P.S.R. ENGINEERING COLLEGE

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An ISO 9001: 2015 Certified Institution
Sevalpatti (P.O), Sivakasi - 626140. Tamilnadu.

Course Materials on

SATELLITE COMMUNICATION

Department of

Electronics and Communication Engineering

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VISION AND MISSION OF THE INSTITUTE

Vision

To contribute to the society through excellence in technical education with societal values and thus a valuable resource for industry and the humanity.

Mission

- To create an ambience for quality learning experience by providing sustained care and facilities.
- To offer higher level training encompassing both theory and practices with human and social values.
- To provide knowledge based services and professional skills to adapt tomorrow's technology and embedded global changes

VISION AND MISSION OF THE DEPARTMENT

Vision

The vision of the Electronics and Communication Engineering Department is to produce graduates with sound knowledge for the betterment of society and to meet the dynamic demands of industry and research.

Mission

- Offering undergraduate and postgraduate programmes by providing effective and balanced curriculum and equip themselves to gear up to the ethical challenges awaiting them.
- Providing the technical, research and intellectual resources that will enable the students to have a successful career in the field of Electronics and Communication Engineering.

- Providing need based training and professional skills to satisfy the needs of society and industry.

PROGRAMME OUTCOMES (POs)

PO:1 Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO:2 Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO:3 Design / Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO:4 Conduct Investigations of Complex Problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO:5 Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO:6 The Engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO:7 Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO:8 Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO:9 Individual and Team Work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO:10 Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO:11 Project Management and Finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO:12 Life-long Learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAMME SPECIFIC OUTCOMES (PSOs)

PSO1: Design, simulate and analyse diverse problems in the field of telecommunication.

PSO2: Able to design and analyse varied electronic circuits for applications.

PSO3: Apply signal and image processing techniques to analyse a system for applications.

PSO4: Construct, test and evaluate an embedded system and control systems with real time constraints.

191ECEP - SATELLITE COMMUNICATION

UNIT-1

SATELLITE ORBITS

INTRODUCTION

The use of satellites in communications systems is very much a fact of everyday life, as is evidenced by the many homes equipped with antennas or "dishes" used for reception of satellite television. What may not be so well known is that satellites form an essential part of telecommunications systems worldwide, carrying large amounts of data and telephone traffic in addition to television signals.

Satellites offer a number of features not readily available with other means of communications. Because very large areas of the earth are visible from a satellite, the satellite can form the star point of a communications net, simultaneously linking many users who may be widely separated geographically. The same feature enables satellites to provide communications links to remote communities in sparsely populated areas that are difficult to access by other means. Of course, satellite signals ignore political boundaries as well as geographic ones, which may or may not be a desirable feature.

A good overview of the role of satellites is given by Pritchard (1984) and Brown (1981). Satellites are also used for remote sensing, examples being the detection of water pollution and the monitoring and reporting of weather conditions. Some of these remote sensing satellites also form a vital link in search and rescue operations for downed aircraft and the like.

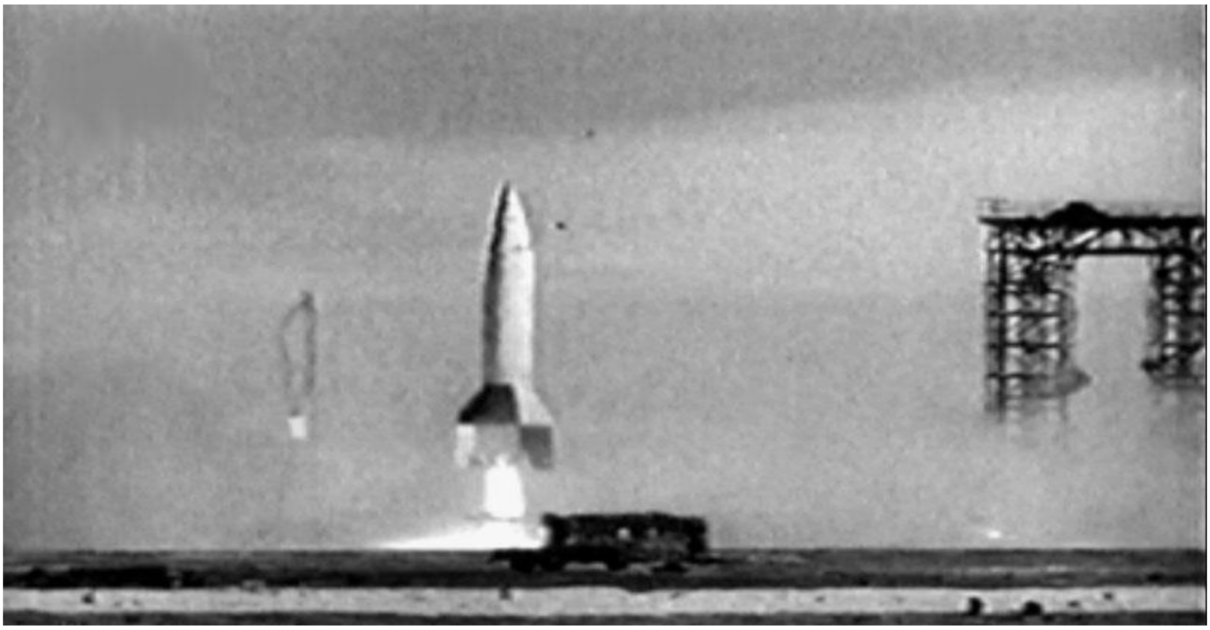
The earth station should be in a position to control the satellite if it drifts from its orbit and if subjected to any kind of drag from the external forces. The following are the applications of satellites.

- Weather Forecasting
- Radio and TV Broadcasting
- Military Satellites
- Navigation Satellites
- Global Telephone
- Connecting Remote Area
- Global Mobile Communication

Important Milestones (before 1950)

- 1600 Tycho Brache's experimental observations on planetary motion.
- 1609-1619 Kepler's laws on planetary motion

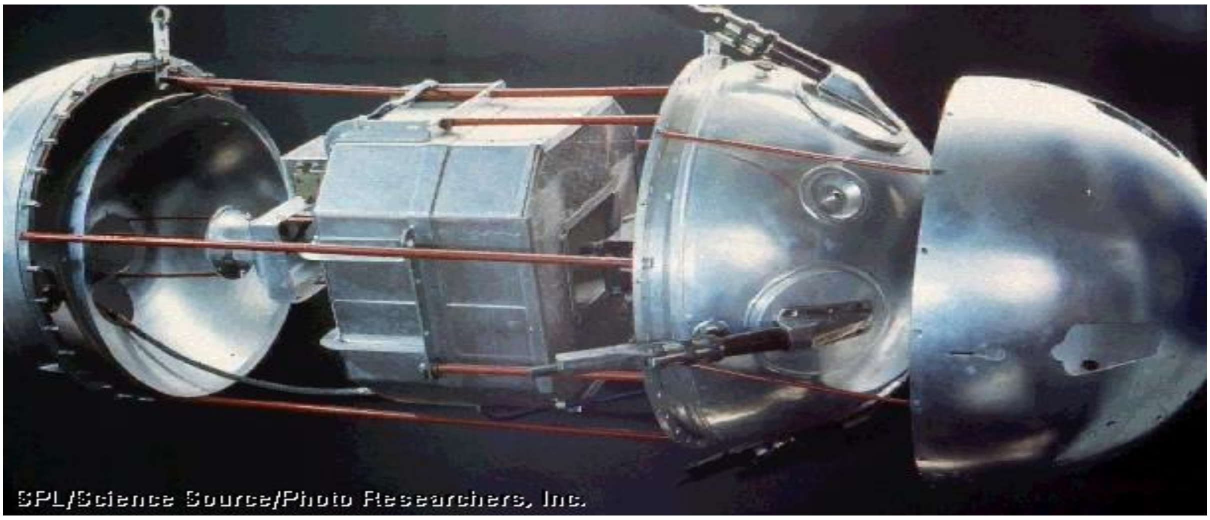
- 1926 First liquid propellant rocket launched by R.H. Goddard in the US.
- 1927 First transatlantic radio link communication
- 1942 First successful launch of a V-2 rocket in Germany.
- 1945 Arthur Clarke publishes his ideas on geostationary satellites for worldwide communications (GEO concept).



Important Milestones (1950's)

- 1956 - Trans-Atlantic cable opened (about 12 telephone channels – operator).
- 1957 First man-made satellite launched by former USSR (Sputnik, LEO).
- 1958 First US satellite launched (SCORE). First voice communication established via satellite (LEO, lasted 35 days in orbit after batteries failed).

Sputnik – I

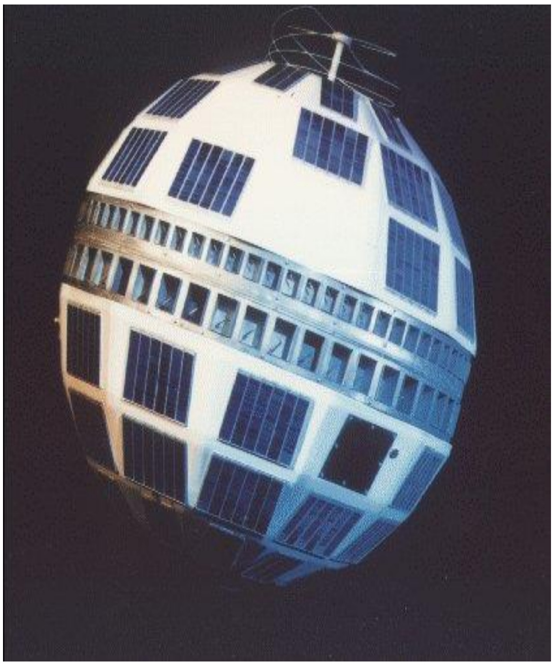


Important Milestones (1960's)

First satellite communications

- 1960 First passive communication satellite launched into space (Large balloons, Echo I and II).
- 1962: First non-government active communication satellite launched Telstar I (MEO).
- 1963: First satellite launched into geostationary orbit Syncom 1 (comms. failed).
- 1964: International Telecomm. Satellite Organization (INTELSAT) created.
- 1965 First communications satellite launched into geostationary orbit for commercial use Early Bird (re-named INTELSAT 1).

ECHO I



Telstar I

Important

Milestones (1970's)

GEO applications development

- 1972 First domestic satellite system operational (Canada). INTERSPUTNIK founded.
- 1975 First successful direct broadcast experiment (one year duration; USA-India).
- 1977 A plan for direct-to-home satellite broadcasting assigned by the ITU in regions 1 and 3 (most of the world except the Americas).
- 1979 International Mobile Satellite Organization (Inmarsat) established.

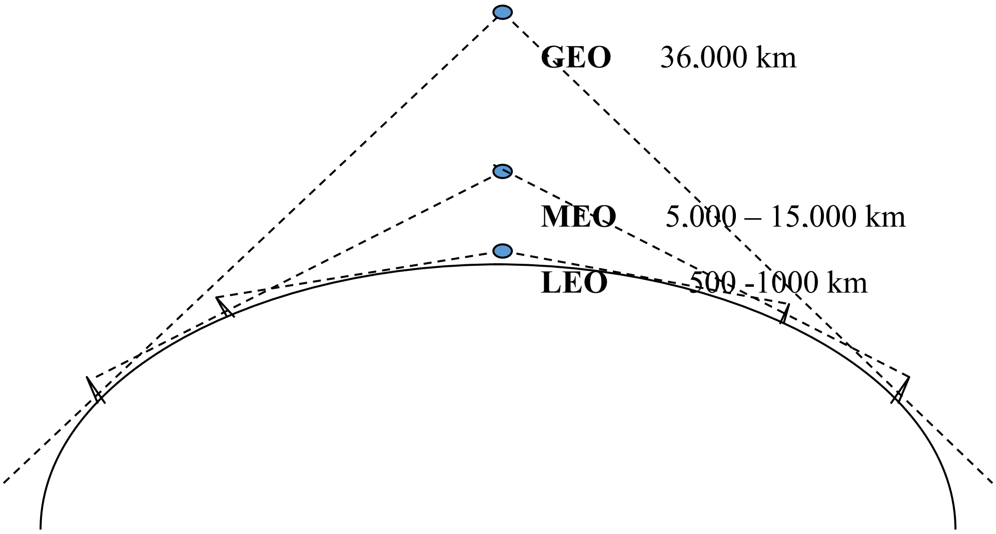
Important Milestones (1980's)

GEO applications expanded

- 1981 First reusable launch vehicle flight.
- 1982 International maritime communications made operational.
- 1983 ITU direct broadcast plan extended to region 2.

- 1984 First direct-to-home broadcast system operational (Japan).
- 1987 Successful trials of land-mobile communications (Inmarsat).
- 1989-90 Global mobile communication service extended to land mobile and aeronautical use (Inmarsat)

Basic concepts of Satellite Communications



USEFUL ORBITS 1:
GEOSTATIONARY ORBIT

- In the equatorial plane
- Orbital Period = 23 hr 56 min. 4.091 s
  = one ***Sidereal Day*** (defined as one complete rotation relative to the fixed stars)
- Satellite appears to be **stationary** over a point on the equator to an observer
- Radius of orbit, r, = 42,164.57 km

USEFUL ORBITS 2:

- Low Earth Orbit (>250 km); T ≈ 92 minutes
- Polar (Low Earth) Orbit; earth rotates about 23° each orbit; useful for surveillance
- Sun Synchronous Orbit (example, Tiros-N/NOAA satellites used for search and rescue operations)
- 8-hour and 12-hour orbits
- Molniya orbit (Highly Elliptical Orbit (HEO); T ≈ 11h 38 min; highly eccentric orbit; inclination 63.4 degrees

MOLNIYA VIEW OF THE EARTH

(Apogee remains over the northern hemisphere)

A Highly Elliptical Orbit (HEO)

A satellite in HEO typically has a perigee at about 500 km above the surface of the Earth and an ‘apogee as high as 50,000 km. The orbit is usually inclined at 63.4 deg to provide communications services to locations at high northern latitudes. Orbit period varies from eight to 24 hours. Owing to the high eccentricity of the orbit, a satellite spends about two-thirds of the orbital period near apogee, during which time it appears to be almost stationary to an observer on the Earth (a phenomenon known as `apogee dwell'). During the brief time the satellite is below the local horizon, a hand-off to another satellite in the same orbit is required in order to avoid loss of communications. Free space loss and propagation delay for this type of orbit are comparable to that of geosynchronous satellites. However, due to the comparatively great movement of a satellite in HEO relative to an observer on the Earth, satellite systems using this type of orbit must cope with large Doppler shifts.

A Medium-Earth Orbit (MEO)

By setting the altitude parameters at 10,000 km, you generated a Medium-Earth orbit (MEO). This one happens to be an Intermediate Circular Orbit (ICO), since the apogee and perigee are equal. Its orbit period measures about seven hours. The maximum time during which a satellite in MEO orbit is above the local horizon for an observer on the Earth is a few hours. A global communications system using this type of orbit requires relatively few satellites in two to three orbital planes to achieve global coverage. MEO systems operate similarly to LEO systems. In MEO systems, however, hand-over is less frequent, and propagation delay and free space loss are greater. Examples of MEO (specifically ICO) systems are Inmarsat-P (10 satellites in 2 inclined planes at 10,355 km), and Odyssey (12 satellites in 3 inclined planes, also at 10,355 km).

A Low-Earth Orbit (LEO)

By selecting a relatively short period (90 minutes), we have generated a satellite in low-Earth orbit (LEO). A typical LEO is elliptical or, more often, circular, with a height of less than 2000 km above the surface of the Earth. The orbit period at those altitudes ranges between 90 minutes and two hours. The radius of the footprint of a communications satellite in LEO ranges between 3000 and 4000 km. The maximum time during which a satellite in LEO is above the local horizon for an observer on the Earth is 20 minutes. A global communications system using this type of orbit requires a large number of satellites, in a number of different orbital planes. When a satellite serving a particular user moves below the local horizon, it must hand over its duties to a succeeding one in the same orbit or in an adjacent one. Due to the comparatively great movement of a satellite in LEO relative to an observer on the Earth, satellite systems using this type of orbit must cope with large Doppler shifts. Satellites in LEO are also affected by atmospheric drag that causes the orbit to gradually deteriorate.

Geosynchronous & Geostationary Orbits

A geosynchronous orbit is defined as an orbit with a period of one sidereal day (1436.1 minutes). A geostationary orbit is a special case of a geosynchronous orbit with zero inclination and zero eccentricity, i.e., an equatorial, circular orbit. A satellite in a geostationary orbit appears fixed above a location on the surface of the Earth. In practice, a geosynchronous orbit typically has small non-zero values for inclination and eccentricity, causing the satellite to trace out a small figure eight in the sky. The footprint or service area of a geosynchronous satellite covers almost one-third of the Earth's surface (from about 75 deg South to about 75 deg North latitude), so that near-global coverage can be achieved with as few as three satellites in orbit. A disadvantage of a geosynchronous satellite in a voice communication system is the round-trip delay of approximately 250 milliseconds.

A Polar Orbit

The plane of a polar orbit is inclined at about 90 deg to the equatorial plane, intersecting the North and South poles. The orbit is fixed in space, and the Earth rotates underneath. Thus, in principle, the coverage of a single satellite in a polar orbit encompasses the entire globe, although there are long periods during which the satellite is out of view of a particular ground station. This gap in coverage may be acceptable for a store-and-forward communications system. Accessibility can, of course, be improved through the deployment of two or more satellites in different polar orbits.

