A recently introduced service that uses near-circular, non-geostationary orbits is the *Global Positioning Satellite* (or GPS) service, which is essentially a navigation and position determination service. The GPS system utilizes 6 orbits with 4 satellites in each. The ascending modes of the orbits are separated by 60° and the inclination of each orbit is 55°.

Geostationary Orbit

A *geostationary* satellite is one that appears to be stationary relative to the earth. There is only one geostationary orbit, but this is occupied by a large number of satellites. It is the most widely used orbit by far, for the very practical reason that earth station antennas do not need to track geostationary satellites (except for certain very high gain earth station antennas that require a limited range of tracking, as will be described later).

The first and obvious requirement for a geostationary satellite is that it must have zero inclination. Any other inclination would carry the satellite over some range of latitudes and hence would not be geostationary. Thus the geostationary orbit must lie in the earth's equatorial plane. The second obvious requirement is that geostationary satellites should travel eastward at the same rotational velocity as the earth. Since this velocity is constant, then from Kepler's second law it can be deduced that the orbit must be circular, since as previously shown the velocity in an elliptical orbit varies from a maximum at perigee to a minimum at apogee and hence is not constant.

The earth makes one complete rotation, relative to the fixed stars, in approximately 23h 56m. Notice that this is slightly less than the time required for one complete rotation about its own axis, which is 24h. Substituting P_o = 23h 56m in Eq. (19.4.1) for Kepler's third law, along with the value for A given in Eq. (19.4.2), results in

$$a_{gso} = 42{,}164 \text{ km} \tag{19.6.1}$$

The subscript gso is included to remind us that this is the value for the geostationary orbit. It will be recalled that because the orbit is circular this is also the radius of the orbit measured from the center of the earth. The earth's equatorial radius is approximately 6378 km. and hence the height of the geostationary orbit above the earth is

$$h = 42{,}164 - 6378$$

$$= 35{,}786 \text{ km} \tag{19.6.2}$$

This value is often rounded up to 36,000 km for use in calculations. It will be seen that there is only the one value of a that satisfies Kepler's third law for the periodic time of 23h 56m, and hence there can only be one geostationary orbit.

19.9 Satellite Station Keeping

Left to itself, a geostationary satellite would in fact drift from its initial position as a result of perturbing forces. The gravitational field of the moon, and to a lesser extent that of the sun, causes a drift in the angle of inclination, which amounts to about 0.85°/year. The drift is cyclic, the angle of inclination increasing from zero to a maximum of 14.67° in a period of about 26.6 years, thereafter drifting back to zero inclination again in about the same period. For satellites operating in the C band (6/4 GHz), the drift must be kept within ±0.1°, and for Ku band (14/12 GHz) satellites, within ±0.05°, so that north–south station keeping maneuvers are required. These are carried out by means of thruster jets once every few weeks. The extra weight added by the fuel needed for the north–south corrections is a major factor in the cost of the launch.

Kepler's laws apply for bodies that are perfectly spherical. The earth departs from a true spherical shape, a flattening occurring at the poles, and the equatorial circumference is not quite circular. Overall, the nonsphericity of the earth results in geostationary satellites drifting eastward toward one of two gravitational nodes separated by 180°. These are located at longitudes 105°W and 75°E and are sometimes referred to as satellite graveyards because satellites that are out of commission tend to drift toward these as their "final resting place." The longitudinal tolerance is also ±0.1° for C band and ±0.05° for Ku band satellites, so that east–west station keeping maneuvers are required in addition to the north–south maneuvers. These are also carried out once every few weeks, but require considerably less fuel than the north–south maneuvers. Typical satellite motion is shown in Fig. 19.9.1.

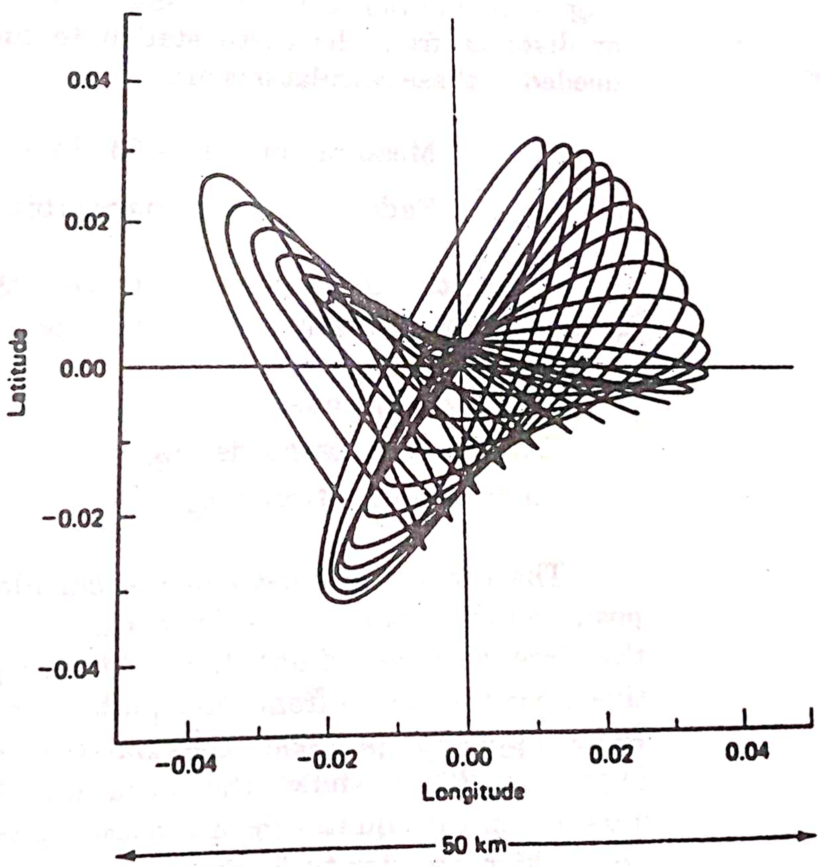


Figure 19.9.1 Typical satellite motion. (from Telesat Canada, 1983, courtesy Telesat Canada.)

19.10 Antenna Look Angles [Elevation and Transmission path]

To maximize transmission and reception, the direction of maximum gain of the earth station antenna, referred to as the antenna *boresight*, must point directly at the satellite. To align the antenna in this way, two angles must be known. These are the *azimuth*, or angle measured from the true north, and the *elevation*, or angle measured up from the local horizontal plane, as shown in Fig. 19.10.1.

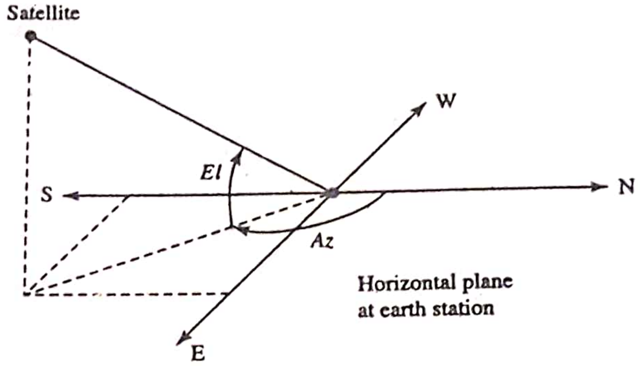


Figure 19.10.1 Angles of azimuth Az, and elevation El, measured with reference to the local horizontal plane and true north.

