UNIT-I : Introduction ①

The origins of Satellite communications can be traced to an article written by Arthur C Clarke in the British radio Magazine "Wireless World" in 1945.

- Clarke suggested that a radio relay satellite in an equtorial orbit with a period of 24h would remain stationary with respect to the earth's surface and make possible long distance radio links.

Ex: October 1957 — USSR Russian Satellite Sputnik — Becon Transmitter
- Geo stationary satellite
- Transmitted telemetry information for only 21 days.
- January 31, 1958, U.S. Explorer I, transmitted telemetry for nearly 5 months.
- The first artificial satellite used for voice communication — Score (Dec, 1958)
- Used to broadcast President Eisenhower's christmas message of that year.
- Score — ICBM (Inter Continental Ballastic Missile)
- Tape recorder with storage for 4 min message
- Batteries failed after 35 days in orbit.

- Passive reflectors — Ballons (Echo I & II)
- Telestar I — July 1962 } Bell Telephone
  Telestar II — May 1963 } laboratories
  - C-band transponder 6389/4169 MHz with 50MHz BW
  - MEO with periods of 158 and 225 min (Telestar I, Telestar II)

July 24, 1961 U.S. President John F Kennedy defined general guideli to Satellite communication

- December 20, 1961, — ITU — exami the aspects of space communicatio
- July 19, 1964 — Intelsat (Internati Telecommunications Satellite organi
- The first Intelsat Satellite, INTELSAT (formly Early Bird) was launched on April 16, 1965 —
  - weight 36 kg
  - two 6/4 GHz Transponders each with 25MHz BW
- Canada was the first country to build a national telecommunication system using GEO satellite
  - Anik 1A was launched in May 1974, just 2 months before the first US domestic satellite WESTAR 1.
- The first regional satellite system
  - USSR Molniya system of highly elliptic orbit (HEO) satellites.
  - launched in April 1965 (the same month INTELSAT I)
- The International Maritime satellite organization (Inmarsat) has provided services to ships and aircraf for several decades through LEO sats.

OEM — Original Equipment Manufacturer

- In 1991, the Gulf war and the second Russian revolution were watched on TV by almost the whole world via Satellites.

A Satellite is a celestial body that orbits ... by humans and orbits Earth or ...

Basic Concepts of Satellite Communications ②

GEO became almost standard for Commercial telecommunications.

Disadvantages of GEO

1. It does not cover the far northern latitudes;
2. It is expensive to launch into; and
3. To cover small terrestial areas at low frequencies, a characteristic need of mobile systems, very large antennas are required in orbit.

Molniya orbit

- Highly elliptical orbit (HEO)
- Synchronous with half the period of the earth's rotation,
- Inclined at that angle for which the anomalies in the earth's gravitational field do not cause the orbit to rotate in its own plane.
- Launching into this orbit has been easy for Russia because of the location of launch sites at latitudes around 60°.

If we fix the terrestial area to be covered and the size of the earth station antenna to a first order, the performance is independent of the orbital altitude and frequency.

If we want a fixed-beamwidth antenna for the terrestial terminal, as would be the case with a small mobile terminal and a quasi-omni antenna beam, then lower frequencies

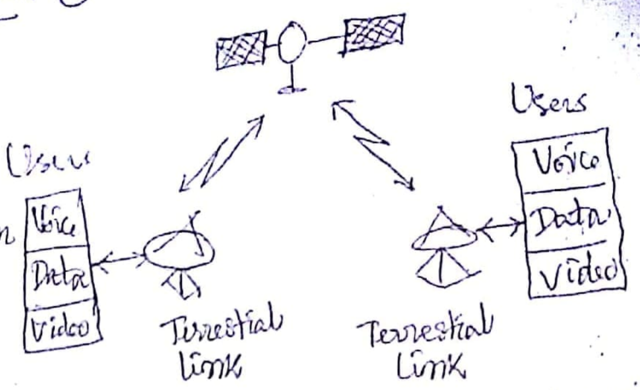


Fig. General Satellite link

- Fig. above shows the end-to-end communications required in establishing a satellite link.
- The link is with transmit and receive facilities at both ends

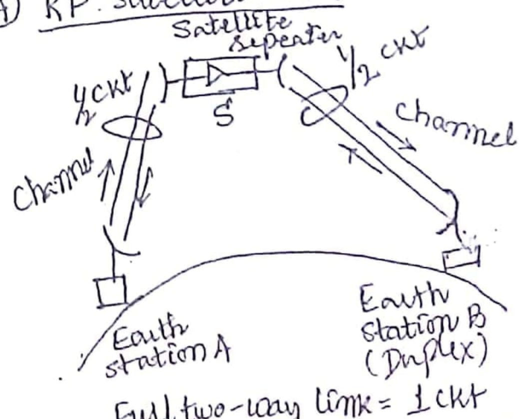
Ex: ① Fixed and Mobile services

② For broadcast and data collection applications are transmitted only at one end and received only at the oth end of the link.

