SATELLITE COMMUNICATION SYSTEM

We will consider a Geostationary orbit communications satellite system

Space Segment

1. Satellite Launching Phase
2. Transfer Orbit Phase
3. Deployment
4. Operation
   - TT&C - Tracking Telemetry and Command Station: Establishes a control and monitoring link with satellite. Tracks orbit distortions and allows correction planning. Distortions caused by irregular gravitational forces from non-spherical Earth and due to the influence of Sun and Moon forces.
   - SSC - Satellite Control Center, a.k.a.:
     - OCC - Operations Control Center
     - SCF - Satellite Control Facility
   - Provides link signal monitoring for Link Maintenance and Interference monitoring.
5. Retirement Phase

REQUIREMENTS

- Type of service required
- Communications capacity (bit rate for given EIRP)
- Coverage area(s)
- Technological constraints

  launcher capability,

  satellite fuel storage capability,

  power generation – solar cells limited

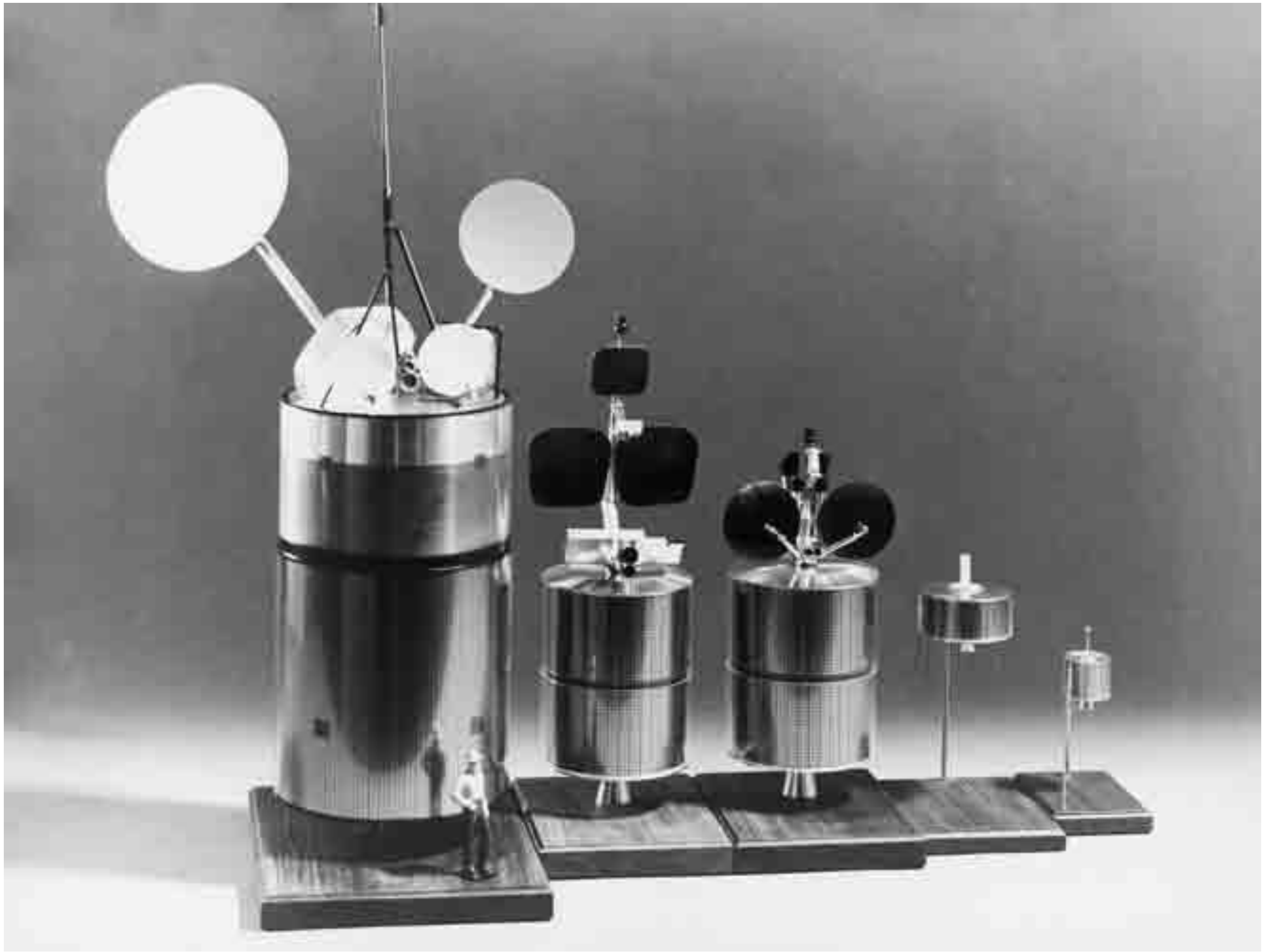
  power consumption – 20% control/command and 80% communications payload

  High reliability needed

  Linear amplifiers to avoid spurious signal generation (interference between transponders and other satellites)

