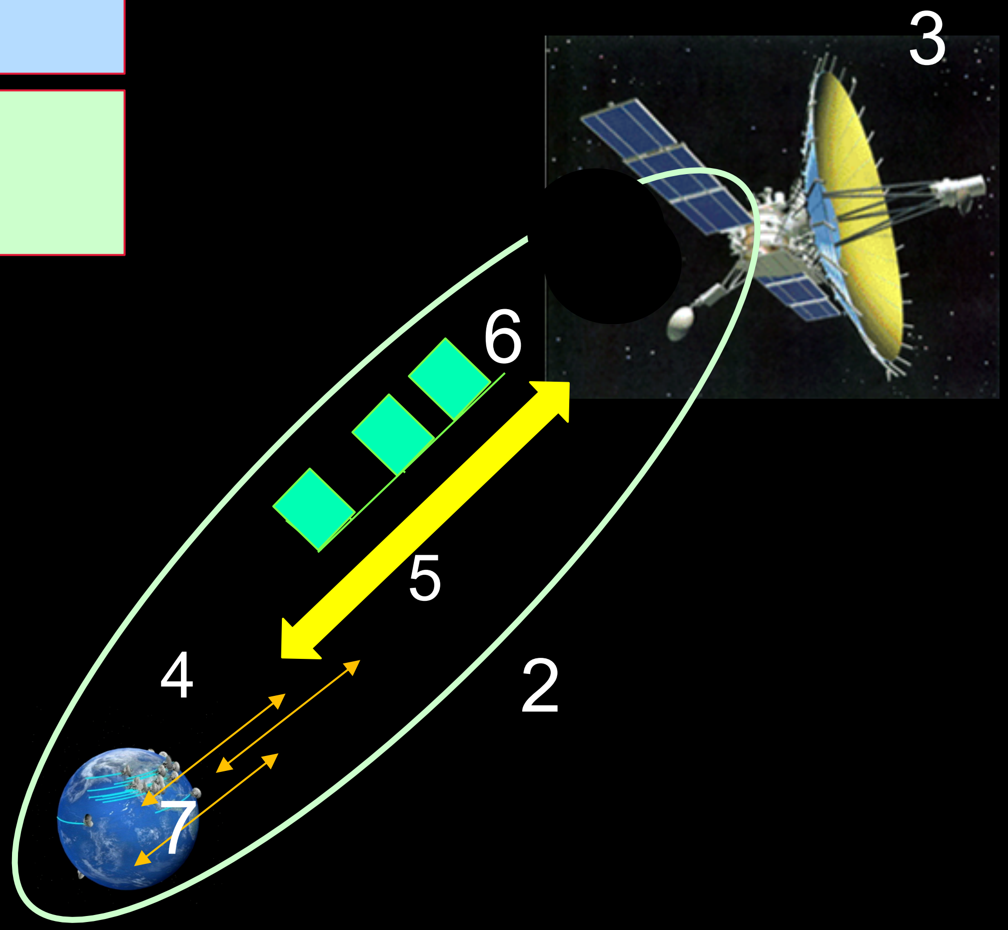
PHYS 3250
Introduction to space communications

Professor N Bartel

Sketch of the 7 chapters

2 Orbital aspects
3 Spacecraft
4 Earth station
5 Communications link
6 Modulation and
   multiplexing techniques
7 Multiple access to a
   satellite



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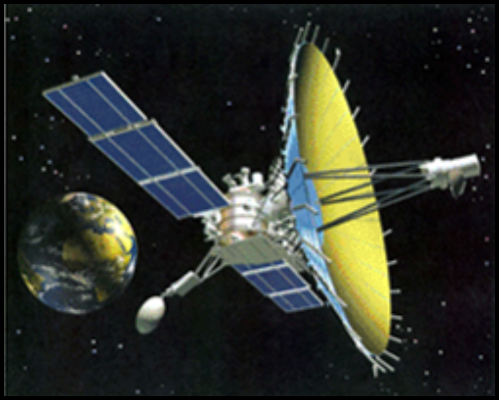
3. Spacecraft

3.1 Power systems
3.2 Attitude and orbit control
3.3 Telemetry, tracking and command (TT&C)
3.4 Transponder
3.5 Antennae



3. Spacecraft
3.1 Power systems

Satellites: i) solar cells

ii) batteries

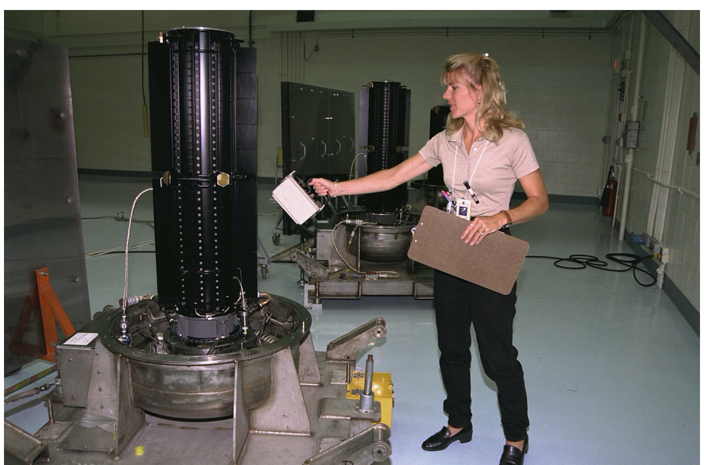
The solar panels on the Solar Maximum Mission (SMM) satellite provided electrical power. Here it is being captured by an astronaut in a mobile space-suit that runs on chemical battery power

NASA-MSFC

Interplanetary spacecraft : i) solar cells (for inner planets)

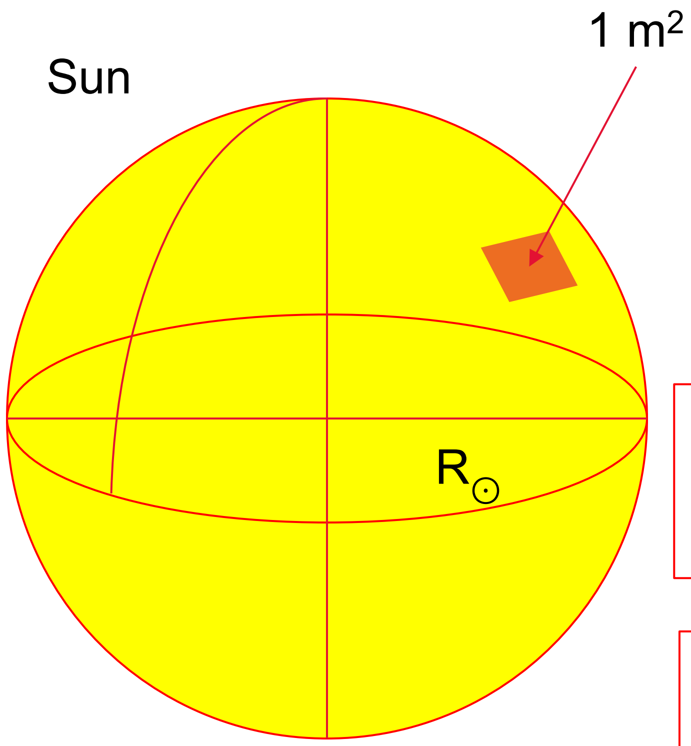
ii) thermonuclear reactors

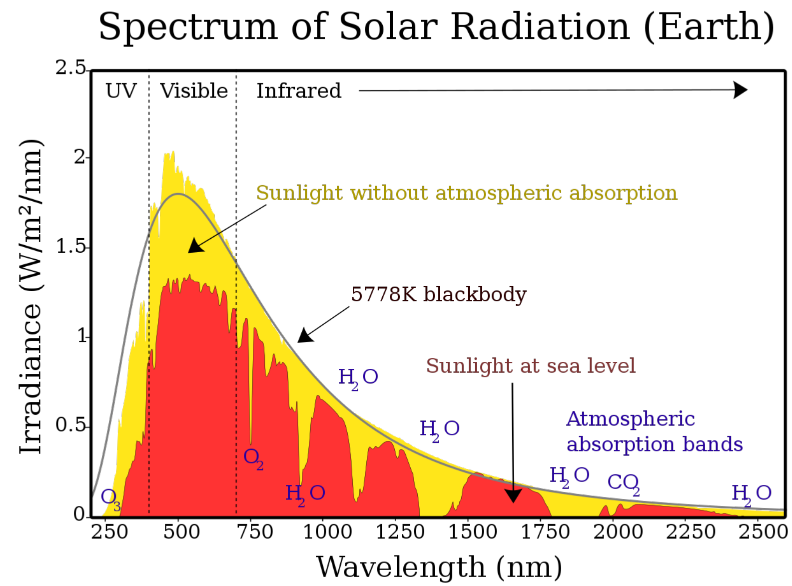
iii) radioisotope thermoelectric generators, RTG (for outer planets)



NASA

Luminosity of Sun ($L_\odot$)





$$F = \sigma T^4$$
$$= 5.670 \cdot 10^{-8} \cdot (5777)^4$$
$$= 6.315 \cdot 10^7 \ \mathrm{Wm^{-2}}$$

$$L_\odot = 4\pi R_\odot^2 \, F$$
$$= 4\pi (6.96 \cdot 10^8)^2 \cdot 6.315 \cdot 10^7$$

$$L_\odot = 3.84 \cdot 10^{26} \ \mathrm{W}$$

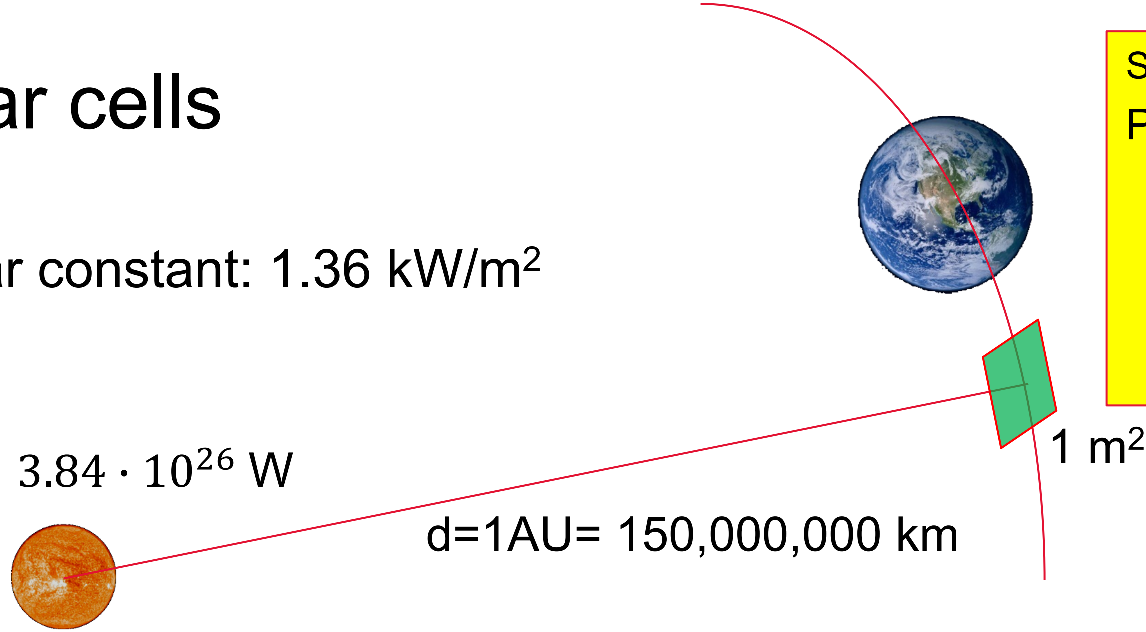
$L_\odot$: Luminosity of Sun
F : Flux through surface area of 1 m^2
$R_\odot$: Radius of the Sun
T =5777 K. (surface temperature)
σ = $5.670 \cdot 10^{-8}$ $\mathrm{Wm^{-2} K^{-4}}$ (Stefan-Boltzmann constant)

Solar cells

Solar constant: 1.36 kW/m^2

Sun

$L_\odot = 3.84 \cdot 10^{26}$ W



Solar constant:

$$P_{sqmAU} = L_\odot / 4\pi d^2$$

$$= \frac{3.84 \cdot 10^{26}}{4\pi \cdot (1.50 \cdot 10^{11})^2}$$

$$= 1.36 \text{ kW m}^{-2}$$

Solar cell efficiency: 10 – 28%, falls off to 85% of peak efficiency after several years.

Reasons: i) aging,

ii) etching through micrometeor impacts,

iii) electrons impingement,

iv) solar flare 3 MeV protons.

Improvements in solar cell technology through

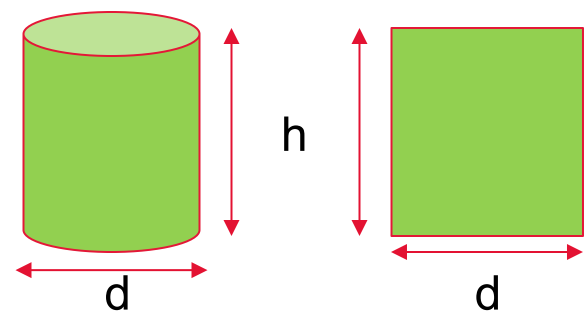
i) increase of efficiency,

ii) protection from environment.

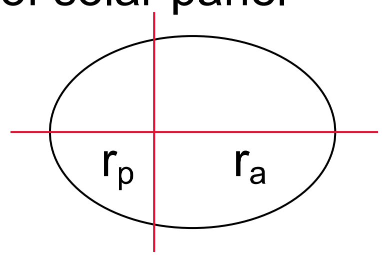
Variation in illumination (example: geostationary satellite)

$$P(t) = d \cdot h \cdot E(t) \cdot (\cos\delta) \cdot \eta \cdot (1 - \varepsilon)$$

P(t): received power from Sun
E(t): solar constant with slight variations due to ellipticity of Earth orbit.
d: diameter of spinner or width of solar panel
h: height of spinner or length of solar panel



$P_{sqmAU} = E_0$: solar constant



Earth orbit : e=0.0167

$r_{a.}$ = a(1+e)

r_p = a(1-e)

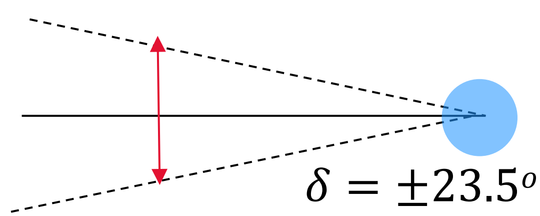
$E_a(t) = E_a = E_0 \frac{1}{(1+e)^2}$

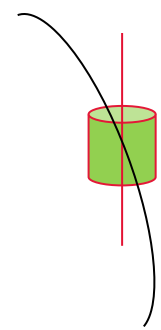
$E_p(t) = E_b = E_0 \frac{1}{(1-e)^2}$

$E(t) = 1.36 \pm 0.05\ \mathrm{W/m^2}$

rounded

δ: declination of Sun





Projected illuminated area changes during year with δ since spin axis and length axis do not adjust to δ

η: peak efficiency of solar cells
ϵ: decay of efficiency

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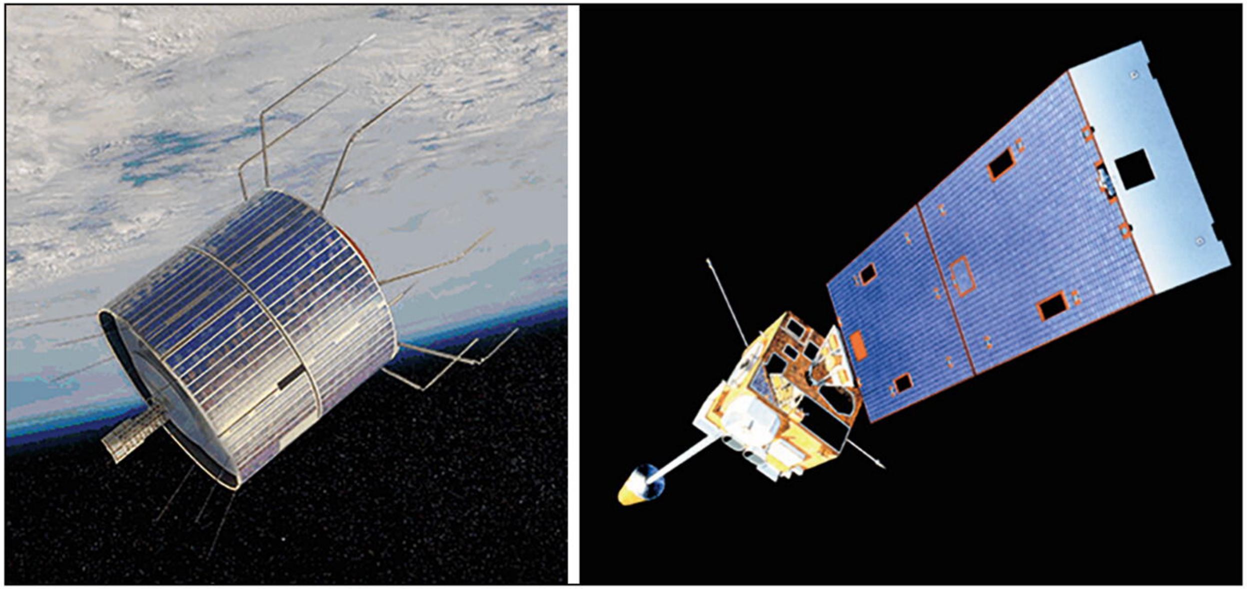
a) Solar cells on cylindrical drum and flat panels

Two kinds of solar cell arrangements



link.springer.com

Cylindrical drum

Flat panel

a) Solar cells on cylindrical drum

-

Advantage: i) straight forward design
ii) cell temperature control through spinning in and out of own shadow (T=20 – 30K)
iii) only one side is exposed to environment

Disadvantage: π times more solar cells are needed for same power generation

b) Solar cells on flat panel

Advantage: i) good use of solar cell area
ii) saving in weight
iii) for given size more power than with spinner

Disadvantage: i) with cells always exposed to full sun light, Cells heat up, T = 50 – 60 K with $dV/dT=-2mV/C^0$
ii) mechanics distort
iii) mechanics needed to unfold and rotate panels (➔ sun sensors needed)

The panels are longitudinal rotatable. Signals from sensors are fed to stepping rotors which rotate the panels $360^o/24h$.

