# SATELLITE COMMUNICATION

COURSE FILE

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# 1. COVER PAGE

GEETHANJALI COLLEGE	OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF Elect	ronics and Communication Engineering
(Name of the Subject / Lab Course) : Sat	tellite Communications
(JNTU CODE - )	Programme : UG
Branch: ECE	Version No : 02
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3) Design :	2) Sign :
4) Date :	3) Design :
	4) Date :
Approved by : (HOD ) 1) Name	e : Dr.P,SRI HARI
2) Sign :	
3) Date :	

# 2. SYLLABUS

# GEETHANJALI COLLEGE OF ENGINEERING & TECHNOLOGY

# Cheeryal, Keesara (M), R.R.Dist. DEPARTMENT OF ECE <u>SYLLABUS</u>

# JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD IV Year B.Tech. ECE. I-Sem T P C

4+1\*04

# SATELLITE COMMUNICATIONS (ELECTIVE – II)

# UNIT I

**INTRODUCTION [2] :** Origin of Satellite Communications, Historical Back-ground, Basic Concepts of Satellite Communications, Frequency allocations for Satellite Services, Applications, Future Trends of Satellite Communications.

# UNIT II

**ORBITAL MECHANICS AND LAUNCHERS** [1]: Orbital Mechanics, Look Angle determination, Orbital perturbations, Orbit determination, launches and launch vehicles, Orbital effects in communication systems performance.

# UNIT III

**SATELLITE SUBSYSTEMS[1] :** Attitude and orbit control system, telemetry, tracking, Command and monitoring, power systems, communication subsystems, Satellite antenna Equipment reliability and Space qualification.

# UNIT IV

**SATELLITE LINK DESIGN [1] :** Basic transmission theory, system noise temperature and G/T ratio, Design of down links, up link design, Design of satellite links for specified C/N, System design example.

# UNIT V

**MULTIPLE ACCESS [1][2] :** Frequency division multiple access (FDMA) Intermodulation, Calculation of C/N. Time division Multiple Access (TDMA) Frame structure, Examples. Satellite Switched TDMA Onboard processing, DAMA, Code Division Multiple access (CDMA),Spread spectrum transmission and reception.

# UNIT VI

**EARTH STATION TECHNOLOGY [3]:** Introduction, Transmitters, Receivers, Antennas, Tracking systems, Terrestrial interface, Primary power test methods.

# UNIT VII

# LOW EARTH ORBIT AND GEO-STATIONARY SATELLITE SYSTEMS[1]: Orbit

consideration, coverage and frequency considerations, Delay & Throughput considerations, System considerations, Operational NGSO constellation Designs

# UNIT VIII

**SATELLITE NAVIGATION & THE GLOBAL POSITIONING SYSTEM** [1] : Radio and Satellite Navigation, GPS Position Location principles, GPS Receivers and codes, Satellite signal acquisition, GPS Navigation Message, GPS signal levels, GPS receiver operation, GPS C/A code accuracy, Differential GPS.

# **TEXT BOOKS:**

- 1. Satellite Communications Timothy Pratt, Charles Bostian and Jeremy Allnutt, WSE, Wiley Publications, 2nd Edition, 2003.
- 2. Satellite Communications Engineering Wilbur L. Pritchard, Robert A Nelson and Henri G.Suyderhoud, 2nd Edition, Pearson Publications, 2003.

# **REFERENCES:**

- 1. Satellite Communications: Design Principles M. Richharia, BS Publications, 2nd Edition, 2003.
- 2. Satellite Communication D.C Agarwal, Khanna Publications, 5th Ed.
- 3. Fundamentals of Satellite Communications K.N. Raja Rao, PHI, 2004
- 4. Satellite Communications Dennis Roddy, McGraw Hill, 2nd Edition, 1996.

# **3.VISION OF THE DEPARTMENT**

To impart quality technical education in Electronics and Communication Engineering emphasizing analysis, design/synthesis and evaluation of hardware/embedded software using various Electronic Design Automation (EDA) tools with accent on creativity, innovation and research thereby producing competent engineers who can meet global challenges with societal commitment.

# 3. MISSION OF THE DEPARTMENT

- i. To impart quality education in fundamentals of basic sciences, mathematics, electronics and communication engineering through innovative teaching-learning processes.
- ii. To facilitate Graduates define, design, and solve engineering problems in the field of Electronics and Communication Engineering using various Electronic Design Automation (EDA) tools.
- iii. To encourage research culture among faculty and students thereby facilitating them to be creative and innovative through constant interaction with R & D organizations and Industry.
- iv. To inculcate teamwork, imbibe leadership qualities, professional ethics and social responsibilities in students and faculty.

# 4. PEOS AND POS

# **Program Educational Objectives of B. Tech (ECE) Program :**

- I. To prepare students with excellent comprehension of basic sciences, mathematics and engineering subjects facilitating them to gain employment or pursue postgraduate studies with an appreciation for lifelong learning.
- II. To train students with problem solving capabilities such as analysis and design with adequate practical skills wherein they demonstrate creativity and innovation that would enable them to develop state of the art equipment and technologies of multidisciplinary nature for societal development.
- III. To inculcate positive attitude, professional ethics, effective communication and interpersonal skills which would facilitate them to succeed in the chosen profession exhibiting creativity and innovation through research and development both as team member and as well as leader.

# Program Outcomes of B.Tech ECE Program:

- 1. An ability to apply knowledge of Mathematics, Science, and Engineering to solve complex engineering problems of Electronics and Communication Engineering systems.
- 2. An ability to model, simulate and design Electronics and Communication Engineering systems, conduct experiments, as well as analyze and interpret data and prepare a report with conclusions.
- 3. An ability to design an Electronics and Communication Engineering system, component, or process to meet desired needs within the realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.
- 4. An ability to function on multidisciplinary teams involving interpersonal skills.
- 5. An ability to identify, formulate and solve engineering problems of multidisciplinary nature.
- 6. An understanding of professional and ethical responsibilities involved in the practice of Electronics and Communication Engineering profession.
- 7. An ability to communicate effectively with a range of audience on complex engineering problems of multidisciplinary nature both in oral and written form.
- 8. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.
- 9. Recognition of the need for, and an ability to engage in life-long learning and acquire the capability for the same.
- 10.A knowledge of contemporary issues involved in the practice of Electronics and Communication Engineering profession
- 11.An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.
- 12.An ability to use modern Electronic Design Automation (EDA) tools, software and electronic equipment to analyze, synthesize and evaluate Electronics and Communication Engineering systems for multidisciplinary tasks.
- 13. Apply engineering and project management principles to one's own work and also to manage projects of multidisciplinary nature.

# 5. Course objectives and outcomes

# **Course objectives:**

- This course will introduce the basic concepts and techniques of Satellite communication and frequency allocations. By the end of the course, you be familiar with the most important methods in satellite launching
- The course emphasizes intuitive understanding and practical implementations of the theoretical concepts.
- To produce graduates who understand how to analyze and manipulate digital signals and to determine the orbital issues to have the fundamental knowledge to do so, for navigation and GPS

# **Course outcomes:**

**CO 1:** Able to obtain different types of satellites

- **CO 2:** Ability to calculate the orbital determination and launching methods
- **CO 3:** Ability to develop commads, monitoring power systems and developments of antennas.
- **CO 4:** Able to calculate multiple access techniques like TDMA, CDMA, FDMA, DAMA.
- **CO 5:** Able to design antennas to provide Uplink and Down link Frequency.
- **CO 6:** Able to design Satellite for real time applications.

