SATELLITE:

A **satellite** is an object that revolves around another object. For example, earth is a satellite of The Sun, and moon is a satellite of earth . **[or]**

A satellite is an object in space that orbits or circles around a bigger object.

There are two kinds of satellites: natural (such as the moon orbiting the Earth) or artificial (such as the International Space Station orbiting the Earth).

COMMUNICATION:

Communication refers to the exchange or sharing of information between sender and receiver through any medium or channel.

SATELLITE COMMUNICATION:

- If the communication takes place between any two earth stations through a satellite, then it is called as satellite communication.
- In this communication, electromagnetic waves are used as carrier signals.
- These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

Satellites are specifically made for telecommunication purpose. They are used for mobile applications such as communication to ships, vehicles, planes, hand -held terminals and for TV and radio broadcasting.

They are responsible for providing these services to an assigned region (area) on the earth. The power and bandwidth of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations.

A satellite works most efficiently when the transmissions are focused with a desired area.

When the area is focused, then the emissions don " t go outside that designated area and thus minimizing the interference to the other systems. This leads more efficient spectrum usage.

Satellites antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape).

Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.

The earth station should be in a position to control the satellite if it drifts from its orbit it is subjected to any kind of drag from the external forces.

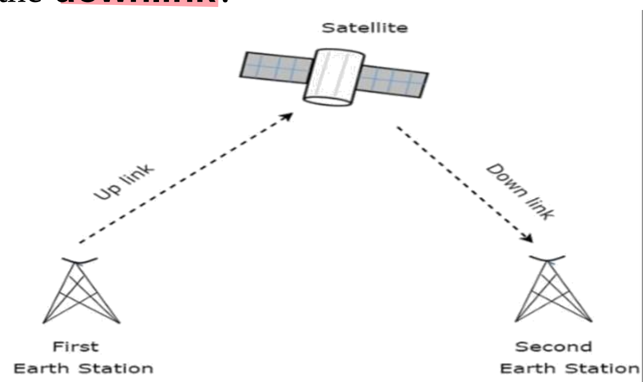
Applications of Satellites:

- ❖ Weather Forecasting
- ❖ Radio and TV Broadcast
- ❖ Military Satellites
- ❖ Navigation Satellites
- ❖ Global Telephone
- ❖ Connecting Remote Area

Global Mobile Communication

BASICS OF SATELLITE COMUNICATION:

- The process of satellite communication begins at an **earth station**.
- Earth stations send information to satellites in the form of high frequency (GHz range) signals.
- The satellites **receive** and **retransmit** the signals back to earth where they are received by other earth stations in the coverage area of the satellite.
- The transmission system from the earth station to the satellite through a channel is called the **uplink**.
- The system from the satellite to the earth station through the channel is called the **downlink**.



NEED FOR SATELLITE COMMUNICATION:

- **Ground wave propagation – Ground wave propagation is suitable for frequencies up to**

  30MHz. This method of communication makes use of the troposphere conditions of the earth.

- **Sky wave propagation – The suitable bandwidth for this type of communication is** broadly between 30–40 MHz and it makes use of the ionosphere properties of the earth.

- **Satellite communication**- It overcomes these limitations. In this method, satellites provide communication for long distances, which is well beyond the line of sight.

ADVANTAGES OF SATELLITE COMMUNICATION:

- The Coverage area is very high than that of terrestrial systems.
- The transmission cost is independent of the coverage area.
- Higher bandwidths are possible

DISADVANTAGES OF SATELITE COMUNICATION:

- Launching satellites into orbits is a costly process.
- The bandwidths are gradually used up.
- High propagation delay for satellite systems than the conventional terrestrial systems.

APPLICATION OF SATELLITE COMMUNICATION:

- Military applications and navigations
- Remote sensing applications.
- Weather condition monitoring & Forecasting
- TV broadcasting such as Direct To Home (DTH)
- Internet applications such as providing Internet connection for data transfer, GPS applications, Internet surfing, etc.

TYPES OF SATELLITE:

- There are two different types of satellites **– natural and man-made.**

NATURAL SATELLITE	MAN-MADE SATELLITE
The natural satellites are the Earth and Moon and The Earth rotates around the Sun and the Moon rotates around the Earth.	A man-made satellite is a machine that is launched into space and orbits around a body in space.

- Based on the usage purpose the artificial satellite is classified into two types - **Geostationary Satellites** and **Polar Satellites.**

GEO-STATIONARY SATELLITE:

- A satellite that appears to be at a stationary from any point in the sky to an observe on earth is called a geostationary satellite.
- The revolution period of earth and the satellite is same i.e, 24hrs.
- This satellite is located at 36,000KM above the surface of the earth.
- USES:

- ➢ Communication of TV signals and Radio signals.
- ➢ To study the atmospheric changes or weather changes.
- ➢ To find the mineral deposits on the surface on the earth.

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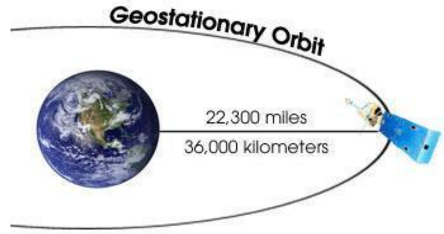


POLAR SATELLITE:

- Polar satellites revolve around the earth in a north-south direction around the earth as opposed to east-west like the geostationary satellites.
- **USES:** They are used in weather applications where predicting weather and climate-based disasters can be done in a short time. They are also used as relay stations.

COMMON TYPES OF SATELLITES:

1. Military and civilian Earth observation satellites.
2. Communications satellites.
3. Navigation satellites.
4. Weather satellites.
5. Space telescopes.
6. Space stations and human spacecraft in orbit are also satellites.