A Sun-Synchronous Orbit

In a Sun-synchronous or helio-synchronous orbit, the angle between the orbital plane and Sun remains constant, resulting in consistent light conditions for the satellite. This can be achieved by careful selection of orbital altitude, eccentricity and inclination, producing a precession of the orbit (node rotation) of approximately 1 deg eastward each day, equal to the apparent motion of the Sun. This condition can be achieved only for a satellite in a retrograde orbit. A satellite in Sun-synchronous orbit crosses the equator and each latitude at the same time each day. This type of orbit is therefore advantageous for an Earth observation satellite, since it provides constant lighting conditions.

Frequency Allocations for Satellite Services

Allocating frequencies to satellite services is a complicated process which requires international coordination and planning. This is carried out under the auspices of the International Telecommunication Union (ITU).

Frequency Spectrum concepts:

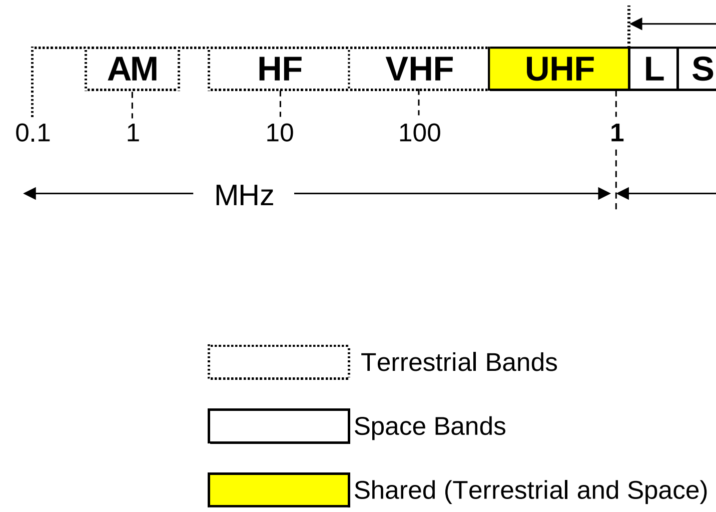
- Frequency: Rate at which an electromagnetic wave reverts its polarity (oscillates) in cycles per second or Hertz (Hz).

- Wavelength: distance between wavefronts in space. Given in meters as: $\lambda = c/f$

  Where: c = speed of light ($3x10^8$ m/s in vacuum)

  f = frequency in Hertz

- Frequency band: range of frequencies.
- Bandwidth: Size or "width" (in Hertz) or a frequency band.
- Electromagnetic Spectrum: full extent of all frequencies from zero to infinity.



International Telecommunication Union

ITU Regions

- Region 1: Europe, Africa, what was formerly the Soviet Union, and Mongolia
- Region 2: North and South America and Greenland
- Region 3: Asia, Australia, and the southwest Pacific

Within these regions, frequency bands are allocated to various satellite services, although a given service may be allocated different frequency bands in different regions.

Services provided by satellites

Name of the satellite	Services

Fixed satellite service	• Telephone Networks • Transmitting TV signals to cable companies
Broadcasting satellite service	Direct Broad cast service or DTH
Mobile satellite services	• Land Mobile • Maritime mobile • Aeronautical Mobile
Navigational satellite services	GPS
Meteorological satellite services	Search and rescue services

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

VHF band is used for mobile and navigational services and for data transfer from weather satellites. L band is used or mobile satellite services and navigation systems. C band is used for FSS and no direct broadcast services are allowed (6/4 GHz). Ku band is used at present for DBS, and it is also used for certain fixed satellite services (14/12 GHz).

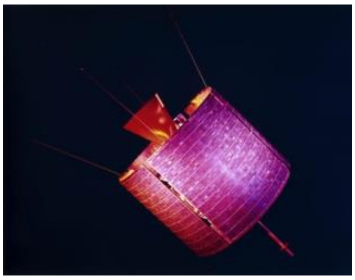
The largest international system, Intelsat, the domestic satellite system in the United States, Domsat and U.S. National Oceanographic and Atmospheric Administration (NOAA) series of polar orbiting satellites used for environmental monitoring and search and rescue.

INTELSAT

- INTELSAT stands for International Telecommunication Satellite.
- The organization was Created in 1964 and currently has over 140 member countries and more than 40 investing entities.
- satellites are in *geostationary orbit,*
- Geostationary satellites orbit in the earth’s equatorial plane and that their position is specified by their longitude.
- Life time is 10 to 15 years

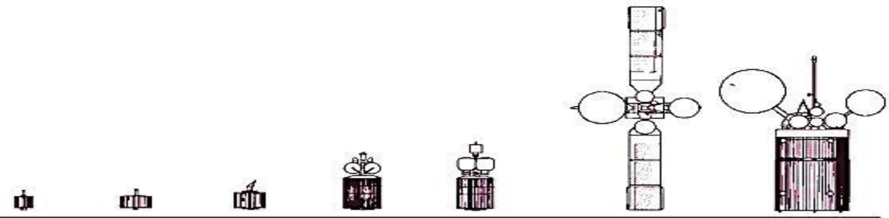
INTELSAT covers three main regions, the

- Atlantic Ocean Region (AOR),
- the Indian Ocean Region (IOR), and
- the Pacific Ocean Region (POR).
- Traffic in the AOR is about three times that in the IOR and about twice that in the IOR and POR combined.
- Thus the system design is tailored mainly around AOR requirements (Thompson and Johnston, 1983)



INTELSAT

<u>Evolution of some of the INTELSAT satellites</u>



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Evolution of INTELSAT satellites. (*From Colino 1985; courtesy of ITU Telecommunications Journal.*)

<u>Intel sat VII capacity</u>

Parameters	VII	VII/A
Two way telephone circuits	18000	22500
TV channels	3	3
Two way telephone circuits achieved with digital circuit multiplication	90000	112500

The Intelsat VIII-VIII/A series of satellites was launched over the period February 1997 to June 1998. Satellites in this series have similar capacity as the VII/A series, and the life time is 14 to 17 years.

U.S Domsats

Domsat is an abbreviation for *Domestic satellite.*

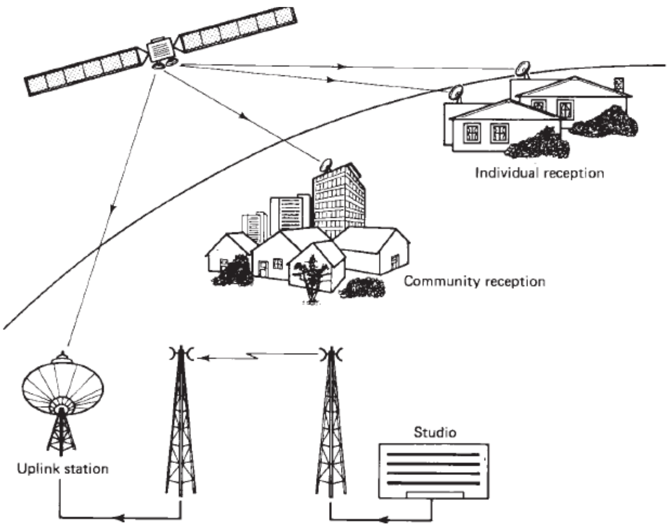
- Used to provide various telecommunications services, such as:
- Voice, data & video transmissions, within a country.
- Situated in geostationary orbit.
- Wide selection of TV channels for the home entertainment market
- A large amount of commercial telecommunications traffic is also handled

- Provides a DTH television service
- Can be classified broadly as
  - high power,
  - medium power, and
  - low power
- the primary purpose of satellites in the high-power category is to provide a DBS service.
- In the medium-power category, the primary purpose is point-to-point services, but space may be leased on these satellites for the provision of DBS services.
- In the low-power category, no official DBS services are provided.

Defining Characteristics of Three Categories of United States DBS Systems

	High power	Medium power	Low power
Band	Ku	Ku	C
Downlink frequency allocation, GHz	12.2–12.7	11.7–12.2	3.7–4.2
Uplink frequency allocation, GHz	17.3–17.8	14–14.5	5.925–6.425
Space service	BSS	FSS	FSS
Primary intended use	DBS	Point to point	Point to point
Allowed additional use	Point to point	DBS	DBS
Terrestrial interference possible	No	No	Yes
Satellite spacing, degrees	9	2	2–3
Satellite spacing determined by	ITU	FCC	FCC
Adjacent satellite interference possible?	No	Yes	Yes
Satellite EIRP range, dBW	51–60	40–48	33–37

ITU: International Telecommunication Union; FCC: Federal Communications Commission.
SOURCE: Reinhart, 1990.



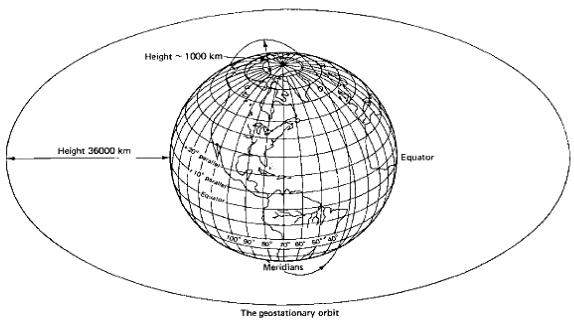
Components of a direct broadcasting satellite system.

Minimum Orbital Spacing - DOMSAT

- In 1983, the U.S. Federal Communications Commission (FCC) adopted a policy objective.
- 2° as the minimum orbital spacing for satellites operating in the 6/4-GHz band and
- 1.5° for those operating in the 14/12-GHz band (FCC, 1983).
- It is clear that interference between satellite circuits is likely to increase as satellites are positioned closer together.

Polar Orbiting Satellites

Polar orbiting satellites orbit the earth in such a way as to cover the north and south polar regions. There is only one geostationary orbit, there are an infinite number of polar orbits. The U.S. experience with weather satellites has led to the use of relatively low orbits, ranging in altitude between 800 and 900 km, compared with 36,000 km for the geostationary orbit. Low earth orbiting (LEO) satellites are known generally by the acronym LEOSATS.

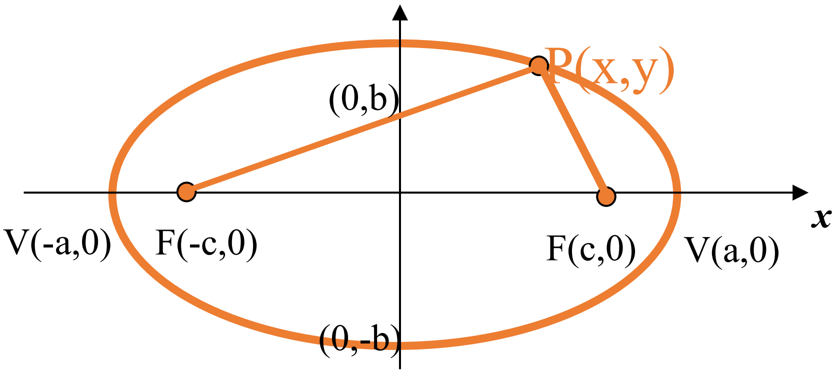


Geostationary orbit and one possible polar orbit

KEPLER'S THREE LAWS

- Orbit is an ellipse with the larger body (earth) at one focus
- The satellite sweeps out equal arcs (area) in equal time (*NOTE*: for an ellipse, this means that the orbital velocity varies around the orbit)
- The square of the period of revolution equals a CONSTANT ×the THIRD POWER of SEMI-MAJOR AXIS of the ellipse

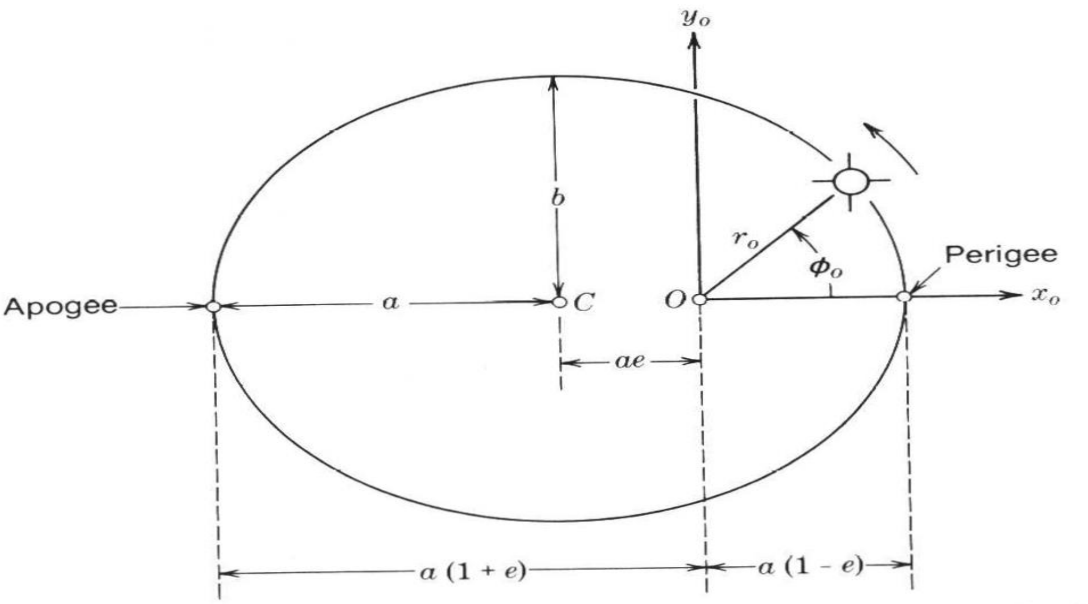
Ellipse analysis



KEPLER 1: ***Elliptical Orbits***

Law 1

The orbit is an ellipse



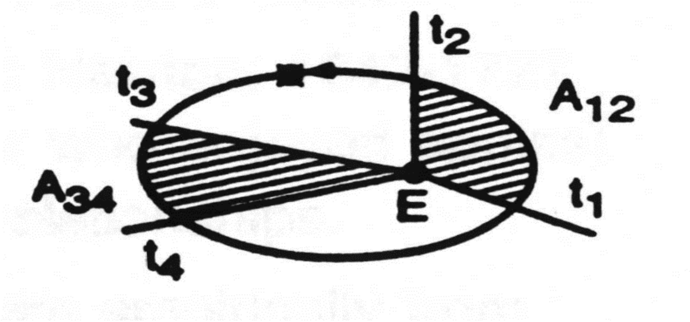
e = ellipse's eccentricity

O = center of the earth (one focus of the ellipse)

C = center of the ellipse

a = (Apogee + Perigee)/2

*KEPLER 2: **Equal Arc-Sweeps***



Law 2

If $t_2 - t_1 = t_4 - t_3$

then $A_{12} = A_{34}$

Velocity of satellite is ***SLOWEST* at *APOGEE; FASTEST* at *PERIGEE***

*KEPLER 3: **Orbital Period***

Orbital period and the Ellipse are related by

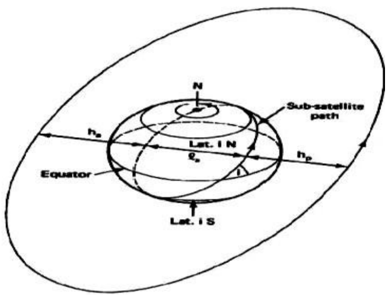
$T^2 = (4 \pi^2 a^3) / \mu$ (Equation 2.21)

That is the **square** of the period of revolution is equal to a **constant** × the **cube** of the semi-major axis.

Definitions of Terms for Earth-orbiting Satellites

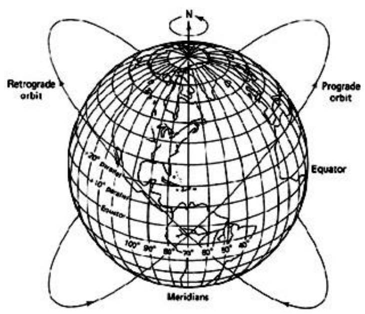
Parameter	Definition
Apogee	A point for a satellite farthest from the Earth. It is denoted as $\mathbf{h_a}$.
Perigee	A point for a satellite closest from the Earth. It is denoted as $\mathbf{h_p}$.
Line of Apsides	Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this lines length is the semi-major axis equivalents to satellite's mean distance from the Earth.
Ascending Node	The point where the orbit crosses the equatorial plane going from north to south
Descending Node	The point where the orbit crosses the equatorial plane going from south to north
Inclination	The angle between the orbital plane and the Earth's equatorial plane. It's measured at the ascending node from the equator to the orbit, going from East to North. This angle is commonly denoted as **i.**

Line of Nodes	The line joining the ascending and descending nodes through the centre of Earth.
Prograde Orbit	An orbit in which satellite moves in the same direction as the Earth’s rotation. Its inclination is always between 0_0 to 90_0
Retrograde Orbit	An orbit in which satellite moves in the same direction counter to the earth’s rotation.
Argument of Perigee	An angle from the point of perigee measure in the orbital plane at the earth’s centre, in the direction of the satellite motion.
Right ascension of ascending node	The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. It could also be defined as “right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object”.
Mean anamoly	It gives the average value to the angular position of the satellite with reference to the perigee.
True anamoly	It is the angle from point of perigee to the satellite’s position, measured at the Earth’s centre.



