EENG 470
Satellite Communications

Lecture # 6 – p2
Chapter 3 : Communications Subsystem + Transponders

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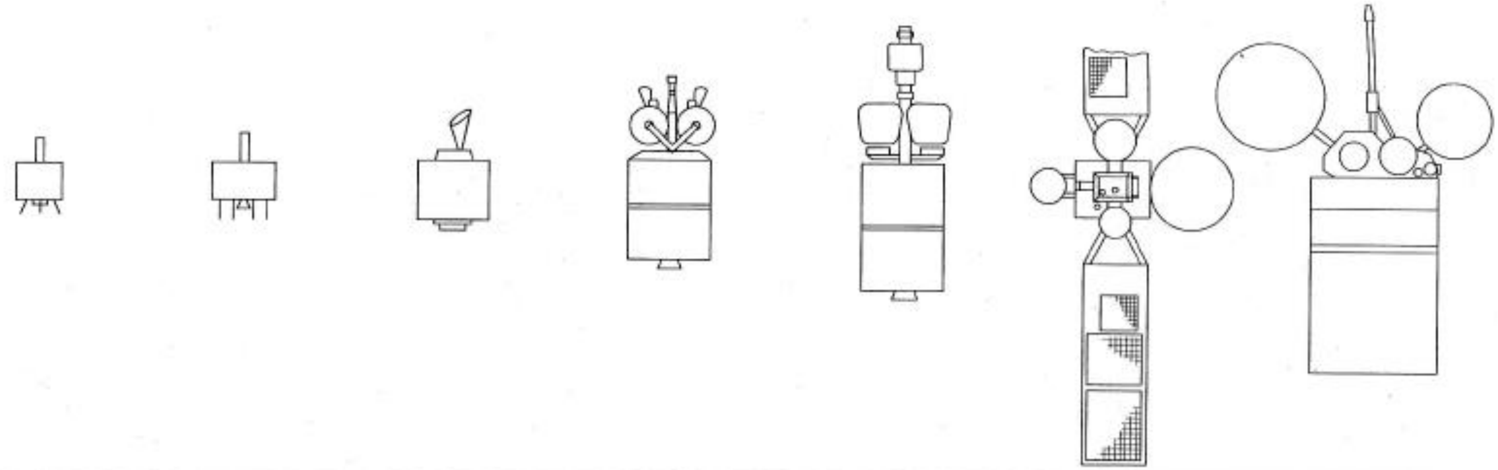


Spacecraft	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV	INTELSAT IV-A	INTELSAT V	INTELSAT VI
Year of first launch	1965	1967	1968	1971	1975	1980	1986 (planned)
Dimensions	0.71 m dia × 0.59 m high	1.42 m dia × 0.67 m high	1.42 m dia × 1.98 m high	2.38 m dia × 7.01 m high	2.38 m dia × 7.01 m high	15.27 m across solar sails × 6.71 m high	3.6 m dia × 11.7 m high
On orbit weight	34 kg	76 kg	152 kg	595 kg	786 kg	1020 kg	1800 kg
End of life primary power	46 W	85 W	125 W	569 W	708 W	1220 W	2100 W
Total bandwidth	50 MHz	130 MHz	360 MHz	450 MHz	720 MHz	2250 MHz	3360 MHz
Notional capacity two-way telephone circuits	240	240	1500	5000	11,000 plus 2 TV channels	24,000 plus 2 TV channels	33,000 plus 2 TV channels
Design lifetime	1.5 years	3 years	5 years	7 years	7 years	10 years	10 years
Spacecraft cost	$3.6 M	$3.5 M	$4.5 M	$14 M	$18 M	$25 M	$140 M (first five satellites)
Launch cost	$4.6 M	$4.6 M	$6 M	$20 M	$20 M	$23 M	?
Cost per telephone circuit year	$23,000	$11,000	$1,600	$810	$494	$200	?
Contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Hughes

FIGURE 3.9 Illustration of the growth in size and weight of Intelsat satellites over 3 decades.

Definition of Satellite Transponder:

Communication satellite transponders is a device that receives radio signals (from earth stations) and retransmits them at a different frequency or with alterations.

- Two types:

(1) Linear or Bent Pipe Transponder:* Amplifies and changes the frequency of received signals.

(2) Onboard Processing (OBP) Transponder:* Processes received signals, typically used for digital signals.

Transponder Design and Operation:

- Signals received by satellites are weak and need **amplification** before retransmission.
- Transmit frequency differs from receive frequency to prevent **feedback and oscillation.**
- **Redundancy** in case of amplifier failure.
- GEO satellite transponders : Wide bandwidths (20–200 MHz) + multiple signals.
- Smaller satellites (like cubesats): single transponders + narrower bandwidths.

Subsystem Block Diagram:

- A simplified block diagram for satellite communication subsystems typically operates in the 6/4 GHz band.

- The bandwidth is divided into twelve channels, each handled by a separate transponder.

- Two sets of transponders for LHCP and RHCP uplink signals.

- Each transponder includes a band pass filter, down converter, and high power output amplifier.

- Redundancy is built in with parallel receivers to ensure continuous operation in case of component failure.

This comprehensive overview highlights the functionality, design considerations, and operational aspects of satellite transponders in communication systems.

3.5 COMMUNICATIONS SUBSYSTEMS

Description of the Communications System

Transponders

Signals (known as *carriers*) transmitted by an earth station are received at the satellite by either a *zone beam* or a *spot beam* antenna. Zone beams can receive from transmitters anywhere within the coverage zone, whereas spot beams have limited coverage. The received signal is often taken to two low noise amplifiers and is recombined at their output to provide *redundancy*. If either amplifier fails, the other one can still carry all the traffic. Since all carriers from one antenna must pass through a low noise amplifier, a failure at that point is catastrophic. Redundancy is provided wherever failure of one component will cause the loss of a significant part of the satellite's communication capacity.

