Basics of Mobile and Satellite Communication , ETOE03

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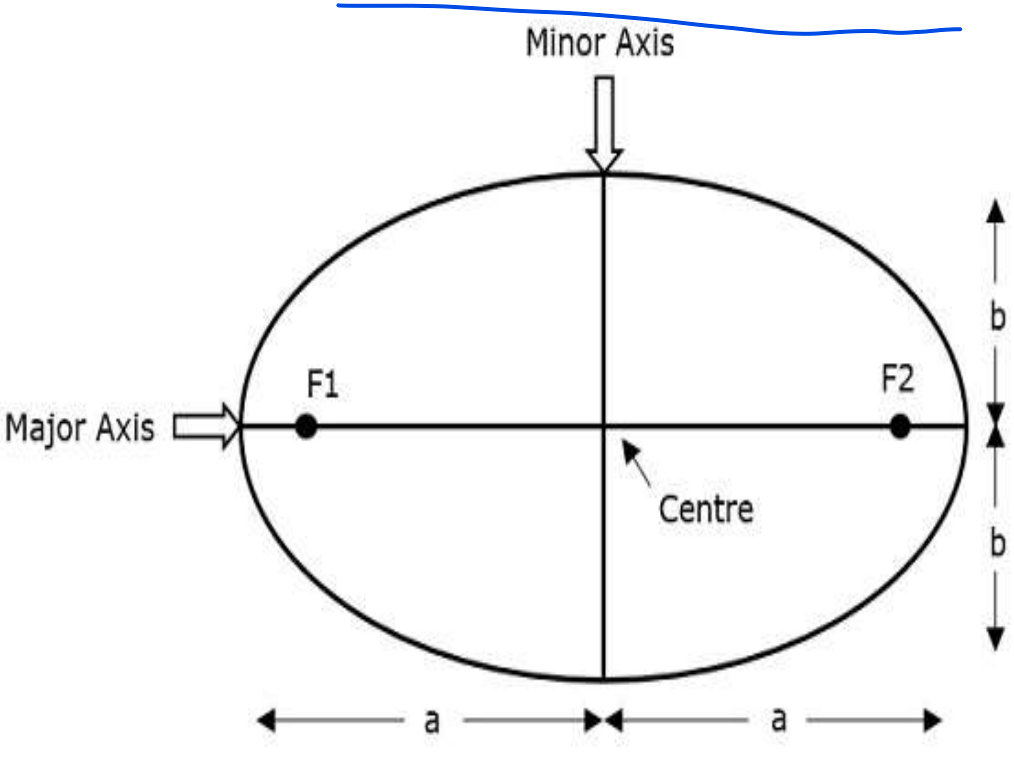
UNIT4

- **Introduction to Satellite Communication:** Orbital parameters and Kepler's laws, Satellite orbits, Satellite subsystems: transponder, antenna, power systems, Frequency bands, Satellite link equation and link budget basics.

Kepler's First Law

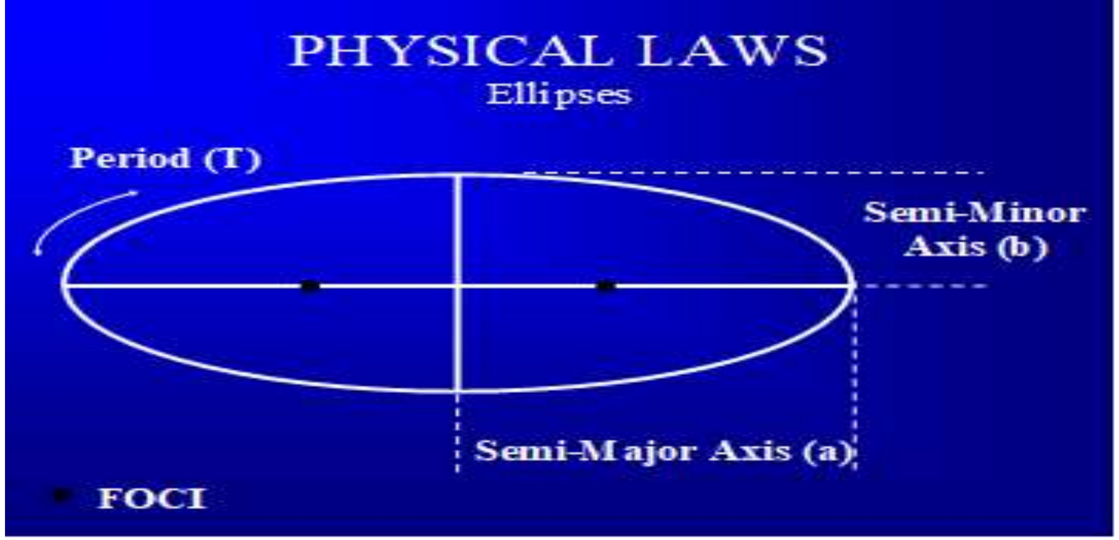
Kepler's first law states that the path followed by a satellite around its primary (the earth) will be an **ellipse**. This ellipse has two focal points (foci) F1 and F2 as shown in the figure below. Center of mass of the earth will always present at one of the two foci of the ellipse.



Kepler's 1st law

If the distance from the center of the object to a point on its elliptical path is considered, then the farthest point of an ellipse from the center is called as **apogee** and the shortest point of an ellipse from the center is called as **perigee**.

