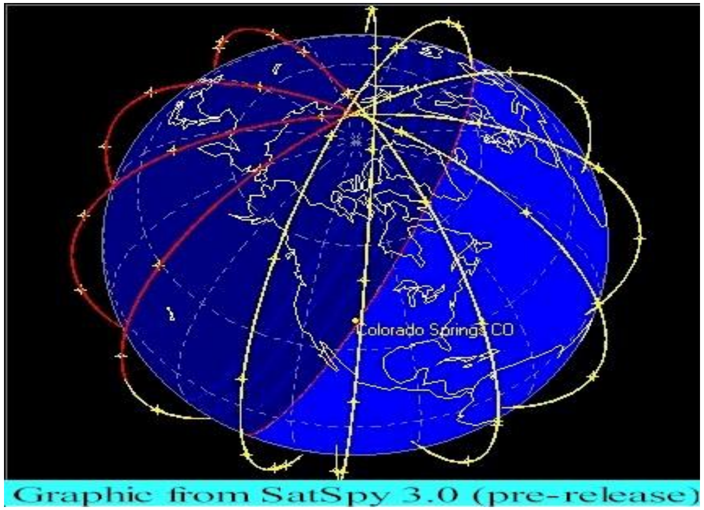
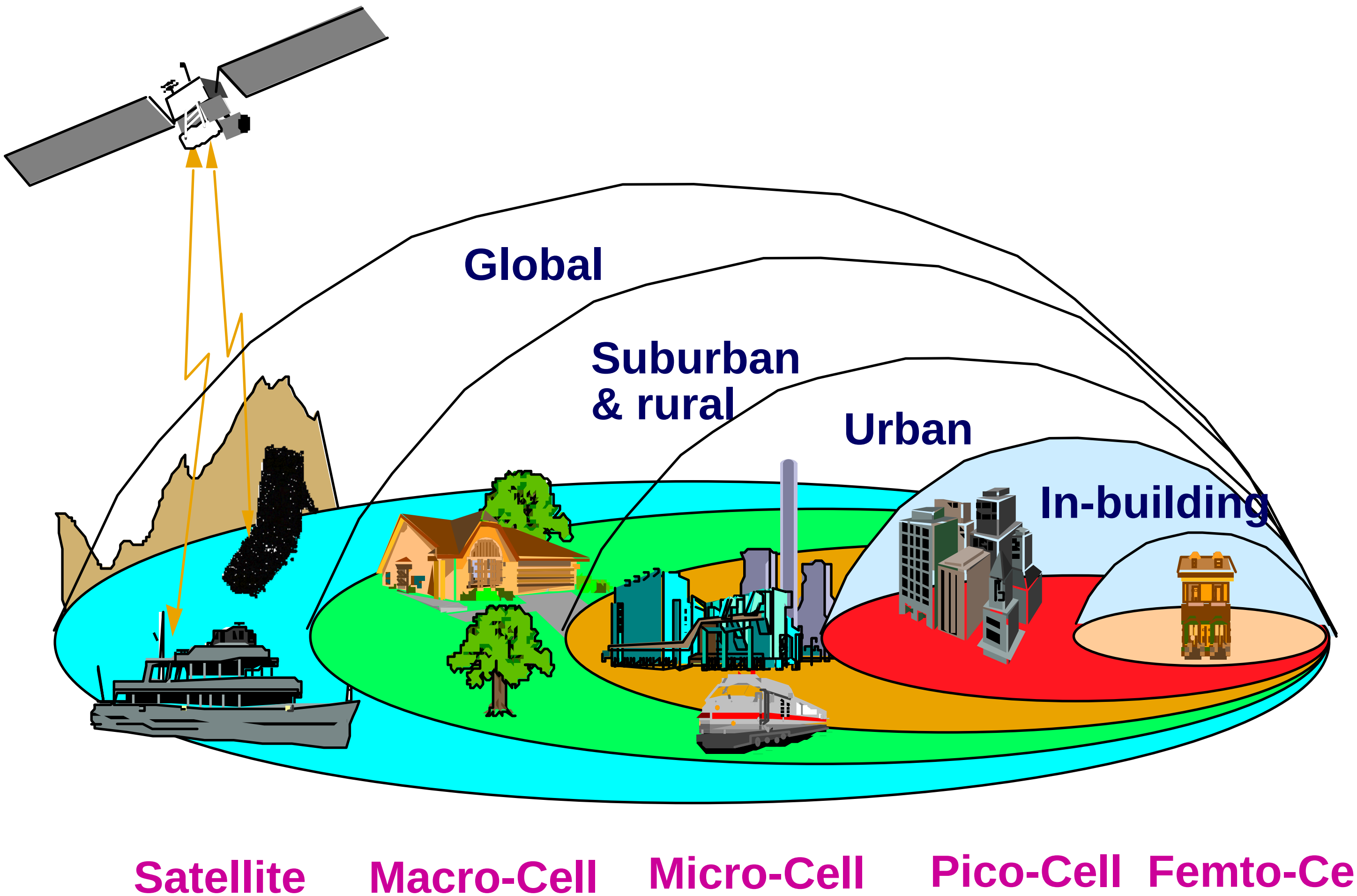
SATELLITE INTRODUCTION



