Module V : **Satellite Communication**

Contents

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Satellite Communication

Satellite is a physical object that orbits, or rotates about, some celestial body. Satellites occur in nature, and our own solar system is a perfect example. The earth and other planets are satellites rotating about the sun.

The moon is a satellite to the earth. A balance between the inertia of the rotating satellite at high speed and the gravitational pull of the orbited body keeps the satellite in place.

Satellites are launched and orbited for a variety of purposes. The most common application is communication in which the satellite is used as a repeater.

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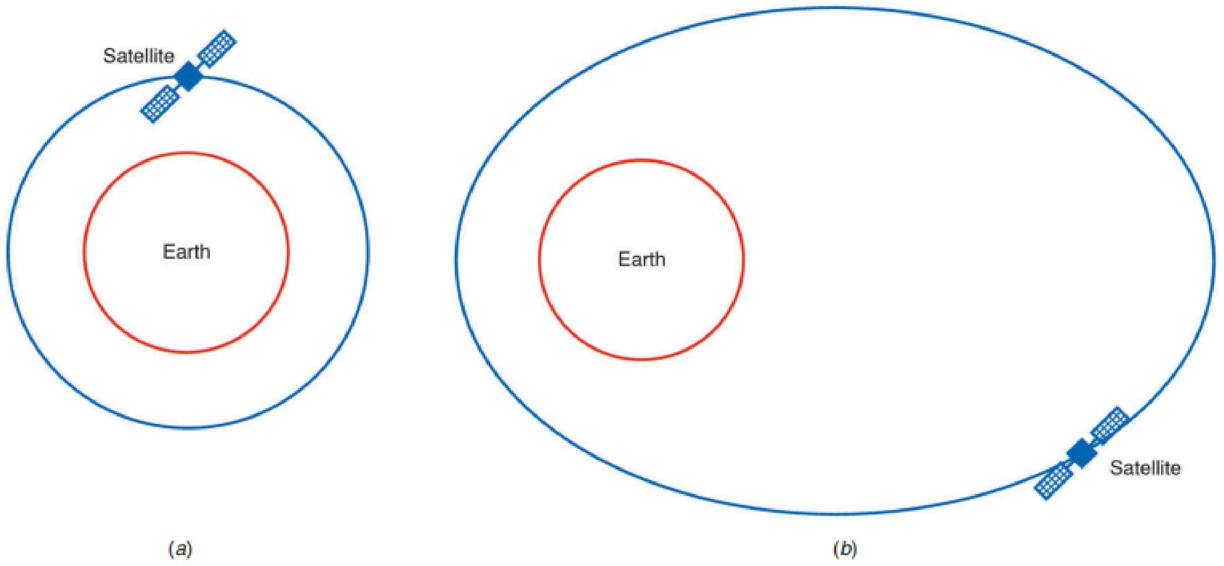
Satellite Orbits

The ability to launch a satellite and keep it in orbit depends upon following well-known physical and mathematical laws that are referred to collectively as orbital dynamics

Principles of Satellite Orbits and Positioning

A satellite rotates about the earth in either a circular or an elliptical path, as shown in Fig. 17-1. Circles and ellipses are geometric figures that can be accurately described mathematically. Because the orbit is either circular or elliptical, it is possible to calculate the position of a satellite at any given time

Figure 17-1 Satellite orbits. (*a*) Circular orbit. (*b*) Elliptical orbit.



Satellite Orbits

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Satellite Height. In a circular orbit, the height is simply the distance of the satellite from the earth. However, in geometric calculations, the height is really the distance between the center of the earth and the satellite. In other words, that distance includes the radius of the earth, which is generally considered to be about 3960 mi (or 6373 km). A satellite that is 5000 mi above the earth in circular orbit is 3960 + 5000, or 8960, mi from the center of the earth (see Fig. 17-3)

Figure 17-2 The orbital plane passes through the geocenter.

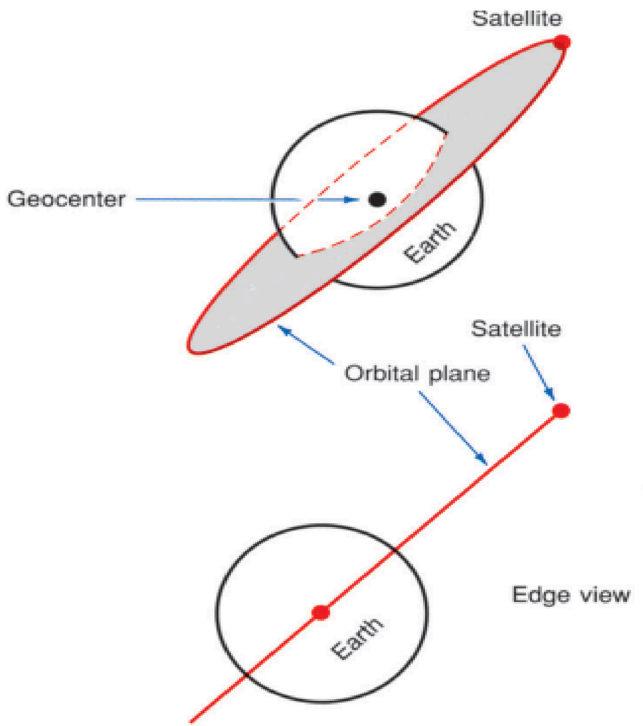
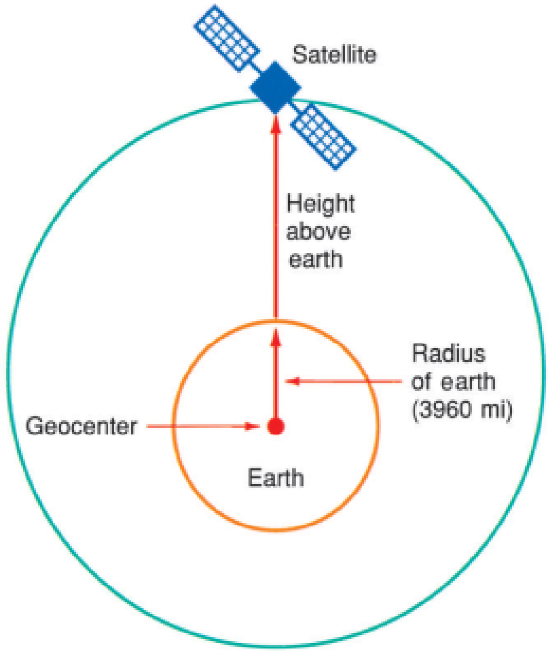


Figure 17-3 Satellite height.

