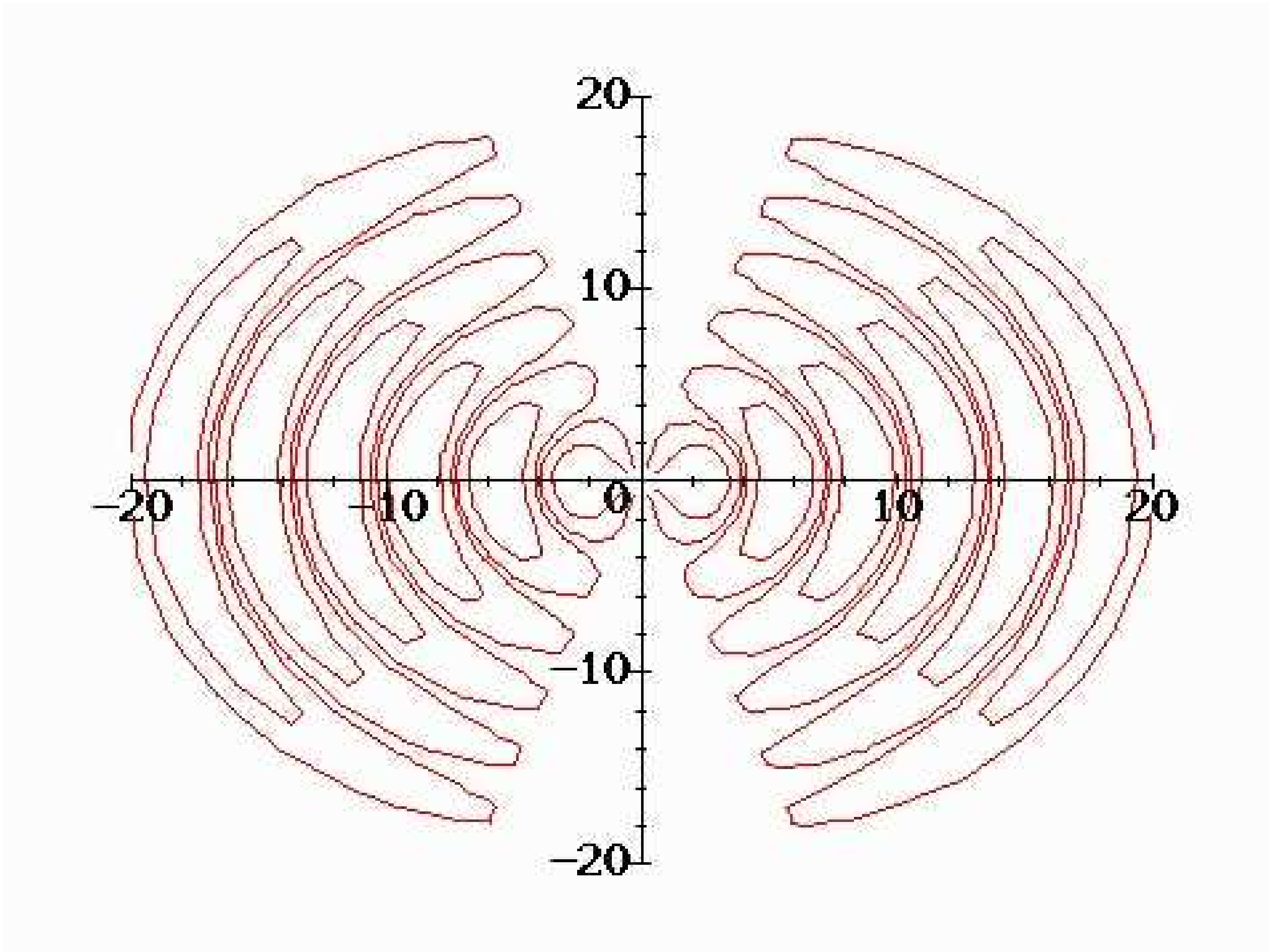
- Follows by reciprocity.