Third Generation: Environment Integration

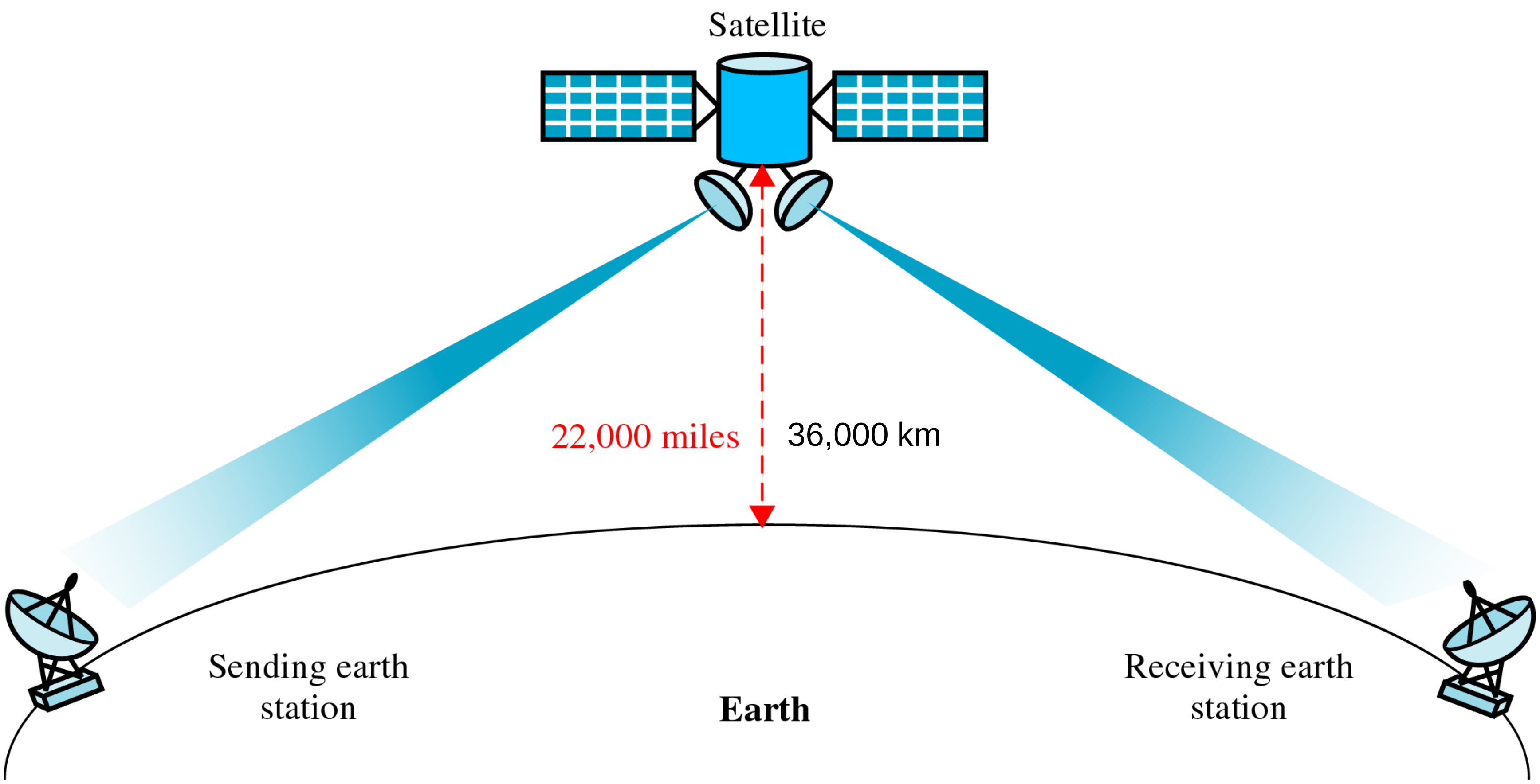


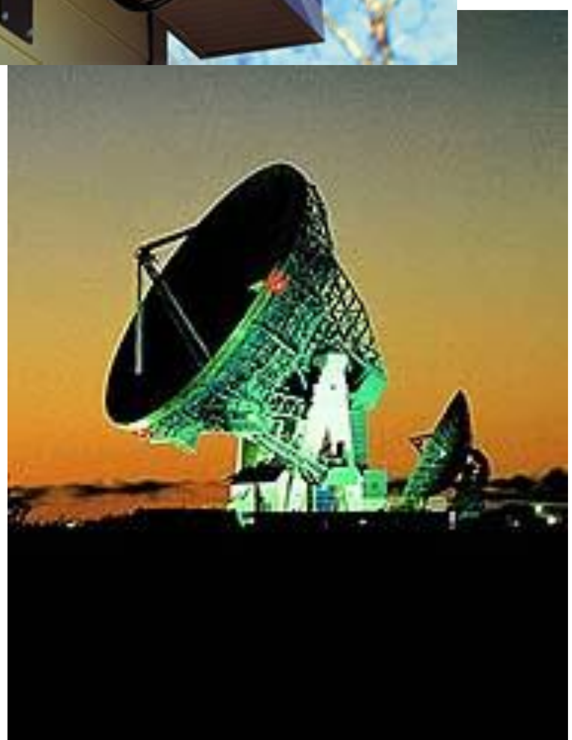
Application of satellite communications

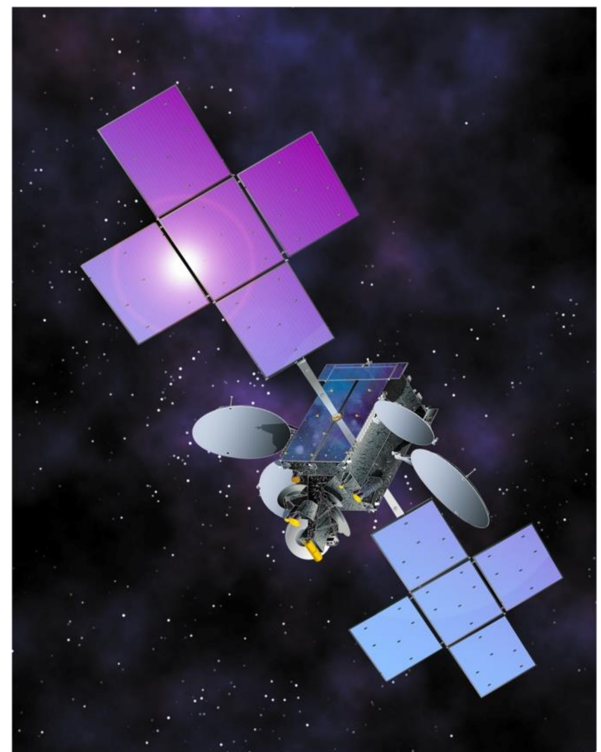
Some of the applications of satellite communications are:

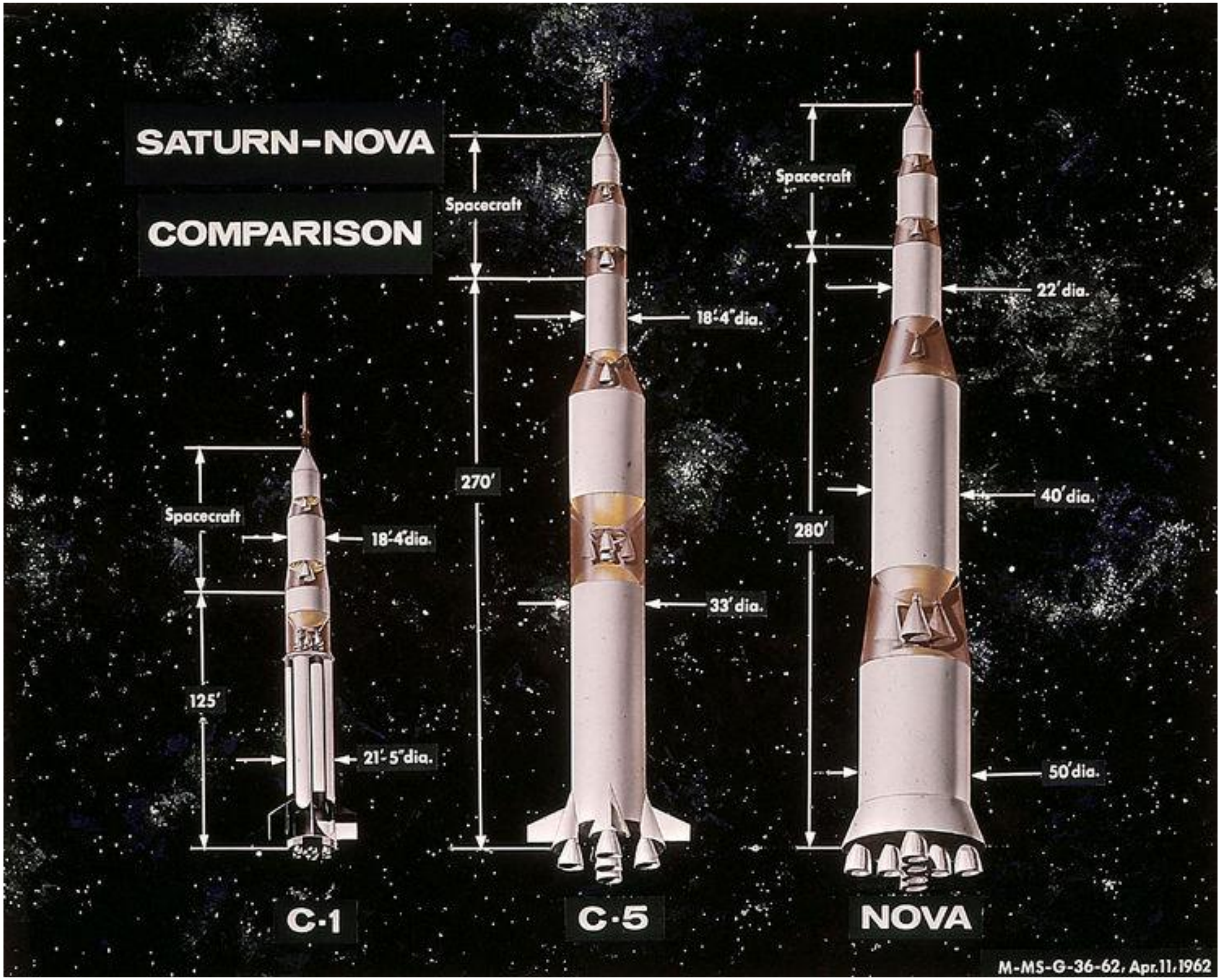
- Digital audio broadcasting
- Television distribution over a wide area
- Serving remote areas
- Point-to-multipoint global communications
- Remote monitoring and control
- Navigation
- Vehicle tracking
- Mobile communications
- Maritime and air navigation
- Video teleconferencing
- Weather satellites

Satellite Communication

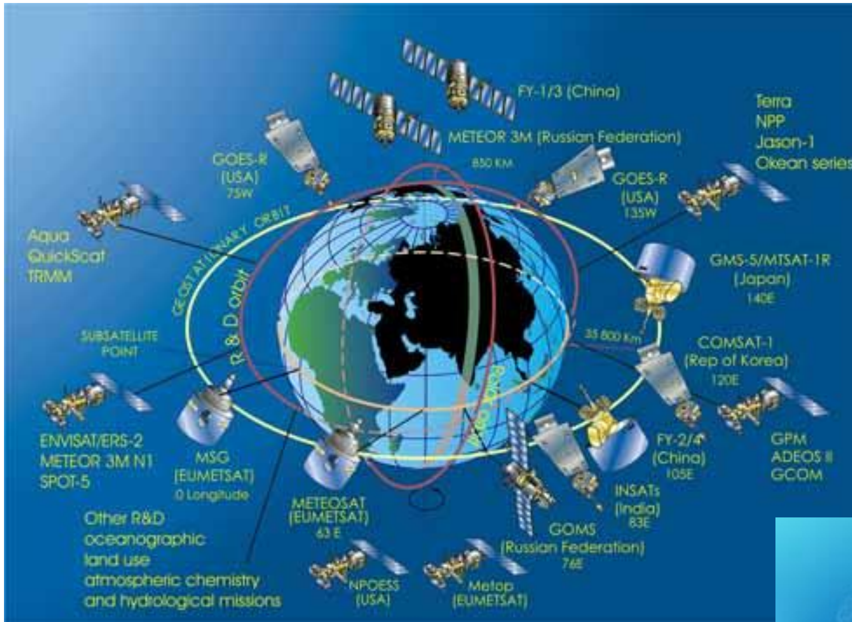





SATURN-NOVA
COMPARISON
Spacecraft
18'4"dia.
21'-5"dia.
125'
Spacecraft
18'-4"dia.
33'dia.
270'
Spacecraft
22'dia.
40'dia.
50'dia.
280'
C-1
C-5
NOVA
M-MS-G-36-62, Apr.11, 1962

Satellites in different orbits with different tasks



Lectures will concentrate on Communications satellites

Why Satellite Communications ?

