6.1 SATELLITE COMMUNICATIONS

The idea of a communication through a satellite, in particular with a synchronous satellite was conceived by Arthur C. Clarke, a famous British science fiction writer in 1945. Clarke had already pointed out that a satellite in a circular equatorial orbit with a radius of about 42,242 km would have an angular velocity that matched the earth's. Thus, it would always remain above the same spot on the ground and it could receive and relay signals from most of a hemisphere. Three satellite spaced 120 degree apart could cover the whole world with some overlap provided that messages could be relayed between satellites and thus reliable communication between any two points in the world was possible. Clarke had also stated that the electrical power for the satellite would be obtained by conversion of the sun's radiation by means of solar cells. Clarke's paper went almost totally unnoticed until man-made satellites became a reality with Sputnik I (October 4, 1957). However, it may be noted that the synchronous orbit was not achieved until 1963.

6.1.1 Structure of Satellite Communications System

Communications Satellites are usually composed of the following subsystems:

- Communication Payload, normally composed of transponders, antenna, and switching systems.
- Engines used to bring the satellite to its desired orbit
- Station Keeping Tracking and stabilization subsystem used to keep the satellite in the right orbit, with its antennas pointed in the right direction, and its power system pointed towards the sun.
- Power subsystem, used to power the Satellite systems, normally composed of solar cells, and batteries that maintain power during solar eclipse.
- Command and Control subsystem, which maintains communications with ground control stations. The ground control earth stations monitor the satellite performance and control its functionality during various phases of its life-cycle.

The bandwidth available from a satellite depends upon the number of transponders provided by the satellite. Each service (TV, Voice, Internet, radio...etc) requires a different

amount of bandwidth for transmission. This is typically known as link budgeting.

6.2 four types of satellites based on their application are:

1- communication.

2- Earth observation.

3- navigation.

4- astronomical.

Our in-depth examination of the characteristics of different types of satellites and their functions continues below.

6.2.1 Communication Satellites

A communication spacecraft, usually located at GEO and equipped with a transponder — an integrated receiver and transmitter of radio signals — may receive signals from Earth and retransmit them back to the planet. As a result, it opens interaction channels between regions that were previously unable to communicate with one another due to large distances or other obstacles. Different types of communication satellites facilitate various forms of media transmissions, such as radio, TV, telephone, and the Internet.

Using the communication type of spacecraft, you can relay many signals at once. Spacecraft for broadcasting and TV signal distribution to ground-based stations typically have individual transponders for each carrier. In most cases, though, several carriers will be relayed by a single transponder. Due to its compatibility with mobile terminals, this type of satellites is ideally suited for long-distance communication.

6.2.2 Earth Observation Satellites

The purpose of Earth observation type of satellites is to monitor our planet from space and report back on any changes they observe. This type of space technology makes possible consistent and repeatable environmental monitoring as well as rapid analysis of events during emergencies like natural disasters and armed conflicts.

The goals of the surveillance mission determine the type of satellite sensors used for Earth observation. Information collected varies depending on the type of sensor employed and the available frequency bands.

Our first EOS SAT constellation satellite, EOS SAT-1, is now orbiting the Earth on the mission to improve farming and forest management through precision technology. Eleven spectral bands of the EOS SAT-1 are specifically designed to monitor diverse agriculture and forestry aspects, from the presence of crop diseases to soil moisture .

It is possible to categorize Earth observation spacecraft into the following types:

Weather satellites are employed for monitoring and forecasting weather trends and providing actual weather data. GEO is ideal for different types of weather satellites, as it provides a constant viewpoint that enables scientists to track cloud patterns and predict their movements.

Remote sensing satellites' primary applications are all types of environmental monitoring and geographical mapping. Machines used for different types of remote sensing circle the Earth in one of three orbits: polar, non-polar LEO, or GEO. Geographical information system (GIS) satellites are a type of remote sensing spacecraft whose main function is to provide images appropriate for GIS mapping and further spatial analysis.