Radiation Pattern of a Dipole Antenna



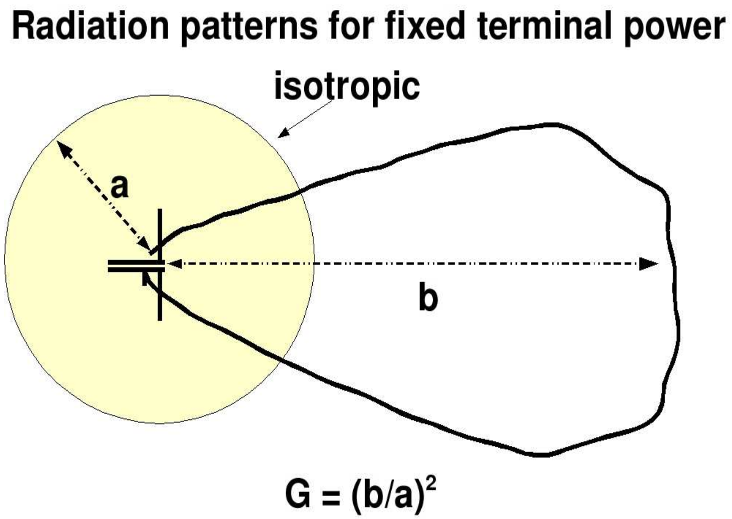
Radiation Pattern of a Dipole Antenna




20
10
−20
−10
0
10
20
−10
−20

Antenna Gain

- The *antenna gain* is the ratio of the maximum power flux density S of the antenna to that for the isotropic radiator with the same terminal power.
- Even though the isotropic radiator does not exist, it would have unity gain.
- An antenna radiation pattern looks as follows,



Antenna Gain

- If b and a represent the magnitudes of the electric field, then the gain is defined as,

$$G = \frac{b^2}{a^2} = \frac{S_{max}}{S_{isotropic}}$$

where $S_{isotropic}$ is the isotropic radiator power flux density $(Watts/m^2)$ for the *same* power at the antenna terminals.

- In dB with respect to isotropic (dBi)

$$G(dBi) = 10 \log_{10} \left(\frac{S_{max}}{S_{isotropic}} \right)$$

- This formula neglects the *insertion loss* in the antenna.

Antenna Gain: Beam Solid Angle

- The *Beam solid angle* is defined as

$$\Omega_A = \int_{4\pi}\int d\Omega \frac{|\mathbf{S}|}{|max\left[|\mathbf{S}|\right]}$$

- The *Antenna Directivity* is defined as,

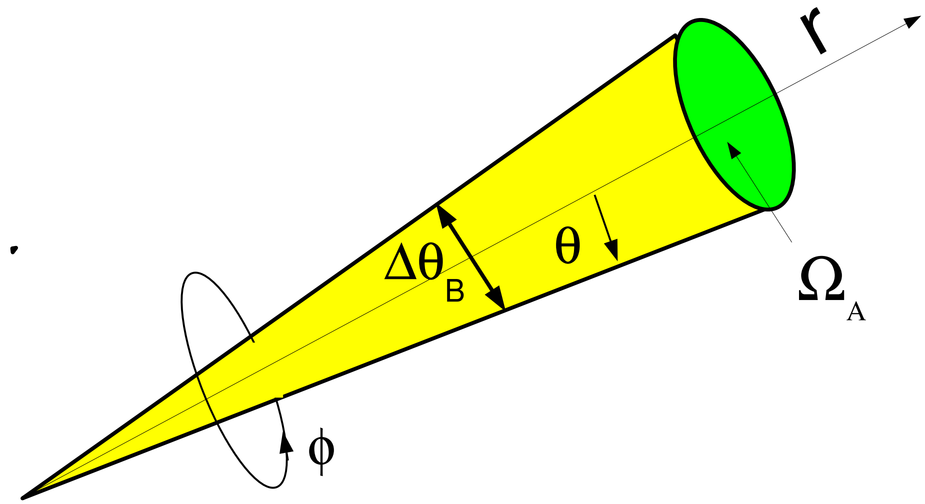
$$D = \frac{4\pi}{\Omega_A}$$

- The *Directivity* is just the antenna *Gain* not including insertion loss (K).

$$G = kD$$

Antenna Gain: Beam Solid Angle

- Let us define $\Delta\theta_B$ to be the angle subtended by the beam solid angle.
- We assume that the radiation pattern has cylindrical symmetry around the radius vector that points along the direction of maximum Poynting flux.



Antenna Gain: Beam Solid Angle

- The beam solid angle Ω_A is related to $\Delta\theta_B$ by,

$$\Omega_A = \int_0^{\Delta\theta_B/2} \int_0^{2\pi} \sin\theta d\theta d\phi = 2\pi \left(1 - \cos\frac{\Delta\theta_B}{2}\right)$$

- The angle ϕ is measured around the r-axis and θ from the r-axis.