Apogee height h_a, Perigee height h_p, and inclination i;

L_a is the line of apsides



Pro-grade and Retrograde Orbits

Orbital Elements

A set of mathematical parameters that enables us to accurately describe satellite motion is called the orbital elements.

- Discriminate one satellite from other satellites

- Predict where a satellite will be in the future or has been in the past
- Determine amount and direction of maneuver or perturbation

The Six Keplerian Elements

Size/Period	• Size is how big or small your satellite's orbit is…. • Defined by semi-major axis "a"
Shape (Circular or Ellipse)	Orbit shapes are either circular or not circular: some sort of an Ellipse
Inclination	Inclination is the *tilt* of your orbit • At 0 degrees of inclination, you are orbiting the equator • At 90 degrees of inclination, you are in a polar orbit
Right Ascension	• Right Ascension is the *swivel* of your tilt, as measured from a fixed point in space, called the First Point of Aries • Right Ascension will determine where your satellite will cross the Equator on the ascending pass • It is measured in degrees
Argument of Perigee	• Argument of Perigee is a measurement from a fixed point in space to where perigee occurs in the orbit • It is measured in degrees
True Anomaly	• True Anomaly is a measurement from a fixed point in space to the actual satellite location in the orbit • It is measured in degrees

Apogee and Perigee Heights

- the length of the radius vectors at apogee and perigee can be obtained from the geometry of the ellipse
- In order to find the apogee and perigee heights, the radius of the earth must be subtracted from the radii lengths,

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

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

The Apogee height, $h_a = r_a - R$ and

The perigee height, $h_p = r_p - R$

Orbit Perturbations

The keplerian orbit described so far is ideal in the sense that it assumes that the earth is a uniform spherical mass and that the only force acting is the centrifugal force resulting from satellite motions balancing the gravitational pull of the earth. In practice, other forces which can be significant are the gravitational forces of the sun and the moon and atmospheric drag. The gravitational pulls of sun and moon have negligible effect on low orbiting satellites. Atmospheric drag on the other hand, has negligible effect on geostationary satellites but does affect low orbiting earth satellites below about 1000km.

Effects of a non-spherical earth

- For a spherical earth of uniform mass, Kepler's third law gives the nominal mean motion n_0 as

$$n_0 = \sqrt{\frac{\mu}{a^3}}$$

- The 0 subscript is included as a reminder that this result applies for a perfectly spherical earth of uniform mass.
- However not practically,

$$n = n_0 \left[\frac{1 + K_1 (1 - 1.5 \sin^2 i)}{a^2 (1 - e^2)^{1.5}} \right]$$

- K_1 is a constant which evaluates to 66,063.1704 km^2.
- The earth's oblateness has negligible effect on the semi major axis *a*,
- If *a* is known, the mean motion is readily calculated.
- The orbital period taking into account the earth's oblateness is termed the *anomalistic period*
- The anomalistic period is

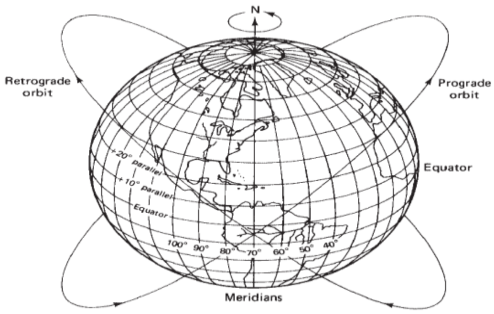
$$P_A = \frac{2\pi}{n} \text{ sec}$$

- where *n* is in radians per second.
- If the known quantity is *n* one can solve the above Equation for *a*, keeping in mind that n_0 is also a function of *a*.
- The above equation may be solved for *a* by finding the root of the following equation:

$$n - \sqrt{\frac{\mu}{a^3}}\left[1 + \frac{K_1(1 - 1.5\sin^2 i)}{a^2(1 - e^2)^{1.5}}\right] = 0$$

- The oblateness of the earth also produces two rotations of the orbital plane.

- *regression of the nodes,*
- where the nodes appear to slide along the equator.
- In effect, the line of nodes, which is in the equatorial plane, rotates about the center of the earth.
- Thus, the right ascension of the ascending node shifts its position.
- If the orbit is prograde the nodes slide westward,
- if retrograde, they slide eastward.
- As seen from the ascending node, a satellite in prograde orbit moves eastward, and in a retrograde orbit, westward.
- The nodes therefore move in a direction opposite to the direction of satellite motion, hence the term *regression of the nodes.*
- For a polar orbit (i = 90°), the regression is zero.



Prograde and retrograde orbits.

Atmospheric Drag

- For satellites below 1000 km, the effects of atmospheric drag are significant.
- Because the drag is greatest at the perigee,
- The drag acts to reduce the velocity at this point, resulting the satellite not to reach the same apogee height on successive revolutions.
- As a result, the semi major axis and the eccentricity are both reduced.
- Drag does not noticeably change the other orbital parameters, including perigee height.

- An approximate expression for the change of major axis is

$$a \cong a_0 \left[\frac{n_0}{n_0 + n_0' (t - t_0)} \right]^{2/3}$$

- The mean anomaly is also changed.
- An approximate expression for the amount by which it changes is

$$\delta M = \frac{n_0'}{2} (t - t_0)^2$$

Inclined Orbits

- A satellite in an inclined elliptical orbit is complicated by the fact that different parameters relate to different reference frames. Determination of the look angles and range involves the following quantities and concepts:
  - The *orbital elements,*
  - Various measures of *time*
  - The *perifocal coordinate system,* which is based on the orbital plane
  - The *geocentric-equatorial coordinate system,* which is based on the earth's equatorial plane
  - The *topo centric-horizon coordinate system,* which is based on the observer's horizon plane

The two major coordinate transformations which are needed are as follows:

- The satellite position measured in the perifocal system is transformed
  - to the geocentric-horizon system in which the earth's rotation is measured, thus enabling the satellite position and the earth station location to be coordinated.
- The satellite-to-earth station position vector is transformed
  - to the topo centric-horizon system, which enables the look angles and range to be calculated.

Sub satellite Point

Sub satellite Point is the point at which a line between the satellite and the center of the Earth intersects the Earth's surface. The location of the point is expressed in terms of latitude and longitude. If one is in the U.S it is common to use -

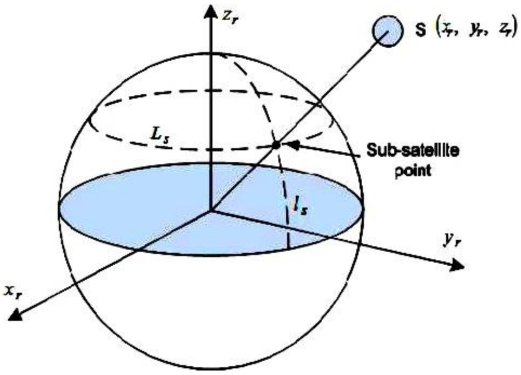
- Latitude – degrees north from equator

- Longitude – degrees west of the Greenwich meridian

The Location of the sub satellite point may be calculated from coordinates of the rotating system as:

$$L_s = \frac{\pi}{2} - \cos^{-1}\left(\frac{z_r}{\sqrt{x_r^2 + y_r^2 + z_r^2}} \right)$$

Sub satellite Point



<u>UNIT-II</u>

SPACE SEGMENT AND SATELLITE LINK DESIGN

A Satellite in a geostationary orbit appears to be stationary with respect to the earth, hence the name geostationary. Three conditions are required for an orbit to be geostationary:

- The satellite must travel eastward at the same rotational speed as the earth.
- The orbit must be circular.
- The inclination of the orbit must be zero.

Geo stationary and Non Geo-stationary orbits

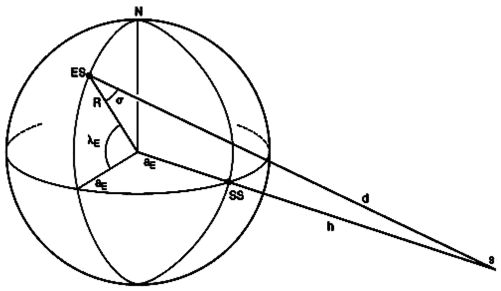
Geo stationary Orbit

A **geostationary** orbit is one in which a satellite orbits the earth at exactly the same speed as the earth turns and at the same latitude, specifically zero, the latitude of the equator. A satellite orbiting in a geostationary orbit appears to be hovering in the same spot in the sky, and is directly over the same patch of ground at all times.

A **geosynchronous** orbit is one in which the satellite is synchronized with the earth's rotation, but the orbit is tilted with respect to the plane of the equator. A satellite in a geosynchronous orbit will wander up and down in latitude, although it will stay over the same line of longitude. A geostationary orbit is a subset of all possible geosynchronous orbits.

<u>Antenna Look Angle</u>

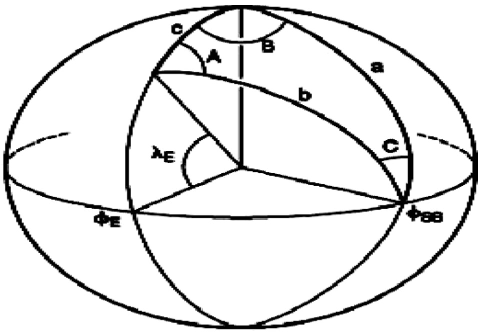
The look angles for the ground station antenna are Azimuth and Elevation angles. They are required at the antenna so that it points directly at the satellite. Look angles are calculated by considering the elliptical orbit. These angles change in order to track the satellite. For geostationary orbit, these angle values do not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications.



Geometry used in determining the look angles for Geostationary Satellites

- ➢ **<u>Azimuth</u>:** Measured eastward (clockwise) from geographic north to the projection of the satellite path on a (locally) horizontal plane at the earth station.
- ➢ **<u>Elevation Angle</u>:** Measured upward from the local horizontal plane at the earth station to the satellite path.

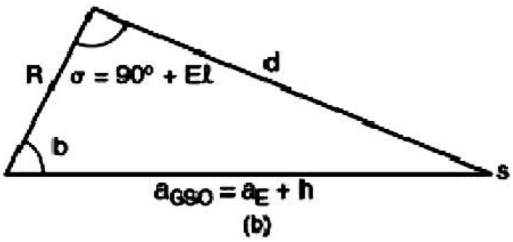
For home antennas, antenna beam-width is quite broad and hence no tracking is essential. This leads to a fixed position for these antennas.



Spherical Geometry

With respect to the above figures the following information is needed to determine the look angles of geostationary orbit.

- Earth Station Latitude: λ_E
- Earth Station Longitude: Φ_E
- Sub-Satellite Point's Longitude: Φ_{SS}
- ES: Position of Earth Station
- SS: Sub-Satellite Point
- S: Satellite
- d: Range from ES to S
- ζ: angle to be determined



Plane triangle

Considering above Figure it's a spherical triangle. All sides are the arcs of a great circle. Three sides of this triangle are defined by the angles subtended by the Centre of the earth.

- Side a: angle between North Pole and radius of the sub-satellite point.
- Side b: angle between radius of Earth and radius of the sub-satellite point.

- Side c: angle between radius of Earth and the North Pole.
- a $=90^0$ and such a spherical triangle is called quadrantal triangle. c = $90^0 - \lambda$
- Angle B is the angle between the plane containing c and the plane containing a.

Thus, B = ΦE-ΦSS

- Angle A is the angle between the plane containing b and the plane containing c.
- Angle C is the angle between the plane containing a and the plane containing b.

Thus, a = 90^0 c = $90^0 - \lambda_E$

B = ΦE-ΦSS

Thus, b = arcos (cos B cos λ_E)

And A = arcsin (sin |B| / sin b)

Applying the cosine rule for plane triangle to the triangle

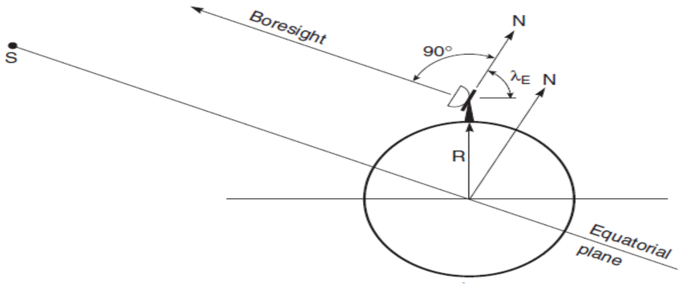
$$d = \sqrt{R^2 + a_{GSO}^2 - 2Ra_{GSO}\cos b}$$

Applying the sine rule for plane triangles to the triangle of Figure, allows the angle of elevation to be found:

$$El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right)$$

POLAR MOUNT ANTENNAS

- These antennas are pointing accurately only for one satellite.
- They have a single actuator which moves the antenna in a circular arc. Generally, some pointing error is seen in these antennas.
- The dish of this antenna is mounted on an axis termed as polar axis such that the antenna bore sight is normal to this axis.

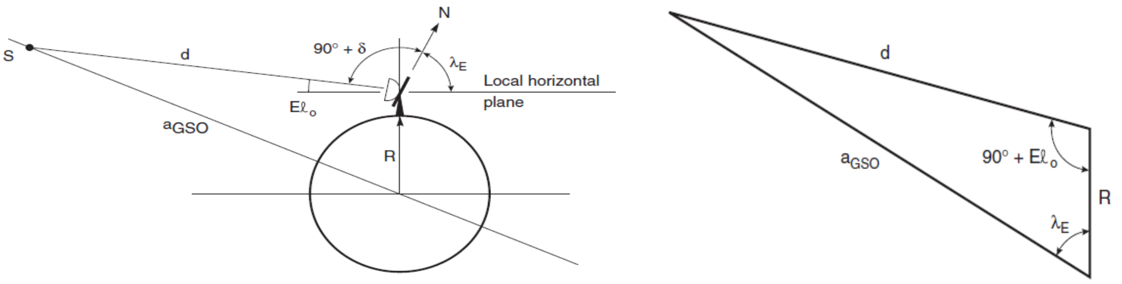


- The angle between polar mount and the local horizontal plane is set equal to the earth station latitude λE, making bore sight lie parallel to the equatorial plane.

- Now the axis is tilted at an angle δ, which is relative to the polar mount until the bore sight is pointing at a satellite position.

$$\delta = 90^o - El_0 - \lambda_E$$

- where El_0 is the angle of elevation required for the satellite position



Thus,

$$\cos El_0 = \frac{a_{GSO}}{d} \sin \lambda_E$$

$$\delta = 90^\circ - \arccos\left(\frac{a_{GSO}}{d} \sin \lambda_E\right) - \lambda_E$$

Limits of Visibility

- There are a number of perturbing forces that cause an orbit to depart from the ideal keplerian orbit.
- The period for a geostationary satellite is 23 h, 56 min, 4 s, or 86,164 s.
- The reciprocal of this is 1.00273896 rev/day,
- The east and west limits of geostationary are visible from any given Earth station.
- These limits are set by the geographic coordinates of the Earth station and antenna elevation.
- The lowest elevation is zero (in theory) but in practice, to avoid reception of excess noise from Earth some finite minimum value of elevation is issued.
- The earth station can see a satellite over a geostationary arc bounded by **+/- (81.3^0)** about the earth station's longitude.

NEAR GEOSTATIONARY ORBITS

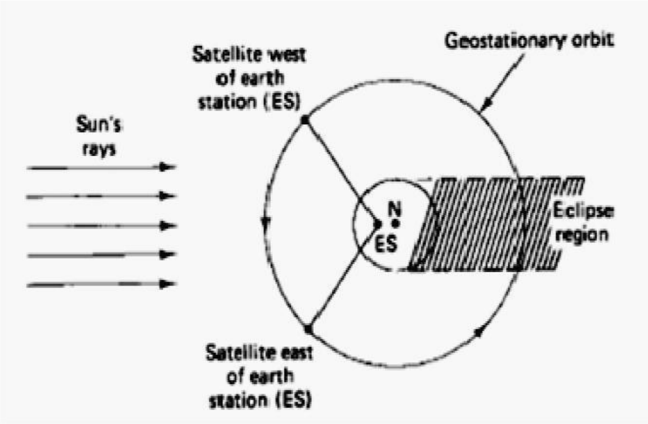
- There are a number of perturbing forces that cause an orbit to depart from ideal Keplerian orbit.
- The most effecting ones are
  - ✓ gravitational fields of sun and moon,
  - ✓ non-spherical shape of the Earth,

- ✓ reaction of the satellite itself to motor movements within the satellites.

- Thus the earth station keeps maneuvering the satellite to maintain its position within a set of nominal geostationary coordinates.
- Thus the exact GEO is not attainable in practice and the orbital parameters vary with time.
- Hence these satellites are called "**Geosynchronous**" satellites or "**Near-Geostationary satellites**".

