# SATELLITE COMMUNICATION

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).

Satellite uses solar energy collected from large arrays of solar cells, which supply the satellite with all the electrical power it needs to function and transmit to earth and a small amount of fuel is used to maintain it in the right orbit.A satellite works by receiving radio signals sent from the Earth and re-sending the radio signals back down to the Earth.

**Satellite communication** refers to using satellites around the Earth to relay messages, data, or other forms of commun
ication between different locations on the planet. In simple terms, communication between any two earth stations through a satellite is referred to as satellite communication

This technology enables long-distance communication in areas where traditional wired or wireless communication infrastructure is either impractical, inefficient, or unavailable.

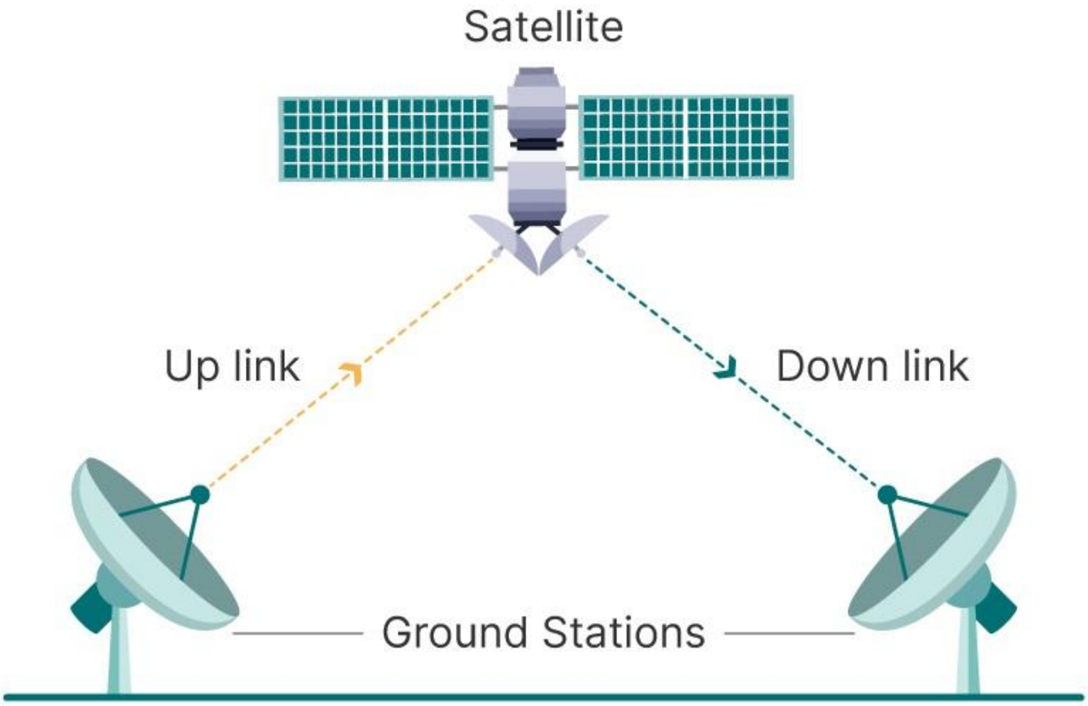
**Working of Satellite Communication:**

An **earth station or ground station** is a collection of equipment installed on the earth's surface that enables communications over one or more satellites. Earth stations consist of a reflector antenna (or parabolic dish), a feed system to send and receive the RF carrier, data handling equipment and mechanical tracking equipment to keep the satellite within the antenna's data send/receive area. Earth stations are typically owned by the company receiving the data from the satellite network, thus must operate within certain specified parameters to maintain the network's stability. Earth stations are part of a satellite network's ground segment, which consists of all earth stations operating in a satellite system. These can be connected to the end user's equipment directly or via a terrestrial network( traditional landline telephones, cellular phones, Wi-Fi)

The term **satellite transponder** refers collectively to a transmitter-receiver subsystem on board the satellite that processes, amplifies and retransmits a range of frequencies (the transponder bandwidth) to another location/terminal/antenna on the earth.

People communicate to a satellite using an antenna on the earth station. The earth station sends up radio signals called uplink frequencies to the satellite. The uplink frequency is the frequency at which the ground station communicates with the satellite.The downlink frequency is the frequency at which the satellite transmits the signal to the receiving station on the Earth’s surface.

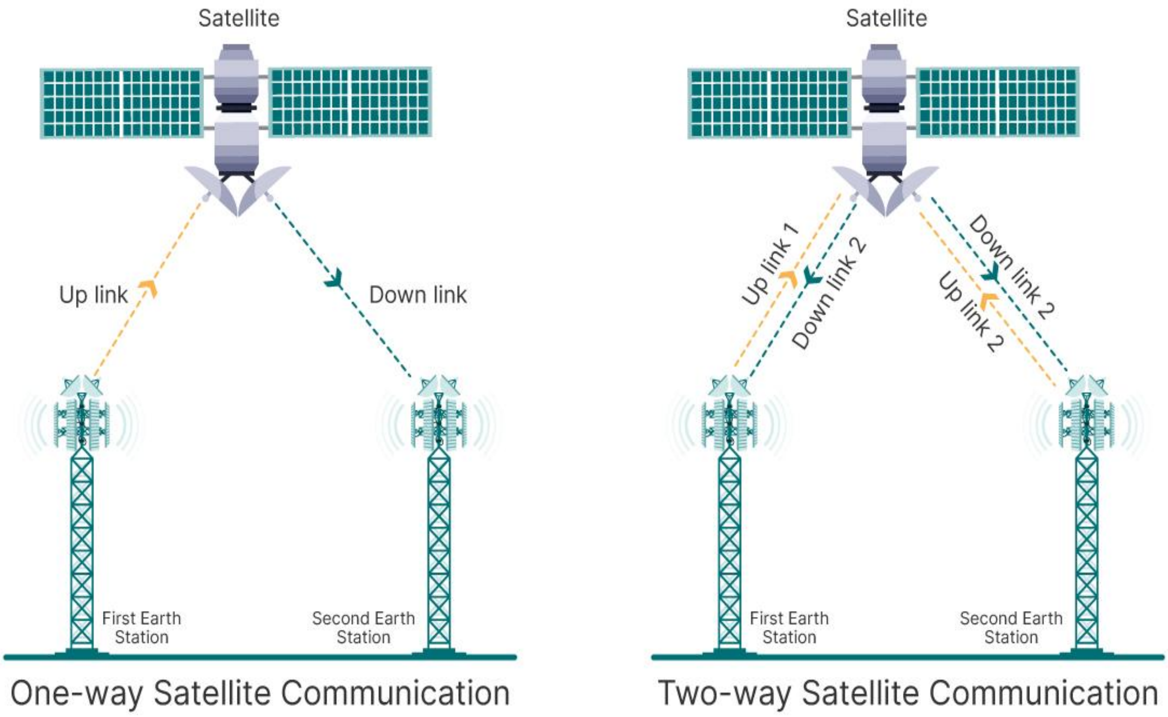
The process begins with a transmission from a ground station, typically a dish antenna, which sends high-frequency signals in the form of radio waves or microwaves up to a satellite in orbit (uplink frequency). The satellite receives the signals using its own dish antenna. Then it changes the signal’s frequency band through a transponder before sending it back to a receiving station on the Earth’s surface (downlink frequency). The satellite acts as a microwave repeater station in space, amplifying and retransmitting signals it receives from the ground station. The image shown in fig(a) below depicts the working of this technology.