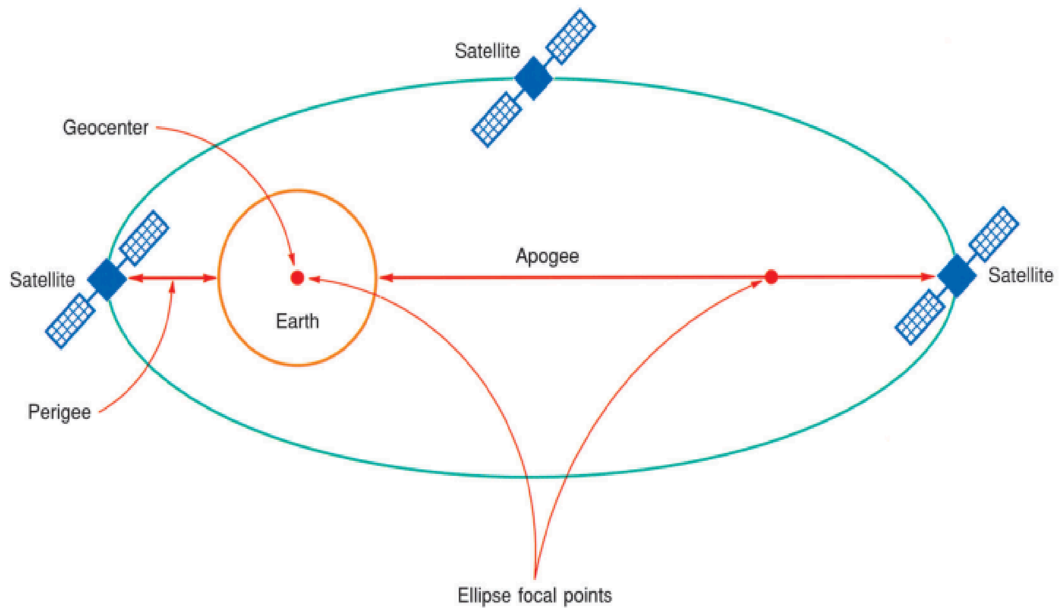


Satellite Orbits

- When the satellite is in an elliptical orbit, the center of the earth is one of the focal points of the ellipse (refer to Fig. 17-4).
- In this case, the distance of the satellite from the earth varies according to its position. Typically the two points of greatest interest are the highest point above the earth—the **apogee**—and the lowest point—the **perigee**

Satellite Speed. As indicated earlier, the speed varies according to the distance of the satellite from the earth. For a circular orbit the speed is constant, but for an elliptical orbit the speed varies according to the height. Low earth satellites of about 100 mi in height have a speed in the neighborhood of 17,500 mi/h. Very high satellites such as communication satellites, which are approximately 22,300 mi out, rotate much more slowly, a typical speed of such a satellite being in the neighborhood of 6800 mi/h.

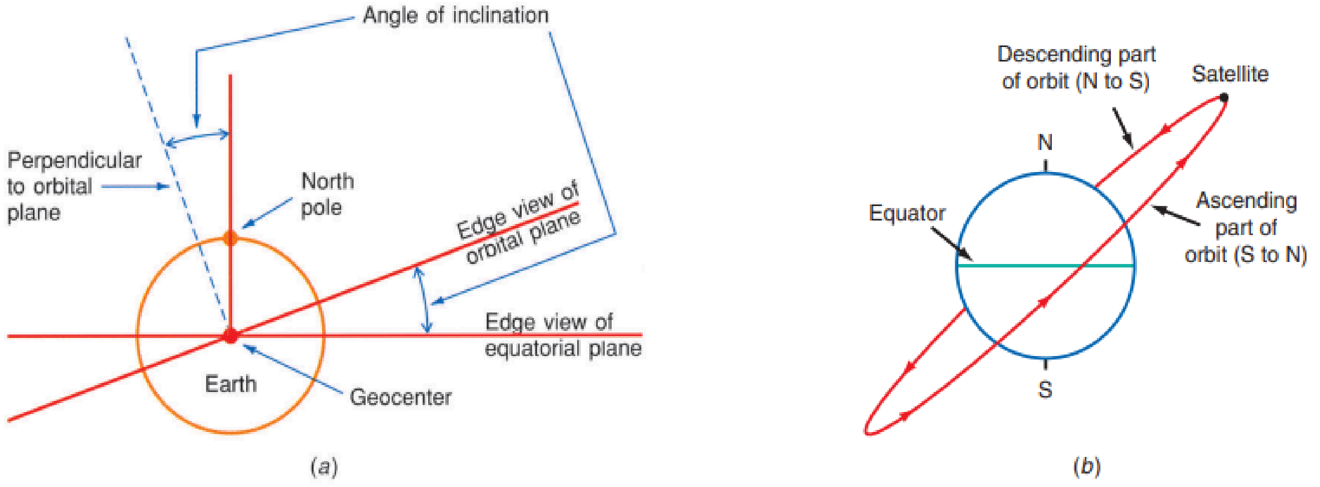
Figure 17-4 Elliptical orbit showing apogee and perigee.



Satellite Orbits

- **Satellite Period.** The period is the time it takes for a satellite to complete one orbit. It is also called the sidereal period
- **Angle of Inclination**. The angle of inclination of a satellite orbit is the angle formed between the line that passes through the center of the earth and the north pole and a line that passes through the center of the earth but that is also perpendicular to the orbital plane. This angle is illustrated in Fig. 17-5(a). Satellite orbits can have inclination angles of 0° through 90°.
- Another definition of inclination is the angle between the equatorial plane and the satellite orbital plane

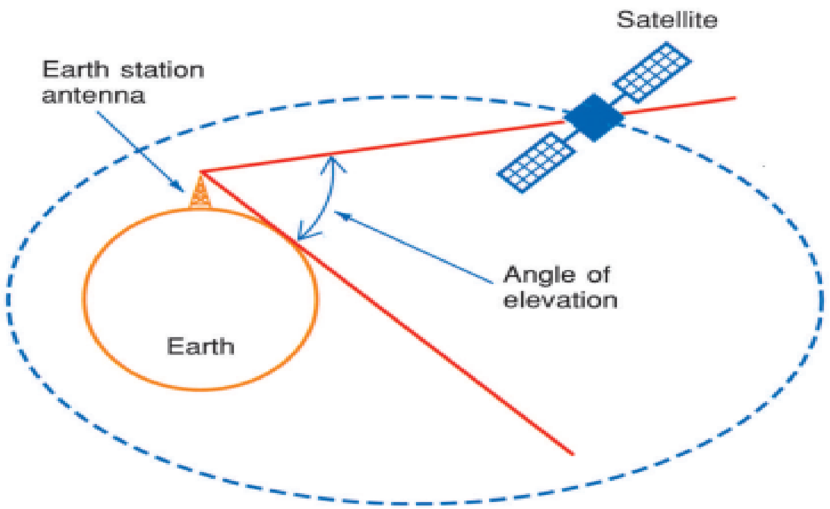
Figure 17-5 (*a*) Angle of inclination. (*b*) Ascending and descending orbits.



Satellite Orbits

- When the angle of inclination is 0°, the satellite is directly above the equator.
- When the angle of inclination is 90°, the satellite passes over both the north and the south poles once for each orbit.
- Orbits with 0° inclination are generally called equatorial orbits, and orbits with inclinations of 90° are referred to as polar orbits.
- **Angle of Elevation.** The angle of elevation of a satellite is the angle that appears between the line from the earth station's antenna to the satellite and the line between the earth station's antenna and the earth's horizon (see Fig. 17-6).
- **Geosynchronous Orbits.**
- Multiple-satellite systems, they are widely deployed in global telecommunication applications. These systems use anywhere from 24 to more than 100 satellite

Figure 17-6 Angle of elevation.



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- **Geosynchronous Orbits.**
- Multiple satellite systems are usually located in two ranges above the earth.

1. Low earth-orbiting satellites, commonly referred to as LEOs, are placed in the range of 400 to 1000 mi above the earth.
2. Medium earth-orbiting satellites or MEOs occupy the range of 1000 to 6000 mi above the earth.