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Batteries

Batteries for satellites must:
a) withstand vibrations,
b) operate in extreme temperature variations,
c) work in vacuum without leaking or bursting,
d) be kept at stable temperatures.

Batteries for satellites are needed during launch and eclipses around equinoxes. Life of batteries is limited by depth of discharge and the number of discharge cycles

Most batteries for satellites are:

a) Nickel-Cadmium (NiCd)
   i. Do not gas when they are discharged
   ii. Long life
   iii. Specific energy of 30 Wh/kg
   iv. Max. discharge allowance of 50% of capacity

b) Nickel-hydrogen (NiH_2)
   i. Sustains greater depth of discharge
   ii. Longer operating life than cadmium
   iii. Specific energy of 60 Wh/kg
   iv. Max. discharge allowance of 80% of capacity

c) Lithium-ion (Li-…(several versions, for small satellites)
   i. Specific energy of 100-200 Wh/kg

d) Hydrogen fuel cells (H)
   i. Highest specific energy of 275 Wh/kg
   ii. Less used

NiH_2 Hubble

Li-ion

electronicsweekly.com

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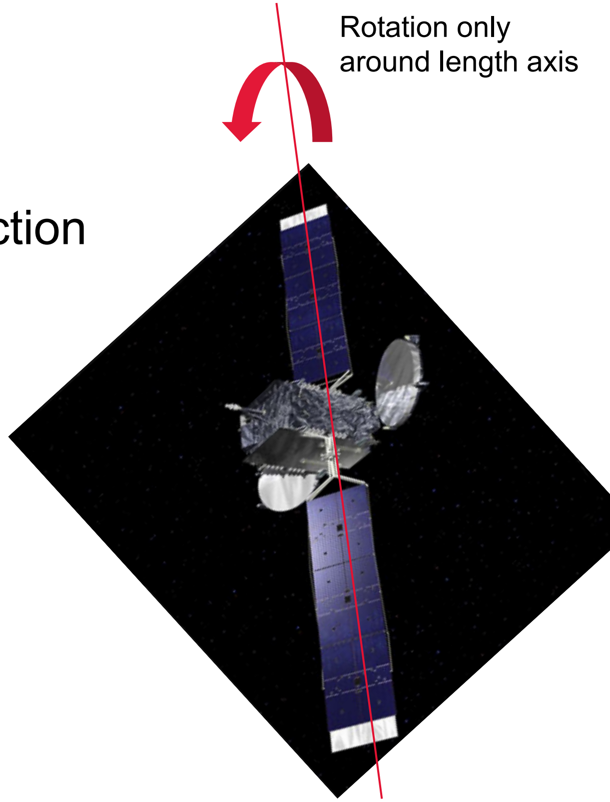
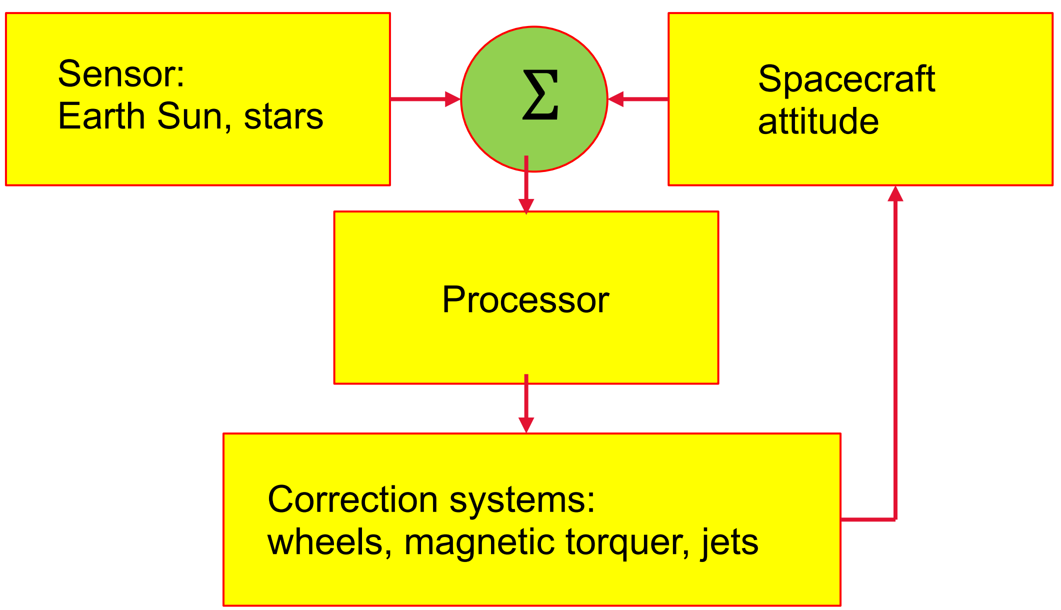
3.2 Attitude and orbit control

Attitude control system

- Antennas need to be pointed into proper direction
- Solar panels need to be pointed towards Sun



Antenna control subsystem senses changes in orientation and then causes satellite to realign itself.



Sources of rotational torque ($\vec{T}=\frac{d\vec{L}}{dt}$), $\vec{L}$: angular momentum vector

- Gravitational forces from Earth, Sun, Moon
- Solar pressure
- Rotation components on satellite (antennas body, panels)
- Magnetic field interactions
- Meteorite impact

Sensors

Sensors	Accuracy (deg)	Mass (kg)	Power needed (W)
Earth sensor	0.05	~5	<10
Sun sensor	0.01	<1	0
Star sensor	0.02	<10	<20

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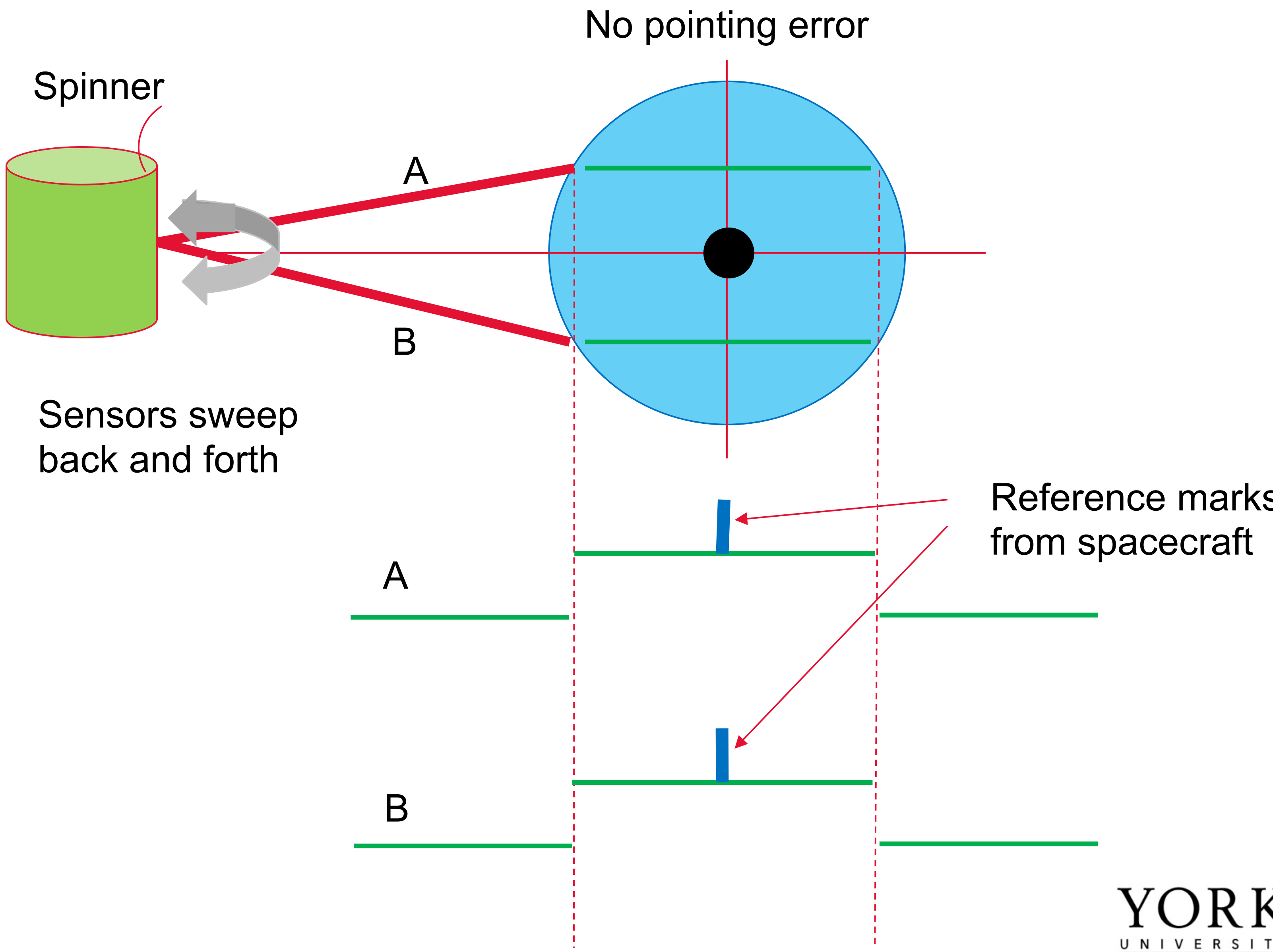
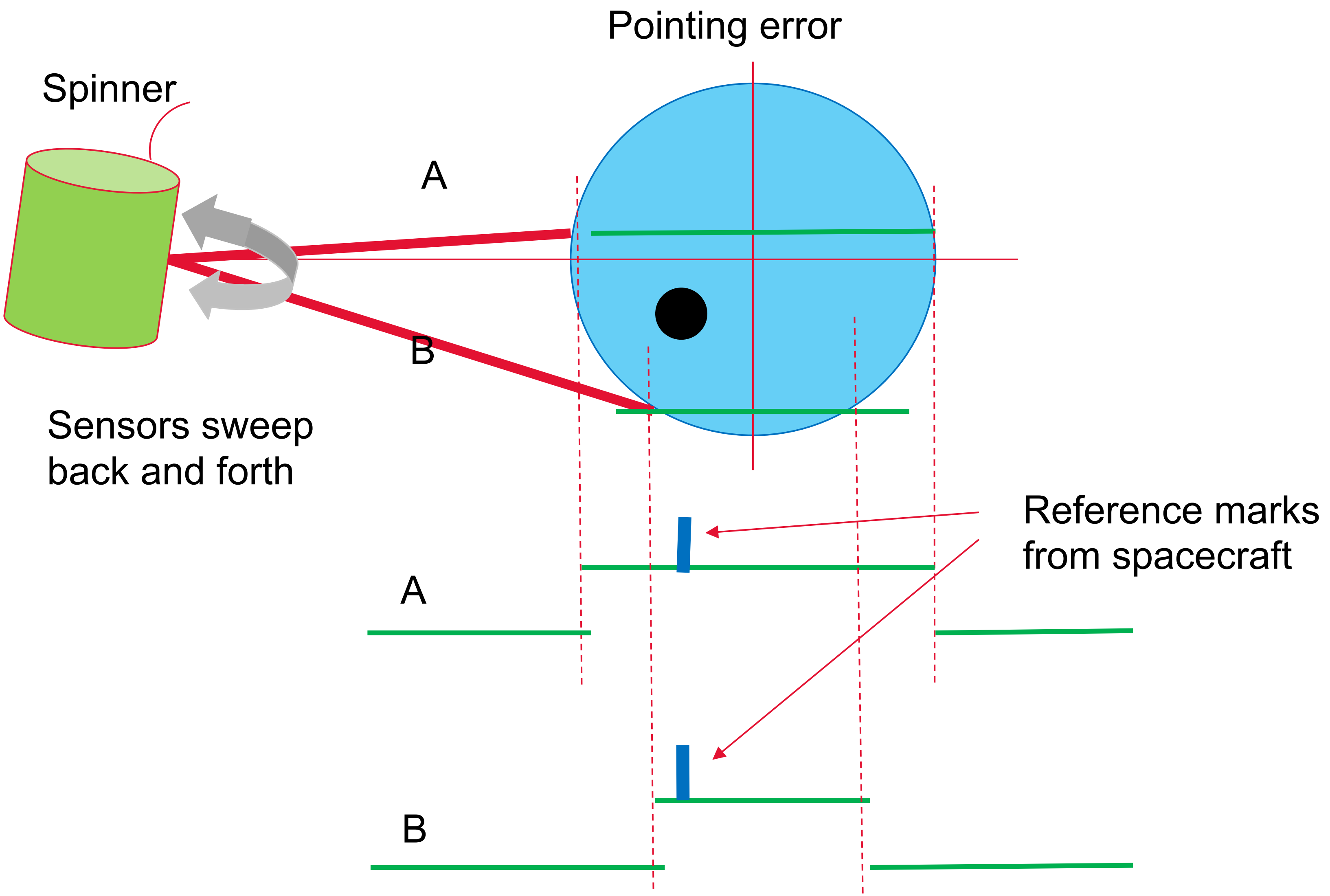
Infrared Earth sensor for spinner



Infrared Earth sensor for spinner



Stabilization

Spin stabilization

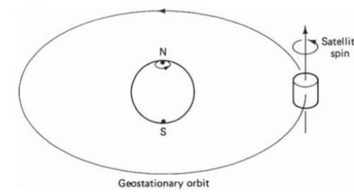
Cylindrical satellite is spinning around its main axis of stabilization with a speed of 50 to 100 rev/min.