**Fig(a): Satellite Communication**

Types of Satellite Communication
Satellite communications can be broadly categorized into two types based on the direction of communication: **one-way and two-way satellite**

**communication** which is shown in fig(b) below**.** As the name implies, **“one-way”** transmits signals in only one direction – from the satellite to the ground station. This communication method is widely used for radio and television signals, where the satellite simultaneously sends signals to numerous ground stations. Direct broadcast satellite (DBS) and satellite radio are prime examples of one-way satellite communication.
In contrast, **“two-way”** is a communication method in which signals are transmitted in both directions – between the satellite and the ground station. This method is employed in various applications, including commercial and military communications, internet access, and remote monitoring. In two-way satellite communication, the ground station transmits a signal to the satellite, which then relays the signal to the intended recipient. The recipient then sends a response back to the satellite, which is then transmitted back to the ground station. Satellite phones, satellite internet systems are all examples of two-way satellite communication.




**Fig(b ): Satellite communication types**

**Applications of Satellite Communication:**
Here are some of the most popular applications of satellite communication:
1) **Navigation:** Satellites help in navigation and location tracking, such as air and sea transportation, surveying, military operations, etc.
2) **Internet access:** Satellites provide internet access in remote or rural areas where other forms of connectivity are unavailable or unreliable.

3) **Broadcasting**: Satellites distribute TV and radio signals, allowing broadcasters to reach a wider audience beyond terrestrial transmission capabilities.
4) **Military and defence**: Satellites are used for various military and defence applications, such as communication, surveillance, intelligence gathering, etc.
5) **Telecommunications**: This type of communication allows long-distance voice and data communication in remote or isolated regions where another communication infrastructure is unavailable.
6) **Remote sensing**: Satellites equipped with sensors can collect data about the Earth's surface, atmosphere, oceans, etc. And this information is used for various purposes, such as weather forecasting, natural disaster monitoring, agricultural monitoring, etc.

**Advantages of Satellite Communication**

Here are some of the most popular advantages:

1. **Scalability:** Satellite networks can be easily expanded or contracted depending on the user's needs.
2. **Global coverage:** This technology can cover any part of the world, including remote and inaccessible areas.
3. **Cost-effective:** This technology can be more cost-effective than laying cables or building terrestrial networks.
4. **Mobility:** It allows for communication while in motion, making it useful for transportation, aviation, and maritime industries.
5. **High-speed connectivity:** This technology provides high-speed data and voice communication services, even in remote areas.
6. **Security:** This type of communication is more secure than other forms of communication since the signals are difficult to intercept.
7. **Reliability:** It is not affected by terrestrial factors such as terrain, weather, or distance, making it more reliable than other forms of communication.
8. **Disaster recovery:** During natural disasters or emergencies, this technology can act as a backup communication system when terrestrial networks are damaged or unavailable.

**Disadvantages of Satellite Communication:**

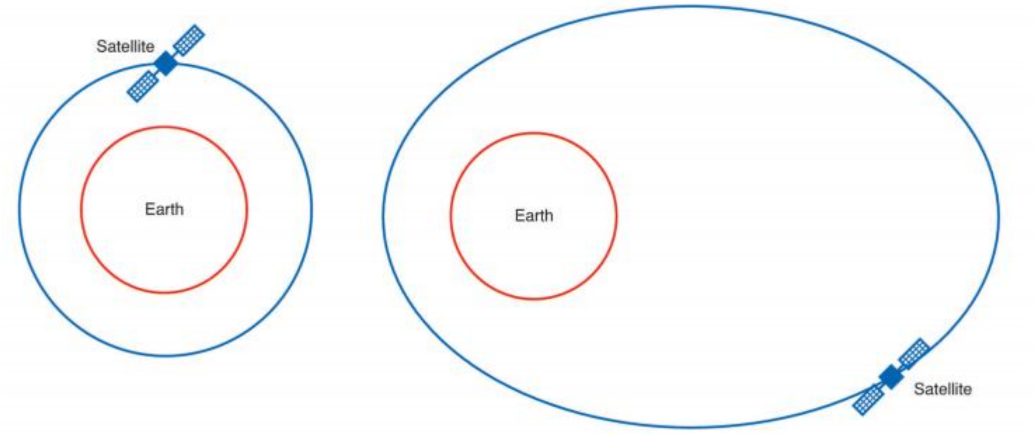
Here are some of the most popular disadvantages:

1) **Cost**: Setting up and maintaining this technology can be expensive, which makes it less accessible for some organizations.
2) **Delay:** The time taken by a signal to travel to and from a satellite can cause delays, which can be detrimental in certain situations.

3) **Weather:** Adverse weather conditions, such as heavy rain or snow, can disrupt or completely interrupt satellite signals, thus affecting quality and reliability.
4) **Vulnerability**: Satellites are vulnerable to space debris, solar flares, and other potential hazards that disrupt communication, making them less reliable in certain scenarios.

## Satellite Orbits

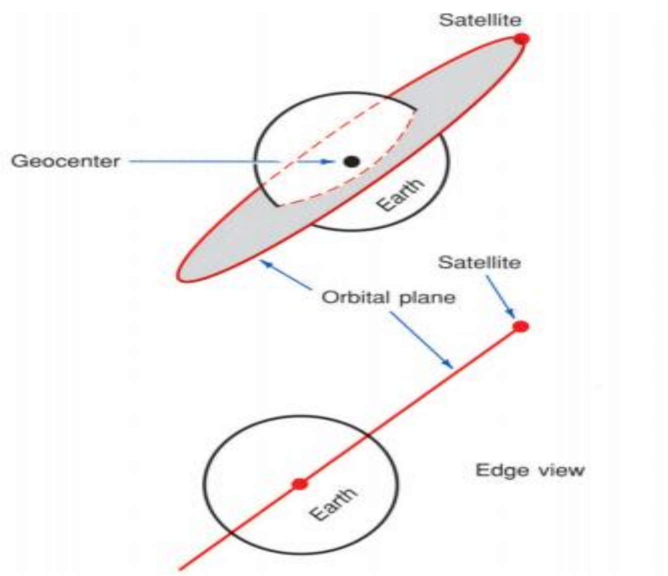
An orbit is the curved path that an object in space (such as a star, planet, moon, asteroid or spacecraft) takes around another object due to gravity. A satellite rotates about the earth in either a circular or an elliptical path, as shown in fig(c ) below.Because the orbit is either circular or elliptical, it is possible to calculate the position of a satellite at any given time.




