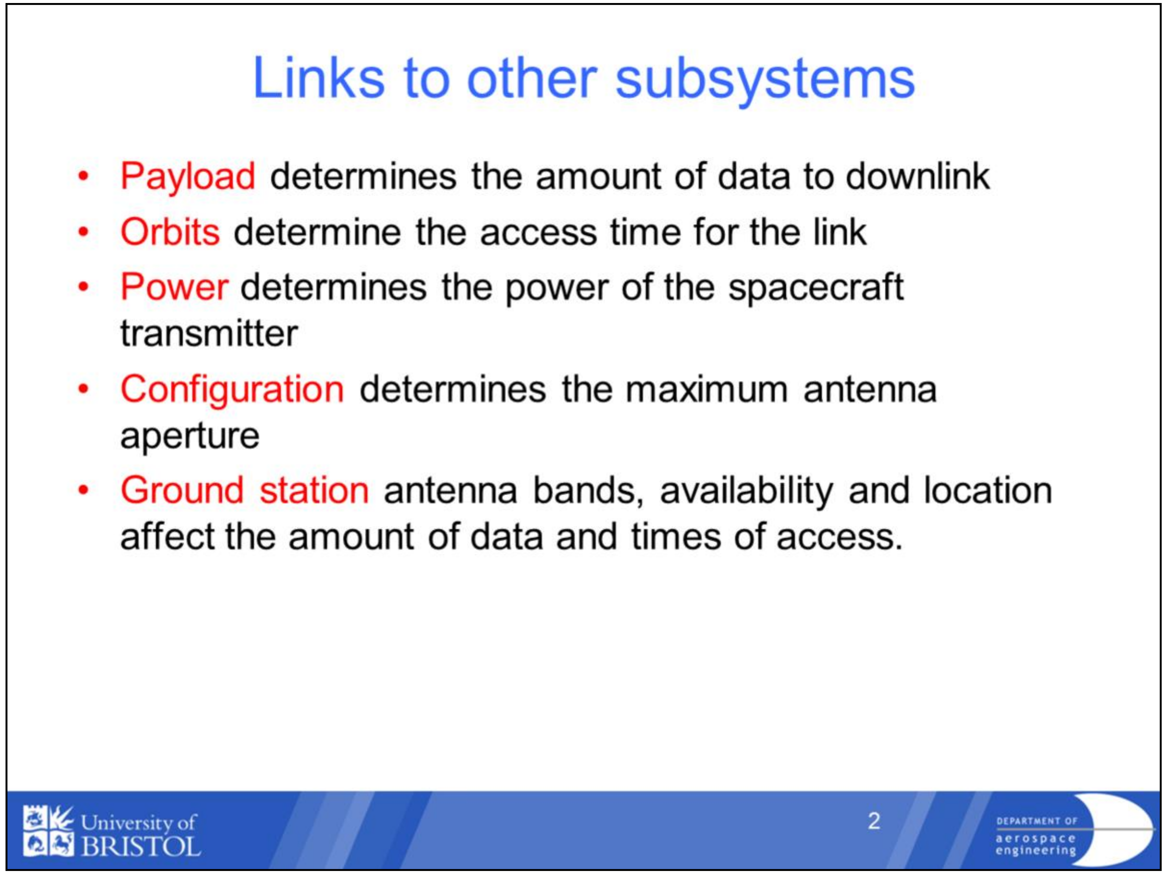

Where do you think this satellite is going? It is the MAVEN spacecraft going to Mars. This is the high gain antenna which will receive and transmit data back to Earth. It needs to have the largest aperture possible.



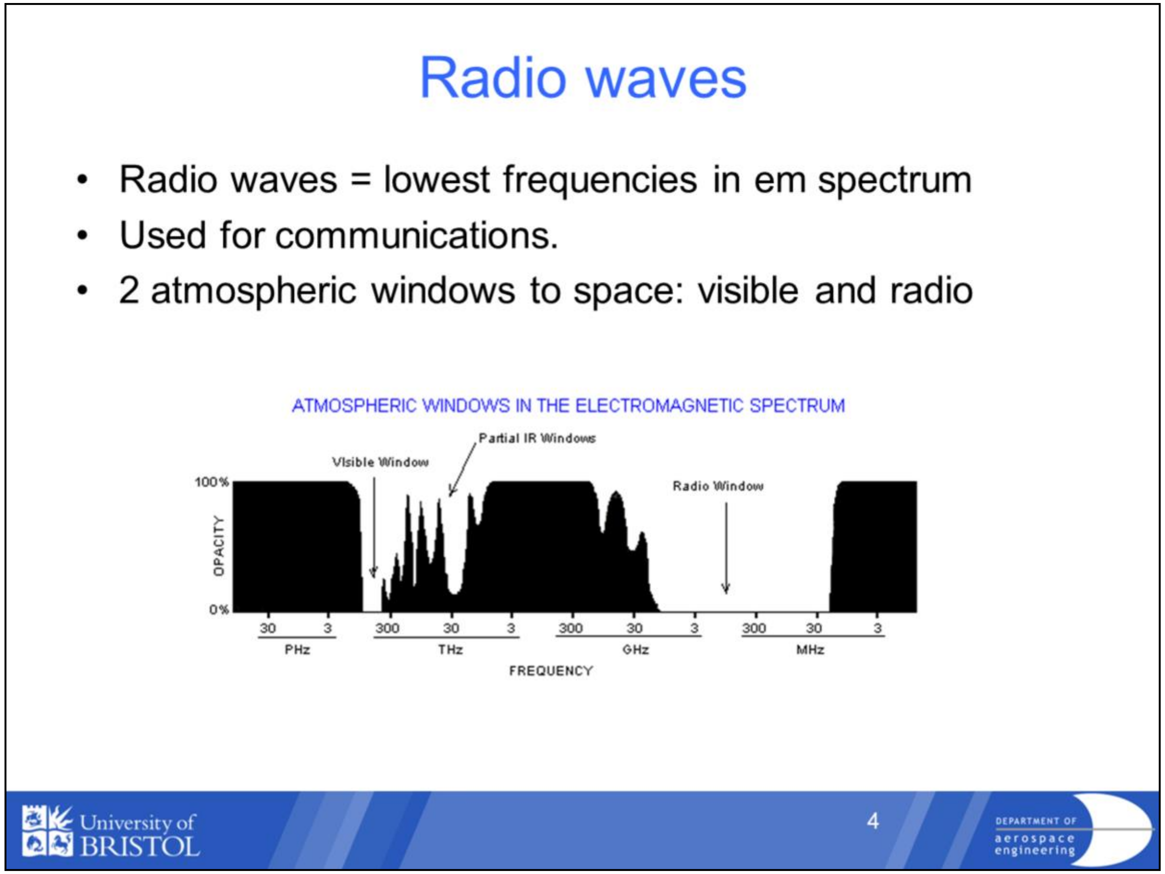

The communications subsystem is intimately linked to the rest of the subsystems. Its design is determined by the above. As well as a power and a mass budget, a mission will have a ‘link budget’ which shows that the spacecraft is capable of downlinking (sending signals from satellite to Earth) and uplinking (sending signals from Earth to satellite) with sufficient margin. Antenna bands refer to the frequency at which they operate eg: UHF/VHF/S-band.

