CONTENTS

KEC 062 : Satellite Communication

1

UNIT

Introduction to Satellite Communication

CONTENTS

PART-1

Introduction to Satellite Communication : History, Overview of Satellite Communication.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **Briefly discuss the history of satellite communication.**

Answer

1. The first artificial satellite, Sputnik 1, was launched successfully by the Soviet Union on October 4, 1957. Sputnik 1 was only 58 cm (23 inches) in diameter with four antennas sending low-frequency radio signals at regular intervals.
2. It orbited earth in an elliptical orbit, taking 96.2 minutes to complete one revolution. It transmitted signals for only 22 days until its battery ran out and was in orbit for only three months.
3. The first satellite to relay voice signals was launched by the U.S. government's Project SCORE (Signal Communication by Orbiting Relay Equipment) from Cape Canaveral, Florida, on December 19, 1958.
4. A tape recorder on SCORE had a storage capacity that allowed a 4 min message received from a earth station to be retransmitted. The batteries on SCORE failed after 35 days in orbit.
5. After some early attempts to use large balloons (Echo I and II) as passive reflectors for communication signals, and some small experimental satellite launches, the first true communications satellites, Telstar I and II, were launched in July 1962 and May 1963.
6. The Telstar satellites were built by Bell Telephone Laboratories and used C-band transponders adapted from terrestrial microwave link equipment.
7. The satellites carried solar cells and batteries that allowed continuous use of the single transponder, and demonstrations of live television links and multiplexed telephone circuits were made across the Atlantic Ocean, emphatically demonstrating the feasibility of satellite communications.

8. The Telstar satellites were launched into what is now called a medium earth orbit, with periods of 158 and 225 min.
9. The orbits chosen for the Telstar satellites took them through several bands of high energy radiation which caused early failure of the electronics on board.
10. The first Intelsat satellite, INTELSAT I (formerly Early Bird) was launched on April 16, 1965. The satellite weighed a mere 36 kg (80 lb) and incorporated two 6/4 GHz transponders, each with 25MHz bandwidth.
11. Intelsat was highly successful and grew rapidly as many countries saw the value of improved telecommunications, not just internationally but for national systems that provided high quality satellite communications within the borders of large countries.
12. Canada was the first country to build a natural telecommunication system using GEO satellites. Anik 1A was launched in May 1974, just 2 months before the first U.S. domestic satellite, WESTAR 1.

Que 1.2. **Give overview on satellite communication.**

Answer

1. Satellite communication systems exist because the earth is a sphere.
2. Satellites, because they can link places on the earth that are thousands of miles apart, are a good place in locate a repeater, and a GEO satellite is the best place of all.
3. Satellite communication systems are dominated by the need to receive very weak signals.
4. In the early days, very large receiving antennas, with diameters up to 30 m, were needed to collect sufficient signal power to drive video signals or multiplexed telephone channels.
5. As satellites have become larger, heavier, and more powerful, smaller earth station antennas have become feasible, and Direct Broadcast Satellite TV (DES-TV) receiving systems can use dish antennas as small as 0.5 m in diameter.
6. Satellite systems operate in the microwave and millimeter wave frequency bands, using frequencies between 1 and 50 GHz.
7. Above 10 GHz, rain causes significant attenuation of the signal and the probability that rain will occur in the path between the satellite and an earth station must be factored into the system design.
8. Above 20 GHz, attenuation in heavy rain (usually associated with thunderstorms) can cause sufficient attenuation that the link will fail.

Que 1.3. What are the elements of satellite communication system ? Explain each with a suitable block diagram.

Answer

1. The basic elements of satellite communication are users, earth station transmitter, satellite and earth station receivers.
2. Fig. 1.3.1 shows the basic block diagram of the satellite communication system. It consists of many earth stations on the ground and these stations are linked with a satellite in space.

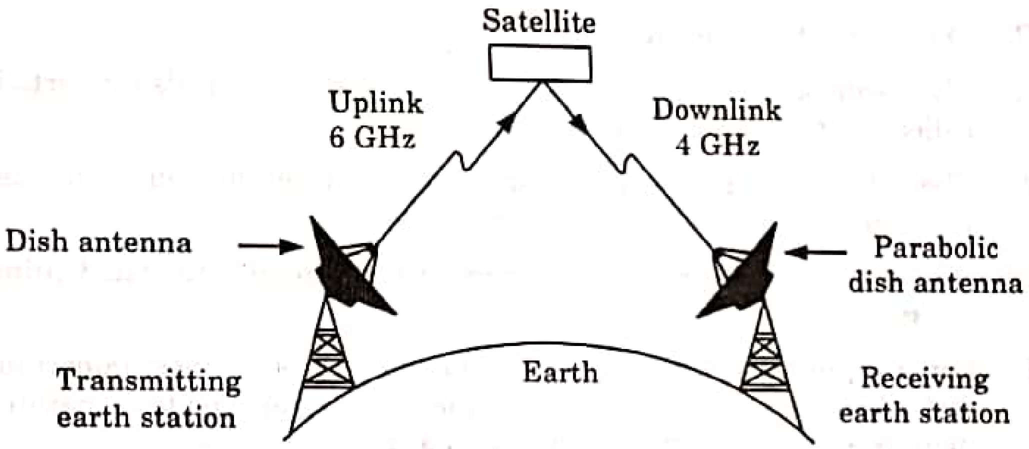

Fig. 1.3.1. Basic elements of satellite communication system.

3. The user is connected to the earth station through a terrestrial network, and this network may be a telephone switch or dedicated link to a earth station.
4. The user generates a baseband signal that gets processed through the terrestrial network and transmitted to a satellite by the earth station.
5. The satellite consists of a large number of repeaters, that receives the modulated radio frequency carrier in its uplink frequency spectrum from all the earth stations in the network, amplifies these carriers, then retransmits them back to the earth station in the downlink frequency spectrum.
6. To avoid the interference, downlink and uplink frequency spectrum should have different frequencies.
7. The signal at the receiving earth station is processed to get back the base band signal, then it is sent to the user through a terrestrial network.

Que 1.4. Explain uplink and downlink frequencies. Also give the reason for the downlink frequency to be lower than uplink frequency.

Answer

A. Uplink Frequency :

1. The frequency of signal transmitted from the earth station to the satellite is called "uplink frequency".
2. The power associated with the uplink signals can be adequately high as they are transmitted from the earth station.
3. The frequency used for the uplink is generally higher than the corresponding downlink frequency.
4. This is to facilitate the satellite to down convert this frequency.

B. Downlink Frequency :

1. The frequency of signal transmitted from satellite towards the earth is called as "downlink frequency".
2. The uplink and the downlink frequencies are different from each other to avoid interference between them.

C. Reasons for the Downlink Frequency to be lower than the Uplink Frequency :

1. **Output power amplifier in transponder :** It is the most important factor because the final power amplifier in the transponder generates more power at lower frequencies than at higher frequencies.
2. **Effective area of the receiving antenna :** The effective capture area of the downlink antenna should be more so as to receive more energy at the earth's receiving antenna. Effective area of an antenna is directly proportional to the square of the frequency. Thus, the frequency should be kept lower.
3. **Path loss :** Path loss is less at lower frequencies.
4. **Beamwidth :** It should be wider as a satellite would send energy to a large number of earth stations. Lower the frequency, higher is the beamwidth.

Que 1.5. **Discuss the advantages and disadvantages of using 6/4 GHz band in the satellite communication system.**

Answer

Advantages :

1. In this band there is no absorption due to rain.
2. There is no change in polarization when the waves pass through ionosphere.
3. Sky noise is low at 4 GHz and therefore signal to noise ratio at the receiving antenna is not much deteriorated.

4. Broad beamwidth allows large areas to be covered.
5. It is easier to generate higher power at 4 GHz at the satellite than at 11 GHz.

Disadvantages :

1. Bandwidth is limited to 500 MHz.
2. Interference from other users is more.
3. Power is not concentrated in small area on the earth.
4. Big sized parabolic dishes are required for the direct reception in home TVs.

PART-2

Types of Satellite, Types of Orbit, Satellite Services, Advantages and Applications of Satellite Communication.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.6. **What are the different types of satellites ?**

Answer

Different types of satellite are :

i. **Communication satellites :** Geostationary satellites when used for the communication applications are called communication satellites. These are classified based on the coverage area as global, regional or domestic satellites. A term INTELSAT is used in satellite communication. These are used for communication of telephony, computer data, TV signals, etc.

ii. **Remote sensing satellites :** This type of satellite can be used to find out the condition of crops, forests or minerals underground. Indian satellite IRS is a remote sensing satellite. From the information obtained from remote sensing satellites detailed maps can be prepared.

iii. **Weather satellites :** These satellites are used for weather prediction, for taking the photographs of clouds. TIROS-1 was the first weather satellite.

iv. **Scientific satellites :** These satellites are simpler and of short life span. They are used to carry out various scientific studies. India's "Aryabhatta" was a scientific satellite.

Que 1.7. **What are active and passive satellites ? Also compare them.**

Answer

A. **Active satellite :** An active satellite is the one that has transmitting equipment such as a transponder. Transponder is a device that receives the signal from the earth, amplifies it and retransmits it back to the earth.

B. **Passive satellite :** A passive satellite merely reflects or scatters incident radiations from the earth. A part of the radiation is reflected or scattered back in the direction of earth.

C. **Comparison :**

S. No.	Active satellite	Passive satellite
1.	Design of active satellite is complex.	It's simple.
2.	It has limited bandwidth hence supports only a finite number of users.	It has wide bandwidth hence accommodated and infinite number of users.
3.	It supports long distance space communication.	It supports shorter distance space communication.
4.	It uses two separate frequencies like uplink and downlink.	It uses only one frequency which is downlink.
5.	Tracking of active satellite is easier.	Tracking of passive reflectors is difficult.

Que 1.8. **What is meant by geostationary orbit and geosynchronous orbit ? How do the geostationary orbit and geosynchronous orbit differ ?**

Answer

A. **Geostationary orbit :**

1. When the satellite rotates in an orbit above the equator, it is called as an equatorial or circular or geostationary orbit.
2. This orbit is exactly in the plane of the equator of the earth.
3. All the points on this orbit are equidistant from the earth's surface.
4. A satellite rotating in this orbit at an angular velocity equal to the earth's angular velocity seems to be stationary with reference to a point on the earth. Hence it is known as geostationary orbit.

B. Geosynchronous orbits :

1. The period of geosynchronous orbits is equal to the period of revolution of the earth itself *i.e.*, the geosynchronous and geostationary orbits have same periods.
2. Geosynchronous orbit has a radius of 42, 242 km and is circular, but it does not lie in the equatorial plane.
3. The position of the geosynchronous satellite changes from time to time due to its inclination with the equatorial plane.

C. Difference :

S. No.	Geostationary orbit	Geosynchronous orbit
1.	It lies in the equatorial plane. Its inclination is zero.	It is inclined with respect to the equatorial plane.
2.	A satellite in this orbit appears to be stationary with respect to the earth.	A satellite in this orbit appears to oscillate with respect to a point on the earth.
3.	The period of satellite is 23 hr, 56 min and 4.1 sec.	There can be many geosynchronous orbits.
4.	The position of the satellite is fixed with respect to the earth station.	The position of the satellite in this orbit changes with time due to its inclination with the equatorial plane.

Que 1.9. **Briefly explain polar orbits. What are their advantages, disadvantages and applications ?**

Answer

A. Polar orbits :

1. When the satellite rotates in an orbit that takes it over the poles, this orbit is known as polar orbits.
2. The low altitude satellites have a height of 100 to 300 miles above the earth and travel at a speed of approximately 17,500 mph.
3. It takes about 1½ hours to complete its rotation.
4. Consequently, the time that the satellite is in line of sight with a particular earth station is only 1/4 hour or less per orbit.

B. Advantages :

1. There are large numbers of polar orbits available.
2. The satellite can cover high altitude regions.

3. The satellites in these orbits can be used for communication as well as many other special purposes.
4. There is no echo and the delay time is also negligible.
5. Station keeping is not required. The gravitational pull of the sun and moon have negligible effect.

C. Disadvantages :

1. Requires a tracking antenna, as the satellite is available for a short duration of time.
2. High altitude satellite suffers from Doppler's shift.
3. A number of satellites are required for complete earth coverage.
4. For the satellite at low orbits below 1000 km, the performance is affected by atmospheric drag.

D. Applications :

1. These satellites are used for remote sensing. They are not normally used for the communication purposes.
2. They are used as navigation satellites.
3. They are used as weather forecasting satellites.

Que 1.10. **What is sun-synchronous orbit ?**

Answer

1. The plane of this orbit maintains a constant aspect angle with the direction of the sun. Hence, they are called as sun-synchronous orbits.
2. The satellite in this orbit covers a particular place on the earth's surface at the same local time each day thus observing under the same illumination conditions.
3. The satellite is placed in a near polar orbit with right altitude and inclination to make its orbit plane twist approximately 1° per day.
4. The angle between the orbit plane and the radius vector to the sun remains constant throughout the year.
5. The satellite has the maximum accessibility from the poles.

Que 1.11. **What are inclined orbits ?**

Answer

1. The satellite following any other orbital path, other than the equatorial or polar is called as an inclined orbit.
2. Inclined orbits are at some angle with the equatorial plane.

3. They are used by many countries for their domestic communication.
4. The height of the inclined orbits is set to cover the area of interest.
5. The time for which the satellite is visible to the point on the earth is also controlled.
6. The satellite cannot remain in continuous contact with the point on the earth if rotating in the inclined orbits.
7. Sometimes they are also called as elliptical inclined orbit.

Que 1.12. **What are prograde and retrograde orbits ?**

Answer

A. Prograde orbit :

1. An orbit in which the satellite moves in the same direction as the earth's rotation is called a prograde orbit.
2. They are also called as direct orbit.
3. Most of the satellites are launched in these orbits, because the earth's rotational velocity provides part of the orbital velocity with a consequent saving in the launch energy.
4. The inclination of these orbits always lies between 0° and 90°.

B. Retrograde orbit :

1. The orbits in which the satellite moves in the direction, opposite to the direction of the rotation of the earth, are called retrograde orbits.
2. The inclination of a retrograde orbit lies between 90° and 180°.

Que 1.13. **Write a short note on Molniya orbits.**

Answer

1. They are highly elliptical orbits. The apogee of a Molniya orbit is at an altitude of 39,152 km and perigee is at an altitude of 500 km. They have an orbital inclination of 62.9° and orbital period of 11 hours 38 minutes.
2. Molniya orbits are used by Russia, due to its extreme latitudes, for its various operations.
3. Two Molniya orbits with the planes of the orbits separated by 180° provide the complete coverage of Russia for 24 hours per day.
4. When one of the satellites is at its apogee, then the other satellite is also at its apogee.
5. By the time the second satellite has moved once more to its apogee in Molniya orbit 2, the earth will have revolved half a turn under it.
6. Both the Molniya orbits are separated by 180° in their orbital planes. By the time the satellite 2 has moved around its orbit once and back to its apogee the earth will have rotated about 180°. The second satellite will be over Russia.

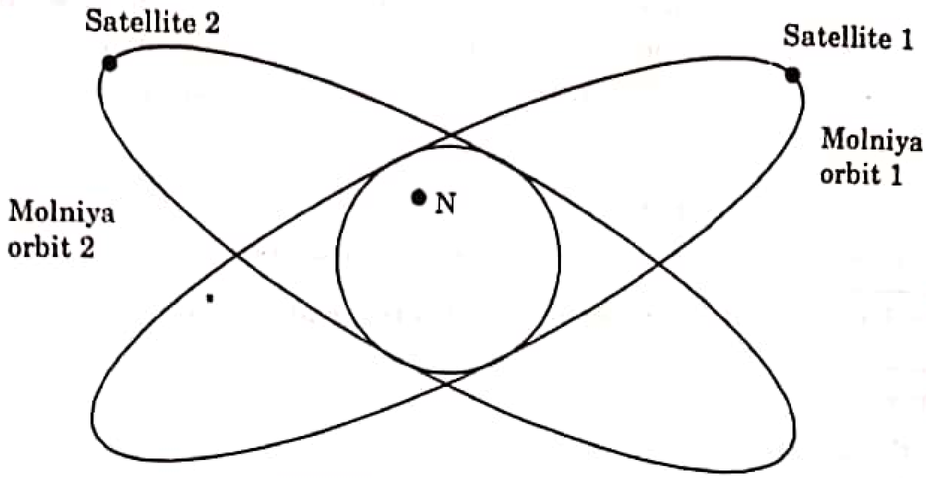

Fig. 1.13.1. Molniya system.

7. Upto eight Molniya orbits can be there, separated by 45°. The drawbacks associated with these orbits are :

i. Tracking the spacecraft.

ii. Need for switching communication to other Molniya satellite.

iii. Satellite has to pass through a radiating environment.

These drawbacks increase the overall end to end costs.

Que 1.14. **Describe briefly LEO and MEO. Give their advantages and disadvantages.**

Answer

A. LEO :

1. A low Earth orbit (LEO) is an orbit that is relatively close to Earth's surface. It is normally at an altitude of less than 1500 km but more than 500 km above Earth.
2. It is the orbit most commonly used for satellite imaging, as being near the surface allows it to take images of higher resolution.
3. It is also the orbit used for the International Space Station (ISS), as it is easier for astronauts to travel to and from it at a shorter distance.

Advantages of LEO :

1. It eliminates need for bulky receiver equipments due to higher C/N signal ratio.
2. Low price satellite equipments are sufficient for ground stations.
3. Better frequency reuse can be achieved due to smaller footprints.
4. It provides high elevation for polar regions of the Earth. Hence better global coverage can be achieved.

Disadvantages of LEO :

1. Large numbers of satellites are required for global coverage.
2. Atmospheric effects are more and hence will cause gradual orbital disorientation of the satellites. This requires regular maintenance of satellites to keep them on track in the LEO orbit.

B. MEO :

1. The region of space in between the low Earth orbit and the geostationary orbit is called the Medium Earth Orbit (MEO).
2. This orbit is at a distance of 10000 to 15000 kms from the earth's surface.
3. This orbit is ideal for navigation and communication satellites.

Advantages of MEO :

1. Less number of satellites is needed to cover entire area of the Earth.

Disadvantages of MEO :

1. The signals become weak when they reach earth from MEO compare to LEO.
2. The system is more expensive compare to LEO.

Que 1.15. **Compare LEO, MEO and GEO.**

Answer

S. No.	Parameter	LEO	MEO	GEO
1.	Height of satellite	500-1500 km	10000-15000 km	Above 36000 km
2.	Orbital Period	15-20 minutes	2-12 hour	24 hour
3.	Number of satellite	40-80	8-20	3
4.	Satellite life	Short	Long	Long
5.	Cost	Very expensive	Expensive	Cheap
6.	Propagation loss	Least	High	Highest

Que 1.16. **What are the services of satellite communication ?**

Answer

The services of satellite communication can be classified into the following two categories :

i. One-way satellite communication link service :

1. In one-way satellite communication link service, the information can be transferred from one earth station to one or more earth stations through a satellite. That means, it provides both point to point connectivity and point to multi-point connectivity.
2. Following are some of the one-way satellite communication link services.
   a. Broadcasting satellite services like Radio, TV and Internet services.
   b. Space operations services like Telemetry, Tracking and Commanding services.
   c. Radio determination satellite service like Position location service.

ii. Two-way satellite communication link service :

1. In two-way satellite communication link, the information can be exchanged between any two earth stations through a satellite. That means, it provides only point to point connectivity.
2. Following are the two-way satellite communication link services :
   a. Fixed satellite services like Telephone, Fax and Data of high bit rate services.
   b. Mobile satellite services like Land mobile, Maritime and Aero mobile communication services.

Que 1.17. **List various advantages and disadvantages of satellite communication. Also mention the applications of satellite communication.**

Answer

A. Advantages :

1. Point to multi-point communication is possible.
2. Circuits for the satellite can be installed rapidly.
3. Mobile communication can be easily achieved.
4. It is economically advantageous *i.e.* the satellite cost is independent of the distance.

B. Disadvantages :

1. There is a delay of 1/4th of a second between the transmitted and received signal. This delay causes an ECHO due to imperfect impedance matching.
2. The time delay reduces the efficiency of data transmission.
3. Over-crowding of available bandwidths due to low antenna gains.
4. High atmospheric losses above 30 GHz limit the carrier frequencies.

C. Applications :

1. To gain meteorological or weather information. The photographs taken from the satellites are used for predicting the weather.

2. Direct broadcast by satellite.
3. Messaging and voice communication.
4. Communication of audio signals (telephones, satellite phones), video signals (TV) and computer data (internet).
5. Used for tracking the enemy movement by military.

PART-3

Satellite Life Phases, Space Debris.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.18. **What are satellite life phases ?**

Answer

1. Typically there are four main stages in the life phase of a satellite.
2. At the end of each stage the project go through a series of technical reviews in order to ensure that the stage has been properly completed.

A. Concept exploration :

1. The first stage is the concept exploration.
2. During this phase the initial mission concept feasibility is studied and a preliminary design is produced.
3. The preliminary design take into account the requirements provided by the customer.

B. Detailed design phase :

1. The second stage is the detailed design phase.
2. At this point, the customer provides more detailed requirements as the design of the mission and the satellite becomes more advanced.
3. By the end of this phase a "baseline" solution for the mission is produced.
4. This provides the starting point for the next stage.

C. Manufacture and testing :

1. The third stage is manufacture and testing.
2. In this stage, the overall satellite design is finalised and the manufacturing of satellite begins.

3. The different parts of a satellite are often supplied by a number of suppliers.
4. The role of the satellite manufacturer is to bring all of the parts together in the correct way in order to build the satellite.
5. This work is known as satellite assembly and integration.

D. Launch and operation :

1. The final stage is launch and operation.
2. The satellite is blast off from the launch site and be propelled into space.
3. Once the satellite has been released from the launcher, it will manoeuvre itself into the desired orbit.
4. After a few months of initial in-orbit testing, it will begin its nominal mission.

Que 1.19. **What is the space debris ? How does space junk get into space ?**

Answer

A. Space Debris :

1. Space junk (space debris) is any piece of machinery or debris left by humans in space.
2. It can refer to big objects such as dead satellites that have failed or been left in orbit at the end of their mission. It can also refer to smaller things, like bits of debris or paint flecks that have fallen off a rocket.

B. Reasons :

1. All space junk is the result of us launching objects from Earth, and it remains in orbit until it re-enters the atmosphere.
2. Some objects in lower orbits of a few hundred km can return quickly. They often re-enter the atmosphere after a few years and, for the most part, they'll burn up so they don't reach the ground.
3. But debris or satellites left at higher altitudes of 36,000 km, where communications and weather satellites are often placed in geostationary orbits can continue to circle earth for hundreds or even thousands of years.
4. Some space junk results from collisions or anti-satellite tests in orbit. When two satellites collide, they can smash apart into thousands of new pieces, creating lots of new debris.
5. This is rare, but several countries including the USA, China and India have used missiles to practice blowing up their own satellites. This creates thousands of new pieces of dangerous debris.