- Satellite RF link establishes comm. link between a transmitter and receiver using the satellite as a repeater.
- overall C/N measured in a BW.

C/N depends on available power & BW

Ⓐ RF satellite link



Full two-way link = 1 ckt

one-way link (A to B) = 1 channel

Two-way link (A to S) = ½ ckt

• A communication satellite operates as a distant line-of-sight (LOS) microwave repeater providing communications services among multiple earth stations in various geographic locations.

• A channel is a one way link from transmitting earth station through the satellite to the receiving earth station.

A circuit is a full duple link between two earth stations.

A half-ckt is a two-way link between an earth station and the satellite only.

• C/N → Thermal noise, receive noise,

AWGN { atmospheric and cosmic noise received at the antennas.

— Interference from other systems

— Nonlinear distortions - Intermodulation products.

→ Deterministic signals (not random)

The system designer must compromise among: ① Power, ② BW and ③ Interference

B) Satellite Transponders

A communication satellite is considered as a distant microwave repeater that receives uplink transmissions and provides filtering, amplification, and frequency translation to the down link band for retransmission.

This kind of transponder is a quasi-linear repeater amplifier.

The uplink and down link bands are seperated in frequency to prevent oscillation within the satellite amplifier, ... simultaneous

③ transmission and reception at dif. frequencies through a device called Multiplexer (duplexer)

• Moreover, the lower-frequency band is used on the down link to exp the lower atmospheric losses (path lo thereby minimizing satellite amplifier requirements.

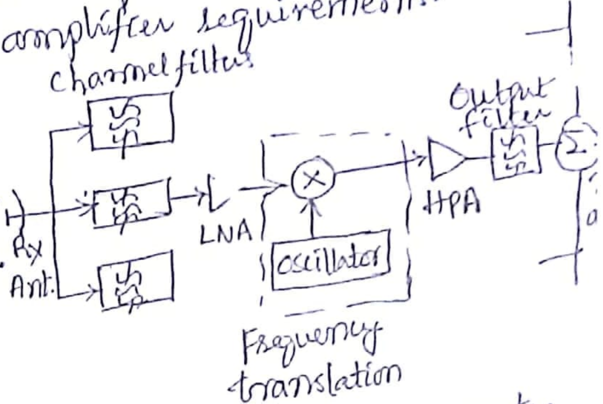


Fig. Basic satellite repeater

• Frequencies between 2 to 8 GHz were employed in satellite comm·s

• These C and X-band frequencies have the advantages of

① Adequate BW

② Negligible fading

③ low rain loss (for earth station elevation angle above 5°) and

④ availability of affordable and reliable microwave devices.

• The Ku-band (14 and 12 GHz) has the advantage of ameliorating the interference problem, a substantial fading margin must be provided to accomodate the severe rain loss.

• Satellite transponder amplifiers must provide large gains (~120 dB) with low noise.

The first stage of transponder amplifier provided by solid state FET amplifier with low noise and intermodulation effects.

Channelizing filters must also be designed to minimize interference from adjacent channels, ISI and group delay distortion.

Final stages of amplification in the transponder are TWTAs, which operate well for constant envelope signals.

Transponders may have regenerative repeaters for digital transmission.

In a regenerative transponder the digital signal is demodulated and remodulated within the transponder itself.

(c) Earth stations

- Most earth stations were both transmit and receive with large antennas (> 30m) with ~~>10~~ 5KW and cryogenic receivers with noise temperatures around 20K

To day for fixed service, smaller antennas, lower powers and uncooled receivers are used. VSATs use antennas between 1.0 and 2.0m with power 1 to 20W.

- Receive only stations, such as used in cable installations to receive TV for redistribution by cable, TVRO stations for direct reception of video from satellites and direct reception of audio, navigational and other kinds of electronic information.

- Transmit only stations for the satellite reception and retransmission of data and messages, either in real-time or in store-and-forward mode.