**CO 7:** Ability to design different kinds of transmitter and receiver antennas.

**CO 8:** Ability to demonstrate the impacts of GPS, Navigation, NGSO constellation design for tracking and launching

# 7. BRIEF NOTE ON THE IMPORTANTANCE OF THE COURSE AND HOW IT FITS IN TO THE CURRICULAM

Satellite communication is concerned with the representation, transformation of signals from earth station to space. After half a century advances, satellite communication has become an important field, and has penetrated a wide range of application systems, such as consumer electronics, digital communications, medical imaging, telecommunication, launching and so on. With the dramatic increase of the processing capability of signal processing, it is the expectation that the importance and role of sc is to accelerate and expand.

# 8. PREREQUISITES, IF ANY

- Types of satellites
- GPS
- Signals and GNNS

# 9. INSTRUCTIONAL LEARNING OUTCOMES

# **UNIT-I (INTRODUCTION)**

- 1) Students can understand the concept of Satellites.
- 2) Analyze and implement digital signal processing systems in satellite launching
- 3) They can understand Frequency representation They can understand the practical purpose of stability and causality for launching
- 4) Able to know the applications.

# UNIT-II

- 1. Students can able to define [1]: orbital mechanics and launchers
- 2. Students may able to find Look Angle
- 3. Able to find Orbital perturbations and Orbit determination
- 4. To study launches and launch vehicles
- 5. To study Orbital effects in communication systems performance

# UNIT-III

- **1.** Able to define satellite subsystems
- 2. To study Altitude and orbit control system
- 3. To know telemetry, tracking, Command and monitoring, power systems, communication subsystems,
- 4. To study Satellite antenna Equipment reliability and Space qualification

# UNIT-IV

- 1.To study satellite link design
- 2.Able to know Basic transmission theory, system noise temperature and G/T ratio,
- 3. Ability to design of down links, up link design,
- 4.To Design of satellite links for specified C/N,
- 5. Ability to solve System design using example

# UNIT-V

- 1. To study multiple access
- 2. Frequency division multiple access (FDMA) Intermodulation,
- 3. To Calculate C/N.
- 4. To study Time division Multiple Access (TDMA) Frame structure

5 Ability to differentiate Satellite Switched TDMA Onboard processing, DAMA, Code Division Multiple access (CDMA), Spread spectrum transmission and reception

# UNIT-VI

- 1. Able to know earth station technology
- 2. Ability to identify Transmitters, Receivers, Antennas, Tracking systems, Terrestrial interface
- **3.** To calculate Primary power test methods.

# UNIT-VII

- 1. To know about low earth orbit and geo-stationary satellite systems
- **2.** To define Orbit consideration, coverage and frequency considerations, Delay & Throughput considerations, System considerations,
- 3. To Operate NGSO constellation Designs

# UNIT-VIII

- 1. To define satellite navigation & the global positioning system
- 2. To define Radio and Satellite Navigation, GPS Position Location principles,
- 3. To define GPS Receivers and codes, Satellite signal acquisition,
- 4. To define GPS Navigation Message, GPS signal levels, GPS receiver operation,
- 5. To define GPS C/A code accuracy and Differential GPS.

# 10. Course mapping with Programme Outcomes:

# Mapping of Course outcomes with Programme outcomes:

\*When the course outcome weightage is < 40%, it will be given as moderately correlated (1). \*When the course outcome weightage is >40%, it will be given as strongly correlated (2).

	POs	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Satellite		2	2		2			2			2	2		
	Communication														
	<b>CO 1: :</b> Able to obtain		2			2									
	different types of														
	satellites														
	sucenites														
ľ	<b>CO 2::</b> Ability to		2			2						2	2		
	calculate the orbital														
	determination and														
	launching methods														
	<b>CO 3:</b> Ability to develop		2	2		2						2	2		
	commads, monitoring											r			
	power systems and														
	developments of														
	antannas														
	antennas.														
	<b>CO 4</b> :. <b>:</b> Able to		2			2						2	2		
	calculate multiple														
	access techniques like														
	TDMA,														s
	CDMA,FDMA,DAMA.														SUO
	, ,														atio
															nic
															nm
	<b>CO 5</b> Able to design		2	1		2						2	2	2	om
	antennas to provide														te c
	Uplink and Down link														elli
	Frequency														Sat
	<b>CO 6:</b> Able to design		2	1		2						2	2	2	
1	· · · · · · · - 0	1									1	1	1	1	

Satellite for real time applications									
<b>CO 7:</b> Ability to design different kinds of transmitter and receiver antennas	2		2			2	2	2	
<b>CO 8: :</b> Ability to demonstrate the impacts of GPS, Navigation, NGSO constellation design for tracking and launching	2		2			2	2	2	

# 11. Class Time Table

To be attached

# 12. Individual time Table

Name: Ms.M.Umarani ver: 1 w.e.f.: 29/12/134 Load:18

Day	1	2	3	4		5	6	7
Mon					LUNCH			

TUE				
WED				
THUR				
FRI				
SAT				

# 13. <u>LECTURE SCHEDULE WITH METHODOLOGY BEING USED/ ADOPTED</u>

SI. No.	Unit No.	Total number of periods	Date	Topic to be covered in One lecture	Regular/ Additional/ Missing	Teaching Aids used LCD /OHP/BB	Remarks
1				Introduction to Satellite Communication	Regular	BB	
2					Regular	BB	
3					Regular	BB	
4		07			Regular	BB	
5					Regular	BB/OHP	
6	IL				Missing	BB/OHP	
7	IN					BB	
8	Í I				Regular	OHP	
9					Regular	BB	
10					Regular	BB	
11					Regular	BB	
12		09			Regular	BB	

13			Additional	BB/OHP/	
				LCD	
14				BB/OHP/L	
				CD	
15				BB/OHP/L	
				CD	
16				BB/OHP/L	
				CD	
17	<b>F</b> _1		Regular	BB	
18	58		Regular	OHP	
	. , ,				

19				Regular	OHP	
20				Regular	OHP	
21				Regular	OHP	
22					BB/OHP	
23				Regular	BB/OHP	
24				Regular	BB/OHP	
25				Regular	BB/OHP	
26	N IV	09		Regular	BB/OHP	
27	LINU			Regular	BB/OHP	
28					BB	
29					BB	
30						
31						
32				Regular	BB/OHP	
33				Regular	BB/OHP	
34	ΓΛ	06		Regular	BB/OHP	
35	INI			Regular	BB/OHP	
36				Additional	BB/OHP	
37					BB	
38	L			Regular	BB/OHP	
39	IT V	08		Regular	BB/OHP	
40	5			Regular	BB/OHP	
			•			

