Satellite and Optical Communication

BEC515D

MODULE 2

Earth Station

Earth Station

- An Earth station is a terrestrial terminal station mainly located on the Earth's surface.
- It could even be airborne or maritime.
- Those located on the Earth's surface could either be fixed or mobile.
- Intended for communication with:
  - One or more **manned/unmanned space stations.**
  - One or more **terrestrial stations of the same type** via reflecting satellites or space objects.
- In most of the applications related to communication satellites, earth stations
  - Transmit to satellites
  - Receive from satellites
- Special cases:
  - Receive-only terminals → Broadcast reception
  - Transmit-only terminals → Data gathering

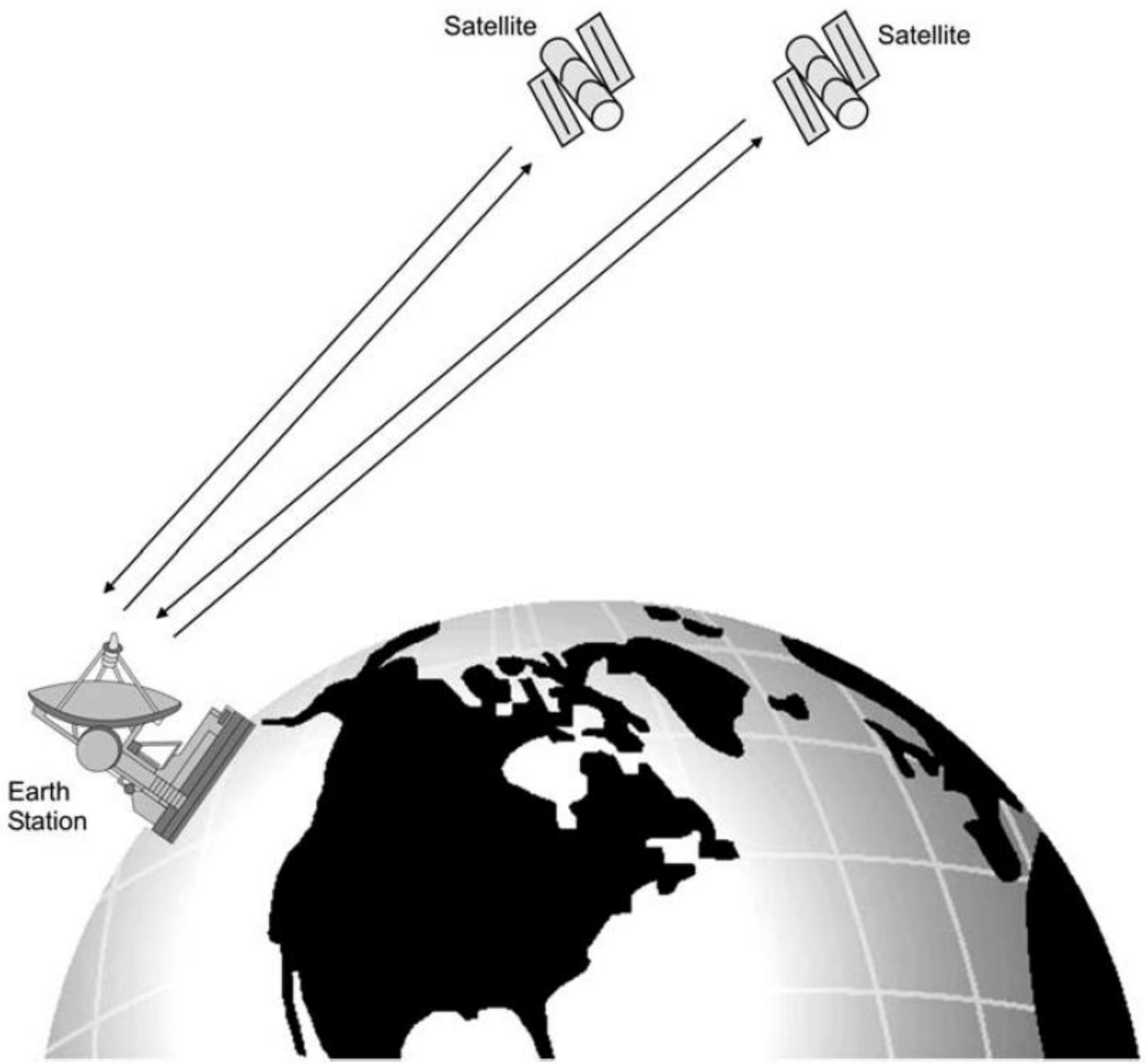


Figure 8.1 Earth station communicating with satellites

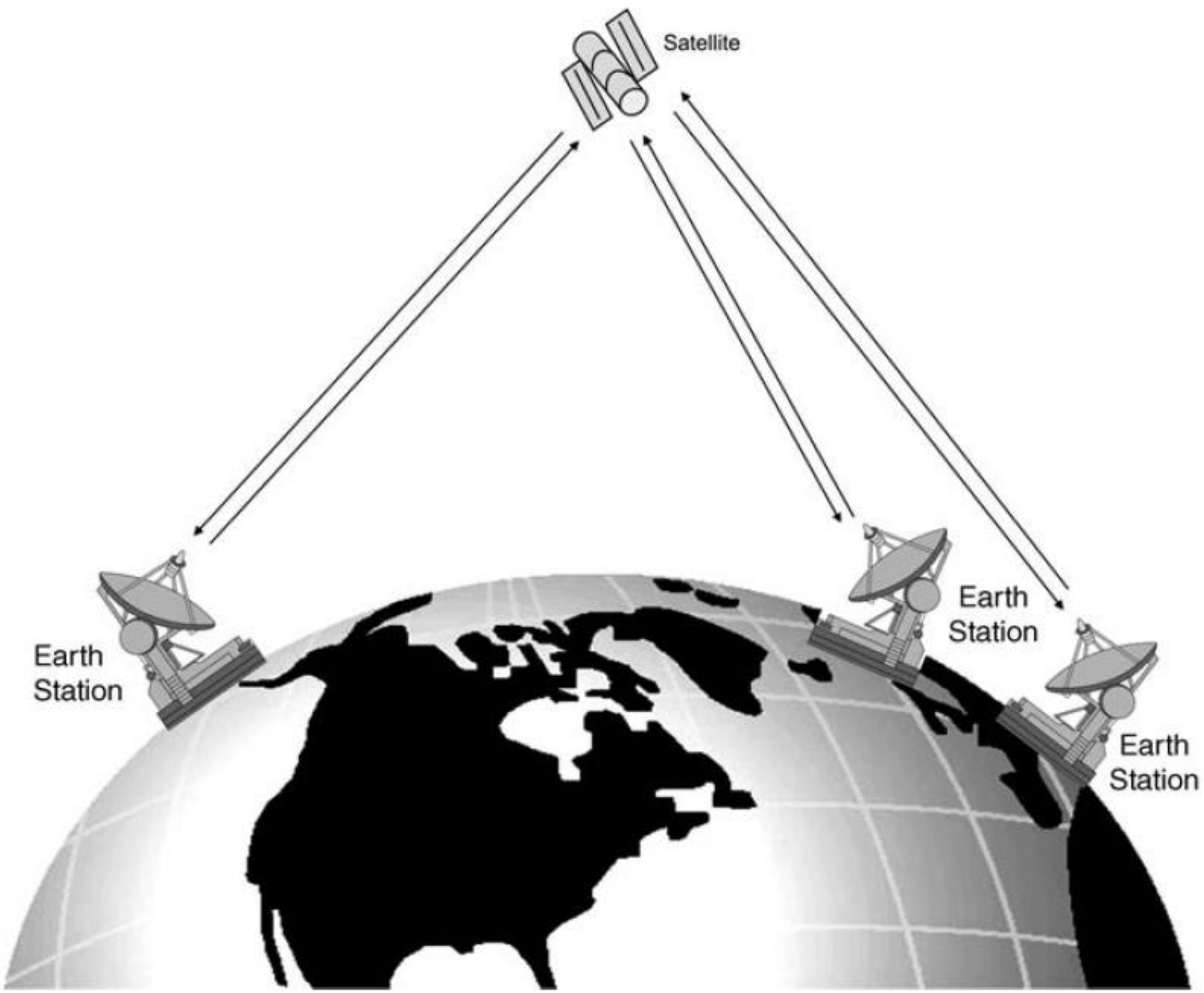


Figure 8.2 Earth station communicating with another Earth station

Earth Station

- Major Subsystems of an Earth Station
  - Transmitter System – sends signals; complexity depends on number of carrier frequencies & satellites
  - Receiver System – receives signals; complexity depends on frequencies & satellites handled
  - Antenna System – usually one antenna for both Tx/Rx with multiplex arrangement
  - Tracking System – keeps antenna pointed at satellite
  - Terrestrial Interface Equipment – connects to ground networks
  - Primary Power – supplies reliable energy to run station
  - Test Equipment – ensures routine maintenance & proper operation

Earth Station

- Earth Station Design Considerations
  - Type of Service – FSS, BSS, MSS, etc.
  - Quality of Service – governed by G/T
  - Communication Requirements – telephony, data, TV, etc.
  - International Regulations
  - Cost & Site Constraints

Earth Station

- The Earth station is characterized by
  - Frequency band (6/4 GHz, 14/12 GHz, etc.)
  - Polarization (linear, circular, etc.)
  - Antenna diameter
  - EIRP (Effective Isotropic Radiated Power)
  - G/T and receive antenna gain
  - Modulation type
  - Access method (FDMA, TDMA, etc.)

Types of Earth Station

Types of Earth Stations

- Based on Service Provided:
  - Fixed Satellite Service (FSS) Earth Stations
  - Broadcast Satellite Service (BSS) Earth Stations
  - Mobile Satellite Service (MSS) Earth Stations
- Based on Functional Usage:
  - Single Function Stations – perform a specific role
  - Gateway Stations – link satellite networks with terrestrial networks
  - Teleports – large facilities supporting multiple services & satellites

Fixed Satellite Service (FSS) Earth Stations

- Fixed Satellite Service (FSS): term mainly used in **North America**
- Uses **geostationary communication satellites**
- Applications:
  - Telephony
  - Data communications
  - Radio & TV broadcast feeds
- **Frequency Bands**
  - **C Band:** 3.7 – 4.2 GHz
  - **Ku Band (Europe):** 11.45 – 11.7 GHz, 12.5 – 12.75 GHz
  - **Ku Band (USA):** 11.7 – 12.2 GHz

Fixed Satellite Service (FSS) Earth Stations

- FSS Earth Station Categories
  - Large Earth stations: G/T ≈ 40 dB/K
  - Medium Earth stations: G/T ≈ 30 dB/K
  - Small Earth stations: G/T ≈ 25 dB/K
  - Very small (Tx/Rx): G/T ≈ 20 dB/K
  - Very small (Rx only): G/T ≈ 12 dB/K

Fixed Satellite Service (FSS) Earth Stations

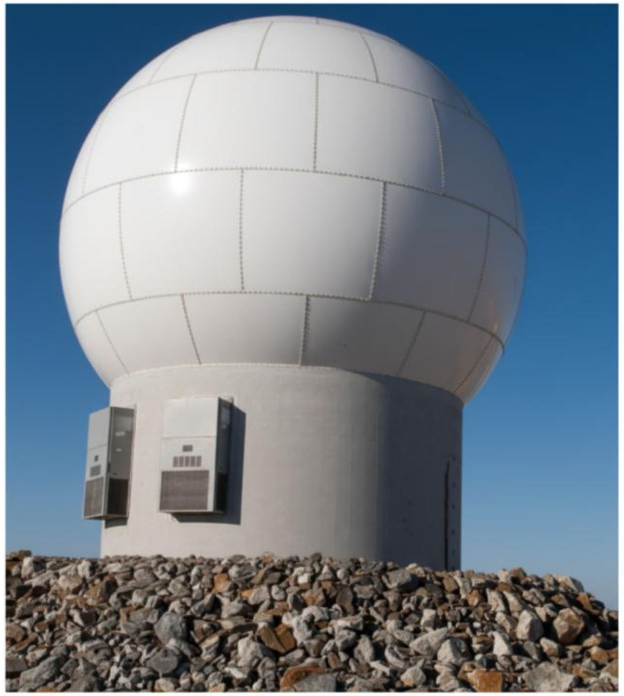


Figure 8.3 Large Earth station

Figure 8.4 Very Small terminal (Transmit/Receive)

Figure 8.5 Very small terminal (Receive only)

Fixed Satellite Service (FSS) Earth Stations

FSS vs BSS Satellites

Feature	FSS Satellites	BSS Satellites
Power	Lower	Higher
Dish Size	Larger required	Smaller sufficient
Polarization	Linear	Circular

Broadcast Satellite Service (BSS) Earth Stations

- BSS refers to satellite broadcast services in specific frequency bands
- International Telecommunications Union (ITU) adopted an international BSS plan in the year 1977.
  - Each country was allotted specific frequencies for use at specific orbital locations for domestic services.
- Frequency Bands
  - Region-1 (Europe, Russia, Africa): 10.7 – 12.75 GHz
  - Region-2 (North & South America): 12.2 – 12.7 GHz
  - Region-3 (Asia, Australia): 11.7 – 12.2 GHz

Broadcast Satellite Service (BSS) Earth Stations

- BSS is also known by the name of Direct Broadcast Service (DBS) or more commonly as Direct-to-Home (DTH)
  - **BSS (Broadcast Satellite Service)** – ITU technical term
  - **DBS (Direct Broadcast Service)** – often interchangeable with DTH
  - **DTH (Direct-to-Home)** – common term for individual dish reception
  - Covers both **analog & digital video/audio** services
- Applications:
  - TV & Radio Broadcasting
  - DTH Services
  - Community & Individual Reception

Broadcast Satellite Service (BSS) Earth Stations

- BSS Earth Station Categories
  - Large Earth Stations: $G/T \approx 15$ dB/K
    - Used for **community reception**
  - Small Earth Stations: $G/T \approx 8$ dB/K
    - Used for **individual reception (DTH)**

Mobile Satellite Service (MSS) Earth Stations

- MSS refers to satellite-based communication for mobile users
- Provides communication via satellites instead of terrestrial towers
- Satellite phone – most common MSS device
- Applications:
  - Voice & data communication
  - Remote area connectivity
  - Maritime & aviation services

Mobile Satellite Service (MSS) Earth Stations

- MSS Earth Station Categories
  - **Large Earth Stations**: G/T ≈ −4 dB/K (with tracking)
  - **Medium Earth Stations**: G/T ≈ −12 dB/K (with tracking)
  - **Small Earth Stations**: G/T ≈ −24 dB/K (without tracking)

Mobile Satellite Service (MSS) Earth Stations

- Satellite Types for MSS
  - Geostationary Satellites (GEO):
    - Require **3–4 satellites** for global coverage
    - Very heavy & costly
    - Disadvantages:
      - Call/data delay (latency)
      - Line-of-sight problems due to obstacles
  - Low Earth Orbit (LEO):
    - Obstacle blocks only briefly (another satellite soon overhead)
    - Requires **constellation of satellites** for uninterrupted coverage
    - Advantage: **Worldwide wireless coverage, minimal gaps**

Mobile Satellite Service (MSS) Earth Stations

- Examples of LEO MSS Systems
  - Iridium
    - 66 satellites
    - Polar orbits → covers **entire globe** including polar regions
    - Uses **inter-satellite radio links** to relay data
  - Globalstar
    - 44 satellites
    - Orbital inclination: **52°**
    - **No coverage** in polar regions
  - Starlink
    - Planned constellation of **over 12,000 satellites** (future expansion up to 42,000)
    - Provides **high-speed broadband internet** globally
    - Uses **laser inter-satellite links** for fast data routing

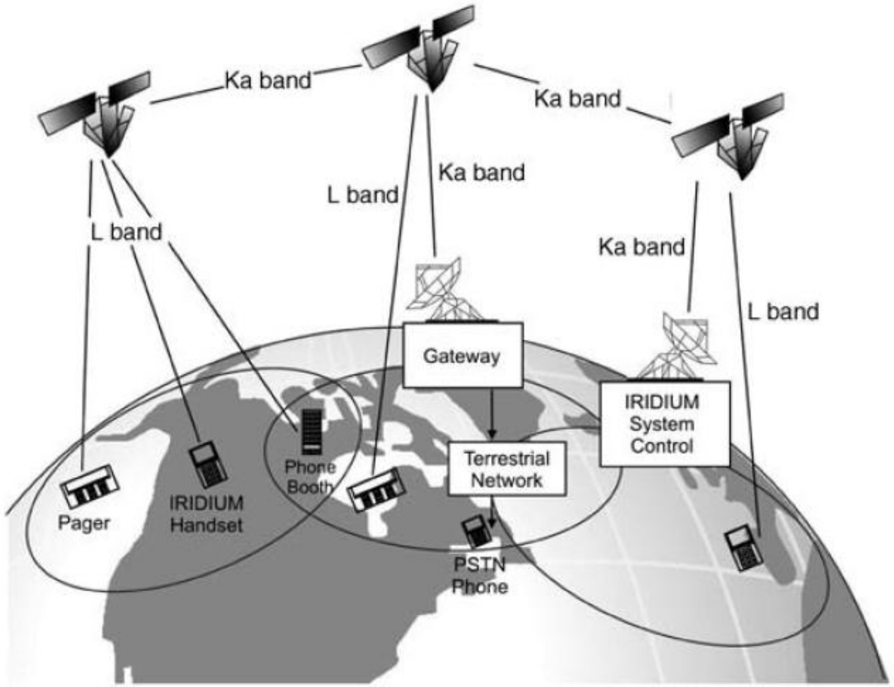


Figure 8.6 Iridium system

Single Function Stations

- Characterized by a single type of link to a satellite (Tx-only, Rx-only, or both)
- Examples:
  - Television receive-only (TVRO) terminals → individual TV reception
  - Satellite radio terminals
  - Receive-only terminals at broadcast stations (contribution feeds)
  - Two-way VSAT terminals → retail point-of-sale communication with hub
  - Handheld satellite phones → designed for one satellite constellation

