Telecommunications
Satellite Communications

Satellite Orbits, Coverage, and Antenna Alignment

Courseware Sample

87768-F0

Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
⚡	Caution, risk of electric shock
♨	Caution, hot surface
⚠	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
∿	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

Since the Soviet Union shocked the western world by launching the first artificial satellite, SPUTNIK I, on October 4, 1957, the science of satellites and satellite communications has undergone an amazing evolution. Today satellites play an essential role in global communications including telephony, data networking, video transporting and distribution, as well as television and radio broadcasting directly to the consumer. They fulfill critical missions for governments, the military and other organizations that require reliable communications links throughout the world, and generate billions of dollars annually in revenue for private enterprise.

Communications satellites offer several important advantages over other types of long-range communications systems: the capability of direct communication between two points on earth with only one intermediate relay (the satellite), the ability to broadcast or collect signals and data to or from any area ranging up to the entire surface of the world, and the ability to provide services to remote regions where ground-based, point-to-point communications would be impractical or impossible.

One of the greatest advantages of satellite communications systems is the ratio of capacity versus cost. Although satellites are expensive to develop, launch and maintain, their tremendous capacity makes them very attractive for many applications. INTELSAT I, launched in 1965, had a capacity of only 240 two-way telephone channels or one two-way television channel, and an annual cost of $32 500 per channel. Since then, the capacity and lifetime of communication satellites have increased tremendously resulting in a drastic reduction in the cost per channel. Communications satellites now have capacities sufficient for several hundred video channels or tens of thousands of voice or data links.

In addition to applications designed specifically for communications purposes, satellites are used extensively for navigation systems, scientific research, mapping, remote sensing, military reconnaissance, disaster detection and relief and for many other applications. All of these applications, however, require at least one communications link between the satellite and one or more earth stations.

The Satellite Communications Training System is a state-of-the-art training system for the field of satellite communications. Specifically designed for hands-on training, the system covers modern satellite communication technologies including analog and digital modulation. It is designed to use realistic satellite uplink and downlink frequencies at safe power levels and to reflect the standards commonly used in modern satellite communications systems.

The Orbit Simulator provides interactive visualization of satellite orbital mechanics and coverage, and the theory behind antenna alignment with geostationary satellites. The optional Dish Antenna and Accessories provides hands-on experience in aligning a typical antenna with real geostationary satellites.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual Objective

When you have completed this manual, you will be familiar with satellite orbital mechanics and satellite coverage. You will understand the six orbital elements that define any stable, closed orbit. You will be familiar with different types of orbits, the coverage they provide and with their advantages and disadvantages for different applications.

You will also be familiar with the theory and practice of aligning a parabolic dish antenna with a geostationary satellite.

Description

Each exercise contains:

- A clearly defined Exercise Objective

- A Discussion Outline listing the main points presented in the Discussion

- A Discussion of the theory involved

- A Procedure Outline listing the main sections in the Procedure

- A step-by-step Procedure in which the student observes and measures the important phenomena, including questions to help in understanding the important principles.

- A Conclusion

- Review Questions

In this manual, all New Terms are defined in the Glossary of New Terms. In addition, an index of New Terms is provided.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Antenna Alignment for Geostationary Satellites

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the theory behind antenna alignment for GEO satellites. You will also have learned and put into practice a practical procedure for antenna alignment.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Antennas used with GEO satellites
  Dish type. Dish size. Low-noise amplifier (LNA, LNB, LNC, LNBF). Polarization.
- Earth station-satellite geometry
  Antenna look angle and skew adjustments.
- Aligning a small dish antenna with a geostationary satellite
  Equipment required for alignment. General alignment procedure.

DISCUSSION

Antennas used with GEO satellites

The high altitude of GEO satellites results in a significant path loss during both uplink and downlink transmission. For this reason, uplink and downlink earth-station antennas used with geostationary satellites are almost always directional, high-gain dish antennas (see Figure 63 to Figure 67).

Figure 63. Cassegrain uplink antennas for television broadcasting.

The fact that a GEO satellite appears to be virtually fixed in space facilitates the use of a directional antenna. The antenna can be permanently aligned with the satellite. No tracking mechanism is required to maintain proper alignment unless the earth station is on a moving platform or the dish size is greater than 16 m.

Most earth-station antennas range in size from large telecommunications carrier dishes, up to 15 meters in diameter, to small VSAT antennas that can be less than one meter in diameter. Uplink antennas for television broadcasting are generally large parabolic dish antennas (see Figure 63). Smaller antennas such as those shown in Figure 64 and Figure 65 are used with transportable and mobile earth stations for many applications such as tactical communications, television broadcasting and satellite news gathering (SNG).

Figure 64. 5-meter transportable earth-station antennas.

Figure 65. Mobile satellite news gathering (SNG) station.

Small portable dish antennas, such as that shown in Figure 66 can easily be deployed in the field or on battlegrounds.

Figure 66. Setting up a satellite antenna for a tactical command post (U.S. Marine Corps).

Undoubtedly the most common GEO satellite antenna is the ubiquitous satellite dish, shown in Figure 67, used to receive residential television programming called Direct Broadcast Service (DBS) or Direct-to-Home (DTH) TV.

Figure 67. Satellite DBS dish antennas.

Dish type

There are several different types of dish antennas. The most common type is the parabolic reflector antenna (see Figure 68). The parabola is illuminated by a source of energy called the feed (usually a waveguide horn) situated at the focus of the parabola and directed towards the center of the parabola.

Because of the characteristics of a parabola, any ray from the feed is reflected by the reflector in a direction parallel to the axis of the parabola. Furthermore, the distance traveled by any ray from the feed to the reflector and then to a plane perpendicular to the axis of the parabola is independent of its path. This means that the signal originating at the feed is converted to a plane wavefront of uniform phase.

The simplest antenna design is the prime focus feed parabolic antenna shown in Figure 68. One disadvantage of this design is that the feed is situated on the boresight and blocks some of the signal. For small dishes, blockage along the boresight causes a significant loss in efficiency. Another disadvantage of this type of antenna, when used for reception, is that the feed horn points downwards toward the ground. Since the feed pattern of the horn is broad and does not stop abruptly at the edge of the dish, spillover from the feed pattern is likely to receive noise from the warm ground. Both of these disadvantages can be remedied by using an offset feed (see Figure 69).
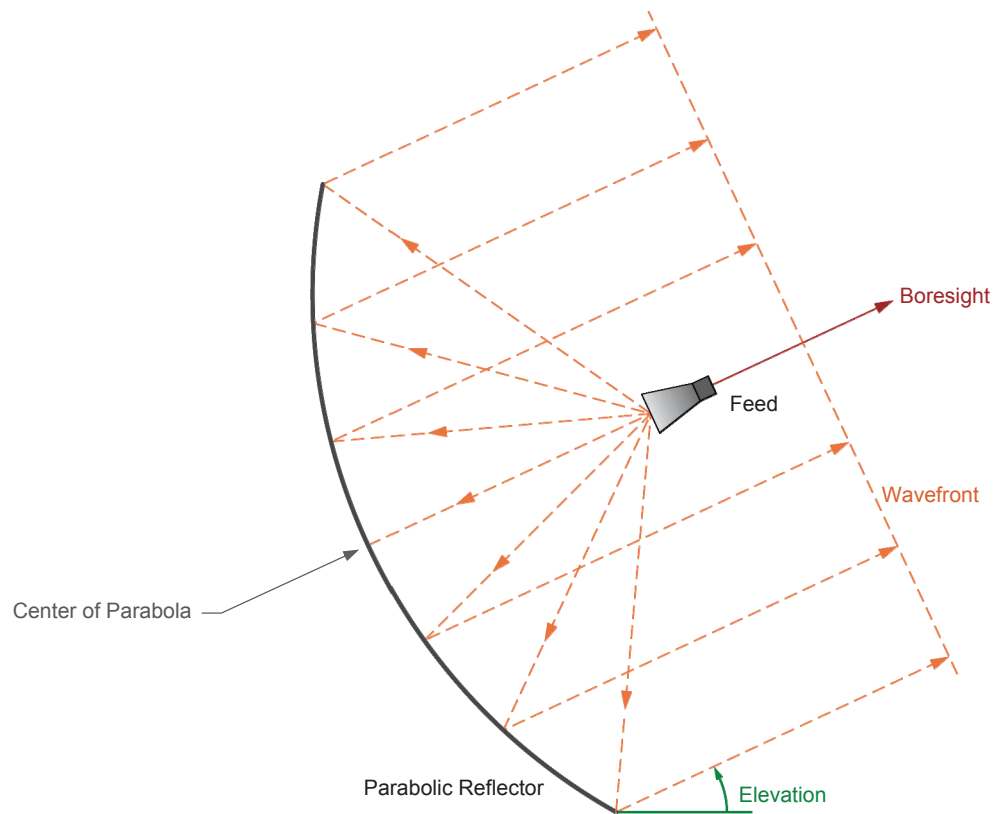
Figure 68. Prime focus feed parabolic antenna.
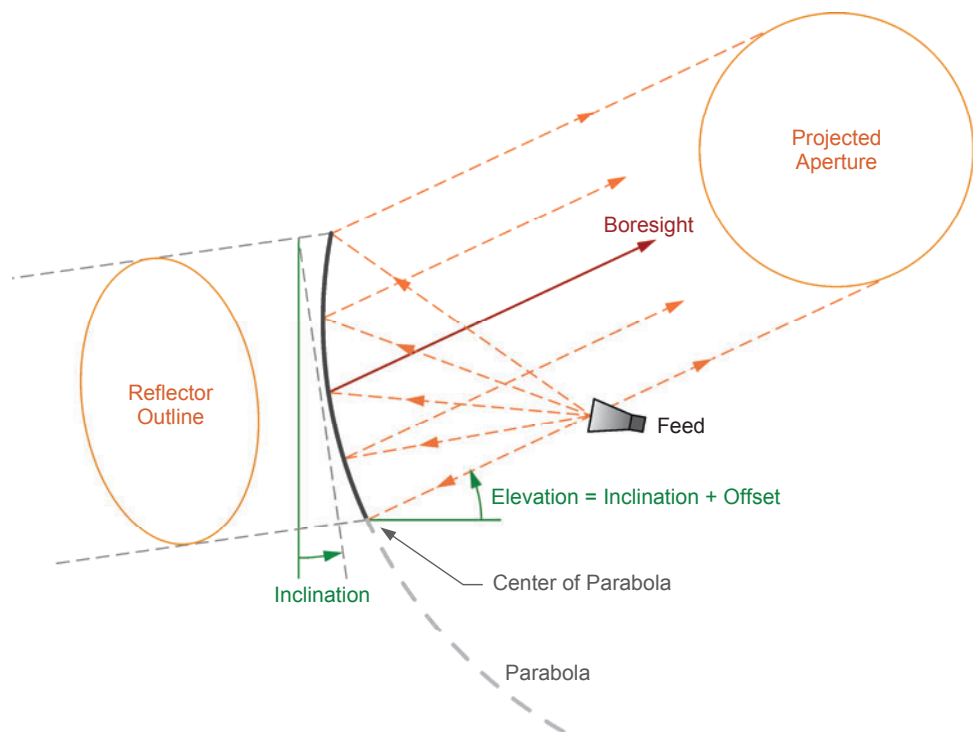
Figure 69. Offset-feed parabolic antenna.

When the lower edge of the reflector coincides with the center of the parabola, a line from the lower edge to the feed is approximately parallel to the boresight.

An offset-feed antenna also has the feed at the focus of the parabola. However, the reflector forms only a section of the parabola. As a result, the feed is no longer on the boresight. If the section does not include the center of the parabola, then none of the radiated beam is blocked by the feed horn. With many antennas, however, the bottom of the reflector coincides with the center of the parabola, as shown in Figure 69. In this case, a small portion of the beam is blocked by the feed, causing a slight loss in efficiency.

Although the antennas shown in Figure 68 and Figure 69 have the same elevation, the feed horn of the offset feed antenna is pointing slightly upwards, which results in less sensitivity to noise from the ground.

The reflector of an offset feed antenna is not perfectly circular, but is slightly elliptical, as shown in Figure 69, with the long axis in the vertical direction. This ensures that the aperture projected along the boresight is circular. The ratio between the short and long axes of the reflector depends on the offset of the antenna:

$$Offset = \cos^{-1}\left(\frac{Short\ axis}{Long\ axis}\right) \tag{34}$$

When setting the elevation of an offset feed antenna with the satellite, the offset must be taken into account. The elevation of the antenna is equal to the inclination of the reflector plus the offset of the antenna. In Figure 69, it can be seen that the elevation of the antenna is greater than the inclination of the reflector. The difference between the two is the offset.