PART-4

Introduction of Geosynchronous and Geostationary Satellites.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.20. **What is Geosynchronous satellite ? Also write it uses.**

Answer

A. Geosynchronous satellite :

1. A geosynchronous satellite is a communication satellite that has an orbital period same as the period of rotation of the earth.
2. Hence, it appears to be permanently in the same area of the sky at a particular time each day when viewed by an observer on the earth.
3. The orbit in which a geosynchronous satellite is placed is called geosynchronous orbit (GSO).
4. Its orbital period is the sidereal day, *i.e.*, 23 hours 56 minutes 4 seconds and its orbital altitude is 35,800 km.

B. Uses :

1. Voice and data communication
2. Internet
3. Broadcasting cable TV and radio signals

Que 1.21. **Explain geostationary satellite.**

Answer

1. A geostationary satellite is an earth-orbiting satellite, placed at an altitude of approximately 35,800 kilometers (22,300 miles) directly over the equator, that revolves in the same direction the earth rotates (west to east).
2. At this altitude, one orbit takes 24 hours, the same length of time as the earth requires to rotate once on its axis.
3. The term geostationary comes from the fact that such a satellite appears nearly stationary in the sky as seen by a ground-based observer.

4. A single geostationary satellite is on a line of sight with about 40 percent of the earth's surface.
5. Three such satellites, each separated by 120 degrees of longitude, can provide coverage of the entire planet, with the exception of small circular regions centered at the north and south geographic poles.
6. A geostationary satellite can be accessed using a directional antenna, usually a small dish, aimed at the spot in the sky where the satellite appears to hover.
7. The principal advantage of this type of satellite is the fact that an earthbound directional antenna can be aimed and then left in position without further adjustment.
8. Another advantage is the fact that because highly directional antennas can be used, interference from surface-based sources, and from other satellites, is minimized.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the elements of satellite communication system? Explain each with a suitable block diagram.

Ans. Refer Q. 1.3.

Q. 2. Explain uplink and downlink frequencies. Also give the reason for the downlink frequency to be lower than uplink frequency.

Ans. Refer Q. 1.4.

Q. 3. What is meant by geostationary orbit and geosynchronous orbit? How do the geostationary orbit and geosynchronous orbit differ?

Ans. Refer Q. 1.8.

Q. 4. Describe briefly LEO and MEO. Give their advantages, disadvantages and applications.

Ans. Refer Q. 1.15.

Q. 5. List various advantages and disadvantages of satellite communication. Also mention the applications of satellite communication.

2 UNIT

Orbital Mechanics

CONTENTS

PART-1

Orbital Mechanics, Kepler's Three Laws of Planetary Motion.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. What are orbit elements ?

Answer

1. To specify the absolute coordinates of a satellite at time t, we need to know six quantities. These quantities are called the orbital elements.
2. Six quantities can be used to describe a unique orbital path. The commonly used in satellite communications :
   i. Eccentricity (e)
   ii. Semi-major axis (a)
   iii. Time of perigee (t_p)
   iv. Inclination (i)
   v. Right ascension of ascending node (Ω)
   vi. Argument of perigee (ω)
3. The semi-major axis and eccentricity describe the shape of the ellipse. The mean anomaly gives an average value of the angular position of the satellite with reference to the perigee.
4. The inclination and right ascension of ascending node relates the orbit plane's position to the earth.
5. The argument of perigee gives the rotation of the orbits perigee point relative to the orbits line of nodes in the earth's equatorial plane.

Que 2.2. Define apogee and perigee heights.

Answer

A. Apogee :

1. It is the farthest point on the satellite's orbit from the surface of the earth.
2. The radius of apogee is given as :

$$r_a = a(1 + e)$$

where a = Length of semi-major axis, and

e = Eccentricity of the elliptical orbit.

B. Perigee :

1. It is the closest point on the orbit from the surface of the earth.
2. The radius of perigee is given as :

$$r_p = a(1 - e)$$

3. To find the apogee and perigee heights the radius of the earth must b subtracted from the radii lengths.

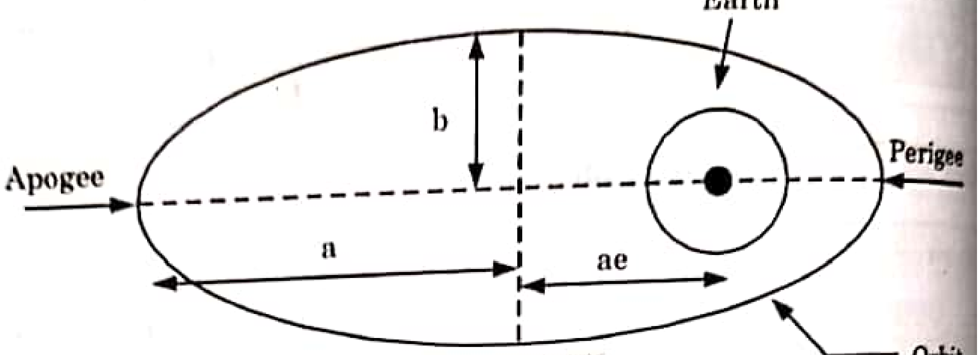

Fig. 2.2.1.

Que 2.3. **Define argument of perigee, mean anomaly and tru anomaly.**

Answer

A. Argument of perigee :

1. It is the angle from the ascending node to perigee, measured in th orbital plane at the earth's centre in the direction of satellite motion.
2. It is denoted by ω.

B. Mean anomaly :

1. It gives an average value of the angular position of the satellite wit reference to the perigee. It is denoted by M.
2. In case of a circular orbit, M gives the angular position of the satellite in the orbit.

C. True anomaly :

1. It is defined as the angle made from the perigee to the satellite position measured at the earth's centre.
2. The true angular position of the satellite in the orbit is a function of time.

Que 2.4. **Define the following :**

1. **Ascending node.**
2. **Descending node.**
3. **Line of apside.**
4. **Line of nodes.**
5. **Inclination.**

Answer

1. **Ascending node :** The point where the orbit crosses the equatorial plane going from south to north is called the ascending node.
2. **Descending node :** The point where the orbit crosses the equatorial plane going from north to south is called the descending nodes.
3. **Line of apside :** The line joining the perigee and apogee through the centre of earth is called as the line of apside.
4. **Line of nodes :** The line joining the ascending and the descending nodes through the centre of earth is called as the line of nodes.

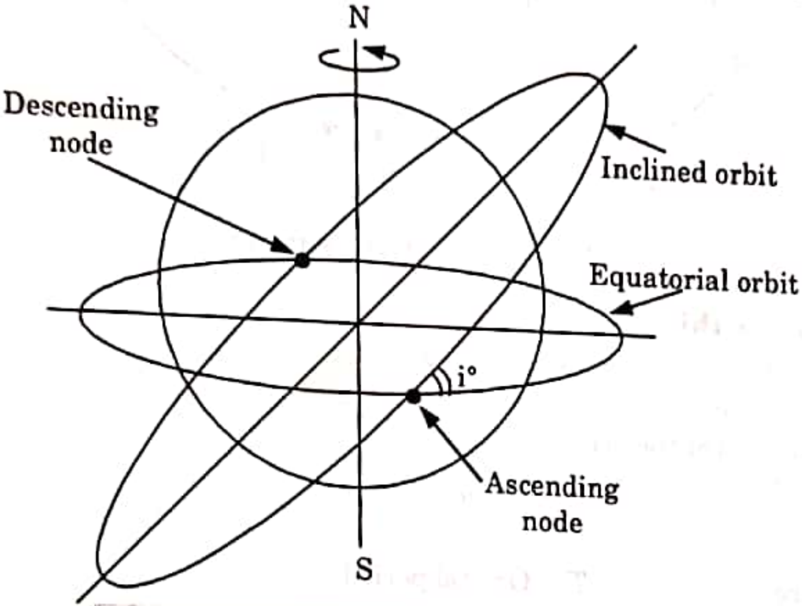

Fig. 2.4.1. Ascending and descending node.

5. **Inclination :** It is the angle between the orbital plane and the earth's equatorial plane. It is denoted by 'i' and is measured at the ascending node from the equator to the orbit going from east to north.

Que 2.5. **Explain Kepler's law of planetary motion.**

Answer

The three Kepler's laws of planetary motion are :

i. **Kepler's first law :**

1. The orbit of any smaller body about a larger body is always an ellipse, with the centre of mass of the larger body as one of the two foci.
2. The eccentricity of the orbit is given by :

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

where, a and b are semi-major and semi-minor axis respectively.

ii. Kepler's second law :

1. The orbit of the smaller body sweeps out equal areas in equal time.
2. If $t_1 - t_2 = t_3 - t_4$, then according to Kepler's second law,

$$A_1 = A_2$$

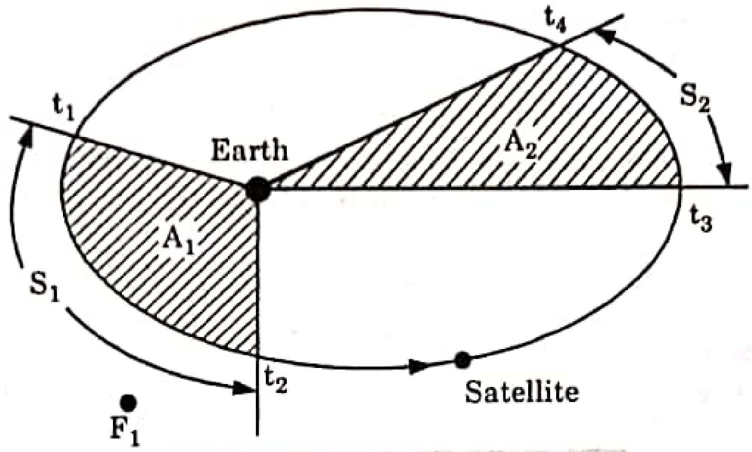

Fig. 2.5.1. Kepler's second law.

iii. Kepler's third law :

1. The square of the period of revolution of the smaller body about the larger body equals a constant multiplied by the third power of the semi-major axis of the orbital ellipse.

i.e.,
$$T^2 = \frac{4\pi^2 a^3}{\mu}$$

where, T = Orbital period

a = Semi-major axis of the orbital ellipses

μ = Kepler's constant

2. And the velocity of the satellite is given as :

$$v^2 = \mu\left[\frac{2}{r} - \frac{1}{a}\right]$$

where, r is the distance of the satellite from the centre of the earth.

Que 2.6. **The apogee and perigee of an elliptical satellite orbits are 3000 km and 200 km. Determine the eccentricity, semi-major axis and semi-minor axis.**

Answer

Given : r_a = 3000 km, r_p = 200 km
To Find : Eccentricity, semi-major axis, semi-minor axis.

1. Semi-major axis, $a = \dfrac{r_a + r_p}{2}$

$$= \frac{3000 + 200}{2} = 1600 \text{ km}$$

2. Eccentricity, $e = \dfrac{r_a - a}{a}$

$$= \frac{3000 - 1600}{1600} = 0.875$$

3. Semi-minor axis, $b = \sqrt{r_a r_b}$

$$= \sqrt{(3000) \times (200)}$$

$$b = 774.59 \text{ km}$$

Que 2.7. **The semi-major and semi-minor axis of an elliptical satellite orbit are 20,000 km and 1600 km respectively. Determine the apogee and perigee distance.**

Answer

Given : Semi-major axis, a = 20,000 km, Semi-minor axis, b = 1,600 km
To Find : Apogee and perigee distance.

1. We have, $a = \dfrac{r_a + r_p}{2}$

$$\therefore \quad 2 \times 20{,}000 = r_p + r_a \qquad ...(2.7.1)$$

$$\therefore \quad r_a + r_p = 40{,}000$$

$$b = \sqrt{r_p r_a}$$

2. Squaring, we get $b^2 = r_p r_a$

$$b^2 = (1600)^2 = r_a r_p$$

$$\therefore \quad r_p = \frac{2560000}{r_a} \qquad ...(2.7.2)$$

3. Substituting eq. (2.7.2) in eq. (2.7.1), we get

$$r_a^{\ 2} + 2560000 = 40000\, r_a$$

$$\therefore \quad r_a^{\ 2} - 40000\, r_a + 2560000 = 0$$

$$r_a = \frac{40000 \pm 39871.8}{2}$$

$$r_a \approx 39936 \text{ km}$$

4. Substituting the value of r_a in eq. (2.7.2), we get

$$r_p = \frac{2560000}{39936}$$

$$r_p \approx 64 \text{ km}$$

$\therefore$ Apogee distance, $r_a = 39936$ km

and perigee distance, $r_p = 64$ km

Que 2.8. **A satellite is an elliptical orbit with a perigee of 1000 km and an apogee of 4000 km. Using mean earth radius of 6378.14 km, find the period of the orbit in hours, minutes and seconds and the eccentricity of the orbit.**

Answer

Given : Height of perigee, $h_p = 1000$ km, Height of apogee, $h_a = 4000$ km, Radius of the earth, $r_e = 6378.14$ km
To Find : Period of orbit

1. The length of semimajor axis (a), is given by

$$2a = 2r_e + h_p + h_a$$
$$= 2 \times 6378.14 + 1000 + 4000$$
$$= 17{,}756.28 \text{ km}$$
$$a = 8878.14 \text{ km}$$

2. Orbital period, T (seconds) is given by

$$T = \sqrt{\frac{4\pi^2 a^3}{\mu}}$$

$$= \sqrt{\frac{4\pi^2 \times (8878.14)^3}{3.986 \times 10^5}} \quad [\because \mu = 3.986 \times 10^5 \text{ km}^3/\text{s}^2]$$

$$= 8325.19 \text{ sec}$$
$$= 138 \text{ min } 45.19 \text{ sec}$$
$$= 2 \text{ hours } 18 \text{ min } 45.19 \text{ sec}$$

3. Eccentricity, $e = \dfrac{h_a - h_p}{h_a + h_p}$

$$= \frac{4000 - 1000}{4000 + 1000} = 0.6$$

Que 2.9. **A satellite moving in a highly eccentric Molniya orbit having the farthest and the closest points as 35000 km and 500 km respectively from the surface of the earth. Determine the orbital time period and the velocity at the apogee and perigee points. (Assume earth's radius equals to 6360 km and Kepler's constant = 3.986×10^5 km^3/s^2).**

Answer

Given : Apogee = 35000 km, perigee = 500 km
To Find : Orbital time period, velocity at apogee and perigee

1. Apogee distance, $r_a = 35000 + 6360 = 41360$ km
2. Perigee distance, $r_p = 500 + 6360 = 6860$ km
3. Semi-major axis,
$$a = \frac{r_a + r_p}{2}$$
$$= \frac{41360 + 6860}{2} = 24110 \text{ km}$$
4. Orbital time period is given as :
$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$
$$= 2\pi\sqrt{\frac{(24110)^3}{(3.986 \times 10^5)}} = 37.26 \times 10^3 \text{ sec}$$
5. Velocity at apogee : $v_a = \sqrt{\mu\left[\frac{2}{r_a} - \frac{1}{a}\right]}$
$$= \sqrt{3.986 \times 10^5\left[\frac{2}{41360} - \frac{1}{24110}\right]} = 1.656 \text{ km/sec}$$
6. Velocity at perigee : $v_p = \sqrt{\mu\left[\frac{2}{r_p} - \frac{1}{a}\right]}$
$$= \sqrt{3.986 \times 10^5\left[\frac{2}{6860} - \frac{1}{24110}\right]} = 9.984 \text{ km/sec}$$

PART-2

Developing the Equations of the Orbit, Look Angle Determination, Earth Stations.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.10. **Derive the equation for the radius of satellite orbit.**

Answer

1. The acceleration a, due to gravity at a distance r from the centre of the earth is
$$a = \mu/r^2 \text{ km/s}^2$$
2. Since, force = mass × acceleration, the centripetal force acting on the satellite, F_{IN}, is given by
$$F_{IN} = m \times (\mu/r^2)$$
$$F_{IN} = m \times (GM_E/r^2)$$
3. The centrifugal acceleration is given by
$$a = v^2/r$$
The centrifugal force
$$F_{out} = m \times (v^2/r)$$

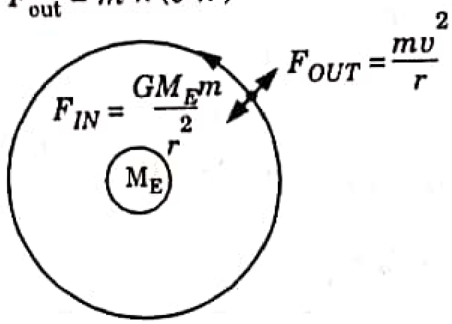

Fig. 2.10.1.

4. If the forces are balanced,
$$F_{IN} = F_{out}$$
$$m \times \mu/r^2 = m \times v^2/r$$
5. Hence the velocity v of a satellite in a circular orbit is given by
$$v = (\mu/r)^{1/2} \quad ...(2.10.1)$$
The period of the satellite is
$$T = (2\pi r)/v = (2\pi r) / (\mu/r)^{1/2}$$
$$T = (2\pi r^{3/2})/(\mu^{1/2}) \quad ...(2.10.2)$$
7. With the coordinate system set up in Fig. 2.10.2, the gravitational force F on the satellite is given by
$$\vec{F} = \frac{-GM_E m\vec{r}}{r^3} \quad ...(2.10.3)$$
where, M_E is the mass of the earth and $G = 6.672 \times 10^{-11}$ Nm²/kg².
8. But, $F = ma$, then eq. (2.10.3) can be written as
$$F = m\frac{d^2\vec{r}}{dt^2} \quad ...(2.10.4)$$
9. From eq. (2.10.3) and (2.10.4) we have
$$\frac{-\vec{r}}{r^3}\mu = \frac{d^2\vec{r}}{dt^2}$$
$$\frac{d^2\vec{r}}{dt^2} + \frac{\vec{r}}{r^3}\mu = 0 \quad ...(2.10.5)$$

This is the second-order linear differential equation and its solution will involve six undetermined constants called the orbital elements.

10. A different set of coordinates can be chosen to describe the location of the satellite. This is shown in Fig. 2.10.2.

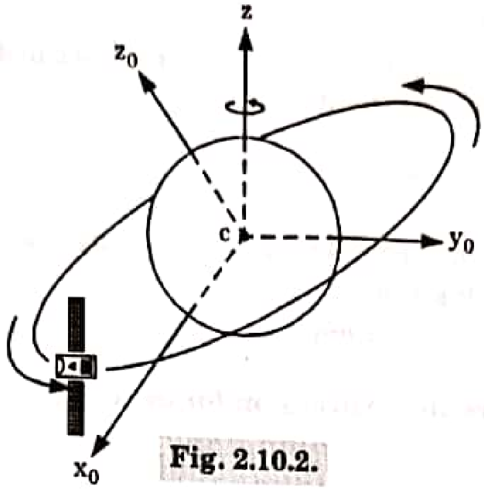

Fig. 2.10.2.

9. Expressing eq. (2.10.5) in terms of the new coordinate axes x_0, y_0 and z_0 gives

$$\hat{x}_0\left(\frac{d^2x_0}{dt^2}\right)+\hat{y}_0\left(\frac{d^2y_0}{dt^2}\right)+\frac{\mu\left(x_0\hat{x}_0+y_0\hat{y}_0\right)}{(x_0^2+y_0^2)^{3/2}}=0 \qquad ...(2.10.6)$$

10. It is easier to solve in polar coordinate system. The polar coordinate system is shown in Fig. 2.10.3.

$$x_0 = r_0 \cos \phi_0$$

$$y_0 = r_0 \sin \phi_0$$

$$\hat{x}_0 = \hat{r}_0 \cos \phi_0 - \hat{\phi}_0 \sin \phi_0$$

$$\hat{y}_0 = \hat{\phi}_0 \cos \phi_0 + \hat{r}_0 \sin \phi_0$$

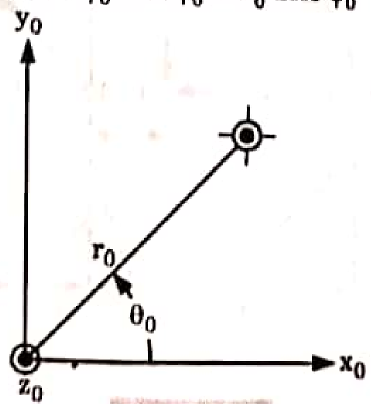

Fig. 2.10.3.

11. Equating the vector components of r_0 and ϕ_0 in turn in eq. (2.10.6) yields

$$\frac{d^2 r_0}{dt^2} - r_0\left(\frac{d\phi_0}{dt}\right) = -\frac{\mu}{r_0^2}$$

and $$r_0\left(\frac{d^2\phi_0}{dt^2}\right) + 2\left(\frac{dr_0}{dt}\right)\left(\frac{d\phi_0}{dt}\right) = 0$$

12. Using standard mathematical procedures, we can develop an equation for the radius of the satellite's orbit, r_0,

$$r_0 = \frac{p}{1 + e\cos(\phi_0 - \theta_0)}$$

where, θ_0 is a constant and e is the eccentricity of an ellipse whose semi-latus rectum p is given by

$$p = h^2/\mu$$

Que 2.11. **Derive the expression for orbital period T and angular velocity.**

Answer

1. We know that the orbit is an ellipse; we can choose x_0 and y_0 so that θ_0 is zero. So, the equation of the orbit is given as

$$r_0 = \frac{p}{1 + e\cos\phi_0}$$

2. The path of the satellite in the orbital plane is shown in Fig. 2.11.1.

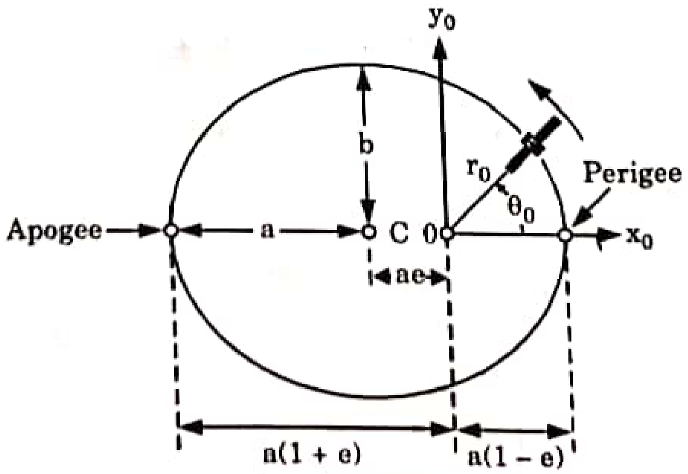

Fig. 2.11.1.

3. The lengths a and b of the semi-major and semi-minor axis are given by

$$a = p/(1 - e^2)$$
$$b = a(1 - e^2)^{1/2}$$

4. The differential area swept out by the vector r_0 from the origin to the satellite in time dt is given by

$$dA = 0.5\, r_0^2 \left(\frac{d\phi_0}{dt}\right) dt = 0.5h\, dt$$

5. By equating the area of the ellipse (πab) to the area swept out in one orbital revolution, then the orbital period T is given as

$$T^2 = (4\pi^2 a^3)/\mu$$

6. The average angular velocity η is :

$$\eta = 2\pi/T$$

$$\eta = \frac{(\mu^{1/2})}{(a^{3/2})}$$

Que 2.12. **What do you mean by look angle ? Explain azimuth and elevation angles.**

Answer

A. Look angle :

In order to orient an earth station antenna towards a satellite, it is essential to know the elevation angle and the azimuth angles. There are called as look angles.