Eccentricity "e" of this system can be written as −



Eccentricity "e" of this system can be written as −

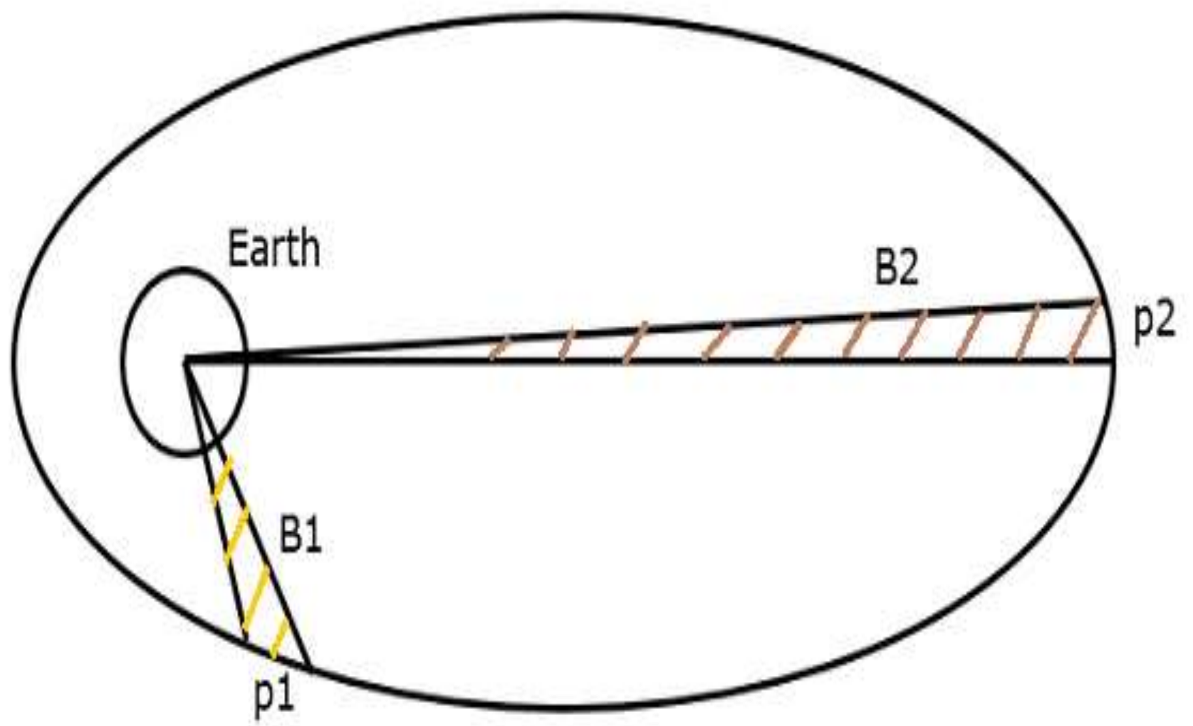
$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

Where, **a** & **b** are the lengths of semi major axis and semi minor axis of the ellipse respectively.

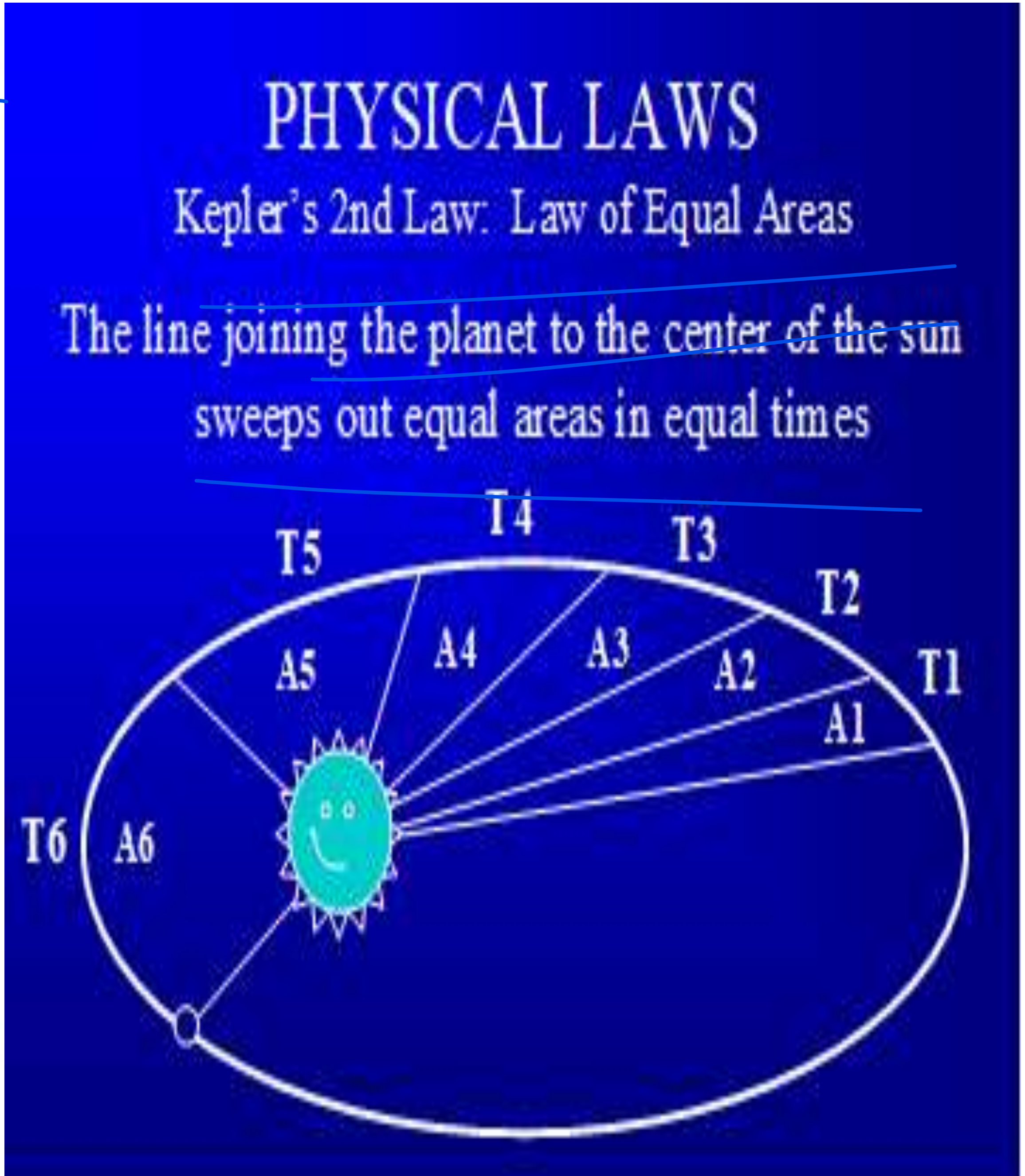
For an **elliptical path**, the value of eccentricity (e) is always lie in between 0 and 1, i.e. $0 < e < 1$, since a is greater than b. Suppose, if the value of eccentricity (e) is zero, then the path will be no more in elliptical shape, rather it will be converted into a circular shape.

