Satellite Payloads

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Outline

- What is a payload?
  - Functions of payload
  - Payload requirements
- Payload Types
  - Transparent and Regenerative
- Payload components
  - Antennas, amplifier and multiplexer
- Transponder Technology Development

What is a payload?

What is a payload?

"A communication satellite payload is the system on board the satellite, which provides the link for the communication signals path"

* D.R. O'Connor – in "Satellite Communication Systems". Edited by B.G. Evans, published by IEE

Functions of the payload

- Capture signals transmitted by earth stations
  - At minimum carrier to noise ratio, C/No
- Amplify signals
  - With minimum distortion and noise
- Down-convert and transmit signals to earth stations
  - With appropriate power according to link budget

Payload Requirements

- Variable high-gain amplification
  - To allow for variations in received signal strength
- Channelisation
  - Limit number of signals through any one amplifier, which limits inter-modulation products
  - Limits effect of non-linearity of amplifiers
- High functional reliability
  - Difficult to fix components once in orbit

Payload Types

Payload Components

- Two basic types of transponder:
  - Transparent
    - No on-board processing
    - Also known as bent-pipe satellites
  - Regenerative
    - On-board processing

Transparent Transponders

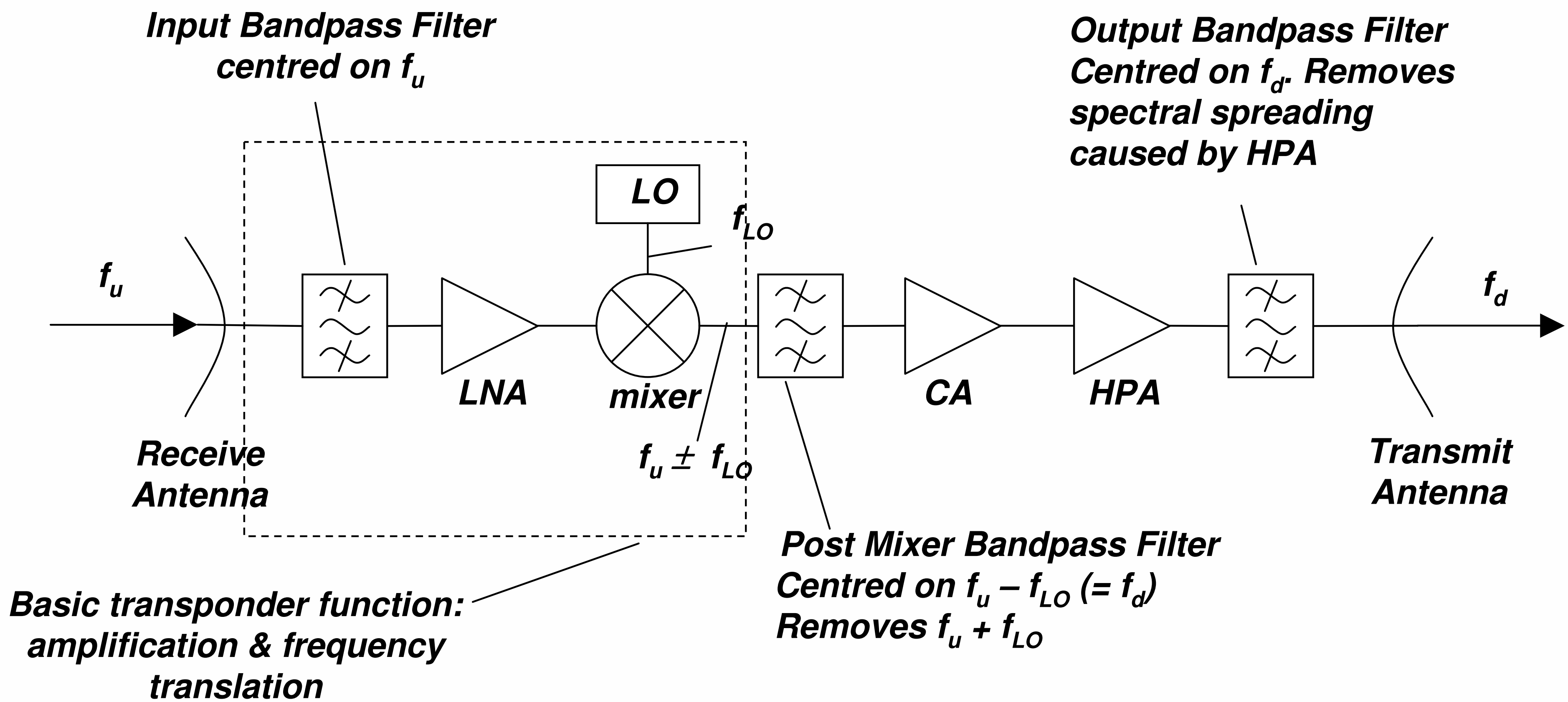
Transparent Transponders - Overview

- Translates the uplink frequency to a suitable downlink frequency and power
- Operate irrespective of access and modulation scheme used by system
- Baseband signal is not recovered
  - No digital processing can be applied to signal

Types of transparent transponder

- Two types:
  - Single Conversion
    - Direct frequency conversion between uplink and downlink frequencies
  - Double Conversion
    - Uses an intermediate frequency of lower value than downlink frequency

Single Conversion – Basic Components



Single Conversion Transparent Transponder

Single Conversion – Basic Components (2)

- Input bandpass filter, centred on uplink transmission frequency, *fu*
- A low noise amplifier (LNA), which provides amplification before the mixer, to minimise transponder noise
  - LNA determines noise performance of transponder
- A mixer to provide frequency translation to downlink frequency, *fd*
  - This results in two products: $fu \pm fLO$, of which only one is required signal
- A post mixer bandpass filter, centred on *fd*, to remove unwanted product of mixer