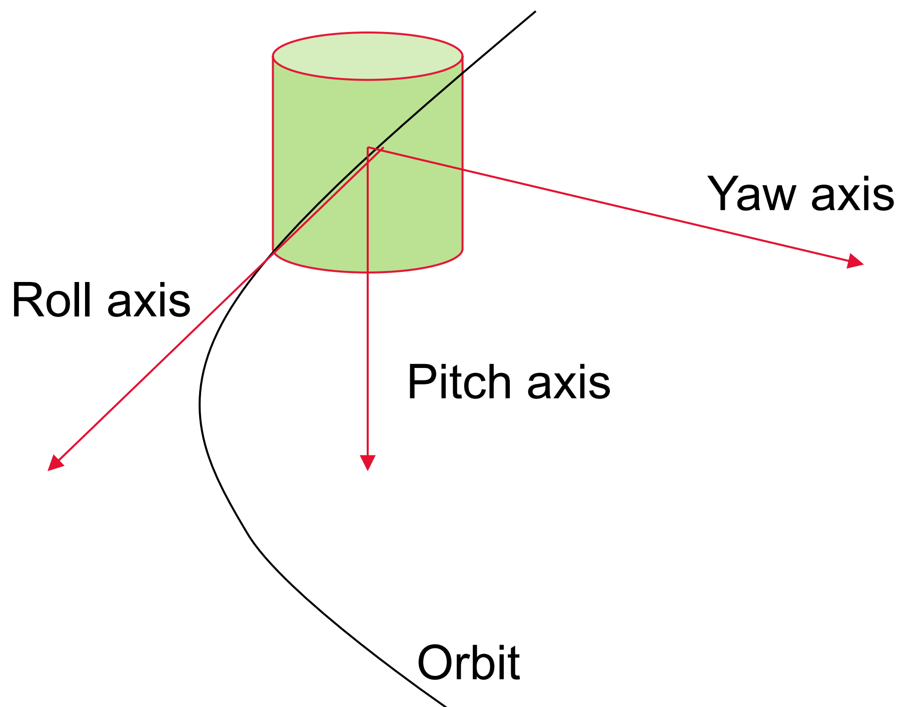
$$\vec{L} = I \cdot \vec{\omega}$$

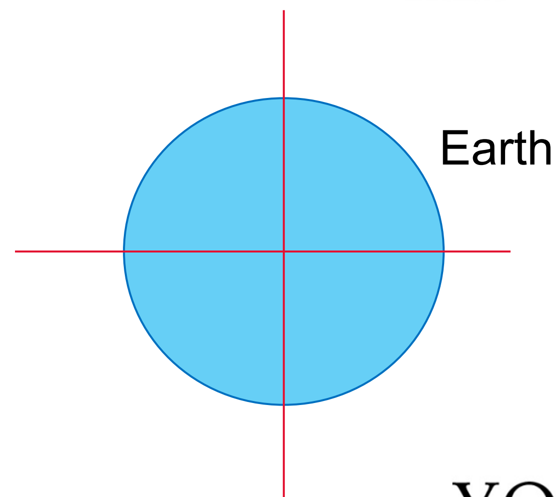
$\vec{L}$ = Angular momentum
I: Moment of inertia
$\vec{\omega}$: angular velocity

Spinning satellite stabilization

- Spin stabilization may be achieved with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis.







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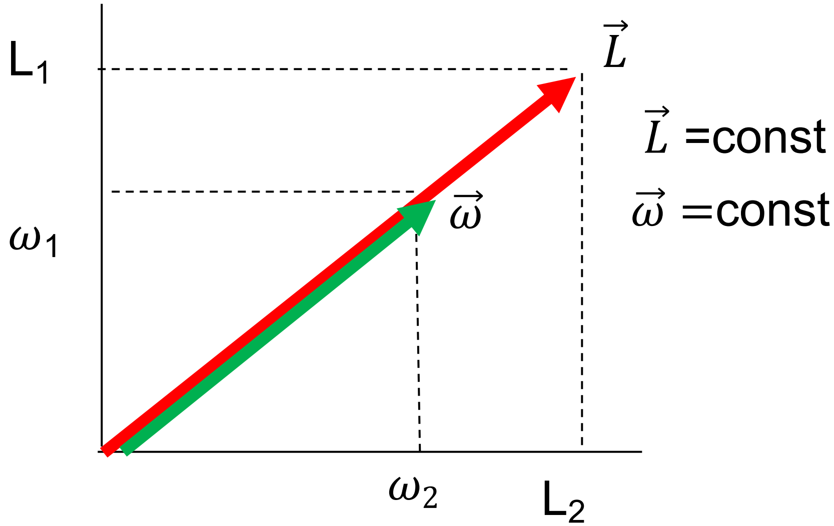
If no external forces exist, angular momentum vector, $\vec{L}$, along pitch axis will maintain direction is space and spin vestor $\vec{\omega}$ will be aligned with $\vec{L}$.

Satellite is spin stabilized

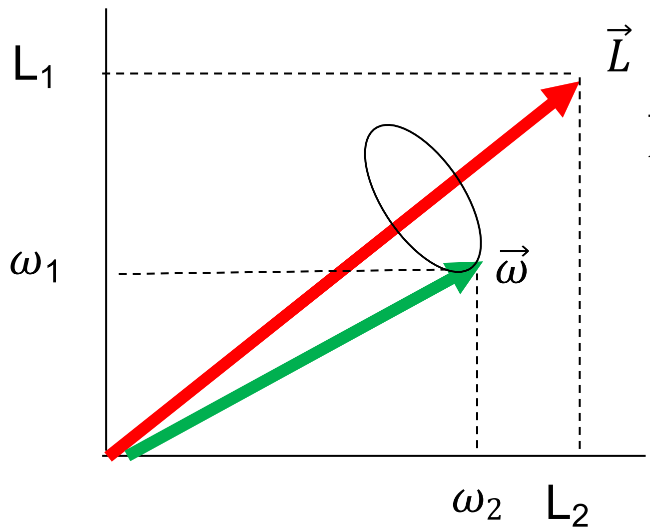


However, directional antennas need to be de-spun.
That means that special lubricants are necessary.

Arising problem: Nutation and Precession

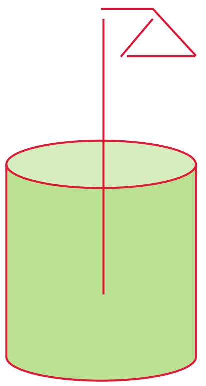
Satellite is not rigid: Dynamic interaction between spun and de-spun sections cause gradual loss of vertical alignment of rotational axis with figure axis:

➡ <u>Nutation</u>



$\vec{L}$ =const

$\vec{\omega}$: changes



Solution: Nutation dampers.
They dissipate energy corresponding to the changes of $\vec{\omega}$.
It is a pendulum − like device

<u>Precession</u>: $\vec{L}$:changes
Force acts on spinner, spinner tries to avert force.

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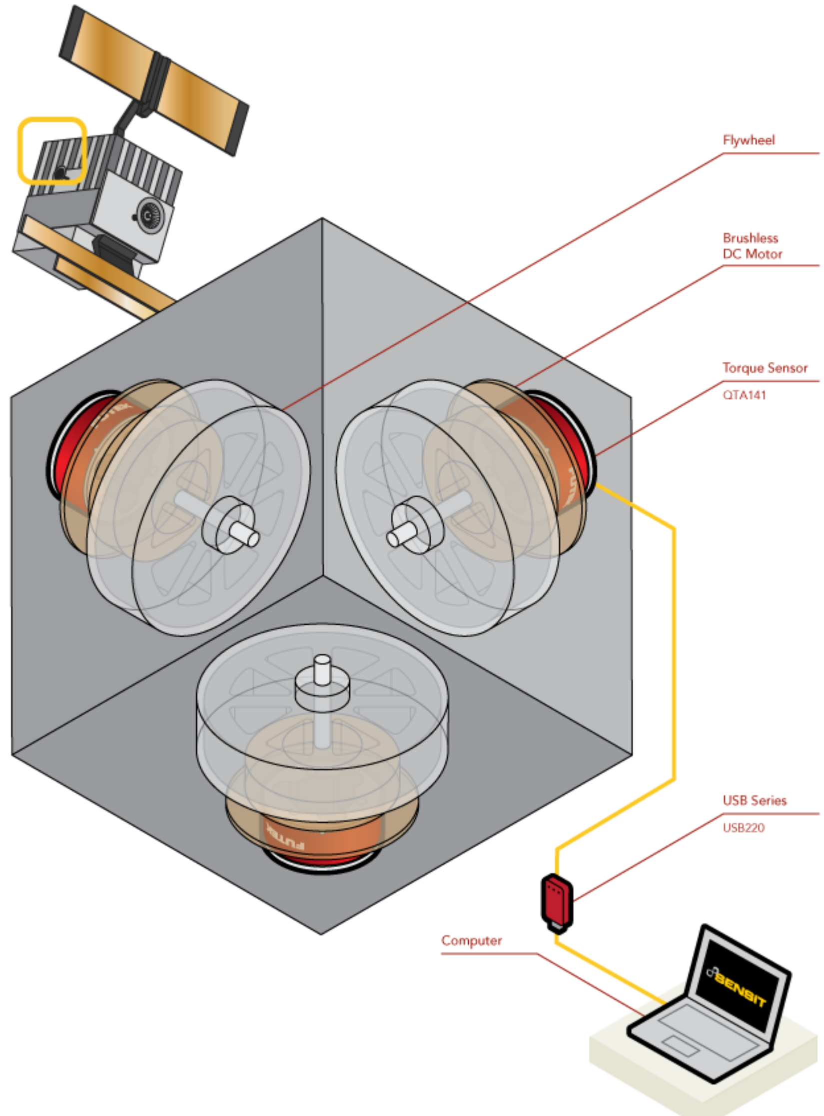
Three-axis stabilization

- Momentum package (motors and wheels)

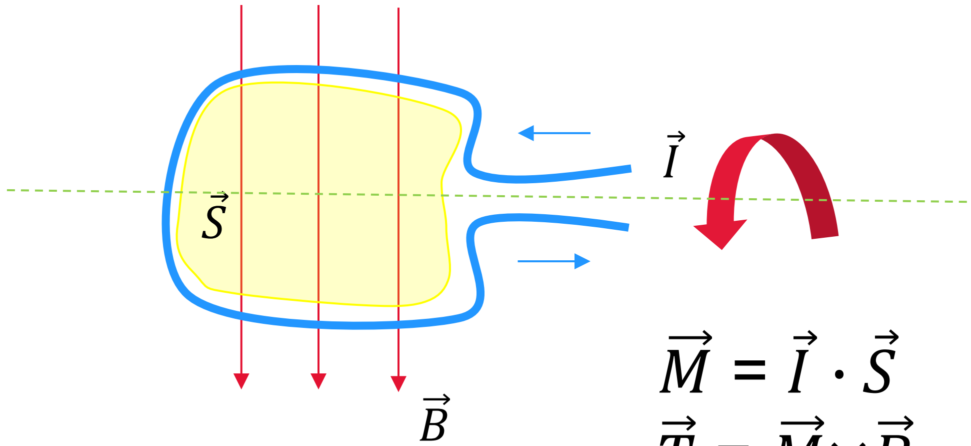
The combination of pitch, yaw and roll wheels can absorb any $\vec{L}$. By accelerating or decelerating the momentum wheels a reaction torque is generated and can counteract the disturbing torque. Angular momentum is transferred from spacecraft to flywheel. When the speed of the wheel reaches maximum speed, unloading is required.



futek.com

Magnetic torquer

Used for LEO satellites and particularly for nano-satellites.
They utilize the magnetic field of the Earth for stabilization.



$$\vec{M} = \vec{I} \cdot \vec{S}$$

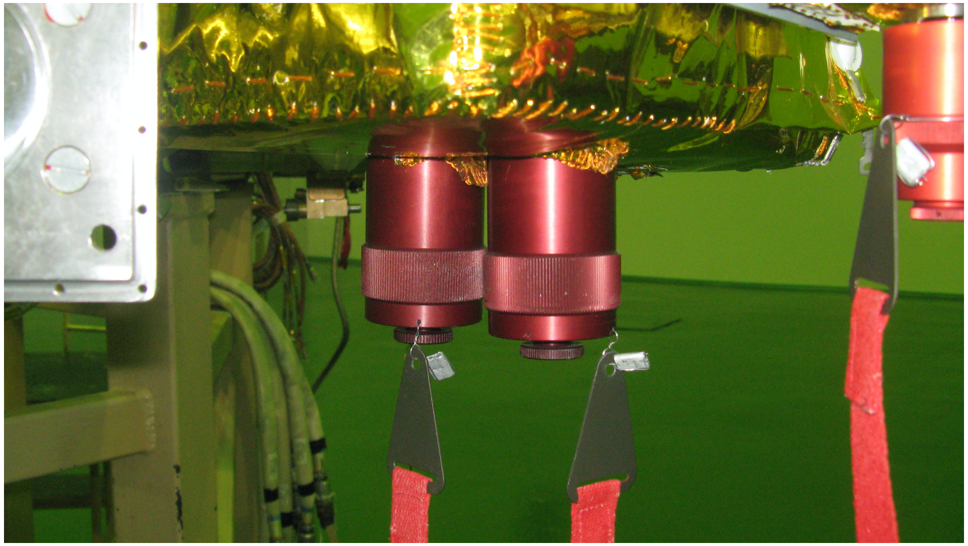
$$\vec{T} = \vec{M} \times \vec{B}$$

https://satsearch.co/products/nanoavionics-magnetorquers-mtq3x

$\vec{I}$	Current
$\vec{S}$	Cross-section
$\vec{T}$	Torque
$\vec{M}$	Magnetic dipole of coil
$\vec{B}$	Earth magnetic field

- Jets

Firing of jets creates torque. $\vec{L}$ can be removed from system and/or from wheels.



Jets for RadioAstron satellite

Orbit control

Satellites are subject to several forces that cause orbit perturbations.
Example: geostationary satellites

Drift in latitude:

$\frac{di}{dt} \approx$ 0.85 deg/yr , due to gravitational; pull of mainly the Moon and the Sun

Drift in longitude:

n$\neq n_0$, $\frac{d\Omega}{dt} \neq 0$, $\frac{d\omega}{dt} \neq 0$, due to equatorial bulge and

satellite drifts toward 75° E and 105° W , due to the ellipticity of the equator.

There are many other forces. Accurate prediction of spacecraft position requires program with ~20 force parameters.
The gas jets impart velocity changes along the 3 axes of the satellite.

<u>Fuel allocation for reaction control system</u>

Maneuvers	Fuel budget
North-south station keeping so that i=±0.1°	68%
Apogee motor firing	16%
East-west station keeping	7%
Injection error removal	4%
Attitude control	3%
Repositioning (if desired during lifetime)	1%
Retirement	1%
	100%

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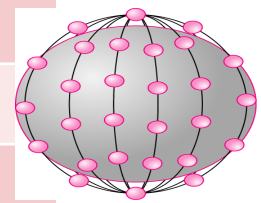
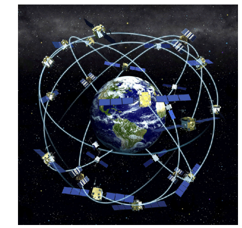
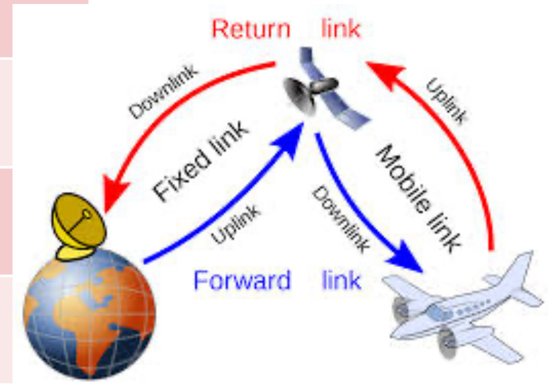
Frequency bands for satellite and spacecraft communications

Band	Frequency range	Total bandwidth	Wavelength	Usage
UHF				MSS
L	1 - 2 GHz	1 GHz	30 to 15 cm	MSS,GPS
S	2 – 4 GHz	2 GHz	15 – 7.5 cm	MSS, deep space
C	4 – 8 GHz	4 GHz	7.5 – 3.8 cm	FSS
X	8 – 12.5 GHz	4.5 GHz	3.8 – 2.4 cm	FSS, deep space
Ku	12.5 – 18 GHz	5.5 GHz	2.4 – 1.7 cm	FSS
K	18 – 26.5 GHz	8.5 GHz	1.7 – 1.1 cm	FSS
Ka	26.5 – 40 GHz	13.5 GHz	1.1 – 0.75 cm	FSS
V	40 – 75 GHz	35 GHz	0.75 – 0.4 cm	Satellite to satellite
Q (sub-band)	33 – 50 GHz	17 GHz	0.9 – 0.6 cm	Satellite to satellite





Space.com



en.wikipedia.org

MSS: mobile satellite service
FSS: Fixed satellite service, e.g., geostationary satellite service

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Frequently used satellite transmission frequencies

Frequency Band	Downlink	Uplink
C	3.7 - 4.2 GHz	5.925-6.425 GHz
Ku	11.7-12.2 GHz	14.0-14.5 GHz
Ka	17.7-21.2 GHz	27.5-31.0 GHz

C band is the most frequently used band. The Ka and Ku bands are reserved exclusively for satellite communication but are subject to rain attenuation. Sometimes transponders are built for both C and KU bands

https://searchmobilecomputing.techtarget.com/definition/downlink-and-uplink

3.3 Telemetry, Tracking and Command (TT&C)

Telemetry measures orientation, environment and health of satellite

Orientation: a) Attitude

Environment:
a) Magnetic field vector
b) Frequency of meteorite impacts
c) Solar wind

Health:
a) Temperature
b) Power supply voltage
c) Fuel pressure
d) Electronics status

The transmission of the telemetry data is done
a) on a low-power carrier at UHF or S-band, or in gaps between communications channels at 4/6 or 11/14 GHz,
b) with narrow bandwidth for high C/N,
c) at low bit rate (few 1000 bits/s).