Figure 3.10 shows a simplified block diagram of a satellite communication subsystem for the 6/4 GHz band. The 500-MHz bandwidth is divided up into channels, often 36 MHz wide, which are each handled by a separate transponder. A transponder consists of a band-pass filter to select the particular channel's band of frequencies, a downconverter to change the frequency from 6 GHz at the input to 4 GHz at the output, and an output amplifier. The communication system has many transponders, some of which may be spares; typically 12 to 44 active transponders are carried by a high-capacity satellite. The transponders are supplied with signals from one or more receive antennas and send their outputs to a switch matrix that directs each transponder band of frequencies to the appropriate antenna or antenna beam. In a large satellite there may be four or five beams to which any transponder can be connected. The switch setting can be controlled from the earth to allow reallocation of the transponders between the downlink beams as traffic patterns change.

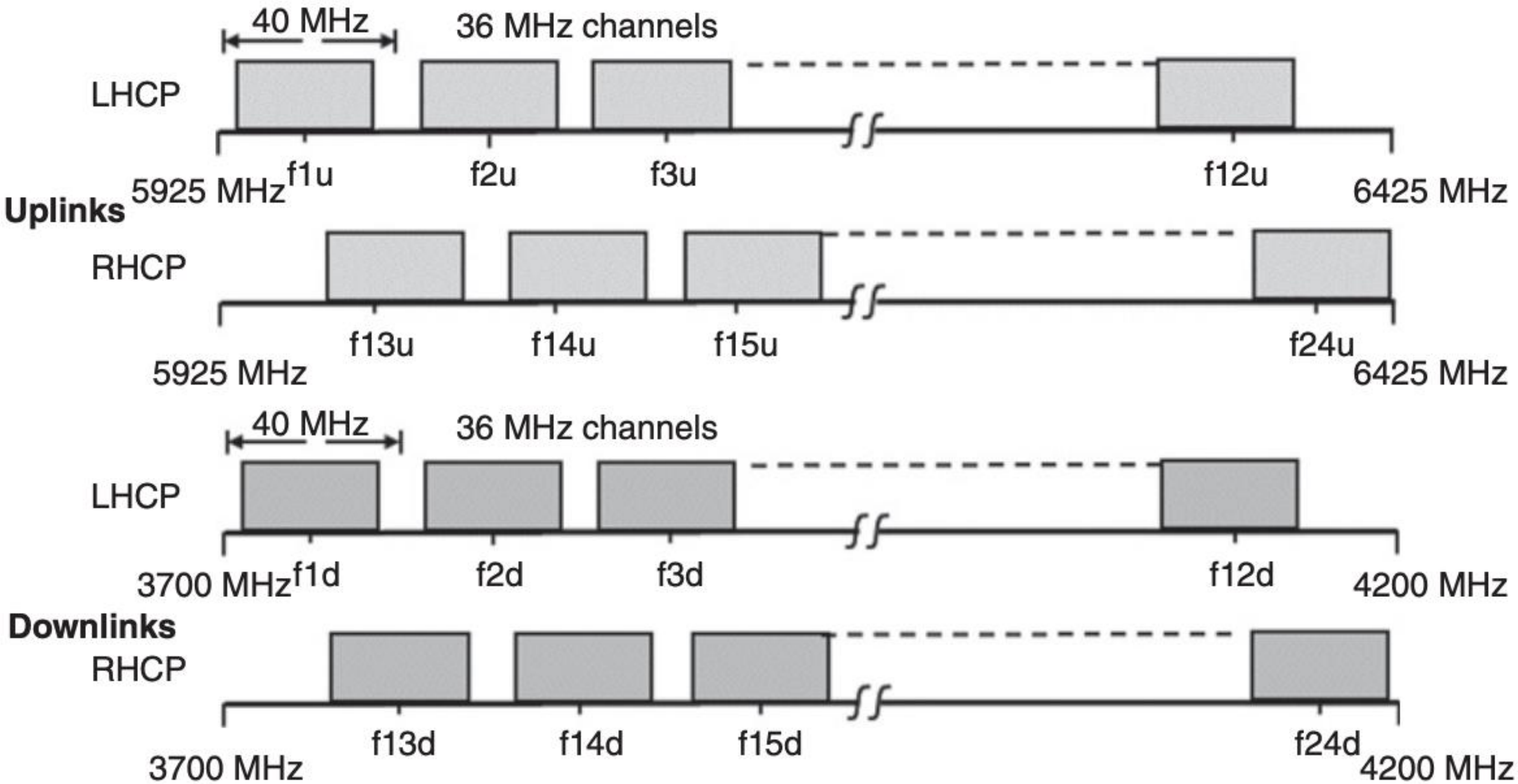
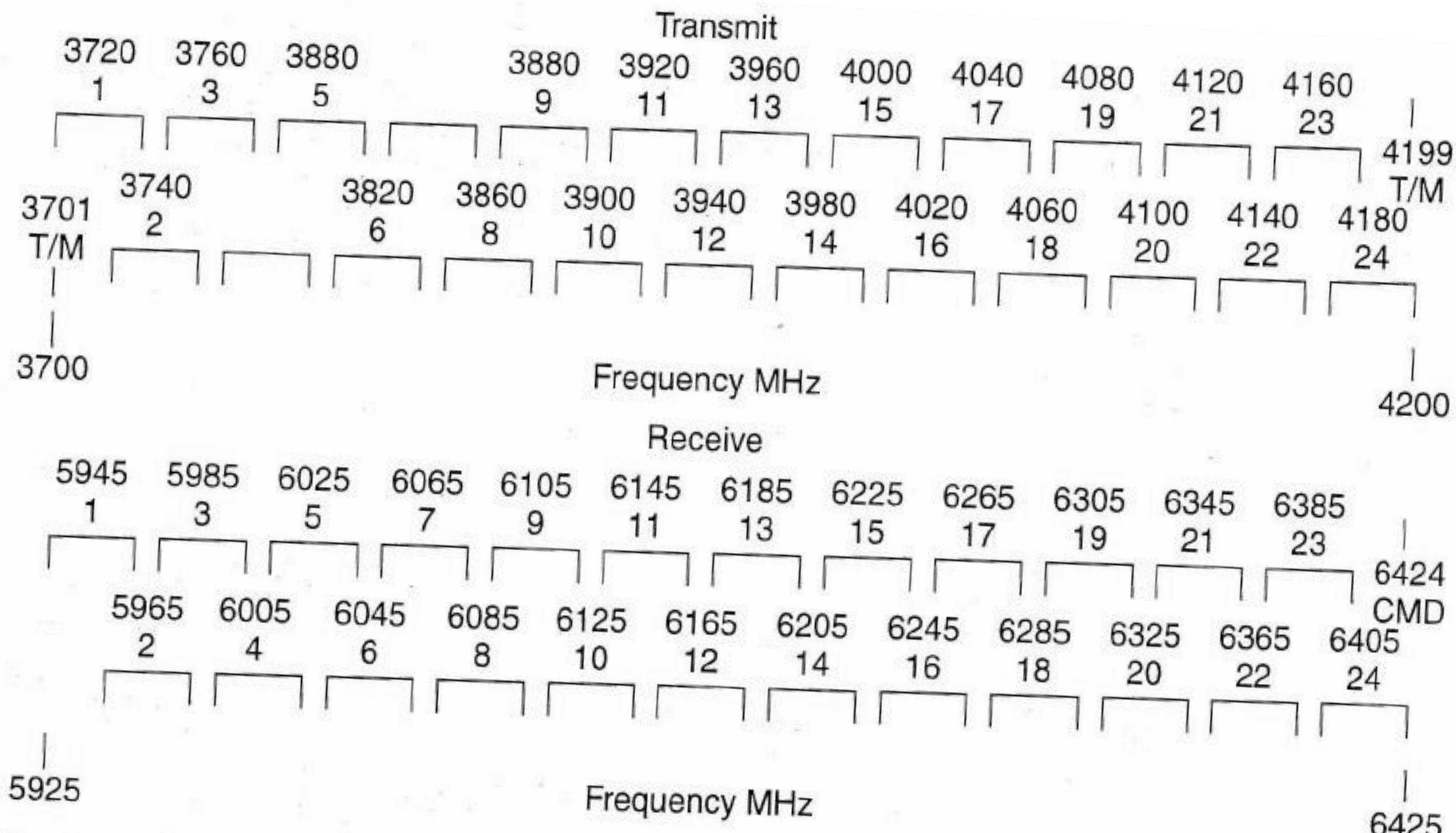