For example, if the elevation required is 63° and the offset is 22°, the reflector must be inclined at an angle of 41° from the vertical. When the reflector is vertical, the elevation is equal to the offset. If the required elevation is less than the offset, the reflector must be tilted downwards. This may require mounting the reflector upside down or using a special mounting adapter.

Fortunately, in most cases, an elevation scale is built onto the back of the antenna that already compensates for the offset. To adjust the elevation, first ensure that the antenna mast or support is perfectly vertical, and then set the antenna to the desired elevation using the scale.

If the diameter of the main reflector is greater than 100 wavelengths, a Cassegrain antenna is often used (see Figure 70). The Cassegrain antenna is a double reflector type that works on the principle of the Cassegrain optical telescope, invented by the French astronomer Laurent Cassegrain. This design uses a parabolic main reflector and a hyperbolic secondary reflector. The main advantages of this design are reduced size and greater flexibility in the design of the feed system. This design allows for shorter feed lines. Cassegrain antennas are widely used as satellite antennas and as radio telescopes.
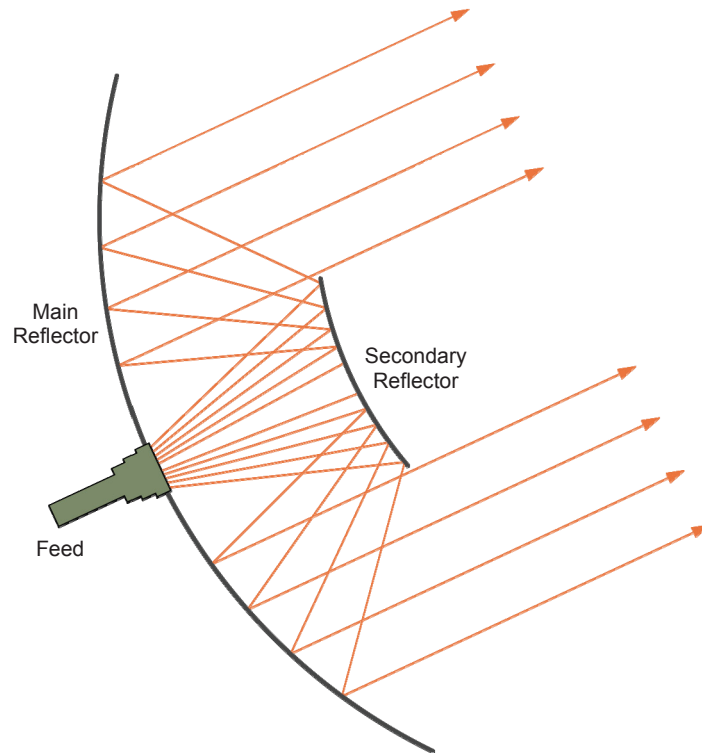
Figure 70. Cassegrain antenna.

With most parabolic dish antennas, the contour of the reflector is round or, in the case of an offset feed antenna, slightly elongated in the vertical direction. However, dish antennas with an elliptical contour are sometimes used in order to achieve high directivity in one plane only while keeping the reflector relatively small. The antenna shown in Figure 71 has higher directivity in the plane of the broad dimension. By aligning the broad axis of the elliptical dish so that it is parallel with the Clarke belt, the directivity of the antenna is optimized.

Figure 71. DBS antenna with an elliptical parabolic dish.

Dish size

Table 14 shows earth-station categories based on the size of the parabolic dish antenna.

Table 14. Earth station dish sizes.

Earth Station Category	Diameter
Very large dish	15 to 30 m diameter
Large dish	7 to 15 m diameter
Medium dish	3 to 7 m diameter
Small dish	0.5 m to 3 m diameter

An **isotropic antenna** is a hypothetical antenna that radiates or accepts power uniformly in all directions

The dish size is directly related to the **gain** of the antenna, which is a measure of how much the antenna focuses the RF signal. The gain varies with direction and is defined as the ratio of the power radiated or received per unit solid angle by the antenna in a given direction to the power radiated or received per unit solid angle by a lossless isotropic antenna fed with the same power.

The gain is maximal along the electromagnetic axis (boresight) of the antenna. When the gain along the boresight is increased, by increasing the diameter of the reflector, the gain in other directions is reduced, making the antenna more directional. When one refers to the "gain" of an antenna, one usually means the maximum gain.

> For an offset feed antenna, the gain depends on the projected aperture of the antenna.

The gain depends on the diameter of the dish, the frequency of the RF signal and an efficiency factor. Figure 72 and Figure 73 show typical relationships between antenna gain and dish size for different frequencies. Figure 72 has a logarithmic horizontal axis and shows that a 1 m dish operating at 4 GHz provides a gain of approximately 30 dB. Doubling the diameter of the dish, or doubling the frequency, increases the gain by 6 dB, that is, by a factor four.
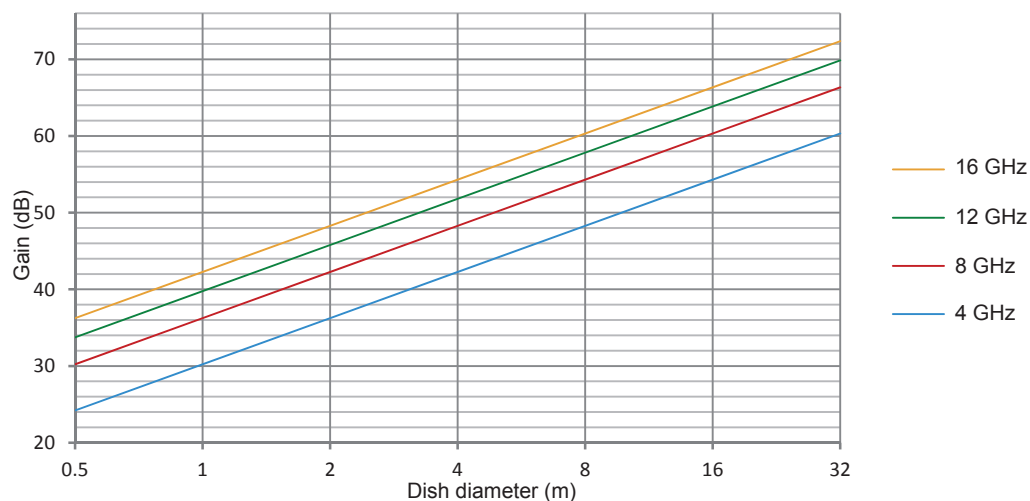
Figure 72. Typical antenna gain versus dish size (0.5 m to 32 m, efficiency factor = 0.6).
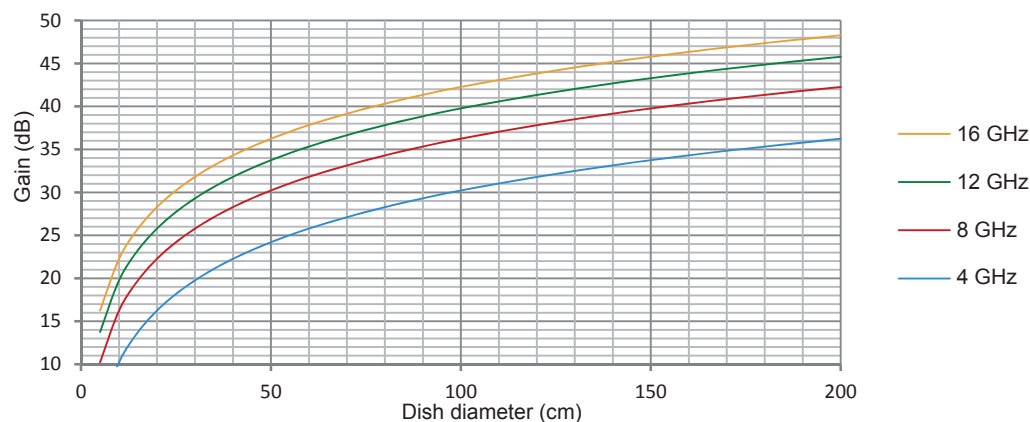
Figure 73. Typical antenna gain versus dish size (up to 2 m, efficiency factor = 0.6).

As the dish size, and the gain, increase, the 3 dB beamwidth of the antenna decreases, as shown in Figure 74.
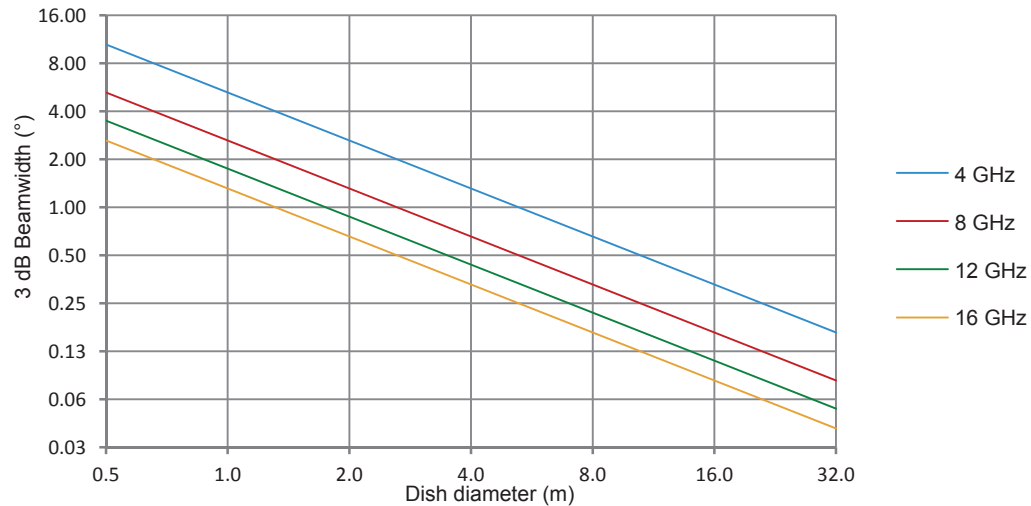
Figure 74. 3 dB (half-power) beamwidth versus dish size (efficiency factor = 0.6).

Because of their relatively wide beamwidth, small dish antennas can be permanently aligned with a geostationary satellite and permanently fixed in place. At 12 GHz, a 1-m dish antenna has a beamwidth of approximately 1.8°, which is much greater than the typical station-keeping box limits of ±0.15° for a geostationary satellite. Dishes greater than 16 m, however, have beamwidths less than 0.15° and therefore may require tracking mechanisms to keep them accurately pointed at a geostationary satellite.

Low-noise amplifier (LNA, LNB, LNC, LNBF)

> An active component is one that is capable of power gain, such as an amplifier

The first active component in a satellite receiver is a special type of amplifier called a **low-noise amplifier (LNA)** which is used to amplify the weak signal captured by the antenna to a usable level while introducing as little noise as possible. This is followed by a down converter to translate the RF signal to an IF frequency range.

Some receivers use a variation of the LNA called a **low-noise converter (LNC)**, which combines a low-noise amplifier and a down converter. Both the LNA and the LNC have a relatively narrow bandwidth, corresponding to the bandwidth of a single transponder (channel) of the satellite. A type of low-noise converter called the **low-noise block (LNB)** handles a large bandwidth spanning several or all transponders of the satellite. A low-noise block combined with a down converter is sometimes called a *low-noise block converter* or *low-noise block down converter*, although the term *low-noise block* is often used instead. An LNB combined with a feedhorn is called an **LNB feedhorn (LNBF)**.

Small antennas designed for television reception or data communications usually have an LNBF (often referred to simply as the LNB) at the focus of the antenna. Placing the LNB at the feedhorn instead of in the receiver reduces losses in the coaxial cable between the antenna and the receiver.

Some dish antennas have multiple LNBFs (see Figure 75). This type of antenna is designed to receive signals from two or more different satellites that are closely spaced in longitude. The signal from each satellite must be reflected by the dish to the corresponding LNBF. This requires that each LNBF be adjusted

separately. A 22 kHz tone generated by the receiver is applied through the coaxial cable to select the desired satellite.

Figure 75. Dish antenna with multiple LNBFs.