Kepler's Second Law

Kepler's second law states that for equal intervals of time, the **area** covered by the satellite will be same with respect to center of mass of the earth. This can be understood by taking a look at the following figure.



Assume, the satellite covers p1 and p2 distances in the same time interval. Then, the areas B1 and B2 covered by the satellite at those two instances are equal.



Kepler's Third Law

Kepler's third law states that, the square of the periodic time of an elliptical orbit is proportional to the cube of its semi major axis length. **Mathematically**, it can be written as follows -

$$T^2 \,\alpha\, a^3$$

$$=> T^2 = \left(\frac{4\pi^2}{\mu}\right) a^3$$

Where, $\frac{4\pi^2}{\mu}$ is the proportionality constant.

μ is Kepler's constant and its value is equal to 3.986005 x $10^{14} m^3 / sec^2$

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$$1 = \left(\frac{2\pi}{T}\right)^2 \left(\frac{a^2}{\mu}\right)$$

$$1 = n^2 \left(\frac{a^3}{\mu}\right)$$

$$=> a^3 = \frac{\mu}{n^2}$$

Where, **'n'** is the mean motion of the satellite in radians per second.

🛰️ 1. Based on Altitude (Height Above Earth)

Orbit Type	Altitude Range	Approx. Period	Main Uses
Low Earth Orbit (LEO)	160 – 2,000 km	~90–120 minutes	Earth observation, remote sensing, Starlink, ISS, small communication satellites
Medium Earth Orbit (MEO)	2,000 – 35,786 km	~2–12 hours	GPS, Galileo, GLONASS, navigation satellites
Geostationary Orbit (GEO)	35,786 km (directly above equator)	24 hours (matches Earth's rotation)	TV broadcasting, weather monitoring, communication satellites
High Earth Orbit (HEO)	>35,786 km	>24 hours	Deep space probes, scientific missions, certain communication relays

Geosynchronous Earth OrbitSatellites

A Geo-synchronous Earth Orbit **(GEO) Satellite** is one, which is placed at an altitude of **22,300** miles above the Earth. This orbit is synchronized with a side real day (i.e., 23 hours 56 minutes). This orbit can have inclination and eccentricity.

It may not be circular. This orbit can be tilted at the poles of the earth. But, it appears stationary when observed from the Earth. These satellites are used for satellite Television.

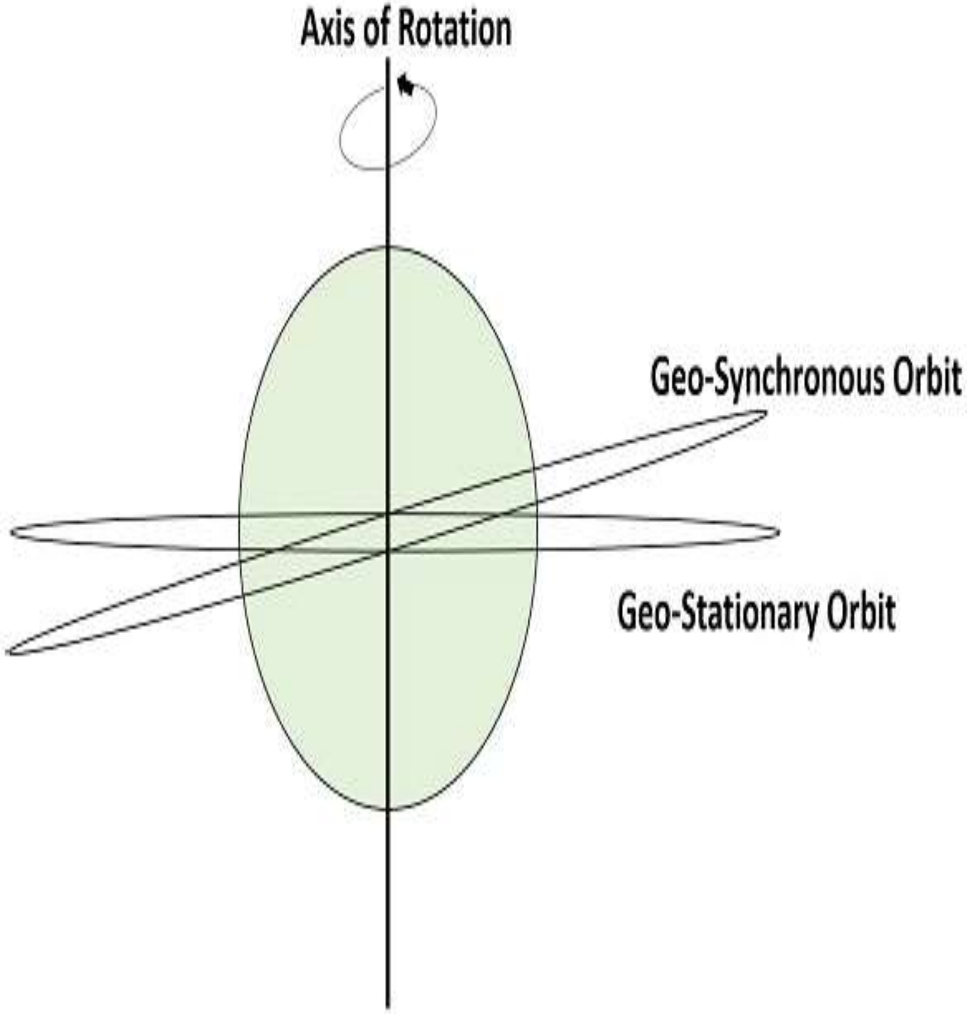
The same geo-synchronous orbit, if it is circular and in the plane of equator, then it is called as **Geostationary orbit**. These Satellites are placed at 35,900kms (same as Geosynchronous) above the Earth's Equator and they keep on rotating with respect to earth's direction (west to east).