The azimuth and elevation angles are usually referred to as the *look angles*. In addition to the look angles, it is often necessary to know the range or distance from the earth station to the satellite. The earth's constants needed in these calculations are

$$\text{Mean radius:} \quad R = 6378 \text{ km} \tag{19.10.1}$$

$$\text{Radius of geostationary orbit:} \quad a_{gso} = 42164 \text{ km} \tag{19.10.2}$$

In addition to these constants, the other pieces of information needed to determine the look angles and the range are

Satellite longitude, ϕ_S
Earth station longitude, ϕ_E
Earth station latitude, λ_E

The conventions used in the calculations are that east longitudes are positive numbers and west longitudes are negative numbers (measured from the Greenwich meridian). Latitudes are positive measured north and negative measured south from the equator. Certain rules known as *Napier's rules*, which apply to spherical trigonometry, must be used in these calculations. Figure 19.10.2(a) shows the situation. SS is the subsatellite point (which must lie on the equator for a geostationary satellite), and ES is the earth station, which for clarity is shown in the southern hemisphere. A property of spherical triangles is that all the dimensions including the sides are in angular measure. Angle a is measured from the north pole to the subsatellite

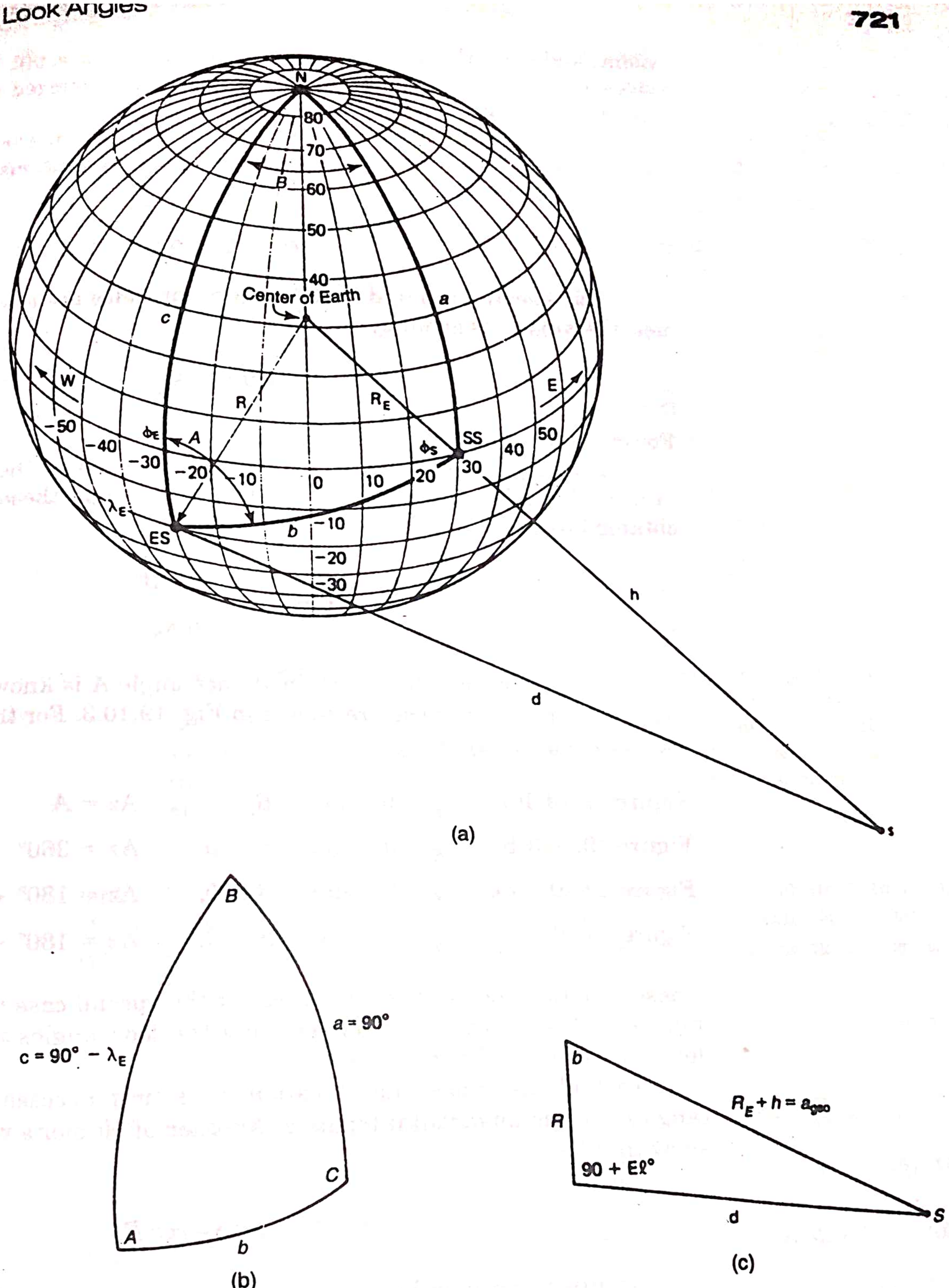


Figure 19.10.2 (a) Geometry used to calculate look angles and range for a geostationary satellite at *S*. (b) Spherical quadrantal triangle obtained from (a). (c) Plane triangle obtained from (a).

point, and since the subsatellite is on the equator, $a = 90°$. Because one of the sides is a right angle, the spherical triangle is referred to as a *quadantal* spherical triangle.

Angle B is the difference in longitude between the earth station and subsatellite longitudes. Keeping in mind the sign conventions referred to above, angle B is given by

$$B = \phi_E - \phi_S \tag{19.10.3}$$

Also keeping in mind that southern latitudes are assigned negative values, the angle c is given by

$$c = 90° - \lambda_E \tag{19.10.4}$$

For example, if $\lambda_E = 30°S$, then $c = 120°$

Knowing angles B and c, angle A can be found by the application of certain of Napier's rules. For the quadrantal triangle these result in A being obtained from

$$\tan A = \frac{-\tan |B|}{\sin \lambda_E} \tag{19.10.5}$$

The azimuth can be determined once angle A is known. Four situations must be considered; these are shown in Fig. 19.10.3. For these situations, the azimuth is given by

Figure 19.10.3(a): $\lambda_E < 0$ and $B < 0$, $Az = A$ (19.10.6)

Figure 19.10.3(b): $\lambda_E < 0$ and $B > 0$, $Az = 360° - A$ (19.10.7)

Figure 19.10.3 (c): $\lambda_E > 0$ and $B < 0$, $Az = 180° + A$ (19.10.8)

Figure 19.10.3(d): $\lambda_E > 0$ and $B > 0$, $Az = 180° - A$ (19.10.9)

These equations do not take into account the special case when the earth station is on the equator, and determining the look angles for this situation is left as an exercise for the reader.

To find the range and elevation, it is first necessary to find the side (angle) b of the quadrantal triangle. Another of Napier's rules can be used to show that

$$\cos b = \cos \lambda_E \cos B \tag{19.10.10}$$

Attention can now be transferred to the *plane triangle,* Fig. 19.10.3(c). This includes the radius of the earth at the given latitude of the earth station. It will be noted that the earth's radius does not come into the calculations for azimuth. The shape of the earth is more closely approximated as an oblate spheroid rather than a perfect sphere, for which the radius is a function of latitude and the surface represents mean sea level. The assumption of a perfectly spherical earth and ignoring earth station altitude introduces about a

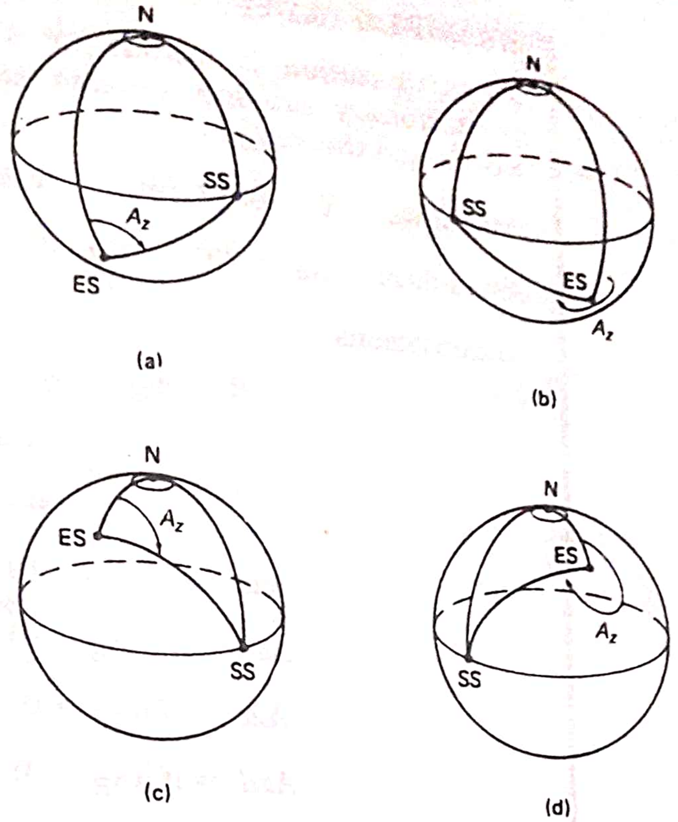


Figure 19.10.3 Azimuth angles for four possible situations: (a) earth station in the southern hemisphere, west of the subsatellite point; (b) earth station in the southern hemisphere, east of the subsatellite point; (c) earth station in the northern hemisphere, west of the subsatellite point; (d) earth station in the northern hemisphere, east of the subsatellite point.