## Learning outcomes

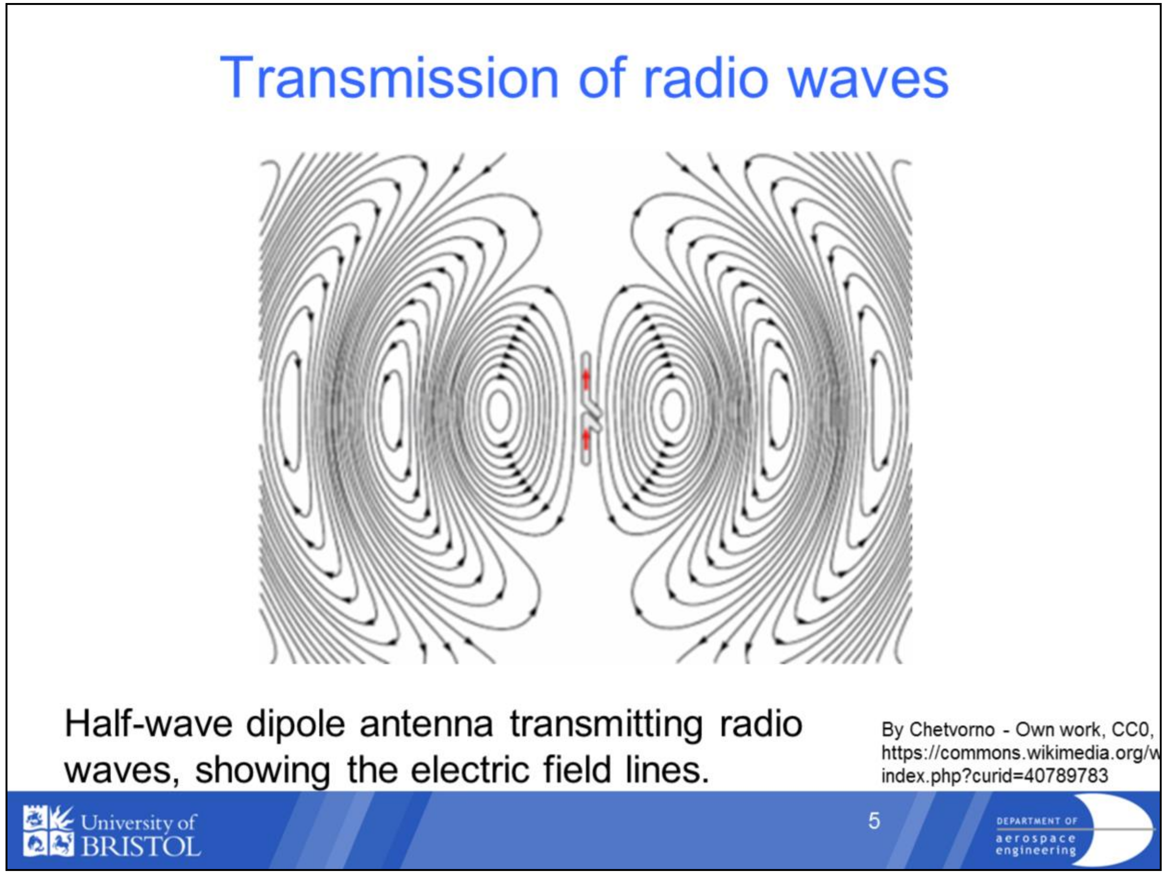
1. Describe how an antenna transmits and receives radio waves
2. Explain and calculate antenna gain (parabolic antennas)
3. Be able to use deciBels
4. Describe the receive and transmit chain for a University ground station using UHF/VHF.
5. Be able to calculate EIRP, received power and path loss for a parabolic receiving antenna.



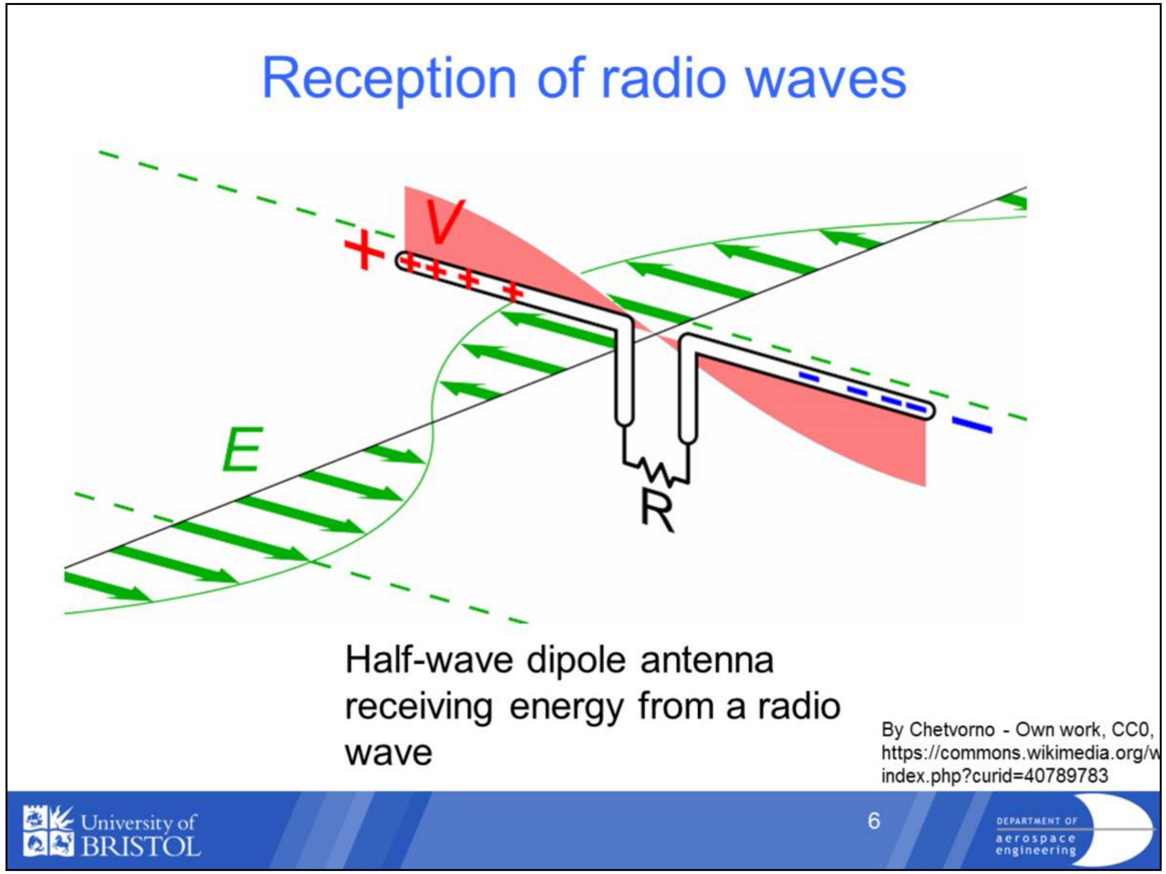
This is what you need to know for the exam. UHF – Ultra High Frequency, a frequency band used by radio amateurs. VHF- very high frequency. EIRP - Equivalent isotropic radiated power (we will see this later).