Figure 3.9b Frequency plan for the transponders in Figure 3.9a. Note that there is a 20 MHz frequency shift between transponders for orthogonal polarized signals. *fnu* is an uplink frequency, *fnd* is the corresponding downlink frequency, 2225 MHz below the uplink frequency.



Frequency plan. Note: Number below channel center frequency refers to transponder identity.

Figure 3.9b shows the frequency plan for this satellite.

There are twelve for each polarization spaced 40 MHz apart. The uplink 36 MHz band- width transponders channels are labeled *fnu* and the downlink are labeled *fnd*.

All downlink channels are centered at a carrier frequency 2225 MHz below the corresponding uplink channel.

There is a 20 MHz offset between transponders at the same nominal frequency with orthogonal polarizations.

The frequency offset helps the earth station receiver separate the two orthogonally polarized signals and reduces crosstalk between the channels.

By employing LHCP and RHCP channels, the effective bandwidth of the communication system, and hence its communication capacity is doubled, compared to a single polarization system. This technique is known as *frequency reuse*.

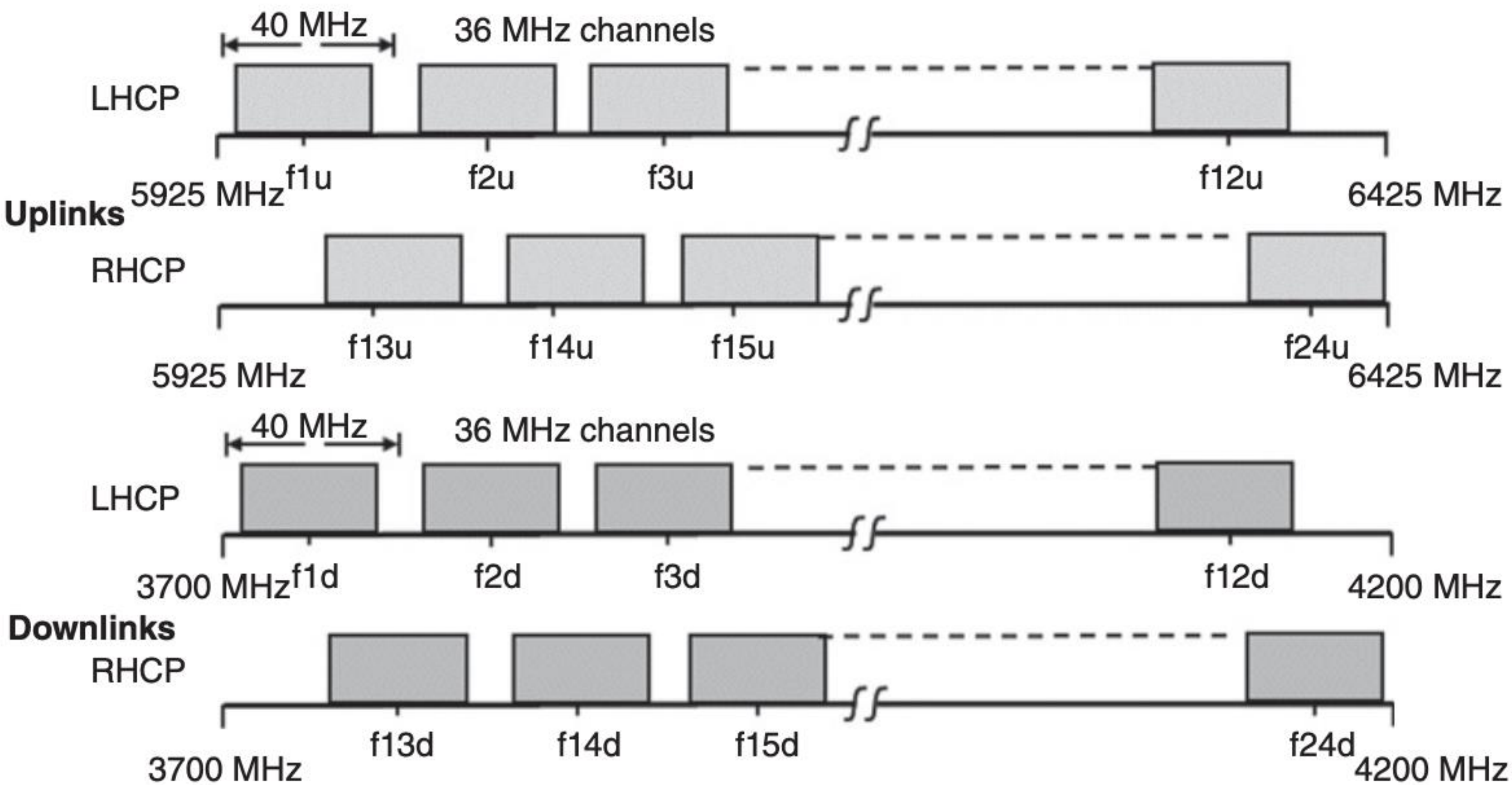


Figure 3.9b Frequency plan for the transponders in Figure 3.9a. Note that there is a 20 MHz frequency shift between transponders for orthogonal polarized signals. *fnu* is an uplink frequency, *fnd* is the corresponding downlink frequency, 2225 MHz below the uplink frequency.