EARTH ECLIPSE OF A SATELLITE

- If the earth's equatorial plane coincided with the plane of the earth's orbit around the sun geostationary satellites would be eclipsed by the earth once each day.
- The equatorial plane is tilted at an angle of 23.4° to the ecliptic plane, and this keeps the satellite in full view of the sun for most days of the year
- Around the spring and autumnal equinoxes, when the sun is crossing the equator, the satellite does pass into the earth's shadow at certain periods**.**
- Eclipses begin 23 days before equinox and end 23 days after equinox.
- The eclipse lasts about 10 min at the beginning and end of the eclipse period and increases to a maximum duration of about 72 min at full eclipse.
- The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries.
- The eclipse will happen at night but for satellites in the east it will happen late evening local time. For satellites in the west eclipse will happen in the early morning hour's local time.

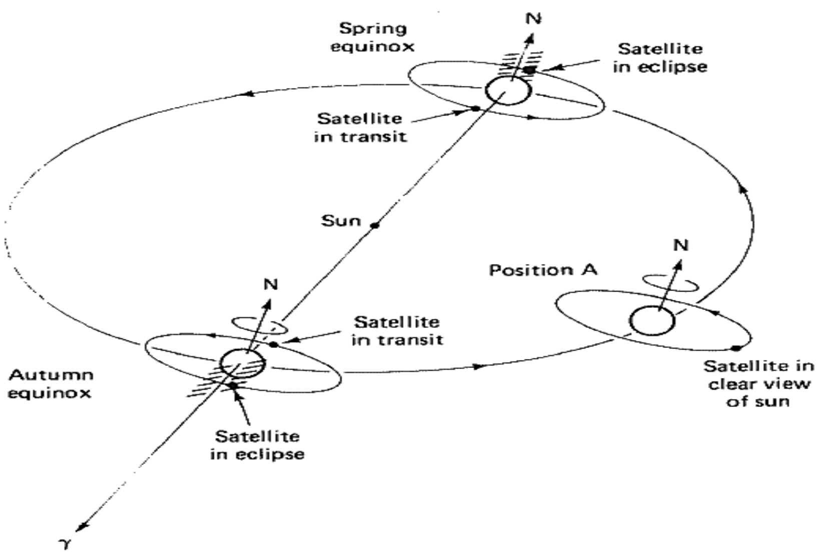


A satellite east of the earth station enters eclipse during daylight busy hours at the earth station. A Satellite west of earth station enters eclipse during night hours

- An earth caused eclipse will normally not happen during peak viewing hours if the satellite is located near the longitude of the coverage area. Modern satellites are well equipped with batteries for operation during eclipse.

Sun Transit Outage

- Transit of the satellite between earth and sun
- The sun comes within the beam width of the earth station antenna.
- When this happens, the sun appears as an extremely noisy source which completely blanks out the signal from the satellite.
- An increase in the error rate, or total destruction of the signal.
- This effect is termed ***sun transit outage***, and it lasts for short periods
- The occurrence and duration of the sun transit outage depends on the latitude of the earth station, a maximum outage time of 10 min.
- Sun outages occur in February, March, September and October, that is, around the time of the equinoxes.
- As the sun radiates strongly at the microwave frequencies used to communicate with satellites (C-band, Ka band and Ku band) the sun swamps the signal from the satellite.

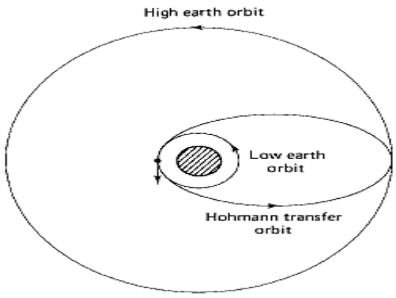


Earth Eclipse of a Satellite and Sun transit Outage

Launching Orbits

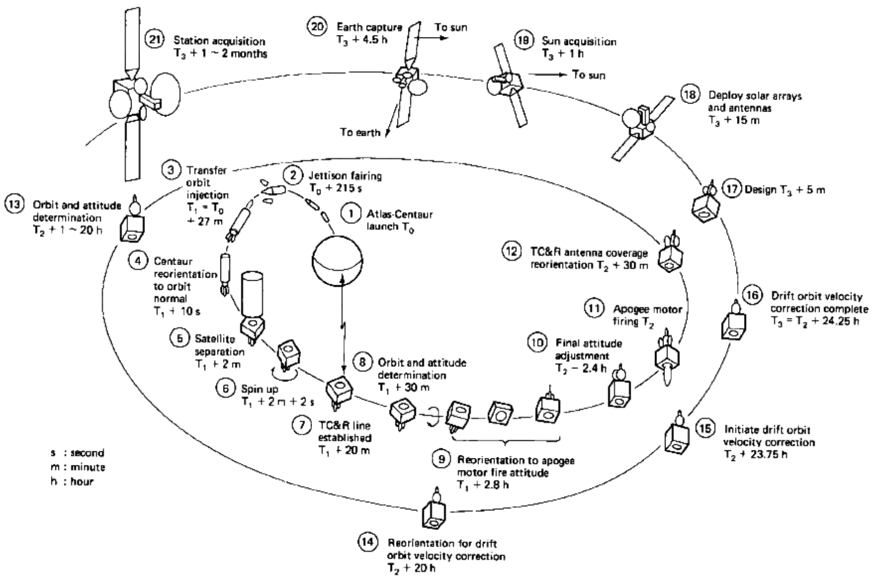
- Low Earth Orbiting satellites are directly injected into their orbits.
- This cannot be done in case of GEOs as they have to be positioned 36,000 kms above the Earth's surface.
- Launch vehicles are hence used to set these satellites in their orbits. These vehicles are reusable.
- They are also known as "Space Transportation System" (STS).

- When the orbital altitude is greater than 1,200 km it becomes expensive to directly inject the satellite in its orbit.
- For this purpose, a satellite must be placed in to a transfer orbit between the initial lower orbit and destination orbit.
- The transfer orbit is commonly known as "Hohmann-Transfer Orbit"



Hohmann-Transfer Orbit

- The transfer orbit is selected to minimize the energy required for the transfer.
- This orbit forms a tangent to the low attitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee.
- The rocket injects the satellite with the required thrust into the transfer orbit.
- With the STS, the satellite carries a perigee kick motor which imparts the required thrust to inject the satellite in its transfer orbit.
- Similarly, an apogee kick motor (AKM) is used to inject the satellite in its destination orbit.



Launching stages of a GEO

- Generally, it takes 1-2 months for the satellite to become fully functional. The Earth Station performs the Telemetry Tracking and Command (TTC) function to control the satellite transits and functionalities
- It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole.
- This extra speed at the equator means a rocket needs less thrust (and therefore less fuel) to launch into orbit.
- In addition, launching at the equator provides an additional 1,667 km/h of speed once the vehicle reaches orbit.
- This speed bonus means the vehicle needs less fuel, and that freed space can be used to carry more pay load.

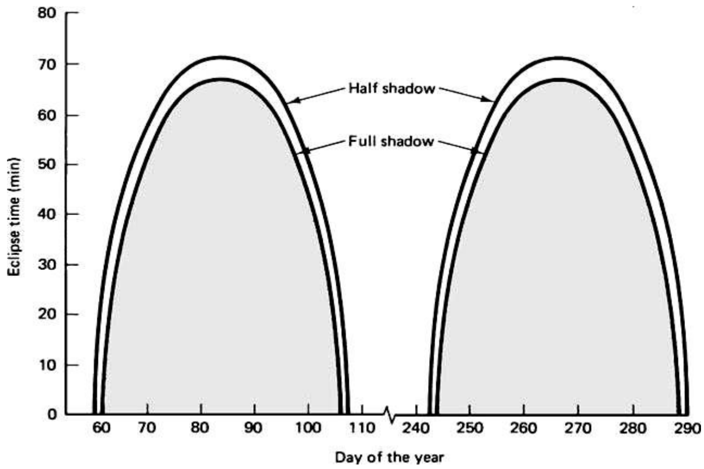
The Power Supply

The primary electrical power for operating the electronic equipment is obtained from solar cells. Individual cells can generate only small amounts of power and therefore, arrays of cells in series-parallel connection are required.

Figure shows the solar cell panels for the HS 376 satellite manufactured by Hughes Space and Communications Company.

In geostationary orbit the telescoped panel is fully extended so that both are exposed to sunlight. At the beginning of life, the panels produce 940 W dc power, which may drop to 760 W at the end of 10 years. During eclipse, power is provided by two nickel-cadmium (Ni-Cd) long-life batteries, which will deliver 830 W. At the end of life, battery recharge time is less than 16 h.

Satellite Eclipse time as a function of the current day of the year



In cylindrical and solar-sail satellites, the cross-over point is estimated to be about 2 kW, where the solar-sail type is more economical than the cylindrical type.

Attitude Control

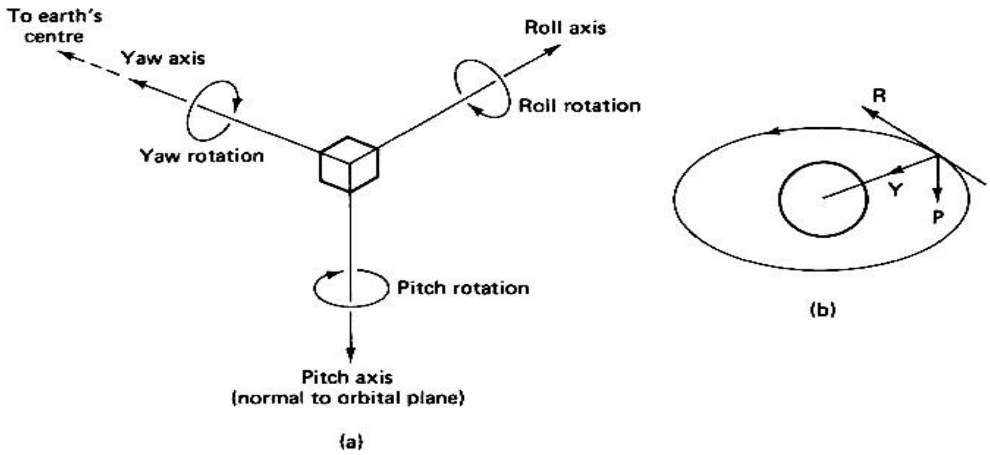
The *attitude* of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is meant for the purpose of controlling its attitude. Attitude control is necessary, to ensure that directional antennas point in the proper directions.

In the case of earth environmental satellites, the earth-sensing instruments must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as *disturbance torques*, can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts.

To exercise attitude control, there must be available some measure of a satellite's orientation in space and of any tendency for this to shift. In one method, infrared sensors, referred to as *horizon detectors*, areused to detect the rim of the earth against the background of space.

With the use of four such sensors, one for each quadrant, the center of the earth can be readily established as a reference point. The attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from earth, based on attitude data obtained from the satellite. Whenever a shift in attitude is desired, an *attitude maneuver* is executed. The control signals needed to achieve this maneuver may be transmitted from an earth station.

Controlling torques may be generated in a number of ways. *Passive attitude control* refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite's energy supplies; at most, infrequent use is made of these supplies, for example, when thruster jets are impulsed to provide corrective torque. Examples of passive attitude control are *spin stabilization* and *gravity gradient stabilization*.



Roll, Pitch, and Yaw Axes (*b*) RPY axes for Geostationary Orbit

The other form of attitude control is *active control*. With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques. Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters.

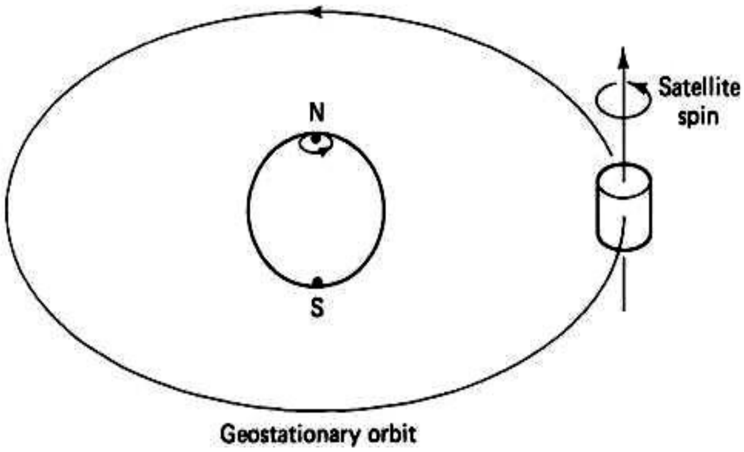
The three axes which define a satellite's attitude are its *roll, pitch*, and *yaw* (RPY) axes. These are shown relative to the earth in Figure. All three axes pass through the center of gravity of the satellite. For an equatorial orbit, movement of the satellite about the roll axis moves the antenna footprint north and south; movement about the pitch axis moves the footprint east and west; and movement about the yaw axis rotates the antenna footprint.

Spinning Satellite Stabilization

Spin stabilization may be achieved with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis. For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth, as illustrated in Figure 2.4. Spin rate is typically in the range of 50 to 100 rev/minute. Spin is initiated during the launch phase by means of small gas jets.

In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torques are generated in a number of ways, both external and internal to the satellite.

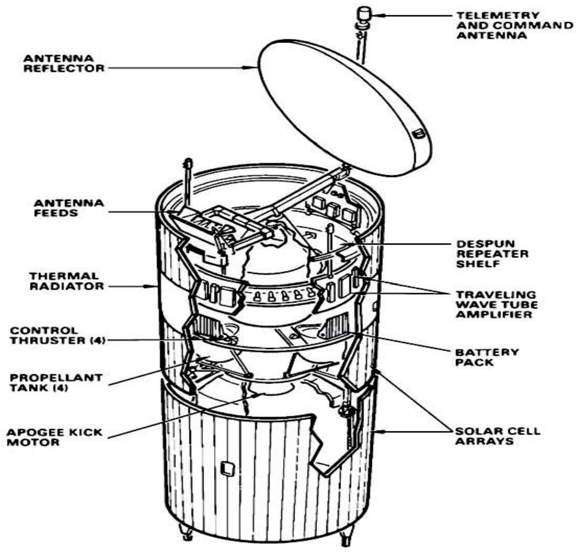
Solar radiation, gravitational gradients, and meteorite impacts are all examples of external forces which can give rise to disturbance torques. Motor-bearing friction and the movement of satellite elements such as the antennas also can give rise to disturbance torques.



Spin stabilization in the geostationary orbit

Nutation, which is a form of wobbling, can occur as a result of the disturbance torques and/or from misalignment or unbalance of the control jets. This nutation must be damped out by means of energy absorbers known as *nutation dampers*. The antenna feeds can be connected directly to the transponders without the need for radiofrequency rotary joints, while the complete platform is despun. Of course, control signals and power must be transferred to the despun section and a mechanical bearing must be provided. The complete assembly for this is known as the *bearing and power transfer assembly* (BAPTA). Figure shows a photograph of the internal structure of the HS 376.

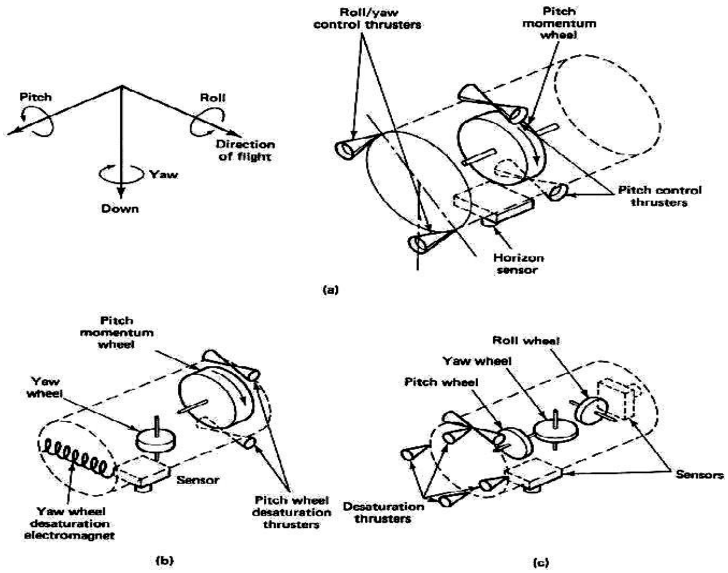
Certain dual-spin spacecraft obtain spin stabilization from a spinning fly- wheel rather than by spinning the satellite itself. These flywheels are termed *momentum wheels*, and their average momentum is referred to as *momentum bias.*



HS 376 Spacecraft

Momentum wheel stabilization

In the previous section the gyroscopic effect of a spinning satellite is shown to provide stability for the satellite attitude. Stability also can be achieved by utilizing the gyroscopic effect of a spinning flywheel, and this approach is used in satellites with cube-like bodies and the INTELSAT V type satellites. These are known as *body-stabilized* satellites. The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic control circuitry. The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action.



Alternative momentum wheel stabilization systems: (*a*) one-wheel, (*b*) two- wheel, (*c*) three- wheel

The stator of the motor is attached to the body of the satellite. Thus the motor provides the coupling between the flywheel and the satellite structure. Speed and torque control of the motor is exercised through the currents fed to the stator.

When a momentum wheel is operated with zero momentum bias, it is generally referred to as a *reaction wheel*. Random and cyclic disturbance torques tends to produce zero momentum on average. However, there will always be some disturbance torques that causes a cumulative increase in wheel momentum, and eventually at some point the wheel *saturates*. Mass expulsion devices are then used to unload the wheel, remove momentum from it. The operation of the mass expulsion devices consumes part of the satellite's fuel supply.