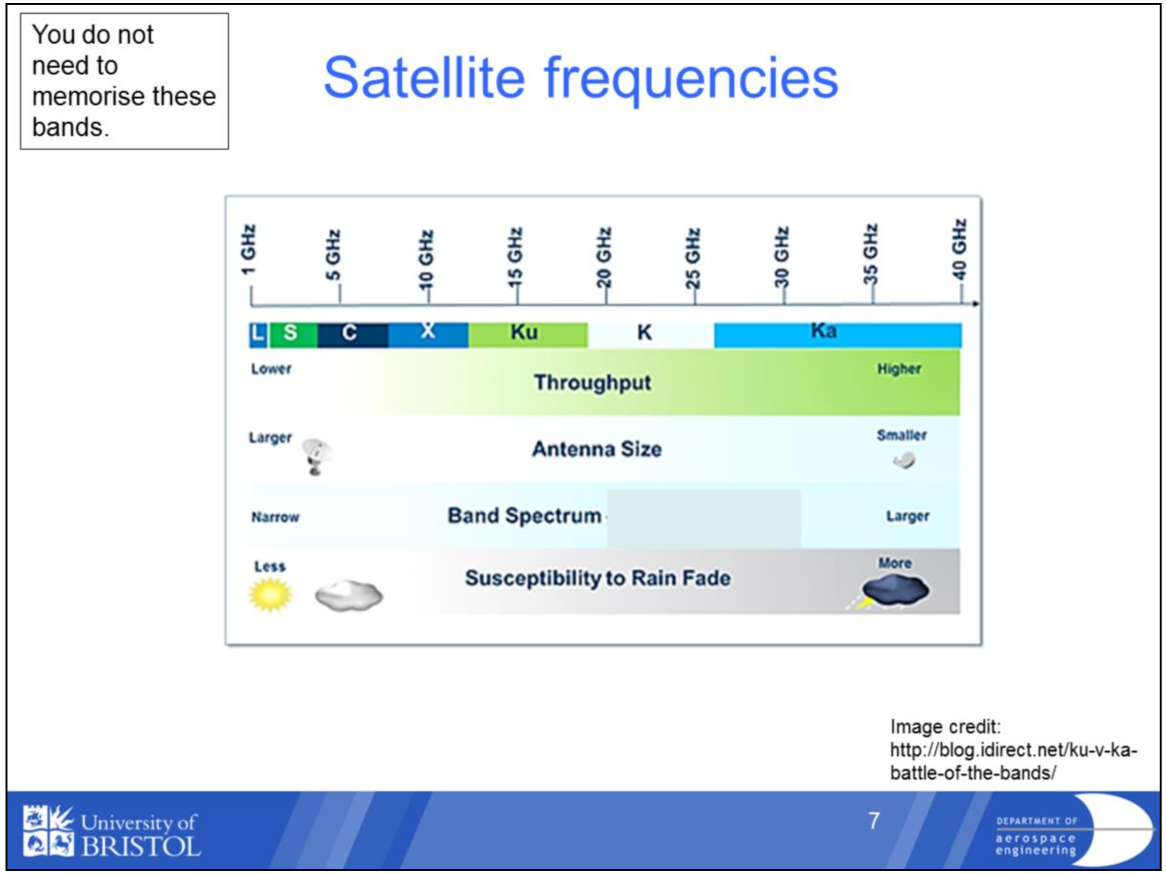

There are in fact only two main windows of the EM spectrum that are open to space. One is the visible spectrum, as mentioned above, and the other is the radio spectrum. The radio spectrum extends from frequencies below 1 Hz up to around 3000 GHz or 3 THz (including microwaves). Different frequencies have different uses because of different propagation, generation and general properties. The radio spectrum is divided into many different bands.




Apply a current to get an em field. If you remove current, the field collapses and sends a wave. If you repeat, you have a series of waves. If you switch polarity you get a wave…The antenna in the center is two vertical metal rods, with an alternating current applied at its center from a radio transmitter (not shown). The voltage charges the two sides of the antenna alternately positive and negative. Loops of electric leave the antenna and travel away at the speed of light; these are the radio waves. This is the most basic kind of antenna and it is called a dipole.

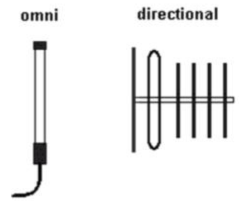



This is a dipole antenna receiving energy from a radio wave. The antenna consists of two metal rods connected to a receiver R. The electric field (E, green arrows) of the incoming wave pushes the electrons in the rods back and forth, charging the ends alternately positive (+) and negative (−). Since the length of the antenna is one half the wavelength of the wave, the oscillating field induces standing waves of voltage (V, represented by red band) and current in the rods. The oscillating currents (black arrows) flow down the transmission line and through the receiver (represented by the resistance R).




Satellites use a part of the spectrum called Super High Frequency (SHF). This goes from 1-40GHz and the bands are L to Ka band. Most common for satellite communications are S, X, Ku and Ka bands. In general usually a L band based service would have lower throughput than a C Band. Ka band on the other hand has potential to offer much higher speeds. This is mainly due to the amount of spectrum available.

# Antenna Gain




- Antennas can be omnidirectional or directional
- **Antenna Gain** : power transmitted in direction of peak radiation compared to isotropic source.
- Measured in deciBels



A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power. Antennas do not create power, they focus the radiated RF into narrower patterns so there appears to be more power in the required direction. The higher the gain of an antenna, the smaller the effective angle of use, as power has been robbed from other directions and superimposed on the radiation in the intended direction.

## Decibels

Comms engineers use deciBels (dB)

If normal power (in W) is $P_W$ and dB power (in dBW) is $P_{dBW}$

Then $P_{dBW} = 10 \log_{10}(P_W)$

- Always use $\log_{10}$
- If X, use $10 \log_{10}(X)$
- If $X^2$, use $20 \log_{10}(X)$
- 3 dB means a factor of 2: $10^{3/10} = 1.9953$
- *dBW* is wrt 1 Watt
- *dBm* or dBmW is wrt 1 mW
- *dBi* is wrt isotropic gain

Why bother with all this? Because adding is easier.

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Comms engineers like to work in decibels. The decibel (dB) is used to measure sound level, but it is also widely used in electronics, signals and communication. The dB is a logarithmic way of describing a ratio. The ratio may be power, sound pressure, voltage or intensity. A gain of 3dB means that you double your signal. Sometimes a comparison is made with an isotropic source (ie: emitting in all directions), in which case we use dBi (isotropic). We convert between dBW and W by using the formula shown.

## Parabolic Antennas

Parabolic receive antenna Gain $G_r$:

$$G_r = \frac{4\pi\eta A}{\lambda^2} \qquad (13\text{-}1)$$

Where:

- $A$ = area of the dish (m)
- $\eta$ = efficiency factor (50-60%, or 0.5-0.6 for parabolic)
- $\lambda$ = wavelength (m)

If frequency increases, do we need smaller or larger antenna?