The satellites present in these orbits have the angular velocity same as that of earth. Hence, these satellites are considered as **stationary** with respect to earth since, these are in synchronous with the Earth's rotation.

The **advantage** of Geostationary orbit is that no need to track the antennas in order to find the position of satellites.

Geostationary Earth Orbit Satellites are used for weather forecasting, satellite TV, satellite radio and other types of global communications.

The following figure shows the difference between Geo-synchronous and Geo-stationary orbits. The axis of rotation indicates the movement of Earth.



Note – Every Geostationary orbit is a Geo-synchronous orbit. But, the converse need not be true.

🌍 Difference between Geosynchronous and Geostationary Orbits

Parameter	Geosynchronous Orbit (GSO)	Geostationary Orbit (GEO)
Definition	An orbit where the satellite's orbital period equals Earth's rotational period (24 hours).	A special type of geosynchronous orbit directly above the equator and moves in the same direction as Earth's rotation.
Orbital Plane	Can be inclined or elliptical.	Must be circular and in Earth's equatorial plane (0° inclination).

🛰 Satellite Subsystems Overview

Every satellite—whether for communication, navigation, or remote sensing—is made up of several **subsystems** that work together to ensure it can survive, operate, and carry out its intended functions in space.

These are broadly divided into **two categories:**

1. **Bus (Support) Subsystems** – enable the satellite to function and survive.
2. **Payload (Mission) Subsystems** – perform the main mission tasks like communication, imaging, or data collection.

1. Structure / Mechanical Subsystem

Purpose: Provides the physical framework and supports all other subsystems.

- **Functions:**
  - Holds components together (antenna, solar panels, payload).
  - Withstands launch vibrations and mechanical stresses.
  - Maintains proper alignment of sensors and antennas.
- **Key Components:**
  - Main body frame (made of lightweight materials like aluminum alloys or composites).
  - Deployment mechanisms (for antennas and solar panels).

⚡🛰️ Power Subsystem of a Satellite

1. Purpose

The **Power Subsystem** is responsible for generating, storing, controlling, and distributing electrical power to all satellite subsystems (communication, control, sensors, payload, etc.).

It ensures **continuous and reliable power supply** in the harsh space environment — even when the satellite passes through Earth's shadow and receives no sunlight.

2. Major Functions

1. **Power Generation** – produce electrical energy (mainly from solar power).
2. **Energy Storage** – store power for use during eclipse (when solar panels are inactive).
3. **Power Regulation** – maintain voltage and current at required levels.
4. **Power Distribution** – deliver power safely to various satellite components.
5. **Protection and Monitoring** – safeguard against overvoltage, short circuits, and power surges.

3. Main Components of the Power Subsystem

(a) Solar Arrays / Solar Panels

- **Function:** Primary source of electrical power.
- **Working Principle:** Convert sunlight into electricity using the **photovoltaic effect.**
- **Materials Used:**
  - Silicon (Si) or Gallium Arsenide (GaAs) solar cells.
- **Arrangement:**
  - Panels are either **fixed** (for small satellites) or **deployable** (for large ones).
  - Mounted on **rotating mechanisms (Solar Array Drive Mechanisms – SADM)** to keep them pointed toward the Sun.
- **Output:** Typically provides **DC power** (around 28 V, 50 V, or higher depending on the satellite).

(b) Batteries

- **Function:** Provide backup power during eclipse or high-demand periods.
- **Types:**
  - Nickel-Cadmium (Ni-Cd) – older type.
  - Nickel-Hydrogen ($Ni\text{-}H_2$) – used in large communication satellites.
  - Lithium-Ion (Li-Ion) – modern satellites (lightweight, high energy density).
- **Charging:** Batteries are recharged by solar panels when the satellite is in sunlight.