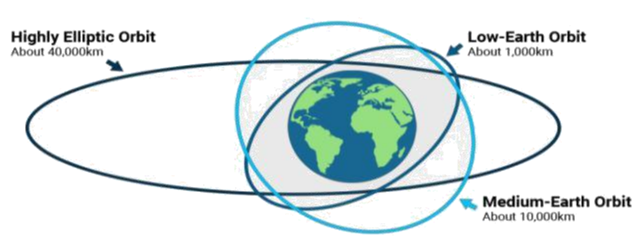
TYPES OF SATELLITE OBITS:

- Low Earth orbit (LEO)
- Medium Earth orbit (MEO)
- Geostationary orbit (GEO)

LOW EARTH ORBIT(LEO):

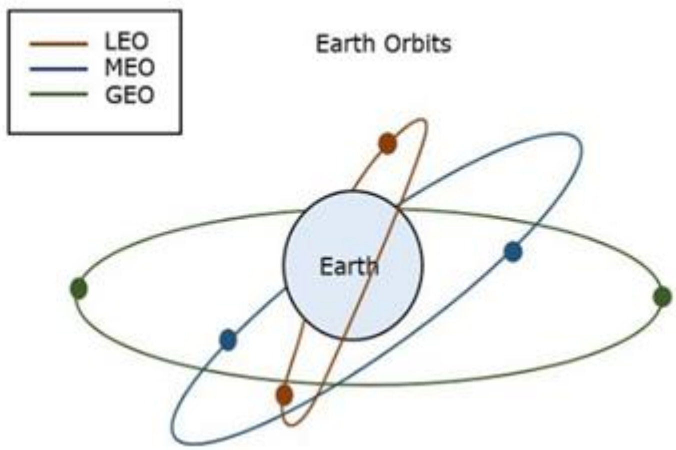
- A low Earth orbit (LEO) is, as the name suggests, an orbit that is relatively close to

  Earth9s surface.
- It is normally at an altitude of less than 1000 km but could be as low as 160 km above Earth.



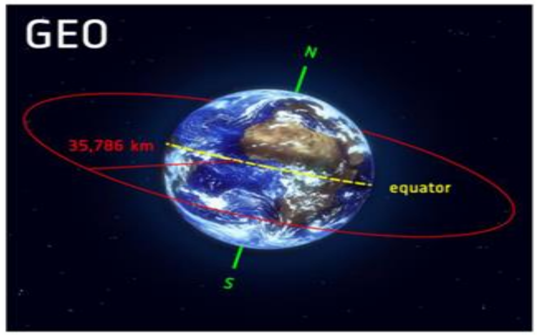
MEDIUM EARTH ORBIT (MEO):

- Medium Earth orbit comprises a wide range of orbits anywhere between LEO and GEO.
- It is similar to LEO in that it also does not need to take specific paths around Earth, and it is used by a variety of satellites with many different applications.

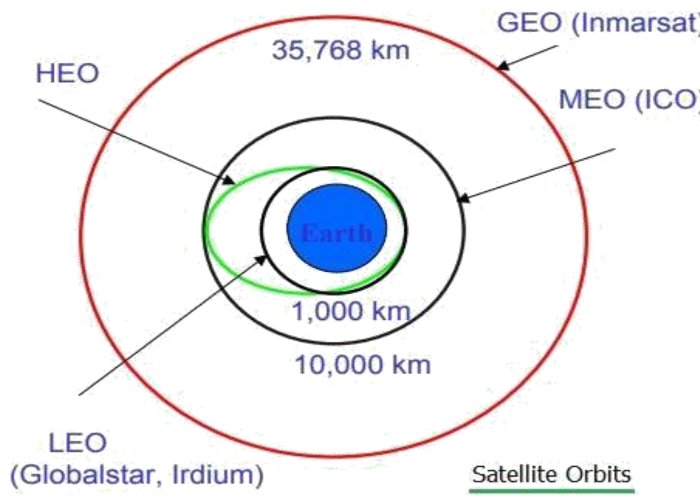


GEOSTATIONARY ORBIT(GEO):

- Satellites in geostationary orbit (GEO) circle Earth above the equator from west to east **following Earth9s rotation –** taking 23 hours 56 minutes and 4 seconds **–** by travelling at exactly the same rate as Earth.
- **This makes satellites in GEO appear to be 8stationary9 over a fixed position.**
- **In order to perfectly match Earth9s rotation, the speed of GEO satellites should be about**
  3 km per second at an altitude of 35 786 km.
- This is much farther fr**om Earth9s surface** compared to many satellites.



SATELITE ORBITS:



ORBIT MECHANICS:

1. Line of Apsides
2. Ascending Node
3. Descending Node
4. Line of Nodes
5. Inclination
6. Prograde Orbit
7. Retrograde Orbit
8. Semi major axis
9. Eccentricity

1. When satellite is in elliptical orbit, the center of earth is one of the focal points of ellipse. In this type of satellite orbit, distance of satellite from earth varies based on its position.

- Two points are very important viz. highest point and lowest point above earth.

A) Apogee- The Point farthest from the earth.

B) Perigee- The Point closest to the earth.

2.ASCENDING NODE:

Line joining perigee and apogee through center of the Earth.

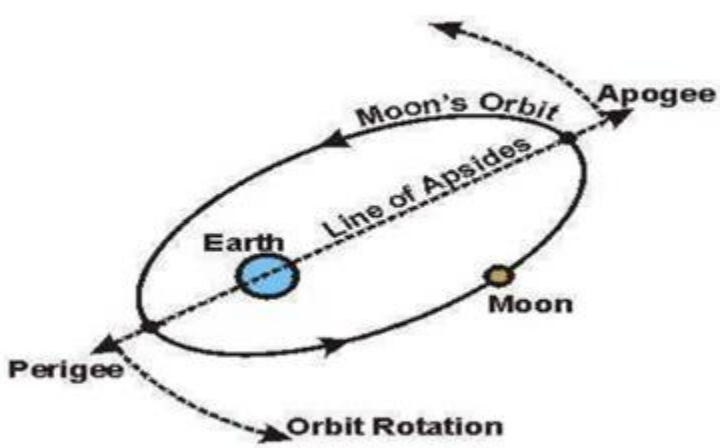
- It is the major axis of the orbit.
- One-half of **this line9s length is the semi-major axis equivalents to satellite9s mean** distance from the Earth.

3.ASCENDING NODE:

The point where the orbit crosses the equatorial plane going from north to south.

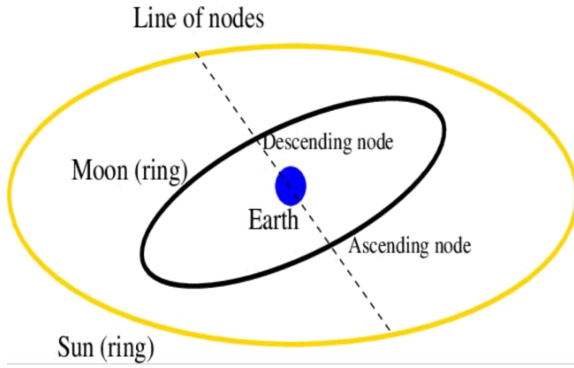
4.DESCENDING NODE:

The point where the orbit crosses the equatorial plane going from south to north.