Polarization

An electromagnetic wave is a combination of an electric and a magnetic field. The two fields always appear simultaneously. The plane of the electric field is orthogonal to the plane of the magnetic field and both planes are perpendicular to the direction of propagation. By convention, the **polarization** of an electromagnetic wave is defined as the orientation of the plane of the electric field.

Polarization can be *linear*, where the electric field is always oriented at the same angle with respect to a reference plane. For antennas on a satellite, the reference plane is usually the equatorial plane. In most cases, linear-polarization is either horizontal, where the electric field is parallel to the plane of the equator, or vertical. For earth-station antennas, however, the reference plane is the local horizontal plane. Because of the curvature of the earth, these two reference planes are not parallel, unless the earth station and the satellite have the same longitude. The angle between these reference planes is called the **polarization angle**, or **skew**. It is the difference between the polarization of the signal transmitted by the satellite and the apparent polarization of the received signal. An adjustment for the polarization angle must be made when aligning a linearly polarized earth-station antenna, in order to maximize the signal.

Polarization can also be *elliptical*, where the plane of the electric field rotates with time making one complete revolution during one period of the wave. An elliptically polarized wave radiates energy in all planes perpendicular to the direction of propagation. The ratio between the maximum and minimum peaks of the electric field during the rotation is called the **axial ratio** AR and is usually specified in decibels. When the axial ratio is near zero dB, the polarization is said to be *circular*. If the axial ratio is infinite, the electric field maintains a fixed direction and the polarization is linear.

If the rotation is clockwise, looking in the direction of propagation, the polarization is called *right-hand*. If it is counterclockwise, the polarization is called *left-hand*.

The polarization of an antenna depends on the shape and the orientation of the waveguide in the feed. The polarization of each antenna in a communications system should be of the same type and, if linear, should be properly aligned. Maximum signal strength at the receiver input occurs when the polarization of the receiving antenna matches the polarization of the incident wave.

Figure 76 shows examples of open waveguides resulting in vertical and horizontal polarization. The waveguide is often energized by a probe protruding through the broad side of the waveguide.

Horizontal Polarization

Vertical Polarization
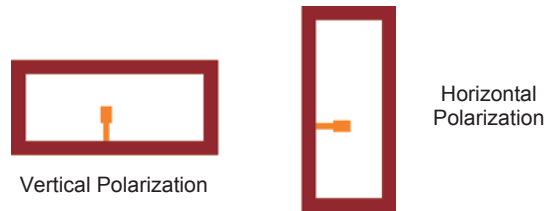
Figure 76. Vertical and horizontal polarization waveguides.

In order to make efficient use of repeater bandwidth, different polarizations are often used for adjacent transponder channels on a satellite. This technique, called *polarization diversity*, minimizes interference between adjacent channels. It is important therefore, to know the polarization of the satellite transponder you wish to link to in order to correctly configure the earth-station antenna. The polarization may be indicated in reference documents as H (horizontal), V (vertical), RHC, RH or R (right-hand circular) or LHC, LH or L (left-hand circular).

Although linearly polarized antennas can be used to communicate with circularly polarized antennas, there will be an **antenna polarization mismatch loss** L_{POL} of approximately 3 dB. For a transmitting and receiving antenna both using linear-polarization, the mismatch loss can be up to 20 dB, as shown by Equation (35).

$$L_{pol} = \cos^2 \theta \qquad\qquad (35)$$
$$= 20 \, \log(\cos \theta) \ [dB]$$

where L_{pol} is the antenna polarization mismatch loss
          θ is the misalignment angle

Circular polarization is often used for satellite communications, particularly for DBS TV broadcasting in North America. With circular polarization, the antenna polarization does not have to be adjusted. This is advantageous because the signal polarization may be rotated as the signal passes through anomalies in the ionosphere. However, it is generally less costly to produce high-performance LNBFs with linear-polarization. When linear-polarization is used, an extra step is required during the alignment procedure in order to correctly adjust the polarization of the antenna.

Many DBS LNBFs are designed for dual polarization (H and V or R and L). A dc voltage of 13 V or 18 V from the receiver is applied to the LNBF through the coaxial cable in order to select the polarization. The lower voltage generally selects the V or R polarization and the higher voltage selects the H or L polarization.

Some VSAT antennas have a feed assembly with a separate transmit and receive port. This assembly is designed to transmit on one polarization and receive on the other.

Earth station-satellite geometry

Communication with geostationary satellites is almost always done using a directional parabolic antenna. Since it is directional, the antenna must be accurately pointed toward the satellite and then fixed in place.

All geostationary satellites orbit about the earth above the equator, and at the same altitude, in the region of space known as the Clarke belt. Before attempting to align an antenna with a geostationary satellite, it is useful to imagine what the Clarke belt would look like if you could see it in the sky from different locations on earth.

The Clarke belt forms an imaginary arc in the sky (see Figure 77). If you are at the equator, the belt passes directly overhead. If you are in the northern hemisphere, the belt stretches from a point on the horizon a little south of due east, rising to its maximum height directly towards the south, and then reaching the horizon a few degrees south of due west. If you are in the southern hemisphere, the maximum height of the arc appears directly north of your location.
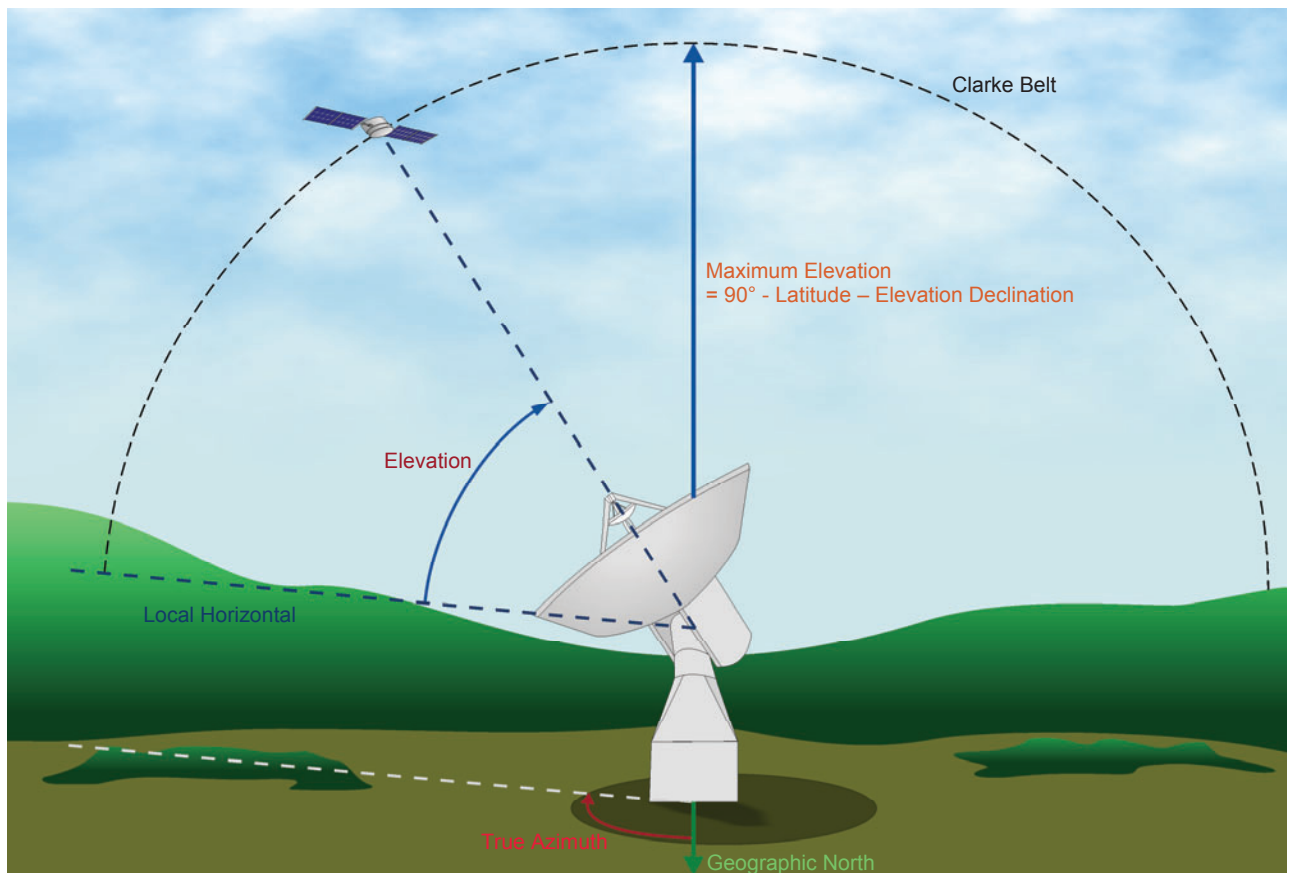
Figure 77. The Clarke belt and antenna look angles (in the northern hemisphere).

When the elevation to a satellite is high, the path of the signal through the atmosphere is relatively short and degradation due to the atmosphere is low. When the elevation is low, the signal follows a much longer path through the atmosphere and degradation is higher. The effect is significant below 10° elevation and very severe below 5°.

The true azimuths of all geostationary satellites that are visible from a location in the northern hemisphere range from a little more than 90° to a little less than 270°. For locations in the southern hemisphere, the true azimuths are greater than 270° or less than 90°.

The elevation of geostationary satellite can range from a little more than 0° (local horizontal) to a maximum elevation that depends on the latitude of the earth station. For an earth station at the equator, the maximum possible elevation is 90°. For latitudes north or south of the equator, the maximum possible elevation is equal to 90° minus the latitude $|\varphi|$ minus the apparent declination $|d|$.

Absolute values of the latitude and the apparent declination are used here because the signs of these values are different in the northern and southern hemispheres.

Look angles for geostationary satellites are usually calculated assuming a spherical, rather than an ellipsoidal, earth. This introduces an error in antenna orientation between 0.02° and 0.03°. This error, however, has little effect on the performance of small dish antennas because their beamwidth is considerably greater than the error. In this exercise, a spherical earth is assumed and no distinction is made between geocentric and geodetic latitude.

The apparent declination d, shown in Figure 78, arises from the fact that the geostationary satellites are not at an infinite distance, as is the celestial equator, but are located approximately 36 000 km from the surface of the earth. This apparent declination varies with the latitude of the earth station and is not the same as the true declination of a GEO satellite which is always close to zero. Since declination is always measured with respect to the celestial equator, the apparent declination of a geostationary satellite is negative for an observer in the northern hemisphere (at positive latitudes) and positive for an observer in the southern hemisphere (at negative latitudes).
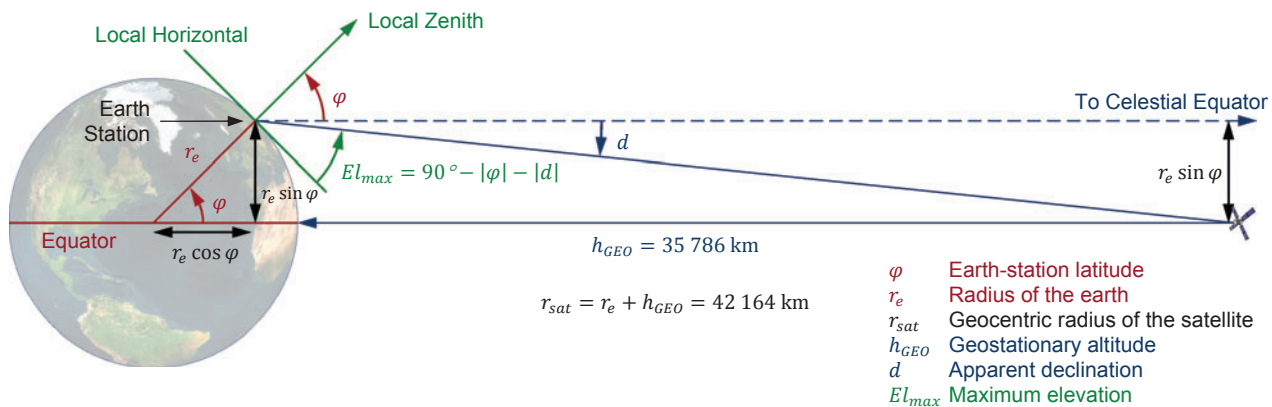
Figure 78. Geostationary satellite maximum elevation (satellite and earth station at the same longitude).