6.2.3 Navigation Satellites

The navigation system constellations are located between 20,000 and 37,000 kilometers from Earth's surface. This type of satellite sends out signals that reveal their time, position in space, and health status. There are two major types of space navigation systems:

The spacecraft of the Global Navigation Satellite System (GNSS) broadcast signals that GNSS receivers pick up and utilize for geolocation purposes, providing global coverage. Galileo in Europe, GPS in the United States, and the BeiDou Navigation Satellite System in China are all examples of GNSS .

The Regional Navigation Satellite System (RNSS) is an autonomous regional navigation system that provides coverage on a regional scale. For instance, India's IRNSS project aims to provide Indian citizens with a reliable location-based service .

6.2.4 Astronomical Satellites

Basically, an astronomical satellite is a giant telescope in orbit. It is able to see well without interference from the Earth's atmosphere, and its infrared imaging technology can function normally without being fooled by the planet's surface temperature. The satellite type used for astronomy has a vision that is up to ten times better than the most powerful telescope on Earth.

Spacecraft used in astronomy can be broken down into several distinct types:

Astronomy satellites are used to investigate different types of celestial bodies and phenomena in space, from the creation of star and planetary surface maps and taking images of the planets in our solar system to the study of black holes.

The use of climate research satellites fitted with specific types of sensors allows scientists to gather comprehensive, multi-faceted data on the world's oceans and ice, land, biosphere, and atmosphere.

Space-based studies on plant and animal cells and structures are possible thanks to biosatellites. Because they allow scientists from different regions to work together, this type of spacecraft plays a crucial role in the progress of medicine and biology.

The vast majority of satellites can perform more than one function simultaneously. Still, it's a common recommendation that researchers diversify the types of satellites they use to obtain more comprehensive and accurate results of their studies. EOSDA Land Viewer is a helpful tool for this because it aggregates space-collected imagery (including

high-resolution) from multiple sources and provides a user-friendly interface for finding and downloading the images you need.

6.3 INTRODUCTION TO ORBITS

Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun. From early times much has been learned about planetary motion through careful observations. Johannes Kepler (1571–1630) was able to derive empirically three laws describing planetary motion. Later, in 1665, Sir Isaac Newton (1642–1727) derived Kepler's laws from his own laws of mechanics and developed the theory of gravitation.

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

Newton's Law of motion can be written as

$$s = ut + \frac{1}{2} at^2$$

$$v = u^2 + 2\,at$$

$$F = ma$$

where: s is the distance travelled from t=0, u is the initial velocity at t=0, v is the final velocity at time=t, a is the acceleration, F is the force acting on the body, and m is the mass of the body.

6.3.1 Kepler's First Law

Kepler's first law states that **the path followed by a satellite around the primary will be an ellipse**. An ellipse has two focal points shown as F1 and F2 in Fig.1. The center of mass of the two body system, termed the barycenter, is always centered on one of the foci. In our specific case, because of the enormous difference between the masses of the earth and the satellite, the center of mass coincides with the center of the earth, which is therefore always at one of the foci.

The semi-major axis of the ellipse is denoted by a, and the semi-minor axis, by b. The eccentricity e is given by: $e = 2\,\frac{a-b}{a+b}$
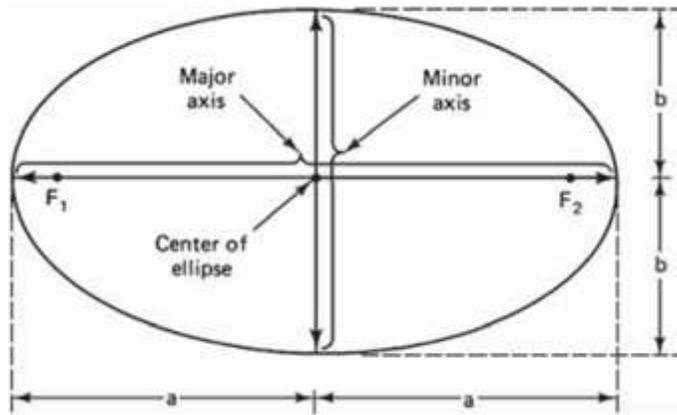
Fig1. The foci F1 and F2 , the semi-major axis a, and the semi-minor axis b of an ellipse.