Station Keeping

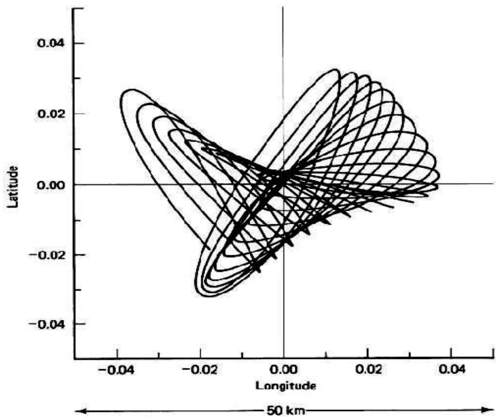
In addition to having its attitude controlled, it is important that a geo- stationary satellite be kept in its correct orbital slot. The equatorial ellipticity of the earth causes geostationary satellites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W. To counter this drift, an oppositely directed velocity component is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks. These maneuvers are called as *east-west station-keeping maneuvers*.

A satellite which is nominally geostationary also will drift in latitude, the main perturbing forces being the gravitational pull o the sun and the moon. These forces cause the inclination to change at a rate of about in the inclination, going from o° to 14.67° in 26.6 years and back to zero, at which the cycle is repeated.

To prevent the shift in inclination from exceeding specified limits, jets may be pulsed at the appropriate time to return the inclination to zero. Counteracting jets must be pulsed when the inclination is at zero to halt the change in inclination.

These maneuvers are termed north-south station keeping maneuvers, and they are much more expensive in fuel than are east-west station keeping maneuvers.

Satellites in the 6/4-GHz band must be kept within 0.1° of the designated longitude and in the 14/12-GHz band, within 0.05°.



Typical Satellite Motion

Thermal Control

Satellites are subject to large thermal gradients, receiving the sun's radiation on one side while the other side faces into space. In addition, thermal radiation from the earth and the earth's *albedo*, which is the fraction of the radiation falling on earth which is reflected, can be significant for low-altitude earth-orbiting satellites, although it is negligible for geostationary satellites.

Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from the communications payload.

The mirrored thermal radiator for the Hughes HS 376 satellite can be seen in Figure 2.5. These mirrored drums surround the communications equipment shelves in each case and provide good radiation paths for the generated heat to escape into the surrounding space.

One advantage of spinning satellites compared with body-stabilized is that the spinning body provides an averaging of the temperature extremes experienced from solar flux and the cold back-ground of deep space. In order to maintain constant temperature conditions, heaters may be switched on to make up for the heat reduction which occurs when transponders are switched off. The INTELSAT VI satellite heaters are used to maintain propulsion thrusters and line temperatures.

Telemetry, Tracking and Command Subsystem (TTC)

The TT&C subsystem performs several routine functions aboard the spacecraft. The telemetry function could be interpreted as *measurement at a distance*. 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 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 etc. and spacecraft information such as temperatures, power supply voltages, and stored-fuel pressure.

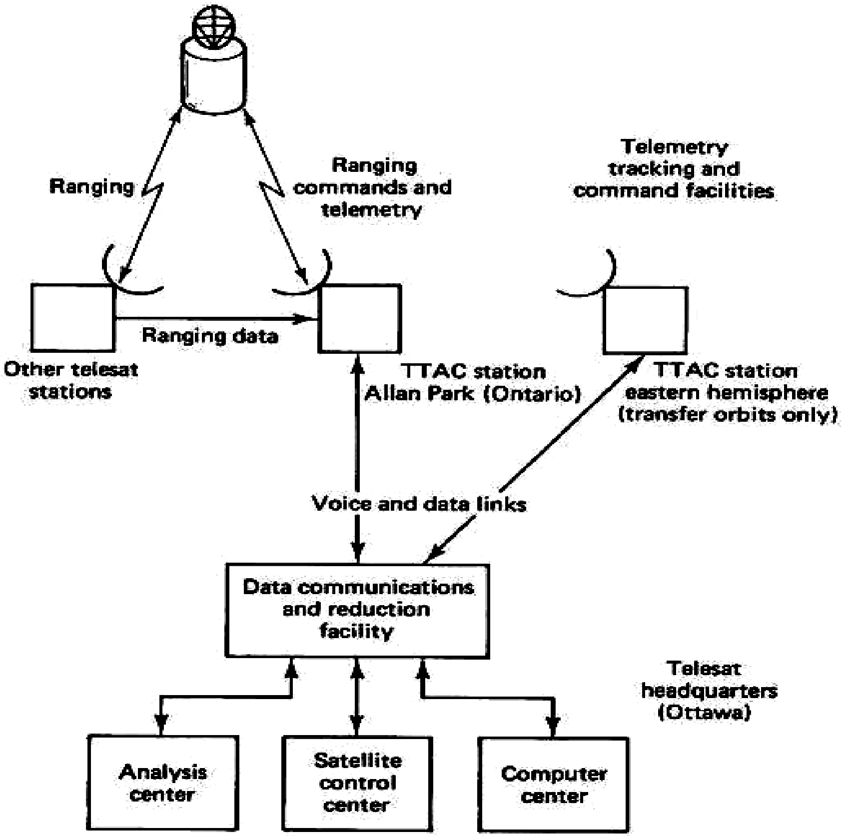
The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command signals from the earth station, often in response to telemetered information. The command subsystem demodulates and decodes the command signals and routes these to the 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 important to prevent unauthorized commands from being received and decoded, and 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 geo-stationary satellite will tend to be shifted as a result of the various disturbing forces. Therefore, it is necessary to be able to track the satellite's movement and send correction signals as required.

Transponders

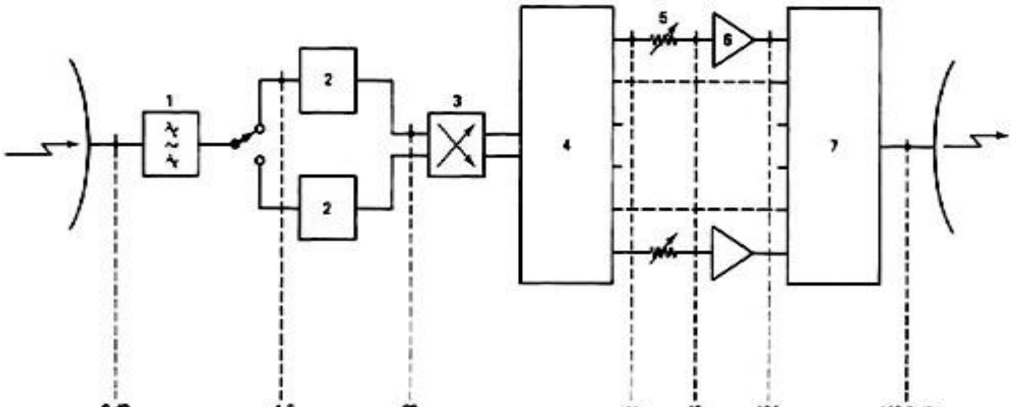
A transponder is the series of interconnected units which forms a single communications channel between the receive and transmit antennas in a communications satellite. Some of the units utilized by a transponder in a given channel may be common to a number of transponders. Thus, although reference may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

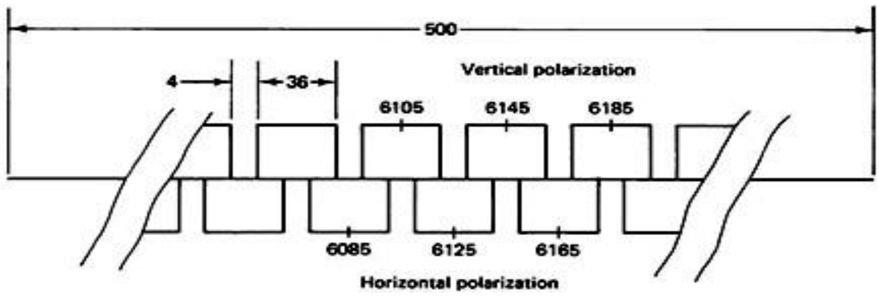
Before describing in detail the various units of a transponder, the overall frequency arrangement of a typical C-band communications satellite will be examined briefly. The bandwidth allocated for C-band service is 500 MHz, and this is divided into sub-bands, one transponder.



Satellite Control System

By making use of *polarization isolation*, this number can be doubled. Polarization isolation refers 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 reuse*. Figure 2.8 shows part of the frequency and polarization plan for a C-band communications satellite.





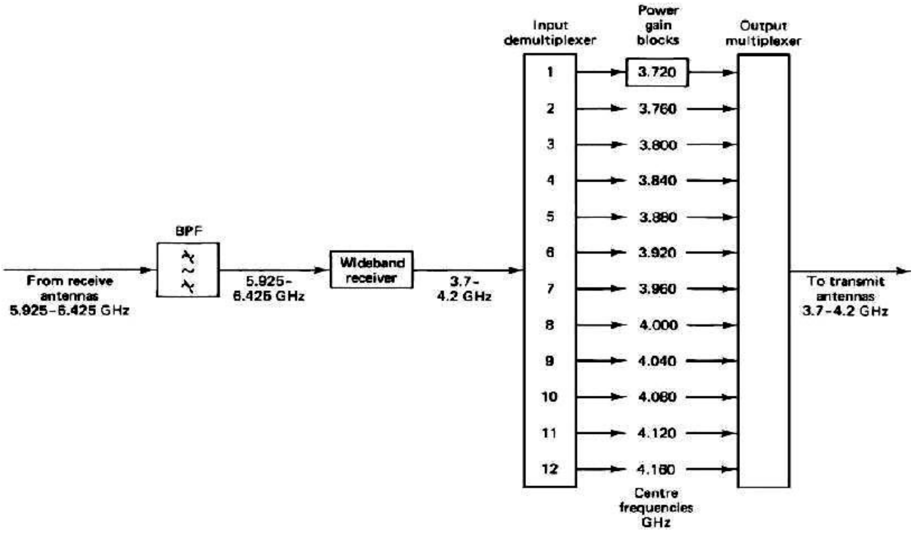
Section of an Uplink Frequency and Polarization Plan

Frequency reuse also may be achieved with spot-beam antennas, and these may be combined with polarization reuse to provide an effective bandwidth of 2000 MHz from the actual bandwidth of 500 MHz. For one of the polarization groups, Figure shows the channeling scheme for the 12 transponders in more detail. The incoming, or uplink, frequency range is 5.925 to 6.425 GHz. The frequency conversion shifts the carriers to the downlink frequency band, which is also 500 MHz wide, extending from 3.7 to 4.2 GHz. At this point the signals are channelized into frequency bands which represent the individual transponder bandwidths.

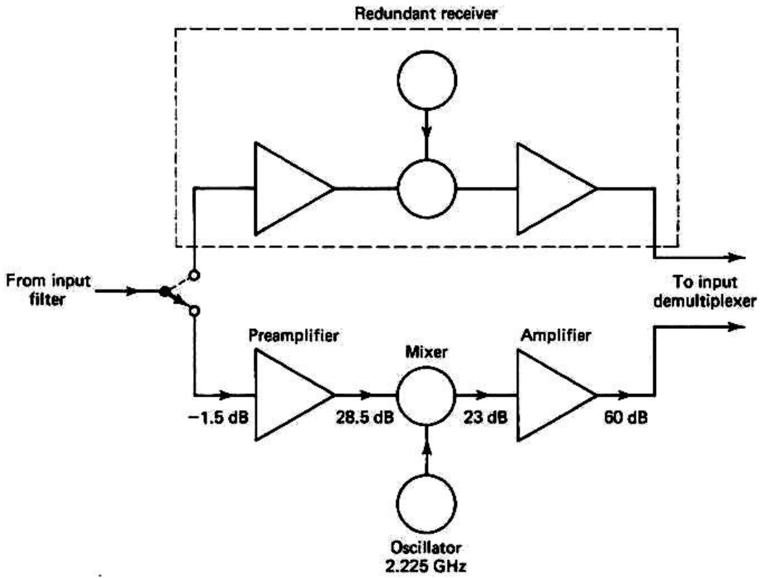
The wideband receiver

The wideband receiver is shown in more detail in Figure. A duplicate receiver is provided so that if one fails, the other is automatically switched in. The combination is referred to as a *redundant receiver*, meaning that although two are provided, only one is in use at a given time.

The first stage in the receiver is a *low-noise amplifier* (LNA). This amplifier adds little noise to the carrier being amplified, and at the same time it provides sufficient amplification for the carrier to override the higher noise level present in the following mixer stage.



Satellite Transponder Channels



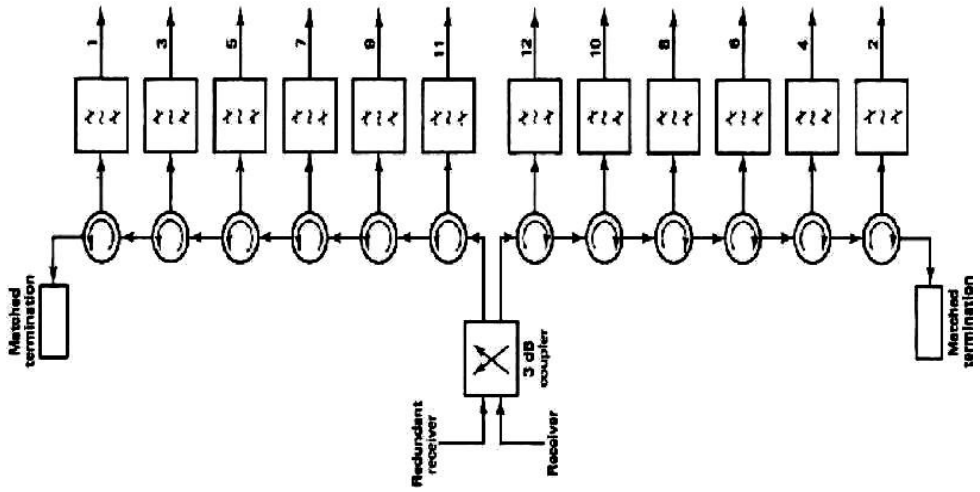
Satellite Wideband Receiver

It is more convenient to refer all noise levels to the LNA input, where the total receiver noise may be expressed in terms of an equivalent noise temperature. In a well-designed receiver, the equivalent noise temperature referred to the LNA input is basically that of the LNA alone. The overall noise temperature must take into account the noise added from the antenna. The equivalent noise temperature of a satellite receiver may be on the order of a few hundred kelvins.

The LNA feeds into a mixer stage, which also requires a *local oscillator* (LO) signal for the frequency-conversion process. With advances in *field-effect transistor* (FET) technology, FET amplifiers, which offer equal or better performance, are now available for both bands. Diode mixer stages are used. The amplifier following the mixer may utilize *bipolar junction transistors* (BJTs) at 4 GHz and FETs at 12 GHz, or FETs may in fact be used in both bands.

The input de-multiplexer

The input de-multiplexer separates the broadband input, covering the frequency range 3.7 to 4.2 GHz, into the transponder frequency channels. This provides greater frequency separation between adjacent channels in a group, which reduces adjacent channel interference. The output from the receiver is fed to a power splitter, which in turn feeds the two separate chains of circulators.



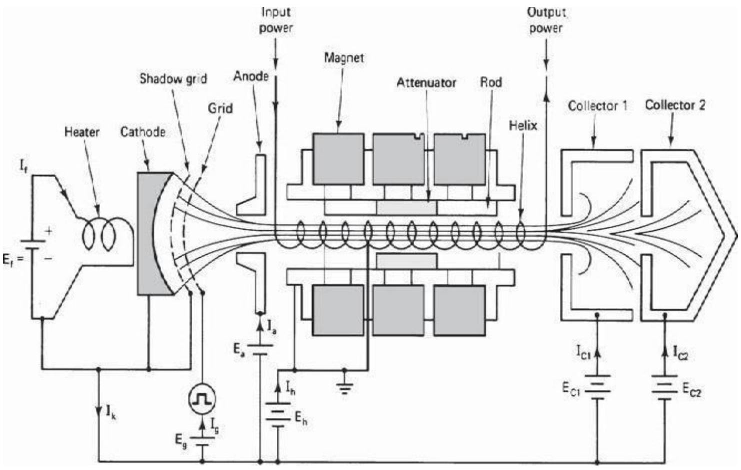
Satellite Input Multiplexer

The full broadband signal is transmitted along each chain, and the channelizing is achieved by means of channel filters connected to each circulator. Each filter has a bandwidth of 36 MHz and is tuned to the appropriate center frequency, as shown in Fig. 2.11. Although there are considerable losses in the demultiplexer, these are easily made up in the overall gain for the transponder channels.

The power amplifier

The fixed attenuation is needed to balance out variations in the input attenuation so that each transponder channel has the same nominal attenuation, the necessary adjustments being made during assembly. The variable attenuation is needed to set the level as required for different types of service. Because this variable attenuator adjustment is an operational requirement, it must be under the control of the ground TT&C station.