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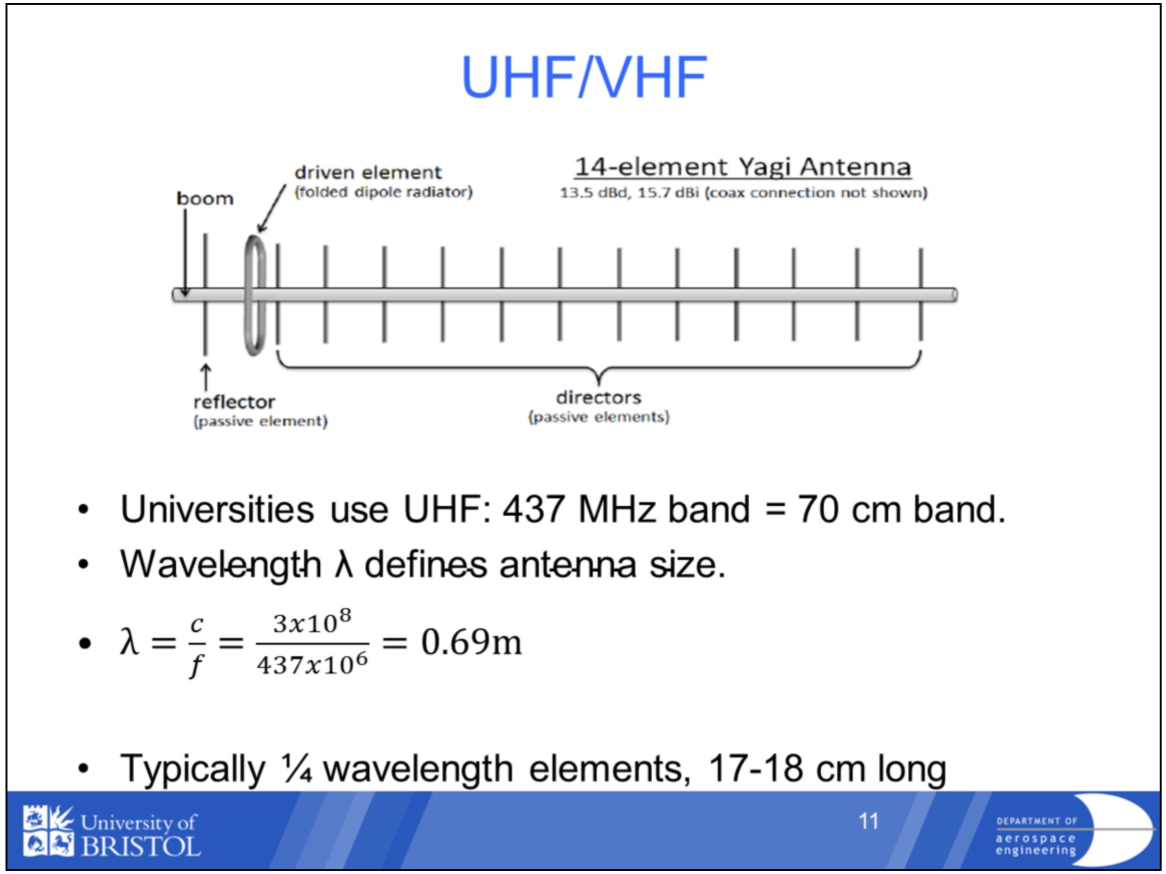
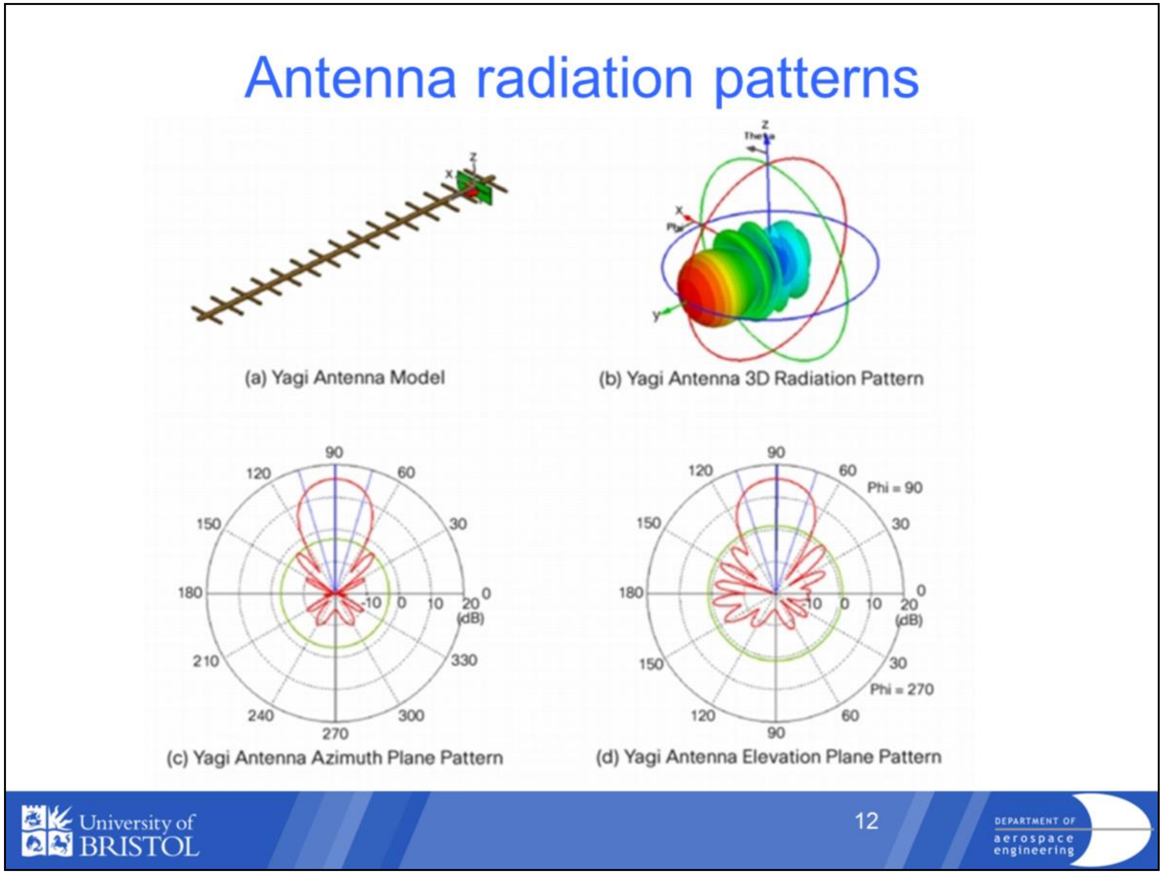
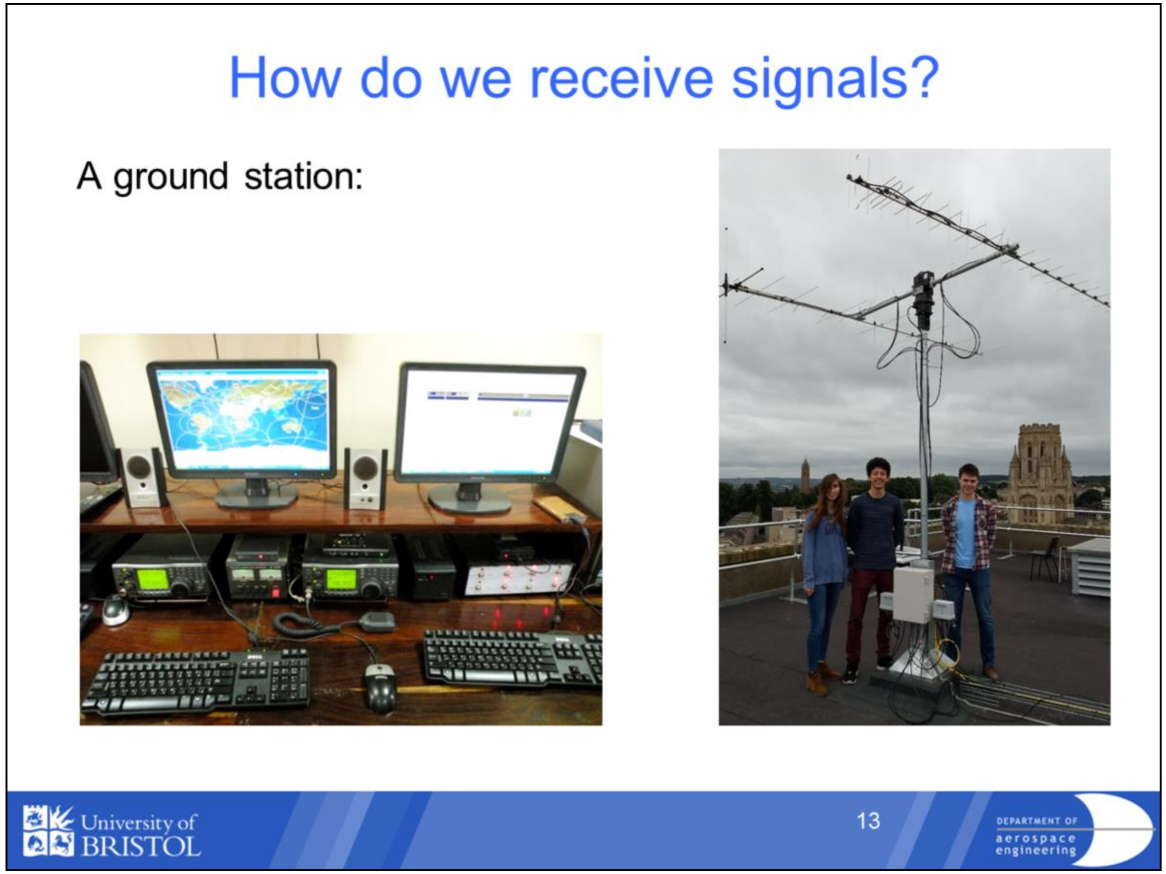
Professional ground stations use parabolic dishes and operate in different bands: S, X, Ku and Ka Bands. The larger the wavelength then the antenna needs to be larger to collect the signal. We can see the formula for gain for a parabolic dish. So, for a given wavelength, the larger the dish, the greater the gain – which is usually what we want. If frequency increases, for the same gain, we need a smaller dish.