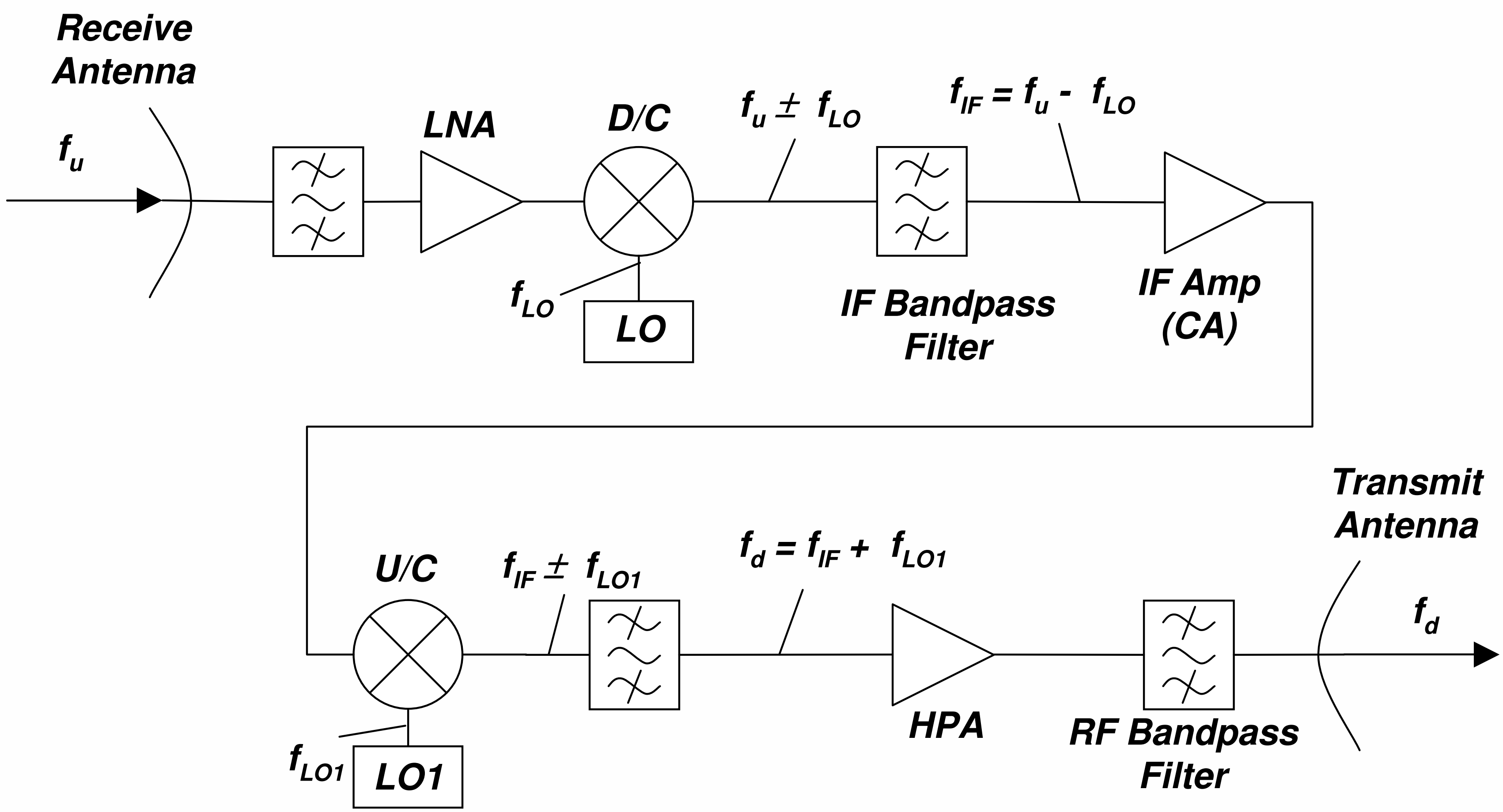
Single Conversion – Basic Components (3)

- A channel amplifer (CA) to provide initial stage of amplification
- A high power amplifier (HPA) to provide majority of required amplification
- An output bandpass filter, centred on *fd*, to ensure output signal bandwidth is equal to input signal bandwidth

Double Conversion Overview

- Used in mobile communication systems satellites to convert from one band to another
  - ACeS uses L-band (1.6/1.5 GHz) for mobile links and C-band (6/4 GHz) for feeder link
  - Convenient for interconnection of Ku-band payload (14/12 GHz) and C-band (6/4 GHz)

Double Conversion – Basic Components

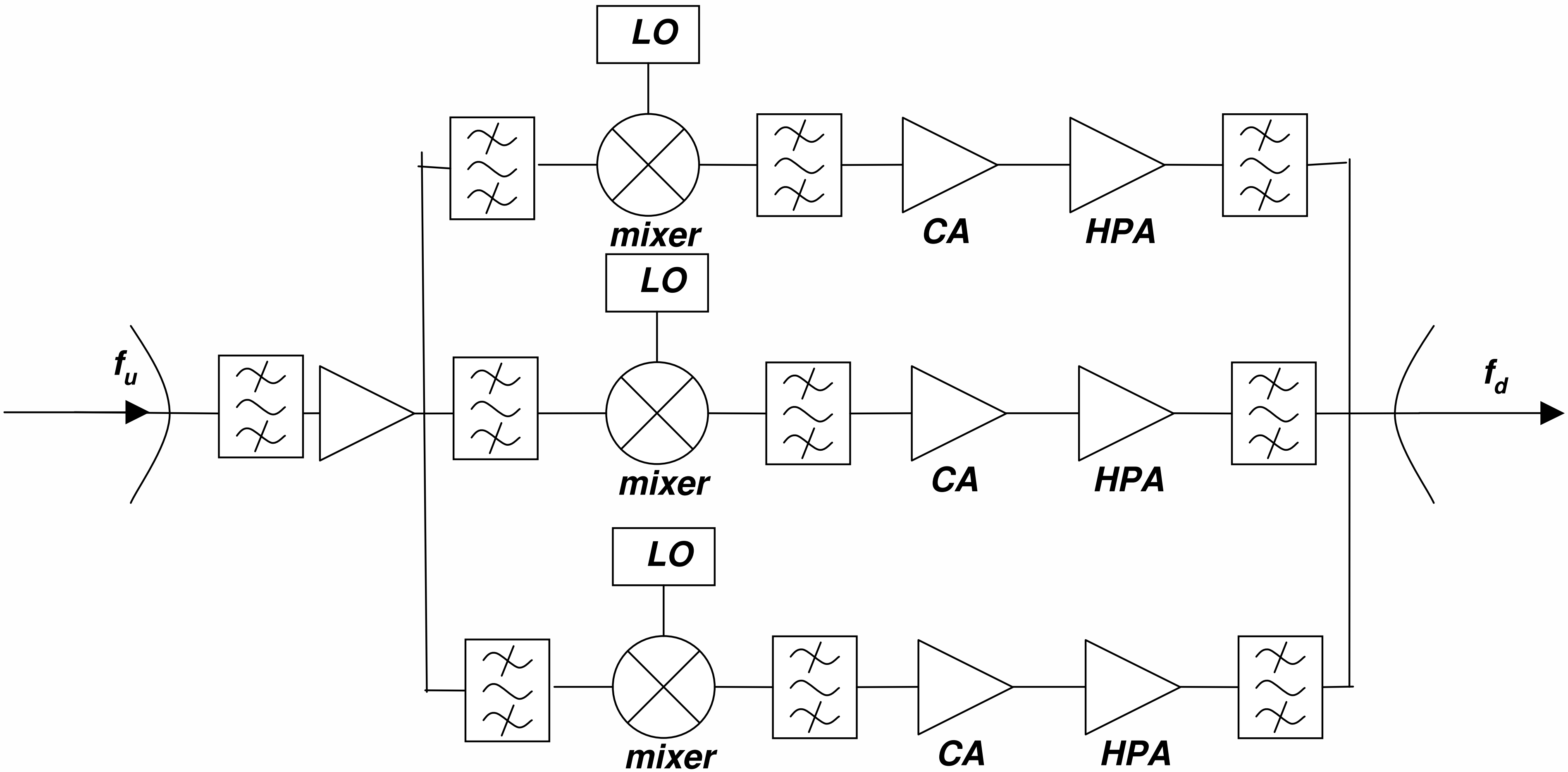


Double Conversion Transparent Transponder

Multi-Carrier Transponders (1)