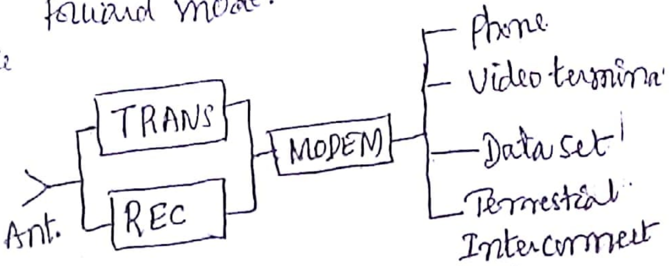
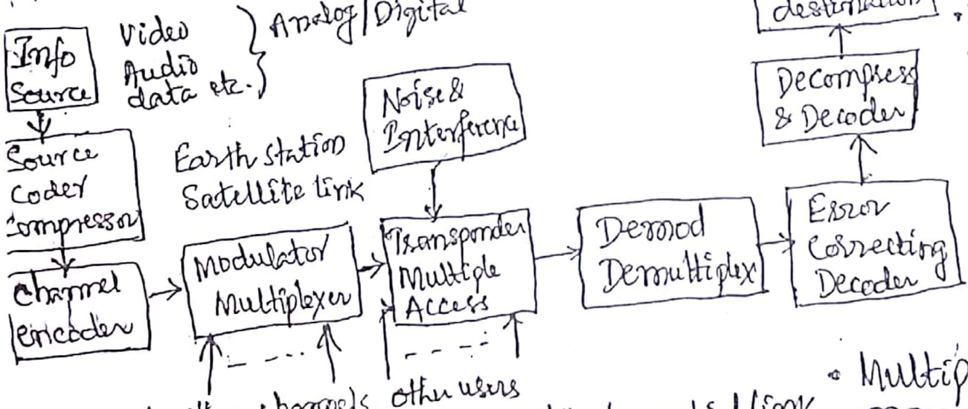


Fig. Generic earth terminal

- Earth stations are available in a wide variety of size, function, sophistic and cost.
- They are categorized by function, by size of the antenna and by the level of the radiated power.
  - Antenna diameters range in 0.5m for direct broadcast receive-only applications to as large as 30m in diameter for large international gateways.
  - Larger stations may require tracking systems to maintain the pointing of the antenna at the satellite.
- An earth station consists of an antenna subsystem, a power amplifier subsystem, a low-noise receiver subsystem and a ground communication equipment (GCE) subsystem.
- Most stations are equipped with separate power supply systems, control, test and monitoring facilities known as telemetry, tracking and command systems (TT&C)
- Smaller stations do not require tracking systems because of the large beamwidth of the antenna compared to larger-aperture stations.

- The performance of an earth station is specified by its equivalent isotropic radiated power (EIRP) and its gain-to-system noise temperature ratio (G/T).
- EIRP is the product of the power output of the high-power amplifier at the antenna and the gain of the transmitting antenna.
- The receiving system sensitivity is specified by G/T, the ratio of the receive gain of the antenna to the system noise temperature.
- The antenna gain is proportional to the square of the diameter and is dependent on the efficiency of the feed / reflector system.
- The system noise temperature is composed of three components:
  1. The noise of the receiver
  2. The noise due to losses between the antenna feed system and the receiver
  3. The antenna noise

5) The Terrestial Link



- Satellite terrestial link

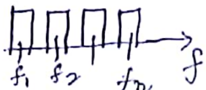
- The source of information can be ~~analog & digital~~ video, audio or data and information can be analog or Digital.
- If the transmission or processing is be digital, the source of information is digitized, made as compact as possible without losing any information by full source coding and then compressed to reduce the transmission requirements at the expense of some acceptable loss in quality.
- After every bit of redundancy is ~~sq~~ squeezed out of the signal, some is then added back selectively in the channel encoder to minimize transmission errors by correcting them using the redundant or parity check bits.
- The round trip delay on a GEO sat link is on the order of ~~0.6~~ 236 ms
- The processed digital or analog sign must now modulate a RF signal suitable for transmission to the SAT
- Because of the nonlinearity of the transponders, it is desirable to use constant envelope modulation method.
- Therefore, digital passband signals use PSK & FSK. and analog signals use FM or SSB

telephone ← FDM

- Multiple access in which many transmitters can use the same transponder

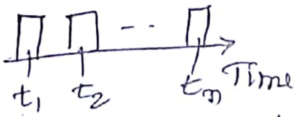
FDMA: Similar to terrestrial frequency division multiplexing, assigns each transmitter its own carrier frequency. They all transmit simultaneously; Receivers select the desired transmitter by filtering its carrier frequency. This method of multiple access is used extensively in fixed telephone service. But the presence of multiple carriers in a single nonlinear transponder causes intermodulation and the effective loss of transmitter power.

TDMA



- It is much used for digital Tx.
- Each seperate transmitter is given its own time slot.
- The stations transmit sequentially in assigned time slots and all at the same carrier frequency.
- The length of the ~~time~~ transmission time can be variable.
- It is more expensive than FDMA

CDMA:



All the transmitters transmit simultaneously and at the same frequency. Each transmitted signal is modulated by its own pseudorandomly coded bit stream.