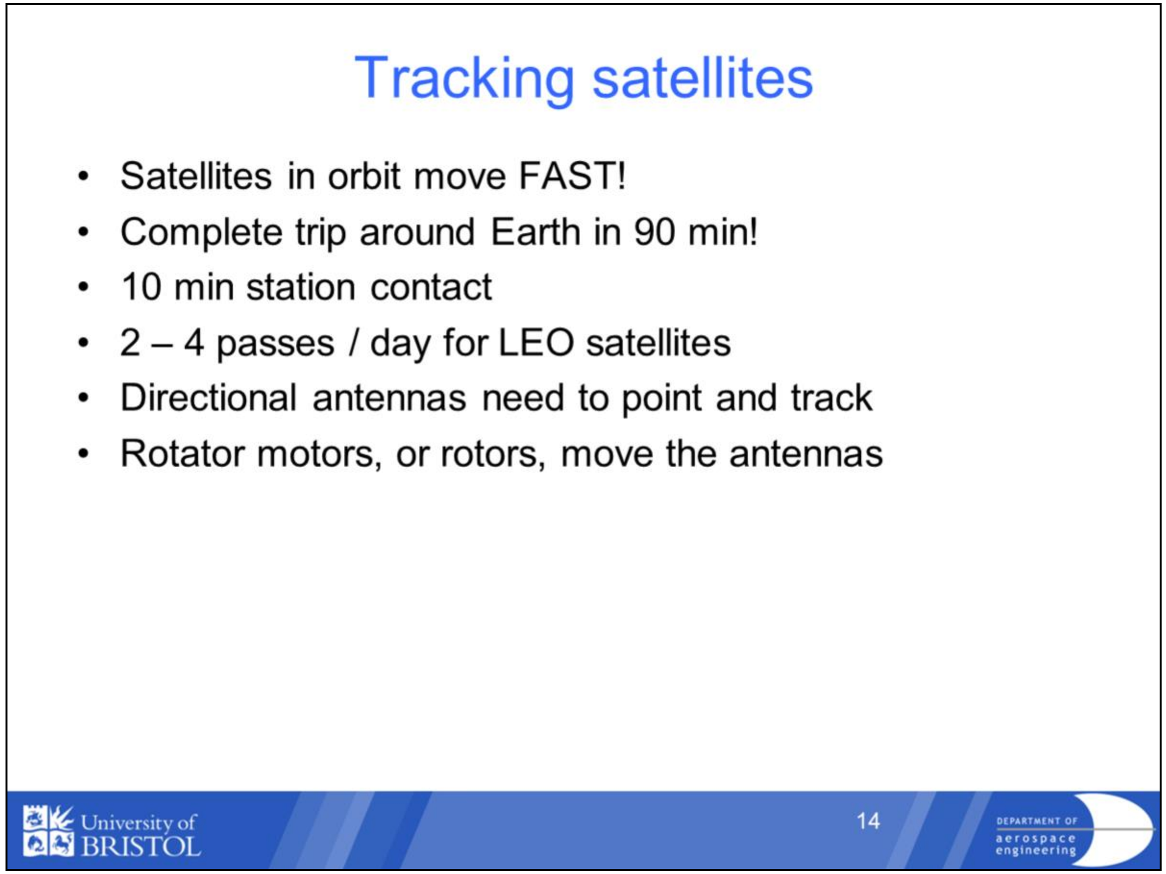

There are other types of antennas. This one is called a Yagi antenna. It is more powerful than a dipole as it has a dipole, a reflector and the these ¼ wavelength director elements. Many universities use amateur radio frequencies. Most universities get assigned to 437.x MHz as 435-438 MHz is the amateur satellite band, aka UHF or 70 cm. Remember that Wavelength λ and $c = speed\ of\ light$ and $f = frequency$.



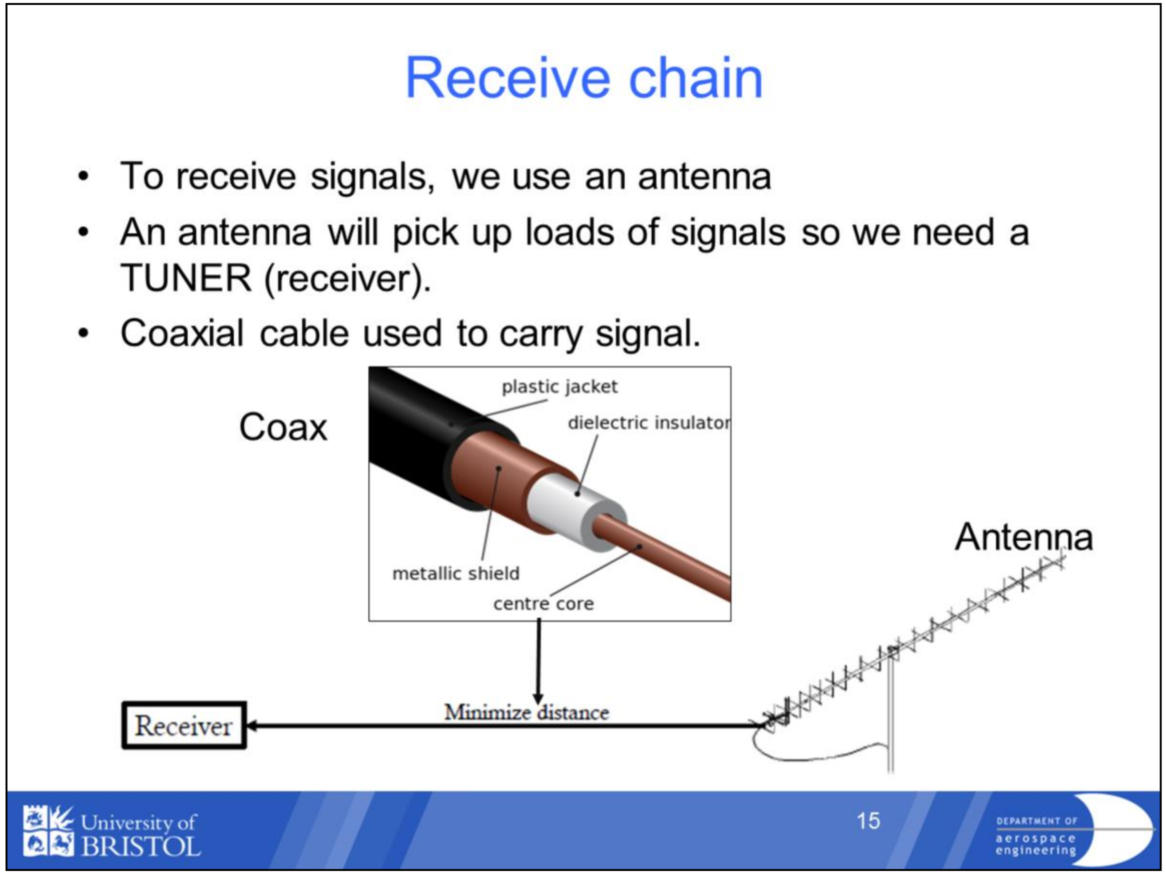

The radiation pattern or antenna pattern is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). It is common, however, to describe this 3D pattern with two planar patterns, called the principal plane patterns: Azimuth and Elevation.