At the earth station the transmission signal is decoded and alarm is activated if vital parameters go outside allowable limits.

Tracking: orbit parameters are monitored through

a) velocity and acceleration sensors
b) Doppler measurements
c) range measurements
d) azimuth and elevation measurements.

➔ position measurement accuracy: 10 to 150 m

Command: based on telemetry and tracking data

➔corrections of attitude + position

➔control of communications system

Secure command structure is needed!!

Here is a typical security procedure that takes a couple of seconds to execute.

Control code :

a) command word sent to satellite
b) Command word is checked in spacecraft
c) Command word is sent back to earth station via telemetry link
d) Command word is checked at earth station
e) If command word is correct, then execution command is sent to spacecraft

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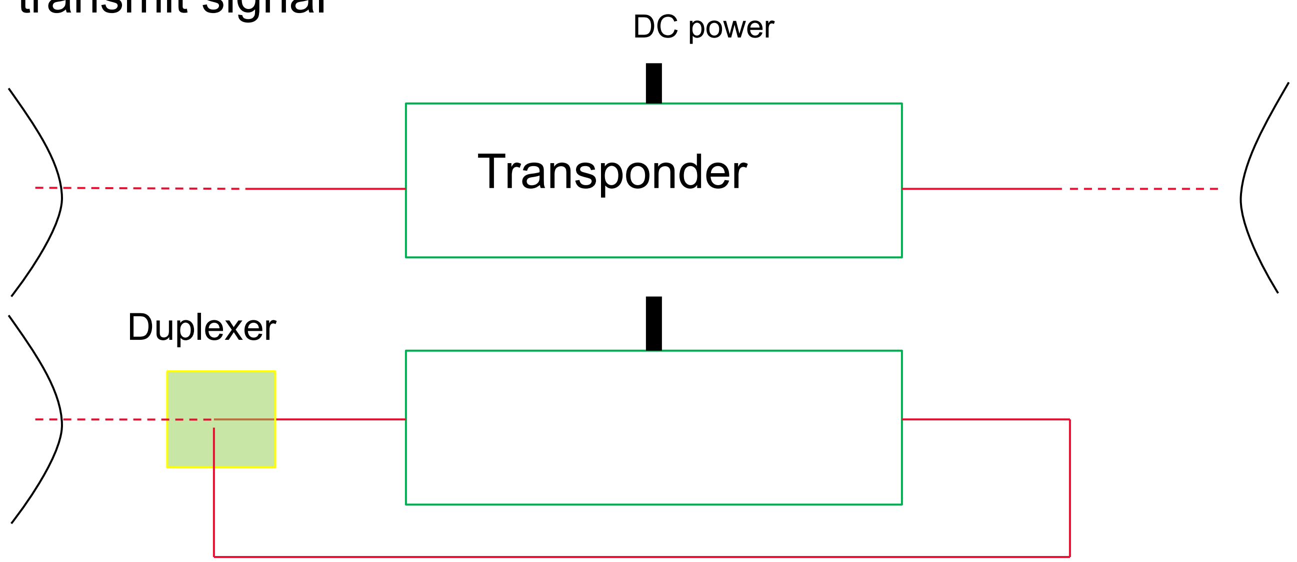
3.4 Transponder

The transponder is the heart of the communications system

Purpose:

a) receive signal
b) transpose signal from uplink frequency to downlink frequency
c) amplify signal
d) transmit signal



i. The higher the frequency, the more information can be modulated on a carrier (the bandwidth is usually 10% of the center frequency).
ii. The higher the frequency, the less terrestrial interference.
iii. The higher the frequency, the sharper the antenna beam, the smaller the minimum spacing necessary for geostationary satellites, but the more attenuation due to rain

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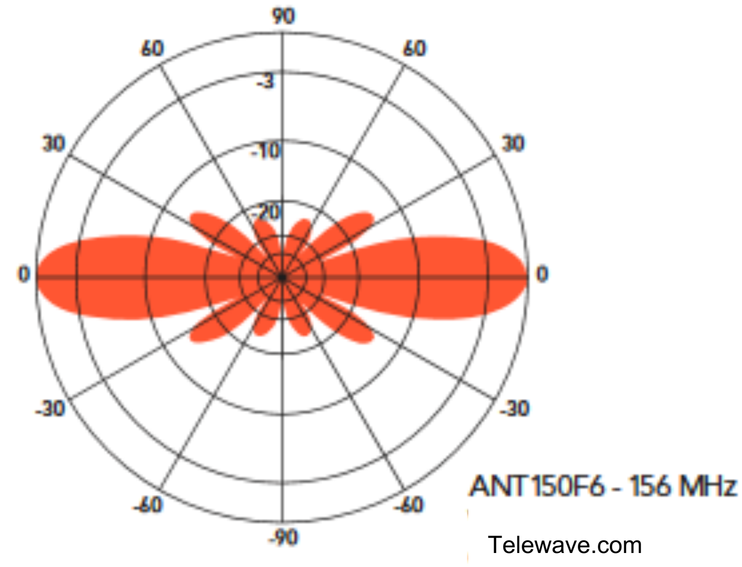
How to use decibels

Decibel: 10 times the $\log_{10}$ of a ratio, y, of two quantities

$$Y = \frac{P}{P_0}$$

$$Y_{dB} = 10 \log_{10} \left(\frac{P}{P_0}\right) \text{ [dB]}$$

$$P = 10^{\frac{Y_{dB}}{10}} \cdot P_0$$



Example 3-1

$Y = \frac{P}{P_0} = \frac{100}{1} = 100$

$Y_{dB} = 10 \log_{10} (100)$ [dB] = 20 dB

$Y = \frac{P}{P_0} = \frac{0.5}{1} = 0.5$

$Y_{dB} = 10 \log_{10} (0.5)$ [dB] = -3 dB

$Y = \frac{P}{P_0} = \frac{2}{1} = 2$

$Y_{dB} = 10 \log_{10} (2)$ [dB] = 3 dB

Y_{dB} = -15 dB.

$\frac{P}{P_0} = 10^{\frac{Y_{dB}}{10}} = 10^{\frac{-15}{10}} = 0.0316$

dBW. : power relative to 1 W

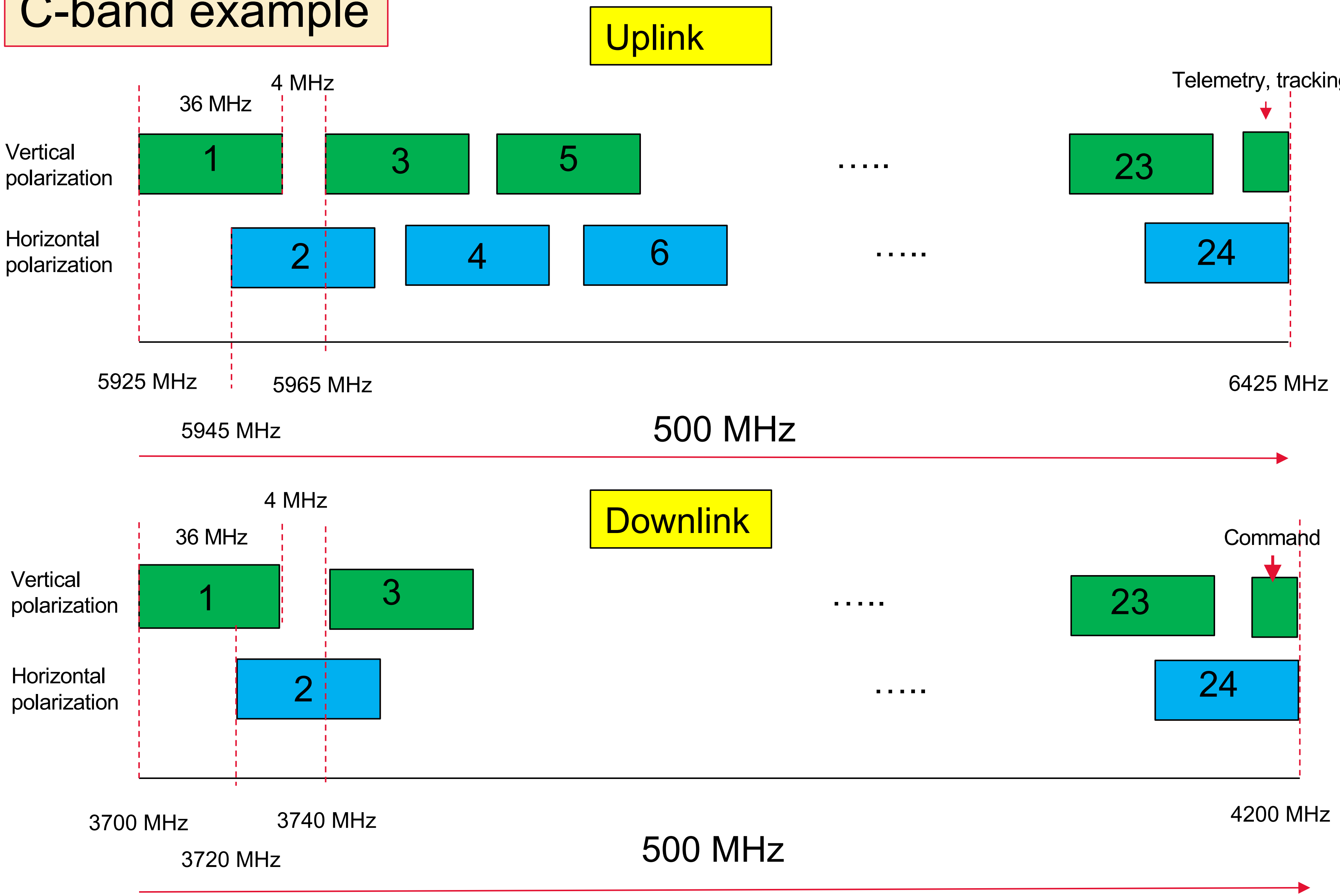
3dBW = 2 W

20dBW = 100 W

dBm power relative to 1 mW

20 dBm = 100 mW

C-band example



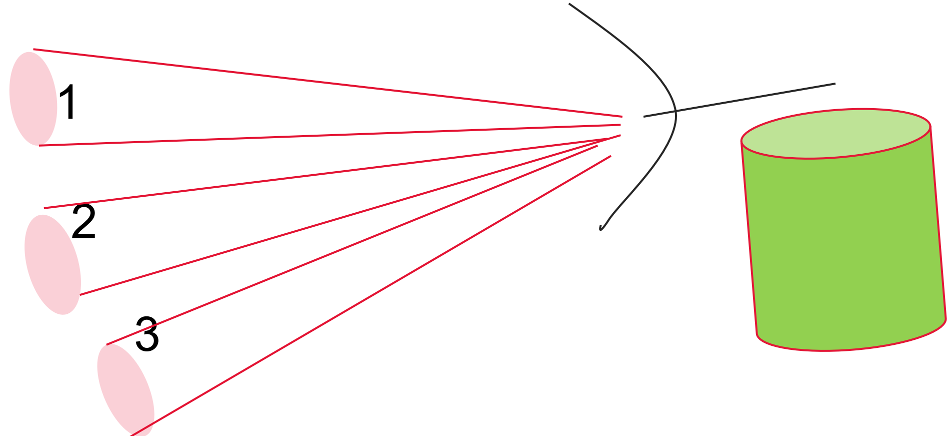
Frequency reuse:

Use of the same band for different information channels

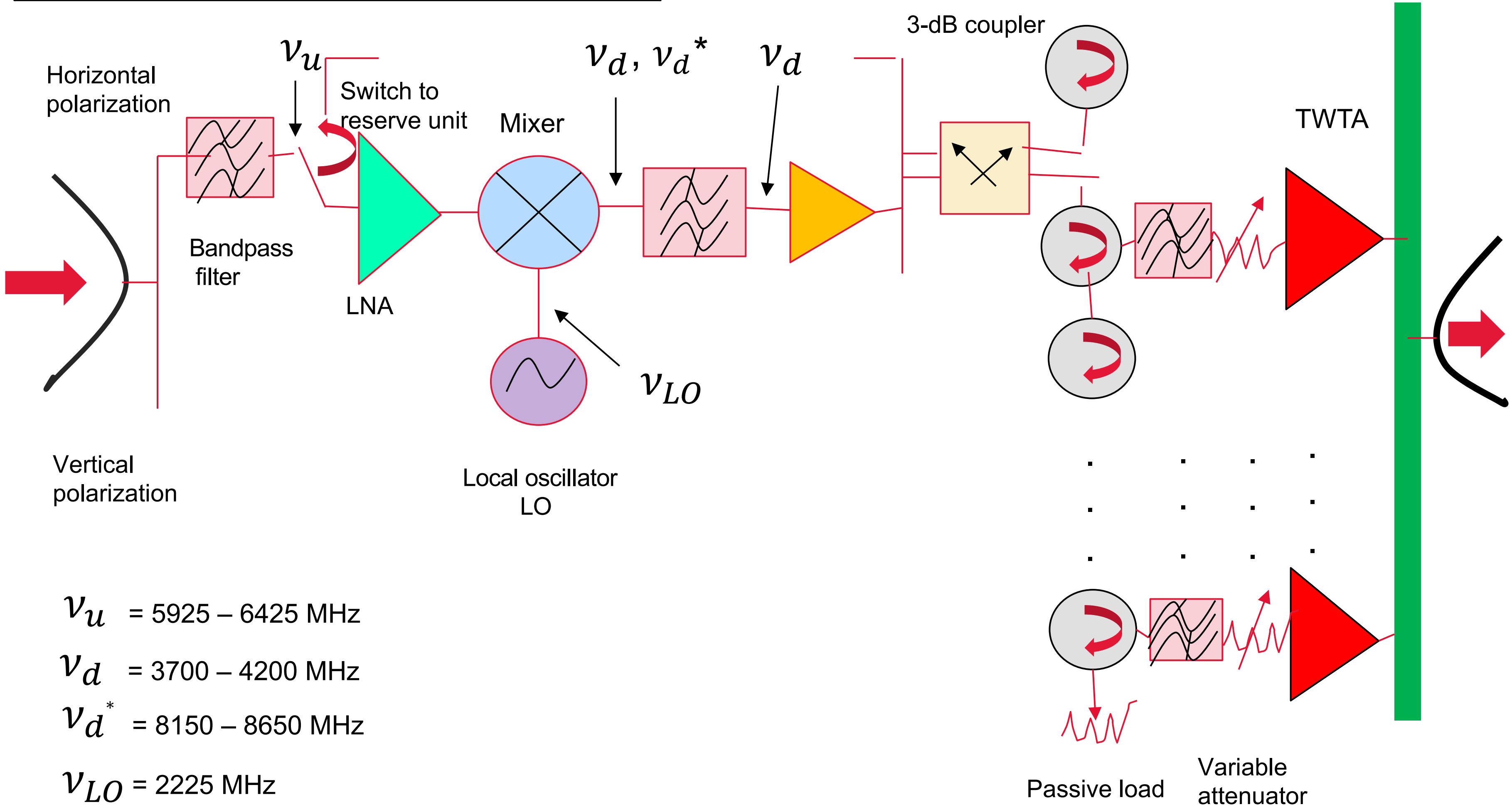
a) Vertical and horizontal polarization channels
   Example: C-band transponder (see sketch)

b) Left and right-hand circular polarization (LHC, RHC)
   (instead of horizontal andvertical polarization)

c) Spot beam antennas



C-band transponder



ν_u = 5925 – 6425 MHz

ν_d = 3700 – 4200 MHz

ν_d^* = 8150 – 8650 MHz

ν_{LO} = 2225 MHz

$$A\cos(2\pi\nu_u t)\cdot B\cos(2\pi\nu_{LO} t) = \frac{1}{2}AB\{[\cos 2\pi(\nu_D+\nu_{LO})t] + [\cos 2\pi(\nu_D-\nu_{LO})t]\}$$