Main Advantages

- Extend capability of existing terrestrial cellular system
- Coverage in remote locations
- Large coverage area
- Seamless service to subscriber in any part of the world

Challenges

- Propagation delay
- Attenuation – path loss 200 dB
- Low Spectral efficiency
- Costs – $100M+
- Power limited
- Reliability – 10 years + lifetime – Voyager 1977

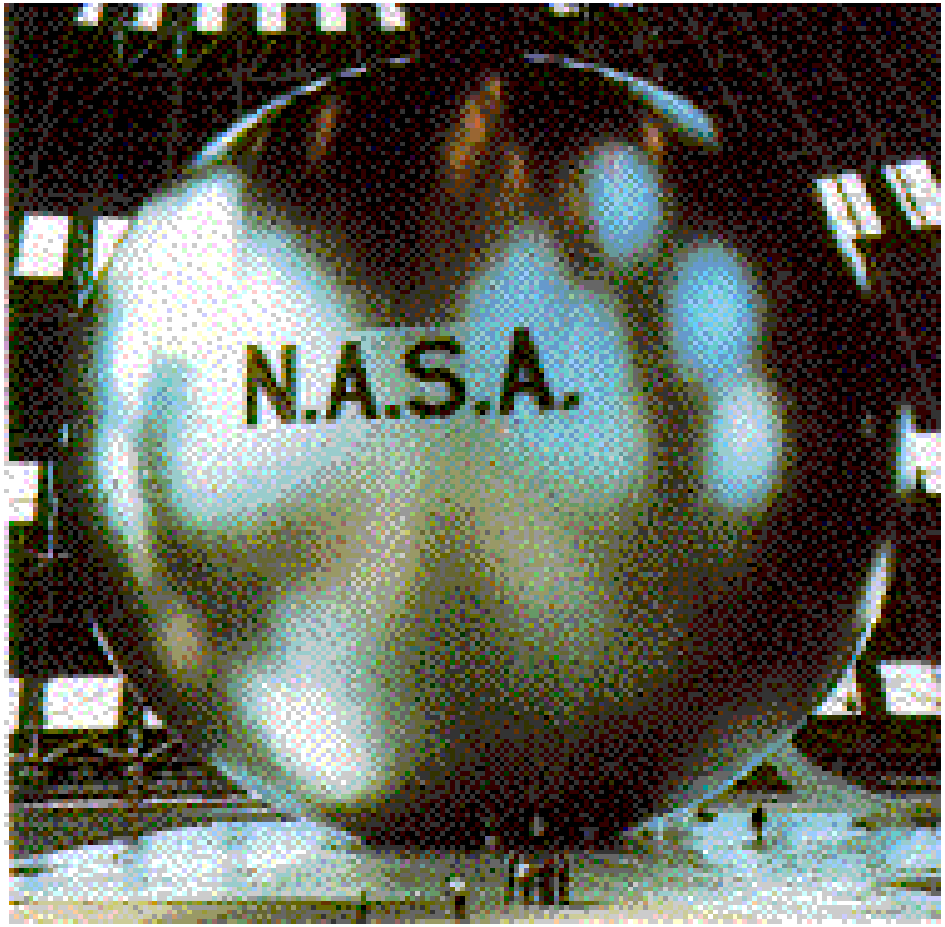
Hostile Environment

- Satellite components need to be specially “hardened”
- Circuits which work on the ground will fail very rapidly in space – cosmic radiation
- Temperature is also a problem – temperature gradient up to 200ºC across satellite - so satellites use electric heaters to keep circuits and other vital parts warmed up - they also need to control the temperature carefully: antennas need to be heat distortion resistant.
- Corrosion
- Withstand launch
- Vacuum

History of satellite communication

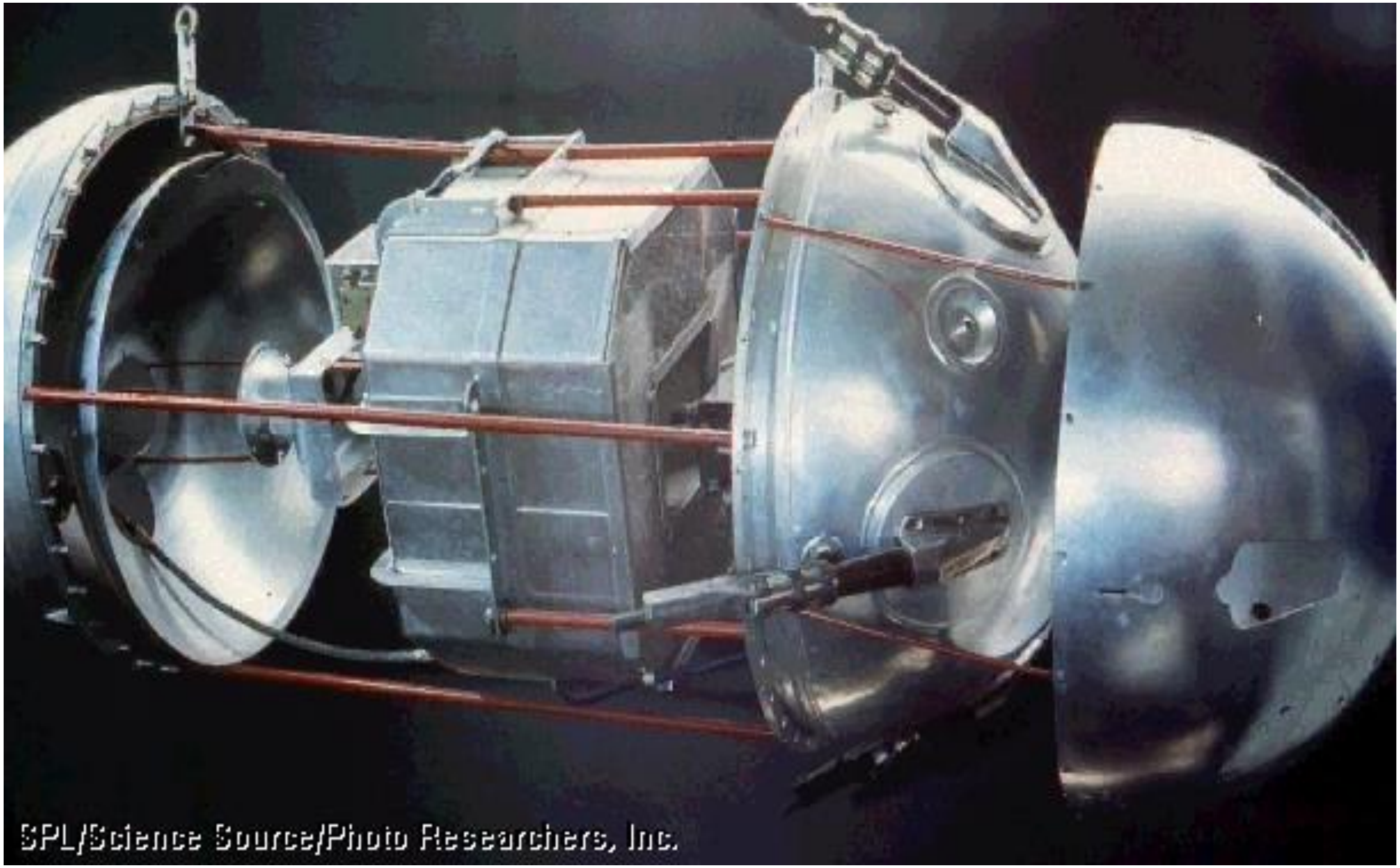
1945	Arthur C. Clarke publishes an essay about “Extra Terrestrial Relays“
1957	first satellite SPUTNIK
1960	first reflecting communication satellite ECHO
1963	first geostationary satellite SYNCOM
1965	first commercial geostationary satellite “Early Bird“ (INTELSAT I): 240 duplex telephone channels or 1 TV channel, 1.5 years lifetime
1969	INTELSAT-III series provides global coverage
1976	three MARISAT satellites for maritime communication
1982	first mobile satellite telephone system INMARSAT-A
1988	first satellite system for mobile phones and data communication INMARSAT-C
1993	first digital satellite telephone system
1998	global satellite systems for small mobile phones