- In actual system, transponder operates on many carriers:
  - Only one carrier can be amplified in HPA due to inter-modulation products
  - LNA can operate efficiently on multi-carrier signal
  - Channelisation occurs between LNA and mixer
    - Using bank of bandpass filters (input demultiplexer)
    - Another bank of bandpass filters (output multiplexer) recombines signals following HPA stage

Multi-Carrier Transponders (2)



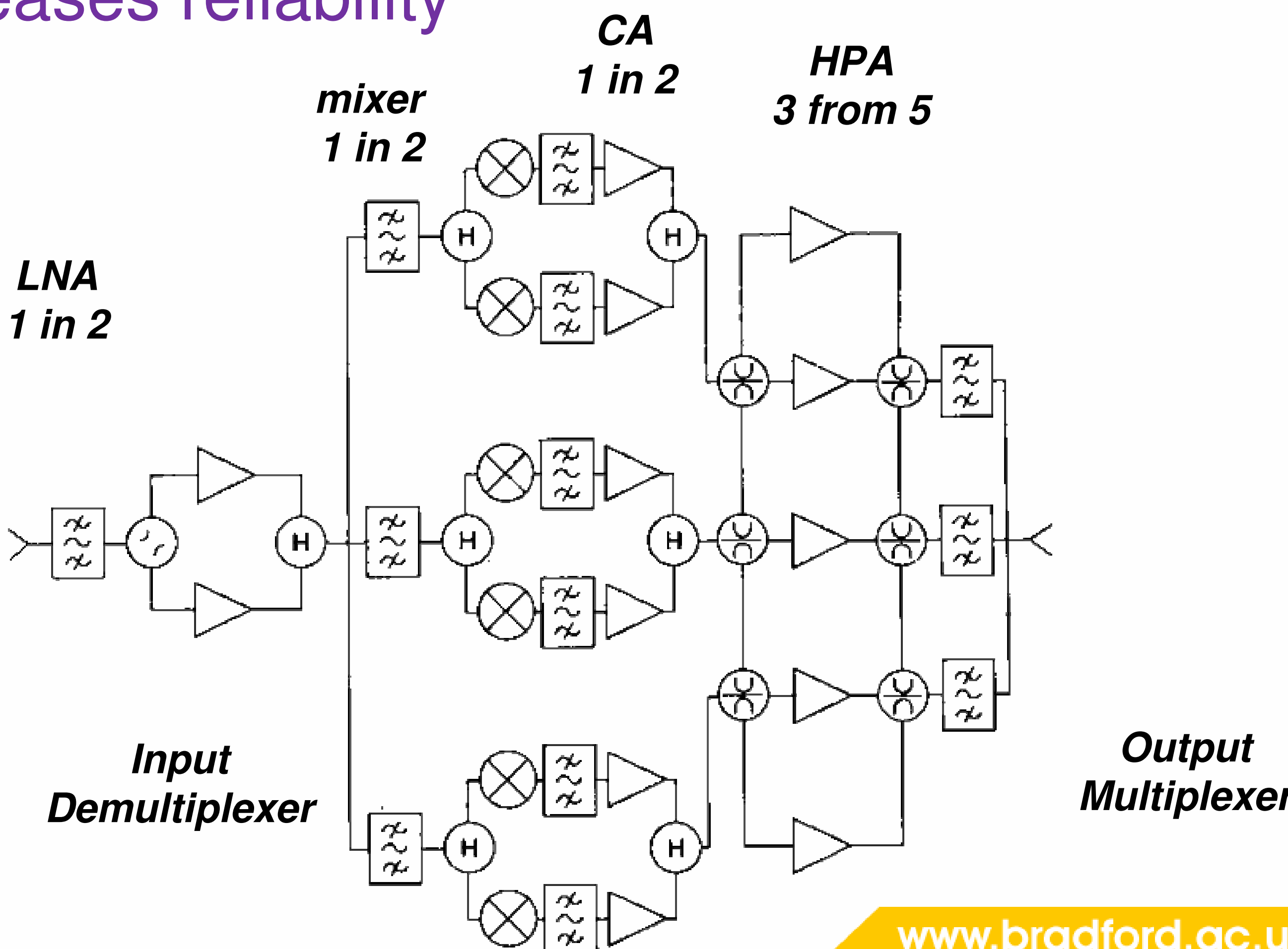
Multi-Carrier Transponder

Payloads Reliability

- Each part of a transponder is a single point failure
  - Malfunction of one part prevents entire transponder channel chain from operating
- Reliability of payload over satellite lifetime is very important
  - Difficult to replace broken components when satellite is in orbit