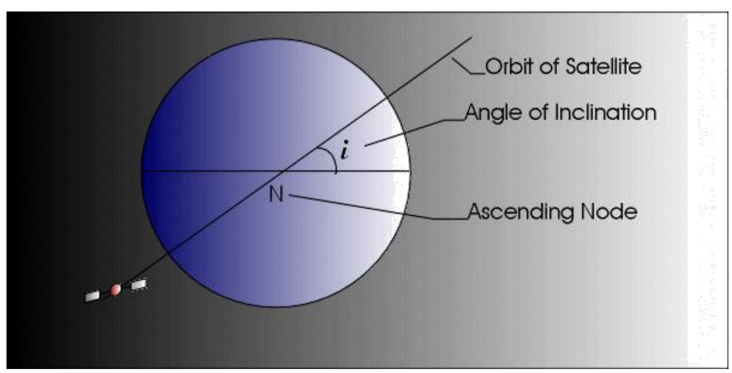
5.LINE OF NODES:

The line joining the ascending and descending nodes through the center of Earth.



6.INCLINATION:

- The **angle between the orbital plane and the Earth's** equatorial plane.
- It's measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as i.



7.PROGRADE ORBIT:

An orbit in which satellite moves in the same direction as the **Earth9s** rotation. Its inclination is always between 0^0 to 90^0. **Many satellites follow this path as Earth9s**
velocity makes it easier to lunch these satellites.

8.RETROGRADE ORBIT:

An orbit in which satellite moves in the same direction counter to the **Earth9s rotation.**

9.SEMI MAJOR AXIS:

- The length of Semi-major axis (a) **defines the size of satellite9s orbit.**
- It is half of the major axis.

- This runs from the center through a focus to the edge of the ellipse.
- So, it is the radius of an orbit at the orbit's two most distant points.

10.ECCENTRICITY:

- The value of **Eccentricity (e) fixes the shape of satellite9s orbit. This parameter indicates the deviation of the orbit9s shape from a perfect circle.**
- If the lengths of semi major axis and semi minor axis of an elliptical orbit are a & b, then the mathematical expression for **eccentricity (e)** will be
- The value of eccentricity of a circular orbit is **zero**, since both a & b are equal. Whereas,

  the value of eccentricity of an elliptical orbit lies between zero and one.

1.2 Kepler's laws

1.2.1 Kepler's law Introduction

Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun.

Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The more massive of the two bodies is referred to as the *primary,* the other, the *secondary* or *satellite*.

1.2.2 Kepler's First Law

Kepler's first law states that the path followed by a satellite around the primary will be an ellipse. An ellipse hast Two focal points shown as $F1$ and $F2$in Fig. 2.1. The center of mass of the two-body system, termed the *bary center,* is always center of the foci.

The semi major axis of the ellipse is denoted by a, and the semi minor axis, by b. The eccentricity e is given by

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

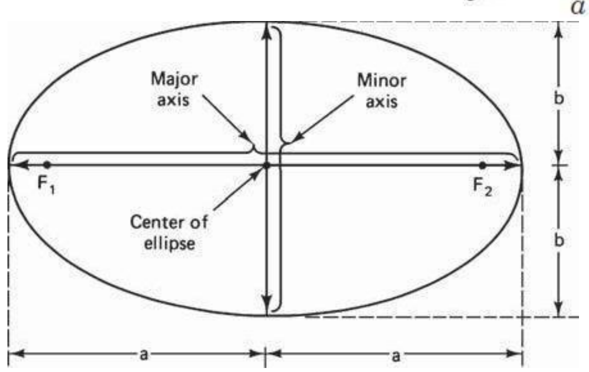


Figure 1.1 The foci $F1$ and $F2$, the semi major axis a, and the semi minor axis b of an ellipse.

1.2.3 Kepler's Second Law

Kepler's second law states that, for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter. Referring to Fig. 2.2, assuming the satellite travels distances $S1$ and $S2$ meters in 1 s, then the areas $A1$ and $A2$ will be equal. The average velocity in each case is $S1$ and $S2$ m/s, and because of the equal area law, it follows that the velocity at $S2$ is less than that at $S1$.

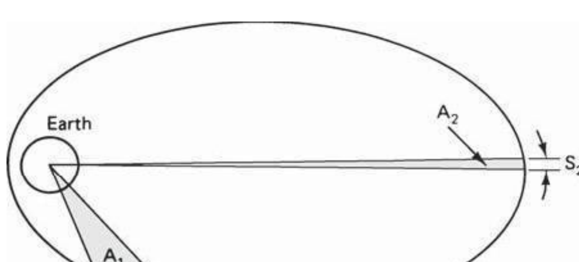


Figure 1.2 Kepler's second law. The areas $A1$and $A2$swept out in unit time are equal.

1.2.4 Kepler's Third Law

Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance is equal to the semi major axis a.

1.3. Newton's law:

1.3.1 Newton's first law

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This law is often called "the law of inertia".

1.3.2 Newton's second law

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

1.3.3 Newton's first law

For every action there is an equal and opposite re-action. This means that for every force there is a reaction force that is equal in size, but opposite in direction. That is to say that whenever an object pushes another object it gets pushed back in the opposite direction equally hard.

1.4. orbital parameters

Apogee: A point for a satellite farthest from the Earth. It is denoted as **ha.**

***Perigee*:** A point for a satellite closest from the Earth. It is denoted as **hp.**

Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line‟s length is the semi-major axis equivalents to satellite‟s mean distance from the Earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from north to south.

Descending Node: The point where the orbit crosses the equatorial plane going from south to north.

Inclination: the angle between the orbital plane and the Earth"s equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as **i.**

Line of Nodes: the line joining the ascending and descending nodes through the centre of Earth.

Prograde Orbit: an orbit in which satellite moves in the same direction as the Earth"s rotation. Its inclination is always between 00 to 900. Many satellites follow this path as Earth"s velocity makes it easier to lunch these satellites.

Retrograde Orbit: an orbit in which satellite moves in the same direction counter to the Earth"s rotation.

Argument of Perigee: An angle from the point of perigee measure in the orbital plane at the Earth"s centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is used.For absolute measurement, a fixed reference point in space is required.

It could also be defined as "*right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object*".

Mean anamoly: It gives the average value to the angular position of the satellite with reference to the perigee.

