Lecture #19 Overview

- Antennas
- link budgets
- Satellites

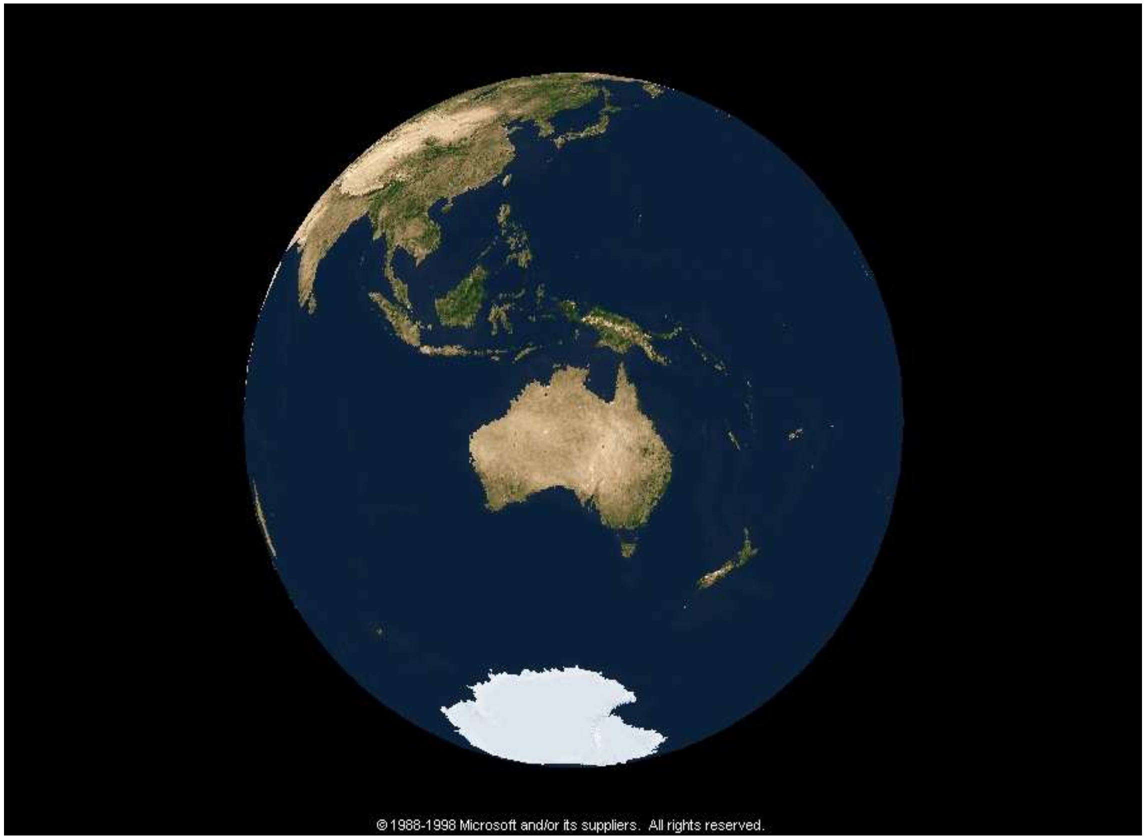
Satellite Communications

- Originally proposed by Arthur C. Clarke (1945)
- Therefore must be science fiction! (2001 a space odyssey is by now known to be science fiction...)
- But 1951: Up went sputnik.
- Then in 1963: The first successful GEO satellite was in orbit (Syncom 2).
- Now there are hundreds of satellites in the geostationary or Clarke orbit.

Satellite Communications Systems

- Have made *transoceanic relaying* of television signals possible (e.g. Olympics, World Cup, Gulf War...)
- Most communication satellites are in *geostationary orbit (GEO)*
- This is a *circular* orbit in the Earth's *equatorial plane* and is around 36000km above the equator so that the orbital period is the same as Earth's spin rotation.
- So, a GEO satellite appears stationary from earth.
- (Note - restricted by *speed*. *Too fast* $\Rightarrow$ take off into space, *too slow* $\Rightarrow$ fall back to earth.)

Earth as seen from geostationary orbit (36,000 kms)



THE AUSTRALIAN NATIONAL UNIVERSITY

So how do they stay up?