Payload Redundancy

- Introducing redundancy in amplifier and mixer components increases reliability

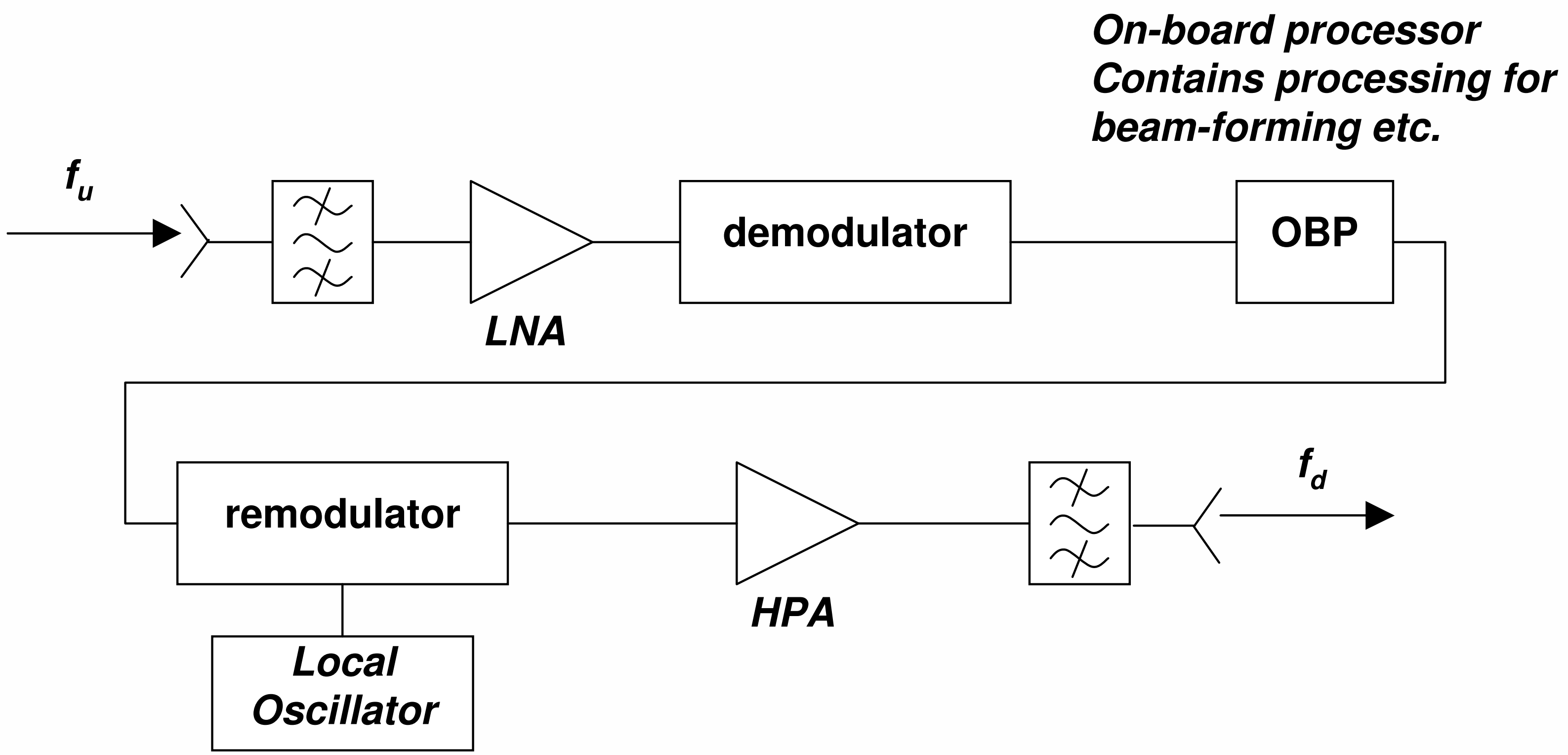


Regenerative Transponder

Regenerative Transponders: Overview

- Include digital on-board processing that recovers/regenerates the baseband information from the received microwave signal by demodulation
- Recovered signal processed and routed to appropriate output
  - Modulated onto downlink carrier
- Regenerative transponders only work with signals modulated by specified modulation scheme

Regenerative Transponders: Basic Components



Regenerative Transponders: Basic Components (1)

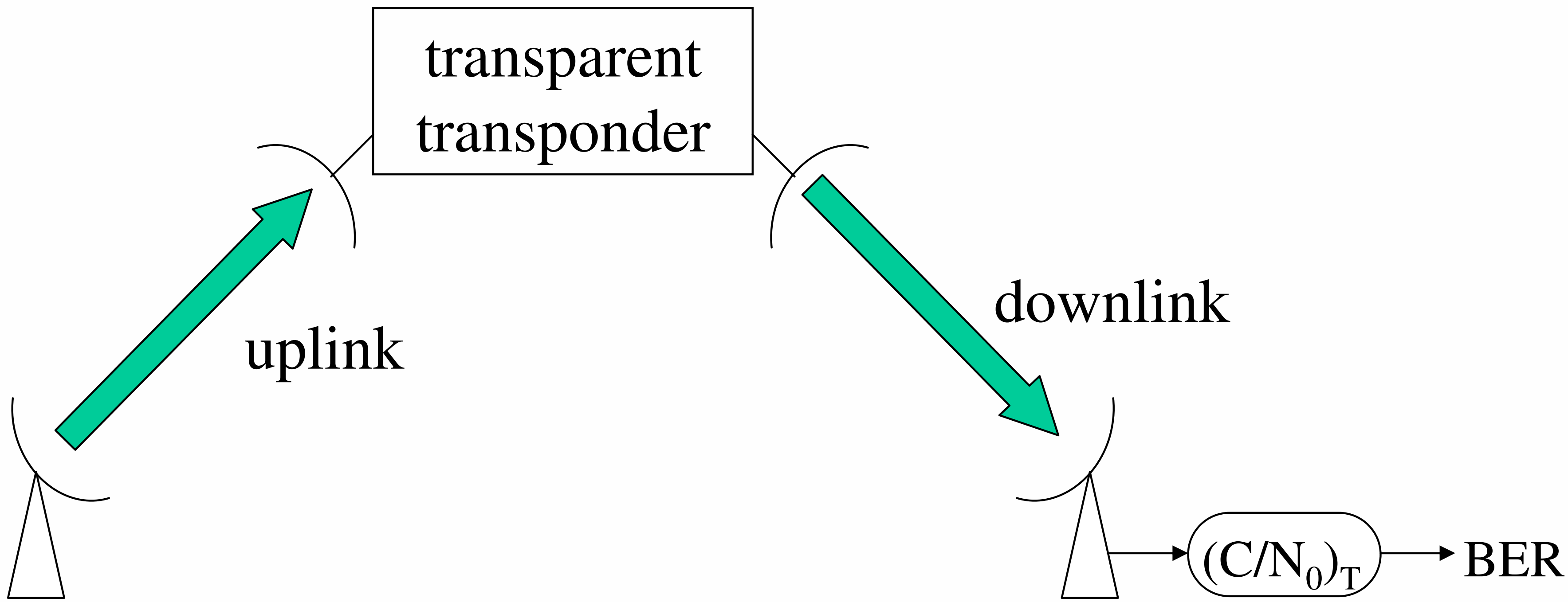
- Input filter – bandpass filter centred on uplink frequency, *fu*, to obtain required bandwidth of received signal
- Low noise amplifier (LNA) – provides first amplification of signal, and low noise
- Demodulator – to recover baseband signals from modulated carrier at uplink frequency, *fu*
- On-board-processor (OBP) – optional component, that processes baseband signals before modulation
  - Contains processing for beam-forming (using phased-array antenna) in a multibeam satellite, for downlink coding etc.