The apparent declination for a GEO satellite at the same longitude as the earth station can be calculated as shown in Equation (36). Its magnitude ranges from 0° at the equator to approximately 8.7° at a latitude of ±80°, which is near the extreme limit for linking with a GEO satellite. For satellites not at the same longitude as the earth station, the apparent declination is slightly different, but varies by less than one degree over the visible region of the Clarke belt.

$$d = \tan^{-1}\left[\frac{-r_e \sin\varphi}{r_{sat} - r_e \cos\varphi}\right] \tag{36}$$

$$= \tan^{-1}\left[\frac{-\sin\varphi}{\dfrac{r_{sat}}{r_e} - \cos\varphi}\right]$$

where d is the apparent declination of the GEO satellite
r_e is the earth's radius (6378 km)
r_{sat} is the geostationary satellite radius (42 164 km)
φ is the latitude of the earth station

Since the position of a geostationary satellite is fixed with respect to the earth, and because we are assuming a spherical earth, all calculations of azimuth and elevation can be performed in a terrestrial (EFG) coordinate system using the earth station latitude and longitude as well as the satellite longitude and radius.

The longitude λ_{sat} of a geostationary satellite is the longitude of the subsatellite point on the earth's surface. The radius of the satellite (distance from the center of the earth) is equal to the satellite's altitude plus the radius of the earth.

The location of the earth station on the surface of earth can also be specified in the EFG coordinate system frame using the earth station's longitude λ_{es} and latitude φ.

Because azimuth and elevation are measured relative to the position of the earth station on the earth's surface, and not to the center of the earth, a topocentric horizontal coordinate system must be used. This is a spherical coordinate system whose origin is centered on the earth station. Since both the position of the satellite and the position of the earth station, expressed in the EFG system are known, equations can be used to express the position of the satellite in the azimuth-elevation coordinate system. Figure 79 and Figure 80 show the geometry involved. (Figure 80 is a screen shot from the Orbit Simulator with added texts and arrows.)
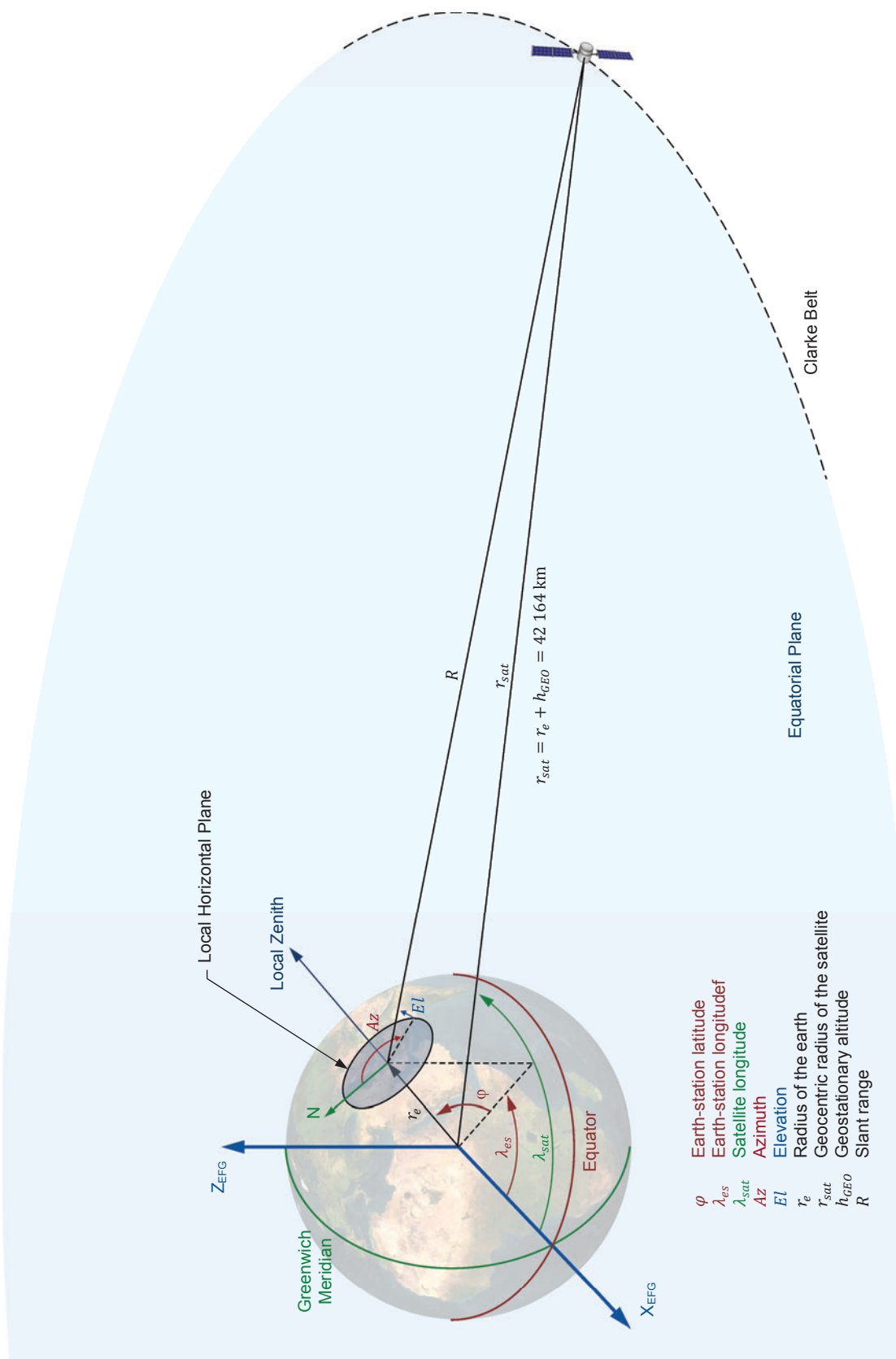
Figure 79. Azimuth-elevation geometry for a geostationary satellite.
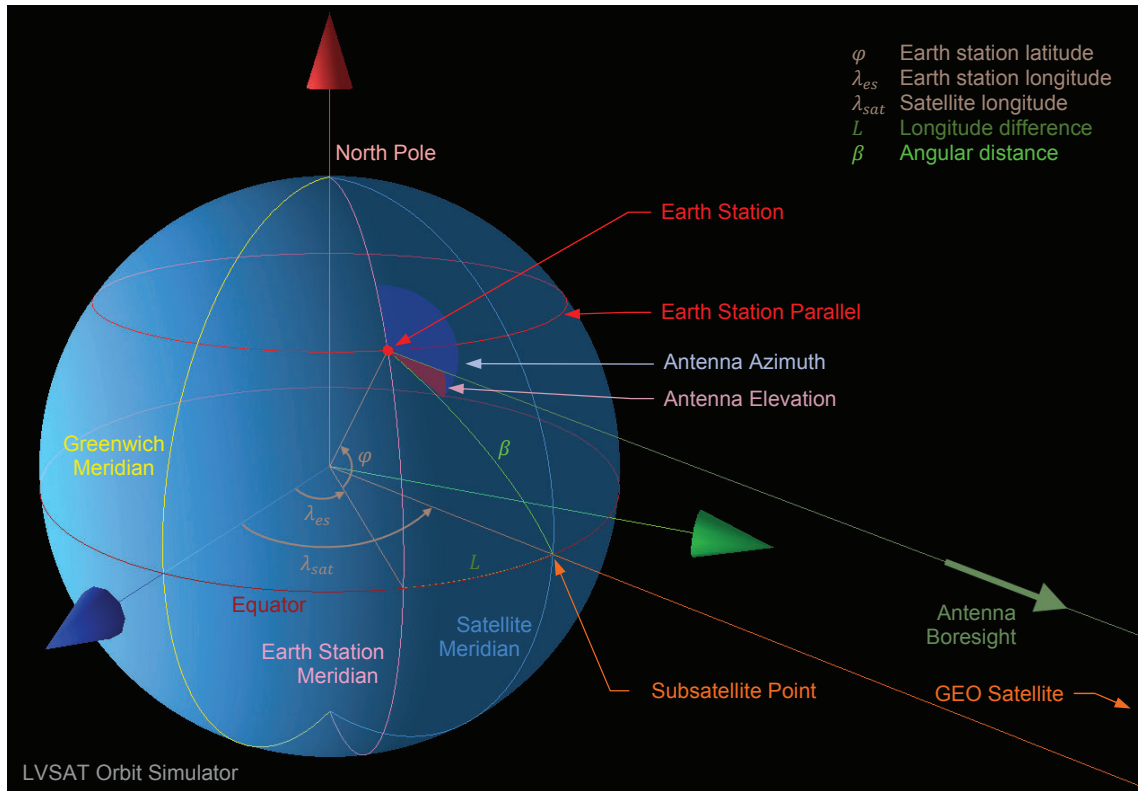
Figure 80. Earth-satellite geometry with EFG axes.

> There are many software tools and Web sites available that facilitate these calculations. If you enter these equations into a spread sheet, be sure to convert all angles to radians and then convert the result into degrees.

The azimuth can be calculated as shown in Equation (37).

In the northern hemisphere ($\varphi > 0$): $Az = \tan^{-1}\left[\dfrac{\tan L}{\sin \varphi}\right] + 180°$ $\qquad$ (37)

In the southern hemisphere ($\varphi < 0$): $Az = \tan^{-1}\left[\dfrac{\tan L}{\sin \varphi}\right]$

where Az is the azimuth in degrees
$\qquad \varphi$ is the earth station latitude in degrees
$\qquad L$ is the difference in longitude, in degrees, between the earth station and the satellite $L = \lambda_{es} - \lambda_{sat}$

> *Because $\tan \theta \neq \tan -\theta$, the sign of L is important in Equation (37). L is positive when the earth station is east of the satellite.*
>
> *By convention, longitudes to the east are positive and longitudes to the west are negative, unless given in degrees west. For an earth station at a longitude of $80°\,W$ and a satellite at $90°\,W$, $L = -80° - (-90°) = 10°$.*

The angular distance β between the earth station and the subsatellite point is given by:

$$\cos \beta = \cos L \cos \varphi \qquad (38)$$

Equations (39) shows how the elevation can be calculated.

$$El = \tan^{-1}\left[\frac{\cos\beta - (r_e/r_{sat})}{\sin\beta}\right] \tag{39}$$

$$= \tan^{-1}\left[\frac{\cos\beta - (r_e/r_{sat})}{\sqrt{1 - \cos^2\beta}}\right]$$

$$= \tan^{-1}\left[\frac{\cos L \cos\varphi - (r_e/r_{sat})}{\sqrt{1 - \cos^2 L \cos^2\varphi}}\right]$$

where El is the elevation in degrees
   β is angular distance between the earth station and the subsatellite point
   r_e is the radius of the earth
   r_{sat} is the radius of the satellite
   φ is the earth station latitude in degrees
   L is the difference in longitude, in degrees, between the earth station and the satellite $L = \lambda_{es} - \lambda_{sat}$

For a geostationary satellite, the ratio r_e/r_{sat} is

$$\frac{r_e}{r_{sat}} = \frac{6378 \text{ km}}{42164 \text{ km}} = 0.1513 \tag{40}$$

To predict the performance of the satellite communications system, it is important to know the slant range R. This can be calculated using Equation (41).

$$R = r_{sat}\sqrt{1 + \left(\frac{r_e}{r_{sat}}\right)^2 - 2\left(\frac{r_e}{r_{sat}}\right)\cos\beta} \tag{41}$$

$$= r_{sat}\sqrt{1 + \left(\frac{r_e}{r_{sat}}\right)^2 - 2\left(\frac{r_e}{r_{sat}}\right)\cos L \cos\varphi}$$

where R is the slant range (the distance from the earth station to the satellite)

Figure 81 shows a graph of the elevation to the Clarke belt versus azimuth for an earth station located at a latitude of 45° (blue curve). The dots on the blue curve represent geostationary satellites spaced 10° apart around the Clarke belt. Because the earth station is in the northern hemisphere, the GEO satellite with the highest elevation is at an azimuth of 180°, that is, due south. Satellites whose longitudes are east or west of that of the earth station have lower elevations.
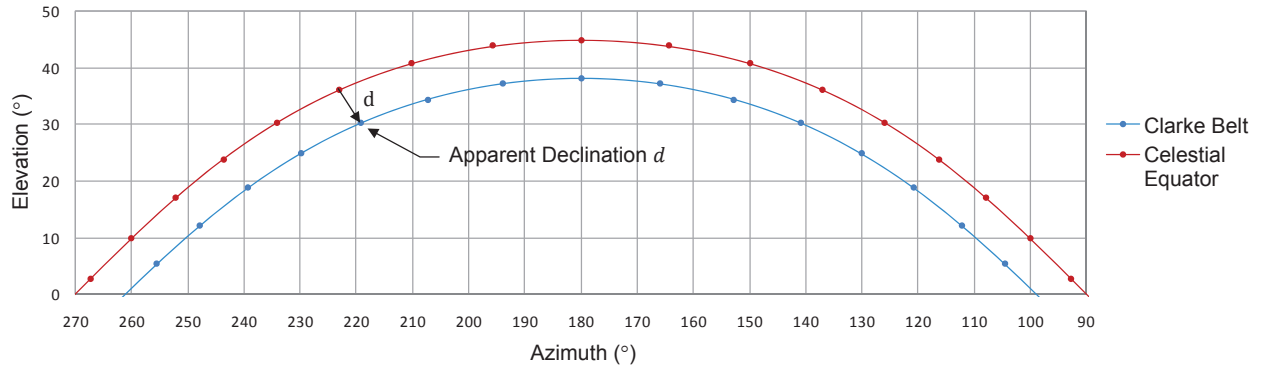
Figure 81. Geostationary satellite elevation vs. azimuth at latitude 45°.