Figure 8.7 TVRO terminal

Gateway Stations

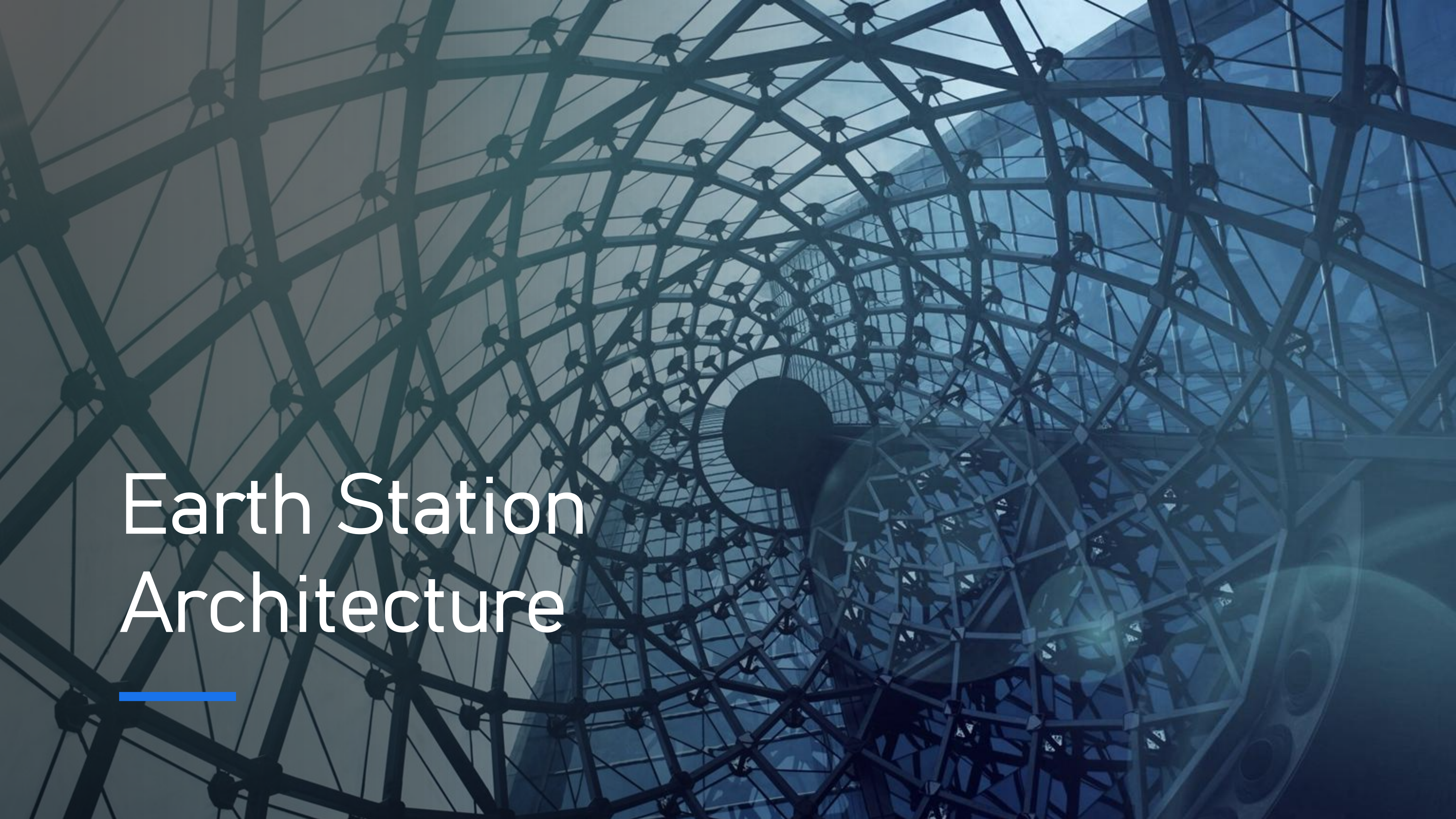
- Interface between satellites & terrestrial networks
- Serve as transit points between satellites
- Connections:
  - Wired → coaxial cables, optical fibres
  - Wireless → microwave towers

Teleports

- Type of gateway station operated by independent firms
- Useful when:
  - Company's satellite needs are not large enough for own dish
  - Obstructed line-of-sight (e.g., tall buildings nearby)
- Key Features:
  - Located on city outskirts
  - Subscriber → Hub → Teleport (via fibre/microwave)
  - Versatile: multiple dishes for many satellite operators

Teleports

- Services Offered:
  - Format conversion & encryption
  - Production / post-production
  - Turn-around services
  - Leasing of transportable uplinks for temporary events



Earth Station Architecture

Earth Station Architecture

- The major components of an Earth station include the *RF section*, the *baseband equipment* and the *terrestrial interface*.
- In addition, every Earth station has certain support facilities such as power supply unit with adequate back-up, monitoring and control equipment and thermal and environment conditioning unit (heating, air-conditioning etc.).
- The actual architecture of an Earth station depends on the application.

Earth Station Architecture

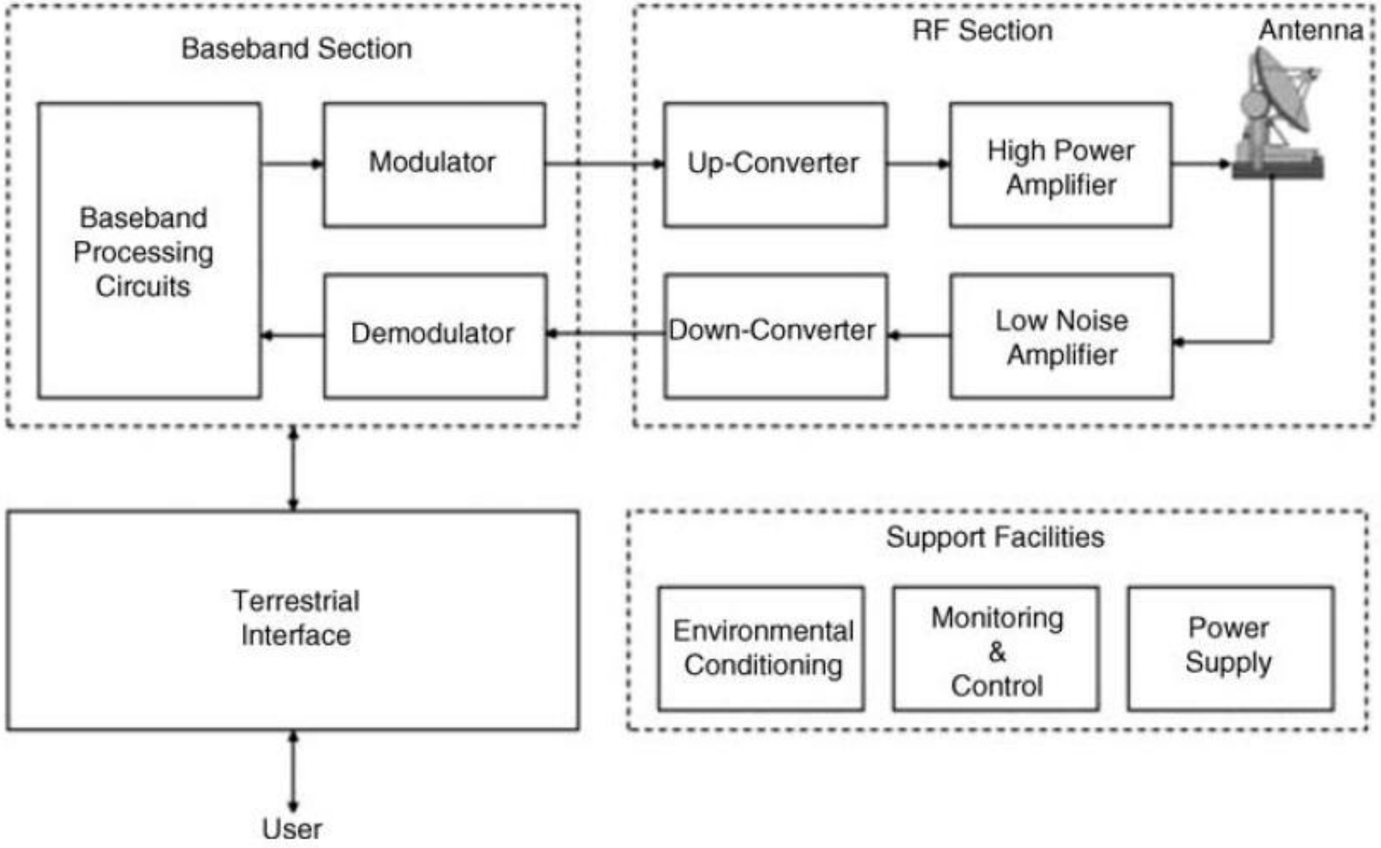


Figure 8.8 Block schematic arrangement of a generalized Earth station

RF Section of an Earth Station

- Antenna Subsystem
  - Transmits & receives signals, provides beam shaping and polarization.
- Uplink Channel
  - Up-converter: Raises baseband to RF uplink frequency.
  - High Power Amplifier (HPA): Boosts signal before transmission.
  - Feed system: Directs signal to antenna, provides Tx/Rx isolation.
- Downlink Channel
  - Low Noise Amplifier (LNA): Amplifies weak signals from satellite with minimal noise.
  - Down-converter: Converts RF signals to intermediate frequency (IF) for baseband processing.
- Reliability
  - Large hubs use **redundant equipment** in RF chain for uninterrupted service.

Baseband Section

- Performs **modulation/demodulation** depending on access technique.
- Example: Two-way digital links use **digital modem + time division multiplexer**.
- Handles multiplexing/demultiplexing of user traffic.
- Connects to terrestrial network via:
  - **Fibre optic links**
  - **Microwave links**
  - Or **direct user access** in small stations.

Terrestrial Interface & Support Facilities

- **Terrestrial Interface** bridges Earth station and user/telecom networks.
- **Support systems** are essential for reliable operation:
  - Power supply with backup (generators, batteries).
  - Tracking, monitoring & control subsystems.
  - Environmental conditioning (cooling, heating, dust-free rooms).

Large FSS Earth Station

- Used to handle **large volumes of traffic** (voice, video, data).
- More **complex design** compared to small stations.
- Incorporates **redundant RF & baseband chains** for reliability.
- Typically part of global networks like INTELSAT.

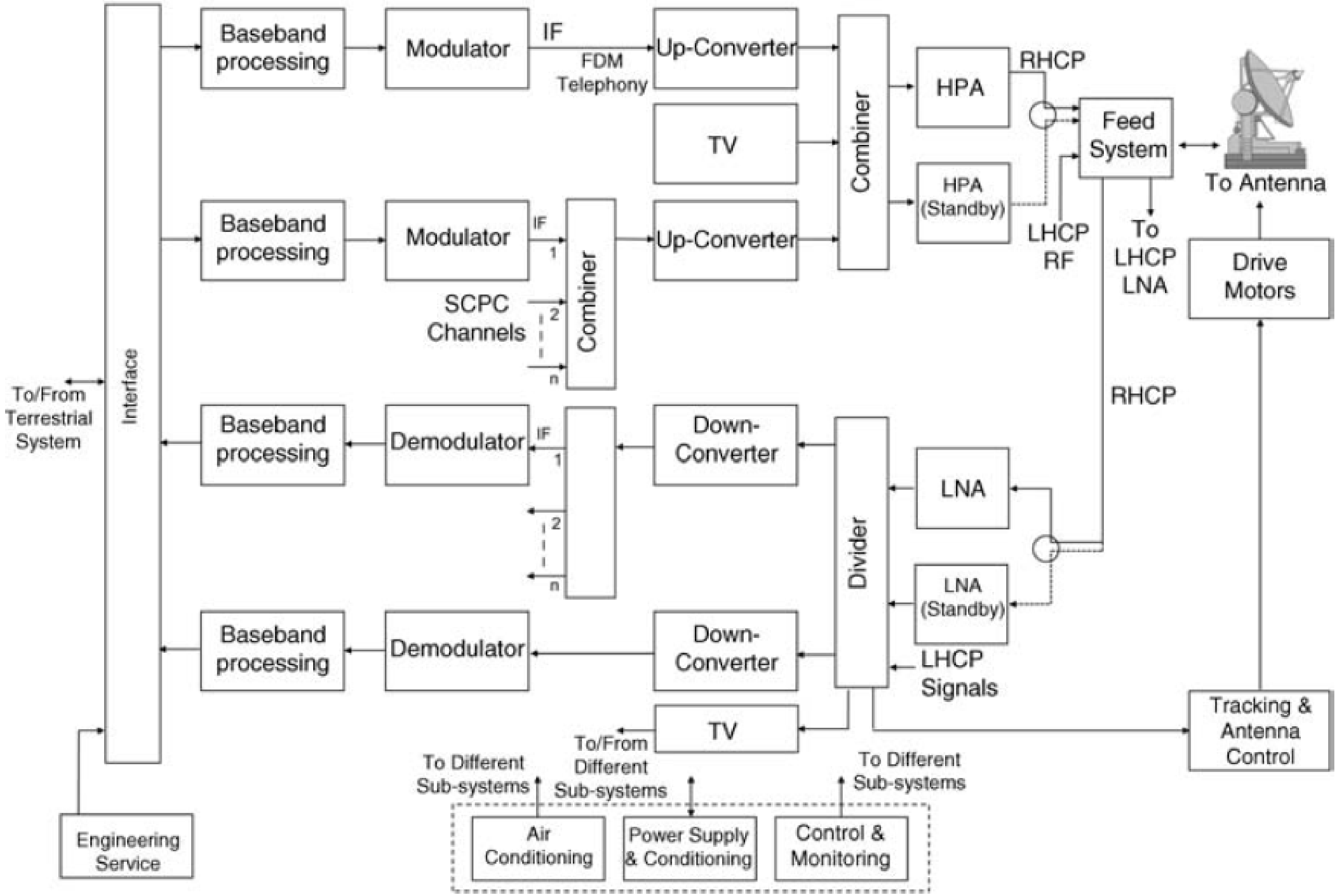


Figure 8.9 Block schematic of a typical large FSS Earth station

VSAT Remote Terminal

- Very Small Aperture Terminal – Designed for **smaller user sites**.
- **Outdoor Unit (RF Section):**
  - Compact box + dish antenna (0.55–2.4 m diameter).
  - Contains RF subsystems for up/down conversion & amplification.
- **Indoor Unit (Baseband Section):**
  - Similar in size to a video recorder.
  - Includes modem, multiplexer/demultiplexer, and user interfaces.
- Provides cost-effective connectivity for **corporates, banks, retail, rural areas**.