Regenerative Transponders: Basic Components (2)

- Modulator – to modulate baseband signals onto downlink carrier
- Local oscillator – generates downlink carrier at downlink frequency, *fd*
- HPA – high power amplifier to amplify downlink modulated signal before transmission
- Output filter – bandpass centred on *fd,* with a pass band equivalent to bandwidth of transmitted signal

Transponder Link Budget

Transparent Transponders Link Budget (1)



Transparent Transponders Link Budget (2)

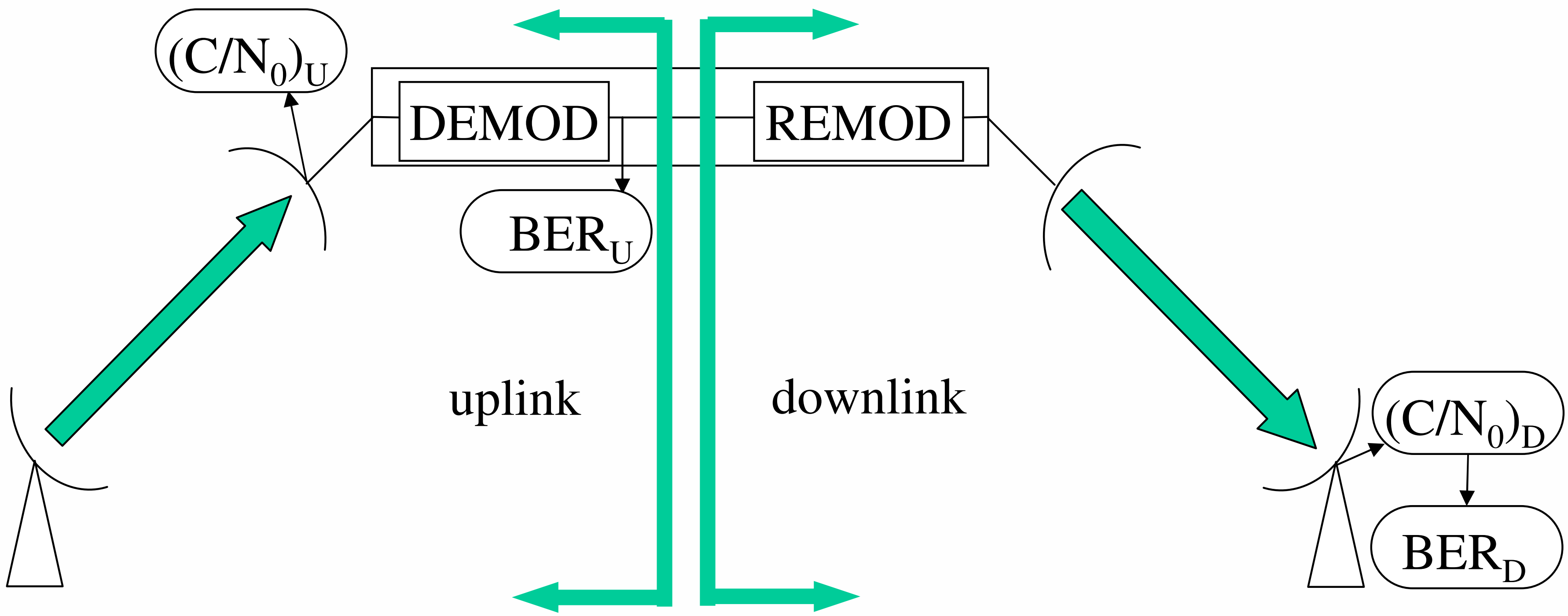
- Total carrier-to-noise ratio $(C/N_0)_T$ depends on uplink and downlink carrier-to-noise ratios:

$$\left(\frac{C}{N_o}\right)_T^{-1} = \left(\frac{C}{N_o}\right)_U^{-1} + \left(\frac{C}{N_o}\right)_D^{-1}$$

- BER depends on ratio $(E_b/N_0) = (C/N_0)/R_c$ where R_c is carrier data rate
- Therefore:

$$\left(\frac{E_b}{N_o}\right)_T^{-1} = \left(\frac{E_b}{N_o}\right)_U^{-1} + \left(\frac{E_b}{N_o}\right)_D^{-1}$$

Regenerative Transponders Link Budget (1)



Regenerative Transponders Link Budget (2)

- BER is specified as probability of an error on uplink (BER_U) and no error on downlink ($1 - BER_D$) or probability of an error on downlink (BER_D) and no error on uplink ($1 - BER_U$):

$$BER = BER_U(1 - BER_D) + BER_D(1 - BER_U)$$

- BER_U and BER_D small compared to 1 hence:

$$BER = BER_U + BER_D$$

Payload Components

Payload Components

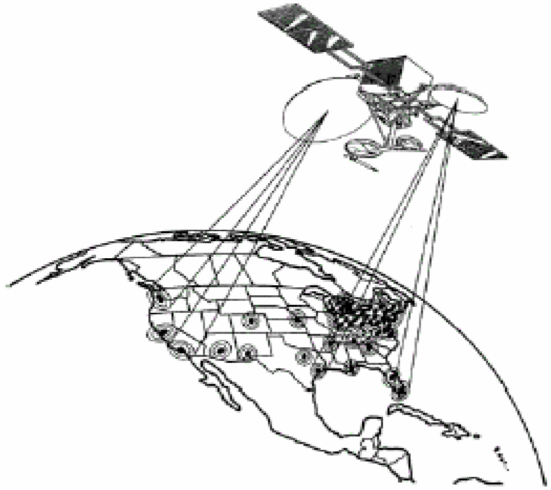
- Antennas
- Amplifier
- Multiplexer

Antennas

Antennas Overview

- Main functions:
  - Collect radio signals transmitted by earth stations
    - Capturing the minimum amount of noise (unwanted signals)
  - Transmit radio signals to earth stations
    - Limiting transmitted power outside specified transmit region

Antennas Beams



- Spot beams
  - Many small beams over coverage area
    - High antenna gain
      - ~39.8 dB at edge
    - Frequency reuse
      - Dynamic resource allocation => response to changing traffic density
    - Limit coverage to specified area
- Global beams
  - Smaller antennas
    - 1.0m @ L-band – compare to 11.0 m for spot beam
  - Lower antenna gain
    - ~18.5 dB at edge
  - Same traffic to all coverage areas

Typical Antennas for Satellite Communications

- Antennas used are of the radiating aperture type
  - Horn antennas
  - Reflector antennas
  - Array antennas
  - Lens antennas

Horn Antennas (1)

- Simplest types of directional antenna
- To produce wide beam coverage
  - Global coverage from a satellite antenna