The blue line in Figure 81 was calculated using Equation (37) and Equations (39), using the ratio $r_e/r_{sat} = 0.1513$. This ratio applies to all satellites on the Clarke belt. The red line represents the celestial equator, which is the imaginary circle in the plane of the equator located at an infinite distance from the earth.

As expected, the maximum elevation to the celestial equator is equal to 90° minus the latitude of the earth station. The red dots represent the projections of the GEO satellites onto the celestial equator. The difference in degrees between a satellite and its projection on the celestial equator is the apparent declination which was illustrated in Figure 78.
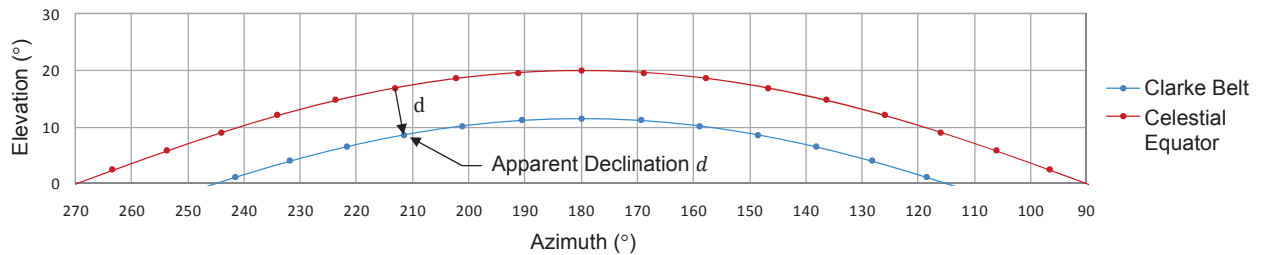
Figure 82. Geostationary satellite elevation vs. azimuth at latitude 70°.

Figure 82 shows a similar graph for an earth station at a latitude of 70° and illustrates the problem with linking to geostationary satellites at latitudes far from the equator. The maximum elevation angle is very low and a smaller part of the Clarke belt is visible at an elevation of 10° or more.

The polarization of the signal is also important. The most common polarizations are linear and circular. To ensure adequate reception of the signal, both the transmitting antenna and the receiving antenna must be designed to use the same type polarization.

If circular polarization is used, no special adjustment of the earth-station antenna is required. The feed horn or LNBF of the antenna, however, must use circular polarization of the same direction (right-hand or left-hand).

If linear-polarization is used, however, the curved surface of the earth causes the local horizontal plane to be tilted, or skewed, with respect to the polarization of the satellite antenna when the earth station and the satellite are at different longitudes (see Figure 83). As a result, the feed horn or LNBF of the earth-station antenna must be rotated by the same angle in order to prevent attenuation.
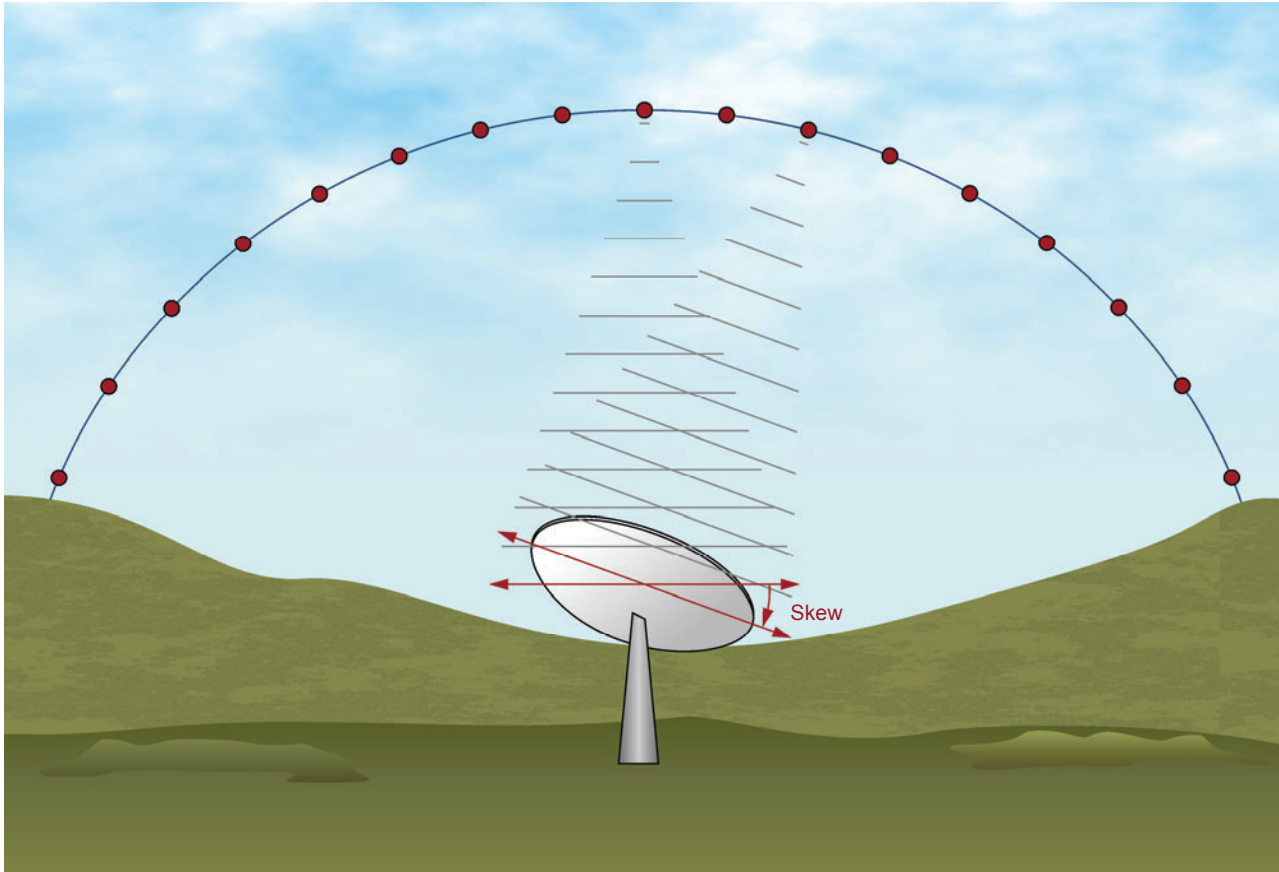
Figure 83. Depolarization due to the earth's curvature.

Equation (42) shows how the skew (polarization angle) can be calculated.

$$\psi = \tan^{-1}\left(\frac{\sin L}{\tan \varphi}\right) \tag{42}$$

where ψ is the skew (polarization angle) of the earth-station antenna
           φ is the earth station latitude in degrees
           L is the difference in longitude, in degrees, between the earth station and the satellite $L = \lambda_{es} - \lambda_{sat}$

Antenna look angle and skew adjustments

Figure 84 shows a typical offset-feed parabolic antenna mounted on a tripod. The dish is supported by a vertical mast. A feed arm attached to the dish supports the low-noise block feedhorn (LNBF).
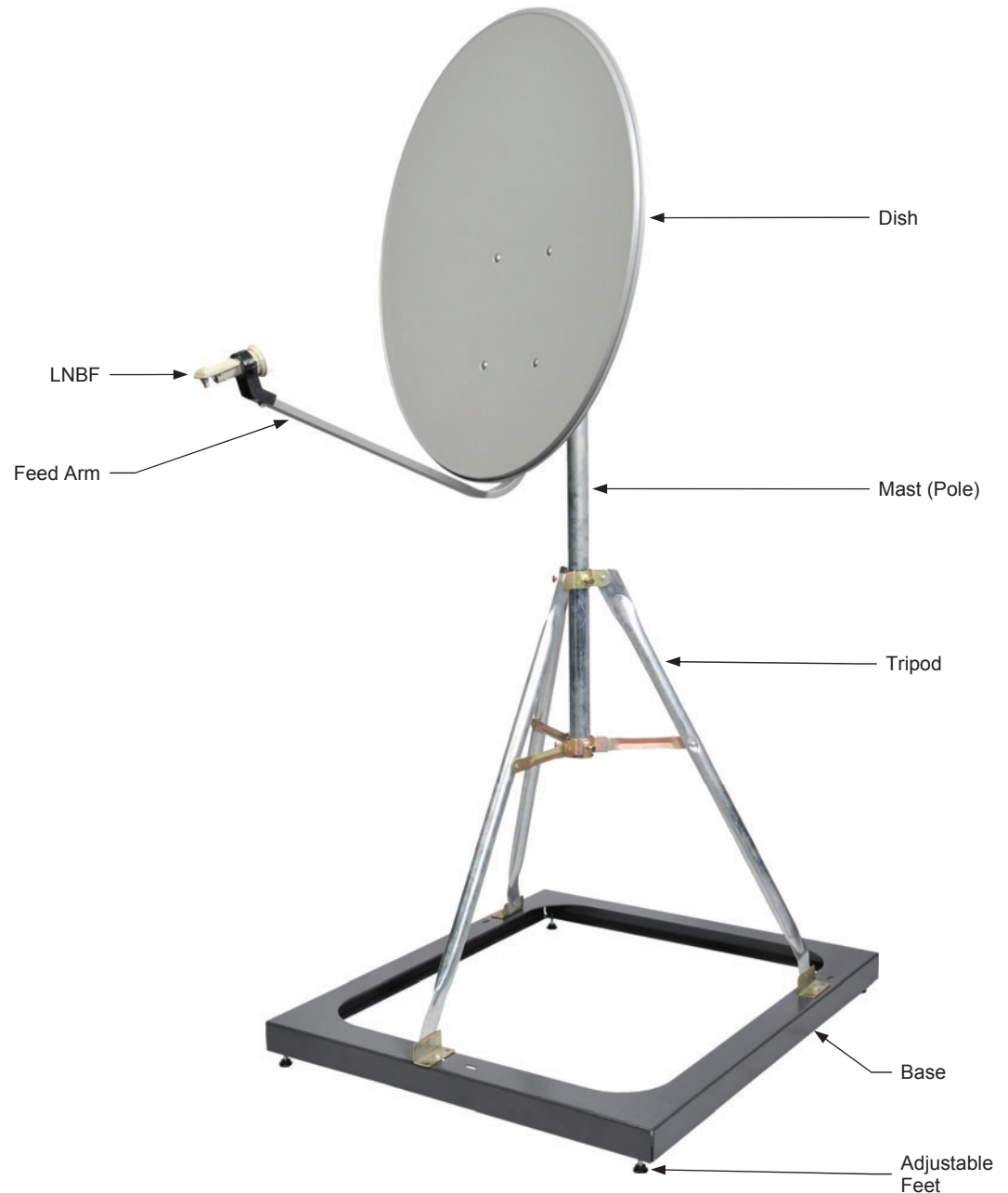
Figure 84. Offset-feed parabolic dish antenna on tripod.

Figure 85 shows the adjustments for azimuth, elevation and skew. Antennas designed for use with GEO satellites usually move about two orthogonal axes. The primary axis is fixed with respect to the earth and is usually adjusted to be perfectly vertical so that movement about this axis sets the azimuth. The secondary axis is horizontal and rotates about the primary axis. Movement about this axis sets the elevation.

