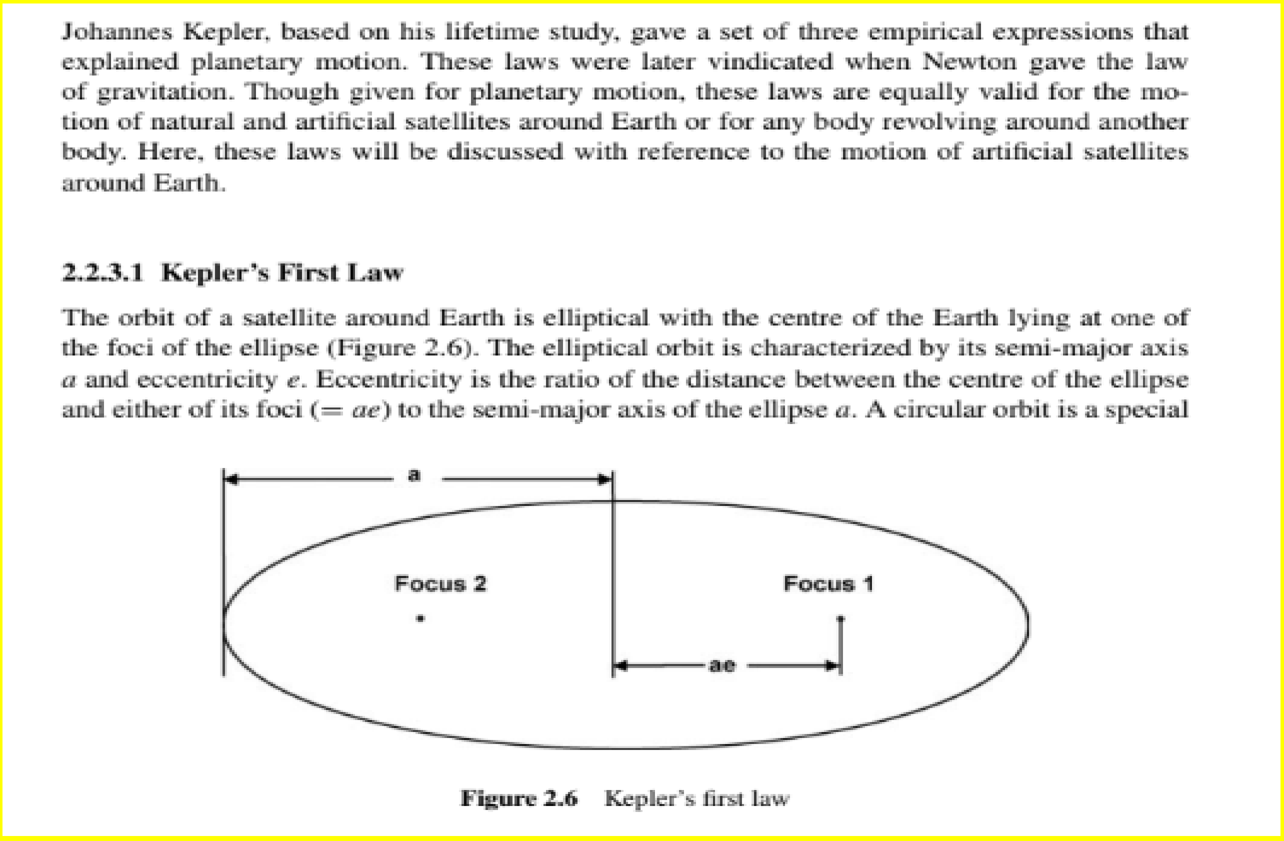
Vtu solution-March 2022
Satellite Communication-18EC732

Q. 1 Outline the kepler's law of planetary motion.Also derive expression for orbital period.

Ans.

Kepler's Laws

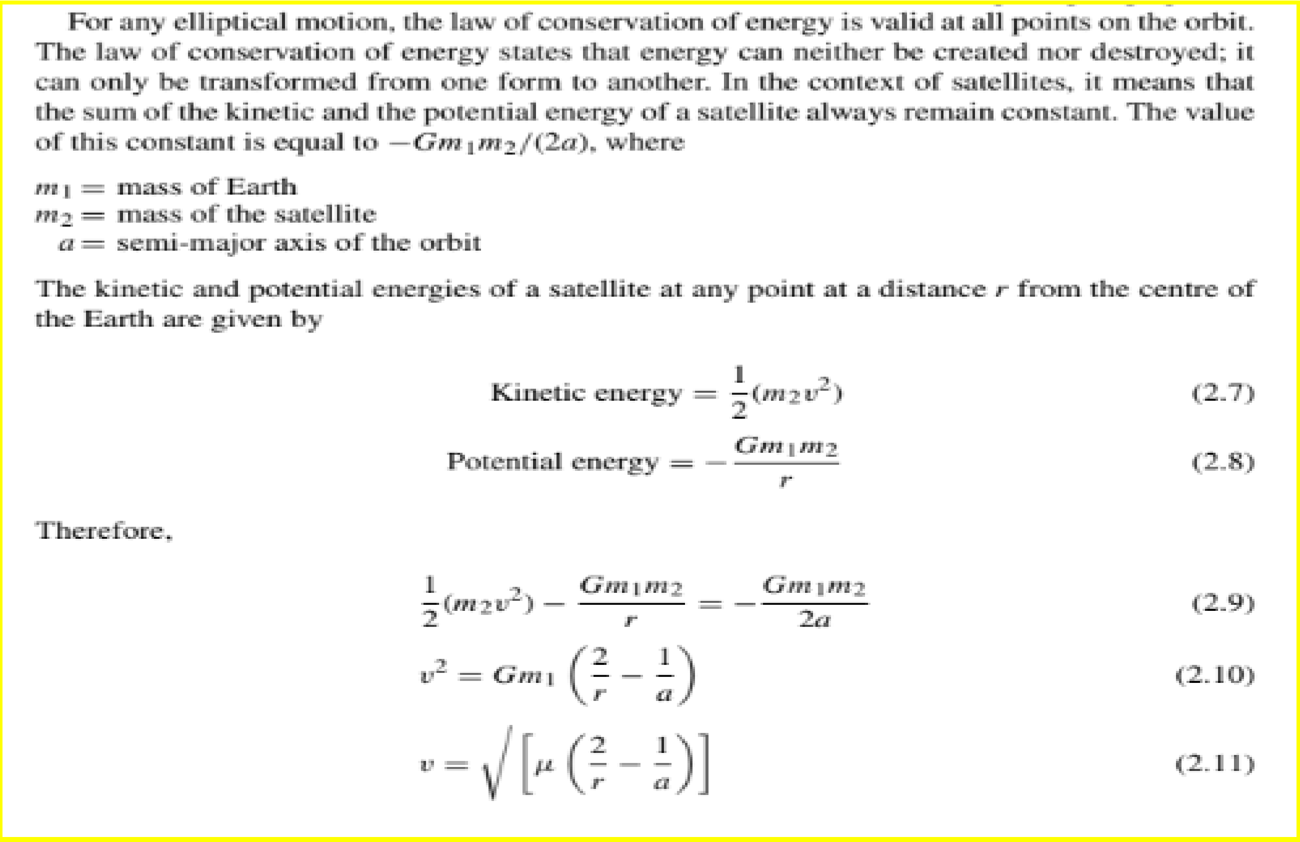


Johannes Kepler, based on his lifetime study, gave a set of three empirical expressions that explained planetary motion. These laws were later vindicated when Newton gave the law of gravitation. Though given for planetary motion, these laws are equally valid for the motion of natural and artificial satellites around Earth or for any body revolving around another body. Here, these laws will be discussed with reference to the motion of artificial satellites around Earth.

2.2.3.1 Kepler's First Law

The orbit of a satellite around Earth is elliptical with the centre of the Earth lying at one of the foci of the ellipse (Figure 2.6). The elliptical orbit is characterized by its semi-major axis *a* and eccentricity *e*. Eccentricity is the ratio of the distance between the centre of the ellipse and either of its foci (= *ae*) to the semi-major axis of the ellipse *a*. A circular orbit is a special

Figure 2.6 Kepler's first law



For any elliptical motion, the law of conservation of energy is valid at all points on the orbit. The law of conservation of energy states that energy can neither be created nor destroyed; it can only be transformed from one form to another. In the context of satellites, it means that the sum of the kinetic and the potential energy of a satellite always remain constant. The value of this constant is equal to $-Gm_1m_2/(2a)$, where

m_1 = mass of Earth
m_2 = mass of the satellite
a = semi-major axis of the orbit

The kinetic and potential energies of a satellite at any point at a distance r from the centre of the Earth are given by

$$\text{Kinetic energy} = \frac{1}{2}(m_2v^2) \tag{2.7}$$

$$\text{Potential energy} = -\frac{Gm_1m_2}{r} \tag{2.8}$$

Therefore,

$$\frac{1}{2}(m_2v^2) - \frac{Gm_1m_2}{r} = -\frac{Gm_1m_2}{2a} \tag{2.9}$$

$$v^2 = Gm_1\left(\frac{2}{r} - \frac{1}{a}\right) \tag{2.10}$$

$$v = \sqrt{\left[\mu\left(\frac{2}{r} - \frac{1}{a}\right)\right]} \tag{2.11}$$

Kepler’s Second Law

The line joining the satellite and the centre of the Earth sweeps out equal areas in the plane of the orbit in equal time intervals (Figure 2.7); i.e. the rate (dA/dt) at which it sweeps area A is constant. The rate of change of the swept-out area is given by

dA
dt = angular momentum of the satellite

2m (2.12)
where m is the mass of the satellite. Hence, Kepler’s second law is also equivalent to the law of conservation of momentum, which implies that the angular momentum of the orbiting satellite given by the product of the radius vector and the component of linear momentum perpendicular to the radius vector is constant at all points on the orbit.

Orbiting Satellites – Basic Principles 39

Figure 2.7 Kepler’s second law

The angular momentum of the satellite of mass m is given by mr2ω, where ω is the angular velocity of the satellite. This further implies that the product mr2ω = (mωr) (r) = mv r

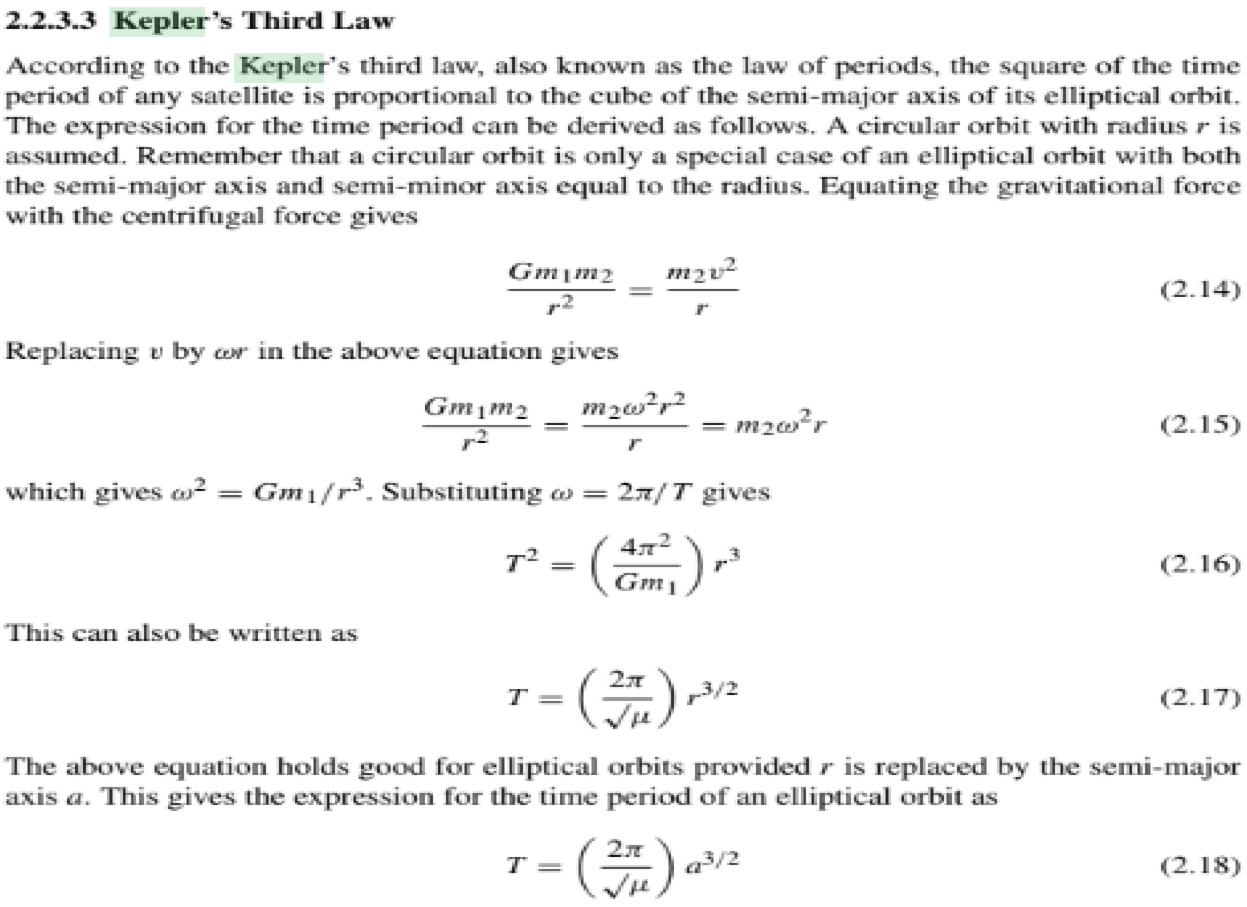
remains constant. Here v is the component of the satellite’s velocity v in the direction perpendicular to the radius vector and is expressed as v cos γ, where γ is the angle between the

direction of motion of the satellite and the local horizontal, which is in the plane perpendicular to the radius vector r (Figure 2.8). This leads to the conclusion that the product rv cos γ is constant. The product reduces to rv in the case of circular orbits and also at apogee and perigee points in the case of elliptical orbits due to angle γ becoming zero. It is interesting to note here that the velocity component v is inversely proportional to the distance r. Qualitatively, this implies that the satellite is at its lowest speed at the apogee point and the highest speed at the perigee point. In other words, for any satellite in an elliptical orbit, the dot product of its velocity vector and the radius vector at all points is constant. Hence,