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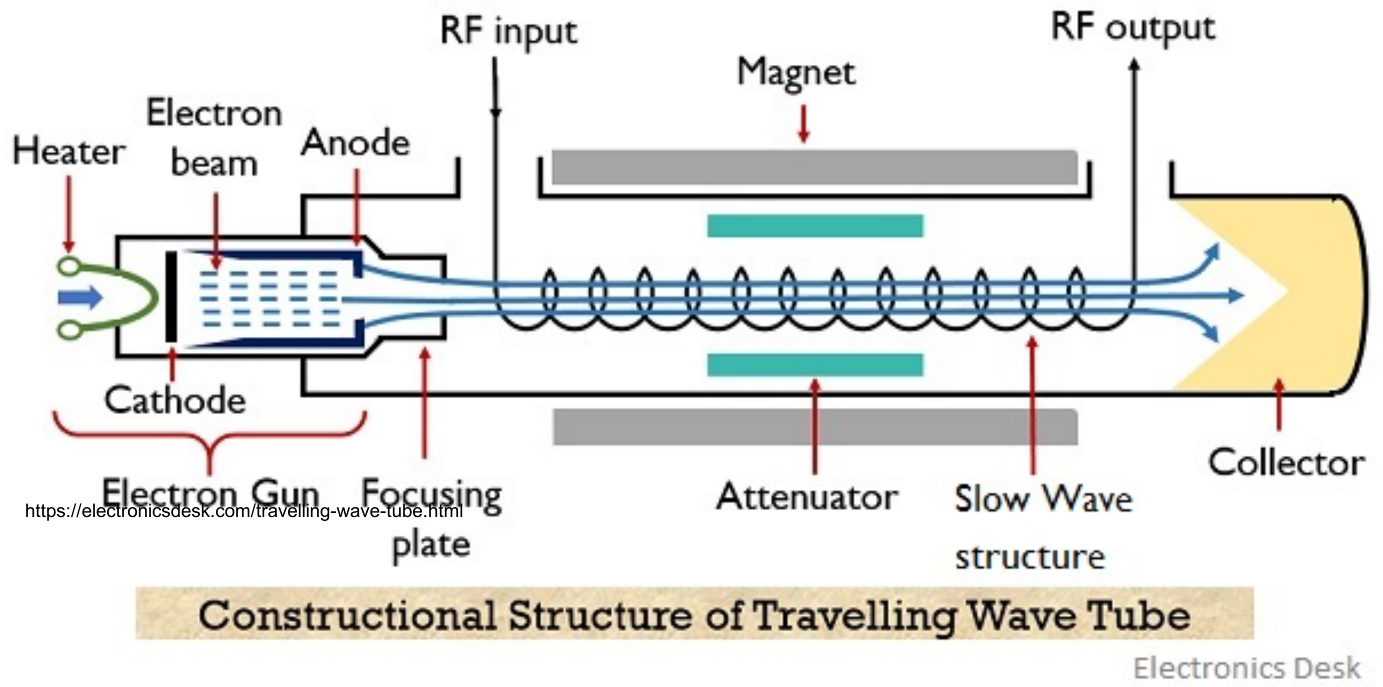
Amplifiers

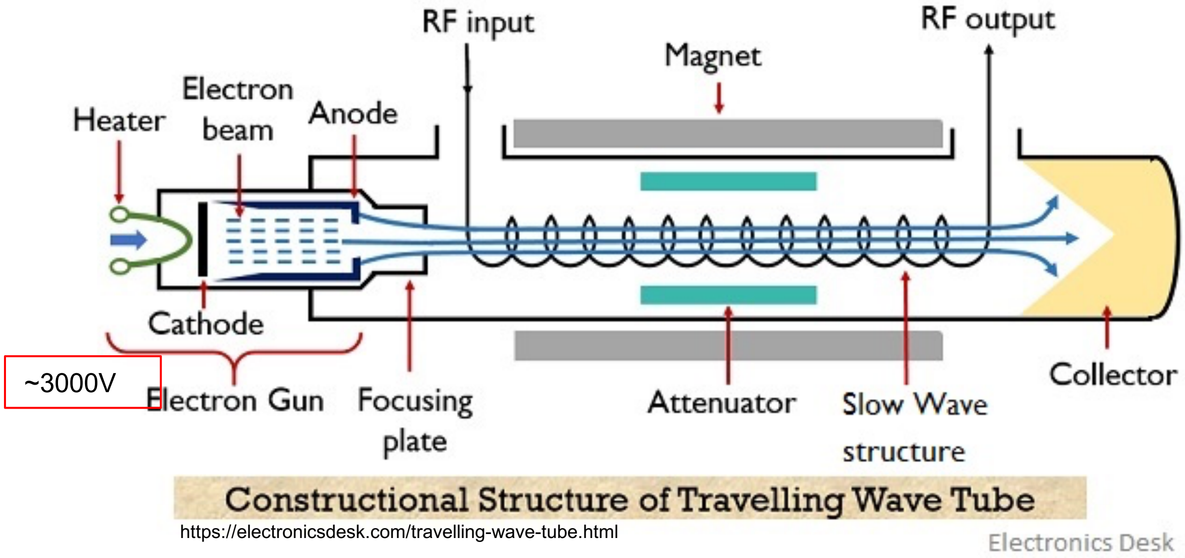
1. Traveling Wave Tube Amplifier (TWTA)



https://electronicsdesk.com/travelling-wave-tube.html

Amplifiers

1. Traveling Wave Tube Amplifier (TWTA)



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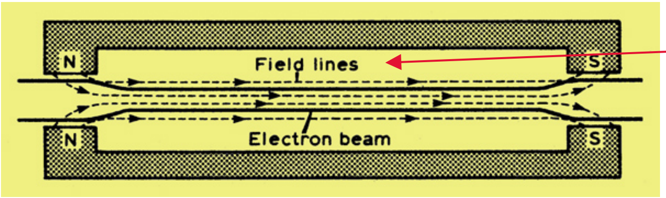
RF: Radio frequency

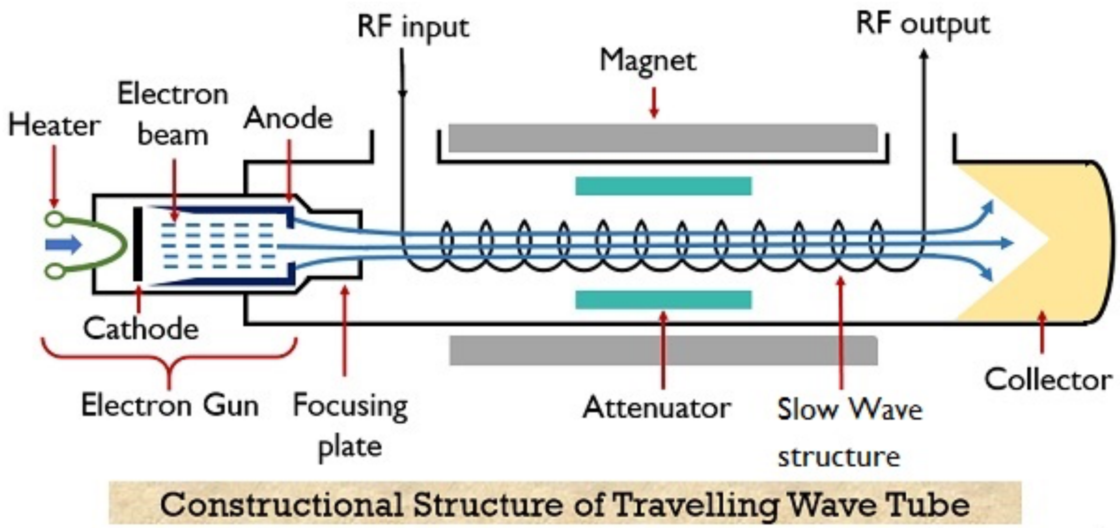


Projection of field lines in the wire on axis along electron beam

Bunching of electrons along axis corresponding to flield lines

Amplifiers

1. Traveling Wave Tube Amplifier (TWTA)



https://electronicsdesk.com/travelling-wave-tube.html

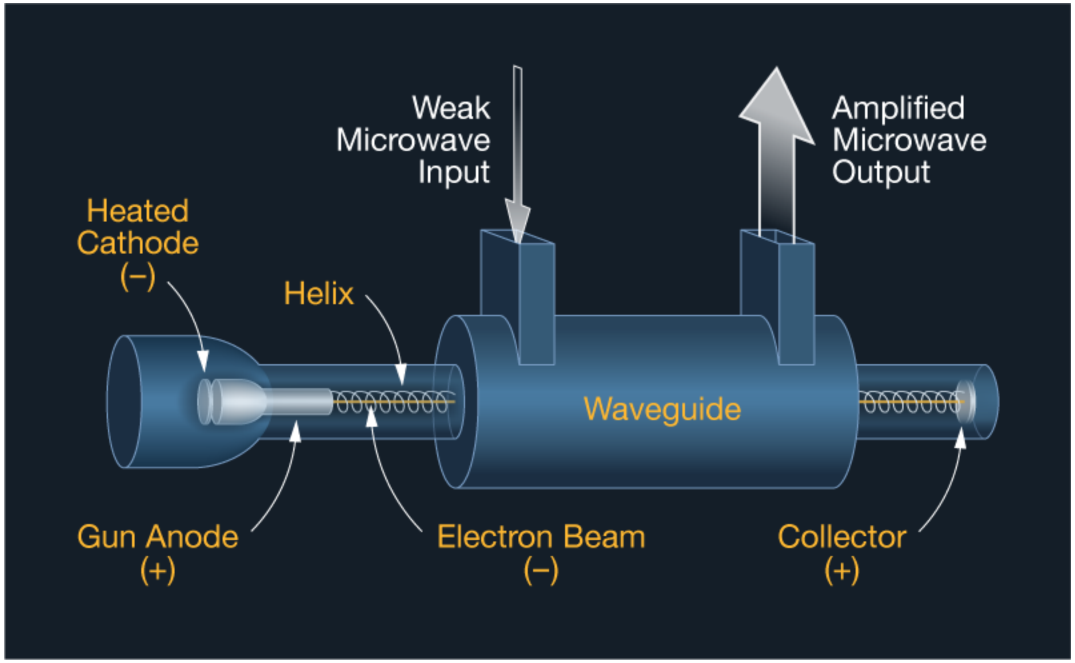
Strong points:
Amplification over large bandwidth
Output power up to ~400 W

Weak points:
i. Cathodes wear out
ii. Amplification is non-linear for large input power
i. Weight, size
ii. Input power requirements

The TWTA consists of:

- Vacuum tube ~ 10^{-8} Torr
- Narrow electron beam guided by magnetic field
- Coil, tightly wound, has RF current and generates an oscillating E-vector component along the coil axis
- Electron beam interacts with current in coil and amplifies current

i) ➔ bunching of electrons along axis
ii) ➔ transfer of energy from electrons to RF
iii) ➔ amplification by ~50 dB



https://solarsystem.nasa.gov/basics/chapter11-2/

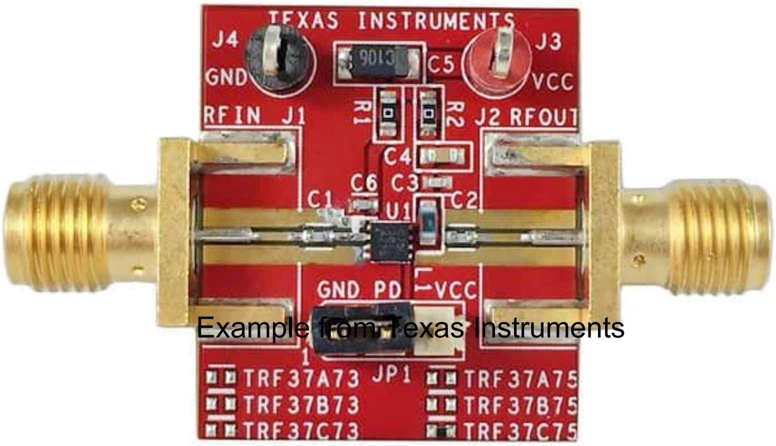
https://www.wikiwand.com/en/Traveling-wave_tube

NASA Glenn Research Center

Examples of TWTAs

2. Solid-state power amplifiers

i. GaAs Fets (Gallium arsenide field effect transistors
ii. GaN Fets (Gallium nitride field effect transistors
iii. GaN HEMT's (high electron mobility transistors)



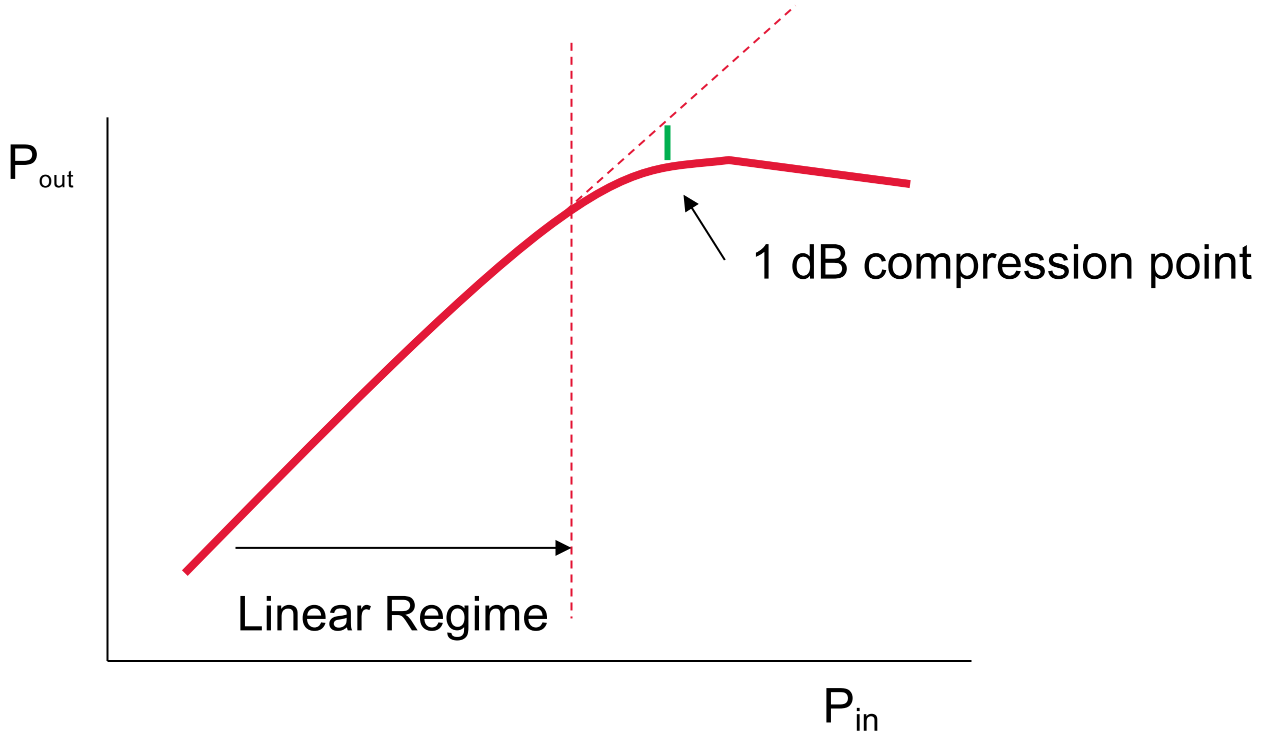
Example from Texas Instruments

Strong points:
i. Solid, do not wear out
ii. Low weight
iii. Small size
iv. Good linearity (amplification)
v. Reliable

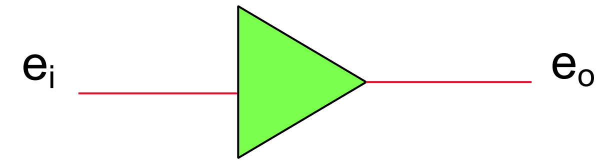
Weak points:
i. Amplification over small bandwidth
ii. Output power ~10 (-70W)
iii. Small efficiency in converting DC power to RF power
iv. Input power requirements

Intermodulation noise

- Intermodulation noise occurs when two or more signal channels are amplified in the non-linear regime of the amplification curve



Spectrum



Input: two unmodulated carriers

$e_i = \cos\omega_1 t + \cos\omega_2 t$ ω_1, ω_2 carrier angular frequencies, 1 and 2

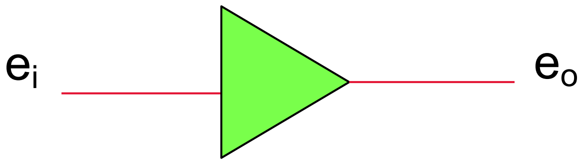
Output for amplification in linear regime