Skew is adjusted by rotating the LNBF. Facing towards the satellite, a positive rotation is clockwise and a negative rotation is counter-clockwise.
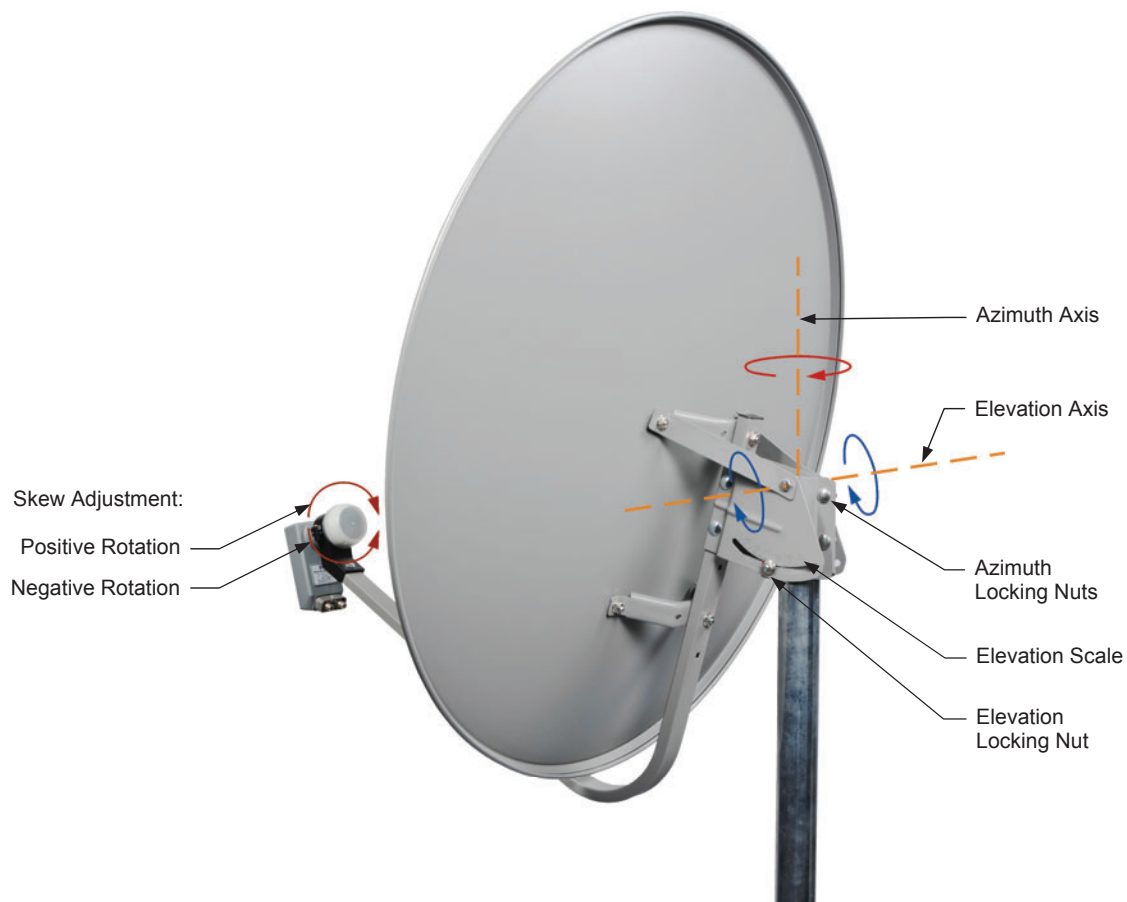
Figure 85. Antenna look-angle adjustments.

Figure 86 shows a close-up of the elevation scale.
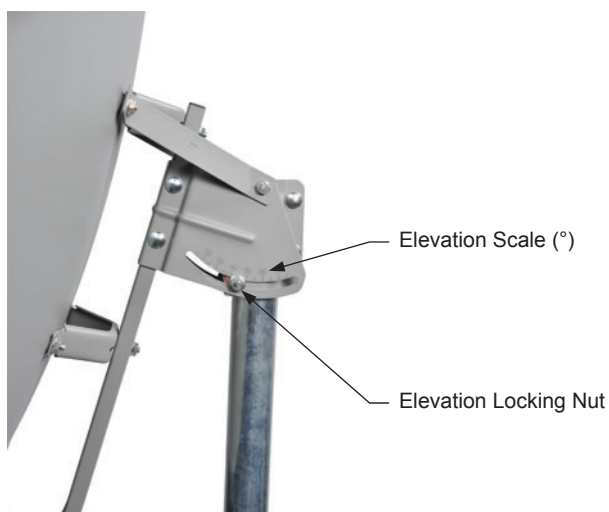
Figure 86. Elevation scale.

With many antennas, either a linear or a circular polarization LNBF can be installed. Figure 87 shows an example of the two types.

Circular Polarization   Linear Polarization

Figure 87. Typical circular and linear polarization LNBFs.

When a linear-polarization LNBF is used, the skew must be adjusted by rotating the LNBF. A scale is usually provided to aid in making this adjustment, as shown in Figure 88.

Positive Rotation   Negative Rotation

LNBF Clamp

Skew Scale (°)

Figure 88. Skew adjustment for linear-polarization.

Aligning a small dish antenna with a geostationary satellite

Equipment required for alignment

To mount and align an antenna, the following equipment is required:

> *Consult the manufacturer's documentation provided with the antenna, the LNBF and all other equipment to be used.*

- The antenna, the LNBF, an antenna mount and all necessary hardware.

- The tools required to tighten the nuts or screws that set the azimuth, elevation and skew.

- A signal strength indicator which can be one of the following:

  - An in-line signal strength meter, sometimes called a satellite finder or *satfinder* (see Figure 89). This type of instrument usually gives an audible and a visual indication of the relative power received but does not identify the satellite. There are a number of analog and digital satellite finders available.

  > *A satellite finder detects power over the entire spectrum of the LNBF. It gives an indication of the total power received from all transponders on the satellite.*
  >
  > *When using a satellite finder, there is a danger of aligning the antenna with the wrong satellite. During an actual installation, it is important to verify with a receiver that the correct satellite was selected.*

Figure 89. Analog satellite finder.

  - A satellite identifier. This professional type of instrument can identify the satellite and individual transponders on the satellite as well as indicate the signal strength.

  - A spectrum analyzer. This provides an indication of the power received and displays the frequency spectrum of the signal. Satellite signals usually have a characteristic spectrum. This type of instrument will help to identify the desired satellite providing that you are familiar with the appearance of the spectrum.

- A commercial satellite receiver and TV. This will indicate when the desired signal is being received and also provide an indication of the signal strength and quality. However, it can be inconvenient to use outdoors and may require time to lock onto the signal. It may be very difficult to determine the optimal antenna position using this method.

- A level to adjust the mount so the mast will be perfectly vertical, ensuring that the scale on the antenna bracket will be fairly accurate and that the azimuth and elevation adjustments will be independent. If there is no elevation scale on the antenna, or if the mast is not vertical, an inclinometer can be used to indicate the antenna elevation directly.

  An **inclinometer** or **clinometer** is an instrument for measuring angles of elevation, inclination or tilt of an object with respect to gravity. Commercial inclinometers are available for aligning satellite antennas, or a homemade one can be made using a protractor and a short plumb line.

  The built-in elevation scale may not be very accurate. However, it should be accurate enough to allow you to find the satellite, after which you can optimize the elevation in order to maximize the received signal power.

- A magnetic compass or GPS receiver to determine azimuth.

- Additional equipment, such as a dc source (battery pack) or a 22 kHz tone generator may be required to actuate switching circuits built into the LNBF (consult the documentation provided with the LNBF). These are usually incorporated into a satellite receiver and are built into some satellite finders. If this is not the case, the dc source or tone generator must be connected to the Receiver connector of the satellite finder.

CAUTION

Some spectrum analyzers can be damaged if a dc voltage is applied to the input. If the cable from the antenna has a dc voltage, a dc block (dc blocking capacitor) may be required at the input of the spectrum analyzer.

General alignment procedure

The Dish Antenna used in the exercise holds one LNBF. Two dual-polarization LNBFs are provided, one for linear polarization (H and V) and one for circular polarization (L and R). The satellite finder supplies the dc voltage used to switch from one polarization to the other as shown in Table 15.

Table 15. LNBF polarization selection.

Voltage	Linear LNBF	Circular LNBF
Low (13 V)	Vertical	Right-hand
High (18 V)	Horizontal	Left-hand

The following procedure summarizes the steps required to align a small dish antenna to a geostationary satellite.

> *When aligning a dish antenna with multiple LNBFs, first align the antenna using the central LNBF and tighten all settings. When this is completed, adjust the position and skew (if using linear polarization) of each of the other LNBFs to maximize the signals from the corresponding satellites.*

1. Obtain the following information about the satellite and the transponder you wish to link to (there are various websites and software tools available for this purpose):

   - The longitude of the satellite.

   - The frequency band of the satellite.

   - The type of polarization used by the satellite (linear or circular) and the polarization used by the transponder whose signals you wish to receive.

   - The footprint of the transponder beam you wish to receive, if possible. Make sure that the earth station is located within this footprint.

   - The minimum recommended dish size for your location. This depends on the power of the satellite transponders and on the elevation and slant range to the satellite.

   > *The dish antenna included in the Dish Antenna and Accessories is large enough to perform the alignment procedure with most geostationary satellites.*

2. Make sure you have an LNBF that is appropriate for the frequency band and polarization used and that the dish meets or exceeds the recommended minimum size.

3. Determine the geographic coordinates (latitude and longitude) of the earth station. This can be done using a GPS receiver, a mapping website, or a software tool designed for this purpose.

4. If you will be setting the azimuth using a magnetic compass, determine the magnetic declination for your location.

   > The easiest way to determine the magnetic declination for your location is to use one of the many websites that provide this information (see Appendix E *Useful Websites*). If this is not possible, refer to Appendix B *Magnetic Declination*. This appendix shows how to compensate for magnetic declination and includes a world map of magnetic declination contours that will allow you to determine the approximate magnetic declination for your location.

The **magnetic declination** at any point on the earth is the angle between the local magnetic field—the direction the north end of a compass points to—and true north. The declination is positive when the magnetic north is east of true north and negative when it is west of true north.

5. Determine the required antenna elevation, azimuth and skew. The necessary equations are provided in the Discussion. There are also several websites and software tools available for this purpose.

   In this exercise, the satellite longitude and polarization as well as the antenna elevation, azimuth and skew can be supplied by the Orbit Simulator.

   These angles only need to be determined to a precision of approximately one degree. The scales on most antennas are not very precise and allow only an approximate adjustment that will help you to find the satellite. Once the satellite is found, you will "tweak" the look-angle adjustments to maximize the signal strength.

   Skew adjustment of the LNBF is only required if the satellite uses linear-polarization (see Step 9). However, if the dish is elliptical, it is always preferable to adjust the skew of the dish (see Step 18).

6. Conduct a site survey at the antenna location to determine if the antenna will be able to "see" the satellite once the elevation and azimuth are set. If obstacles will block the signal, choose a different location.

7. If necessary, assemble the antenna mount or tripod according to the manufacturer's instructions. It may also be necessary to assemble the feed arm and install the LNBF.

8. Install the mast on a stable surface or on a tripod. Use a level to make sure that the mast is perfectly vertical.

9. If the satellite beam uses linear polarization, set the skew of the LNBF. In a permanent installation, it is usually easier to do this before you mount the antenna on the mast.

   If the dish is elliptical and the feed arm is fixed onto the dish, setting the skew of the dish sets the skew of the LNBF. It may be easier to do this at the end of the procedure.

   As shown in Appendix C Satellite Transponders, the downlink beam of a satellite is composed of signals from many transponders using different polarizations. Because a satellite finder detects power over the entire transponder bandwidth, it cannot distinguish between individual frequencies as a receiver does. For this reason, changing the skew of the LNBF is not likely to change the signal strength displayed by the satellite finder. Setting the skew correctly will, however, improve the strength of the signal detected by the receiver.

   • To set the skew, orient the feed horn or LNBF the same as the nominal polarization of the transponder beam. For vertical polarization, the broad faces of the waveguide are on the top and bottom, as shown in Figure 76. If you have a dual-polarization LNBF, the default polarization is usually vertical.