- For an antenna with sufficiently high gain where x is small, $\cos x \approx 1 - x^2/2$, so that

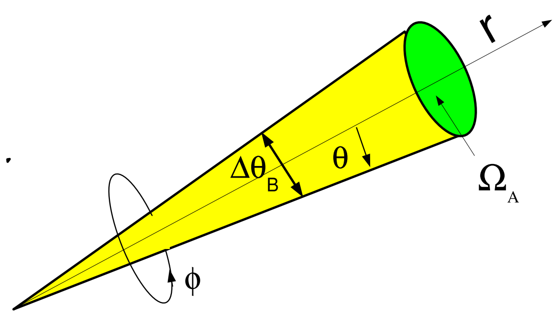
$$\Omega_A = \frac{\pi}{4} (\Delta\theta_B)^2$$

Antenna Gain

- For small beamwidths,

$$D = \frac{4\pi}{\Omega_A} = \frac{4\pi r^2}{\pi \frac{\Delta\theta_B r}{2}^2} = \frac{16}{\Delta\theta_B^2}$$

- $http : //www.ece.rutgers.edu/\ orfanidi/ewa/ch14.pdf$ p. 497



Equivalent Isotropic Radiated Power.

- *Equivalent Isotropic Radiated Power (EIRP)* is the power applied at the terminals of an isotropic antenna.

- EIRP is often used to specify a legal emitted power limit at a certain frequency.

- EIRP limits the allowed terminal power of an antenna such that the maximum flux density so produced is less than or equal to that of an isotropic radiator with a terminal power equal to the EIRP.

$$P_{allowed\,at\,antenna\,terminals} = \frac{EIRP}{G}$$

Maximum Radiated Power Flux Density of an Antenna

- The maximum power flux density of a radiating antenna is just given by the gain multiplied by the power of the isotropic radiator excited with the same terminal power.

$$S_{MAX} = \frac{GP_{transmitted}}{4\pi r^2}$$

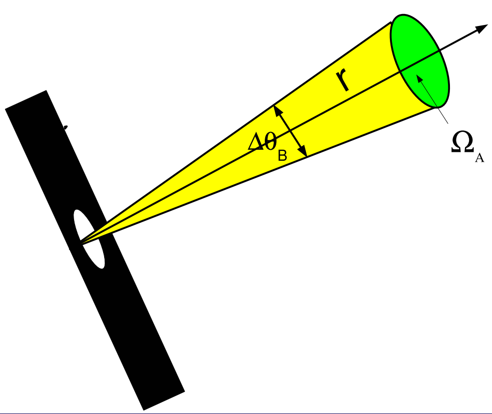
Effective Aperture of a Dish Antenna

- Imagine a planar light beam illuminating a round hole on a black screen at normal incidence.

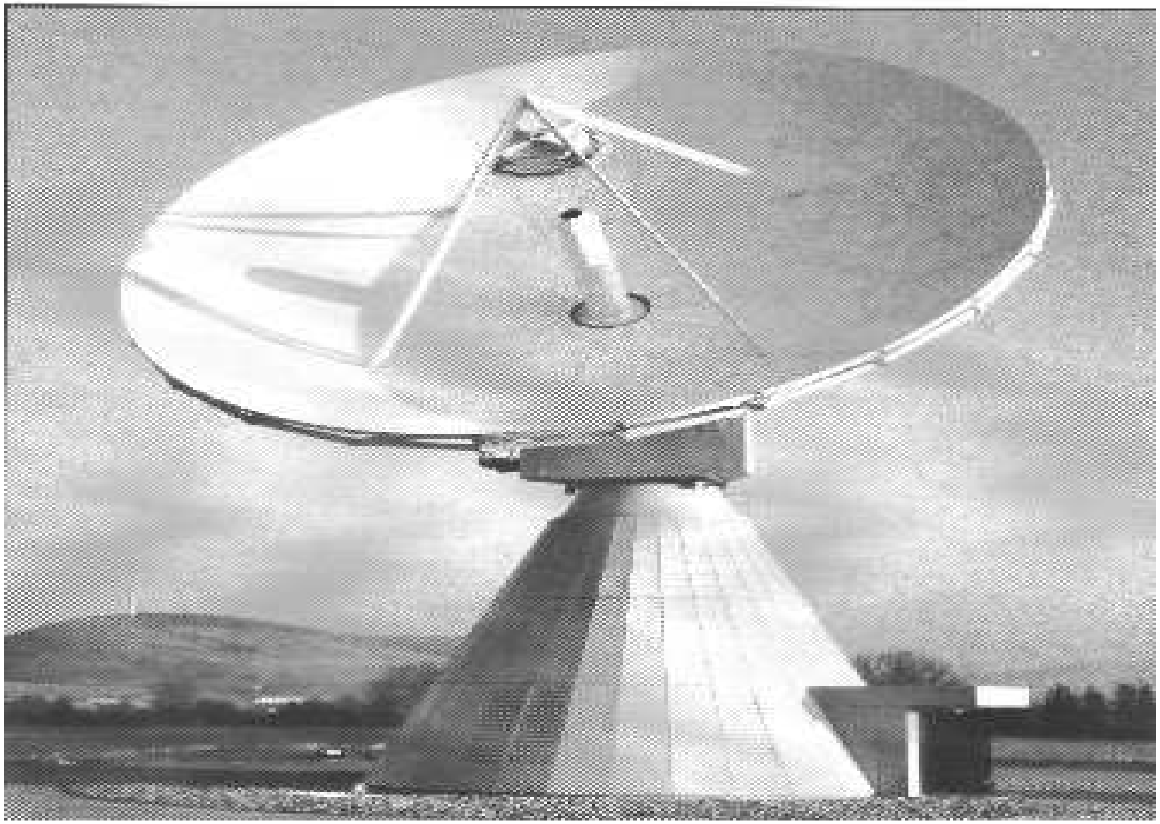
- The Rayleigh condition for a diffraction limited aperture describes the angle of expansion of the beam on exit from the hole.