- This bit stream serves to identify the transmitter and to spread the signal spectrum over a very wide BW compared to what would be needed to transmit the information alone.
- The codes are ~~chose~~ chosen from orthogonal set, and the receivers cross correlate the composite received signal with the known code of the desired transmitter.
- CDMA is an effective multiple-access system that permits stations to come and go on a network in a demand-assignment mode.
- It is well suited for low-data rate systems in crowded spectra.
- If the total traffic is fixed and high, it is not as efficient in its use of power and spectrum as FDMA and TDMA

Frequency Allocations for Satellite Services

- Allocating frequencies to satellite services is a complicated process which requires international coordination and planning.
- This carried out under the auspices of the ITU.
- To facilitate frequency planning, the world is divided into 3 regions:
  1. Europe, Africa, Soviet Union and Mongolia
  2. North and South America and Greenland
  3. Asia, Australia, and South west Af
- Within these regions, frequency band are allocated to various satellite services, although a given service may be allocated different frequen bands in different regions.
- Some of the services provided by satellites are:
  1. Fixed Satellite Service (FSS)

3. Mobile Satellite Service
4. Navigational Satellite Services
5. Meteorological Satellite Services

There are many subdivisions within these broad classifications:

ex: The FSS provides links for existing telephone N/ws as well as for transmitting TV signals to cable companies for distribution over cable systems.

Broadcasting Satellite Services are intended mainly for direct broadcast to the home, sometimes referred to as direct broadcast satellite (DBS) service (In Europe, it is known as DTH).

Mobile Satellite services would include land mobile, maritime mobile and aeronautical mobile.

Navigational Satellite services include GPS, GNSS, Galileo, IRNSS, GAGAN etc.

Meteorological Satellite service provide a Search and Rescue (SAR) service.

Table 1.1 Frequency band designations

Frequency Range (GHz)	Band Designation	Application
0.1 – 0.3	VHF	Mobile & Navigational Services
0.3 – 1.0	UHF	
1.0 – 2.0	L	Mobile Satellite & Navigation
2.0 – 4.0	S	
4.0 – 8.0	C	FSS
8.0 – 12.0	X	

(7)

27.0 – 40.0	—	Ka
40.0 – 75	—	V
75 – 110	—	W
110 – 300	—	mm
300 – 3000	—	μm

C-band : 6/4 GHz — FSS
6 GHz – Uplink
4 GHz – Down Link

Ku-band : 14/12 GHz

Ka-band : 40/20 GHz

Table 1.2 ITU Frequency band designations

Band No.	Symbols	Frequency range	metric subdivision
4	VLF	3 – 30 KHz	Myriametric waves
5	LF	30 – 300 K	Kilometric
6	MF	300 – 3000 K	Hectometric
7	HF	3 – 30 MHz	Decametric
8	VHF	30 – 300 MHz	Metric
9	UHF	300 – 3000 MHz	Decimetric
10	SHF	3 – 30 GHz	Centimetric
11	EHF	30 – 300 GHz	Millimetric
12		300 – 3000 GHz	Decimillimetric

Applications of satellite Comm. System

- At present, coaxial and optical fiber cables are used in subscriber loop and junction lines in Telephone N/w for a typically 10's of kms. But trunk routes are much longer. For this purpose radio relays or optical fiber cables. In [illegible]

involved are large in the order of several 100's of kms.
- Use in special situations like the presence of difficult terrain or sea between switching centers.
- The International switching centers (ISCs) are interconnected through satellites or cables.

Satellites are used for the rapid deployment of Telecomm. services between or with isolated communities. Hence several countries where populated areas are seperated by vast distances or difficult terrain or sea (an archipelago), use satellites on trunk routes.
satellites also provide a useful back-up for existing terrestial services.

- Very small Aperture Terminals (VSAT) are interconnected to bypass entire public switched networks
- In several countries such bypass N/ws are gaining in popularity because:

(a) For many applications the use of a VSAT N/W is cost effective than use of Public switched N/W (PSN).
(b) VSAT eliminates delay/faults associated with the PSN; and
(c) A user can access the N/W quickly.

(4) Mobile satellite communications, capable of providing coverage over a much wider area such as oceans, intercontinental flight corridors and large expanses of land mass.
Additionally, it provides full international

(8) – Satellites are used to provide voice and data communications to aircraft, ships, land vehicles and handsets.
– Some of the novel applications are provision of live TV to ships using advanced picture compression technique
– Messaging and voice communication to desk-top and pocket size terminals
– Tracking of fleet or yachts
– Supporting relief operations in remote areas
– Instant contact with news reporters from inaccessible areas,
– responding to distress call from ships; and
– World wide paging.