41			Regular	BB/OHP
42			Regular	BB/OHP
43				BB
43				
44				BB
45				BB/OHP
46			Regular	BB/OHP
47			Regular	BB/OHP
48	Ι		Regular	BB/OHP
49	IV TI	07	Regular	BB/OHP
50	NN		Regular	BB/OHP
51			Missing	BB/OHP
52				BB
53			Regular	BB/OHP
54			Regular	BB/OHP
55	III		Regular	BB/OHP
56	UNIT V	09	Regular	BB/OHP
57			Regular	BB/OHP
58			Regular	BB/OHP

59					
60				BB	
61				BB	
62					
63					
64					
		MID TEST II			

### **GUIDELINES:**

Distribution of periods:

•	No. of classes required to cover JNTU syllabus		: 46
•	No. of classes required to cover Additional topics		: 02
•	No. of classes required to cover Assignment tests (for every 2 units 1 test)	: 04	
•	No. of classes required to cover tutorials	:08	
•	No of classes required to solve University	: 04	
•	Question papers	:04	
	Total periods		: 64

# **INTRODUCTION TO THE SUBJECT**

In the class, starting from the basic definitions of a satellite, we will work our way through frequency allocations enough to analyze a practical communication system in detail. Hands-on examples and demonstration will be routinely used to close the gap between theory and practice for real time applications. Attitude and orbit control system, telemetry, tracking, Command and monitoring, power systems, communication subsystems, Satellite antenna Equipment reliability

Basic transmission theory, system noise temperature and G/T ratio, Design of down links, up link design, Design of satellite links for specified C/N. Frequency division multiple access (FDMA) Intermodulation, Calculation of C/N. Time division Multiple Access (TDMA) Frame structure,

Examples. Satellite Switched TDMA Onboard processing, DAMA, Code Division Multiple access (CDMA),Spread spectrum transmission and reception. Radio and Satellite Navigation, GPS Position Location principles, GPS Receivers and codes, Satellite signal acquisition, GPS Navigation Message, GPS signal levels, GPS receiver operation, GPS C/A code accuracy, Differential GPS.

# 14. <u>DETAILED NOTES:</u>

Hard copy attached

### 15. ADDITIONAL TOPICS

#### Additional/missing topics

GNNS UNIT\_1

#### **Origin of satellite**

The concept of using object in space to reflect signals for communication was proved by Naval Research Lab in communication when it use the Moon to establish a very low data rate link between Washington and Hawaii very low data rate link between Washington and Hawaii in late 1940's. Russian started the Space age by successfully launching SPUTNIK the first artificial spacecraft to orbit the earth, This transmitted telemetry information for 21 days in Oct. 1957. The American followed by launching an experimental satellite EXPLORER In 1958. In 1960 two satellite were deployed "Echo" & "Courier"In 1963 first GSO "SyncomThe first commercial GSO (Intelsat & Molnya) in 1965 these provides video (Television) and voice (Telephone) For their audience

#### INTRODUCTION

Satellites are specifically made for telecommunication purpose. They are used for mobile applications such as

Communications to ships, vehicles, planes, hand-held terminals and for TV and radio broadcasting. They are responsible for providing these services to an assigned region (area) on the earth. The power and bandwidth

of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations. A satellite works most efficiently when the transmissions are

Focused with a desired area. When the area is focused, then the emissions don't go outside that designated area and thus minimizing the interference to the other systems. This leads more efficient spectrum usage.

Satellites antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape). Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time. The earth station should be in a position to control the satellite if it drifts from its orbit it is subjected to any kind of drag from the external forces. Satellites orbit around the earth. Depending on the application, these orbits can be circular or elliptical. Satellites in circular orbits always keep the same distance to the earth's surface

#### APPLICATIONS OF SATELLITES

1) Weather Forecasting Certain satellites are specifically designed to monitor the climatic conditions of earth. They continuously monitor the assigned areas of earth and predict the weather conditions of that region. This is done by taking images of earth from the satellite. These images are transferred using assigned radio frequency to the earth station. (Earth Station: it is a radio station located on the earth and used for relaying signals from satellites.) These satellites are exceptionally useful in predicting disasters like hurricanes, and 4monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

#### 2) Radio and TV Broadcast

These dedicated satellites are responsible for making 100s of channels across the globe available for everyone. They are also responsible for broadcasting live matches, news, world-wide radio services. These satellites require a 30-40 cm sized dish to make these channels available globally.

#### 3) Military Satellites

These satellites are often used for gathering intelligence, as a communications satellite used for military purposes, or as a military weapon. A satellite by itself is neither military nor civil. It is the kind of payload it carries that enables one to arrive at a decision regarding its military or civilian character.

#### 4) Navigation Satellites

The system allows for precise localization world-wide, and with some additional techniques, the precision is in the range of some meters. Ships and aircraft rely on GPS as an addition to traditional navigation systems. Many vehicles come with installed GPS receivers. This system is also used, e.g., for fleet management of trucks or for vehicle localization in case of theft.

#### 5) Global Telephone

One of the first applications of satellites for communication was the establishment of international telephone backbones. Instead of using cables it was sometimes faster to launch a new satellite. But, fiber optic cables are still replacing satellite communication across long distance as in fiber optic cable, light is used instead of radio frequency, hence making the communication much faster (and of course, reducing the delay caused due to the amount of distance a signal needs to travel before reaching the destination.).Using satellites, to typically reach a distance approximately 10,000 kms away, the signal needs to travel almost 72,000 kms, that is, sending data from ground to satellite and (mostly) from satellite to another location on earth. This cause's substantial amount of delay and this delay becomes more prominent for users during voice calls.

#### 1.3.6) Connecting Remote Areas

Due to their geographical location many places all over the world do not have direct wired connection to the telephone network or the internet (e.g., researchers on Antarctica) or because of the current state of the infrastructure of a country. Here the satellite 5provides a complete coverage and (generally) there is one satellite always present across a horizon.

#### 7) Global Mobile Communication

The basic purpose of satellites for mobile communication is to extend the area of coverage. Cellular phone systems, such as AMPS and GSM (and their successors) do not cover all parts of a country. Areas that are not covered usually have low population where it is too expensive to install a base station. With the integration of satellite communication, however, the mobile phone can switch to satellites offering world-wide connectivity to a customer. Satellites cover a certain area on the earth. This area is termed as a "footprint" of that satellite. Within the footprint, communication with that satellite is possible for mobile users. These users communicate using a Mobile-User-Link (MUL). The base-stations communicate with satellites using a Gateway-Link (GWL). Sometimes it becomes necessary for satellite to create a communication link between users belonging to two different footprints. Here the satellites send signals to each other and this is done using Inter-Satellite-Link (ISL).

#### FREQUENCY ALLOCATION FOR SATELLITE

1) Geostationary or geosynchronous earth orbit (GEO) GEO satellites are synchronous with respect to earth. Looking from a fixed point from Earth, these satellites appear to be stationary. These satellites are placed in the space in such a way that only three satellites are sufficient to provide connection throughout the surface of the Earth (that is; their footprint is covering almost  $1/3^{rd}$  of the Earth). The orbit of these satellites is circular. There are three conditions which lead to geostationary satellites. Lifetime expectancy of these satellites is 15 years. 1) The satellite should be placed 37,786 kms (approximated to 36,000 kms) above the surface of the earth.

2) These satellites must travel in the rotational speed of earth, and in the direction of motion of earth, that is eastward.