Output: e_o= ae_i a: amplification

e_o= a $(\cos\omega_1 t + \cos\omega_2 t)$

Spectrum for output for amplification in linear regime

Spectrum



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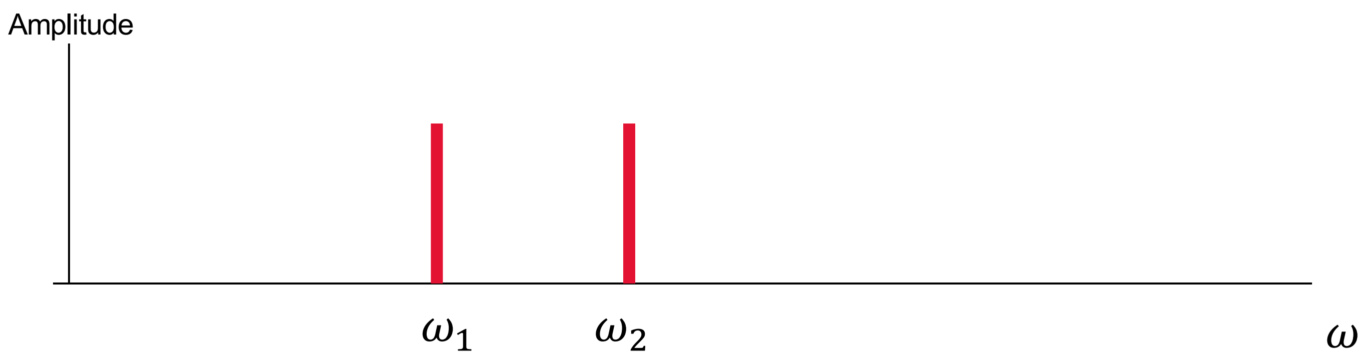


Spectrum

Output for amplification in non-linear regime

Output: $e_o = ae_i + be_i^2 + ce_i^3 \ldots$ Approximation by polynomial

$$e_i = \cos\omega_1 t + \cos\omega_2 t$$

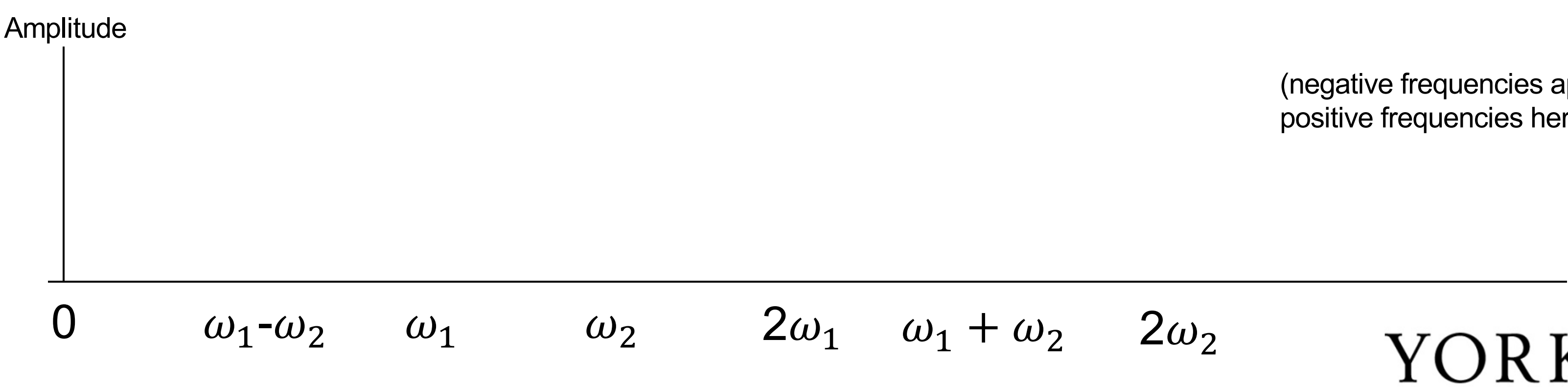
$$e_i^2 = (\cos\omega_1 t + \cos\omega_2 t)2$$

$$e_i^2 = \cos^2\omega_1 t + 2\cos\omega_1 t\cos\omega_2 t + \cos^2\omega_2 t$$

Frequencies: $0,\ 2\omega_1$ $\omega_1 - \omega_2,\ \omega_1 + \omega_2$ $0,\ 2\omega_2$

$$e_i^3 = (\cos\omega_1 t + \cos\omega_2 t)^3$$

Spectrum for output for amplification in linear regime $\omega_2 - \omega_1. = \Delta\omega$



(negative frequencies appear as positive frequencies here)

Spectrum

Output for amplification in non-linear regime

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Frequencies:

$$e_i{}^3 = (\cos\omega_1 t + \cos\omega_2 t)^3$$

Spectrum for output for amplification in linear regime $\omega_2 - \omega_1. = \Delta\omega$

Amplitude

(negative frequencies appear as positive frequencies here)

0 ω_1-ω_2 ω_1 ω_2 $2\omega_1$ $\omega_1 + \omega_2$ $2\omega_2$

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Spectrum

Output for amplification in non-linear regime

Output: $e_o = a e_i + b e_i{}^2 + c e_i{}^3 \ldots.$ Approximation by polynomial

$$e_i = \cos \omega_1 t + \cos \omega_2 t$$

$$e_i{}^2 = \cos \omega_1 t + \cos \omega_2 t$$

$$e_i{}^2 = \cos^2 \omega_1 t + 2 \cos \omega_1 t \cos \omega_2 t + \cos^2 \omega_2 t$$

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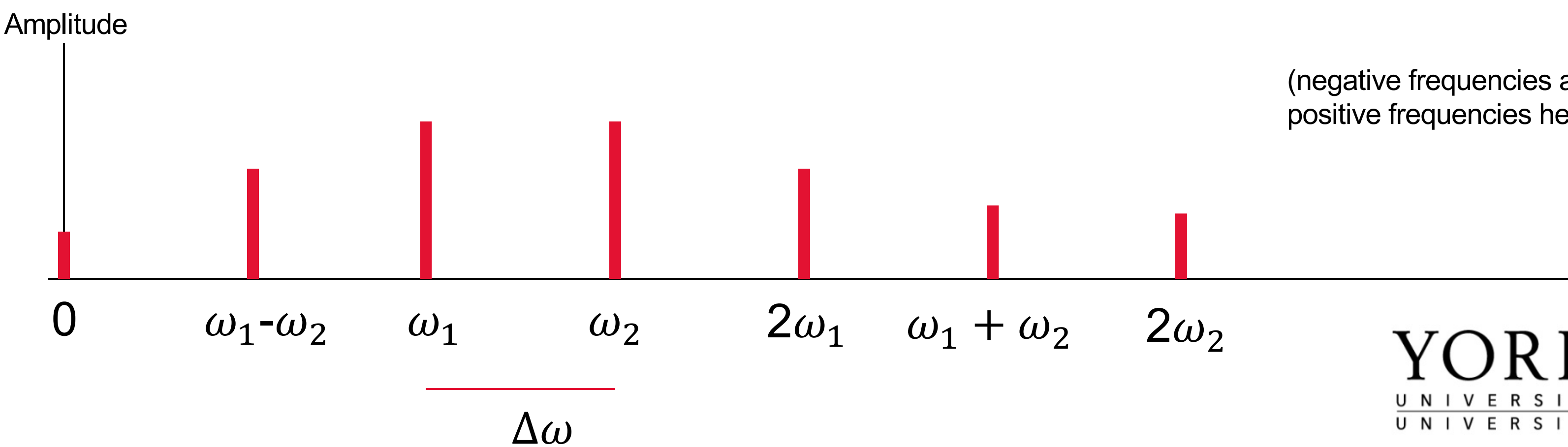

(negative frequencies appear as positive frequencies here)

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Spectrum

Output for amplification in non-linear regime

Output: $e_o = ae_i + be_i^2 + ce_i^3 \ldots.$ Approximation by polynomial

$$e_i = \cos\omega_1 t + \cos\omega_2 t$$

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Frequencies: $0, 2\omega_1$ ω_1-ω_2, $\omega_1 + \omega_2$ $0, 2\omega_2$

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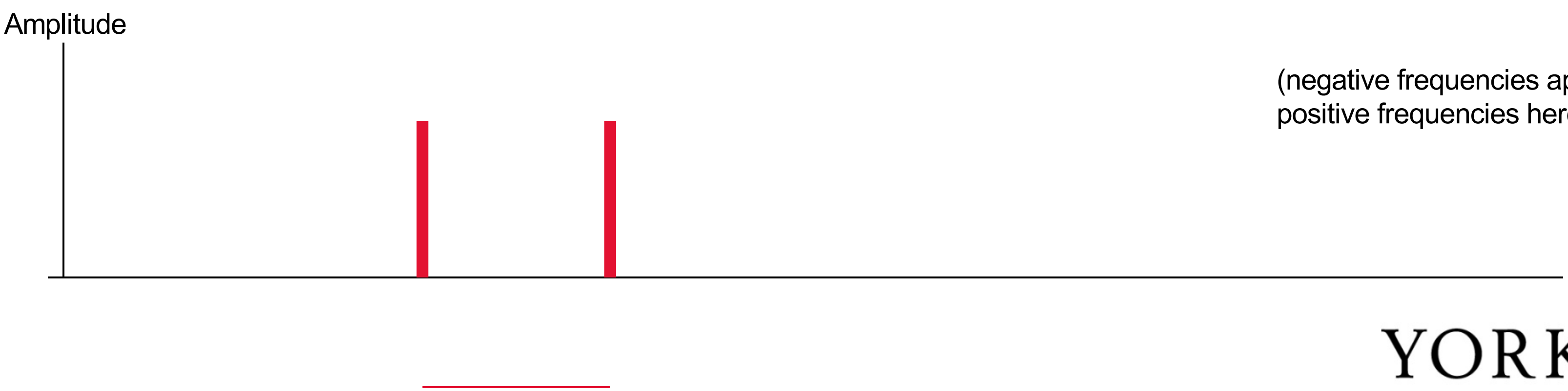
Spectrum for output for amplification in linear regime $\omega_2 - \omega_1. = \Delta\omega$



(negative frequencies appear as positive frequencies here)

Spectrum

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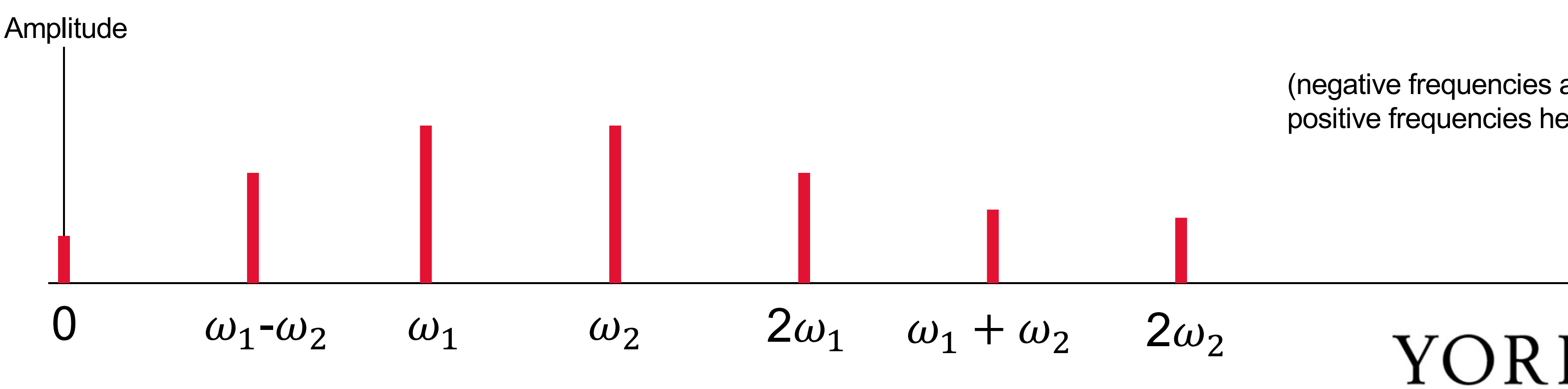


(negative frequencies appear as positive frequencies here)

Spectrum

Output for amplification in non-linear regime

Output: $e_o = ae_i + be_i{}^2 + ce_i{}^3$ …. Approximation by polynomial

$$e_i = \cos\omega_1 t + \cos\omega_2 t$$

$$e_i{}^3 = (\cos\omega_1 t + \cos\omega_2 t)3$$

$$e_i{}^3 = \cos^3\omega_1 t + \quad 2\cos^2\omega_1 t\cos\omega_2 t + \quad \cos\omega_1 t\cos^2\omega_2 t$$

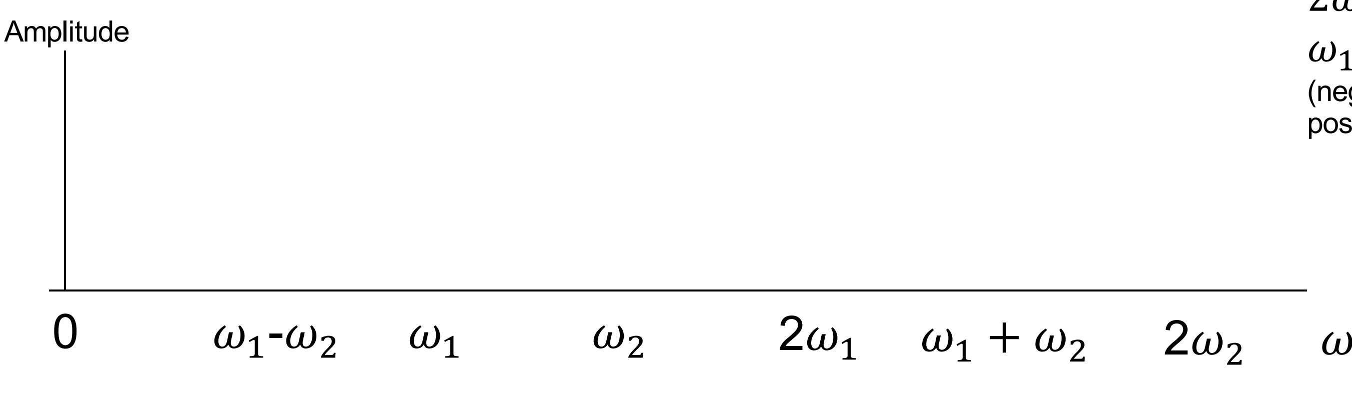
Frequencies: $\omega_1, 3\omega_1$ | $\omega_2, 2\omega_1+\omega_2, 2\omega_1-\omega_2$ | $\omega_1, \omega_1+2\omega_2, \omega_1-2\omega_2$

$$+ \quad \cos^2\omega_1 t\cos\omega_2 t + 2\cos\omega_1 t\cos^2\omega_2 t + \cos^3\omega_2 t$$

Frequencies: $\omega_2, 3\omega_2$

Spectrum for output for amplification in linear regime

$\omega_2 - \omega_1. = \Delta\omega$
$2\omega_1 - \omega_2 = \omega_1 - \Delta\omega$
$\omega_1 - 2\omega_2 = \omega_1 + 2\Delta\omega$
(negative frequencies appear as positive frequencies here)



Spectrum

Output for amplification in non-linear regime

Output: $e_o = ae_i + be_i^2 + ce_i^3 \ldots.$ Approximation by polynomial

$$e_i = \cos\omega_1 t + \cos\omega_2 t$$

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$$e_i^3 = \cos^3\omega_1 t + \quad 2\cos^2\omega_1 t\cos\omega_2 t + \quad \cos\omega_1 t\cos^2\omega_2 t$$

Frequencies: $\omega_1, 3\omega_1$ | $\omega_2, 2\omega_1 + \omega_2, 2\omega_1 - \omega_2$ | $\omega_1, \omega_1 + 2\omega_2, \omega_1 - 2\omega_2$

$$+ \quad \cos^2\omega_1 t\cos\omega_2 t + 2\cos\omega_1 t\cos^2\omega_2 t + \cos^3\omega_2 t$$