True anamoly: It is perigee to the satellite"s position, the angle from point of measure at the Earth"s centre.

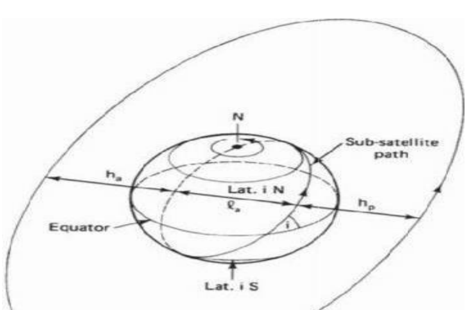


Figure1.2 Apogee height *ha*, perigee height *hp*, and inclination *i*. *La*is the line of apsides.

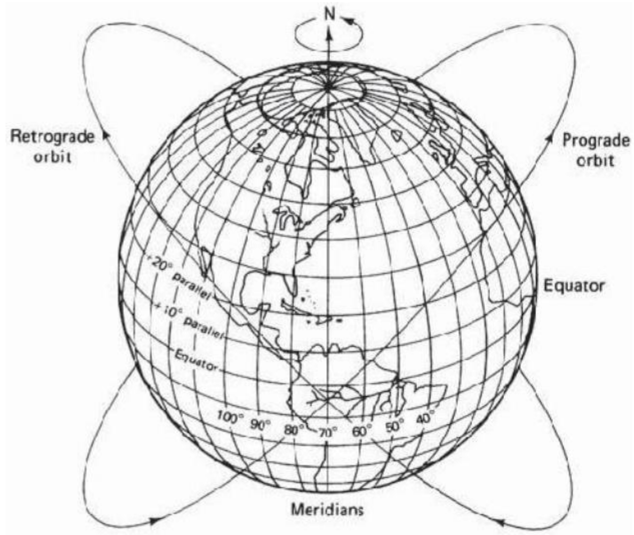


Figure 1.3(a) Prograde and retrograde orbits.

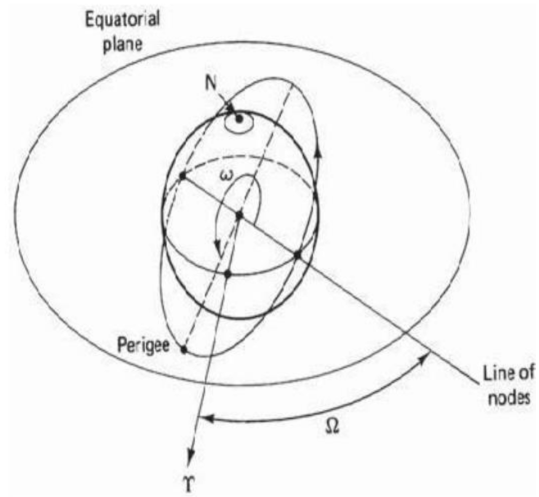


Figure.1.4 The argument of perigee w & right ascension of the ascending node Ω.

1.5. Orbital Perturbations

Theoretically, an orbit described by Kepler is ideal as Earth is considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth.

In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag.

Effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

1.5.1 Effects of non-Spherical Earth

As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, and keeping in mind that an orbit is not a physical entity, and it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters.

This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee (point closest to the Earth). This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

Due to the non-spherical shape of Earth, one more effect called as the "Satellite Graveyard" is seen. The non-spherical shape leads to the small value of eccentricity (10-5) at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

Geo stationary and Non Geo-stationary orbits

1.7.1 Geo stationary

A **geostationary** orbit is one in which a satellite orbits the earth at exactly the same speed as the earth turns and at the same latitude, specifically zero, the latitude of the equator. A satellite orbiting in a geostationary orbit appears to be hovering in the same spot in the sky, and is directly over the same patch of ground at all times.

A **geosynchronous** orbit is one in which the satellite is synchronized with the earth's rotation, but the orbit is tilted with respect to the plane of the equator. A satellite in a geosynchronous orbit will wander up and down in latitude, although it will stay over the same line of longitude. Although the terms 'geostationary' and 'geosynchronous' are sometimes used interchangeably, they are not the same technically; geostationary orbit is a subset of all possible geosynchronous orbits.

The person most widely credited with developing the concept of geostationary orbits is noted science fiction author Arthur C. Clarke (Islands in the Sky, Childhood's End, Rendezvous with Rama, and the movie 2001: a Space Odyssey). Others had earlier pointed out that bodies traveling a certain distance above the earth on the equatorial plane would remain motionless with respect to the earth's surface. But Clarke published an article in 1945's Wireless World that made the leap from the Germans' rocket research to suggest permanent manmade satellites that could serve as communication relays.

Geostationary objects in orbit must be at a certain distance above the earth; any closer and the orbit would decay, and farther out they would escape the earth's gravity altogether. This distance is 35,786 kilometers (22,236 miles) from the surface.

The first geosynchrous satellite was orbited in 1963, and the first geostationary one the following year. Since the only geostationary orbit is in a plane with the equator at 35,786 kilometers, there is only one circle around the world where these conditions obtain.

This means that geostationary 'real estate' is finite. While satellites are in no danger of bumping in to one another yet, they must be spaced around the circle so that their frequencies do not interfere with the functioning of their nearest neighbors.

Geostationary Satellites

There are 2 kinds of manmade satellites in the heavens above: One kind of satellite ORBITS the earth once or twice a day, and the other kind is called a communications satellite and it is PARKED in a STATIONARY position 22,300 miles (35,900 km) above the equator of the STATIONARY earth.

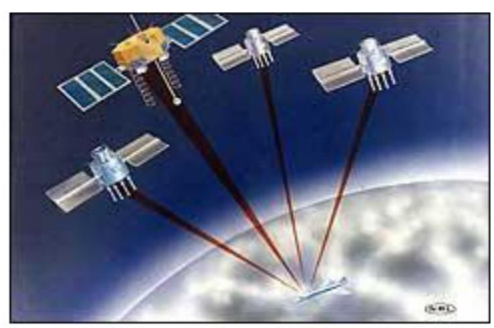
A type of the orbiting satellite includes the space shuttle and the international space station which keep a low earth orbit (LEO) to avoid the deadly Van Allen radiation belts.

The most prominent satellites in medium earth orbit (MEO) are the satellites which comprise the GLOBAL POSITIONING SYSTEM or GPS as it is called.