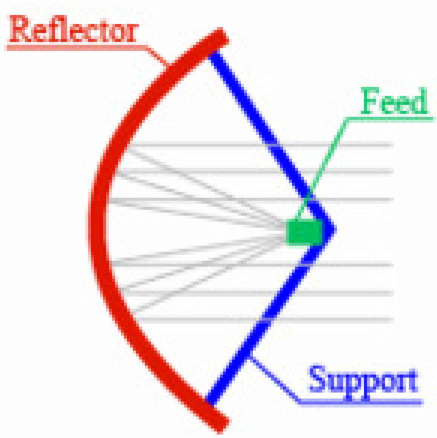
Horn Antennas (2)

- Advantages:
  - Provide significant level of directivity and gain
    - Greater level of gain, should have large aperture
- Disadvantage:
  - Small beam-width require a horn with larger aperture and greater length
    - Installation on the satellite difficult
  - Poor side lobe characteristics

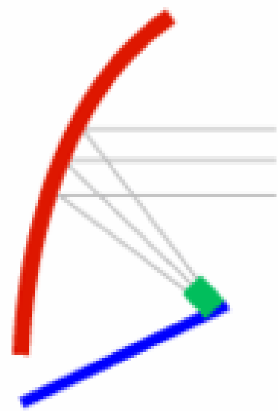
Reflector Antennas (1)

- A device that reflects electromagnetic waves
- Commonly used for spot beams
- Consist of parabolic reflector illuminated by one or more feed elements

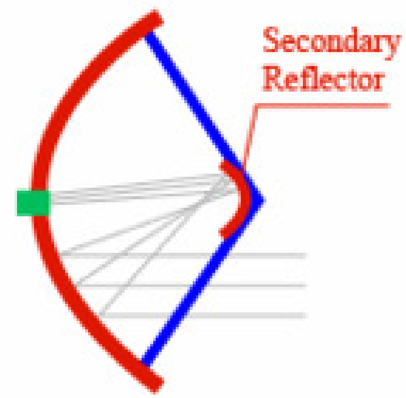
Reflector Antennas (2)



Parabolic



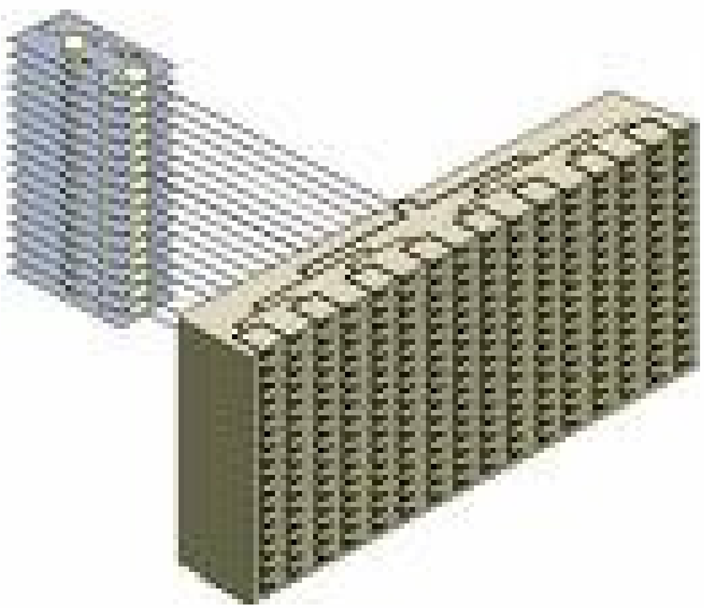
Off-centre



Cassegrain

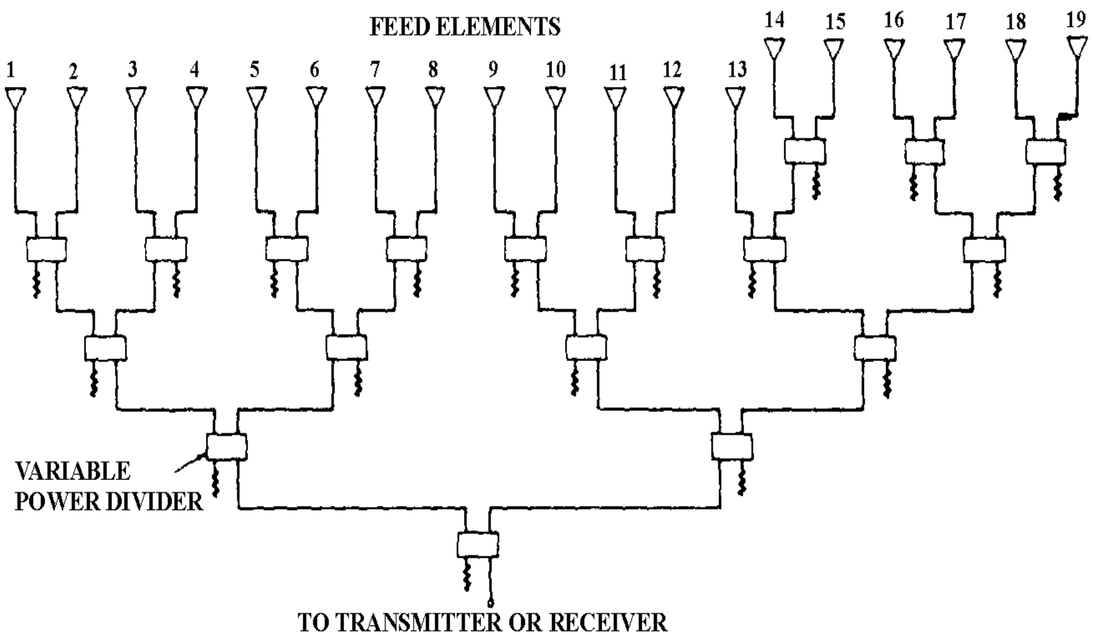
Phased Array Antennas (1)

- Large number of radiating elements distributed over radiating aperture



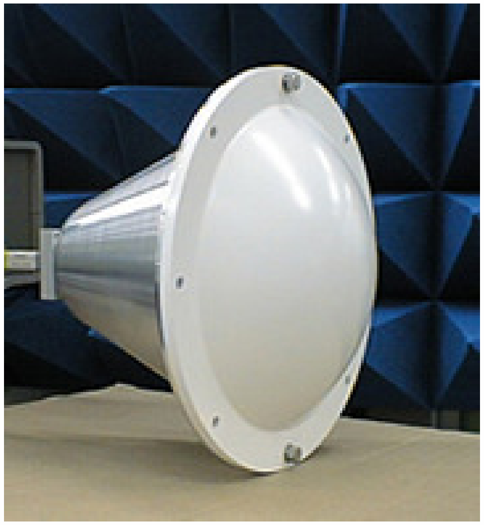
Phased Array Antennas (2)