Frequencies: $\omega_2, 3\omega_2$

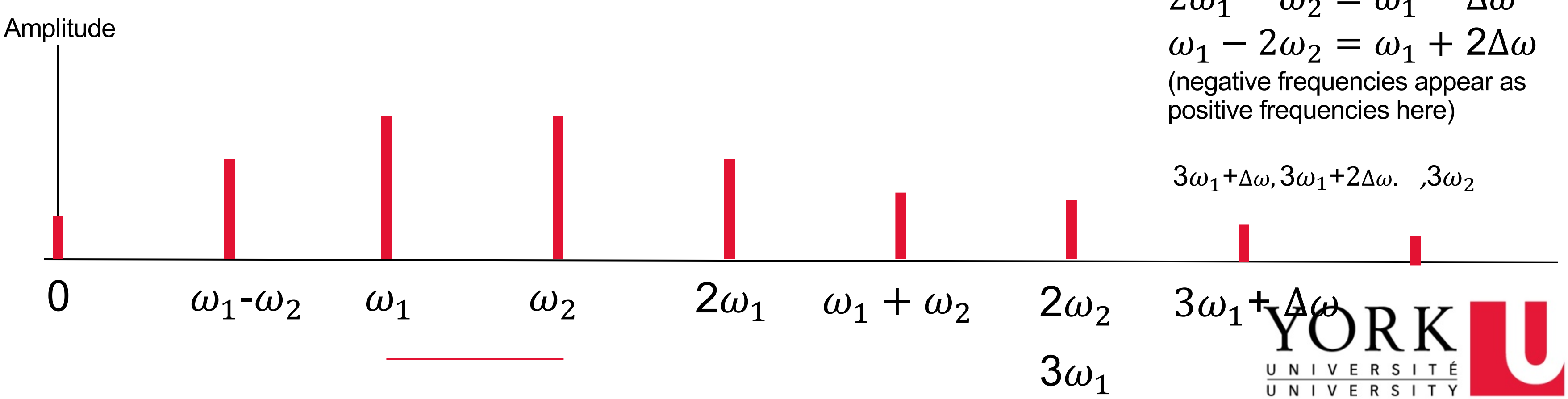
Spectrum for output for amplification in linear regime

$\omega_2 - \omega_1. = \Delta\omega$

$2\omega_1 - \omega_2 = \omega_1 - \Delta\omega$

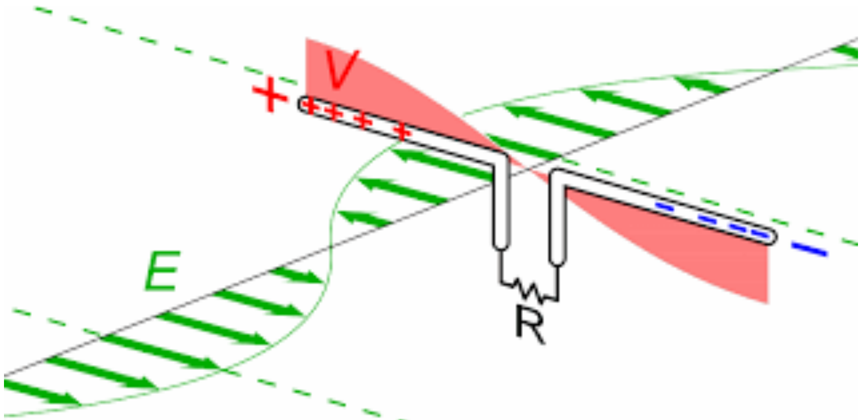
$\omega_1 - 2\omega_2 = \omega_1 + 2\Delta\omega$

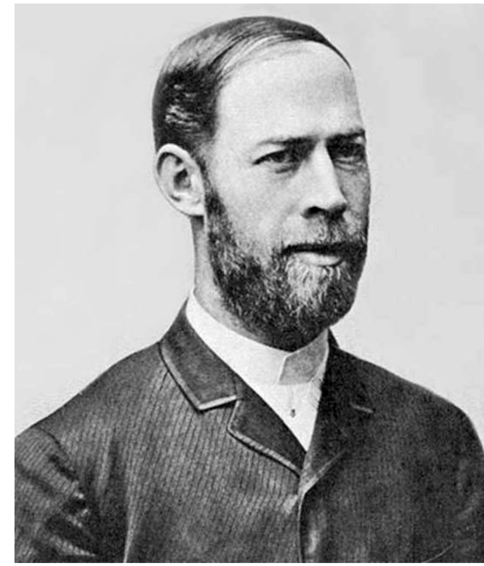
(negative frequencies appear as positive frequencies here)



3.5 Antennae

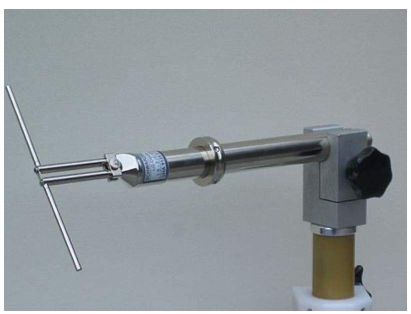
a) Wire antenna: dipole (omni-directional)

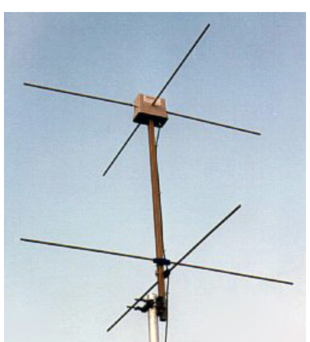




1857-1894

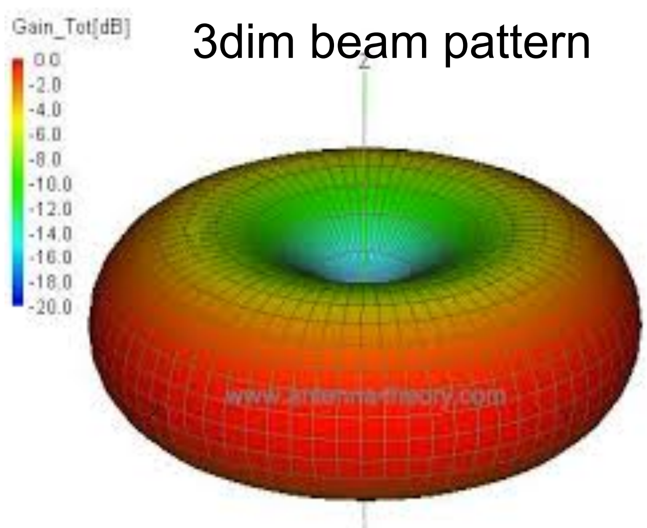
Discovered radio waves





Dipole examples

3dim beam pattern



antenna-theory.com

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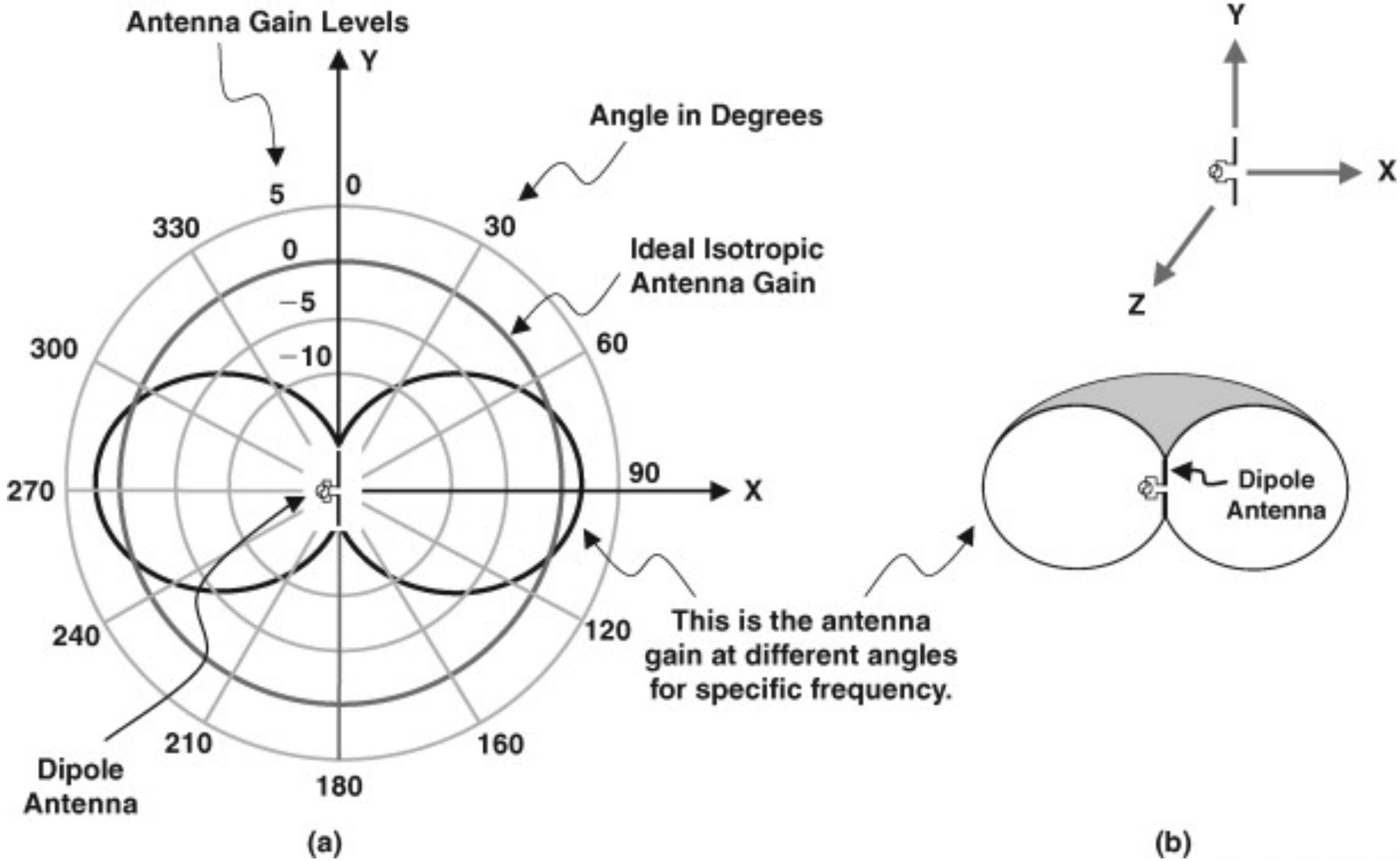
Dipole beam pattern

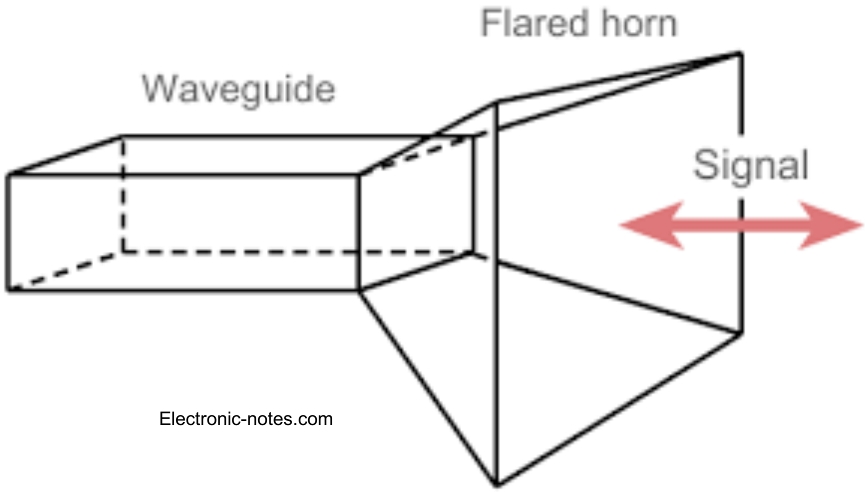
Gain as a function of angles



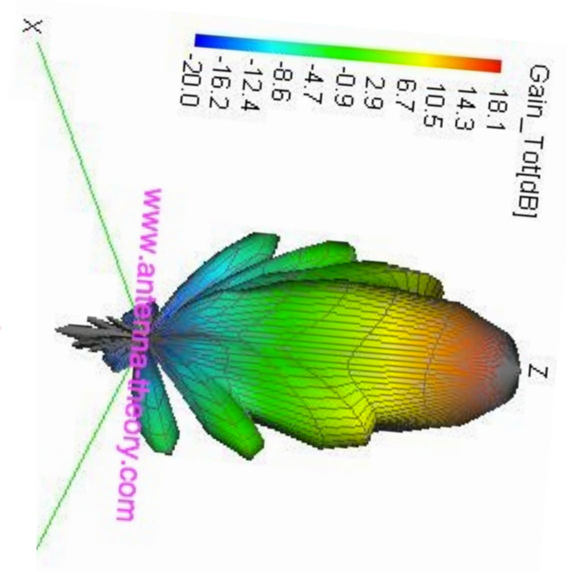
https://www.sciencedirect.com/topics/computer-science/dipole-antenna

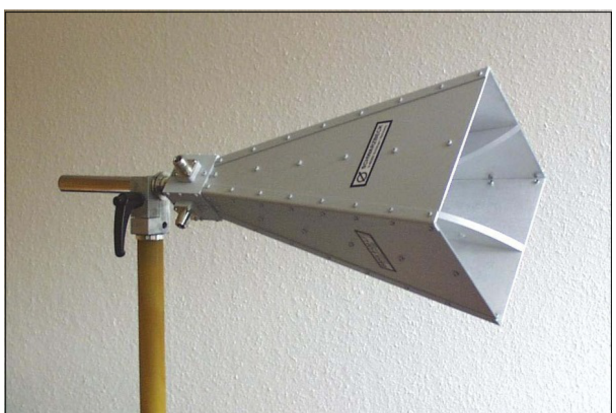
b) Horn antenna

A flared metal waveguide to direct radiation in a forward beam. It has a relatively wide beam of ~10^0 and has global coverage from the geostationary orbit. Horn antennas have very low noise figures.

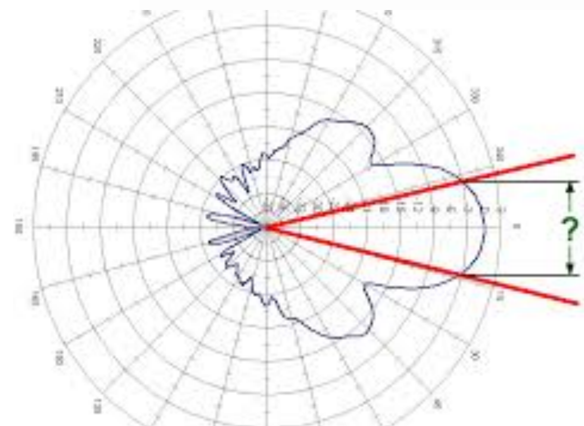


Electronic-notes.com



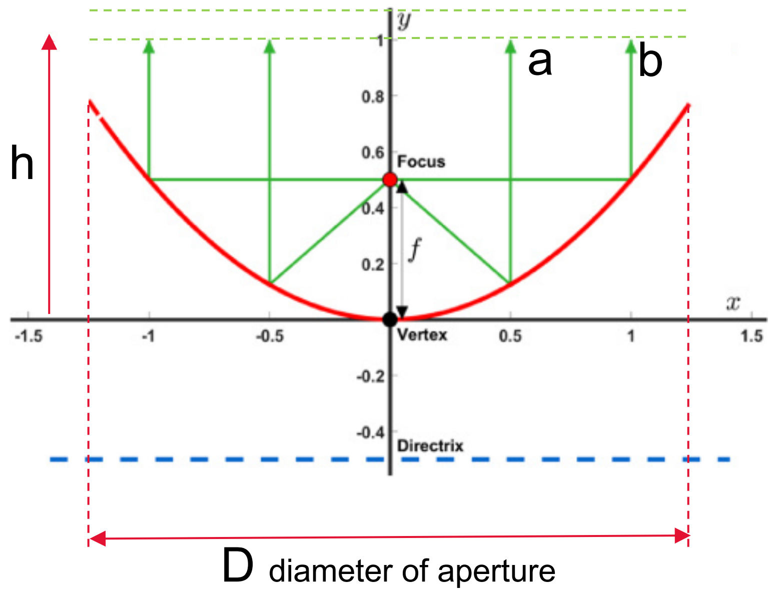


Tutorialspoint.com

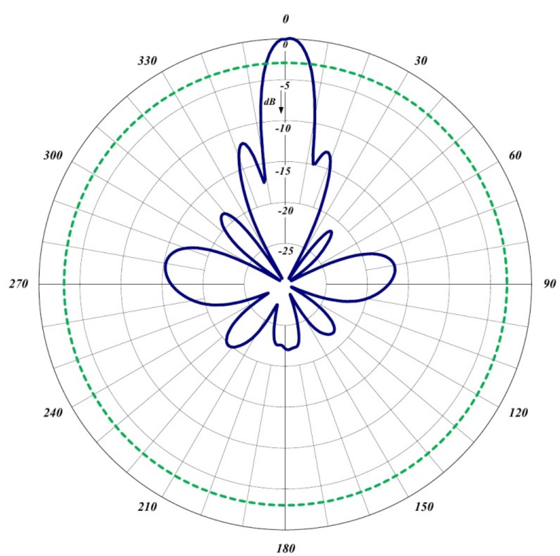


ahsystems.com

c) Reflector antenna

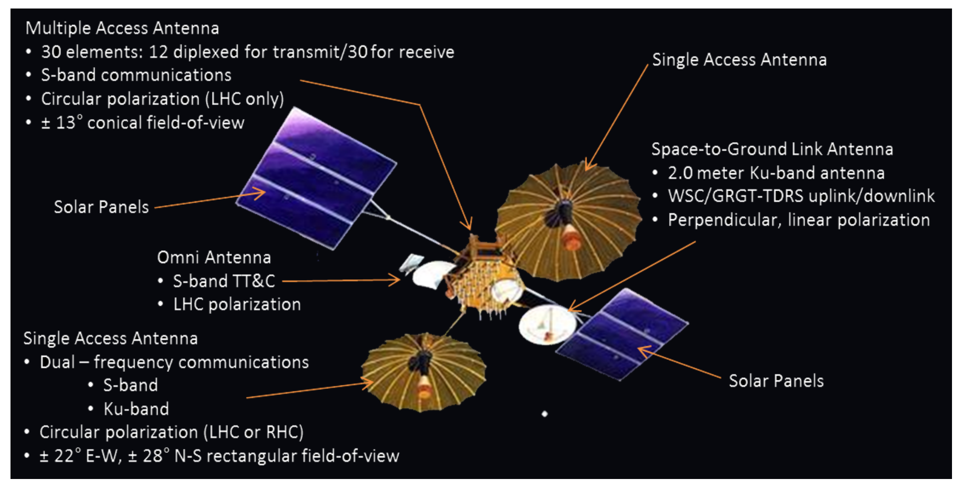


The parabolic reflector is the most popular reflector antenna. Radiation from the focal point is collimated through the reflector of conductive material into a collimated plane wave. The length of the path from the focal point to the reflector surface and then to any wavefront at a height h above the vertex is the same for any other such path. In the figure on the left, the pathlength to a is the same as the pathlength to b. The distance from the focus to the vertex is the focal length, f. The ratio , f/D, of f to the diameter of the aperture, D, is an important characteristic for every parabolic reflector.