**Fig(c ):Circular and Elliptical path**

An **orbital plane** is the flat, disk-shaped space that connects the center of the object being orbited with the center of the orbiting objects.
The **altitude** of a satellite is the distance between the Earth's surface and the satellite.
The **attitude** of a satellite refers to its orientation in space.
The **orbital period** is the time it takes for an object to make one complete orbit of another object. Another way of stating this is that it is the time it takes for an object to arrive back to the same point in its orbit.

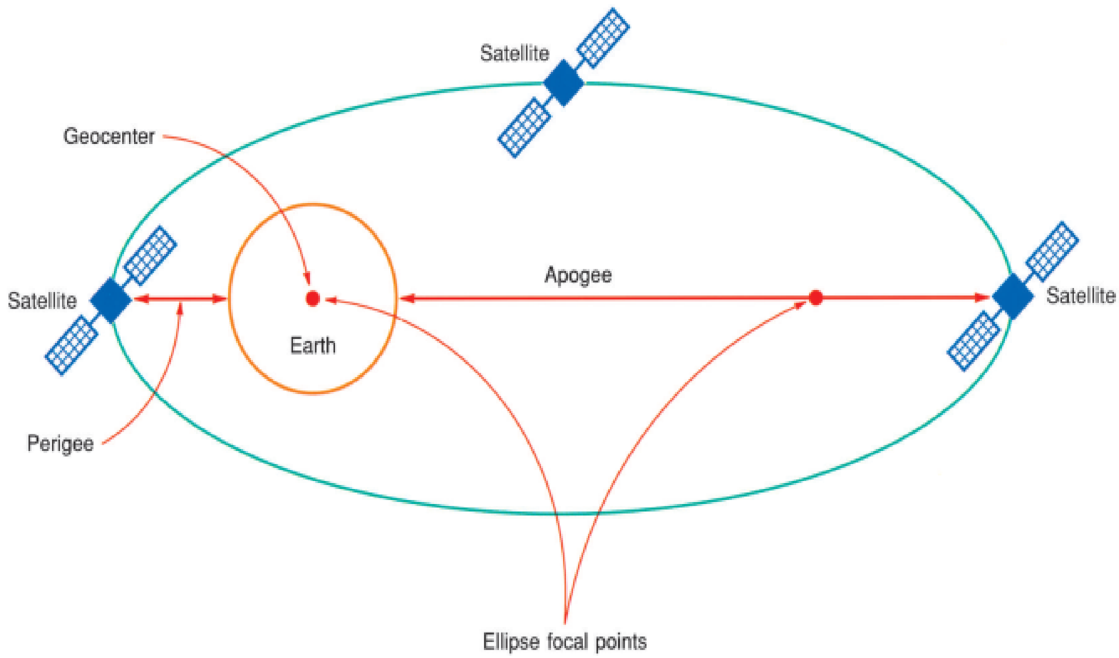
A satellite rotates in an orbit that forms a plane passing through the center of gravity of the earth called the *geocenter* shown in fid (d).




**Fig(d):The orbital plane passes through the geocenter.**

In addition, the direction of satellite rotation may be either in the same direction as the earth's rotation or against the direction of earth's rotation. In the former case, the orbit is said to be **posigrade**, and in the latter case, **retrograde.** Most orbits are posigrade. In a circular orbit, the speed of rotation is constant. However, in an elliptical orbit, the speed changes depending upon the height of the satellite above the earth. Naturally the speed of the satellite is greater when it is close to the earth than when it is far away.

When the satellite is in an elliptical orbit, the center of the earth is one of the focal points of the ellipse as shown in fig(e ).



**Fig(f):Elliptical orbit showing apogee and perigee.**

In this case, the distance of the satellite from the earth varies according to its position. Typically the two points of greatest interest are the highest point above the earth—the **apogee**—and the lowest point—the **perigee.** The apogee and perigee distances typically are measured from the geocenter of the earth.

Satellites are usually classified based on their orbital altitude (distance from the Earth's surface), which directly affects their coverage and the speed at which they travel around the planet. When choosing the type of orbit, spacecraft developers should consider its intended purpose, the data it acquires, and the services it offers, as well as the cost, coverage area, and feasibility of different orbits. The 5 main types of satellites based on their orbits are:

1. Low Earth orbit (LEO)
2. Medium Earth orbit (MEO)
3. Geostationary orbit (GEO)
4. Sun-synchronous orbit (SSO)
5. Geostationary transfer orbit (GTO)

## LOW EARTH ORBIT(LEO):

**Low Earth Orbit (LEO)** refers to the orbital region closest to Earth, typically ranging from **160km to 2,000 kilometers (km)** above the planet's surface. It's a popular destination for many satellites due to its accessibility and unique characteristics

To maintain orbit at these lower altitudes, satellites need to travel at very high speeds. For an orbit around 400 km (like the International Space Station), the speed is approximately **7.8 kilometers per second (around 17,500 miles per hour)**. This high speed is crucial to balance the Earth's gravitational pull, preventing the satellite from falling back to Earth.Because of their high speed and close proximity to Earth, satellites in LEO complete a full orbit in a relatively short time, typically **90 minutes.** This means they circle the Earth multiple times a day.

A single LEO satellite has a limited field of view and covers only a small portion of the Earth's surface at any given time due to its rapid movement. To provide continuous coverage over a large area, **large constellations** of interconnected LEO satellites are required.

The close proximity of LEO satellite to Earth makes the signals travel shorter distances, resulting in very low latency. This is a major advantage for real-time applications.Shorter distances also mean that less power is needed for signal transmission, and signals can be stronger and more stable compared to those from higher orbits.LEO satellites typically have a **shorter operational lifespan**, often between 7 to 10 years

**LEO orbits are ideal for a variety of applications due to their unique characteristics:**

**1.Earth Observation and Remote Sensing**: Satellites in LEO can capture high-resolution images and data of the Earth's surface, making them invaluable for environmental monitoring, mapping, agriculture, disaster management, and intelligence gathering.

**2.Global Internet and Communications:** Large LEO satellite constellations (like Starlink, OneWeb) are revolutionizing internet access, providing high-speed, low-latency connectivity to remote and undeserved areas worldwide. They are also used for satellite phones and other communication services.

**3.Scientific Research:** Instruments on LEO satellites can conduct various scientific experiments, study Earth's atmosphere and climate, and monitor space weather. The International Space Station (ISS) is a prime example of a large scientific laboratory in LEO.

•**Geostationary orbit (GEO):**

Satellites in geostationary orbit (GEO) circle Earth above the equator from west to east following Earth's 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 'stationary' over a fixed position. In order to perfectly match Earth's rotation, the speed of GEO satellites should be about 3 km per second at an altitude of 35,786 km. This is much farther from Earth's surface compared to many satellites.