tenth of a degree error in angle of elevation, and a few km at most in a range of about 40km. For our purposes the assumption of a spherical earth and ignoring earth station altitude is quite adequate. The mean radius is taken as:

$$R = 6371 \text{ km} \tag{19.10.11}$$

Application of the cosine rule to the plane triangle gives the range d as

$$d = \sqrt{R^2 + a_{\text{gso}}^2 - 2Ra_{\text{gso}} \cos b} \tag{19.10.12}$$

The elevation can now be determined from application of the sine rule for plane triangles. This yields

$$\cos El = \frac{a_{\text{gso}}}{d} \sin b \tag{19.10.13}$$

These computations are illustrated in the following example, worked out in Mathcad.

EXAMPLE 19.10.1

An earth station at latitude 20° S and longitude 30° W is working into a geostationary satellite situated at longitude 30° E. Determine the look angles and the range.

Constants: $R := 6371$ km, $a_E := 42{,}164$ km

Given data: $\phi_S := 30°$, $\phi_E := -30°$, $\lambda_E := -20°$

Computations:

$$B := \phi_E - \phi_S \qquad \text{Eq. (19.10.3)}$$

$$A := a\,\tan\left(\frac{-\tan(|B|)}{\sin(\lambda_E)}\right) \qquad \text{Eq. (19.10.5)}$$

$$Aza := \text{if}\,[(\lambda_E < 0)\cdot(B < 0), A, 0]$$

$$Azb := \text{if}\,[(\lambda_E < 0)\cdot(B > 0), 2\pi - A, 0]$$

$$Azc := \text{if}\,[(\lambda_E > 0)\cdot(B < 0), \pi + A, 0]$$

$$Azd := \text{if}\,[(\lambda_E > 0)\cdot(B > 0), \pi - A, 0]$$

Since only one of these will be other than zero, the azimuth can be found by setting

$$Az := Aza + Azb + Azc + Azd, \qquad \mathbf{Az = 78.8°}$$

$$b := \text{acos}(\cos(\lambda_E)\cos(B)) \qquad \text{Eq. (19.10.10)}$$

$$d := \sqrt{R^2 + a_E^2 - 2Ra_E\cos(b)} \qquad \text{Eq. (19.10.11)}, \qquad \mathbf{d = 39{,}572\ km}$$

$$El := \text{acos}\left(\frac{a_E}{d}\sin(b)\right) \qquad \text{Eq. (19.10.12)}, \qquad \mathbf{El = 19.9°}$$

A plot of azimuth and elevation for an earth station located at the authors' home city is shown in Fig. 19.10.4. For accurate pointing, the azimuth and the elevation angles must be adjusted independently, which requires two drive motors. Many domestic (backyard) installations use what is termed a *polar mount,* which employs a single drive motor. This can be installed so that the pointing is accurate for one satellite, but pointing errors occur for satellites on either side of this. Figure 19.10.5 shows the arc followed by the antenna boresight compared to the true geostationary arc. Figure 19.10.6 shows how a polar mount antenna is installed.

The antenna is first installed so that its *polar axis* is pointing to true north and elevated so that its boresight is parallel to the earth's equatorial plane. Assuming a spherical earth, the earth station latitude is λ_E as shown, and its complement is $\alpha = 90° - \lambda_E$. Since the polar axis is parallel to the earth's axis, the angle α also appears between the polar axis and the normal to

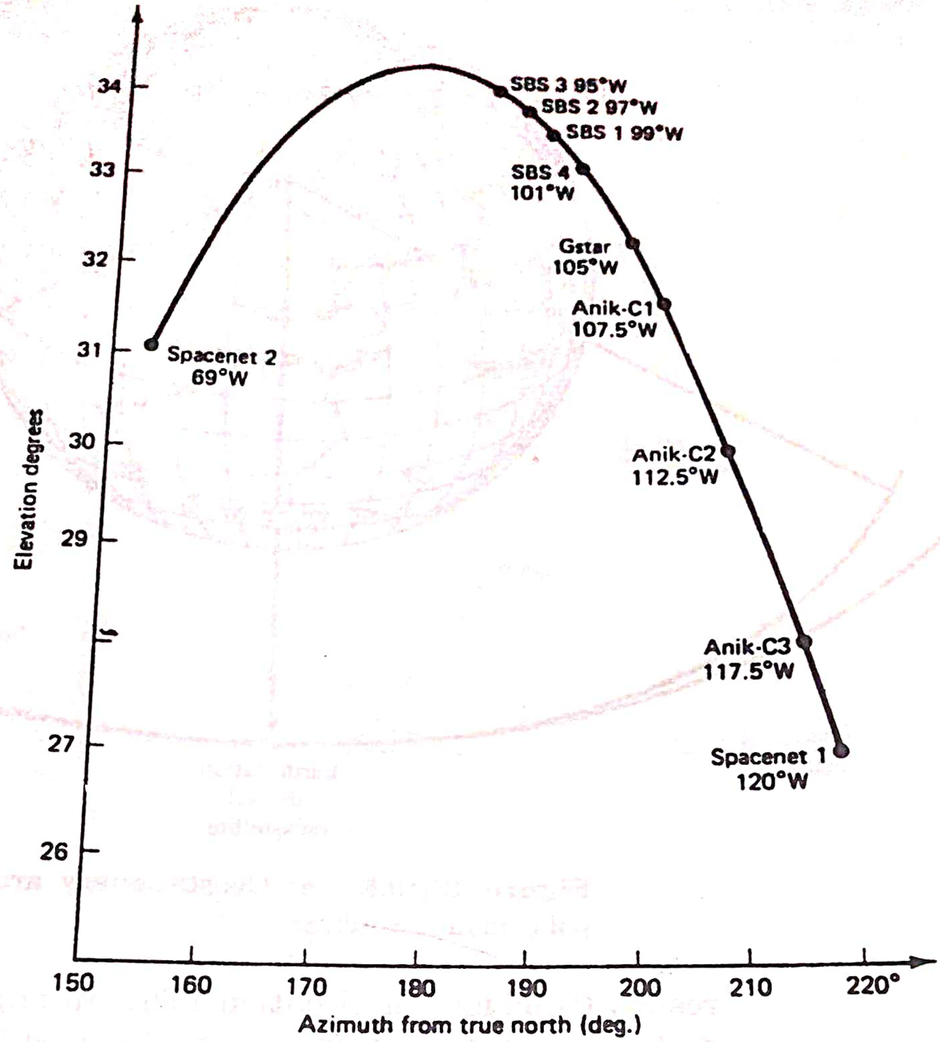


Figure 19.10.4 Azimuth–elevation angles for an earth station location 48.42°N, 89.26°W (Thunder Bay, Ontario). Ku band satellites are shown.

the local horizontal plane. This is shown in detail in Fig. 19.10.6(b). It follows therefore that the angle between the polar axis and the local horizontal plane is

$$\beta = 90° - \alpha$$

$$= \lambda_E \tag{19.10.13}$$

Thus the first adjustment to make when installing the antenna is to point the polar axis to the true north, and adjust the elevation of the *polar axis* to be equal to the earth station latitude.