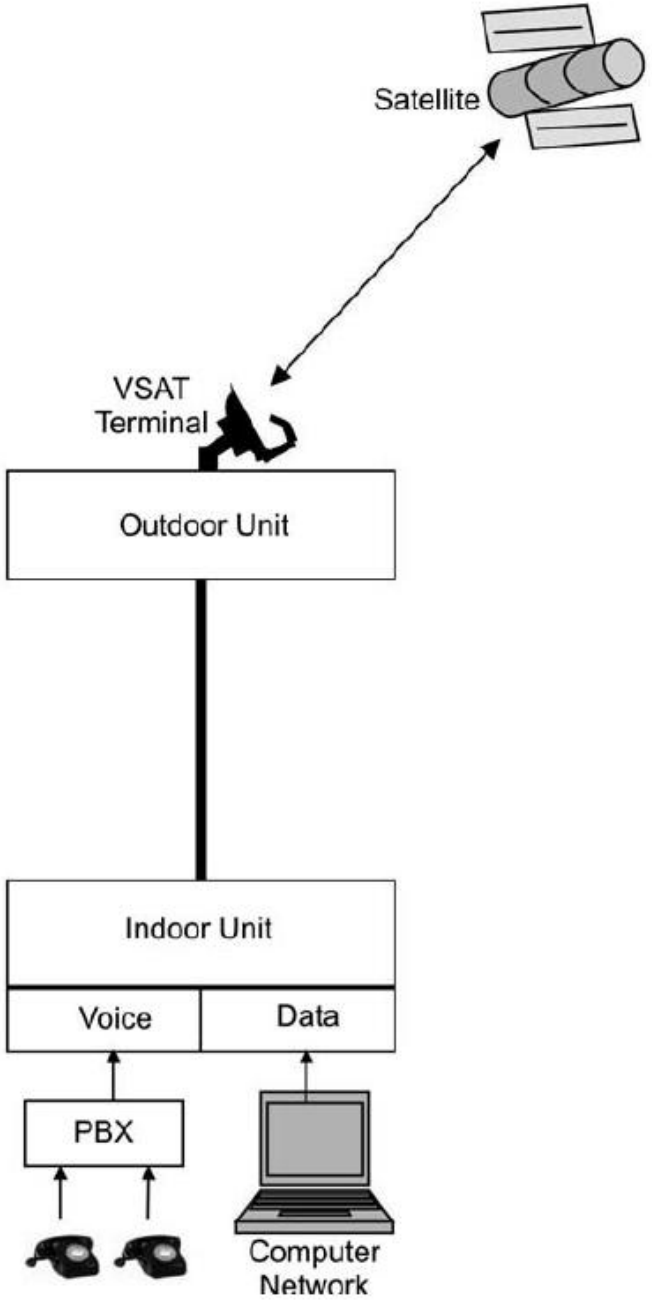


Figure 8.10 Block schematic of VSAT remote terminal

Earth Station Design Considerations

Earth Station Design Considerations

- Design is a two-step process:
  - Identify requirement specifications
  - Choose cost-effective architecture
- Balance between technical performance and economic feasibility

Earth Station Design Considerations

- Requirement Specifications
  - Type of service: FSS, BSS, MSS
  - Communication needs: Telephony, data, TV, etc.
  - Baseband quality at destination
  - System capacity & reliability
- Key Design Parameters
  - Transmitter EIRP (Effective Isotropic Radiated Power)
  - Receiver figure-of-merit (G/T)
  - System noise & interference
  - Allowable tracking error

Earth Station Design Considerations

- Cost Considerations
  - Goal: **Minimize overall system costs** (Earth + Space segment)
  - **Trade-off**:
    - Lower Earth station cost ↔ Higher space segment cost or vice versa
- Economic Principle in Satcom
  - **Every dollar spent on space segment** → cost **shared by many users**
  - **Every dollar spent on user terminal** → cost **multiplied across users**
  - Result: Prefer **less expensive terminals** + **more advanced satellites**

Earth Station Design Considerations

- Design Trade-offs & Constraints
  - Multiple trade-offs possible (cost vs. performance)
  - But subject to:
    - **Technical limits** (noise, interference, reliability)
    - **Regulatory constraints** (spectrum allocation, licensing)

Key Performance Parameters

- Earth station design is governed mainly by:
  - **EIRP (Effective Isotropic Radiated Power)** – transmitter performance
  - **G/T Ratio (Figure of Merit)** – receiver performance
- Together, they determine **signal strength, sensitivity, and overall link quality**.

Key Performance Parameters

Effective Isotropic Radiated Power (EIRP)

- The effective power radiated by the antenna if it were isotropic (radiating equally in all directions).
- Combines **Transmitter Power (HPA)** + **Antenna Gain**.
- Expressed in **dBW**.
- Higher EIRP → stronger signal reaching the satellite.
  - Example: **60 dBW** means the antenna radiates as much as an isotropic radiator that would need 1 million times more input power.
- Used for both **uplink (Earth to satellite)** and **downlink (satellite to Earth)** footprints.

Key Performance Parameters

Receiver Figure-of-Merit (G/T)

- Ratio of **Antenna Gain (G)** to **System Noise Temperature (T)**.
- Expressed in **dB/K**.
- **Importance:**
  - Measures **receiver sensitivity** (ability to detect weak signals).
  - Higher G/T → better link performance.
- **Ways to Improve:**
  - Increase **antenna gain**
  - Reduce **system noise temperature**

Key Performance Parameters

- Link Design Balance:
  - EIRP and G/T **work together** to achieve reliable communication.
  - If **G/T is low**, a **higher EIRP** is required to maintain link quality.
  - If **G/T is high**, required **EIRP can be lower**, reducing power/cost.

Earth Station Design Optimization

- Transmitter EIRP and Receiver G/T dictate system performance
- One can be traded off against the other during design optimization
- Early satellites: low EIRP → required large, costly Earth stations
- Current trend: minimize Earth station complexity, shift burden to space segment
- Possible trade-offs can be best understood by resorting to expression for Earth station *G/T*.

$$G/T = C/N_o - EIRP + (L_p + L_m) + k$$

C/N_o is carrier-to-total noise power spectral density, $EIRP$ is satellite's effective isotropic radiated power, L_p is path loss, L_m is link margin and k is Boltzmann constant (in dBs)

Earth Station Design Optimization

- For minimal cost → G/T should be minimized
- Achieved by:
  - Higher satellite EIRP
  - Lower carrier-to-noise ratio (C/N)
  - Noise-immune modulation & coding techniques
- Other Governing Factors
  - Earth station EIRP requirements
  - Antenna tracking & size
  - Traffic handling capacity
  - Terrestrial interface needs
  - International regulations & technical constraints

Earth Station Design Optimization

- ITU Constraints & Solutions
  - Early ITU limits on satellite EIRP (to protect terrestrial systems)
  - Impact: lower limit on Earth station antenna size
  - Small antennas → higher side lobes → interference
  - Solution: exclusive frequency allocations → allow higher EIRP

Earth Station Design Optimization

- Satellite EIRP is limited by:
  - Satellite DC power availability
  - Onboard high power amplifier capacity
  - Practical antenna size constraints
  - Frequency dependence: lower gain at lower frequencies (e.g., L-band)

Earth Station Design Optimization

- **Achieving Desired Values:** Once EIRP and G/T values are set, the next step is to choose the optimal antenna, HPA, and LNA (Low-Noise Amplifier) configuration.
- **Trade-offs:** Designers can choose between:
  - A small, low-cost antenna paired with an expensive, low-noise LNA.
  - A large antenna and a higher noise figure LNA.
- **Interdependence:** The antenna size also impacts the required HPA power; a smaller antenna may need a very large HPA.

Environmental and Site Considerations

- **Environmental factors:** temperature, humidity, rainfall/snow, wind, earthquakes, corrosion
- **Interference control:** minimize radio frequency interference (RFI) and electromagnetic interference (EMI) (survey required before finalizing site)
- **Line-of-sight:** clear visibility to target satellites is essential
- **Practical needs:** sufficient space, transport access, reliable power supply
- **Best practices:**
  - Operators must specify site/environmental constraints
  - Manufacturers should design equipment for reliable operation under these conditions

Earth Station Testing

Earth Station Testing

- **Purpose:** To ensure the Earth station meets all technical specifications and avoids causing interference to other users or satellites.
- **Three-Phase Process:**
  - **Unit & Subsystem Testing:**
    - Components are tested at the manufacturer's facility.
    - Subsystems are tested for electrical, mechanical, and environmental performance.
    - Users often witness critical tests both at the factory and on-site.
  - **System Level Testing (Acceptance Tests):**
    - The complete integrated system is tested on-site.
    - Verifies performance specifications and compliance with satellite system requirements and international regulations.
    - Includes a wide range of transmit and receive tests, categorized as mandatory and additional.
  - **Line-Up Testing:**
    - Checks the Earth station's performance in conjunction with other stations it will communicate with.
    - Carrier EIRP is adjusted to achieve the desired carrier-to-noise ratio.
    - The final step before the station is cleared for traffic.

Mandatory Tests

- Mandatory tests include measurements of:
  - Transmit cross-polarization isolation
  - Receiver figure-of-merit
  - EIRP stability
  - Spectral shape

Transmit Cross-Polarization Isolation Measurement

- Transmit cross-polarization isolation measurement is performed to guarantee that the power level of the cross-polarized component is either nil or within the tolerance limit so as not to cause any significant interference to other users.
- Measured on-axis, often with a monitoring station, to confirm the antenna's polarization is correctly aligned.

Transmit Cross-Polarization Isolation Measurement

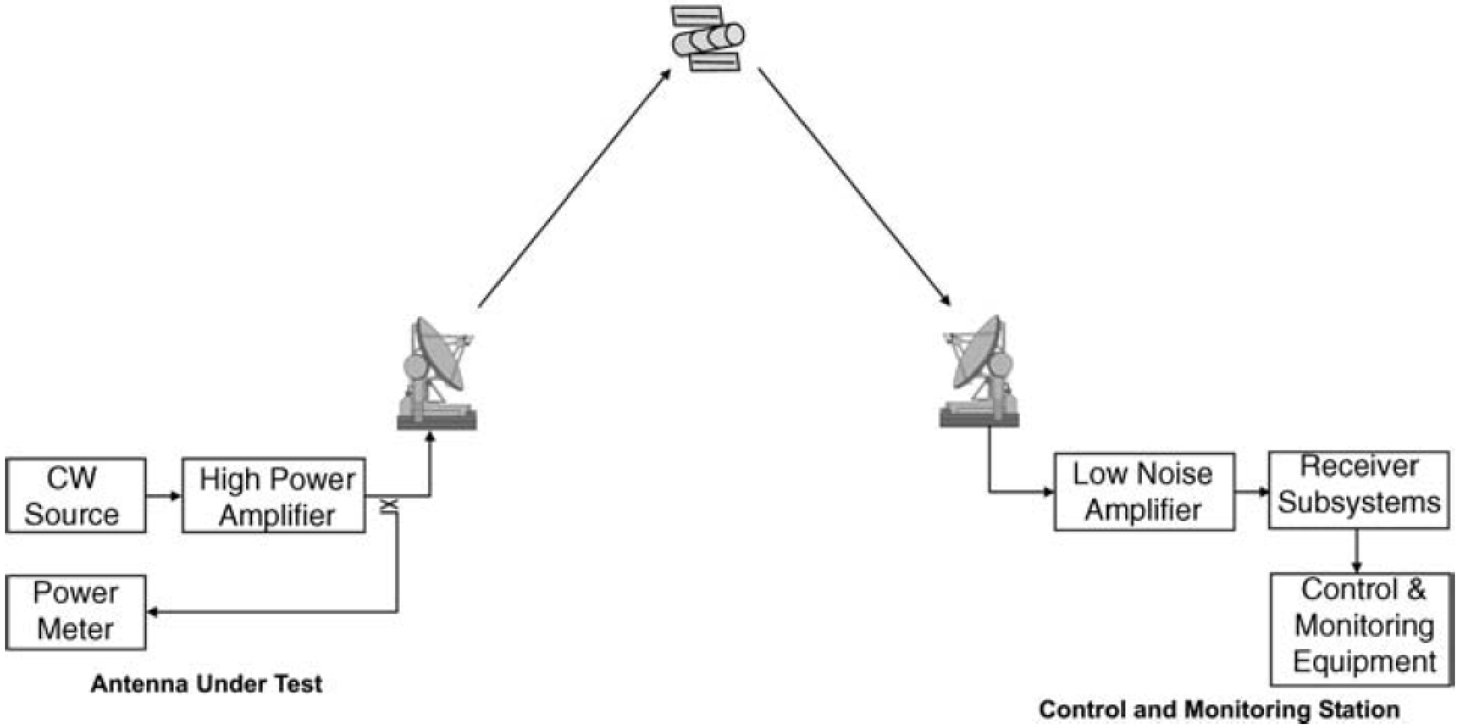
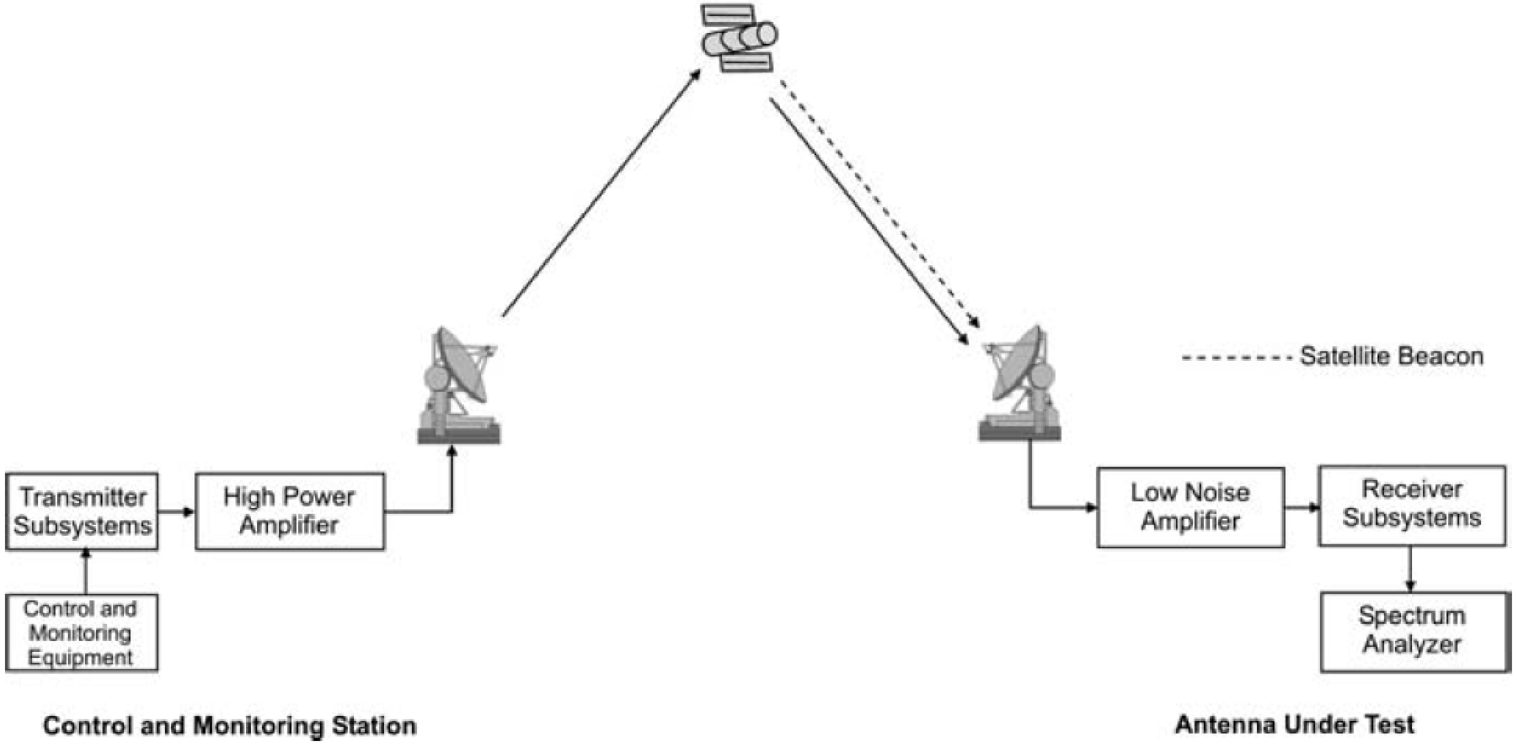


Figure 8.11 Schematic arrangement of transmit cross-polarization isolation measurement

Receiver Figure-of-Merit Measurement

- Determines the station's receiving performance.
- **Method 1 (Spectrum Analyzer):** Measures downlink C/No and satellite EIRP, then calculates G/T. (Simple but less accurate due to atmospheric variations).
- **Method 2 (Gain & System Temperature):** More accurate method that measures the antenna gain and system noise temperature (using the Y-factor method) to calculate G/T.