ECHO I



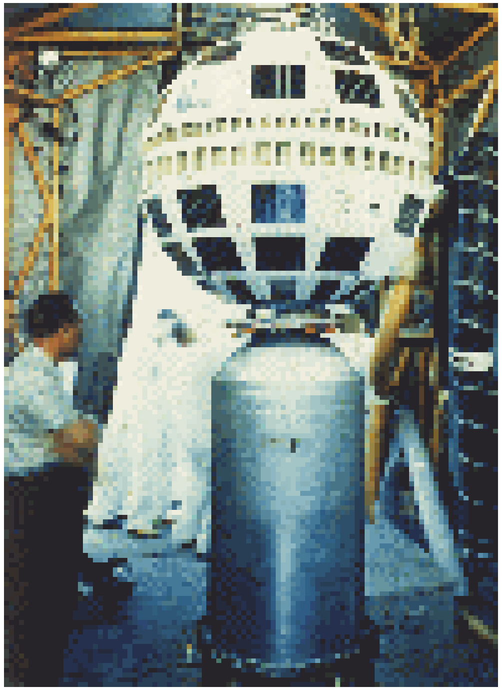
1960   first reflecting communication satellite ECHO

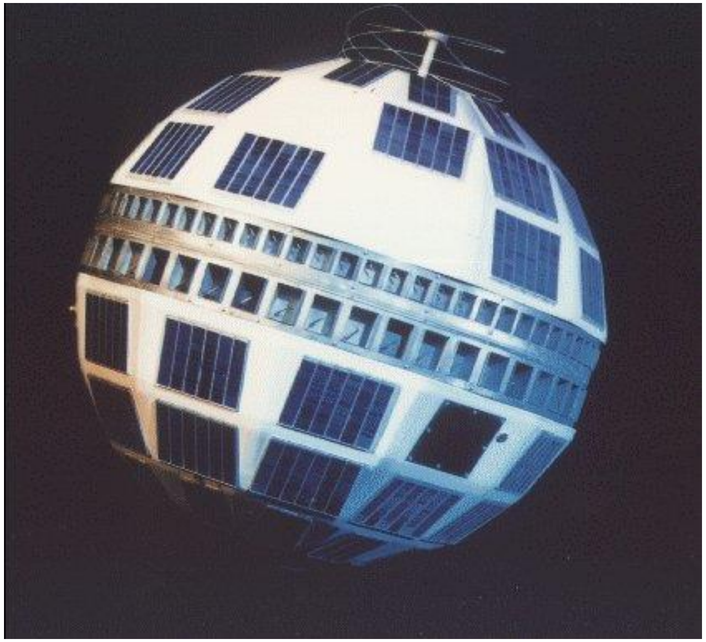
Sputnik - I



LEO satellite

Telstar was the first active communications satellite. Belonging to AT&T as part of a multi-national agreement between AT&T, Bell Telephone Laboratories, NASA, the British General Post Office, and the French National PTT (Post Office.) to develop satellite communication. It was launched by NASA from Cape Canaveral on July 10, 1962, the first privately sponsored space launch. Telstar was placed in an elliptical orbit (completed once every 2 hours and 37 minutes), rotating at a 45 degree angle above the equator.



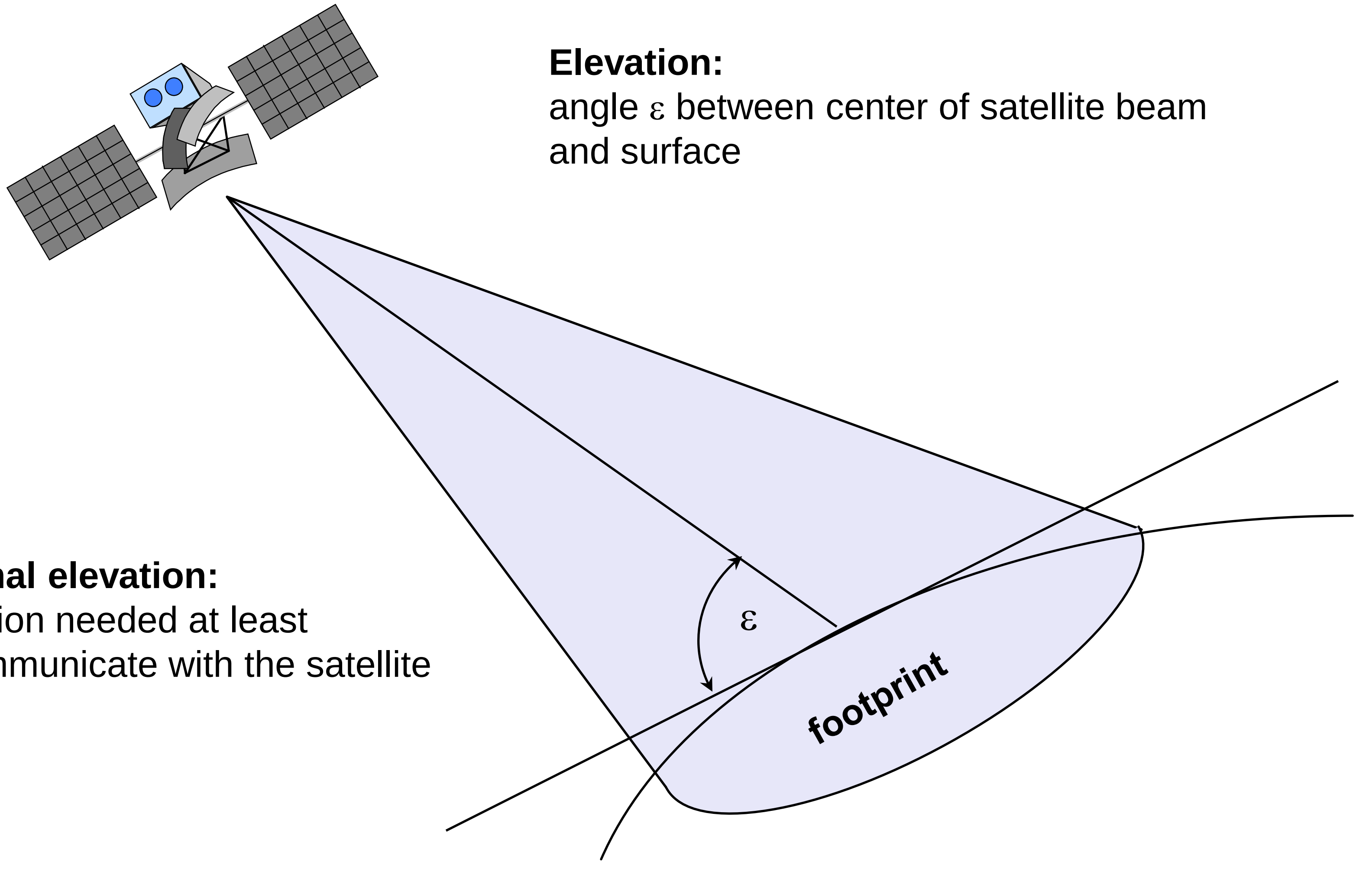


Initial application of GEO Satellites: Telephony

- **1965** Early Bird 34 kg 240 telephone circuits
- **1968** Intelsat III 152 kg 1500 circuits
- **1986** Intelsat VI 1,800 kg 33,000 circuits
- **2000** Large GEO 3000 kg 8 - 15 kW power
  1,200 kg payload

Elevation

Elevation:
angle ε between center of satellite beam and surface



minimal elevation:
elevation needed at least
to communicate with the satellite

Satellite communication

Elevation Angle: The angle of the horizontal of the earth surface to the center line of the satellite transmission beam.

- This effects the satellites coverage area. Ideally, you want a elevation angle of 0 degrees, so the transmission beam reaches the horizon visible to the satellite in all directions.
- However, because of environmental factors like objects blocking the transmission buildings, trees, atmospheric attenuation, and the earth electrical background noise, there is a minimum elevation angle of earth stations.

Satellite communication

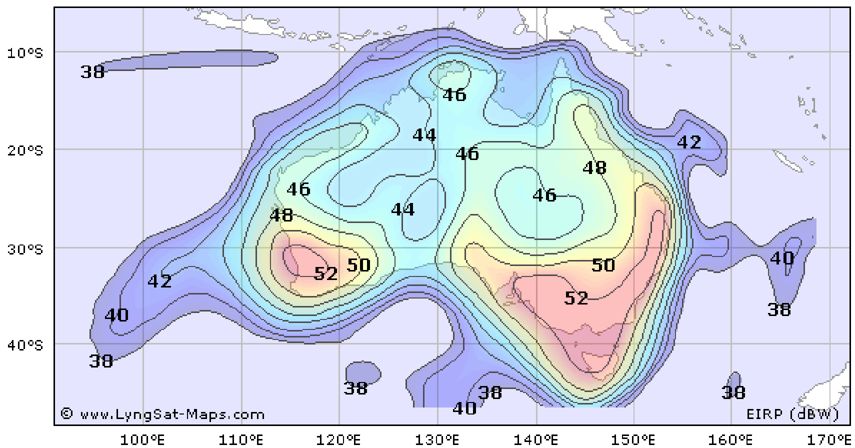
Other impairments to satellite communication:

- The distance between an earth station and a satellite (free space loss).
- Satellite Footprint: The satellite transmission's strength is strongest in the center of the transmission, and decreases farther from the center as free space loss increases.
- Atmospheric Attenuation caused by air and water can impair the transmission. It is particularly bad during rain and fog.