B. Azimuth angle (A_z) :

1. It is an angle made by projected satellite path with respect to north. It is calculated in clockwise direction.
2. A local horizontal plane is formed by the north and the east axis. The third axis is a local vertical axis. An earth station is considered to be at the centre of the coordinate system.

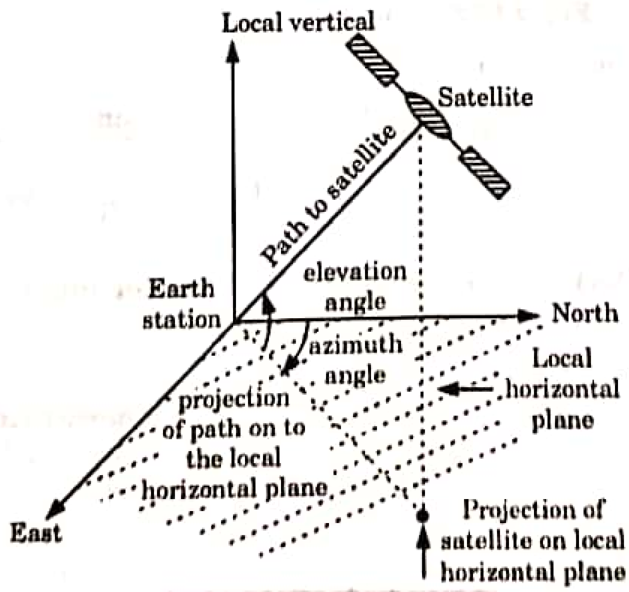

Fig. 2.12.1. Look angles.

3. To find the azimuth angle a projection of the satellite path is taken on the local horizontal plane.
3. The azimuth angle A_z is between 0 and 360°. Depending on the location of the earth station with respect to the subsatellite points, the azimuth angle A_z is given by :

a. **Northern hemisphere :**

i. Earth station west of satellite :

$$A_z = 180° - \alpha$$

ii. Earth station East of satellite :

$$A_z = 180° + \alpha$$

b. **Southern hemisphere :**

i. Earth station west of satellite : $A_z = \alpha$

ii. Earth station east of satellite : $A_z = 360° - \alpha$

C. **Elevation angle (El) :**

1. The elevation angle is an angle made by the satellite path with respect to local horizontal plane.
2. The elevation angle determines the height of the satellite from the horizontal plane.

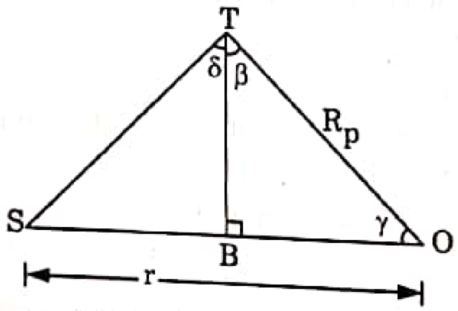

Fig. 2.12.2. Triangle to calculate elevation.

3. The angle of elevation is,

$$\cos(El) = \frac{r_s \sin\gamma}{d} = \frac{\sin\gamma}{\left[1+\left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos\gamma\right]^{1/2}}$$

Que 2.13. **Derive the expression for elevation angle.**

Answer

1. In Fig. 2.13.1, r_s is the vector from the center of the earth to the satellite, r_e is the vector from the center of the earth to the earth station, and d is the vector from the earth station to the satellite.
2. These three vectors lie in the same plane and form a triangle. The central angle γ measured between r_e and r_s is the angle between the earth station and satellite, and ψ is the angle measured from r_e to d.

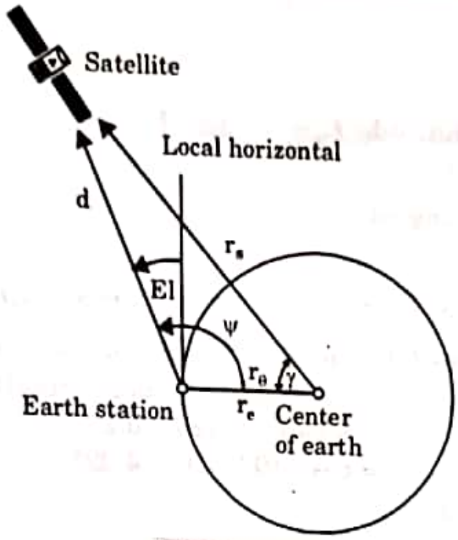

Fig. 2.13.1.

3. γ is related to the earth station north latitude L_e and west longitude l_e and the subsatellite point at north latitude L_s and west longitude l_s by

$$\cos(\gamma) = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s) \quad ...(2.13.1)$$

4. The law of cosines allows us to relate the magnitudes of the vectors joining the center of the earth, the satellite and the earth station. Thus,

$$d = r_s\left[1+\left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos(\gamma)\right]^{1/2} \quad ...(2.13.2)$$

5. Since the local horizontal plane at the earth station is perpendicular to r_e, the elevation angle El is related to the central angle ψ by

$$El = \psi - 90° \quad ...(2.13.3)$$

5. By law of sines we have

$$\frac{r_s}{\sin(\psi)} = \frac{d}{\sin(\gamma)} \quad ...(2.13.4)$$

6. Combining the eq. (2.13.2), eq. (2.13.3) and eq. (2.13.4) yields

$$\cos(El) = \frac{r_s\sin(\gamma)}{d}$$

$$\cos(El) = \frac{\sin\gamma}{\left[1+\left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos\gamma\right]^{1/2}}$$

This equation permits the elevation angle (El).

Que 2.14. **An earth station has the following specifications. Calculate the look angles. Earth station has 50° latitude and 0° longitude. Subsatellite point is 65° E. Assume that the satellite is geosynchronous with r_s = 42164.17 km and radius of earth, r_e = 6378.137 km.**

Answer

Given : Earth's latitude, $L_e = 50°$, Earth's longitude, $l_e = 0°$, Satellite's longitude, $l_s = 65°$

To Find : Look angles.

1. We know that :

$$\cos(\gamma) = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s)$$

$$\cos(\gamma) = \cos(50°)\cos(0°)\cos(65° - 0°) + \sin(50°)\sin(0°)$$

$\{L_s = 0°$ as the satellite is geostationary$\}$

$$= 0.643 \times 0.423 = 0.272$$

$$\gamma = \cos^{-1}(0.272) = 74.22°$$

∴ Central angle,

$$\gamma = 74.24°$$

2. Elevation angle,

$$El = \tan^{-1}\left[\frac{\frac{r_s}{r_e} - \cos\gamma}{\sin\gamma}\right] - \gamma$$

$$= \tan^{-1}\left[\frac{\frac{42164.17}{6378.137} - \cos 74.22°}{\sin 74.22°}\right] - 74.22°$$

$$= \tan^{-1}\left[\frac{6.611 - 0.272}{0.9624}\right] - 74.22°$$

$$El = 81.367° - 74.22° = 7.147°$$

3. Intermediate angle,

$$\alpha = \tan^{-1}\left[\frac{\tan|l_s - l_e|}{\sin L_e}\right]$$

$$= \tan^{-1}\left[\frac{\tan|65° - 0|}{\sin 50°}\right] = 70.34°$$

4. Since the earth station is in the northern hemisphere, and the sub-satellite point is on its south-east.

∴ Azimuth angle, $A_z = 180° - \alpha = 109.65°$

Que 2.15. **Calculate the slant range of a geostationary satellite orienting at 42200 km from an earth station making an elevation angle of 25°. Also find the viewing angle of the satellite.**

Answer

Given : Radius of the orbit, $r_s = 42200$ km, Elevation angle, $El = 25°$

To Find : Slant range, viewing angle.

1. Now central angle, $\gamma = \cos^{-1}\left[\frac{r_e \cos El}{r_s}\right] - El$ [$\because$ Assume r_e = 6378 km]

$$= \cos^{-1}\left[\frac{6378}{42200}\cos 25°\right] - 25° = 57.13°$$

2. The slant range will be :

$$d_s = r_s\left[1 + \left[\frac{r_e}{r_s}\right] - 2\left(\frac{r_e}{r_s}\right)\cos\gamma\right]^{1/2}$$

$$= 42200\left[1 + \left[\frac{6378}{42200}\right]^2 - \frac{2 \times 6378}{42200}\cos 57.13\right]^{1/2}$$

$$= 39107.0713 \text{ km}$$

3. Viewing angle, S is given by :

$$\sin S = \frac{r_e}{r_e + h}\cos El = \frac{6378}{42200}\cos 25° = 0.1369$$

$$S = \sin^{-1}(0.1369) = 7.868°$$

Que 2.16. **An earth station is located at a longitude of 76° east and latitude of 13° north while the satellite is at 83° east. Calculate the elevation and azimuth requirement of a transmitting antenna. Assume the radius of satellite's orbit, r_s = 42164.17 km and radius of earth, r_e = 6378.137.**

Answer

Given : Earth's longitude, l_e = 76° east, Earth's Latitude, L_e = 13° north
To Find : Elevation and azimuth angle.

1. Satellite is at 83° east.
2. We have :

$$\lambda = l_s - l_e = 83° - 76° = 7°$$

3. So the satellite is 7° west of earth station.

$$\cos\gamma = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin L_e \sin L_s$$
$$= \cos 13° + \cos 7° + \sin 83° \sin 0°$$
$$\cos\gamma = 0.967$$
$$\gamma = 14.736$$

4. Elevation angle, $El = \tan^{-1}\dfrac{\left[\frac{r_s}{r_e} - \cos\gamma\right]}{\sin\gamma} - \gamma$

$$= \tan^{-1}\frac{\left[\frac{42164.17}{6378.137} - \cos 14.736\right]}{\sin 14.736} - 14.736$$

$$= \tan^{-1}\left[\frac{6.611 - 0.9671}{0.2544}\right] - 14.736$$

$$= \tan^{-1}[22.185] - 14.736 = 87.42 - 14.736$$

$$= 72.68$$

5. Intermediate angle, $\alpha = \tan^{-1}\left[\frac{\tan\lambda}{\sin L_e}\right] = \tan^{-1}\left[\frac{\tan 7^\circ}{\sin 13^\circ}\right] = 28.63^\circ$
6. Since the sub-satellite point is at south-west of earth station :
The azimuth angle, $A_z = 180^\circ + \alpha = 180^\circ + 28.62^\circ = 208.63^\circ$

PART-3

Orbital Perturbations, Orbital Effects in Communication System Performance.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.17. **What are orbital perturbations ?**

Answer

Following are the orbital perturbations due to gravitational and non-gravitational forces or parameters.

1. Irregular gravitational force around the Earth due to non-uniform mass distribution. Earth's magnetic field too causes orbital perturbations.
2. Main external perturbations come from Sun and Moon. When a satellite is near to these external bodies, it receives a stronger gravitational pull.
3. Low-orbit satellites get affected due to friction caused by collision with atoms and ions.
4. Solar radiation pressure affects large GEO satellites, which use large solar arrays.
5. Self-generated torques and pressures caused by RF radiation from the antenna.

Que 2.18. **What is the effect of the earth's oblateness ?**

Answer

1. The earth is neither a perfect sphere nor a perfect ellipse.
2. The earth is flattened at the poles; the equatorial diameter is about 20 km more than the average polar diameter.

3. The equatorial radius is not constant, although the non-circularity is small.
4. In addition to these non-regular features of the earth, there are regions where the average density of the earth appears to be higher. These are referred to as regions of mass concentration or Mascons.
5. For a low earth orbit satellite, the rapid change in position of the satellite with respect to the earth's surface will lead to an averaging out of the perturbing forces in line with the orbital velocity vector.
6. A geostationary satellite is weightless when in orbit. The smallest force on the satellite will cause it to accelerate and then drift away from its nominal location.
7. The satellite is required to maintain a constant longitudinal position over the equator, but there will generally be an additional force toward the nearest equatorial bulge in either an eastward or a westward direction along the orbit plane.
8. Due to the position of the Mascons and equatorial bulges, there are four equilibrium points in the geostationary orbit : two of them stable and two unstable.
9. The stable points are at about 75 °E and 252 °E and the unstable points are at around 162 °E and 348 °E.
10. If a satellite is perturbed slightly from one of the stable points, it will tend to drift back to the stable point without any thruster firings required.
11. A satellite that is perturbed slightly from one of the unstable points will immediately begin to accelerate its drift toward the nearer stable point and, once it reaches this point, it will oscillate in longitudinal position about this point until (centuries later) it stabilizes at that point.
12. These stable points are sometimes called the graveyard geosynchronous orbit locations.

Que 2.19. **Discuss the effects of the sun and moon, on the movement of the satellite in its orbit.**

Answer

1. The plane of the earth's orbit around the sun (the ecliptic) is at an inclination of 7.3° to the equatorial plane of the sun as shown in Fig. 2.19.1.
2. The earth is titled about 23° away from the normal to the ecliptic.
3. The moon circles the earth with an inclination of around 5° to the equatorial plane of the earth.
4. Due to the fact that the various planes (the sun's equator), the ecliptic, the earth's equator and the moon's orbital plane around the earth are all different, a satellite in orbit around the earth will be subjected to a variety of out-of-plane forces.

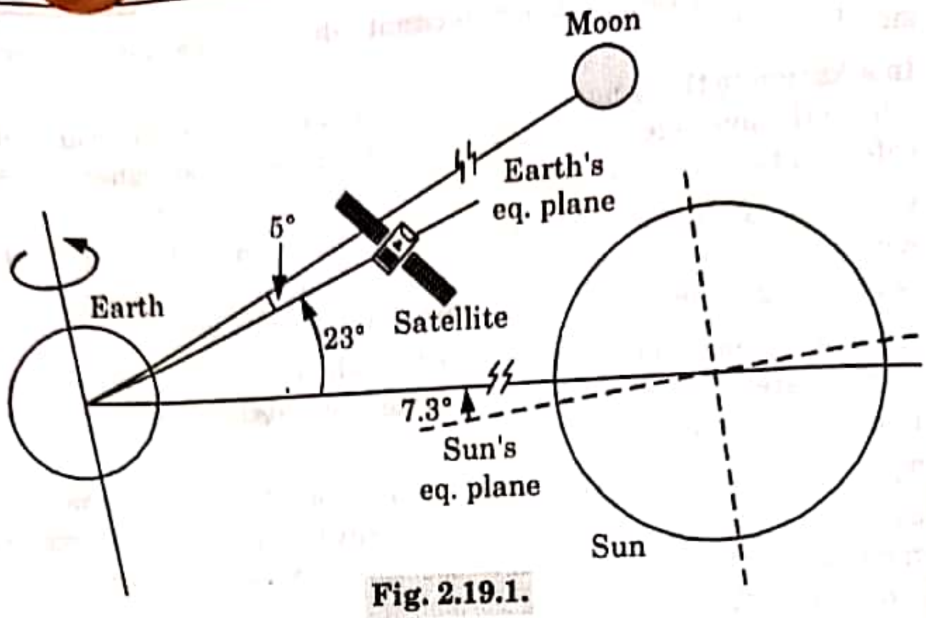

Fig. 2.19.1.

5. There will generally be a net acceleration force that is not in the plane of the satellite's orbit, and this will tend to try to change the inclination of the satellite's orbit from its initial inclination.
6. Under these conditions, the orbit will precess and its inclination will change.
7. The mass of the sun is significantly larger than that of the moon but the moon is considerably closer to the earth than the sun. For this reason, the acceleration force induced by the moon on a geostationary satellite is about twice as large as that of the sun.
8. The net effect of the acceleration forces induced by the moon and the sun on a geostationary satellite is to change the plane of the orbit at an initial average rate of change of 0.85°/year from the equatorial plane.
9. When both the sun and moon are acting on the same side of the satellite's orbit, the rate of change of the plane of the geostationary satellites orbit will be higher than average.
10. When they are on opposite sides of the orbit, the rate of change of the plane of the satellite's orbit will be less than average.

Que 2.20. **Write short notes on :**

i. **Solar eclipse effects.**
ii. **Sun transit outage.**

Answer

i. **Solar eclipse effects :**

1. Earth and moon affect the working of a satellite because of solar eclipse. So the periodicity and duration of solar eclipse are important.

2. Eclipses occur during two periods that begin 23 days before the equinoxes (about 21 March and 23 September) and end 23 days after the equinox periods.
3. In the Fig. 2.20.1 the inclination angle of the earth's equatorial plane $i_e(t)$ with respect to the sun's direction is shown.
4. Here the angle $i_e(t)$ mathematically is :

$$i_e(t) = 23.5 \sin \frac{2\pi t}{T}$$

where, T = Annual period = 365 days and

$$i_e(t)|_{max} = 23.5°$$

$i_e(t)$ is maximum on summer and winter and it is zero at spring and autumn equinoxes.

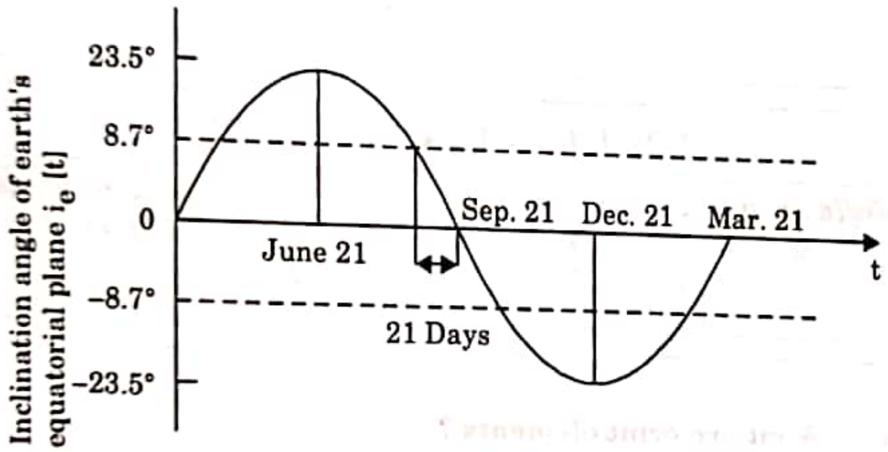

Fig. 2.20.1. Variation of the earth's equatorial plane inclination angle $i_e(t)$.

5. In the degree and annual variation is sinusoidal in nature. The apparent movement of the sun relative to the earth is shown in Fig. 2.20.2.

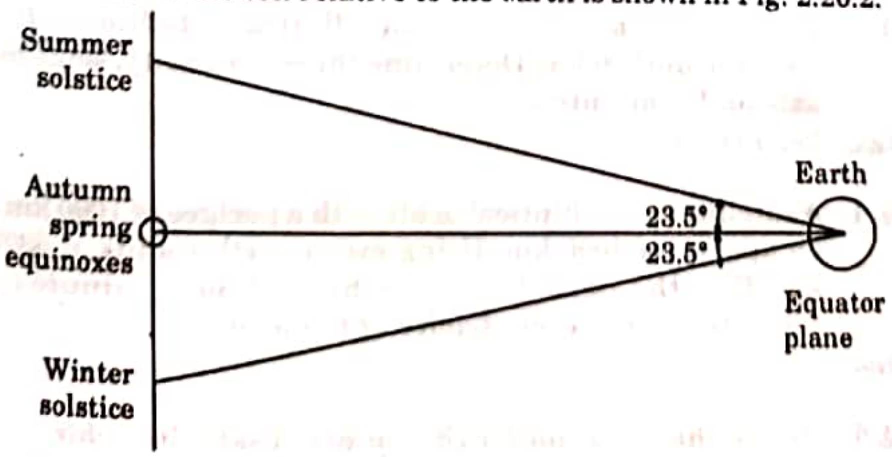

Fig. 2.20.2. Apparent movement of the sun relative to the earth.

ii. Sun transit outage :

1. Sun transit outage is an event that occurs during the equinoxes. It is the transit of the satellite between the earth and the sun that the sun enters within the beamwidth of the earth station antenna.
2. As a result, the sun appears to be a noisy source. The noise level at the satellite rises. The signal from the satellite is blanked out.
3. This effect is called as sun transit outage. It lasts for short periods every day but around the equinoxes it lasts for about 6 days.
4. Its occurrence and duration is dependent on the latitude of the earth station.
5. The receiving earth station has to wait for the sun to move out of the beamwidth of the earth station antenna.
6. It appears in the day time and forces the domestic data users to arrange alternate channels.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are orbit elements ?

Ans. Refer Q. 2.1.

Q. 2. Explain Kepler's law of planetary motion.

Ans. Refer Q. 2.5.

Q. 3. The apogee and perigee of an elliptical satellite orbits are 3000 km and 200 km. Determine the eccentricity, semi-major axis and semi-minor axis.

Ans. Refer Q. 2.6.

Q. 4. A satellite is an elliptical orbit with a perigee of 1000 km and an apogee of 4000 km. Using mean earth radius of 6378.14 km, find the period of the orbit in hours, minutes and seconds and the eccentricity of the orbit.

Ans. Refer Q. 2.8.

Q. 5. Derive the equation for the radius of satellite orbit.

Ans. Refer Q. 2.10.

3

UNIT

Satellite Sub-systems

CONTENTS

PART-1

Satellite Sub-Systems : Seven Segments of Satellite Communication.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **What are the various satellite subsystems ? Explain each of them briefly.**

Answer

The various satellite subsystems are :

i. **Attitude and orbit control system (AOCS) :**

1. The external forces acting on the satellite try to move it away from its original position.
2. To move the satellite back to its correct orbit rocket motors, gas jets, inertial devices are used. They control the attitude of the satellite.

ii. **Telemetry, tracking, command and monitoring (TTC&M) :**

1. These systems are partly on the earth station and partly on the satellite.
2. The various sensors on the satellite send data to the controlling earth station via a telemetry link.
3. The tracking system is located at the earth station. It provides information about the various orbital elements, if there is any change, then they are detected by the tracking system.
4. Based on this the control system corrects the position and the attitude of the satellite.
5. It is also used to configure the communication system to suit the current traffic requirements and operate switches on the satellite.

iii. **Power system :**

1. The communication satellites get electrical power from solar cells. They convert the solar energy directly into the electrical energy. The electrical energy produced is used mainly in transmitters.
2. The satellite also has battery backup facility which is useful at the time of launch and eclipses.

iv. **Communication subsystems :**

1. They are one of the major components of communication satellites.

2. It consists of one or more antennas which receive and transmit over wide bandwidths of microwave frequencies.
3. The set of transmitters and receivers amplify and retransmit the incoming signals. The transmitter-receiver units are called transponders.

v. **Satellite antennas :**

1. The antenna system produces beams with shapes that match the areas on the earth's surface.
2. There are various types of antennas that are used such as reflector antennas, horn antennas, wire antennas etc.

Que 3.2. **What are the segments of satellite communications ? Explain each of them.**

Answer

A satellite communications system can be broadly divided into following two segments :

i. **Ground segment :**

1. The earth segment of a satellite communications system consists of transmit and receive earth stations.
2. The simplest of these are the home TV receive-only (TVRO) systems, and the most complex are the terminal stations used for international communications networks.
3. Also included in the earth segment are those stations which are on ships at sea, and commercial and military land and aeronautical mobile stations.

ii. **Space segment :**

1. The space segment will obviously include the satellites, but it also includes the ground facilities needed to keep the satellites operational, these being referred to as the tracking, telemetry, and command (TT&C) facilities.
2. In many networks it is common practice to employ a ground station solely for the purpose of TT&C.