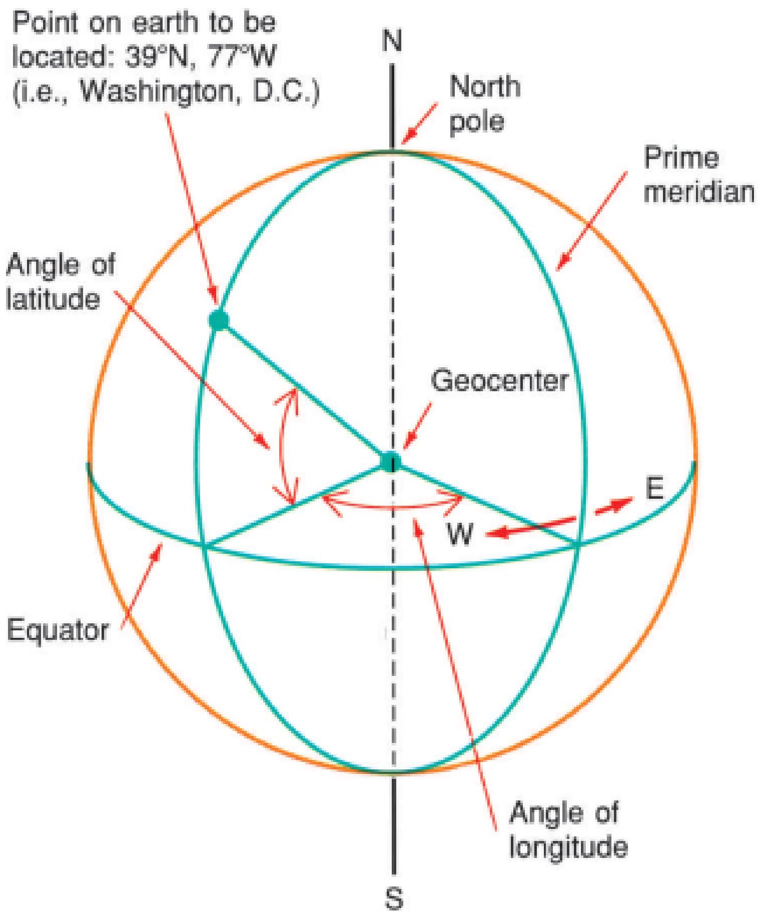
- The greater the height above the earth, the better the view and the greater the radio area coverage on the earth’s surface, the MEO is obviously preferred over the LEO. power required for reliable communication and the longer the delay. For MEOs, the round-trip delay averages about 100 ms. The delay in LEOs averages 10 ms
- The best solution is to launch a synchronous or geostationary satellite. In a geosynchronous earth orbit (GEO), the satellite orbits the earth about the equator at a distance of 22,300 mi (or 35,888 km).
- A satellite at that distance rotates about the earth in exactly 24 h. In other words, the satellite rotates in exact synchronism with the earth. For that reason, it appears to be fixed or stationary, thus the terms synchronous, geosynchronous, or geostationary orbit

Satellite Orbits

- **Latitude and Longitude**.

- **Latitude** is defined as the angle between the line drawn from a given point on the surface of the earth to the point at the center of the earth called the geocenter and the line between the geocenter and the equator (see Fig. 17-7). The 0° latitude is at the equator, and 90° latitude is at either the north or south pole. Usually an N or an S is added to the latitude angle to designate whether the point is in the northern or southern hemisphere.
- A line drawn on the surface of the earth between the north and south poles is generally referred to as a meridian. A special meridian called the prime meridian is used as a reference point for measuring longitude

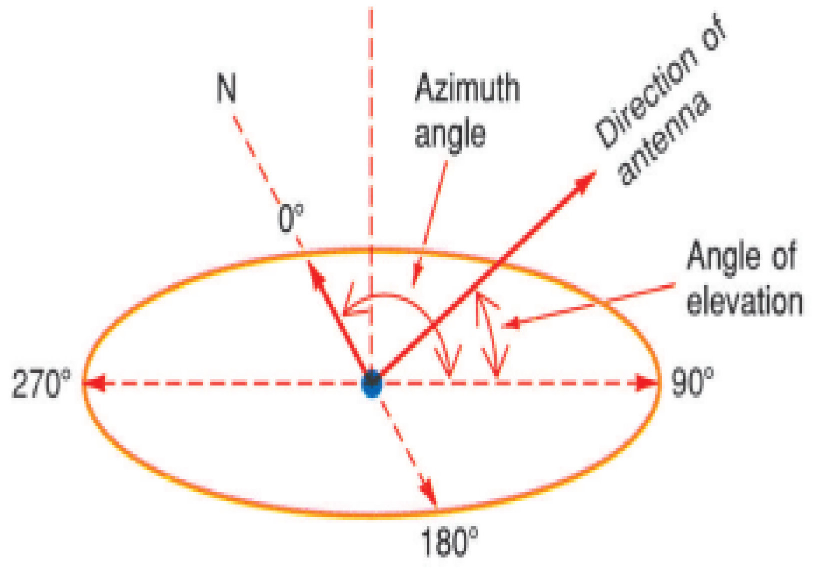
Figure 17-7 Tracking and navigation by latitude and longitude.



Satellite Orbits

- **Azimuth and Elevation.** The azimuth and elevation designations in degrees tell where to point the antenna (see Fig. 17-9).
- Azimuth refers to the direction where north is equal to 0°. The **azimuth angle** is measured clockwise with respect to north.
- The **angle of elevation** is the angle between the horizontal plane and the pointing direction of the antenna

Figure 17-9 Azimuth and elevation: Azimuth = 90°; elevation = 40°.



Satellite Communication Systems

Repeaters and Transponders Fig. 17-10 shows the basic operation of a communication satellite. An earth station transmits information to the satellite. The satellite contains a receiver that picks up the transmitted signal, amplifies it, and translates it on another frequency.

Figure 17-10 Using a satellite as a microwave relay link.