   • Then rotate the LNBF the same number of degrees as the skew angle determined in Step 5. Looking from behind the dish towards the LNBF and the satellite, a positive rotation is clockwise and a negative rotation is counter-clockwise.

10. If not already done, install the antenna on the mast according to the manufacturer's instructions.

11. Set the elevation as determined in Step 5 using the scale on the antenna or an inclinometer. Tighten the elevation adjustment bolts until they are snug.

   > *It is usually easier to set and lock the elevation first, as this prevents the antenna from tilting down under its own weight, and then set the azimuth.*

12. Set the azimuth as determined in Step 5. If you are using a compass, make sure to compensate for magnetic declination. Tighten the azimuth locking nuts just enough to avoid accidental movement of the antenna.

   > *Be sure to hold the compass where it will not be affected by metal objects.*
   >
   > *It may be helpful to identify a building or other object located in the desired direction, and then point the antenna in that direction.*

The dc voltage sets the polarization of the LNBF as follows:

13 V:	V or R
18 V:	H or L

Since the LNBF may draw a considerable amount of current, use a battery-powered indicator sparingly. Activating the high voltage may drain the battery more quickly.

13. Connect the signal strength indicator to the LNBF using a coaxial cable according to the manufacturer's instructions. If a dc source or 22 kHz tone generator is required, connect it to the Receiver connector on the detector.

   - If the LNBF is designed for dual polarization selected using a dc voltage, make sure that the low voltage is being applied.

   - If the antenna uses a 22 kHz tone to select different satellites, set this tone as required.

14. Observing the signal strength indicator, slowly vary the azimuth of the antenna until you find the satellite. Depending on the satellite and the location of the earth station, it may require some time to find the desired satellite.

   > *If the indicator saturates on a strong signal, activate the built-in attenuator.*

15. Fine tune the azimuth by moving the antenna slightly from one side to the other. Identify two points on either side where the signal strength decreases by the same amount, then position the antenna in the center. Tighten the azimuth locking nuts until they are snug and verify that the antenna has not moved.

16. Check the elevation and azimuth adjustments by bending the dish slightly in both the vertical and horizontal directions (push or pull gently on the edge of the dish). When you bend the dish, the signal level as shown on the detector should decrease slightly. When you remove pressure from the dish, it should spring back to its original position and the signal level should increase.

17. Firmly tighten the elevation and azimuth locking nuts and check the adjustments again.

18. If the dish is elliptical, tilt the long axis of the dish to the skew angle determined in Step 5. The long axis of the dish, shown as a dashed line in Figure 90, should be approximately parallel to the Clarke belt. If the feed arm is fixed to the dish, this will also set the skew of the LNBF.
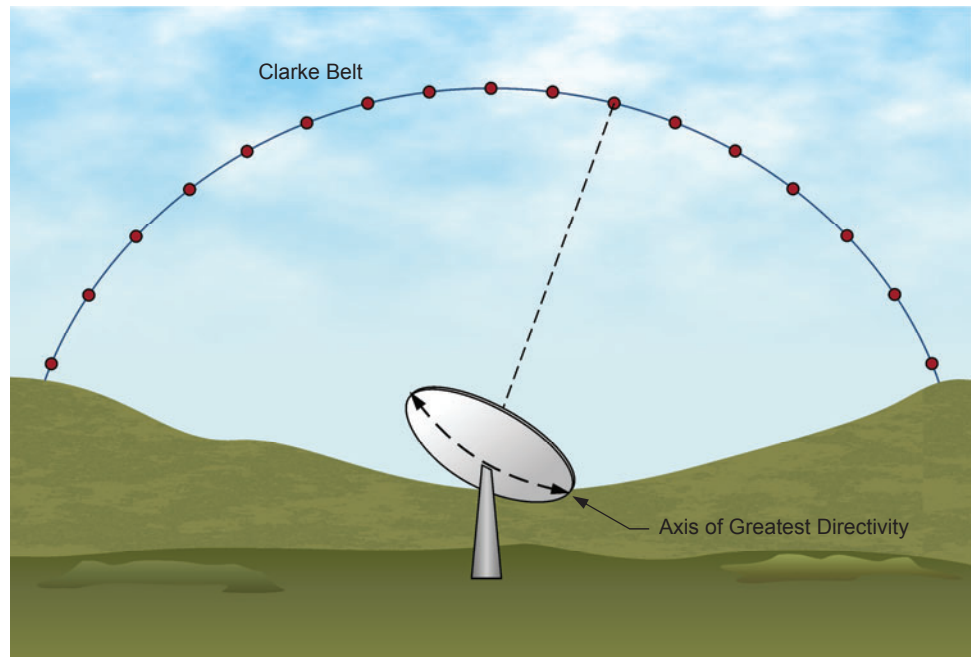
Figure 90. Elliptical dish alignment.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- GEO maximum elevation
- Visibility of the Clarke belt
- Antenna look angles
- Preparation for pointing the antenna
- Pointing the Dish Antenna

Pointing the Dish Antenna

The last section of the Procedure requires the optional Dish Antenna and Accessories, or equivalent. In this section, you will set up the antenna outdoors and align it with several different geostationary satellites. You will require the following items, all of which are included with the Dish Antenna and Accessories:

- Parabolic Dish Antenna
- Linear-polarization LNBF
- Circular-polarization LNBF
- Satellite Finder
- Coaxial cable
- Tripod
- Magnetic Level
- Wrench
- Screwdriver
- Compass
- Tape measure

PROCEDURE

GEO maximum elevation

In this section, you will determine the maximum elevation to a geostationary stationary satellite from several different locations on earth.

1. Start the LVSAT Orbit Simulator software.

    Load the file **GEO.xml** (remove all current satellites).

    Show the Earth Station Location as a Meridian-Parallel.

    Show the Azimuth/Elevation Angles and the Earth-Satellite Geometry.

    Make sure Time is paused at 00:00:00.

    For each city in Table 16, use the Orbit Simulator to determine the maximum elevation angle of a GEO satellite for that location.

    Then calculate the maximum elevation angle using the equations in the Discussion and compare these with the observed maximum elevation angles.

    🔅 Modify the orbital elements of the satellite as required to facilitate your observations. Recall that the elevation is highest when the satellite and the earth station have the same longitude.

    You may wish to change the 3D Earth setting as you wish in order to show the earth's surface or reveal all of the earth-satellite geometry.

Table 16. Cities and maximum elevation to a GEO satellite.

City	Latitude	Longitude	Observed maximum elevation	Calculated maximum elevation
Sydney, Australia				
Abidjan, Côte d'Ivoire				
Tokyo, Japan				
Boston, MA				
Berlin, Germany				
Moscow, Russia				
North Pole				

Explain why Santa Claus cannot receive satellite TV programs broadcast from a GEO satellite.

The elevation to a GEO satellite is at its maximum when the satellite is at the same longitude as the earth station. In the Orbit Simulator, at Time 00:00:00, $RAGM_0 = 0$. Therefore, the longitude λ of a GEO satellite is equal to:

$$\lambda_{GEO} = RAAN + \omega + M_0$$

Therefore, to observe the maximum elevation in the Orbit Simulator, set one of these orbital elements equal to the longitude of the earth station and leave the others set to zero. The Information window will indicate that the longitude of the satellite and that of the earth station are equal. The Elevation displayed in the Information window will then be the observed maximum elevation for the satellite at the current earth station location.

Table 16. Cities and maximum elevation to a GEO satellite.

City	Latitude	Longitude	Observed maximum elevation	Calculated maximum elevation
Sydney, Australia	-33.51	151.12	51.03	51.03
Abidjan, Côte d'Ivoire	5.20	-4.01	83.88	83.88
Tokyo, Japan	35.42	139.42	48.87	48.87
Boston, MA	42.36	-71.06	41.09	41.09
Berlin, Germany	52.30	13.24	30.19	30.19
Moscow, Russia	55.45	37.37	26.79	26.79
North Pole	90.00	0.00	-8.6	-8.6

The maximum elevation can be calculated using:

$$El_{max} = 90° - |\varphi| - |d|$$

where φ is the earth station latitude. The declination d is:

$$d = \tan^{-1}\left[\frac{-\sin\varphi}{\frac{r_{sat}}{r_e} - \cos\varphi}\right]$$

The maximum elevation from the North Pole to a GEO satellite is negative. This means that all GEO satellites are below the local horizon and are therefore not visible from that location.

Visibility of the Clarke belt

In this section, you will observe how the latitude of the earth station affects the visibility of the Clarke belt.

2. Set the Earth Station City to Mexico City, Mexico. Use the Orbit Simulator to determine what percentage of the Clarke belt is visible from this location with an elevation of 10° or more. Then do the same for Edmonton, Alberta and compare your results for the two cities using Table 17.

   🔆 You can set the satellite longitude so that the elevation from the earth station is approximately 10° as shown in Figure 91. Then you can fine tune the satellite longitude while observing the Elevation displayed in the Information window.

Figure 91. Determining the satellite longitude for 10° elevation to Mexico City.

Table 17. Percentage of Clarke belt visible at 10° elevation or more.

Value	Symbol	Mexico City	Edmonton
Earth station latitude	φ		
Earth station longitude	λ_{es}		
Satellite longitude for 10° elevation	λ_{sat}		
Longitude difference	$\|\lambda_{es} - \lambda_{sat}\|$		
Percentage of Clarke belt visible at 10° elevation or more	$\dfrac{\|\lambda_{es} - \lambda_{sat}\|}{180°} \times 100\%$		

How does the latitude of the earth station affect the visibility of the Clarke belt?

Table 17. Percentage of Clarke belt visible at 10° elevation or more.

Value	Symbol	Mexico City	Edmonton
Earth station latitude	φ	19.26°	53.57°
Earth station longitude	λ_{es}	-99.08°	-113.52°
Satellite longitude for 10° elevation	λ_{sat}	-28.79° or -169.37	-55.95° or -171.1
Longitude difference	$|\lambda_{es} - \lambda_{sat}|$	70.29°	57.57°
Percentage of Clarke belt visible at 10° elevation or more	$\frac{|\lambda_{es} - \lambda_{sat}|}{180°} \times 100\%$	39%	32%

The closer the Earth station is to the equator, the greater the visible portion of the Clarke belt.

Antenna look angles

In this section, you will calculate the azimuth, elevation and skew angles for geostationary satellites and compare your results to the angles shown in the Orbit Simulator.

3. Load the file **Geostationary (active).txt** (remove all current satellites).

   This file shows most of the active geostationary satellites using the orbital elements that were available at the time of writing.

   A text satellite file contains a Two-Line Element (TLE) set for each satellite which gives the actual parameters for the satellite as they were measured at a given epoch. Because geostationary satellites drift and require periodic corrections, the orbital positions defined by these parameters may be slightly different from the assigned orbital positions.

   Hide the Paths of all satellites.

   Show the Azimuth/Elevation Angles and the Earth-Satellite Geometry.

   If you live in one of the cities listed in the Orbit Simulator, set the Earth Station City to your city. If not, set the Earth Station Latitude and Longitude to the geographical coordinates of your location.

   Many websites allow you to determine your geographical coordinates precisely (see Appendix E *Useful Websites*). A GPS receiver can also be used, if you have one. Alternately, an atlas will provide your approximate coordinates.

   Click on a satellite whose longitude is close to the longitude of the Earth station, in order to activate it. The azimuth and elevation angles are shown graphically in the 3D view. The Information window displays the Azimuth, Elevation and Skew as numerical values. Activate satellites further and further from your longitude as you observe these angles.

> When the Earth-Satellite Geometry is shown, a line is drawn from the Earth Station to the active satellite as long as the elevation is positive. No line is shown when the elevation negative.
>
> You may wish to try this while viewing the Earth from above the North or South Pole.

4. Activate one of the satellites whose longitude is relatively near your longitude. Use Equation (37), Equation (39) and Equation (42) to calculate the azimuth Az and elevation El to that satellite and calculate the skew ψ. Then calculate the slant range R using Equation (41) (or Equation (22)). Repeat this with a satellite whose longitude is considerably different from yours but which is visible from your location. For each satellite, compare the results of your calculations with the values displayed in the Information window.

The following is an example of the calculations required:

For Quebec City, QC, $\varphi = 46.82°$ and $\lambda_{es} = -71.22°$.

For the satellite NIMIQ 5, $\lambda_{sat} = -72.75°$

The latitude difference is $L = \lambda_{es} - \lambda_{sat} = 1.53°$.