PART-2

Attitude and orbit control systems, Telemetry, Tracking and Command Control System, Power Supply System.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.3. **Explain how attitude and orbit control is achieved from an earth station ?**

Answer

1. There is a need to control the attitude and orbit of the satellite so that the satellite antenna always points towards the earth. The user will have the knowledge about where to look into the sky to search for the satellite.
2. The geostationary satellites have a fixed position; if this satellite moves away from its fixed position then the signal will be lost.
3. There are number of factors that cause the satellite to change its attitude and orbit.
4. The most significant amongst them are the gravitational fields of sun and moon, irregularities of the earth's gravitational field, solar pressure from the sun and variations in the earth's magnetic field.
5. The gravitational field from the moon is twice as strong as from the sun at geostationary altitude.
6. The solar pressure from the sun acts on the satellite's solar cells and antennas.
7. The magnetic field of the earth generates eddy currents in the satellites metallic body. This causes rotation of the satellite's body as it travels through the magnetic field.
8. The imperfect shape of earth causes the irregularities in its gravitational field.
9. In order to maintain the accurate position of the satellite, it must be accelerated in the opposite direction periodically.
10. Once the initial attitude of the satellite is set, it must be maintained in this position. This is done by two stabilization techniques :

i. Spin stabilization satellites.

ii. 3-axis stabilization satellites.

Que 3.4. **Briefly explain the various methods of satellite stabilization.**

Answer

Once the initial attitude of the satellite is set, it must be maintained in its position. This is done by two stabilization techniques :

i. Spin stabilization satellites :

1. These satellites are cylindrical in shape.
2. They consist of a cylindrical drum covered with solar cells that contain power systems and rocket motors.

3. The communication system is mounted at the top of the drum. It is driven by an electric motor in the opposite direction to keep the antenna pointing towards the earth.
4. The satellite is spun by operating small radial jets that are mounted on the periphery of the drum, at an appropriate point in the launch phase. These types of satellites are known as spinners.

ii. **3-axis stabilization satellites :**

1. The satellites can be stabilized by using one or more momentum wheels.
2. The basic control of such satellites is to speed up or slow down the momentum wheel depending on the direction in which the satellite is perturbed.
3. The satellite rotates in the direction opposite to that of speed change of the wheel.
4. There must be one momentum wheel for each of the three axis of the satellite. The three axis of the spin stabilized satellite are called pitch, roll and yaw.
5. The 3-axis stabilization system is more accurate in attitude control and positioning than the spin stabilization satellite. It is applicable where pin-point accuracy is required.

Que 3.5. **With the help of suitable block diagram, explain the function of telemetry, tracking and command (TTC) subsystem.**

Answer

1. When the satellite is placed in the transfer orbit, throughout the launch and acquisition phases, a network of ground stations spread across the earth is required to perform the tracking, telemetry, command and monitoring (TTC and *M*) functions.
2. These systems perform several routine functions aboard the spacecraft. Their main functions are to monitor the status of all the sensors, control the attitude and orbit of the satellite, switch ON-OFF different sections of the communication system.
3. The TTC and *M* system on the satellite uses two different antennas in the satellite lifetime. They are the transmitting and the receiving antennas.

i. **Telemetry and monitoring system :** It collects the data from various sections like the pressure in the fuel tank, voltage and current in the power conditioning unit, current drawn by each subsystem, and critical voltages and currents in the communications electronics etc., and sends this data to the controlling earth station.

ii. **Tracking system :** It sends correction signals because of the various perturbing forces that are acting on a satellite.

iii. **Command system :** It is a secure and effective system for the successful launch and operation of the communication satellite.

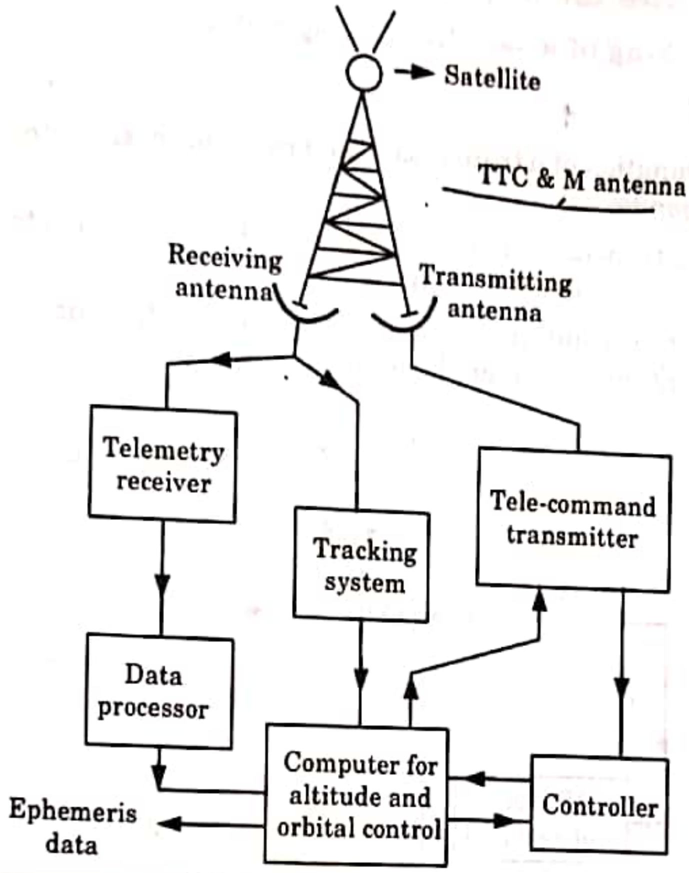

Fig. 3.5.1. Telemetry, tracking, command and monitoring system.

Que 3.6. **Write a short note on communication subsystem.**

Answer

1. The communication subsystem is the major part for the operation of spacecraft.
2. It provides the only link between an operational vehicle and the ground control station.
3. It consists of a communication antenna and a communication repeater.
4. The communication antenna serves as an interface between the earth stations on the ground and various satellite subsystems during operation.
5. The main function of the antenna is to provide shaped uplink and downlink beams for transmission and reception of communication signals in the operating frequency bands, *e.g.*, C or Ku band.

6. Broadly it can be defined as the system which allows data transfer to and from extravehicular sources.

Que 3.7. **With the help of a simple block diagram, explain the function/working of a satellite transponder.**

Answer

1. The combination of a transmitter and receiver on the satellite is known as transponder.
2. A satellite transponder receives the uplink transmission from the earth station and retransmits it on the downlink.
3. The uplink transmission is received by the satellite antenna. It is given to the front end receiver through the duplexer.

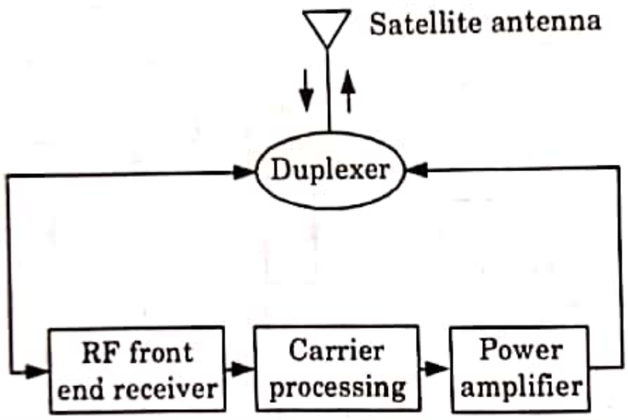

Fig. 3.7.1. Satellite transponder block diagram.

4. The front end receiver increases the signal to noise ratio of this signal and amplifies it.
5. Carrier processing involves the demodulation of the uplink carrier frequencies and remodulation of the information on downlink frequencies.
6. The duplexer does the job of simultaneous transmission and reception through the antenna.
7. The power amplifier increases the power level of remodulated downlink carrier, as the power level should be satisfactory to reach the earth station.

Que 3.8. **Explain single and double conversion transponder.**

Answer

A. Single conversion transponder :

1. Fig. 3.8.1 shows single conversion transponder for a 6/4 GHz band.

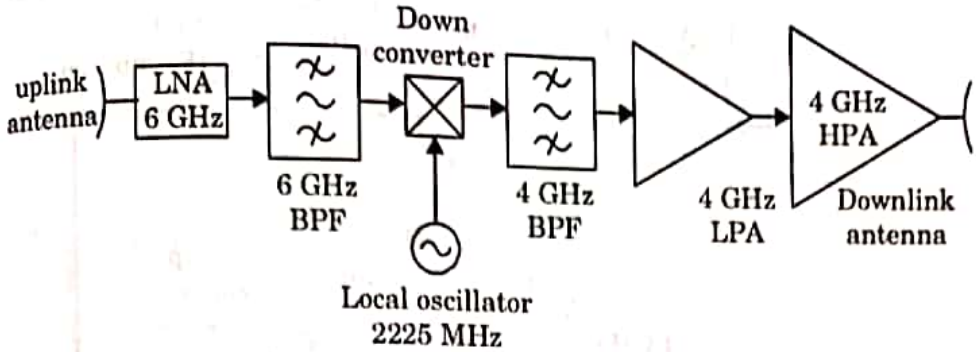

Fig. 3.8.1. Single conversion transponder.

2. The output power amplifier is generally a solid state power amplifier or a travelling wave tube amplifier (TWTA).
3. The local oscillator is at 2225 MHz. It will provide an appropriate shift in the frequency from 6 GHz uplink frequency to the 4 GHz downlink frequency.
4. The BPF that is placed after the mixer removes the unwanted frequencies resulting from the down conversion operation.
5. The attenuator can be controlled through the uplink command system to set the gain of the transponder.
6. For the high power amplifier redundancy is provided in each transponder and provides the necessary control to back off the output TWT or solid state power amplifier that can be switched into the circuit if a primary power amplifier fails.
7. The life span of HPA is limited. The HPAs have larger bandwidths than the allocated frequency band.

B. Double conversion transponder :

1. Fig. 3.8.2 shows the double conversion transponder for the 14/11 GHz band.
2. It employs a double frequency conversion scheme.
3. It is easier to implement amplifiers, filters and equalizers at an intermediate frequency (IF).
4. The intermediate frequency may be 1100 MHz than 14 or 11 GHz.
5. Hence, the incoming 14 GHz carrier is translated to an IF around 1 GHz.
6. The amplification and filtering are performed at 1 GHz. A high level carrier is translated back to 11 GHz for amplification by the HPA.

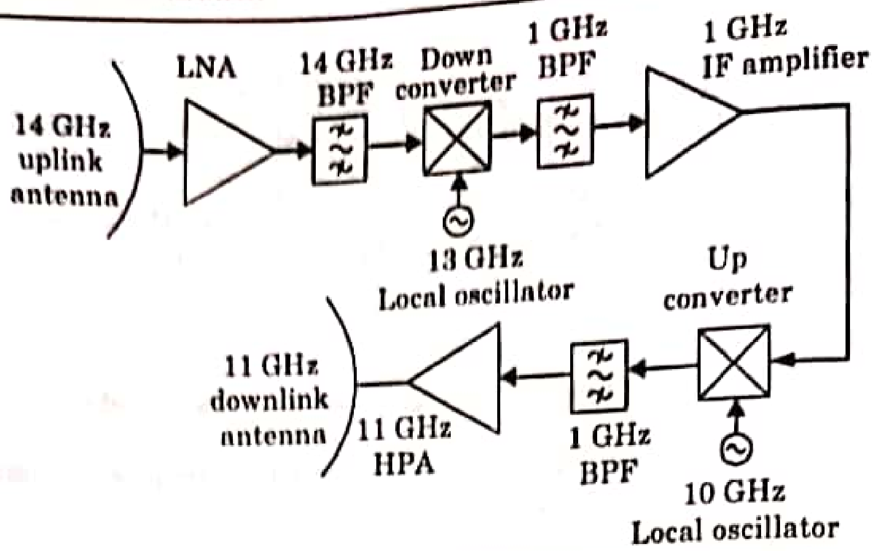

Fig. 3.8.2. Double conversion satellite transponder.

7. Filters must provide good rejection of the unwanted frequencies like the intermodulation products.
8. They have very low amplitude and phase ripple in their pass bands.
9. A filter may be followed by an equalizer that smoothes out the amplitude and phase variation in the passband.
10. Phase variation across the passband generates a group delay distortion.

Que 3.9. **Explain the following term :**

i. **Power gain**
ii. **Effective isotropically radiated power (EIRP).**

Answer

i. **Power gain :**

1. It is defined as the ratio of the power fed to an isotropic antenna to the power fed to a directional antenna to develop the same field strength at the same distance, in the direction of maximum radiation. It is denoted by G.
2. Power gain,
$$G = \frac{\text{Power fed to isotropic antenna}}{\text{Power fed to the directional antenna}}$$
The relation between power gain and directive gain is given as :
$$G = \eta D$$
where, η = Antenna efficiency

ii. **EIRP :**

1. For a transmitter with output power driving a lossless antenna with gain, the flux density in the direction of antenna boresight, at a distance R is given by :

$$F = \frac{P_t G_t}{4\pi R^2} \text{ W/m}^2$$

where, G_t = Gain of the antenna

P_t = Power transmitted by isotropic source

2. The product $P_t G_t$ is called as the effective isotropically radiated power (EIRP).
3. It describes the combination of transmitter and antenna in terms of an equivalent isotropic source with power $P_t G_t$ watts radiating uniformly in all directions.

$\therefore$ $$\text{EIRP} = P_t G_t \text{ watts}$$

Que 3.10. **The EIRP of a 240 W transponder is 57 dBW. Calculate the approximate gain of the antenna if the transponder is switched to 120 W. Also calculate the new EIRP, assuming that the same antenna is used.**

Answer

Given : Power transmitted, P_t = 240 W, EIRP = 57 dBW

To Find : Gain, new EIRP

1. Converting to dB,

$$\text{EIRP} = 10 \log (P_t G_t)$$

$$57.0 = 10 \log (240 \times G_t)$$

$$G_t = 2088.28 = 33.2 \text{ dB}$$

2. The transponder is switched to 120 W.

So, power transmitted

$$P_t = 120 \text{ W}$$

$$\text{EIRP} = 10 \log (120 \times 2088.28)$$

$$= 54 \text{ dBW}$$

Que 3.11. **Explain power system of satellite.**

Answer

1. The satellite must carry batteries to power the subsystems during launch and during eclipses. Eclipses occur twice per year, around the spring and fall equinoxes, when the earth's shadow passes across the satellite.
2. The longest duration of eclipse is 70 min, occurring around March 21 and September 21 each year.

3. To avoid the need for large, heavy batteries, part or all of the communications system load may be shut down during eclipse, but this technique is rarely used when telephony or data traffic is carried.
4. TV broadcast satellites may not carry sufficient battery capacity to supply their high-power transmitters during eclipse, and may shut down.
5. By locating the satellite 20° W of the longitude of the service area, the eclipse will occur after 1 A.M. local time for the service area, when shutdown is more acceptable.
6. Batteries are usually of the nickel-hydrogen type which do not gas when charging and have good reliability and long life, and can be safely discharged to 70 % of their capacity.
7. A power-conditioning unit controls the charging current and dumps excess current from the solar cells into heaters or load resistors on the cold side of the satellite.
8. Sensors on the batteries, power regulator, and solar cells monitor temperature, voltage, and current and supply these data to both the onboard control system and the controlling earth station via the telemetry downlink.

PART-3

Basic Transmission Theory, System Noise Temperature and G/T Ratio.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.12. **Give the basic transmission theory for the power transmitted by the satellite.**

OR

Derive the expression for Friis transmission formula.

Answer

1. For a transmitting source, in free space, radiating a total power P_t uniformly in all directions, the flux density crossing the surface of a sphere of radius R is given as :

$$F = \frac{P_t}{4\pi R^2} \text{ W/m}^2 \quad ...(3.12.1)$$

2. The antenna gain $G(\theta)$ in the direction θ is given by :

$$G(\theta) = \frac{P(\theta)}{P_0/4\pi} \quad ...(3.12.2)$$

where, $P(\theta)$ = Power radiated per solid angle by test antenna.
P_0 = Total power radiated by the test antenna.
$G(\theta)$ = Gain of the antenna at an angle θ.

3. Antenna gain is defined as the ratio of power per unit solid angle radiated in the direction θ to the average power radiated per solid angle.
4. The angle θ is known as the boresight direction of the antenna, it is the direction in which maximum power is radiated.
5. The flux density in this direction is given as :

$$F = \frac{P_t G_t}{4\pi R^2} \text{ W/m}^2 \quad ...(3.12.3)$$

$P_t G_t$ is known as the effective isotropically radiated power (EIRP).

6. The power collected, P_r is given by :

$$P_r = E \times A$$

where, A = Aperture area of antenna in m^2

7. Practically, the antennas are incapable of delivering the power completely as some of the incident energy is reflected away from the antenna and some of the energy is absorbed by the lossy components.
8. The effective aperture A_e, is given as :

$$A_e = \eta A_r$$

where, η = Aperture efficiency of the antenna

9. The gain and area of the antenna are related as :

$$G_r = \frac{4\pi A_e}{\lambda^2} \quad ...(3.12.4)$$

where, λ = Wavelength at the frequency of operation.

10. And the power received by a real antenna with a physical receiving area A_r, and effective area A_e is :

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \quad ...(3.12.5)$$

11. Substituting eq. (3.12.4) in eq. (3.12.5), we get

$$P_r = \frac{P_t G_t G_r}{(4\pi R/\lambda)^2} \quad ...(3.12.6)$$

This eq. (3.12.6) is known as the link equation or Friis transmission formula.

12. The path losses are given as :

$$L_p = \left(\frac{4\pi R}{\lambda}\right)^2$$

and the general expression for received power in dB is given by :

$$[P_r] = [\text{EIRP}] + [G_r] - [L_p]$$

Que 3.13. **A satellite stationed at a distance 38000 km from the surface of earth radiates a power of 3 watts, in the direction of an earth station. Calculate the flux density at earth station and power received by the antenna of effective area 8 m². Also calculate the received power if the operating frequency is 10 GHz and gain of the antenna is 30 dB. Assume satellite antenna gain to be 20 dB.**

Answer

Given : Distance of satellite from the earth's surface, R = 38,000 km, Radiated power, P_t = 3 W, Effective area of antenna, $A_e = 8\ \text{m}^2$, Gain of the antenna, G_t = 20 dB = 100, Gain of receiving antenna, G_r = 50 dB, Operating frequency = 10 GHz.

To Find : Flux density at earth, power received.

i. Flux density at earth,

$$F = \frac{P_t\, G_t}{4\pi R^2} = \frac{3 \times 100}{4\pi \times (38{,}000 \times 10^3)^2}$$

$$F = 1.65 \times 10^{-14}\ \text{W/m}^2$$

ii. Power received by 8 m² antenna,

$$P_r = F \times A = 1.65 \times 10^{-14} \times 8 = 1.32 \times 10^{-13}\ \text{W}$$

iii. The received power in decibels is given by :

$$[P_r] = [\text{EIRP}] + [G_r] - [\text{Path loss (dB)}]$$

when $\text{EIRP} = 10 \log P_t G_t = 10 \log(3 \times 100)$

$\therefore$ $\text{EIRP} = 24.77$ dB

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{10 \times 10^9} = 3 \times 10^{-2}\ \text{m}$$

Path loss, $$L_p = 20 \log\left(\frac{4\pi R}{\lambda}\right)$$

$$= 20 \log\left(\frac{4 \times \pi \times 3.8 \times 10^7}{3 \times 10^{-2}}\right) = 204\ \text{dB}$$

So, $$[P_r] = 24.77 + 50 - 204 = -129.3\ \text{dBW}$$

Que 3.14. **A geostationary satellite carries a transponder with a 20 W transmitter at 4 GHz. The transmitter is operated at an output power of 10 W and drives an antenna with a gain of 30 dB. An earth station is at the centre of coverage zone of the satellite, at a range of 36,500 km. Using decibels for all calculations, find :**

i. The flux density at the earth station in dBW/m².

ii. **The power received by an antenna with a gain of 39 dB, in dBW.**

iii. **The EIRP of the transponder in dBW.**

Answer

Given : Distance of satellite from earth's surface, R = 38,500 km, Operating frequency, f = 4 GHz, Transmitted power, P_t = 10 W, Gain of antenna, G_t = 30 dB

To Find : Flux density, Power received, EIRP.

1. We know $$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{4 \times 10^9} = 0.075 \text{ m}$$

i. Flux density is given as :

$$F = 10 \log (P_t G_t / 4\pi R^2) \text{ dBW/m}^2$$

$$= 10 \log (P_t) + 10 \log (G_t) - 10 \log (4\pi) - 20 \log (38{,}500 \times 10^3)$$

$$= 10 + 30 - 11 - 151.7 = -122.7 \text{ dBW/m}^2$$

ii. Path loss :

$$L_p = 20 \log\left(\frac{4\pi R}{\lambda}\right) = 20 \log\left(\frac{4\pi \times 3.85 \times 10^7}{0.075}\right)$$

$$= 196.2 \text{ dB}$$

iii. Downlink power budget is given by :

$$[P_r] = [P_t] + [G_t] + [G_r] - [L_p] \text{ dBW}$$

$$= 10 + 30 + 39 - 196.2 = -117.2 \text{ dBW}$$

So, power received, $[P_r] = -117.2$ dBW

iv. The EIRP of the transponder in dBW

$$[\text{EIRP}] = [P_t] + [G_t] = 10 + 30 = 40 \text{ dBW}$$

Que 3.15. **What do you understand by system noise temperature and G/T ratio for the earth station ?**

OR

Explain system noise temperature ? Derive its relation for equivalent system noise temperature.

Answer

A. Noise temperature :

1. The noise temperature provides a method of determining the amount of thermal noise generated by active and passive devices.
2. Hence, it is significant in communication devices. The noise power is given as : $$P_n = kT B_n$$

where, k = Boltzmann's constant = 1.39×10^{-23} J/K
T = Source temperature
B_n = Noise bandwidth in Hz

3. The power, P_n will be delivered to the load whose impedance matches with the noise source.
4. In the satellite communication system, the signal involved is very weak due to large distance between the satellite and the earth station.
5. Therefore, the noise in the receiver should be reduced to maintain the best possible carrier to noise ratio. This can be done by :
   i. Setting the receiver bandwidth to be just large enough to allow the signal to pass.
   ii. The front end amplifier of the receiver is immersed in liquid helium to hold its temperature at about 4 K.
6. If the overall gain introduced by the RF and IF stages of a satellite receiver is G with bandwidth equal to B. Then the noise power at the demodulator output is given by :

$$P_n = kT_sBG \text{ watts}$$

where, G = Receiver gain from RF input to demodulator input
T_s = System noise temperature

7. If the receiver antenna delivers a signal power P_r to the receiver at the input to the RF section.
8. Then signal power at the demodulator input is given by :

$$C = P_rG \text{ watts}$$

9. The carrier to noise ratio is given by :

$$\frac{C}{N} = \frac{P_rG}{kT_sBG} = \frac{P_r}{kT_sB} \text{ W/K}$$

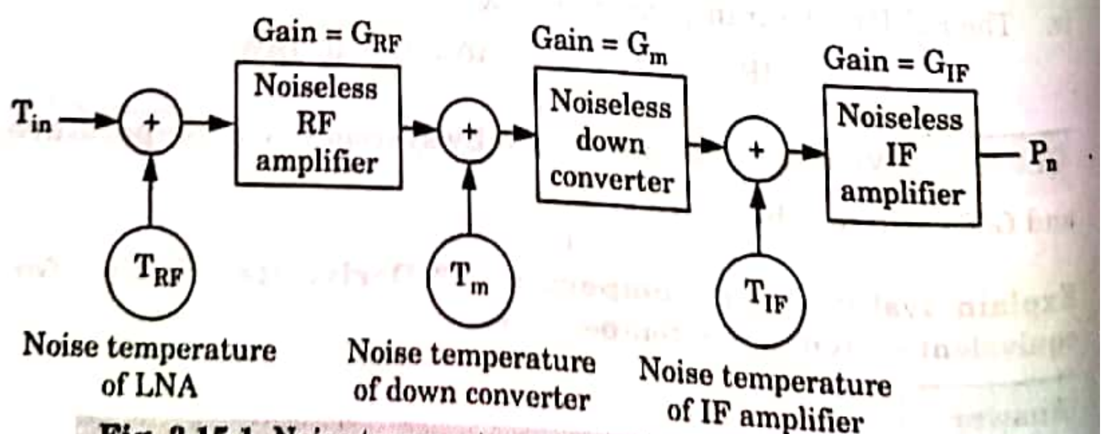

Fig. 3.15.1. Noise temperature equivalent of the receiver.