  Redundancy

INTELSAT SATELLITES I, II, IV, IVA & VI



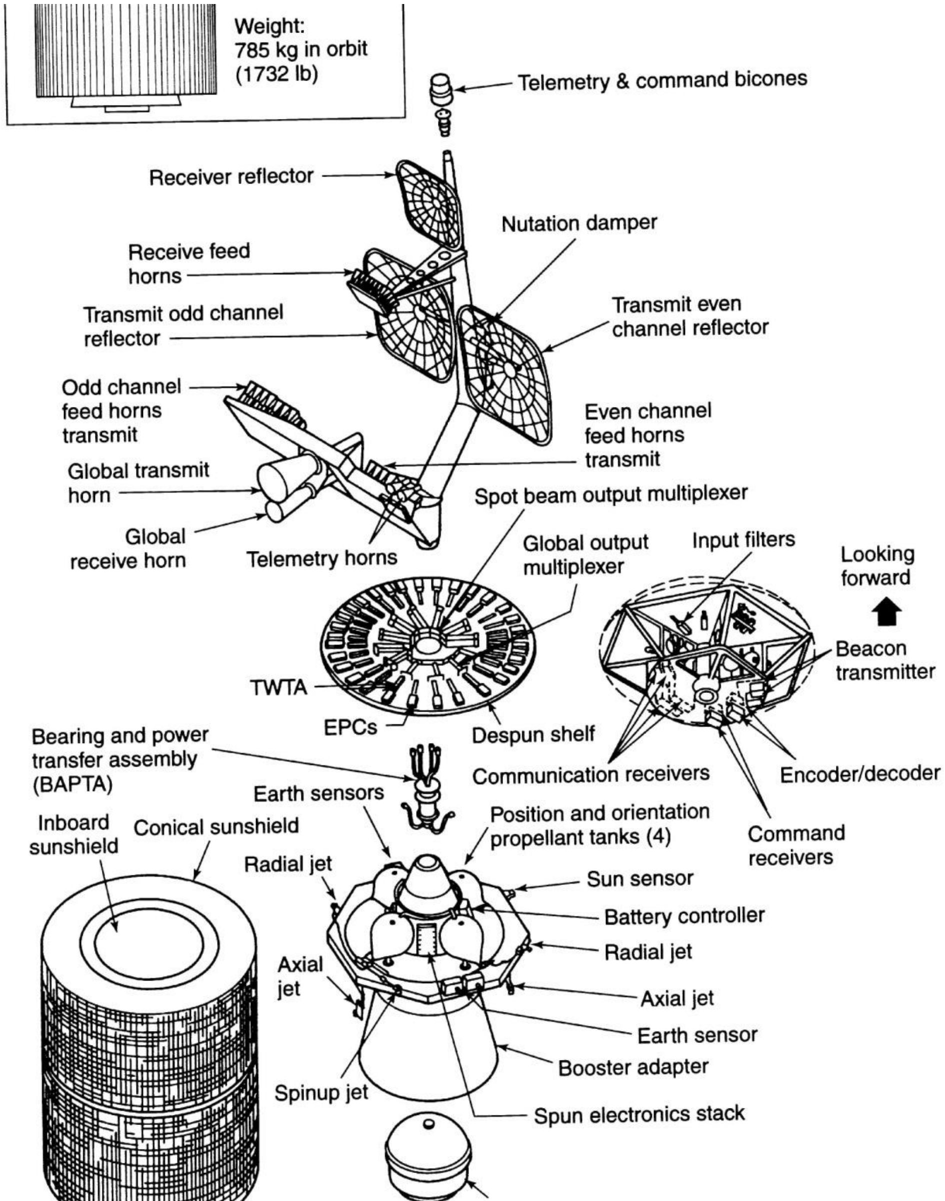


FIGURE 3.1 Exploded view of a spinner satellite based on the Boeing (Hughes) HS 376 design. INTELSAT IVA (courtesy of Intelsat)

Introduction

Within the satellite are two major sections:

- The spacecraft bus (*the bus*).
  - Contains the support vehicle and control subsystems that allow the payload to perform its mission as a microwave repeater in space. (Solar panels, Attitude and spacecraft control processing, command and control, power, propulsion, thermal control…)

– The communications payload (*the payload*).
  - business-end of the satellite, consisting of Repeater (microwave receivers, RF multiplexers, power amplifiers, channel processing and switching) and Antennas

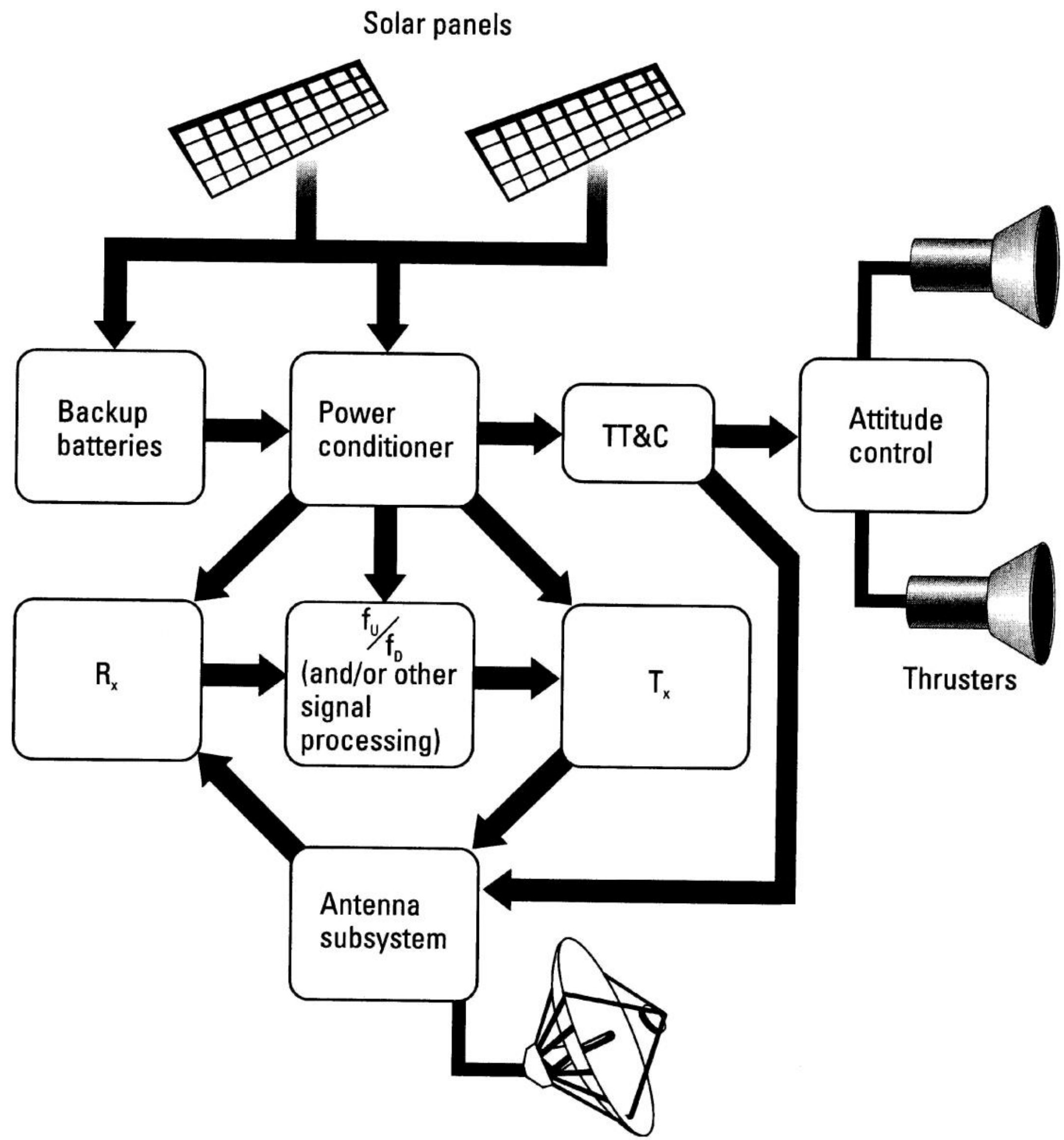


Figure 2.3 Geostationary satellite subsystems.