- Satellite Communication Subsystem:

  - Block diagram shown in **Figure 3.9a,** designed for the 6/4 GHz band.
  - 500 MHz bandwidth allocated to the satellite.
  - Divided into twelve channels, each 36 MHz wide.
  - Each channel is handled by a separate transponder.

- Transponder Setup:
  - Two sets of transponders:
    - One set for LHCP (left hand circularly polarized) uplink signals.
    - Another set for RHCP (right hand circularly polarized) uplink signals.
  - Each transponder consists of:
    - Band pass filter (BPF) to select the channel's band of frequencies.
    - Downconverter to change the input frequency from 6 GHz to 4 GHz at the output.
    - High-power output amplifier.
- Redundancy and Fail-Safe Mechanism:
  - Two receivers operate in parallel.
  - If one receiver fails, the other continues to operate.
  - Parallel arrangement preferred over an input switch to avoid catastrophic failure if the switch malfunctions.

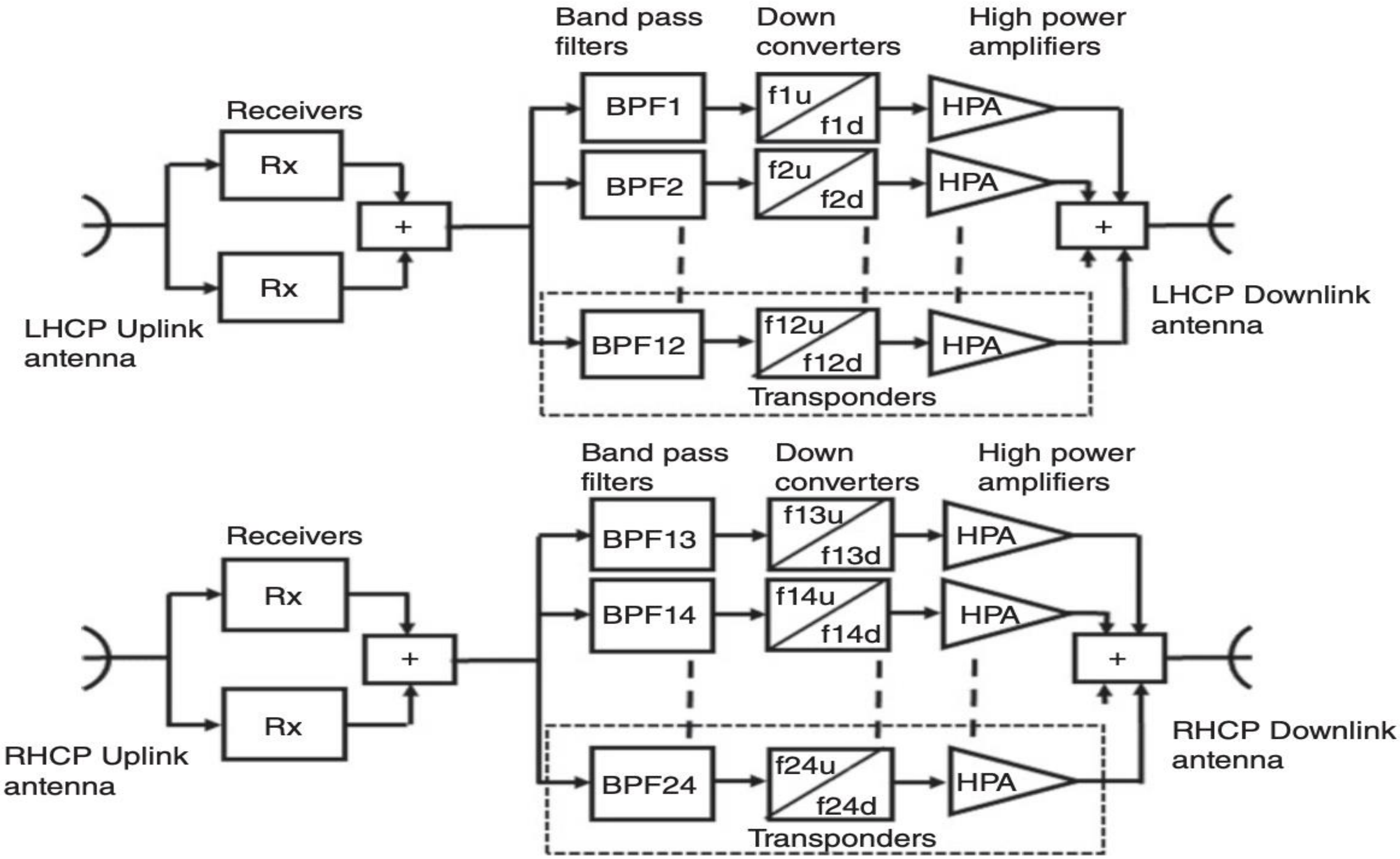


Figure 3.9a Example of a system of 24 transponders for a 6/4 GHz satellite operated with orthogonal circularly polarized signals. Each bandpass filter has a different center frequency according to the frequency plan in Figure 3.9b. The down conversion frequency shift is 2225 MHz. LHCP, left hand circular polarization; RHCP, right hand circular polarization.