- Satellite orbit is a balance between the centrifugal and gravitational forces (typical of planetary motion)

$$m\Omega^2 R = \frac{GM_e m}{R^2}$$

where $\Omega = \frac{2\pi}{T}$ is the angular rotation speed, R is the satellite orbital radius, G $= 6.67 \times 10^{-11}$ $SI\,units$, M_e the mass of the earth 5.98×10^{24} kgs and m is the mass of the satellite.

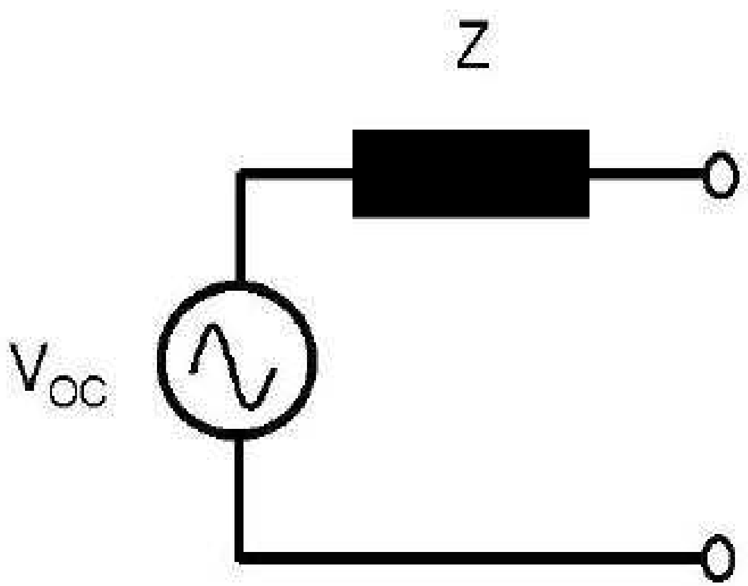
- **Orbital parameters do NOT depend on the mass of the satellite**. *Kepler's law*:

$$\frac{R^3}{T^2} = \frac{GM_e}{4\pi^2}$$

- For a GEO satellite, $R = 36000 kms \; => \; T = \sqrt{\frac{4\pi^2 R^3}{GM_e}} \approx 1\, day$.

Antennas

- Antennas look like a linear impedance to a transmitter - *Radiation impedance,* $Z = Z_{ANT}$ *(-same for reception)*
- Antennas look like a *Thevenin source* to a receiver. What is the O.C. voltage of the source? - Depends on many things.. local signal strength, antenna tuning and orientation.



Antennas

- *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*.