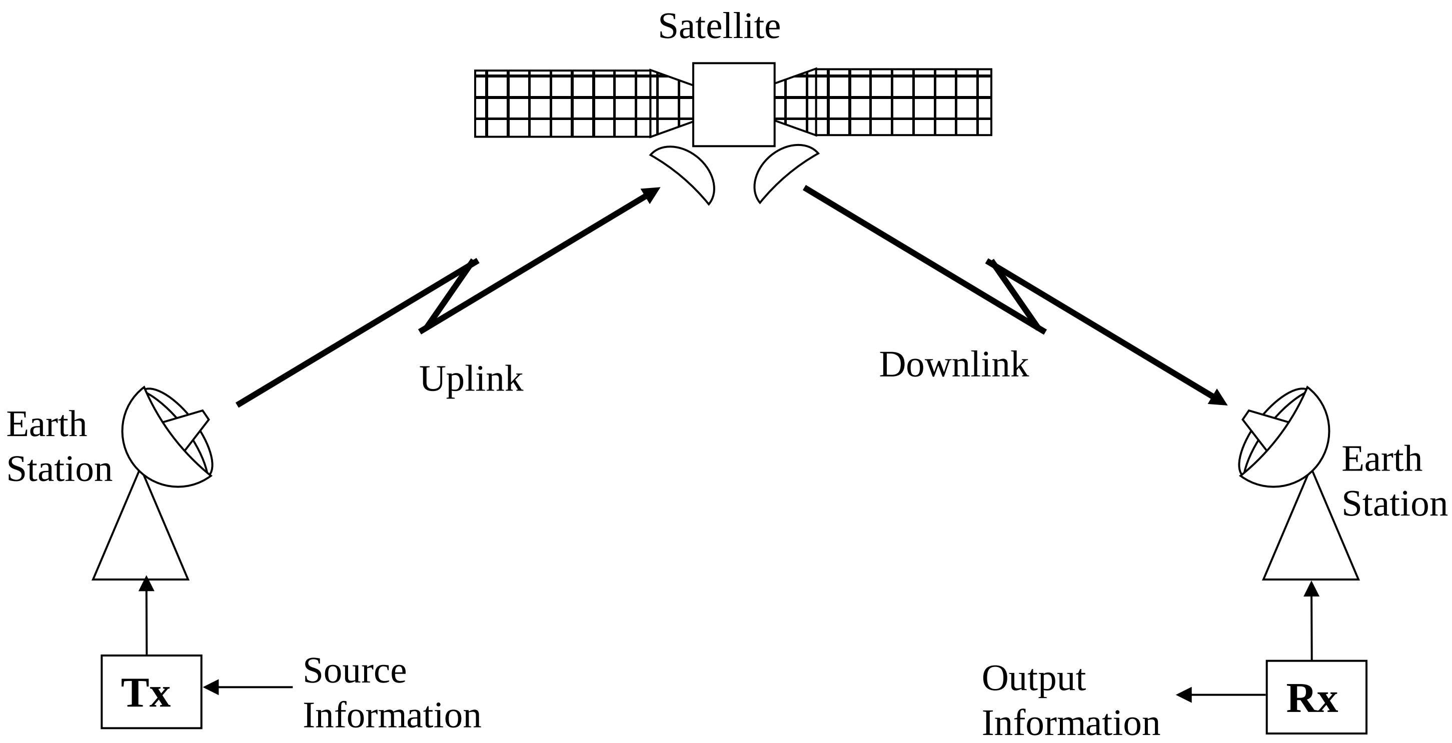
Spacecraft bus **- Thermal Control**

- To control the temperature of individual components to ensure proper operation

- High temperature limits the reliability and lifetime of components.

- can be divided into two classes: passive (using gold foil blankets as insulation) and active thermal control (heat or cool)

Basic Principles



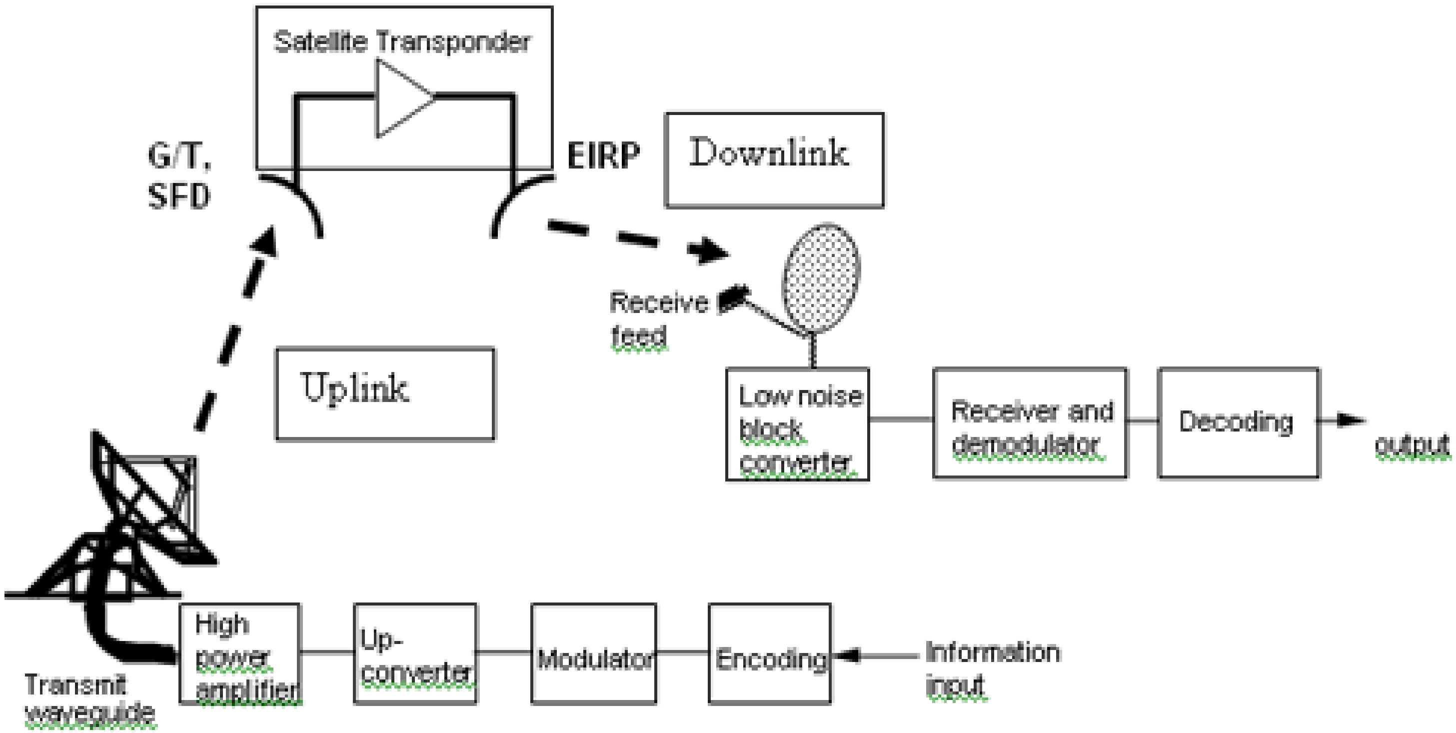
Satellite-Related Terms

- Earth Stations – antenna systems on or near earth
- Uplink – transmission from an earth station to a satellite
- Downlink – transmission from a satellite to an earth station
- Transponder – electronics in the satellite that convert uplink signals to downlink signals, requires frequency translation

Satellite system link

- Uplink
  - Path of the satellite signal from the earth transmitter to the receiver of the satellite.
  - The freq. signal being transmitted from the earth station to the satellite is called uplink frequency
  - eg: uplink freq. for C-band is 6 GHz
- Downlink
  - Path of the satellite signal from the satellite transmitter to the receiver on the earth
  - The retransmitted signal from the satellite to the receiving stations is called the down-link
  - eg: downlink freq. for C-band is 4 GHz

Satellite Communication System



EIRP

- The downlink power is referred to as Effective Isotropic Radiated Power (EIRP) and is measured in units of power (i.e. decibel Watts or dBW)
- EIRP is a product of transmit antenna gain (G_T) and transponder output power (P_T)
  - e.g.