The Global Positioning System

The global positioning system was developed by the U.S. military and then opened to civilian use. It is used today to track planes, ships, trains, cars or literally anything that moves. Anyone can buy a receiver and track their exact location by using a GPS receiver.

GPS satellites orbit at a height of about 12,000 miles (19,300 km) and orbit the earth once every 12 hours.

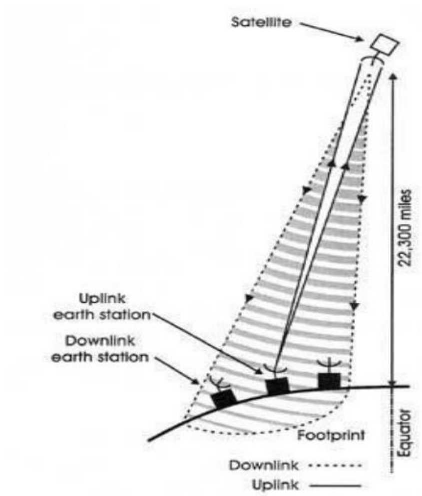


About 24 GPS satellites orbit the earth every 12 hours.

These satellites are traveling around the earth at speeds of about 7,000 mph (11,200 kph). GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running in the event of a solar eclipse, when there's no solar power.

Small rocket boosters on each satellite keep them flying in the correct path. The satellites have a lifetime of about 10 years until all their fuel runs out.

At exactly 22,300 miles above the equator, the force of gravity is cancelled by the centrifugal force of the rotating universe. This is the ideal spot to park a stationary satellite.



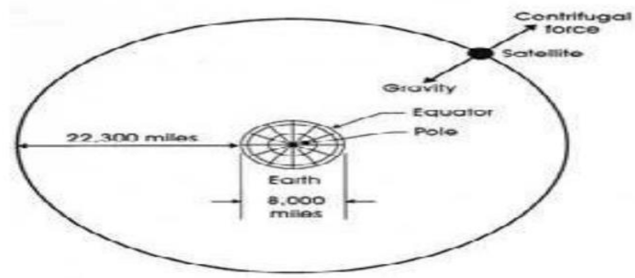


Figure. 1.6 & 1.7 At exactly 22,000 miles (35,900 km) above the equator, the earth's force of gravity is canceled by the centrifugal force of the rotating universe. .

1.7.2 Non Geo-Stationary Orbit

For the geo- stationary case, the most important of these are the gravitational fields of the moon and the sun, and the nonspherical shape of the earth.

Other significant forces are solar radiation pressure and reaction of the satellite itself to motor movement within the satellite. As a result, station-keeping maneuvers must be carried out to maintain the satel - lite within set limits of its nominal geostationary position.

An exact geostationary orbit therefore is not attainable in practice, and the orbital parameters vary with time. The two-line orbital elements are published at regular intervals.

1.10. Eclipse

It occurs when Earth‟s equatorial plane coincides with the plane f he Earth‟s orbit around the sun.

Near the time of spring and autumnal equinoxes, when the sun is crossing the equator, the satellite passes into sun‟s shadow. This happens for some duration of time every day.

These eclipses begin 23 days before the equinox and end 23 days after the equinox. They last for almost 10 minutes at the beginning and end of equinox and increase for a maximum period of 72 minutes at a full eclipse.

The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries.

A satellite will have the eclipse duration symmetric around the time t=Satellite Longitude/15 + 12 hours. A satellite at Greenwich longitude 0 will have the eclipse duration symmetric around 0/15

UTC +12hours = 00:00 UTC.

The eclipse will happen at night but for satellites in the east it will happen late evening local time.

For satellites in the west eclipse will happen in the early morning hour's local time.

An earth caused eclipse will normally not happen during peak viewing hours if the satellite is located near the longitude of the coverage area. Modern satellites are well equipped with batteries for operation during eclipse.

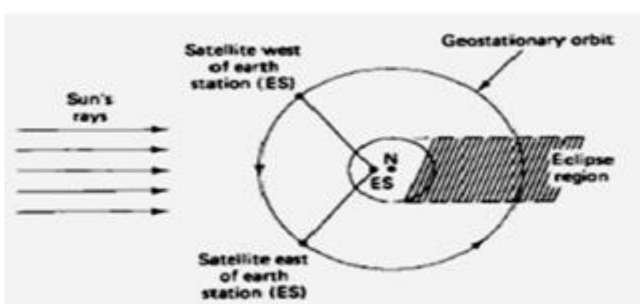


Figure 1.11(i): A satellite east of the earth station enters eclipse during daylight busy) hours at the earth station. A Satellite west of earth station enters eclipse during night and early morning hours (non busy time).

1.11. Sub satellite Point

Point at which a line between the satellite and the center of the Earth intersects the Earth's surface

Location of the point expressed in terms of latitude and longitude
If one is in the US it is common to use

- o Latitude – degrees north from equator
- o Longitude – degrees west of the Greenwich meridian

Example 12.8 Repeat the calculation when the system of Fig. 12.6*a* is arranged as shown in Fig. 12.6*b*.

Solution In this case the cable precedes the LNA, and therefore, the equivalent noise temperature referred to the cable input is

$$T_S = 35 + (3.16 - 1) \times 290 + 3.16 \times 150 + \frac{3.16 \times (15.85 - 1) \times 290}{10^5}$$

$$= \underline{1136\ \mathrm{K}}$$

Examples 12.7 and 12.8 illustrate the important point that the LNA must be placed ahead of the cable, which is why one sees amplifiers mounted right at the dish in satellite receive systems.

12.6 Carrier-to-Noise Ratio

A measure of the performance of a satellite link is the ratio of carrier power to noise power at the receiver input, and link-budget calculations are often concerned with determining this ratio. Conventionally, the ratio is denoted by C/N (or CNR), which is equivalent to P_R/P_N. In terms of decibels,

$$\left[\frac{C}{N}\right] = [P_R] - [P_N] \tag{12.33}$$

Equations (12.17) and (12.18) may be used for $[P_R]$ and $[P_N]$, resulting in

$$\left[\frac{C}{N}\right] = [\mathrm{EIRP}] + [G_R] - [\mathrm{LOSSES}] - [k] - [T_S] - [B_N] \tag{12.34}$$

The G/T ratio is a key parameter in specifying the receiving system performance. The antenna gain G_R and the system noise temperature T_S can be combined in Eq. (12.34) as

$$[G/T] = [G_R] - [T_S]\ \mathrm{dBK}^{-1} \tag{12.35}$$

Therefore, the link equation [Eq. (12.34)] becomes

$$\left[\frac{C}{N}\right] = [\mathrm{EIRP}] + \left[\frac{G}{T}\right] - [\mathrm{LOSSES}] - [k] - [B_N] \tag{12.36}$$

The ratio of carrier power to noise power density P_R/N_0 may be the quantity actually required. Since $P_N = kT_N B_N = N_0 B_N$, then

$$\left[\frac{C}{N}\right] = \left[\frac{C}{N_0 B_N}\right]$$

$$= \left[\frac{C}{N_0}\right] - [B_N]$$

and therefore

$$\left[\frac{C}{N_0}\right] = \left[\frac{C}{N}\right] + [B_N] \tag{12.37}$$

$[C/N]$ is a true power ratio in units of decibels, and $[B_N]$ is in decibels relative to 1 Hz, or dBHz. Thus, the units for $[C/N_0]$ are dBHz.