$vprp = vara = vr \cos \gamma$ (2.13)

Figure 2.8 Satellite’s position at any given time

where
vp = velocity at the perigee point
rp = perigee distance
va = velocity at the apogee point
ra = apogee distance
v = satellite velocity at any point in the orbit
r = distance of the point
γ = angle between the direction of motion of the satellite and the local horizontal.



2.2.3.3 Kepler's Third Law

According to the Kepler's third law, also known as the law of periods, the square of the time period of any satellite is proportional to the cube of the semi-major axis of its elliptical orbit. The expression for the time period can be derived as follows. A circular orbit with radius r is assumed. Remember that a circular orbit is only a special case of an elliptical orbit with both the semi-major axis and semi-minor axis equal to the radius. Equating the gravitational force with the centrifugal force gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2v^2}{r} \tag{2.14}$$

Replacing v by ωr in the above equation gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2\omega^2r^2}{r} = m_2\omega^2r \tag{2.15}$$

which gives $\omega^2 = Gm_1/r^3$. Substituting $\omega = 2\pi/T$ gives

$$T^2 = \left(\frac{4\pi^2}{Gm_1}\right)r^3 \tag{2.16}$$

This can also be written as

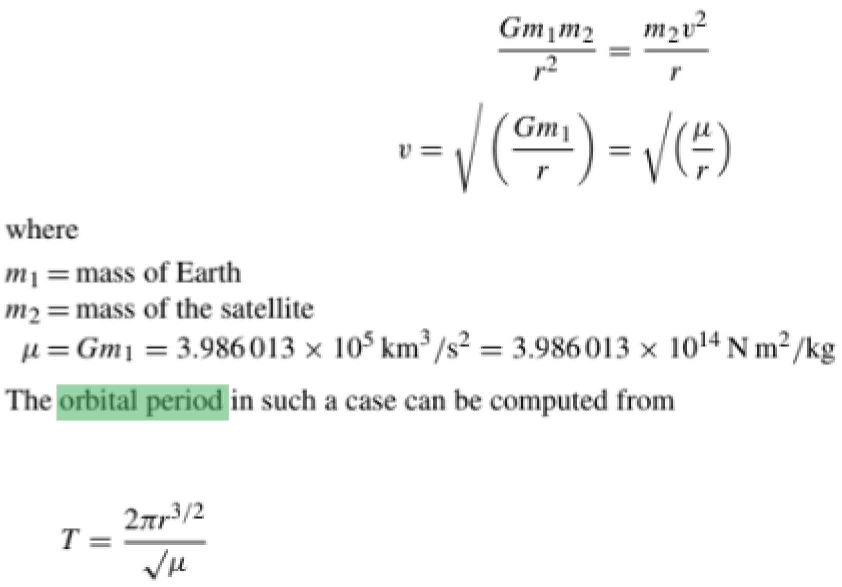
$$T = \left(\frac{2\pi}{\sqrt{\mu}}\right)r^{3/2} \tag{2.17}$$

The above equation holds good for elliptical orbits provided r is replaced by the semi-major axis a. This gives the expression for the time period of an elliptical orbit as

$$T = \left(\frac{2\pi}{\sqrt{\mu}}\right)a^{3/2} \tag{2.18}$$

—-------------------------Orbital Period—----------------------------

According to Newton’s second law of motion, the force equals the product of mass and acceleration. In the case of a satellite orbiting Earth, if the orbiting velocity is v, then the acceleration, called centripetal acceleration, experienced by the satellite at a distance r from the centre of the Earth would be v2/r. If the mass of satellite is m, it would experience a reaction force of mv2/r. This is the centrifugal force directed outwards from the centre of the Earth and for a satellite is equal in magnitude to the gravitational force.
If the satellite orbited Earth with a uniform velocity v, which would be the case when the satellite orbit is a circular one, then equating the two forces mentioned above would lead to an expression for the orbital velocity v as follows:



$$\frac{Gm_1m_2}{r^2} = \frac{m_2v^2}{r}$$

$$v = \sqrt{\left(\frac{Gm_1}{r}\right)} = \sqrt{\left(\frac{\mu}{r}\right)}$$

where

m_1 = mass of Earth

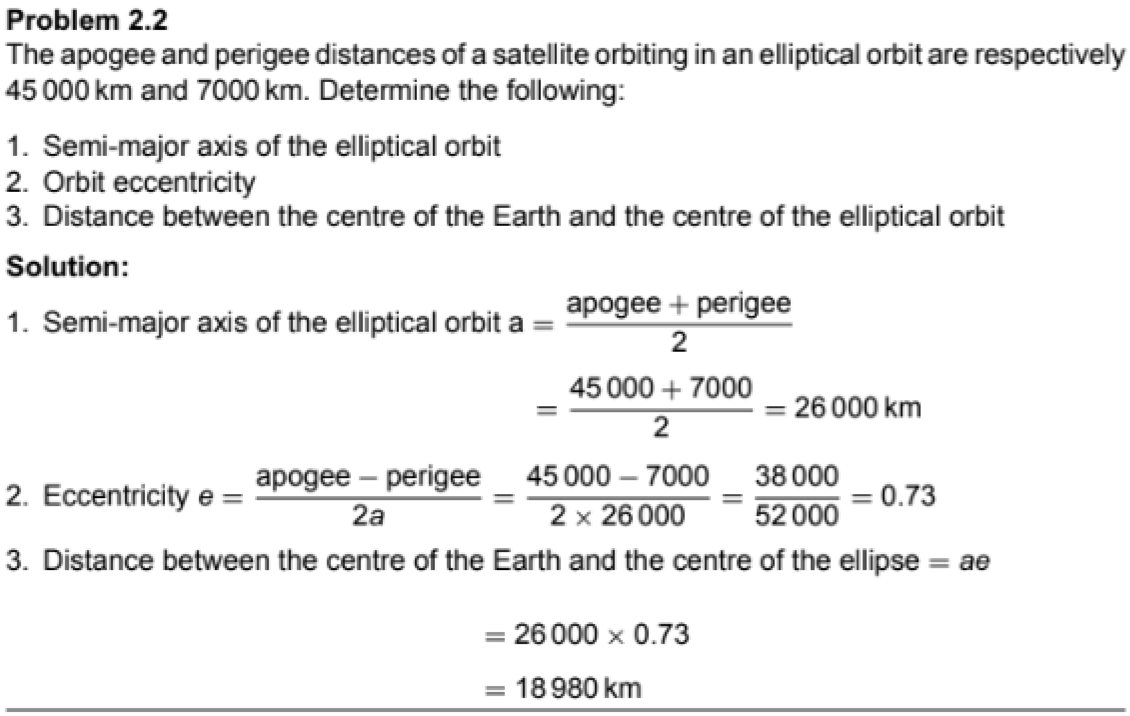
m_2 = mass of the satellite

$\mu = Gm_1 = 3.986013 \times 10^5\ \text{km}^3/\text{s}^2 = 3.986013 \times 10^{14}\ \text{N m}^2/\text{kg}$

The orbital period in such a case can be computed from

$$T = \frac{2\pi r^{3/2}}{\sqrt{\mu}}$$

Q.2



Problem 2.2

The apogee and perigee distances of a satellite orbiting in an elliptical orbit are respectively 45 000 km and 7000 km. Determine the following:

1. Semi-major axis of the elliptical orbit
2. Orbit eccentricity
3. Distance between the centre of the Earth and the centre of the elliptical orbit

Solution:

1. Semi-major axis of the elliptical orbit $a = \dfrac{\text{apogee} + \text{perigee}}{2}$

$$= \frac{45\,000 + 7000}{2} = 26\,000\ \text{km}$$

2. Eccentricity $e = \dfrac{\text{apogee} - \text{perigee}}{2a} = \dfrac{45\,000 - 7000}{2 \times 26\,000} = \dfrac{38\,000}{52\,000} = 0.73$

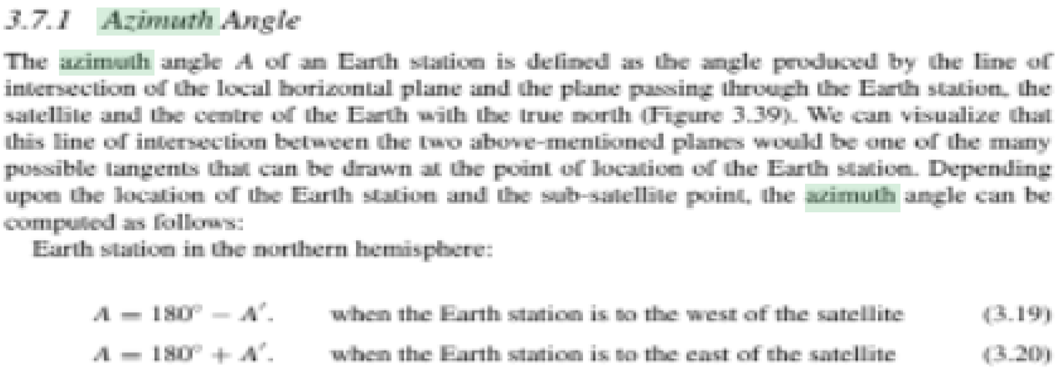
3. Distance between the centre of the Earth and the centre of the ellipse $= ae$

$$= 26\,000 \times 0.73$$

$$= 18\,980\ \text{km}$$

Q.3 Define the significance of Azimuth & Elevation angle angle on satellite earth station.