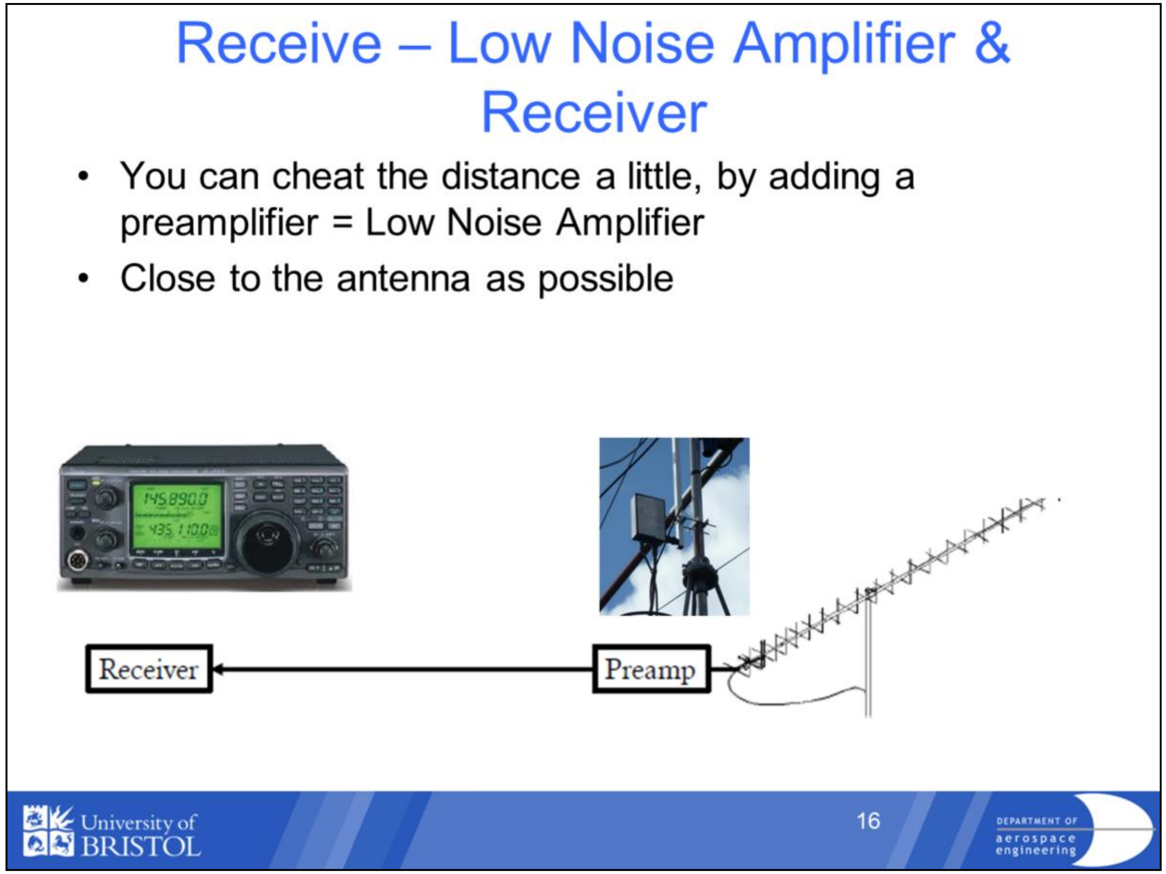

We receive satellite signals with a ground station.



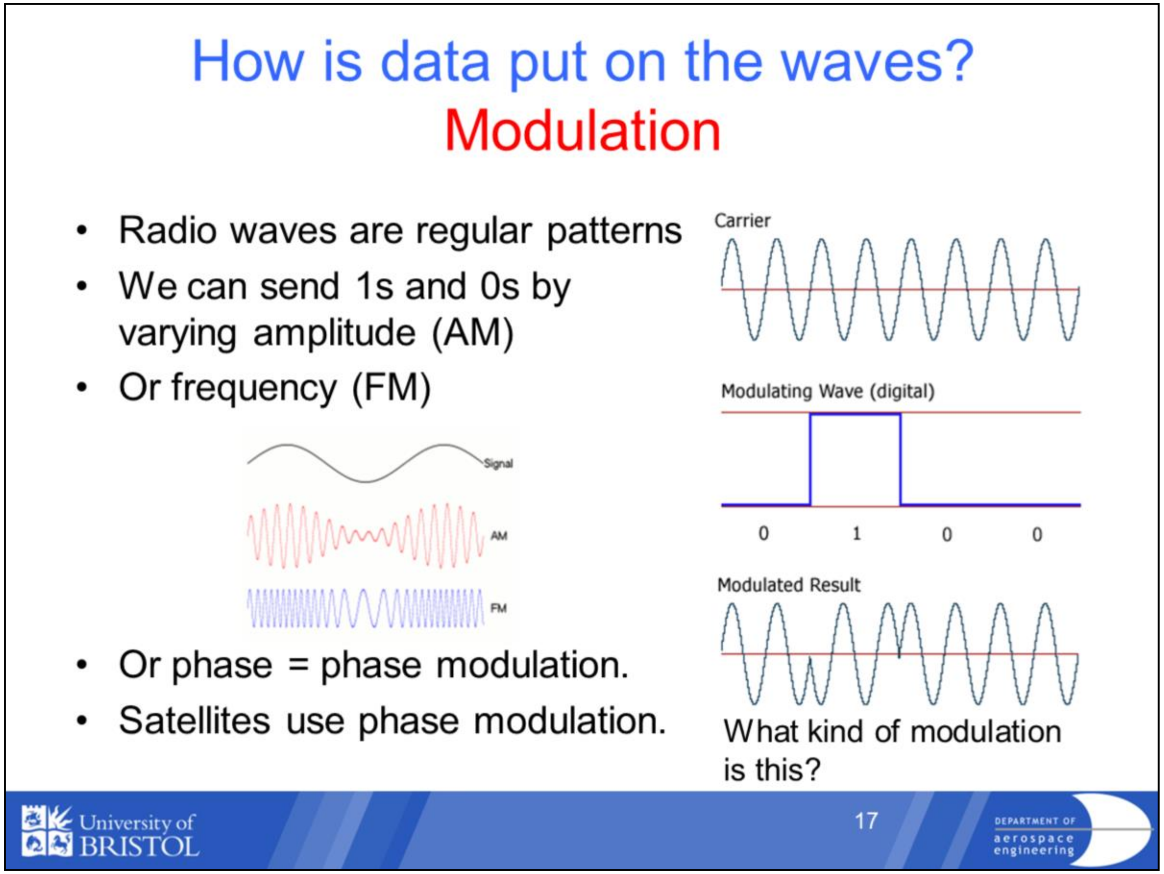

Doppler shift affects radio too. For example: at 437 MHz, frequency shifts about 20 kHz during a pass.
Appears 10 kHz higher as the satellite approaches
Appears 10 kHz lower as the satellite goes away



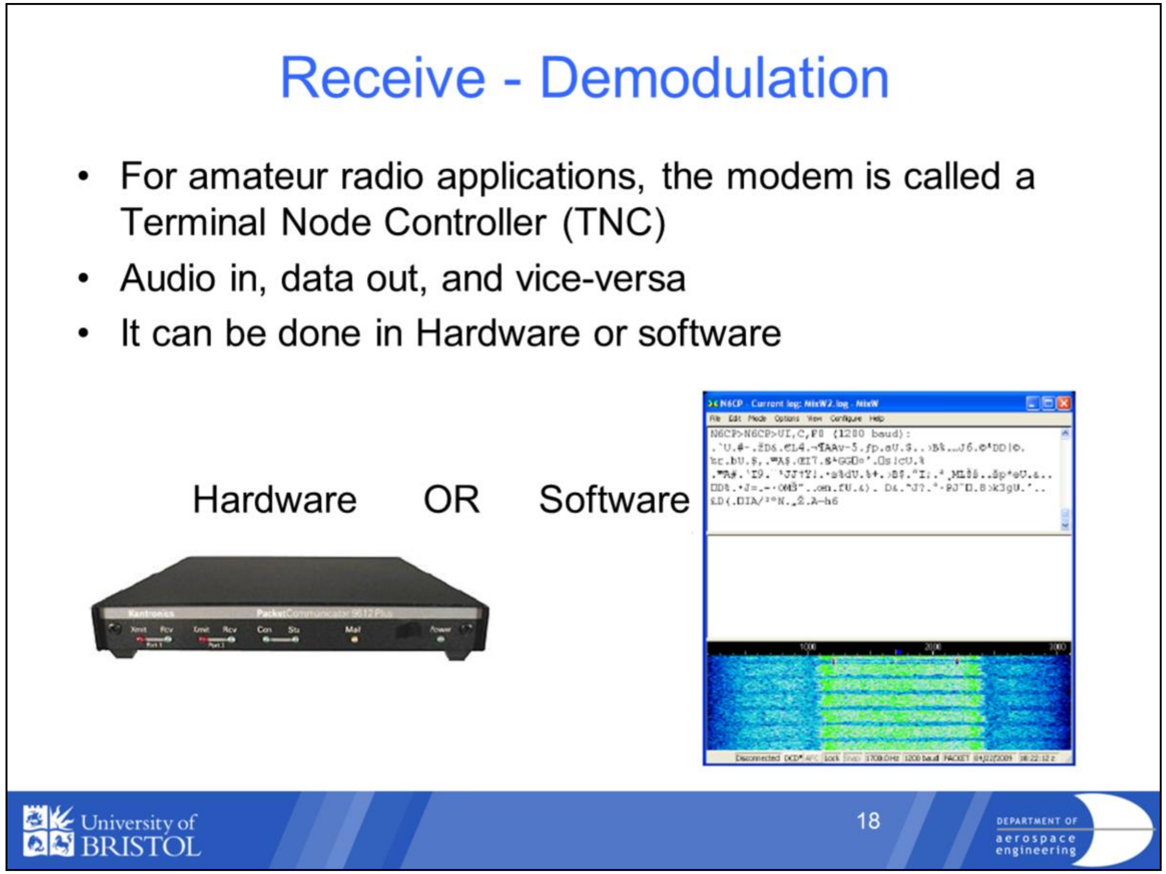

The antenna intercepts radio waves (electromagnetic waves) and converts them to tiny alternating currents which are applied to the receiver. Coaxial cable is used as a transmission line for radio frequency signals. Its applications include feedlines connecting radio transmitters and receivers with their antennas, computer network (Internet) connections, digital audio (S/PDIF), and distributing cable television signals.