As shown, this points the boresight parallel with the equatorial plane. The antenna dish is now tilted to make the boresight intersect the geostationary arc. For this intersection, there will be zero pointing error, but errors will be introduced for satellites at either side. The intersection can be at any point on the arc, but to spread the error evenly on either side, it will be assumed to meet the arc at a point directly south of the earth station. The angle of tilt δ is

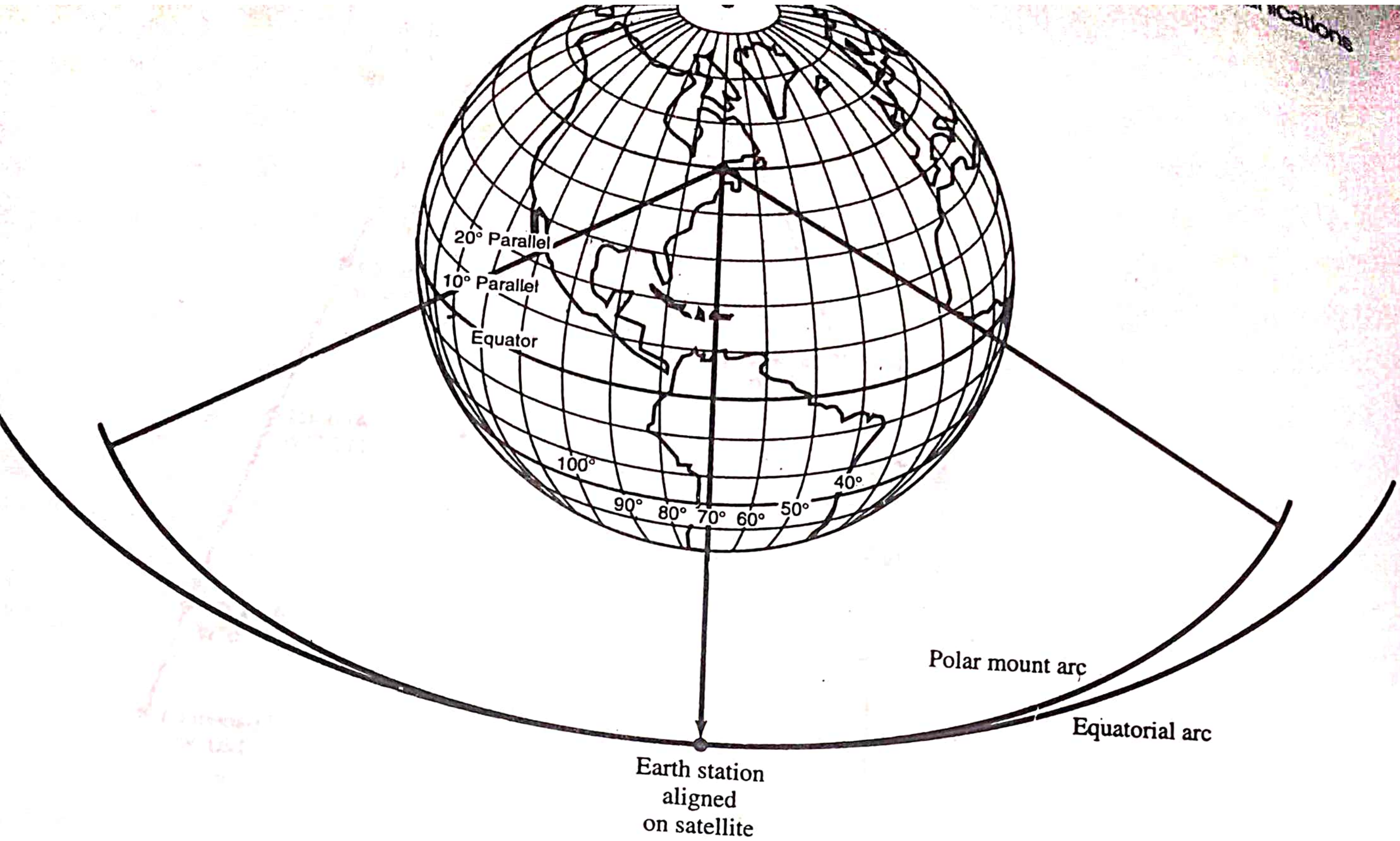


Figure 19.10.5 (a) Geostationary arc and (b) arc followed by a polar mount antenna.

readily found for this situation. (The tilt angle is sometimes referred to as the *declination,* but the term tilt will be used here to avoid confusion with magnetic declination used in compass correction.) The geometry is shown in Figure 19.10.7. From this, the angle of tilt is seen to be given by

$$\delta = 90° - El - \lambda_E \qquad (19.10.14)$$

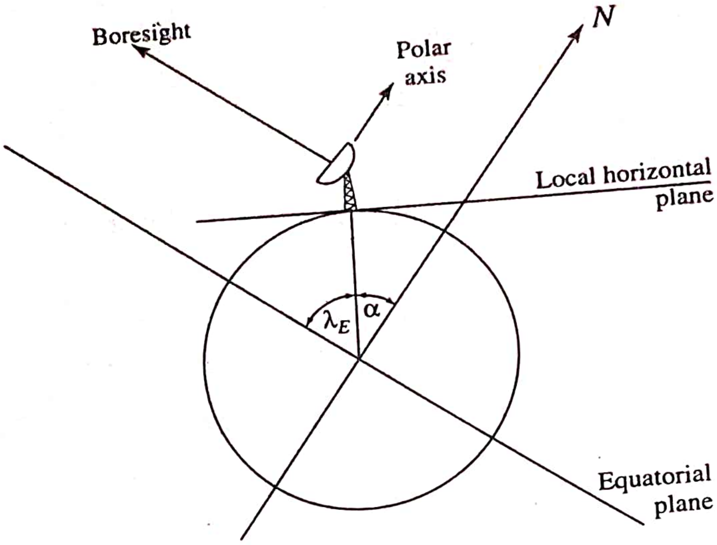
But from Eq. (19.10.3) for a point due south, the angle $B = 0$, and hence from Eq. (19.10.10) $b = \lambda_E$. This in turn can be substituted into Eq. (19.10.13) to get

$$\cos El = \frac{a_{\text{gso}}}{d} \sin \lambda_E \qquad (19.10.15)$$

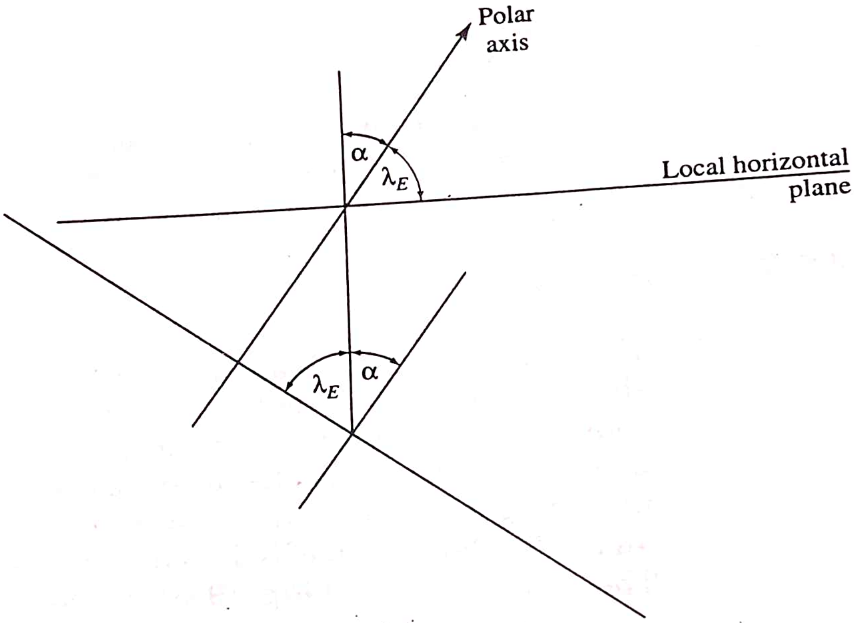
Thus, in terms of earth station latitude and distances only, the angle of tilt is given by

$$\delta = 90° - \operatorname{acos}\left(\frac{a_{\text{gso}}}{d} \sin \lambda_E\right) - \lambda_E \qquad (19.10.16)$$

Evaluation of s for a range of latitudes is left as Problem 19.11. It should be noted that in practice, rather than calculating s, the installation may be



(a)



(b)

Figure 19.10.6 Installation of a single-drive antenna. (a) Antenna boresight adjusted to be parallel to the equatorial plane. (b) Geometrical relationships.

optimized by adjusting the antenna for maximum received signal from a satellite nearest to the due south point. This will introduce some asymmetry into the error curve, as a function of displacement east or west of the earth station longitude. In any case, the attenuation resulting from the pointing error is generally quite small and may only be significant at the limits of visibility for the earth station.