GEO is used by satellites that need to stay constantly above one particular place over Earth, such as telecommunication satellites. This way, an antenna on Earth can be fixed to always stay pointed towards that satellite without moving. It can also be used by weather monitoring satellites, because they can continually observe specific areas to see how weather trends emerge there.Satellites in GEO cover a large range of Earth so as few as three equally-spaced satellites can provide near global coverage.

This is because when a satellite is this far from Earth, it can cover large sections at once.Major uses of Geostationary satellites are Communication, Disaster Management, Climate Control, Weather Forecasting etc.

**MEDIUM EARTH ORBIT(MEO):**

Medium earth orbit refers to a specific region in space situated between Low Earth Orbit (LEO) and Geostationary Orbit (GEO). MEO satellites occupy an altitude range typically between 2,000 to 35,000 kilometer (1,243 to 22,300 miles) above the Earth's surface.Satellites in this orbit travel at a speed of around 3.13 km per second and at this speed, a satellite takes approximately 127 minutes to circle Earth

MEO satellites are commonly known for their significant role in global navigation systems, with the most prominent example being the Global Positioning System (GPS). These satellites form a constellation that provides precise positioning, navigation, and timing services to users worldwide. By deploying multiple satellites in MEO, the GPS system ensures that a sufficient number of satellites are visible from any given location on Earth, enabling accurate positioning and navigation capabilities.

Compared to the thousands of satellites required for stable LEO, MEO satellites offer far more efficient coverage. Just six satellites groups in MEO provide stable coverage for virtually the entire globe. This broader coverage area enhances network reliability by minimizing service disruptions and ensuring a more consistent internet connection across larger geographic regions.

**SATELLITE SUBSYSTEM:**

Satellite communication mainly consists of two segments:

1) **Space segment:** Space segment means the satellite is in space so the components or the subsystems of this segment are the communication satellite itself, satellite payloads, launch vehicles, etc. Major space segment subsystems are:

a) Power Subsystem
b) Attitude and Orbit Control(AOC)Subsystem
c) Telemetry,Command and Control Subsystem(TC&C)
d) Communication Subsystem

**2)Earth segment:** The subsystems present in the ground segment have the ability to access the satellite repeater in order to provide the communication between the users. Earth segment is also called as ground segment.
Earth segment performs mainly two functions. Those are transmission of a signal to the satellite and reception of signal from the satellite. Earth stations are the major subsystems that are present in earth segment.

## SPACE SEGMENT

### Power Subsystem:
Every satellite uses solar panels for its basic power source. Solar panels are large arrays of photocells connected in various series and parallel circuits to create a powerful source of direct current. Early solar panels could generate hundreds of watts of power. Today huge solar panels are capable of generating many kilowatts. A key requirement is that the solar panels always be pointed toward the sun. There are two basic satellite configurations. In cylindrical satellites, the solar cells surround the entire unit, and therefore some portion of them is always exposed to sunlight. In body- stabilized, or three-axis, satellites, individual solar panels are manipulated with various controls to ensure that they are correctly oriented with respect to the sun.

Solar panels generate a direct current that is used to operate the various components of the satellite. However, the dc power is typically used to charge secondary batteries that act as a buffer. When a satellite goes into an eclipse or when the solar panels are not properly positioned, the batteries take over temporarily and keep the satellite operating. The batteries are not large enough to power the satellite for a long time; they are used as a backup system.

The basic dc voltage from the solar panels is conditioned in various ways. For example, it is typically passed through voltage regulator circuits before being used to power individual electronic circuits. Occasionally, voltages higher than those produced by the solar panels must also be generated. For example, the TWT(Travelling Wave Tube) amplifiers in most communication transponders require thousands of volts for proper operation. Special dc-to-dc converters are used to translate the lower dc voltage of the solar panels to the higher dc voltage required by the TWTs.

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## Attitude And Orbit Control(AOC)

This is very important subsystem of a satellite. It controls the orbit of the satellites besides maintaining stabilization and its position. There are various forces acting on the satellites which may change the attitude and orbit of a satellite.The earth is not a true sphere, there are certain bulging flattening so there are certain forces that may impact the satellite gravitational forces due to sun, moon and other planets pressure due to solar radiation, magnetic field of the earth. So there are various orbital perturbations which may impact the satellite orbit. So there is a requirement of attitude and orbit control unit which are capable of placing the satellite into the right orbit, whenever it is deviated from the respective orbit. AOC subsystem is helpful in order to make the antennas, which are of narrow beam type points towards earth.

The AOC sub system is divided into two parts:
a) Attitude Control Subsystem
**b)** Orbital Control Subsystem

**Attitude Control Subsystem:**
Attitude control subsystem takes care of the orientation of satellite (which way the satellite is pointing) in its respective orbit. Following are the two methods to make the satellite that is present in an orbit as stable.

a) Spinning the satellite
b) Three axes method

**Spinning the satellite**
In this method, the body of the satellite rotates around its spin axis. In general, it can be rotated at 30 to 100 rpm in order to produce a force, which is of gyroscopic type( rotating object tendency to maintain its orientation). Due to this, the spin axis gets stabilized and the satellite will point in the same direction. Satellites are of this type are called as spinners.Spinner contains a drum, which is of cylindrical shape. This drum is covered with solar cells.

Communication subsystem is placed on top of the drum. An electric motor drives this communication system. The direction of this motor will be opposite to the rotation of satellite body, so that the antennas point towards earth. The satellites, which perform this kind of operation are called as de-spin.

During launching phase, the satellite spins when the small radial gas jets are operated. After this, the de-spin system operates in order to make the antennas point towards earth station.

**Three Axis Method**

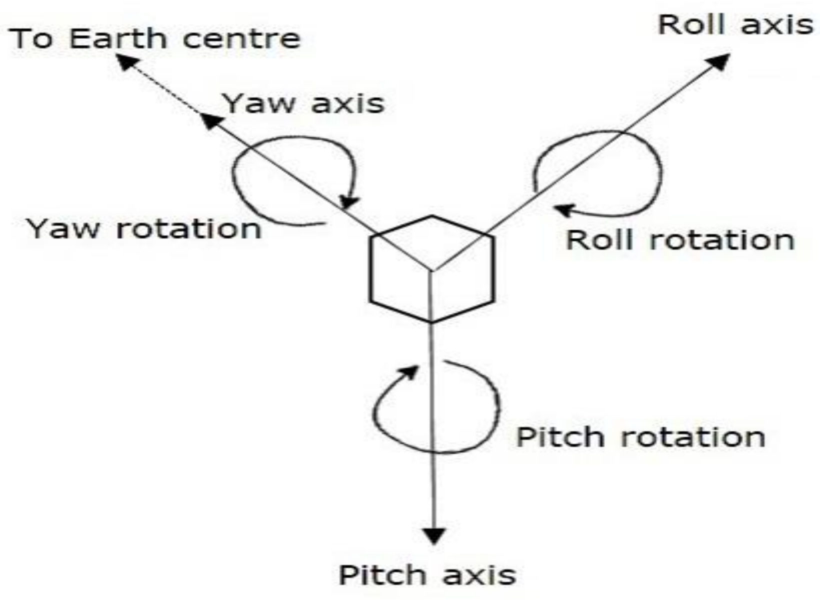
In this method, we can stabilize the satellite by using one or more momentum wheels. This method is called as three-axis method. The advantage of this method is that the orientation of the satellite in three axes will be controlled and no need of rotating satellite's main body.
In this method, the following three axes are considered..

a) Roll axis is considered in the direction in which the satellite moves in orbital plane.

b) Yaw axis is considered in the direction towards earth.

c) Pitch axis is considered in the direction, which is perpendicular to orbital plane.

