Workshop Technical & Regulatory Satellite Course

Luanda 11 to 15 July 2011

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Agenda

- Day 1 - Basics of Satellite Communications
- Day 2 - Policy and Regulatory Guidelines for Satellite Services (first half / second half)
- Day 3 - Network Planning and Link Budget Analisys
- Day 4 - Vsat Installation and Maintenance
- Day 5 - Vsat Equipment and Bandwith Procurement

DailyTimeframe

- 08h30 – Morning Session kicks off
- 10h00 – Coffee Break
- 12h00 – Lunch time
- 13h30 – Afternoon Session kicks off
- 15h00 – Coffee Break
- 16h00 – Daily session ends

Day 1

BASICS

Basics of Satellite Com

- Birth of satellite communications
- Development of satellite communications
- Configuration of a satellite communications service ..
- Type of orbits
- Orbital positions and radio interferences
- Type of antennas and performance measures..
- RF equipments..
- Earth Station Measurements
- Services
- Technology trends

Birth of satellite communications

The HF spectrum saturation was a seriously limitation for the long distance development communications, particularly through the Ocean and the existing alternatives namely submarine cable solutions at least up to 1960, were very expensive.

…Such way and out of radio wave the moon reflexion – initially detected at 1946, - and latter developed through radar technics for the WWII .

….By 1957 a signal reception reflected in the moon has been tested and in 1959 concluded a well successful communication between

UK and US and US and CAN. Although the communication has been established in poor conditions, that represented an importante goal.

…At 1954 in an internal meeting "Institute of Radio Engineers" J.R.Pearce made the presentation of an automatic plattform for the radio signal reflexion .

……In October 1957 URSS launched Sputnik I – a non stationery satellite – who transmited teleme try data for 21 days. January 1958 USA put in orbit Explorer I who during 5 month relayed space effects and his own circuitry.

Birth of satellite communications

- SATELLITE COMMUNICATIONS, or just COMSAT are defined as a communication process using artificial satellites using radio frequency waves called microwaves.
- Most satellite communications use geostationary orbits or nearly stationary although others use low orbits. It is a complementary technology to the cable, generically speaking, or fiber optic. The concept was proposed by Arthur C. Clarke based on Herman Potočnik's work of 1929

Chronology

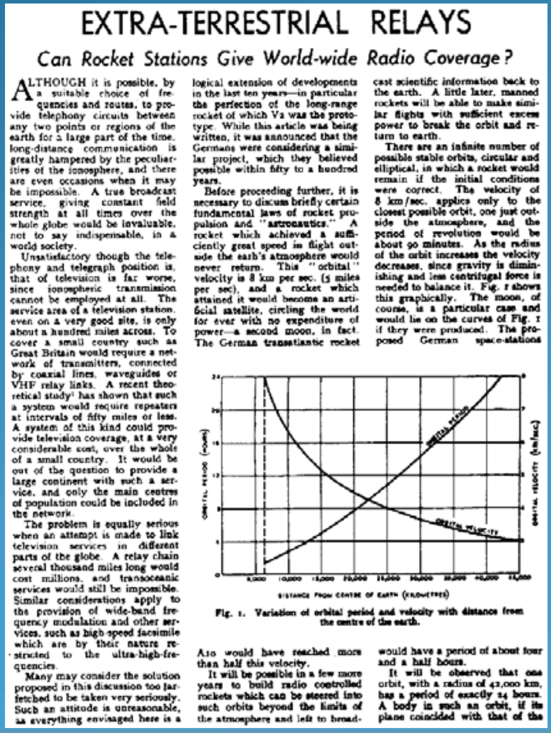
- **1945 Arthur C. Clarke Article: "Extra-Terrestrial Relays"**
- 1955 John R. Pierce Article: "Orbital Radio Relays"
- 1956 First Trans-Atlantic Telephone Cable: TAT-1
- **1957 Sputnik: Russia launches the first earth satellite.**
- 1960 1st Successful DELTA Launch Vehicle
- 1960 AT&T applied to FCC for experimental sat comms license
- 1961 Formal start of TELSTAR, RELAY, and SYNCOM programs
- 1962 TELSTAR and RELAY launched
- **1962 Communications Satellite Act (U.S.)**
- 1963 SYNCOM launched
- **1964 INTELSAT was formed**

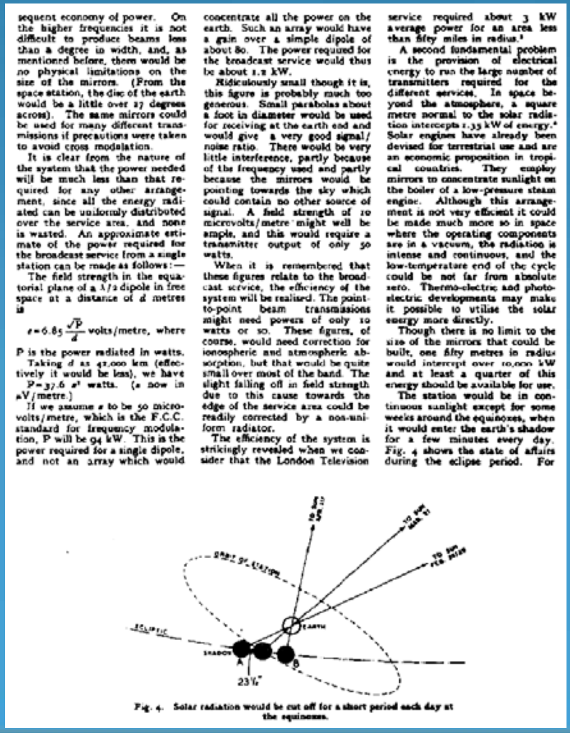
Chronology

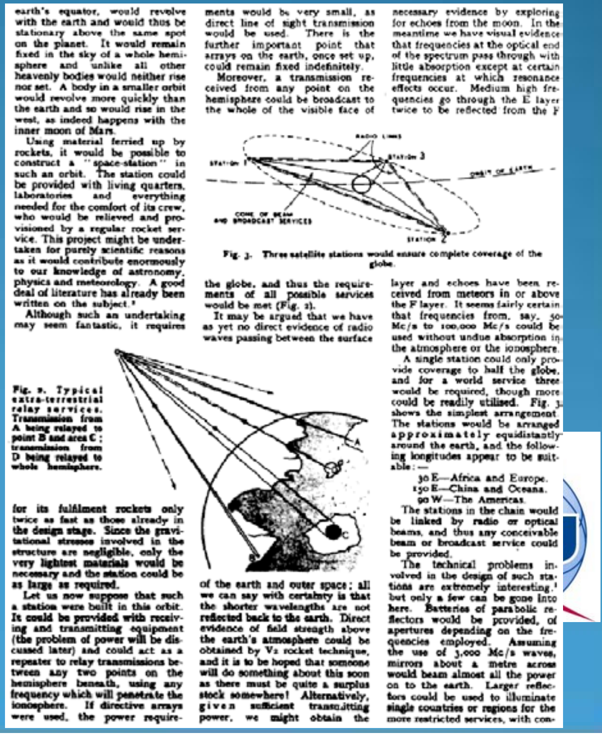
- **1965 COMSAT's EARLY BIRD: 1st commercial comm. satellite**
- 1969 INTELSAT-III series provides global coverage
- 1972 ANIK: 1st Domestic Communications Satellite (Canada)
- 1974 WESTAR: 1st U.S. Domestic Communications Satellite
- 1975 INTELSAT-IVA: 1st use of dual-polarization
- 1975 RCA SATCOM: 1st operational body-stabilized comm. satellite
- **1976 MARISAT: 1st mobile communications satellite**
- 1976 PALAPA: 3rd country (Indonesia) to launch dom comm. satellite
- **1979 INMARSAT formed**.
- 1988 TAT-8: 1st Fiber-Optic Trans-Atlantic telephone cable
- ……
- 2010 AVANTI

Birth of satellite communications

- In 1945 Clarke wrote an article "Extra Terrestrial Relays" in Wireless World magazine, which described the fundamentals of the development of artificial satellite in geostationary orbit elements as signal reflection, he became known as the father of satellite communications



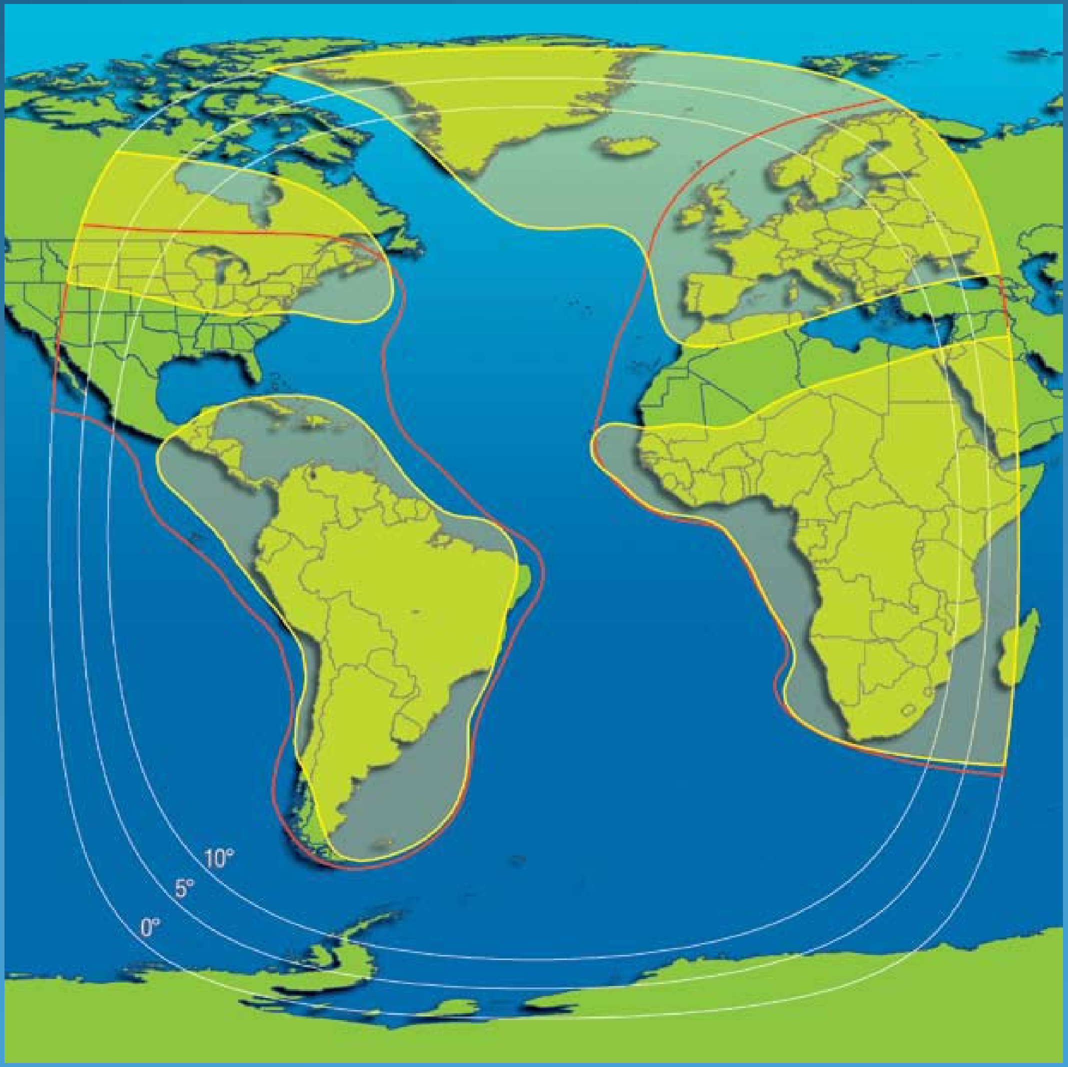




Development of satellite comm

- Types of Sat Systems
  - Global general purpose (ex.Intelsat)
  - Global maritime coverage (ex.Inmarsat)
  - Regional
  - Domestic
- Categories of Sat Communications Systems
  - Fixed Sat Services (FSS)
  - Direct Broadcast Services (DBS)
  - Mobile Sat services (Maritime, Aeronautic, Land mobile)
  - Other (Meteological, Educational, Scientific, Militar)

Development of satellite comm footprint



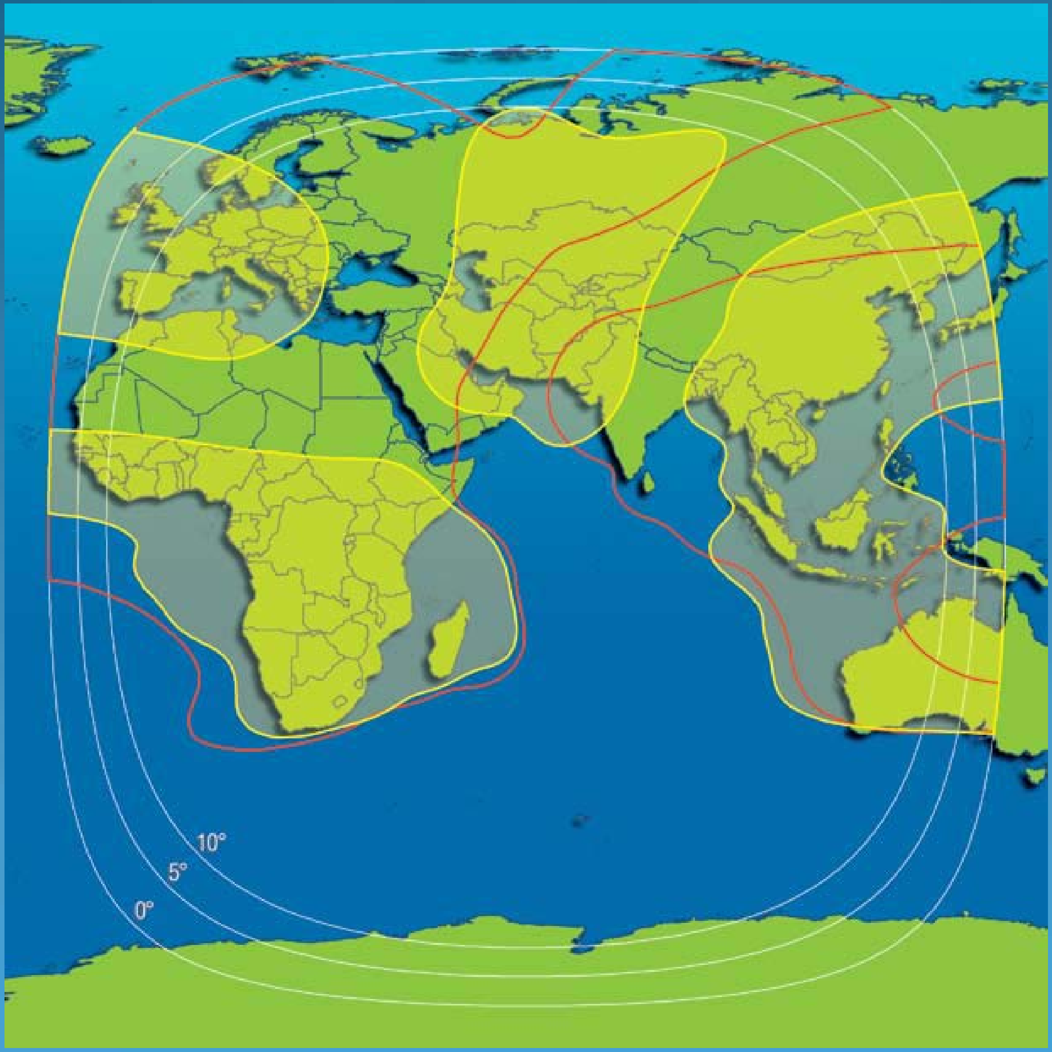
Atlantic Zone
Intelsat IS 903
325,5 º E

Global

Hemi

Zona

Development of satellite comm footprint



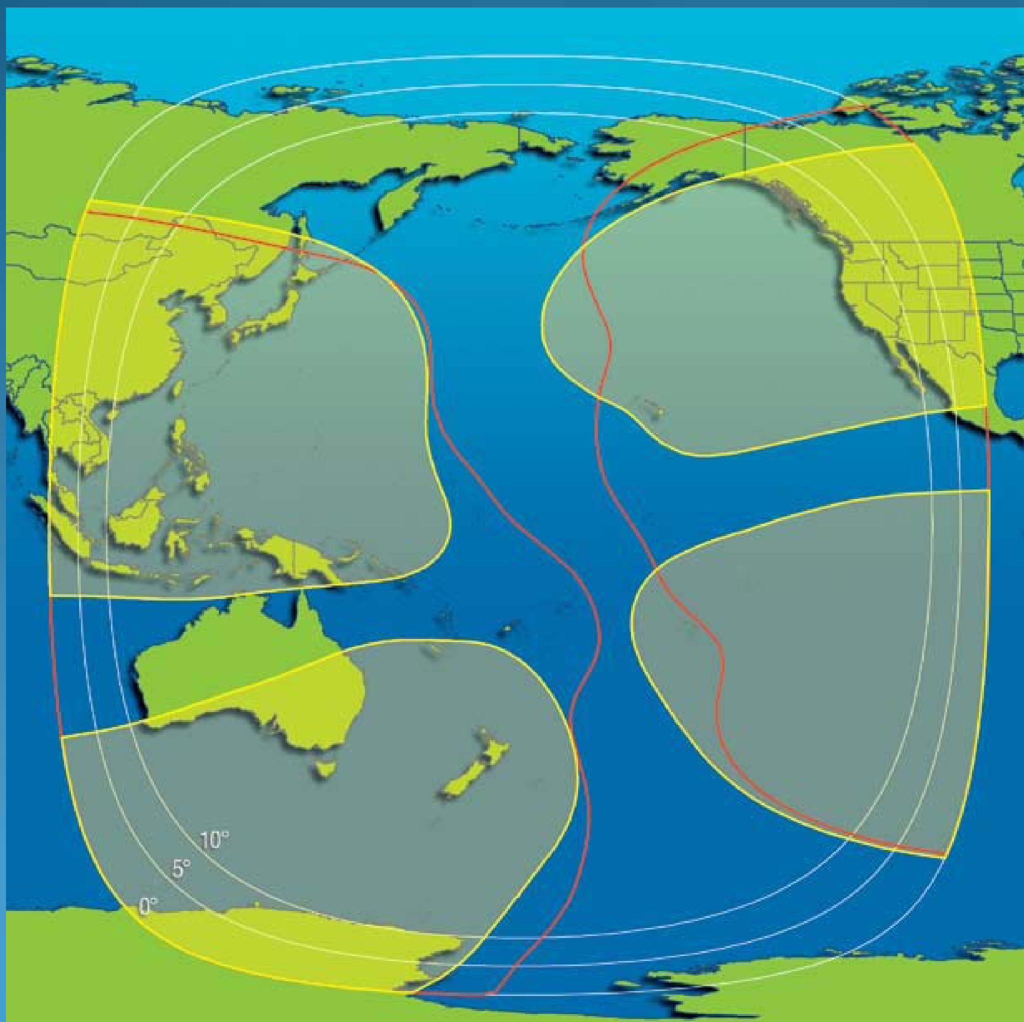
Indic Zone
Intelsat IS 904
60 º E

Global

Hemi

Zona

Development of satellite comm footprint



Pacific Zone
Intelsat IS 701
180 º E

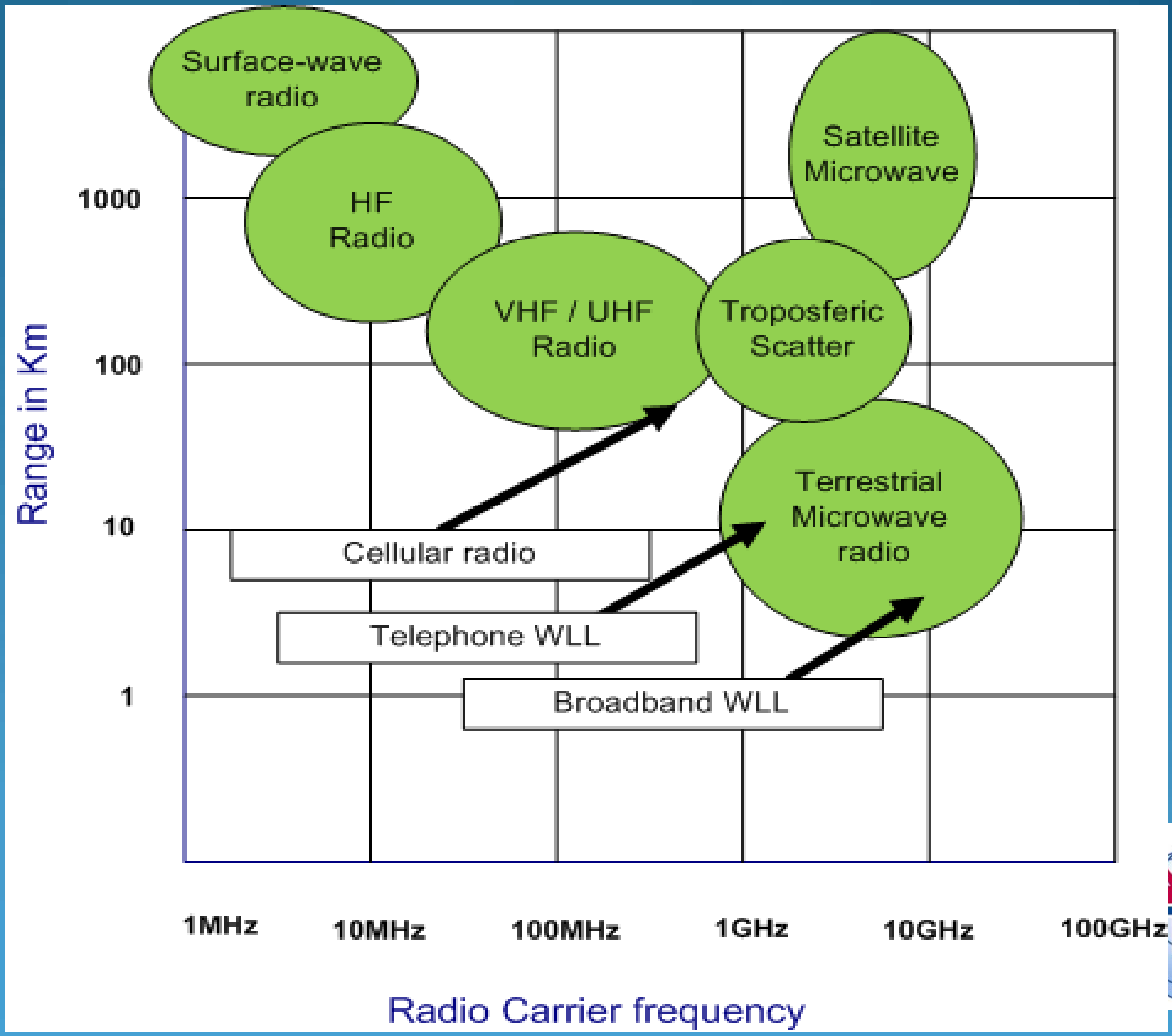
Global

Hemi

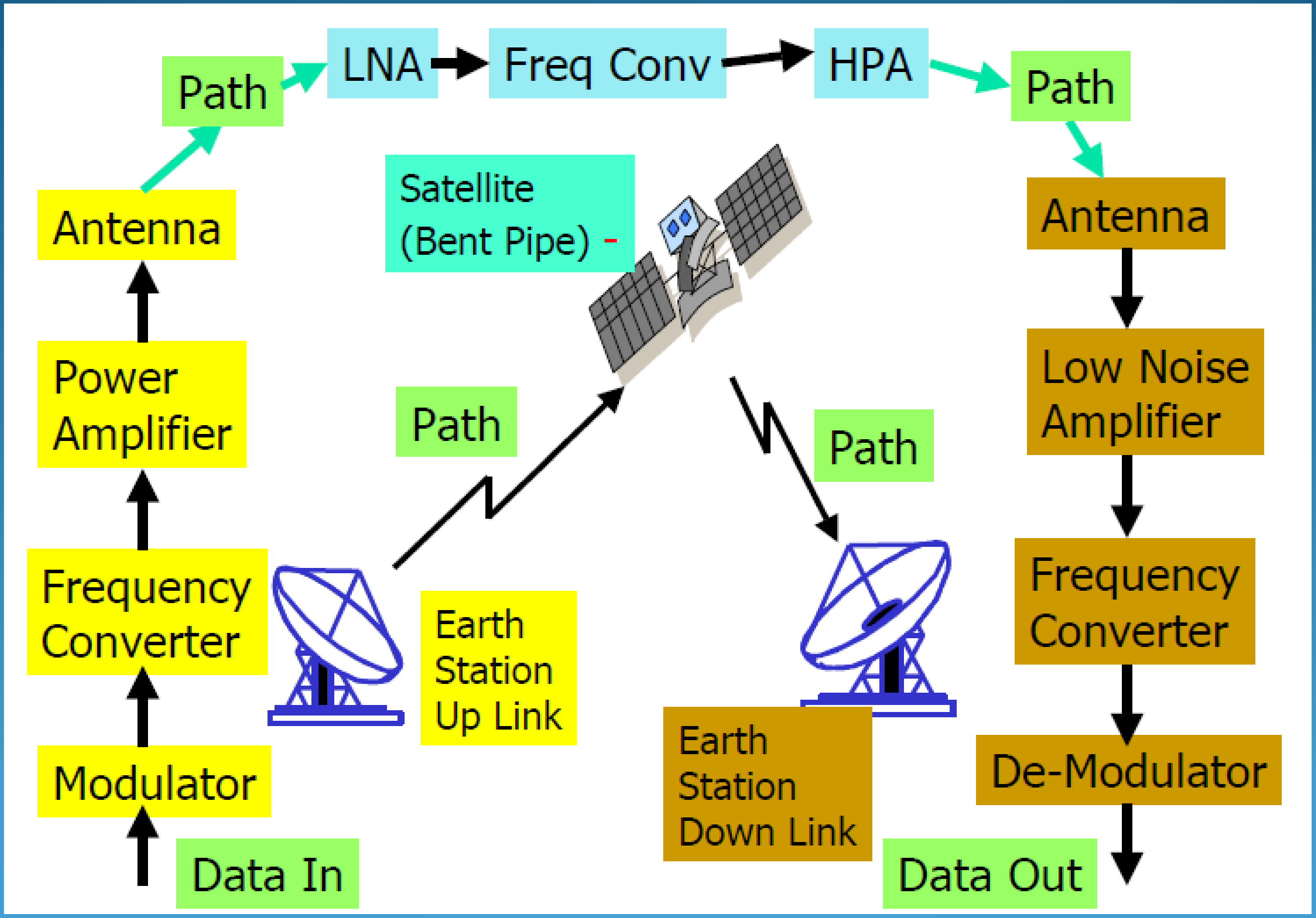
Zona

Configuration of satellite communications

COMMUNICATIONS PLANNING SYSTEMS



Configuration of communications link



Configuration sat. communications link (objectives & design premises)