P_T	= 100 W	=	20 dBW
G_T	= 1000	=	30 dBi
EIRP	= 100 kW	=	50 dBW

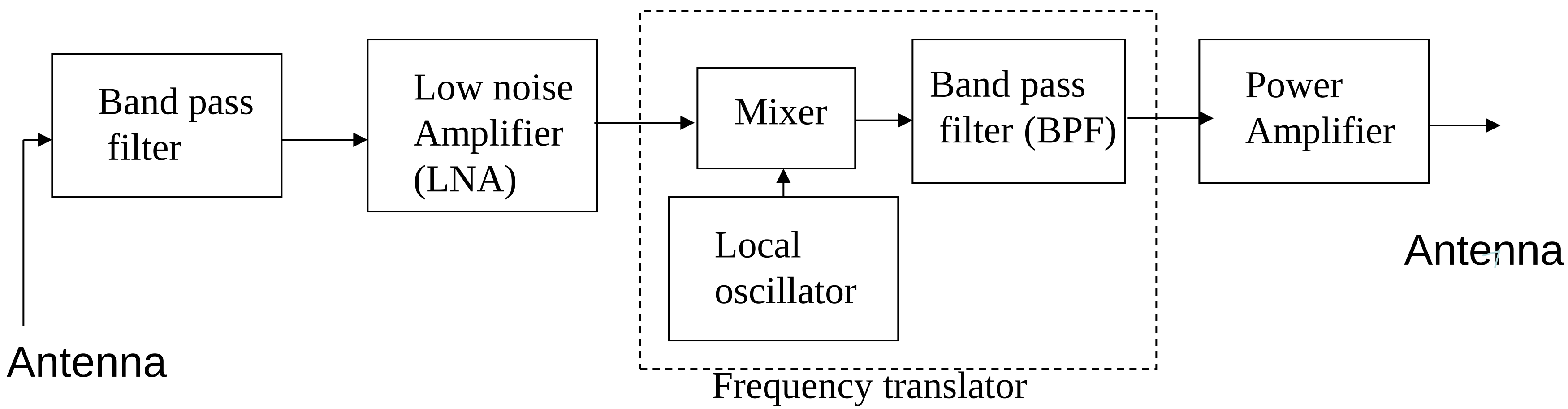
- This implies that if an antenna that concentrates the beam within the service area was not used (isotropic radiator), the satellite would have to transmit 100 kW of power equally in all directions to provide an equivalent performance
- EIRP variation is typically due to antenna thermal distortion, satellite attitude instabilities, atmospheric disturbance (i.e. rain) and aging effects

- The signal power also diminishes as it propagates to the earth and this is called the “path loss”
- The path loss is proportional to the square of the distance from the satellite to the earth (which is 36,000 km) and amounts to 162 dB/m^2
  - Using the 50 dBW EIRP example:

- The uplink signal strength is referred to as the power flux density (PFD) measured in units of power per unit area (i.e. dBW/m^2)
- The PFD required to saturate the power amplifier is called the Saturating Flux Density (SFD)
  - SFD variation is due to the same phenomena as EIRP variation
  - e.g. an uplink EIRP of 70 dBW = 10 MW would also experience a path loss of 162 dB/m^2
  - the signal strength at the satellite would be:

    -92 dBW/m^2 = ???

Satellite transponder



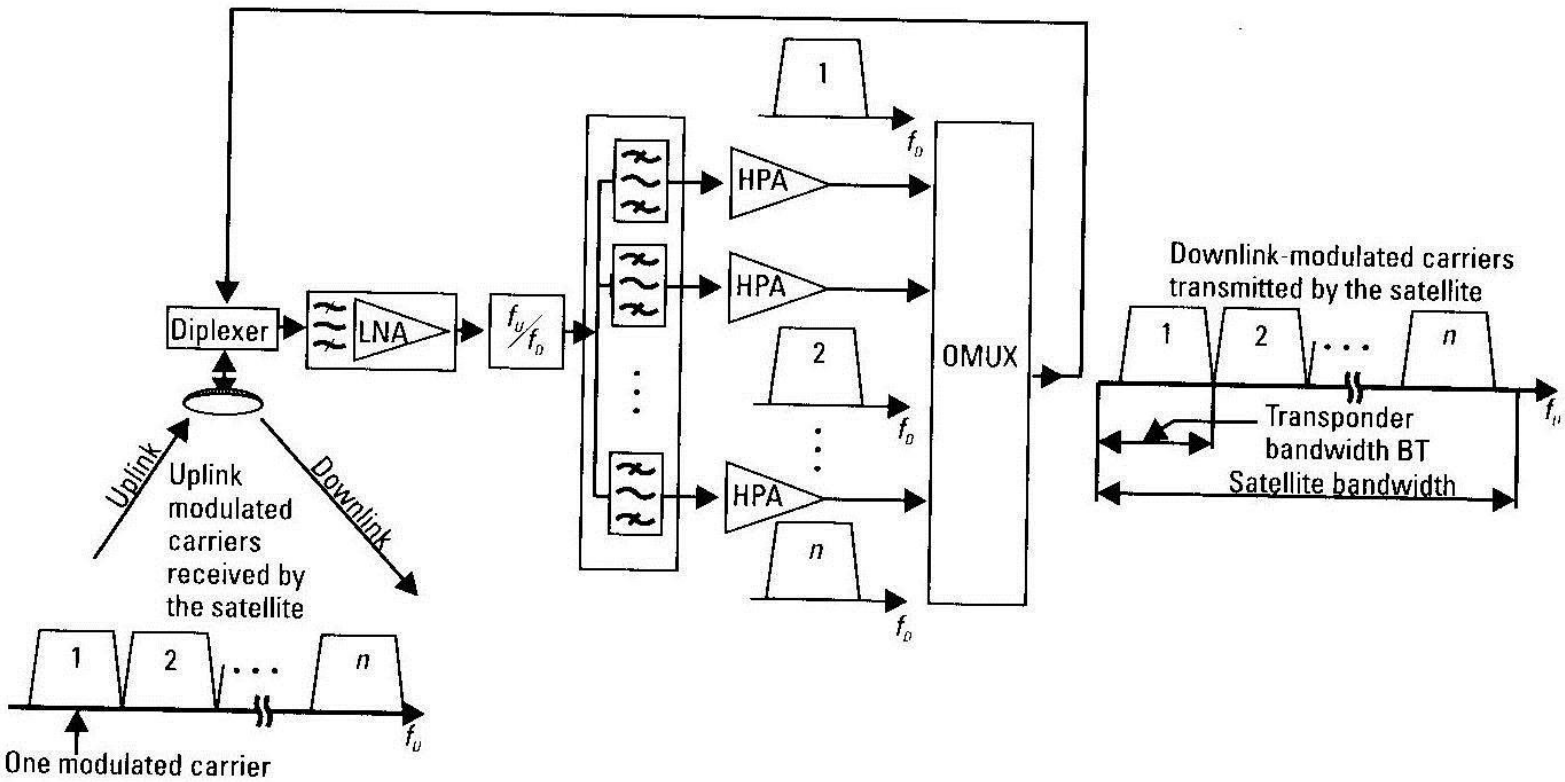
A satellite transponder

BPF – limits the total noise
LNA amplifiers – receive signal and fed it to the frequency translator
Freq. translator – convert the high-band uplink frequency to the low-band downlink frequency

Satellite transponder

- Satellite transponder acts like a repeater, consists of a receiver and a transmitter. The main functions of a satellite transponder are:
  - To pick up the transmitted signal from the transmission on the earth
  - To amplify the signal
  - To translate the carrier frequency to another frequency
  - To retransmit the amplified signal to the receiver on the earth