These three axes are shown in below(g) figure.




**Fig(g): Three axes Method**

**Three Axis Method**

Let XR, YR and ZR are the roll axis, yaw axis and pitch axis respectively. These three axis are defined by considering the satellite's position as reference. These three axes define the attitude of satellite.

Let X, Y and Z are another set of Cartesian axes. This set of three axis provides the information about orientation of the satellite with respect to reference axes. If there is a change in attitude of the satellite, then the angles between the respective axes will be changed.

In this method, each axis contains two gas jets. They will provide the rotation in both directions of the three axes.

The first gas jet will be operated for some period of time, when there is a requirement of satellite's motion in a particular axis direction.

The second gas jet will be operated for same period of time, when the satellite reaches to the desired position. So, the second gas jet will stop the motion of satellite in that axis direction.

**Orbit Control Subsystem**

The Orbit Control Subsystem (OCS) is the part of a satellite responsible for maintaining, adjusting, and controlling the satellite's orbit around Earth. While the satellite is in space, its orbit can change due to gravitational perturbations, solar radiation pressure, or drag (for low-Earth orbit satellites). The OCS ensures the satellite stays in its assigned orbital slot.

**Telemetry,Command and Control Subsystem(TC&C):**

All satellites have a telemetry, command and control (TC&C) subsystem that allows a ground station to monitor and control conditions in the satellite. The telemetry system is used to report the status of the onboard subsystems to the ground station.The telemetry system typically consists of various electronic sensors for measuring temperatures, radiation levels, power supply voltages, and other key operating characteristics. Both analog and digital sensors may be used. The sensors are selected by a multiplexer and then converted to a digital signal, which then modulates an internal transmitter. This transmitter sends the telemetry information back to the earth station, where it is recorded and monitored. With this information, the ground station then determines the operational status of the satellite at all times.

A command and control system permits the ground station to control the satellite. Typically, the satellite contains a command receiver that receives control signals from an earth station transmitter. The control signals are made up of various digital codes that tell the satellite what to do. Various commands may initiate a telemetry sequence, activate thrusters for altitude correction, reorient an antenna, or perform other operations as required by the special equipment specific to the mission. Usually, the control signals are processed by an onboard computer.

**Communication Subsystem:**
The communication subsystem performs the function of a repeater or relay station. An earth station takes the signals to be transmitted, known as baseband signals, and modulates a microwave carrier. The three most common baseband signals are voice, video, and computer data.

These uplink signals are then amplified, translated in frequency, and retransmitted on the downlink to one or more earth stations. The component that performs this function is known as a transponder. Most modern communication satellites contain at least 12 transponders. More advanced satellites contain many more. These transponders operate in the microwave frequency range.

The basic purpose of a transponder is simply to rejuvenate the uplink signal and retransmit it over the downlink. In this role, the transponder performs the function of an amplifier. By the time the uplink's signal reaches the satellite, it is extremely weak. Therefore, it must be amplified before it can be retransmitted to the receiving earth station.

Three basic transponder configurations are used in communication satellites. They are all essentially minor variations of one another, but each has its advantages and disadvantages. These are the single-conversion and regenerative transponders.

Single conversion transponders are also known as bent pipe transponders. It receives a microwave frequency signal. It converts the frequency of the input signal to RF frequency and then amplifies it.The frequency conversion from uplink to downlink happens in a single stage. Hence, it is known as the single conversion transponder. The single conversion transponder is suitable for both analog & digital signals.
A regenerative transponder performs the function of a single conversion transponder. i.e., frequency translation and amplification. In addition to these functions, the regenerative transponder also performs demodulation and modulation of a given downlink signal post frequency conversion

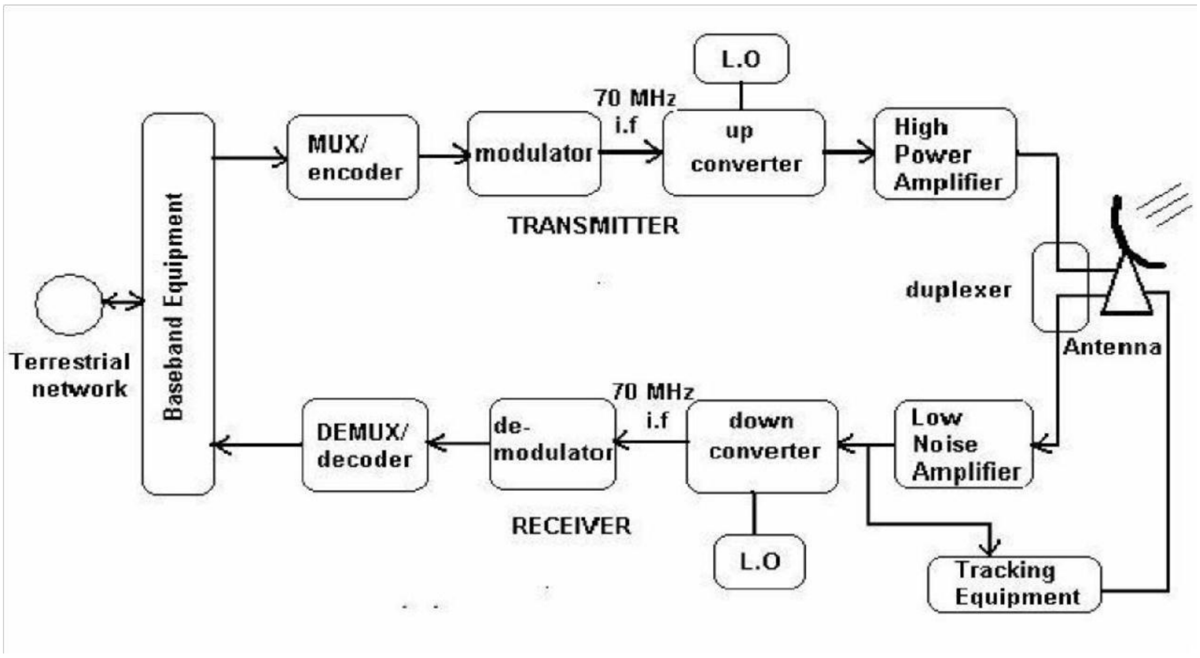
which provides a significant improvement in the signal-to-noise ratio. However, this type of transponder is only suitable for digital signals.