- Objectives
  - Recover information (above noise, spurious & undistorted)
  - Community obligations (don’t interfere)
  - Cost effective
- Design premises
  - Distance between users (2 x 36000 Km)
  - Weather effects (adjust adverse weather)
  - Availability of communication link (Internet, voice, television, data)
  - Maintaining signal quality
  - Using minimum bandwith

Configuration of satellite communications (objectives 1)

- Due to the distance involved up signal reaching the “repeater”, shall be recovered notwithstanding the noise level, and regenerated. Same will be done on the downpath being mandatory the balance between spuroius signals and wiithout any distortion
- To fullfil the above objectives, some decision shall be assumed, concerning, maximizing transmission data rate and power delivered to the “repeater”…**How?**

- **Link budget analysis we will show it**

Configuration of satellite communications (objectives 2)

- Information transmitters are located in a community setting and satellite signals cover a wide area, and so for multiple signals, technical restrictions regarding non interference - to third or from third party - or from users to users have to be adopted.
- In addtion “multiple transmissions” are used where for example each carrier has an assigned frequency (FDM), or each carrier has an assigned time to transmit (TDM) or each carrier has an assigned transmit code (CDM)…..How?

Access schemes will show it

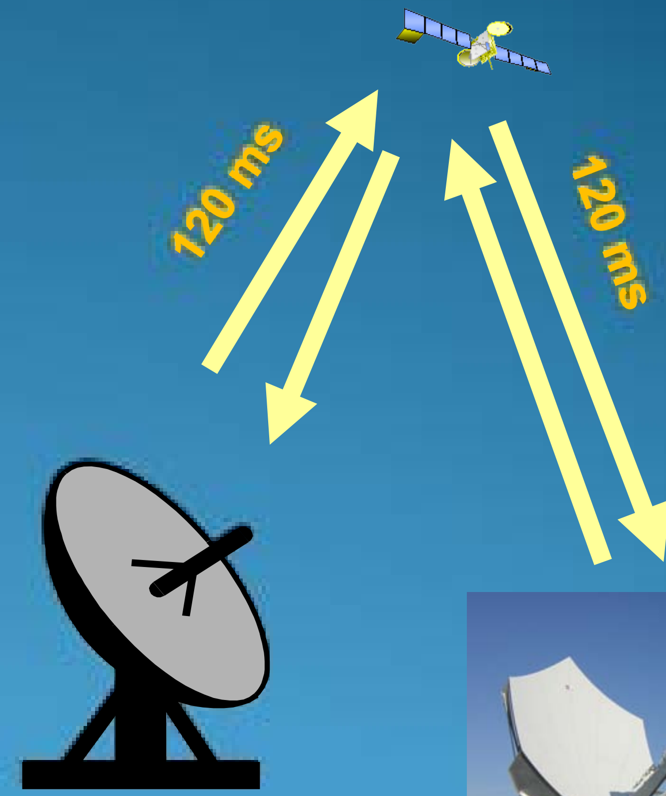
Configuration of satellite communications (objectives 3)

- Satellite communications to compete against terrestrial or submarine shall be positioned sometimes as alternate solution, sometimes as complementary, but in any case with cost effectiveness in consideration so someone could use it…How ?

Frequency bands, digital communications and modulation techniques , will show it

Configuration of satellite communications (design premises 1)

- Due to <u>the distance from terminals to geo satellite</u> - 36x10^3 km - and considering the light speed 3 x 10^8 km.s^{-1}, the two way transmission will have 240 ms, straight on the path, or *sat link delay.*
- To this shall be added the processing timing (e.g modem, switching), so we can talk about 400 -500 ms. For voice this means that echo is distinguishable, or in other words, that some echo cancellation shall be considered.



Configuration of satellite communications (design premises 2)

- Satellite operators demand that the signals entering the satellite have a fixed power spectral density, to prevent signals from interfering with each other
- Satellite users have different expectations, e.g internet users are conditioned to wait, but voice and TV directs users are not.
- Rain is the most weather adverse effect on satellite transmissions.

Configuration of satellite communications (design premises 2A)

Fortunately:

- Adverse weather is usually locallized
- Some aditional power shall be spared to compensate adverse weather
- Actual rain fade margin depends on E/S location and rain model of region
- Weather affects only first 10 Km
- C band rain margin is 2-3 dB
- K_u band rain margin is 5-15 dB
- K_a band rain margin is 20-50 dB

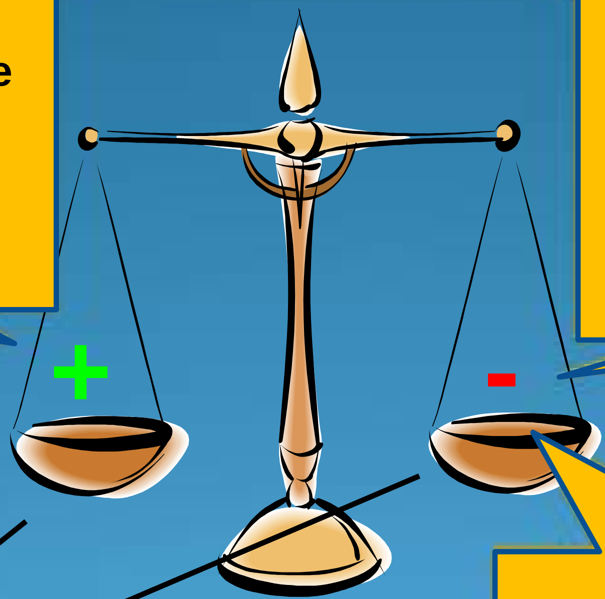
Configuration of satellite communications (design premises 3)

Availability is defined as % time, a link is yearly operational, being responsability of service provider to inform client, what kind of contract has been established (sold agreed or awarded) e.g:

- 5 - 9’s, inoperative 5´/ year
- 4 -9’s, inoperative 53 ‘ / year
- 3 - 9’s,inoperative 8,75 h / year
- 99,8 % ,inoperative 17,5 h / year

Configuration of satellite communications (design premises 4)

- EIRP
- U / L pattern advantage
- Transponder gain
- D / L pattern advantage
- Receive antena gain



- Free space loss
- Waveguide loss
- Atmospheric loss
- Rain attenuation
- Tracking errors

- E/S intermodulation
- U / L thermal noise
- D / L thermal noise
- Transponder intermod.
- Co-channel interferenc

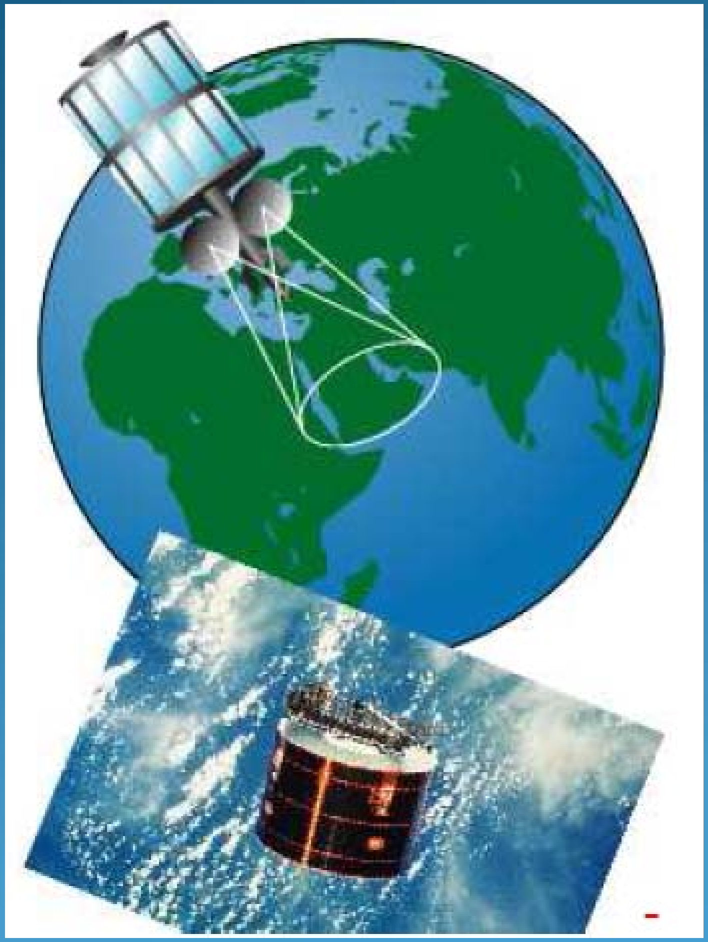
BER

Signal quality

Configuration of satellite communications (design premises 5)

- Bandwith is very expensive in other words, is a limited natural resource, and has a limited availability
- To get more bandwith one's needs greater EIRP - Electrical Isotropic Radiated Power
- Power amplifers are expensive
- Larger antennas are expensve, and accordingly pointing large antennas can be a problema, e.g a 3m antenna at K_u 14 GHz has a 1,5º beamwith (assume beamwith ~ 21 (F*D) degrees, being F – frequency GHz and D – diameter parabolic)

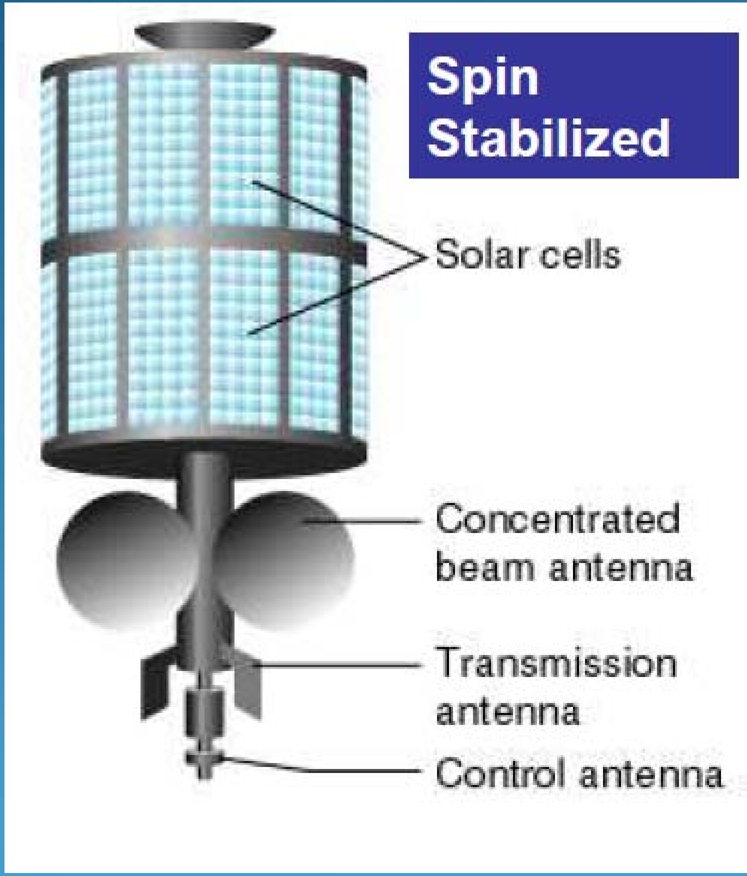
Configuration of space segment



Configuration of space segment

Subsystem	Function	Main characteristícs
Attitude & Orbit (AOCS)	Attitude and orbit stabilization	Accuracy
Propulsion	Provides velocity increments and torques	Specific impulse Mass of propellent
Telemetry tracking and command (TTCM)	Exchange of house-keeping data with control centre	Number of channels Security of communication
Thermal control	Temperature regularion	Heat dissipation capability
Structure	Support equipments	Stifiness
Electric power supply	Provides electric energy at various voltage levels	Power voltage regulation
Antennas	Receive and transmit RF signals	Coverage and gain
Repeaters	Amplify signals and change frequency	Noise figure, linearity, Output RF power

Configuration of space segment attitude & orbit stabilization



- Satellite body spin stabilized
- Gyroscop stability
- Spins to minimize thermal effects
- Half sollar cells face the sun at one time
- More efficient for small sattelite
- Antenna must de-spun

Configuration of space segment

TRI AXIS
BODY STABILIZED

- All sollar cells face the sun at one time
- Thermal control more difficult
- Requires more stabilization control
- More sollar cells than spin stabilized satellite
- Better design for larger satellites

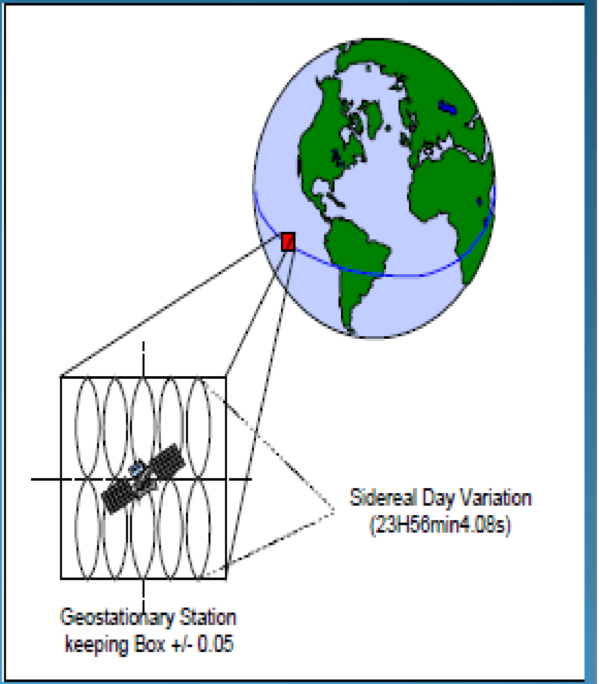
Configuration of space segment

Satellite station keeping

Gravitational effects of the sun and the moon, the radiation pressure of the sun, the earth's magnetic field and other forces cause perturbations in the orbit of a satellite.

Satellite must contain fuel to correct for these perturbations and hence the life of a satellite is determined by how well the on board fuel is managed by the satellite operator. Hydrazine fuel is used and thrusters are mounted on the body of the satellite which are fired as required to maintain a specific tolerance. Approximately

20 to 40% of the dry mass of a satellite is allocated for station keeping fuel. Typically, a +/- 0.05 degree station keeping box wrt North South and West-East is maintained by satellite operator. Majority of fuel used for N S station keeping corrections.



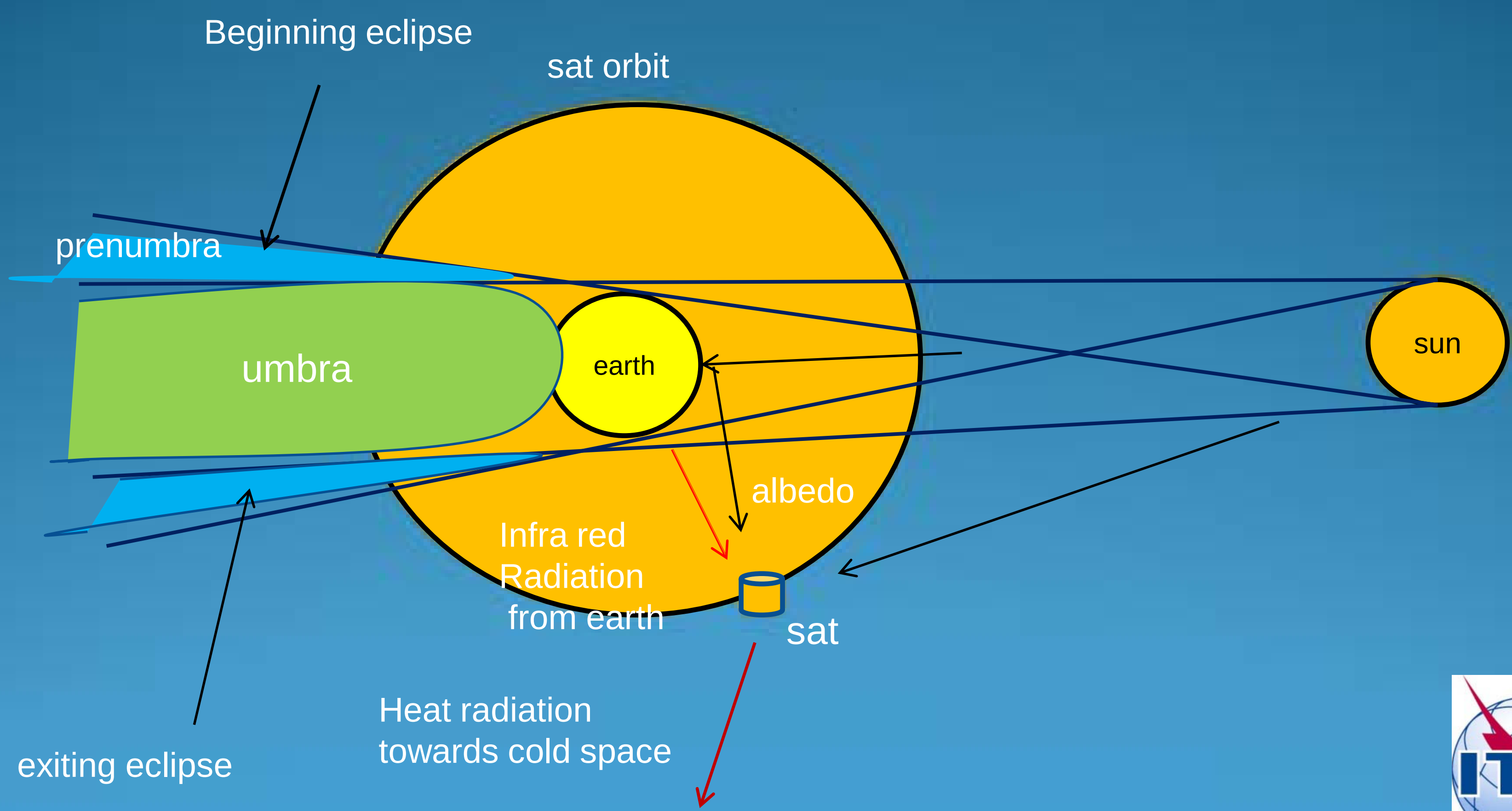
Configuration of space segment propulsion sub-system

- Aims generating forces to:
  - Low thrust actuators devoted to attitude and orbit corrections which provide an annual velocity increment of the order 50 m/s and boosts from 10-3 N up to 20 N, and can operate from several hundreds to several thousands of hours made up of many short operating cycles , a long life about seven to tem years for communications satellite;
  - High thrust motors (400N up to 50KN) named apogee kick motor, which provides the velocity increment required for the geostationary satellite orbit injection at the transfer orbit apogee (about 1500 m/s);
  - Very high thrust which provides the velocity increment required to inject the satellite into the transfer orbit (about 2430 m/s)
  - Chemical (0,5 N up to 10 N) and electric (2 to 10 mN)

Configuration of space segment telemetry sub-system

- Transmit housekeeping information and status of the satellite to the ground control station;
- Provide angular and range measurements to permit locallization of the satellite
- Receive command signals from the ground control station to initiate attitude and station keeping manoeuvres and operations of the on-board equipments
- The frequencies generally used are either VHF (148 to 149,9 MHz UL or 136 to 138 MHz DL) or S band (2025 to 2120 MHz UL or 2200 to 2300 MHz DL)

Configuration of space segment thermal control sub-system 1



Configuration of space segment thermal control sub-system 2

- Required to maintain equipments and structure of the satellite within specified temperature ranges. This must be ensured whether the equipments are operating or not;
- Is designed considering the different requirements of the operational and transfer orbit phases, which involve different attitudes and orbits and different status of the apogee motor ;
- Acceptable temperature ranges, e.g
  - Batteries 0 º C a +20 º C
  - Solar Cells -100 º C a +50 º C
  - Electronic equipment -10 º C a +60 º C
  - Propeller Tanks +10 º C a +50 º C
  - Infrared sensors -20 º C a +45 º C

Configuration of space segment thermal control sub-system 3

- Passive thermal control
  - Based on the absorption α and emittance ε of the surface finish, and the ratio α / ε is of prime importance in determining the surface mean temperature when exposed to the sun (white paint, aluminium paint, black paint, polished metal surface)
- Active thermal control
  - Heat pipes ensuring adiabatic transfer of heat from heat sources to radiators by successive vaporization and condensation of a fluid at the two extremities of a pipe
  - Hinged flaps and multiple blade louvers mechanisms arranged to expose or to cover radiator areas
  - Electrical heaters activated either by thermostats or telecommand

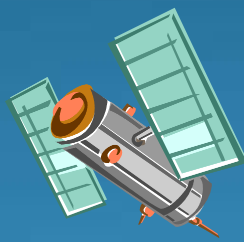
Configuration of space segment structure sub-system

- Structural materials must have resistance to deformation and lightweight. These are conflicting requirements. Current techniques allow about 6 % of the satellite's total mass only to be used for its structure (aluminium, magnesium alloys, honeycomb panels, bonded assemblies and carbon fiber reinforced plastic materials for solar panels, antenna towers)
  - Support the on-board equipment especially during the launch phases where the mechanical stresses are higher
  - Ensure correct positioning of the equipment (alignement of sensors, thrust axes of thrusters, axes of antennas…)
  - Allow the various separations and deployments
  - Avoid electrical charge accumulation

Configuration of space segment power supply sub-system 1

- Primary energy source
  - Solar panel and cells (requiring sun sensors, electronics for measurement and control , a servo motor and a bearing and power transfer assembly)
- Secondary energy sources
  - Electrochemical accumulators:
    - Sufficient Lifetime whitch depends on the depth of discharge and temperature
    - Hight specific energy in Wh / Kg
  - Ni-Cd, Ag-Cd, Ni-H2, Ag-H2)
- Power conditioning and protection circuits
  - Unregulated (simpler, lower mass, however equipments subjected to variations in voltage) and regulated (not subjected to variation voltages , but costly to the masss budget and output power, and less reliability)
- Spin stabilized satellite *(specific power unit~ 9,7 W / Kg) body fixed satellite (specific power unit ~ 19 W/Kg)*

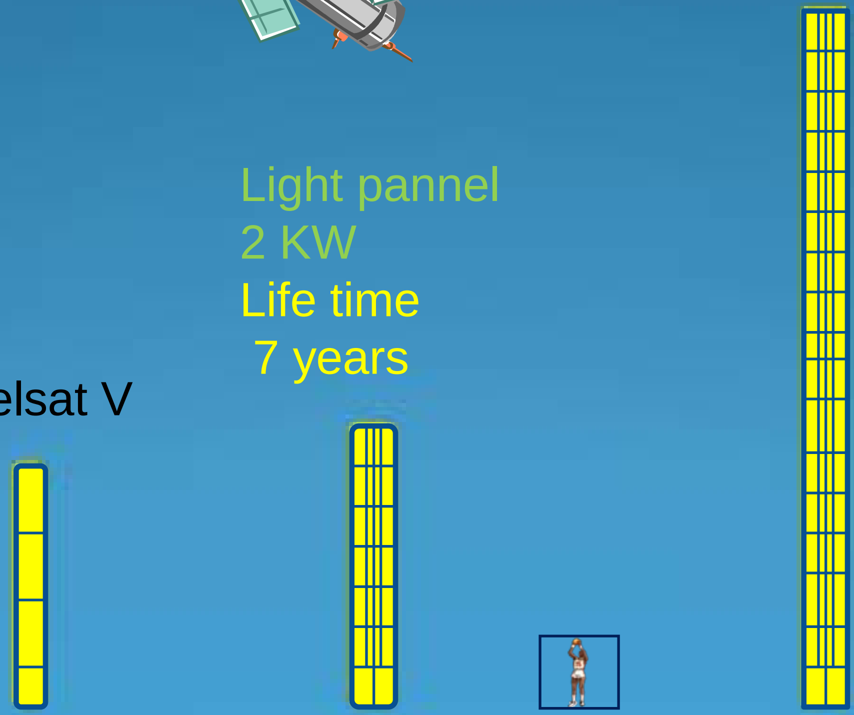
Configuration of space segment power supply sub-system 2



Ultra light pannel
4,7 KW
Life time
7 years

Light pannel
2 KW
Life time
7 years

Intelsat V



1 m

Configuration of space segment antenna sub-system 1

The approach to the design and sizing of satellite antennas is related directly with the desired coverage on the satellite, but also related with the stress of mechanical effects - torques - on the structure on the satellite.