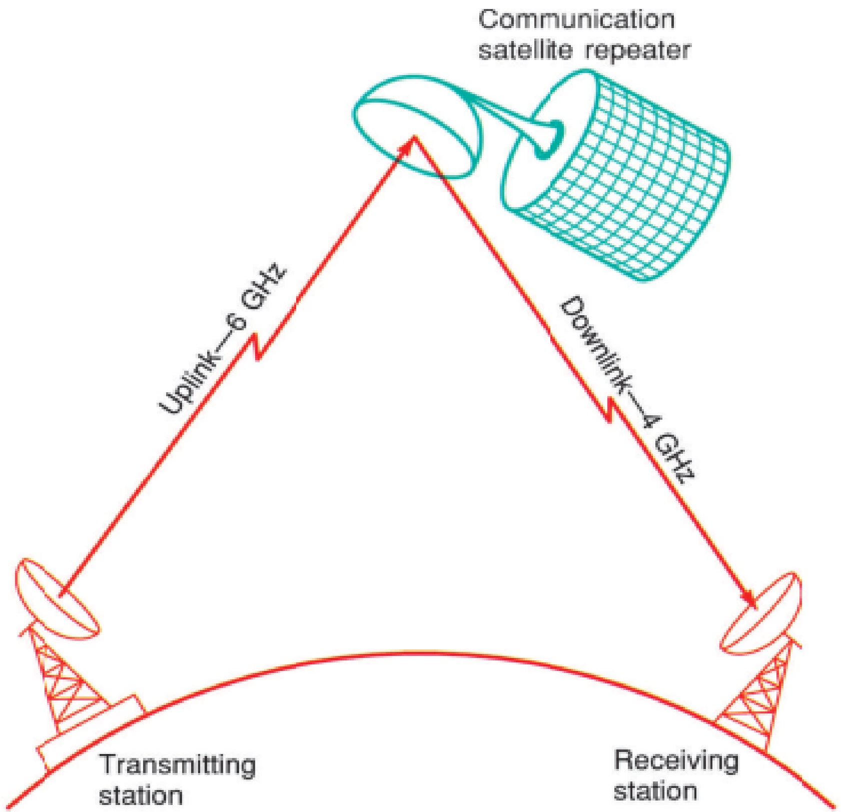
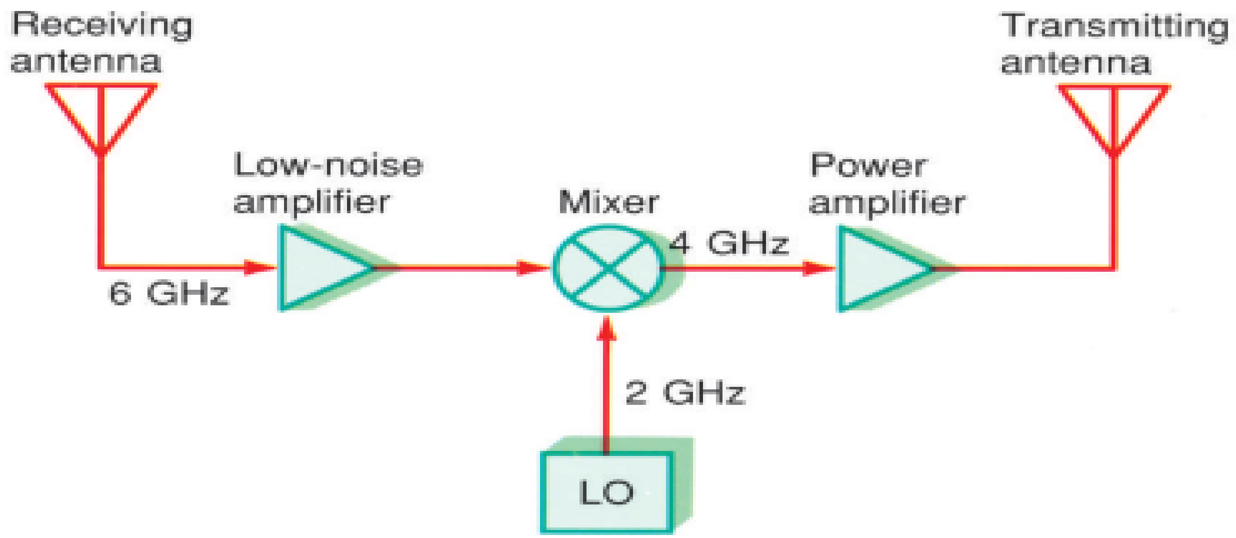


Figure 17-11 A satellite transponder.



Satellite Communication Systems

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Repeaters and Transponders

- The signal on the new frequency is then retransmitted to the receiving stations on earth. The original signal being transmitted from the earth station to the satellite is called the uplink, and the retransmitted signal from the satellite to the receiving stations is called the downlink. Usually, the downlink frequency is lower than the uplink frequency.
- A typical uplink frequency is 6 GHz, and a common downlink frequency is 4 GHz.
- The transmitter-receiver combination in the satellite is known as a transponder. The basic functions of a transponder are amplification and frequency translation (see Fig. 17-11).
- The reason for frequency translation is that the transponder cannot transmit and receive on the same frequency. The transmitter's strong signal would overload, or "desensitize," the receiver and block out the very small uplink signal, thereby prohibiting any communication.
- Widely spaced transmit and receive frequencies prevent interference. Transponders are also wide-bandwidth units so that they can receive and retransmit more than one signal.

Satellite Communication Systems

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Repeaters and Transponders

- Any earth station signal within the receiver's bandwidth will be amplified, translated, and retransmitted on a different frequency. Although the typical transponder has a wide bandwidth, it is used with only one uplink or downlink signal to minimize interference and improve communication reliability.
- **Frequency Allocations(Frequency bands used in satellite communication)**

Figure 17-12 Frequency bands used in satellite communication

Band	Frequency
P	225–390 MHz
J	350–530 MHz
L	1530–2700 MHz
S	2500–2700 MHz
C	3400–6425 MHz
X	7250–8400 MHz
Ku	10.95–14.5 GHz
Ka	17.7–31 GHz
Q	36–46 GHz
V	46–56 GHz
W	56–100 GHz

Satellite Communication Systems

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- **Frequency Allocations(Frequency bands used in satellite communication)**
- The microwave spectrum is divided up into frequency bands that have been allocated to satellites as well as other communication services such as radar frequency bands are generally designated by a letter of the alphabet. Fig. 17-12 shows the various frequency bands used in satellite communication.
- One of the most widely used satellite communication bands is the C band. The uplink frequencies are 5.925 to 6.425 GHz. In any general discussion of the C band, the uplink is generally said to be 6 GHz. The downlink is in the 3.7- to 4.2-GHz range. But again, in any general discussion of the C band, the downlink is nominally said to be 4 GHz.
- Occasionally, the C band is referred to by the designation 6/4 GHz, where the uplink frequency is given first. Over the past several years, there has been a steady move toward the higher frequencies. Currently, the Ku band is receiving the most attention. The uplinks are in the 14- to 14.5-GHz range, and the downlinks are from 11.7 to 12.2 GHz.