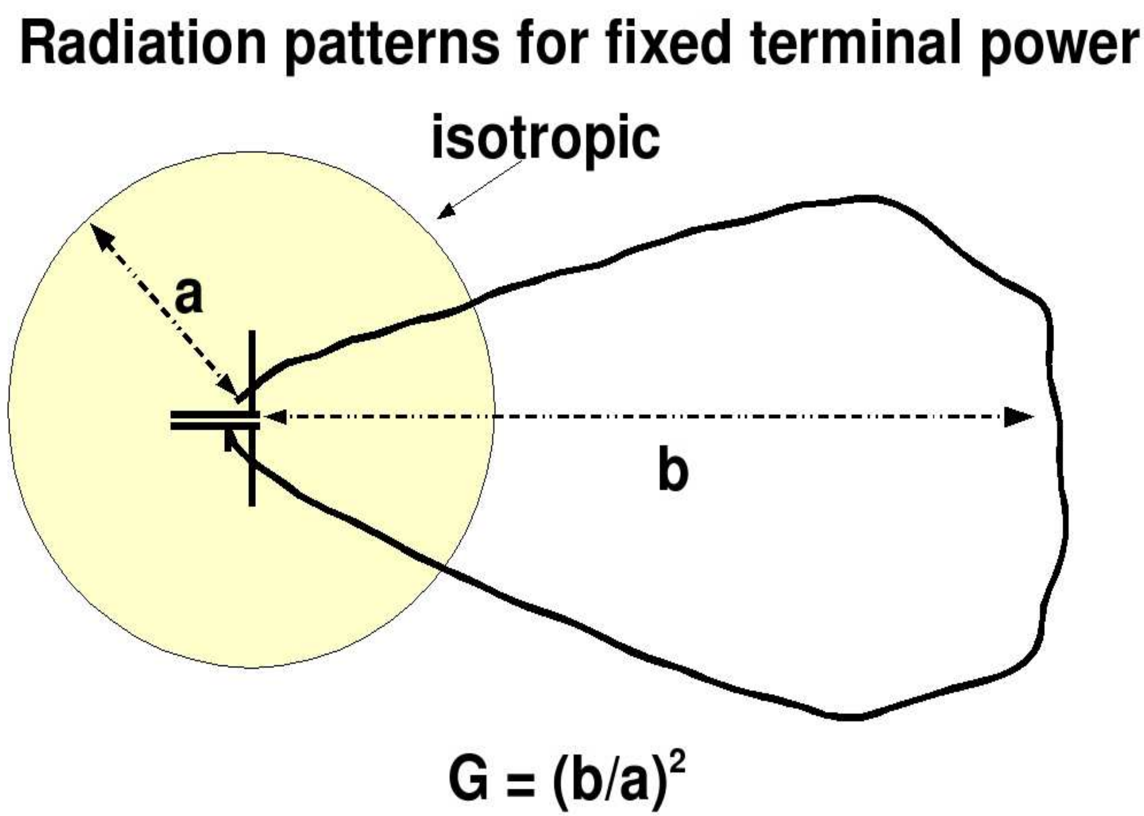
Antennas: Gain

- Suppose we have a hypothetical point source radiator.
- Then the power radiated leads to a power flux S as follows

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

- Such a source (even though it does not exist) has unity gain.
- Antennas beam or focus electromagnetic energy. Thus there are preferred directions in which they radiate and receive their energy.
- 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 overall radiated or terminal power (unit: dBi=dB isotropic).
- Related quantity: *equivalent isotropic radiated power or EIRP* restricts the maximum radiated power flux equal to that of the isotropic antenna.

Antennas: Gain (Cont.)



Antennas (Cont.): Antenna Effective Aperture

- The antenna effective aperture 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.

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

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

Antennas (Cont.): Antenna Effective Aperture

- The Rayleigh condition for a diffraction limited aperture

$$\Delta\theta = \frac{4\lambda}{\pi D}$$

where λ is the wavelength and $\Delta\theta$ is the opening angle of the beam.