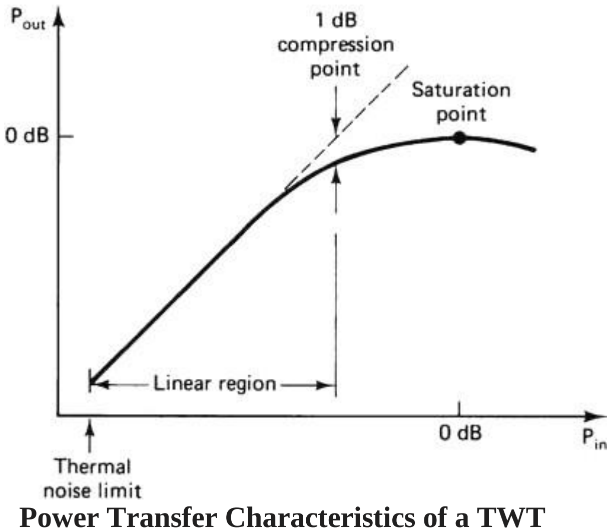
Traveling-wave tube amplifiers (TWTAs) are widely used in transponders to provide the final output power required to the transmit antenna. Figure shows the schematic of a *traveling wave tube* (TWT) and its power supplies. In the TWT, an electron-beam gun assembly consisting of a heater, a cathode, and focusing electrodes is used to form an electron beam. A magnetic field is required to confine the beam to travel along the inside of a wire helix.



Satellite TWTA

The magnetic field can be provided by means of a solenoid and dc power supply. The comparatively large size and high power consumption of solenoids make them unsuitable for use aboard satellites and lower-power TWTs are used which employ permanent-magnet focusing. The wave will travel around the helical path at close to the speed of light, but it is the axial component of wave velocity which interacts with the electron beam.

This component is less than the velocity of light approximately in the ratio of helix pitch to circumference. Because of this effective reduction in phase velocity, the helix is referred to as a *slow wave structure*. The advantage of the TWT over other types of tube amplifiers is that it can provide amplification over a very wide bandwidth. Input levels to the TWT must be carefully controlled, however to minimize the effects of certain forms of distortion. The results from the nonlinear transfer characteristic of the TWT are illustrated in Figure

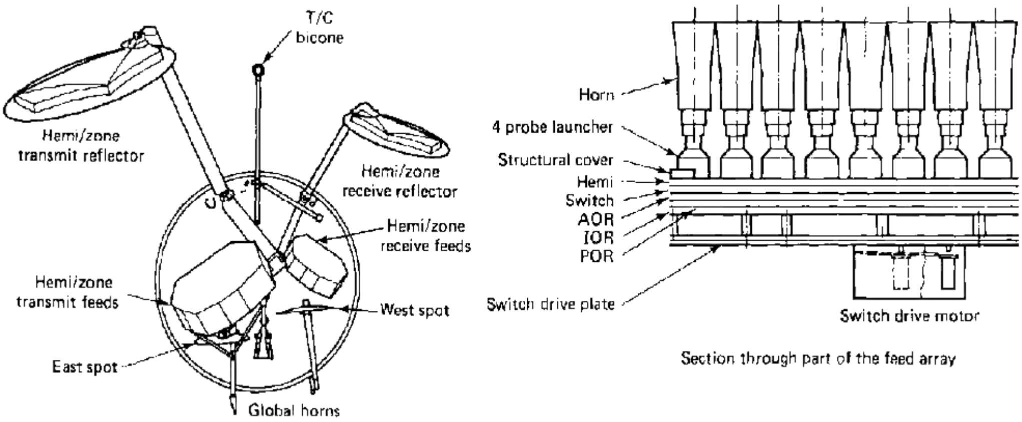


Power Transfer Characteristics of a TWT

At low-input powers, the output-input power relationship is linear. At higher power inputs, the output power saturates, the point of maximum power output being known as the *saturation point*. The saturation point is a very convenient reference point and input and output quantities are usually referred to it. The linear region of the TWT is defined as the region bound by the thermal noise limit at the low end and by what is termed the *1-dB compression point* at the upper end. This is the point where the actual transfer curve drops.

The antenna subsystems

- The antennas carried aboard a satellite provide the dual functions of receiving the uplink and transmitting the downlink signals.
- dipole-type antennas where omnidirectional characteristics are required
- Highly directional antennas required for telecommunications purposes and TV relay and broadcast.
- Directional beams are usually produced by means of reflector-type antennas,
- The paraboloidal reflector being the most common.
- Wide beams for global coverage are produced by simple horn antennas at 6/4 GHz.
- These horns beam the signal directly to the earth without the use of reflectors.



The antenna subsystem or the INTELSAT VI satellite

- Wide beams or global coverage are produced by simple horn antennas at6/4/ GHz. These horns beam the signal directly to the earth without the use of reflectors.
- A simple biconical dipole antenna is used for the tracking and control signals.
- The same feed horn may be used to transmit and receive carriers with the same polarization.
- The transmit and receive signals are separated in device known as a diplexer, and the separation is further aided by means of frequency filtering.
- Polarization discrimination also may be used to separate the transmit and receive signals using the same feed horn. For example, the horn may be used to transmit horizontally polarized waves in the downlink frequency band, while simultaneously receiving vertically polarize waves in the uplink frequency band.
- The polarization separation takes place in a device known as an ortho-coupler or orthogonal mode transducer (OMT)/ Separate horns also may be used for the transmit and receive functions, with both horns using the same reflector.

UNIT-III

EARTH SEGMENT

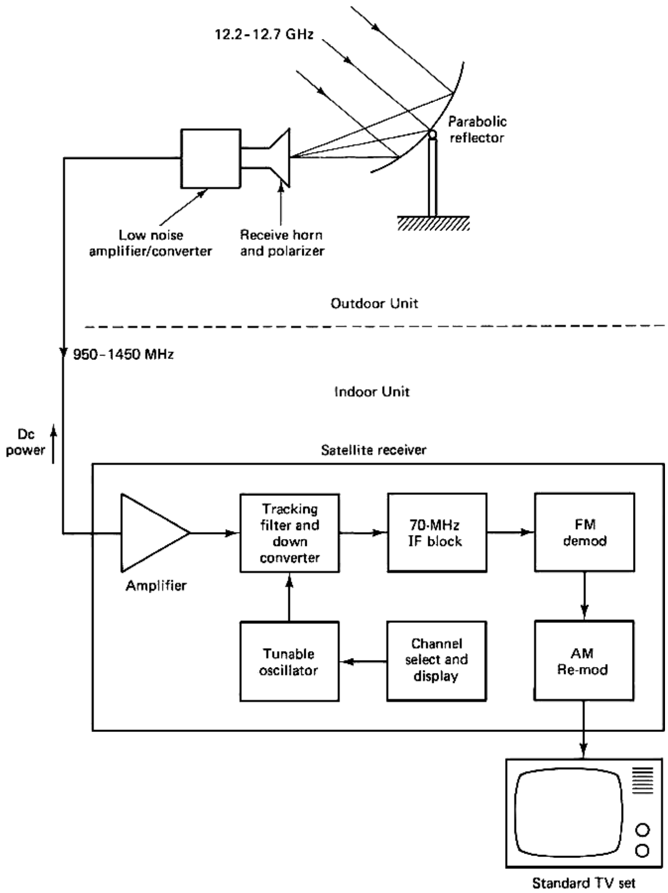
INTRODUCTION

The earth segment of a satellite communications system consists of transmit and receive earth stations. 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. Also included in the earth segment are those stations which are on ships at sea, and commercial and military land and aeronautical mobile stations.

RECEIVE-ONLY HOME TV SYSTEMS

Planned broadcasting directly to home TV receivers takes place in the Ku (12- GHz) band. This service is known as *direct broadcast satellite* (DBS) service. There is some variation in the frequency bands assigned to different geographic regions. In the Americas, for example, the down- link band is 12.2 to 12.7 GHz.

The comparatively large satellite receiving dishes [ranging in diameter from about 1.83 m (6 ft) to about 3-m (10 feet) in some locations], which may be seen in some "backyards" are used to receive downlink TV signals at C band (4 GHz).



Block diagram showing a home terminal for DBS TV/FM reception

Originally such downlink signals were never intended for home reception but for network relay to commercial TV outlets (VHF and UHF TV broadcast stations and cable TV "head-end" studios).

Equipment is now marketed for home reception of C-band signals, and some manufacturers provide dual C-band/Ku-band equipment. A single mesh type reflector may be used which focuses the signals into a dual feed- horn, which has two separate outputs, one for the C-band signals andone for the Ku-band signals.

Much of television programming originates as *first generation signals*, also known as *master broadcast quality signals*. These are transmitted via satellite in the C band to the network head- end stations, where they are retransmitted as compressed digital signals to cable and direct broadcast satellite providers.

- Another of the advantages, claimed for home C-band systems, is the larger number of satellites available for reception compared to available for direct broadcast satellite sys-terms.
- Although many of the C-band transmissions are scrambled, there are free channels that can be received, and what are termed "wild feeds."
- These are also free, but unannounced programs, of which details can be found in advance from various publications and Internet sources.
- C-band users can also subscribe to pay TV channels, and another advantage claimed is that subscription services are cheaper than DBS or cable because of the multiple- source programming available.
- The most widely advertised receiving system for C-band system appears to be 4DTV manufactured by Motorola.

This enables reception of:

- Free, analog signals and "wild feeds"
- Video Cipher II plus subscription services
- Free Digi-Cipher 2 services
- Subscription Digi-Cipher 2 services

The Outdoor Unit

This consists of a receiving antenna feeding directly into a low-noise amplifier/converter combination. A parabolic reflector is generally used, with the receiving horn mounted at the focus. A common design is to have the focus directly in front of the reflector, but for better interference rejection, an offset feed may be used as shown. Comparing the gain of a 3-m dish at 4 GHz with a 1-m dish at 12 GHz, the ratio *D*/*l* equals 40 in each case, so the gains will be about equal. Although the free- space losses are much higher at 12 GHz compared with 4 GHz.

The downlink frequency band of 12.2 to 12.7 GHz spans a range of 500 MHz, which accommodates 32 TV/FM channels, each of which is 24-MHz wide. Obviously, some overlap occurs between channels, but these are alternately polarized *left-hand circular* (LHC) and *right-hand circular* (RHC) or vertical/horizontal, to reduce interference to accept- able levels. This is referred to as *polarization interleaving*. A polarizer that may be switched to the desired polarization from the indoor control unit is required at the receiving horn.

The receiving horn feeds into a *low-noise converter* (LNC) or possibly a combination unit consisting of a *low-noise amplifier* (LNA) followed by a converter. The combination is referred to as an LNB, for *low-noise block*. The LNB provides gain for the broadband 12-GHz signal and then converts the signal to a lower frequency range so that a low-cost coaxial cable can be used as feeder to the indoor unit.

The indoor Unit for Analog (FM) TV

The signal fed to the indoor unit is normally a wideband signal covering the range 950 to 1450 MHz This is amplified and passed to a tracking filter which selects the desired channel, as shown in Fig. 4.3. As previously mentioned, polarization interleaving is used, and only half the 32 channels will be present at the input of the indoor unit for any one setting of the antenna polarizer. This eases the job of the tracking filter, since alternate channels are well separated in frequency.

The selected channel is again down converted, this time from the 950- to 1450- MHz range to a fixed intermediate frequency, usually 70 MHz although other values in the *very high frequency* (VHF) range are also used. The 70-MHz amplifier amplifies the signal up to the levels required for demodulation. A major difference between DBS TV and conventional TV is that with DBS, frequency modulation is used, whereas with conventional TV, amplitude modulation in the form of *vestigial single side- band* (VSSB) is used.

The 70-MHz, FM *intermediate frequency* (IF) carrier therefore must be demodulated, and the baseband information used to generate a VSSB signal which is fed into one of the VHF/UHF channels of a standard TV set.

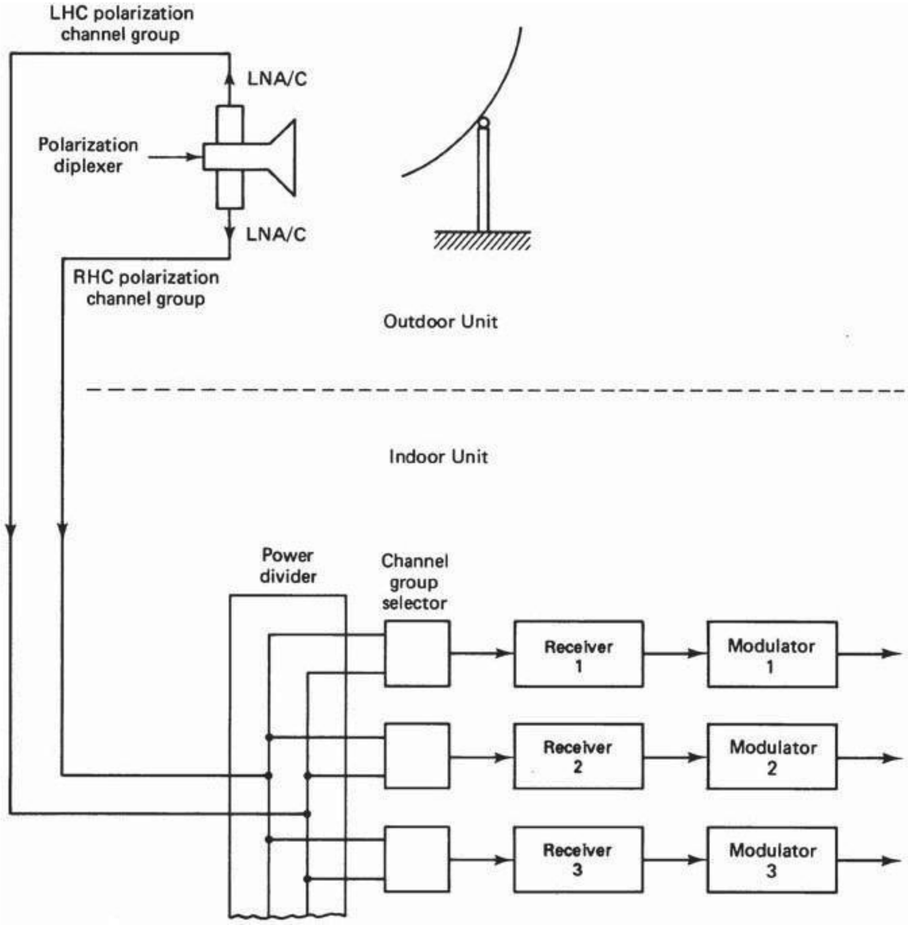
MASTER Antenna TV System

A *master antenna TV* (MATV) system is used to provide reception of DBS TV/FM channels to a small group of users, for example, to the tenants in an apartment building. It consists of a single outdoor unit (antenna and LNA/C) feeding a number of indoor units.

It is basically similar to the home system already described, but with each user having access to all the channels independently of the other users. The advantage is that only one outdoor unit is required, but as shown, separate LNA/Cs and feeder cables are required for each sense of polarization.

Compared with the single- user system, a larger antenna is also required (2- to 3-m diameter) in order to maintain a good signal-to-noise ratio at all the indoor units.

Where more than a few subscribers are involved, the distribution system used is similar to the *community antenna* (CATV) system described in the following section.



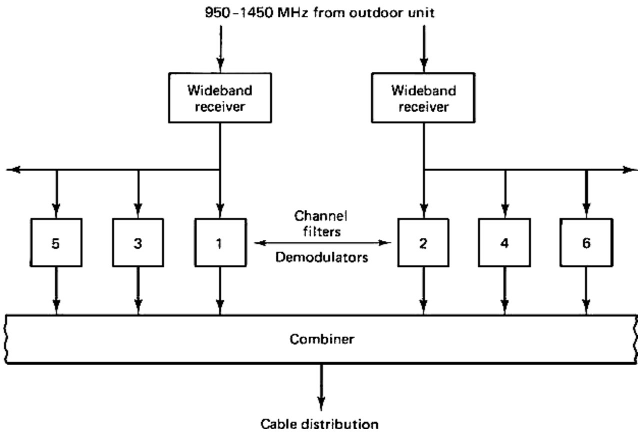
MATV System Block Diagrams

COMMUNITY ANTENNA TV SYSTEM

The CATV system employs a single outdoor unit, with separate feeds available for each sense of polarization, like the MATV system, so that all channels are made available simultaneously at the indoor receiver. Instead of having a separate receiver for each user, all the carriers are demodulated in a common receiver-filter system, as shown in Figure. The channels are then combined into a standard multiplexed signal for transmission over cable to the subscribers.

In remote areas where a cable distribution system may not be installed, the signal can be rebroadcast from a low-power VHF TV transmitter. Figure shows a remote TV station which employs an 8-m (26.2-ft) antenna for reception of the satellite TV signal in the C band.

With the CATV system, local programming material also may be distributed to subscribers, an option which is not permitted in the MATV system.