Note that: e=0 for circular orbits, i.e., a=b

The eccentricity and the semi major axis are two of the orbital parameters specified for satellites (spacecraft) orbiting the earth. For an elliptical orbit, $0 < e < 1$. When e =0, the orbit becomes circular.

6.3.2 Kepler's Second Law

Kepler's second law states that, **for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter.**

Referring to fig. 2, assuming the satellite travels distances S1and S2 meters in 1 s, then the areas A1 and A2 will be equal. The average velocity in each case is S1 and S2 m/s, and because of the equal area law, it follows that the velocity at S2 is less than that at S1. An important consequence of this is that the satellite takes longer to travel a given distance when it is farther away from earth. Use is made of this property to increase the length of time a satellite can be seen from particular geographic regions of the earth.
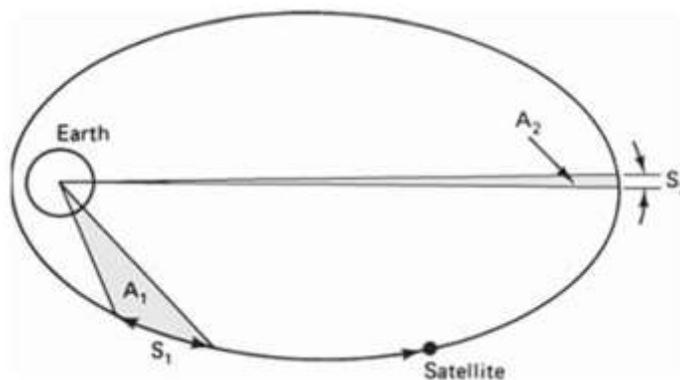

Fig.2 Kepler's second law. The areas A1 and A2 swept out are equal in time.

6.3.3Kepler's Third Law

Kepler's third law states that **the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies.** The mean distance is equal to the semi major axis a. For the artificial satellites orbiting the earth, Kepler's third law can be written in the form:

$$a^3 = \frac{\mu}{\eta^2}$$

where η is the mean angular velocity of the satellite in radians per second and μ is the earth's geocentric gravitational constant. Its value is:

$$\mu = 3.986005 * 10^{14} \ m^3/s^2$$

The orbital period in seconds is given by:

$$T = \frac{2\pi}{\eta}$$

The importance of Kepler's third law is that it shows there is a fixed relationship between period and semi major axis. One very important orbit in particular, known as the geostationary orbit, is determined by the rotational period of the earth. In anticipation of this, the approximate radius of the geostationary orbit is determined in the following example.

Example: Calculate the radius of a circular orbit for which the period is 1 day.

Solution: There are 86,400 seconds in 1 day, and therefore the angular velocity/mean motion is:

$$\eta = \frac{2\pi}{86400} = 7.272 * 10^{-5} \ rad/s$$

From Kepler's third law:

$$a = \sqrt[3]{\left[\frac{3.986055 * 10^{14}}{(7.272 * 10^{-5})^2}\right]}$$

$$a = 42,241 \ km$$

Since the orbit is circular, the semi major axis is the same as the radius.

6.4 Earth-Orbiting Satellites

As mentioned previously, Kepler's laws apply in general to satellite motion around a primary body. For the particular case of earth-orbiting satellites, certain terms are used to describe the position of the orbit with respect to the earth.

Sub satellite path. This is the path traced out on the earth's surface directly below the satellite.

Apogee is the point farthest from earth.

Perigee is the point of closest approach to earth.

6.4.1 Apogee and Perigee Heights

Although not specified as orbital elements, the apogee height and perigee height are often required. The length of the radius vectors at apogee and perigee can be obtained from the geometry of the ellipse:

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

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

Example: Calculate the apogee and perigee heights for the following orbital parameters:

Mean earth radius of R= 6371 km, e =0.0011501 and a =7192.335 km.