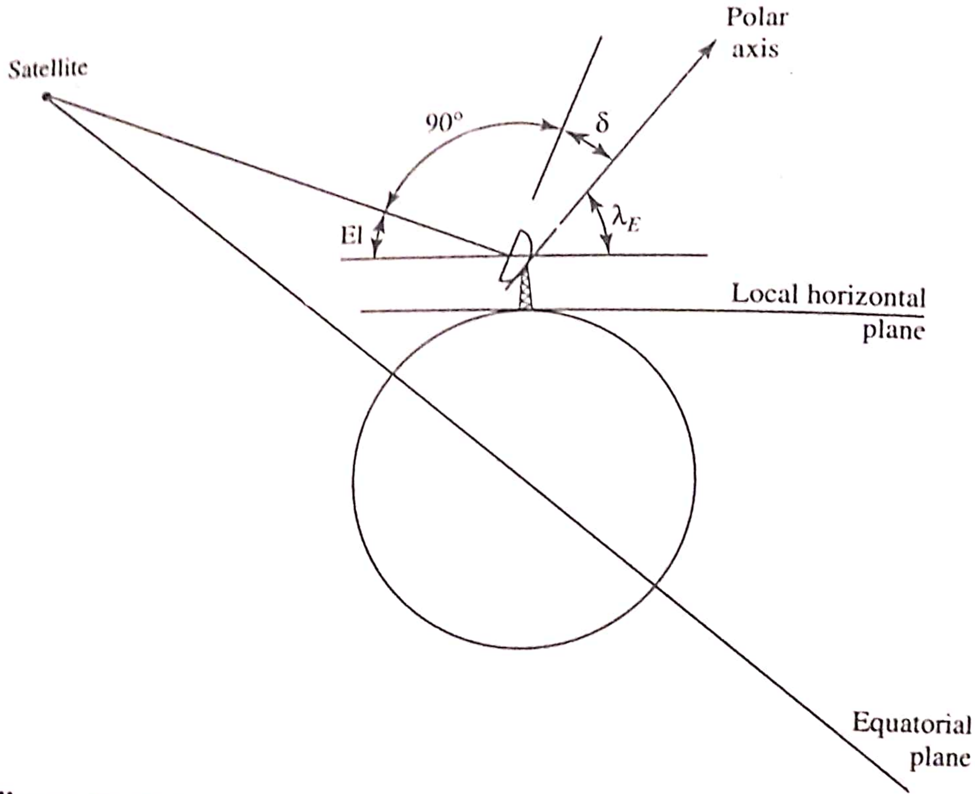


Figure 19.10.7 Angle of tilt δ: needed to make the boresight intersect the geostationary arc at a point due south of the earth station.

L

$$\phi_E - B = -41°$$

$$\phi_E + B = 101°$$

Frequency Plans and Polarization

There are well-defined frequency bands allocated for satellite use, the exact frequency allocations depending on the type of service (for example, mobile communications and broadcast). The frequency bands also differ depending on the geographic region of the earth in which the earth stations are located. Frequency allocations are made through the International Telecommunication

Union (ITU). The most widely used bands at present are the C band and the Ku band. Uplink transmissions in the C band are nominally at 6 GHz and downlink transmissions nominally at 4 GHz. The band is sometimes referred to as the 6/4 GHz band. Uplink transmissions in the Ku band take place in the region of 14 GHz and downlink in the region of 12 GHz, this being referred to as the 14/12 GHz band. (The designation Ku arises from the fact that this frequency is *u*nder a microwave band known as the K band, and the *u* is sometimes shown as a subscript.) For each band, the bandwidth available is 500 MHz.

For each band mentioned, the higher-frequency range is used for the uplink (very rarely the situation is reversed, the higher frequency being used for the downlink). The reason for using the higher frequency on the uplink is that losses tend to be greater at higher frequencies, and it is much easier to increase the power from an earth station rather than from a satellite to compensate for this.

To make the most of the available bandwidth, *polarization discrimination* is used. Adjacent transponder channels can be assigned alternate polarizations, for example horizontal and vertical. Figure 19.12.1 shows the frequency and polarization plan for the C band in the *Anik-E* satellite. The 24 transponder channels are first of all formed into two groups of 12, labelled A and B transponders. The downlink signals for group A are horizontally polarized and for group B vertically polarized. Thus, although there is some overlap in the transponder bandwidths, the different polarizations prevent interference from occurring. For example, transponder 2A has a center frequency of 3760 MHz, and its bandwidth (including guard bands) extends from 3740 to 3780 MHz. Transponder 2B has a center frequency of 3780 MHz, and its bandwidth extends from 3760 to 3800 MHz. The use of polarization to increase the available frequency bandwidth is referred to as *frequency reuse*. It will also be observed from Fig. 19.12.1 that the uplink signals in each group are polarized in the opposite sense to the downlink signals.

Right-hand circular (RHC) and left-hand circular (LHC) polarization may also be used in addition to vertical and horizontal polarization, which permits a further increase in frequency reuse. The Intelsat series of satellites utilize all four types of polarization.