The inclination of satellite with respect to earth must be 0Geostationary satellite in practical is termed as geosynchronous as there are multiple factors which make these satellites shift from the ideal geostationary condition.

1) Gravitational pull of sun and moon makes these satellites deviate from their orbit. Over the period of time, they go through a drag. (Earth" s gravitational force has no effect on these satellites due to their distance from the surface of the Earth.)

2) These satellites experience the centrifugal force due to the rotation of Earth, making them deviate from their orbit.

3) The non-circular shape of the earth leads to continuous adjustment of speed of satellite from the earth station. These satellites are used for TV and radio broadcast, weather forecast and also, these satellites are operating as backbones for the telephone networks. Disadvantages of GEO: Northern or southern regions of the Earth (poles) have more problems receiving these satellites due to the low elevation above a latitude of 60°, i.e., larger antennas are needed in this case. Shading of the signals is seen in cities due to high buildings and the low elevation further away from the equator limit transmission quality. The transmit power needed is relatively high which causes problems for battery powered devices. These satellites cannot be used for small mobile phones. The biggest problem for voice and also data communication is the high latency as without having any handovers, the signal has to at least travel 72,000 kms. Due to the large footprint, either frequencies cannot be reused or the GEO satellite needs special antennas focusing on a smaller footprint. Transferring a GEO into orbit is very expensive.

2) Low Earth Orbit (LEO) satellites: These satellites are placed 500-1500 kms above the surface of the earth. As LEOs circulate on a lower orbit, hence they exhibit a much shorter period that is 95 to 120 minutes. LEO systems try to ensure a high elevation for every spot on earth to provide a high quality communication link. Each LEO satellite will only be visible from the earth for around ten minutes. Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication. LEOs even provide this bandwidth for mobile terminals with Omni directional antennas using low transmit power in the range of 1W. The delay for packets delivered via a LEO is relatively low (approx 10 ms). The delay is comparable to long-distance wired connections (about 5–10 ms). Smaller footprints of LEOs allow for better frequency reuse, similar to the concepts used for cellular networks. LEOs can provide a much higher e used in remote sensing an providing mobile communicat levation in Polar Regions and so better global coverage.8These satellites are mainly ion services (due to lower latency).

Disadvantages: The biggest problem of the LEO concept is the need for many satellites if global coverage is to be reached. Several concepts involve 50–200 or even more satellites in orbit. The short time of visibility with a high elevation requires additional mechanisms for connection handover between different satellites. The high number of satellites combined with the fast movements resulting in a high complexity of the whole satellite system. One general problem of LEOs is the short lifetime of about five to eight years due to atmospheric drag and radiation from the inner Van Allen belt1. Assuming 48 satellites and a lifetime of eight years, a new satellite would be needed every two months. The low latency via a single LEO is only half of the story. Other factors are the need for routing of data packets from satellite to if a user wants to communicate around the world. Due to the large footprint, a GEO typically does not need this type of routing, as senders and receivers are most likely in the same footprint.

#### 3) Medium Earth Orbit (MEO) satellites:

MEOs can be positioned somewhere between LEOs and GEOs, both in terms of their orbit and due to their advantages and

Disadvantages. Using orbits around 10,000 km, the system only requires a dozen satellites which is more than a GEO system, but much less than a LEO system. These satellites move more slowly relative to the earth" s rotation allowing a simpler system design (satellite periods are about six hours). Depending on the inclination, a MEO can cover larger populations, so requiring fewer handovers.

Disadvantages: Again, due to the larger distance to the earth, delay increases to about 70–80 ms. the satellites need higher transmit power and special antennas for smaller footprints. The above three are the major three categories of satellites, apart from these, the satellites are also classified based on the following types of orbits:

#### 4) Sun- Synchronous Orbits satellites:

These satellites rise and set with the sun. Their orbit is defined in such a way that they are always facing the sun and hence they never go through an eclipse. For these satellites, the surface illumination angle will be nearly the same every time.(Surface illumination angle: The illumination angle is the angle between the inward surface normal and the direction 9of light. This means that the illumination angle of a certain point of the Earth's surface is zero if the Sun is precisely overhead and that it is 90 degrees at sunset and at sunrise.)Special cases of the sun-synchronous orbit are the noon/midnight orbit, where the local mean solar time of passage for equatorial longitudes is around noon or midnight, and the dawn/dusk orbit, where the local mean solar time of passage for equatorial longitudes is around sunrise or sunset, so that the satellite rides the terminator between day and night.

#### 5) Hohmann Transfer Orbit:

This is an intermediate orbit having a highly elliptical shape. It is used by GEO satellites to reach their final destination orbits. This orbit is connected to the LEO orbit at the point of perigee forming a tangent and is connected to the GEO orbit at the point of apogee again forming a tangent.

#### 6) Prograde orbit:

This orbit is with an inclination of less than  $90^{\circ}$ . Its direction is the same as the direction as the rotation of the primary (planet).

#### 7) Retrograde orbit:

This orbit is with an inclination of more than  $90^{\circ}$ . Its direction is counter to the direction of rotation of the planet. Only few satellites are launched into retrograde orbit because the quantity of fuel required to launch them is much greater than for a prograde orbit. This is because when the rocket starts out on the ground, it already has an eastward component of velocity equal to the rotational velocity of the planet at its launch latitude.

This orbit passes above or nearly above both poles (north and south pole) of the planet on each of its revolutions. Therefore it has an inclination of (or very close to) 90 degrees. These orbits are highly inclined in shape.

#### FREQUENCY ALLOCATION FOR SATELLITE

Allocation of frequencies to satellite services s a complicated process which requires international coordination and planning. This is done as per the International Telecommunication Union (ITU). To implement this frequency planning, the world is divided into three regions:

□ Region1: Europe, Africa and Mongolia

□ Region 2: North and South America and Greenland

□ Region 3: Asia (excluding region 1 areas), Australia and south-west Pacific.

Within these regions, the frequency bands are allocated to various satellite services. Some of them are listed below.

□ Fixed satellite service: Provides Links for existing Telephone Networks Used for transmitting television signals

to cable companies

□ Broadcasting satellite service: Provides Direct Broadcast to homes. E.g. Live Cricket matches etc

□ Mobile satellite services: This includes services for:

Land Mobile

Maritime Mobile

Aeronautical mobile

□ Navigational satellite services : Include Global Positioning systems6

□ Meteorological satellite services: They are often used to perform Search and Rescue service Below are the frequencies allocated to these satellites:

Frequency Band (GHZ) Designations:

□ VHF: 01-0.3

UHF: 0.3-1.0

□ L-band: 1.0-2.0

□ S-band: 2.0-4.0

□ C-band: 4.0-8.0

□ X-band: 8.0-12.0

 $\Box$  Ku-band: 12.0-18.0 (Ku is Under K Band)

 $\Box$  Ka-band: 18.0-27.0 (Ka is Above K Band)

□ V-band: 40.0-75.0

□ W-band: 75-110

of the decimator is Mm-band: 110-300

□ µm-band: 300-3000

Based on the satellite service, following are the frequencies allocated to the satellites:

Frequency Band (GHZ) Designations:

□ VHF: 01-0.3 ---Mobile & Navigational Satellite

Services

L-band: 1.0-2.0 --- Mobile & Navigational Satellite

Services

C-band: 4.0-8.0 --- Fixed Satellite Service

□ Ku-band: 12.0-18.0 --- Direct Broadcast Satellite

Services

# UNIT-2

#### **Orbital Mechanic**

100 miles (160 km) enough

• ISS injected into orbit at 397 km on 9 June 1999

• It was down to 360 km by the end of 1999 Is

• Need to raise the orbit or it will decay into the atmosphere times >5 years are at • Most satellites with life500+ miles (800+ km)Orbit Limits

Launced between inward • There must be a gravitational (centripetal) forces and outward centrifugal forces

• Must not be too close to the earth as it will be slowed down by the atmosphere right direction • Velocity must be in the (parallel to earth surface). Locating the Satellite in Orbit - lordinates in orbital • Goal: Find satellite coplane

• Need to develop a procedure that will allow the average angular velocity to be used

• If the orbit is not circular, the procedure is circumscribed circle to use a

• A circumscribed circle is a circle that has a radius equal to the semi-major axis length of the ellipse and also has the same center Locating Satellite with respect to Earth

• The orbital constants define the orbit of the of the CENTER satellite with respect to the earth

• To know where to look for the satellite in space, we must relate the orbital plane and time of perigee to the earth's axis

#### of the decimator is Look Angle

#### Look angles: The coordinates to which an ES must point to communicate with a satellite. These are

(EL) elevation angle (AZ) and azimuth– AZ: The angle measured from N to E to projection of satellite path onto horizontal plane– EL: The angle measured from the horizontal plane to the orbit plane The point, on the earth's subsatellite point  $\cdot$  The surface, of intersection between a line from the Calculating the Look Angle

six Orbital Elements at time Locate •Point of Ariesof the Greenwich Meridian relative to Find location •the first point of Ariesto find the position of Use Spherical Trigonometry • Latitude: • Operational Limitations Need •the orbit from these Orbital Elements Calculate •the orbital plane Define •First with respect to the t satellite

#### • For Geostationary Satellites

**81.3**  $\leq \gamma$ 

• This would give an elevation angle = 0

• Not normal to operate down to zero

• usual limits are C-Band 5

Ku-Band 10

Ka- and V-Band 20

O degrees, north or south of the equator.from -90 to +90 (or from 90S to 90N) LAngular distance, measured in Longitude: •degrees, from a given reference longitudinal line (Greenwich, London). •from geographic north to the projection of the satellite path on a (locally) horizontal Measured upward from Elevation Angle: •the local horizontal plane at the earth station surfaceearth's center to the satellite.

#### **Orbital Perturbation**

Reality: Orbit perturbations - 1

#### **IRREGULAR EARTH:**

It can be modeled as an ellipsoid with a slight bulge at the equator.21 km difference between POLAR and • Irregular gravitational force around the Earth due to non uniform mass distribution.

• Earth is not a sphere EQUATORIAL radiuses on the satellite because • Results in additional forcet from the center of the the gravitational pull is offs

#### OTHER HEAVENLY BODIES:

a two-body solution, but • Orbit calculation is not rather a N-body solution.

• Main external perturbations come from Sun and Moon.

• When satellite is near to those external bodies it receives a stronger gravitational pull.- Moon's gravitational force tends to pull satellite out of equatorial plane (GEO)

• Main effect is change in inclination (geostationary)

#### ATMOSPHERIC DRAG:

- Due to friction caused by collision with atoms and ions.
- Affects more low-orbit satellites.
- Reduces ellipticity of an elliptical orbit, making it more circular.
- Reduces altitude in circular orbits.
- At extreme conditions (very low altitudes), results in loss by burning. orbit). Earth.
- Sun-synchronous orbit benefits from this effect.

#### OTHER PERTURBATIONS:

• Solar radiation pressure: affects large GEO satellites which use large solar arrays. Increases cts north-south axis of orbital eccentricity and affect the satellite.

- Earth's magnetic field
- Meteorites
- Self-generated torques and pressures caused by RF radiation from the antenna.

One of the systems of any object that is set to be launched into space including satellites is the structural sub-system. The structural sub-system of a satellite is mostly a very strong and rugged frame. You may ask, why a satellite would need a very strong frame when it will exist most of its life in space where the environment around it is relatively very quite and relatively low gravitational forces act on it (the environment of weightlessness). The answer is that the strong frame is not needed for space but is needed for the launching process as it is a very violent process that shakes the satellite violently until the satellite reaches its orbit. You would not want a satellite to reach orbit with some broken or deformed parts that may force it to function improperly or even not function at all.

#### Pre-Launch Testing

After the satellite is built and before it is launched, it is subjected to a test called "shake and bake" where it is literally put into an oven that heats its components up and is shaken severely to make sure that all the electronics survive the high and cold temperatures that exist in space. Note that on Earth, things that heat up as a result of being exposed to sun beams usually get cooled by 1 of several methods: conduction (transfer of heat by contact of two objects), radiation (transfer of heat by infrared radiation), and convection (transfer of heat by Brownian motion of fluids). Conduction passing colder air around them. Since air does not exist in space, a satellite that is exposed to the sun will heat up to high temperatures of around will heating satellite cool down Launching Cost

Let us do a little bit of math. Let us compare the amount of fuel different vehicles use to carry

#### cargo:

• Let us say an average small car that carrier 5 people with luggage (something like 5\*70 kg + 100 kg = 450 kg) travels approximately that 10 km for each 1 letter of fuel. Since the lowest grade of fuel costs SR 0.45/letter in our country, this means that it costs approximately SR 0.45 to carry 450 kg a distance of 10 km, which is equivalent to costing SR 0.0001 to carry 1 kg a distance of 1 km. Assume that you had a highway along Earth's equator (40,000 km) that you were driving over. Therefore, it would cost approximately SR 4 to take 1 kg around the world (a distance of 40,000 km). • A Boeing 747 is capable of carrying approximately 500 people with their luggage (500\*70 kg + 10,000 kg = 45,000 kg) a distance of 1 km using approximately 10 letters of fuel. Assuming the jet fuel is the same price as gasoline (that is, SR 0.45 / letter), this would be equivalent to SR 4.5 to carry 45,000 kg a

distance of 1 km, or SR 0.0001 to carry 1 kg a distance of 1 km. Again, this would be roughly equivalent to SR 4 to carry 1 kg around the world (or 40,000 km)

• Comparing the above with taking cargo to space, it costs approximately SR 100,000 tocarry 1 kg to a GEO orbit. WOW. That is so expensive. The point here is that this comparison is unfair. Remember that an airplane or a car carry you horizontally, while a rocket carries you vertically, so you would need much more fuel to travel the roughly 35,000 km upwards than you would need to travel horizontally. In addition, carrying the same weight using an airplane or a car again would consume the same amount of money each time, while it costs money to launch a piece of cargo to space during the launch but it almost costs nothing to keep the cargo traveling in space at a particular orbit at the speed of several km Launch Vehicles Now, how would you launch an object into space? The answer is using something with a rocket engine. Remember that there is no oxygen above approximately 20 km above sea level so a jet engine would not be able to operate. The answer is to carry both rocket fuel and an oxidizer with you in tanks on your rocket. The important question is this: Why are rockets designed such that they have stages? The answer is simple. If you designed your rocket such that it is a single stage, this means that even when the fuel tank is almost empty, you rocket engine would be forced to carry the whole weight of the rocket in addition to the cargo. This is clearly inefficient. The ideal thing would be to have an infinite-stage rocket where the rocket throws away infinitesimally small fuel tanks as the fuel held in each tank is consumed. However, this is also not practical, so they usually design rockets to have two or more stages.