10. The total noise power at the receiver output (P_n) is given as :

$$P_n = kT_{IF}BG_{IF} + (kT_mBG_m)\,G_{IF} + [k(T_{IF} + T_{in})\,BG_{RF}]\,G_mG_{IF}$$

11. The system noise temperature :

$$T_s = T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \text{ K}$$

12. The noise power at the output 'P_n' is given as :

$$P_n = G_{IF} G_m G_{RF} kT_s B$$

B. *G/T* ratio for earth station :

1. We know,

$$\frac{C}{N} = \frac{P_r}{kT_s B} \quad ...(3.15.1)$$

and

$$P_r = \frac{P_t G_t G_r}{(4\pi R / \lambda)^2} \quad ...(3.15.2)$$

2. Putting the value of P_r in eq. (3.15.1)

$$\frac{C}{N} = \frac{P_t G_t G_r}{kT_s B} \times \frac{1}{(4\pi R / \lambda)^2}$$

$$\therefore \quad \frac{C}{N} = \left[\frac{P_t G_t}{kB}\right]\left[\frac{\lambda^2}{4\pi R^2}\right]\left[\frac{G_r}{T_s}\right] \quad ...(3.15.3)$$

3. As first two terms of eq. (3.15.3) are constant and do not depend on the earth station,

$$\therefore \quad \frac{C}{N} \propto \frac{G_r}{T_s} \quad ...(3.15.4)$$

4. The ratio $\frac{G_r}{T_s}$ is used to specify the quality of receiving earth station or a satellite receiving system, since increasing G_r / T_s increases the received *C/N* ratio. Its unit is dB/K.

Que 3.16. **A satellite TV signal occupies the full 36 MHz transponder bandwidth and is desired to provide a (*C/N*) ratio of 22 dB at the earth station. If a downlink frequency of 4 GHz is employed and other losses amount to 3.4 dB, what must be the (*G/T*) ratio of the earth station if EIRP is 37 dBW ? The path length may be assumed to be 40000 km.**

Answer

Given : $\frac{C}{N}$ = 22 dB, EIRP in dBW = 37 dBW, [other losses]$_D$ = 3.4 dB, Length of path, R = 40,000 km, Downlink frequency, f = 4 GHz

To Find : (*G/T*) ratio.

1. EIRP in dB is given as :

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

2. We know, $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{4 \times 10^9} = 0.075 \text{ m}$

$$\text{Path loss} = \left[\frac{4\pi R}{\lambda}\right]^2 = \left[\frac{4\pi \times 40000 \times 10^3}{0.075}\right]^2 = 4.49 \times 10^{19}$$

$$[\text{Path loss}]_{dB} = 10 \log[4.49 \times 10^9] = 196.524$$

3. Boltzmann's constant,

$$k = 1.38 \times 10^{-23} \text{ J/K}$$
$$= -228.6 \text{ dB}$$

4. Bandwidth, B = 36 MHz = 75.56 dBHz

$$\left[\frac{G}{T}\right]_D = -[\text{EIRP}]_D + \left[\frac{C}{N}\right]_D + [\text{other losses}]_D + [k] + [B] + [\text{Path losses}]$$

$$= -37 + 22 + 3.4 + (-228.6) + 75.56 + 196.524$$
$$= 31.884 \text{ dB}$$

Que 3.17. **A C-band earth station has an antenna with a transmit gain of 54 dB. The transmitter output power is set to 100 W at a frequency of 6.1 GHz. The signal is received by a satellite at a distance of 37,500 km by an antenna with a gain of 26 dB. The signal is then routed to a transponder with a noise temperature of 300 K, a bandwidth of 36 MHz, and a gain of 110 dB.**

i. Calculate the path loss at 6.1 GHz.

ii. Calculate the power at the output port of the satellite antenna, in dBW.

iii. Calculate the noise power at the transponder input in dBW, in a bandwidth of 36 MHz.

iv. Calculate the C/N ratio, in the transponder.

v. The carrier power in dBW, at the transponder output.

Answer

Given : Transmitted power, P_t = 100 W = 20 dB, Transmitter gain, G_t = 54 dB, Receiver gain, G_r = 25 dB, Path loss, L_p = 199.6 dB, Frequency, f = 61 GHz.

To Find : Path loss, Power at the output, Noise power, C/N ratio carrier power.

1. Wavelength, $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{6.1 \times 10^9}$ m = 0.04918 m

2. Path loss, $L_p = 20 \log\left(\frac{4\pi R}{\lambda}\right) = 20 \log\left(\frac{4\pi \times 37{,}500 \times 10^3}{0.04918}\right)$ dB

$L_p = 199.6$ dB

3. Since using the uplink power budget we have :

Power received, $[P_r] = [P_t] + [G_t] + [G_r] - [L_p]$

$= 20 + 54 + 26 - 199.6 = -99.6$ dBW

4. Bandwidth, $B_N = 36$ MHz = 75.6 dB

Noise temperature, $T_S = 500$ K = 27 dB

$\therefore$ noise power, P_n in dBW = $[k] + [T_s] + [B_N]$

$= -228.6 + 27 + 75.6 = -126.0$ dBW

5. *C/N* ratio in dB, at the transponder :

$= [P_r] - [P_n]$

$= -99.6 + 126.0 = 26.4$ dB

6. The carrier power in dBW, at the transponder output :

$P_t = [P_r] + [G]$

$= -99.6 + 110 = 10.4$ dBW

Que 3.18. **Define the term noise figure and write its relation with noise temperature.**

Answer

1. The noise figure F is defined as the ratio of the signal to noise ratio at the input to the signal to noise at the output of a system. It is mostly expressed in decibels.

$$\therefore \quad F = \frac{\left(\frac{S}{N}\right)_{in}}{\left(\frac{S}{N}\right)_{out}}$$

2. The noise temperature is more useful than the noise factor in the satellite communication. It is related to noise figure as :

$$\therefore \quad T_s = T_0(F - 1)$$

where, T_0 = Room temperature

Que 3.19. **The noise figure of an amplifier is 4 dB, calculate its equivalent noise temperature. Assume room temperature to be 290 K.**

Answer

Given : Noise figure, F_{dB} = 4 dB, Room temperature, T_0 = 290 K
To Find : Noise temperature.

Noise figure (in dB), $F_{dB} = 10 \log(F_r)$

$\therefore \quad 4 = 10 \log(F_r)$

Noise figure (in ratio), $F_r = 2.512$

Room temperature, $T_0 = 290$ K

$\therefore$ Noise temperature, $T_e = T_0 (F - 1) = 290 (2.512 - 1) = 438.48$ K

PART-4

Design of Downlink and Uplink, Design of Satellite Links for Specified C/N.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.20. **What is downlink design of geostationary satellite ? Explain the factors that affect the downlink design of geostationary satellite communication.**

Answer

A. **Satellite downlink :**

1. The satellite downlink deals with the power generation on the satellite, various power gains and losses associated with the signal travelling "down" from the satellite to the earth.

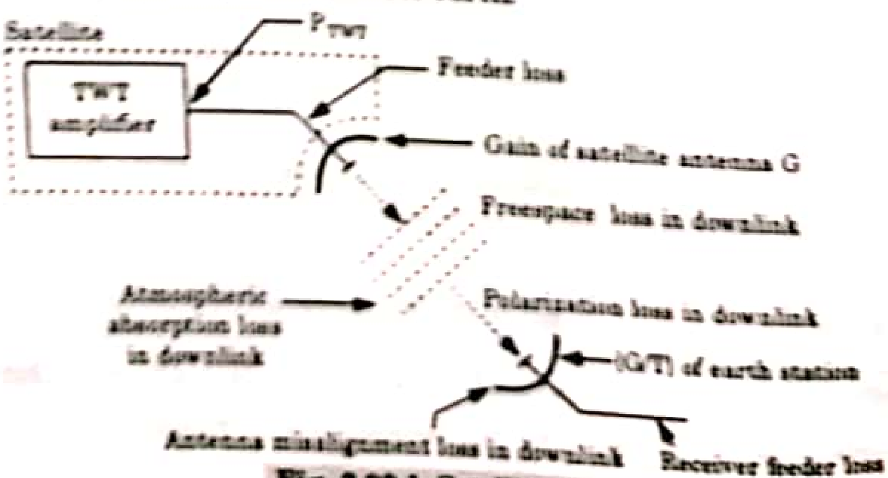

Fig. 3.20.1. Satellite downlink.

2. The TWT amplifier at the satellite emits the power.

B. Factor which affect the down link design of geostationary satellite communication are :

1. **Effective isotropic radiated power in downlink :** It is given as

$$[EIRP]_D = [P_t] + [G_t] - [TFL]_D$$

$[P_t]$ = Power transmitted by satellite amplifier

$[G_t]$ = Gain of the satellite antenna

$[TFL]_D$ = Transmit feeder loss in the downlink

2. **Losses in downlink :** The communication media is same for both the uplink and the downlink. Their losses are also the same. The losses in downlink are given as :

$$[TPL]_D = [FSL]_D + [AML]_D + [PL]_D + [AA]_D.$$

3. **Carrier power at the earth station :** It is given as

$$[P_r] = [EIRP] + [G_r] - [L_p]$$

$[P_r]$ = Power at the receiver

$[G_r]$ = Gain of the receiver antenna

$[L_p]$ = [FSL] = Free space loss

4. Noise power is given as :

$$P_n = kT_sB$$

$$[P_n]_D = [N]_D = [kT_sB]$$

5. Carrier to noise power (C/N) for the downlink is :

$$\left[\frac{C}{N}\right]_D = [EIRP]_D - [TPL]_D - [RFL]_D + \left[\frac{G_r}{T_s}\right] - [k] - [B]$$

6. Carrier to noise power density ratio (C/N_0) :

$$\left[\frac{C}{N}\right]_D = [EIRP]_D - [TPL]_D - [RFL]_D + \left[\frac{G_r}{T_s}\right] - [k]$$

in terms of flux density, it is given as :

$$\left[\frac{C}{N}\right]_D = [\phi]_D + [A_0] - [RFL]_D + \left[\frac{G_r}{T_s}\right] - [k]$$

Que 3.21. **Explain uplink design in geostationary satellite. What are the factors that affect the uplink design in geostationary satellite communication ?**

Answer

A. Uplink design in geostationary satellite :

1. The satellite uplink deals with the power generation at the earth station, various power gains and losses associated with the signal travelling in the upward direction associated with the signal *i.e.*, from the earth station to the satellite.

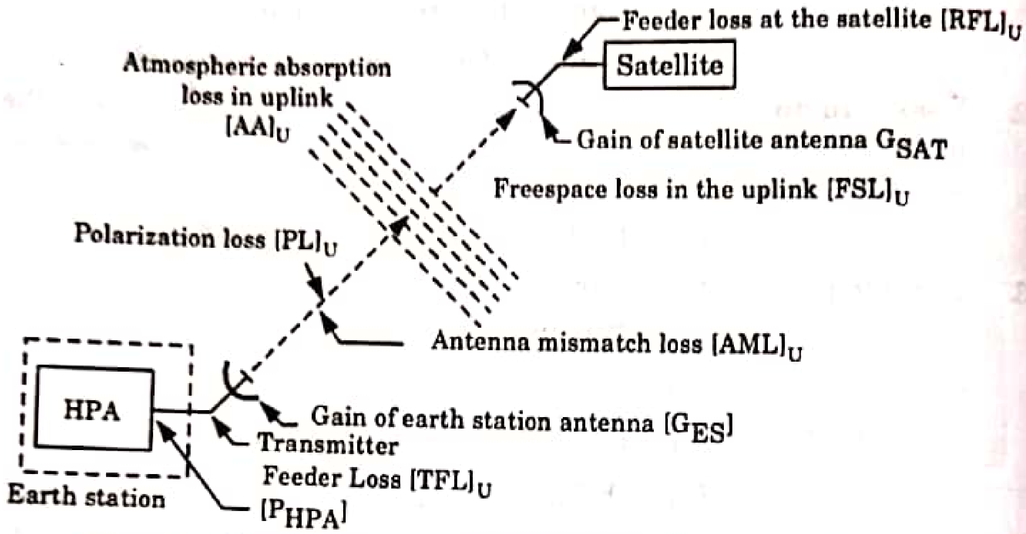

Fig. 3.21.1. Block diagram of the uplink power budget.

2. It describes all the factors that are associated with the transmission from the earth station to the satellite transponder.
3. The earth station's high power amplifier has to supply the power radiated.
4. Some part of the power is wasted as transmit feeder losses [TFL].

B. Factors which affect the uplink design in geostationary satellite are :

1. **Losses in uplink :** The transmission path loss $[TPL]_U$ is equal to the sum of all the losses incurred in the uplink.

$$[TPL]_U = [FSL]_U + [AML]_U + [PL]_U + [AA]_U$$

where, $[FSL]_U$ = Free space loss in uplink

$[AML]_U$ = Antenna misalignment loss

$[PL]_U$ = Polarization loss

$[AA]_U$ = Atmospheric absorption loss

2. **Carrier power in satellite :** The power received by the satellite receiver $[P]_U$ is expressed as :

$$[P]_U = [EIRP]_U - [TPL]_U + [G_{SAT}] - [RFL]_U$$

where, $[EIRP]_U$ = Effective isotropically radiated power

$[TPL]_U$ = Transmission path loss

$[G_{SAT}]_U$ = Isotropic power gain of the satellite antenna

$[RFL]_U$ = Receiver feeder loss at satellite

3. **Noise power :** The noise power of the satellite is given as :

$$[P_n]_U = [kT_{SAT}B]$$

where,

k = Boltzmann's constant

T_{SAT} = Equivalent noise temperature at satellite receiver

4. **Carrier to noise ratio :** For the uplink the carrier to noise ratio is given as :

$$\left[\frac{C}{N}\right]_U = \left[\frac{P_U}{kT_{SAT}B}\right]_U$$

$$\left[\frac{C}{N}\right]_U = [EIRP]_U - [TPL]_U - [RFL]_U + \left[\frac{G}{T}\right]_{SAT} - [k] - [B]$$

5. **Carrier to noise power density ratio :** For the uplink it is given as :

$$\left[\frac{C}{N_o}\right]_U = [P]_U - [kT_{SAT}]$$

$$\left[\frac{C}{N_o}\right]_U = [EIRP]_U - [TPL]_U - [RFL]_U + \left[\frac{G}{T}\right]_{SAT} - [k]$$

and in terms of flux density :

$$\left[\frac{C}{N_o}\right]_U = [\phi]_U + [A_0] - [RFL]_U + \left[\frac{G}{T}\right]_{SAT} - [k]$$

where,

ϕ = Flux density

A_0 = Effective area of an isotropic antenna

Que 3.22. **For a satellite earth station receiver with equivalent noise temperature of 200 K, a noise bandwidth of 18 MHz and receiving antenna gain of 50 dB, determine gain to equivalent noise temperature ratio, noise density and total noise power. Assume carrier frequency of 12 GHz.**

Answer

Given : Noise temperature, T_e = 200 K, Noise bandwidth, B = 18 MHz

Receiving antenna gain, G_r = 50 dB, Carrier frequency, f = 12 GHz

To Find : Gain of receiving antenna, noise density, total noise power.

i. The gain of receiving antenna, $[G_r]$ = 50 dB

$$T_e = 200 \text{ K}$$

$$[T_s]_{dB} = 10\log(T_s) = 10\log[200]$$
$$[T_s] = 23 \text{ dBK}$$

$$\therefore \quad \left[\frac{G_r}{T_s}\right] = 10\log\left[\frac{G_r}{T_s}\right]$$
$$= 10\log(G_r) - 10\log(T_s)$$
$$= [G_r] - [T_s] = 50 - 23 = 27 \text{ dB/K}$$

ii. Total noise power :

$$P_n = kT_sB = 1.39 \times 10^{-23} \times 200 \times 18 \times 10^6$$
$$= 5 \times 10^{-14} \text{ W}$$

iii. Noise density : $\dfrac{P_n}{B} = \dfrac{kT_s B}{B} = kT_s$

$$= 1.39 \times 10^{-23} \times 200 = 2.78 \times 10^{-21} \text{ W/Hz}$$

Que 3.23. **What are the various interferences that may affect the satellite link performance ? Explain in short.**

Answer

i. **Effects due to rain :**

1. Rain affects the signal on both the uplink as well as the downlink. On downlink, noise is introduced by various factors like attenuation by absorption, scattering of signal energy.
2. The effective noise temperature due to rain is given as :

$$T_{rain} = T_a\left[1 - \frac{1}{A}\right]$$

where, T_{rain} = Effective noise temperature of the rain

T_a = Apparent absorber temperature; ranges between 270 to 290 K

A = Rain attenuation caused by absorption

3. The overall noise temperature, $T_{sky} = T_s + T_{rain}$

where, T_s = System noise temperature

4. The downlink C/N power ratio is related to clear sky by :

$$\left(\frac{N}{C}\right)_{rain} = \left(\frac{N}{C}\right)_{cs}\left[A + (A-1)\frac{T_a}{T_s}\right]$$

5. Rain does not affect the uplink much because the satellite antenna is pointed towards hot earth therefore; there is no considerable increase in the noise temperature due to rain attenuation.
6. Rain attenuation on the uplink path to the satellite reduces the power at the satellite receiver input and thus reduces the $(C/N)_U$ in direct proportion to the attenuation on the slant path.

7. For a linear transponder :

$$\left(\frac{C}{N_0}\right)_{rain} = \left(\frac{C}{N_0}\right)_{cs} - A \text{ dB}$$

8. In a non-linear transponder, the reduction in the input power caused by uplink attenuation of A dB results in a small reduction in the output power ΔN_{rain} dB. For non-linear transponder :

$$\left(\frac{C}{N_0}\right)_{D\,rain} = \left(\frac{C}{N_0}\right)_{cs} - A + \Delta N_{rain} \text{ dB}$$

$$\text{where, } \Delta N_{rain} = 10 \log\left[\frac{kT_{s\,rain}\, B_n}{kT_{sca}\, B_n}\right] = 10 \log\left[\frac{T_{s\,rain}}{T_{sca}}\right]$$

ii. Intermodulation noise :

1. Intermodulation occurs where multiple carriers pass through any device with non-linear characteristics.
2. Both amplitude and phase non-linearities give rise to intermodulation products when a large number of modulated carriers are present, the intermodulation products cannot be distinguished separately but appear as a type of noise termed as intermodulation noise.

$$\left(\frac{N_0}{C}\right) = \left(\frac{N_0}{C}\right)_U + \left(\frac{N_0}{C}\right)_D + \left(\frac{N_0}{C}\right)_{IM}$$

where, $\left(\frac{N_0}{C}\right)_{IM}$ = Reciprocal of intermodulation carrier to noise ratio

Que 3.24. Derive the expression for (C/N) of uplink, downlink and overall satellite link.

Answer

1. The power is transmitted from the earth station on uplink. At the satellite, the received signal power is P_{RU}.

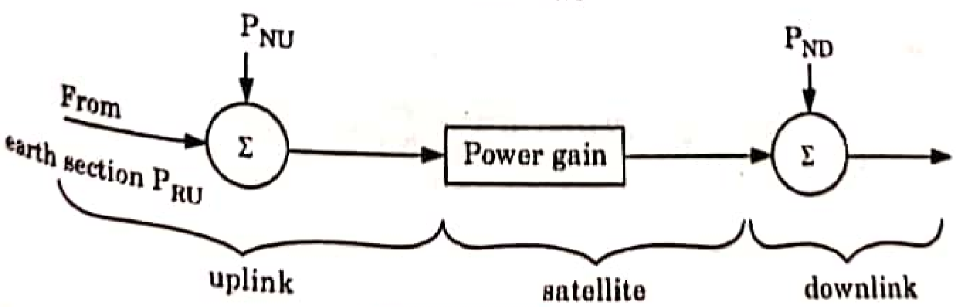

Fig. 3.24.1.