- The antenna gain G is given by

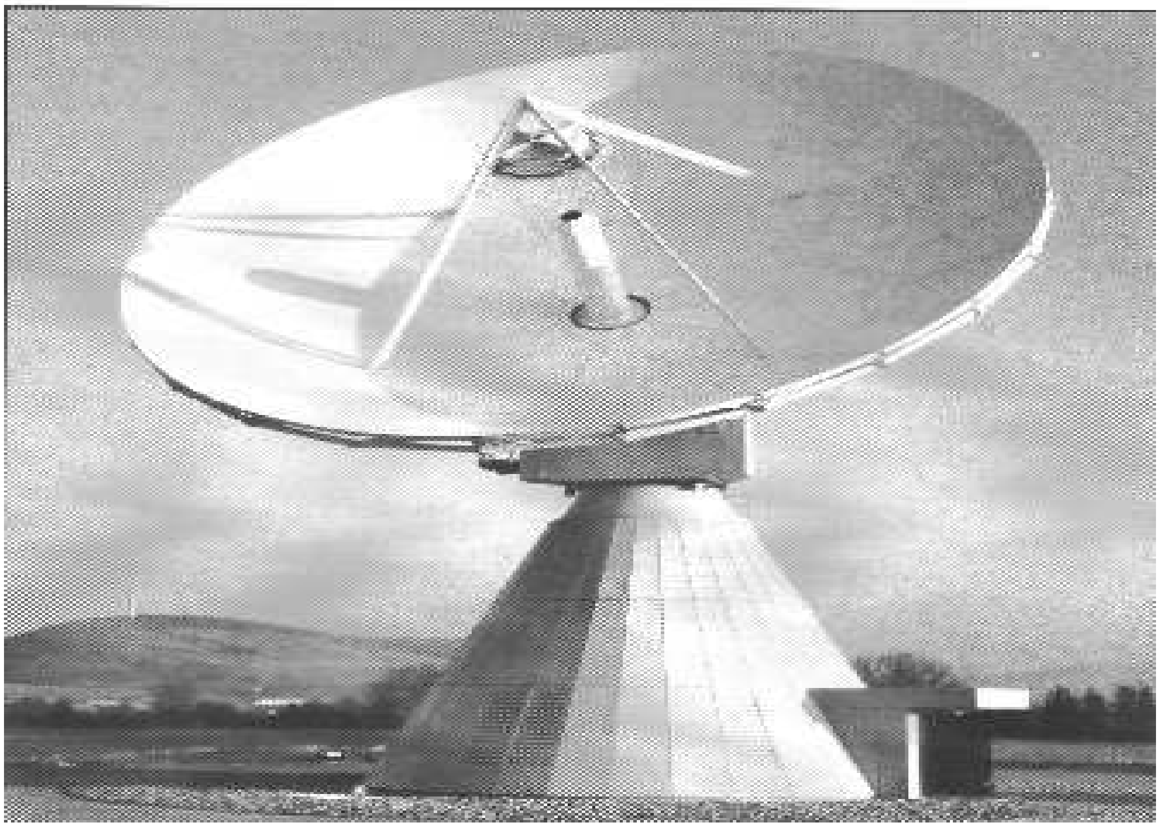
$$G = \frac{16}{\Delta\theta^2}$$

- Thus

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

♣ for a satllite dish, $A_e = G\lambda^2/4/\pi$!!!

18.3 m INTELSAT Standard A Earth Station



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 $= 10^5$

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

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 = $1.38 \times 10^{-23} J/^o K$ 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

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

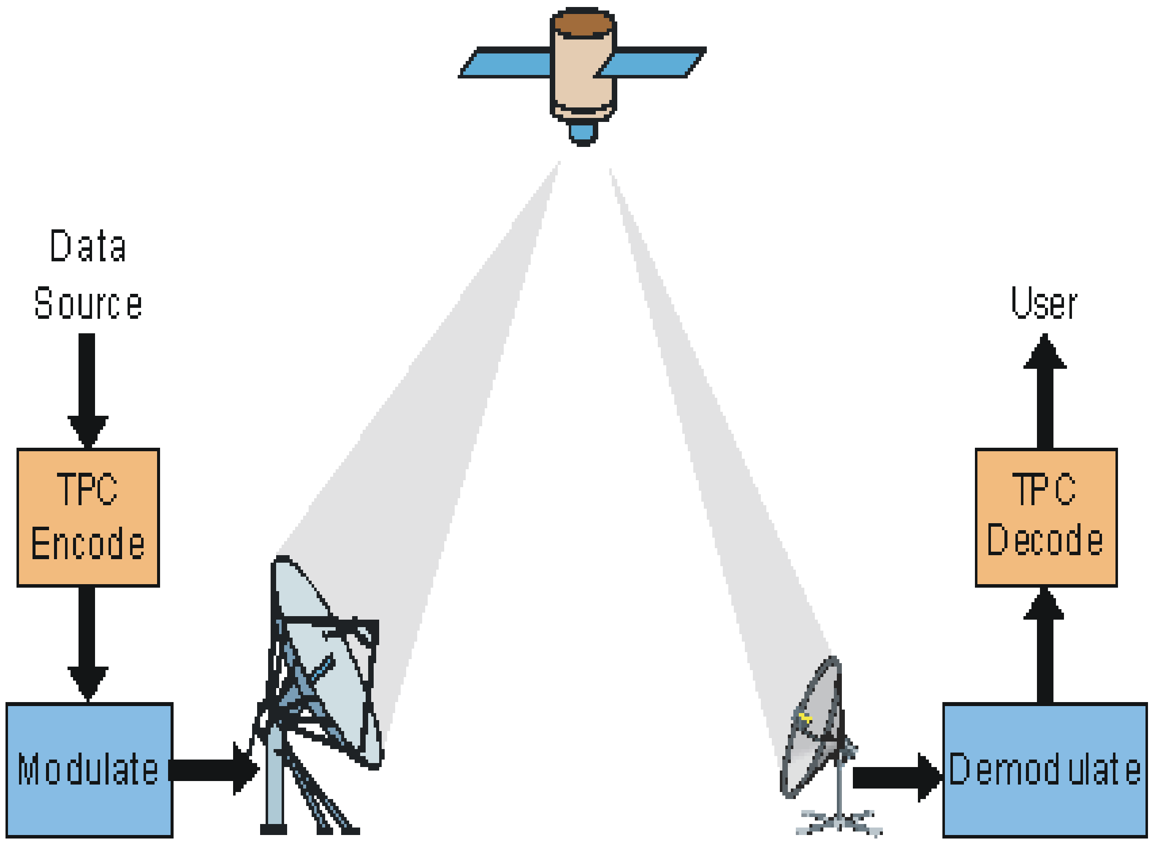
and $D_{earth} = 3.12m$.