Solu-



3.7.1 Azimuth Angle

The azimuth angle A of an Earth station is defined as the angle produced by the line of intersection of the local horizontal plane and the plane passing through the Earth station, the satellite and the centre of the Earth with the true north (Figure 3.39). We can visualize that this line of intersection between the two above-mentioned planes would be one of the many possible tangents that can be drawn at the point of location of the Earth station. Depending upon the location of the Earth station and the sub-satellite point, the azimuth angle can be computed as follows:

Earth station in the northern hemisphere:

$$A = 180^\circ - A', \quad \text{when the Earth station is to the west of the satellite} \tag{3.19}$$

$$A = 180^\circ + A', \quad \text{when the Earth station is to the east of the satellite} \tag{3.20}$$

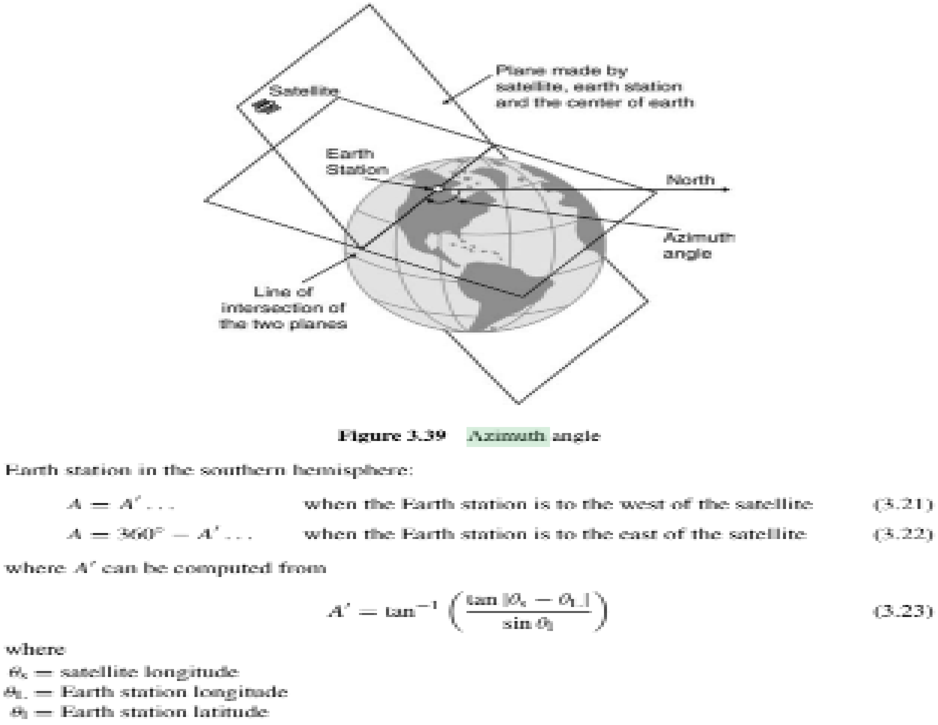


Figure 3.39 Azimuth angle

Earth station in the southern hemisphere:

$$A = A' \ldots \quad \text{when the Earth station is to the west of the satellite} \tag{3.21}$$

$$A = 360^\circ - A' \ldots \quad \text{when the Earth station is to the east of the satellite} \tag{3.22}$$

where A' can be computed from

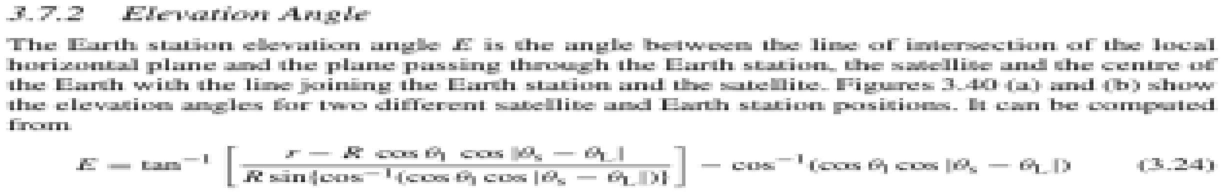
$$A' = \tan^{-1}\left(\frac{\tan|\theta_s - \theta_L|}{\sin\theta_l}\right) \tag{3.23}$$

where

θ_s = satellite longitude

θ_L = Earth station longitude

θ_l = Earth station latitude

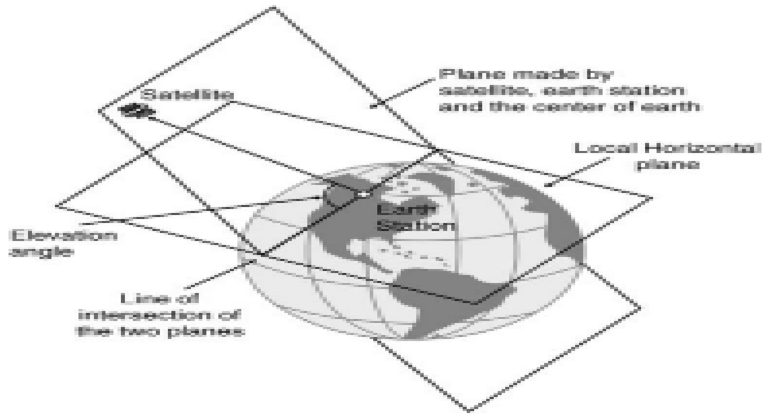


3.7.2 *Elevation Angle*

The Earth station elevation angle E is the angle between the line of intersection of the local horizontal plane and the plane passing through the Earth station, the satellite and the centre of the Earth with the line joining the Earth station and the satellite. Figures 3.40 (a) and (b) show the elevation angles for two different satellite and Earth station positions. It can be computed from

$$E = \tan^{-1}\left[\frac{r - R\cos\theta_l\cos|\theta_s - \theta_L|}{R\sin\{\cos^{-1}(\cos\theta_l\cos|\theta_s - \theta_L|)\}}\right] - \cos^{-1}(\cos\theta_l\cos|\theta_s - \theta_L|) \qquad (3.24)$$

110 Satellite Launch and In-orbit Operations



Question-4

Problem 3.9

An Earth station is located at 30°W longitude and 60°N latitude. Determine the Earth station's azimuth and elevation angles with respect to a geostationary satellite located at 50°W longitude. The orbital radius is 42 164 km. (Assume the radius of the Earth to be 6378 km.)

Solution: Since the Earth station is in the northern hemisphere and is located towards east of the satellite, the azimuth angle A is given by $(180^\circ + A')$, where A' can be computed

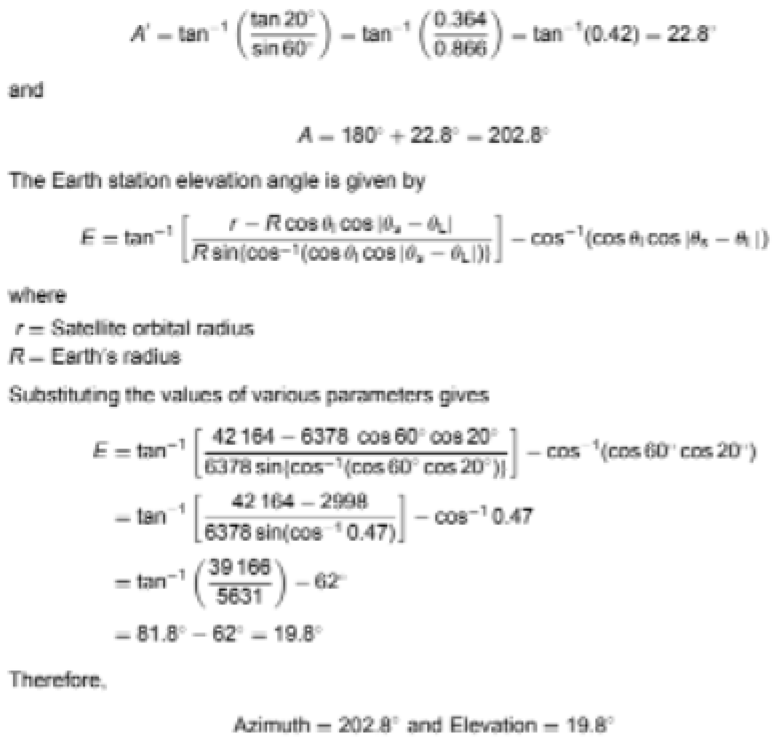
from

$$A' = \tan^{-1}\left(\frac{\tan|\theta_\mathrm{s} - \theta_\mathrm{L}|}{\sin\theta_\mathrm{l}}\right)$$

where

θ_s = satellite longitude = 50°W
θ_L = Earth station longitude = 30°W
θ_l = Earth station latitude = 60°N

Therefore



$$A' = \tan^{-1}\left(\frac{\tan 20^\circ}{\sin 60^\circ}\right) = \tan^{-1}\left(\frac{0.364}{0.866}\right) = \tan^{-1}(0.42) = 22.8^\circ$$

and

$$A = 180^\circ + 22.8^\circ = 202.8^\circ$$

The Earth station elevation angle is given by

$$E = \tan^{-1}\left[\frac{r - R\cos\theta_l \cos|\theta_s - \theta_L|}{R\sin(\cos^{-1}(\cos\theta_l \cos|\theta_s - \theta_L|))}\right] - \cos^{-1}(\cos\theta_l \cos|\theta_s - \theta_l|)$$

where

r = Satellite orbital radius

R = Earth's radius

Substituting the values of various parameters gives

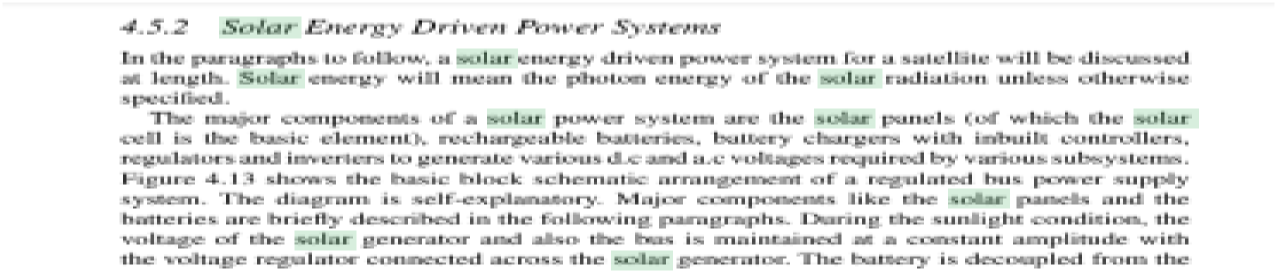
$$\begin{aligned}
E &= \tan^{-1}\left[\frac{42\,164 - 6378\ \cos 60^\circ \cos 20^\circ}{6378\sin(\cos^{-1}(\cos 60^\circ \cos 20^\circ))}\right] - \cos^{-1}(\cos 60^\circ \cos 20^\circ) \\
&= \tan^{-1}\left[\frac{42\,164 - 2998}{6378\sin(\cos^{-1} 0.47)}\right] - \cos^{-1} 0.47 \\
&= \tan^{-1}\left(\frac{39\,166}{5631}\right) - 62^\circ \\
&= 81.8^\circ - 62^\circ = 19.8^\circ
\end{aligned}$$

Therefore,

$$\text{Azimuth} = 202.8^\circ \text{ and Elevation} = 19.8^\circ$$

Q.5 Explain solar energy driven power supply system for a satellite.

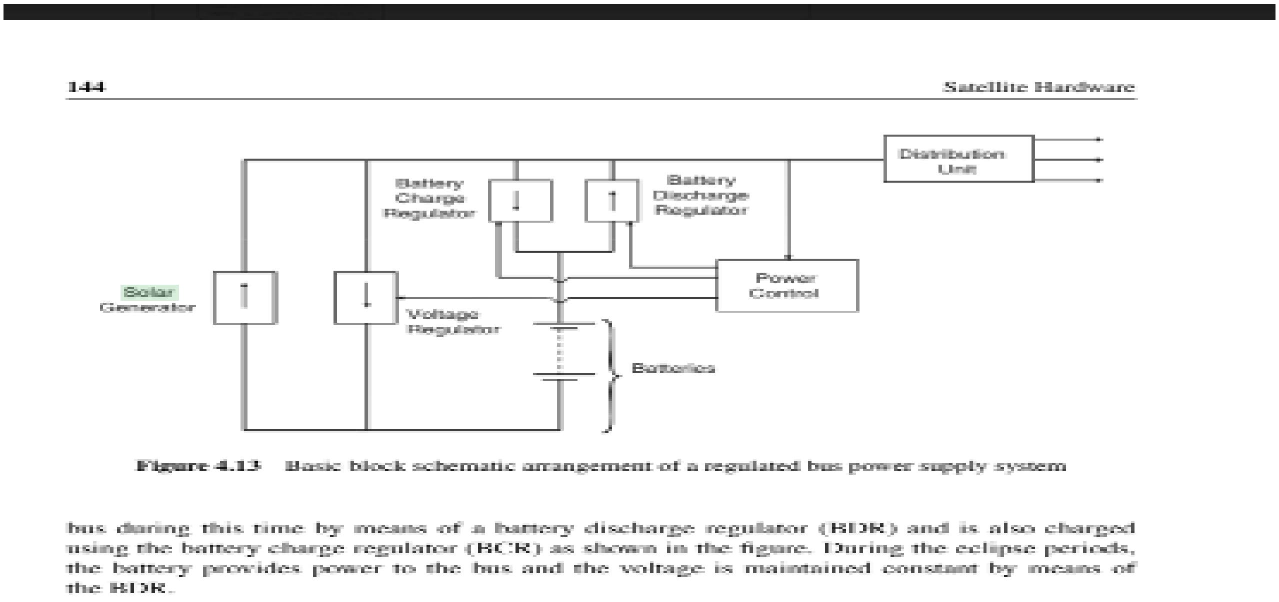
sol.



4.5.2 *Solar Energy Driven Power Systems*

In the paragraphs to follow, a solar energy driven power system for a satellite will be discussed at length. Solar energy will mean the photon energy of the solar radiation unless otherwise specified.