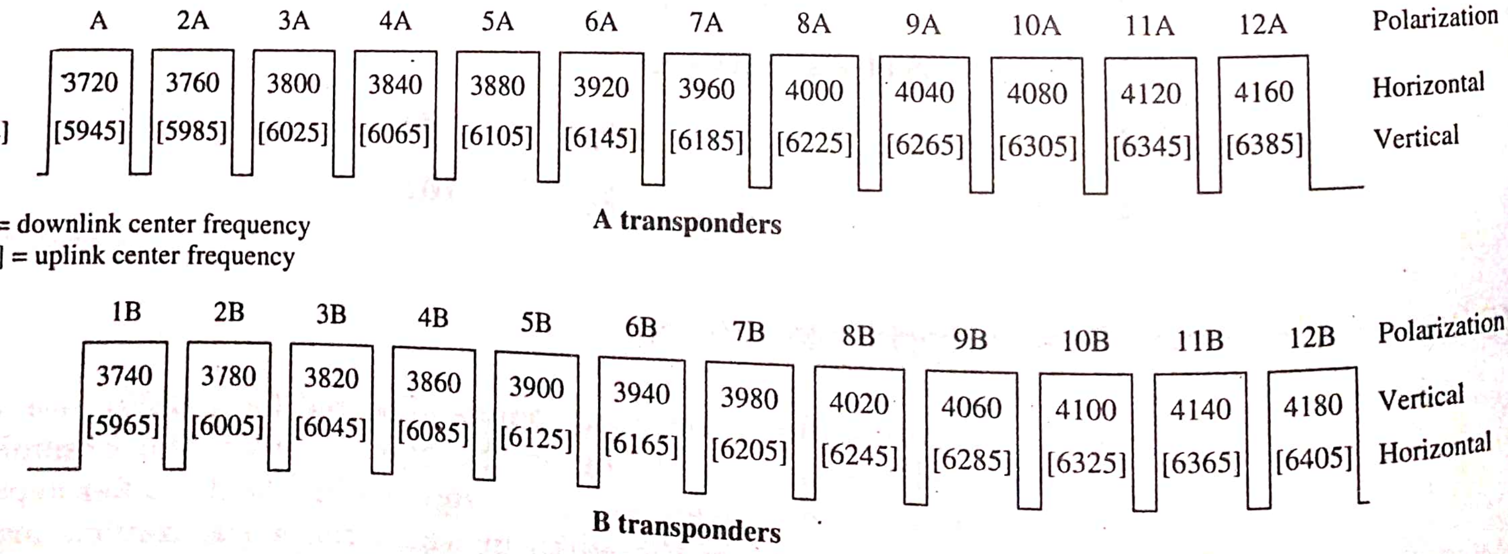
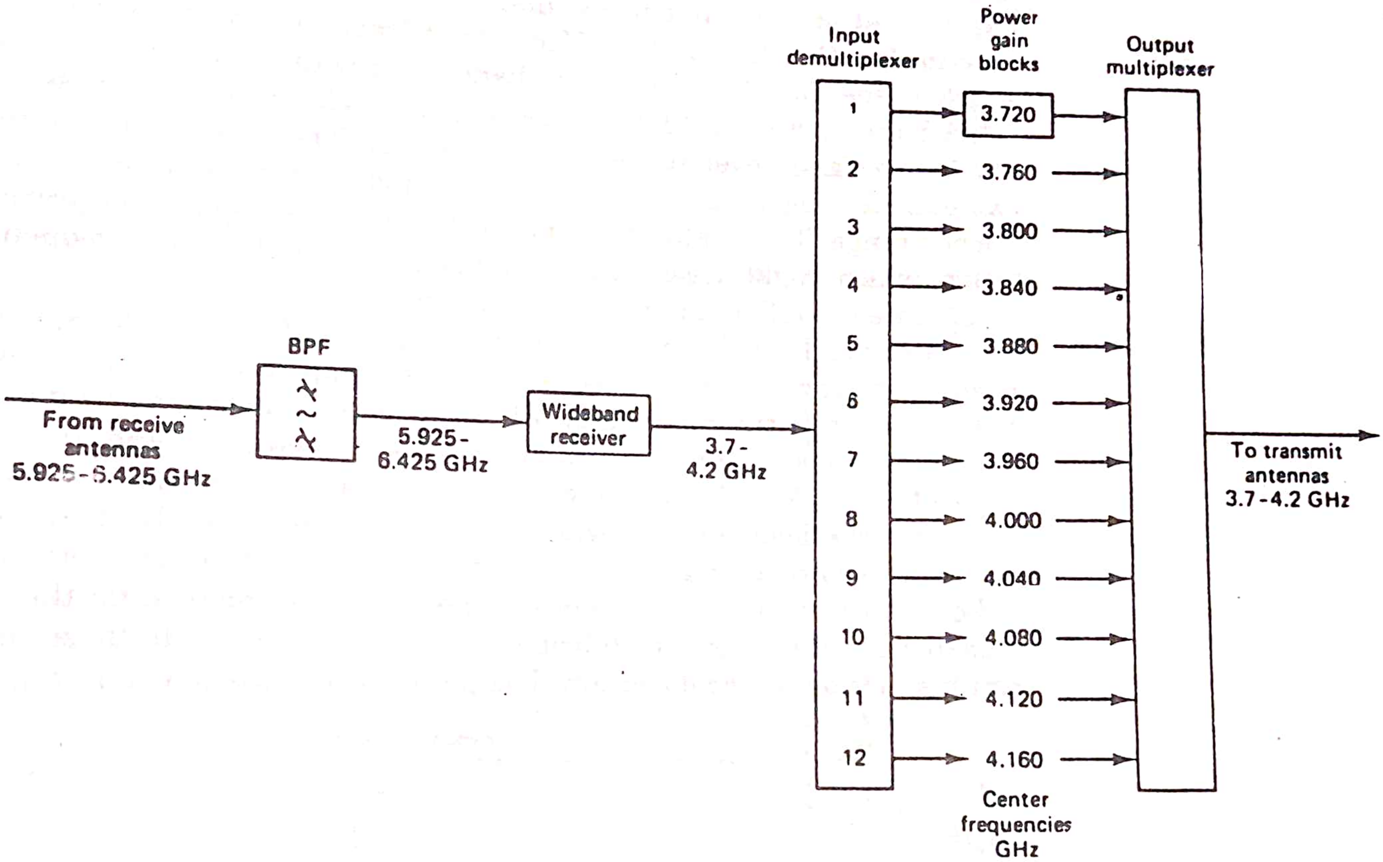
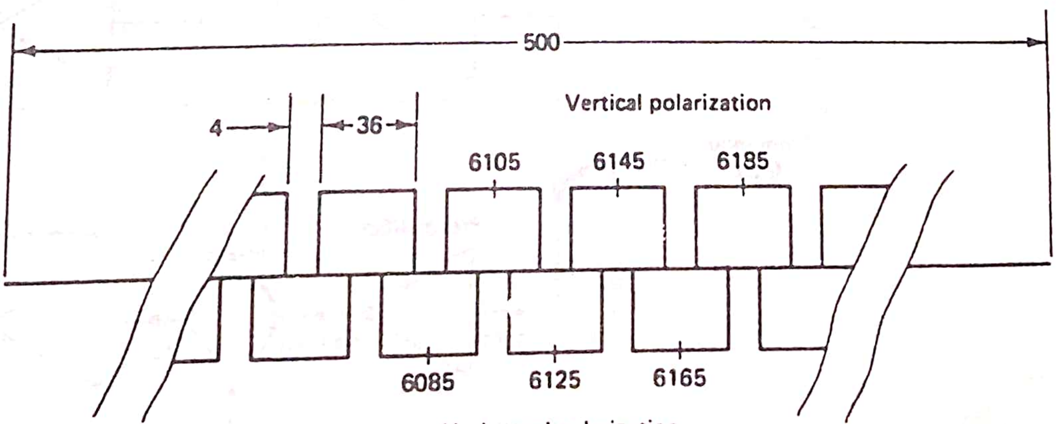


Figure 19.12.1

The word *transponder* is coined from *transmitter–responder* and it refers to the equipment channel through the satellite that connects the receive antenna with the transmit antenna. The transponder itself is not a single unit of equipment, but consists of some units that are common to all transponder channels and others that can be identified with a particular channel. Figure 19.13.1(a) shows in block schematic form typical transponder



(a)