2. A noise P_{NU} adds on the uplink. The gains of satellite antennas, amplifiers and other circuits are represented as power gain g. On downlink, the power received by earth station is P_R.

$$P_R = gP_{RU}$$

3. The total noise power at the receiving station is,

$$P_N = gP_{NU} + P_{ND}$$

4. The overall noise power to carrier ratio is,

$$\frac{N}{C} = \frac{P_N}{P_R} = \frac{\gamma P_{NU} + P_{ND}}{P_R}$$

$$\frac{N}{C} = \frac{\gamma P_{NU}}{P_R} + \frac{P_{ND}}{P_R}$$

But, $P_R = gP_{RU}$

$$\therefore \quad \frac{N}{C} = \frac{P_{NU}}{P_{RU}} + \frac{P_{ND}}{P_R}$$

$$\frac{P_{NU}}{P_{RU}} = \left(\frac{N}{C}\right)_U$$

i.e., noise to carrier power ratio on uplink

and $$\frac{P_{ND}}{P_R} = \left(\frac{N}{C}\right)_D$$

i.e., noise to carrier power ratio on downlink

$$\therefore \quad \left(\frac{N}{C}\right)_{\text{overall}} = \left(\frac{N}{C}\right)_{\text{uplink}} + \left(\frac{N}{C}\right)_{\text{downlink}}$$

$$\therefore \quad \left(\frac{C}{N_0}\right)_O = \frac{1}{\left(\frac{C}{N_0}\right)_U^{-1} + \left(\frac{C}{N_0}\right)_D^{-1}}$$

Que 3.25. **The downlink C/N of the satellite is 25.0 dB and that of the uplink is 22.0 dB. Determine the value of overall C/N. If C/I of 24 dB is introduced into the link, how is the overall C/N modified?**

Answer

Given : $(C/N)_{\text{uplink}} = 22.0$ dB, $(C/N)_{\text{uplink}} = 25.0$ dB, $(C/I) = 24$ dB
To Find : $(C/N)_{\text{overall}}$.

$$\left(\frac{C}{N}\right)_{\text{overall}} = \left[\frac{1}{\frac{1}{(C/N)_{\text{uplink}}} + \frac{1}{(C/N)_{\text{downlink}}}}\right]$$

$$= \left[\frac{1}{\frac{1}{22.0} + \frac{1}{25.0}}\right] = 11.70 = 10.68 \text{ dB}$$

with interference,

$$\left(\frac{C}{N}\right)_{\text{overall}} = \left[\frac{1}{\frac{1}{(C/N)_{\text{uplink}}} + \frac{1}{(C/N)_{\text{downlink}}} + \frac{1}{(C/I)}}\right]$$

$$= \left[\frac{1}{\frac{1}{22.0} + \frac{1}{25.0} + \frac{1}{24.0}}\right] = 7.866 = 8.957 \text{ dB}$$

Que 3.26. **The uplink $\frac{C}{N_0}$ ratio is 88 dBHz and downlink value is 78 dBHz. Calculate overall $\frac{C}{N_0}$ ratio.**

Answer

Given : $\left(\frac{C}{N_0}\right)_U$ = 88 dBHz, $\left(\frac{C}{N_0}\right)_D$ = 78 dBHz

To Find : $\left(\frac{C}{N_0}\right)_{\text{overall}}$

in ratio, $\left(\frac{C}{N_0}\right)_U = 10 \log\left(\frac{C}{N_0}\right)_U = 88 \text{ dB}$

in ratio, $\left(\frac{C}{N_0}\right)_U = 6.309 \times 10^8$

$$\left(\frac{N_0}{C}\right)_U = 1.584 \times 10^{-9}$$

Similarly $\left(\frac{C}{N_0}\right)_D = 78 \text{ dBHz}$

in ratio, $\left(\frac{C}{N_0}\right)_D = 10 \log\left(\frac{C}{N_0}\right)_D = 78 \text{ dB}$

in ratio, $\left(\frac{N_0}{C}\right)_D = 1.584 \times 10^{-8}$

Overall, $\left(\frac{N_0}{C}\right)_O = \left(\frac{N_0}{C}\right)_U + \left(\frac{N_0}{C}\right)_D$

$$\left(\frac{N_0}{C}\right)_0 = 1.584 \times 10^{-9} + 1.584 \times 10^{-8} = 1.7424 \times 10^{-8}$$

$$\left(\frac{C}{N_0}\right)_0 = 57.392 \times 10^6 = 10 \log(57.392 \times 10^6) \text{ dB}$$

$$= 77.58 \text{ dB}$$

Que 3.27. **A satellite carrying a 11.7 GHz continuous wave (CW) beacon transmitter is located in geosynchronous orbit 38000 km from an earth station. The beacon's output power is 200 mW, and it feeds an antenna with 18.9 dB gain towards the earth station. The earth station receiving antenna efficiency is 50 percent. The effective aperture area is 10 sq. mt. Calculate :**

1. **EIRP**
2. **Path-loss**
3. **Receiving antenna gain.**

Answer

Given : P_t = 200 mW, G_t = 18.9 dB, f = 11,7 GHz, A_e = 10 sq. meter.
To Find : EIRP, Path loss, Receiving antenna gain.

1.

$$\text{EIRP} = 10 \log_{10}(P_t G_t) \text{ dBW}$$

$$= 10 \log_{10}(P_t) + 10 \log_{10}(G_t) \text{ dBW}$$

$$= 10 \log_{10}(200 \times 10^{-3}) + 18.9$$

$$= 11.911 \text{ dBW}$$

2.

$$\text{Path loss} = 20 \log_{10}\left(\frac{4\pi R}{\lambda}\right) \text{ dBW}$$

$$= 20 \log_{10}\left(\frac{4\pi R}{c/f}\right)$$

$$= 20 \log_{10}\left(\frac{4 \times \pi \times 3.8 \times 10^7}{3 \times 10^8 / 11.7 \times 10^9}\right)$$

$$= 205.40 \text{ dBW}$$

3. Receiving antenna gain

$$G = \frac{4\pi A_e}{\lambda^2}$$

$$= \frac{4 \times 3.1416 \times 10}{(3 \times 10^8 / 11.7 \times 10^9)^2} \text{ W}$$

$$= 1.69 \times 10^5 \text{ W} = 52.27 \text{ dBW}$$

Que 3.28. **Under condition of heavy rain, the C-band path to the receiving station suffers an attenuation of 1.5 dB. Assuming 100 % coupling of sky noise into antenna noise, and 0.3 dB clear air gaseous attenuation, calculate the overall *C/N* under these conditions, and find the downlink margin.**

Answer

1. Under clear air conditions, the gaseous attenuation of 0.3 dB gives a sky noise temperature of approximately $0.3 \times 6.7 = 20.1$ K

   Rain attenuation = 1.5 dB, and

2. Total attenuation on downlink, $A = (1.5 + 0.3)$ dB

$$= 1.8 \text{ dB} = 10 \log A(\text{in ratio})$$

$$18 = 10 \log A(\text{in ratio})$$

$$A \text{ (in ratio)} = 1.514$$

3. Noise temperature in rain, $T_{\text{rain}} = T_0\left[1 - \frac{1}{A}\right]$

$$T_{\text{rain}} = 290\left[1 - \frac{1}{1.514}\right] = 290[1 - 0.661] = 98.4 \text{ K}$$

   Assume $T_{LNA} = 55$ K

   Hence, new system noise temperature in rain is :

$$T_{s\,\text{rain}} = T_{\text{LNA}} + T_A$$

$$T_s = (55 + 98.4) \text{ K} = 153.4 \text{ K}$$

4. The increase in system noise power is proportional to increase in system noise temperature.
5. The system noise temperature in clear air conditions was 75 K.

   Hence, $\Delta N = 10 \log\left[\frac{T_{rs\,\text{rain}}}{T_{sca}}\right]$ dB

$$\Delta N = 10 \log\left(\frac{153.4}{75}\right) = 3.1 \text{ dB}$$

6. The carrier power has fallen by 1.5 dB because of the rain attenuation, so the total effect of C/N is a reduction of $1.5 + 3.1 = 4.6$ dB.
7. Hence the downlink *C/N* ratio with 1.5 dB of rain attenuation in the downlink path is :

$$\left(\frac{C}{N_0}\right)_{rain} = \frac{1}{\left(\frac{C}{N_0}\right)^{-1}_{D\,rain} + \left(\frac{C}{N_0}\right)^{-1}_{U\,ra}}$$

$$= \frac{1}{\frac{1}{7.25} + \frac{1}{400}} = 7.12 \text{ or } 8.5 \text{ dB}$$

8. The signal is below the permitted overall C/N ratio, so the downlink margin is negative. The lowest permitted $(C/N)_D$ for $(C/N_0) = 9.5$

$$\left(\frac{C}{N_0}\right)_{D\min} = 9.5 \text{ dB} = 8.91$$

$$\left(\frac{C}{N_0}\right)_{\min} = \frac{1}{\frac{1}{8.91} - \frac{1}{400}} = 9.11 \text{ or } 9.6 \text{ dB}$$

∴ The downlink margin under the stated rain condition is $(8.5 - 9.6) = -1.1$ dB.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the various satellite subsystems ? Explain each of them briefly.

Ans. Refer Q. 3.1.

Q. 2. Explain how attitude and orbit control is achieved from an earth station ?

Ans. Refer Q. 3.3.

Q. 3. Explain the following term :
i. Power gain
ii. Effective isotropically radiated power (EIRP).

Ans. Refer Q. 3.9.

Q. 4. The EIRP of a 240 W transponder is 57 dBW. Calculate the approximate gain of the antenna if the transponder is switched to 120 W. Also calculate the new EIRP, assuming that the same antenna is used.

Ans. Refer Q. 3.10.

4

UNIT

Introduction to Various Satellite Systems

CONTENTS

PART-1

VSAT, Direct Broadcast Satellite Television and Radio.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. **Write a short note on VSAT.**

Answer

1. The underlying concept behind most VSAT system is to bring telecommunications service directly to the end user without any intermediate distribution hierarchy.
2. The VSAT/WLL concept usually has an optimum range of user densities where the economics are most favorable.
3. The schematic diagram of a VSAT communication is shown in Fig. 4.1.1.

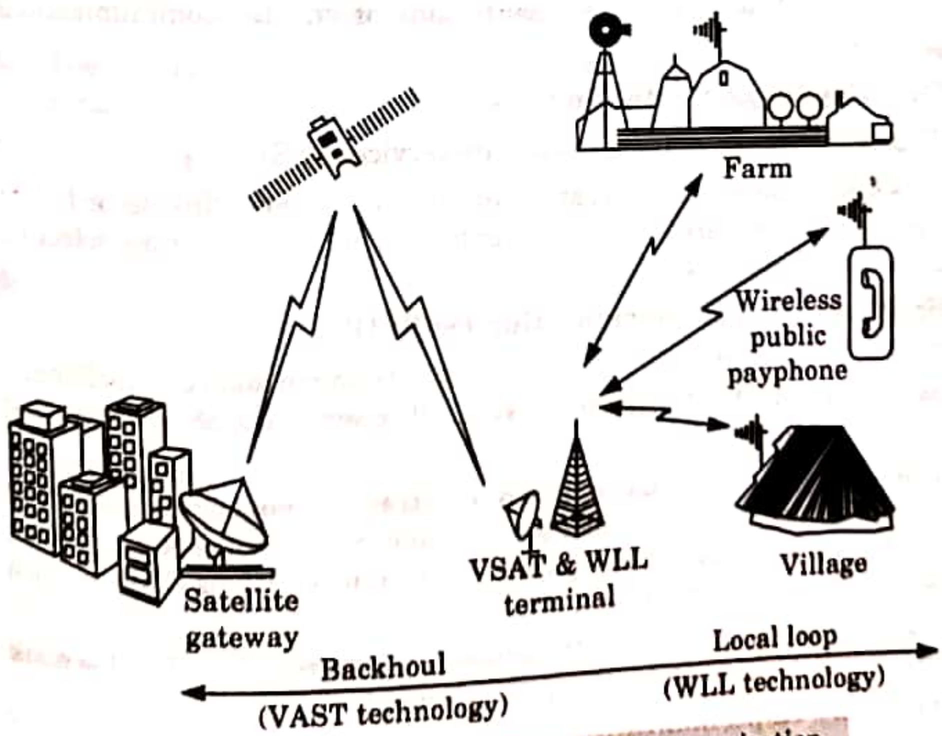

Fig. 4.1.1. Schematic of a VSAT/WLL communication.

4. VSAT network allow multimedia traffic to be brought directly to the end user, but generally handle only small traffic streams.

5. The traffic stream is also usually intermittent in nature : the user accesses the satellite in a demand assigned multiple access (DAMA) mode whenever a message is to be sent and receives a short reply in due course.
6. This is typical in a point of sale (POS) VSAT system that is used to transmit credit card information at a gas pump or a store register.
7. Information about the sale and the customer's credit is sent to a central computer facility, and an authorization or denial is received in response.
8. The interaction between the VSAT and the main hub earth station in the POS transaction is completely automatic and transparent to the user, the customer in this case.
9. Most VSAT networks do not generate enough traffic to justify a dedicated satellite.
10. Many do not even have enough traffic at any given instant to fill one satellite transponder. For this reason, most VSAT networks are designed around the use of leased transponders.

Que 4.2. **What are the various network architectures used for telecommunications service ? Explain.**

Answer

There are three basic implementations of any telecommunications service :

i. One-Way Implementation :

1. This is used in the broadcast satellite service (BSS).
2. This allows the user to access different parts of downlink according to the programs ordered from the supplier. This form of channel selection is called narrow casting.

ii. Split-Two-Way Implementation (Split IP) :

1. This implementation is used when there is no normal return channel, as for example, Ku-band broadcast satellite service (BSS) systems that carry internet traffic.
2. The relatively high capacity downlink stream is not complemented by the uplink capacity from the user terminal. So the only option the user has for a return link is via another telecommunications channel, such as a standard telephone line.
3. The Internet Protocol (IP) is therefore split between a satellite downlink channel and a terrestrial telephone channel.

iii. Two-Way Implementation :

1. In this case, the return link is designed into service so that two-way communication can be set up over the same satellite, from the hub to the user and from the user back to the hub.

Que 4.3. Explain briefly about the Direct Broadcast Satellite (DBS).

Answer

1. The Direct Broadcast Satellite (DBS) refers to satellite television (TV) systems in which the subscribers, or end users, receive signals directly from geostationary satellites.
2. Signals are broadcast in digital format at microwave frequencies.
3. DBS is the descendant of direct-to-home (DTH) satellite services.
4. A DBS subscriber installation consists of a dish antenna two to three feet in a diameter, a conventional TV set, a signal converter placed next to the TV set, and a length of coaxial cable between the dish and converter.
5. The dish intercepts microwave signals directly from the satellite.
6. The converter produces output that can be viewed on the TV receiver.

Que 4.4. Explain digital DBS-TV.

Answer

1. Digital TV signals are transmitted as a 20 Mbps QPSK signal occupying about 27 MHz of transponder bandwidth.
2. The 40 Mbps signal has a data rate between 23 to 27 Mbps with the remaining bits used for error control and system operation.
3. DBS-TV signals make extensive use of error correction and error detection techniques in the form of a double layer of error control coding with interleaving.
4. Each DBS-TV satellite carries up to 32 high power transponders covering part of the 12.2 to 12.7 GHz broadcast satellite band, and the satellite at each orbit location transmit in opposite hands of circular polarization.
5. An electronically controlled polarizer is used behind the antenna feed.
6. The polarizer converts the circularly received polarization signal to a linearly polarized signal in a section of waveguide, and a linear probe in the waveguide converts the signals to currents that drive the LNA input.

Que 4.5. With the help of a suitable block diagram, explain the working of DBS television network in detail.

OR

Explain the working of direct broadcast satellite (DBS) television network.

Answer

1. Fig. 4.5.1 shows a block diagram of a DBS-TV receiver.

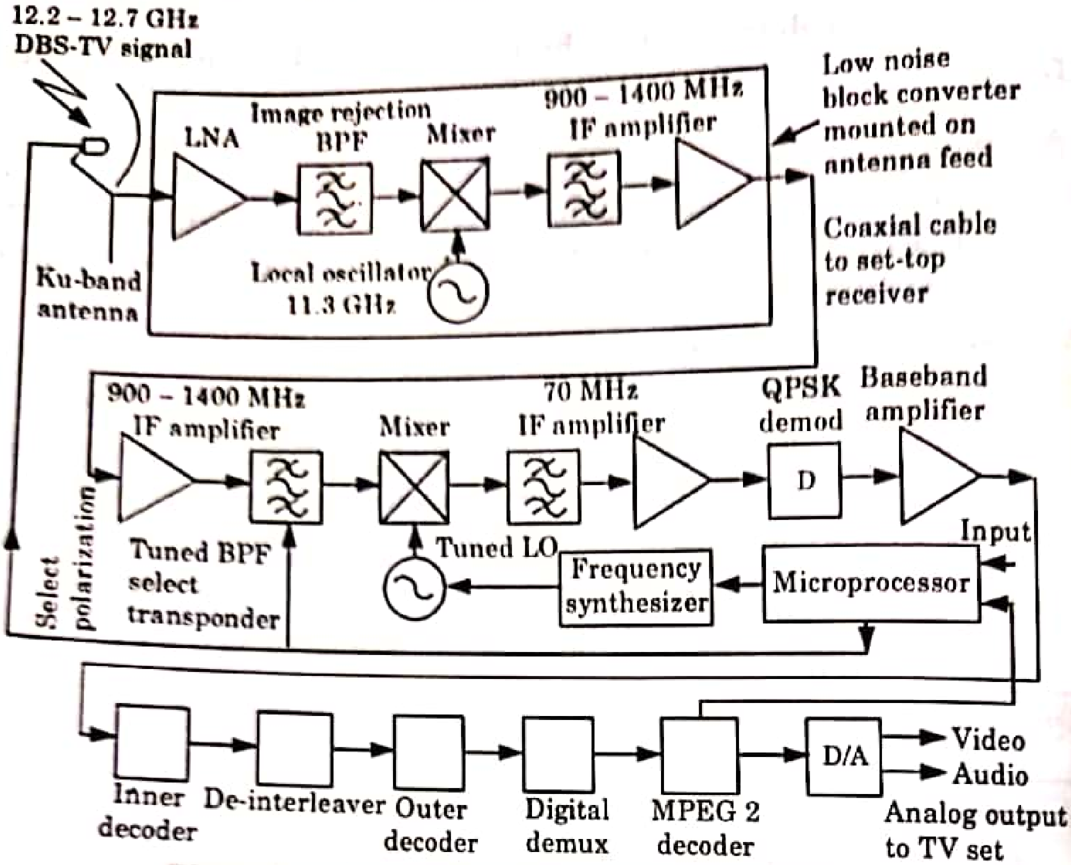

Fig. 4.5.1. Block diagram of a DBS-TV receiver.

2. The entire front end of the receiver is located at the antenna feed in the form of an LNB to minimize loss of signal and hence to maintain the lowest possible system noise temperature.
3. The electronic polarizer is switched by changing the voltage supplied to the LNB via the cable that interconnects the antenna and set-top receiver.
4. The entire 12.2 – 12.7 GHz band is down-converted by the LNB to the 900 – 1400 MHz band.
5. The down-converter consists of a dielectric resonator, local oscillator and mixer, followed by an IF amplifier and band-pass filter.
6. The high gain LNB can drive 100 m of coaxial cable without any reduction in signal quality.
7. Where longer cable runs are needed, amplifiers for the 900–1400 MHz band can be used to boost the signal strength.
8. The set-top box accepts the entire 500 MHz band and separates out the individual transponder frequencies.
9. Any one of these frequencies can be selected on the demand by the user.
10. The user enters a desired channel number into the set-top box using an IR remote control, for example, channel 362, which is converted via a

stored look-up table in the receiver to an RF channel frequency and polarization.

11. The signal from the required transponder is then selected by the receiver by setting the correct polarization at the antenna and tuning the set-top local oscillator to appropriate IF channel frequency.
12. The QPSK signal is then demodulated.
13. The result is a multiplexed bit stream, typically at a bit rate upto 40 Mbps which contains the bits for channel 362 and other video signals.
14. The bit stream is encrypted and contains error control coding bits and data bits.
15. The bit stream is processed to correct and detect errors, de-interleaved and decrypted.
16. A digital demultiplexer then extracts the bits for the wanted channel, 362 in this example, sends them to a MPEG 2 decoder and finally generates analog video and audio signals with *D/A* converters to drive the TV set.

Que 4.6. **Briefly describe the video compression process used in MPEG-2 used in direct broadcast satellite television.**

Answer

1. A 23 Mbps data stream can carry three live compressed digital video signals using MPEG–2 encoding, or up to 10 prerecorded and processed video signals.
2. When prerecorded material such as movies is digitized and processed through MPEG–2 compression, the data rate can be reduced to 1.6 Mbps, but results in digital artifacts appearing in the picture, especially when there is lot of motion in the scene.
3. A digital artifact appears as a freezing of the entire picture for a fraction of second, caused by overloading of the MPEG–2 processing, or as a block, or pixel of the wrong colour.
4. Live program material with a lot of motion in the picture can cause the bit rate of an MPEG–2 coded signal to increase above the average value of 6.2 Mbps.
5. MPEG–2 achieves a compression ratio of 8 to 10 with live video, so a single word error in an MPEG–2 encoded bit stream might be expected to cause errors in 8 or 10 pixels on the TV screen, or even more pixels if error propagation occurs.

Que 4.7. **Write short notes on :**

A. DBS-TV system design

B. DBS-TV link budget

Answer

A. DBS-TV system design :

1. The DBS-TV system must provide a received signal power at the small receiving antenna that provides an adequate *C/N* margin in clear air.
2. Heavy rain will cause attenuation that exceeds the link margin, so occasional outages will be experienced during summer when thunderstorms and heavy rain are more frequent.
3. Hence, the *C/N* margins used in DBS-TV systems are small, to avoid the need for a large receiving antenna.
4. The selection of a *C/N* margin is a design trade-off between the outage level that the customers can be expected to tolerate, the maximum allowable diameter of the receiving dish antenna, and the power output from the satellite transponders.
5. The antennas are 0.45 and 0.9 m in range and 100 to 250 W satellite transponders yield rain attenuation margins of 3 to 8 dB.
6. Thunderstorms occur more often in late-evenings and afternoon, resulting in more outages during prime viewing time.
7. The Ku-band transmit beam from the satellite carrying the DBS-TV signal is shaped to deliver more power to the areas that suffer the highest occurrence of heavy rain.
8. This creates a larger link margin in those areas and helps to keep outages to an acceptable level.

B. DBS-TV link budget : There are two budgets :

a. Downlink power budget :

1. The link margin of 7.7 dB is obtained for a receiver located on – 3 dB contour of the satellite antenna beam.
2. The earth stations that are closed to – 6 dB contour of the satellite beam have a link margin of 4.7 dB.
3. The receiver located within the – 2 dB contour of the satellite beam has a link margin of 8.7 dB.
4. The transponder output power is 160 W, corresponding to a transponder with saturated output power of 200 W and 1 dB output back-off.
5. The receiving antenna is a high efficiency design with an offset parabolic reflector 0.45 m in diameter and a circularly polarized feed.

b. Noise power budget :

1. It is based on the receiver noise bandwidth of 20 MHz, an antenna noise temperature of 35 K in clear air, and a 12 GHz LNA with a noise temperature of 110 K.
2. The result is a noise power of – 134.0 dBW in a noise bandwidth of 20 MHz, referred to the input of the LNA and a clear air *C/N* ratio of

14.3 dB. The noise bandwidth of the digital receiver is set by the bandpass filter.

3. The filter must be designed to match the symbol rate of the transmitted signal.
4. The noise bandwidth of all RRC filters is equal to the symbol rate of digital transmission.

Que 4.8. **Explain the coding and decoding operations in a DBS-TV signal.**

OR

Explain the phenomena of error control in digital DBS-TV.

Answer

1. The block diagram of the coding and decoding operation in a DBS-TV signal is shown in Fig. 4.8.1.

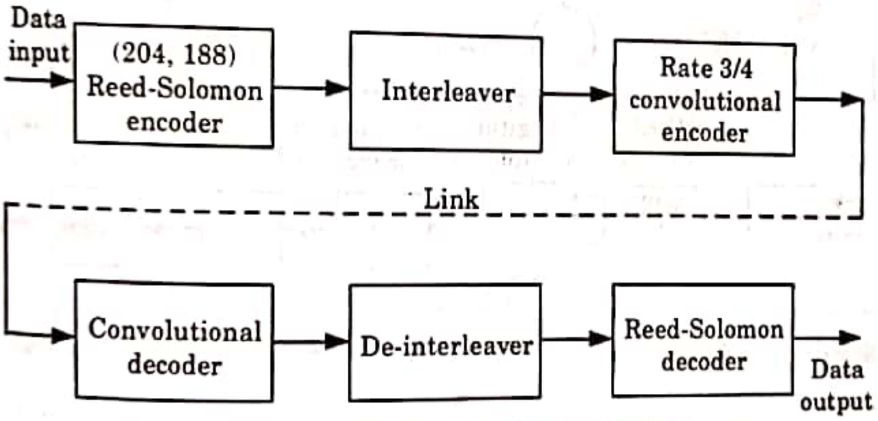

Fig. 4.8.1. Block diagram of the coding and decoding operations in a DBS-TV signal.