Attitude and Orbit Control Subsystem (AOCS / ADCS)

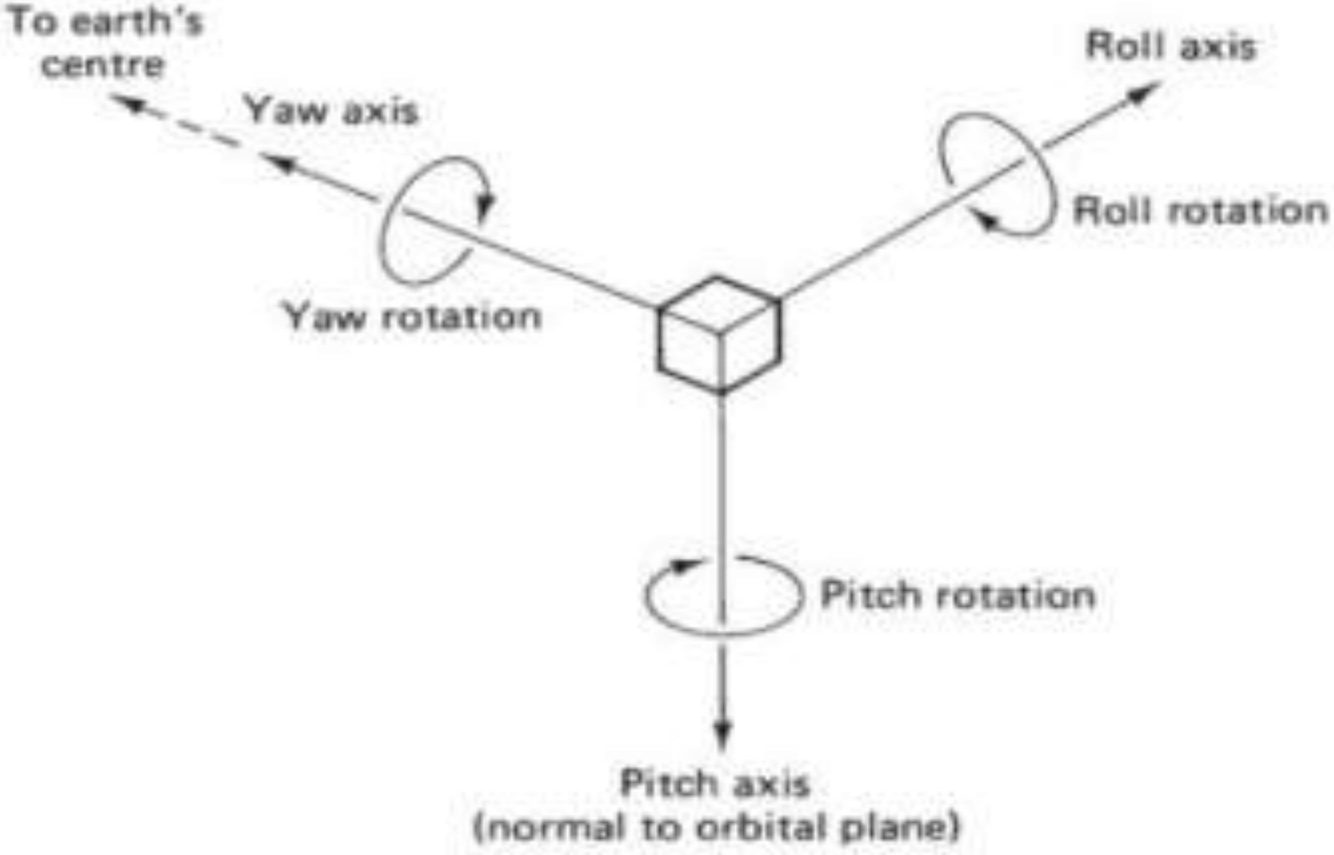
1. Definition

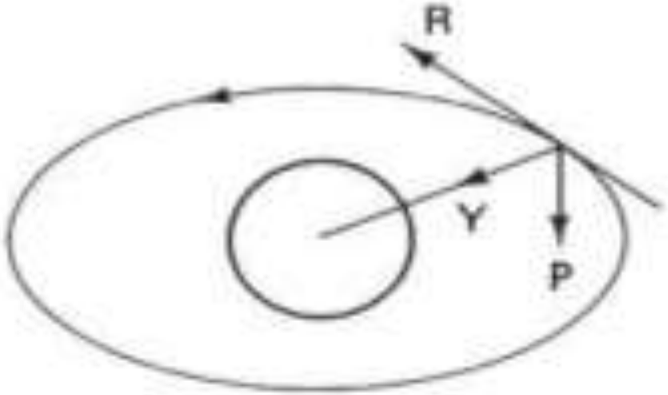
The **Attitude and Orbit Control Subsystem (AOCS)** — also called **Attitude Determination and Control Subsystem (ADCS)** — is responsible for **determining and controlling**:

- The **orientation (attitude)** of the satellite → *which direction it is pointing*, and
- The **orbit (position and velocity)** of the satellite → *where it is around Earth*.

2. Purpose / Objectives

1. **Attitude Determination:**
   Measure and calculate the current orientation of the satellite in space.
2. **Attitude Control:**
   Adjust or maintain the satellite's orientation as required (e.g., keep antennas pointing to Earth, solar panels toward the Sun).
3. **Orbit Control:**
   Maintain the desired orbit, perform corrections or maneuvers (station-keeping, orbit transfer, deorbit).
4. **Stabilization:**
   Ensure stability during operations like imaging, communication, and docking.





(b)

- **Roll axis** is considered in the direction in which the satellite moves in orbital plane.
- **Yaw axis** is considered in the direction towards earth.
- **Pitch axis** is considered in the direction, which is perpendicular to orbital plane.