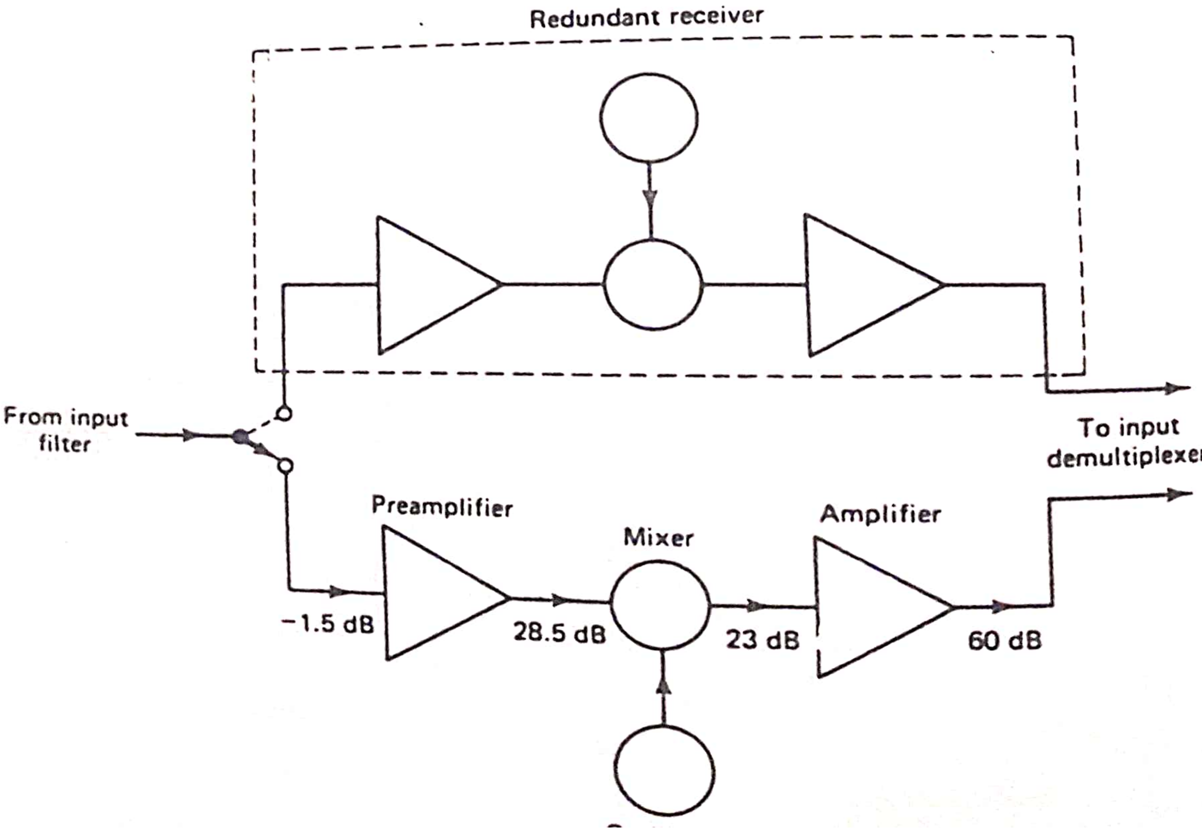
(b)

Figure 19.13.1 (a) C band satellite transponder channels. (b) Section of an uplink frequency and polarization plan. Numbers refer to frequency in megahertz.

channels for a C band satellite, and Figure 19.13.1(b) the typical frequency assignments.

Typically, a basic bandwidth of 500 MHz is available at the C band frequencies encompassing all the transponder channels and corresponding to an input (uplink) frequency range of 5.925 to 6.425 GHz, as shown in Fig. 19.13.1(a). This input range of signals is passed through a wideband, bandpass filter (BPF) to limit noise and interference and then on to a wideband receiver, which provides a frequency down-conversion common to all channels. The wideband receiver also provides the common low-noise amplification needed at the input to maintain a satisfactory signal-to-noise ratio, as described in the Section 4.11. The output frequency range is 3.7 to 4.2 GHz, which is the downlink frequency band. The wideband receiver is shown in more detail in Fig. 19.13.2. Typical signal levels are shown in decibels relative to the signal level at the receive antenna. The overall gain is provided in two sections, one at the input frequency range and the other at the output frequency range. This makes for a more stable arrangement and prevents oscillation, which might arise if the gain was provided all at one frequency range. Solid-state amplifiers are used throughout.

Because the wideband receiver is critical to all transponders, a *redundant* receiver is provided. This is essentially a backup receiver that is switched in automatically if the other fails. An input *demultiplexer* following the wideband receiver is an arrangement of microwave circulators and filters that separates the 500-MHz band into the separate transponder channel bandwidths. A typical transponder bandwidth is 36 MHz, or 40 MHz including guardbands, as shown in Fig. 19.13.1, although other values are commonly used. Following the demultiplexer, power amplifiers are provided for the individual transponder channels, which brings the power levels up to those required for retransmission on the downlink. The power levels are shown in Fig. 19.13.3.



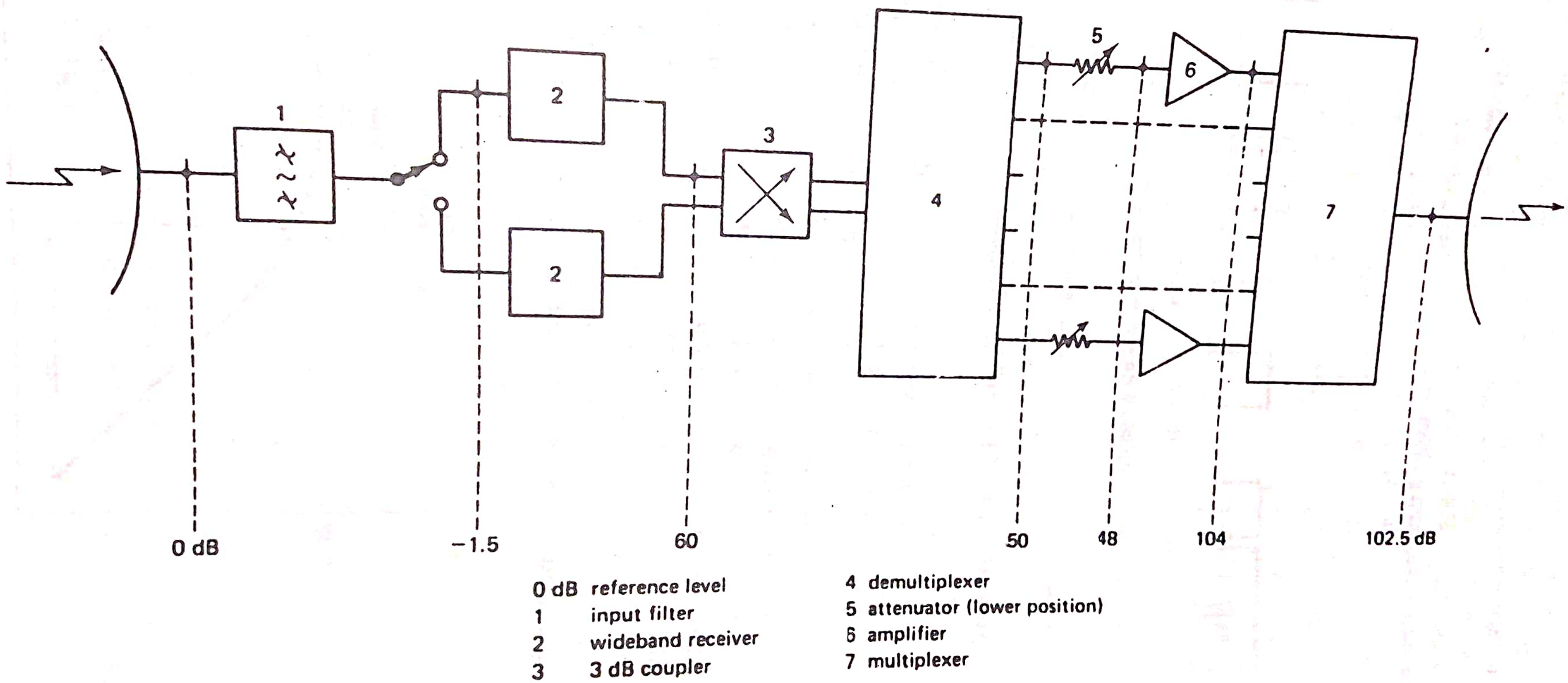


Figure 19.13.3 Typical relative power levels in a transponder. (Courtesy of CCIR. *CCIR Fixed Satellite Services Handbook,* p. 19, sect 4.2.2, final draft 1984).

The transponder bandwidth of 36 MHz may be used by a single carrier modulated with a wideband signal, such as a TV signal or an FDM telephony baseband signal. It is also possible to divide the 36-MHz bandwidth into smaller bandwidths, which are then assigned to different carriers. This gives rise to a method of accessing a transponder known as *frequency division multiple access* (FDMA). Figure 19.13.4 shows one scheme in which about 800 one-way telephony channels may be assigned in the 36-MHz bandwidth.