1. Gravitational torque

These effects may cause the satellite to rotate about its centre of mass unless the axis of smaller inertia of the satellite is aligned with the local vertical, and depend on the distance of gravitational centre of earth to the satellite centre. This torque which may be used to stabilize satellites placed in a low orbit is rather inefficient for the stabilization of geostationary satellites

Configuration of space segment antenna sub-system 2

2. Operational (automatic or manned) torques to:
   - Antenna pointing
   - Solar panels pointing
   - Station keeping manoeuvres or
   - Consequence of propellent tanks emptiness

In conclusion the geostationary satelliteis subject to perturbations which cause it to drift away from its nominal position and which create attitude perturbing torques.The drift in lattitude is the most significant, and results from the luni-solar attraction, due to a variation in the inclination of the orbital plane of about 1º/y.The drift in longitude is basically due to the asymmetry of the terrestrial potential and depends on nominal situation of the satellite relative to 2 eqilibrium points e.g 105ºlong W and 76ºlong E

Configuration of space segment antenna sub-system 3

- So we do come to the satellite need of stabilization what is achieved through the well known *gyroscopic stiffness effect* to torques tending to disturb the orientation of rotational axis.
- Spin stabilization is achieved by rotation of the geostationary satellite body between 30 and 120 rpm creating an internal stiffness which maintains the satellite axis perpendicular to the equatorial plane. Hence this simple technique benefits from the properties of a gyroscope, but has the inconvenience of either accepting a toroidal pattern antenna (and therefore low gain), or imposing the use of a de-spun antenna or communication payload which requires specific technology.

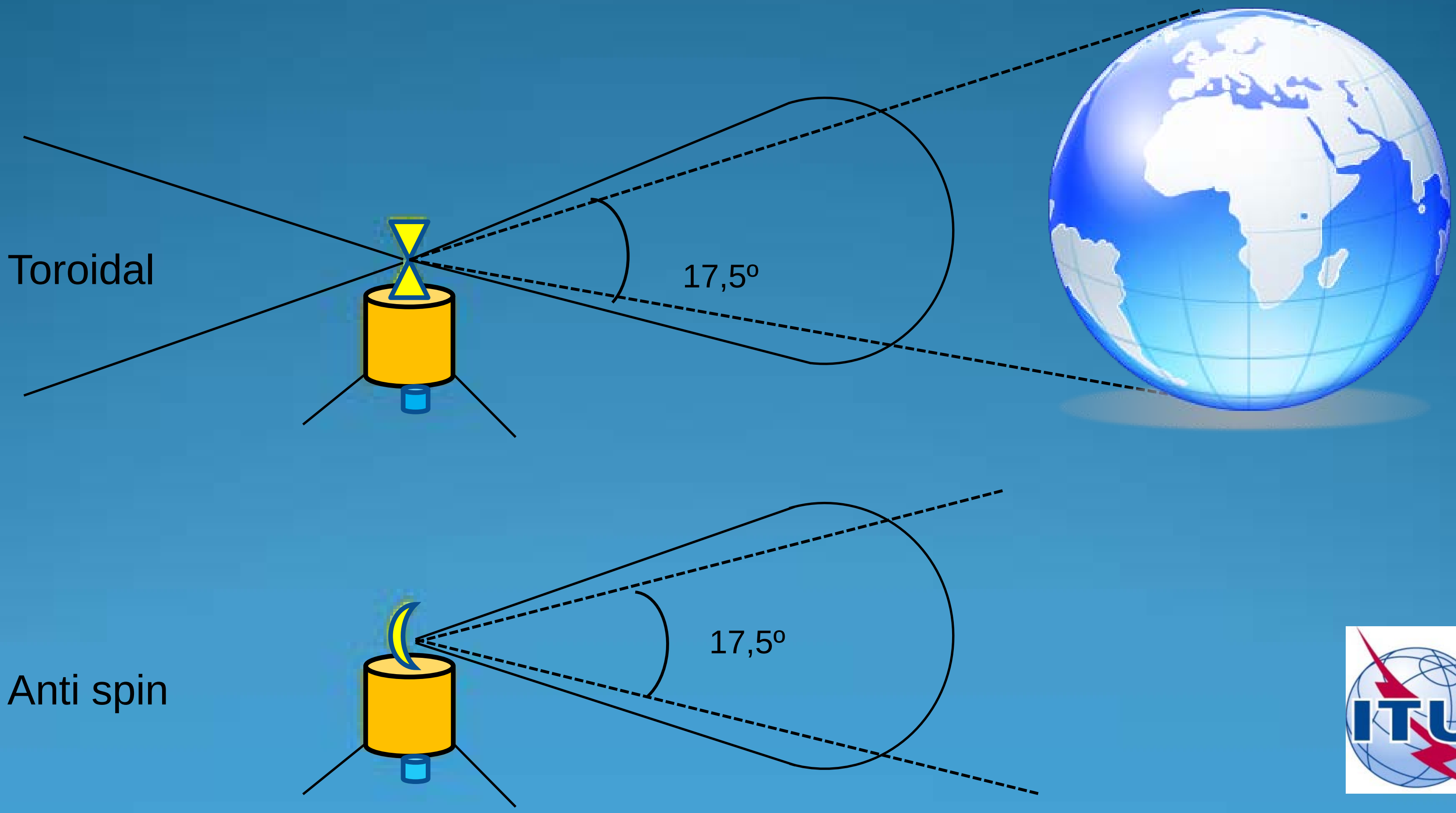
Configuration of space segment antenna sub-system 4

- Depending on the satellite stabilization, hence :
  - Rotating antenna platfform (spin satbilized sat)
    - Wired antenas (monopole, dipole TTCM, UHF e VHF)
    - Toroidal antenna
    - *Electronically De-spun antenna*
  - Stabilized antenna platform (dual spin or body stab. sat)
    - *Horn antenna*
    - Double reflector antenna
    - Multibeam reflector antennas

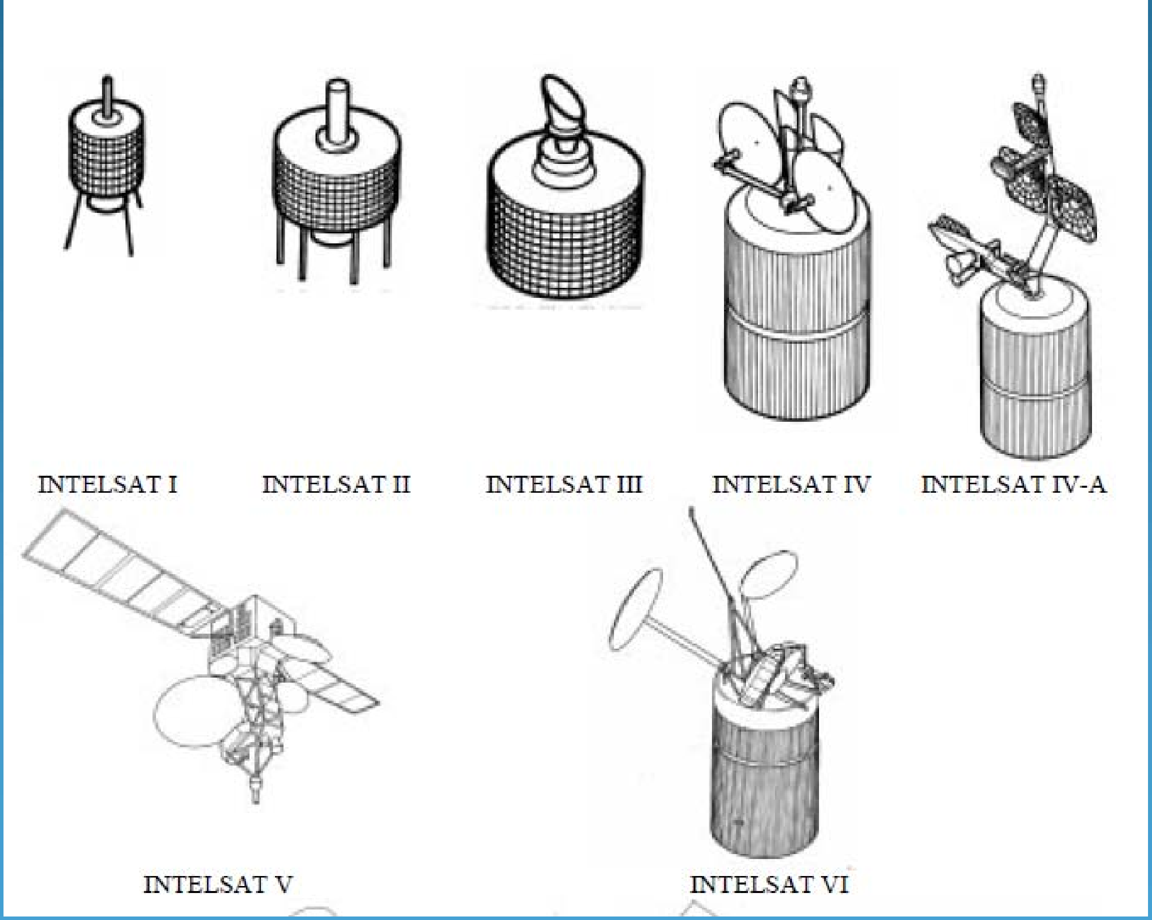
and with the coverage footprints

- Global, Hemi, Zone beams
- Spot beam
- Shaped, Multiple beam

Configuration of space segment antenna sub-system 5



Configuration of space segment antenna sub-system 6



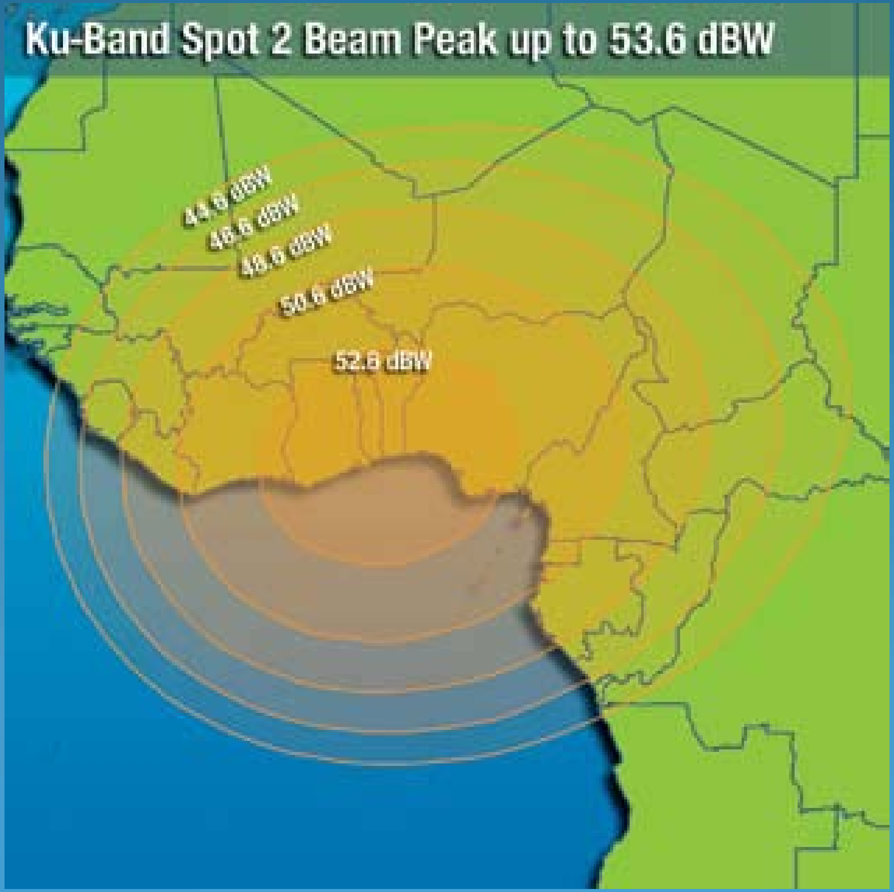
Configuration of space segment antenna footprint sub-system 1

Global

Zone

Hemi

Configuration of space segment antenna footprint sub-system 2



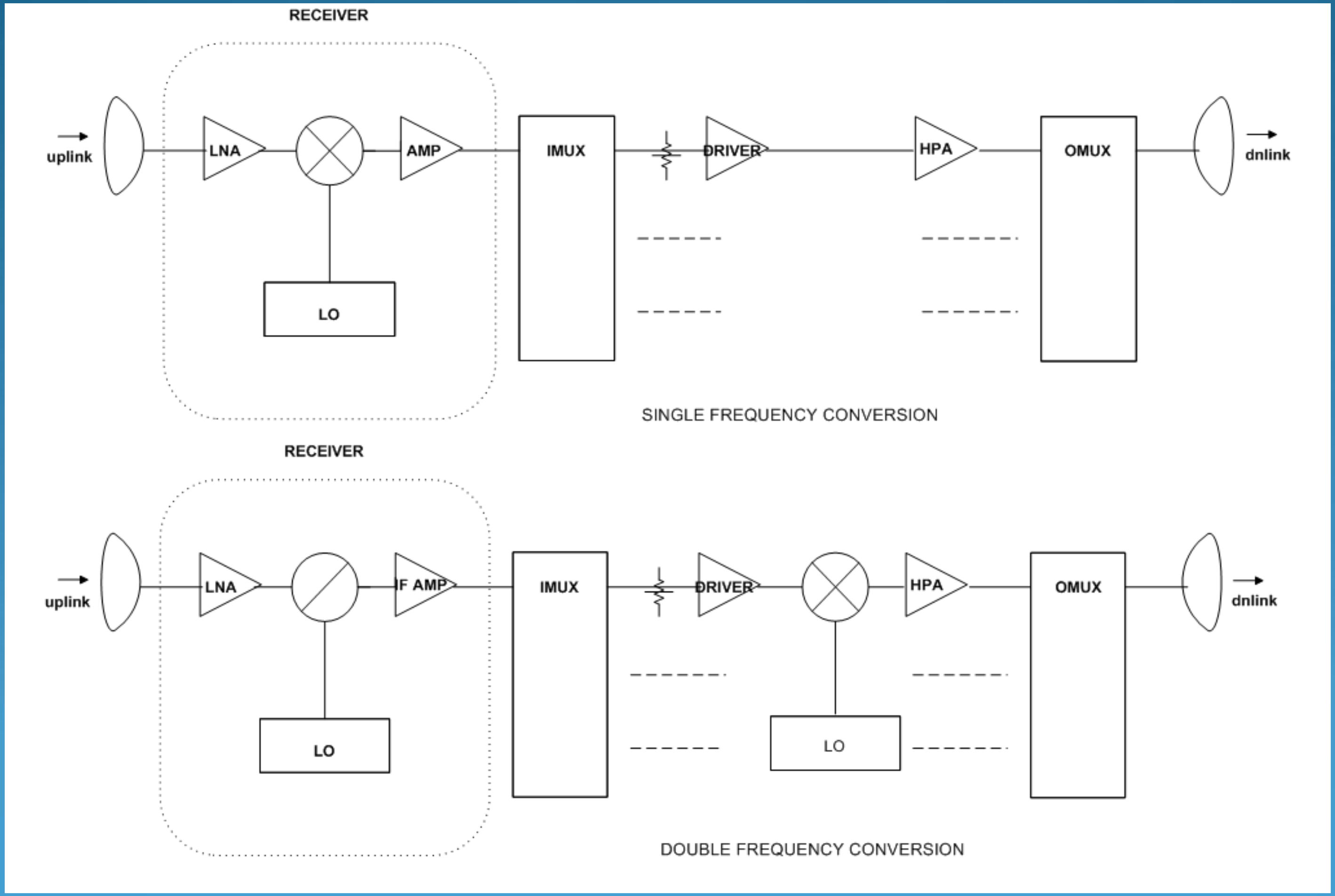
Configuration of space segment transponder sub-system 1

- Electronic devices that:
  - Amplifly signal received form earth at very low level, to signal output to be sent to earth from -100 dBW to 10 dBW which means 110 dB of gain;
  - Convert the frequency , which avoids interference between the powerful transmitted signal and the weak incoming signal.
  - And in some particular cases (regenerative repeater) also provides on-board detection of the received signal prior to baseband processing and remodulation for down link transmission.

Configuration of space segment transponder sub-system 2

- The basic building block of any satellite communications package is the transponder. This device receives the uplink carriers, amplifies them, converts them to the correct downlink frequency band and transmit them via a high power amplifier back to earth.
- In the early satellite a few transponder – e.g Intelsat I and II employed 1 or 2 250 MHz - and those used had a relative low output power (1 or 2 W). As the demand for circuits had grown the design of communications package changed to offer more transponder. Each covering a small portion of the available band thus providing better linearity and a higher output power capability. Intelsat IV contained 12, 40 MHz transponder (36 MHz usable and 4 MHz guard band) whtch means 480 MHz used and 20 MHz for flight beacon.
- To achieve the optimization of the frequencies used, spatial frequency reuse became common as well as frequency polarization reuse, in such way that the initial 500 MHz bandwith became 2500 MHz.

Configuration of space segment transponder architeture



Configuration of space segment transponder components 1

- Low Noise Amplifiers
- Down converter
- Post converter amplifier
- Input and output multiplexers
- Switch matrix (multibeam sat)
- Channel power amplifier
  - Driver
  - Output stage
  - Multi carrier operation
  - HPA (TWTA)
- Regeneration repeater

Configuration of space segment transponder components 2

- The overall performance of communications payload is closely related to the characteristics of repeater.For instance the receiver G/T of satellite depends on the receiver input amplifier noise figure.
- The downlink frequency stability depends on that of the local oscilattor.Out of band signals are generated by the repeater non linearities and are sensitive to filter characterisitcs.The EIRP of satellite depeends on the saturated power of HPA and the loss of output devices (filters, feeders etc)
  - Low Noise Amplifiers
    - Basically the low noise amplifier (preamplifier) conditions the repeater global noise figure .High gain 5 to 20 dB, and NF of 3 dB (6GHz), 4dB (14GHz) 8dB (30 GHz)
  - Down Converter
    - Includes mixer, filter, local oscillator.Typically mixer conversion loss is 5 to 7 dB.