Receiver Figure-of-Merit Measurement



Method 1

Figure 8.12 Schematic arrangement of test set-up for measurement of receiver G/T

Receiver Figure-of-Merit Measurement

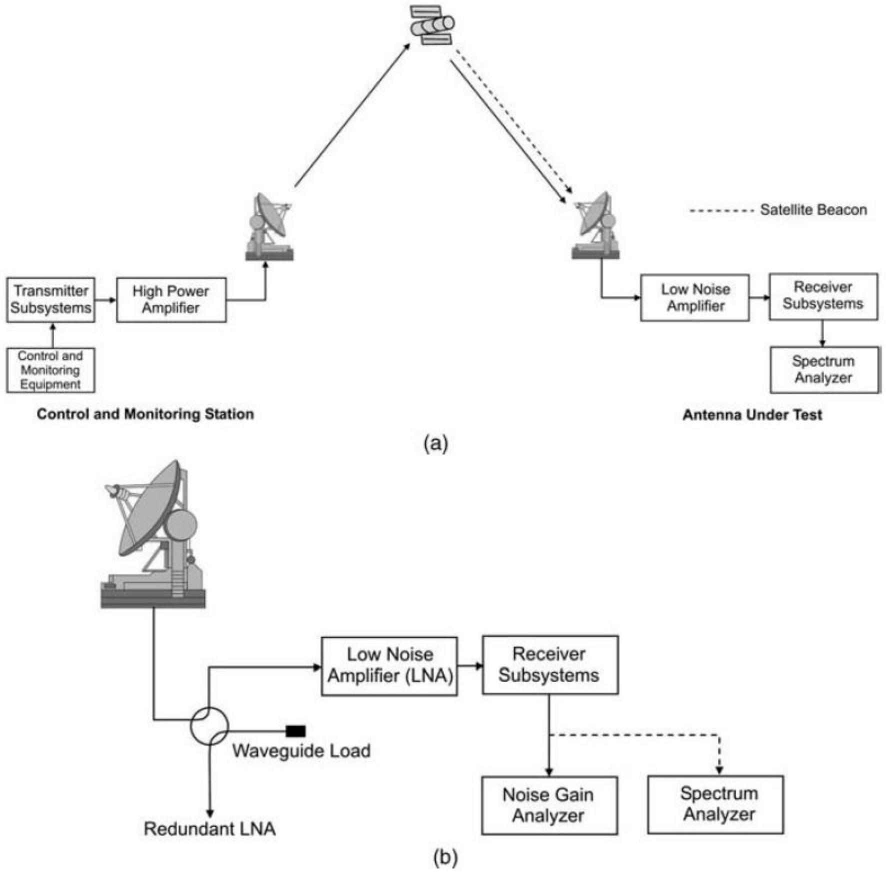


Figure 8.13 Receiver gain and system temperature method (a) Measurement of receiver gain (b) Measurement of system temperature

Method 2

EIRP Stability

- Verifies that the station's transmitted power remains stable.
- Crucial for digital services, with a typical requirement of better than ±0.5 dB.

Spectral Shape

- The spectral shape of the modulated carrier is initially measured during carrier line-up testing and is also measured subsequently on a regular basis.
- Confirms the modulated carrier's bandwidth to prevent interference with other users.

Additional Tests

- Antenna Pattern Measurements:
  - Transmit Sidelobe Pattern: Measures the transmitted signal's power in unwanted directions to ensure it falls within specified limits.
  - Receive Sidelobe Pattern: Measures the antenna's ability to reject signals from unwanted directions, minimizing interference from adjacent satellites.

Additional Tests

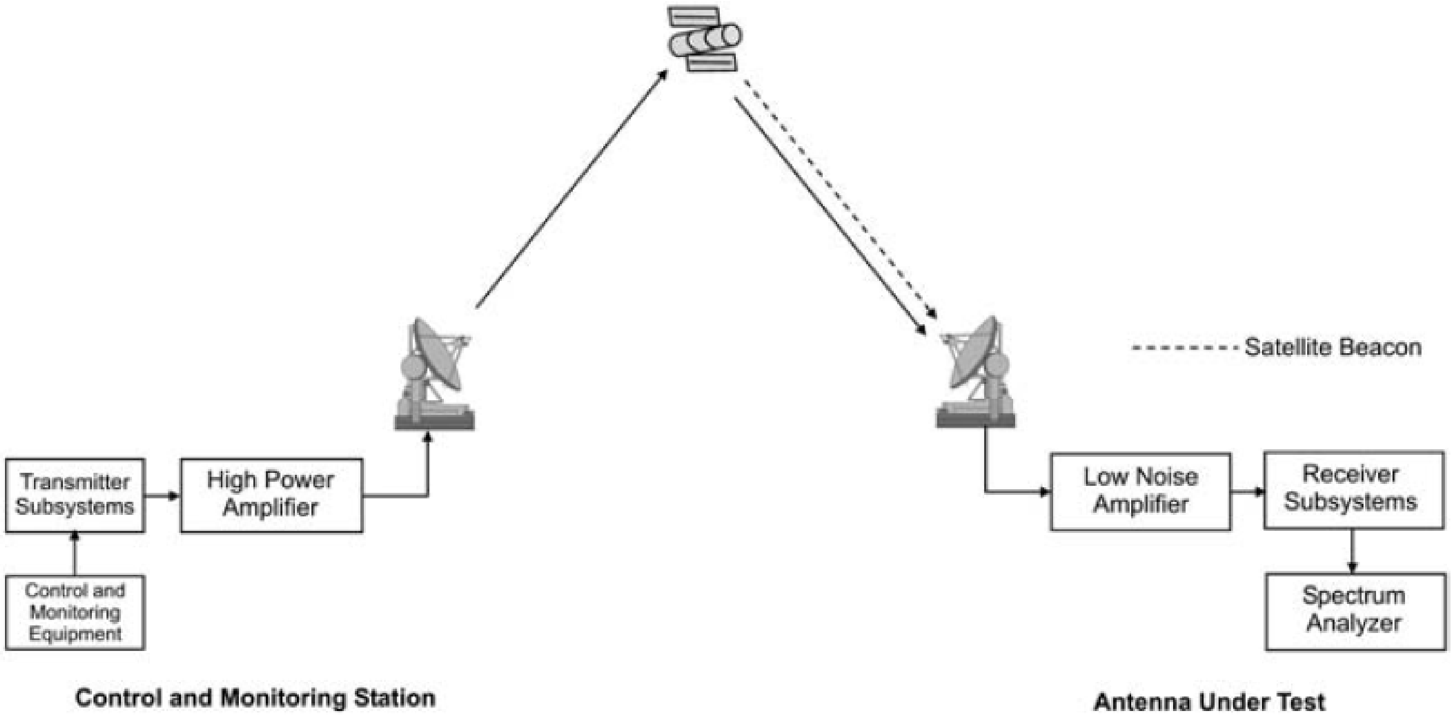


Figure 8.15 Test set-up for receive sidelobe pattern measurement

Line-Up Tests

- Confirms the Earth station can successfully establish a link with its intended partners and the satellite operator's control station.
- The link is only cleared for operational use after this test is successfully completed.

Earth Station Hardware

Earth Station Hardware

- Earth station hardware can be categorized into one of the three groups:
  - RF Equipment
  - IF and Baseband Equipment
  - Terrestrial Interface Equipment

RF Equipment

- The radio frequency (RF) equipment in an Earth station handles the signal transmission and reception.
  - **Transmit Channel:** It consists of **up-converters**, **High Power Amplifiers (HPAs)**, and the **transmit antenna**. The HPA output is fed directly to the transmit antenna.
  - **Receive Channel:** It includes the **receive antenna**, **Low Noise Amplifiers (LNAs)**, and **down-converters**. The receive antenna is connected to the LNA input.
- **Antenna Function:** The same antenna is almost always used for both transmitting and receiving signals.

RF Equipment

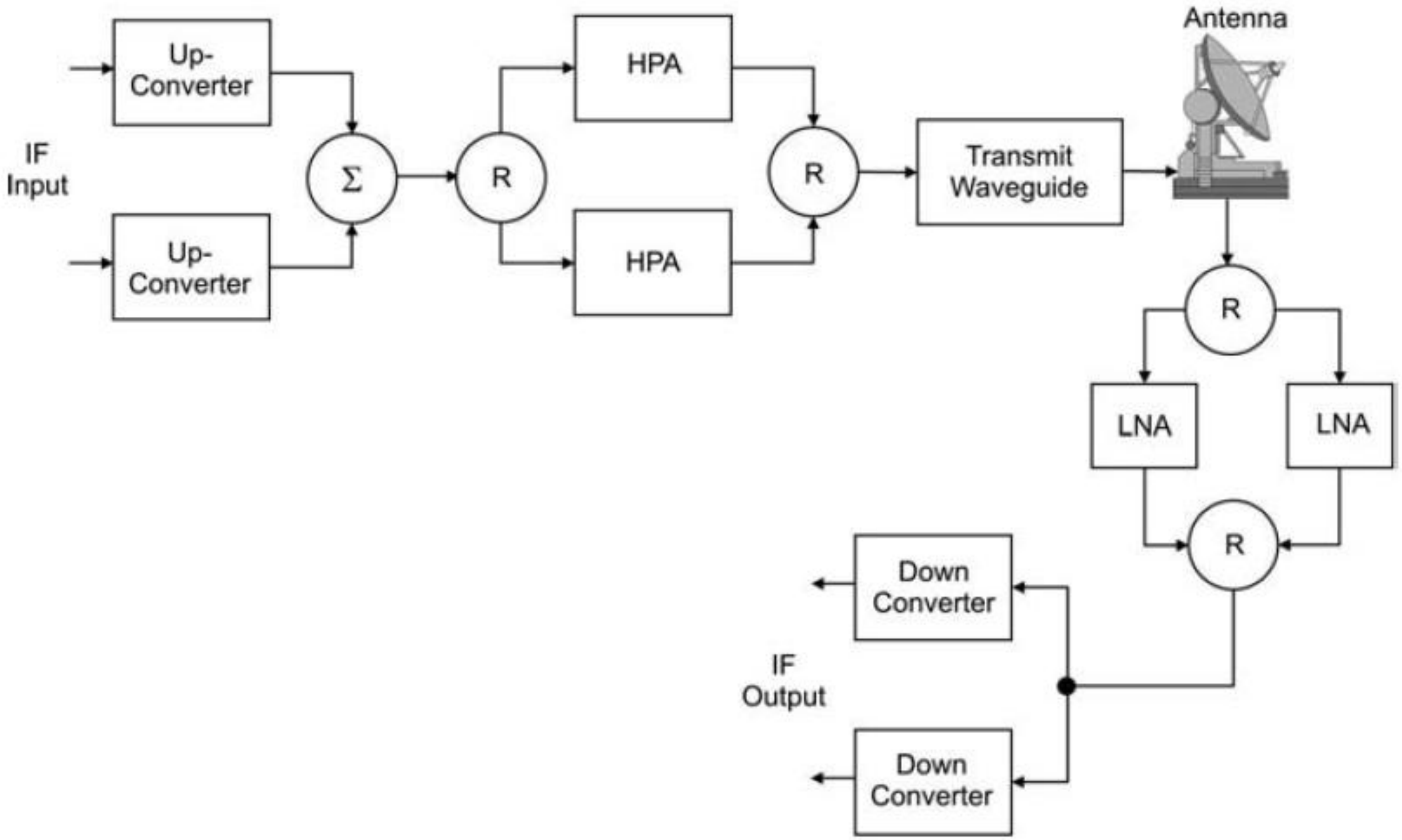


Figure 8.16 Block schematic of the RF portion of the Earth station

RF Equipment

- **Minimizing Signal Loss:** To ensure maximum EIRP and G/T, it is critical to minimize losses in the waveguide or cable connecting the antenna to the HPA and LNA.
  - **Strategic Placement:** One solution is to place the RF equipment in a shelter or cabinet right next to the antenna.
  - **Separate Packaging:** Another common practice is to package the uplink (modulator, up-converter) and downlink (down-converter, demodulator) equipment separately.
- **VSAT & TVRO Terminals:** Small terminals like VSATs and TVROs often use a **Low Noise Block (LNB)**, which combines the LNA and the first stage of the down-converter.
  - This allows for the use of cheaper coaxial cables to carry the signal after down-conversion to the L-band.

Antenna

- Different variants of reflector antenna are commonly used as Earth station antenna.
  - Prime focus fed parabolic reflector antenna
  - Offset fed sectioned parabolic reflector antenna
  - Cassegrain antenna
  - Gregorian antenna

Prime Focus Fed Parabolic Reflector

- Used for antennas with a diameter less than 4.5 meters.
- Often found in receive-only Earth stations.
- A variation includes a hook-shaped waveguide to move the Low-Noise Block (LNB) behind the reflector, improving access and preventing signal blockage.

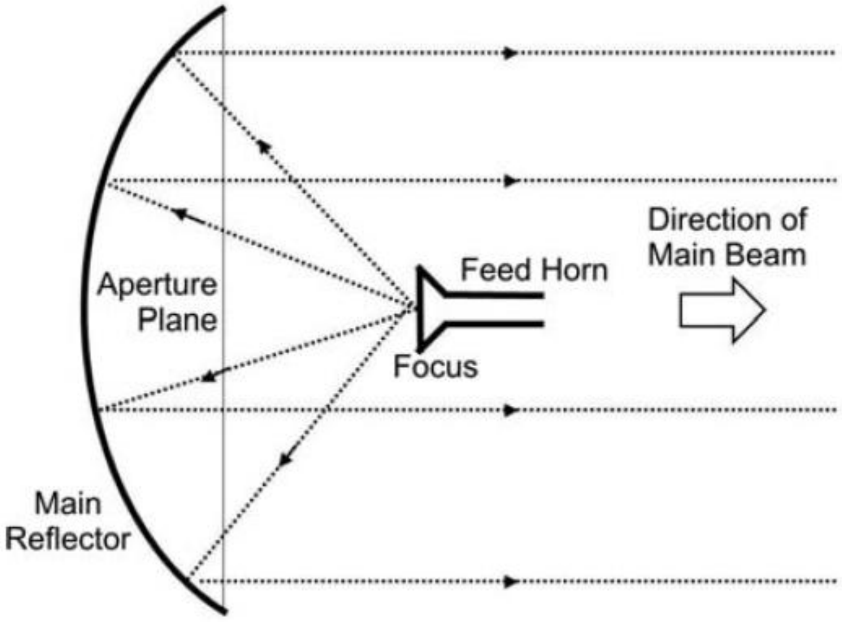


Figure 8.17 Prime focus fed parabolic reflector antenna

Offset Fed Parabolic Reflector

- Used for antennas with a diameter less than 2 meters.
- Eliminates beam blockage by the feed, increasing efficiency and reducing sidelobes.

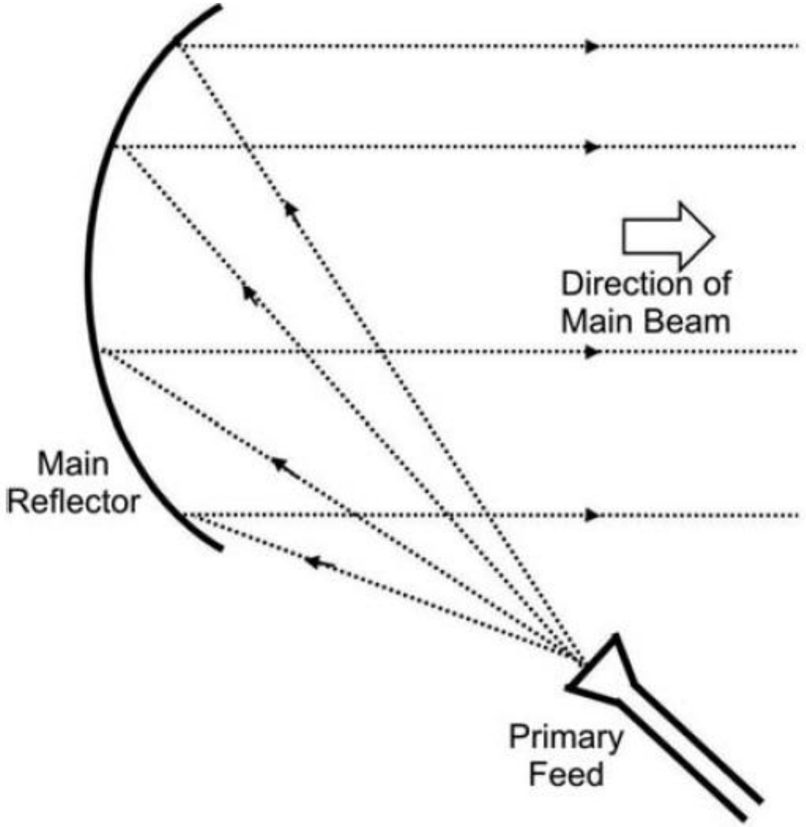


Figure 8.18 Offset fed sectioned parabolic reflector antenna

Cassegrain Antenna

- Overcomes many prime focus antenna shortcomings.
- Uses a hyperbolic sub-reflector to redirect waves from a feed located near the main reflector's center, allowing electronics to be placed at or behind the main dish.
- Can also be configured with an offset feed.