7. Attitude Control Methods

Method	Description	Used In
Spin Stabilization	Satellite spins about its axis (like a gyroscope) for stability.	Early communication satellites, small satellites.
Three-Axis Stabilization	Satellite actively controls all 3 axes using reaction wheels or thrusters.	Modern communication and imaging satellites.

TABLE 1.1 Frequency Band Designations

Frequency range, (GHz)	Band designation
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	μm

🛠️ Transponder Subsystem (Communication Payload Subsystem)

1. Definition

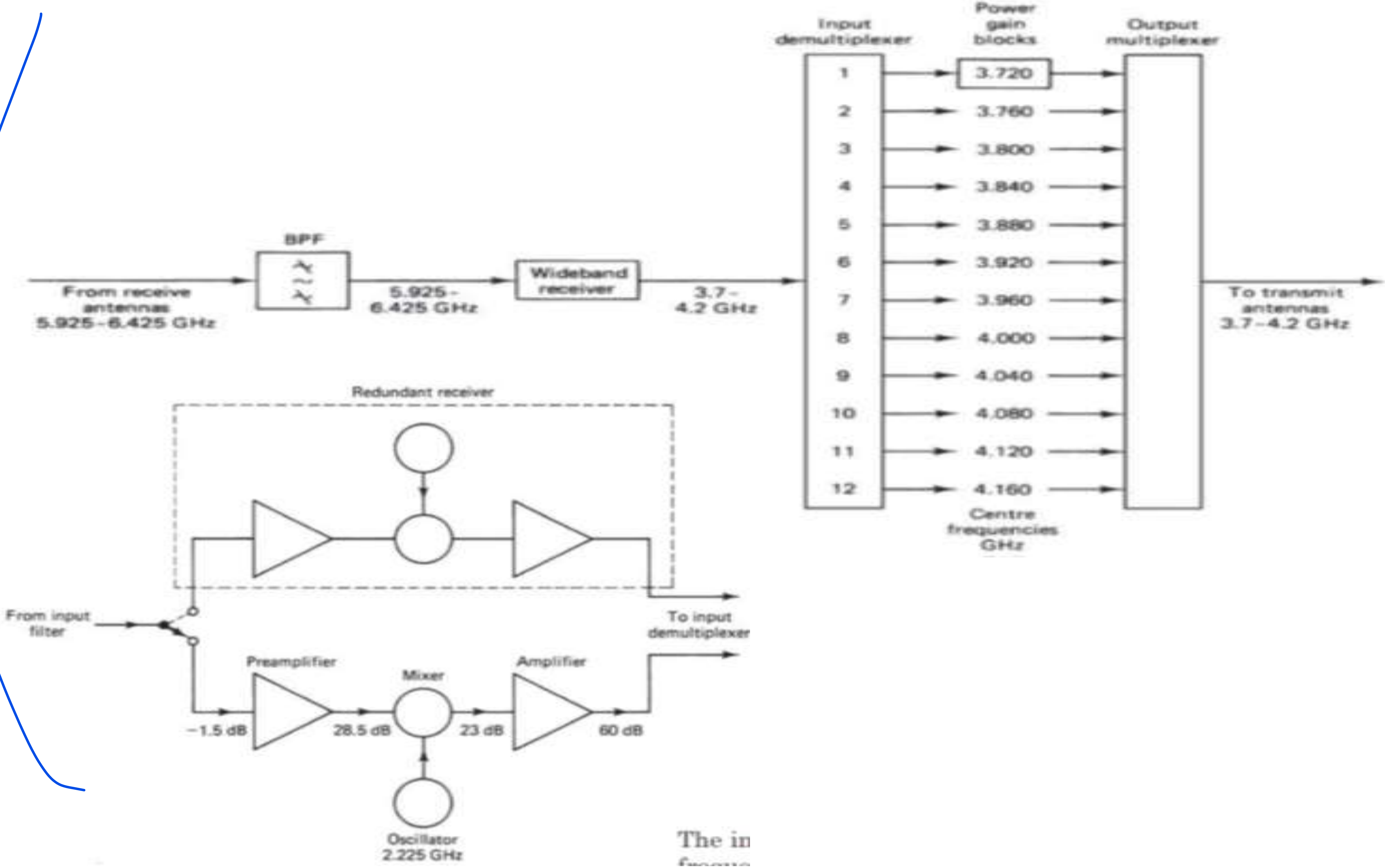
A **transponder** is the **core communication unit** of a satellite.

It is a **radio repeater** in space that **receives, amplifies,** and **retransmits** signals between the **ground station (uplink)** and **user terminals (downlink)** at different frequencies.

> In simple terms:
>
> **Transponder = Receiver + Frequency Converter + Amplifier + Transmitter**