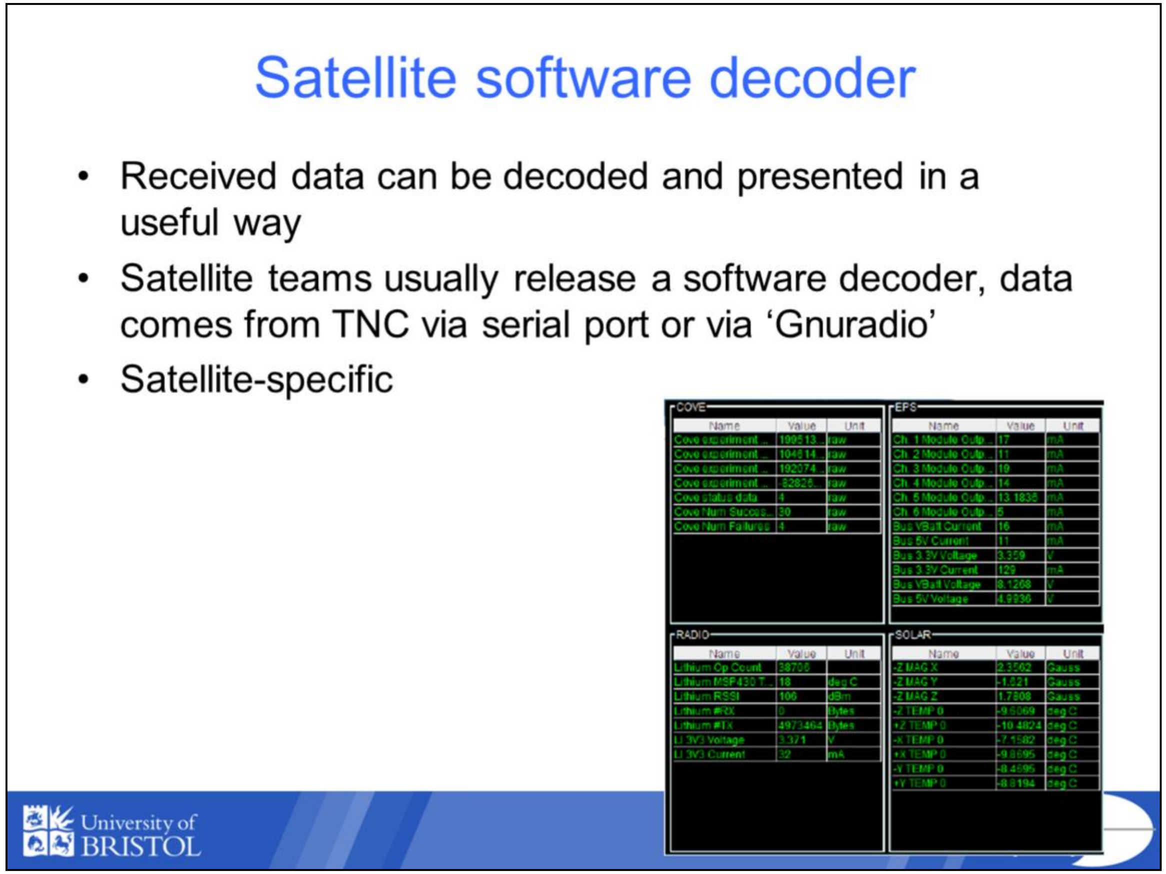

The Low Noise Amplifier maximizes received signal without amplifying the noise that leaks into the long cable. The receiver uses electronic filters to separate the desired radio frequency signal from all the other signals picked up by the antenna, the"tuning" means adjusting the frequency of the receiver (its passband) to the frequency of the desired radio transmitter, to receive the desired radio transmission.  It then uses an electronic amplifier to increase the power of the signal for further processing.



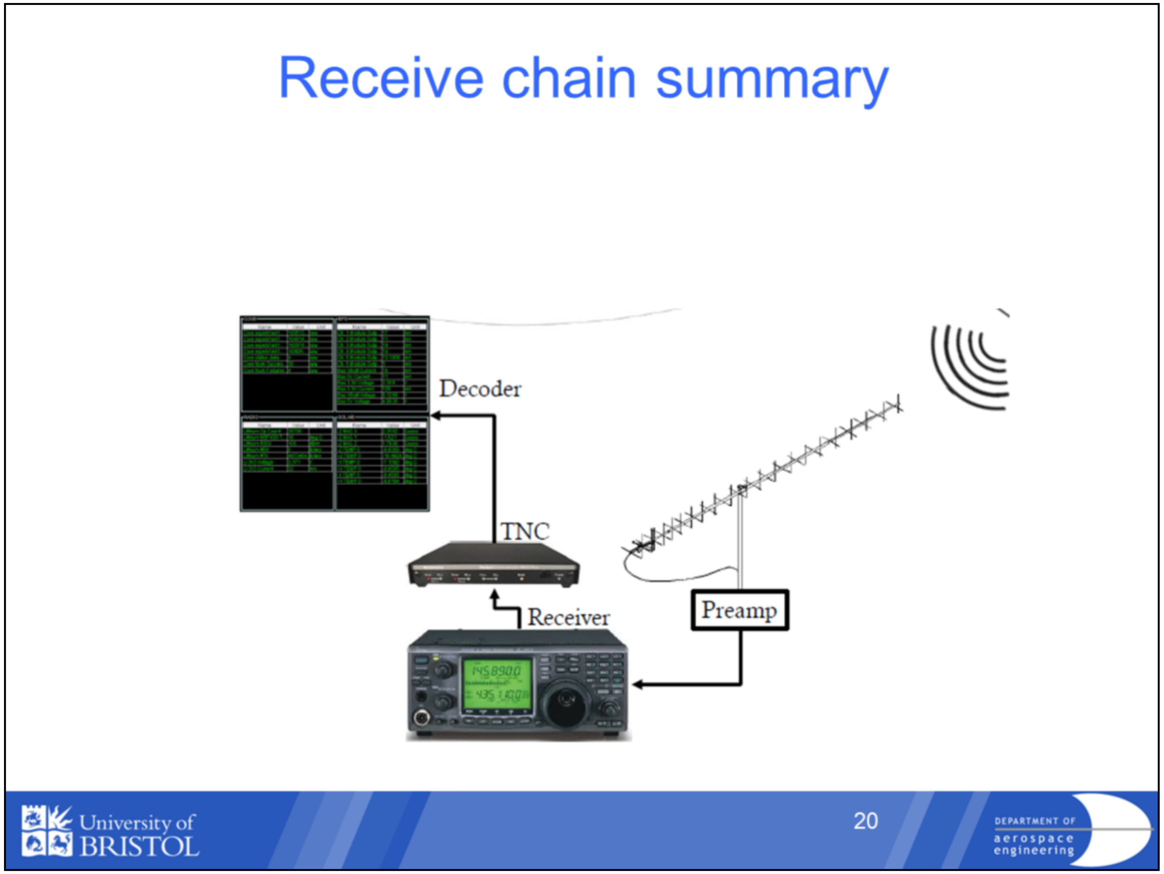

Any strategy that combines an input signal with a carrier wave to encode speech or other useful information is called a modulation scheme. Satellites use phase modulation which is shown in the diagram.