Coverage

- Coverage refers to the uplink & downlink beam patterns created on the earth by the satellite receive & transmit antennas
- Coverage can be tailored to any predefined shape using conventional antenna reflector and feed technology
- Some examples of coverage beams include global, international, national and spot beams
- Multiple coverage area systems can provide dedicated or switchable inter-beam connectivity

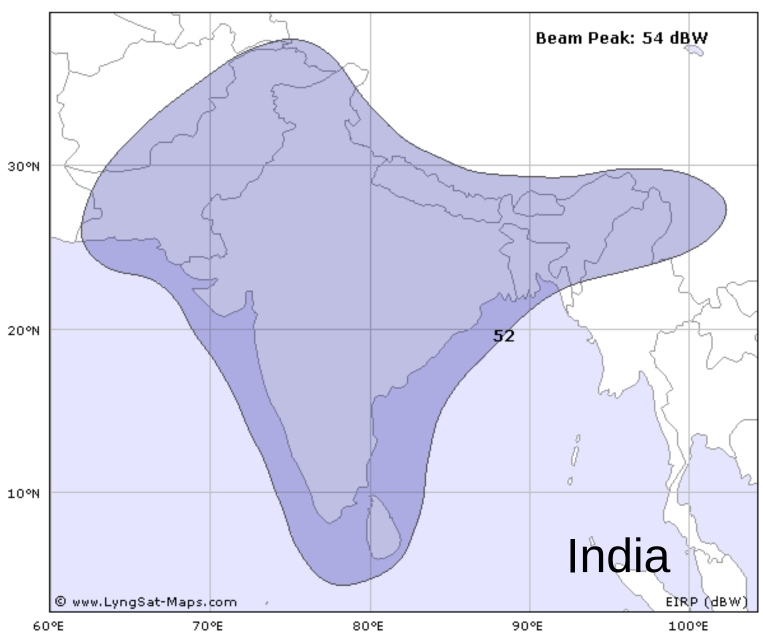
Coverage contours



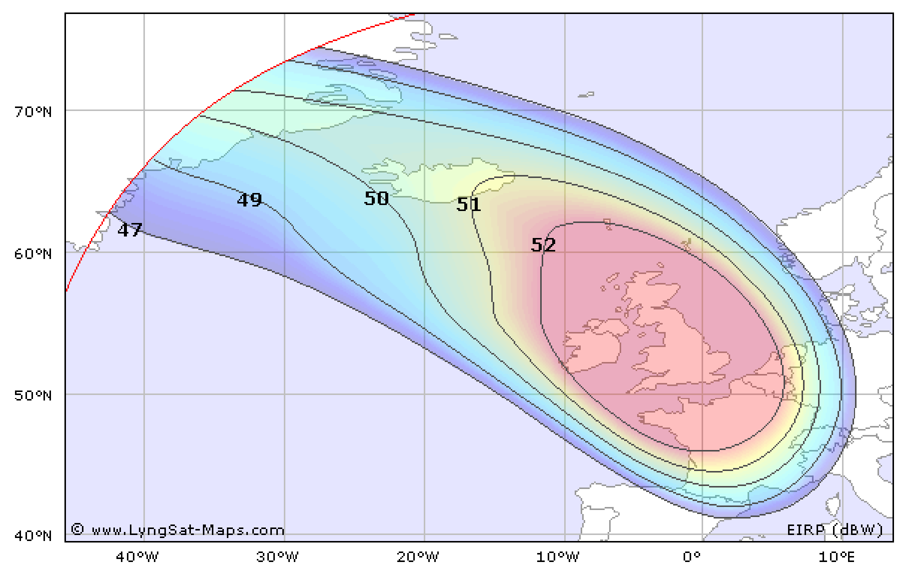
Australia

Area of earths surface seen by a satellite is

$$A_s = 2\pi R_E^{\ 2}\{h/(h+R_E)\}$$

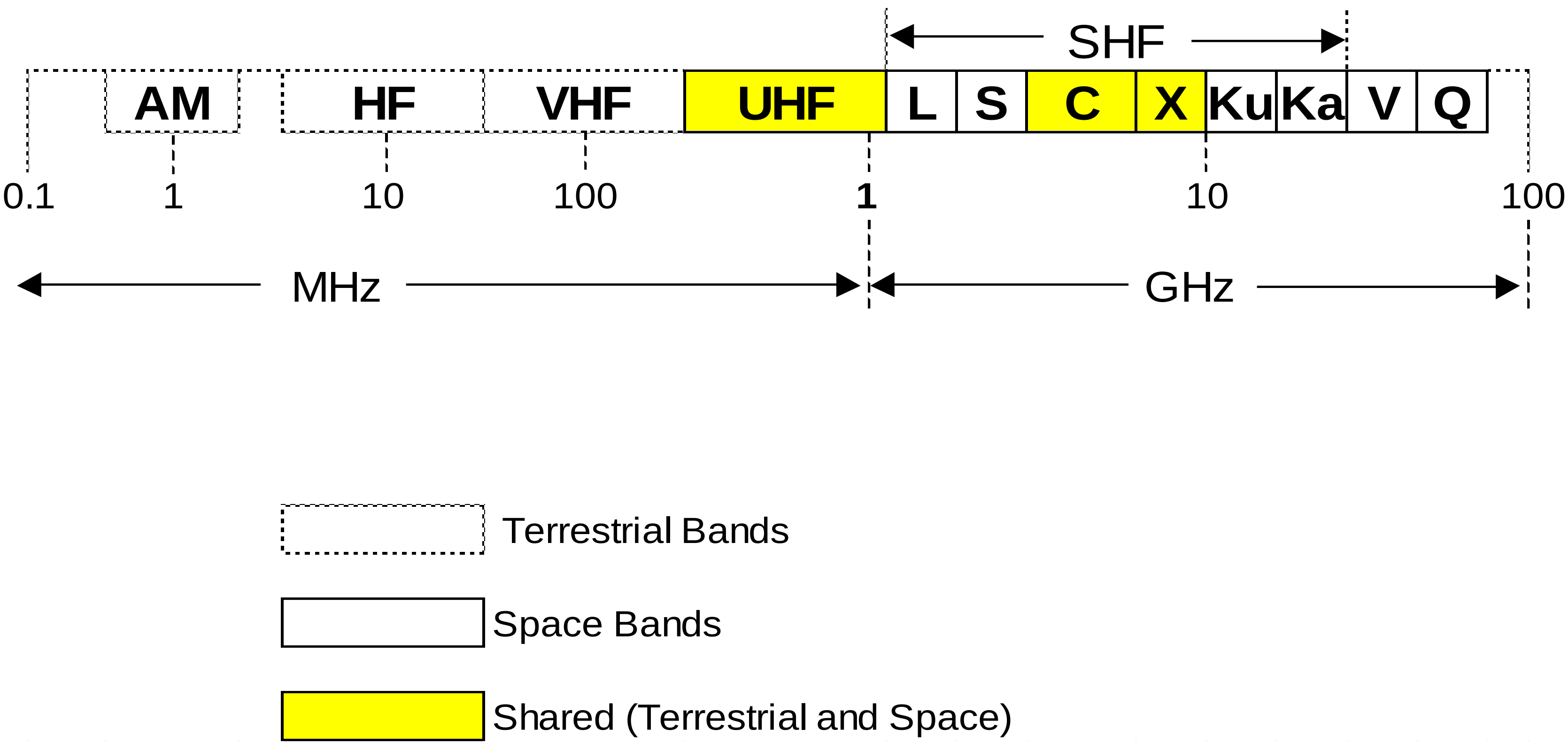


India



Radio Frequency Spectrum

Commonly Used Bands



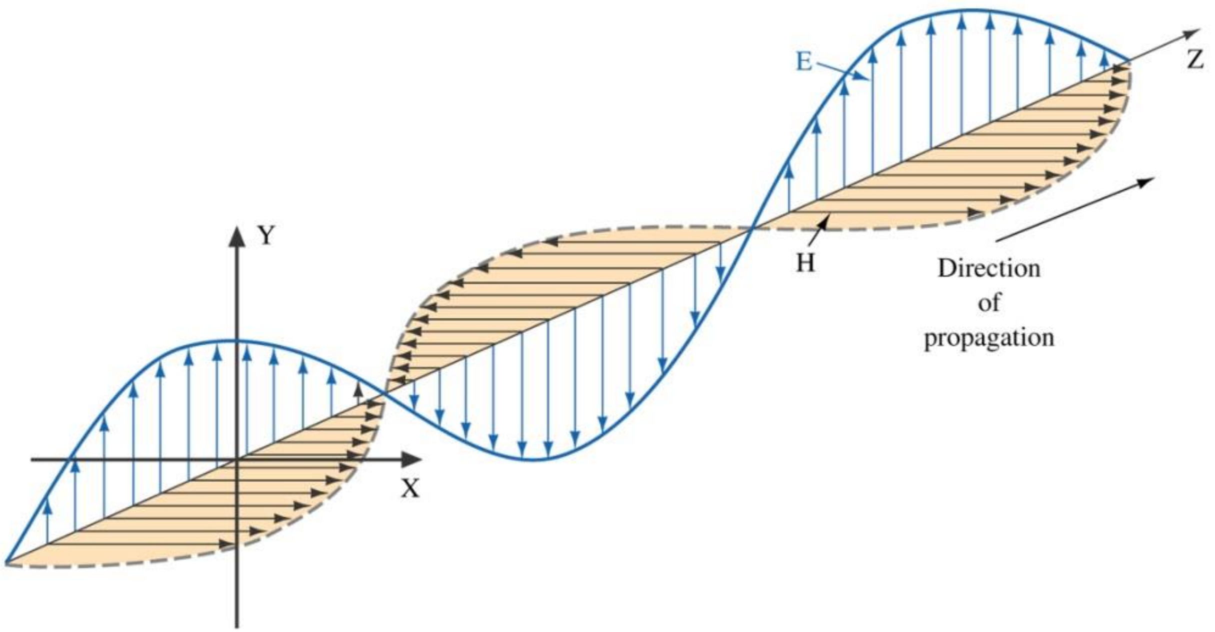
The International Telecommunications Union (ITU) recommended frequency assignments for satellite communications developed at WARC-85 are listed as follows:

Sub Band Designation	Frequency Range
L Band	1.5 - 1.6 GHz