3. Major Functions of a Transponder

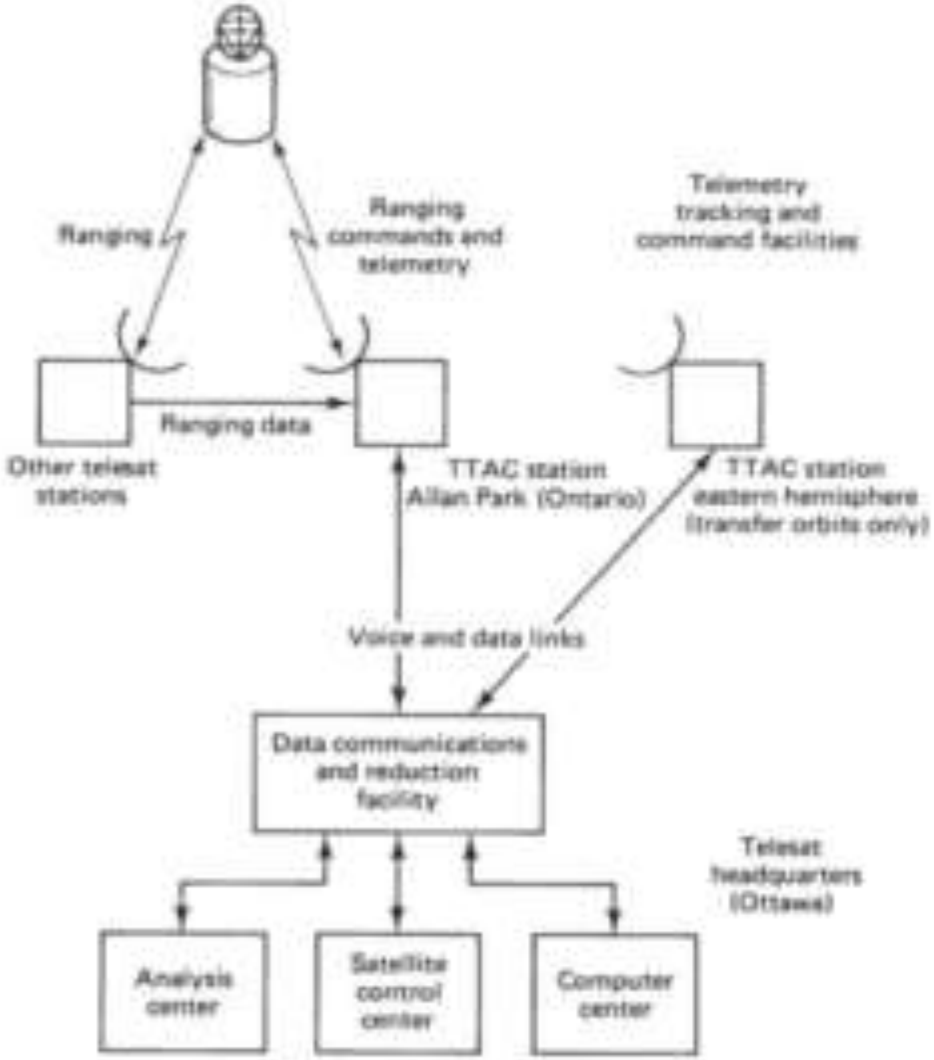
Function	Description
Reception (Uplink)	Receives radio signals from the Earth station.
Frequency Translation	Converts uplink frequency to downlink frequency (to prevent interference).
Amplification	Increases signal strength before re-transmission.
Transmission (Downlink)	Sends the processed signal back to the Earth's coverage area.


Input demultiplexer
Power gain blocks
Output multiplexer
1
2
3
4
5
6
7
8
9
10
11
12
3.720
3.760
3.800
3.840
3.880
3.920
3.960
4.000
4.040
4.080
4.120
4.160
Centre frequencies GHz
BPF
From receive antennas 5.925-6.425 GHz
5.925-6.425 GHz
Wideband receiver
3.7-4.2 GHz
To transmit antennas 3.7-4.2 GHz
Redundant receiver
From input filter
To input demultiplexer
Preamplifier
Mixer
Amplifier
−1.5 dB
28.5 dB
23 dB
60 dB
Oscillator 2.225 GHz

The in

- **Duplexer** is a two-way microwave gate. It receives uplink signal from the satellite antenna and transmits downlink signal to the satellite antenna.
- **Low Noise Amplifier** (LNA) amplifies the weak received signal.
- **Carrier Processor** performs the frequency down conversion of received signal (uplink). This block determines the type of transponder.
- **Power Amplifier** amplifies the power of frequency down converted signal (down link) to the required level.

TT&C Subsystem



The telemetry, or telemetering, function could be interpreted as *measurement at a distance*. Specifically, it refers to the overall operation of generating an electrical signal proportional to the quantity being measured and encoding and transmitting this to a distant station, which for the satellite is one of the earth stations. Data which are transmitted as telemetry signals include attitude information such as that obtained from sun and earth sensors; environmental information such as the magnetic field intensity and direction, the frequency of meteorite impact, and so on; and spacecraft information such as temperatures, power supply voltages, and stored-fuel pressure. Certain frequencies

Telemetry and command may be thought of as complementary functions. The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command signals from the earth station, often in response to telemetered information. The command subsystem demodulates and, if necessary, decodes the command signals and routes these to the appropriate equipment needed to execute the necessary action. Thus attitude changes may be made, communication transponders switched in and out of circuits, antennas redirected, and station-keeping maneuvers carried out on command. It is clearly important to prevent unauthorized commands from being received and decoded, and for this reason, the command signals are often encrypted. *Encrypt* is derived from a Greek word *kryptein*, meaning *to hide*, and represents the process of concealing the command signals in a secure code. This differs from the normal process of encoding which converts characters in the command signal into a code suitable for transmission.

Tracking of the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations. Tracking is obviously important during the transfer and drift orbital phases of the satellite launch. Once it is on station, the position of a geostationary satellite will tend to be shifted as a result of the various disturbing forces, as described previously. Therefore, it is necessary to be able to track the satellite's movement and send correction signals as required. Tracking beacons may be transmitted in the telemetry channel, or by pilot carriers at frequencies in one of the main communications channels, or by special tracking antennas. Satellite range from the ground station is also required from time to time. This can be determined by measurement of the propagation delay of signals especially transmitted for ranging purposes.