Satellite Communication Systems

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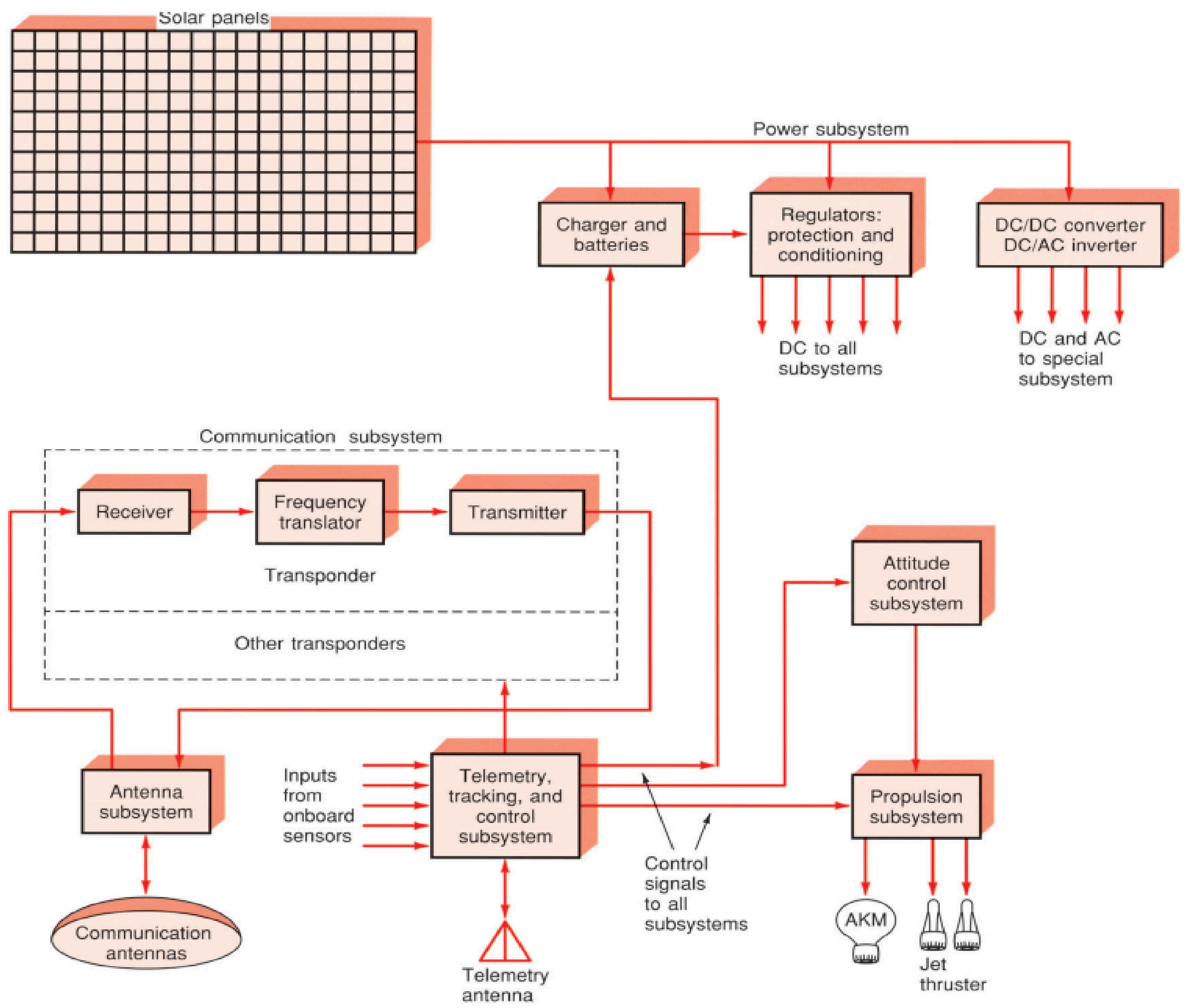
- **Frequency Allocations(Frequency bands used in satellite communication)**
- The Ku band designated as **14/12 GHz**. Use of the Ka band is also increasing.
- Most new communication satellites will operate in the Ku band. This upward shift in frequency is happening because the C band is overcrowded.
- Many communication satellites are in orbit now, most of them operating in the C band. However, there is some difficulty with interference because of the heavy usage. The only way this interference will be minimized is to shift all future satellite communication to higher frequencies.
- Naturally, the electronic equipment that can achieve these higher frequencies is more complex and expensive. Yet, the crowding and interference problems cannot be solved in any other way. Furthermore, for a given antenna size, the gain is higher in the Ku band than in the C band.
- This can improve communication reliability while decreasing antenna size and cost. Two other bands of interest are the X and L bands. The military uses the X band for its satellites and radar. The L band is used for navigation as well as marine and aeronautical communication and radar

Satellite Subsystems

- All satellite communication systems consist of two basic parts, the satellite or spacecraft and two or more earth stations.

- The satellite performs the function of a radio repeater or relay station.
- Two or more earth stations may communicate with one another through the satellite rather than directly point-to-point on the earth.

Figure 17-14 General block diagram of a communication satellite.



Satellite Subsystems

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Communication Subsystems

- The communication subsystem consists of multiple transponders.
- These receive the uplink signals, amplify them, translate them in frequency, and amplify them again for retransmission as downlink signals.
- The transponders share an antenna subsystem for both reception and transmission. The telemetry, tracking, and command (TT&C) subsystem monitors onboard conditions such as temperature and battery voltage and transmits this data back to a ground station for analysis.
- The ground station may then issue orders to the satellite by transmitting a signal to the command subsystem, which then is used to control many spacecraft functions such as firing the jet thrusters.
- The jet thrusters and the apogee kick motor (AKM) are part of the propulsion subsystem.
- They are controlled by commands from the ground.

Satellite Subsystems

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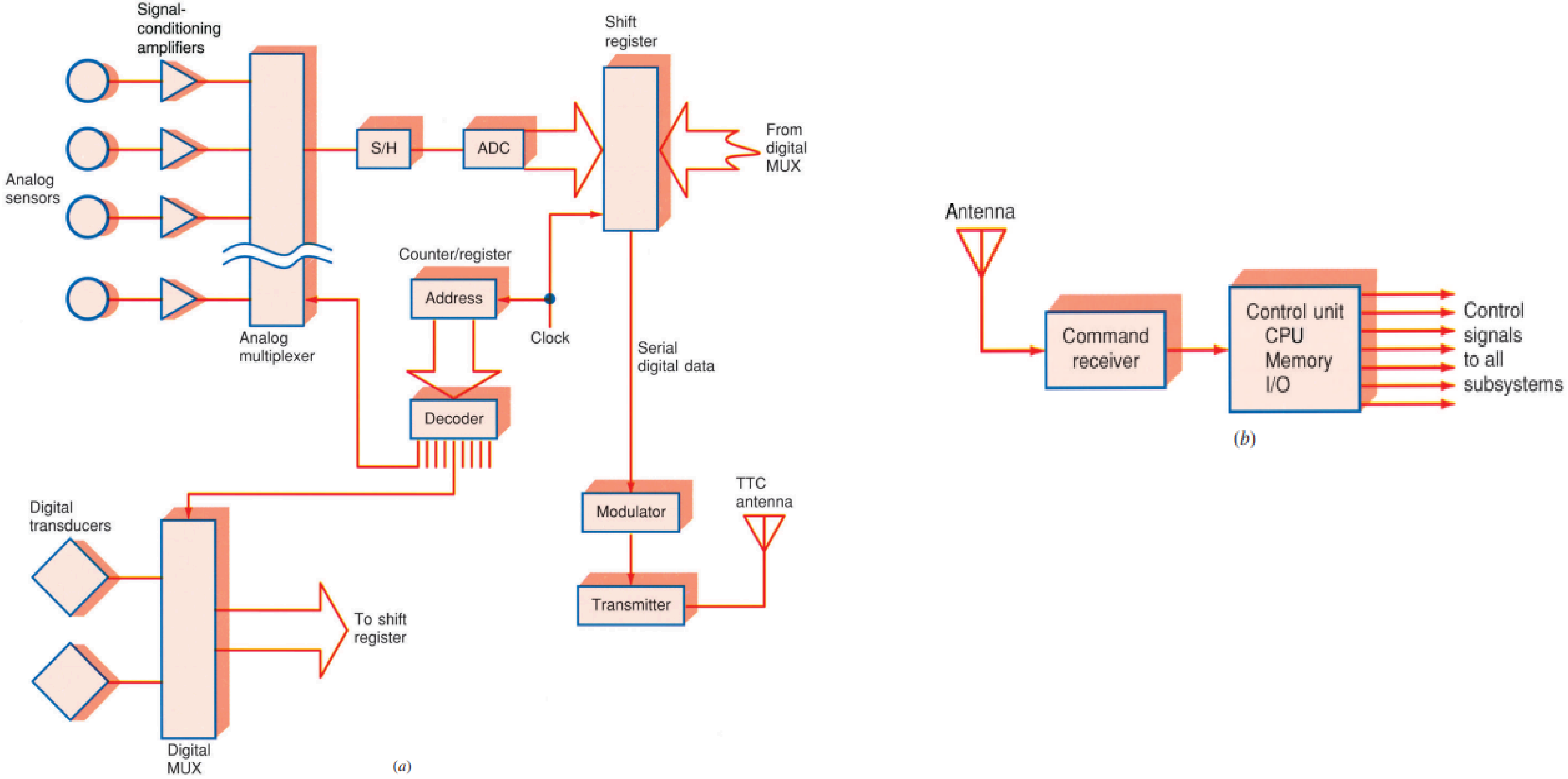
Telemetry, Command, and Control Subsystems