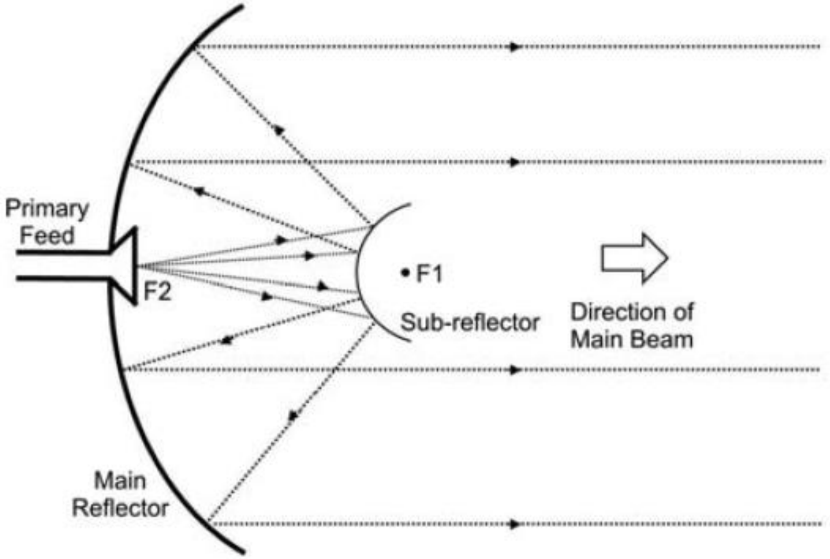


Figure 8.19 Cassegrain antenna

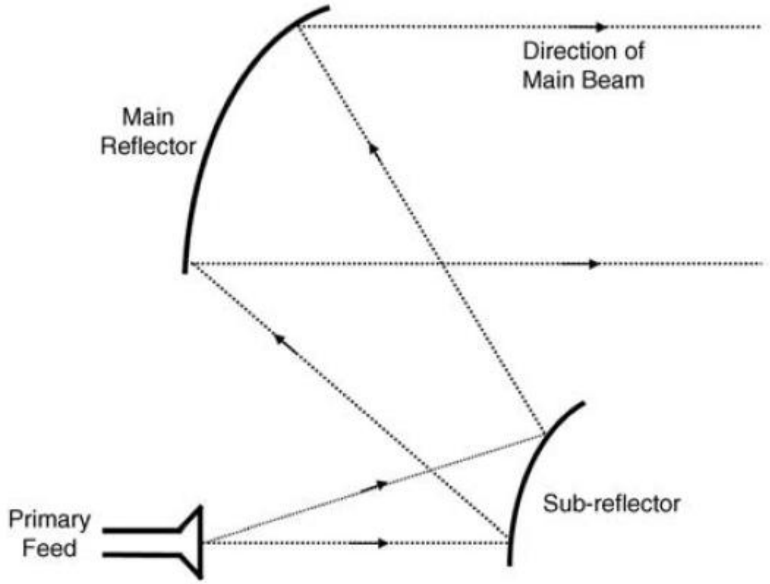


Figure 8.20 Offset fed Cassegrain antenna

Gregorian Antenna

- Similar to the Cassegrain, but uses a concave secondary reflector positioned behind the prime focus to bounce waves back towards the main dish.
- Electronics are placed between the two reflectors.
- Also supports an offset feed configuration.

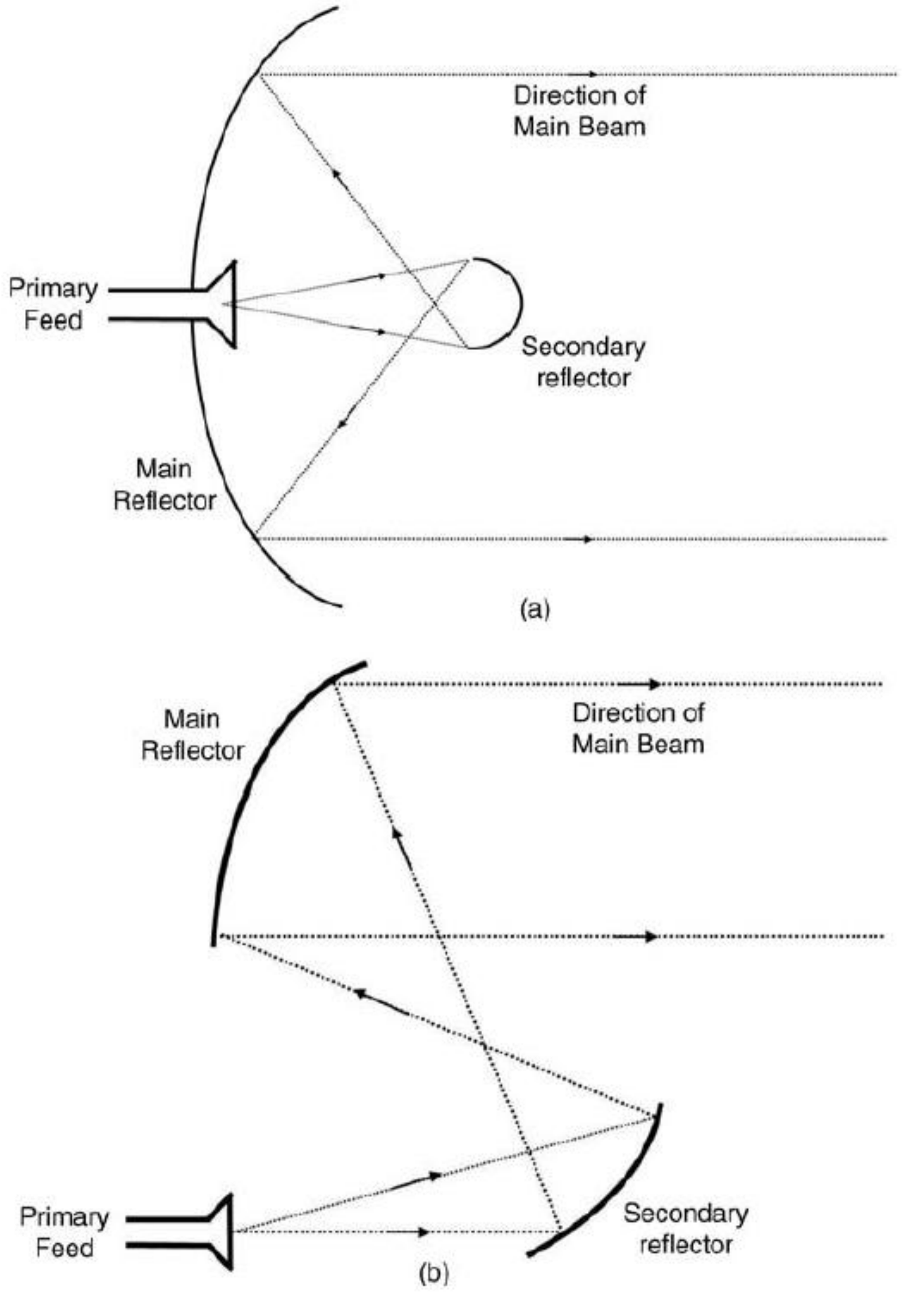


Figure 8.21 (a) Gregorian antenna (b) Offset fed Gregorian antenna

High Power Amplifier (HPA)

- The High Power Amplifier is a key component in the Earth station's transmit channel.
- Its output power, combined with antenna gain and waveguide losses, determines the station's EIRP (Effective Isotropic Radiated Power).
- **HPA & Antenna Trade-off:** The desired EIRP can be achieved by balancing HPA power and antenna size.
  - **Option A:** Use a moderate power HPA with a high-gain (large) antenna.
  - **Option B:** Use a high power HPA with a moderate-sized antenna.
  - *Example:* An 80 dB EIRP at C-band can be achieved with a 6m antenna and an 800W HPA, or a 10m antenna with a 300W HPA.

Types of HPA

- Traveling Wave Tube (TWT) Amplifiers:
  - **Wideband:** Bandwidths of 500 MHz or more.
  - **Power Levels:** A few watts to several kilowatts.
  - Used for high-power, wideband applications.
- Klystron Amplifiers:
  - **Narrowband:** 40 to 80 MHz bandwidth, tunable over a wider range.
  - **Power Levels:** Several hundred watts to a few kilowatts.
  - **Pros:** Less expensive, simpler to operate, and easy to maintain than TWTAs.
- Solid State Power Amplifiers (SSPAs):
  - **Pros:** Cheaper and more reliable.
  - **Limitation:** Power level is lower compared to TWTAs and Klystrons.

HPA Characteristics

- **Gain:** The amount of signal amplification.
- **Group Delay:** Variation with frequency, which can cause intermodulation.
- **Noise Performance:** The level of unwanted noise introduced.
- **AM/PM Conversion:** Produces intelligible crosstalk and intermodulation noise.

HPA Configurations for Multi-Carrier Operation

- Single Amplifier
  - Multiple carriers are combined and amplified by one HPA.
  - The amplifier is operated in its linear region to minimize inter-modulation noise.
  - Redundancy is often used for reliability.
- Multiple Amplifiers
  - Each HPA amplifies a single carrier or a group of carriers.
  - This allows HPAs to operate closer to their full power rating, increasing efficiency, but at the cost of additional hardware.

HPA Configurations for Multi-Carrier Operation

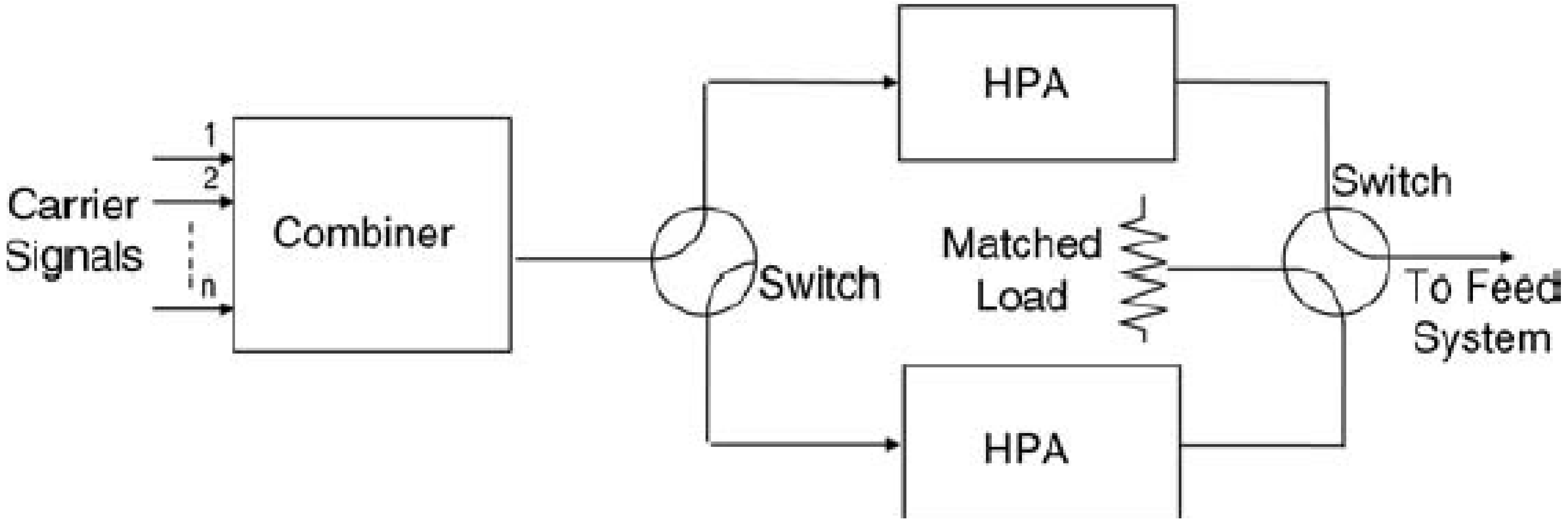


Figure 8.23 Single amplifier HPA configuration

HPA Configurations for Multi-Carrier Operation

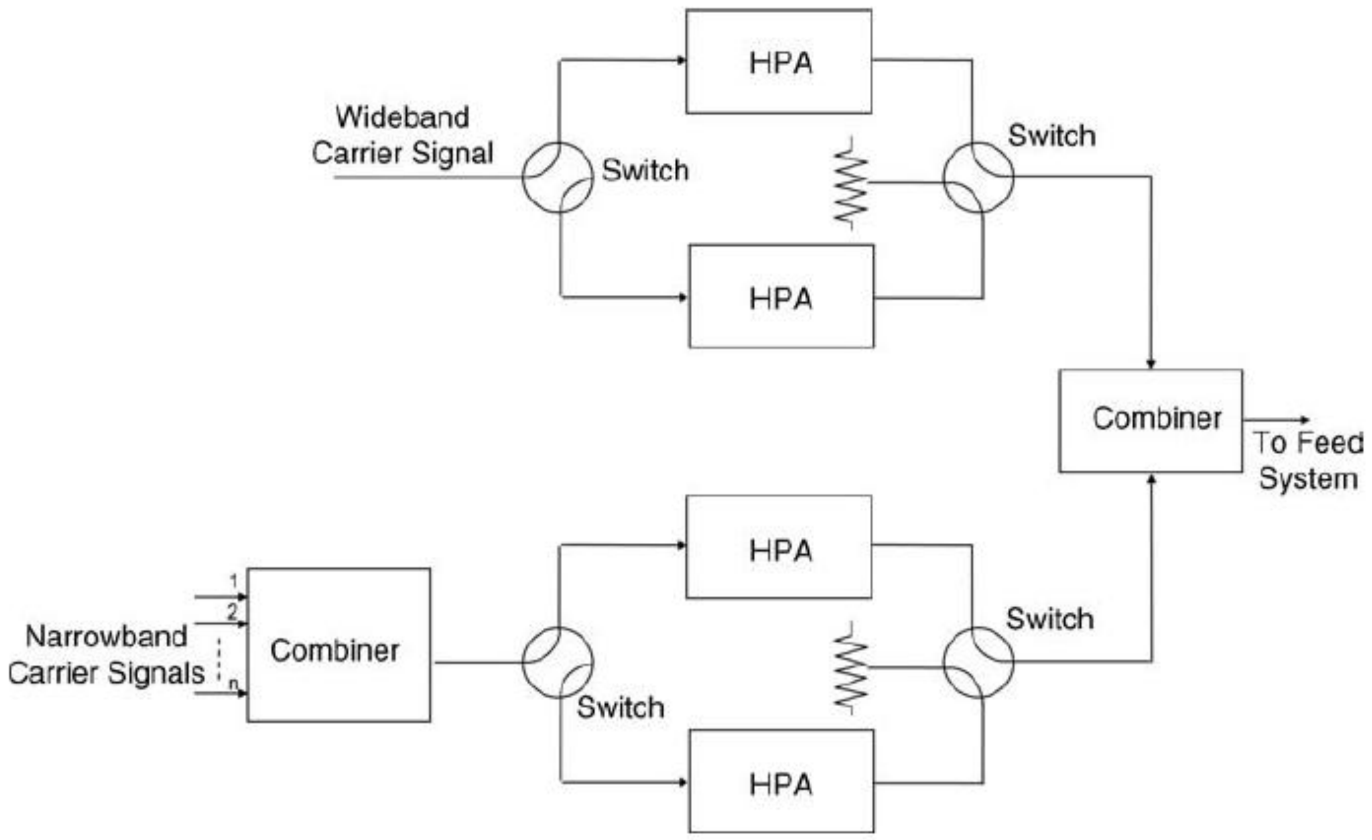


Figure 8.24 Multiple amplifier HPA configuration

Up-converters and Down-converters

- These are frequency translators that convert signals between the Intermediate Frequency (IF) used by modems and the Radio Frequency (RF) used for satellite communication.
- Up-converter:
  - Converts the IF signal (e.g., 70 MHz or 140 MHz) from the modulator to the operational RF frequency band (C, Ku, or Ka band).
- Down-converter:
  - Converts the received RF signal (C, Ku, or Ka band) to the IF signal, which is then fed to the demodulator.
- Either single or double frequency conversion topologies are used for up-converters and down-converters.

Single Frequency Conversion

- This topology uses a single mixer stage to perform the frequency conversion.
- Up-converter:
  - An amplifier precedes the mixer stage to boost the signal.
  - A **local oscillator (LO)**, often a frequency synthesizer, provides a tunable frequency for conversion.
  - A **bandpass filter** at the output eliminates the LO frequency and harmonics.
- Down-converter:
  - An amplification stage is used to provide gain and reduce noise contributions from the mixer and IF equipment.
  - A frequency synthesizer provides agility in the received frequency.