Solution:

Using Eqs. above:

r_a =7192.335(1 + 0.0011501) = 7200.607km

r_p =7192.335(1 - 0.0011501) = 7184.063 km

The corresponding heights are:

$$h_a = r_a - R = 829.6 \, Km$$

$$h_p = r_p - R = 813.1 \, Km$$

6.4.2 The 5 main types of satellites based on their orbits are:

1- low Earth orbit (LEO).

2- medium Earth orbit (MEO).

3- geostationary orbit (GEO).

4- Sun-synchronous orbit (SSO).

5- geostationary transfer orbit (GTO).

The table below shows the orbital velocity, height and period of four satellite system.

Satellite system	Orbital height (km)	Orbital velocity (km/s)	Orbital period (h min s)		
Intelsat (GEO)	35,786.03	3.0747	23	56	4.1
New-ICO (MEO)	10,255	4.8954	5	55	48.4
Skybridge (LEO)	1,469	7.1272	1	55	17.8
Iridium (LEO)	780	7.4624	1	40	27.0

Mean earth radius is 6378.137 km and GEO radius from the center of the earth is 42,164.17 km.

1- Low-Earth-orbit (LEO)

A Low Earth Orbit (LEO) typically is a circular orbit stretch approximately 160 to 1600 km above the earth's surface. In addition, satellites in low earth orbit change their position relative to the ground position quickly. So even for local applications, a large number of satellites are needed if the mission requires uninterrupted connectivity.

Low earth orbiting satellites are less expensive to launch into orbit than geostationary satellites and, due to proximity to the ground, do not require as high signal strength (Recall that signal strength falls off as the square of the distance from the source, so the effect is dramatic). Thus there is a trade-off between the number of satellites and their cost. In addition, there are important differences in the onboard and ground equipment needed to support the two types of missions.

LEOs are subject to aerodynamic drag caused by resistance of the earth's atmosphere to the satellite passage. The exact value of the force caused by the drag depends on atmospheric density, the shape of the satellite, and the satellite's velocity. This force may be expressed in the form:

$$F_d = -0.5\rho_a C_d A_{eq} v^2 \quad kg \cdot m/sec^2$$

where

p_a: atmospheric density. This density is altitude-dependent, and its variation is exponential.
C_d : coefficient of aerodynamic drag.
A_{eq} : equivalent surface area of the satellite that is perpendicular to the velocity,
v : velocity of the satellite.

If the mass ms of the satellite is known, the acceleration a_d due to aerodynamic drag can be expressed as:

$$a_d = \frac{F_d}{m_s} \quad m/sec^2$$

The effect of the drag is a decrease of the orbit's semi-major axis due to the decrease in its energy. A circular orbit remains as such, but its altitude decreases whereas its velocity increases. Due to drag, the apogee in the elliptical orbit becomes lower and, as a consequence, the orbit gradually becomes circular.

$$F_d = -0.5\rho_a C_d A_{eq} v^2 \quad kg \cdot m/sec^2$$

The longer the influence on the orbit, the slower the satellite becomes, and it eventually falls from orbit. Aerodynamic drag is more significant at low altitudes (200 to 400 km) and negligible only about 3000 km because, in spite of the low value of atmospheric density encountered at the altitudes of satellites, their high orbital velocity implies that perturbations due to drag are very significant.

- Aerodynamic drag tends to reduce orbital height & eccentricity. It does not affect inclination and it is negligible in geosynchronous satellite.

- The effect is to remove kinetic energy from spacecraft & causing it to fall toward the earth, which in turn increases the orbital velocity resulting in higher drag & faster orbital decay.

2 - Medium and High Earth orbit (MEO) & (HEO)

Medium Earth orbit (MEO), sometimes called intermediate circular orbit (ICO), is the region of space around the Earth above low Earth orbit (altitude of 2,000 kilometers) and below geostationary orbit (altitude of 35,786 kilometers).