Antenna Subsystems

Satellite antennas perform **two types** of functions. Those are receiving of signals, which are coming from earth station and transmitting signals to one or more earth stations based on the requirement. In other words, the satellite antennas receive uplink signals and transmit downlink signals.

The antennas, which are used in satellite are known as satellite antennas. There are mainly four **types of Antennas**. They are:

- Wire Antennas
- Horn Antennas
- Array Antennas
- Reflector Antennas

SATELLITE LINK BUDJET DESIGN

In satellite communication systems, there are two types of power calculations. Those are transmitting power and receiving power calculations. In general, these calculations are called as **Link budget calculations**. The unit of power is **decibel**.

Basic Terminology

An **isotropic radiator** (antenna) radiates equally in all directions. But, it doesnt exist practically. It is just a theoretical antenna. We can compare the performance of all real (practical) antennas with respect to this antenna.

Equivalent Isotropic Radiated Power

Equivalent isotropic radiated power (EIRP) is the main parameter that is used in measurement of link budget. **Mathematically**, it can be written as

$$EIRP = G\ P_s$$

We can represent EIRP in **decibels** as

$$[EIRP] = [G] + [P_s]\, dBW$$

Where, **G** is the Gain of Transmitting antenna and P_s is the power of transmitter.

Example 12.1 A satellite downlink at 12 GHz operates with a transmit power of 6 W and an antenna gain of 48.2 dB. Calculate the EIRP in dBW.

Solution

$$[\mathrm{EIRP}] = 10 \log\left(\frac{6\mathrm{W}}{1\mathrm{W}}\right) + 48.2$$

$$= \underline{\underline{56 \text{ dBW}}}$$

$$[P_R] = [\mathrm{EIRP}] + [G_R] - 10 \log\left(\frac{4\pi r}{\lambda}\right)^2$$

ceived power in dBW is therefore given as the sur
IRP in dBW plus the receiver antenna gain in dB
ich represents the free-space loss in decibels. The
nt in decibels is given by

$$[\mathrm{FSL}] = 10 \log\left(\frac{4\pi r}{\lambda}\right)^2$$

$$[P_R] = [\mathrm{EIRP}] + [G_R] - [\mathrm{FSL}]$$

$$[\text{LOSSES}] = [\text{FSL}] + [\text{RFL}] + [\text{AML}] + [\text{AA}] + [\text{PL}]$$

The decibel equation for the received power is then

$$[P_R] = [\text{EIRP}] + [G_R] - [\text{LOSSES}]$$

where [PR] = received power, dBW
[EIRP] = equivalent isotropic radiated power, dBW
[FSL] = free-space spreading loss, dB
[RFL] = receiver feeder loss, dB
[AML] = antenna misalignment loss, dB
[AA] = atmospheric absorption loss, dB
[PL] = polarization mismatch loss, dB

Example 12.4 A satellite link operating at 14 GHz has receiver feeder losses of 1.5 dB and a free-space loss of 207 dB. The atmospheric absorption loss is 0.5 dB, and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for clear-sky conditions.

Solution The total link loss is the sum of all the losses:

$$[\text{LOSSES}] = [\text{FSL}] + [\text{RFL}] + [\text{AA}] + [\text{AML}]$$

$$= 207 + 1.5 + 0.5 + 0.5$$

$$= \underline{209.5 \text{ dB}}$$

System Noise

System Noise

the antennas as radiation.

The available noise power from a thermal noise source is given by

$$P_N = kT_N B_N \tag{12.14}$$

Here, T_N is known as the equivalent noise temperature, B_N is the equivalent noise bandwidth, and $k = 1.38 \times 10^{-23}$ J/K is Boltzmann's con-

The main characteristic of thermal noise is that it has a *flat frequency spectrum*; that is, the noise power per unit bandwidth is a constant. The noise power per unit bandwidth is termed the *noise power spectral density*. Denoting this by N_0, then from Eq. (12.14),

$$N_0 = \frac{P_N}{B_N} = kT_N \text{ J} \tag{12.15}$$

Example 12.5 An antenna has a noise temperature of 35 K and is matched into a receiver which has a noise temperature of 100 K. Calculate (*a*) the noise power density and (*b*) the noise power for a bandwidth of 36 MHz.

Solution

(*a*) $N_0 = (35 + 100) \times 1.38 \times 10^{-23} = \underline{\underline{1.86 \times 10^{-21}\text{ J}}}$

(*b*) $P_N = 1.86 \times 10^{-21} \times 36 \times 10^6 = \underline{\underline{0.067\text{ pW}}}$

In addition to these thermal noise sources, intermodulation distortion

Link budget calculations

There are two types of link budget calculations since there are two links namely, **uplink** and **downlink**.

Earth Station Uplink

It is the process in which earth is transmitting the signal to the satellite and satellite is receiving it. Its **mathematical equation** can be written as

$$\left(\frac{C}{N_0}\right)_U = [EIRP]_U + \left(\frac{G}{T}\right)_U - [LOSSES]_U - K$$

$k = 1.38 \times 10^{-23}$ J/K is Boltzmann's con-

Satellite Downlink

In this process, satellite sends the signal and the earth station receives it. The equation is same as the satellite uplink with a difference that we use the abbreviation D everywhere instead of U to denote the downlink phenomena.

Its **mathematical** equation can be written as;

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

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

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

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

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

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

Solution Equation (12.54) can be rearranged as

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

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

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

Refer All the Problems solved in class