GEO: The best place to launch a GEO satellite would be from a point on Earth's equator. This has two reasons: 1. Launching from a location on the equator places both the LEO and GTO in the same plane of the equator, and therefore the launching rocket or launched satellite does not need to spend some of fuel to its correct the inclination of its original launch orbit to 0, which is needed for a GEO satellite.

2. Earth rotates around its axis. Because Earth is a sphere, the speed at which different points on its surface rotate is a function of the distance of each point from the rotation axis. Therefore, points on the equator rotate at the highest speed. Given this, it makes sense to launch a GEO satellite from a point on the equator because this additional speed it gets from the rotation of Earth itself reduces the consumed fuel of the satellite, and hence extending its life. This may increase the life of a satellite by several months or a year. Effect of Sun on Satellite Operation Previously, we discussed that the Sun's gravity has an effect on the orbit of satellites. However, we are interested here on other effects of the Sun. The two effects here are on the power system and on signal reception from satellites.

1. Satellites get their power from the Sun using solar cells. There is plenty of sun in space however depending on satellite orbits, a satellite may be in the shadow of Earth during part of its period and may not. If a satellite passes through the shadow of Earth, it cannot use solar cells to power itself but will have to depend on power stored in batteries that were charged during the period of solar cell illumination. Sometimes the period over which a satellite will remain in the shadow of Earth may be relatively long for batteries to power the operation of the satellite for that whole period (for example, a communication satellite that use from 10 kWatts of power). In this case, part of the satellite that contains non-essential components may be shut down until the satellite comes out of the region of Earth's shadow.

a. A LEO satellite will pass through Earth's shadow almost in each orbit and will remain in Earth's shadow for almost half of its period each time (around 40 minuets of the 90 minutes). Therefore, the use of batteries is extremely important.

b. A GEO satellite will pass through Earht's shadow only during some parts of the year. During the periods around the equinoxes (Fall and Spring) where the Sun becomes perpendicular on the equator, a GEO satellite will pass through Earth's shadow for periods of time that are less than around 70 minutes per period (or 24 hours). Before and after the equinoxes, the period over which a GEO satellite will be less than this 70 minutes. Far away from these equinoxes, a GEO satellite will be illuminated by the sun for the orbital period.

2. The satellite sometimes may pass exactly between the Sun and Earth (relative to a specific point on Earth). That is, the Sun may appear exactly behind a satellite from a specific point on Earth. In this case, the signal received from the

satellite by an Earth station will be accompanied by a huge amount of noise that orbiginates from the Sun that causes the satellite signal to become useless. This is called SUN OUTAGE. This will to different locations receiving from the same satellite at different times of the year of different times of the day depending on the relative latitudes and longitudes of the locations.

### UNIT-3

The major subsystems required on the communications satellite are:

• Attitude & orbit control system (AOCS), consists of rocketmotors that are used to move the satellite back to the correct orbit when external forces causes it to drift.

• Telemetry, Tracking & Command (TT&C), this is partly on the satellite and partly on the controlling earth station dedicated earth station is used for this purpose.

• Power system (mainly solar cells)

• Communications subsystem, these are the major components of acommunications satellite (transponders & antennas)Attitude & Orbital Control

• AOC system is necessary to ensure that the narrow beamantennas are pointing correctly to the earth, (within ±0.10)

• Several factors make the space craft tend to rotate and wobbleand change orbit (e.g. gravitational forces from sun, moon, andother planets.)

• Different forms of stabilization are used e.g. entire craft is rotatedat 30-100 RPM to provide gyroscopic action by using spinners. 3-axis stabilization using 3 momentum wheels mounted on 3orthogonal axes. Also closed loop control of the attitude.)Telemetry System

• Collects data from many sensors and sends them to the controlearth station.

- Pressure in fuel tanks.
- Current drawn by each subsystem
- Critical voltages & currents
- Temperatures.
- Status & positions of switches
- Sighting devices used to maintain attitude

• Low data rate is used to allow the receiver at the earth station.

Tracking

- The determination of the current orbit and position of thespacecraft.
- Velocity & acceleration sensors are employed.

• The control earth station can observe the Doppler shift of the telemetry carrier to determine the rate of change of the range.

• Triangulation can be used from measurements from several earth stations observing the satellite. Command System

• Secure & effective command structure is vital for the successful launch and operation of a communication satellite.

- The command system is used for:
- Making changes in attitude & orbit correction
- Controlling the communications system
- Controlling the firing of the apogee boost motor
- Spinning up a spinner spacecraft Extending the solar sails of a 3-axis stabilized spacecraft

• Safeguards against errors in received commands are built in command structure. Command originates at the control terminal by converting a control code into a command word which is sent in a TD to the satellite. Validity is checked and sent back via the telemetry link where it is checked again in the computer. If the command word is received correctly, an execute instruction will be sent to the satellite. The entire process takes 5-10 sec. And minimizes the risk of malfunctioning

•Power System

- ► All communication satellites obtain their power from solar cells.
- Solar radiation falling on a geostationary spacecraft has intensity of 1.39 kw/m2( solar cell efficiency is 10-15%).
- ► Efficiency of solar cells falls with time due to aging and etching of the surface.
- Space craft's carry batteries to power the subsystems during launch and eclipses.Communications System
- ► A communications satellite exists to provide a platform in the orbit for relaying of voice, video, and data.
- ► Comm. Satellites are designed to provide the largest traffic

capacity possible. (e.g. the INTELSAT system)

→ The INTELSAT example shows that successive satellites become larger, heavier, more expensive, and handles more traffic. Result: lower cost per telephone circuit.

→ down link design is the critical part due to the limited transmitter power and antenna size and gain.

→ Received power levels ~ 10-10 W. Satisfactory performance (S/N ~5 - 25 dB) depending on the bandwidth of tr. Signal & modulation used.

a  $\rightarrow$  Low power transmitter leads to narrow rec. bandwidth to maintain the required S/N.

→ High power transmitters & more directional antennas enable large bandwidths and increased sat. capacity. trend in high capacity satellites is to reuse the available bands by employing different techniques:

→ multiple directional antenna beams at the same frequency (spatial frequency reuse).

► Orthogonal polarizations at the same frequency (polarization reuse).

→ Example: INTELSAT V achieves and effective bandwidth of 2250MHz in its communication system within 00 MHz band at 6/4 GHz and 250 MHz at the 14/11 GHz by of spatial & polarization reuse.

#### Attitude and Orbit Control System (AOCS)

Control of the attitude of a satellite is necessary so that the antennas, which often have narrow beams, are pointed correctly at the earth. Gravitational forces from the sun, moon, planets, and planets will set up rotational moments on the satellite if it is not perfectly balanced. Also solar pressure acting on antennas, satellite body, and solar sails may create rotational forces. The earth's magnetic field also can produce forces on the satellite if there is net magnetic moment on a satellite.