- Radiation Pattern is combination of wave amplitudes and phases from individual elements
- Used to produce multiple beams simultaneously



Lens Antennas

- Associate one or more radiating elements with a lens which focuses the radiated electromagnetic energy



Amplifier

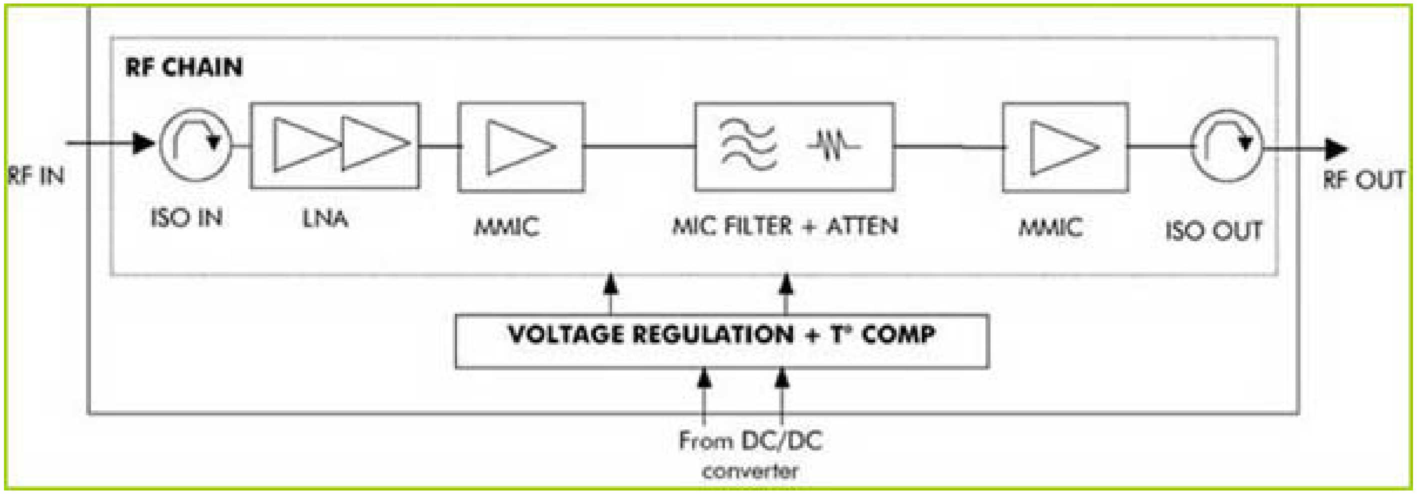
Low Noise Amplifier (1)

- Amplifier across entire bandwidth of beam
- Determines noise performance of payload:
  - Recall that overall noise figure (a measure of degradation of SNR, caused by components in the RF signal chain) is given by Friis' Formula:

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

  - Therefore first device in payload chain (LNA) is most critical for noise performance

Low Noise Amplifier (2)



High Power Amplifier (1)

- Operating Point defined by input (or output) back-off
- Value of back-off is compromise as
  - Small back-off (operation close to saturation) leads to high available output power, but high inter-modulation noise occurs as amplifier operates in highly non-linear region
  - Large back-off limits inter-modulation noise, but also reduces available output power

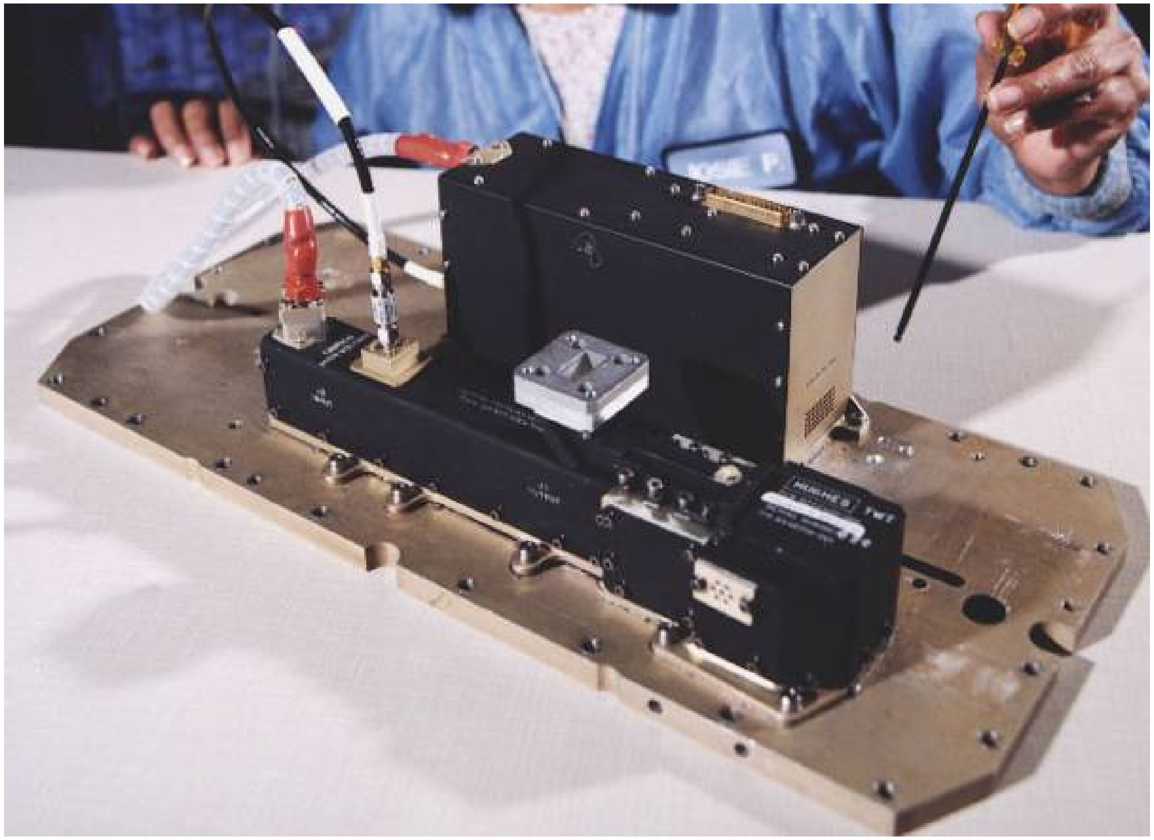
High Power Amplifier (2)

- Two types of power amplifiers used on-board satellites:
  - Travelling Wave Tube Amplifier (TWTA)
  - Transistor Solid State Power Amplifier (SSPA)