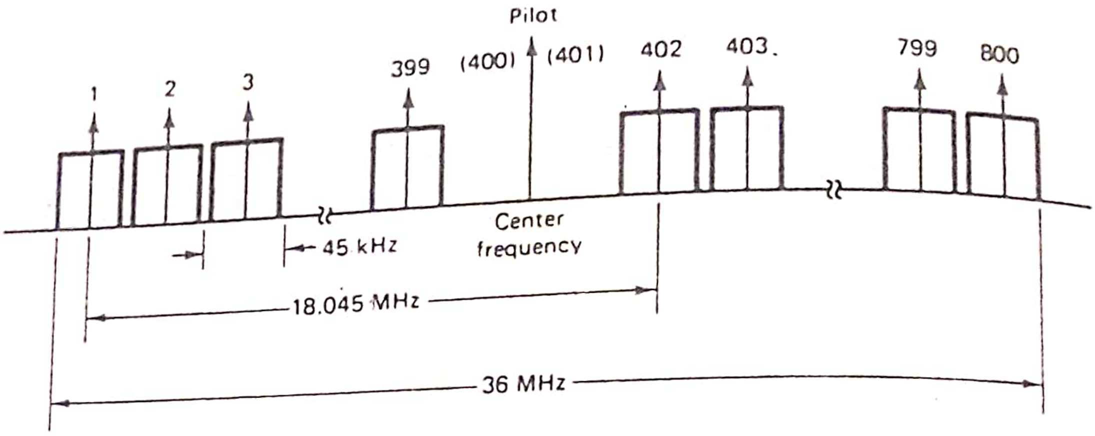


Figure 19.13.4 Channeling arrangements for Intelsat SCPC system.

A problem that arises with FDMA is that of nonlinearity in the power amplifier. The transfer curve for a typical high power amplifier is shown in Fig. 19.13.5. This is seen to be nonlinear, and operation in the nonlinear region near the peak results in a form of distortion known as *intermodulation distortion* when multiple carriers are present, such as occurs with FDMA. In earlier satellites, microwave tubes known as *traveling wave tubes* (TWTs) provided the required power amplification. These tubes continue to be used because they provide high power output at wide bandwidths, but gradually solid-state high-power amplifiers (SSHPAs) are being developed for this application. Compared to TWTAs, the SSHPAs cannot deliver as high a power output, but they produce less intermodulation distortion.

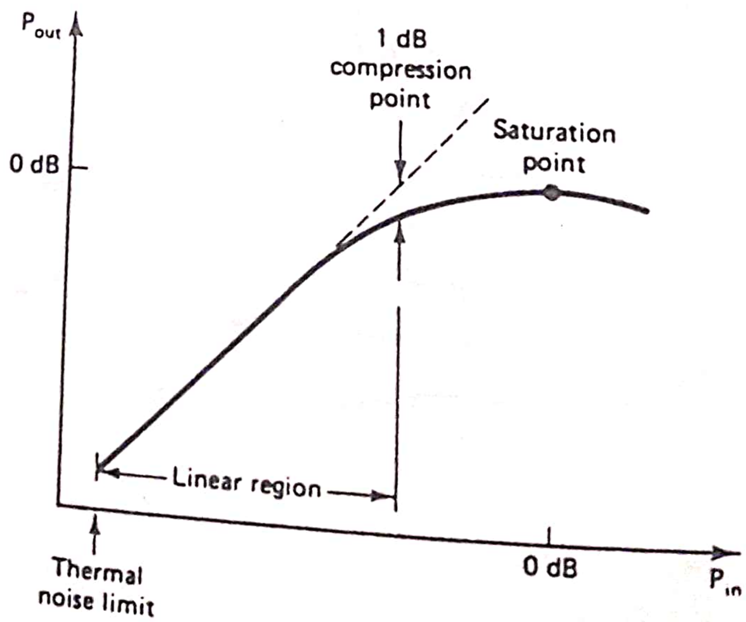


Figure 19.13.5 Power transfer curve for a satellite TWTA.

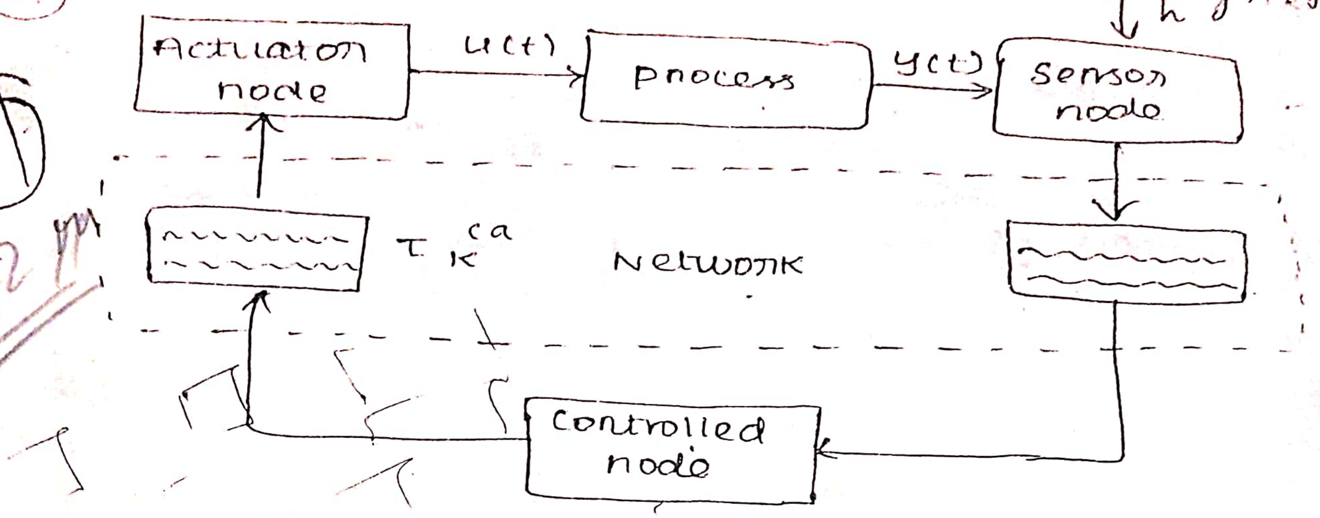
The peak point on the curve for single carrier operation is referred to as the *saturation point.* When multiple carriers are present, the power input is *backed off* from the saturation point to avoid the worst of the nonlinearity, which reduces intermodulation distortion to an acceptable level. Appropriately enough, the term *backoff* is used to describe this operation. There is an *input backoff* with a corresponding *output backoff* which typically is about 5 dB less than the input backoff. Where the carriers in an FDMA system transmit equal powers, the power in each carrier must be reduced by the input backoff amount, usually expressed in decibels.

Once the individual transponder signals have been amplified to the required power levels, they are combined in a multiplexer to form a wideband signal covering the downlink frequency range of 3.7 to 4.2 GHz, and this wideband signal is radiated by the transmit antenna or antennas.

Unit - IV

II - M.Sc Ph

NCS ⇒ Network controlled system



NCS: Network control system have been available in the market since the 1970's. The most popular and familiar NCS protocol in CAN.

It was developed by BOSCH to communicate control data form different control nodes in order to replace the traditional point links present in the early control system.

The automotive industry is the principal driving force behind the development of new control system. this is CAN has special version for automotive in board network implementation, since Ethernet appeared in the world of wired communication system.

Thus implementation of ethernet as a communication medium for NCS was a must. many, people reluctant to implement Ethernet Networked control system because of the non-deterministic nature of 802.3

But research showed that 802.3 has good performance for NCS either by changing packed format for real time Control messages, or by giving higher priority for this messages

Rockwell Automation & the ODVA also proposed the ethernet / IP as an industrial version of ethernet & they have developed the CIP.

It was successfull not only for pure control load implementation, but also when using mixed communication traffic as well

Ethernet NCS was first tested at low speeds It was only used to relay control packets b/w sensors, controlled & actuators.

Nilson studied induced network delays for a real network when communicating