(5) Satellites are also well suited for rapid provision of TV and sound broadcasts to large or otherwise unserved areas.
– A satellite comm. system can provide coverage over wide areas in a relative short period.
– For planning to deployment of satellite may take 4-5 years only. Where as to provide terrestial comm., it may take very longer time.

(6) Other applications for which satellite are well suited are:
(a) Provision of service to regions of sparse population spread over large areas
(b) Augmenting the communication infrastructure of developing countries that have limited terrestial

Limitations of Sat. Comm.

1. High cost during introduction
   - A careful techno-economic study is required before taking the decision to introduce satellites.

- Loss of Service to large areas
  - If a satellite fail or malfunction during launch or deployment
  - The problem of in-orbit catastrophic failure, is solved by deploying an in-orbit spare, often leased from another organization to minimize cost.

3. Emerging low and medium earth orbit satellite systems are naturally resistant to satellite failure because of distributed architecture.
4. Another limitation of GEO satellite is its transmission delay caused by long propagation path.
   - Echo cancellers/suppressors
   - Delay associated with two satellite hops can become excessive.
   - Delay is not a problem for data transfer applications (except for voice comm.).
5. - The problem of transmission delay has been solved by deploying LEO satellites.

Future Trends

- FSS - the advent of trans-oceanic fiber optic cables may have an impact on the rate of growth.
  ~~— — — — very small aperture terminals~~ expected to grow in all parts of the wo
- Personal VSATs are expected to provide broadband services accompanied by a significant reduction in call charges.
- A number of mobile satellite systems using non geostationary orbit will offer voice and broadband personal services. Several regional mobile satellite systems are likely to emerge.
- The use of DTH broadcasting is expected to rise in many parts of the world.
- Introduction of digital television employing highly efficient digital compression will offer a number of innovative services such as download of large files, movies on demand etc.
- For applications such as VSAT or personal mobile terminals, simple inexpensive ground receivers are essential. One possible solution is the use of satellites with regenerative repeaters.
- Intelligent satellites together with multiple beam coverage and inter-satellite links are likely to play an increasing role in the future.
- The use of non-geostationary orbits for specific applications, intersatellite links in space to increase space segment capacity and connectivity

Satellites – Non Synchronous ~~Orbital~~ Patterns (10)

Non synchronous satellites rotate around earth in elliptical or circular orbits.

- In a circular orbit, the speed or rotation is constant.
- In elliptical orbits, the speed depends on the height of the satellite (above the earth).
  - The speed of the satellite is greater when it is close to Earth than when it is farther way.

If the satellite is ~~of~~ orbiting in the same direction as Earth's rotation (Counter clock wise (CCW)) and an angular velocity greater than that of Earth ($\omega_s > \omega_e$), the orbit is called a prograde or posigrade orbit.

If the satellite is orbiting in the opposite direction as Earth's rotation ~~as~~ or in the same direction with an angular velocity less than that of Earth ($\omega_s < \omega_e$), the orbit is called retrograde orbit.

Most nonsynchronous satellites revolve around Earth in a prograde orbit.
- Therefore, the position of satellites in non synchronous orbits is continuously changing in respect to a fixed ~~point~~ position on Earth.

Consequently nonsynchronous ~~t~~ satellites have to be used when available, which may be as little as 15 minutes per orbit.

Another disadvantage is the need for equipment at earth stations, so they can locate the satellite as it comes into view on each orbit and then lock its antenna onto the satellite and track it passes overhead.

- A major advantage of orbital satelli is that propulsion rockets are not required onboard the satellite to keep them in their respective orbits.

Satellite Elevation categories

- Satellites are classified as
  1. Low earth orbit (LEO),
  2. Medium earth orbit (MEO), and
  3. Geosynchronous earth orbit (GEO)

LEO: Most LEO satellites operate in the 1.0 – 2.5 GHz (L band) frequency range.

- Motorola's satellite based mobile telephone system (Iridium) is a LEO system utilizing a 66-satellite constellation orbiting about ~~400 mile~~ 780 km above earth's surface.
- The main advantage of LEO satellite is that the path loss between earth stations and space vehicles is much lower than for satellites revolving in MEO or GEO
  - Less ~~path~~ path loss equates to lower transmit powers, smaller antenn and less weight.

MEO: MEO satellites operate in the 1.2 – 1.66 GHz frequency band and orbit between ~~@~~ 10000–20,000 km abov the Earth.

- The DoD's GPS (NAVSTAR) is a MEO

working satellites and 6 spares orbiting about 20,180km above the Earth.

GEO: GEO satellites are high altitude earth orbit satellites operating primarily in the ~~2GHz to 18GHz~~ 2-40GHz frequency spectrum with orbits around 36,000km above earth's surface.