TRANSPONDER BANDS

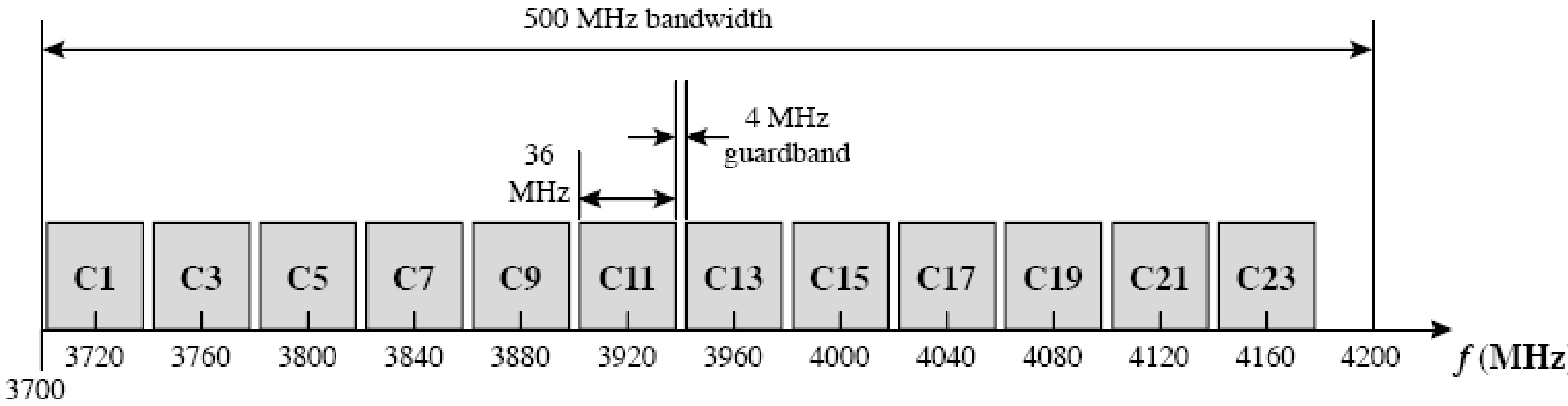


Note: there are many transponders, each at a different frequency band to provide reliability and redundancy – if just one was used if it failed satellite down completely. Each transponder will have a spare power amplifier that can be switched in.

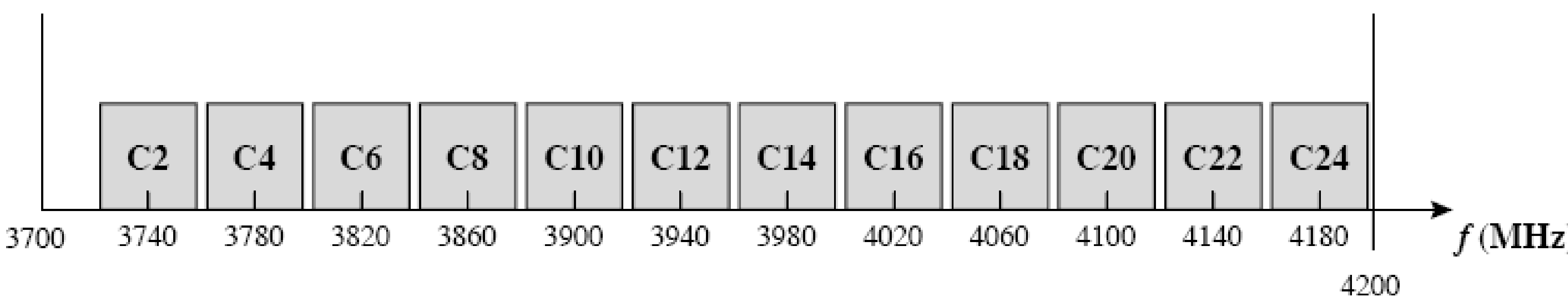
Transponder bandwidths

- Many C and Ku band payloads occupy a total bandwidth of 500 MHz. Each payload consists of a number of channels, also called transponders. Operating bandwidth of each channel is typically:
  - L - Band: 1.7 & 3.4 MHz
  - C - Band: 36, 41 & 72 MHz
  - Ku - Band: 24, 27, 36, 54, 72, 77 & 150 MHz
  - Ka - Band: 250, 500 & 1000 MHz
- Each channel can be used to carry 1 signal or many signals each with a reduced bandwidth

Frequency-Division Multiplexing



(a) Horizontal Polarization



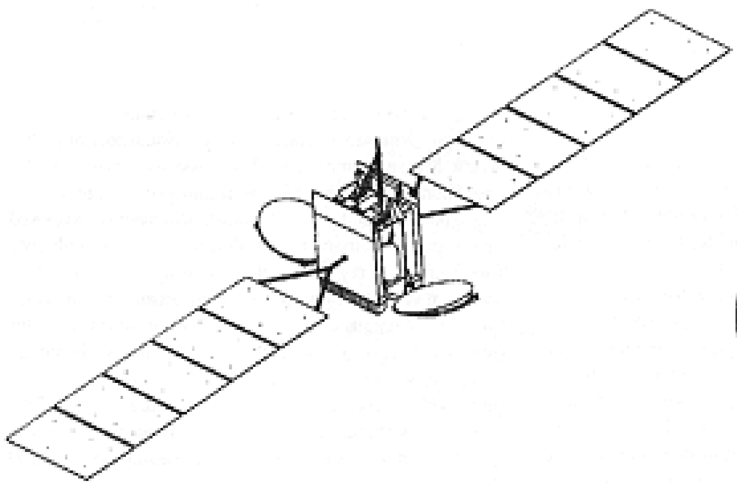
(b) Vertical Polarization

Communications payload - **Antennas**

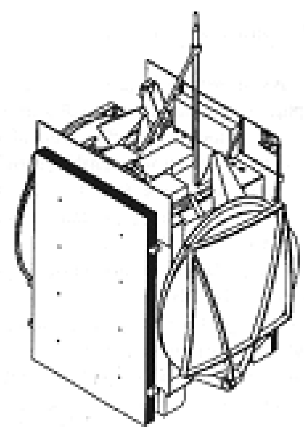
- antenna subsystem often a critical factor in the spacecraft

  → impact on total mass and stability

  → need of storage during launch and deployment in orbit



fully-deployed satellite



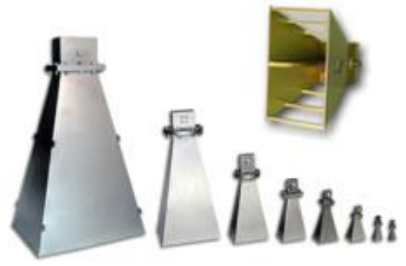
Stored satellite

Antennas

- <u>Constraints</u>: required coverage area on earth ➔ beamwidth ➔ antenna type, size

The main types of antennas:

- *horn antenna*
  - » small aperture needed for earth coverage
  - » 4GHz or higher frequencies



- *reflector antenna*
  - » especially used for narrow beam requirement

Antennas

- Spot and zone beams – cover less than 10% of earth's surface. Signal power more concentrated allowing use of of small receiving antennas for DBS (Sky TV).

- Hemisphere beam - covers up to 20% of earth's surface needing larger receiving antenna.

- Global beam - covers 42% of earth's surface, very large receiving antennas needed.