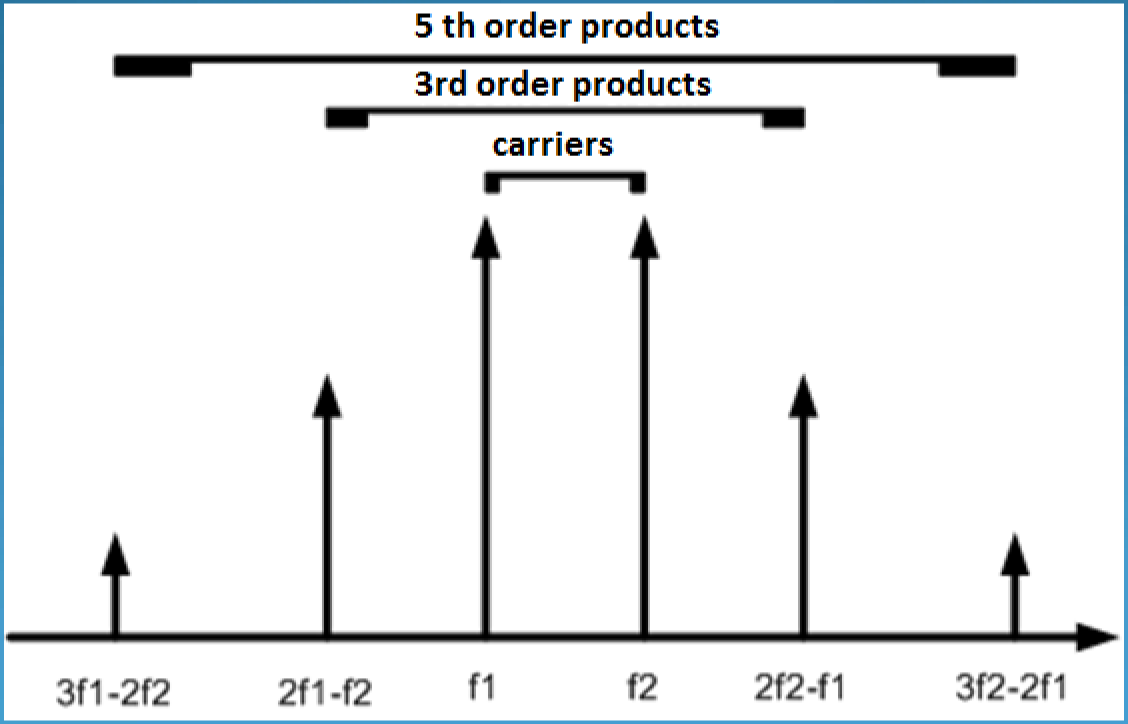
Configuration of space segment transponder components 3

- Post conversion amplifier
  - After frequency conversion hjgh gain amplifier is necessary to bring signals to a hjgh level for the input of transmitter power stages
- Input & output multiplexer
  - Determine the input and output of the channelized part of the repeater, making use of high Q's band pass filter which impose the transponder bandwith.:
    - IMUX splits into separate channels the total bandwith, through circulators and a set of bandpass filters.
    - *OMUX combines the channels after power amplification. Tig requirements are imposed concerning the insertion of the OMU as any power loss reduces the satellite EIRP and generates hea*

Configuration of space segment transponder components 4

- Switch matrix
  - With multibeam satellite switches are required to modify the beam interconnectivity.Switches operated through ground command allow fora semi-fixed interconnection scheme .Rapid switches (several times switch within a millisecond) implies:
    - Solid state switches
    - On board control
- Channel power amplifier
  - Comprises one or several stages of power amplification (driver) and the output stage.
  - Power amplifiers are not linear and non-linear operation generates undesirable signals as intermodulation products, e.g when a non-linear amplifier is driven by two equal power carriers at frequencies f1 and f2 (next slide) the products of third and fifth order are significants, or 2f2-f1 and 2f1-f2 and also 3f2- 2f1 and 3f3-2f1

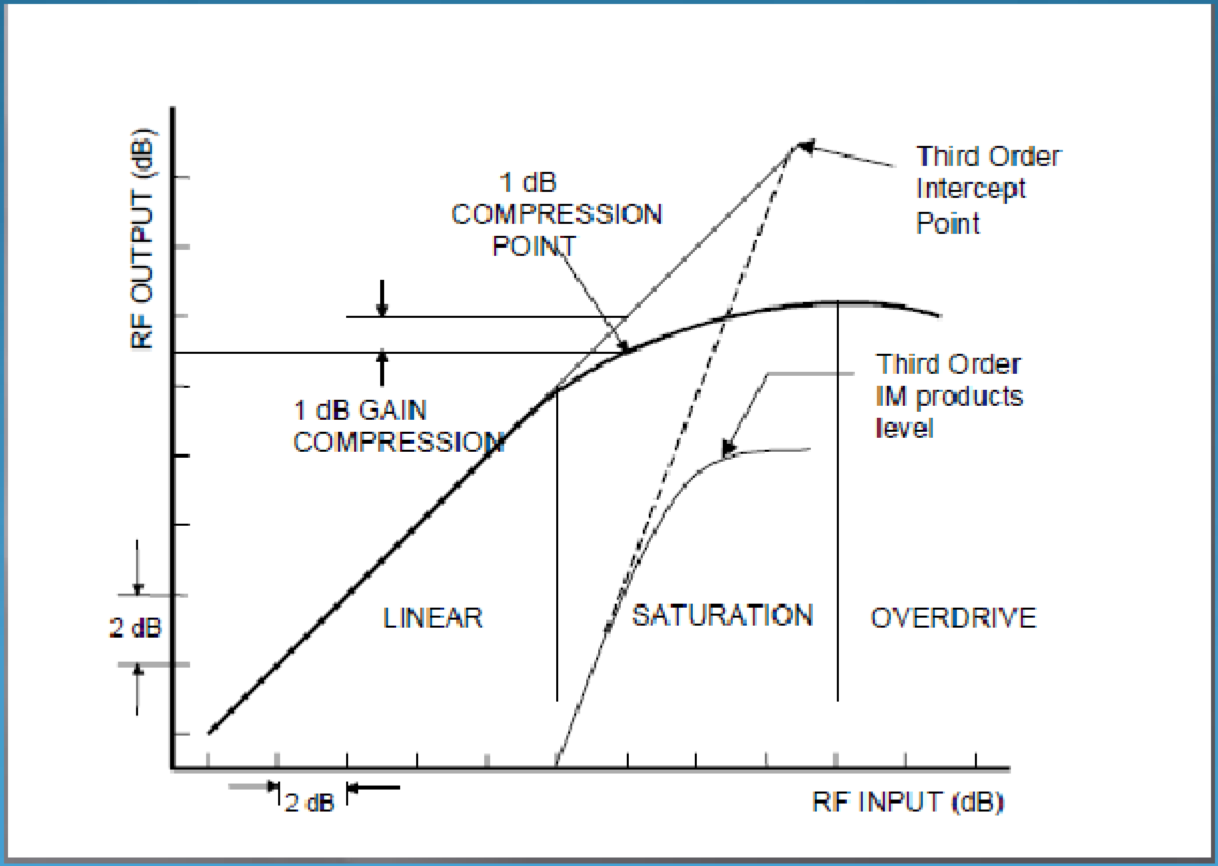
Configuration of space segment transponder components 5



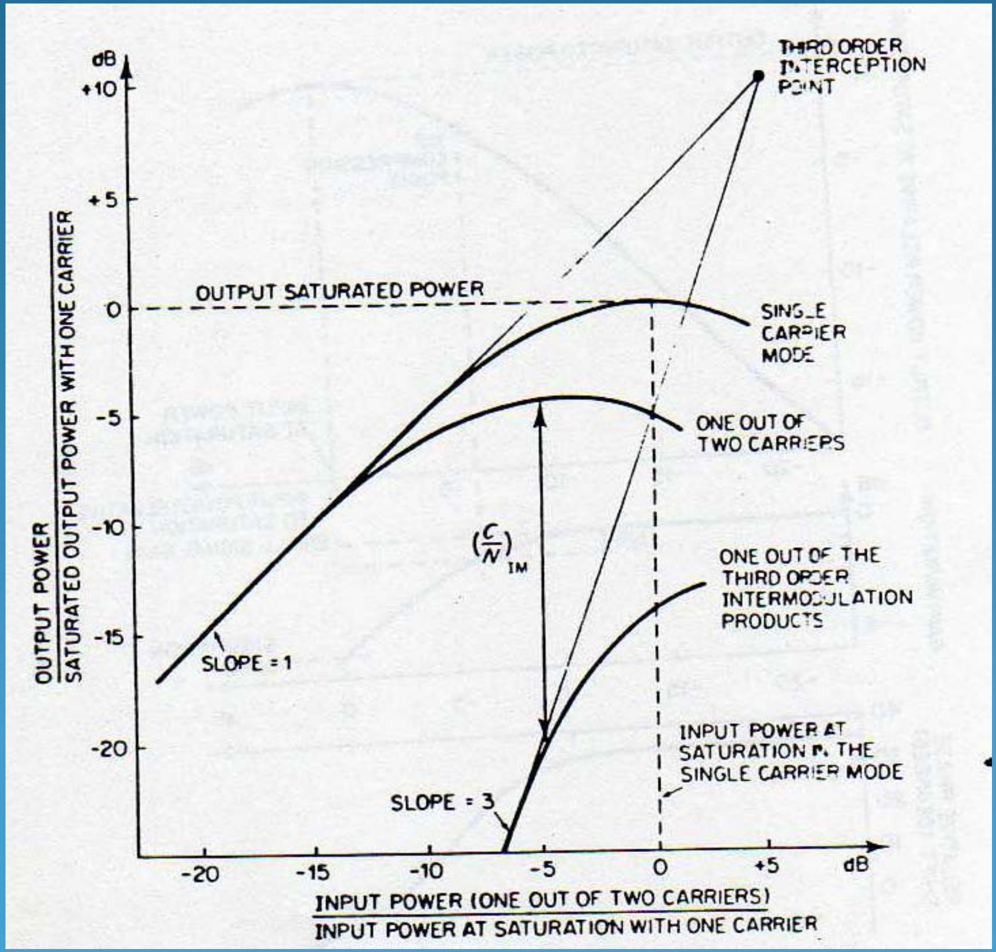
Configuration of space segment transponder components 6

- Driver is a narrowband amplifier which amplifies signals at the IMUX output to the power level required to drive the output stage.
- Output Stage as well as the HPA, refers the common situation where output power gain and phase shift in terms of input power are achieved. The variations in phase shift of the output carrier when the input power varies, turns into phase modulation when the input carrier is amplitude modulated or what is called AM / PM conversion showed in the following slides, respectively for mono carrier and multicarrier situation
- Nowadays output stages are implemented mostly with travelling wave tubes (TWT) but solid state power (SSPA) is being the winner, because they are lighter in weight more linear and offer a significant improvement in reliability, meaning improved linearity increased transponder capacity.

Configuration of space segment transponder components 7



Configuration of space segment transponder components 8



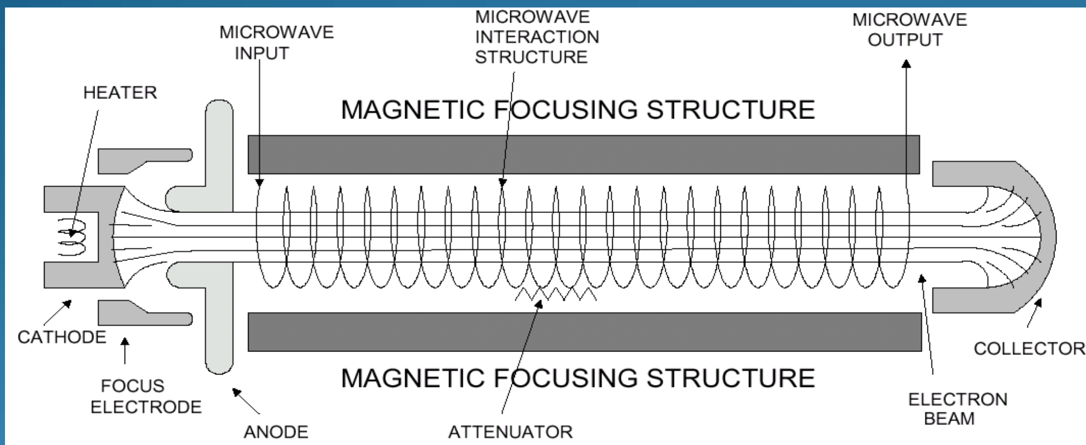
Configuration of space segment transponder components 9

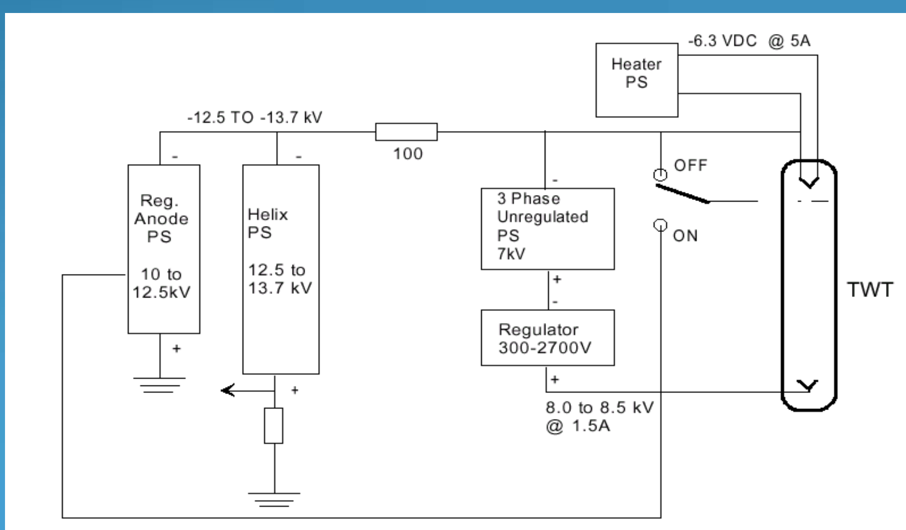
- The RF wave's electric field traveling in the slow-wave structure penetrates into the electron beam region, and causes some electrons to accelerate and some others to decelerate producing a periodic velocity modulation approximately in phase with the RF electric field.
- The electron bunches thus formed tend to concentrate ahead of the accelerating field and behind the decelerating ones. Because the average velocity of the electron beam is slightly greater than that of the RF wave, the bunches will tend to move "back" into regions where the RF field will decelerate the electrons. As the electrons lose velocity, the energy lost by the electrons is transferred to the RF energy in the RF wave.This transfer of energy registers a constant gain in the amplitude of the RF wave per unit of length.
- . The wave traveling from input to output will be amplified, and the wave traveling from output to input will not be amplified.

Configuration of space segment transponder components 10

- However, in the presence of the inevitable reflections at the output and input couplers, some RF energy could be reflected back towards the input along the helix, and upon reflection from the input coupler, this signal will represent RF feedback.
- All practical TWTAs have sufficient gain for this feedback mechanism to result in self-oscillation. It is fairly simple to interrupt this feedback path by placing RF attenuation on one or more of the helix support rods. The attenuation is formed by placing a carefully controlled pattern of a resistive material on the rods prior to their installation into the helix structure.
- Pyrolytic graphite (carbon) and titanium carbide are the most commonly used substances. The density of this attenuation pattern is selected to provide a very low reflection of RF energy so that any energy reflected from the output of the TWTA is absorbed in the attenuation.

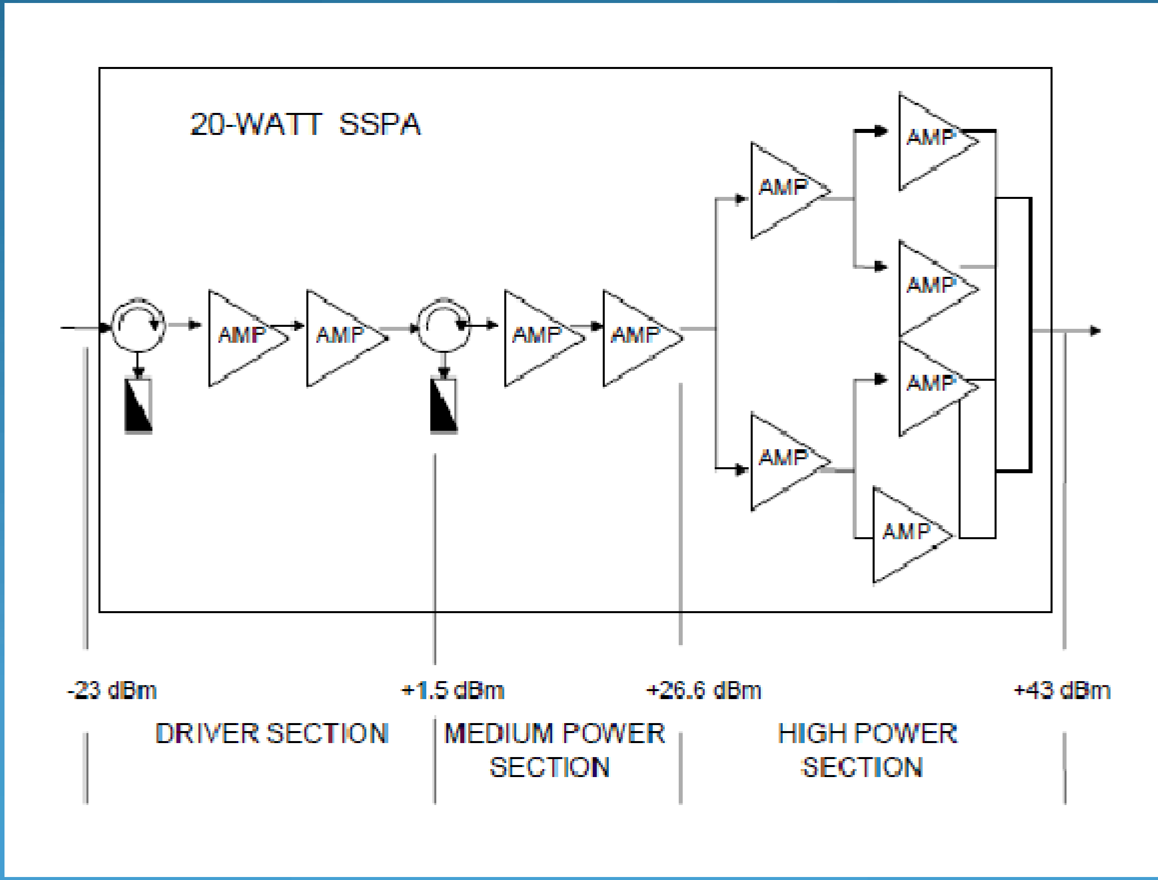
Configuration of space segment transponder components 11





- Electron gun
  - Cathode
  - Heater
  - Focus electrode
  - Anode
- Helix
- Collector
- Magnetic focusing
- Heater voltage (≈ 6
- High Voltage ≈ 11 kV

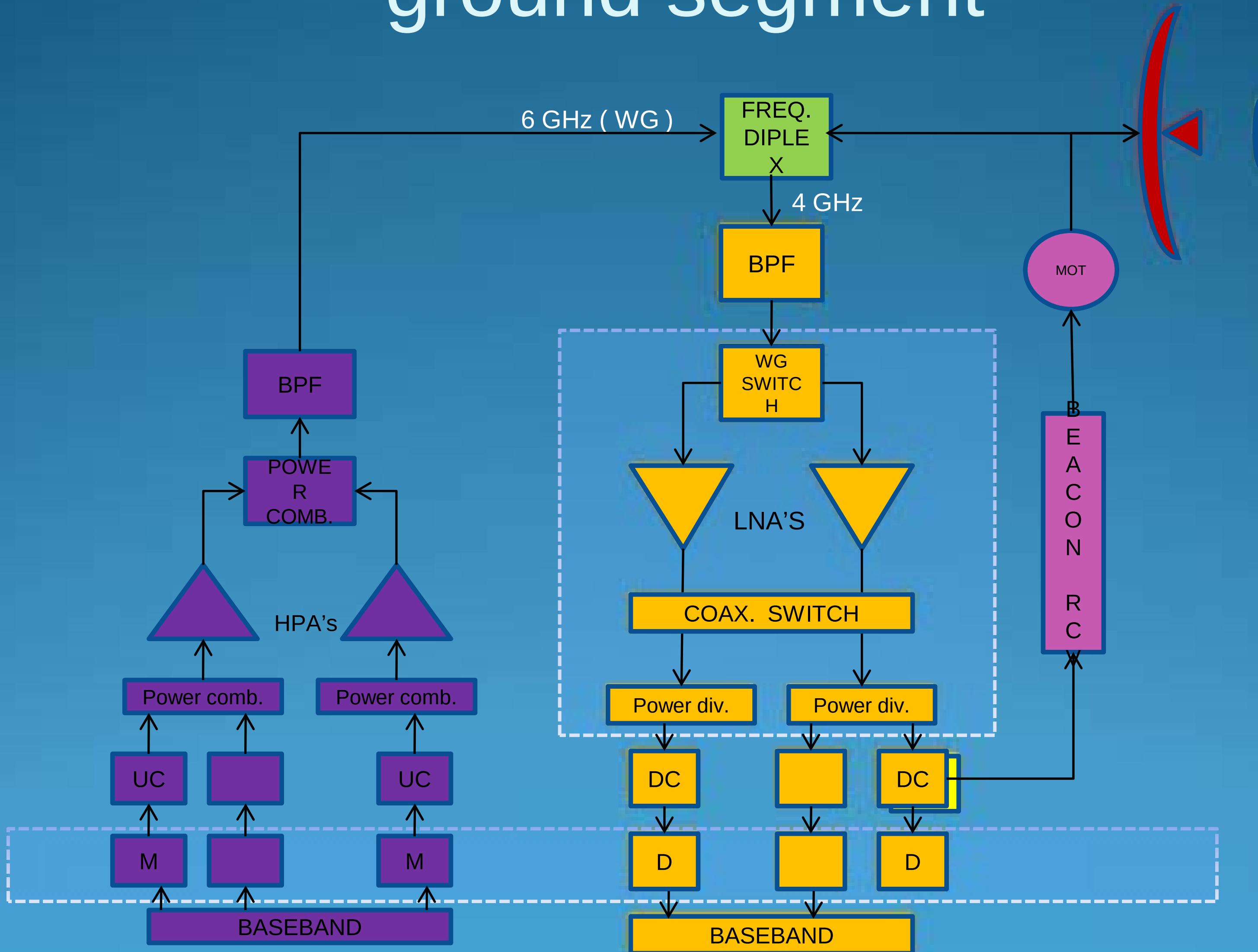
Configuration of space segment transponder components 12



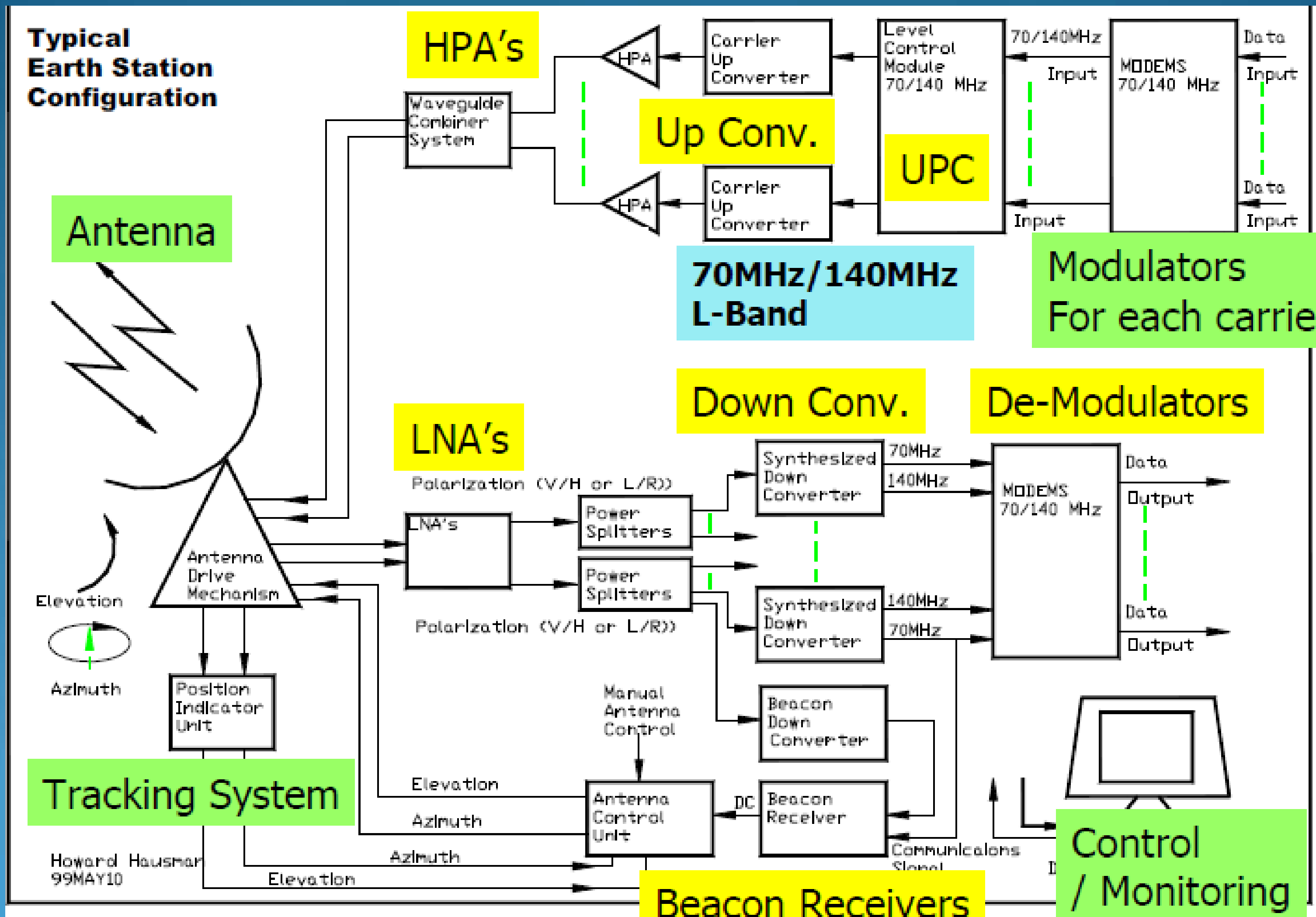
Configuration of space segment transponder components 13

Item	**TWTA**	**SSPA**
Operation range	3,4-4,2 GHz	3,7-4,2 GHz
Saturated outpout power	8,5 W	8,5 W
Saturation gain	58 dB	58 dB
IP 3ª order $(C/N)_{IM}$	11 dB	15 dB
Conversion AM / PM	4,5º / dB	2º / dB
Eficiency DC / RF (EPC)	32%	28%
Weight including EPC	2,2 Kg	0,9 Kg
Outages 10^9 hours	➢2000	< 500