- Most commercial communications satellites are in geosynchronous orbit.
- Geosynchronous or Geostationary satellites are those that orbit in a circular pattern with an angular velocity equal to that of earth.
- Geostationary satellites have an orbital time of approximately 24 hours, the same as earth; thus, stationary satellites appear to be stationary, as they remain in a fixed position in respect to a given point on Earth.
- Satellites in high elevation, non-synchronous circular orbits between 30,000 to 36,000km above Earth, the ~~Satellite's time is lower than Earth's rotational period~~ are said to be in near synchronous orbit.

→ Therefore the satellite is moving slowly around Earth in a west-to-east direction.

- This type of near synchronous orbit is called Sub-synchronous.

* When the near synchronous orbit is slightly lower than 36,000km above Earth ...

(ii) If the orbit is higher than 36,000km above earth, the satellite orbital time is longer than Earth's rotational period and the satellite will appear to have a reverse (Retrograde) motion from east to west.

Satellite Orbital patterns

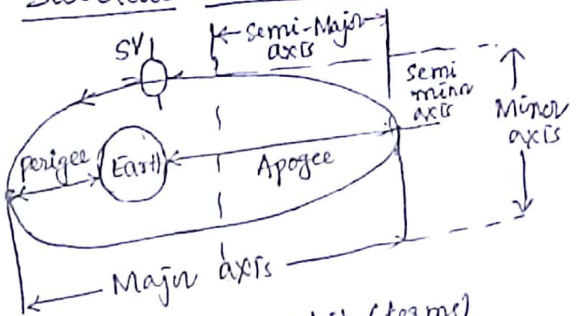


Fig. Elliptical orbit (terms).

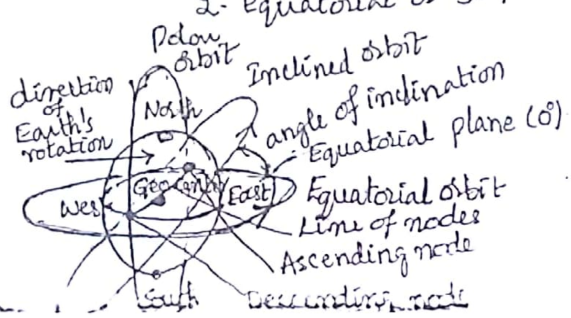
Apogee: The point on the orbit that is located farthest from earth.

Perigee: The point on an orbit that is located closest to earth.

Major axis: The line joining the perigee and apogee through the center of Earth (called also as Line of apside).

Minor axis: The line perpendicular to the major axis and half way between the perigee and apogee (Half distance of the minor axis is cal the semiminor axis.)

- Although there is an infinite number of orbital paths, only three are useful for communications satellites. They are: 1. Inclined, 2. Equatorial or 3. Polar



All satellites rotate around Earth in an orbit that forms a plane that passes through the center of gravity of Earth called the Geocenter.

(i) Inclined orbits: are virtually all orbits except those that travel directly above the equator or directly over the north and South poles.

The angle of inclination is the angle between the Earth's equatorial plane and the orbital plane of a satellite measured counter clockwise at the point in the orbit where it crosses the equatorial plane travelling from South to North.

- This point is called the ascending node.

The point where a polar or inclined orbit crosses the equatorial plane travelling from north to south is called the descending node, and the line joining the ascending and descending nodes through the center of the Earth is called the line of nodes.

Angles of inclination vary between 0° and 180°.

To provide coverage to regions of high latitudes, inclined orbits are generally elliptical

Kepler's second law shows that the angular velocity of the satellite is slowest at its apogee.

- Therefore, the satellite remains visible for a longer period of time to the higher latitude regions, if the apogee is placed above the high-latitude region.

(ii) An equatorial orbit is when the satellite rotates in an orbit directly above the equator, usually in a circular path

- With an equatorial orbit, the angle of inclination is 0°, and there are no ascending or descending nodes and hence, no line of nodes.
- All geosynchronous satellites are in equatorial orbits.

(iii) A polar orbit is when the satellite rotates in a path that takes it over the North and South poles in an orbit perpendicular to the equatorial plane.

- Polar orbiting satellites follow a low latitude path that is close to earth and passes over and very close to both the north and South poles.
- The angle of inclination of a satellite in polar orbit is nearly 90°

NOTE: 100% of Earth's surface can be covered with a single satellite in a polar orbit.

- Satellites in polar orbits rotate around Earth in a longitudinal orbit while earth is rotating on its axis in a latitudinal rotation.

- Consequently, the satellite's radiation pattern is a diagonal line that form a spiral around the surface of Earth that resembles a barber pole.

- As a result, every location on Earth lies within the radiation pattern of a satellite in a polar orbit twice each day.