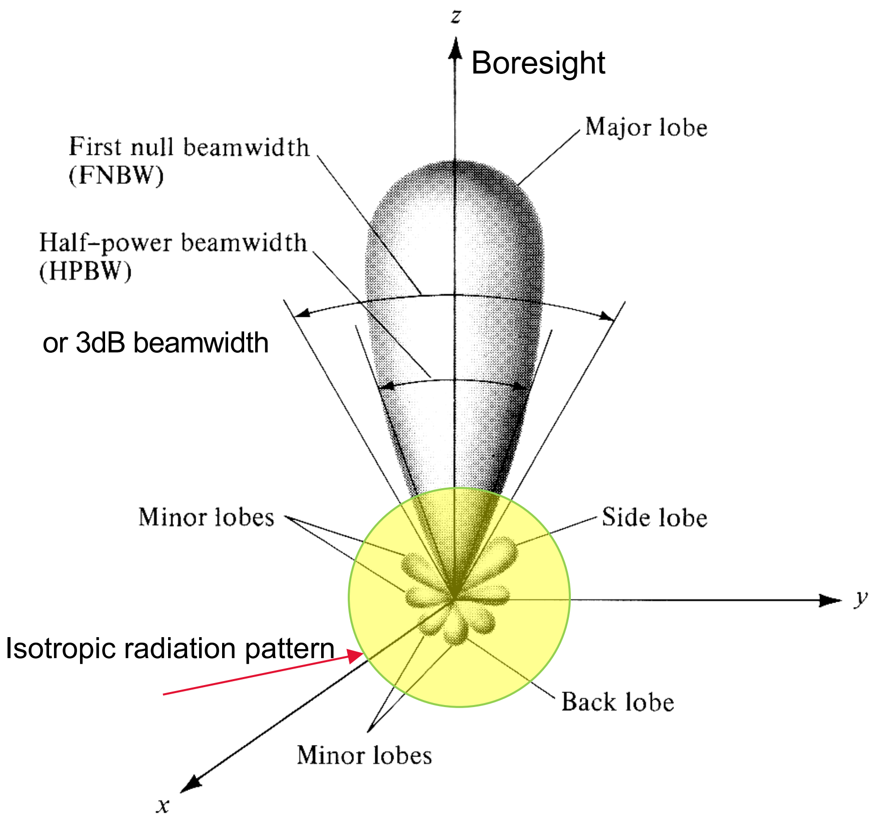


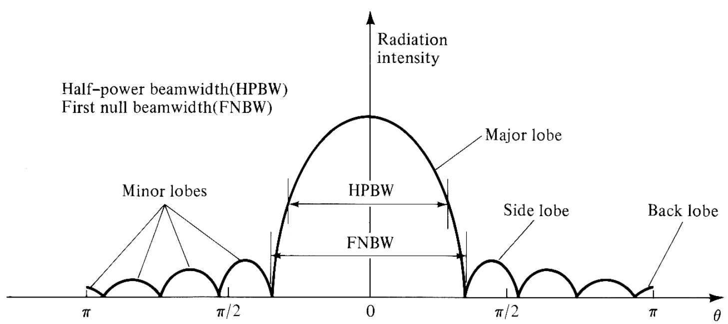
Comprod.com

Horizontal radiation pattern



Radiation pattern or beam pattern





Wikipedia

Peak gain or boresight gain or simply gain of an antenna, G: measurement or capability of directing power in one direction rather than in all directions

$$G = \frac{I_{max}}{I_0}$$

$$G = \eta \left(\frac{\pi D}{\lambda}\right)^2$$

$$\theta_{3dB} \approx 1.23\, \frac{\lambda}{D}\, rad \approx 70\, \frac{\lambda}{D}\, deg$$

η: Aperture efficiency $\approx 50\ to\ 70\ \%$
D: Diameter of aperture
λ: Wavelength
θ_{3dB} : 3dB beamwidth or HPBW

Example 3-1

D=1m. $\nu = 6$ GHz $\quad \lambda = \frac{c}{\nu}$ = 5 cm $\quad \eta$=55%

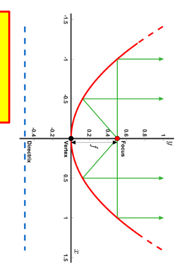
G=$0.55\left(\frac{\pi \cdot 1}{0.05}\right)^2$ = 2171 ➔ [G]=10logG=33.4 dB

Our antenna produces a signal along boresight 2171 times as strong as if the signal were spread isotropically.

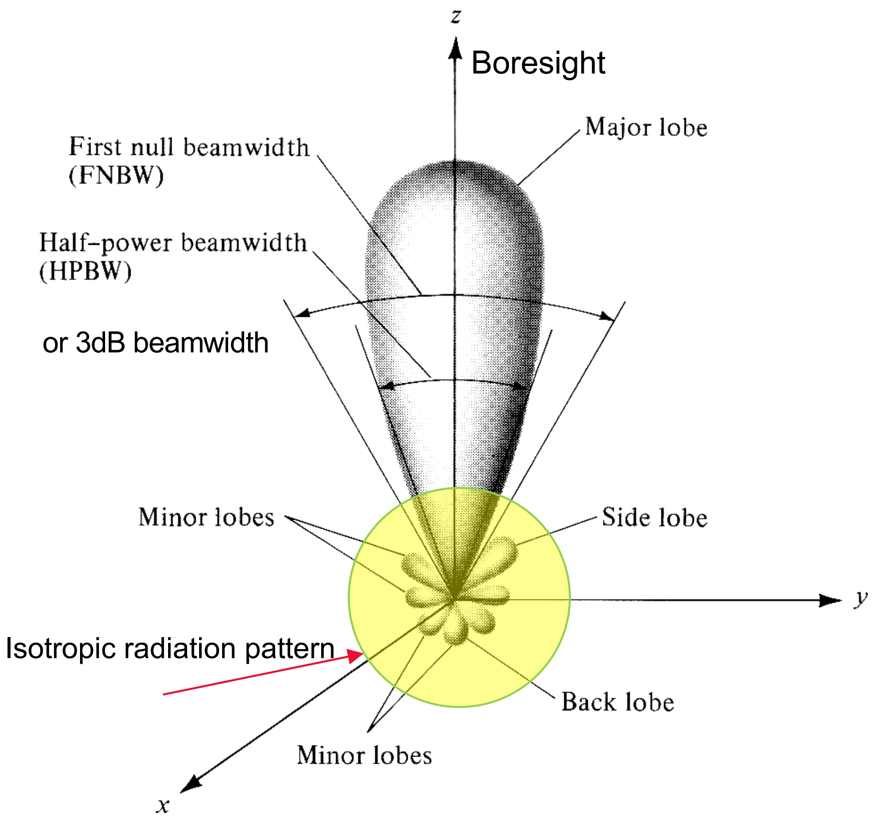
For a rough or distorted reflector the gain is reduced to G_d with:.

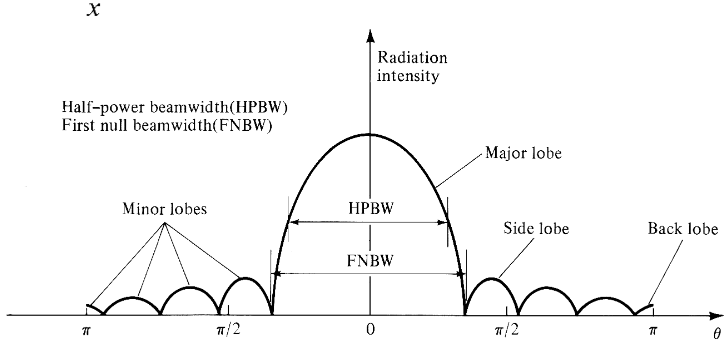
$$G_d = Ge^{-\left(\frac{4\pi\sigma}{\lambda}\right)^2}$$

σ: rms surface variation with respect to a perfect paraboloid



Radiation pattern or beam pattern





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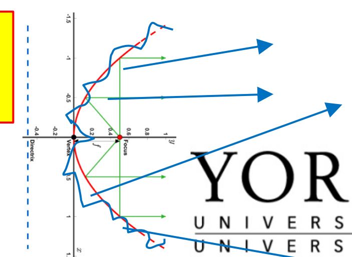

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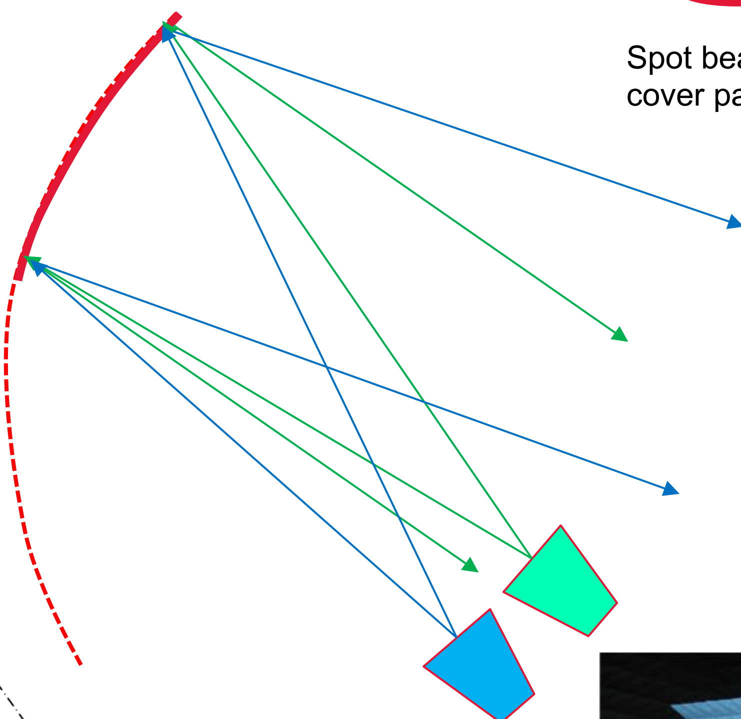
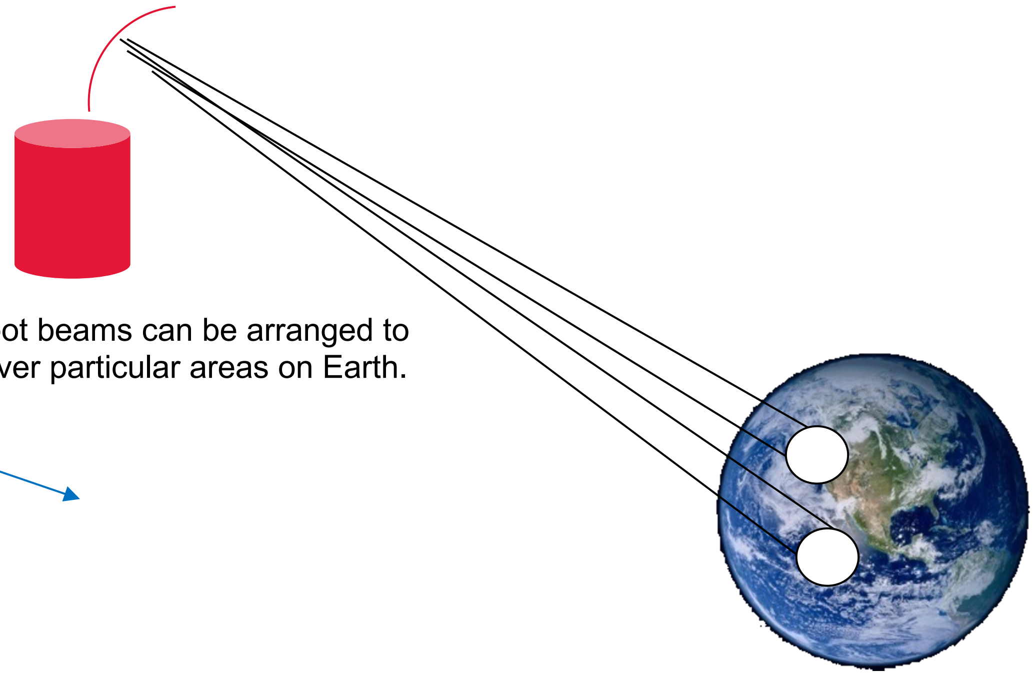
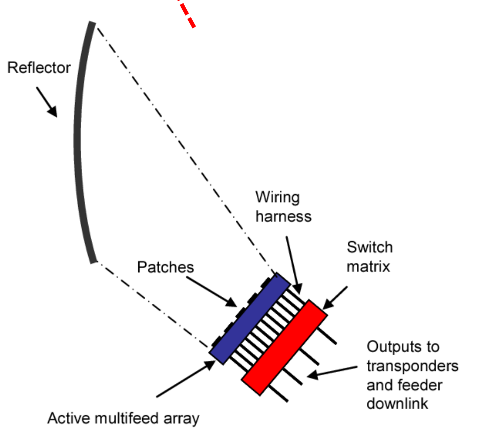
Spot beam technology



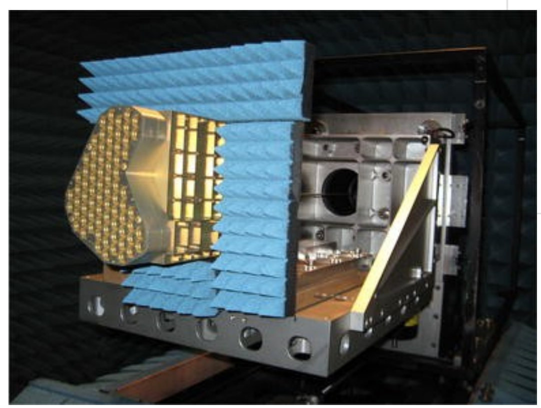


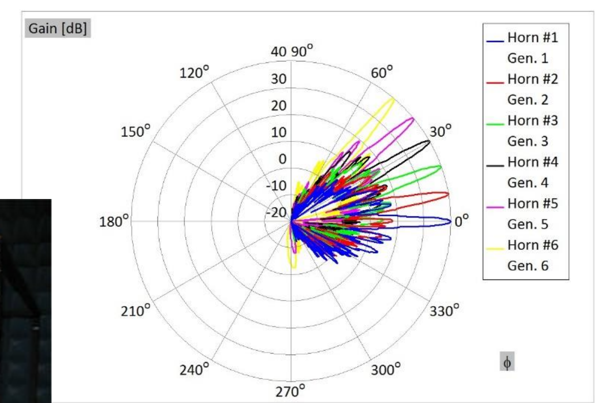
Spot beams can be arranged to cover particular areas on Earth.



ïig. 1 Schematic view of a single offset reflector antenna with multib

Multifeed array





Spot beam pattern

https://link.springer.com/article/10.1007/s12567-011-0012-z/figures/7

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