As the satellite moves around the earth, these forces vary cyclically through a 24 -hour periodThis tends to cause nutation (a wobble) of the satellite which must be damped out mechanically. The variation in gravitational field causes not only attitude changes but also acceleration on the satellite tochange its orbit. The major influence is moon's gravitational field which is about 3 times (it was twice in Section 2.3)stronger than that of the sun at the geostationary altitudes.

The rate of change of inclination is about 0.860 per year for a satellite initially in a geostationary orbit. If no North-South station keeping corrections were applied, the orbit inclination would increase to a maximum of 14.670 from an initial 00 in 26.7 years.

As the earth is not truly spherical, there is a bulge in the equator region of about 65 m at longitudes of 150W and 1650E, the satellite experiences acceleration toward a stable point in the geostationary orbit at



Figure 3.2 Forces on a synchronous satellite.

#### **Attitude Control System**

There are two ways to make a satellite stable when it is in orbit and weightless: spinning the satellite and using momentum wheels. The entire body of satellites can be rotated at 30 to 100 rpm to create a gyroscopic force which providesstability of the spin axis and keeps it pointing in the same direction. Such satellites are known as spinners. The Hughes 376 (now Boeing 376) satellite is an example of a spinner design. stabilized satellite, of which the Hughes (Boeing) 701 series is an example. The momentum wheel is Alternatively, a satellite can be stabilized by one or more momentum wheels. This is called three-axis a solid metal disk driven by an electrical motor.

Increasing the speed of the momentum wheel causes the satellite to process in the opposite direction, according the principle of conservation of the angular momentum .Figure 3.3 shows the examples of the spinner and three-axis design of satellite As shown in Figure 3.1 and Figure 3.3a the spinner consists of a cylindrical drum covered with solar cellsthat contains the power systems and the rocket motors. The communication system is mounted at the top of the drum and is driven by an electric motor in theopposite direction to the rotation of the satellite body to keep the antennas pointing toward the earth. Such systems are called despun. At an appropriate point in the launch phase, the satellite is spun up by operating small radial gas jets on theperiphery of the drum. Then the despin system operates so that the main TT&C antenna could point toward the earth. There are two types of rocket motors used on the satellites: the bipropellant thruster and arc jets or ionthrusters. fuel that is stored on a GEO satellite is used for two

purposes: to fire the apogee kick motor that injects the satellite into its final orbit, and to maintain the satellite in that orbit over its lifetime.



(a)

Figure 3.4 (a) Forces on a satellite.



**Figure 3.5** Principle of N-S control of a spinner satellite using infrared Earth sensors. Figure 3.6 shows a typical control system loop using the technique shown Figure 3.5.

The control system is more complex for a three-axis stabilized satellite than a spinner.

#### **Orbit Control System**

orbit must be circular at a correct altitude on the equatorial plane. If the orbit is not circular, velocity change is to be A geostationary made along the orbit. For altitude correction, Z -axis gas jet is used. The inclination of an orbit increases at about 0.850 per year. Most GEO satellites are specified to remain within in a box of  $\Box 0.050$  and so, in practice, correctionscalled a north-south station-keeping maneuver are made every 2 to 4 weeks to keep the error small.has become normal to split the E-W and N-S maneuvers so that at intervals of 2weeks the E-W



# Telemetry, Tracking, Command, and Monitoring

The TT&C system is essential to the successful operation of a communication satellite. The main functions of satellite management are to control the orbit and attitude of the satellite, monitor thestatus of all sensors and subsystems on the satellite, and switch on or off sections of the communication system. On large geostationary satellites, some re-pointing of individual antennas is also possible, under the functions of a controlling earth station. Figure 3.8 shows the functions of a controlling earth station.



Figure 3.8 Typical tracking, telemetry, command, and monitoring system.

# **Telemetry and Monitoring System**

The telemetry system at the satellite collects data from many sensors within satellite and sends them to the controlling earth station. As many as 100 or more sensors monitor pressure on fuel tanks, voltage and current in the power conditioning unit, critical voltage and current in communication electronics, temperature of subsystems, statusof subsystems, positions of switches, and sighting device for altitude control. Telemetry data is usually transmitted as FSK or PSK of low-power telemetry carrier using time divisiontechniques.Low data rate is normally used to allow the earth station receiver to have a narrow bandwidth and thusmaintain high carrier-to-noise ratio (CNR). An entire TDM frame may contain thousands of bits of data and take several seconds to transmit. Tracking The tracking system at the control earth station provides information about the range, elevation, and azimuthfor a satellite.Data from velocity and acceleration sensors on the satellite can be used to establish the change in the orbitfrom the last known position by integrating data.Doppler shift observation at the control earth station provides the rate of range change. Active determination of range can be achieved by transmitting pulses to the satellite from the control earthstation and measuring its round-trip delay. The position of a satellite can be measured by triangulation from multiple earth stations. The position of a satellite can be determined within 100 m.Command.A secure and effective command structure is vital to the successful launch and operation of any communication satellite. The command system makes changes the position and attitude of the satellite, controls antenna positioningand communication system configuration, and operates switches at the satellite.launch it is used to control the firing of the apogee kick motor (AKM) and to spin up a spinner orextend the solar sails of a three-axis stabilization satellite. The command structure must have safeguards against inadvertent operation of a control due to error. The control code is converted into a command word

which is sent in a TDM frame. After checking for validity in the satellite, the command word is sent back to the control earth station via the link where it is checked again. If it is received correctly, then an execute instruction is sent to the satellite so that the command is executed.



# **Power Systems**

All communications satellites obtain their electric power from solar cells which convert incident sunlight into electrical energy.Some deep space planetary research spacecrafts have used thermonuclear generators to supply electricalpower.But because of the danger to people on the earth in case of launch fail and consequent nuclear spread,communications satellites have not used nuclear generator s. Solar radiation falling on a satellite at

geostationary orbit has an intensity of 1.39 kW/m2 .The efficiency of solar cell is typically 20 to 25 % at the beginning of life (BOL), but falls with timedue to aging of cells and etching of the surface by micrometeor impacts. Since sufficient power must be available at the end of life (EOL) of the satellite to supply all the systems on board, about 15 % extra area of solar cells is usually provided as an allowance for aging.A spin-stabilized satellite has a cylindrical body covered with solar cells.Wireless and Satellite Communications Prof. Jae Hong Lee, SNU Chapter 3. Satellite - 33 - 2nd Semester, 2010Because the cylindrical shape, half of the solar cells are not illuminated at all, and at the edges of theilluminated half, the low angle of incidence of sunlight results in little electric power being generated.Recently a large communication satellite for direct broadcasting generates up to 6 kW from solar power.A three-axis stabil This causes the cells to heat up, typically to 50 to 800 C, which causes a drop in ized satellite can make better use of its solar cell areas than a spinner, since solar sails canbe rotated to maintain normal incidence of the sunlight to the cells.Only one-third of the total area of solar cells is needed relative to a spinner, with some saving in weight.With large arrays, a three-axis stabilized satellite can have more than 10 kW of power generated.In a three-axis stabilized satellite, solar sails must be rotated by an electric motor once every24 hours tokeep the cells in full sunlight. output voltage.In a spinner design, the cells cool down when in shadow and run at 20 to 30 oC , with somewhat higherthan a three-axis stabilized satellite.