S Band	2.5 - 2.6 GHz
C Band	3.4 - 4.2, 5.9 - 6.7 GHz
Ku Band	10.7 - 14.5, 17.3 - 17.8 GHz
Ka Band	18.3 - 22.2, 27.0 - 31.0 GHz

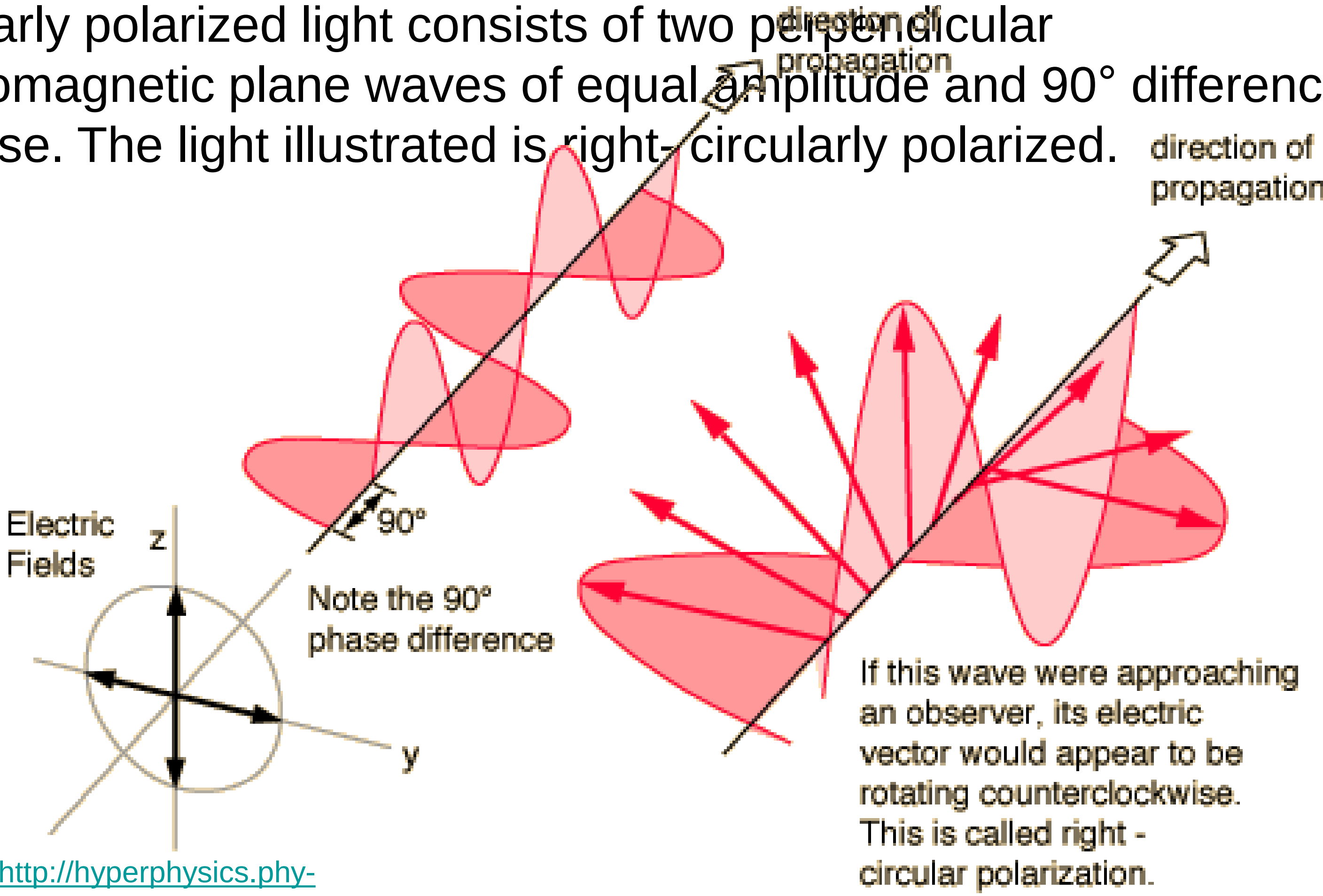
Frequency reuse

- Because of operating frequency and bandwidth limitations, payloads typically employ polarisation frequency reuse schemes to maximize the system capacity
- **Spatial frequency reuse** is accomplished by using multiple uplink/downlink beams each dedicated to different coverage areas

- Within each beam/coverage area, frequency reuse is accomplished by using orthogonally polarized beams
  - linear polarization schemes use vertical and horizontal electric field (e-field) beams
  - circular polarization schemes use left and right hand circularly rotating e-field beams

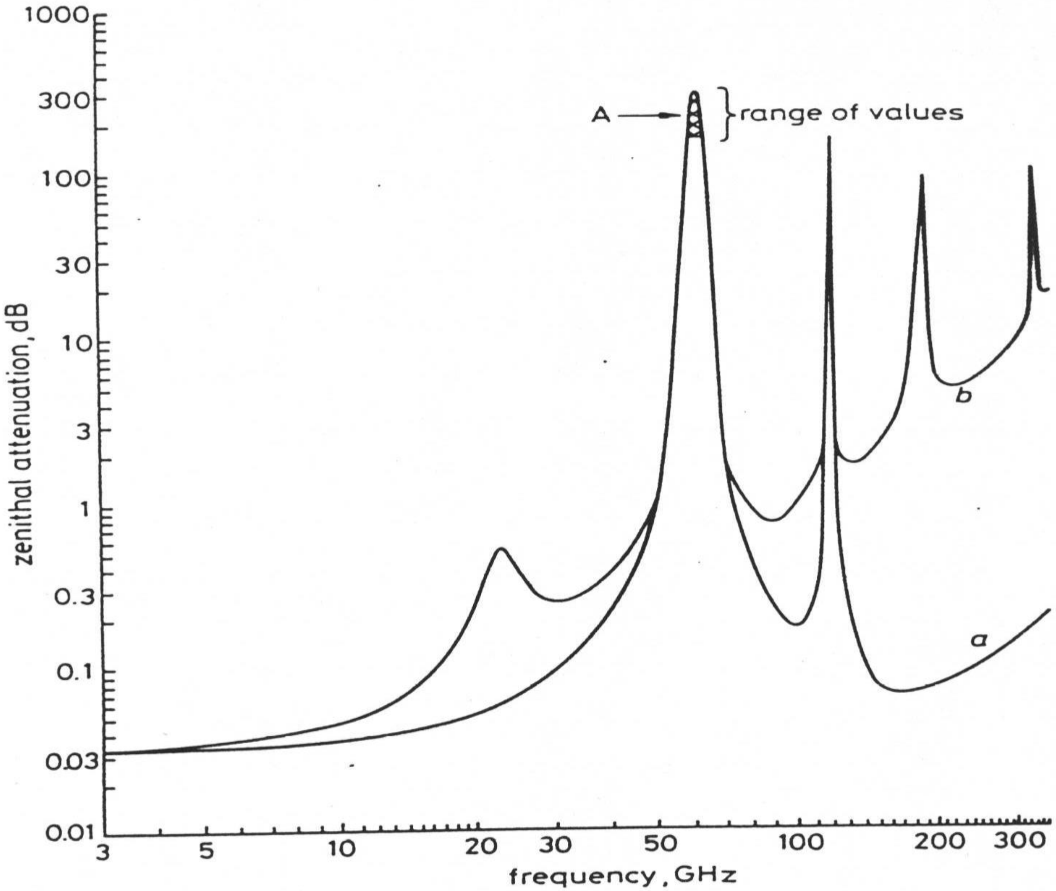


Circularly polarized light consists of two perpendicular electromagnetic plane waves of equal amplitude and 90° difference in phase. The light illustrated is right- circularly polarized.