CATV System

TRANSMIT-RECEIVE EARTH STATIONS

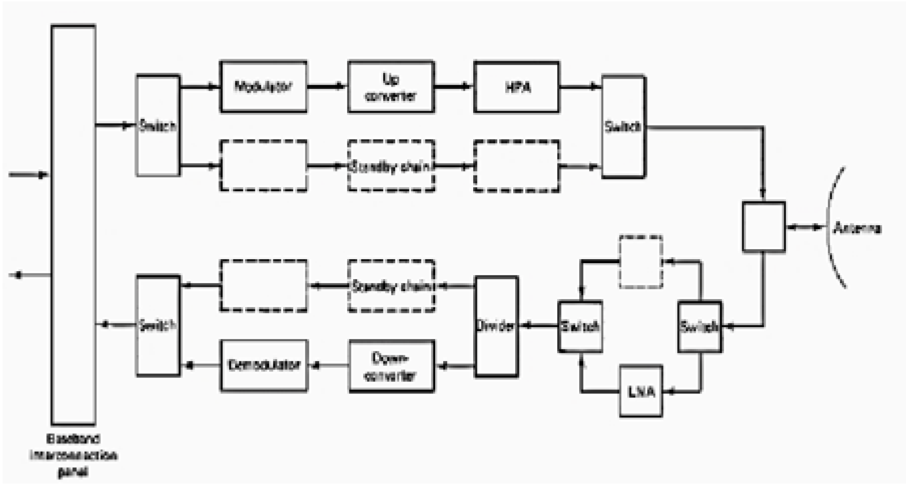
The block diagram of transmit receive earth station used for telephone traffic is shown in Fig. Starting at the bottom of the diagram, the first block shows the interconnection equipment required between satellite station and the terrestrial network. For the purpose of explanation, telephone traffic will be assumed. This may consist of a number of telephone channels in a multiplexed format. Multiplexing is a method of grouping telephone channels together, usually in basic groups of 12, without mutual interference

The groupings different from those used in the terrestrial network are required for satellite transmission, and the next block shows the multiplexing equipment in which the reformatting is carried out.

Following along the transmit chain, the multiplexed signal is modulated onto a carrier wave at an intermediate frequency, usually 70 MHz Parallel IF stages are required, one for each microwave carrier to be transmitted.

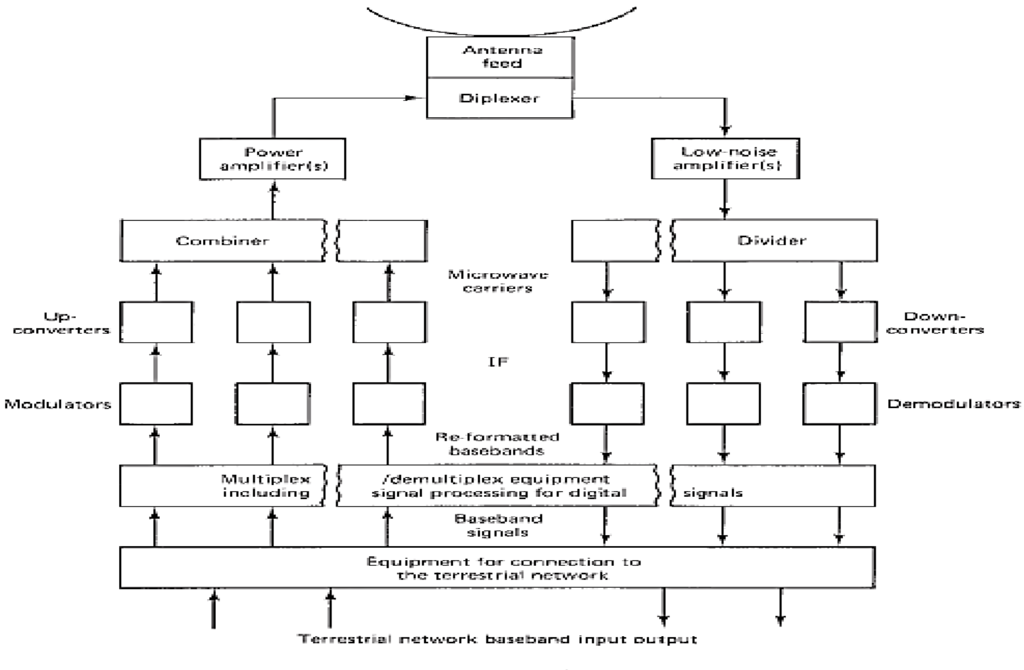
After amplification at the 70 MHz IF, the modulated signal is then up converted to the required microwave carrier frequency. A number of carriers may be transmitted simultaneously, and although these are at different frequencies they are generally specified by their nominal frequency, for example, as 6-GHz or 14-GHz carriers.

After passing through the up converters, the carriers are combined, and the resulting wideband signal is amplified. The wideband power signal is fed to the antenna through a diplexer, which allows the antenna to handle transmit and receive signals simultaneously.



Basic elements of a redundant earth station

The basic elements for a redundant earth station are shown in Figure. Redundancy means that certain units are duplicated. A duplicate, or redundant, unit is automatically switched into a circuit to replace a corresponding unit that has failed. Redundant units are shown by dashed lines in Figure.



More detailed block diagram of a transmit receive earth station

A number of different classes of earth stations are available, depending on the service requirements. Traffic can be broadly classified as heavy route, medium route and thin route. In a thin rote circuit, a transponder channel may be occupied by a number of single carrier, each associated with its own voice circuit. This mode of operation is known as single carrier per channel (SCPC), a multiple access mode.

A medium route circuit also provides multiple access, either on the basis of frequency division multiple access (FDMA) or time division multiple access (TDMA), multiplexed baseband signals being carried in either case.

In a 6/4 GHz heavy route system, each satellite channel is capable of carrying over 960 one-way voice circuits simultaneously or a single color analog TV signal with associated audio. Thus the transponder channel for a heavy route circuit carries one large bandwidth signal, which may be TV or multiplexed telephony.

Equivalent Isotropic Radiated Power

A key parameter in link-budget calculations is the *equivalent isotropic radiated power*, conventionally denoted EIRP. The maximum power flux density at some distance '*r'* for transmitting antenna of gain '*G* i'

$$Pr= \frac{GP}{4\pi^2}$$

An isotropic radiator with an input power equal to GP*S* would produce the same flux density. Hence, this product is referred to as the EIRP, or EIRP is often expressed in decibels relative to 1 W, or dBW. Let *PS* be in watts; then [EIRP] = [*PS*] x [*G*] dB, where [*PS*] is also in dBW and [*G*] is in dB.

Transmission Losses

The [EIRP] may be thought of as the power input to one end of the transmission link, and the problem is to find the power received at the other end. Losses will occur along the way, some of which are constant. Other losses can only be estimated from statistical data, and some of these are dependent on weather conditions, especially on rainfall.

The first step in the calculations is to determine the losses for *clear- weather* or *clear-sky conditions*. These calculations take into account the losses, including those calculated on a statistical basis which does not vary with time. Losses which are weather-related, and other losses which fluctuate with time, are then allowed for by introducing appropriate *fade margins* into the transmission equation.

Free-space transmission:

As a first step in the loss calculations, the power loss resulting from the spreading of the signal in space must be determined. This calculation is similar for the uplink and the downlink of a satellite circuit.

$$M = \frac{EIRP}{4r^2}$$

The power delivered to a matched receiver is this power-flux density multiplied by the effective aperture of the receiving antenna. The received power is therefore

$$P_R = (EIRP)(G_R)\left(\frac{\lambda}{4\pi r^2}\right)$$

Recall that *r* is the distance, or range, between the transmit and receive antennas and G_R is the isotropic power gain of the receiving antenna. The subscript *R* is used to identify the receiving antenna.

The received power in dBW is therefore given as the sum of the transmitted EIRP in dBW plus the receiver antenna gain in dB minus a third term, which represents the free-space loss in decibels. The free-space loss component in decibels is given by,

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

The received power in dBW is therefore given as the sum of the transmitted EIRP in dBW plus the receiver antenna gain in dB minus a third term, which represents the free-space loss in decibels. The free-space loss component in decibels is given by,

$$[FSL] = 32.4 + 20\log r + 20\log f$$

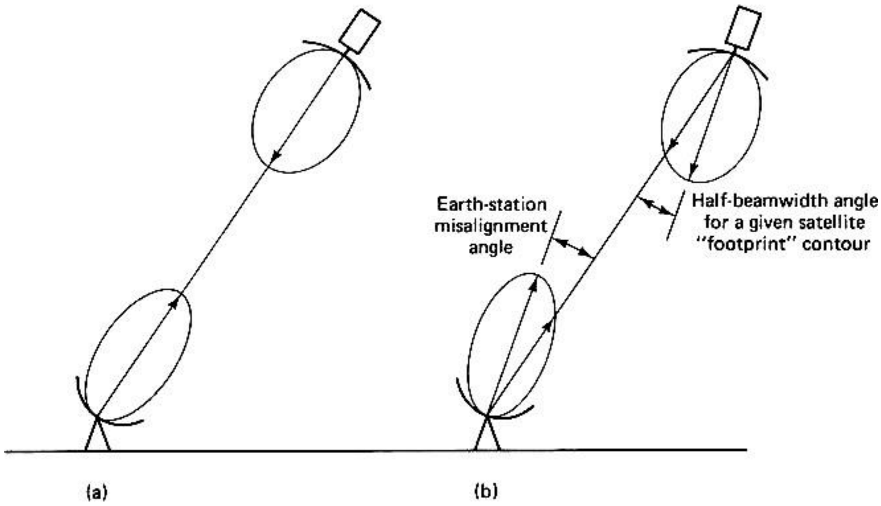
if the transmit power is a specified constant, rather than the EIRP, then the received power will increase with increasing frequency for given antenna dish sizes at the transmitter and receiver. It is left as an exercise for the student to show that under these conditions the received power is directly proportional to the square of the frequency.

Feeder losses:

Losses will occur in the connection between the receive antenna and the receiver proper. Such losses will occur in the connecting waveguides, filters, and couplers. These will be denoted by RFL, or [RFL] dB, for *receiver feeder losses*.

Antenna misalignment losses:

When a satellite link is established, the ideal situation is to have the earth station and satellite antennas aligned for maximum gain, as shown in Figure. There are two possible sources of off-axis loss, one at the satellite and one at the earth station. The off-axis loss at the satellite is taken into account by designing the link for operation on the actual satellite antenna contour; this is described in more detail in later sections. The off-axis loss at the earth station is referred to as the *antenna pointing loss*. Antenna pointing losses are usually only a few tenths of a decibel. In addition to pointing losses, losses may result at the antenna from misalignment of the polarization direction. The polarization misalignment losses are usually small, and it will be assumed that the antenna misalignment losses, denoted by [AML], include both pointing and polarization losses resulting from antenna misalignment.



(*a*) Satellite and earth-station antennas aligned for maximum gain;

(*b*) earth station situated on a given satellite "footprint," and earth-station antenna misaligned.

Fixed atmospheric and ionospheric losses

Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases. These losses are treated quite separately from those which result from adverse weather conditions, which of course are also atmospheric losses. To distinguish between these, the weather-related losses are referred to as atmospheric attenuation and the absorption losses simply as atmospheric absorption.

Radio waves traveling between satellites and earth stations must pass through the ionosphere. The ionosphere has been ionized, mainly by solar radiation. The free electrons in the ionosphere are not uniformly distributed but form in layers. Clouds of electrons may travel through the ionosphere and give rise to fluctuations in the signal. The effects include scintillation, absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change, and polarization rotation.

The Link-Power Budget Equation

The losses for the link have been identified, the power at the receiver, which is the power output of the link, may be calculated simply as [EIRP] [LOSSES] [GR], where the last quantity is the receiver antenna gain. The major source of loss in any ground-satellite link is the free-space spreading loss [FSL], the basic link-power budget equation taking into account this loss only. However, the other losses also must be taken into account, and these are simply added to [FSL].
The losses for clear-sky conditions are

[LOSSES] = [FSL] +[RFL] +[AML]+[AA] -[PL]

equation for the received power is then

$$[PR] = [EIRP] \times [GR] - [LOSSES]$$

Where,

[PR] - the 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 mismatchloss, dB

System Noise

The receiver power in a satellite link is very small, on the order of picowatts. This by itself would be no problem because amplification could be used to bring the signal strength up to an acceptable level. However, electrical noise is always present at the input, and unless the signal is significantly greater than the noise, amplification will be of no help because it will amplify signal and noise to the same extent. In fact, the situation will be worsened by the noise added by the amplifier.

The major source of electrical noise in equipment is that which arises from the random thermal motion of electrons in various resistive and active devices in the receiver. Thermal noise is also generated in the lossy components of antennas, and thermal-like noise is picked up by the antennas as radiation.

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

$$P_N = kT_NB_N$$

Here, T_N is known as the equivalent noise temperature, B_N is the equivalent noise bandwidth, and k =1.38 x10^{23} J/K is Boltzmann's constant. With the temperature in kelvins and bandwidth in hertz, the noise power will be in watts. The noise power bandwidth is always wider than the 3-dB bandwidth determined from the amplitude-frequency response curve, and a useful rule of thumb is that the noise bandwidth is equal to 1.12 times the 3-dB bandwidth, or $B_N \approx 1.12 \times B_{-3dB}$. The bandwidths here are in hertz (or a multiple such as MHz).

The noise temperature is directly related to the physical temperature of the noise source but is not always equal to it. This is discussed more fully in the following sections. The noise temperatures of various sources which are connected together can be added directly to give the total noise.

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*.

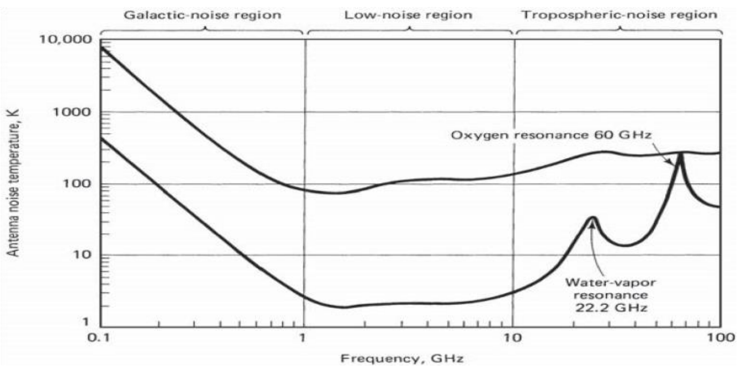
Antenna noise

Antennas operating in the receiving mode introduce noise into the satellite circuit. Noise therefore will be introduced by the satellite receive antenna and the ground station receive antenna. Although the physical origins of the noise in either case are similar, the magnitudes of the effects differ significantly.

The antenna noise can be broadly classified into two groups: noise originating from antenna losses and *sky noise*. Sky noise is a term used to describe the microwave radiation which is present throughout the universe and which appears to originate from matter in any form at finite temperatures. Such radiation in fact covers a wider spectrum than just the microwave spectrum.

The lower graph is for the antenna pointing directly overhead, while the upper graph is for the antenna pointing just above the horizon. The increased noise in the latter case results from the thermal radiation of the earth, and this in fact sets a lower limit of about 5° at C band and 10° at Ku band on the elevation angle which may be used with ground-based antennas.

The graphs show that at the low-frequency end of the spectrum, the noise decreases with increasing frequency. Where the antenna is zenith pointing, the noise temperature falls to about 3 K at frequencies between about 1 and 10 GHz. This represents the residual background radiation in the universe. Above about 10 GHz, two peaks in temperature are observed, resulting from resonant losses in the earth's atmosphere.

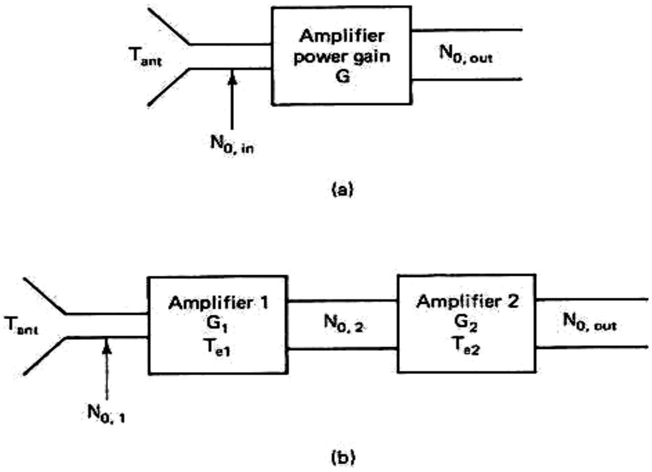


Irreducible noise temperature of an ideal, ground-based antenna

Antenna losses add to the noise received as radiation, and the total antenna noise temperature is the sum of the equivalent noise temperatures of all these sources. For large ground-based C-band antennas, the total antenna noise temperature is typically about 60 K, and for the Ku band, about 80 K under clear-sky conditions. These values do not apply to any specific situation and are quoted merely to give some idea of the magnitudes involved. Figure shows the noise temperature as a function of angle of elevation for a 1.8-m antenna operating in the Ku band.

Amplifier Noise Temperature

Consider first the noise representation of the antenna and the *low noise amplifier* (LNA) shown in Figure. The available power gain of the amplifier is denoted as G, and the noise power output, as Pno.



LNA Amplifier Gain

The input noise energy coming from the antenna is

$$N_{0,ant} = kT_{ant}$$

The output noise energy $N_{0,out}$ will be $GN_{0,ant}$ plus the contribution made by the amplifier. Now all the amplifier noise, wherever it occurs in the amplifier, may be *referred to the input* in terms of an equivalent input noise temperature for the amplifier T_e. This allows the output noise to be written as

$$N_{0,out} = Gk(T_{ant}\ \ T_e)$$

The total noise referred to the input is simply $N_{0,out}/G$, or

$$N_{0,in} = k(T_{ant}\ \ T_e)$$

T_e can be obtained by measurement, a typical value being in the range 35 to 100 K.