Substituting Eq. (12.37) for $[C/N]$ gives

$$\left[\frac{C}{N_0}\right] = [\mathrm{EIRP}] + \left[\frac{G}{T}\right] - [\mathrm{LOSSES}] - [k] \tag{12.38}$$

Example 12.9 In a link-budget calculation at 12 GHz, the free-space loss is 206 dB, the antenna pointing loss is 1 dB, and the atmospheric absorption is 2 dB. The receiver $[G/T]$ is 19.5 dB/K, and receiver feeder losses are 1 dB. The EIRP is 48 dBW. Calculate the carrier-to-noise spectral density ratio.

Solution The data are best presented in tabular form and in fact lend themselves readily to spreadsheet-type computations. For brevity, the units are shown as decilogs, (see App. G) and losses are entered as negative numbers to take account of the minus sign in Eq. (12.38). Recall that Boltzmann's constant equates to −228.6 decilogs, so $-[k] = 228.6$ decilogs, as shown in the following table.

Entering data in this way allows the final result to be entered in a table cell as the sum of the terms in the rows above the cell, a feature usually incorporated in spreadsheets and word processors. This is illustrated in the following table.

Quantity	Decilogs
Free-space loss	−206
Atmospheric absorption loss	−2
Antenna pointing loss	−1
Receiver feeder losses	−1
Polarization mismatch loss	0
Receiver G/T ratio	19.5
EIRP	48
$-[k]$	228.6
$[C/N_0]$, Eq. (12.38)	86.1

The final result, 86.10 dBHz, is the algebraic sum of the quantities as given in Eq. (12.38).

12.7 The Uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and the satellite is receiving it. Equation (12.38) can be applied to the uplink, but subscript U will be used to denote specifically that the uplink is being considered. Thus Eq. (12.38) becomes

$$\left[\frac{C}{N_0}\right]_U = [\text{EIRP}]_U + \left[\frac{G}{T}\right]_U - [\text{LOSSES}]_U - [k] \tag{12.39}$$

In Eq. (12.39) the values to be used are the earth station EIRP, the satellite receiver feeder losses, and satellite receiver G/T. The free-space loss and other losses which are frequency-dependent are calculated for the uplink frequency. The resulting carrier-to-noise density ratio given by Eq. (12.39) is that which appears at the satellite receiver.

In some situations, the flux density appearing at the satellite receive antenna is specified rather than the earth-station EIRP, and Eq. (12.39) is modified as explained next.

12.7.1 Saturation flux density

As explained in Sec. 7.7.3 the *traveling-wave tube amplifier* (TWTA) in a satellite transponder exhibits power output saturation, as shown in Fig. 7.21. The flux density required at the receiving antenna to produce saturation of the TWTA is termed the *saturation flux density*. The saturation flux density is a specified quantity in link budget calculations, and knowing it, one can calculate the required EIRP at the earth station. To show this, consider again Eq. (12.6) which gives the flux density in terms of EIRP, repeated here for convenience:

$$\Psi_M = \frac{\text{EIRP}}{4\pi r^2}$$

Ψ_M = Psi

In decibel notation this is

$$[\Psi_M] = [\text{EIRP}] + 10\log\frac{1}{4\pi r^2} \tag{12.40}$$

But from Eq. (12.9) for free-space loss we have

$$-[\text{FSL}] = 10\log\frac{\lambda^2}{4\pi} + 10\log\frac{1}{4\pi r^2} \tag{12.41}$$

Substituting this in Eq. (12.40) gives

$$[\Psi_M] = [\text{EIRP}] - [\text{FSL}] - 10\log\frac{\lambda^2}{4\pi} \tag{12.42}$$

The $\lambda^2/4\pi$ term has dimensions of area, and in fact, from Eq. (6.15) it is the effective area of an isotropic antenna. Denoting this by A_0 gives

$$[A_0] = 10\log\frac{\lambda^2}{4\pi} \tag{12.43}$$

Since frequency rather than wavelength is normally known, it is left as an exercise for the student to show that with frequency f in gigahertz, Eq. (12.43) can be rewritten as

$$[A_0] = -(21.45 + 20 \log f) \tag{12.44}$$

Combining this with Eq. (12.42) and rearranging slightly gives the EIRP as

$$[\text{EIRP}] = [\Psi_M] + [A_0] + [\text{FSL}] \tag{12.45}$$

Equation (12.45) was derived on the basis that the only loss present was the spreading loss, denoted by [FSL]. But, as shown in the previous sections, the other propagation losses are the atmospheric absorption loss, the polarization mismatch loss, and the antenna misalignment loss. When allowance is made for these, Eq. (12.45) becomes

$$[\text{EIRP}] = [\Psi_M] + [A_0] + [\text{FSL}] + [\text{AA}] + [\text{PL}] + [\text{AML}] \tag{12.46}$$

In terms of the total losses given by Eq. (12.12), Eq. (12.46) becomes

$$[\text{EIRP}] = [\Psi_M] + [A_0] + [\text{LOSSES}] - [\text{RFL}] \tag{12.47}$$

This is for clear-sky conditions and gives the *minimum* value of [EIRP] which the earth station must provide to produce a given flux density at the satellite. Normally, the saturation flux density will be specified. With saturation values denoted by the subscript S, Eq. (12.47) is rewritten as

$$[\text{EIRP}_S]_U = [\Psi_S] + [A_0] + [\text{LOSSES}]_U - [\text{RFL}] \tag{12.48}$$

Example 12.10 An uplink operates at 14 GHz, and the flux density required to saturate the transponder is −120 dB(W/m^2). The free-space loss is 207 dB, and the other propagation losses amount to 2 dB. Calculate the earth-station [EIRP] required for saturation, assuming clear-sky conditions. Assume [RFL] is negligible.