(image taken from http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html)

Space-Earth Frequency Usability



Resonance frequencies below 100GHz:

- 22.2GHz (H_20)
- 53.5-65.2 GHz (Oxygen)

Atmospheric attenuation effects for Space-to-Earth as a function of frequency (clear air conditions). (a) Oxygen; (b) Water vapor. [Source: ITU © 1988]

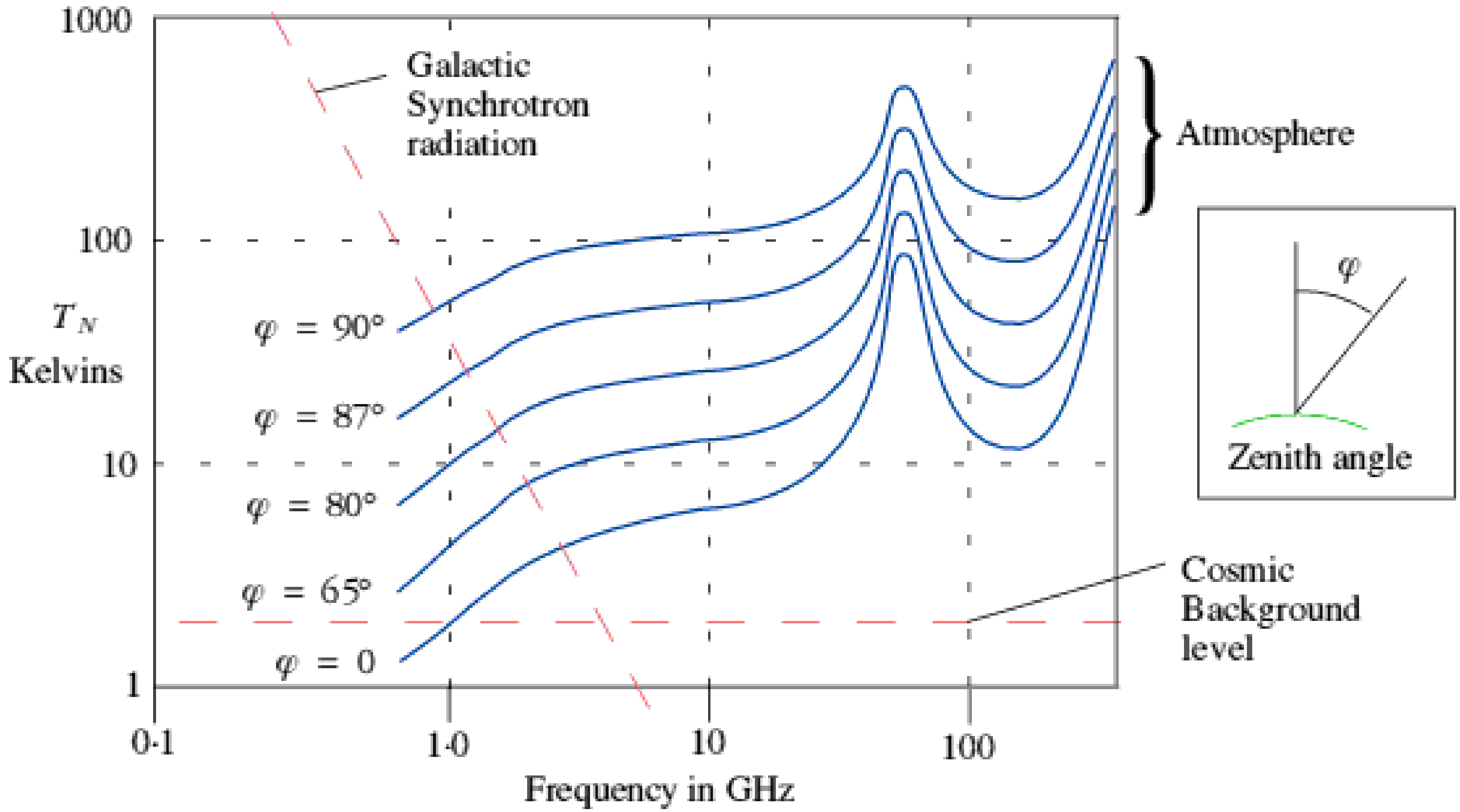


Figure 8.5 Combined atmospheric & sky noise for standard atmosphere.