Configuration of satellite communications ground segment



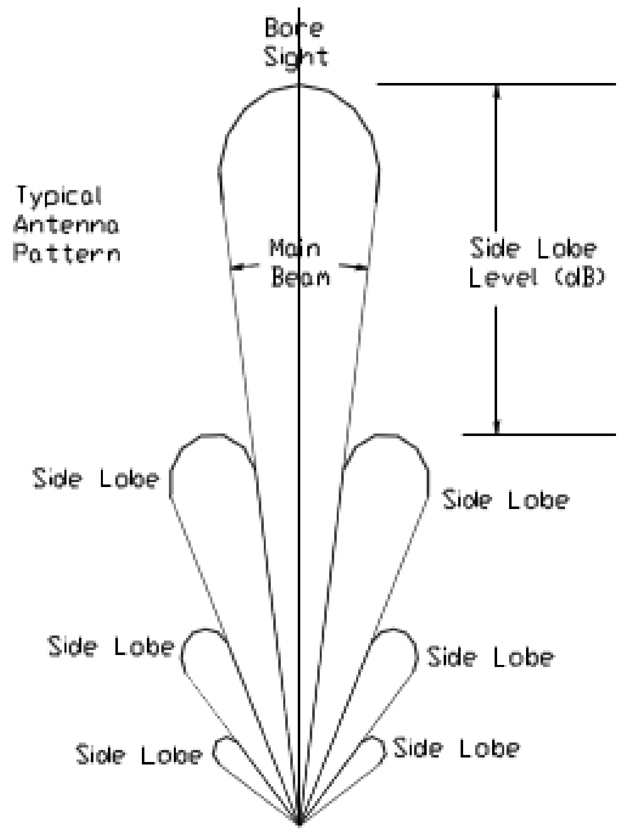
Configuration of satellite communications ground segment



Configuration of satellite communications ground segment

- Antenna system
- Transmission system
- Reception system
- Beacon receiver
- Tracking system
- Ancillary systems, namely
  - Battery
  - UPS
  - Power generator
  - Air conditioning

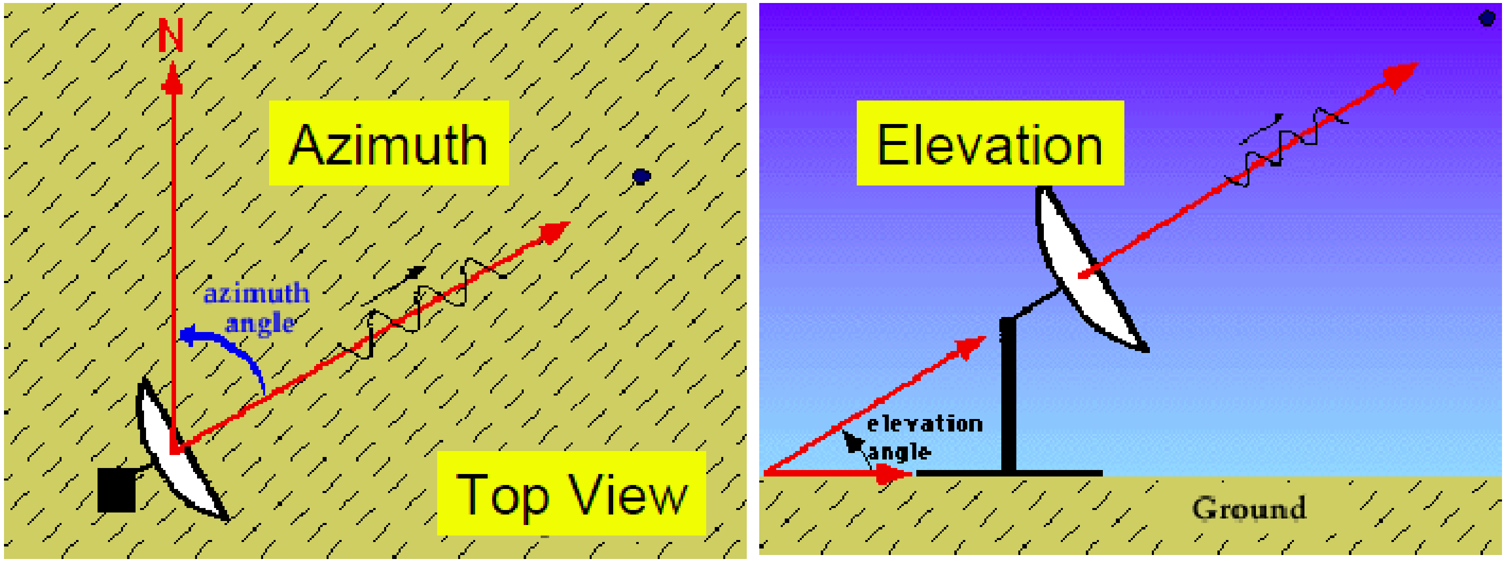
Configuration of satellite communications ground segment (antenna1)



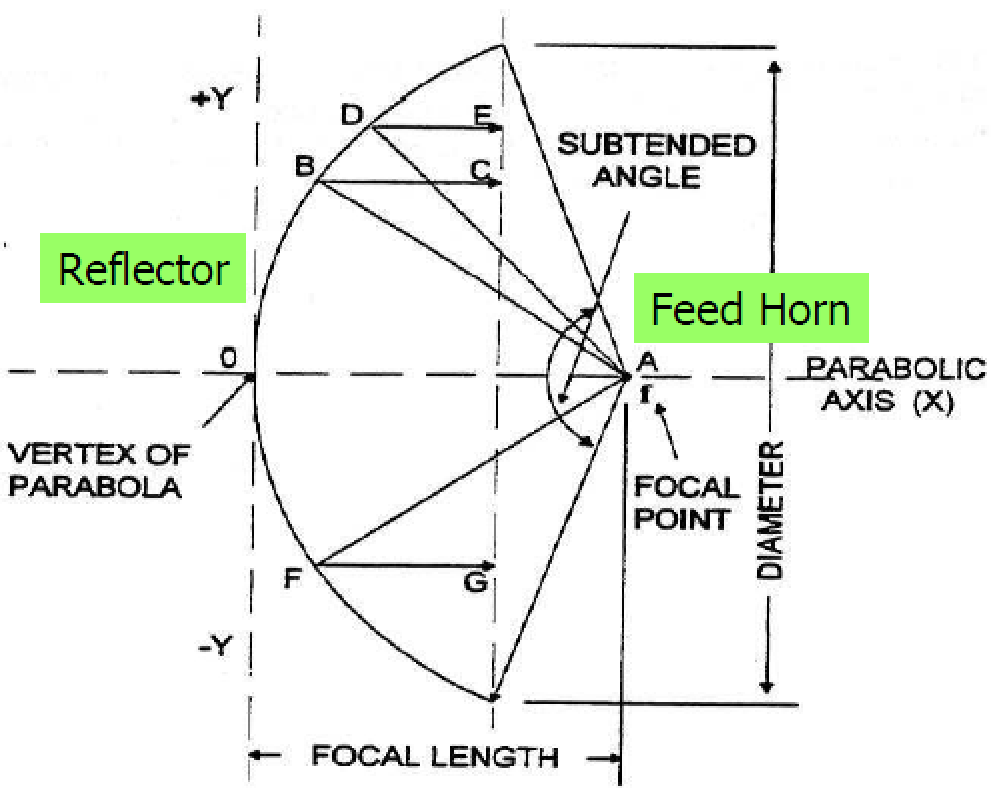
- **Fixed:**
  - **views one satellite**
  - **Inexpensive**
- **Elevation-Azimuth:**
  - **Vertical and horizontal movement**
  - **Narrow Beam Width**
  - **High Gain**

Configuration of satellite communications ground segment (antenna 2)

- Azimuth is the axis of angular rotation
- Elevation is the Angle with respect to the horizon



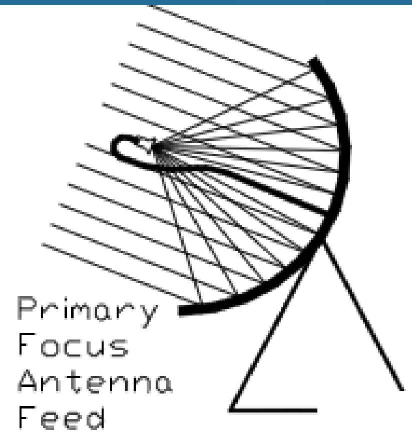
Configuration of satellite communications ground segment (antenna 3)

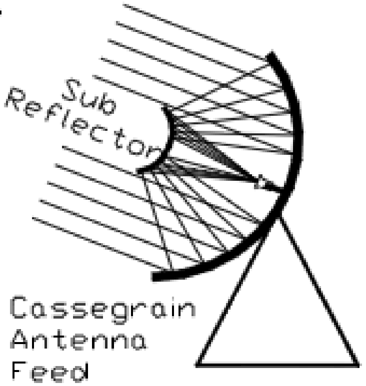


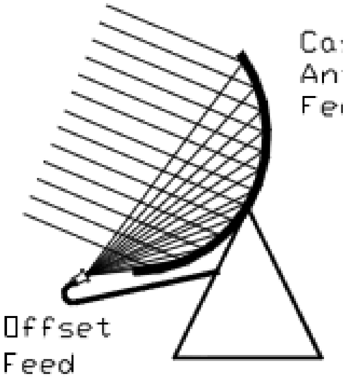
- Signals are fed from a point source
- Feed Horn is the antenna
- Dish is a Reflector
- Geometry is such that all signals are reflected in parallel

Configuration of satellite communications ground segment (antenna 4)

- Prime Focus Feed
  - Simplest Antenna Design
- Cassegrain Feed
  - Allows for Shorter Feedlines
- Offset Feed
  - Minimizes Feed Blockage -

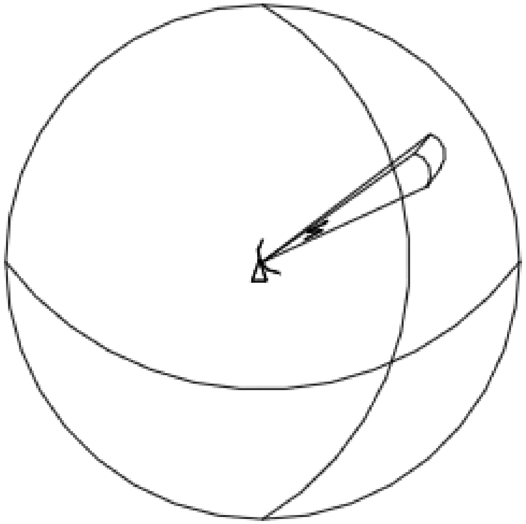






Configuration of satellite communications ground segment (antenna 5)

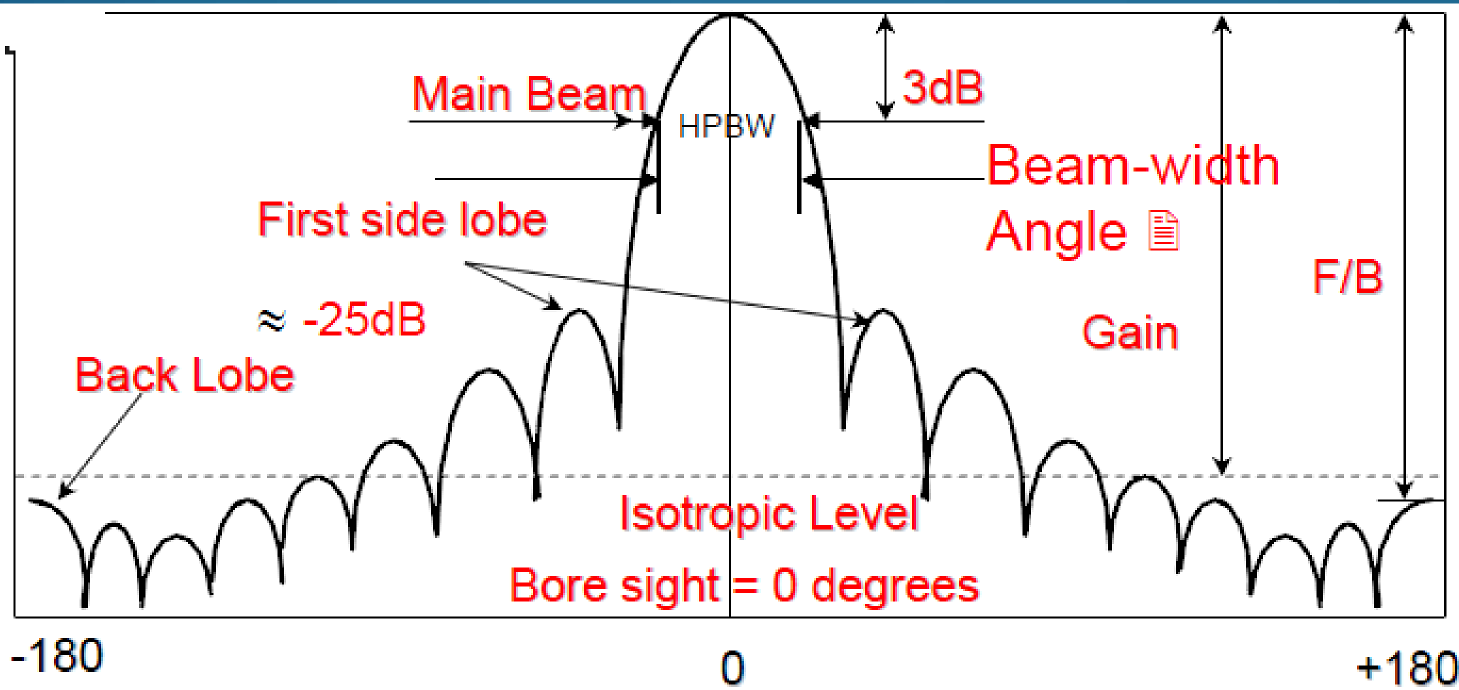
Antenna Beam Width



- Example: 3 Meter Antenna @ 4 GHz has a 1.75° Beam width (-3 dB)

- Beam width is the angle where the antenna power is within 3 dB of the peak
  - Beam Mid-Point: Boresight
- Beam width is a solid angle
- Beam width ≈ 21 / (F*D) in degrees (Parabolic dish)
  - F = Frequency in GHz
  - D = diameter of the dish in Meters
- For a parabolic dish D is the same in all directions

Configuration of satellite communications ground segment (antenna 6)

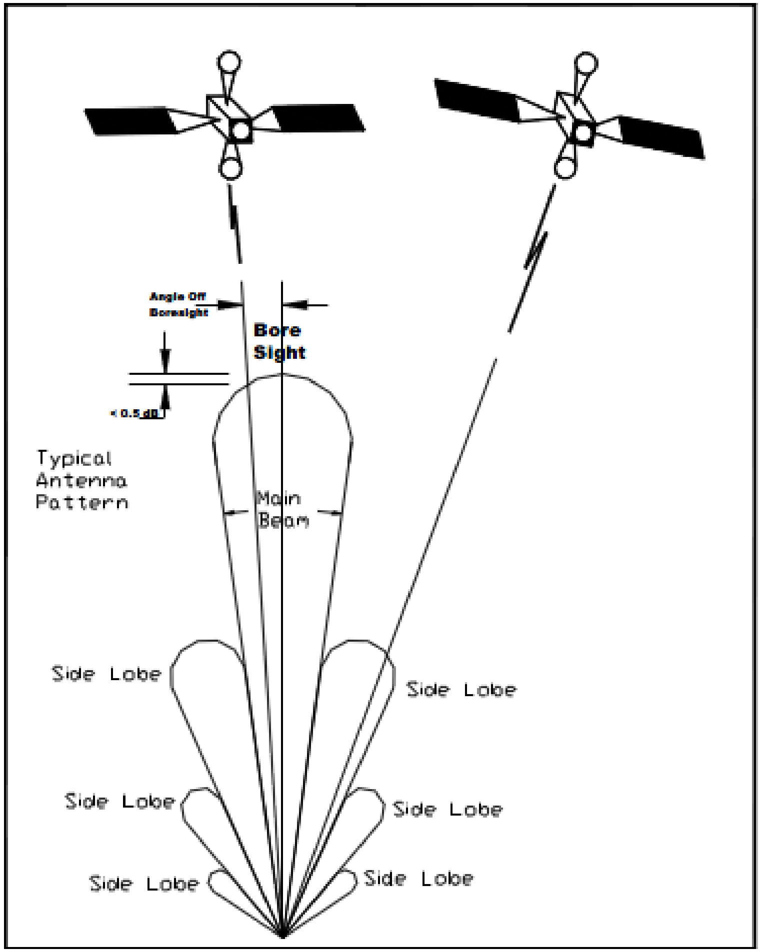


- All angles are referenced to Bore-sight
- 🗎 is the ½ Power (3dB) Beam Width
- Side Lobes: **The antenna patterns are repeated at lower gains on either side of the main beam**

Configuration of satellite communications ground segment (antenna 7)

Side Lobe Radiation Problem

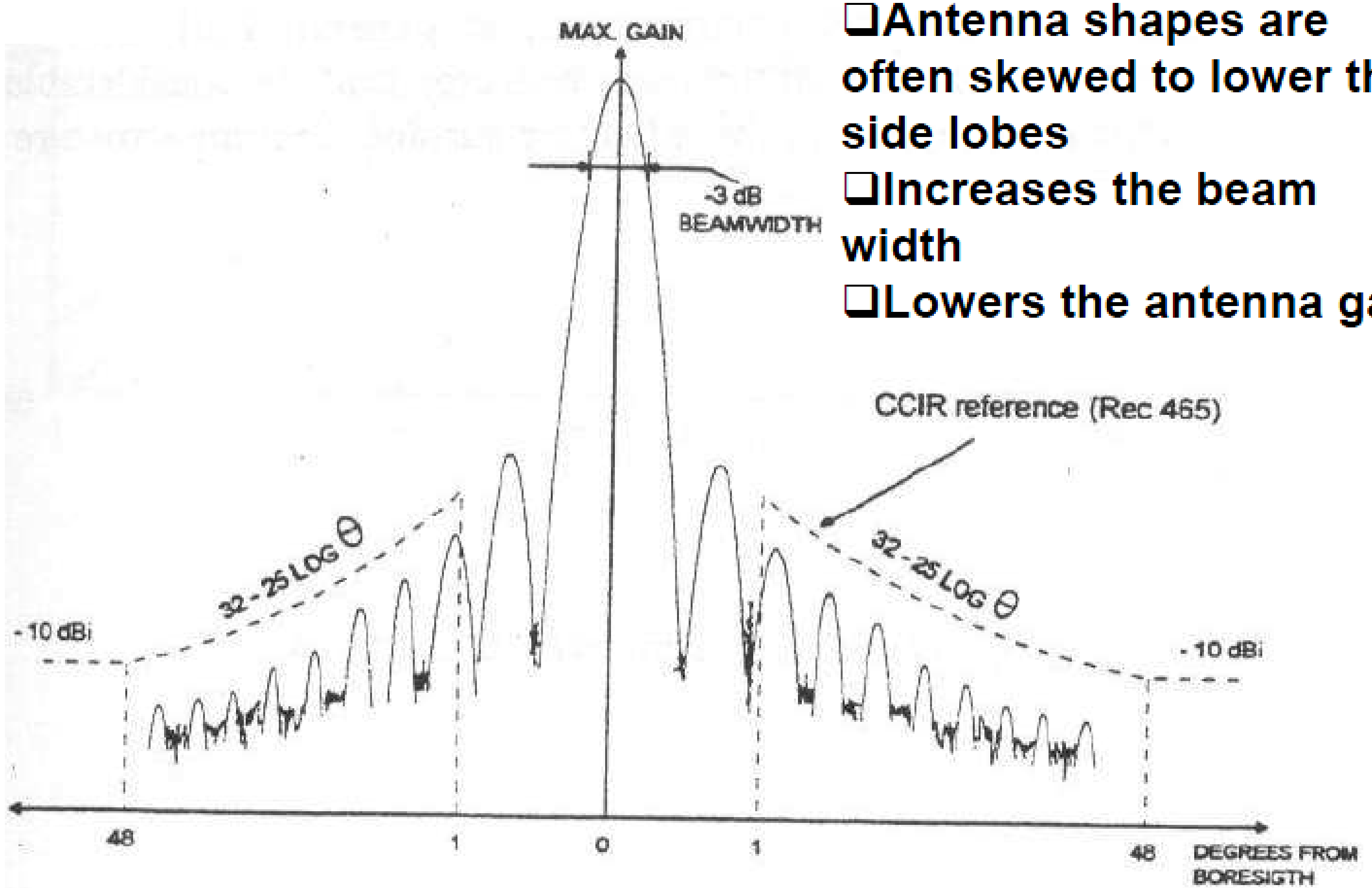
- **Side Lobe Energy Limits:** Limit interference to nearby satellites
- **IESS Spec: Side Lobe Max:** $\leq 29 - 25^{*} \log_{10}(A)$ in dB
  A = the angle off boresight.



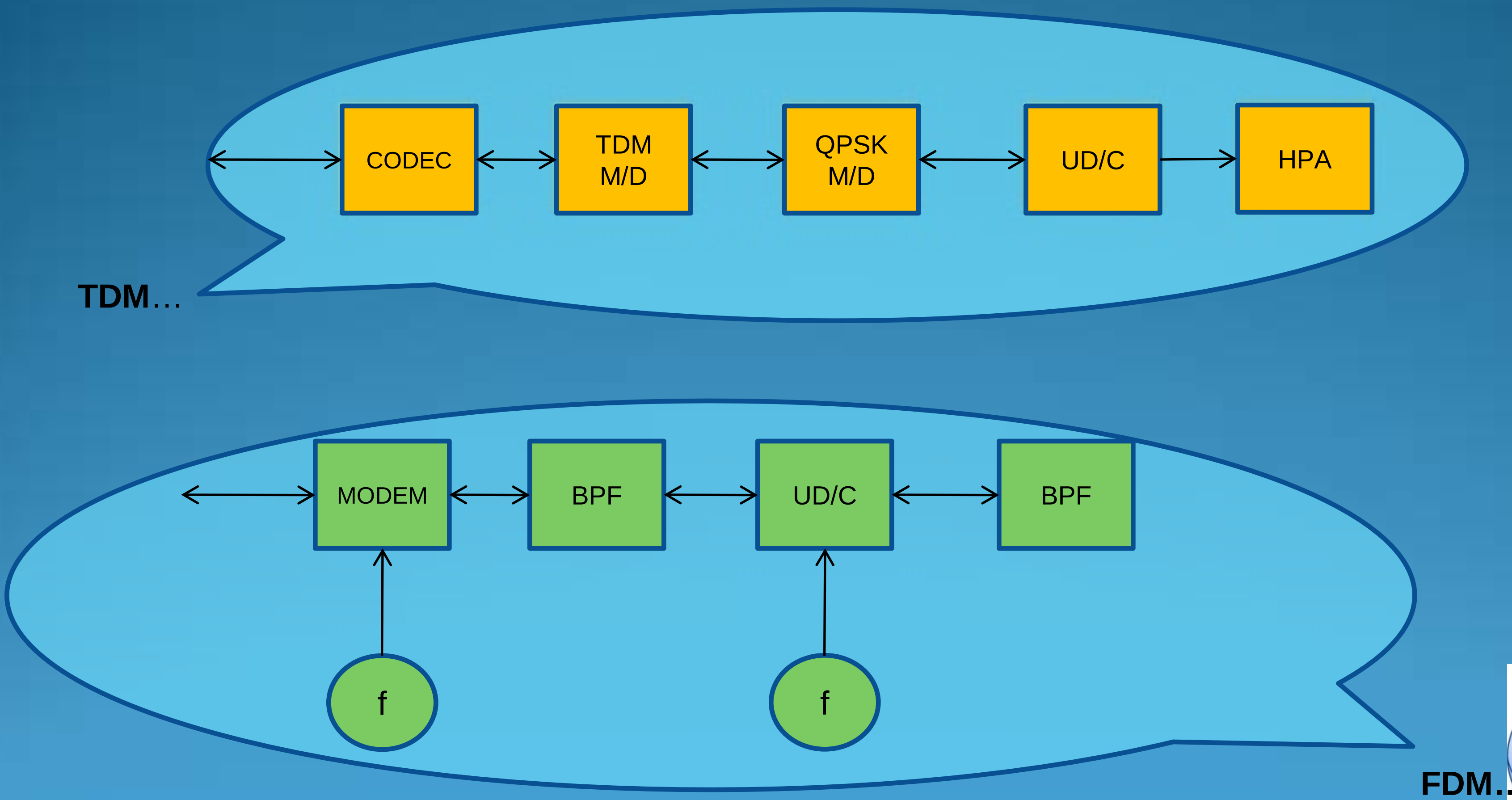
Configuration of satellite communications ground segment (antenna 8)

Antenna Side Lobes Limits

- Antenna shapes are often skewed to lower the side lobes
- Increases the beam width
- Lowers the antenna gain