Solution At 14 GHz,

$$[A_0] = -(21.45 + 20 \log 14) = -44.37 \text{ dB}$$

The losses in the propagation path amount to 207 + 2 = 209 dB. Hence, from Eq. (12.48),

$$[\text{EIRP}_S]_U = -120 - 44.37 + 209$$
$$= \underline{\underline{44.63 \text{ dBW}}}$$

12.7.2 Input backoff

As described in Sec. 12.7.3, where a number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of intermodulation distortion. Such multiple carrier operation occurs with *frequency-division multiple access* (FDMA), which is described in Chap. 14. The point to be made here is that *backoff* (BO) must be allowed for in the link-budget calculations.

Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single-carrier saturation level. The earth-station EIRP will have to be reduced by the specified BO, resulting in an uplink value of

$$[\text{EIRP}]_U = [\text{EIRP}_S]_U - [\text{BO}]_i \tag{12.49}$$

Although some control of the input to the transponder power amplifier is possible through the ground TT&C station, as described in Sec. 12.7.3, input BO is normally achieved through reduction of the [EIRP] of the earth stations actually accessing the transponder.

Equations (12.48) and (12.49) may now be substituted in Eq. (12.39) to give

$$\left[\frac{C}{N_0}\right]_U = [\Psi_S] + [A_0] - [\text{BO}]_i + \left[\frac{G}{T}\right]_U - [k] - [\text{RFL}] \tag{12.50}$$

Example 12.11 An uplink at 14 GHz requires a saturation flux density of -91.4 dBW/m^2 and an input BO of 11 dB. The satellite $[G/T]$ is -6.7 dBK^{-1}, and receiver feeder losses amount to 0.6 dB. Calculate the carrier-to-noise density ratio.

Solution As in Example 12.9, the calculations are best carried out in tabular form.

$[A_0] = -44.37$ dBm^2 for a frequency of 14 GHz is calculated by using Eq. (12.44) as in Example 12.10.

Quantity	Decilogs
Saturation flux density	−91.4
$[A_0]$ at 14 GHz	−44.4
Input BO	−11.0
Satellite saturation $[G/T]$	−6.7
$-[k]$	228.6
Receiver feeder loss	−0.6
Total	74.5

Note that $[k] = -228.6$ dB, so $-[k]$ in Eq. (12.50) becomes 228.6 dB. Also, [RFL] and $[BO]_i$ are entered as negative numbers to take account of the minus signs attached to them in Eq. (12.50). The total gives the carrier-to-noise density ratio at the satellite receiver as 74.5 dBHz.

Since fade margins have not been included at this stage, Eq. (12.50) applies for *clear-sky* conditions. Usually, the most serious fading is caused by rainfall, as described in Sec. 12.9.

12.7.3 The earth station HPA

The earth station HPA has to supply the radiated power plus the transmit feeder losses, denoted here by TFL, or [TFL] dB. These include waveguide, filter, and coupler losses between the HPA output and the transmit antenna. Referring back to Eq. (12.3), the power output of the HPA is given by

$$[P_{\mathrm{HPA}}] = [\mathrm{EIRP}] - [G_T] + [\mathrm{TFL}] \tag{12.51}$$

The [EIRP] is that given by Eq. (12.49) and thus includes any input BO that is required at the satellite.

The earth station itself may have to transmit multiple carriers, and its output also will require back off, denoted by $[\mathrm{BO}]_{\mathrm{HPA}}$. The earth station HPA must be rated for a saturation power output given by

$$[P_{\mathrm{HPA,sat}}] = [P_{\mathrm{HPA}}] + [\mathrm{BO}]_{\mathrm{HPA}} \tag{12.52}$$

Of course, the HPA will be operated at the backed-off power level so that it provides the required power output $[P_{\mathrm{HPA}}]$. To ensure operation well into the linear region, an HPA with a comparatively high saturation level can be used and a high degree of BO introduced. The large physical size and high power consumption associated with larger tubes do not carry the same penalties they would if used aboard the satellite. Again, it is emphasized that BO at the earth station may be required quite independently of any BO requirements at the satellite transponder. The power rating of the earth-station HPA should also be sufficient to provide a fade margin, as discussed in Sec. 12.9.1.

12.8 Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation (12.38) can be applied to the downlink, but subscript D will be used to denote specifically that the downlink is being considered. Thus Eq. (12.38) becomes

$$\left[\frac{C}{N_0}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{G}{T}\right]_D - [\mathrm{LOSSES}]_D - [k] \tag{12.53}$$

In Eq. (12.53) the values to be used are the satellite EIRP, the earth-station receiver feeder losses, and the earth-station receiver G/T. The free space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio given by Eq. (12.53) is that which appears at the detector of the earth station receiver.

Where the carrier-to-noise ratio is the specified quantity rather than carrier-to-noise density ratio, Eq. (12.38) is used. This becomes, on assuming that the signal bandwidth B is equal to the noise bandwidth B_N:

$$\left[\frac{C}{N}\right]_D = [\mathrm{EIRP}]_D + \left[\frac{G}{T}\right]_D - [\mathrm{LOSSES}]_D - [k] - [B] \qquad (12.54)$$

Example 12.12 A satellite TV signal occupies the full transponder bandwidth of 36 MHz, and it must provide a C/N ratio at the destination earth station of 22 dB. Given that the total transmission losses are 200 dB and the destination earth-station G/T ratio is 31 dB/K, calculate the satellite EIRP required.

Solution Equation (12.54) can be rearranged as

$$[\mathrm{EIRP}]_D = \left[\frac{C}{N}\right]_D - \left[\frac{G}{T}\right]_D + [\mathrm{LOSSES}]_D + [k] + [B]$$

Setting this up in tabular form, and keeping in mind that $+[k] = -228.6$ dB and that losses are numerically equal to $+200$ dB, we obtain

Quantity	Decilogs
$[C/N]$	22
$-[G/T]$	-31
[LOSSES]	200
$[k]$	-228.6
$[B]$	75.6
[EIRP]	38

The required EIRP is 38 dBW or, equivalently, 6.3 kW.

Example 12.12 illustrates the use of Eq. (12.54). Example 12.13 shows the use of Eq. (12.53) applied to a digital link.