EXAMPLE

Determine the maximum number of TV channels that a satellite, using a zone beam of gain 32.2 dBi, can provide given that:

EIRP/channel = 53 dBW

Electrical power available = 4.3 kW

d.c. to RF conversion efficiency = 50%

90% of electrical power is used by the RF power amplifiers

Solution;

Low Noise Amplifier (LNA)

- the first AND MOST IMPORTANT stage in the receiver.
- ensure that no noise is added to the carrier being amplified due to thermal effects .
- high gain
- good linearity characteristic is needed in order to avoid inter-modulation products

Note: there will be two LNAs to provide redundancy in case of failure

Frequency Convertors

- converts the signal to/from a different frequency (Intermediate Frequency IF)
- Down-converter: lower frequency at which much of the amplification takes place or to higher frequency.
- Up-converter translate the frequency at which the signals will be transmitted.

At satellite frequency is down-converted from say 6 GHz to 4 GHz as it is more efficient to amplify at lower frequencies and power is limited on spacecraft.

Power amplifier

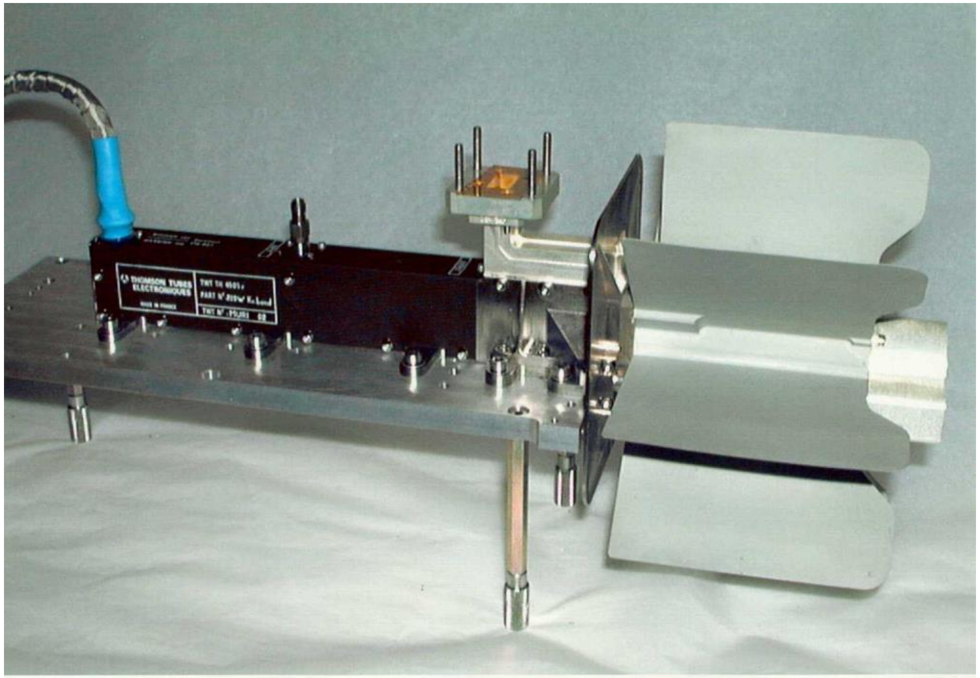
Travelling Wave Tube Amplifier (TWTA) – key element in transponder

Amplifies signal for transmission to ground station

<u>Working principle:</u> amplification achieved by interaction between electron beam and signal in form of electromagnetic travelling wave.

The key TWTA performance specifications are:

- RF Output Power: 10-250 Watts
- Saturated Gain: 50-60 dB & Efficiency : 55-65 %
- Weight: ~ 2.5 - 3.5 Kilograms



THOMSON TUBES ELECTRONIQUES
220 W Ku Band TWT S/R version

TWTA amplifier

- Advantages:
  - good gain
  - high efficiency (~60%)
  - high power output (10W-450W)

- Disadvantages:
  - non-linearities
  - high voltage supply
  - lifetime restricted

Solid-State Power Amplifiers (SSPA)

- competitive technology for the TWT
- transistor power amplifier

Dual SSPA (L-Band)

- <u>Advantages</u> compared to an equivalent TWTA:
  - lower mass
  - higher reliability
  - low power supply
  - lower cost
- <u>Disadvantage</u>
- relatively low max output (~60Watt)
  - low efficiency (~30%).

Typical SSPA performance specifications are:

RF output power: 5 - 40 Watts
Saturated Gain: 55-65 dB & Efficiency: 20-40 %
More linear than TWTAs
Weight: ~ 1.5 - 2.5 Kilograms

INTERMODULATION

- INTERMODULATION
  - WHEN TWO, OR MORE, SIGNALS ARE PRESENT IN A CHANNEL, THE SIGNALS CAN "MIX" TOGETHER TO FORM SOME UNWANTED PRODUCTS
  - WITH THREE SIGNALS, ω_1, ω_2 AND ω_3, PRESENT IN A CHANNEL, IM PRODUCTS CAN BE SECOND-ORDER, THIRD-ORDER, FOURTH-ORDER, ETC.