2. The compressed digital video signal bit stream is first split into blocks of bits and encoded with a Reed-Solomon linear block code.
3. The coded bit stream is then interleaved and encoded again with a convolutional code.
4. The double layer of error control coding is called a concatenated code.
5. At the receiver, the recovered bit stream is first decoded with a Viterbi decoding algorithm to remove the convolutional coding, and a limited number of errors in the bit stream are corrected.
6. The corrected bit stream is then de-interleaved, and a Reed-Solomon decoding algorithm is applied.
7. Bit errors in a digital video or audio result in the wrong voltage occurring when the errored word is converted to a voltage by receiver's digital to analog converter.

8. If the system knows that a particular word is in error, that word can be flagged and the error can be removed by interpolation of the analog waveform.
9. When a word is known to contain a bit error, it is replaced by a new word.

Que 4.9. **Draw and explain the block diagram of a DBS-TV uplink earth station.**

Answer

1. A block diagram of the transmitting equipment at an uplink station is shown in Fig. 4.9.1.

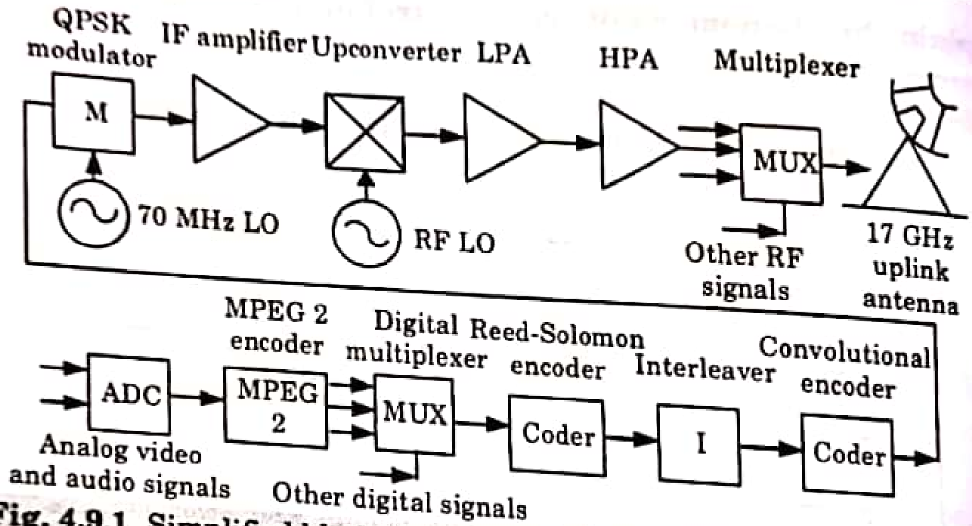

Fig. 4.9.1. Simplified block diagram of a DBS-TV uplink earth station.

2. One uplink antenna will typically transmit upto 16 RF channels to one DBS-TV satellite.
3. Each RF signal is a QPSK modulated Ku-band carrier with a symbol rate of upto 20 Mbps, occupying a bandwidth upto 27 MHz.
4. The encoded, compressed and multiplexed bit stream drives a video exciter which generates QPSK modulation of an intermediate frequency carrier, typically at 70 MHz.
5. The 70 MHz signal is upconverted to the transponder input frequency which contains a travelling wave tube high-power amplifier (HPA).
6. The HPA is usually rated at a much higher power than its normal operating output power level, which provides sufficient output back-off of the HPA to ensure linear operation.
7. The signals from any number of HPAs are multiplexed together in microwave combiners and sent to the antenna feed for transmission to the satellite.

Que 4.10. **Describe in brief satellite radio broadcasting.**

Answer

1. In United States, two companies commenced transmission of digital radio signals from satellites, each offering 50 radio channels. The system is called as satellite digital audio radio service (SDARS).
2. The target audience is in automobiles and other road vehicles.
3. A vehicle equipped with SDARS receiver can receive the same program anywhere in North America.
4. SDARS is the first attempt to create a subscription radio service in contrast to terrestrial radio broadcasting which has been free to the listener, supported by the revenue of the advertiser.
5. The SDARS satellites have high power transponders to compensate for low gain omnidirectional antenna on the vehicle and both system use terrestrial repeaters in large cities to allow the satellite signals when blockage occurs by tall buildings.
6. Sirius satellite radio in New York has three satellites that are equally spaced in a 24 hrs polar elliptical orbit centered at a longitude of 100° W.
7. The highly elliptical orbit of the Sirius satellite can provide a higher elevation angle than a GEO satellite, which is desirable in cities to minimize blockage by tall buildings.
8. Because of the high probability of the satellite signals being blocked by buildings in a city and trees in rural areas, both system utilize time diversity to overcome short interruption in signal.

PART-2

Satellite Navigation and the Global Positioning Systems, GPS Position Location Principle.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.11. **Write a short note on radio and satellite navigation.**

Answer

1. Prior to the development of radio navigation, shipwrecks caused by inaccurate navigation and foggy weather were a common occurrence.
2. Pilots of light aircraft, relying only on a map and landmarks, would get lost and run out of the fuel before they found somewhere to land.

3. With GPS receiver and a map, it is impossible to get lost.
4. GPS can provide a single navigation system with better accuracy and reliability.
5. It can provide a navigation of aircraft directly between airports, while providing absolute position readout of latitude and longitude.
6. Differential GPS can be used instead of ILS to provide the required straight line in the sky for an instrument approach to a runway and can provide automatic landing of aircraft in zero visibility conditions.
7. GPS will replace all other means of navigation, although some may be retained as backup systems in case of failure or jamming of signals.
8. GPS was preceded by an earlier satellite navigation system called transit, built for the US navy, for ship navigation, which achieved much lower accuracy and become obsolete when GPS was introduced.

Que 4.12. **Explain the position location principle of GPS. Also explain the GPS time.**

Answer

A. General arrangement of position locations with GPS :

1. Fig. 4.12.1 shows the general arrangement of position location with GPS.
2. The three satellites provide distance information when the GPS receiver makes three measurements of range, R from the receiver to three known points.
3. Each distance R can be thought of as the radius of a sphere with a GPS satellite at its center.

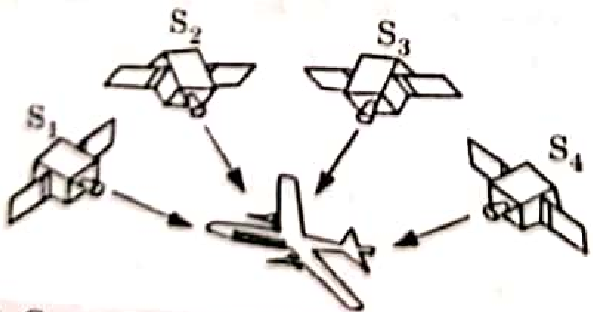

Fig. 4.12.1. General arrangement of position locations with GPS.

4. The receiver lies at the intersection of three such spheres, with a satellite at the center of each sphere.
5. Locally at the receiver, the spheres will appear to be planes since the radii of the spheres are very large.
6. A basic principle of geometry is that the intersection of three planes completely defines a point.
7. Thus, three satellites, through measurement of their distances to the receiver, define the receiver location close to the earth's surface.

8. The aircraft must receive signals from four GPS satellites to be able to determine its position.
9. The principles by which GPS locates a receiver are very simple, requiring only the accurate measurement of three ranges to three satellites.
10. Range is calculated from the time delay incurred by the satellite signal in travelling from the satellite to the GPS receiver, using the known velocity of EM waves in free space.
11. To measure the time delay, we must know the precise instant at which the signal was transmitted, and we must have a clock in the receiver that is synchronized to the clock on the satellite.

B. GPS time :

1. The clock bias value τ which is found as a part of the position location calculation process can be added to the GPS receiver clock time to yield a time measurement that is synchronized to the GPS time standard.
2. The crystal oscillator used in the GPS receiver is highly stable over a period of a few seconds, but will have a frequency which changes with temperature and with time.
3. Every GPS receiver is automatically synchronized to every other GPS receiver anywhere in the world through GPS time.
4. This makes every GPS receiver a super clock, which knows time more accurately than any other time standard.

PART-3

GPS Receivers and Codes, Satellite Signal Acquisition.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.13. **Write short notes on the GPS codes and signal levels.**

Answer

A. GPS Codes : The GPS design contains two ranging codes :

1. **Coarse / Acquisition (*C/A*) code :** It is freely available to the public. The C/A code is a 1023 bit with deterministic sequence called pseudo random noise, which when transmitted at 1.023 megabits per second, repeats after every millisecond.

2. **Restricted precision (*P*) code :** It is usually reserved for military application. The *P* code is also PRN (pseudorandom), however each satellite *P* code is 6.1871×10^{12} bits long and repeats only once a week.

B. Signal levels :

1. The *C/A* code transmitted by GPS satellite is a direct sequence spread spectrum signal, so the *C/N* ratio in the *C/A* codes RF bandwidth is less than 0 dB.
2. The low *C/N* ratio of spread signal is converted to a usable *S/N* by correlation of the code sequence, which adds a despreading (processing) gain to the *C/N* ratio.
3. The theoretical processing gain of a DSSS signal is equal to ratio of the chip rate to bit rate in the spreading sequence, but losses in the correlation process always make practical gains a little power.
4. For *C/A* code transmitted at 1.023 Mbps and 1 ms correction time, the theoretical processing gain is 30.1 dB. The corresponding processing gain for *P* code is 40.1 dB.
5. Table 4.13.1, shows downlink signal power budget for *L*1 and *L*2 carriers. The receiving antenna gain of 0 dB is assumed.

Table 4.13.1.

	Carrier *L*1		Carrier *L*2
Code	***C/A* code**	***P* code**	***P* code**
EIRP (dBW)	26.8	23.8	19.7
Path loss (dB)	– 186.8	– 106.8	– 185.7
P_r (dBW)	– 160.0	– 163.0	– 166.0

Que 4.14. **How the signal can be generated in a GPS satellite ? Explain with suitable block diagram.**

Answer

1. GPS satellites transmit signals using pseudo-random sequence (PN) codes.
2. All satellites transmit a *C/A* code at the same carrier frequency, 1575.42 MHz, called *L*1, using BPSK modulation.
3. The *L*1 frequency is 154 times the master clock frequency of 10.23 MHz.
4. The *C/A* code has a clock rate of 1.023 MHz and the *C/A* code sequence has 1023 bits, so the PN sequence lasts exactly 1.0 ms.
5. The exact values of the frequencies are about 0.005 Hz lower than stated here to allow for relativistic effects caused by the high velocity of the satellites in their orbits.

6. The *P* code is transmitted using BPSK modulation at the *L*2 carrier frequency of 1227.6 MHz (120 × 10.23 MHz), and is also transmitted with BPSK modulation on the *L*1 carrier frequency, in phase quadrature with the *C/A* code BPSK modulation.

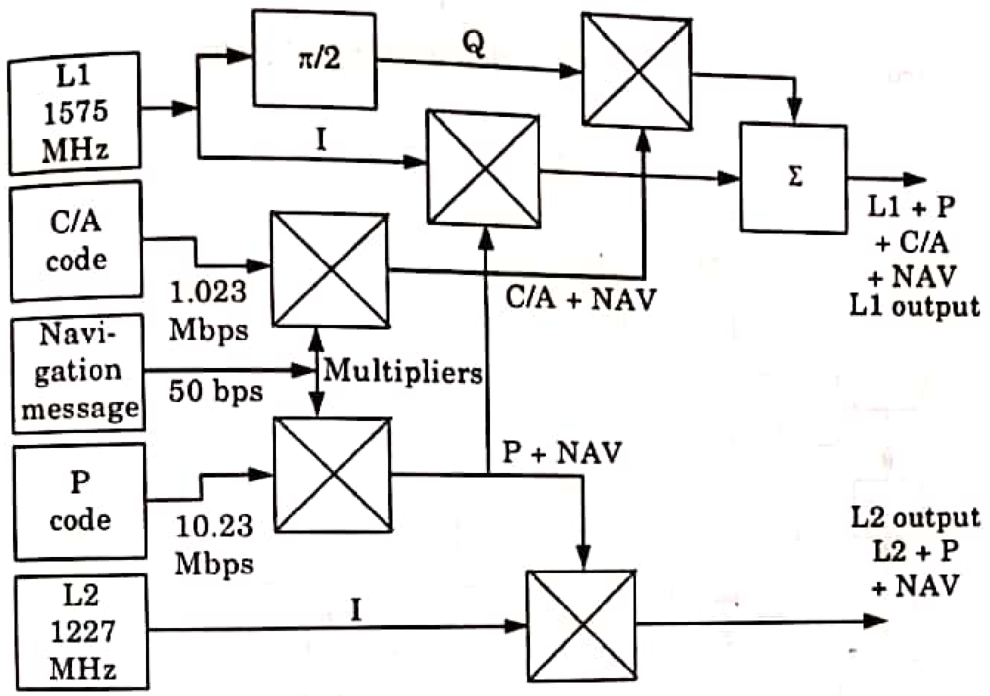

Fig. 4.14.1. Signal generation in a GPS satellite.

7. The *C/A* and *P* code transmissions from all GPS satellites are overlaid in the *L*1 and *L*2 frequency bands, making GPS a direct sequence spread spectrum (DSSS) system.
8. The receiver separates the signals from individual GPS satellites.

Que 4.15. **Explain the working of *C/A* code generator.**

Answer

1. The *C/A* codes transmitted by GPS satellites are all 1023 bit gold codes.
2. GPS *C/A* gold codes are formed from two 1023 bit *m*-sequences, called G_1 and G_2 by multiplying together the G_1 and G_2 sequences with different time offsets.
3. A shift register with n-stages can generate a PN sequence $2^n - 1$ bits in length.
4. The PN sequences G_1 and G_2 are generated by 10-bit shift registers.
5. The clock rate for the *C/A* code is 1.023 MHz, so each sequence lasts 1.0 ms.
6. Fig. 4.15.1 shows a generator diagram for the *C/A* code.

7. The C/A code for a particular satellite is created with an algorithm that includes the identification number of the GPS satellite, thus creating a unique code for each satellite.
8. The satellite with ID number i has a C/A code sequence $C_i(t)$.

$$C_i(t) = G_1(t) \times G_2 (t + 10iT_c)$$

where, T_c = Clock period for the C/A code.

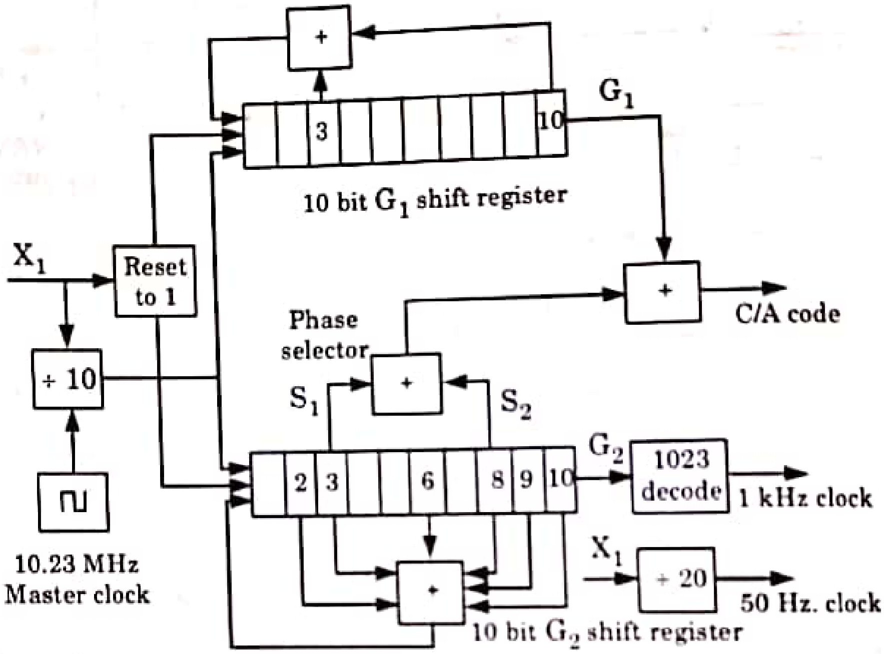

Fig. 4.15.1. C/A code generator.

Que 4.16. **Draw the block diagram of a simplified GPS receiver and also explain its working.**

OR

Explain the position location principle of GPS. Also draw the block diagram of a GPS receiver and explain its working.

Answer

A. GPS position location principle : Refer Q. 4.12, Page 4–11D, Unit-4.

B. GPS receiver :

1. Fig. 4.16.1 shows a simplified block diagram of a C/A code GPS receiver.
2. The antenna is a circularly polarized patch antenna with an LNA mounted on the printed circuit board.
3. A superheterodyne receiver is used to generate an IF signal in a bandwidth of about 2 MHz, which is sampled using I and Q sampling techniques and processed digitally.

4. The digital portion of the receiver includes a C/A code generator, a correlator and a microprocessor that makes the timing measurements and calculates the receiver's position.

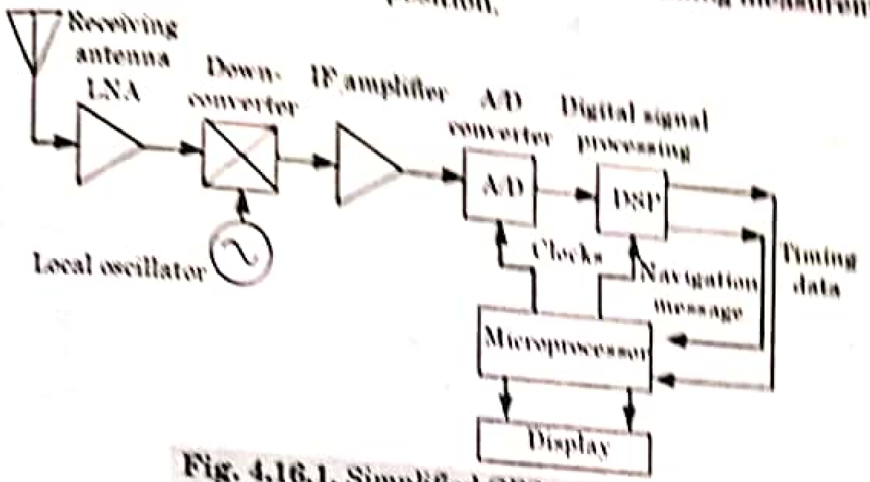

Fig. 4.16.1. Simplified GPS receiver.

Que 4.17. **Write short note on satellite signal acquisition.**

Answer

1. The GPS receiver must find the starting time of the unique C/A code for each of the four satellites. This is done by correlating the received signal with stored C/A codes, as in any direct sequence spread spectrum system.
2. The receiver will automatically select the four strongest signals and correlate to those. If the geometry of the strongest satellite is poor *i.e.*, the satellites are close together and have pseudo-ranges that are equal, the receiver may also use several weak signals.
3. If the receiver is making a cold start with no information about the current position of GPS satellite, or its own location, it must search all 37 possible C/A codes until it can correlate with one.
4. Once the correlation is obtained, the data stream from that satellite can be read by the receiver.
5. The data stream contains information about the adjacent satellites, so once one signal is correlated, the receiver no longer needs to search through all the 36 possible codes to find the next satellite, it can go directly to the code.
6. A direct sequence spread spectrum receives locks to a given code by matching the locally generated code to the received code.
7. The locally generated code is compared to the received code, bit by bit, through all 1023 bits of the sequence, until either lock is found or receiver concludes that this is not the correct code.
8. If the starting time for the locally generated code was not selected correctly, correlation will not be obtained immediately.

9. The process of correlation is continued for 1023 times until all possible starting times for the locally generated code have been tried.
10. If the satellite with the particular *C/A* code is not visible then no correlation will occur and hence lock will not be achieved.
11. Once one *C/A* code is found, the remaining satellite can then be acquired in a few seconds because then IDs are known.
12. GPS receivers used for navigation of aircraft in instrument metrological condition and for instrument landings are required to have integrity monitoring to guard against receiver or satellite failure and interference with or jamming of GPS signals.
13. Thus, GPS signal acquisition is a search process. The main purpose of acquisition is to identify the visible satellite in the data and then find the beginning point of the *C/A* code and the Doppler frequency by correlating the incoming signal with the received generated signal.

PART-4

GPS Navigation Message, GPS Signal Levels, Timing Accuracy, GPS Receiver Operation.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.18. **Write a short note on GPS navigation message.**

Answer

1. It is the key feature of the GPS *C/A* code.
2. The navigation message contains a large amount of information that is used by the GPS receivers to optimize the acquisition of satellite signals and calculate position.
3. The navigation message is sent at 50 bps by BPSK modulation of the *C/A* and *P* codes.
4. Effectively, 20 *C/A* code sequences form one navigation message bit.
5. The phase of the 20 sequences is inverted between the 1 and 0 bits of the message by modulo-2 addition of the navigation message data to the *C/A* and *P* code sequences.
6. The navigation signal is extracted by a 50 bps BPSK demodulator that follows the *C/A* and *P* code correlator.

7. The narrow bandwidth of the navigation message ensures a high S/N ratio at the demodulator input and low probability of bit errors in the navigation message.

Que 4.19. **Discuss in brief GPS signal levels.**

Answer

1. GPS satellites have an array of helical antennas that provide gain toward the earth and 10 W transmitters, leading a EIRP values in the range 19 to 27 dBW.
2. The C/A code transmitted by the satellite is a direct sequence spread spectrum signal, so the C/A ratio in the C/A code's.
3. RF bandwidth will be less than 0 dB. The low C/N ratio of the spread spectrum signal is converted to a usable S/N by correlation of the code sequences, which adds a despreading (processing) gain to the C/N ratio.
4. The theoretical processing gain of a direct sequence spread spectrum signal is equal to the ratio of the chip rate to the bit rate in the spreading sequence, but losses in the correlation process always make practical gains a little lower.
5. For the C/A code transmitted at 1.023 Mbps and a 1-ms correlation time, the theoretical processing gain in 1023, or 30.1 dB. The corresponding processing gain for the P code is 40.1 dB.

Que 4.20. **Explain GPS timing accuracy.**

Answer

1. The position location process requires an accurate measurement of the time of arrival of the code sequence at the receiver.
2. The accuracy with which a timing measurement can be made on a single pulse is

$$\delta t \approx \frac{1}{[B_n \sqrt{S/N}]} \text{ seconds}$$

where, δt is the rms timing error, B_n is the noise bandwidth of the RF channel, and S/N is the signal to noise power ratio for the pulse in the noise bandwidth B_n.
3. The S/N ratio after the correlator is

$$\frac{S}{N} = \frac{C}{N} + G_p - \text{losses}$$

where, G_p is the correlator processing gain. For the C/A code $G_p = 1023 = 30.1$ dB and

$$\frac{S}{N} = -19.3 + 30.1 \text{ dB} - \text{losses}$$

$$= 11.7\text{dB} - \text{losses}$$

4. The theoretical noise bandwidth of the correlator is B_n = 1 MHz so,

$$\delta t = \frac{1}{[10^6 \sqrt{10}]s} = 0.316 \ \mu s$$

5. The accuracy achieved by commercial *C/A* code GPS receivers was better than expected by the designers of the GPS system.

Que 4.21. What is the function of the non-coherent delay loop in GPS receiver ? Explain with the suitable diagram.