**Ground Stations:**

The earth segment of satellite communication system mainly consists of two earth stations. Those are transmitting earth station and receiving earth station. The transmitting earth station transmits the information signals to satellite. Whereas, the receiving earth station receives the information signals from satellite. Sometimes, the same earth station can be used for both transmitting and receiving purposes.

In general, earth stations receive the baseband signals in one of the following forms.Voice signals and video signals either in analog form or digital form. Initially, the analog modulation technique, named FM modulation is used for transmitting both voice and video signals, which are in analog form. Later, digital modulation techniques, namely Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) are used for transmitting those signals. Because, both voice and video signals are used to represent in digital by converting them from analog.

The block diagram of digital earth station is shown in below figure(h) below.




There are five major subsystems that are present in any earth station. Those are power, transmitter, receiver, antenna and tracking subsystem.

**Power Subsystem:**

Most earth stations receive their power from the normal ac mains. Standard power supplies convert the ac power to the dc voltages required to operate all subsystems. However, most earth stations have backup power systems. Satellite systems, particularly those used for reliable communication of telephone conversations, TV programs, computer data, and so on, must not go down. The backup power system takes over if an ac power failure occurs.

The backup power system may consist of a diesel engine driving an ac generator. When ac power fails, an automatic system starts the diesel engine. The generator creates the equivalent ac power, which is automatically switched to the system. Smaller systems may use uninterruptible power supplies (UPS), which derive their main power from batteries . Uninterruptible power supplies are not suitable for long power failures and interruptions because the batteries quickly become exhausted. However, for short interruptions of power, i.e., less than an hour, they are adequate.

**Antenna Sub system:**

All earth stations have a relatively large parabolic dish antenna that is used for sending and receiving signals to and from the satellite. Early satellites had very low power transmitters and so the signals received on earth were extremely small. Huge high-gain antennas were required to pick up minute signals from the satellite. The earth station dishes were 80 to 100 ft or more in diameter. Antennas of this size are still used in some satellite systems today, and even larger antennas have been used for deep-space probes.

Modern satellites now transmit with much more power. Advances have also been made in receiver components and circuitry. For that reason, smaller earth station antennas are now practical. In some applications, antennas having as small as 18-in diameter can be used.

Typically, the same antenna is used for both transmitting and receiving. A diplexer is used to permit a single antenna to be used for multiple transmitters and/or receivers. In some applications, a separate antenna is used for telemetry and control functions.The antenna in an earth station must also be steerable. That is, it must possible to adjust its azimuth and elevation so that the antenna can be properly aligned with the satellite.

**Transmitter**

The terrestrial network is the ground-based communication infrastructure that connects the Earth station to the end-users and the broader public network, like the internet or a telephone network. The binary (digital) information enters at base band equipment of earth station from terrestrial network. Encoder includes error correction bits in order to minimize the bit error rate. In satellite communication, the Intermediate Frequency (IF) can be chosen as 70 MHz by using a transponder having bandwidth of 36 MHz. Similarly, the IF can also be chosen as 140 MHz by using a transponder having bandwidth of either 54 MHz or 72 MHz. Up converter performs the frequency conversion of modulated signal to higher frequency. This signal will be amplified by using High power amplifier. The earth station antenna transmits this signal.

**Receiver**

During reception, the earth station antenna receives downlink signal. This is a low-level modulated RF signal. In general, the received signal will be having less signal strength. So, in order to amplify this signal, Low Noise Amplifier (LNA) is used. Due to this, there is an improvement in Signal to Noise Ratio (SNR) value. RF signal can be down converted to the Intermediate Frequency (IF) value, which is either 70 or 140 MHz. Because, it is easy to demodulate at these intermediate frequencies.
The function of the decoder is just opposite to that of encoder. So, the decoder produces an error free binary information by removing error correction bits and correcting the bit positions if any. This binary information is given to base band equipment for further processing and then delivers to terrestrial network.

**Tracking Subsystem:**

The Tracking subsystem keeps track with the satellite and

make sure that the beam comes towards it in order to establish the communication.The Tracking system present in the earth station performs mainly two functions- satellite acquisition(location) and tracking of satellite.The tracking can be done in the following three ways.

1) Automatic tracking
2) Manual tracking
3) Program tracking

Before communication can be established it is necessary to acquire a satellite.One method is to make the antenna to perform a scan-around the predicted position of the satellite.

After acquisition a satellite needs to be tracked continuously.This function is performed by the automatic tracking system.Auto-track systems are closed-loop control systems and are therefore highly accurate. This tracking mode is the preferred configuration when accuracy is the dominant criterion.

To avoid a total loss of communication due to a failure in the tracking system, earth stations generally also have manual tracking mode.In this mode an antenna is moved through manual commands.

In program tracking mode the antenna is driven to the predicted satellite position by a computer.The satellite position predictions are usually supplied by the satellite operators. Since a program track system is an open loop control system, its accuracy is mainly governed by the accuracy of the prediction data.

## GLOBAL POSITIONING SYSTEM(GPS)

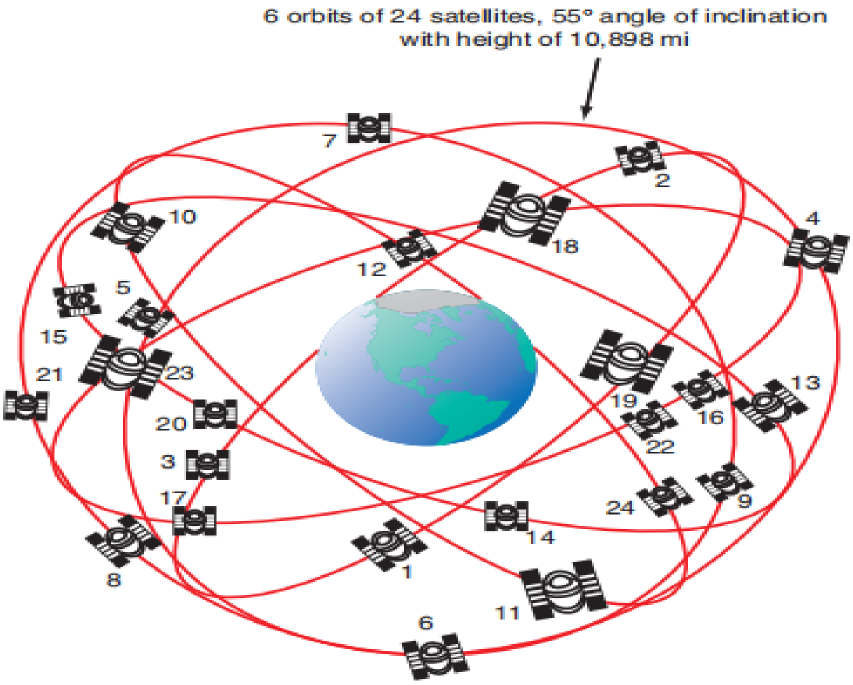
The Global Positioning System (GPS), also known as Navstar, is a satellite-based navigation system that can be used by anyone with an appropriate receiver to pinpoint her or his location on earth. The array of GPS satellites transmits highly accurate, time-coded information that permits a receiver to calculate its exact location in terms of the latitude and longitude on earth as well as the altitude above sea level.