$$\Delta\theta_B = \frac{4\lambda}{\pi d}$$

where λ is the wavelength, $\Delta\theta_B$ is the opening angle of the beam and d is the diameter of the aperture.



18.3 m INTELSAT Standard A Earth Station



Effective Aperture of a Dish Antenna

- Such a beam can also be formed by a parabolic dish of diameter d which is excited at its focus.

- The antenna gain G of the dish is given by

$$G = \frac{16}{\Delta\theta_B^2} = \left(\frac{\pi d}{\lambda}\right)^2$$

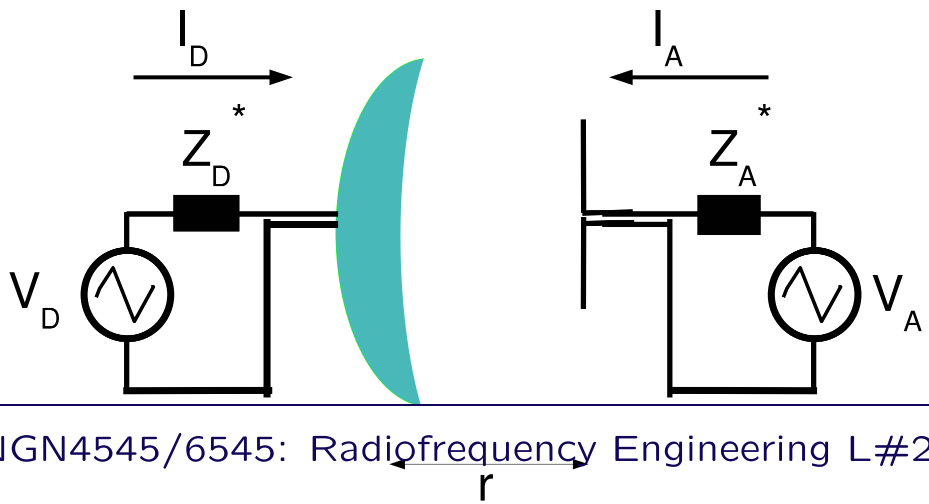
- Thus

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

- For a dish antenna, $A_e = \frac{G\lambda^2}{4\pi}$

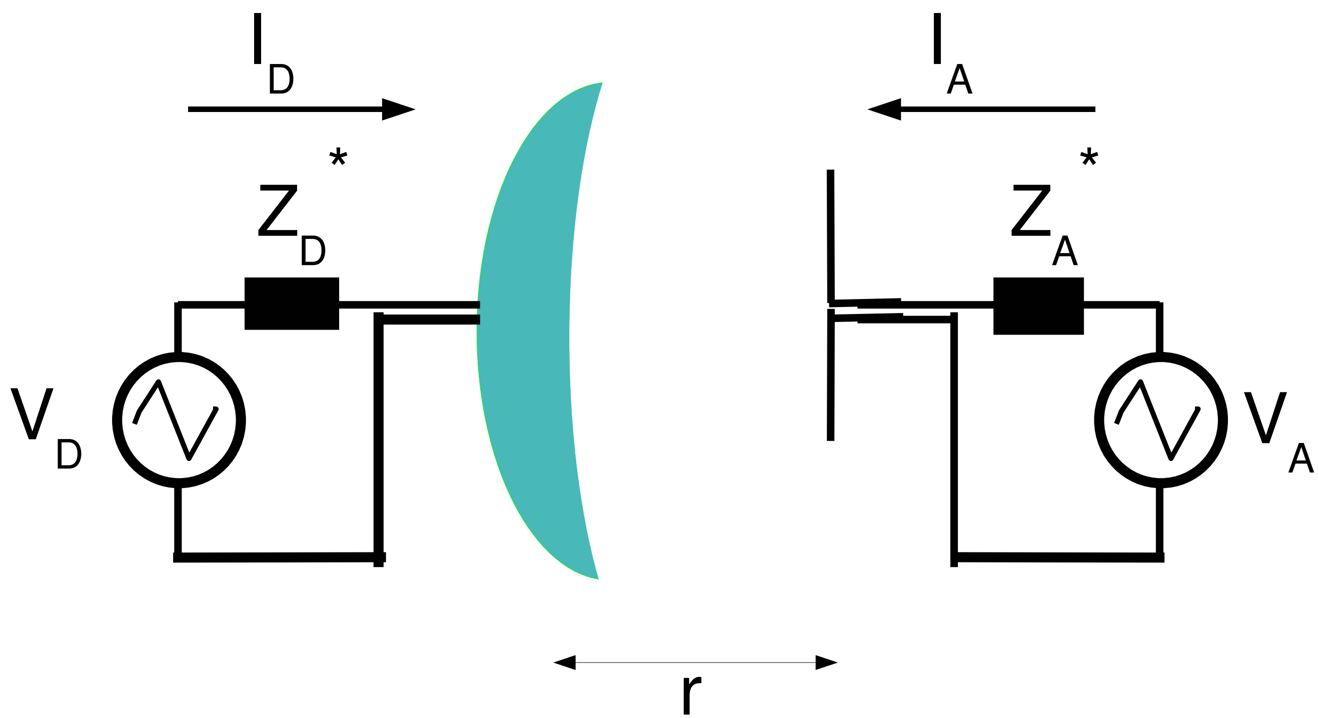
Non-Rigorous Proof of Antenna Aperture

- Consider communications between a dish and an arbitrary antenna each matched to a pair of signal generators.
- If the dish transmits and the antenna receives then $P_A = \frac{A_A G_D P}{4\pi r^2}$