TWTA Travelling Wave Tube Amplifier (1)

- Operate by interaction between electron beam and radio wave
- At saturation, typical characteristics are:
  - Output Power : 20 – 200 W
  - Efficiency : 55 – 70%
  - Gain : around 55 dB
  - Inter-modulation $(C/N)_{IM}$: 10 – 12 dB (2 carriers of equal amplitude)

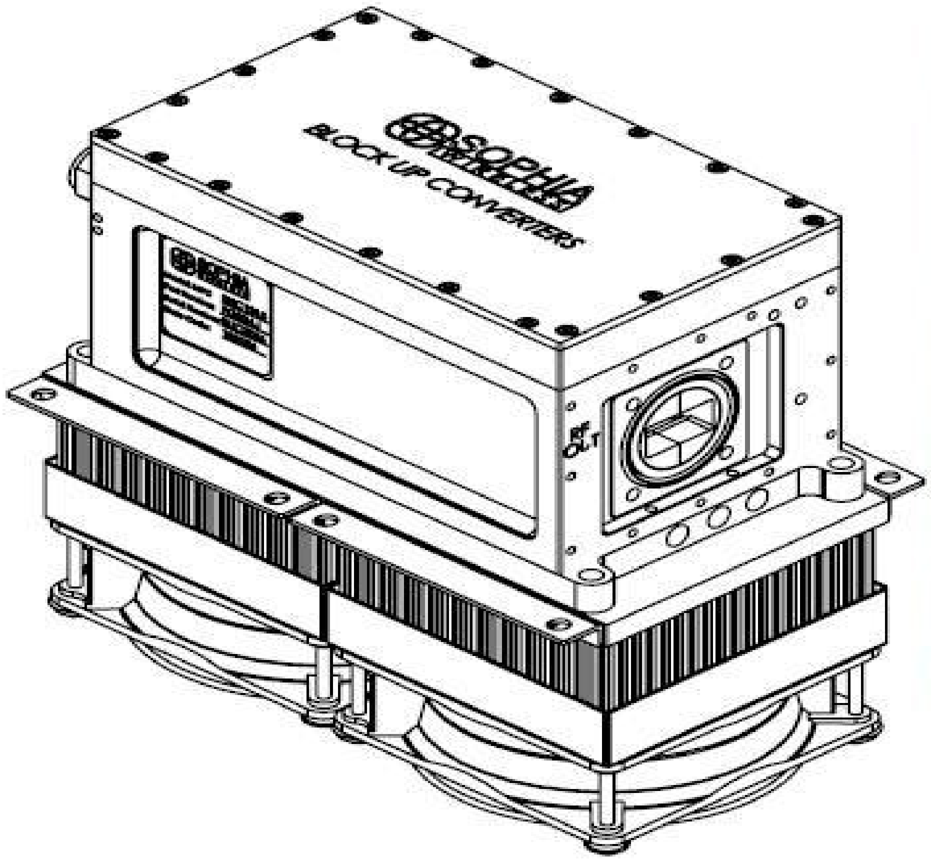
TWTA Travelling Wave Tube Amplifier (2)



SSPA (Solid State Power Amplifier) (1)

- Use a series of FETs (Field Effect Transistor) to amplify signal
- Typical characteristics are:
  - Output power: 20 – 40 W
  - Efficiency: 30 – 45 %
  - Gain: 70 – 90 dB (depends on number of stages)
  - Inter-modulation $(C/N)_{IM}$: 14 – 18 dB (2 carriers of equal amplitude)

SSPA (Solid State Power Amplifier) (2)



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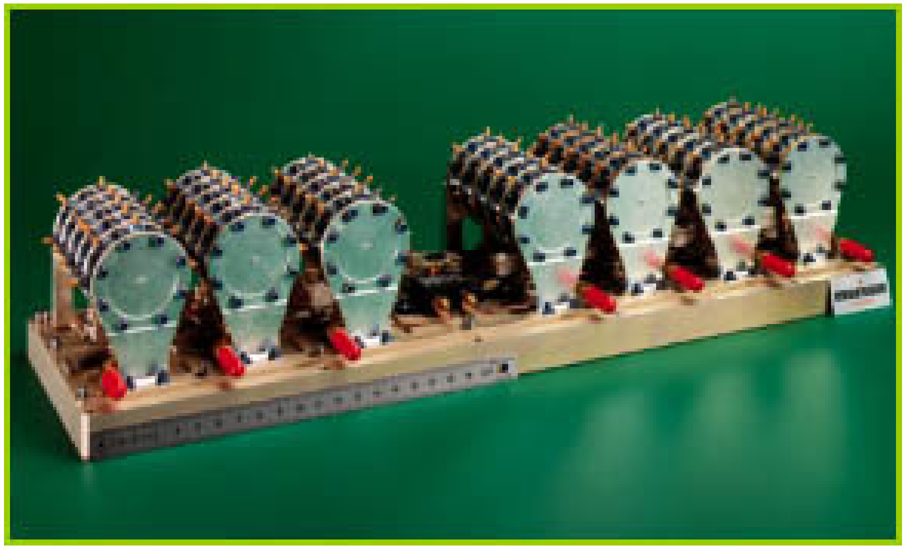
Multiplexer

Multiplexers

- In multi carrier system, require de-multiplexer at input of payload to separate carriers, and multiplexer at output to recombine carriers
- Both formed by a bank of bandpass filters (number of filters = number of channels)
  - Filters centred on a channel with 3dB bandwidth = bandwidth of channel

Input De-multiplexer



Output Multiplexer

Payload Technology

Developments in Payload Technology (1)

- Use of regenerative payloads commercially is rare:
  - Current technology locks satellite to one access scheme and one modulation scheme
  - Economic considerations
    - More expensive to develop and takes longer
  - Inherent risks from complex payload in space

Developments in Payload Technology (2)

- Reconfigurable payloads require space-hardened FPGA technology
- December 14, 2002, saw launch of Australian research satellite
  - Contains reconfigurable processor
  - Based on Xilinx FPGA chip
  - July 2003 'healed' itself of problem caused by space radiation
  - See links on Blackboard for details

Summary

Summary

- Examined two types of payload:
  - Transparent
  - Regenerative
- Investigated components of payload
  - Antenna
  - Amplifiers
  - Multiplexers

Further Reading

Further Reading

- "Satellite Communications Systems" by G. Maral & M. Bousquet:
  - Chapter 6 (Regenerative Networks)
  - Chapter 9 (Communications Payload)

Homework

Homework

- Summarise:
  - On-board Processors (OBP) Approaches
    - Narrowband approach
    - Wideband approach
  - Comparison
  - Advantages and disadvantages of OBP