Therefore,

$$Az = \tan^{-1}\left[\frac{\tan L}{\sin \varphi}\right] + 180°$$

$$= \tan^{-1}\left[\frac{0.0267}{0.7292}\right] + 180°$$

$$= 182.1°$$

$$El = \tan^{-1}\left[\frac{\cos L \cos \varphi - (r_e/r_{sat})}{\sqrt{1 - \cos^2 L \cos^2 \varphi}}\right]$$

$$= \tan^{-1}\left[\frac{0.9996 \times 0.6843 - 0.1513}{\sqrt{1 - 0.9996^2 \times 0.6843^2}}\right]$$

$$= \tan^{-1}(0.7302)$$

$$= 36.14°$$

$$\psi = \tan^{-1}\left(\frac{\sin L}{\tan \varphi}\right)$$

$$= 1.4°$$

The slant range R can be calculated using Equation (41):

$$R = r_{sat}\sqrt{1 + (r_e/r_{sat})^2 - 2(r_e/r_{sat})\cos L \cos \varphi}$$

$$= 42164 \text{ km}\sqrt{1 + 0.1513^2 - 2(0.1513)(0.6840)}$$

$$= 38085.86 \text{ km}$$

Alternately, the slant range can be calculated from the elevation using Equation (22).

$$R = \sqrt{r_{sat}^2 - r_e^2 \cos^2 \theta} - r_e \sin El$$

$$= \sqrt{42164^2 - 6378^2 \cos^2 36.14} - 6378 \sin 36.14$$

$$= 38086.72 \text{ km}$$

In the Information window, Azimuth = 182.1°, Elevation = 36.16°, Skew = 1.44°, Slant Range = 38078.4 km.

Preparation for pointing the antenna

In this section, you will gather the information necessary to align the optional Dish Antenna with real geostationary satellites. To do this, you will use the Orbit Simulator to select several geostationary satellites that are visible from your location and that transmit in the Ku band (approximately 12 to 18 GHz). You will determine the type of polarization used by each satellite and determine the look angles as well as the magnetic azimuth.

5. Load the file **Geostationary Ku-band (EW).xml** (remove all current satellites).

   Hide the Path of each satellite. Show the Earth-Satellite Geometry.

   This file contains most of the geostationary satellites that transmit in the Ku band (approximately 12 to 18 GHz). The satellites are shown in their assigned positions and not at their actual positions observed at a certain epoch.

   The name of each satellite is preceded by its assigned longitude in degrees East or West, as shown in Table 18.

   Table 18. Examples of satellite names in Geostationary Ku-band (EW).xml.

Displayed Name	Satellite Name	Longitude
E003 Telecom 2C	Telecom 2C	3° E
E013 Hotbird 9	Hotbird 9	13° E
E122 Asiasat 4	Asiasat 4	122°E
W000.8 Thor 5	Thor 5	0.8° W (-0.8° E)
W129 Ciel 2	Ciel 2	129° W (-129° E)

   *A similar file, called **Geostationary Ku-band (E).xml**, is also included with the Orbital Simulator. In this file, the displayed names begin with the longitude in degrees East, ranging from 0° to 360°.*

6. Make sure that the Latitude and Longitude settings in the Orbit Simulator correspond to your location. Record your location, latitude and longitude below.

Location (city, town, village, etc.): _____

Latitude (°N): _____

Longitude (°E): _____

Magnetic declination: _____

Determine the magnetic declination for your location and record it, using a positive value for eastward declination and a negative value for westward declination.

> Many websites allow you to determine your geographical coordinates precisely (see Appendix E *Useful Websites*). Many GPS receivers can display the magnetic declination after the position is established. Alternately, a world map in Appendix B *Magnetic Declination* can be used to determine your approximate magnetic declination.

Each GEO satellite used for television broadcasting has one or more transponders and each transponder on the satellite transmits at a different frequency and at a particular polarization: horizontal (H), vertical (V), right-hand circular (R), or left-hand circular (L). Most satellites with several transponders transmit using two different polarizations: linear (H and V) or circular (R and L).

The currently loaded satellite file (**Geostationary Ku-band (EW).xml**) uses different colors to show the polarizations used by each satellite, as shown in Table 19.

Using the Orbit Simulator, determine which portion of the Clarke belt is visible from your location. Select at least five satellites that will be visible. Referring to the color code used in Table 19, try to select satellites that broadcast using as many different polarizations as possible. Enter the names of these satellites in the appropriate rows, entering more than one satellite per row if necessary. Later in this exercise, you will set up the optional Dish Antenna outdoors and align it with these satellites.

> *The Orbit Simulator does not show the footprints of the satellites. In some cases, the name of the satellite indicates the service zone it is intended to cover (e.g. Eurobird, Asiasat, Chinasat). It is possible that the beam from a visible satellite does not cover your location. For this reason, it is preferable to select a few extra satellites.*

Table 19. Ku-band satellites for pointing the antenna.

Polarization and color	Satellite Names	Longitude (°E)	True Azimuth (°)	Magnetic Azimuth (°)	Elevation (°)	Skew (°)
H only (Red)						
H and V (Yellow)						
V only (Green)						
R and L (Blue)						(not required)
Both linear and circular (Grey)						

Some satellites are colored grey even if they transmit only one type of polarization because they are so close to a satellite that uses the other type of polarization that it would be difficult to separate the two signals.

Activate in turn each satellite entered in Table 19 and record the Azimuth (true azimuth), the Elevation, and the Skew displayed in the Information window. Then determine the magnetic azimuth for each satellite and enter this in the table as well.

Enter the longitudes West with a minus sign, as shown in the Information window.

You can round off the numbers you enter in this table. The scales on most antennas allow setting look angles to approximate values only.

If you prefer, you can use one of the dish pointing web sites or software tools to obtain the look angles for these satellites (see Appendix E *Useful Websites*). Make sure the satellites transmit in the Ku band.

The following is an example of a valid answer for the indicated location.

Location (city, town, village, etc.):   Quebec City, QC

Latitude (°N):   46.82

Longitude (°E):   -71.22

Magnetic declination: -16.6° (16° 37′ W)

Table 19. Ku-band satellites for pointing the antenna.

Polarization and color	Satellite Names	Longitude (°E)	True Azimuth (°)	Magnetic Azimuth (°)	Elevation (°)	Skew (°)
H only (Red)	Star One C1	-65.0	171.5	188.1	35.8	-5.6
H and V (Yellow)	Galaxy 16	-99.0	215.9	232.3	29.7	23.5
V only (Green)	Intelsat 1R	-50.0	152.0	168.6	32.3	-18.8
R and L (Blue)	Anik F3	-118.7	236.1	252.7	19.4	(not required)
Both linear and circular (Grey)	Galaxy 17	-91	206.1	222.7	32.7	17.5

The magnetic azimuth for the first satellite in Table 19 is calculated as follows:

$$Magnetic\ Azimuth = True\ Azimuth - Magnetic\ Declination$$
$$= 171.4° - (-16.6°)$$
$$= 188.0°$$

Pointing the Dish Antenna

This section requires the optional Dish Antenna and Accessories. In this section, you will set up the Dish Antenna outdoors and align it with several geostationary satellites.

> 📝 *It is preferable to work in teams of two students while carrying out the steps in this section.*

7. A satellite finder is included with the optional Dish Antenna and Accessories. Read the instructions provided with this instrument and become familiar with its operation. The functions you are likely to use are (the actual names on your instrument may differ slightly):

   - VIEW SIGNAL   Indicates signal strength

   - 13/18 V   Selects the dc output voltage applied to the LNBF

   - ATTEN   Turns the attenuation on and off

8. The optional Dish Antenna should be assembled and mounted on its tripod.

   Examine the Dish Antenna. Describe the type of antenna.

   This is a small offset parabolic dish antenna.

   Measure the height and width of the dish. What is the diameter of the projected aperture?

   The dimensions of one model are approximately 82 cm by 75 cm. The projected aperture is approximately 75 cm.

   Referring to Figure 73, estimate the gain of the antenna when operating at 12 GHz.

   The gain of the antenna is approximately 37 dB at 12 GHz.

   Determine the approximate offset of the antenna.

   The approximate offset is:

   $$Offset = \cos^{-1}\left(\frac{Short\ axis}{Long\ axis}\right)$$
   $$= \cos^{-1}\left(\frac{75}{82}\right)$$
   $$= 24°$$

9. Set up the Dish Antenna on its tripod outdoors at a location where the selected satellites should be visible.

Follow the alignment procedure given in the Discussion in order to point the antenna to each of the selected satellites. For each satellite, you must make sure that the correct LNBF (linear or circular polarization) is installed on the antenna.

💡 If the satellite finder applies a dc voltage to the LNBF in order to select the polarization, it is important to apply the higher voltage (18 V) only when necessary as using this voltage will drain the battery more quickly. Set the skew angle, if necessary, with the lower voltage applied.

If any of the satellites you have selected uses only one polarization (H, V, R or L), then you may be able to observe polarization mismatch loss. With the satellite pointed at the antenna, change the polarization of the LNBF and note whether the signal level increases or decreases.

📝 *If a satellite transmits with both horizontal and vertical polarization, changing the polarization of the LNBF will make little or no difference in the signal strength indicated by the satellite finder. This is because a satellite finder does not discriminate between different frequencies. When performing a real antenna installation, however, it is important to adjust the skew of the LNBF because the receiver is tuned to only one frequency at a time.*

10. When you have finished using the Dish Antenna and Accessories, bring all items inside and return them to their proper location.

If you have not already done so, exit the Orbital Simulator software when you have finished using it.

CONCLUSION

In this exercise, you learned about antenna alignment for geostationary satellites. You became familiar with the different type of parabolic dish antennas and LNBFs used with geostationary satellites. You became familiar with the theory behind antenna alignment to geostationary satellites and with look angle and polarization skew adjustments. If you have the optional parabolic dish antenna, you aligned this antenna with several different geostationary satellites.

REVIEW QUESTIONS

1. All geostationary satellites are located on the Clarke belt. Describe what the Clarke belt would look like if you could see it from the earth.

   The Clarke belt forms an imaginary arc in the sky. If you are at the equator, the belt passes directly overhead. If you are in the northern hemisphere, the belt stretches from a point on the horizon a little south of due east, rising to its maximum height directly towards the south, and then reaching the horizon a few degrees south of due west. If you are in the southern hemisphere, the maximum height of the arc appears directly north of your location. The elevation to the center of the Clarke belt is equal to 90° minus the latitude $|\varphi|$ minus the apparent declination $|d|$.

2. What is the purpose of the low-noise amplifier in a receiving earth station? Describe the different types of low noise amplifier used in satellite reception.

   The low-noise amplifier (LNA) is used to amplify the weak signal captured by the antenna to a usable level while introducing as little noise as possible. A low-noise converter (LNC) combines a low-noise amplifier and a down converter. A low-noise block (LNB) handles a large bandwidth spanning several or all transponders of the satellite and often includes a down converter. A low-noise block feedhorn (LNBF) is a low-noise block combined with a feedhorn.

3. Explain why are dish antennas often used in satellite earth stations.

   A parabolic dish antenna is used for high gain and directivity. Directivity is a measure of the degree to which the radiated energy is concentrated in one direction and is proportional to the square of the dish diameter. High directivity in transmission allows the power to be directed towards the desired satellite while minimizing interference to other satellites. High directivity in reception allows minimizing the interference received from other satellites and nearby earth stations.

4. Explain why alignment of an earth-station antenna to a geostationary satellite can be done using a coordinate system fixed to the earth.

   To an observer on the earth, a geostationary satellite appears to be fixed in space because its orbital period is synchronized with the earth's rotation and because its inclination is near 0°. Therefore, the position of the satellite, as well as the position of the earth station, can be conveniently expressed using any coordinate system attached to the terrestrial reference frame.

5. When aligning a small dish antenna with a geostationary satellite that uses linear polarization, what is the order in which you should normally adjust the three angles. Explain why.

The skew of the LNB is normally adjusted first for two reasons: because it is usually easier to adjust this before mounting the antenna on the mast, and because it is not possible to tweak the skew using a satellite finder when the satellite uses both horizontal and vertical polarization. The elevation is adjusted next and the elevation locking bolt tightened to prevent the elevation changing accidently. Finally, with the antenna free to pivot on the principal axis, the azimuth can be set in order to find the satellite and maximize the received power.

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