- If the antenna transmits and the dish receives then $P_D = \frac{A_D G_A P}{4\pi r^2}$
- By reciprocity $P_A = P_D$, therefore $A_A/G_A = A_D/G_D$.
- Because $A_D = \frac{G_D \lambda^2}{4\pi}$, then $A_A = \frac{G_A \lambda^2}{4\pi}$ Q.E.D



Rigorous Proof of Antenna Aperture

- Consider communications between a dish and an arbitrary antenna each matched to a pair of signal generators.



Rigorous Proof of Antenna Aperture

- The two antenna system is a four port network so that,

$$I_D = y_D V_D + y_{DA} V_A$$

$$I_A = y_{AD} V_D + y_A V_A$$

- **We must assume that the dish absorbs all the radiation incident upon it in both its terminating impedances**

- Effectively we are going to show that any antenna can do the same as a dish antenna... Dish antennas are just convenient mathematical objects.

Rigorous Proof of Antenna Aperture

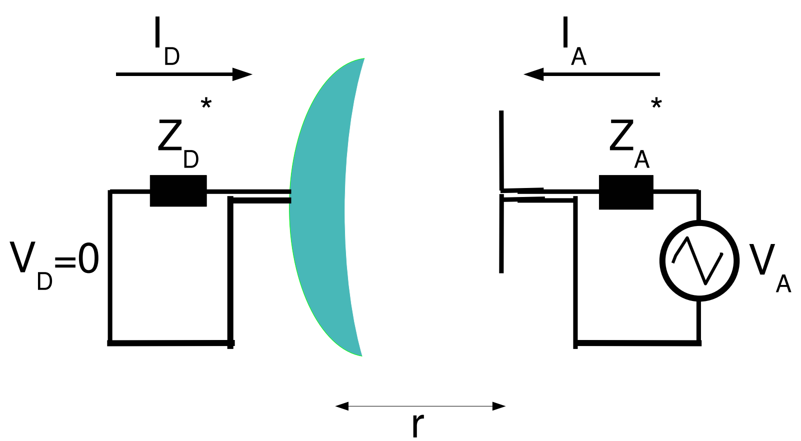
- Step 1: Let the antenna be the transmitter and the dish the receiver.