The parallel arrangement is preferable to an input switch, which creates a catastrophic failure if it fails to operate.

Figure 3.11 shows a typical single conversion bent pipe transponder of the type used on many satellites for the 6/4 GHz band. The signal from the uplink antenna is amplified in a **wideband low noise amplifier (LNA)** and then applied to a **band pass filter that covers the entire 6 GHz uplink band.** The signal is then **down converted to the 4 GHz band with a mixer and local oscillator (LO)**. **The local oscillator has a frequency of 2225 MHz and is followed by a 4 GHz band pass filter.** The frequency conversion process generates two signals known as sum and difference components. The sum signal frequency is equal to the sum of the input frequency and the LO frequency and the difference frequency is equal to the input frequency minus the LO frequency. The difference frequency is needed in a down converter, so a band pass filter must follow the mixer to block the sum component.

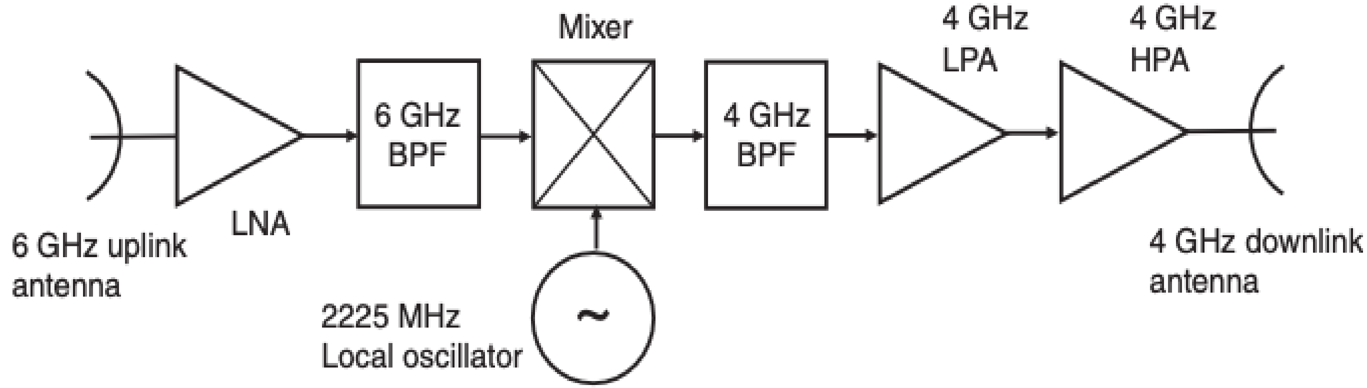


Figure 3.11 Simplified diagram of a bent pipe transponder for the 6/4 GHz band. The mixer and local oscillator form a down converter that changes the 6 GHz frequency of signals received from the uplink to 4 GHz for retransmission to earth. LNA, Low noise amplifier; BPF, Band pass filter; LPA, Low power amplifier; HPA, High power amplifier.

For example, if a signal received by the transponder in Figure 3.11 has a carrier frequency of **6.100 GHz** and a bandwidth of **36 MHz,** the output of the mixer will have two components: a difference component centered at **6.100–2.225 GHz = 3.875 GHz**, and a sum component centered **at 6.100 + 2.225 GHz = 8.325 GHz**. The BPF following the down conversion mixer will be centered **at 3.875 MHz** to accept the difference component and block the sum component, with a bandwidth of 36 MHz. The 6 GHz receiver in Figure 3.11 **typically covers 500 MHz,** or a larger bandwidth, depending on which portion of the **6/4 GHz band** is used. Multiple carriers can be sent to the satellite from one earth station, or from many earth stations, with a typical carrier frequency spacing of 40 MHz as illustrated in Figure 3.9b.

Transponders for use in the 14/11-GHz bands normally employ a double frequency conversion scheme as illustrated in Figure 3.13. It is easier to make filters, amplifiers, and equalizers at an intermediate frequency (IF) such as 1100-MHz than at 14 or 11 GHz, so the incoming 14-GHz carrier is translated to an IF of around 1 GHz. The amplification and filtering are performed at 1 GHz and a relatively high-level carrier is translated back to 11 GHz for amplification by the HPA.