- All satellites have a telemetry, command, and control (TC&C) subsystem that allows a ground station to monitor and control conditions in the satellite.
- The telemetry system is used to report the status of the onboard subsystems to the ground station (see Fig. **17-16**).
- The telemetry system typically consists of various electronic sensors for measuring temperatures, radiation levels, power supply voltages, and other key operating characteristics.
- A command-and-control system permits the **ground station** to control the satellite.
- Typically, the satellite contains a command receiver that receives control signals from an earth station transmitter

Figure 17-16 (*a*) General block diagram of a satellite telemetry unit. (*b*) The command receiver and controller.



Ground Stations

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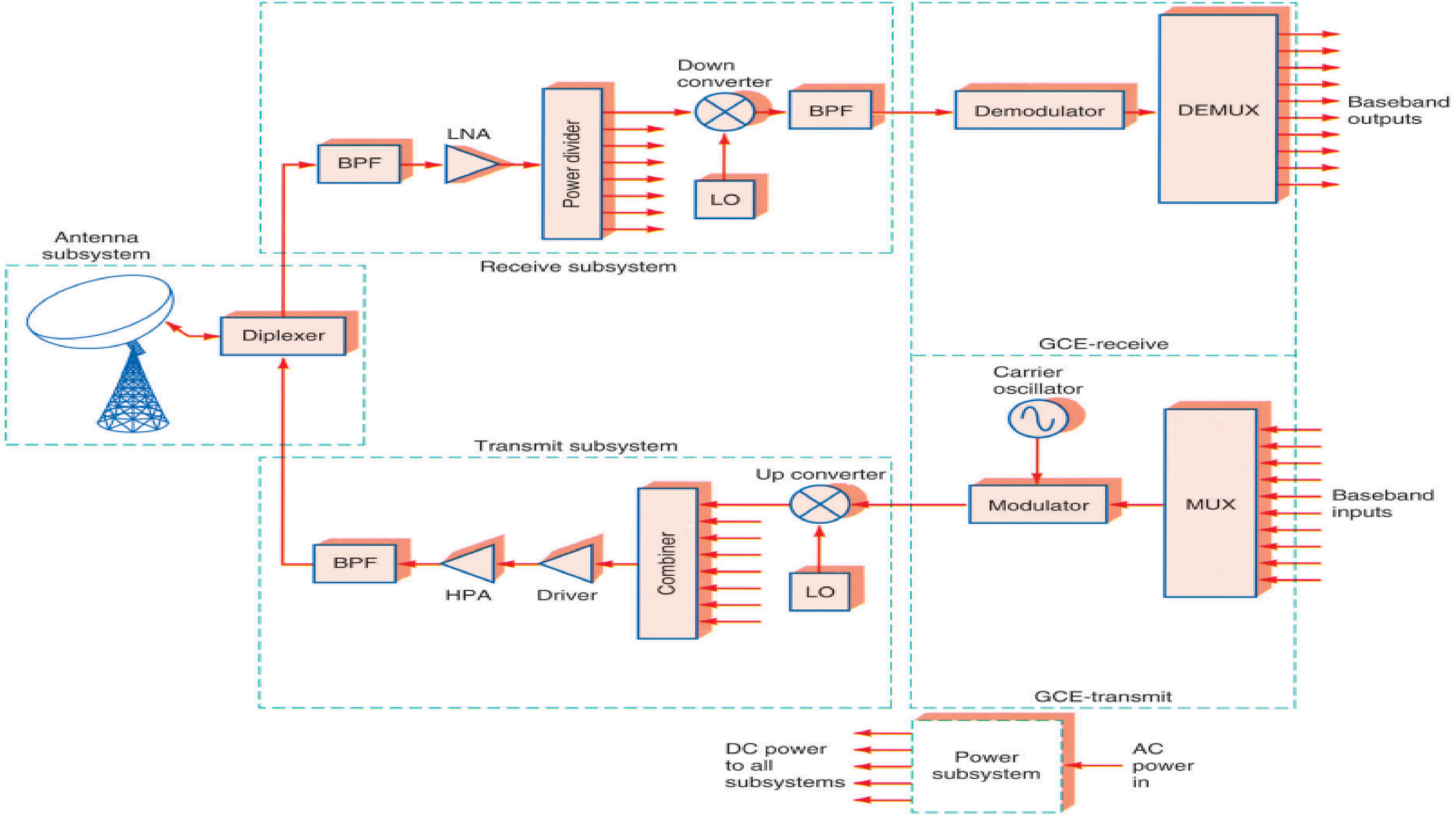
- The **ground station**, or earth station, is the terrestrial base of the system. The ground station communicates with the satellite to carry out the designated mission.
- An earth station consists of five major subsystems: the antenna subsystem, the receive subsystem, the transmit subsystem, the ground control equipment (GCE) subsystem, and the power subsystem (see Fig. 17-17). Not shown here are the telemetry, control, and instrumentation subsystems
- As shown in Fig. 17-17, the antenna subsystem usually includes a diplexer, i.e., a waveguide assembly that permits both the transmitter and the receiver to use the same antenna

Ground Stations(Earth Stations)

Figure 17-17 General block diagram of an earth station.



Ground Stations(Earth Stations)

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Antenna Subsystems:

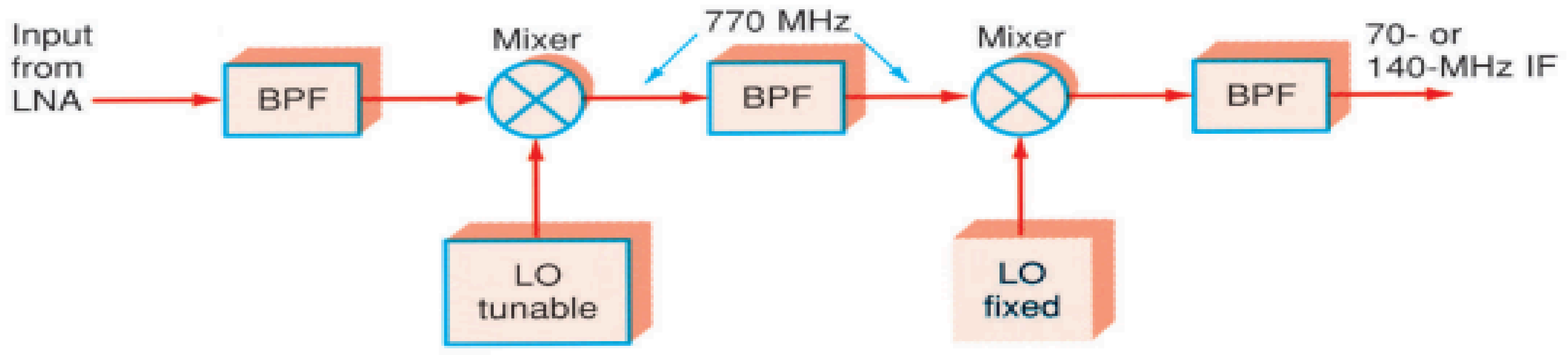
- All earth stations have a relatively large parabolic dish antenna that is used for sending and receiving signals to and from the satellite
- Huge high-gain antennas were required to pick up minute signals from the satellite. The earth station dishes were 80 to 100 ft or more in diameter
- Typically, the same antenna is used for both transmitting and receiving. A diplexer is used to permit a single antenna to be used for multiple transmitters and/or receivers.