$$I_D = y_{DA} V_A$$

- Power balance:

$$2.\frac{1}{2} I_D^2 R_D = \frac{A_D G_A P_A}{4\pi r^2}$$

- where $P_A = \frac{V_A^2}{4R_A}$



Rigorous Proof of Antenna Aperture

- Step 1: Substitute

$$I_D^2 R_D = \frac{A_D G_A V_A^2}{16\pi R_A r^2}$$

- $I_D^2 = |y_{DA}|^2 |V_A|^2$ so

$$|y_{DA}|^2 R_A R_D = \frac{A_D G_A}{16\pi r^2}$$

Rigorous Proof of Antenna Aperture

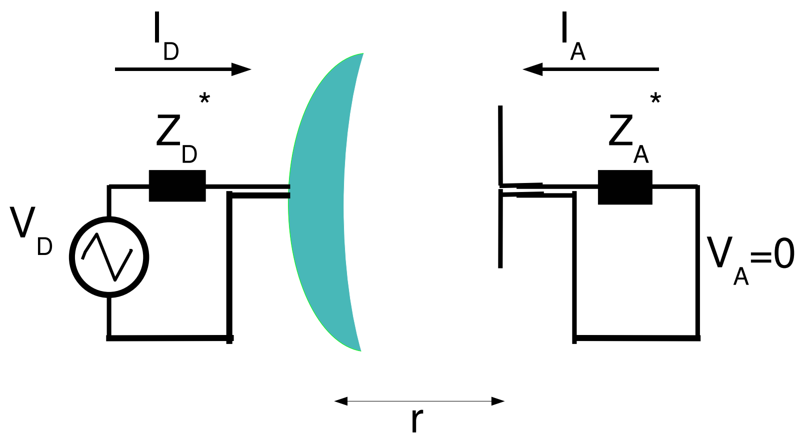
- Step 2: Let the dish be the transmitter and the antenna the receiver.

$$I_A = y_{AD} V_D$$

- Power balance:

$$2.\frac{1}{2} I_A^2 R_A = \frac{A_A G_D P_D}{4\pi r^2}$$

- where $P_D = \frac{V_D^2}{4R_D}$



Rigorous Proof of Antenna Aperture

- Step 2: Substitute

$$I_A^2 R_A = \frac{A_A G_D V_D^2}{16\pi R_D r^2}$$

- $I_A^2 = |y_{DA}|^2 |V_D|^2$ so

$$|y_{AD}|^2 R_D R_A = \frac{A_A G_D}{16\pi r^2}$$

Rigorous Proof of Antenna Aperture

- Compare the results of steps 1 and 2.

$$|y_{DA}|^2 R_A R_D = \frac{A_D G_A}{16\pi r^2}; \qquad |y_{AD}|^2 R_A R_D = \frac{A_A G_D}{16\pi r^2}$$

- Divide these two equations...

$$\frac{|y_{DA}|^2}{|y_{AD}|^2} = \frac{A_D G_A}{A_A G_D}$$

- Thus provided that reciprocity holds, we may finally write,

$$A_A = \frac{A_D G_A}{G_D} = \frac{G_D \lambda^2 G_A}{4\pi G_D} = \frac{G_A \lambda^2}{4\pi}$$

Antenna Aperture: Useful to compute received power.

- The effective aperture of **any antenna** is given by:

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

where λ is the wavelength, G is the antenna gain.

- Effective aperture only depends on antenna gain and the wavelength of operation.

- E.G. A low gain monopole tuned to 3 MHz has an aperture $A_e = G\lambda^2/4/\pi \approx 100^2/4/\pi = 800m^2$!!!

Antenna Aperture

- *If an antenna is oriented for maximum signal and correctly tuned $Z_{load} = Z^*_{ANT}$, it will intercept a maximum signal power equal to:*

$$P = S_i A_e$$

- where S_i is the incident power flux density (Watts per m^2) and A_e is the *antenna effective aperture*.

- An antenna absorbs half this power into a matched load and reradiates (scatters) the other half **WHY?**.

Example: The gain of a satellite dish

- Consider a dish of diameter D for 4 GHz ($\lambda = 7.5cm$). How big must D be for a gain of 50 dBi?

$$A_e = \frac{\pi D^2}{4}$$

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

- Thus we can compute the diameter. 50dBi $= 10^5$

$$D = \sqrt{(G)}\frac{\lambda}{\pi} = \sqrt{(10^5)}\frac{\lambda}{\pi} = 7.55\,m$$

The Friis Transmission Formula

- We know how to calculate the power radiated by an antenna, the maximum flux density of an antenna from its gain and the power intercepted by an antenna from A_e

- If we assume that the antennas are aligned for maximum transmission and reception, then in free space,

$$P_r = \frac{G_t A_r P_t}{4\pi r^2}$$

where A_r is the receiving aperture of the receiving antenna.