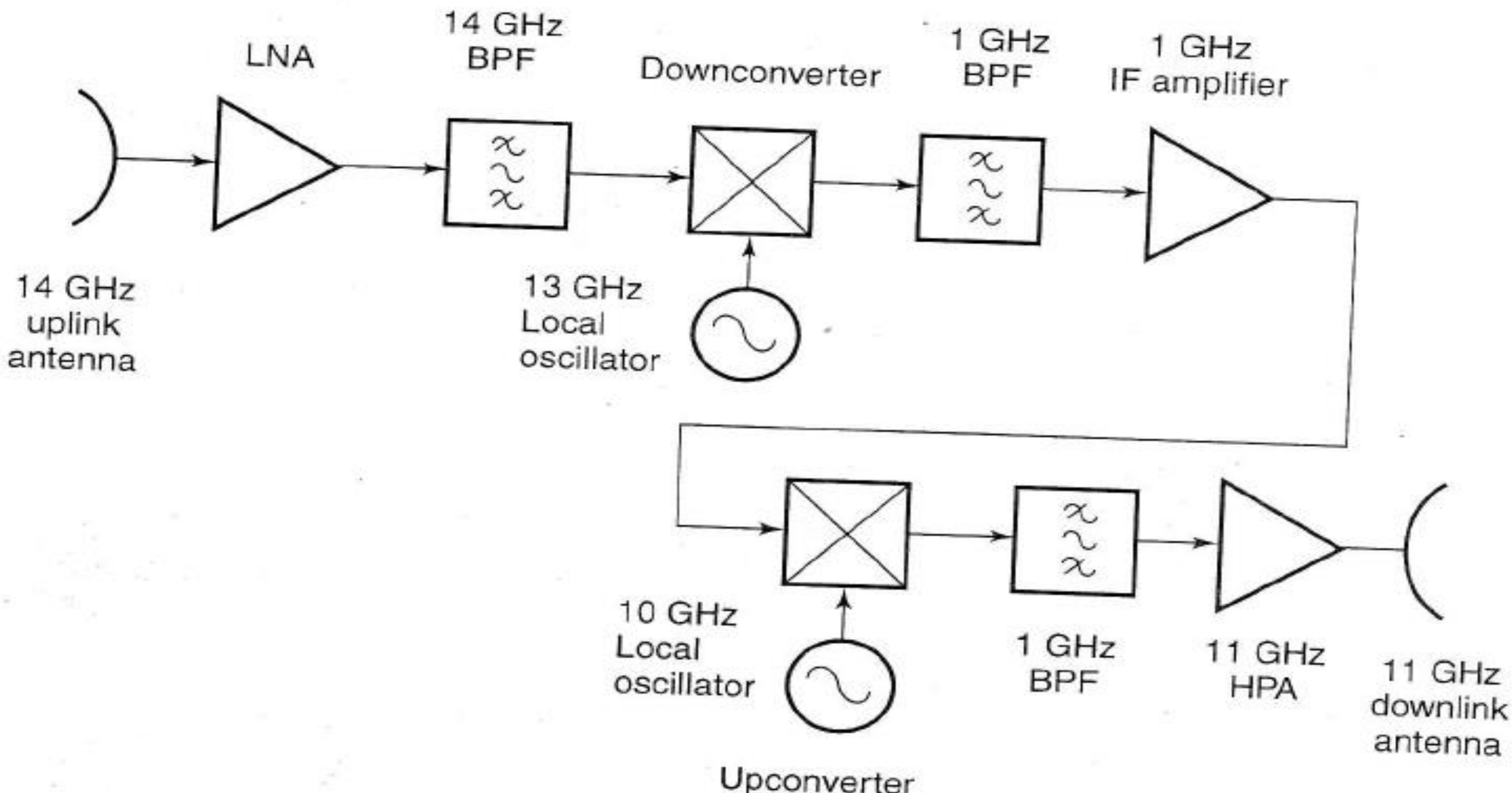


FIGURE 3.13 Simplified double conversion transponder (bent pipe) for 14/11 GHz band.

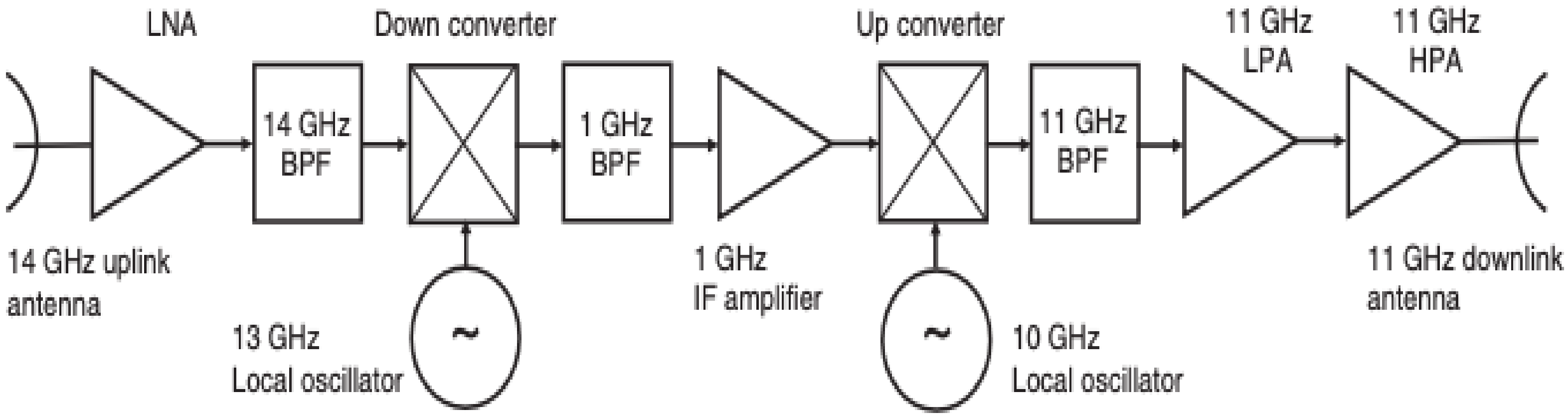


Figure 3.12 Double frequency conversion bent pipe transponder for the 14/11 GHz band. The uplink signals at 14 GHz are downconverted to an intermediate frequency of 1 GHz, amplified, and then up converted to the 11 GHz downlink frequency for retransmission to earth. LNA, Low noise amplifier; BPF, Band pass filter; LPA, Low power amplifier; HPA, High power amplifier; IF, Intermediate frequency.

Transponders for use in the **14/11 and 30/20 GHz bands normally employ a double frequency conversion scheme** as illustrated in Figure 3.12. It is easier to make filters, amplifiers, and equalizers at an intermediate frequency such as **1 GHz** than at 14 or 11 GHz, **so the incoming 14 GHz carrier is translated to an IF around 1 GHz**. The amplification and filtering are performed at 1 GHz and a relatively high level carrier is trans- lated back to 11 GHz for amplification by the HPA.

(2) Onboard Processing (OBP) Transponder:

Figure 3.13 illustrates the structure of an **OBP transponder**. The information needed to select the correct spot beam is contained in the headers of the packets received at the satellite, so the transponder must recover the headers at baseband to extract the spot beam pointing data. A complete digital receiver is required, followed by a conventional transmitter, and a control system that selects which beam receives which packet.