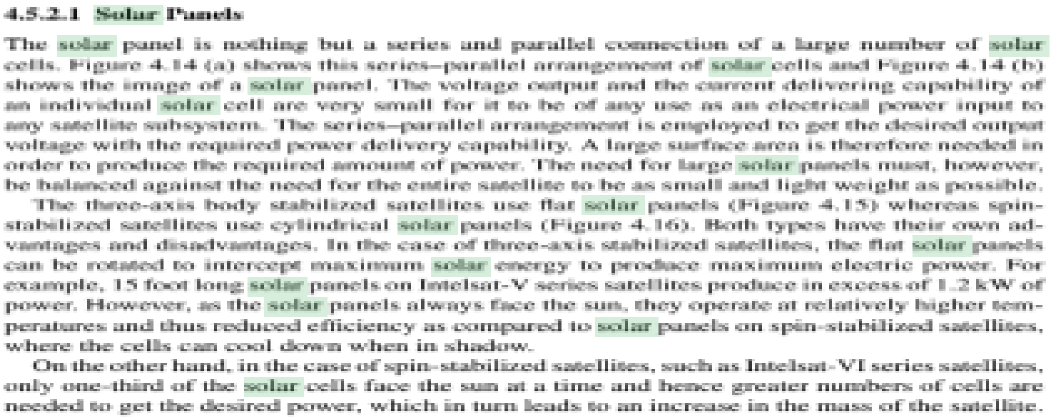
The major components of a solar power system are the solar panels (of which the solar cell is the basic element), rechargeable batteries, battery chargers with inbuilt controllers, regulators and inverters to generate various d.c and a.c voltages required by various subsystems. Figure 4.13 shows the basic block schematic arrangement of a regulated bus power supply system. The diagram is self-explanatory. Major components like the solar panels and the batteries are briefly described in the following paragraphs. During the sunlight condition, the voltage of the solar generator and also the bus is maintained at a constant amplitude with the voltage regulator connected across the solar generator. The battery is decoupled from the



144 Satellite Hardware

Figure 4.13 Basic block schematic arrangement of a regulated bus power supply system

bus during this time by means of a battery discharge regulator (BDR) and is also charged using the battery charge regulator (BCR) as shown in the figure. During the eclipse periods, the battery provides power to the bus and the voltage is maintained constant by means of the BDR.



4.5.2.1 Solar Panels

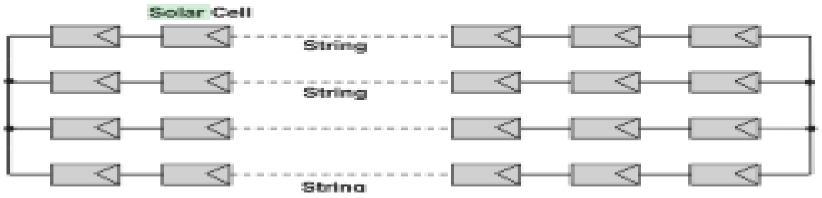
The solar panel is nothing but a series and parallel connection of a large number of solar cells. Figure 4.14 (a) shows this series–parallel arrangement of solar cells and Figure 4.14 (b) shows the image of a solar panel. The voltage output and the current delivering capability of an individual solar cell are very small for it to be of any use as an electrical power input to any satellite subsystem. The series–parallel arrangement is employed to get the desired output voltage with the required power delivery capability. A large surface area is therefore needed in order to produce the required amount of power. The need for large solar panels must, however, be balanced against the need for the entire satellite to be as small and light weight as possible.

The three-axis body stabilized satellites use flat solar panels (Figure 4.15) whereas spin-stabilized satellites use cylindrical solar panels (Figure 4.16). Both types have their own advantages and disadvantages. In the case of three-axis stabilized satellites, the flat solar panels can be rotated to intercept maximum solar energy to produce maximum electric power. For example, 15 foot long solar panels on Intelsat-V series satellites produce in excess of 1.2 kW of power. However, as the solar panels always face the sun, they operate at relatively higher temperatures and thus reduced efficiency as compared to solar panels on spin-stabilized satellites, where the cells can cool down when in shadow.

On the other hand, in the case of spin-stabilized satellites, such as Intelsat-VI series satellites, only one-third of the solar cells face the sun at a time and hence greater numbers of cells are needed to get the desired power, which in turn leads to an increase in the mass of the satellite.

Nov 9, 2021

Power Supply Subsystem 145



Q.6 Explain different type of earth station .

Types of Earth Station

Earth stations are generally categorized on the basis of type of services or functions provided by them though they may sometimes be classified according to the size of the dish antenna. Based on the type of service provided by the Earth station, they are classified into the following three broad categories.

1. Fixed Satellite Service (FSS) Earth Stations
2. Broadcast Satellite Service (BSS) Earth Stations
3. Mobile Satellite Service (MSS) Earth Stations

8.2.1 Fixed Satellite Service (FSS) Earth Station

Under the group of FSS Earth stations, we have the large Earth stations ($G/T \cong 40$ dB/K) (Figure 8.3), medium Earth stations ($G/T \cong 30$ dB/K), small Earth stations ($G/T \cong 25$ dB/K), very small terminals with transmit/receive functions ($G/T \cong 20$ dB/K) (Figure 8.4) and very small terminals with receive only functions ($G/T \cong 12$ dB/K) (Figure 8.5).

8.2.2 Broadcast Satellite Service (BSS) Earth Stations

Under the group of BSS Earth stations, we have large Earth stations ($G/T \cong 15$ dB/K) used for community reception and small Earth stations ($G/T \cong 8$ dB/K) used for individual reception. Technically, broadcast satellite service or BSS as it is known by the International Telecommunications Union (ITU) refers only to the services offered by satellites in specific frequency bands. These frequency bands for different ITU regions include 10.7 GHz to 12.75 GHz in ITU region-1 (Europe, Russia, Africa), 12.2 GHz to 12.7 GHz in ITU region-2 (North and South America) and 11.7 GHz to 12.2 GHz in ITU region-3 (Asia, Australia). ITU adopted an international BSS plan in the year 1977. Under this plan, each country was allotted specific frequencies for use at specific orbital locations for domestic services. It is also known by the name of Direct Broadcast Service or DBS or more commonly as Direct-to-Home or DTH. The term DBS is often used interchangeably with DTH to cover both analog and digital video and audio services received by relatively small dishes.

8.2.3 Mobile Satellite Service (MSS) Earth Stations

Under the group of MSS Earth stations, we have the large Earth stations ($G/T \cong -4$ dB/K), medium Earth stations ($G/T \cong -12$ dB/K) and small Earth stations ($G/T \cong -24$ dB/K). While both large and medium Earth stations require tracking, small MSS Earth stations are without tracking equipment.

Satellite phone is the most commonly used mobile satellite service. It is a type of mobile that connects to satellites instead of terrestrial cellular sites. Mobile satellite services are provided both by the geostationary as well as low Earth orbit satellites. In the case of the former, three or four satellites can maintain near continuous global coverage. These satellites are very heavy and therefore very expensive to build and launch. Geostationary satellite based mobile services also suffer from noticeable delay while making a telephone call or using data services. Yet another

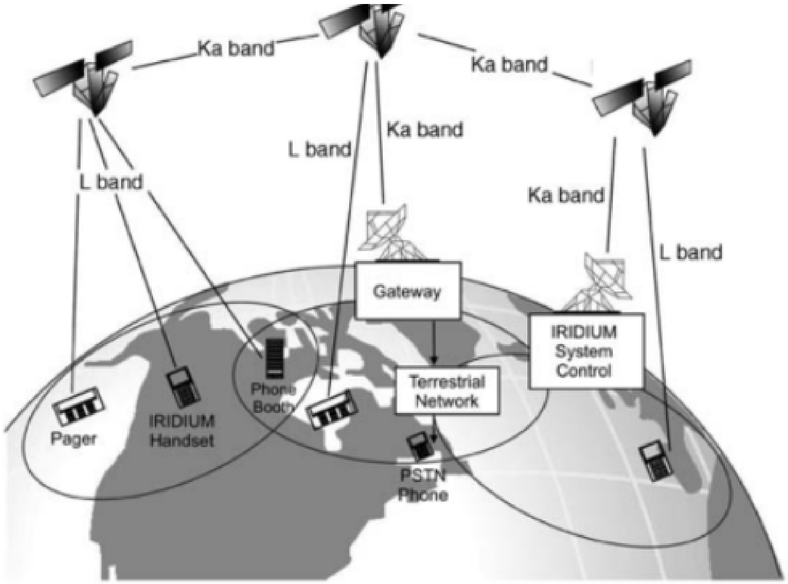


Figure 8.6 Iridium system

disadvantage of geostationary satellite system is frequent absence of line-of-sight between the satellite and the phone due to obstacles present in between the two.

The disadvantages of the geostationary satellite system are overcome in Low Earth Orbit (LEO) satellite systems. In the case of LEO satellite systems, an obstacle would block the satellite access only for a short time until another satellite passes overhead. The major advantage of LEO satellites based communication system is worldwide wireless coverage with no gaps. However, a constellation of LEO satellites would be required to maintain uninterrupted coverage. Iridium (Figure 8.6) and Globalstar are the two major LEO satellite systems offering mobile satellite services. Globalstar uses 44 satellites with the orbital inclination of the satellites being 52°. It may be mentioned here that the polar regions are not covered by the Globalstar constellation. Iridium operates 66 satellites orbiting in polar orbits. Radio links are used between the satellites in order to relay data to the nearest satellite connected to the Earth station.

Q.7 Explain following- 1) Up/Down Converter 2) Antenna

Solution

8.6.1.3 Up-converters/Down-converters
Up-converters and down-converters are frequency translators that convert the IF used in the modems and baseband equipment to the operating RF frequency bands (C, Ku and Ka) and vice
versa. The up-converter translates the IF signal at 70 MHz (or 140 MHz) from the modulator
to the operating RF frequency in C or Ku or Ka band as the case may be. The down-converter
translates the received RF signal in C or Ku or Ka band into IF signal, which is subsequently

fed to the demodulator. Either single or double frequency conversion topologies are used for up-converters and down-converters.

Figures 8.25(a) and (b) respectively show the schematic diagrams of up-converters and down-converters employing single frequency conversion topology. A typical up-converter uses a stage of amplification before the mixer stage. Mixer along with local oscillator (LO) provides frequency conversion. A frequency synthesizer is used for LO so as to be able to generate any frequency within the satellite up-link band. The signal is further amplified after frequency conversion before it is fed to the high power amplifier. A band pass filter at the output of the mixer eliminates LO frequency and its harmonics from reaching the up-link path. Insertion loss in the filter causes a reduction of the effective isotropic radiated power (EIRP). The operation of down-converter can be explained on similar lines. Amplification stage provides gain and reduces the noise contribution of mixer and the IF equipment. The frequency synthesizer provides frequency agility in the receive frequency operation.

Double frequency conversion topology employs a two mixer conversion stage. In the case of an up-converter using double conversion, the IF frequency is first up-converted to another intermediate frequency usually in the L-band. The signals is then amplified and fed to the second mixer stage where it is up-converted to the final operational RF frequency band. As outlined in the case of single stage converters, an amplifier precedes the mixer and a band pass filter follows the same. Figure 8.26(a) shows block schematic of a C-band up-converter employing double frequency conversion topology. Figure 8.26(b) shows the arrangement of double frequency conversion topology based down-converter for C-band operation.

2. Antenna

Different types of antenna and their performance parametres of relevance to satellite communications have been discussed earlier in Chapter-4 on satellite hardware. A brief description of antennas of relevance to Earth stations is given in this section.

Different variants of reflector antenna are commonly used as Earth station antenna. These mainly include the prime focus fed parabolic reflector antenna, offset fed sectioned parabolic reflector antenna and cassegrain fed reflector antenna. The prime focus fed parabolic reflector antenna as shown in Figure 8.17 is used for an antenna diameter of less than 4.5 m, more so for receive only Earth stations. An offset fed sectioned parabolic reflector antenna (Figure 8.18) is used for antenna diameters of less than 2 m. Offset feed configuration eliminates the blockage of the main beam due to feed and its mechanical support system and thus improves antenna efficiency and reduces side lobe levels.