Single Frequency Conversion

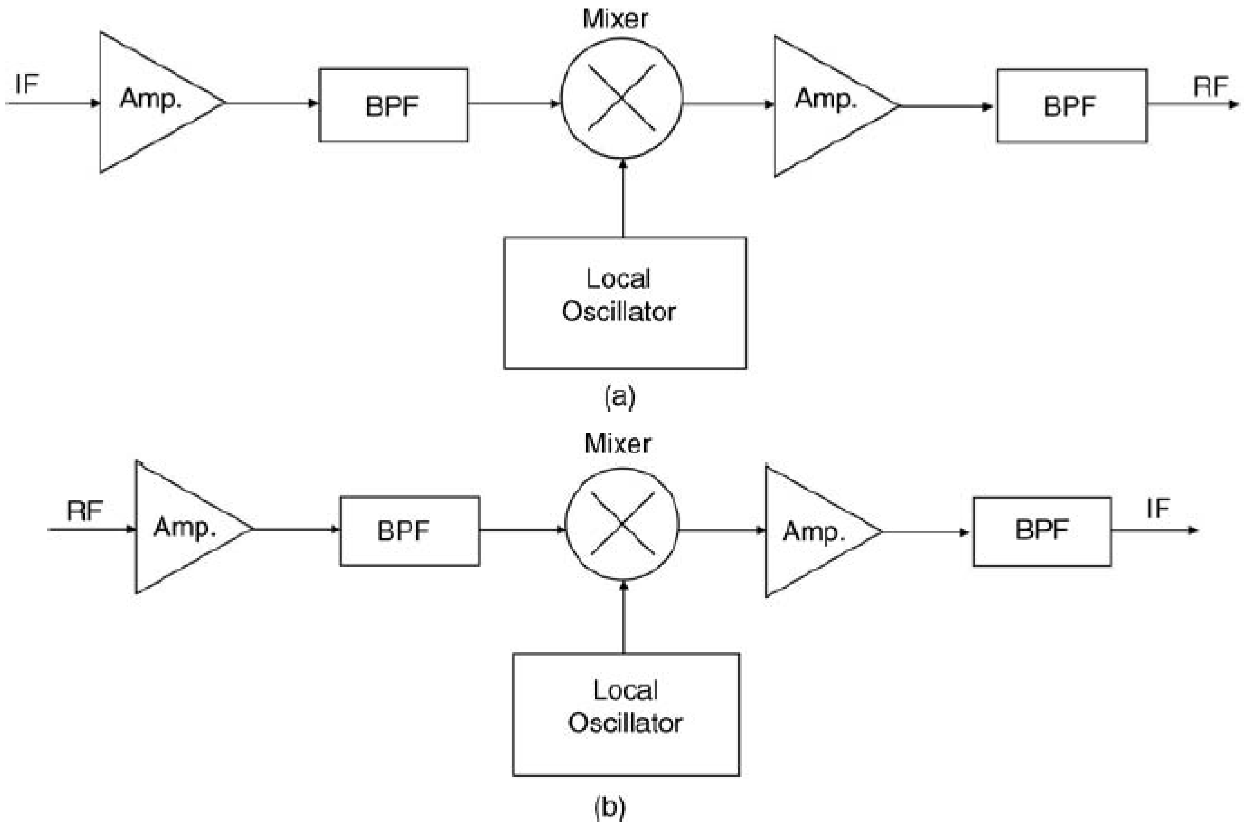


Figure 8.25 Simplified block diagram of single frequency conversion frequency converters (a) up-converter (b) down-converter

Double Frequency Conversion

- This topology uses a two-stage mixer conversion process.
- Up-converter:
  - The IF signal is first up-converted to an intermediate frequency (often in the L-band).
  - The signal is then amplified and fed to a second mixer stage, where it is up-converted to the final operational RF frequency.
- Down-converter:
  - The received RF signal is first down-converted to an intermediate frequency.
  - It is then converted to the final IF signal.
- This method is more complex but offers greater flexibility and control over the frequency conversion process.

Double Frequency Conversion

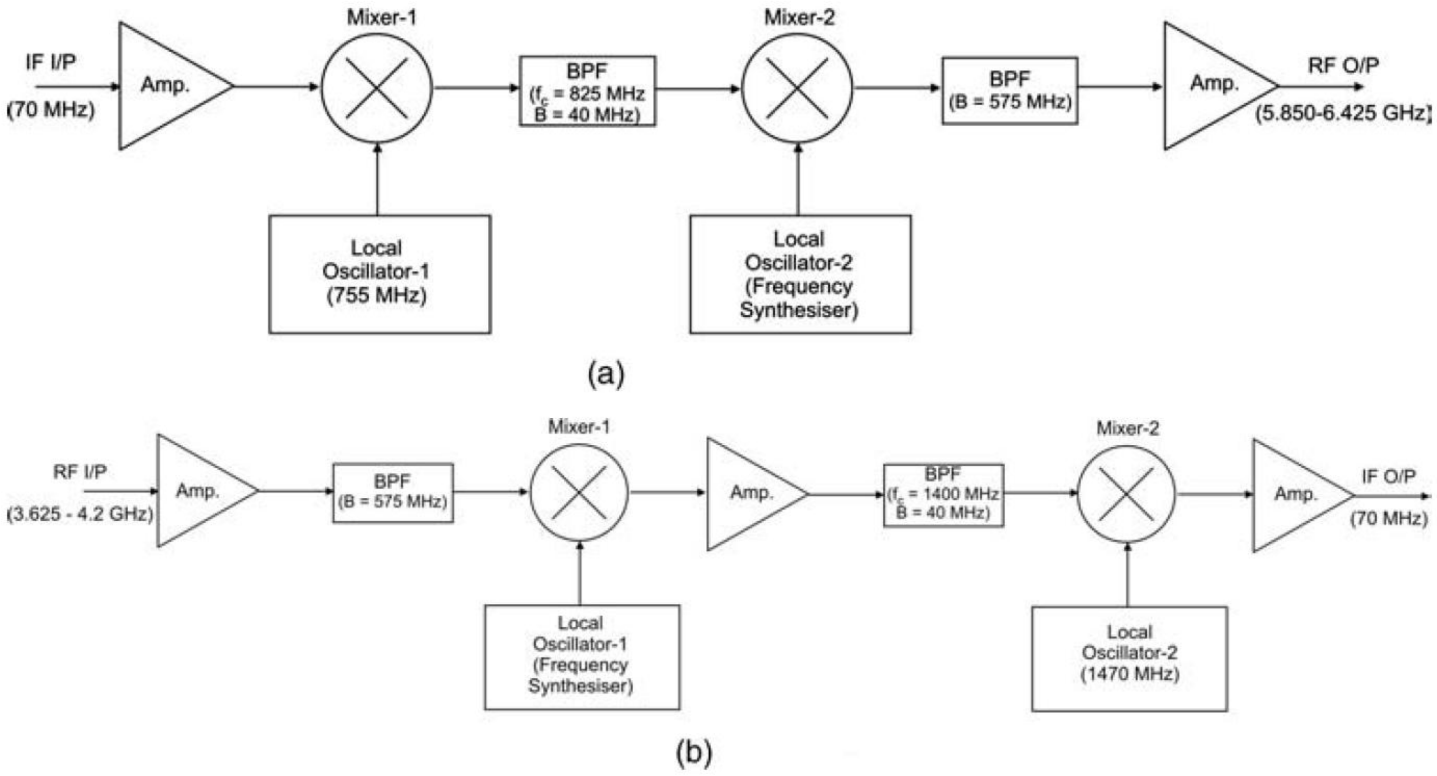


Figure 8.26 Simplified block diagram of double frequency conversion frequency converters (a) up-converter (b) down-converter

Low Noise Amplifier (LNA)

- The Low Noise Amplifier (LNA) is one of the key components deciding the system noise temperature and hence the figure-of-merit *G/T* of the Earth station.
- **Technological Evolution:**
  - **Early Days:** Designs were based on masers and parametric amplifiers.
  - **Present Day:** LNAs are configured around **Gallium Arsenide FET (GaAs FET)** or **High Electron Mobility Transistors (HEMT)**.
- **Performance Comparison:** Modern designs are more compact and reliable, made possible by improvements in antenna efficiency and increased satellite transmit power.
  - These designs are far more compact and reliable than their parametric amplifier counterparts.
  - The uncooled GaAs FET or HEMT based LNAs offer a noise temperature of about 75–170 K and compared with cryogenically cooled parametric amplifiers of early days giving noise temperature of 30–90 K.

Low Noise Amplifier (LNA)

Table 8.1 Performance comparison of LNA technologies

Type of Amplifier	Frequency Range (GHz)	Typical Noise Temperature (K)
Parametric Amplifier (Cooled)	3.7–4.2	30
	11–12	90
Parametric Amplifier (Uncooled)	3.7–4.2	40
	11–12	100
GaAs FET (Cooled)	3.7–4.2	50
	11–12	125
GaAs FET (Uncooled)	3.7–4.2	75
	11–12	170

LNA Variations

- Low Noise Block (LNB):
  - Combines the LNA and a single-stage down-converter into one unit.
  - Converts the received frequency to a lower IF (around 1 GHz), allowing for the use of inexpensive coaxial cable.
  - Used for smaller antennas (e.g., TVRO, VSAT) for DTH or small business applications.
  - Capable of handling a block of frequencies from **different transponders**.
- Low Noise Converter (LNC):
  - The LNA can be tuned to amplify and down-convert the entire bandwidth of a **single transponder**.
  - The basic difference from an LNB lies in the conversion bandwidth; LNBs handle a wider block of frequencies.

LNA Variations

Figure 8.27 DTH dish and co-located LNB

LNA Variations

Low Noise Block (LNB) vs. LNC (Low Noise Converter)

Feature	LNB (Low Noise Block)	LNC (Low Noise Converter)
Primary Function	Amplifies and converts a block of frequencies.	Amplifies and converts the bandwidth of a single transponder.
Conversion Bandwidth	Handles a block of frequencies from **different transponders.**	Tuned to handle the entire bandwidth of a **single transponder**.
Typical Use	Smaller terminals like TVRO and VSAT for direct-to-home or small business applications.	Systems where a single transponder's signal is of primary interest.

IF and Baseband Equipment

- Important building blocks of IF and baseband equipment of the Earth station hardware include
  - Baseband processing circuits
  - Modulator/demodulator (MODEM)
  - Multiplexer/ demultiplexer

IF and Baseband Equipment

- The architecture of the IF and baseband section depends on the modulation and multiple access schemes used.
- For example, FDMA and TDMA systems have very different requirements.

FDMA Earth Station Architecture

- Each carrier has its own dedicated modem tuned to a separate frequency.
- This results in the use of a large number of modems.
- Modems interface with the terrestrial network via a TDM multiplexer, combining individual channels.
- Full or partial redundancy is almost always included for high reliability.

FDMA Earth Station Architecture

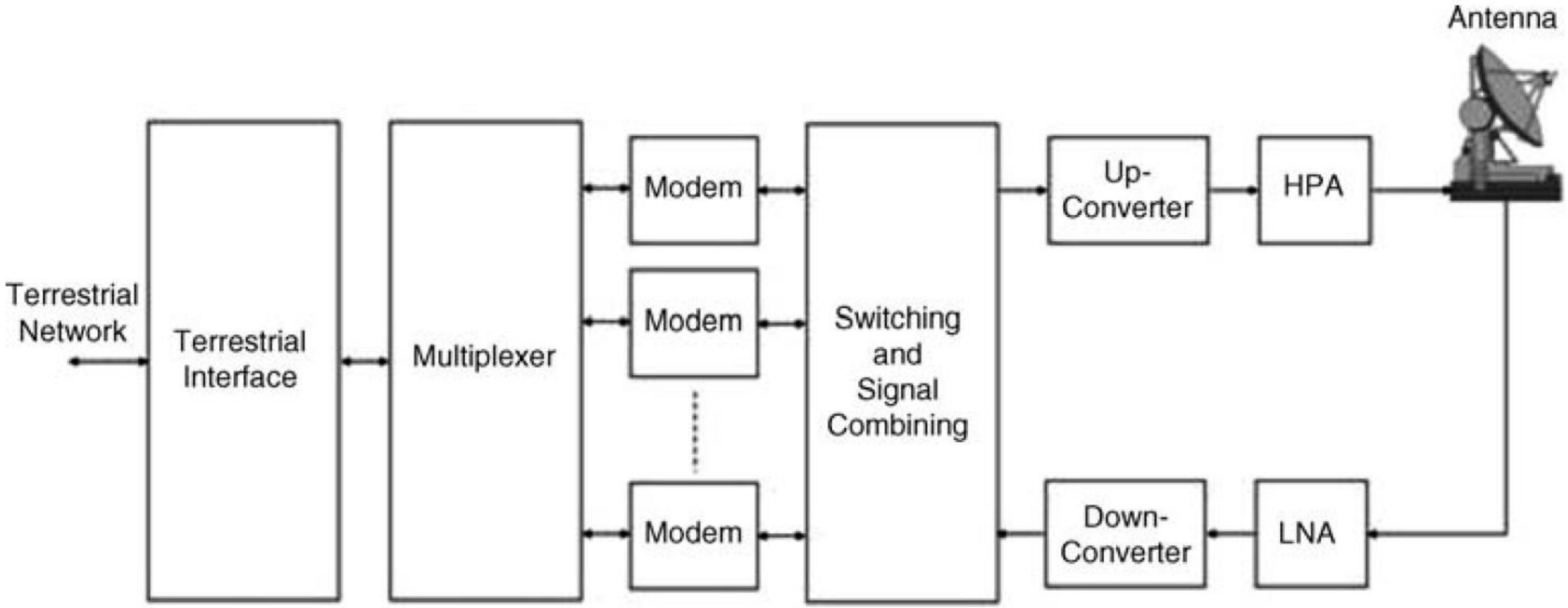


Figure 8.28 Block schematic of a full duplex FDMA digital communication Earth station

TDMA and CDMA Earth Station

- TDMA:
  - Requires only a single modem per Earth station.
  - Several Earth stations share the frequency band on a time basis.
  - The modem must handle a much larger bandwidth.
  - Bursts of data are received from different Earth stations without temporal overlap.
- CDMA:
  - Different stations transmit simultaneously on the same frequency.

TDMA and CDMA Earth Station

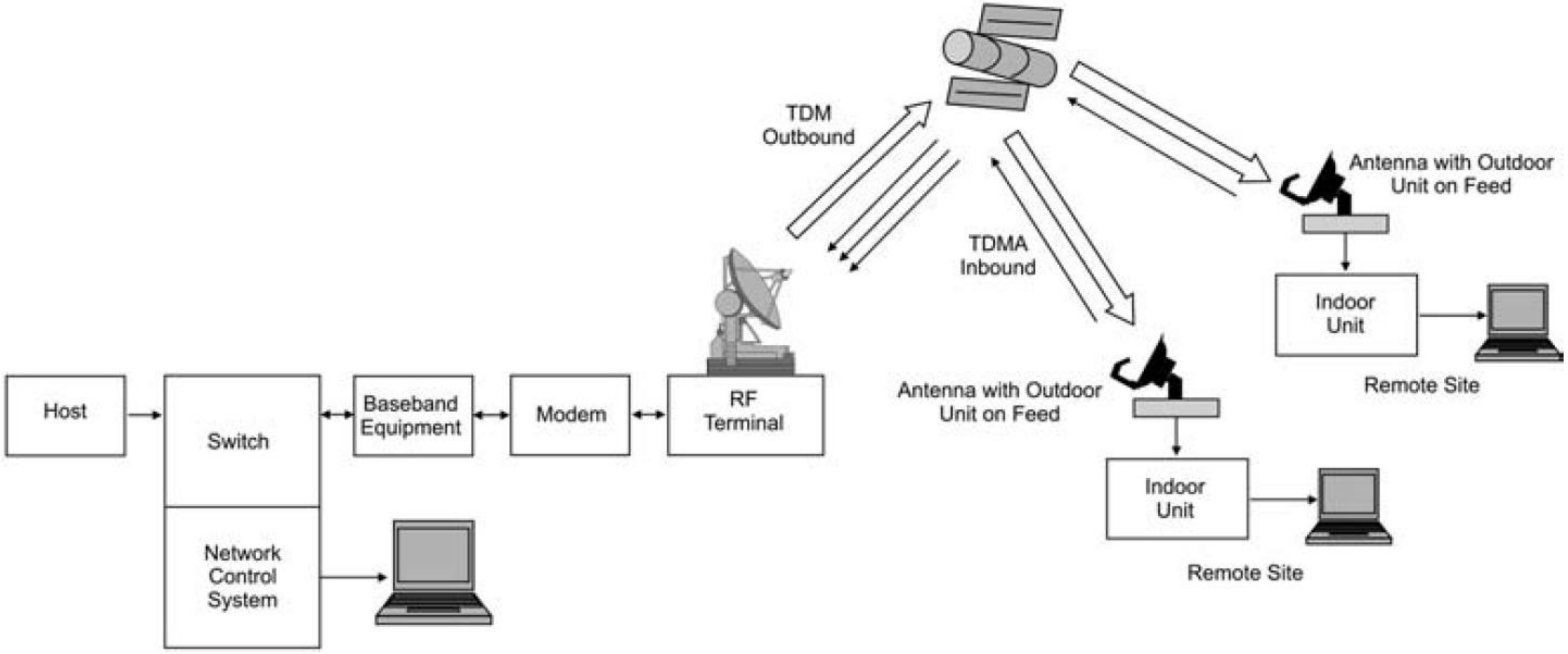


Figure 8.29 Block schematic arrangement of a typical TDM/ TDMA interactive VSAT terminal

Terrestrial Interface

- Terrestrial interface is that part of the Earth station that connects the Earth station to the users.
- Its proper design is crucial to avoid degrading the quality of service.
- Its complexity depends on the services provided.
- Can range from a simple connection for satellite phones to a complex setup resembling a telephone exchange for large Earth stations.