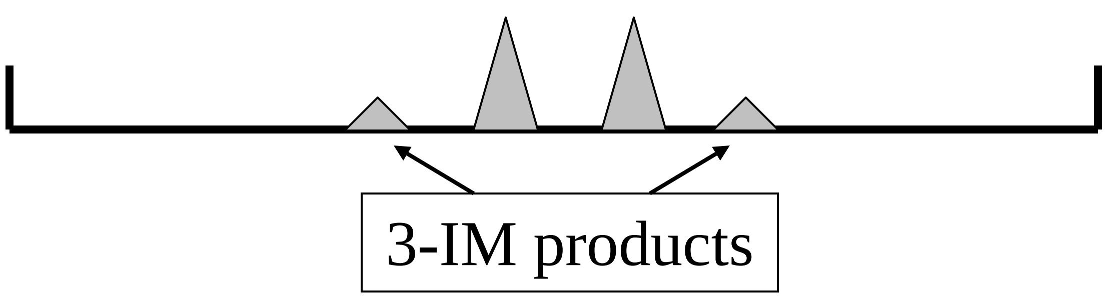
ORDER OF IM PRODUCTS

IM PRODUCT ORDER

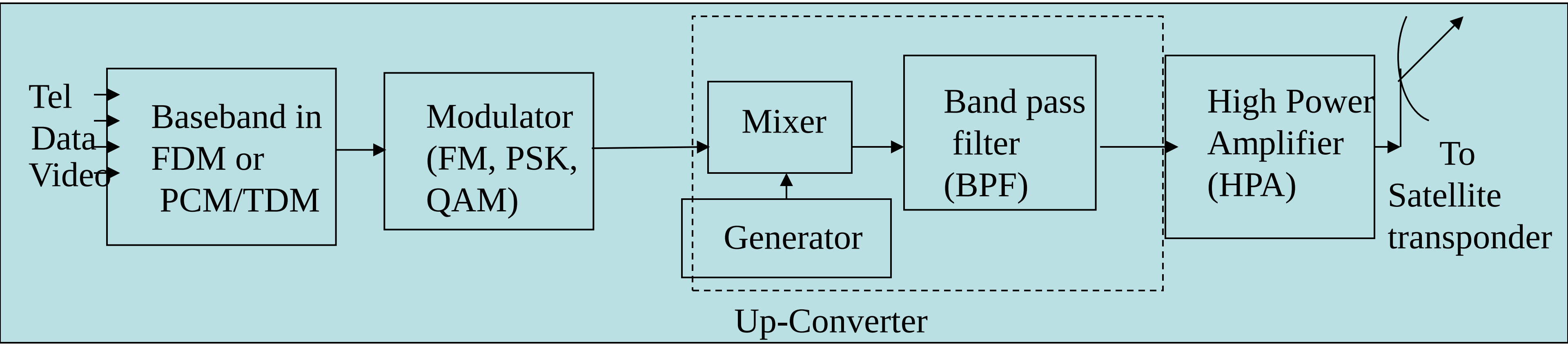
- Second-order is $\omega_1 + \omega_2$, $\omega_2 + \omega_3$, $\omega_1 + \omega_3$
- Third-order is $\omega_1 + \omega_2 + \omega_3$, $2\omega_1 - \omega_2$, $2\omega_2 - \omega_1$..
- Usually, only the **odd-order** IM products fall within the passband of the channel
- Amplitude reduces as order rises
- Only **third-order IM products** are usually important

IM EXAMPLE

- There are two 10 MHz signals at 6.01 GHz and 6.02 GHz centered in a 72 MHz transponder
- 2-IM product is at 12.03 GHz
- 3-IM products are at [2(6.01) - 6.02] = 6.00 and [2(6.02) - 6.01] = 6.03 GHz



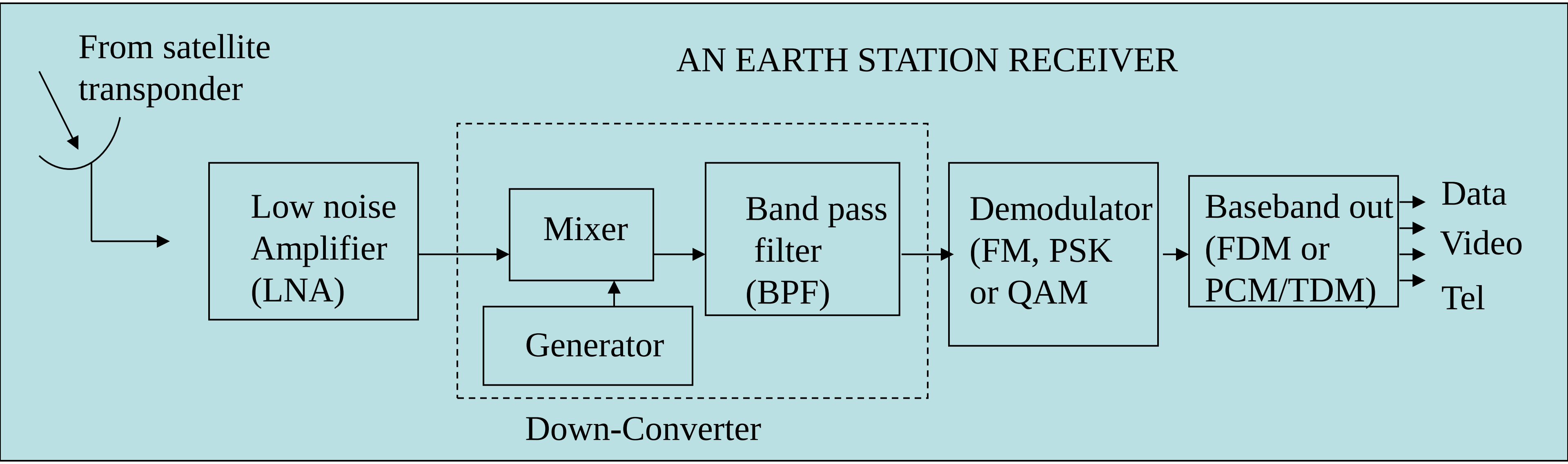
Earth station - transmitter



AN EARTH STATION TRANSMITTER

- **Intermediate freq (IF) modulator converts the input baseband signals to either an FM, a PSK or a QAM modulated intermediate frequency.**
- **The up converter converts the IF to an appropriate RF carrier freq.**
- **The High Power Amplifier (HPA) provides the adequate input sensitivity and output power to propagate the signal to the satellite transponder.**

Earth station - Receiver



- LNA which is highly sensitive and low-noise device amplifiers the received signal.
- The RF to IF down-converter is a mixer and band pass filter combination, which converts the received RF signal to an intermediate frequency (IF)

Satellite Link equations

System divided into :

Earth – satellite link – uplink

[Satellite repeater (transponder)]

Satellite – earth link – downlink

Link Power Budget

Tx *EIRP*

Transmission:
HPA Power
Transmission Losses
(cables & connectors)
Antenna Gain

Antenna Pointing Loss
Free Space Loss
Atmospheric Loss
(gaseous, clouds, rain)
Rx Antenna Pointing Loss

Reception:
Antenna gain
Reception Losses
(cables & connectors)
Noise Temperature Contribution

Rx P_r

Downlink

$$\left(\frac{C}{N}\right)_D = E_s - L_D - M + G_e - N_D \text{ dB}$$

E_s = satellite effective isotropic radiated power (eirp)

= antenna gain x output power = P_s x G_s

L_D = path loss

M = operating margin

G_e = earth station gain

N_D = down link receiver noise = k T_e B_{RF}

= -228.6 + 10log T_e + 10log B_{RF} dB

B_{RF} = bandwidth

T_e = earth station noise temperature

Downlink

$$\left(\frac{C}{N}\right)_D = E_s - L_D - M + \frac{G_e}{T_e} + 228.6 - 10\log B_{RF}$$

G_e/T_e = earth station “Figure of Merit” (dB/K)

Now $\left(\frac{C}{N}\right)_D = \left(\frac{C}{T}\right)_D - 10\log(kB_{RF})$ dB

where T_D is equivalent noise temperature

Hence $\left(\frac{C}{T}\right)_D = E_s - L_D - M + \frac{G_e}{T_e}$ dBW/K

Uplink

$$\left(\frac{C}{N}\right)_U = E_e - L_U - M + G_s - N_U \text{ dB}$$

E_e = earth station eirp = P_e x G_e

L_U = uplink path loss

M = operating margin

G_s = earth station gain

N_U = uplink thermal noise = k T_s B_{RF}

= -228.6 + 10log T_e + 10log B_{RF} dB

B_{RF} = bandwidth

T_s = satellite transponder noise temperature (antenna + receiver)

Uplink

$$\left(\frac{C}{T}\right)_U = E_e - L_U - M + \frac{G_s}{T_s} \qquad \text{dBW/K}$$

Overall $$\left(\frac{C}{T}\right)_T = \frac{1}{\dfrac{1}{(C/T)_U} + \dfrac{1}{(C/T)_D}}$$

C/T must be ratios not dBs for last equation

EXAMPLE

A communications satellite is used to link a number of mobile ground stations which transmit and receive information at 14 GHz and 12 GHz respectively. Given the following information, determine the C/N for the system.