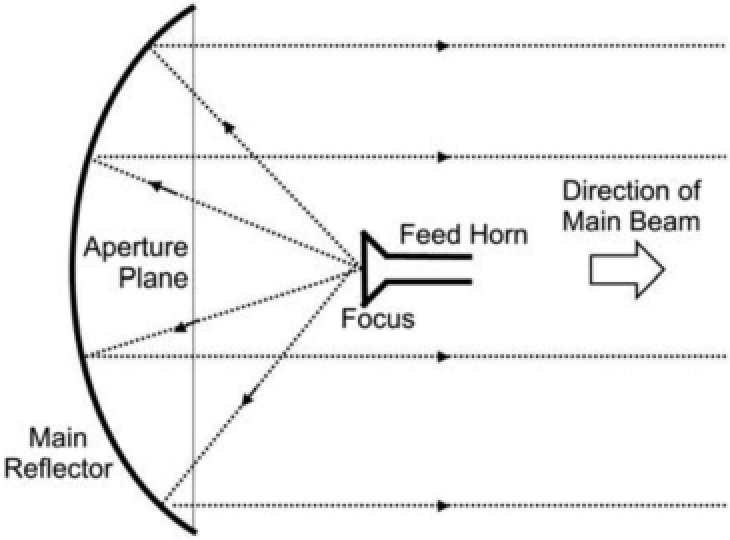
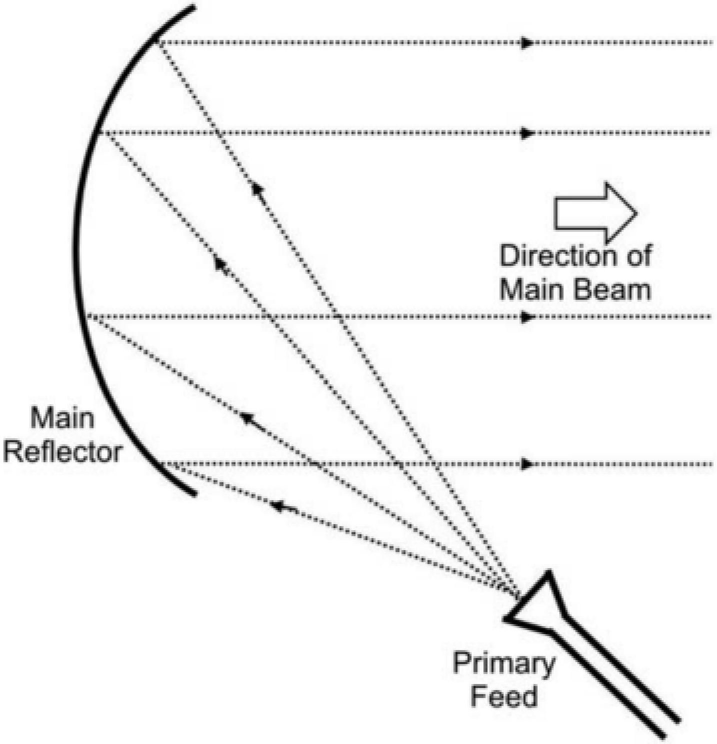
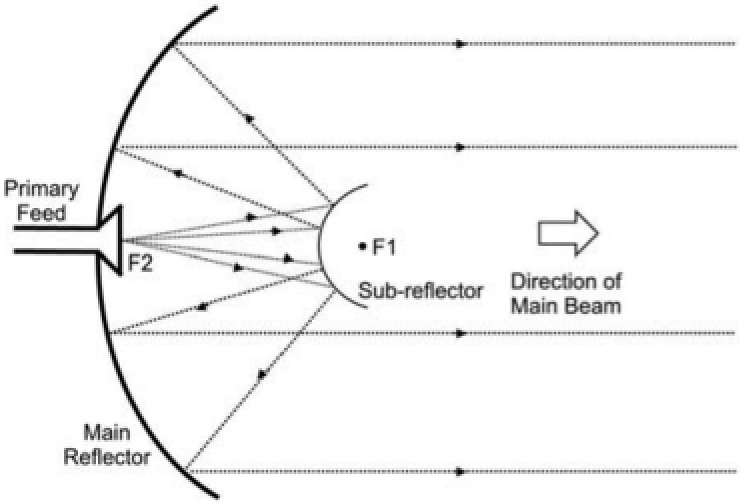


Figure 8.17 Prime focus fed parabolic reflector antenna

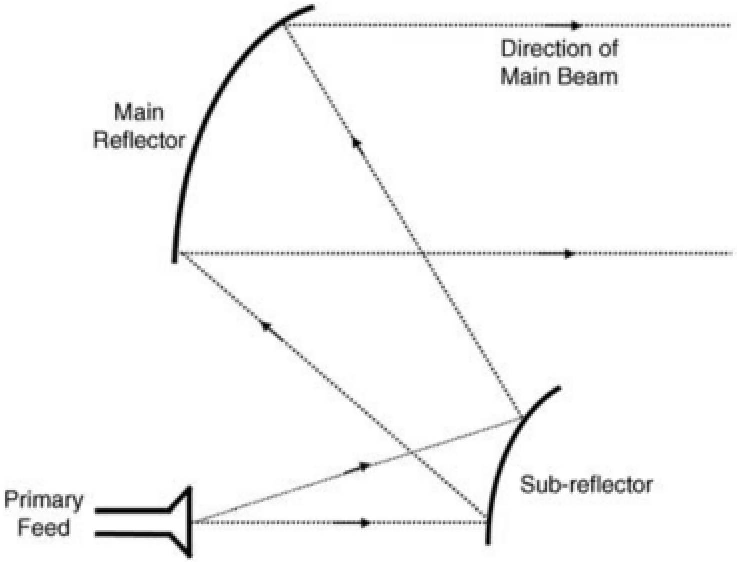


In a variation of the prime focus fed parabolic reflector antenna, a piece of hook shaped waveguide extending from the vertex of the parabolic reflector is connected to the feed horn. In this case, the low noise block (LNB) is connected to the waveguide behind the parabolic reflector. This allows placement of electronics without causing any obstruction to the main beam in addition to allowing an easy access to it.

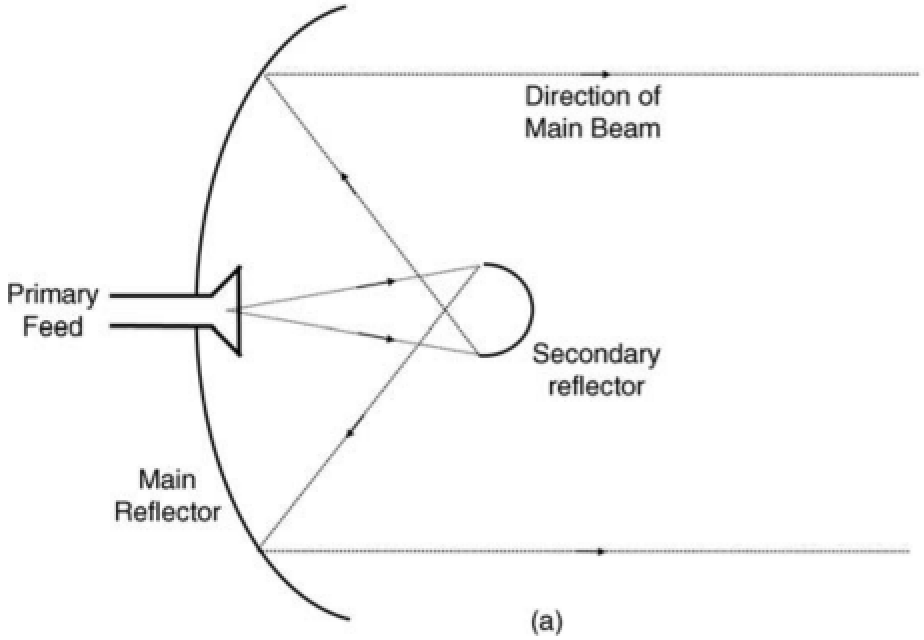


Cassegrain antennas overcome most of the shortcomings of the prime focus fed parabolic reflector antennas. The cassegrain antenna uses a hyperbolic reflector placed in front of the main

reflector, closer to the dish than the focus as shown in Figure 8.19. This hyperbolic reflector receives the waves from the feed placed at the centre of the main reflector and bounces them back towards the main reflector. In the case of cassegrain antenna, the front end electronics instead of being located at the prime focus is positioned on or even behind the dish. Offset feed configuration is also possible in case of Cassegrain antenna



Yet another common reflector antenna configuration is the Gregorian antenna [Figure 8.21(a)]. This configuration uses a concave secondary reflector just behind the prime focus. The purpose of this reflector is also to bounce the waves back towards the dish. The front end in this case is located between the secondary reflector and the main reflector. Offset feed configuration is also possible in case of Gregorian antenna



Q.8 Explain the typical TDMA frame structure.

TDMA Frame Structure

As mentioned above, in a TDMA network, each of the multiple Earth stations accessing a given satellite transponder transmits one or more data bursts. The satellite thus receives at its input a set of bursts from a large number of Earth stations. This set of bursts from various Earth stations is called the TDMA frame. Figure 6.6 shows a typical TDMA frame structure.
It is evident from the frame structure that the frame starts with a reference burst transmitted from a reference station in the network. The reference burst is followed by

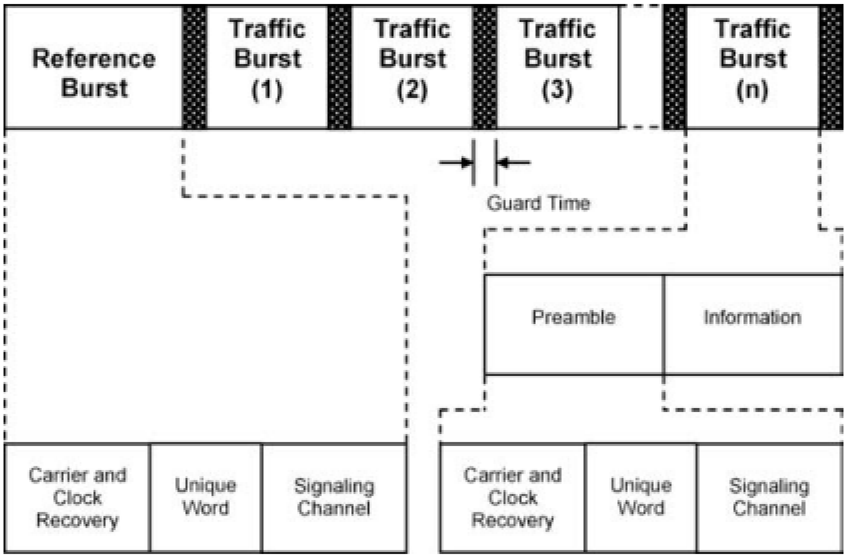


Figure 6.6 Typical TDMA frame structure

traffic bursts from various Earth stations with a guard time between various traffic bursts from different stations. The traffic bursts are synchronized to the reference burst to fix their timing reference. Different parts of the TDMA frame structure are briefly described in the following Paragraphs.

Reference Burst

The reference burst is usually a combination of two reference bursts (RB-1 and RB-2). The primary reference burst, which can be either RB-1 or RB-2, is transmitted by one of the stations, called the primary reference station, in the network. The secondary reference burst, which is

RB-1 if the primary reference burst is RB-2 and RB-2 if the primary reference burst is RB-1, is transmitted by another station, called the secondary reference station, in the network.

The reference burst automatically switches over to the secondary reference burst in the event of primary reference station's failure to provide reference burst to the TDMA network. The reference burst does not carry any traffic information and is used to provide timing references to various stations accessing the TDMA transponder.

Traffic Burst

Different stations accessing the satellite transponder may transmit one or more traffic bursts per TDMA frame and position them anywhere in the frame according to a burst time plan that coordinates traffic between various stations. The timing reference for the location of the traffic burst is taken from the time of occurrence of the primary reference burst. With this reference, a station can locate and then extract the traffic burst or portions of traffic bursts intended for it. The reference burst also provides timing references to the stations for transmitting their traffic bursts so as to ensure that they arrive at the satellite transponder within their designated positions in the TDMA frame.

Guard Time
Different bursts are separated from each other by a short guard time, which ensures that the bursts from different stations accessing the satellite transponder do not overlap. This guard time should be long enough to allow for differences in transmit timing inaccuracies and also for differences in range rate variations of the satellite.

Q.9 Explain MCPC & SCPC System.