The most common use for satellites in this region is for navigation, communication, and geodetic/space environment science. The most common altitude is approximately 20,200 kilometers, which yields an orbital period of 12 hours, as used, for example, by the Global Positioning System (GPS). Other satellites in Medium Earth Orbit include Glonass (with an altitude of 19,100 kilometers) and Galileo (with an altitude of 23,222 kilometers). Communications satellites that cover the North and South Pole are also put in MEO.
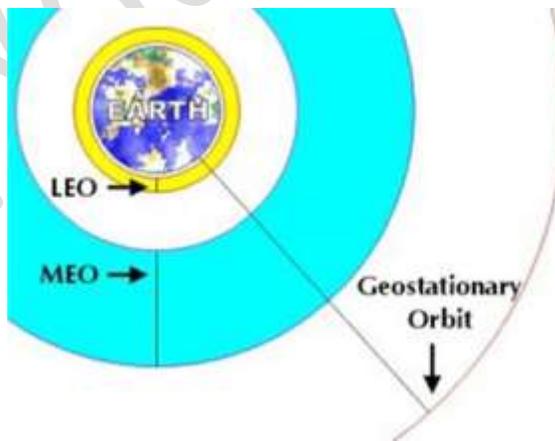
The orbital periods of MEO satellites range from about 2 to nearly 24 hours.

- A high Earth orbit (HEO) is a geocentric orbit with an altitude above that of a geosynchronous orbit.
- A highly elliptical orbit (HeO) is an elliptic orbit with a low-altitude (about 1,000 kilometers) perigee and a high-altitude (over 35,786 kilometers) apogee.

Such extremely elongated orbits have the advantage of long dwell times at a point in the sky during the approach to, and descent from, apogee. Visibility near apogee can exceed twelve hours of dwell at apogee with a much shorter and faster-moving perigee phase. Bodies moving through the long apogee dwell can appear still in the sky to the ground.

Examples of HEO orbits offering visibility over Earth's Polar Regions, Molniya orbits, named after the Molniya Soviet communication satellites which used them.

3- Geostationary Orbit (GEO) Satellites

Spacecraft in geostationary Earth orbit are positioned 35,786 kilometers above Earth's surface, precisely over the equator. Three evenly spaced machines in GEO can give nearly worldwide coverage thanks to the huge area they cover on Earth.

Objects in GEO appear motionless from the ground because their orbital period is identical to Earth's rotation — 23 hours, 56 minutes, and 4 seconds. This allows a terrestrial antenna to always point toward the same device in space. That's why this type of satellites is perfect for always-on communication services like TV and phones. Also, this type can be used in meteorology to keep an eye on the weather in particular regions and track the development of local patterns. The downside of GEO type of spacecraft for real-time communication is the longer signal delay caused by their great distance from Earth.

What type of satellite is used to monitor cloud cover?

Satellites in geostationary orbit provide observations of cloud patterns that are used to calculate wind speeds.

4- Sun-Synchronous Orbit (SSO) Satellites

The Sun-synchronous orbit type of satellites goes from north to south across the polar regions at an altitude of 600 to 800 km above the Earth. The orbital inclination and altitude of SSO spacecraft are calibrated so that they always cross any given location at precisely the same local solar time. Thus, the lighting conditions are consistent for imaging, making this type of satellite ideal for earth observation and environmental monitoring.

This also implies that SSO's current and historical satellite images are well-suited for change detection . Scientists use these image sequences to learn about the development of weather patterns, forecast cyclones, monitor and prevent wildfires and floods, and gather information on long-term issues like deforestation and coastline

changes. But because of their lower orbital altitude, SSO type of spacecraft can only cover a smaller region at once and need more machines to do so continuously.

5- Geostationary Transfer Orbit (GTO) Satellites

The most frequent type of satellite transfer orbit is a geostationary one utilized to migrate from a transition orbit to GEO. Spacecraft are not always placed directly into their ultimate orbit when propelled from Earth into space by launch vehicles such as Falcon 9. Rockets carrying payload to GEO drop it off at transfer orbits, which are halfway points on the path to its final position. Then a satellite's engine fires to reach its destination orbit and adjust its inclination . This shortcut allows the machine to reach geostationary orbit with minimal resources.

6.5 Transponder

A transponder is the series of interconnected units which forms a single communications channel between the receive and transmit antennas in a communications satellite. Some of the units utilized by a transponder in a given channel may be common to a number of transponders. Thus, although reference may be made to a specific transponder, this must be thought of as an equipment channel rather than a single item of equipment.