- Since $A_r = G_r \lambda^2/(4\pi)$

$$P_r = G_t G_r P_t \left[\frac{\lambda}{4\pi r}\right]^2$$

Antennas (Cont.): Antenna Noise

- Random noise comes from the sky: E.G. The *cosmic radiation background at* $3^o K$.

- Black body radiation => *it must be there at finite temperature even in a vacuum!*

- This noise can be picked up by antennas. In a receiver it adds to the noise of the receiver electronics.

- PSD $= N_o = KT$ where K $= 1.38 \times 10^{-23} J/^oK$ and T is the absolute temperature. Thus the noise power is

$$P_n = kTB$$

- Such noise picked up by the antenna leads to the definition of antenna *temperature*.

Link Budget: Friis transmission

- The Friis transmission formula describes e.m. propagation between line of sight antennas:
$$P_r = P_t \frac{G_1 G_2 \lambda^2}{(4\pi r)^2}$$
where P_t and P_r are the transmit and received powers, $G (= G_1, G_2)$ is the gains of the antennas at each end of the link, r is the distance between the antennas and λ the wavelength.

- Note in particular the dB with respect to 1 mW.. dBm

$$P(dBm) = 10 \log_{10} \frac{P(Watts)}{.001}$$

Link Budget: Example

Determine required parabolic dish diameter of a 4 GHz earth station antenna if its system temperature is 100k for an S/N ratio of 20 dB, Bw 30MHz and satellite transponder power of 5 Watts, dish diameter 2 m and spacing between (GEO) satellites = 2^o

In dB...

$$G_{earth} = (-P_t + 20 + P_n) - G_{sat} - 10log_{10}[(\frac{\lambda}{4\pi 36000000})^2]$$

where $G_{sat} = \frac{4\pi A_{sat}}{\lambda^2} = 35.4dB$ and $A_{sat} = \pi D_{sat}^2/8 = 1.6m^2$ is the satellite antenna aperture (assuming 50% aperture efficiency).

Link Budget: Example

- Using noise and transmitted powers (dBm)

$$P_n = 10\log_{10}(KTB/.001) = -104$$

$$P_t = 10\log_{10}(5/.001) = 37$$

we obtain $G_{earth} = 39.3dB$ and

$$A_{earth} = (10^{G_{earth}/10})\frac{\lambda^2}{4\pi} => D_{earth} = 2\sqrt{(2A_{earth}/\pi)}$$

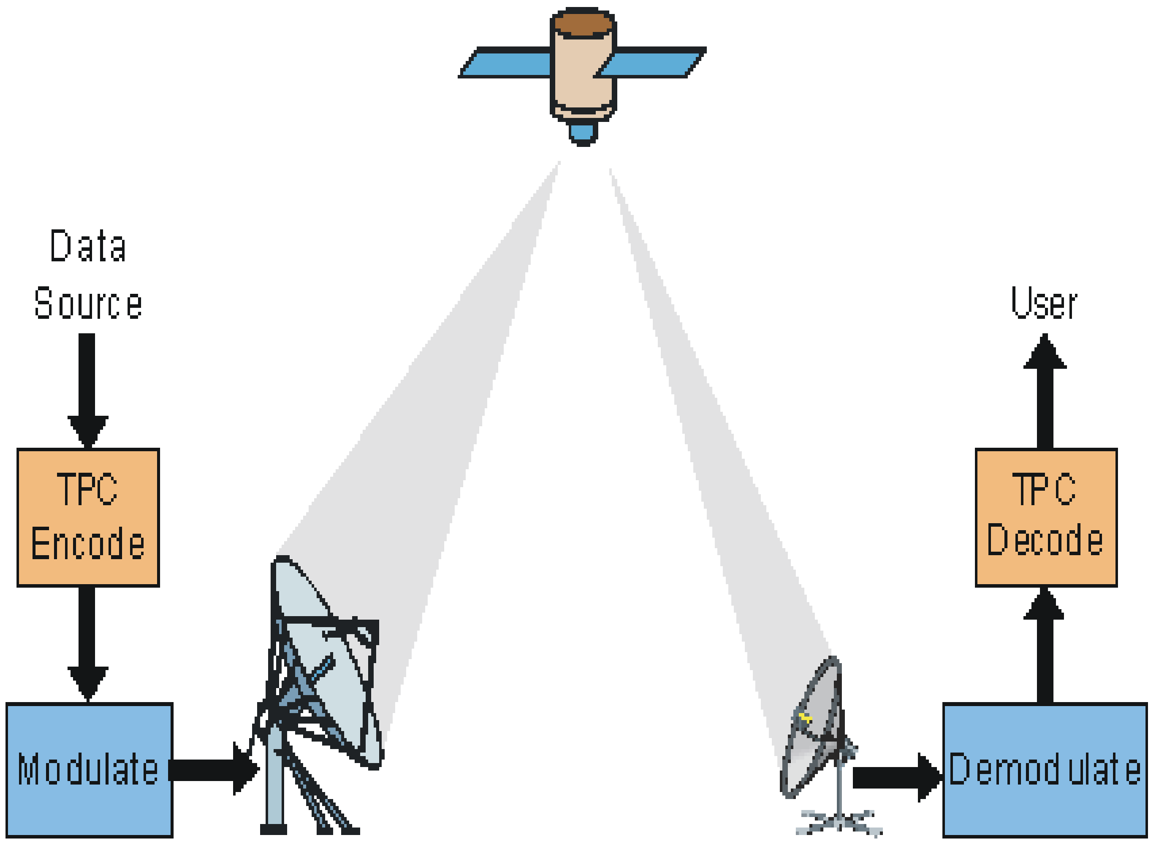
and $D_{earth} = 3.12m$.