Receive Subsystems: The downlink is the receive subsystem of the earth station

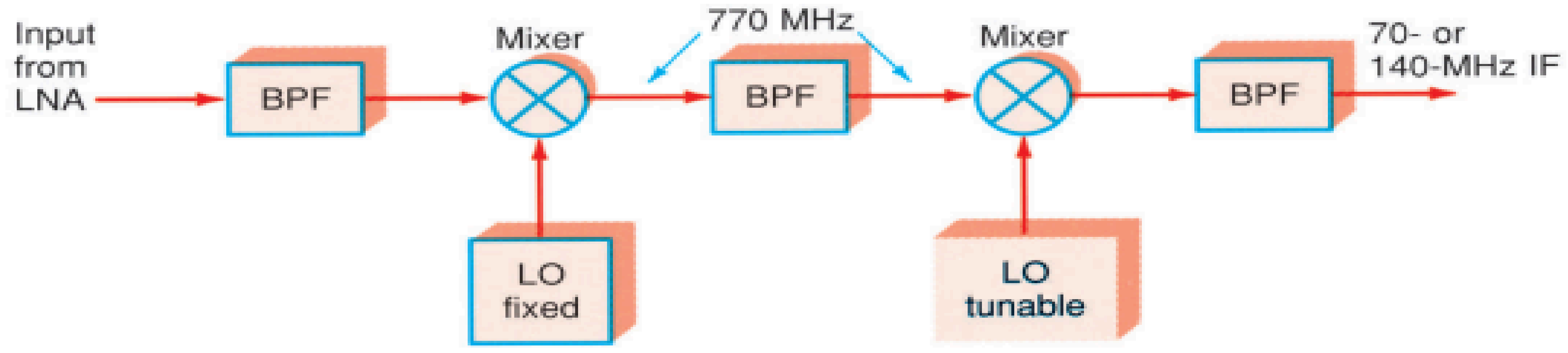
- **Receiver Circuits**. The receive subsystem consists of the LNA, down converters, and related components. The purpose of the receive subsystem is to amplify the downlink satellite signal and translate it to a suitable intermediate frequency
- The general block diagram of the receive subsystem shown in Fig. 17-18. Fig. 17-18(a) shows a typical dual-conversion down converter

Ground Stations(Earth Stations)

Figure 17-18 Dual-conversion down converters. (*a*) RF tuning. (*b*) IF tuning.



(*a*)



(*b*)

Ground Stations(Earth Stations)

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- **Receiver Ground Control Equipment**. The receiver ground control equipment (GCE) consists of one or more racks of equipment used for demodulating and demultiplexing the received signals.
- The down converters provide initial channelization by transponder, and the demodulators and demultiplexing equipment

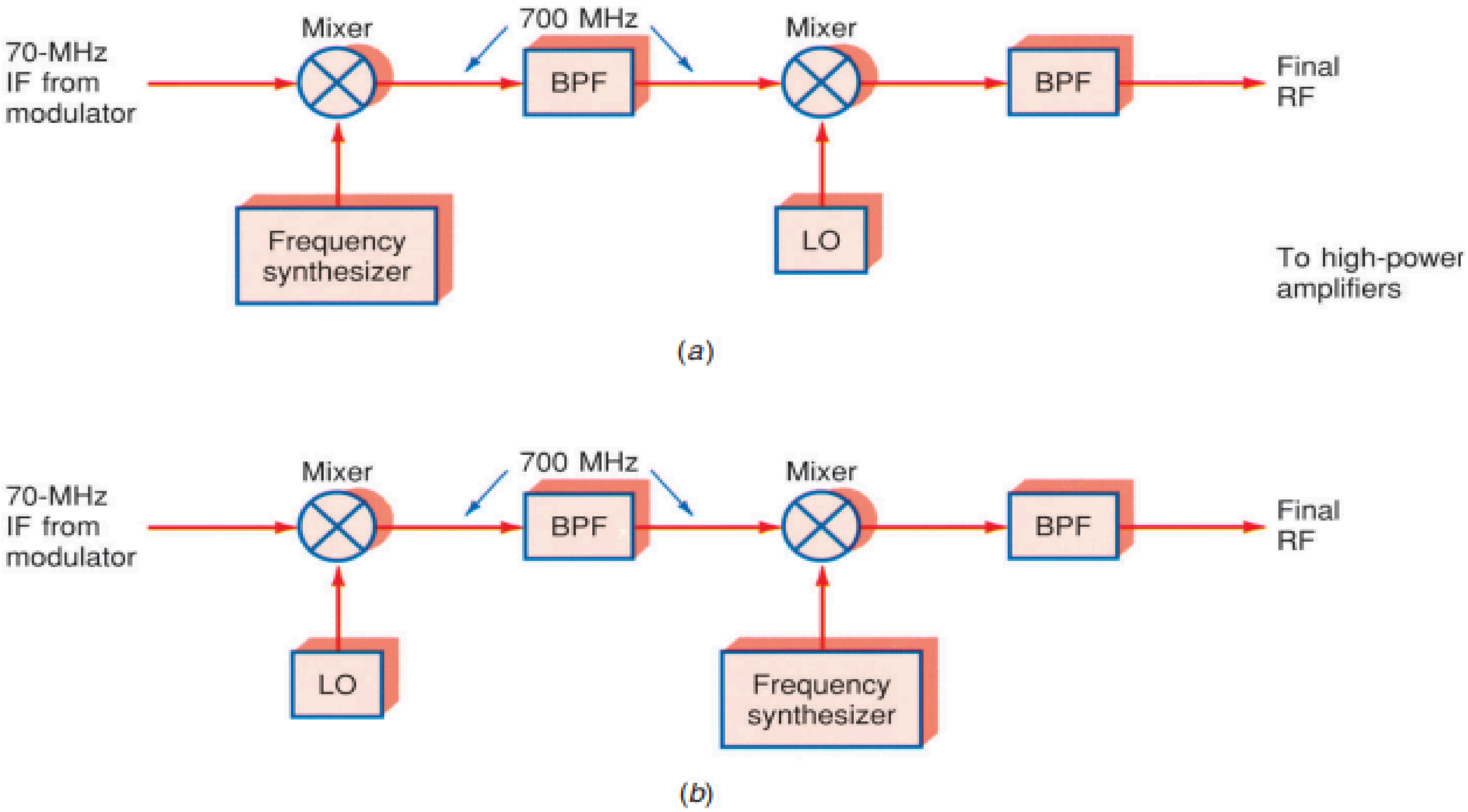
Transmitter Subsystems: The uplink is the transmitting subsystem of the earth station. It consists of all the electronic equipment that takes the signal to be transmitted, amplifies it, and sends it to the antenna

The transmit subsystem consists of two basic parts, the up converters and the power amplifiers.