Terrestrial Interface

- Major Components of terrestrial interface include:
  - The Terrestrial Tail
    - Links connecting the Earth station to remote user locations.
    - Primary options: Line-of-sight microwave and fiber optic cable.
    - Length can vary from tens of meters to hundreds of kilometers.
  - The Interface
    - Equipment that handles the connection between the satellite link and terrestrial networks.
    - Common types: Telephone (voice), Data transmission (data), and Television (video).

Terrestrial Tail Options

- Fiber Optic Cable:
  - Preferred for short tails (< 20 km) or connecting facilities within the complex.
  - Low noise and immune to electromagnetic interference (EMI).
  - Can be more expensive for long tails, especially in metropolitan areas.
- Microwave Link:
  - A better choice for long and elaborate tails (> 20 km).
  - Single hop microwave is a good alternative for short tails as well.

Terrestrial Tail Options

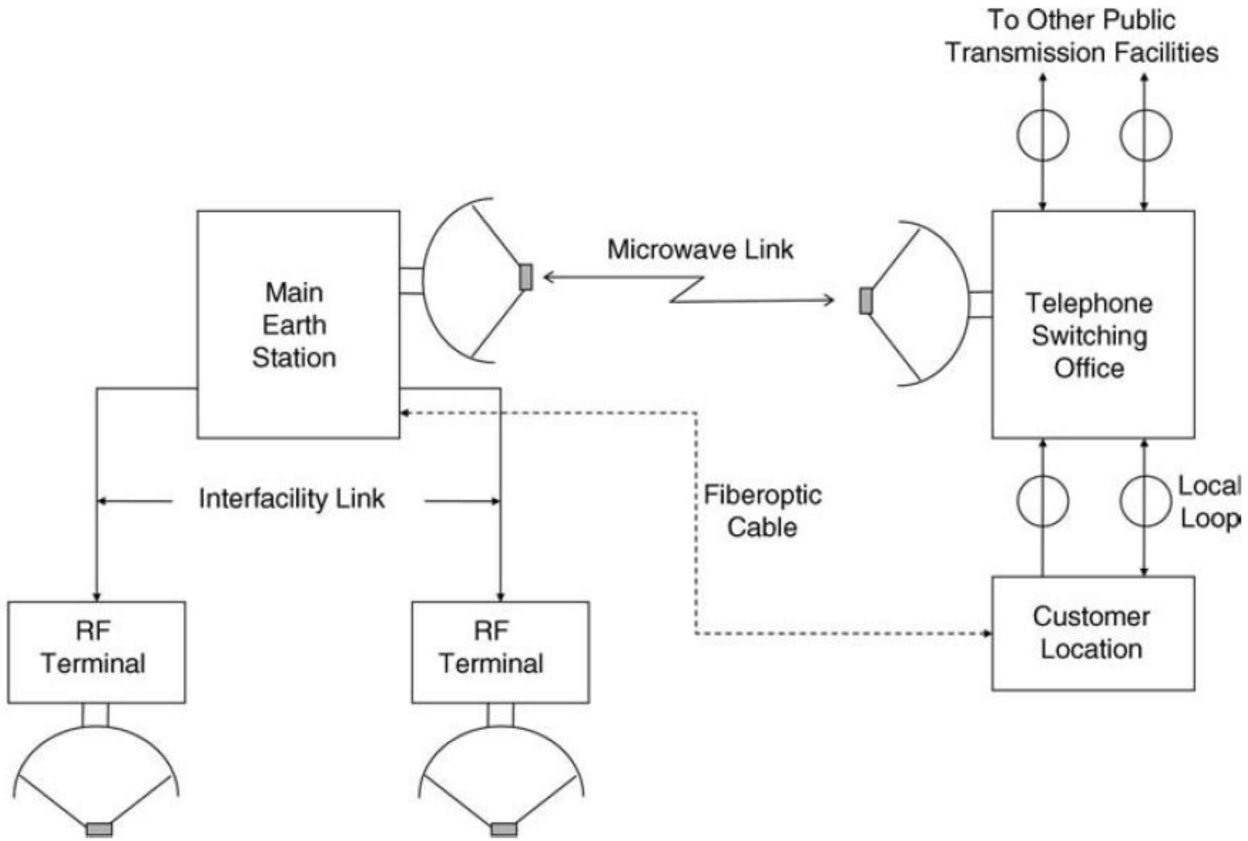


Figure 8.30 Typical Earth station set-up with terrestrial tail links

Interface

- Interface equipment varies from simple to very elaborate.
- Large stations handle massive traffic (voice, data, video) from terrestrial networks.
- **Key function:** De-multiplexing terrestrial signals and changing their format to be suitable for satellite transmission (and vice-versa).

Interface

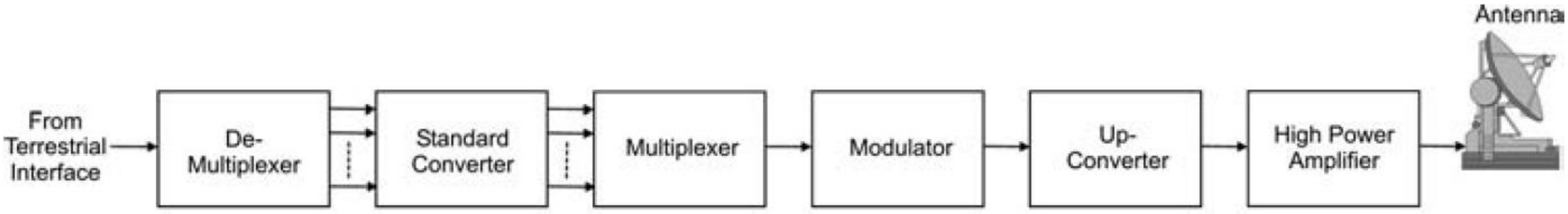


Figure 8.31 Terrestrial interface – up-link

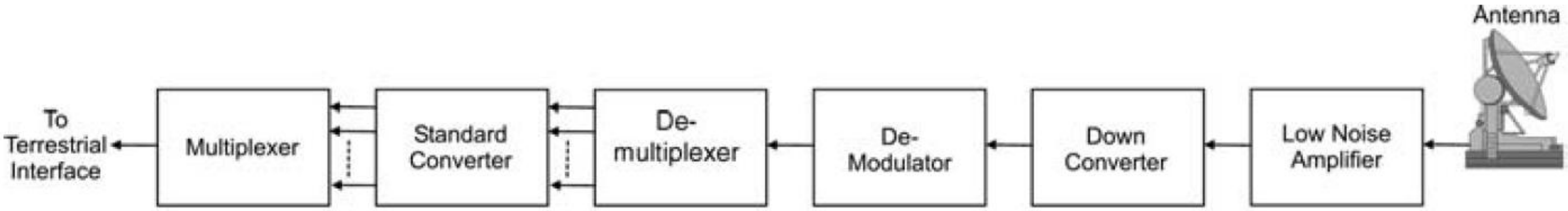


Figure 8.32 Terrestrial interface – down-link

Interface

- Digital Signal Handling
  - A specific challenge arises from data rate variation caused by changes in satellite path length.
  - Terrestrial networks cannot accommodate these variations.
  - An **elastic buffer** is used to solve this problem.
  - It is a FIFO (First-in First-out) random access memory.
  - It absorbs the peak-to-peak data rate variations to ensure seamless interfacing.
  - The smallest possible memory size is used to minimize additional delay

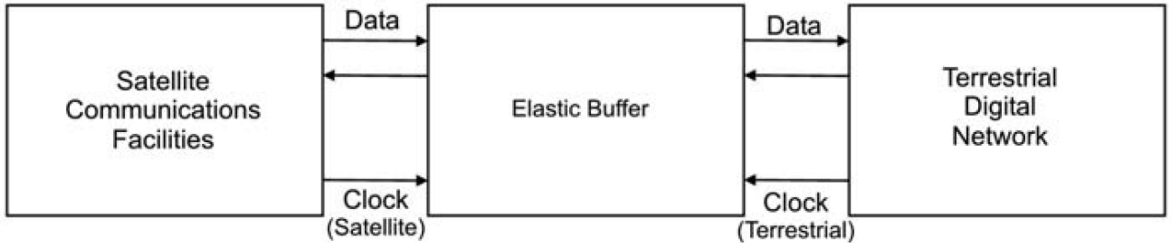


Figure 8.33 Use of elastic buffer to absorb data rate variations

Satellite Tracking

Satellite Tracking

- Satellite tracking is required when the Earth station's antenna beam width is only slightly wider than the satellite's drift.
- Large earth stations require some form of tracking.
- Antennas with large beam widths (e.g., DBS receivers) do not need to track.

Tasks of a Satellite Tracking System

- Satellite Acquisition: Acquires the satellite by manually or programmatically scanning the expected position.
- Manual Tracking: A backup option used in the event of total auto-track system failure.
- Automatic Tracking: A closed-loop system that ensures continuous tracking of the satellite. It begins when the beacon signal strength is above a certain threshold.
- Programme Tracking: An open-loop system where the antenna is driven to a pre-predicted position. Its accuracy is lower than automatic tracking.

Satellite Tracking System – Block Diagram

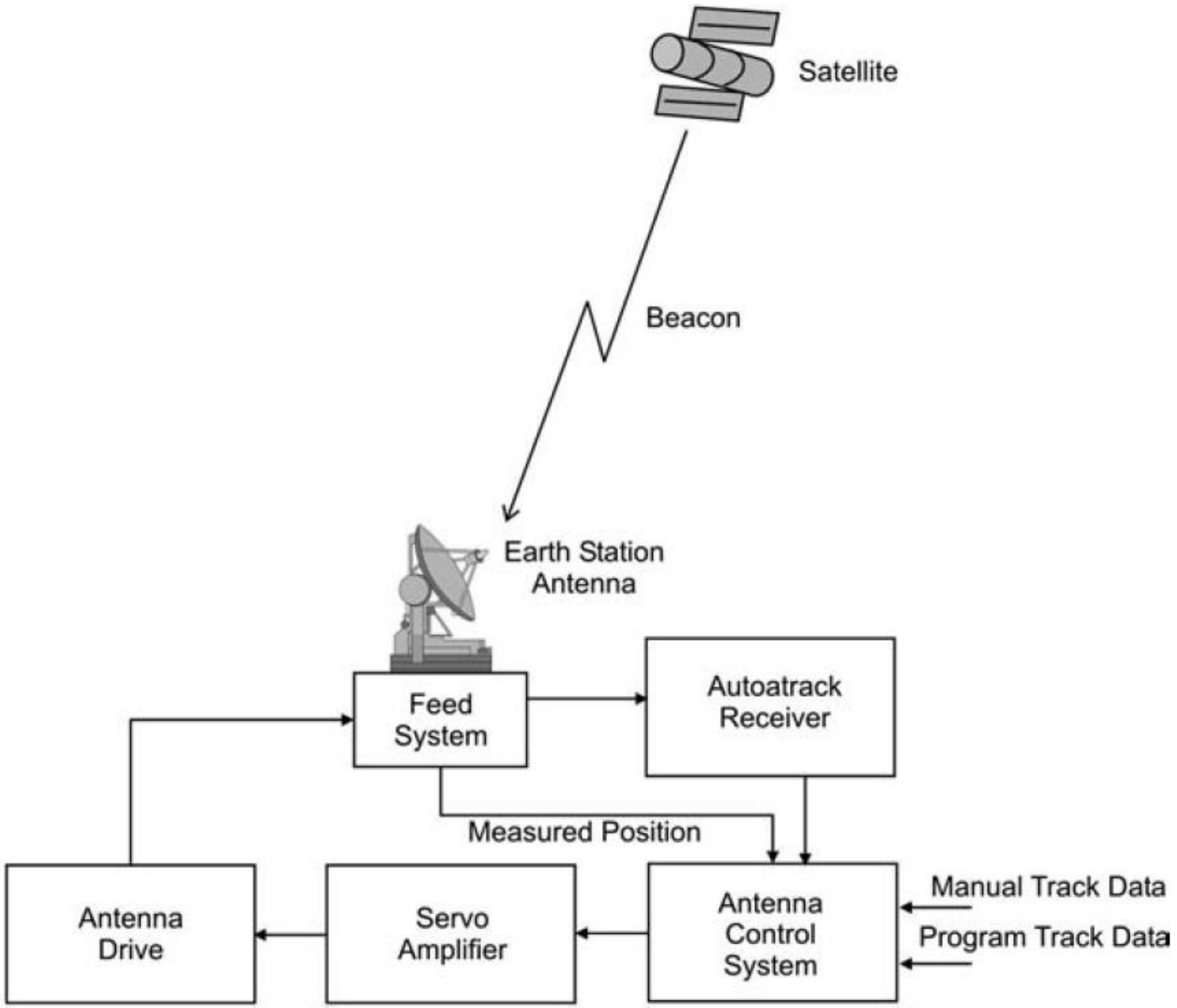


Figure 8.34 Block schematic arrangement of satellite tracking system

Satellite Tracking System – Block Diagram

- The Earth station antenna makes use of the beacon signal to track itself to the desired positions in both azimuth and elevation.
- The auto track receiver derives the tracking correction data or in some cases the estimated position of the satellite.
- The estimated position is compared with the measured position in the control subsystem whose output feeds the servomechanism.
- In the case of manual and programme track modes, the desired positions of the satellite in the two orthogonal axes are respectively set by the operator and the computer.
- The difference in actual and desired antenna positions constitutes the error signal that is used to drive the antenna.

Tracking Techniques

- Tracking techniques are classified based on the methodology used to generate angular errors.
- Commonly used tracking techniques include the following:.
  1. Lobe switching
  2. Sequential lobing
  3. Conical scan
  4. Monopulse track
  5. Step track
  6. Intelligent tracking

Lobe Switching

- The antenna beam is rapidly switched between two positions in a single plane.
- The amplitudes of the echoes are compared to determine the target's location relative to the antenna axis.
- The difference signal is used to generate a correction signal that steers the antenna.
- **Disadvantage:** Prone to inaccuracies if the object's cross-section changes during the scan.

Lobe Switching

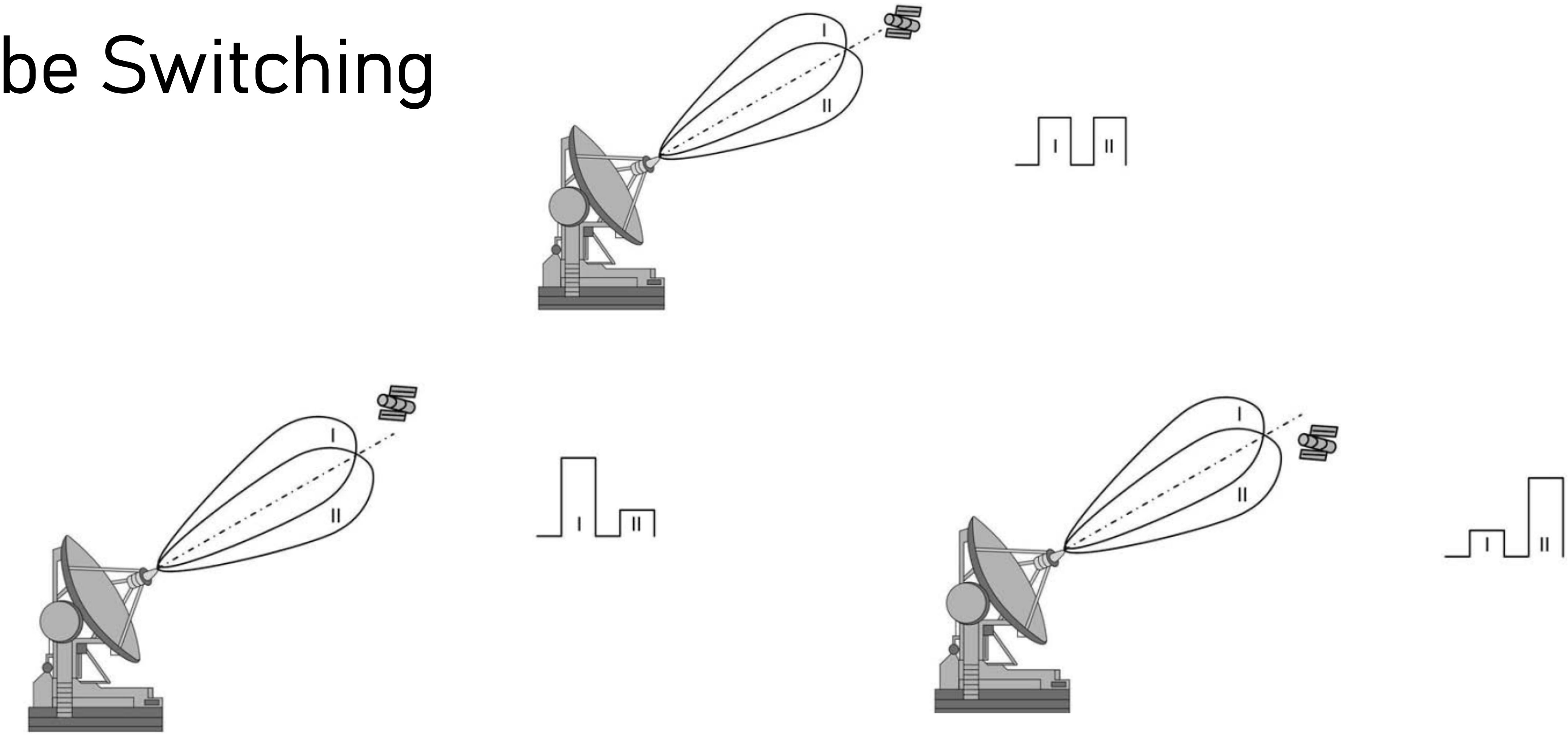


Figure 8.35 Principle of lobe switching technique

Sequential Lobing

- A squinted beam is sequentially placed in discrete angular positions, usually four, around the antenna axis.
- Angular error information is derived from variations in the echo signal amplitude.
- This can be done very rapidly, simulating simultaneous lobing.