Satelllite Frequency Bands

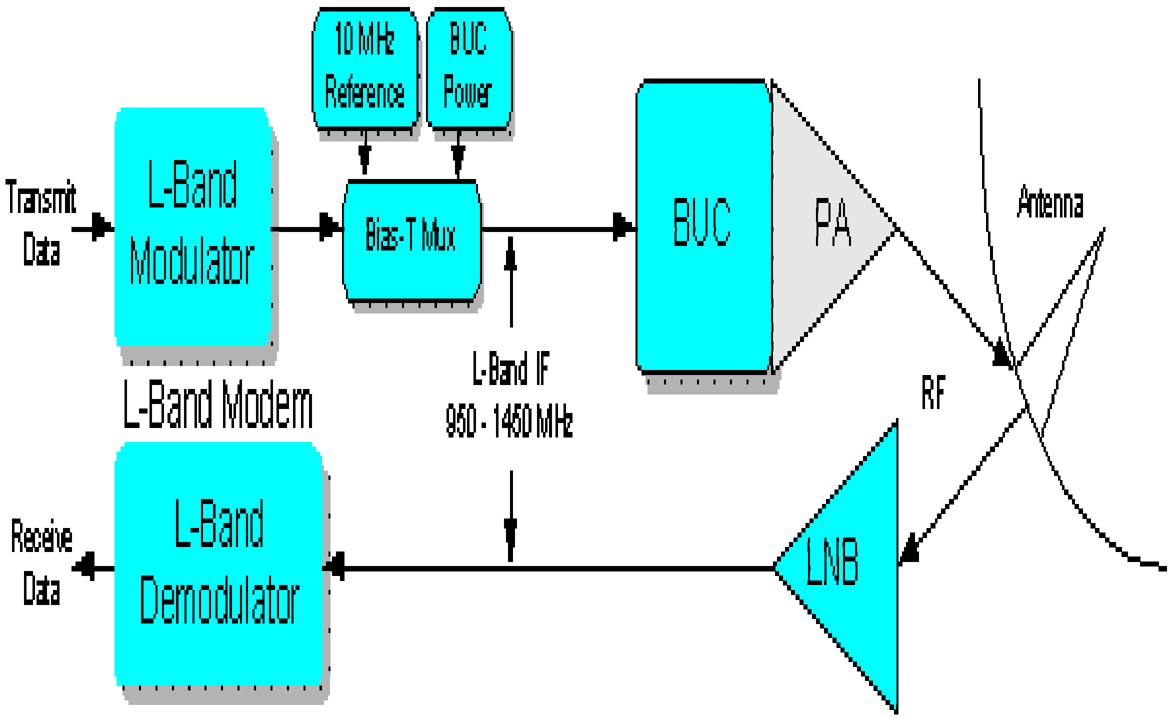
SATELLITE FREQUENCY BANDS

• L BAND	1-2 GHZ	MOBILE SERVICES
• S BAND	2.5-4 GHZ	MOBILE SERVICES
• C BAND	3.7-8 GHZ	FIXED SERVICES
• X BAND	7.25-12 GHZ	MILITARY
• Ku BAND	12-18 GHZ	FIXED SERVICES
• Ka BAND	18-30.4 GHZ	FIXED SERVICES
• V BAND	37.5-50.2 GHZ	FIXED SERVICES

General Satellite System Block Diagram.



Typical ground terminal



Full L-Band IF Satellite Station Components