GPS was developed by the U.S. Air Force for the Department of Defense as a continuous global radio navigation system that all elements of the military services would use for precision navigation. Development was started in 1973, and by 1994, the system was fully operational.
The GPS Navstar system is an open navigation system; i.e., anyone with a GPS receiver can use it. The system is designed, however, to provide a base navigation system with a horizontal accuracy to within 3 m. This precision is available to any GPS user. As a result, GPS is gradually replacing older military systems and civilian land-based navigation systems.The GPS is an excellent example of a modern satellite-based system and the high technology communication techniques used to implement it.

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

**Space Segment:**

The space segment is the constellation of satellites orbiting above the earth with transmitters that send highly accurate timing information to GPS receivers on earth. The receivers in the user segment themselves may be on land, sea, or air.The fully implemented GPS consists of 24 main operational satellites plus multiple active spare satellites shown in fig (h) below.
The satellites are arranged in six orbits, each orbit containing three or four satellites. The orbital planes form a 55° angle with the equator. The satellites orbit at a height of 10,898 nautical miles above the earth (20,200 km). The orbital period for each satellite is approximately 12h (11 h 58 min).




**Fig(h):The GPS space segment**

Each of the orbiting satellites contains four highly accurate atomic clocks. Atomic clocks are electronic oscillators that use the oscillating energy of a gas to provide a stable operating frequency. Certain chemicals have atoms that can oscillate between low and high energy levels. This frequency of oscillation is extremely precise and stable. Cesium and rubidium are used in atomic clocks. In gaseous form, they are irradiated by electromagnetic energy at a frequency near their oscillating point. The GPS satellite contains two cesium clocks and two rubidium clocks. Only one is used at any given time. The clocks are kept fully operational so that if one fails, another can be switched in immediately.

They provide precision timing pulses used to generate a unique binary code, i.e., a pseudorandom code identifying the specific satellite in the constellations that is transmitted to earth.

The satellite also transmits a set of digitally coded ephemeris data(The term ephemeris is normally associated with specifying the location of a celestial body that completely defines its precise orbit). This data tells where the satellite is at any given time and its location can be specified in terms of the satellite precise latitude and longitude measurements. Ephemeris information is coded and transmitted from the satellite, providing an accurate indication of the exact position of the satellite above the earth at any given time. The satellite's ephemeris data is updated once a day by the ground control station to ensure accuracy.

A GPS receiver on earth is designed to pick up signals from three, four, or more satellites simultaneously. The receiver decodes the information and, using the time and ephemeris data, calculates the exact position of the receiver. The receiver contains a high-speed, floating-point microcomputer that performs the necessary calculations. The output of the receiver is a decimal display of latitude and longitude as well as altitude. Readings from only three satellites are necessary for latitude and longitude information only. A fourth satellite reading is required to compute altitude. Each GPS satellite carries two transmitters that together transmit the timing and location signals to the earth receivers.

All GPS satellites broadcast on at least two carrier frequencies: L1, at 1575.42 MHz, and L2, at 1227.6 MHz (newer satellites also broadcast on L5 at 1176 MHz). There are two types of pseudo-random codes(PRC) generated by the GPS Satellite.Each satellite has a unique pseudo-random code.The first pseudo-random code is called the C/A (Coarse Acquisition) code. It modulates the L1 carrier.The chip rate is 1023 chips per millisecond. The C/A code is the basis for civilian GPS use.
The second pseudo-random code is called the P (Precise) code.It modulates both the L1 and L2 carriers.The chip rate is 10230 chips per millisecond. This code is intended for military users and can be encrypted. When it's encrypted it's called "Y" code.
Like all other satellites, GPS satellites contain a TT&C unit that is used by the ground stations to transmit updated ephemeris data and to make sure the satellite is in its exact position.

**Control Segment:**
The control segment of the GPS refers to the various ground stations that monitor the satellites and provide control and update information. The

master control station is operated by the U.S. Air Force in Colorado Springs. Additional monitoring and control stations are located in Hawaii, Kwajalein, Diego Garcia and the Ascension Islands. These four monitoring stations are not staffed. They constantly monitor the satellites and collect range information from each. The positions of these monitoring stations are accurately known. The information is sent back to the master control station in Colorado, where all the information is collected and position data on each satellite calculated. The master control station then transmits new ephemeris and clock data to each satellite on the S-band uplink once per day. This data updates the NAV-msg or navigation message, a 50 bps signal that modulates the L1 carrier and contains bits that describe the satellite orbits, clock corrections, and other system characteristics.

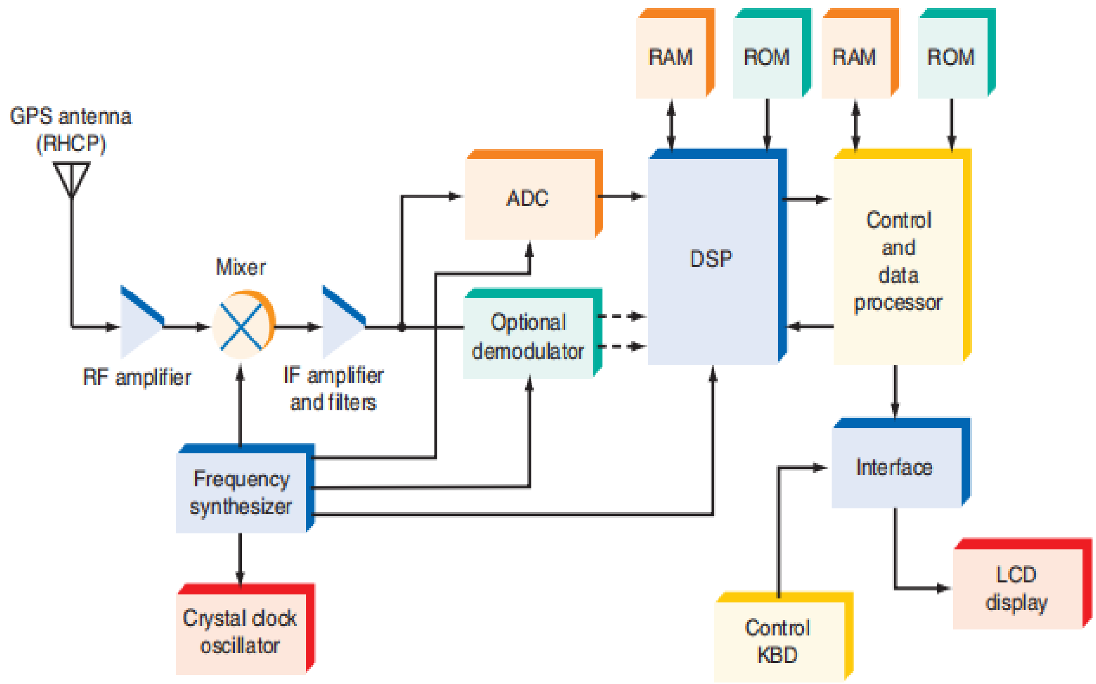
The telemetry data transmitted as part of the NAV-msg is also received by the ground control station to keep track of the health and status of each receiver. The uplink S-band control system allows the ground station to do some station keeping to correct the satellite position as needed. Positioning is accomplished with the thrusters.