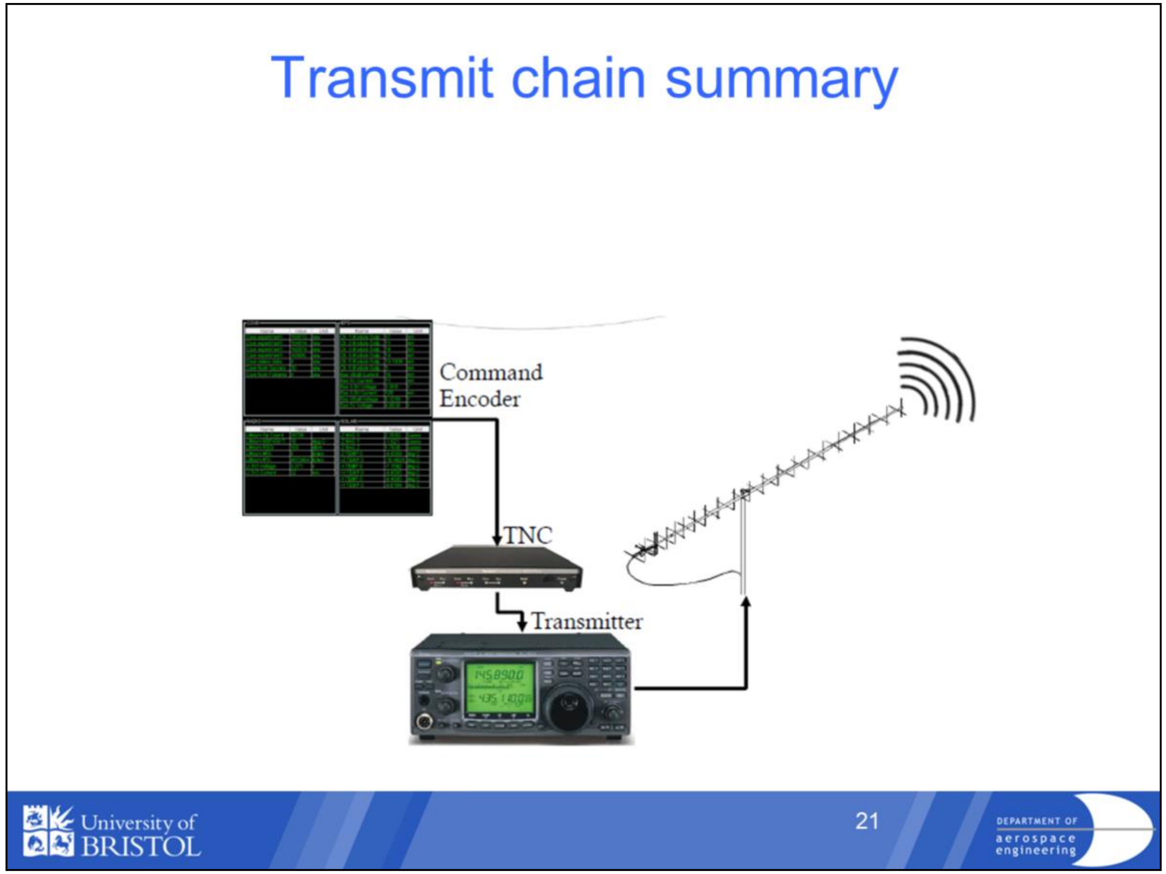

Demodulation is the opposite of modulation and is a way of decoding the signal from the satellite. Modem stands for modulator-demodulator




This decoder shows data for an experiment called COVE, the power system, the radio, magnetometer and temperature sensors

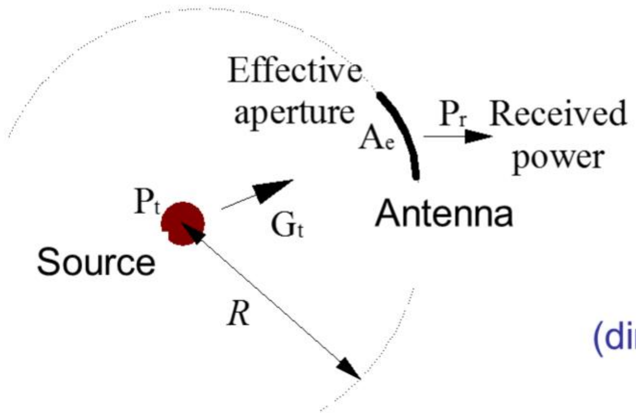



This is the receive chain, ie: the signal comes in to the antenna (in this case a Yagi), it is amplified by the low noise amplifier right near the antenna, then a coaxial cable (as short as possible) takes the signal to the radio tuner /receiver. The receiver tunes in to the particular frequency of interest. The Terminal Node Controller or software is used to demodulate the signal and then another software decodes the signal.




The differences with the transmit chain is that you decide your commands, encode them using some software called a command encoder, use modulation to put the information on a carrier wave, use the transmitter to turn the signal into a radio wave and amplify it, then send it out through the antenna.

## Propagation




Total Flux density (W/m$^2$)
(isotropic source)

$$F = \frac{P_t}{4\pi R^2} \qquad (13\text{-}2)$$

Flux density (W/m$^2$)
(directive source of gain $G_t$)

$$F = \frac{P_t G_t}{4\pi R^2} \qquad (13\text{-}3)$$



Source with gain of Gt radiates a signal of power Pt and by the time it gets to the antenna the signal is of power Pr and it is received by antenna with gain Gr and an effective aperture of antenna Ae. We can calculate from geometry the flux density in W/m2 for an isotropic source (one that is radiating in all directions) and a directive source (one that has a gain in a particular direction Gt).

## Received power

Flux density (directive source of gain $G_t$): $F = \dfrac{P_t G_t}{4\pi R^2}$ (13-3)

Received power collected by antenna : $P_r = F A_e = \dfrac{P_t G_t A_e}{4\pi R^2}$ (13-4)

Remember, gain of antenna: (13-1) $G_r = \dfrac{4\pi \eta A}{\lambda^2}$ so $A = G_r \dfrac{\lambda^2}{4\pi\eta}$

Received power collected by antenna: $P_r = \dfrac{P_t G_t G_r}{4\pi R^2}\left(\dfrac{\lambda^2}{4\pi\eta}\right)$ (13-5)

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The larger an antenna's aperture is, the more power it can collect from a given field of radio waves. Received power in watts will be flux density * effective aperture of the antenna.

# Received power

*(Frii's Free-space wave Equation)*

Received power collected by antenna: $P_r = \frac{P_t G_t G_r}{4\pi R^2}\left(\frac{\lambda^2}{4\pi}\right)$ (13-5)

Simplifying: $P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$ (13-6)

In dBs: $P_r = P_t + G_t + G_r - 20log_{10}\left(\frac{4\pi R}{\lambda}\right)$ (13-7)

Or: $P_r = EIRP + G_r + L_p + L_a$ (13-8)

EIRP: Equivalent Isotropic Radiated Power $= P_t + G_t$

$L_a$ : other losses (i.e. atmospheric absorption, polarisation)

Propagation path loss $L_p$



The Frii's equation is valid for direct line of sight radio waves only. Note the antenna efficiency is dropped from the equation but is usually included in real life. There are 2 path loss terms one for propagation caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), one for absorption when the signal passes through media not transparent to electromagnetic waves, such as rain.

## Example

*A satellite transponder is operating at a carrier frequency of 12GHz, and transmitting 10dBW through an antenna with a gain in the direction of an earth station of 40dBi. The earth station antenna has gain of 35dBi towards the satellite.*

(a) What is the EIRP of the transmit antenna?

$$\mathrm{EIRP} = P_t + G_t = 10 + 40 = 50dBi$$

(b) Assuming the earth station-satellite range (R) is 39,241km, determine the path loss at the earth station.

$$L_p = 20log_{10}\left(\frac{4\pi R}{\lambda}\right) = 20log_{10}\left(\frac{4\pi 39241000}{3x10^8/12x10^9}\right) = 205.9dB$$

(c) Calculate the power received at the output from the earth station antenna.

$$P_r = EIRP + G_r + L_p + L_a = 50 + 35 - 205.9 = -120.9dBW$$

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## Summary

1. Radio waves are produced by oscillating magnetic fields
2. Comms engineers use deciBels, eg: $P_{\mathrm{dBW}} = 10 \log_{10} P_{\mathrm{W}}$
3. Antennas can be omnidirectional or directional dependent on their gain pattern
4. Parabolic gain can be calculated from: $G_r = \frac{4\pi\eta A}{\lambda^2}$
5. Receive chain is: antenna-preamp-receiver-TNC-decoder
6. Frii's free space equation:

$$P_r = P_t + G_t + G_r - 20log_{10}\left(\frac{4\pi R}{\lambda}\right) + L_a$$