Answer

1. The function of the non-coherent delay lock loop is to set the frequency of the voltage controlled oscillator (VCO) in the receiver to match *C/A* code rate of the received signal, and to align the received chip transitions correctly.
2. GPS satellites generate all their signals from a master clock, which means that there is a phase coherence between the chips, the codes and the RF frequencies of all GPS signals from a particular satellite.

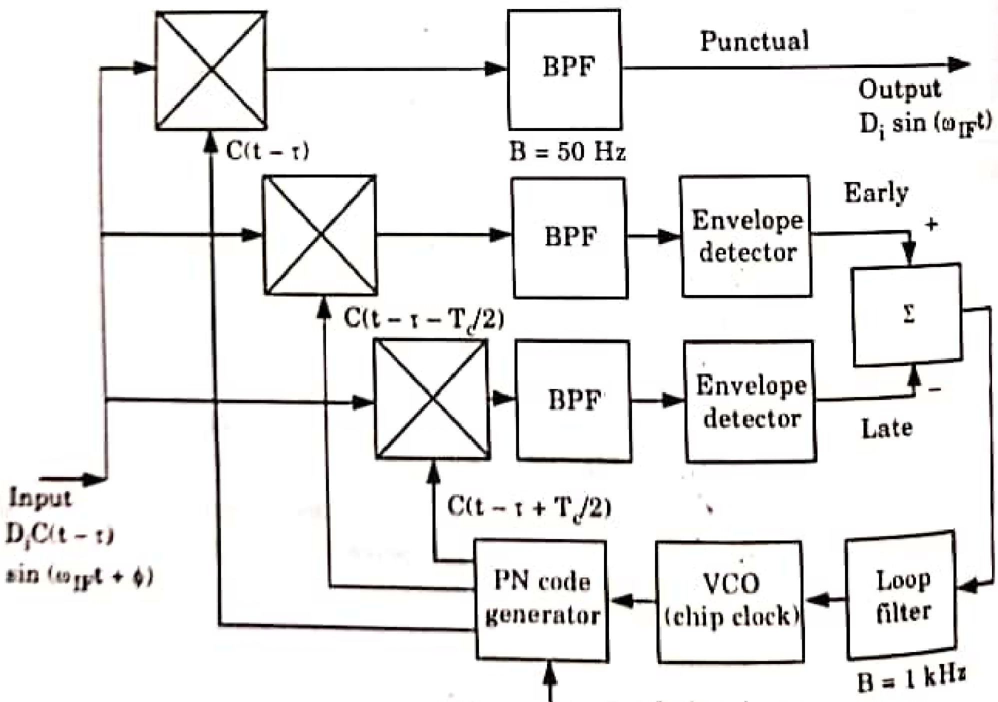

Fig. 4.21.1. Non-coherent code lock loop.

3. The delay lock loop is shown in Fig. 4.21.1.
4. It takes the advantage of the coherent nature of the GPS *C/A* signals, so that the VCO becomes both a time reference for the *C/A* code signals and also the chip clock.
5. The PN code generator must be set to the correct code, and its start time must also be set correctly, for the loop to lock.
6. The delay lock loop has three paths : punctual, early and late.
7. The delay lock loop steers the chip clock so that the punctual output can be used to drive the *C/A* code generator.
8. The *C/A* code chip rate is generated by the VCO. The incremental process of trial and error which finds the correct sequence and timing.
9. The early-late channels in the delay lock loop generate output signals which steer the phase of the VCO so that the navigation message is recovered correctly.

Que 4.22. **Discuss the various applications of GPS system.**

Answer

The various applications of GPS systems are :

1. **Location :** GPS was the first positioning system to offer highly precise location data for any point on the planet, in any weather.
2. **Navigation :** GPS was designed to provide navigation information for ships and planes.
3. **Tracking :** GPS used in conjunction with communication links and computer can provide the backbone for system tailored to application in agriculture man transit, urban delivery, public safety, vessel and vehicle tracking.
4. **Mapping :** GPS can generate maps and models of everything in the world, mountains, sea, rivers, cities etc., and manages the effect of damage and disasters.
5. **Timing :** GPS can be used to determine precise time, time intervals and frequency.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Write a short note on VSAT.

Ans. Refer Q. 4.1.

Q. 2. Explain briefly about the Direct Broadcast Satellite (DBS).

Ans. Refer Q. 4.3.

Q. 3. With the help of a suitable block diagram, explain the working of DBS television network in detail.

Ans. Refer Q. 4.5.

Q. 4. Write short notes on :

A. DBS-TV system design

B. DBS-TV link budget

Ans. Refer Q. 4.7.

Q. 5. Explain the position location principle of GPS. Also define the GPS time ?

Ans. Refer Q. 4.12.

Q. 6. How the signal can be generated in a GPS satellite ? Explain with suitable block diagram.

Ans. Refer Q. 4.14.

Q. 7. Draw the block diagram of a simplified GPS receiver and also explain its working.

Ans. Refer Q. 4.16.

PART-1

Mechanism of Satellite Launching, Launch Vehicles.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **What are the techniques of launching a satellite ?**

Answer

There are basically three techniques of launching a satellite :

i. **First technique :**

1. In the first technique, first the satellite is placed in lower circular earth orbit at an altitude of around 300 km. Then a velocity increment is required and it is carried out by various auxiliary propulsion stages.
2. The first velocity increment changes the satellites lower circular earth orbit into an elliptical transfer orbit with a perigee of about 300 km and apogee at 42164.2 km (radius of geosynchronous orbit).
3. The second velocity increment is required and it finally places the satellite into the desired orbit. Space transport system (STS) follows this technique.

ii. **Second technique :**

1. The second technique has been used by expandable launch vehicles such as Ariane, Delta or Atlas-centaur launchers.
2. In this case, there is no initial circular orbit and the vehicle provides necessary velocity at the perigee of the elliptical transfer orbit.
3. Thus here only one velocity increment is required from the satellite at apogee.

iii. **Third technique :**

1. The third technique has been used by special expandable launcher vehicles such as US Titan III C and the USSR Proton launcher.
2. In this case, satellites are directly placed into geostationary orbit.

Que 5.2. **Write a short note on launch vehicles.**

Answer

1. Satellite launch vehicles launch the satellites into a particular orbit based on the requirement.

2. Satellite launch vehicles have multiple stages and as each stage is completed that portion of the launcher is expanded. This is done until the final stage places the satellite into the desired trajectory.
3. Following are the two types of satellite launch vehicles.

i. **Expendable Launch Vehicles (ELV) :**

1. Expendable launch vehicles (ELV) get destroyed after leaving the satellites in space.
2. The ELV contains three stages. First and second stages of ELV raise the satellite to an about 50 miles and 100 miles.
3. Third stage of ELV places the satellite in transfer orbit.
4. The task of ELV will be completed and its spare parts will be fallen to earth, when the satellite reached to transfer orbit.

ii. **Reusable Launch Vehicles (RLV) :**

1. Reusable launch vehicles (RLV) can be used multiple times for launching satellites.
2. Generally, this type of launch vehicles will return back to earth after leaving the satellite in space.
3. The functions of space shuttle (RLV) are similar to the functions of first and second stages of ELV.
4. Satellite along with the third stage of space shuttle is mounted in the cargo bay. It is ejected from the cargo bay when the space shuttle reaches to an elevation of 150 to 200 miles.
5. Then, the third stage of space shuttle gets fired and places the satellite into a transfer orbit. After this, the space shuttle will return back to earth for reuse.

Que 5.3. **Briefly describe the satellite launch sequence.**

Answer

1. The launch of a satellite into a geostationary orbit involves a sequence of steps that start with satellite and the vehicle leaving the launch platform.
2. They end with the satellite being positioned at the desired parking slot.
3. Satellites can be launched using the Expendable Launch Vehicles (ELVs) like Delta and Ariane.
4. They place the satellite in an inclined elliptical orbit called a transfer orbit with an apogee at the geosynchronous altitude and perigee at 300 km.
5. The spin of the satellite is stabilized in the transfer orbit so that ground control can communicate with its telemetry system.

6. When the orbit and altitude of the satellite have been determined exactly and when the satellite is at apogee of the transfer orbit, a rocket engine called apogee kick motor places the satellite into a geosynchronous orbit with zero inclination.
7. The apogee kick motor is capable of increasing the satellite's velocity from 1585 m/s to about 3048 m/s, in its transfer from transfer orbit to the geosynchronous orbit while reducing the orbital inclination to zero at the same time.

PART-2

Advanced Launching Tech Like SpaceX, Intelligent Testing, Control and Decision Making for Space, Inter Satellite Like.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.4. **Explain SpaceX launch system.**

Answer

1. The SpaceX reusable launch system development program is a privately funded program to develop a set of new technologies for an orbital launch system that may be reused many times in a manner similar to the reusability of aircraft.
2. SpaceX has been developing the technologies over several years to facilitate full and rapid reusability of space launch vehicles.
3. The project's long-term objectives include returning a launch vehicle first stage to the launch site in minutes and to return a second stage to the launch pad following orbital realignment with the launch site and atmospheric reentry in up to 24 hours.
4. SpaceX's long term goal is that both stages of their orbital launch vehicle will be designed to allow reuse a few hours after return.
5. SpaceX first achieved a successful landing and recovery of a first stage in December 2015.
6. The first re-flight of a landed first stage occurred in March 2017 with the second occurring in June 2017, that one only five months after the maiden flight of the booster. The third attempt occurred in October 2017 with the SES-11/EchoStar-105 mission.
7. Second flights of refurbished first stages then became routine, with individual boosters - namely B1049 and B1051- having powered up to eight missions as of January 2021.

Que 5.5. **Write a short note on intelligent testing, control and decision making for space.**

Answer

1. Intelligent testing, control, and decision-making technology imply obtaining all information automatically and realizing testing, control, diagnosis, monitoring, and decision-making during space launch on the basis of computer science, communication, control, operational research, real-time modeling, artificial intelligence, and expert systems.
2. The significant feature of the technology is "intelligent," meaning that it possesses the analytic and decision-making ability to solve specific problems.
3. The whole system consists of parameter testing, network transmission and control, comprehensive data possessing and analysis, condition monitoring and trend analysis, fault diagnosis, and intelligent decision-making.
4. Intelligent testing, control, and decision-making for space launch are challenging domains that hold great significance for applying intelligence theories and technology to space launch testing and control,
5. They have played an important part in boosting the space sector and increasing launch efficiency and success rate.

Que 5.6. **What do you mean by inter-satellite link ?**

Answer

1. Inter-Satellite Links (ISLs) are intended to improve precision of orbit determination and satellite clock estimation.
2. The ISLs provide a precise pseudo range measurements between satellites in a specific constellation.
3. Inter-Satellite links (ISLs) are used for ranging and communication between navigation satellites and can also serve space users that are outside the navigation constellation.
4. Inter-Satellite Link (ISL) applications can improve and expand communication satellite services in a number of ways.
5. As the demand for orbital slots within prime regions of the geostationary arc increases, attention is being focused on ISLs as a method to utilize this resource more efficiently and circumvent saturation.

PART-3

Indian Satellite Systems : History and Overview of Indian Satellite System, Achievements.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.7. **Discuss about the history of Indian satellite system.**

Answer

1. ISRO's first satellite, Aryabhata, was launched by the Soviet Union on April 19, 1975.
2. Rohini, the first satellite to be placed in orbit by an Indian-made launch vehicle (the Satellite Launch Vehicle 3), was launched on July 18, 1980.
3. ISRO has launched several space systems, including the Indian National Satellite (INSAT) system for telecommunication, television broadcasting, meteorology, and disaster warning and the Indian Remote Sensing (IRS) satellites for resource monitoring and management.
4. The first INSAT was launched in 1988, and the program expanded to include geosynchronous satellites called GSAT.
5. The first IRS satellite was also launched in 1988, and the program developed more-specialized satellites, including the Radar Imaging Satellite-1 (RISAT-1, launched in 2012) and the Satellite with Argos and Altika (SARAL, launched in 2013), a joint Indian-French mission that measures ocean wave heights.
6. ISRO subsequently developed three other rockets: the Polar Satellite Launch Vehicle (PSLV) for putting satellites into polar orbit, the Geostationary Space Launch Vehicle (GSLV) for placing satellites into geostationary orbit, and a heavy-lift version of the GSLV called the GSLV Mark III or LVM.
7. Those rockets launched communications satellites and Earth-observation satellites as well as missions to the Moon (Chandrayaan-1, 2008; Chandrayaan-2, 2019) and Mars (Mars Orbiter Mission, 2013). ISRO plans to put astronauts into orbit in 2021.

Que 5.8. **Explain Indian national satellite system.**

Answer

1. The Indian National Satellite System (INSAT) is a series of multipurpose geostationary satellites launched by ISRO to satisfy the telecommunications, broadcasting, meteorology, and search and rescue operations.
2. INSAT is the largest domestic communication system in the Indo-Pacific Region.

3. It is a joint venture of the Department of Space, Department of Telecommunications, India Meteorological Department, All India Radio and Doordarshan. The overall coordination and management of INSAT system rests with the Secretary-level INSAT Coordination Committee.
4. INSAT satellites provide transponders in various bands to serve the television and communication needs of India. Some of the satellites also have the Very High Resolution Radiometer (VHRR), CCD cameras for meteorological imaging.
5. The satellites also incorporate transponder(s) for receiving distress alert signals for search and rescue missions in the South Asian and Indian Ocean Region, as ISRO is a member of the Cospas-Sarsat program.

Que 5.9. **What are the biggest achievements of ISRO ?**

Answer

1. **Launch of Aryabhata, India's first satellite in 1975 :**

i. It was launched in a Russian rocket Kosmos-3M from Kapustin Yar, Astrakhan Oblast in 1975.

ii. The satellite was in space for 17 years before re-entering Earth's atmosphere on 10th February 1992. However, ISRO lost all communication with the satellite in March 1981.

2. **Launch of INSAT in 1983 :**

i. INSAT stands for the Indian National Satellite System, which is one of the few largest domestic communication satellite systems in the Indo-Pacific Region or Asia-Pacific Region.

ii. It has 9 communication satellites that are placed in the Geo-stationary orbit. It was commissioned in 1983 to satisfy broadcasting, telecommunications, weather forecasting, search & rescue operations, disaster warning and meteorology.

iii. The launch of INSAT commenced a major revolution in the country's communication sector.

3. **SRE-1 in 2007 :**

i. SRE-1 was launched on January 10, 2007 from Satish Dhawan Space Centre First Launch Pad in Sriharikota, Andhra Pradesh. The rocket used to launch SRE-1 was PSLV C7 along with 3 other satellites.

ii. The objective of this entire mission was to showcase the potential of an orbiting space capsule's recovery. The capsule orbited in space for 12 days before re-entering earth. Other scientific objectives were guidance control, navigation, communication management and many others.

4. **2008's Chandrayaan 1 :**

i. Chandrayaan 1 was launched in October 2008 and was the first lunar probe under the Chandrayaan program. The mission had a lunar impactor and orbiter and was in operation until August 2009.

ii. It was launched to collect scientific information about the moon's mineralogy, geology and topography. While the mission was concluded, some also consider it a failure as ISRO lost contact with the spacecraft before even completing a year in space.

5. **GSLV MK3 in 2014 :**

i. GSLV MK3 stands for Geosynchronous Satellite Launch Vehicle Mark III. It is a 3-stage medium lift launch space craft developed by ISRO to launch Chandrayaan 2.

ii. It is ISRO's most powerful rocket that can carry up to 4000 kgs into the orbit. It can also carry 3 astronauts, which is a huge accomplishment for India as not many organizations have been able to do so.

6. **2014's Mangalyaan or MOM :**

i. Undoubtedly, MOM or Mars Orbiter Mission is ISRO's biggest achievement. Reaching Mars has not been easy for any country.

ii. To this date, India remains the only country to reach mars on its first attempt. Not only this, they accomplished the mission on a tight budget of INR 450 crore, which was the lowest till date. India is the 4th country to reach the red planet after the U.S., Russia and Europe.

7. **Launching the heaviest commercial mission in 2015 :**

i. In 2015, ISRO created or broke a record of the heaviest commercial mission. Carrying 1440 kg, Polar Satellite Launch Vehicle-C28 (PSLV-C28) was launched on July 10, 2015.

ii. The spacecraft carried 5 British satellites and was operated by ISRO as well as Antrix Corporation. The spacecraft travelled 647 km in 19 minutes 22 seconds from the Satish Dhawan Space Centre.

8. **Development of RLV :**

i. The next mission of ISRO that deserves a spot in this list is the development of a Reusable Launch Vehicle (RLV).

ii. Unlike NASA, ISRO does not have an unlimited budget and freedom, which is why they have to be cost effective as well as cost efficient. This is the reason why the development of RLV is major for ISRO.

iii. If this reusable unmanned space rocket is given the green light, it will give the organization a chance to go further in their mission of pursuing science research and space exploration. While the RLV is still a prototype, it took its first flight on 23 May 2016.

9. **Launching IRNSS in 2016 :**

i. Indian Regional Navigation Satellite System (IRNSS) is an independent navigational satellite system designed to give accurate information to users in India. Launching IRNSS made India the fifth country to have its own navigation system.

Seven satellites had to be launched to complete the satellite system, which ISRO was able to complete on 29 April 2016. It is a big leap for the future and is something every Indian is proud of.

10. **Launched 104 satellites in 1 mission :**

i. After carrying out the heaviest commercial mission, ISRO created another world record of launching the greatest number of satellites in a single mission in 2017 using the Indian rocket Polar Satellite Launch Vehicle from Sriharikota, Andhra Pradesh.

ii. Out of the 104 satellites lifted off, 101 were foreign satellites. Putting all the satellites in a single go into their right orbit was one of ISRO's biggest achievements till date.

PART-4

GSLV, PSLV, Advanced Technology Vehicle.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.10. **What is geosynchronous satellite launch vehicle (GSLV) ? Also explain the stage of GSLV.**

Answer

A. **GSLV :**

1. Geosynchronous Satellite Launch Vehicle (GSLV) is a space launch vehicle designed, developed, and operated by the Indian Space Research Organization (ISRO) to launch satellites and other space objects into Geosynchronous Transfer Orbits.

2. GSLV has the capability to put a heavier payload in the orbit than the Polar Satellite Launch Vehicle (PSLV).

B. **Stages of GSLV :**

i. **First Stage : GS1**

The first stage uses the 138 tonne S139 solid rocket motor with four liquid engine strap-on motors. This stage generates maximum thrust of 4700 kilo Newton.

ii. **Second Stage : GS2**

The second stage uses a liquid rocket engine which is known as Vikas engine. It generates maximum thrust of 800 kilo Newton.

iii. **Third Stage : CUS**

1. The third stage uses a Cryogenic engine, which uses liquefied oxygen and hydrogen as fuel. In the initial launches, GSLV used the Russian Cryogenic engine in CUS stage. These engines were made by a Russian company, Glavcosmos.
2. In 1994, ISRO started a project called Cryogenic Upper Stage Project to develop India's own Cryogenic engine with the aim of ending its reliance on foreign Cryogenic engines.
3. The CE-7.5 is India's first cryogenic engine.

Que 5.11. **What do you mean by Polar Satellite Launch Vehicle? Also explain the stages of PSLV.**

Answer

A. **Polar Satellite Launch Vehicle :**

1. Polar Satellite Launch Vehicle (PSLV) is the third generation launch vehicle of India. It is the first Indian launch vehicle to be equipped with liquid stages.
2. After its first successful launch in October 1994, PSLV emerged as the reliable and versatile workhorse launch vehicle of India with 39 consecutively successful missions by June 2017.
3. During 1994-2017 period, the vehicle has launched 48 Indian satellites and 209 satellites for customers from abroad.
4. Besides, the vehicle successfully launched two spacecraft - Chandrayaan-1 in 2008 and Mars Orbiter Spacecraft in 2013 - that later traveled to Moon and Mars respectively.

B. **Stages of PSLV :**

i. **First Stage : PS1**

PSLV uses the S139 solid rocket motor that is augmented by 6 solid strap-on boosters.

ii. **Second Stage : PS2**

PSLV uses an Earth storable liquid rocket engine for its second stage, known as the Vikas engine, developed by Liquid Propulsion Systems Centre.

iii. **Third Stage : PS3**

The third stage of PSLV is a solid rocket motor that provides the upper stages high thrust after the atmospheric phase of the launch.

iv. **Fourth Stage : PS4**

The PS4 is the uppermost stage of PSLV, comprising of two Earth storable liquid engines.

Que 5.12. **Differentiate between PSLV and GSLV.**

Answer

S. No.	PSLV	GSLV
1.	PSLV is designed mainly to deliver earth observation or remote sensing satellites.	GSLV has been designed for launching communication satellites.
2.	PSLV is a four-stage launch vehicle with first and third stage using solid rocket motors and second and fourth stage using liquid rocket engine.	GSLV is a third-stage launch vehicle with first using solid rocket motors, second stage using liquid rocket fuel and third stage using Cryogenic engine.
3.	PSLV has 6 solid boosters.	GSLV has 4 liquid boosters.
4.	PSLV is more reliable.	GSLV is less reliable.

Que 5.13. **What is vehicle and technical specification of GSLV ?**

Answer

A. Vehicle specifications :

Height : 49.13 m
Number of Stages : 3
Lift Off Mass : 414.75 tonnes

B. Technical specifications :

i. **Payload to GTO : 2,500 kg :** GSLV's primary payloads are INSAT class of communication satellites that operate from Geostationary orbits and hence are placed in Geosynchronous Transfer Orbits by GSLV.

ii. **Payload to LEO : 5,000 kg :** Further, GSLV's capability of placing up to 5 tonnes in Low Earth Orbits broadens the scope of payloads from heavy satellites to multiple smaller satellites.

Que 5.14. **What is vehicle and technical specifications of PSLV ?**

Answer

A. Vehicle specifications :

Height : 44 m
Diameter : 2.8 m
Number of Stages : 4

Lift Off Mass	: 320 tonnes (XL)
Variants	: 3 (PSLV-G, PSLV - CA, PSLV - XL)

B. **Technical specifications :**

i. **Payload to SSPO: 1,750 kg :** PSLV earned its title 'the Workhorse of ISRO' through consistently delivering various satellites to Low Earth Orbits, particularly the IRS series of satellites. It can take up to 1,750 kg of payload to Sun-Synchronous Polar Orbits of 600 km altitude.

ii. **Payload to Sub GTO: 1,425 kg :** Due to its unmatched reliability, PSLV has also been used to launch various satellites into Geosynchronous and Geostationary orbits, like satellites from the IRNSS constellation.

Que 5.15. **What is advanced technology vehicle ? Enlist the critical technologies successfully tested for advanced technology vehicle.**

Answer

A. **Advanced Technology Vehicle :**

1. Advanced Technology Vehicle is an experimental mission carried out by Indian Space Research Organization (ISRO) in the year 2016.
2. This experimental mission was a step towards accomplishing the development of the Air Breathing Propulsion System.
3. The test was carried out from Satish Dhawan Space Centre (SHAR), Sriharikota, Nellore District of Andhra Pradesh.

B. **The lists of critical technologies successfully tested in the mission are :**

1. Holding the flame while the vehicle is moving at supersonic speed.
2. Mechanism of air intake technology.
3. Ignition of engines that have air breathing technology.
4. Fuel injection systems.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What is the mechanism of launching a satellite ?

Ans. Refer Q. 5.1.

Q. 2. Briefly describe the satellite launch sequence.

Ans. Refer Q. 5.3.