Amplifiers in cascade

The cascade connection is shown in Figure. For this arrangement, the overall gain is

$$G = G_1G_2$$

The noise energy of amplifier 2 referred to its own input is simply kT_{e2}. The noise input to amplifier 2 from the preceding stages is $G_1k(T_{ant}\ \ T_{e1})$, and thus the total noise energy *referred to amplifier 2 input* is

$$N_{0,2} = G_1 k(T_{ant}\ T_{e1})\ kT_{e2}$$

This is a very important result. It shows that the noise temperature of the second stage is divided by the power gain of the first stage when referred to the input. Therefore, in order to keep the overall system noise as low as possible, the first stage (usually an LNA) should have high power gain as well as low noise temperature.

Noise factor

An alternative way of representing amplifier noise is by means of its *noise factor, F*. In defining the noise factor of an amplifier, the source is taken to be at *room temperature*, denoted by T_0, usually taken as 290 K. The input noise from such a source is kT_0, and the output noise from the amplifier is

$$N0,\text{out} = FGkT0$$

Here, G is the available power gain of the amplifier as before, and F is its noise factor.

A simple relationship between noise temperature and noise factor can be derived. Let T_e be the noise temperature of the amplifier, and let the source be at room temperature as required by the definition of F. This means that $T_{ant}\ T_0$. Since the same noise output must be available whatever the representation, it follows that

$$Gk(T_{0\,+}\ T_e) = FGkT_0$$

As a matter of convenience, in a practical satellite receiving system, noise temperature is specified for low-noise amplifiers and converters, while noise factor is specified for the main receiver unit. The *noise figure* is simply F expressed in decibels:

$$\text{Noise figure} = [F] = 10 \log F$$

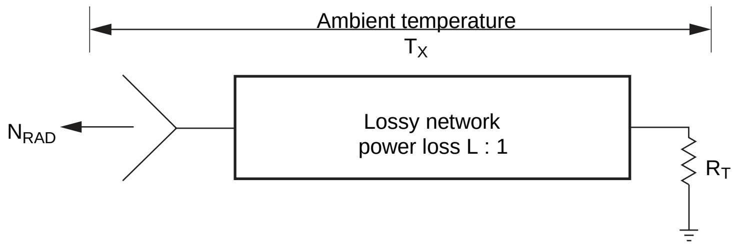
Noise temperature of absorptive networks

An *absorptive network* is one which contains resistive elements. These introduce losses by absorbing energy from the signal and converting it to heat. Resistive attenuators, transmission lines, and waveguides are all examples of absorptive networks, and even rainfall, which absorbs energy from radio signals passing through it, can be considered a form of absorptive network. Because an absorptive network contains resistance, it generates thermal noise.

Consider an absorptive network, which has a power loss L. The power loss is simply the ratio of input power to output power and will always be greater than unity. Let the network be matched at both ends, to a terminating resistor, R_T, at one end and an antenna at the other, as shown in Figure, and let the system be at some ambient temperature T_x. The noise energy transferred from R_T into the network is kT_x. Let the network noise be represented at the output terminals (the terminals connected to the antenna in this instance) by an equivalent noise temperature $T_{NW,0}$. Then the noise energy radiated by the antenna is,

$$N_{out} = \frac{kT_x}{L} + kT_{x,0}$$

Because the antenna is matched to a resistive source at temperature T_x, the available noise energy which is fed into the antenna and radiated is $N_{rad} = kT_x$. Keep in mind that the antenna resistance to which the network is matched is fictitious, in the sense that it represents radiated power, but it does not generate noise power



Network matched at both ends, to a terminating resistor R_T at one end and an antenna at the other.

Overall system noise temperature

shows a typical receiving system. Applying the results of the previous sections yields, for the system noise temperature referred to the input,

$$T_s = T_{ant} + T_{e1} + \frac{(L-1)T_O}{G_1} + \frac{L(F-1)T_O}{G_1}$$

The significance of the individual terms is illustrated in the following examples.

Carrier-to-Noise Ratio

A measure of the performance of a satellite link is the ratio of carrier power to noise power at the receiver input, and link-budget calculations are often concerned with determining this ratio. Conventionally, the ratio is denoted by C/N (or CNR), which is equivalent to P_R/P_N. In terms of decibels,

$$\left[\frac{C}{N}\right] = [P_R] - [P_N]$$

Therefore, the link equation,

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

The ratio of carrier power to noise power density PR/N0 may be the quantity actually required.

$$\left[\frac{C}{N}\right] = \left[\frac{C}{N_o B_N}\right]$$

$$= \left[\frac{C}{N}\right] - [B_N]$$

The Uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and he satellite is receiving it [t]specifically that the uplink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the earth station EIRP, the satellite receiver feeder losses, and satellite receiver *G*/*T*. The free-space loss and other losses which are frequency-dependent are calculated for the uplink frequency.

Saturation flux density

The flux density required at the receiving antenna to produce saturation of the TWTA is termed the saturation flux density. The saturation flux density is a specified quantity in link budget calculations, and knowing it, one can calculate the required EIRP at the earth station.

The uplink of the satellite is the one in which the earth station is transmitting the signal and the satellite is receiving it. The carrier to noise ratio for uplink is given as:

$$[CN_0]_U=[EIRP]_U+[G/T]_U-[Losses]_U-[k] \ldots\ldots(1)$$

Consider the flux density in terms of EIRP,

$$\psi M=EIRP/4\pi r2 \ldots\ldots\ldots\ldots\ldots(2)$$

$$[\psi M]=[EIRP]+10log(14\pi r2) \ldots\ldots\ldots(3)$$

know free space loss is given as

$$-[FSL]=10log(\lambda 24\pi)+10log(14\pi r2)\ldots\ldots(4)$$

Using equation (4) in equation (3)

$$[\psi M]=[EIRP]-[FSL]-10log(\lambda 24\pi)\ldots...(5)$$

The $\lambda 24\pi$

term has dimensions of area and it is the effective area of an isotropic antenna. Denoting this by $A0$

given as:

$[A0]=10log(\lambda 24\pi)$……….(6)

Combining equation (5) and (6) and rearranging the terms we get

$[EIRP]=[\psi M]+[FSL]+[A0]$…………(7)

The above equation is derived on the basis that only loss present was the spreading loss denoted by $[FSL]$

. However other propagation losses are the atmospheric absorption loss, the polarization mismatch loss, and the misalignment loss.

$[EIRP]=[\psi M]+[A0]+[FSL]+[AA]+[PL]+[AML]$…..(8)

We know $[Losses]=[FSL]+[AA]+[PL]+[AML]+[RFL]$

Hence equation(8) becomes

$[EIRP]=[\psi M]+[A0]+[Losses]-[RFL]$……(9)

This is for clear sky conditions and gives minimum value of [EIRP] which the earth station must provide to produce a given flux density at the satellite. Normally the saturation flux density is specified. With saturation values denoted by subscript S in equation (9) we get

$$[EIRP]_S=[\psi_M]+[A_0]+[Losses]_U-[RFL]\text{…..}(10)$$

Input back-off

Since the number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of inter modulation distortion. Such multiple carrier operation occurs with *frequency- division multiple access* (FDMA). The point to be made here is that *backoff* (BO) must be allowed for in the link- budget calculations. Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single- carrier saturation level.

earth-station EIRP will have to be reduced by the specified BO, resulting in an uplink valueof $[EIRP]_U = [EIRP_S]_U + [BO]_i$

The earth station HPA

The earth station HPA has to supply the radiated power plus the transmit feeder losses, denoted here by TFL, or [TFL] dB. These include waveguide, filter, and coupler losses between the HPA output and the transmit antenna. The earth station may have to transmit multiple carriers and its output also will require back off, denoted by $[BO]_{HPA}$. The earth station HPA must be rated for a saturation power output given by

$$[P_{HPA,sat}] = [P_{HPA}] + [BO]_{HPA}$$

Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation can be applied to the downlink, but subscript *D* will be used to denote specifically that the downlink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the satellite EIRP, the earth- station receiver feeder losses, and the earth-station receiver *G*/*T*. The free space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio appears at the detector of the earth station receiver.

Output back-off

Where input BO is employed as described in a corresponding output BO must be allowed for in the satellite EIRP. As the curve of Figure 2.16 shows that output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output BO is $[BO]_0$ $[BO]_i$ 5 dB. For example, with an input BO of $[BO]_i$ 11 dB, the corresponding output BO is $[BO]_0$

Satellite TWTA output

The satellite power amplifier, which usually is a TWTA, has to supply the radiated power plus the transmit feeder losses. These losses include the waveguide, filter, and coupler losses between the TWTA output and the satellites transmit antenna. Referring back to Eq. (12.3), the power output of the TWTA is given by,

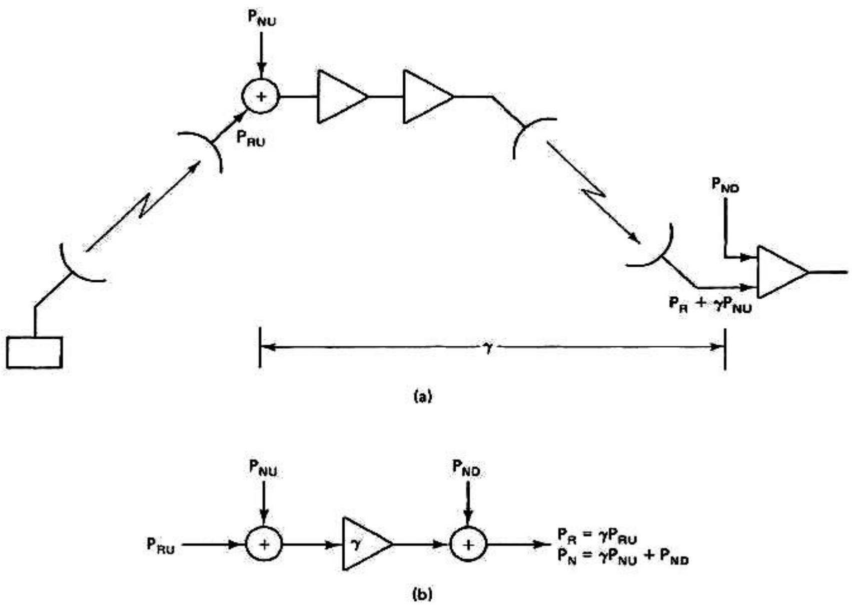
$$[P_{TWTA}] = [EIRP]_D - [G_T]_D + [TFL]_D$$

Once $[P_{TWTA}]$ is found, the saturated power output rating of the TWTA is given by

$$[P_{TWTA}]_S = [P_{TWTA}] + [BO]_0$$

<u>**Effects of Rain**</u>

In the C band and, more especially, the Ku band, rainfall is the most significant cause of signal fading. Rainfall results in attenuation of radio waves by scattering and by absorption of energy from the wave. Rain attenuation increases with increasing frequency and is worse in the Ku band compared with the C band. This produces a depolarization of the wave; in effect, the wave becomes elliptically polarized. This is true for both linear and circular polarizations, and the effect seems to be much worse for circular polarization. The C/N_0 ratio for the downlink alone, not counting the PNU contribution, is P_R/P_{ND}, and the combined C/N_0 ratio at the ground receiver is



(*a*) Combined uplink and downlink (*b*) power flow diagram

The reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers, which are present are additive. Similar reasoning applies to the carrier-to-noise ratio, C/N.

<u>**Uplink rain-fade margin**</u>

Rainfall results in attenuation of the signal and an increase in noise temperature, degrading the $[C/N_0]$ at the satellite in two ways. The increase in noise, however, is not usually a major factor for the uplink. This is so because the satellite antenna is pointed toward a "hot" earth, and this added to the satellite receiver noise temperature tends to mask any additional noise induced by rain attenuation. What is important is that the uplink carrier power at the satellite must be held within close limits for certain modes of operation, and some form of *uplink power control* is necessary to compensate for rain fades. The power output from the satellite may be monitored by a central control station or in some cases by each earth station, and the power output from any given earth station may be increased if required to compensate for fading. Thus the earth-station HPA must have sufficient reserve power to meet the fade margin requirement.

Some typical rain-fade margins are shown in Table 12.2. As an example, for Ottawa, the rain attenuation exceeds 1.9 dB for 0.1 percent of the time. This means that to meet the specified power requirements at the input to the satellite for 99.9 percent of the time, the earth station must be capable of providing a 1.9-dB margin over the clear-sky conditions.

Downlink rain-fade margin

The results given by Equations are for clear-sky conditions. Rainfall introduces attenuation by absorption and scattering of signal energy, and the absorptive attenuation introduces noise as discussed in Sec. 12.5.5. Let [*A*] dB represent the rain attenuation caused by absorption. The corresponding power loss ratio is $A\ \ 10^{[A]/10}$, and substituting this for *L* in Equation gives the effective noise temperature of the rain as

$$T_{rain} = T_a\left(1 - \frac{1}{A}\right)$$

Here, T_a, which takes the place of T_x, is known as the *apparent absorber temperature*. It is a measured parameter which is a function of many factors including the physical temperature of the rain and the scattering effect of the rain cell on the thermal noise incident upon it (Hogg and Chu, 1975). The value of the apparent absorber temperature lies between 270 and 290 K, with measured values for North America lying close to or just below freezing (273 K). For example, the measured value given by Webber et al. (1986) is 272 K.

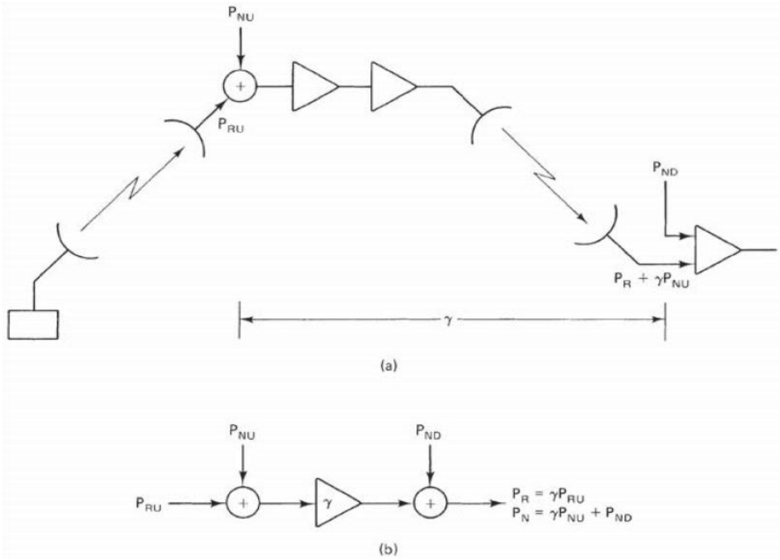
Combined Uplink and Downlink *C/N* Ratio

The complete satellite circuit includes an uplink and a downlink, as sketched in Fig. 12.9*a*. Noise will be introduced on the uplink at the satellite receiver input. Denoting the noise power per unit bandwidth by P_{NU} and the average carrier at the same point by P_{RU}, the carrier-to noise ratio on the uplink is $(C/N_0)_U$ (P_{RU}/P_{NU}). It is important to note that power levels, and not decibels, are being used here.

The carrier power at the end of the space link is shown as P_R, which of course is also the received carrier power for the downlink. This is equal to *times* the carrier power input at the satellite, where *is* the system power gain from satellite input to earth-station input, as shown in Fig. 12.9*a*. It includes the satellite transponder and transmit antenna gains, the downlink losses, and the earth-station receive antenna gain and feeder losses.

The noise at the satellite input also appears at the earth station input multiplied by, and in addition, the earth station introduces its own noise, denoted by P_{ND}. Thus the end-of-link noise is $P_{NU}\ \ P_{ND}$.

The C/N_0 ratio for the downlink alone, not counting the P_{NU} contribution, is P_R/P_{ND}, and the combined C/N_0 ratio at the ground receiver is



(*a*) Combined uplink and downlink; (*b*) power flow diagram for (*a*).

To obtain the combined value of C/N_0, the reciprocals of the individual values must be added to obtain the N_0/C ratio and then the reciprocal of this taken to get C/N_0. Looked at in another way, the reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers, which are present are additive. Similar reasoning applies to the carrier-to-noise ratio, C/N.

Intermodulation Noise

Intermodulation occurs where multiple carriers pass through any device with nonlinear characteristics. In satellite communications systems, this most commonly occurs in the traveling-wave tube HPA aboard the satellite, both amplitude and phase nonlinearities give rise to intermodulation products.

As shown in Figure, third-order intermodulation products fall on neighbouring carrier frequencies, where they result in interference. Where a large number of modulated carriers are present, the intermodulation products are not distinguishable separately but instead appear as a type of noise which is termed *intermodulation noise*.

The carrier-to-intermodulation-noise ratio is usually found experimentally, or in some cases it may be determined by computer methods. Once this ratio is known, it can be combined with the carrier-to-thermal-noise ratio by the addition of the reciprocals in the manner. Denoting the intermodulation term by $(C/N_0)_{IM}$ and bearing in mind that the reciprocals of the C/N_0 power ratios (and not the corresponding dB values) must be added, In order to reduce intermodulation noise, the TWT must be operated in a BO condition as described previously. Figure 12.10 shows how the $[C/N_0]_{IM}$ ratio improves as the input BO is increased for a typical TWT.