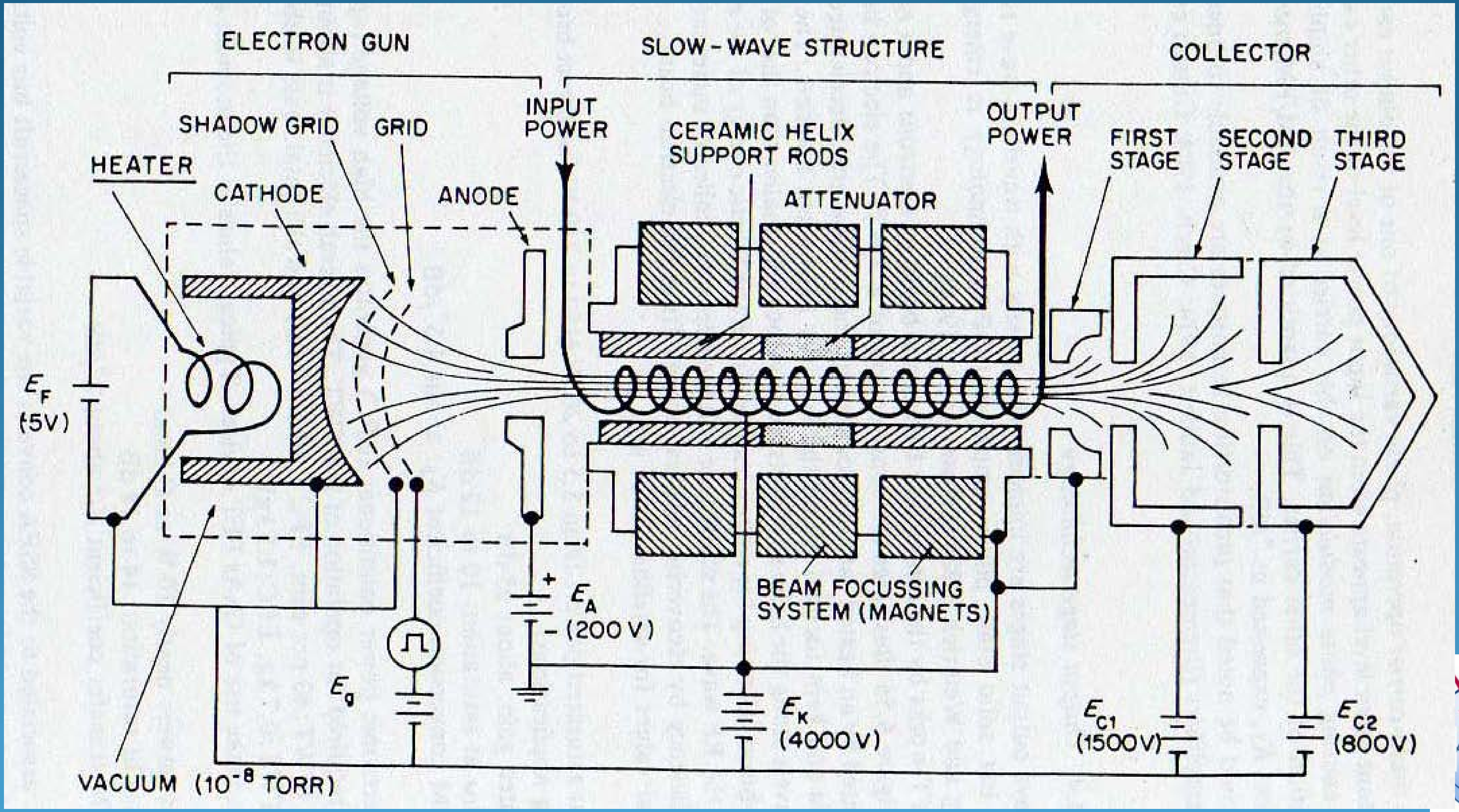
Configuration of satellite communications ground segment (transmission system)



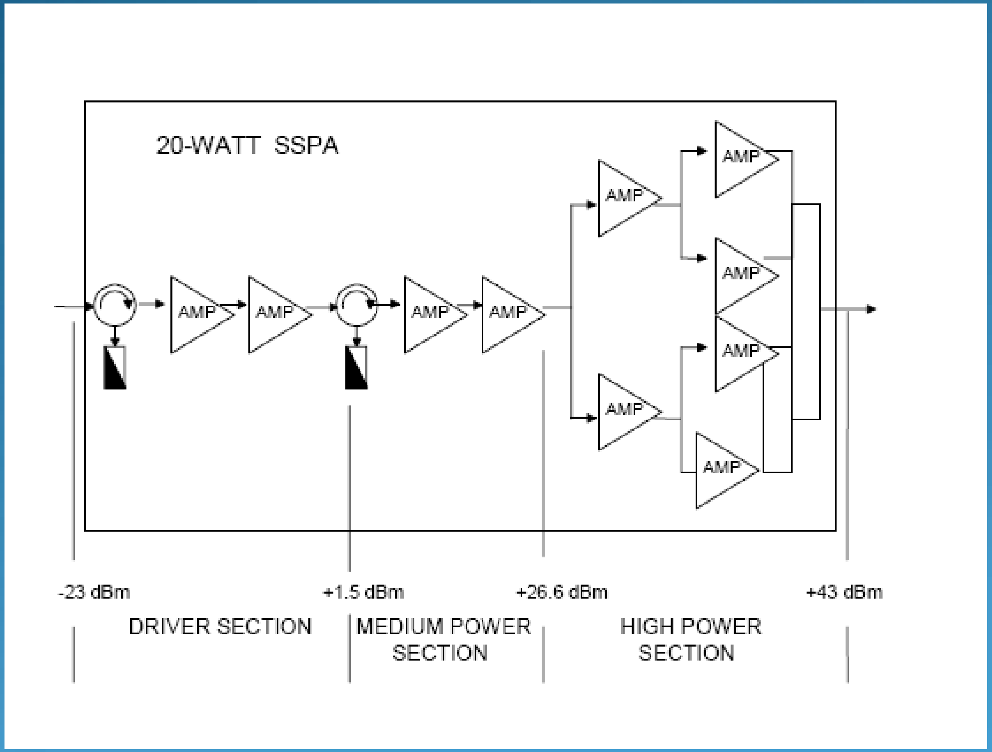
Configuration of satellite communications ground segment (transmission system)

- Large earth stations frequently use large numbers of high power amplifiers (HPA) with output power levels up to 8,5KW. The configuration employed depends on the number of carriers to be transmitted and whether these are, FDM or TDM signals. The most common configuration employ one HPA for each transponder to be used. At 6GHz HPA having bandwith of 40 or 80MHz are used in large earth stations, using either air cooled TWT (Travel wavetube) amplifiers or water cooled Klystrons. TWTA have wider operating bandwiths than Klystrons and can cover the full 500 MHz bandwith at 6 GHz allowing the TWT to be tuned to any transponder band
- Small and medium earth stations instead of using TWT, use SSPA - Solid State Power Amplifier that do not need very high voltages as those of TWT(10-50KV)
- When several HPA are used with one antenna a combining network is needed to sum their outputs into a single transmit waveguide.
- HPA act as interface between antenna (meaning RF free space propagation) and the transceiver (IF) is nothing more than a step to treatment of baseband signals that aggregate through modems the communications channel.

Configuration of satellite communications ground segment (TWT)



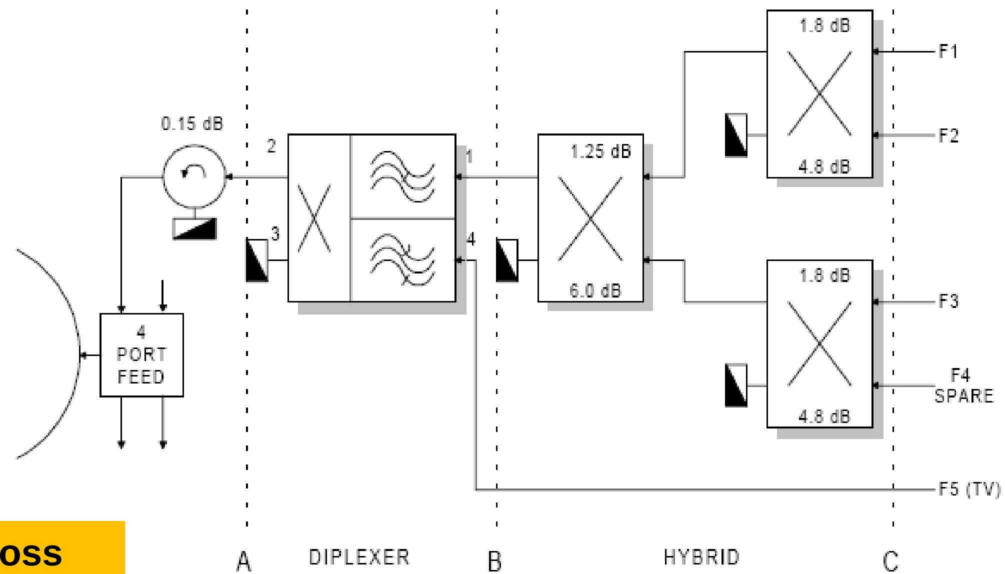
Configuration of satellite communications ground segment (SSPA)



SSPAs offer the following advantages over TWTAs.

- Superior intermodulation distortion performance
- Higher reliability
- Lower maintenance costs
- Lower cost for spares
- Longer operating life compared to TWTA (one SSPA outlasts several tubes)
- Higher personnel safety - no dangerous high voltages
- Lower power consumption
- Lower total cost of ownership

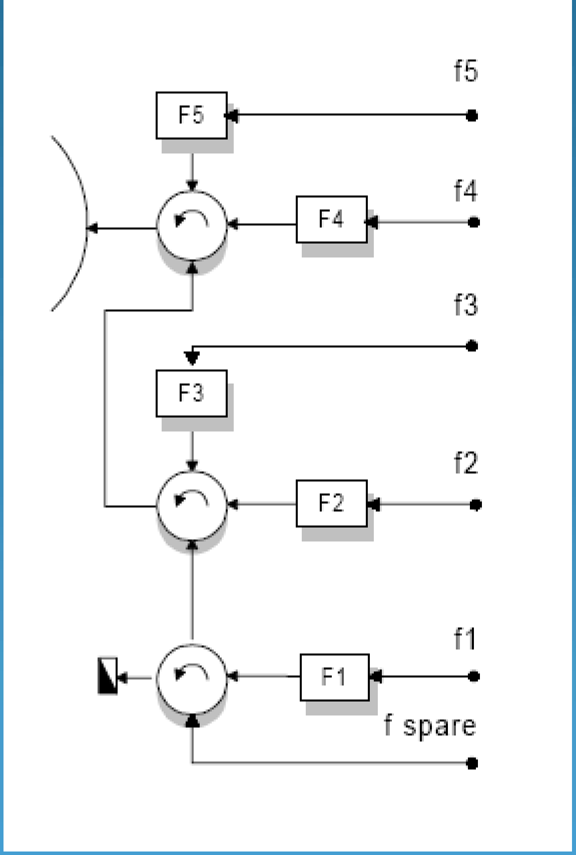
Configuration of satellite communications ground segment (tx hybrid+combiner)



Input	Hib loss (dB)	Dip loss (dB)	Total loss (dB)
F1	3	0,8	3,8
F2	6	0,8	6,8
F3	7,8	0,8	8,6
F4	10,8	0,8	11,6
F5	…..	1,8	

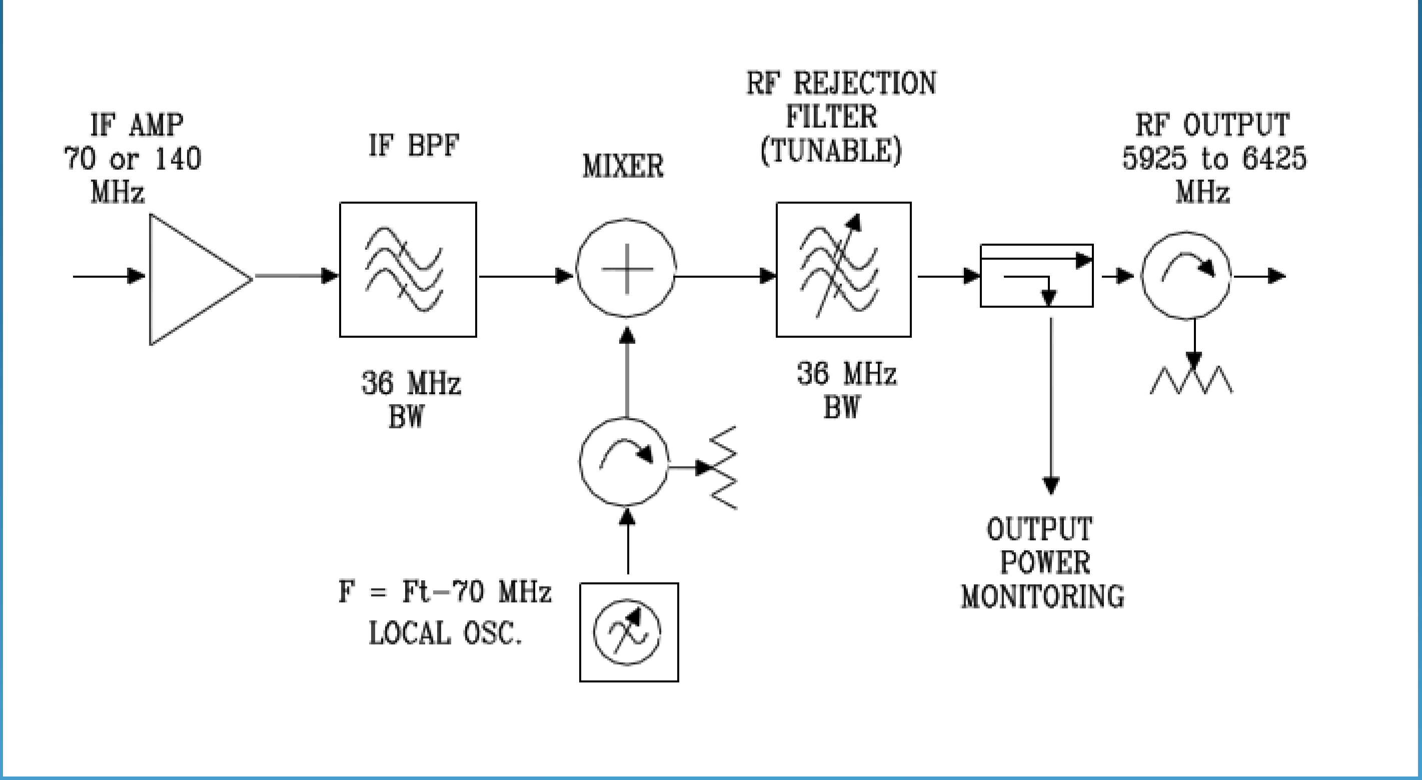
Low loss on combiner, being diplexer specific frequency tunning

Configuration of satellite communications ground segment (tx circulator)

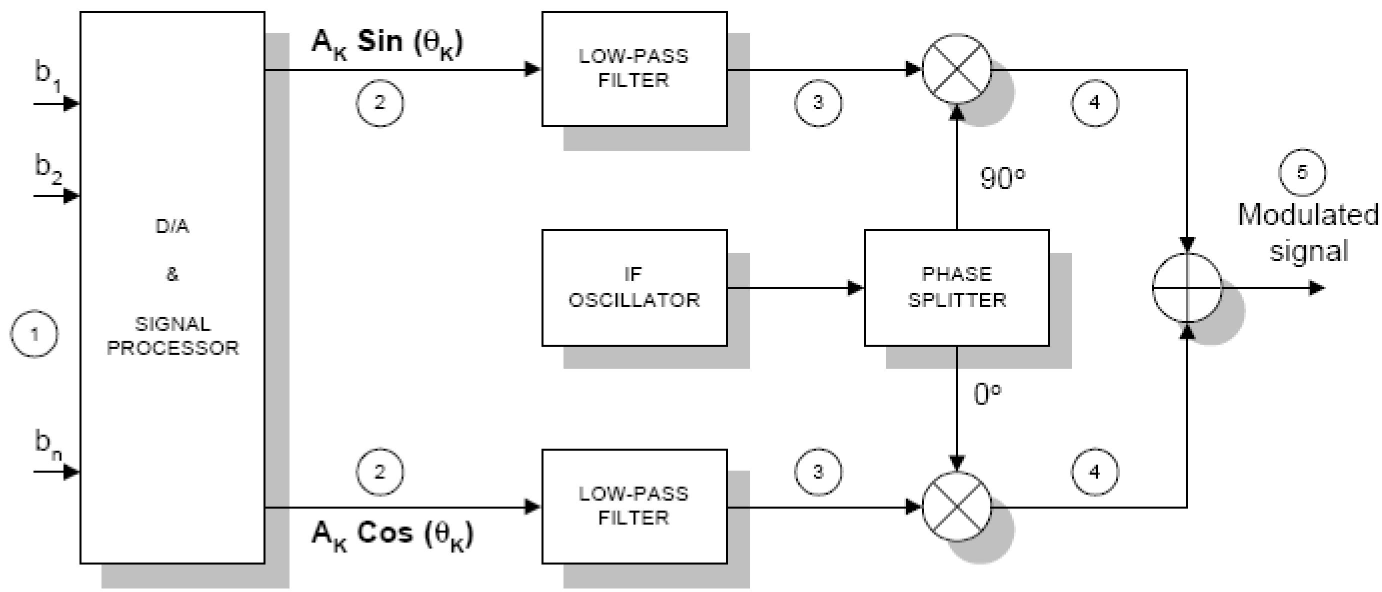


Low loss combiner
Narrow bandwith

Configuration of satellite communications ground segment (single conversion upconverter)

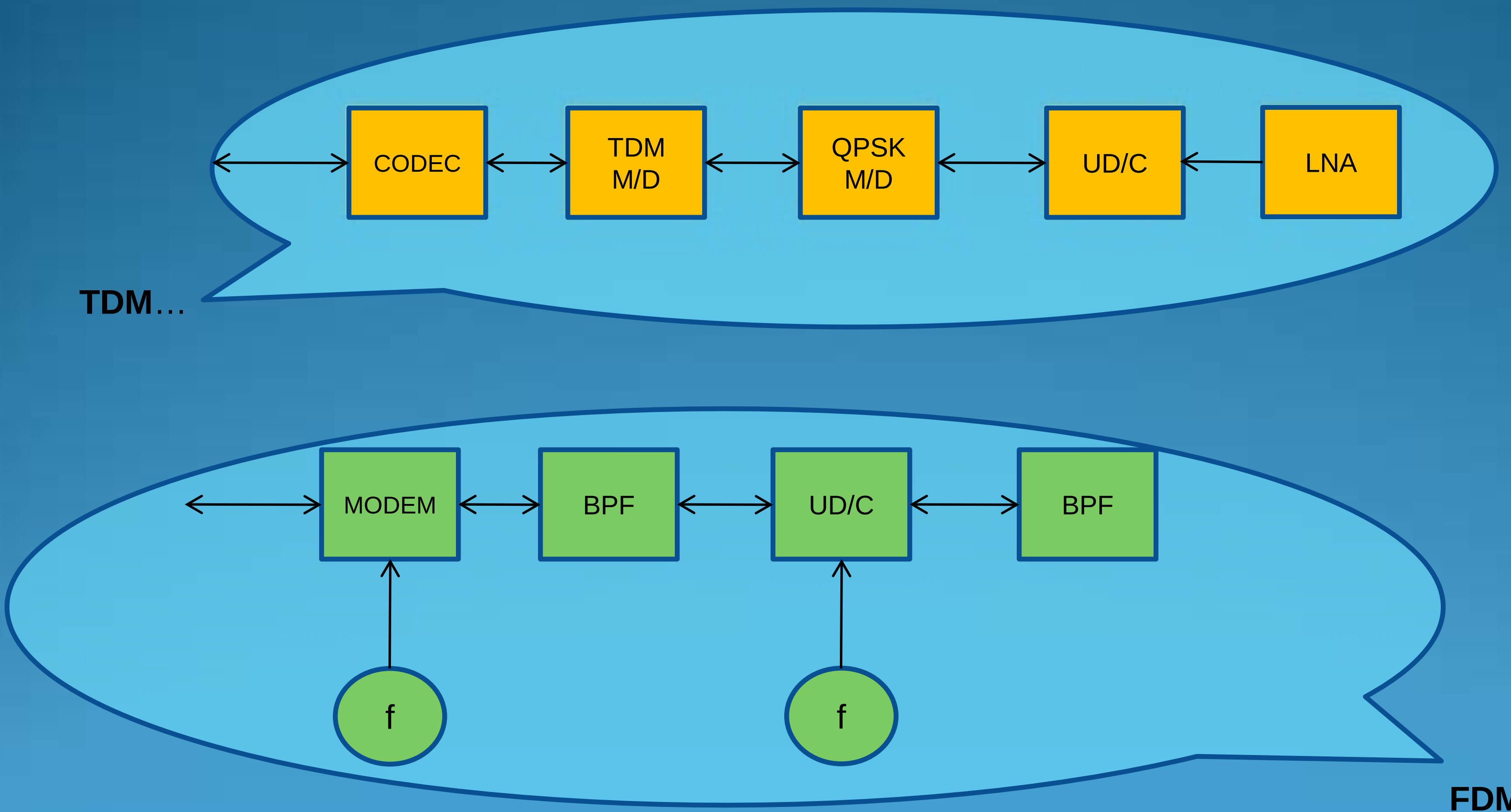


Configuration of satellite communications ground segment (PSK modulator)



Block Diagram of a PSK Modulator

Configuration of satellite communications ground segment (reception system)

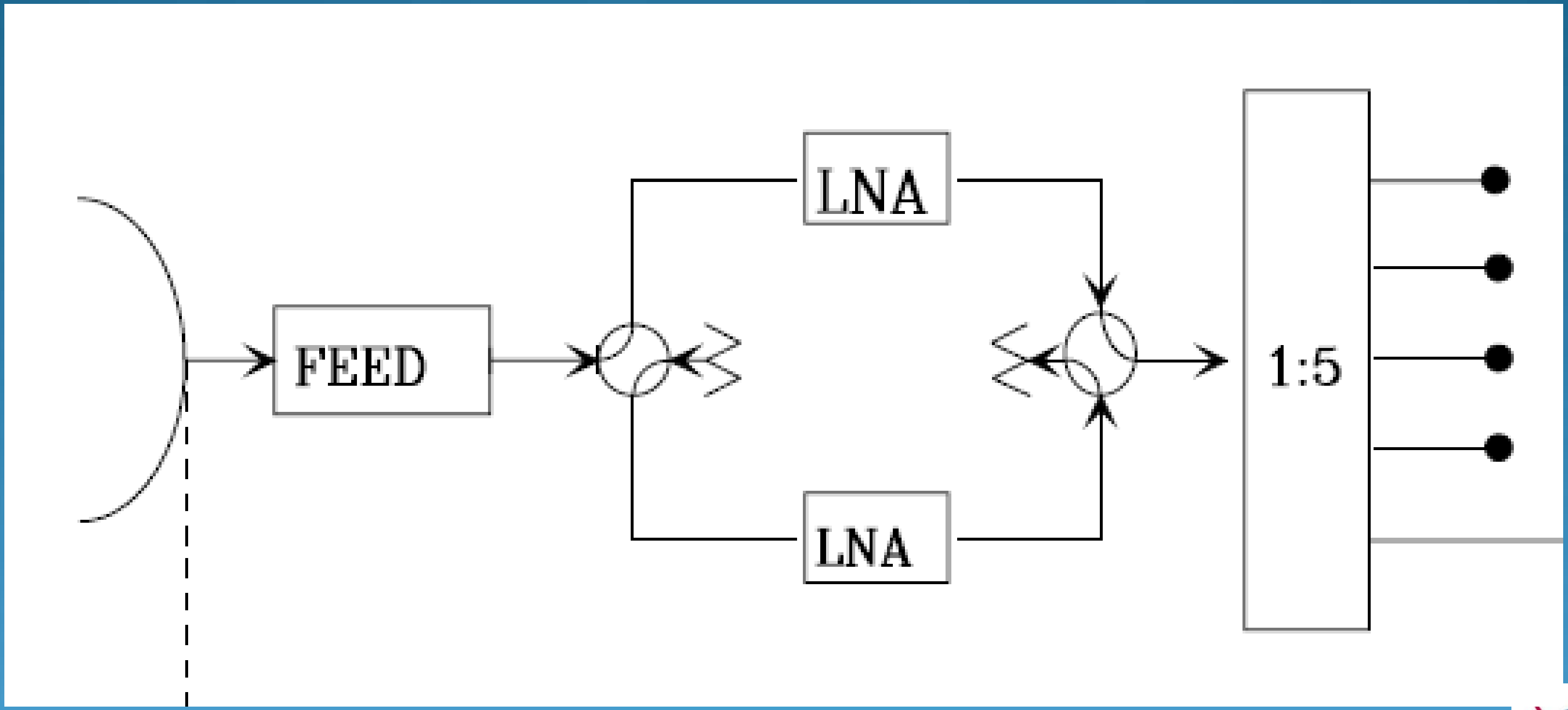


Configuration of satellite communications ground segment (reception system)