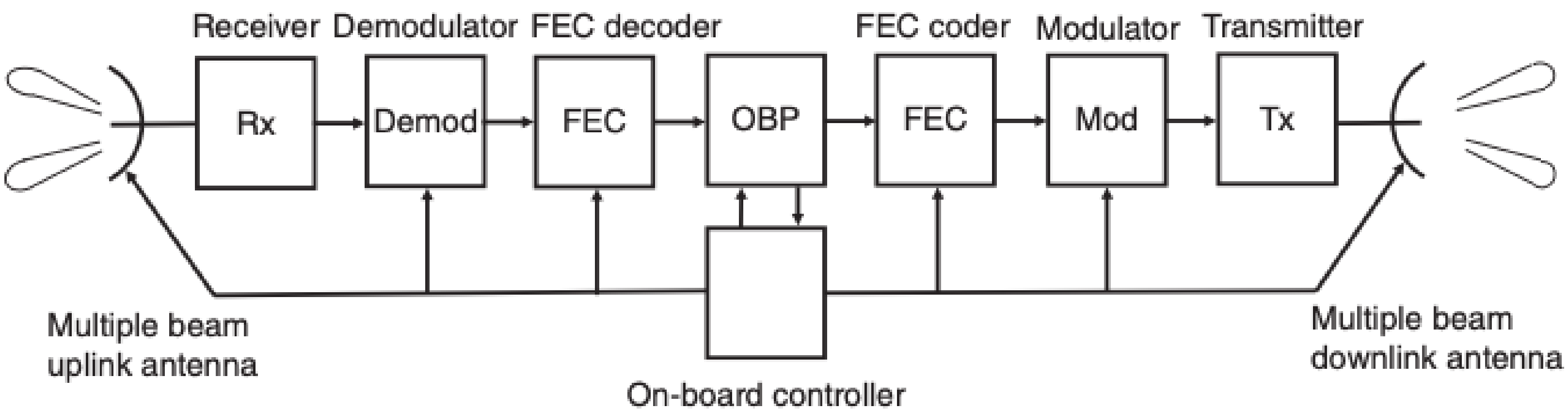


Figure 3.13 Onboard processing (OBP) transponder with multiple beam antennas. The processor extracts the header from each received packet, reads the beam designation, and sets switches to direct the packet to the correct downlink beam. Information in control packets tells the processor which uplink beam to use. Both uplink and downlink can have adaptive coding and modulation. FEC: Forward error correction.

Onboard processing can be used

- Onboard processing transponders have independent **receivers and transmitters**, allowing the transmitter to operate at a fixed output level.

- This is called a ***regenerative*** **transponder**. When rain affects the uplink reducing the power level of the received uplink signal, the transmitter output power remains the same, unlike a true bent pipe transponder.

- When the processor has **FEC** decoding on the uplink, errors can be removed before the packets are transmitted back to the ground.

- **Automatic gain control** can be implemented in a bent pipe transponder to maintain a constant transmitter power, but the uplink receiver noise power adds to the earth station receiver noise power and the resulting bit error rate at the receiving earth station is higher than with a regenerative transponder.

Figure 3.10a shows a simplified diagram of the communication system carried by a typical Intelsat satellite serving the Atlantic Ocean region. Figure 3.10b shows the various beams generated by the satellite.

The switch matrix has **six inputs and six outputs** allowing a very large number of variations in connecting the 6-GHz receivers to the 4- GHz transmitters, and also interconnecting the 6/4 and 14/11 GHz sections. This provides Intelsat with a great deal of flexibility in setting up links through the satellite.