• Earth is not a perfect sphere, (13) as it bulges at the equator.

• Earth's equatorial bulge is causing elliptical orbits to rotate in a manner that causes the apogee and perigee to move around the Earth.

- This phenomena is called rotation of the line of apsides;
- However, for an angle of inclination of 63.4°, the rotation of the line of apsides is zero.
- Thus, satellites required to have an apogee over a particular location are launched into orbit with an angle of inclination of 63.4°, which is referred to as 63° slot.

IV) Soviet Molniya satellite orbit:

• one of the more interesting orbital satellite systems currently in use is the common wealth of Independent ~~sat~~ states (CIS) Molniya system of satellites, which is shown in fig. below:

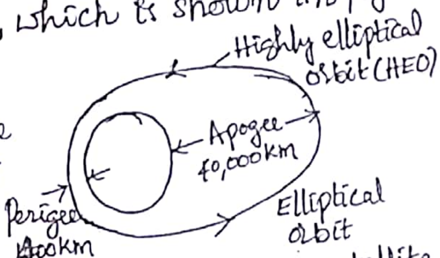


Fig. Soviet Molniya satellite orbit.

The CIS is the former Soviet Union (SU). Molniya can also be spelled Molnya and Molnia, which means "lightning" in Russian (in colloquial Russian, Molniya means "news flash").

Molniya satellites are used for government communications, telephone, TV and video.

The Molniya series of satellites use highly inclined elliptical orbits to provide services to the more northerly regions

from geostationary space vehicle rotating in an equatorial orbit.

• Molniya satellites have an apogee at about 40,000km and a perigee about 400km.

• The apogee is reached while over the Northern Hemisphere and the perigee while over the Southern Hemisphere.

• The size of the ellipse was choosen to make its period exactly one half a sidereal day (11h 56m 2.01sec).

• One sidereal day is the time it takes Earth to rotate back to the same constellation.

• Because of its unique orbital pattern the Molniya satellite is synchronous with the rotation of Earth.

• During a satellite's 12-hours orbit, it spends about 11 hours over the Northern Hemisphere.

- 3 ore more space vehicles (SVs) follow each other in this orbit and pass communications to each other so that continuous communications is possible while minimal earth station antenna tracking is necessary.

• Satellites with orbital patterns like Molniya are sometimes classified as having a highly elliptical orbit (HEO)

Geosynchronous Satellites (14)

Geosynchronous satellites orbit around Earth above the equator with the same angular velocity as Earth.

Hence, geosynchronous (sometimes Geostationary) satellites appear to remain in a fixed location above one spot on Earth's surface.

'ince a geosynchronous satellite appears to remain in a fixed location no special antenna tracking equipment is necessary — earth station antennas are simply pointed at the satellite.

A single high-altitude geosynchronous satellite can provide reliable communications to approximately 40% of the earth's surface.

The closer to Earth a satellite rotates, the greater the gravitational pull and the greater the velocity required to keep it from being pulled to Earth.

- Low altitude satellites orbiting 160Km above earth travel at approximately 28,160kmph.
  - At this speed, it takes approximately 1.5 hours to rotate around earth
  - Consequently, the time that a satellite is in line of sight (LOS) of a particular earth station is 0.25hour or less per orbit.
- Medium-altitude Earth orbit satellites have a rotation period of between 5 and 12 hours and remain in LOS for 2 to 4 hours per orbit.
- High altitude earth-orbit satellites in geosynchronous orbit travel at

- Geosynchronous orbits are circular, therefore, the speed of rotation is constant throughout the orbit.
- There is only one geosynchronous earth orbit; however it is occupied by a large number of satellites.
- The geosynchronous orbit remain in a fixed position relative to Earth and therefore, do not have to be tracked by earth station antennas.
- However, the sun and the moon exert gravitational forces, solar winds sweep past Earth, and earth is not perfectly spherical.
- Therefore, these unbalanced forces cause geosynchronous satellites to drift slowly away from their assigned locations in a figure-eight excursion with a 24 hour period that follows a wandering path slightly above and below the equatorial plane.
- In essence, it occurs in a special type of inclined orbit some-times called a stationary inclined orbit.
- Ground controllers must periodically adjust satellite positions to counter these forces.
  - If not, the excursion above and below the equator would build up a rate of between 0.6° and 0.9° per year.
- In addition, geosynchronous satellites in an elliptical orbit also drift in an east or west direction as viewed from Earth.
- The process of maneuvering a satellite within a preassigned window is

- There are several requirements (15) for satellites in geostationary orbits:

① Satellite must have a 0° of inclination with equator

② Satellite should orbit in the same direction as earth (eastward) direction.

③ Satellite angular velocity is same as Earth, which causes

④ One revolution per day.