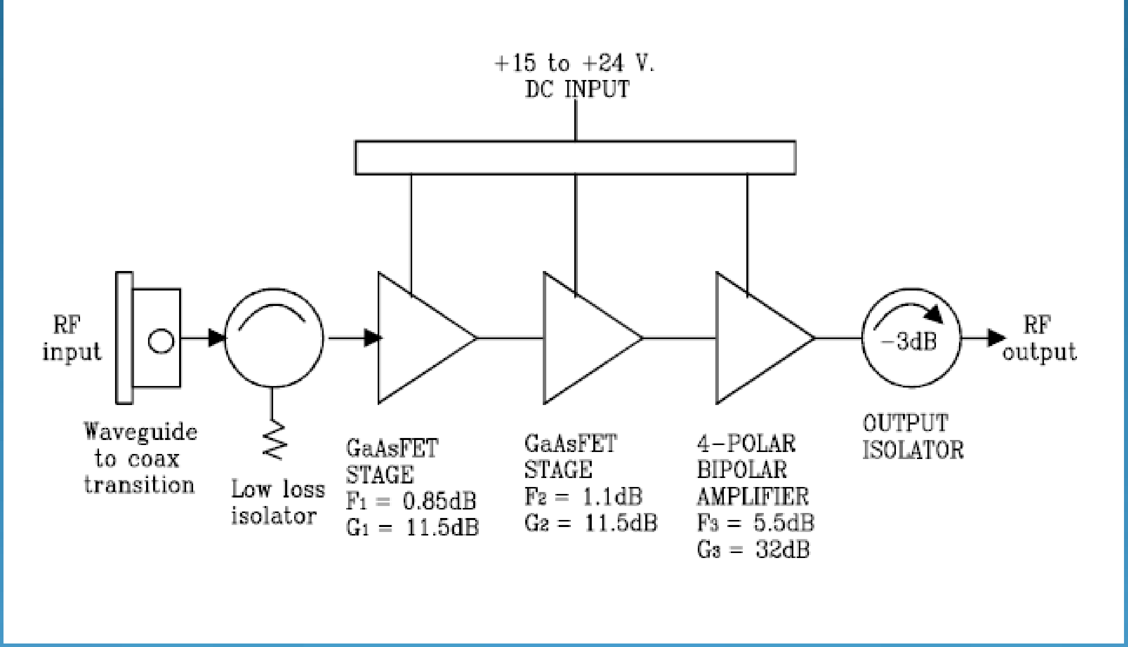
Large earth stations need very low noise amplifiers. Cryogenically cooled parametric amplifiers are used with liquid helium cooling at 4ºK to achieve noise temperatures of 20º to 40ºK at 4GHz. Medium and small earth stations use GaAsFET amplifiers uncooled or electrothermaly cooled.These achieve noise temperatures in the range 50 to 120ºK at 4GHz and 120 to 300ºK at 11GHz. FET amplifier is much simpler than the cooled parametric amplifier and is particularly attractive for unattended and TVRO stations especially where costs are important.

- LNA‟s used in earth stations usually cover the 500 MHz fixed service band at 4 GHz and 750 MHz at 11 GHz. In large stations a one – for – one redundancy arrangement such as indicated next slide is widely used. Failure of one LNA indicated by a loss in the pilot signal at receiver output results in immediate switchover to the second LNA. The spare (unused) LNA is often kept on test with a pilot signal or noise source input so that its state of readiness can be monitored continuously

Configuration of satellite communications ground segment (LNA's redundancy)

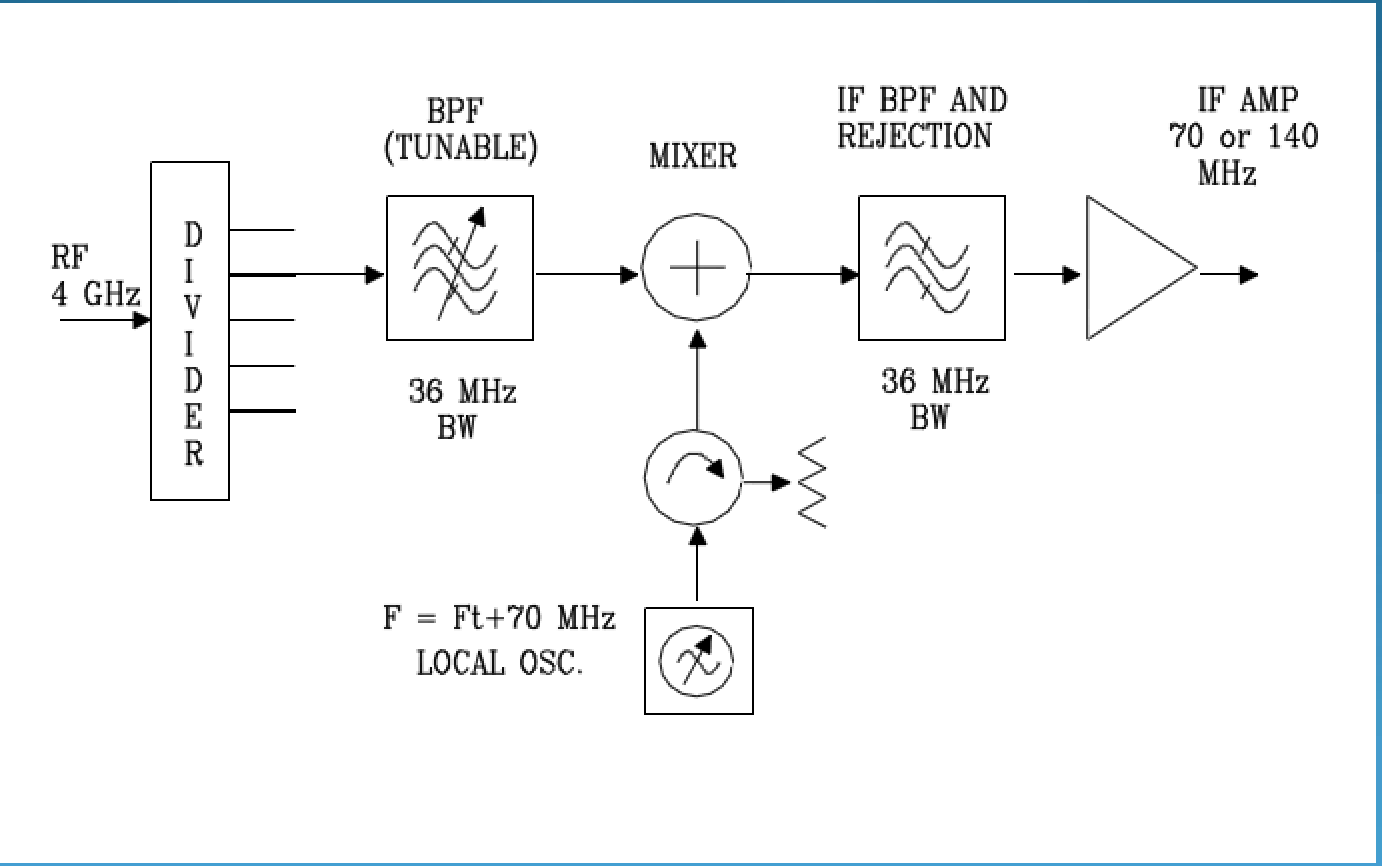


Configuration of satellite communications ground segment (LNA SSPA)

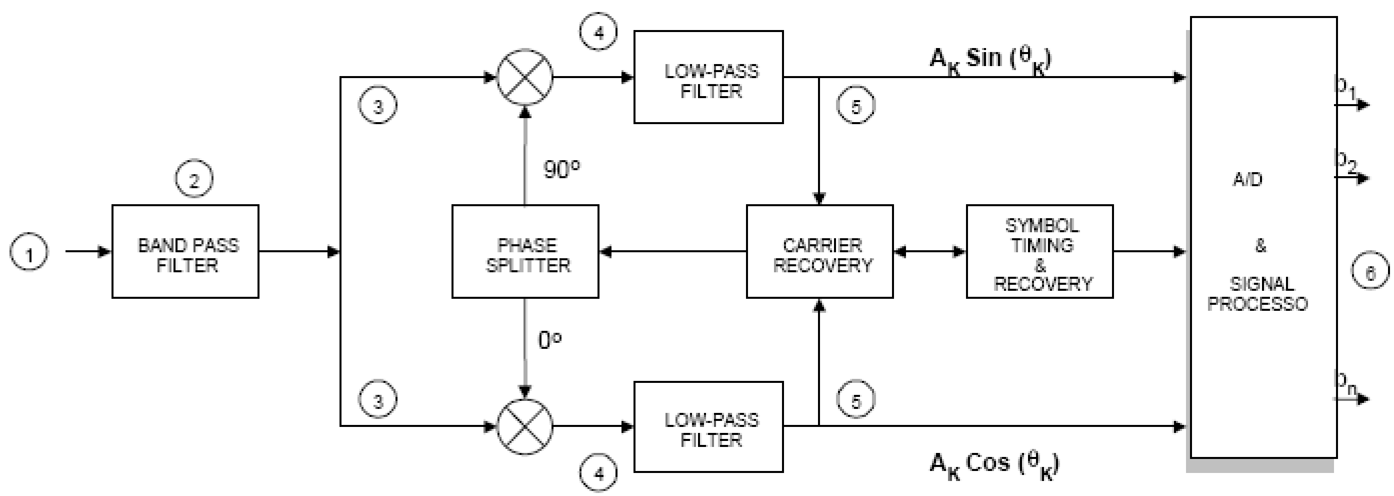


A SSPA LNA FET typically uses three amplification stages, the 1st being thermo-electrically cooled to - 40 ° C producing a TS 55 to 80 ° K for a total gain of 60 dB.

Configuration of satellite communications ground segment (single conversion downconverter)



Configuration of satellite communications ground segment (PSK demodulator)



Block Diagram of a PSK Demodulator

Configuration of satellite communications ground segment (Beacon receiver 1)

The satellite beacon is a very weak signal of 1.5 x 10^{-15} W (1.5 fW) or - 118 dBm - usually unmodulated - whose purpose is to allow the “uplink power control” as well as telemetry operations and research.

The signal is then "shifted" in converter units and amplified in order to put the beacon centered at 70 MHz IF in the "beacon receiver" which selects one of the pilots (each satellite has more than 1) and provides a DC signal to unity antenna control…

Configuration of satellite communications ground segment (Beacon receiver 2)

- ..This unit is responsible for taking decisions to optimize the search signal from the antenna over the satellite, generating commands suitable in azimuth and elevation.
- Transducers "Synchros or variable potentiomenters" in each axis of the antenna, provide position feedback at every moment for a centralized display at the control room.

Configuration of satellite communications ground segment (tracking system)

Pointing an antenna at a geosatellite requires the knowledge of azimuth and elevation of antenna in terms of the geographic location of the station. Tracking consists of maintaining the axis of the antenna beam in the direction of the satellite despite the movement of the satellite or the station. Pointing depends on:

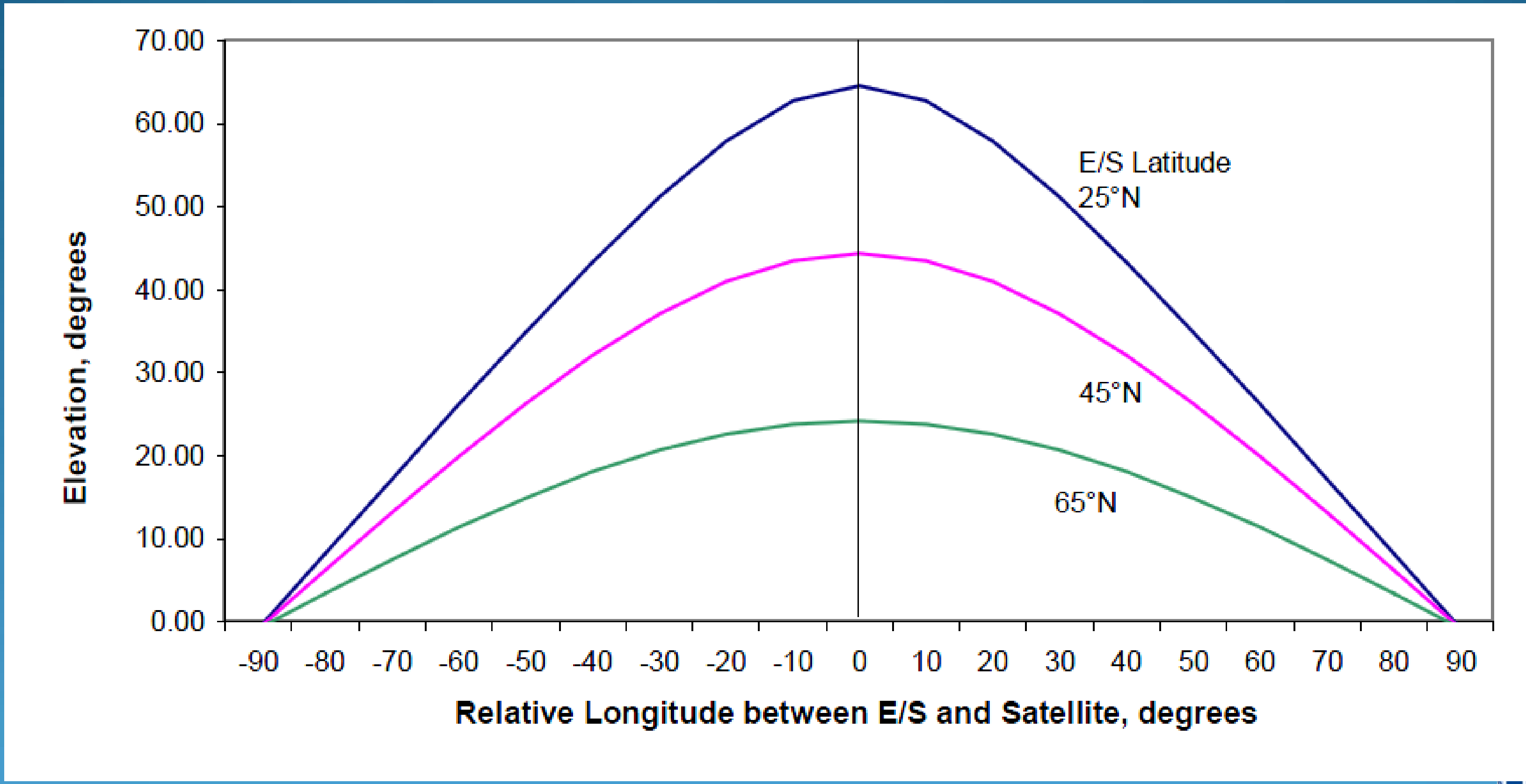
- Beamwith of the antenna beam
- Aparent motion of the satellite
- Type of the station,fixed or mobile

Just as an example the 3dB beamwith of a 25 m antenna operating at 4GHz is typically 10´ of arc, so the antenna must be pointed with an accuracy of +/-1´of arc if pointing loss is to be avoided. If a satellite moves at all – worst in inclined orbit satellite - a very accurate program track facility is required or auto track must be used.

Configuration of satellite communications ground segment (visible arc)

- Geostationary satellites visible from an Earth station location can be determined using elevation angle as a function of the Earth station latitude and longitude difference between the Earth station and satellite.
- The center of the chart corresponds to the situation when the E/S and the satellite have the same longitude. For a given minimum elevation angle, the chart gives the relative longitudes of the visible satellites..
- Next picture shows the visible arc for three Earth stations located at 25° N, 45° N, and 65° N.

Configuration of satellite communications ground segment (visible arc)



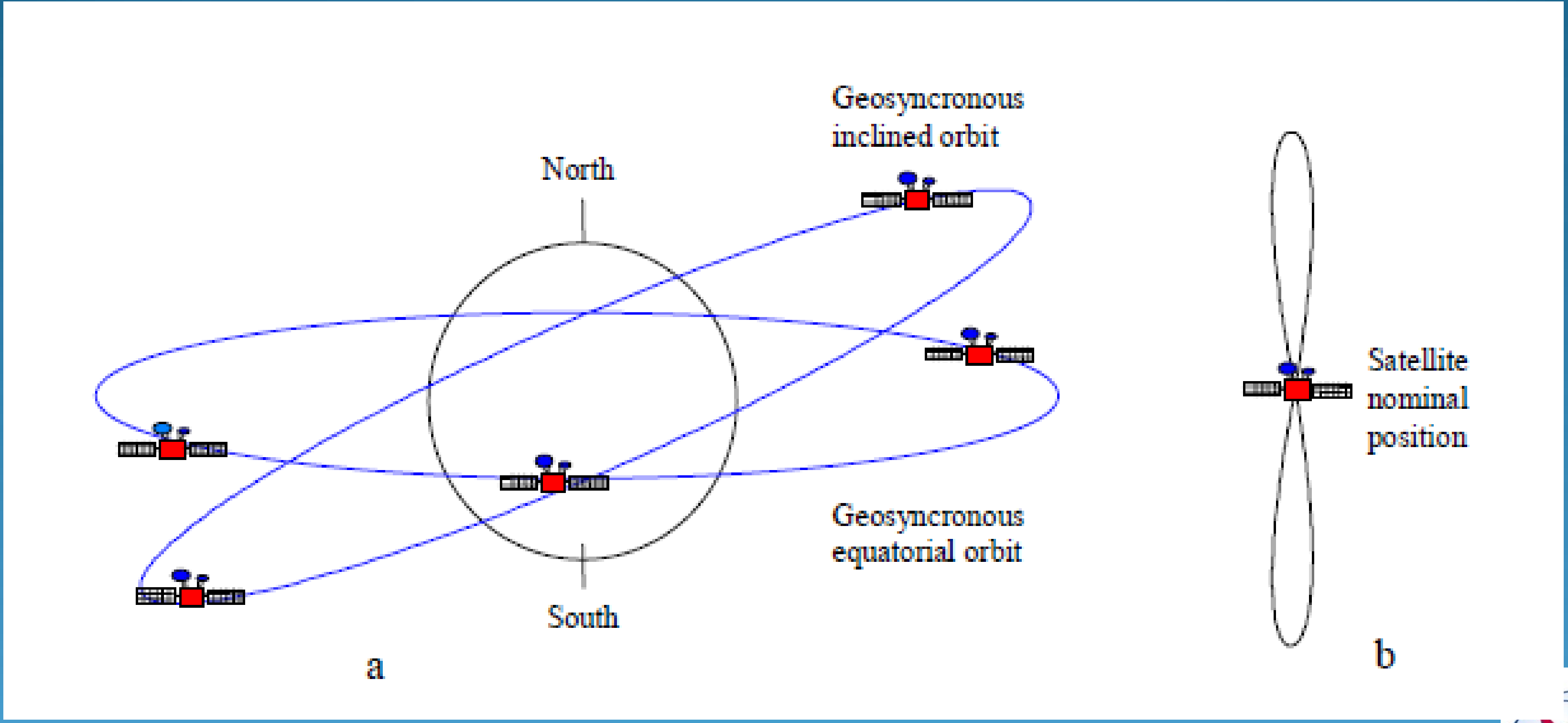
Configuration of satellite communications ground segment (tracking inclined orbit)

- The movement of the satellite orbits coincides with the plane of the equator and its period of rotation of the earth, however due to the movements of attraction of the moon and the sun and the strength of solar radiation influences, the stationary natyre cannot be maintained
- In fact satellite oscillates (drift) over the north - south and east - west, being the swing more heavily in the north - south, reaching a range of 0.86°per year. As a consequence it is necessary to correct the path, controlled by TTCM systems and subsequent fu consumption…

Configuration of satellite communications ground segment (tracking inclined orbit)

Without the correction indicated the satellite parks in circular orbit, inclined to the plane of the equator - e.g Intelsat Satellite Series V has a tolerance of about 0.1°(NS,EW), Series VI 0.06° and subsequent Satellite less tolerance yet - but ensuring that the satellites even in an inclined orbit may still provide service - and even being operational with 3º variations - has the advantage of consuming less fuel. As an example the fuel saved in a month of adjustments can ensure the continuation of the life of a satellite over one year, provided there are corrections EW.