Satelllite Frequency Bands

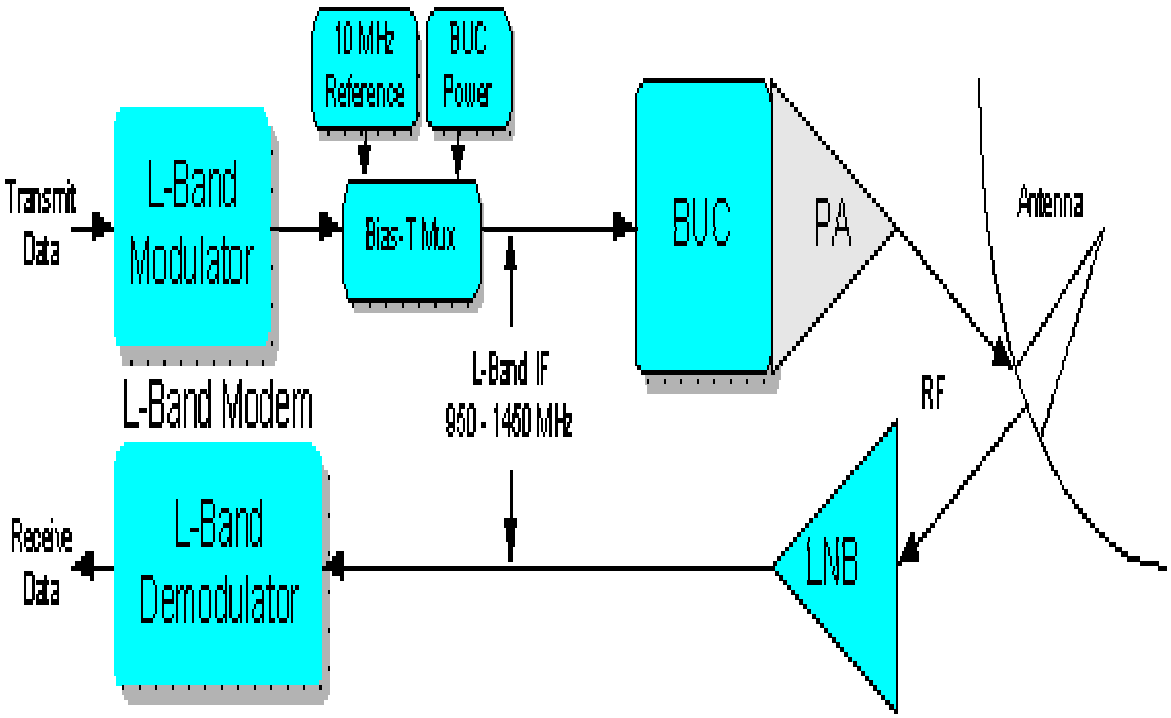
SATELLITE FREQUENCY BANDS

- 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

Satellite Communications Systems (cont.)

- The most *desired frequency band* for satellite communications is 6GHz on the *uplink (Earth to satellite)* and 4GHz on the *downlink (satellite to earth)*.

- **Why?** In this range: 1) *equipment* is relatively inexpensive, 2) *cosmic noise* is small and 3) *rainfall* does not appreciably *attenuate* the signals (worse for higher $f \Rightarrow$ smaller wavelength of order of size of raindrops.)

- Unfortunately, these bands are already allocated to *terrestrial microwave radio relay links* so the *power* density on Earth from satellites operating in these bands is *restricted*.

Satellite Communications Systems (cont.)

- Also need to *carefully place receivers* for satellites in these bands so that they do not receive *interference signals* from these microwave links.

- In the 6GHz/4GHz band, satellites are assigned a *spacing* of 2°.

- Many satellite *transponders* do not *demodulate* the received signal before retransmission. They simply *amplify, down-convert* (from say 6GHz to 4GHz) and then *retransmit*.

- As technology allows, satellites will also *process* the incoming signals (e.g. filter noise, reshape pulses) before retransmission. Will result in better BER.