Mobile ground station:

Transmit power = 2 kW = 33 dBW

Feeder loss = 3 dB

Antenna gain = 49 dB at 14 GHz, 47.5 dB at 12 GHz

Noise temperature = 910 K = 29.6 dBK

Uplink: Path length = 40,167 km

Rain loss = 3 dB

Satellite pointing loss = 1.2 dB

Downlink: Path length = 38,532 km

Rain loss = 1 dB

Satellite pointing loss = 1 dB

Satellite:

At 14 GHz – Antenna gain = 37.5 dB

Noise temperature = 2120K = 33.3 dBK

Bandwidth = 23 MHz = 73.6 dBHz

At 12 GHz - Antenna gain = 35.5 dB

Transmit power = 100 W = 20 dBW

3) **<u>Uplink</u>** (14GHz)

Mobile Station:

	Tx power	=	33	dBW
	Feeder loss	=	3	dB
	Antenna gain	=	49	dB
$\therefore$	Eirp	=	79	dBW

(92.5 + 20log 40167 + 20 log 14)	Path loss	=	207.5	dB
	Rain loss	=	3	dB
	Pointing loss	=	1.2	dB
	Total loss	=	211.7	dB

Satellite:

	Antenna gain	=	37.5	dB
	Noise temp	=	33.3	dBK
$\therefore$	$\dfrac{G}{T}$	=	4.2	dB / K
$\therefore$	$\dfrac{C}{T}$	=	- 128.5	dBW/K
	k	=	228.6	dBW/K/Hz
	B	=	73.6	dBHz
	Uplink $\left(\dfrac{C}{N}\right)_u$	=	26.5	dB

Downlink (12GHz)

Satellite:

Tx power	=	20	dBW
Antenna gain	=	35.5	dB
Eirp (on axis)	=	55.5	dBW
Path loss	=	205.8	dB
Rain loss	=	1	dB
Satellite pointing loss	=	1	dB
Total loss	=	207.8	dB

Mobile Station:

Antenna gain	=	47.5	dB
Feeder loss	=	3	dB
Noise temp	=	29.6	dB/K
$\therefore$ G/T	=	14.9	dB / K

$$\frac{C}{T} = -137.4 \text{ dBW / K / Hz}$$

$$k = -228.6 \text{ dBW/K/Hz}$$

$$\underline{B = 73.6 \text{ dBHz}}$$

$$\therefore \quad \text{Downlink} \left(\frac{C}{N}\right)_D = 17.6 \text{ dB}$$

$$\therefore \quad \left(\frac{C}{N}\right)_T^{-1} = \text{total } C/N = \left(\frac{C}{N}\right)_U^{-1} + \left(\frac{C}{N}\right)_D^{-1}$$

$$\therefore \quad \underline{\underline{\left(\frac{C}{N}\right)_T = 17.1 \text{ dB}}}$$

More EXAMPLES

ASTRA DIRECT BROADCAST TV SYSTEM

Family of satellites providing TV, business networks and news links

SATELLITE TV RECEIVER

The receiving system is made up of 4 items:

- Antenna
- Low noise block (down converter)
- Set top box
- TV receiver

Antenna

Normally a parabolic dish either circular or elliptical in shape and 40-80 cm in diameter. Dish provides signal collecting area and focuses signal onto a small horn antenna at the front of the low noise block.

Low noise block - LNB

This amplifies the incoming signal (either horizontally or` vertically polarised), depending on the satellite channel being received) and down converts it from around 11 GHz to ~1 GHz.
Signal fed to set top box via coaxial cable.
Power and control signals are fed up the same coaxial cable.

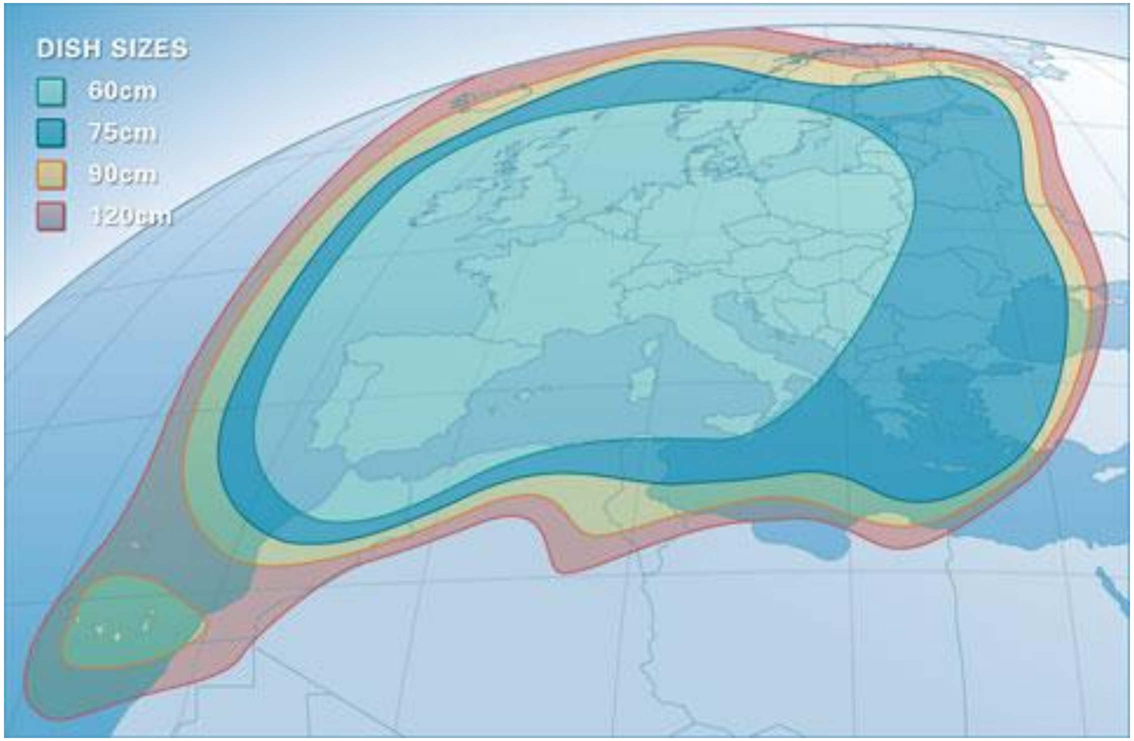
The satellite signal polarisation is selected by changing the supply voltage – 13V (vertical) or 18V (horizontal).

LNB receives signals in 2 sub bands, 10.7-11.7 GHz and 11.7-12.75 GHz, by switching local oscillator to 9.75 GHz or 10.6 GHz.

ASTRA SATELLITE DEVELOPMENT

Satellite	ASTRA 1B	ASTRA 1H
Launch date	1991 19.2°E	1999 19.2°E
Launch mass	2617 kg	3700 kg
Lifetime	>12 years	>15 years
Total power	3.4 kW	6.6 kW
Transponders	13	32
Channels	16 11.45-11.7 GHz	56 20 11.7-12.1 GHz 20 12.1-12.5 GHz 16 12.5-12.75 GHz 2 29.5-30 GHz
TWTA power	60 W	98 W
EIRP	51 dBW	51 dBW
Transponder bandwidth	26 MHz	26 MHz 33 MHz 500 MHz

Satellite	ASTRA 2D
Launch date	2000 28.2°E
Launch mass	1420 kg
Lifetime	>12 years
Total power	1.6 kW
Transponders	16
Channels	16 10.7 – 10.95 GHz
TWTA power	39 W
EIRP	51 dBW
Transponder bandwidth	26 MHz



ASTRA footprint on Europe