Sol .SCPC
Single Channel Per Carrier (SCPC) Systems

In the paragraphs to follow, we shall discuss two common forms of SCPC systems namely:
1. SCPC/FM/FDMA system
2. SCPC/PSK/FDMA system
Each one of them is briefly described below.
6.3.1 SCPC/FM/FDMA System
As outlined earlier, in this form of SCPC system, each signal channel modulates a separate RF carrier and the modulation system used here is frequency modulation. The modulated signal is then transmitted to the FDMA transponder. The transponder bandwidth is subdivided in such a way that each base band signal channel is allocated a separate transponder subdivision and an individual carrier. This type of SCPC system is particularly used on thin route satellite communication networks. Though it suffers from the problem of power limitation resulting from the use of multiple carriers and the associated intermodulation problems, it does enable a larger number of Earth stations to access and share the capacity of the transponder using smaller and more economic units as compared to multiple channels per carrier systems. Another
advantage of the SCPC/FM/FDMA system is that it facilitates the use of voice activated carriers. This means that the carriers are switched off during the periods when there is no speech activity,
thus reducing power consumption. This in turn leads to availability of more transponder power and hence higher channel capacity. This type of SCPC system also has the advantage that the power of the individual transmitted carriers can be adjusted to the optimum value for given link conditions. Some channels may operate at higher power levels than others, depending on the requirement of back-off for the transponder output power device. It may be mentioned here that the output back-off or simply the back-off of the transponder output power device is the ratio of the saturated output power to the desired output power. However, this type of SCPC system requires automatic frequency control to maintain spectrum centering for individual channels, which is usually achieved by transmitting a pilot tone in the centre of the transponder bandwidth.
Figure 6.3 shows the transmission path for an SCPC/FM/FDMA system. The diagram is

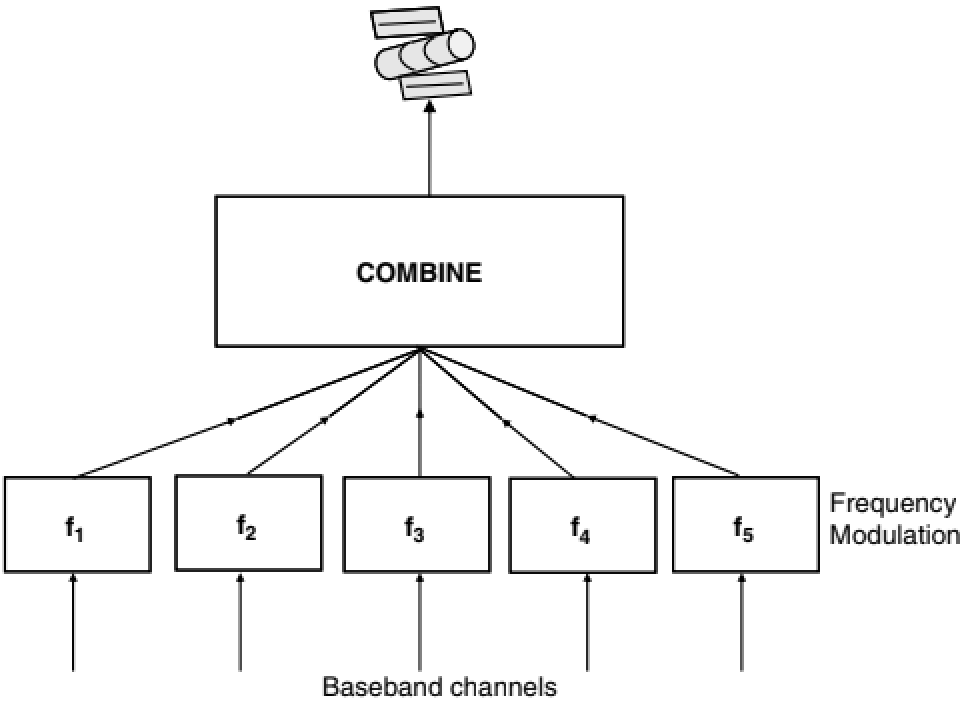
self-explanatory. Different base band signals frequency-modulate their respective allocated carriers, which are combined and then transmitted to the satellite over the uplink.

The signal-to-noise power ratio (S/N) at the output of the demodulator for the SCPC/FM/FDMA system can be computed from.

$$\frac{S}{N} = \left(\frac{C}{N}\right) \times 3B \times \left(\frac{f_d{}^2}{f_2{}^2 - f_1{}^2}\right)$$

where

C = carrier power at the receiver input (in W)
N = noise power (in W) in bandwidth B (in Hz)
B = RF bandwidth (in Hz)
f_d = test tone frequency deviation (in Hz)
f_2 = upper base band frequency (in Hz)
f_1 = lower base band frequency (in Hz)



Multiple Channels Per Carrier (MCPC) Systems

As the name suggests, in this type of multiple access arrangement, multiple signal channels are first grouped together to form a single base band signal assembly. These grouped base band signals modulate preassigned carriers which are then transmitted to the FDMA transponder. Based on the multiplexing technique used to form base band assemblies and the carrier modulation technique used for onward transmission to the satellite transponder, there are two common forms of MCPC systems in use. These are:

1. MCPC/FDM/FM/FDMA system
2. MCPC/PCM-TDM/PSK/FDMA system

Each of them is briefly described in the following paragraphs.

6.4.1 MCPC/FDM/FM/FDMA System

In this arrangement, multiple base band signals are grouped together by using frequency division multiplexing to form FDM base band signals. The FDM base band assemblies frequency

modulate pre-assigned carriers and are then transmitted to the satellite. The FDMA transponder receives multiple carriers, carries out frequency translation and then separates out individual

carriers with the help of appropriate filters. Multiple carriers are then multiplexed and transmitted back to Earth over the downlink. The receiving station extracts the channels assigned

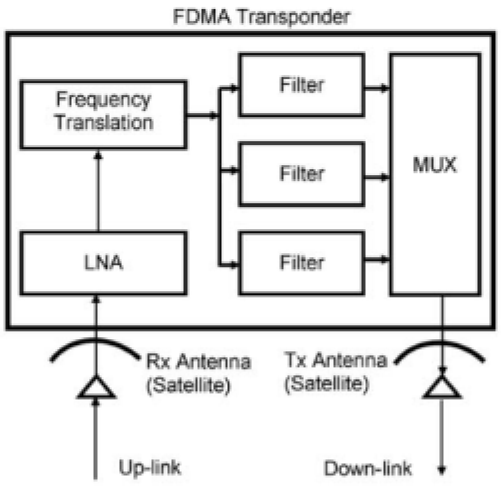
to that station. Figure 6.4 shows the typical block schematic arrangement of such a system, which is suitable only for limited access use. The channel capacity falls with an increase in the number of carriers. Larger number of carriers causes more intermodulation products, with the result that intermodulation-prone frequency ranges cannot be used for traffic.

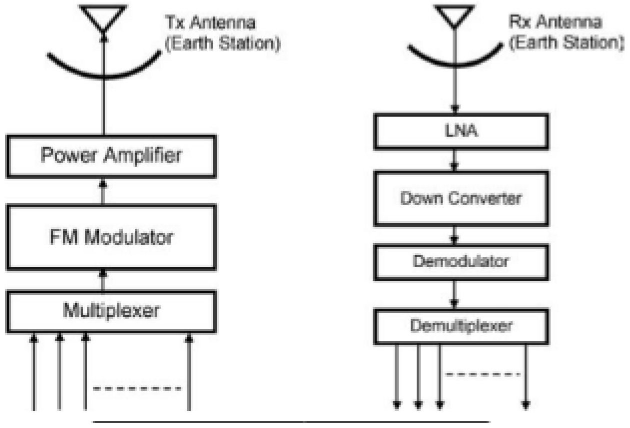
The signal-to-noise ratio at the demodulator output for such a system is given by:

$$\frac{\mathrm{S_b}}{\mathrm{N_b}} = \left(\frac{f_\mathrm{d}}{f_\mathrm{m}}\right)^2 \times \left(\frac{B}{b}\right) \times \left(\frac{C}{N}\right)$$

where

f_d = RMS (root mean square) test tone deviation (in Hz)
f_m = highest modulation frequency (in Hz)
B = bandwidth of the modulated signal (in Hz)
b = base band signal bandwidth (in Hz)
C = carrier power at the receiver input (in W)
N = noise power (= kTB) in bandwidth B (in W)





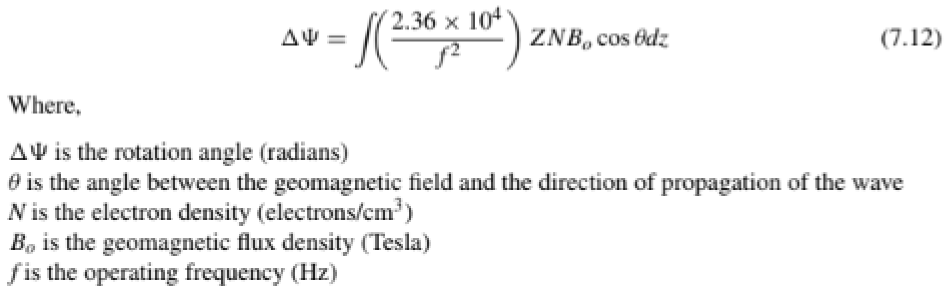
Q.10 Explain Faraday's effect & Scintillation with respect to propagation consideration.
Polarization Rotation – Faraday Effect

When an electromagnetic wave passes through a region of high electron content like the ionosphere, the plane of polarization of the wave gets rotated due to interaction of the electromagnetic wave with the Earth's magnetic field. The angle through which the plane of polarization

rotates is directly proportional to the total electron content of the ionized region and - inversely proportional to the square of the operating frequency. It also depends upon the state of the ionosphere, time of the day, solar activity, the direction of the incident wave, etc. Directions of polarization rotation are opposite for transmit and receive signals.
Due to its 1/f 2 dependence, the effect is observed to be pronounced only at frequencies below 2 GHz. The worst case polarization rotation angle may be as large as 150◦ in certain conditions at 1 GHz. Applying 1/f 2 dependence, the rotation angle may be as small as 9◦ at 4 GHz and 4◦ at 6 GHz. It would reduce to a fraction of a degree in the Ku band frequency range.

Except for a small time period during unusual atmospheric conditions caused by intense solar activity, magnetic storms, etc., the Faraday effect is more or less predictable and therefore can be compensated for by adjusting the polarization of the recieving antenna. Circular polarization is virtually unaffected by Faraday effect and therefore its impact can be minimized by using circular polarization.

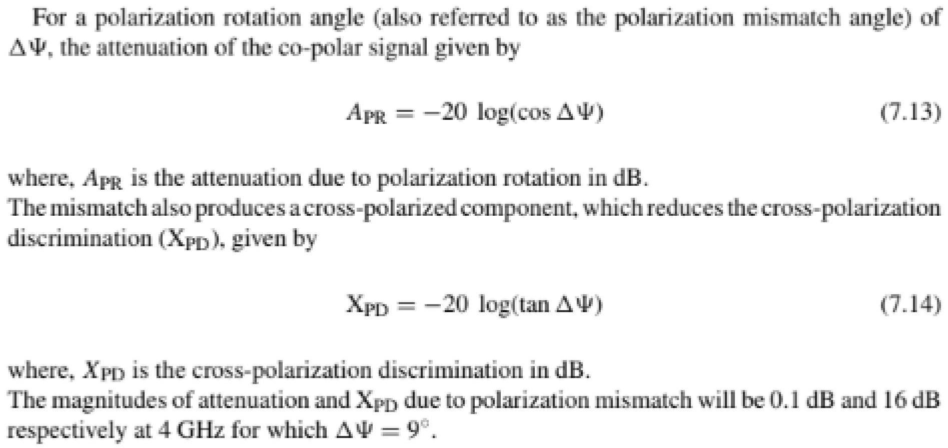
The polarization rotation angle () for a path length through the ionosphere of Z metres is given by



$$\Delta\Psi = \int\left(\frac{2.36 \times 10^4}{f^2}\right) ZNB_o \cos\theta dz \quad (7.12)$$

Where,

$\Delta\Psi$ is the rotation angle (radians)
θ is the angle between the geomagnetic field and the direction of propagation of the wave
N is the electron density (electrons/cm^3)
B_o is the geomagnetic flux density (Tesla)
f is the operating frequency (Hz)



For a polarization rotation angle (also referred to as the polarization mismatch angle) of $\Delta\Psi$, the attenuation of the co-polar signal given by

$$A_{PR} = -20 \log(\cos \Delta\Psi) \quad (7.13)$$

where, A_{PR} is the attenuation due to polarization rotation in dB.
The mismatch also produces a cross-polarized component, which reduces the cross-polarization discrimination (X_{PD}), given by

$$X_{PD} = -20 \log(\tan \Delta\Psi) \quad (7.14)$$

where, X_{PD} is the cross-polarization discrimination in dB.
The magnitudes of attenuation and X_{PD} due to polarization mismatch will be 0.1 dB and 16 dB respectively at 4 GHz for which $\Delta\Psi = 9°$.