Example 12.13 A QPSK signal is transmitted by satellite. Raised-cosine filtering is used, for which the rolloff factor is 0.2 and a *bit error rate* (BER) of 10^{-5} is required. For the satellite downlink, the losses amount to 200 dB, the receiving earth-station G/T ratio is 32 dBK^{-1}, and the transponder bandwidth is 36 MHz. Calculate (*a*) the bit rate which can be accommodated, and (*b*) the EIRP required.

Solution Equation (10.16) gives

$$R_b = \frac{2B}{1 + \rho}$$

$$= \frac{2 \times 36 \times 10^6}{1.2}$$

$$= 60 \text{ Mbps}$$

Hence,

$$[R_b] = 10 \log\left(\frac{60 \times 10^6}{1\text{s}^{-1}}\right)$$

$$= 77.78 \text{ dBbps}$$

For BER $= 10^{-5}$, Fig. 10.17 gives an $[E_b/N_0] = 9.6$ dB.

From Eq. (10.24) the required C/N_0 ratio is

$$\left[\frac{C}{N_0}\right] = \left[\frac{E_b}{N_0}\right] + [R_b]$$

$$= 77.78 + 9.6$$

$$= 87.38 \text{ dBHz}$$

From Eq. (12.53),

$$[\text{EIRP}]_D = \left[\frac{C}{N_0}\right]_D - \left[\frac{G}{T}\right]_D + [\text{LOSSES}]_D + [k]$$

$$= 87.38 - 32 + 200 - 228.6$$

$$\cong \underline{\underline{26.8 \text{ dBW}}}$$

12.8.1 Output back-off

Where input BO is employed as described in Sec. 12.7.2, a corresponding output BO must be allowed for in the satellite EIRP. As the curve of Fig. 7.21 shows, output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion, as shown in Fig. 12.7. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output BO is $[\text{BO}]_0 = [\text{BO}]_i - 5$ dB. For example, with an input BO of $[\text{BO}]_i = 11$ dB, the corresponding output BO is $[\text{BO}]_0 = 11 - 5 = 6$ dB.

If the satellite EIRP for saturation conditions is specified as $[\text{EIRP}_S]_D$, then $[\text{EIRP}]_D = [\text{EIRP}_S]_D - [\text{BO}]_0$ and Eq. (12.53) becomes

$$\left[\frac{C}{N_0}\right]_D = [\text{EIRP}_S]_D - [\text{BO}]_0 + \left[\frac{G}{T}\right]_D - [\text{LOSSES}]_D - [k] \tag{12.55}$$

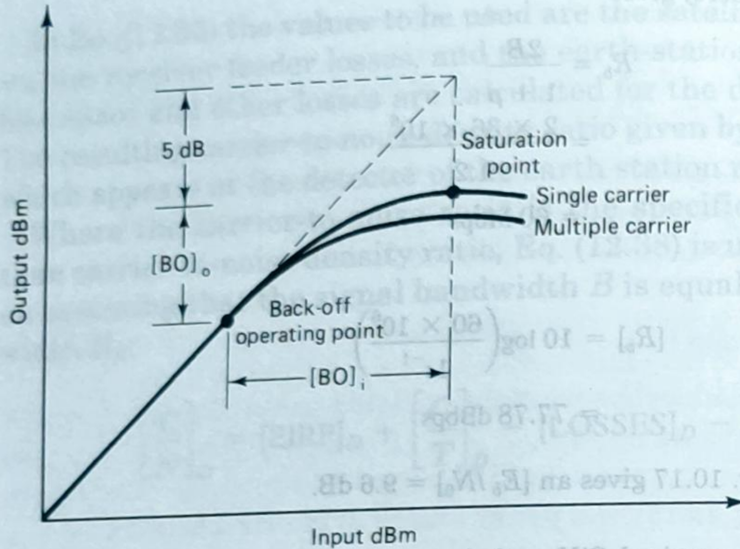


Figure 12.7 Input and output back-off relationship for the satellite traveling-wave-tube amplifier; $[BO]_i = [BO]_0 + 5$ dB.

Example 12.14 The specified parameters for a downlink are satellite saturation value of EIRP, 25 dBW; output BO, 6 dB; free-space loss, 196 dB; allowance for other downlink losses, 1.5 dB; and earth-station G/T, 41 dBK^{-1}. Calculate the carrier-to-noise density ratio at the earth station.

Solution As with the uplink budget calculations, the work is best set out in tabular form with the minus signs in Eq. (12.55) attached to the tabulated values.

Quantity	Decilogs
Satellite saturation [EIRP]	25.0
Free-space loss	−196.0
Other losses	−1.5
Output BO	−6.0
Earth station [G/T]	41.0
−[k]	228.6
Total	91.1

The total gives the carrier-to-noise density ratio at the earth station in dBHz, as calculated from Eq. (12.55).

For the uplink, the saturation flux density at the satellite receiver is a specified quantity. For the downlink, there is no need to know the saturation flux density at the earth-station receiver, since this is a terminal point, and the signal is not used to saturate a power amplifier.

12.8.2 Satellite TWTA output

The satellite power amplifier, which usually is a TWTA, has to supply the radiated power plus the transmit feeder losses. These losses include the waveguide, filter, and coupler losses between the TWTA output and the satellite's transmit antenna. Referring back to Eq. (12.3), the power output of the TWTA is given by

$$[P_{\text{TWTA}}] = [\text{EIRP}]_D - [G_T]_D + [\text{TFL}]_D \tag{12.56}$$

Once $[P_{\text{TWTA}}]$ is found, the saturated power output rating of the TWTA is given by

$$[P_{\text{TWTA}}]_S = [P_{\text{TWTA}}] + [\text{BO}]_0 \tag{12.57}$$

Example 12.15 A satellite is operated at an EIRP of 56 dBW with an output BO of 6 dB. The transmitter feeder losses amount to 2 dB, and the antenna gain is 50 dB. Calculate the power output of the TWTA required for full saturated EIRP.

Solution Equation (12.56):

$$\begin{aligned}[P_{\text{TWTA}}] &= [\text{EIRP}]_D - [G_T]_D + [\text{TFL}]_D \\ &= 56 - 50 + 2 \\ &= 8 \text{ dBW}\end{aligned}$$

Equation (12.57):

$$\begin{aligned}[P_{\text{TWTA}}]_S &= 8 + 6 \\ &= \underline{14 \text{ dBW (or 25 W)}}\end{aligned}$$