The bandwidth allocated for C-band service is 500 MHz, and this is divided into sub-bands, one for each transponder. A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guard band between transponders, 12 such transponders can be accommodated in the 500-MHz bandwidth. By making use of polarization isolation, this number can be doubled. Polarization isolation refers to the fact that carriers, which may be on the same frequency but with opposite senses of polarization, can be isolated from one another by receiving antennas matched to the incoming polarization. With linear polarization, vertically and horizontally polarized carriers can be separated in this way, and with circular polarization, left-hand circular and right-hand circular polarizations can be separated.

Because the carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as *frequency Re-use*. Figure shows part of the frequency and polarization plan for a C-band communications satellite.
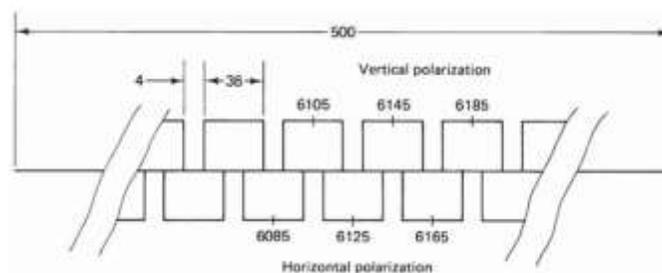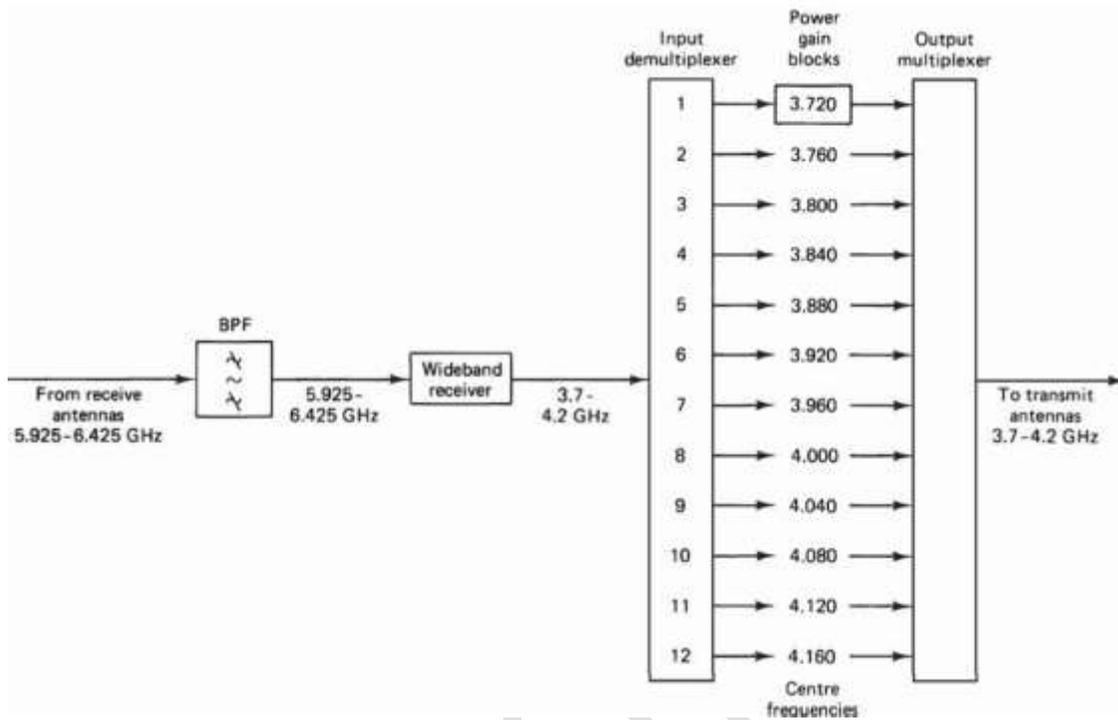

Fig.(4) Section of an uplink frequency and polarization plan. Numbers refer to frequency in megahertz.