Scintillation

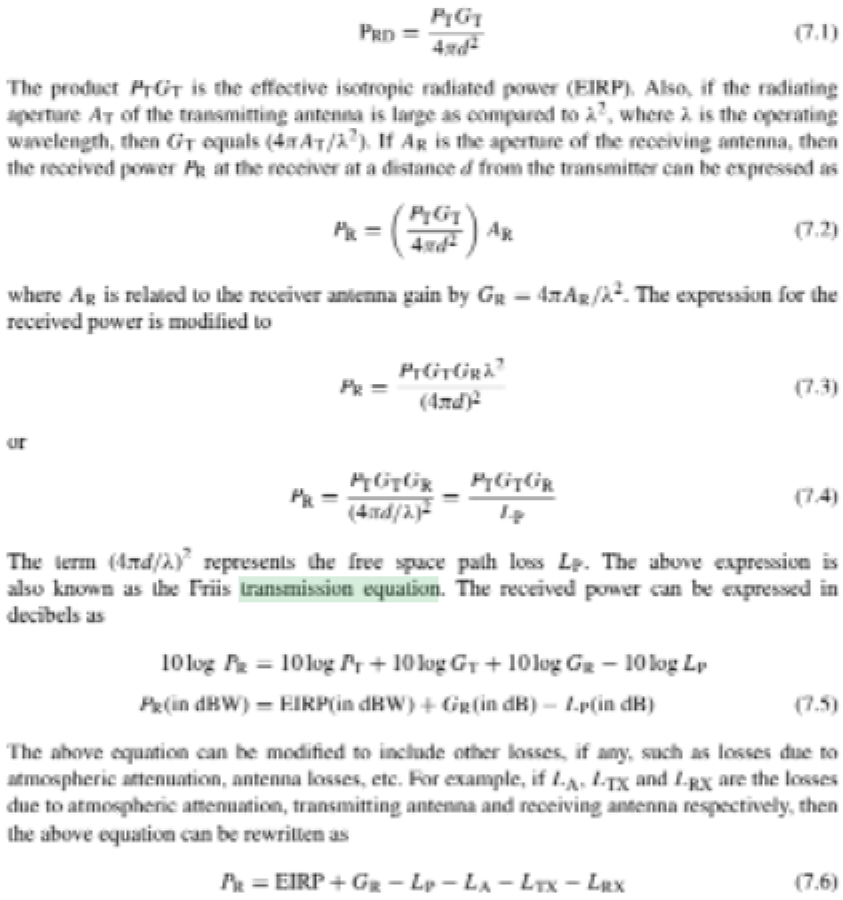
As mentioned above, scintillation is nothing but the rapid fluctuations of the signal amplitude, phase, polarization or angle-of-arrival. In the ionosphere, scintillation occurs due to small scale refractive index variations caused by local electron concentration fluctuations. The total electron concentration (total number of electrons existing in a vertical column of 1m2 area) of the ionosphere increases by two orders of magnitude during the day as compared to night due to the energy received from the sun. This rapid change in the value of total electron concentration from the daytime value to the nighttime value gives rise to irregularities in the ionosphere. It mainly occurs in the F-region of the ionosphere due to the highest electron concentration in that region.

The irregularities cause refraction resulting in rapid variations in the signal amplitude and phase, which leads to rapid signal fluctuations that are referred to as ionospheric scintillations.

As a result, the signal reaches the receiving antenna via two paths, the direct path and the refracted path, as illustrated in Figure 7.6. Multipath signals can lead to both signal enhancement as well as signal cancellation depending upon the phase relationship with which they arrive at the receiving antenna. The resultant signal is a vector addition of the direct and the refracted signal. In the extreme case, when the strength of the refracted signal is comparable to that of the direct signal, cancellation can occur when the relative phase difference between the two is 180◦. On the other hand, an instantaneous recombination of the two signals in phase can lead to signal amplification up to 6 dB.

The scintillation effect is inversely proportional to the square of the operating frequency and is predominant at lower microwave frequencies, typically below 4 GHz. Scintillation, however, increases during periods of high solar activity and other extreme conditions such as the occurrence of magnetic storms. Scintillation has also been observed to be maximum in the region that is ±25◦ around the equator. Under such adverse conditions, scintillation can cause problems at 6/4 GHz band too. At the Ku band and beyond, however, the effect is negligible. Also, unlike scintillation caused by the troposphere, ionospheric scintillation is independent of the elevation angle.

Q11. Derive Satellite’s transmission equation.



$$P_{RD} = \frac{P_T G_T}{4\pi d^2} \qquad (7.1)$$

The product $P_T G_T$ is the effective isotropic radiated power (EIRP). Also, if the radiating aperture A_T of the transmitting antenna is large as compared to λ^2, where λ is the operating wavelength, then G_T equals $(4\pi A_T/\lambda^2)$. If A_R is the aperture of the receiving antenna, then the received power P_R at the receiver at a distance d from the transmitter can be expressed as

$$P_R = \left(\frac{P_T G_T}{4\pi d^2}\right) A_R \qquad (7.2)$$

where A_R is related to the receiver antenna gain by $G_R = 4\pi A_R/\lambda^2$. The expression for the received power is modified to

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2} \qquad (7.3)$$

or

$$P_R = \frac{P_T G_T G_R}{(4\pi d/\lambda)^2} = \frac{P_T G_T G_R}{L_P} \qquad (7.4)$$

The term $(4\pi d/\lambda)^2$ represents the free space path loss L_P. The above expression is also known as the Friis transmission equation. The received power can be expressed in decibels as

$$\begin{aligned} 10\log P_R &= 10\log P_T + 10\log G_T + 10\log G_R - 10\log L_P \\ P_R(\text{in dBW}) &= \text{EIRP(in dBW)} + G_R(\text{in dB}) - L_P(\text{in dB}) \qquad (7.5) \end{aligned}$$

The above equation can be modified to include other losses, if any, such as losses due to atmospheric attenuation, antenna losses, etc. For example, if L_A, L_{TX} and L_{RX} are the losses due to atmospheric attenuation, transmitting antenna and receiving antenna respectively, then the above equation can be rewritten as

$$P_R = \text{EIRP} + G_R - L_P - L_A - L_{TX} - L_{RX} \qquad (7.6)$$

Q12 . Explain the weather forecasting application.

Weather Forecasting – An Overview

Weather forecasting, as people call it, is both a science as well as an art. It is about predicting the weather, which can be both long term as well as short term. Generally, short term predictions are based on current observations whereas long term predictions are made after understanding the weather patterns, on the basis of observations made over a period of several years. Weather watching began as early as the 17th century, when scientists used barometers to measure pressure. Weather forecasting as a science matured in the early 1900s when meteorological kites carrying instruments to measure the temperature, pressure and the relative humidity were flown. After that came the era of meteorological aircraft and balloons carrying instruments for weather forecasting.

The year 1959 marked a significant beginning in the field of satellite weather forecasting, when for the first time a meteorological instrument was carried on board a satellite, Vanguard-2, which was launched on 17 February 1959. The satellite was developed by National Aeronautics and Space Administration (NASA) of USA. Unfortunately, the images taken by the instrument could not be used as the satellite was destroyed while on mission. The first meteorological

instrument that was successfully used on board a satellite was the Suomi radiometer, which was flown on NASA's Explorer-7 satellite, launched on 13 October 1959. All these satellites were not meteorological satellites; they just carried one meteorological instrument.
The first satellite completely dedicated to weather forecasting was also developed by NASA. The satellite was named TIROS-1 (television and infrared observation satellite) and was launched on 1 April 1960. It carried two vidicon cameras, one having low resolution and the other with a higher resolution. Both these cameras were adaptations of standard television cameras. Though the satellite was operational for only 78 days, it demonstrated the utility of using satellites for weather forecasting applications. The first picture was transmitted by the TIROS-1 satellite on 1 April 1960. It showed the cloud layers covering the Earth [Figure 11.1 (a)]. The first useful transmitted weather pictures were that of the Gulf of St Lawrence [Figure 11.1 (b)]. The images, taken during 1–3 April 1960, showed the changing state of the pack ice over the Gulf of St Lawrence and the St Lawrence River.
Weather forecasting satellites are referred to as the third eye of meteorologists, as the images provided by these satellites are one of the most useful sources of data for them. Satellites measure the conditions of the atmosphere using onboard instruments. The data is then transmitted to the collecting centres where it is processed and analysed for varied applications. Weather satellites offer some potential advantages over the conventional methods as they can cover the whole world, whereas the conventional weather networks cover only about 20 % of the globe. Satellites are essential in predicting the weather of any place irrespective of its location. They are indispensable in forecasting the weather of inaccessible regions of the world, like oceans, where other forms of conventional data are sparse. As a matter of fact, forecasters can predict an impending weather phenomenon using satellites 24 to 48 hours in advance. These forecasts are accurate in more than 90 cases out of 100.
Satellites offer high temporal resolution (15 minutes to 1 hour between images) as compared to other forecasting techniques. However, their spatial resolution is less, of the order of 1 to 10 km. Moreover, satellites are not forecasting devices. They merely observe the atmosphere from above. This implies that the data collected by satellites needs to be further processed, so that it can be converted into something meaningful. Satellites have poor vertical resolution as it is difficult to assign features to particular levels in the atmosphere and low-level features are often hidden.

Q.13 Discuss advantages and disadvantages of satellite over terrestrial network.

Satellite versus Terrestrial Networks

Satellites, initially conceived to provide support services to terrestrial communication networks, have made a great deal of progress in the last fifty years. Satellites have established themselves as a pioneering element of communication networks. However, with the advances made in the field of terrestrial communication network technology, like the advent of fibre optic technology, satellites are facing tough competition from the terrestrial networks. When compared with each other, both satellites as well as terrestrial networks have certain advantages and disadvantages w.r.t. each other. Some of the important ones are outlined below:

Advantages of Satellites Over Terrestrial Networks

Satellites offer certain advantages over terrestrial networks. Some of the advantages are as follows:

1. Broadcast property – wide coverage area. Satellites, by virtue of their very nature, are an ideal means of transmitting information over vast geographical areas. This broadcasting property of satellites is fully exploited in point-to-multipoint networks and multipoint interactive networks. The broadcasting property is one of the major plus points of satellites over terrestrial networks, which are not so well suited for broadcasting applications.
2. Wide bandwidth – high transmission speeds and large transmission capacity. Over the years, satellites have offered greater transmission bandwidths and hence more transmission capacity and speeds as compared to terrestrial networks. However, with the introduction of fibre optic cables into terrestrial cable networks, they are now capable of providing transmission capabilities comparable to those of satellites.
3. Geographical flexibility – independence of location. Unlike terrestrial networks, satellite networks are not restricted to any particular configuration. Within their coverage area, satellite networks offer an infinite choice of routes and hence they can reach remote locations having rudimentary or nonexistent terrestrial networks. This feature of satellite networks makes them particularly attractive to Third World countries and countries having difficult geographical terrains and unevenly distributed populations.
4. Easy installation of ground stations. Once the satellite has been launched, installation and maintenance of satellite Earth stations is much simpler than establishing a terrestrial infrastructure, which requires an extensive ground construction plan. This is particularly helpful in setting up temporary services. Moreover, one fault on the terrestrial communication link can put the entire link out of service, which is not the case with satellite networks.
5. Uniform service characteristics. Satellites provide a more or less uniform service within their coverage area, better known as a ‘footprint’. This overcomes some of the problems related to the fragmentation of service that result from connecting network segments from various terrestrial telecommunication operators.

6. Immunity to natural disaster. Satellites are more immune to natural disaster such as floods, earthquakes, storms, etc., as compared to Earth-based terrestrial networks.

7. Independence from terrestrial infrastructure. Satellites can render services directly to the users, without requiring a terrestrial interface. Direct-to-home television services, mobile satellite services and certain configurations of VSAT networks are examples of such services. In general, C band satellites usually require terrestrial interfaces, whereas Ku and Ka band systems need little or no terrestrial links.

8. Cost aspects – low cost per added site and distance insensitive costs. Satellites do not require a complex infrastructure at the ground level; hence the cost of constructing a receiving station is quite modest – more so in case of DTH and mobile receivers. Also, the cost of satellite services is independent of the length of the transmission route, unlike the terrestrial networks where the cost of building and maintaining a communication facility is directly proportional to the distances involved.

Hence, by virtue of their broadcast nature coupled with uniform services offered within the coverage area and easy installation of ground stations, satellites remain the most flexible means for providing links between all points on the globe with a minimum of terrestrial facilities.

Disadvantages of Satellites with Respect to Terrestrial Networks

For certain applications, satellites are at disadvantage with respect to terrestrial networks:

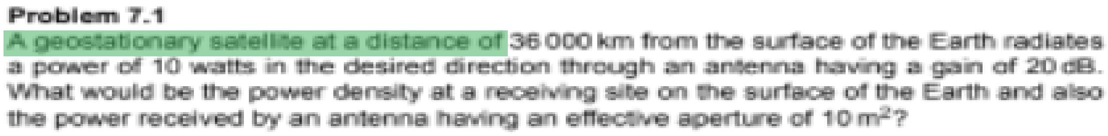
1. Transmission delay. Transmission delays of the order of a quarter of a second are involved in transmission of signals from one Earth station to another via a geostationary satellite. It may be mentioned here that for satellite-based data communication services, the data communication protocols that require acknowledgement feedback further add to the delay. Hence, GEO satellites are not suited for certain applications like interactive media, which require small transmission delays. Large transmission delays also have an adverse impact on the quality of voice communication and data transmission at high data rates.