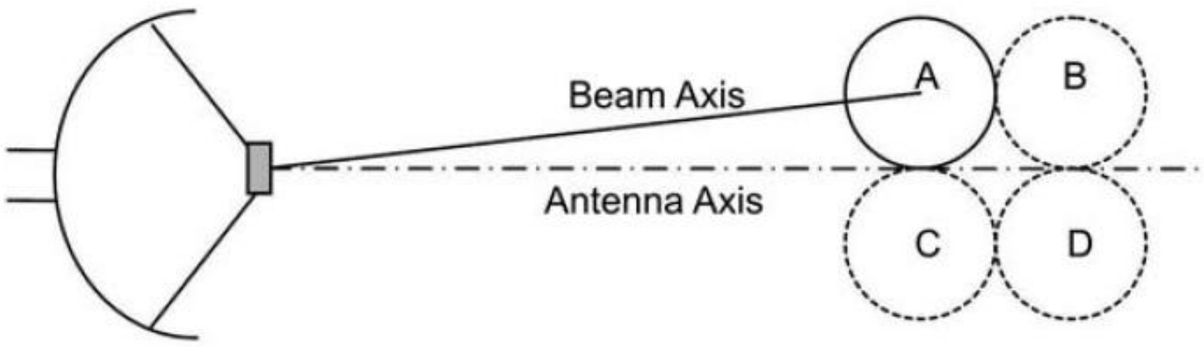


Figure 8.36 Principle of sequential lobing

Conical Scan

- A squinted beam is scanned rapidly and continuously in a circular path around the antenna axis.
- The amplitude variation and phase delay of the echo signal are used to determine the angular error's magnitude and direction.
- Offers good tracking accuracy and average response time, but is not in common use now.

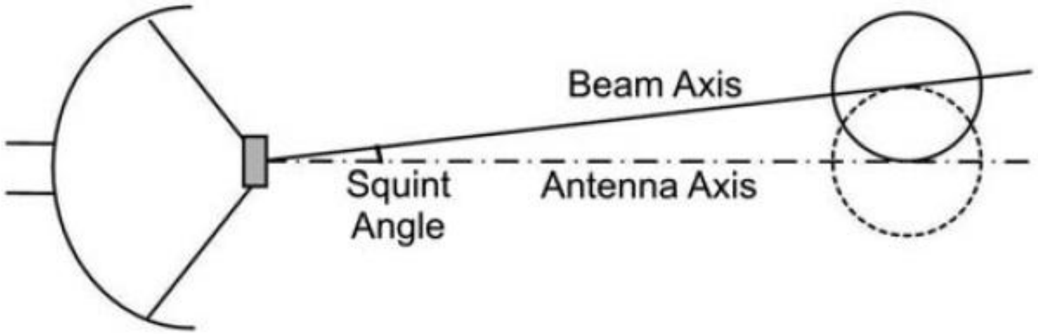


Figure 8.37 Principle of conical scan

Monopulse Tracking

- Overcomes the inaccuracies of sequential methods by simultaneously lobing the received beacon.
- Two main types:
  - Amplitude Comparison: Uses four feeds to compare signal amplitudes from different quadrants.
  - Phase Comparison: Uses the phase difference between signals received by multiple antenna elements to determine angular errors.
- Offers very high tracking accuracy and fast response time.
- Requires complex and expensive feed systems and receivers.

Monopulse Tracking

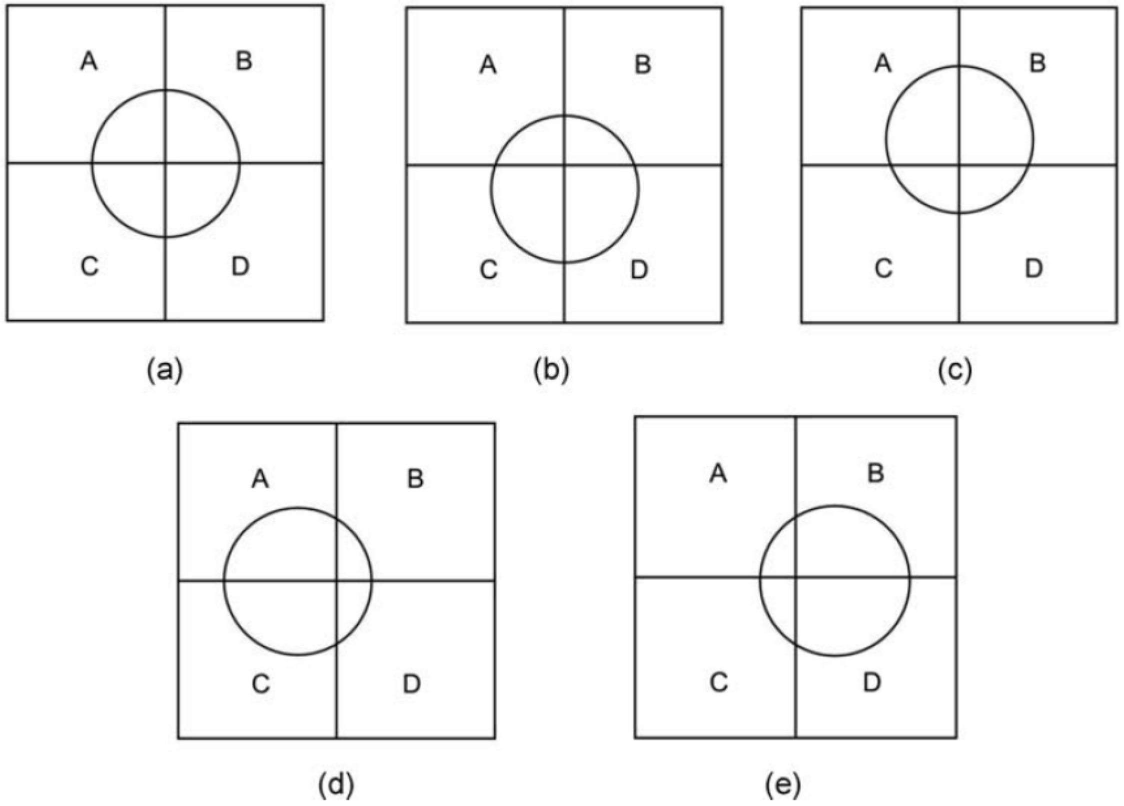


Figure 8.39 Amplitude comparison monopulse tracking – Spot for different angular positions

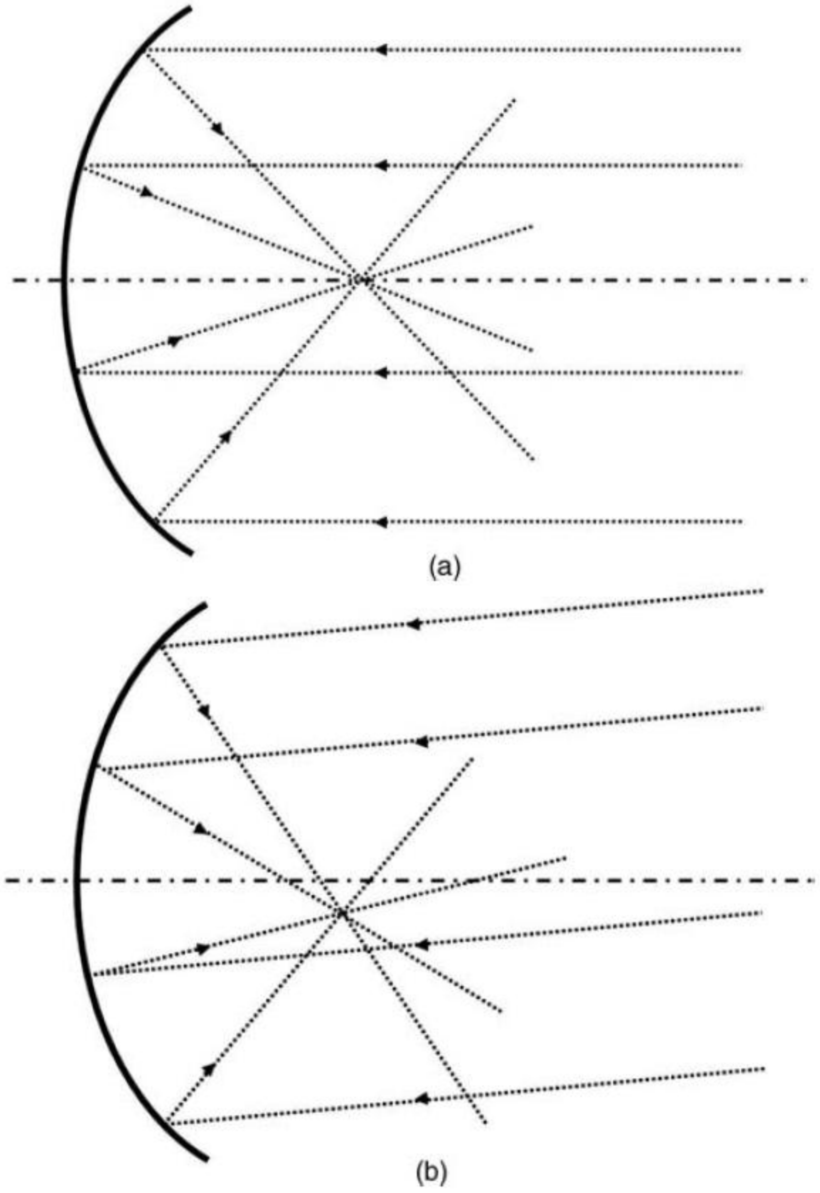


Figure 8.38 Amplitude comparison monopulse tracking – Received wavefront

Monopulse Tracking

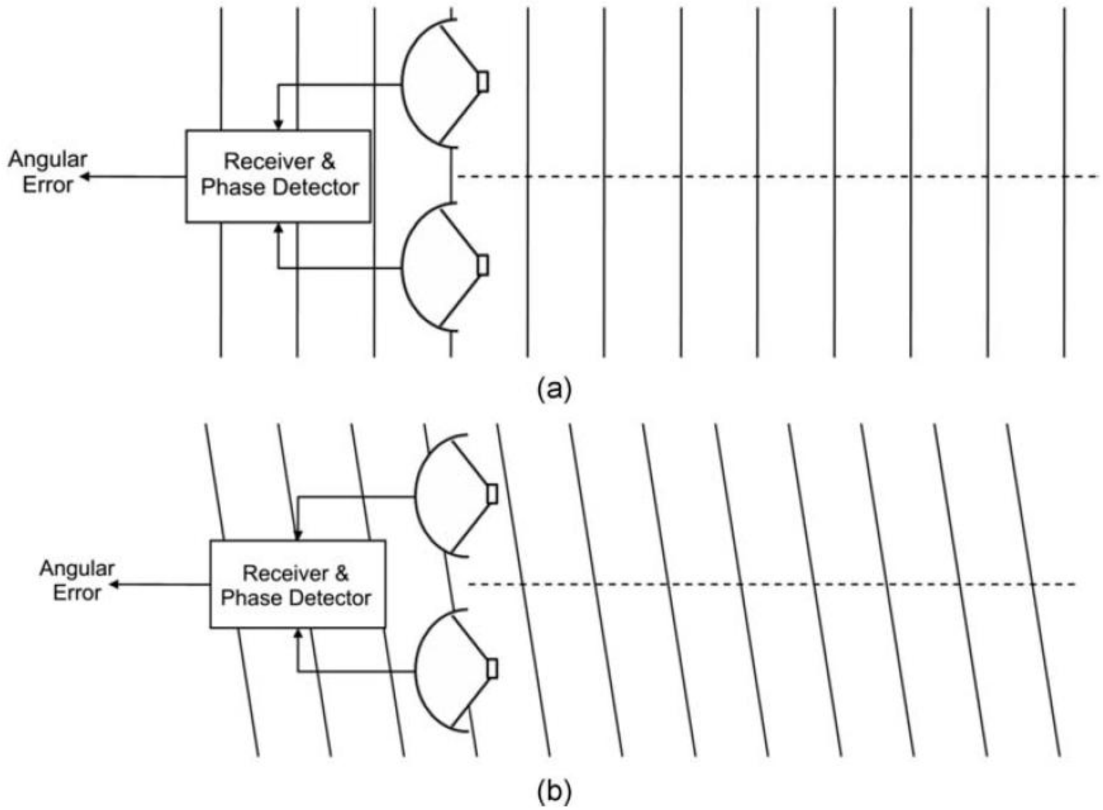


Figure 8.40 Phase comparison monopulse tracking technique

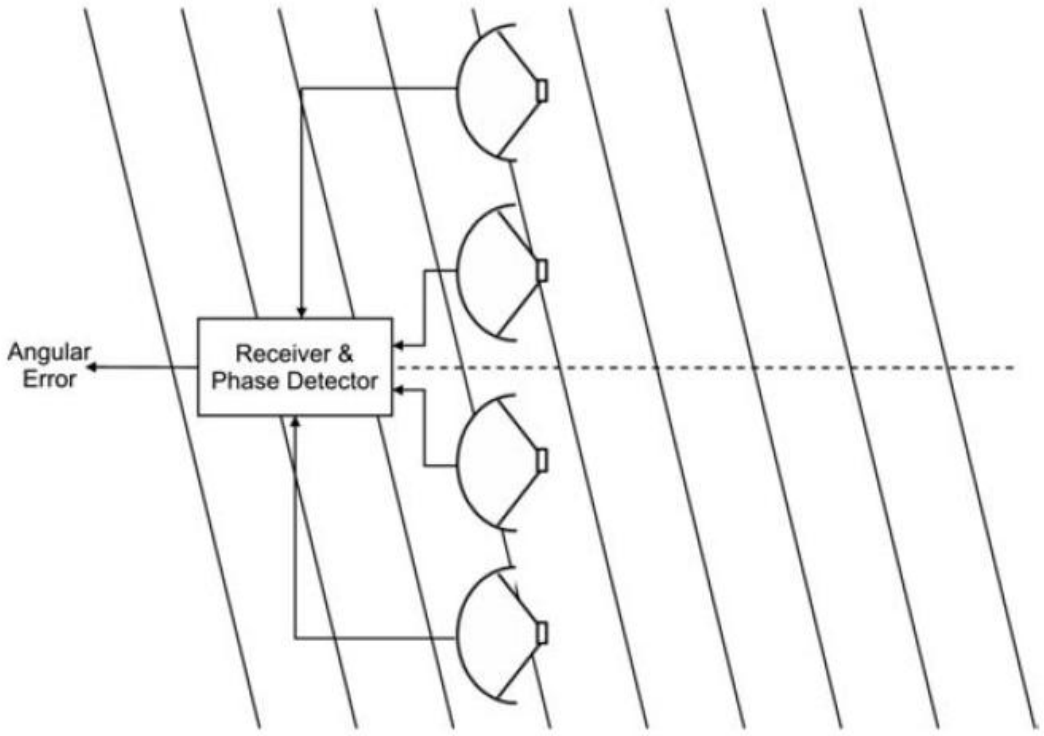


Figure 8.41 System to resolve ambiguity in phase comparison monopulse tracking technique

Step Track

- An amplitude-sensing methodology where the antenna is moved in small incremental steps to maximize received signal strength.
- **Advantages:** Simple, low-cost, and does not require RF phase stability.
- **Disadvantages:** Susceptible to amplitude perturbations (scintillation, fading). Tracking accuracy is dependent on step size and signal-to-noise ratio.

Intelligent Tracking

- Combines data from a gradient tracking algorithm with a satellite position prediction model.
- Uses prediction data to update the antenna position during signal fluctuations.
- **Advantages:** Offers the benefits of step track, and is well-suited for situations with scintillation and signal fades.
- **Disadvantage:** Can be susceptible to amplitude fluctuations during initial acquisition.

Reference

- Anil K. Maini, Varsha Agrawal, ***Satellite Communications***, Wiley India Pvt. Ltd., 2015, ISBN: 978-81-265-2071-8.