**GPS Receiver:**

A GPS receiver is a complex superheterodyne microwave receiver designed to pick up the GPS signals, decode them, and then compute the location of the receiver. The output is usually an LCD display giving latitude, longitude, and altitude information and/or a map of the area.There are many different types of GPS receivers. More than 40 manufacturers now make some form of GPS receiver. The larger and more sophisticated units are used in military vehicles.

The most widely used GPS receiver is the popular handheld portable type, not much larger than an oversized handheld calculator. Most of the circuitry used in making a GPS receiver has been reduced to integrated-circuit form, thereby permitting an entire receiver to be contained in an extremely small, portable battery-operated unit.

The general block diagram of a GPS receiver is shown in fig(i )below, typical of the simpler, low-cost handheld units on the market.

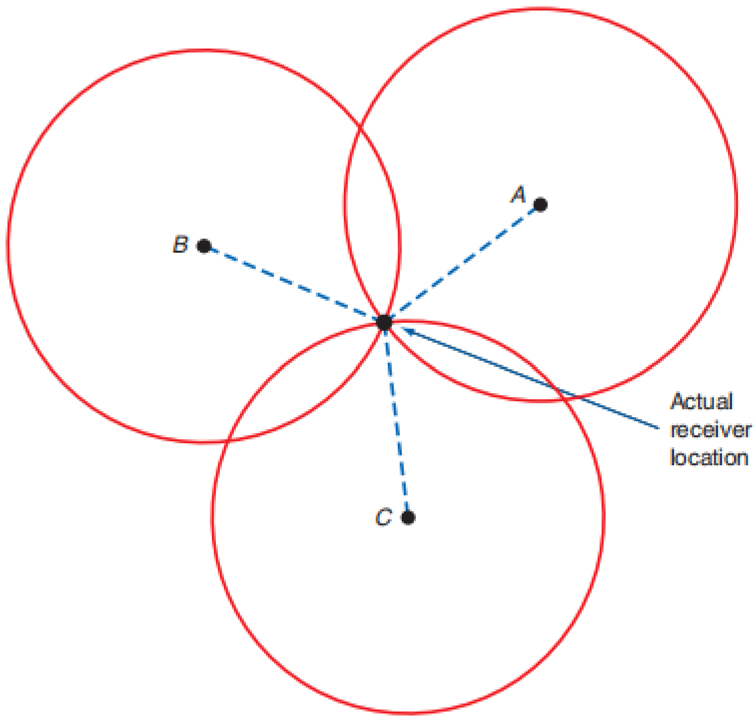



**Fig(i ): A GPS Receiver**

The receiver consists of the antenna, the RF/IF section, the frequency standard clock oscillator, and a frequency synthesizer that provides local-oscillator signals as well as clock and timing signals for the rest of the receiver.Other sections of the receiver include a digital signal processor and a control microcomputer along with its related RAM and ROM. Interface circuits provide connection to the LCD or other type of display.

The antenna system is a type of patch antenna made on a printed-circuit board. It receives signals from the GPS satellites. In the handheld units, the antenna is part of the single physical structure and is connected directly to the receiver front end. In some larger and more complex GPS receivers, the antenna is a separate unit and may be mounted at a high clear point and connected to the receiver with coaxial cable.

The receiver can determine its exact position only by computing the position information obtained from four satellites. The receiver picks up signals from four satellites simultaneously.The determination of the location of a GPS receiver is based on measuring the distance between the receiver and three satellites. The distance is determined by measuring the time of arrival of the satellite signals and then computing distance based on the speed of radio waves, with correction factors. Assume three satellites A, B, and C as shown in fig(j) below.This method is known as GPS Trilateration Method.




**Fig(j) GPS Trilateration Method**

The receiver first computes the distance from the receiver to satellite A. Note that the distance from A is on a circle that falls on a wide range of locations on earth. Then the receiver calculates the distance to satellite B. That distance is defined along another circle. The two circles intersect at two points. One of those is the exact location, but we don't know which until we get a third satellite reading. The distance from satellite C intersects with the other circles at only one point. That is the location of the receiver. Using a fourth satellite gives a fourth intersection point that enables the altitude to be determined.

Once the receiver locks on the one satellite, all the information is extracted from the satellite.The receiver performs a time multiplexing operation on the four satellites within view of the receiver. The data is extracted from each of the four satellites and stored in the receiver's memory. Data from three satellites is needed to fix the receiver's position. If data from a fourth satellite is available, altitude can be calculated.

Once all the data has been accumulated, the high-speed control and data microprocessor in the receiver performs the final calculations. The microprocessor is typically a 16-bit unit with floating-point capability. Floating-point numbers must be used to provide the precision of calculation for accurate location.

The computations performed by the receiver are given below. First the receiver calculates the ranges R1 through R4 to each of the four satellites. These are obtained by measuring the time shift between the received pulses, which is the delay in transmission between the satellite and the receiver. These are the T1 through T4 times given below. Multiplying these by the speed of light c gives the range in meters between the satellite and the receiver. These four range values are used in the final calculations:

R1 = c x T1

R2 = c x T2

R3 = c x T3

R4 = c x T4

The basic ranging calculation is the solution to four simultaneous equations, as indicated in Fig(k) below .

Compute position coordinates
(four equations with four unknowns)

$$(X_1 - U_X)^2 + (Y_1 - U_Y)^2 + (Z_1 - U_Z)^2 = (R_1 - C_B)^2$$
$$(X_2 - U_X)^2 + (Y_2 - U_Y)^2 + (Z_2 - U_Z)^2 = (R_2 - C_B)^2$$
$$(X_3 - U_X)^2 + (Y_3 - U_Y)^2 + (Z_3 - U_Z)^2 = (R_3 - C_B)^2$$
$$(X_4 - U_X)^2 + (Y_4 - U_Y)^2 + (Z_4 - U_Z)^2 = (R_4 - C_B)^2$$

Solve for position coordinates
($U_X, U_Y, U_Z$) and clock bias ($C_B$)

**Fig(k):The equations solved by GPS Receiver**

The X, Y, and Z values are derived from the data transmitted by each of the satellites which are the satellite positions. The $C_B$ is the clock bias. Because there is a difference between the clock frequency in the receiver and the clock in the satellites, there will be some difference called the bias. The goal of the microprocessor is to solve for the user position, designated $U_X$, $U_Y$, and $U_Z$ in the equations. Once the calculation has been made, the microprocessor converts that information to the latitude, longitude, and altitude data, which is displayed on the LCD screen. The receiver display also shows the time of day, which is highly precise because it is derived from the atomic clocks in the satellites.