Transmission path effects

1. Path loss $P_L = \frac{P_T}{P_R} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$ dB

If f is GHz, d in km then P_L = 92.5 + 20 log f + 20 log d **dB**

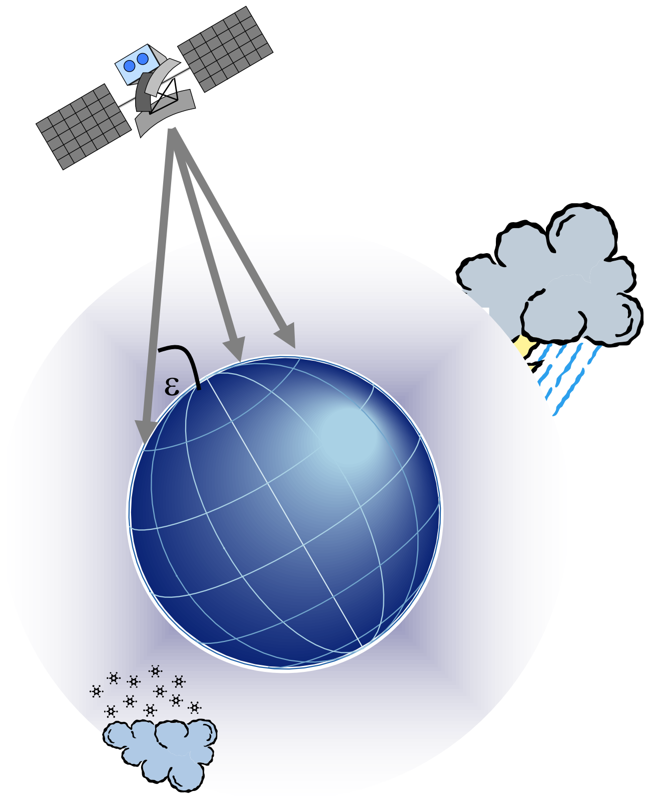
2. Depolarisation due to rain > 15 GHz

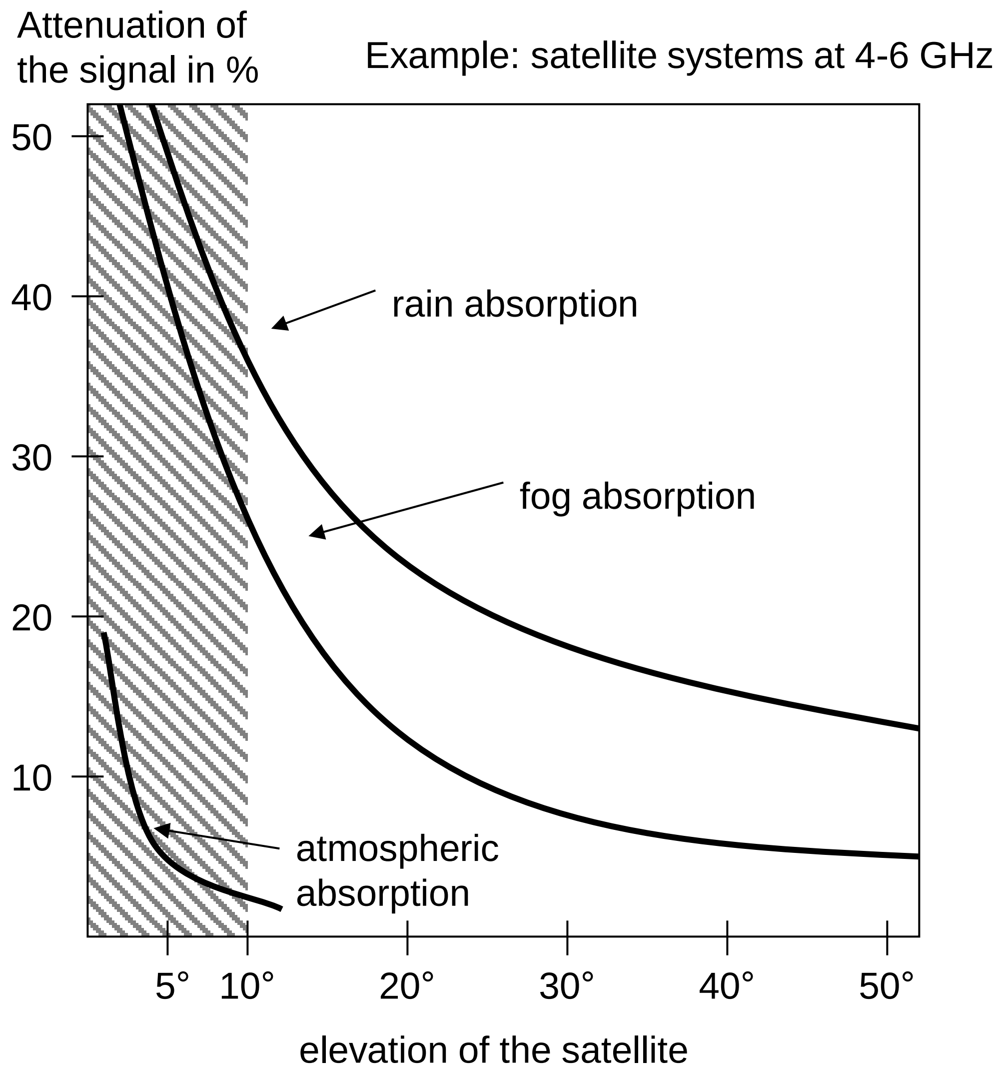
3. Faraday rotation for f < 1 GHz

4. A small operating margin of up to 4 dB is used

For satellite comms use 2 – 15 GHz

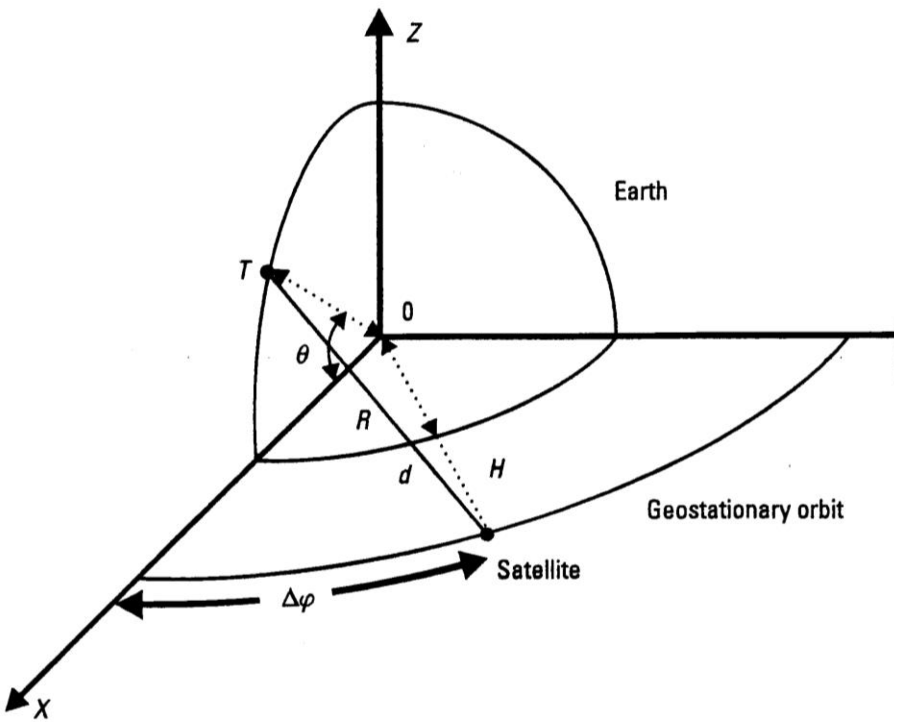
Atmospheric attenuation





SATELLITE LINK GEOMETRY

Slant Range



Ground station: latitude = θ
longitude = φ_G

Satellite: longitude = φ_S

(north latitudes and east longitudes are positive)

Define difference in longitudes as $\Delta\varphi = \varphi_S - \varphi_G$

From the diagram, the ground station coordinates on the ZX plane are $R\cos\theta$, 0, $R\sin\theta$

From diagram the ground station coordinates on the ZX plane are $R_E\cos\theta$, 0, $R_E\sin\theta$ and the satellite coordinates are $(R_E + h)\cos\Delta\varphi$, $(R_E + h)\sin\Delta\varphi$, 0.

Slant range d is given by

$$d = \sqrt{(R_E + h)^2 + {R_E}^2 - 2R_E(R_E + h)\cos\Delta\varphi\cos\theta}$$

Example: A ground station located at 22º N, 80 º W is receiving signals from the geostationary satellite Galaxy V at 125 º W. What is the free space path loss at 4 GHz?

Now R_E= 6378 km, R_E + h = 42164 km

GROUND STATION ANTENNA POINTING ANGLES

From Gomez "Satellite broadcast systems engineering"

Elevation angle (degs)

$$EL = \tan^{-1}\left[\frac{(R_E + h)\cos\Delta\varphi\cos\theta - R_E}{(R_E + h)\sqrt{1 - \cos^2\Delta\varphi\cos^2\theta}}\right]$$

Azimuth angle (degs)

$$AZ = 180° - \tan^{-1}\left[\frac{\tan\Delta\varphi}{\sin\theta}\right]$$

Example: Calculate the azimuth and elevation antenna pointing angles for a ground station located at 52° N, 1° W when it is receiving signals from the ASTRA 1A satellite located at 5.2° E.

Answer:

$$\frac{R_E}{R_E + h} = 0.1513$$

$$EL = \tan^{-1}\left[\frac{\cos(6°)\cos(52°) - 0.1513}{\sqrt{1 - \cos^2(6°)\cos^2(52°)}}\right] = 30.2°$$

$$AZ = 180° - \tan^{-1}\left[\frac{\tan(6°)}{\sin(52°)}\right] = 172.4°$$

NOTE: for azimuth, 0° corresponds to due north, 180° to due south, etc as measured using a compass

Stability

It is vital that satellites are stabilised
- to ensure that solar panels and antennas are aligned properly

Early satellites used spin stabilisation
- either this required an inefficient omni-directional aerial
- or antennae were precisely counter-rotated in order to provide stable communications

Modern satellites use reaction wheel stabilisation - a form of gyroscopic stabilisation

Power

- Modern satellites use a variety of power means
- Solar panels are used to generate electricity
- Batteries are needed as sometimes the satellites are behind the earth - this happens about half the time for a LEO satellite
- Nuclear power has been used - but not recommended

Positioning in ORBIT

This can be achieved by several methods

- One method is to use small rocket motors
- These use fuel - over half of the weight of most satellites is made up of fuel
- Often it is the fuel availability which determines the lifetime of a satellite
- Commercial life of a satellite typically 10-15 years

Equinox problems

- Sun outage – when an earth station sees the satellite with the sun directly behind it (again around the equinoxes) there is a communication blackout. This is because the sun is a hot microwave source with an equivalent noise temperature of 6000-10000 K.

- Solar eclipse – when earth blocks the sun the solar panels receive no sunlight and the satellite must rely on battery power. This happens around the equinoxes (21st March & September) and lasts for up to 1 hour. Extreme heating effects also take place.

Using Decibels - 1

Rules:

- Multiply A x B:

  (Add dB values)

$$10\log_{10}(A \text{ x } B)$$
$$= 10\log_{10}(A) + 10\log_{10}(B)$$
$$= A\text{dB} + B\text{dB}$$
$$= (A + B)\text{dB}$$

- Divide A / B:

  (Subtract dB values)

$$10\log_{10}(A / B)$$
$$= 10\log_{10}(A) - 10\log_{10}(B)$$
$$= A\text{dB} - B\text{dB}$$
$$= (A - B)\text{dB}$$

Using Decibels - 2

Rules:

- Squares:

  (Multiply by 2)

$$10\log_{10}(A^2)$$
$$= 2 \text{ x } 10\log_{10}(A)$$
$$= 20\log_{10}(A)$$
$$= 2 \text{ x } (A \text{ in dB})$$

- Square roots:

  (Divide by 2)

$$10\log_{10}(\sqrt{A})$$
$$= \frac{10}{2}\log_{10}(A)$$
$$= \frac{1}{2} \text{ x } (A \text{ in dB})$$

Decibels

1 Watt = 1000 mW

If $P_0 = x$ W then $P_0 = 10\log_{10}(x)$ dBW and $x = 10^{\frac{P_0}{10}}$ W

E.g. 1 W = 0 dBW = 30 dBm

1 mW = -30 dBW = 0 dBm

0.5 W = -3 dBW = 27 dBm

0.1 W = -10 dBW = 20 dBm

1 pW = -120 dBW = -90 dBm

Confirm the following table (do a few mW to dBm, a few dBm to mW)

Power (mW)	Power (dBm)
100	20
10	10
1.6	2.04
1	0
0.32	-5
0.1	-10
0.01	-20

References in dB

- dB values can be referenced to a standard
- The standard is simply appended to dB
- Typical examples are:

Units	Reference
dBi	isotropic gain antenna
dBW	1 watt
dBm	1 milliwatt
dBHz	1 Hertz
dBK	1 Kelvin
dBi/K	isotropic gain antenna/1 Kelvin
dBW/m^2	1 watt/m^2
dB$	1 dollar