Configuration of satellite communications ground segment (inclined orbit)

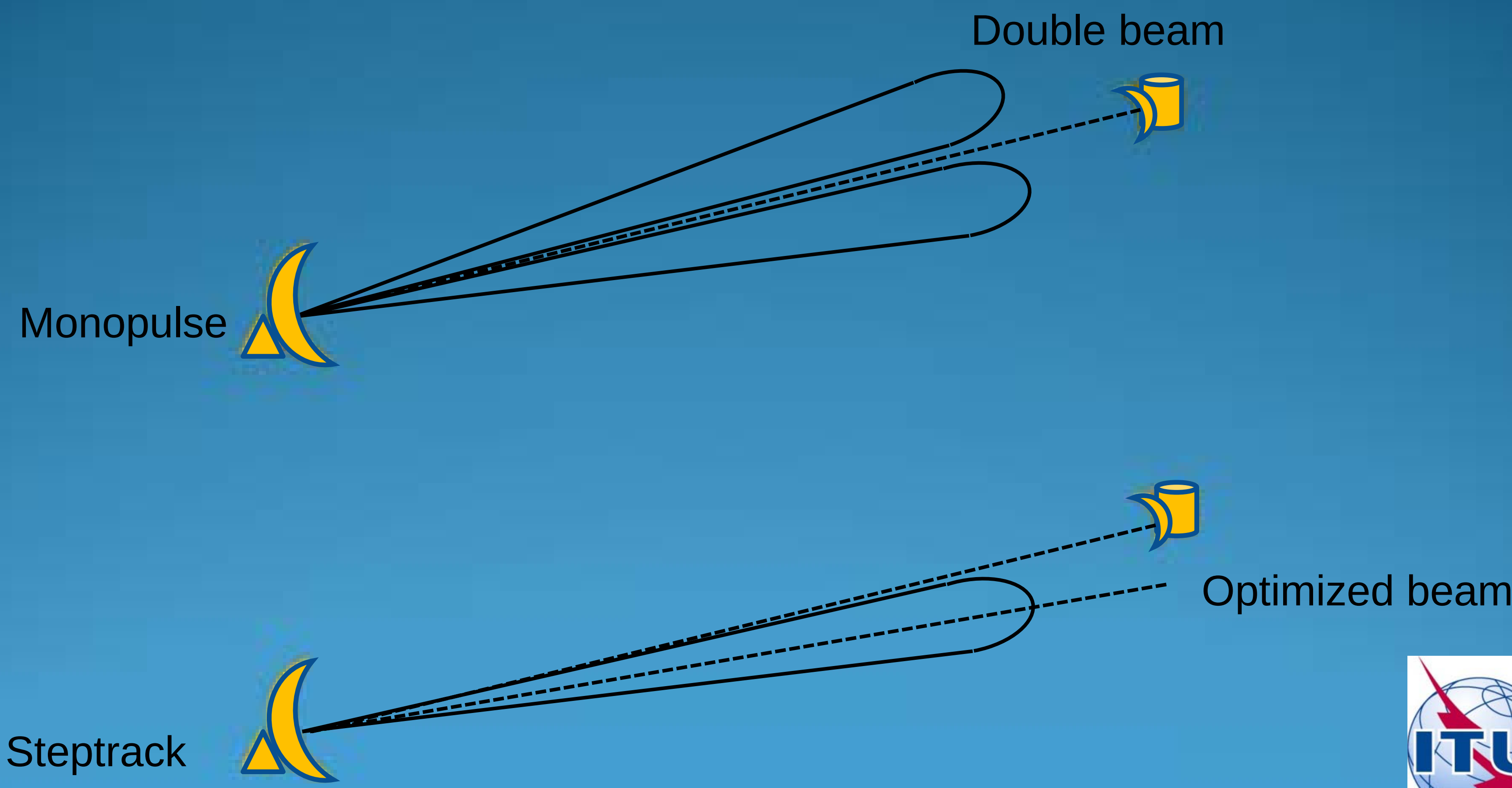


Configuration of satellite communications ground segment (tracking systems)

- There are 3 main tracking process:
  - Monopulse (expensive)
  - Step track (more common)
  - Tracking by program memory

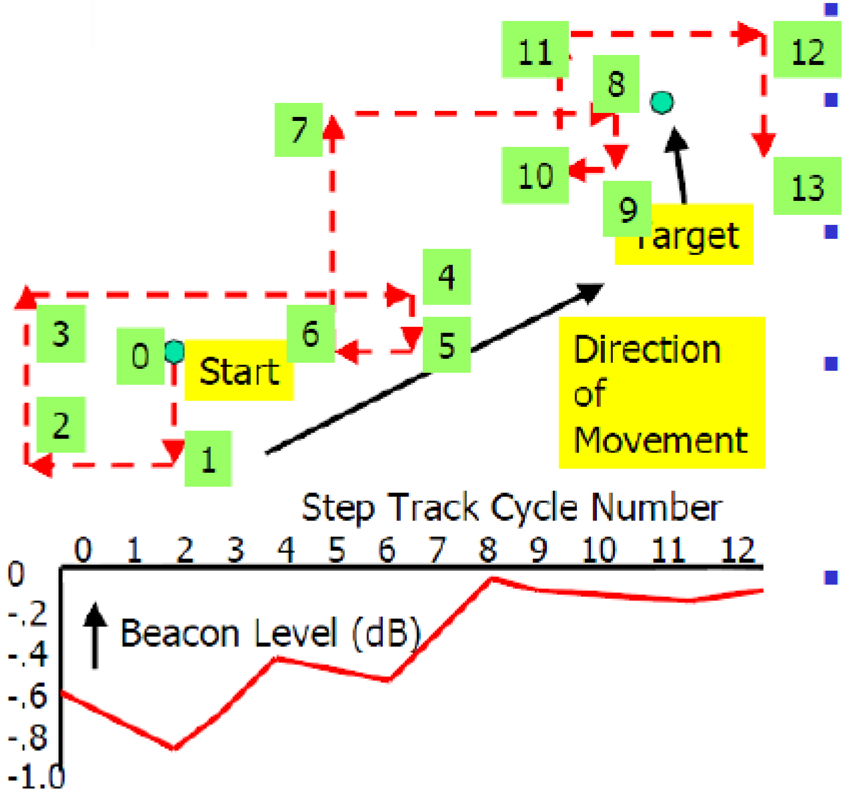
- Step tracking (or hill climbing) the antenna beam is moved about a pre determined fashion and the signal amplitude noted. Maximum signal indicates the best beam position. The beam must be moved continually to check that it is in the right position. In a hill climbing system the antenna is pointed away from the nominal position of the satellite (by a fraction of degree in several directions). From a knowledge of the main beam shape the true direction of satellite is estimated and and the antenna is then pointed in that direction

Configuration of satellite communications ground segment (tracking systems)



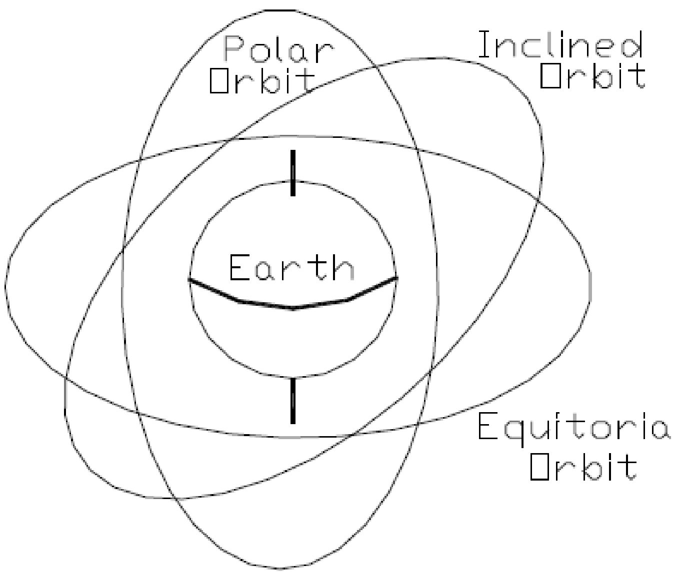
Configuration of satellite communications ground segment (antenna step tracking)

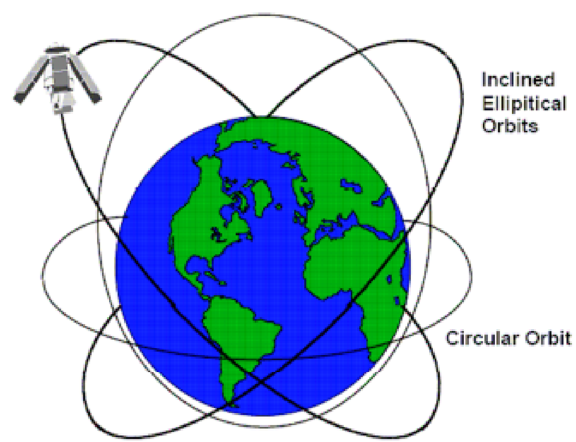
Antenna Step Tracking



- Used for Low Relative Motion
- Beacon Receiver Monitors Signal Strength
- Moves Antenna in Small Az/El Increments
- Compares Signal Strength with Previous Values to Determine Direction & Size of Next Step
- Once Signal Strength is "Peaked" Waits for Next Scheduled Step Track Cycle -

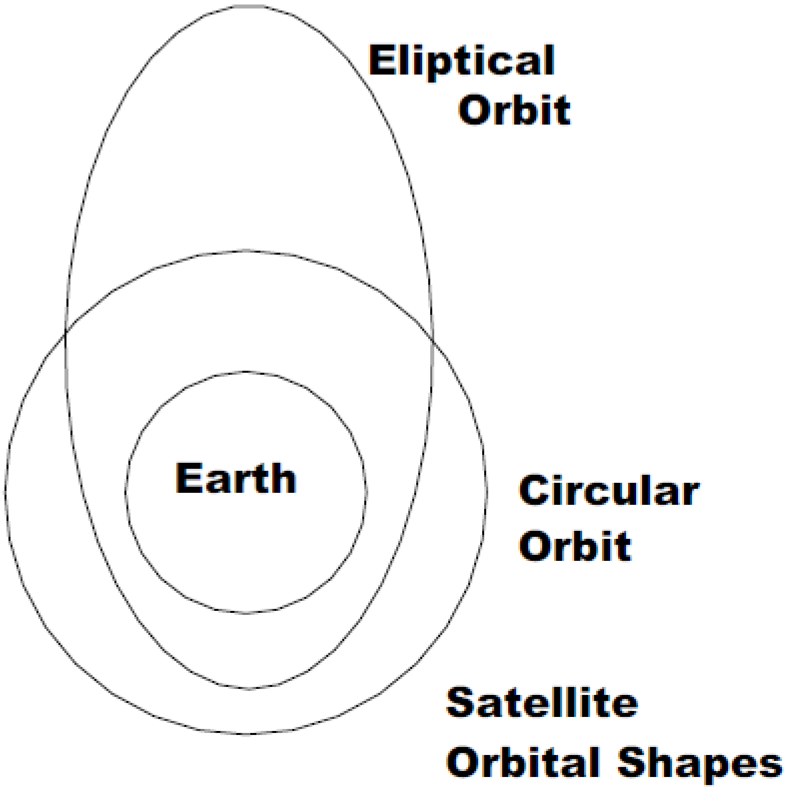
Types of orbits





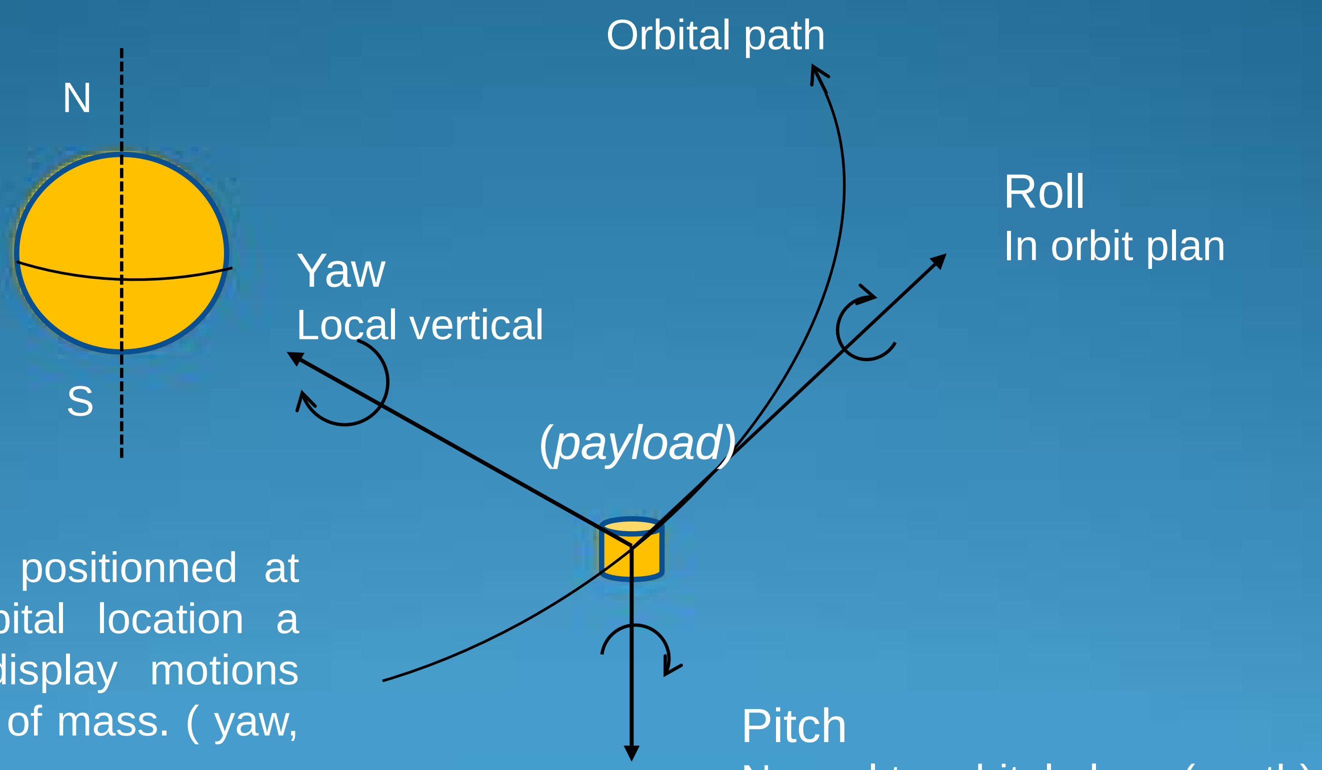
- Polar
- Equatorial
- Inclined

Orbit shapes



- Circular
- Elliptical

Types of orbits 1



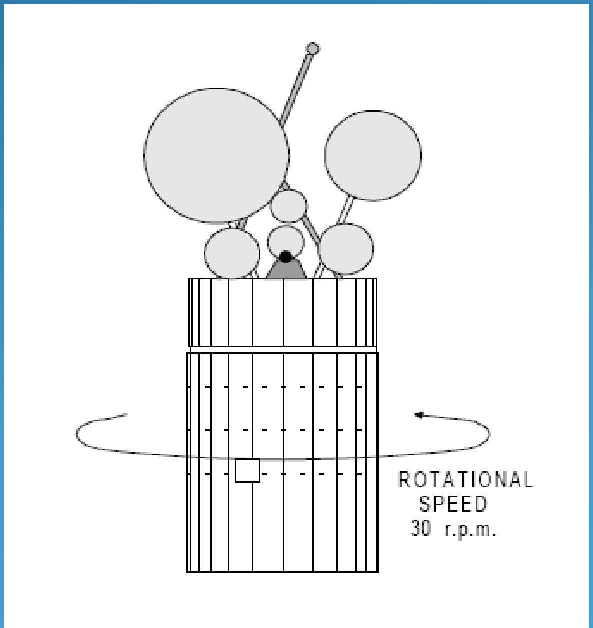
When correctly positionned at its nominal orbital location a satellite may display motions about its centre of mass. (yaw, pitch and roll).
The satellite attitude is determined by the angles that the satellite body make with this reference axis

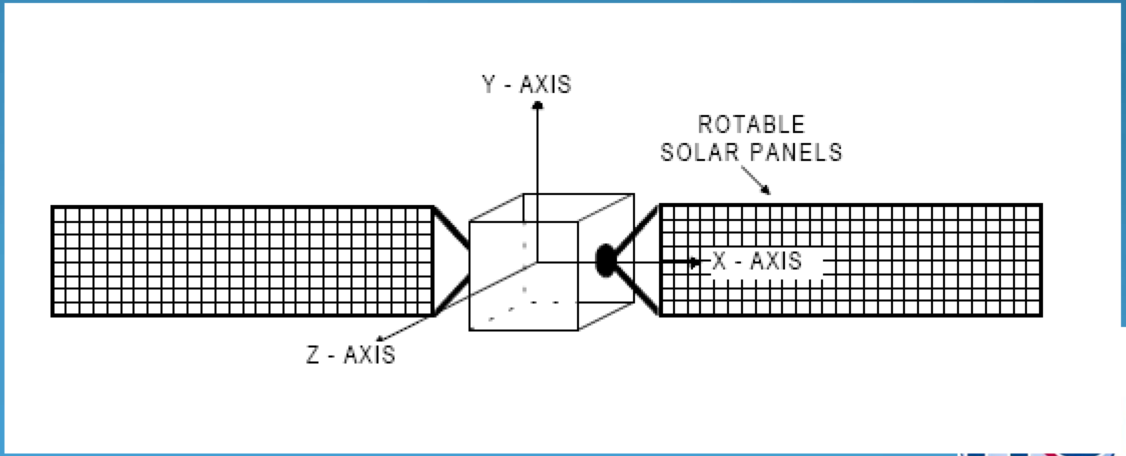
Types of orbits 2

- Sensors for attitude detection
  - Sun sensors
  - Horizon sensors
  - Stelar sensors
  - Inertial sensors
  - Radiofrequence sensors
  - Laser sensors
- Actuators for attitude control
  - Momentum devices
  - Thrusters
  - Magnetic coils
  - Solar sails

Types of orbits 3

- Attitude control techniques
  - Stabilization by gravitational gradient (LEO)
  - Spin stabilization (transfer orbit)[note]
  - Dual spin stabilization (spot beams satellite)
  - **Three axis satbilization**





Types of orbits 4

- Station Keeping
  - Determination of position
    - Angle measurement (achieved by varying the ground antenna pointing and searching maximum reception gain or using monopulse techniques)
    - Range measurement (through phase shift between transmitted and received signals)
- North - South station keeping (…as the luni-solar attraction reflects in a change of inclination, annual velocity increment must be applied)
- East - West station keeping (due to asphericity of the earth's gravity)

Types of orbits 5

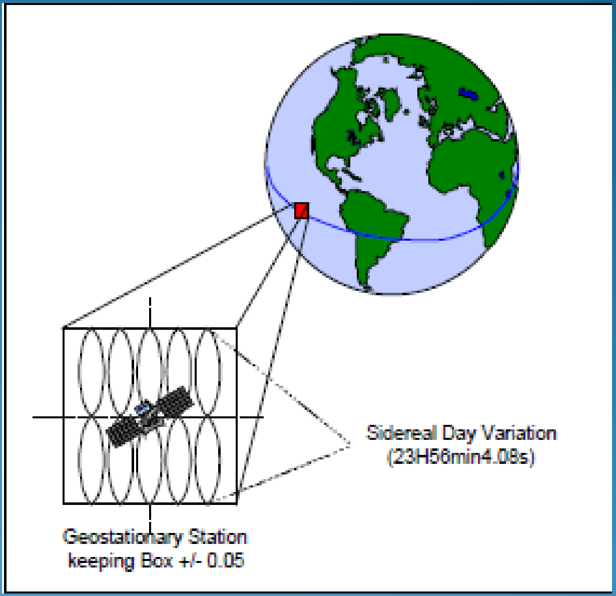
Satellite station keeping

Gravitational effects of the sun and the moon, the radiation pressure of the sun, the earth's magnetic field and other forces cause perturbations in the orbit of a satellite.

Satellite must contain fuel to correct for these perturbations and hence the life of a satellite is determined by how well the on-board fuel is managed by the satellite operator.

Hydrazine fuel is used and thrusters are mounted on the body of the satellite which are fired as required to maintain a specific tolerance.

Approximately 20 to 40% of the dry mass of a satellite is allocated for station keeping fuel. Typically, a +/- 0.05 degree station keeping box wrt North-South and West-East is maintained by satellite operator. Majority of fuel used for N-S station keeping corrections.

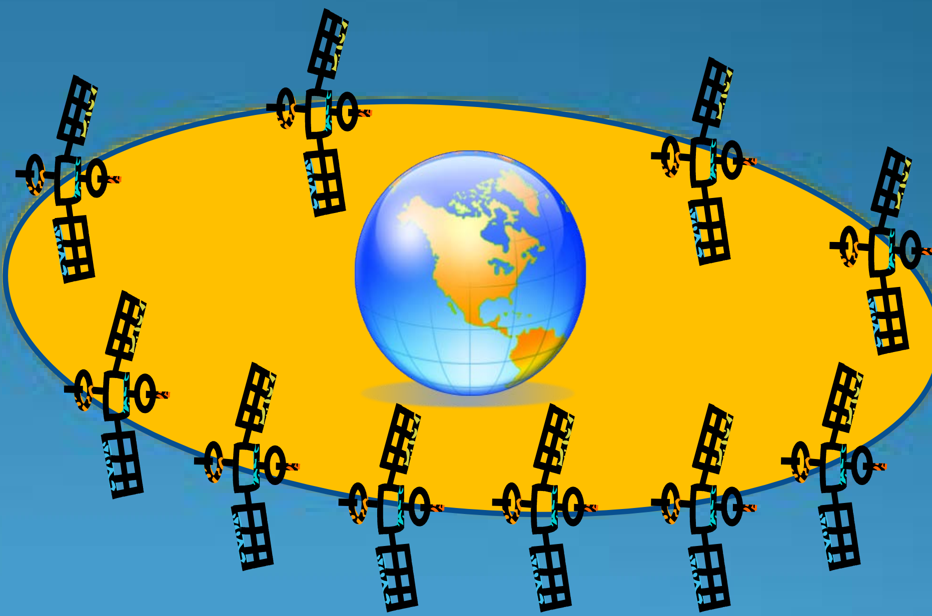


Basics of Satellite Com (orbital positions & radio interferences)

- The space is now given as an infinite resource. However the "arc" of the area in which satellites operate - called the “Clark orbit” - is itself a finite resource, with a number of orbital positions geostationary limited, making it as each increasingly essential to have a regulatory framework for the management segments of the orbital.
- Some precautions shall be taken, such as:
  - Do not interfere with or from 3rd service
  - Safeguard increases in capacity

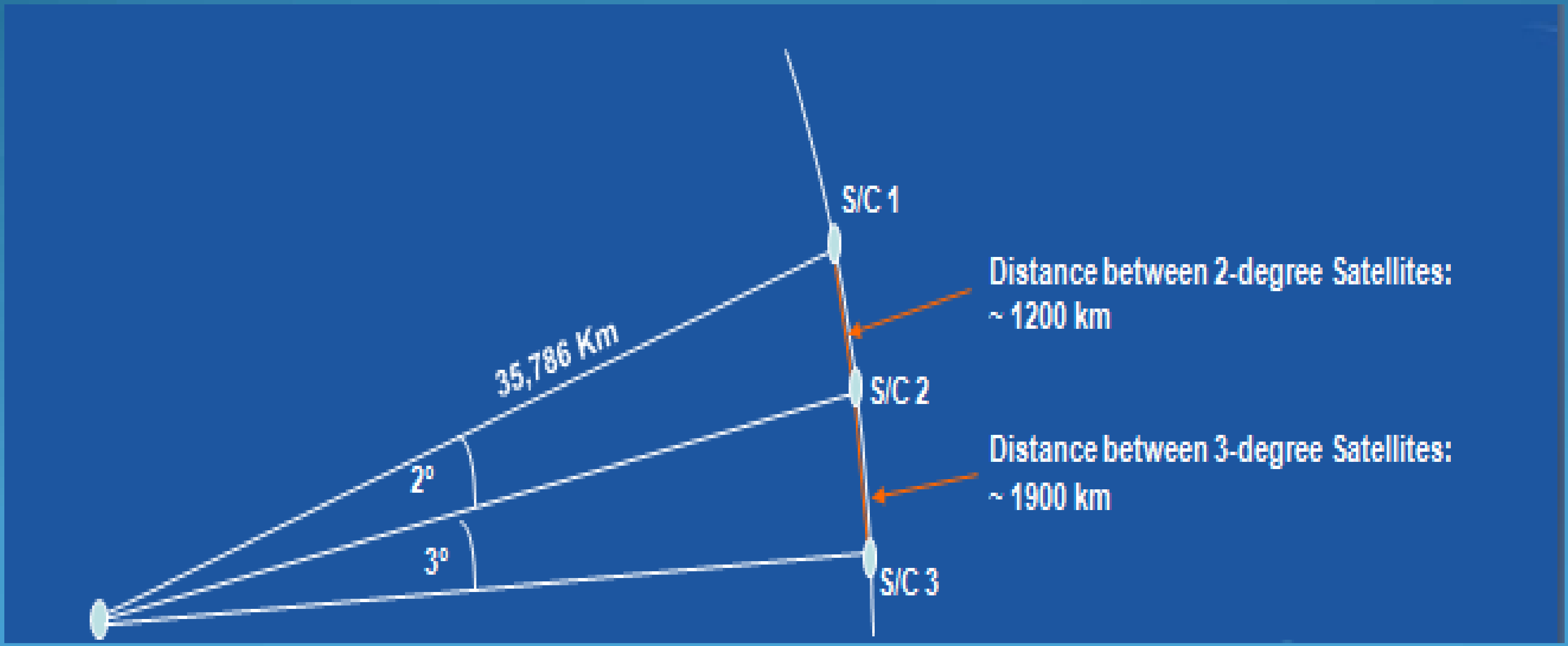
Basics of Satellite Com (orbital positions 1)

The ITU regulates the portion of the geoarc orbits.This has 360º that is being imposed a separation between satellites 2º for no interference, remaining therefore 180 parts to be occupied. Each one can have two or more satellites working simultaneously since working on diferente frequencies



Basics of Satellite Com (orbital positions 2)

Preventing pointing errors, avoids interference between satellites working in the same frequency



Basics of Satellite Com (orbital window 1)

Created in 1959 at the UN COPUOS - Committee on the Peaceful Uses of Outer Space (64 members present), has developed diverse international regulations on the Space Exploitation treaty, namely:

- Interstellar space
- Junk in space
- Promotion of international cooperation
- Nuclear power sources
- Communications, namely these:
  - Agreement on the INTELSAT (August 1971)
  - Convention liability for damage caused by space bodies (1972)
  - Convention Registration bodies thrown into space (1975)
  - Convention on the INMARSAT (1979)

Basics of Satellite Com (orbital window 2)

With the increasing number of countries interested in launching their own satellites it became necessary to discipline its occupation and it was constituted the ITU International Telecommunications Union (May 17, 1865), currently with over 189 member states and more than 500 organizations public and private, and targeted at:

- ITU-T (former CCITT regulates telecommunications)
- ITU-R (former CCIR, regulate radiocommunications and allocate frequencies)
- ITU-D (assistance in developing countries technically)