2. Echo effects. The echo effect, in which the speaker hears his or her own voice, is more predominant in satellite-based telephone networks as compared to terrestrial networks. This is due to larger transmission delays involved in the case of satellites. However, with the development of new echo suppressors, satisfactory link quality has been provided in the case of single-hop GEO satellite networks. However, for double-hop GEO networks, the problem of echo still exists.

3. Launch cost of a satellite. Although the cost of a satellite ground station is less than that of terrestrial networks and the cost of satellite services are independent of the distances involved, the cost of launching a satellite is huge.

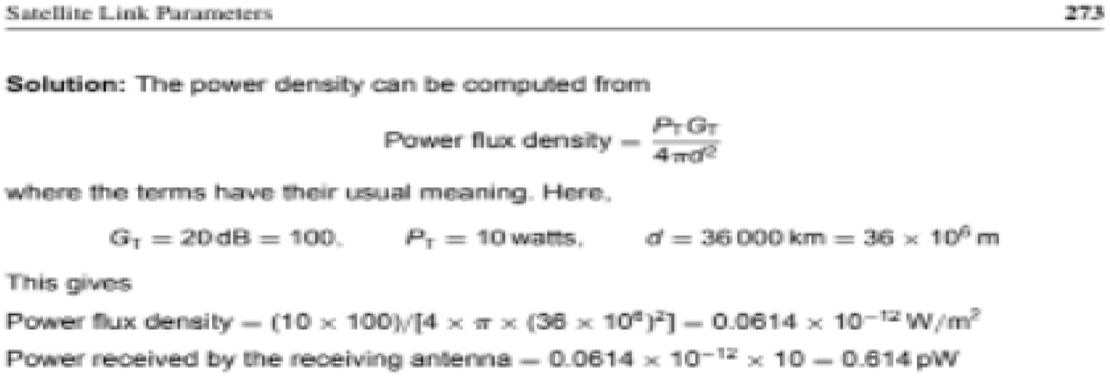
To conclude, although satellites have an edge over terrestrial networks in terms of quality, connectivity and reliability of services offered, the problem they face is that the terrestrial networks already exist and transferring the service over to a satellite network becomes a complex and difficult task. Moreover, due to improvements in the terrestrial network technology, satellites are facing tough competition from terrestrial networks. In fact, satellites correspond to only a small part of communications as a whole, around 2 %. Current trends in the field of telecommunication favour space systems that complement terrestrial networks rather than maintaining their independence from them.

Q.14



Problem 7.1

A geostationary satellite at a distance of 36 000 km from the surface of the Earth radiates a power of 10 watts in the desired direction through an antenna having a gain of 20 dB. What would be the power density at a receiving site on the surface of the Earth and also the power received by an antenna having an effective aperture of 10 m^2?



Satellite Link Parameters 273

Solution: The power density can be computed from

$$\text{Power flux density} = \frac{P_T G_T}{4\pi d^2}$$

where the terms have their usual meaning. Here,

$$G_T = 20\,\text{dB} = 100, \qquad P_T = 10\ \text{watts}, \qquad d = 36\,000\ \text{km} = 36 \times 10^6\ \text{m}$$

This gives

Power flux density $= (10 \times 100)/[4 \times \pi \times (36 \times 10^6)^2] = 0.0614 \times 10^{-12}\ \text{W/m}^2$

Power received by the receiving antenna $= 0.0614 \times 10^{-12} \times 10 = 0.614$ pW

Q.15 Explain the working principle of GPS.

Working Principle of the GPS

12.3.1 Principle of Operation

The basic principle of operation of the GPS is that the location of any point can be determined if its distance is known from four objects or points with known positions. Theoretically, if the distance of a point is known from one object, then it lies anywhere on a sphere with the

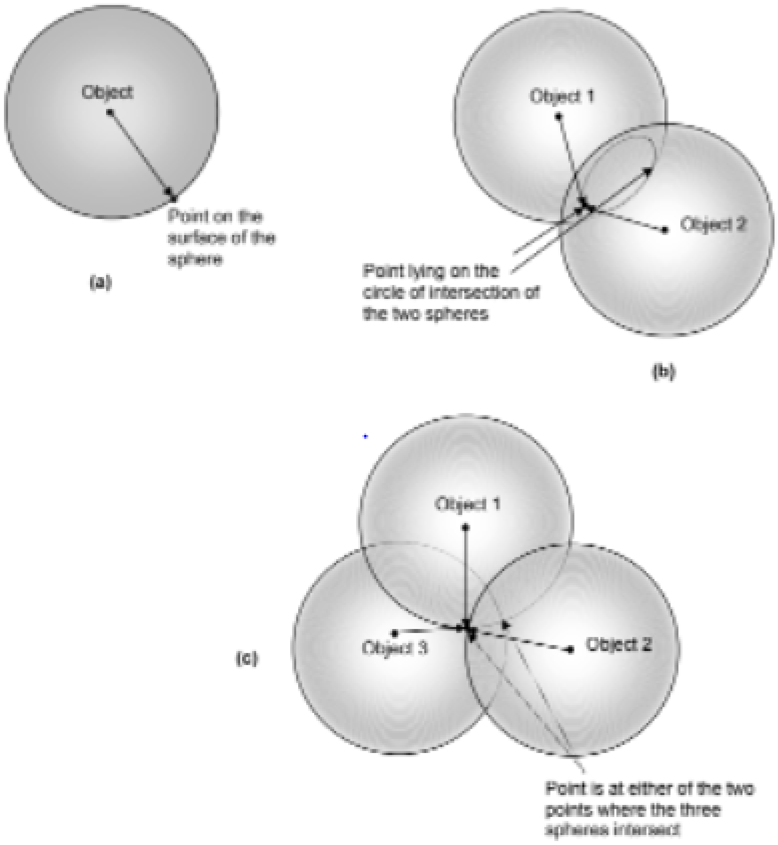


Figure 12.15 Determination of the position of any point

object as the centre having a radius equal to the distance between the point and the object [Figure 12.15 (a)]. If the distance of the point is known from two objects, then it lies on the circle formed by the intersection of two such spheres [Figure 12.15 (b)]. The distance from the third object helps in knowing that the point is located at any of the two positions where the three spheres intersect [Figure 12.15 (c)]. The information from the fourth object reveals the exact position where it is located i.e., at the point where the four spheres intersect.

In the GPS, the position of any receiver is determined by calculating its distance from four satellites. This distance is referred to as the ‘Pseudorange’. (The details of calculating the pseudorange are covered later in the chapter.) The information from three satellites is sufficient for calculating the longitude and the latitude positions; however, information from the fourth satellite is necessary for altitude calculations. Hence, if the receiver is located on Earth, then its position can be determined on the basis of information of its distance from three satellites. For air-borne receivers the distance from the fourth satellite is also needed. In any case, GPS receivers calculate their position on the basis of information received from four satellites, as this helps to improve accuracy and provide precise altitude information. The GPS is also a source of accurate time, time interval and frequency information anywhere in the world with unprecedented precision.

The GPS uses a system of coordinates called WGS-84, which stands for World Geodetic System 1984. It produces maps having a common reference frame for latitude and longitude lines. The system uses time reference from the US Naval Observatory in Washington DC in order to synchronize all timing elements of the system.

Q.16 Write a short note on 1) Visibl image 2) IR image

1) **Visible Image** -

Satellites measure the reflected or scattered sunlight in the wavelength region of 0.28 to 3.0 m. The most commonly used band here is the visible band (0.4 to 0.9 m). Visible images represent the amount of sunlight being reflected back into space by clouds or the Earth's surface in the visible band. These images are mainly used in the identification of clouds. Mostly, weather satellites detect the amount of radiation without breaking it down to individual colours. So these

Images from Weather Forecasting Satellites 475

images are effectively black and white. The intensity of the image depends on the reflectivity (referred to as albedo) of the underlying surface or clouds

Different shades of grey indicate different levels of reflectivity. The most reflective surfaces appear in white tones while the least reflective surfaces appear in shades of dark grey or black. In general, clouds have a higher reflectivity as compared to the Earth's surface and hence they appear as bright (white) against the darker background of the Earth's surface. Visible images give information on the shape, size, texture, depth and movement of the clouds. Brighter clouds have larger optical depth, higher water or ice content and smaller average cloud droplet size than darker looking clouds. Visible band is also used for pollution and haze detection, snow and ice monitoring and storm identification. Almost all satellites have instruments operating in the visible band. Examples include the GOES (the GOES imager has one channel in the visible band of 0.52 to 0.72 m and the GOES sounder also operates in the visible band), Meteosat [the SEVIRI (spinning enhanced visible and infrared imager) on the MSG-2] and the ATN [AVHRR (advanced very high resolution radiometer) has one channel in the 0.58 to 0.68 m band] satellites.

Other than the visible band, weather satellites also measure the reflected solar light in the near-IR, shortwave-IR and UV bands The near-IR band provides useful information for water, vegetation and agricultural crops. The shortwave IR band is used for identification of fog at night and for discrimination between water clouds and snow or ice clouds during daytime. Measurements of the amount and vertical distribution of the atmospheric ozone are carried out in the UV band.

Figure 11.2 shows a visible image taken by the GOES satellite. The continental outlines have been added to the image. The bright portions of the image indicate the presence of clouds. It can be inferred from the image that about half of the image is covered by clouds. The other half, which is not covered by clouds, is the Earth's surface. From the visible images, it can also be identified as to whether it is a land or water area.

Visible images are very frequently used for weather forecasting. Sometimes they provide information that may not appear in IR images. Two objects having the same temperatures can be discriminated using a visible image but not from an IR image. For instance, if the temperature of fog is the same as that of land, then they will appear similar on the IR image, but will appear different on the visible image as they have different albedo. However, one of the main limitations of using visible images is that they are available only during the daytime. It is also difficult to distinguish between low, middle and high level clouds in a visible satellite image, since they can all have a similar albedo. Similarly, it is difficult to distinguish between clouds and ground covered with snow.

2) IR Images

Another common type of satellite imagery depicts the radiation emitted by the clouds and the Earth’s surface in the IR band (10 to 12 m). IR images provide information on the temperature of the underlying Earth’s surface or cloud cover. This information is used in providing temperature forecasts, in locating areas of frost and freezes and in determining the distribution of sea surface temperatures offshore. Since the temperature normally decreases with height, IR radiation with the lowest intensity is emitted from clouds farthest from the Earth’s surface. The Earth’s surface emits IR radiation with the highest intensity. Hence, in IR images clouds appear dark as compared to Earth. Moreover, high lying clouds are darker than low lying clouds. High clouds indicate a strong convective storm activity and hence IR images can be used to predict storms. One of the potential advantages of IR imagery is that it is available 24 hours a day, as the temperatures can be measured regardless of whether it is day or night. However, IR images generally cannot distinguish between two objects having the same temperature. For instance, using IR images it may not be possible to distinguish between thin and thick clouds present at the same altitude, especially if they are present at higher altitudes. Also, IR images have poorer resolution than visible images. This is so because the emitted IR radiation is weaker in intensity than the visible radiation. Therefore, the payload on the satellite has to sense radiation from a broader area so as to be able to detect it. Examples of satellite sensors operating in the IR band include the GOES imager and AVHRR sensor on the ATN satellites.

IR images can be grey-scale images or can be colour-enhanced images with different colours for features having different temperatures. Grey scale images are black and white images where darker shades correspond to lower temperatures. The normal convention is to reverse the appearance of these images so as to make them consistent with the visible images. Hence in the reversed images, lighter shades will correspond to lower temperatures, so the clouds appear as white against the darker background of the Earth’s surface. Figures 11.3 (a) and (b) show the IR images taken by the GOES satellite, both in the raw and the normal conventional formats respectively. The portions that appear as bright in the raw image are the warmest areas. They are the Mexican deserts and the oceans. Dark patches in the raw image correspond to the clouds. In the conventional IR image shown in Figure 11.3(b), the pattern is reversed. Here, the Mexican deserts and the oceans appear dark whereas the clouds appear bright. In coloured IR images, features having the same temperature are assigned a particular colour. This is done in order to extract more information from the images. These images are discussed in detail in Section 11.6 on image processing and enhancement.