- **Transmitter Circuits**. Once the modulated IF signals have been generated, up conversion and amplification will take place prior to transmission
- As in down converters, most modern up converters use dual conversion. Both RF tuning and IF tuning are used (Fig. 17-19)

Ground Stations(Earth Stations)

Figure 17-19 Typical up converter circuits. (*a*) IF tuning. (*b*) RF tuning.



Satellite Applications

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Communication Satellites: The main application for satellites today is in communication. Satellites used for this purpose act as relay stations in the sky.

The primary use of communication satellites is in long-distance telephone service. Satellites greatly simplify long-distance calls not only within but also outside the United States

Another major communication application is TV. For years, TV signals have been transmitted through satellites for redistribution

Direct Broadcast Satellite (DBS). A more recent satellite TV service is the Direct Broadcast Satellite (DBS) that uses special broad U.S. coverage satellites with high power to transmit cable-TV

Satellite Cell Phones. A common satellite application today is satellite-based cellular telephone service. Current cellular telephone systems rely on many low-power,

ground-based cells

1. Data communication E-mail and other computer communication.
2. Fax Two-way facsimile.
3. Paging Global paging to receivers with a two-line alphanumeric display.
4. Radio Determination Services (RDSs) A subsystem that permits satellites to locate transceivers on earth

Satellite Applications

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Digital Satellite Radio: One of the most popular options in new cars and trucks is digital satellite radio. This service provides hundreds of channels of music, news, sports, and talk radio primarily to car portable and home radios

Surveillance Satellites: Another application of satellites is in surveillance or observation. From their vantage point high in the sky, satellites can look at the earth and transmit what they see to ground stations for a wide variety of purposes

Global Navigation Satellite Systems

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Global Navigation Satellite System (GNSS) refers to the multiple satellite systems used for worldwide navigation. The original GNSS was the U.S.'s Global Positioning System (GPS) and still is the most widely used across the globe

GPS was developed by the U.S. Air Force for the Department of Defense as a continuous global radio navigation system that all elements of the military services would use for precision navigation. Development was started in 1973, and by 1994, the system was fully operational

The GPS consists of three major segments: the space segment, the control segment, and the user segment.

- **The space segment** is the constellation of satellites orbiting above the earth with transmitters that send highly accurate timing information to GPS receivers on earth. The receivers in the user segment themselves may be used on land, sea, or air

Global Navigation Satellite Systems

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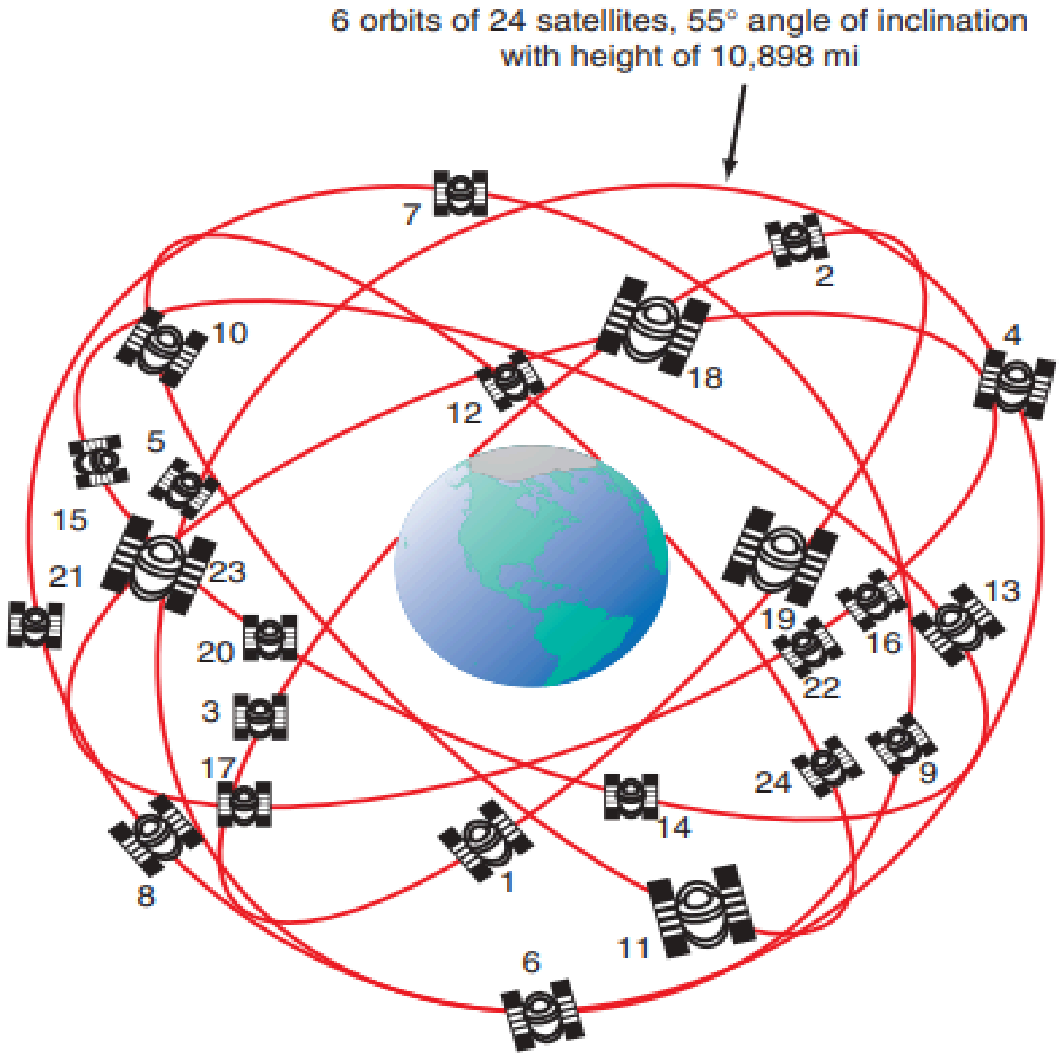
- The fully implemented GPS consists of 24 main operational satellites plus multiple active spare satellites (see Fig. 17-23).
- The satellites are arranged in six orbits, each orbit containing three or four satellites. The orbital planes form a 55° angle with the equator.
- The satellites orbit at a height of 10,898 nautical miles above the earth (20,200 km).
- The orbital period for each satellite is approximately 12h (11 h 58 min).

Figure 17-23 The GPS space segment.



Global Navigation Satellite Systems

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Control Segment and Atomic Clocks: The control segment of the GPS refers to the various ground stations that monitor the satellites and provide control and update information. The master control station is operated by the U.S

- **Atomic Clocks.** The precision timing signals are derived from atomic clocks. Most digital systems derive their timing information from a precision crystal oscillator called a clock
- Atomic clocks are electronic oscillators that use the oscillating energy of a gas to provide a stable operating frequency
- **GPS TRIANGULATION** The determination of the location of a GPS receiver is based on measuring the distance between the receiver and three satellites. The distance is determined by measuring the time of arrival of the satellite signals and then computing distance based on the speed of radio waves, with correction factors. See Fig. 17-26. Assume three satellites A, B, and C. The receiver first computes the distance from the receiver to satellite A. Note that the distance from A is on a circle that falls on a wide range of locations on earth.

Global Navigation Satellite Systems

Figure 17-26 How triangulation works to locate a GPS receiver.