- The semimajor axis of a geosynchronous earth orbit is the distance from a satellite revolving in the geosynchronous orbit to the center of the Earth (i.e., the radius of the orbit measured from Earth's geocenter to the satellite vehicle).

- Using Kepler's third law (harmonic law)

$\alpha = A p^{2/3}$

where A = constant (unitless)

P = mean solar earth days

α = semi major axis (km)

— with $A = 42241.0979$ and $P = 0.9972$ the semimajor axis α is

$\alpha = Ap^{2/3} = (42241.0979)(0.9972)^{2/3}$

$= 42,164 km$.

- The Earth's equatorial radius $r = 6,378 km$

∴ The height above mean sea level (h) of a satellite in geosynchronous orbit around Earth is

$h = \alpha - r = 42,164 km - 6,378 km$

$= 35,786 km$

Geosynchronous Satellite Orbital Velocity

- The circumference (C) of a geosynchronous orbit is $C = 2\pi \alpha = 2\pi(42,164 km)$

$C = 2,64,794 km$.

∴ The velocity (v) of geosynchronous satellite is

Round-Trip Time Delay of Geosynchronous Satellites:

- The round-trip propagation delay between a satellite and an earth station located directly below it is

$t = \frac{distance}{velocity} = \frac{d}{c} = \frac{2 \times h}{c}$

$= \frac{2 \times 35,768 km}{3 \times 10^5 km/s} = \underline{238 ms}$

NOTE 1: Including the time delay with the earth station and satellite equip it takes more than a quarter of a second for an EM wave to travel from earth station to satellite and back when the earth station is located a a point on earth directly below the satellite.

2. For earth stations located at more distant locations, the propagation delay is even more substantial and can be significant with two-way telephone conversations or data transmissions.

Clarke orbit

- A geosynchronous earth orbit is sometimes referred to as the clarke orbit or clarke belt, after Arthur C. Clarke, who first suggested its existance in 1945 and proposed its use for communications satellites.

- Clarke was an engineer, a scientist and a science fiction author, who wrote several books including 2001: A space odyssey.

- The clarke orbit meets the concise set of specifications for geosynchronous satellite orbits:

(1) be located directly above the equator

2. travel in the same direction as earth's rotation at 11,033 km/h

4. Complete one revolution in 24 hours.(Vo)

As shown in Fig. below, three satellites in clarke orbits seperated by 120° in longitude can provide communications over the entire globe except the polar regions.

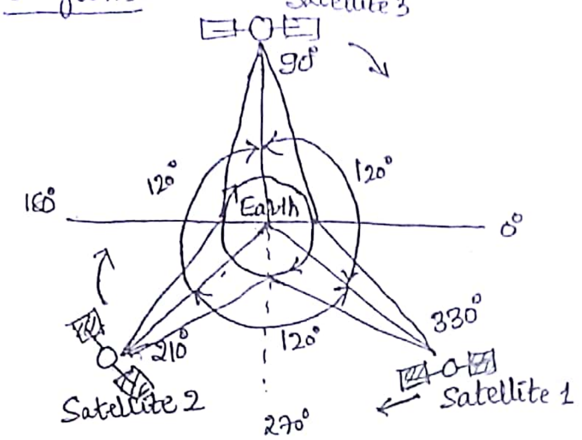


Fig. Three geosynchronous satellites in Clarke orbits.

NOTE 1: An international agreement initially mandated that all satellites placed in the clarke orbit must be seperated by atleast 2,950 km.

— This equates to angular seperation of 4° or more, which limits the number of SVs in a geosynchronous earth orbit to less than 100.

The advantages of geosynchronous satellites

1. Geosynchronous satellites remain almost stationary in respect to a given earth station. Consequently, expensive tracking equipment is not required at the earth stations.

2. Geosynchronous satellites are available to all earth stations within their shadow 100% of the time.

— The shadow of a satellite includes all the earth stations that have a LOS path to it and lie within the radiation pattern of the satellite's antennas.

3. There is no need to switch from one geosynchronous satellite to another as they orbit overhead. Consequently, there are no transmission breaks due to switching times.

4. The effects of Doppler shift are negligible

— The disadvantages of geosynchronous satellites are as follows:

1. Geosynchronous satellites require sophisticated and heavy propulsion devices onboard to keep them in a fixed orbit.

2. High-altitude geosynchronous satellite introduce much longer propagation delays.
   — The round-trip propagation delay between two earth stations through a geosynchronous satellites is between 500ms and 600ms.

3. Geosynchronous satellites require higher transmit powers and more sensitive receivers because of the longer distances and greater path losses.

4. High precision spacemanship is required to place a geosynchronous satellite into orbit and to keep it there.