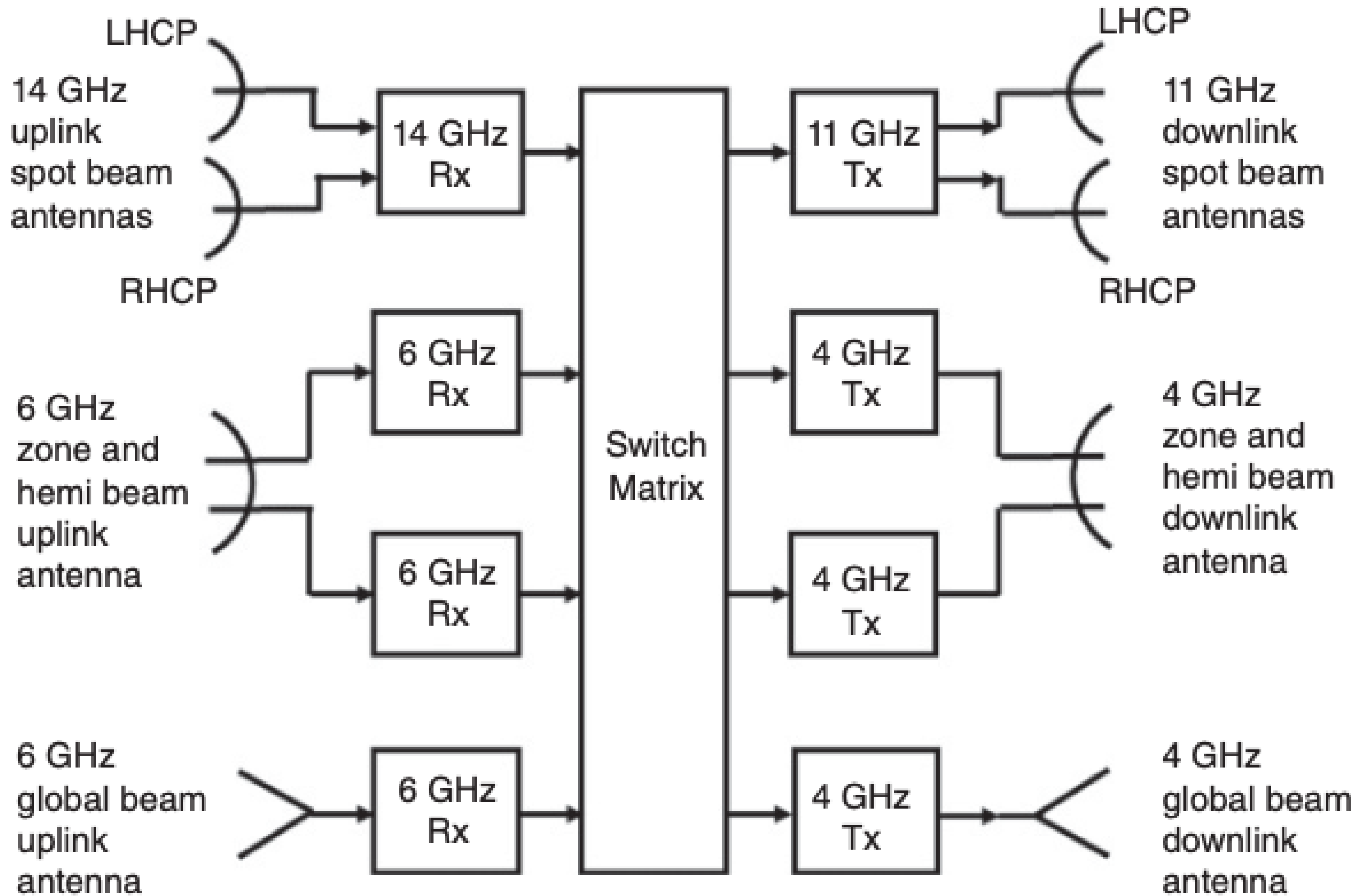
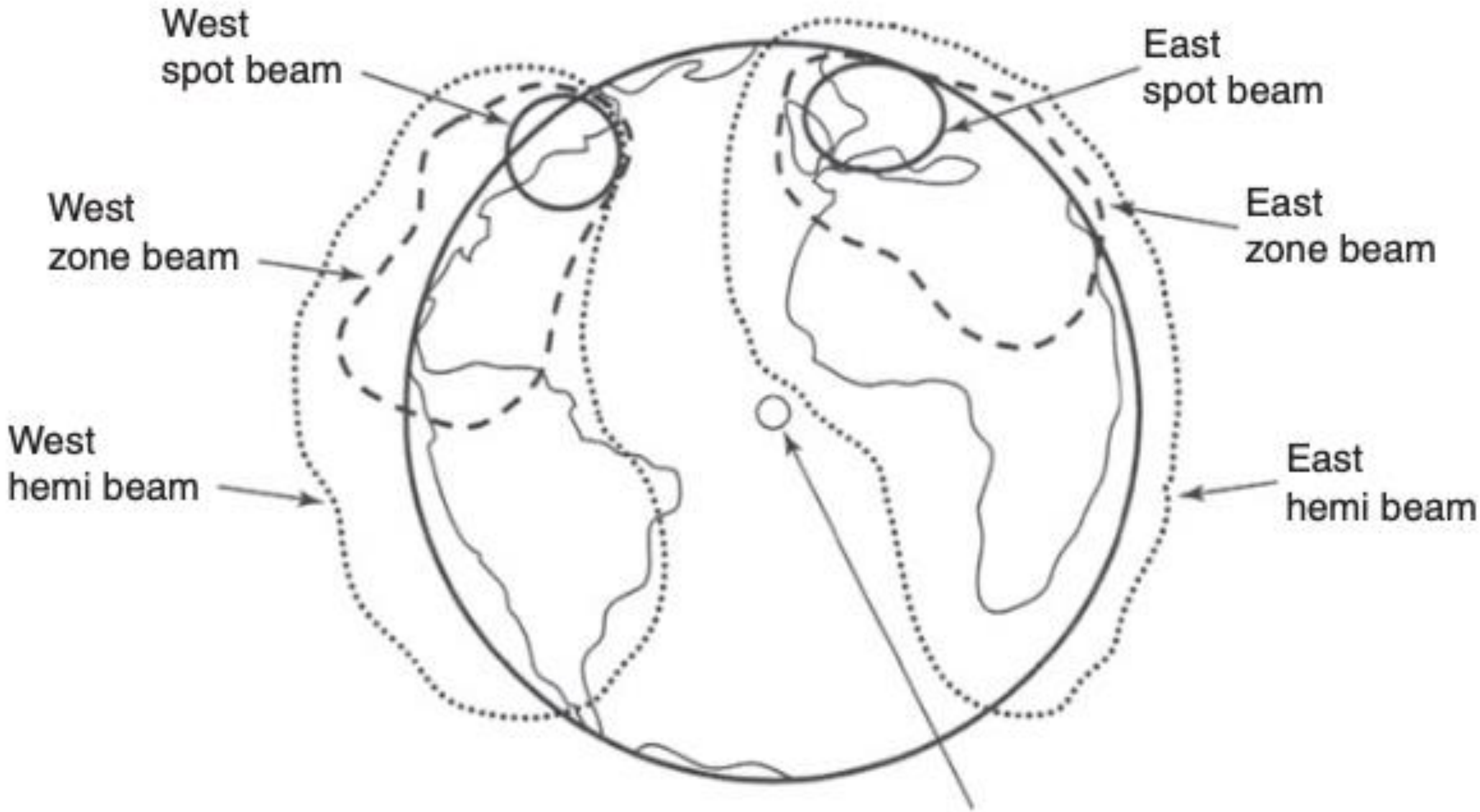


Figure 3.10 (a) Simplified diagram showing the communication system of a typical Intelsat satellite serving the Atlantic Ocean region using the 6/4 and 14/11 GHz bands. (b) The satellite generates seven beams which operate in both receive and transmit. There is a 6/4 GHz global beam with a small number of transponders, two 6/4 GHz hemisphere beams and two 6/4 GHz zone beams that carry the bulk of the 6/4 GHz traffic, and two 14/11 GHz spot beams centered on North America and Western Europe. The switch matrix is a 6 × 6 microwave switch that allows interconnection between beams, a form of on-board processing that works for both analog and digital signals.



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