#### **Satellite Antennas**

1.Wire antennas: monopoles and dipoles

- 2. Horn antennas
- 3. Reflector antennas
- 4. Array antennas.

Wire antennas are used to provide omni-directional coverage mainly at VHF and UHF for the TT&C systems. As most satellites are only a few wavelength long at VHF frequencies, it is difficult to get the required antenna patterns and there tend to be some orientations of satellite in which the gain for the TT&C system is reduced by nulls in the antenna pattern.

Typical satellite antenna coverage zones are



antenna for the global beam is usually a waveguide horn.Scanning beams and shaped beams require phased array antennas or reflector antennas with phased arrayfeeds.The pattern is specified by its 3-dB beamwidth.

Figure 3.16 The shows the contours of satellite transmit antenna gain expressed by the EIRP of the satelliteantenna and transmitter.

#### **Satellite Antenna in Practice**

In an ideal satellite, there would be one antenna beam for each earth station, completely isolated from all other beams, for transmit and receive. However, if two earth stations are 300 km apart on the earth's surface and the satellite is on the geostationary orbit, their angular separation at the satellite is merely 0.50. For  $3dB \square$  to be 0.50, D must be 150, which requires an aperture diameter of 11.3 m at 4 GHz. Antennas this large have been used on some satellites (for example, ATS-6 deployed 2.5 GHz, 10-mdiameter antenna). However, at 20 GHZ, an antenna with D 150 is only 1.5 m wide, and such an antenna can readily be flown on a 30 / 20 GHz satellite.



Subsatellite point

The largest reflector on the satellite transmits at 4 GHz to produce "peanut" shaped patterns for the zone beams, which are designed to concentrate the transmitted energy onto densely populated areas where muchtelephone traffic is generated. The smaller antennas provide hemisphere transmit and receive beams, and 14/11 GHz spot beams. Note that antenna beamwidth inversely proportional to the square of frequency. In addition, horn antennas provide global beam coverage. In many larger satellites, the antennas use offset paraboloidal reflectors with clusters of feeds to provide controlled beam shapes. The feeds are mounted on the body of the satellite, close to communication subsystems, and the reflector is

mounted on a hinged arm. The reliability of a component can be expressed in terms of the probability of a failure after time t, () F P t .most electronic equipments, probability of a failure is higher at the beginning of life  $\Box$  the burn-in period than at some alter time. As the component ages, failure becomes more likely, leading to the bathtub curve shown in Figure 3.20



# Reliability

We want to know the probability that the subsystem is still working after a given time period, and we need to

provide redundant components or subsystems there the probability of a failure is too great to be accepted.

Components for satellite are selected only after extensive testing.

RedundancyIn a satellite, many devices, each with a different MTTF, are used, and failure of one device may cause catastrophic failure of a complete subsystem.

If redundant devices are incorporated, the subsystem can continue to function correctly.

Consider three different situations shown in Figure 3.21: series connection, parallel connection,

series/parallel connection, and switched connection.



(a)



# (b)

**Figure 3.21** Redundancy connections. (*a*) Series connection, (*b*) Parallel connection. (cont'd) **UNIT-4** 

**Basic Transmission Theory Isotropic Radiator**
- Consider an *isotropic* source radiating P<sub>t</sub> [Watts] of power uniformly into free space
- At distance R from the source, the area of the spherical shell with center at the source is  $4\pi R^2$
- *Power flux density* (power per unit area or *PFD*) at distance R is given by

$$PFD = \frac{P_t}{4\pi R^2} \left[ W / m^2 \right]$$

**Basic Transmission Theory: Isotropic Radiator** 



P<sub>t</sub> Watts

Surface area of sphere enclosing  $P_t = 4\pi R^2$  **Power Flux Density:** 

 $PFD = \frac{P_t}{4\pi R^2} \left[ W / m^2 \right]$ 

Basic Transmission Theory:Effective Isotropic Radiated Power •Effective Isotropic Radiated Power (EIRP), also known as Equivalent Isotropically Radiated Power

•It is the amount of power that would have to be emitted by an isotropic antenna (that evenly distributes power in all directions and is a theoretical construct) to produce the peak power density observed in the direction of maximum antenna gain

•EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna

of the decimator is Basic Transmission Theory:

Rewrite the PFD now considering the transmit antenna gain

$$PFD = \frac{\text{EIRP}}{4\pi R^2} = \frac{P_t G_t}{4\pi R^2} [W/m^2]$$

**Basic Transmission Theory:Path Loss** 

The inverse of the term  $\left(\frac{\lambda}{4\pi R}\right)^2$  is called *path* loss or free space loss,  $L_p$ 

- Accounts for spherical spreading of wave

- Usually written as

$$L_{p} = \left(\frac{4\pi R}{\lambda}\right)^{2}$$
  
So, received power is  
$$P_{r} = \frac{P_{t}G_{t}G_{r}}{L_{p}}$$

This is the basic link budget equation

Measurement of the G/T ratio with the aid of radio stars

# 1 Introduction

It is desirable to establish a practical method of measuring the G/T ratio with high accuracy, which will permit comparison of values measured at various stations. This Annex describes a method for the direct measurement of the G/T ratio using radio stars. It should be noted however, that the radio star method is not practical in certain cases (see § 5).

# 2 Method of measurement

By measuring the ratio, r, of the noise powers at the receiver output, the G/T ratio can be determined using the formula:

$$\frac{G}{T} = \frac{8\pi k (r-1)}{\lambda^2 \Phi(f)} \tag{1}$$

where:

- *k*: Boltzmann's constant  $(1.38 \times 10^{-23} \text{ J/K}^{-1})$
- $\lambda$ : wavelength (m)
- $\Phi(f)$ : radiation flux-density of the radio star as a function of f, frequency (W/(m<sup>2</sup> · Hz))
- $r = (P_n + P_{st}) / P_n$

 $P_n$ : noise power corresponding to the system noise temperature T

 $P_{st}$ : additional noise power when the antenna is in exact alignment with the radio star *G* (antenna gain) and *T* (system noise temperature) are referred to the receiver input.

In equation (1), account is taken of the fact that the radiation of the star is generally randomly polarized and only a portion corresponding to the received polarization is received. The radiation flux-density  $\Phi(f)$ is obtained by radio astronomical measurements.

This method has a basic advantage when compared with the calculation of G/T from G and T measured separately as only one relative measurement is necessary to determine the ratio, instead of two absolute measurements.

# 3 Suitable radio stars

The discrete radio sources Cassiopeia A, Cygnus A and Taurus A appear to be the most appropriate for measurements of G/T by earth stations in the Northern Hemisphere, while Orion, Virgo and Omega are similarly appropriate for earth stations in the Southern Hemisphere. The flux-densities of Cygnus A and Virgo, however, may not be sufficient in every case. Table 1 gives values of the flux-density of the radio stars indicated, where the frequency is between 1 and 20 GHz.

#### TABLE 1

Flux-densities from radio sources

Basic Transmission Theory:Effective Isotropic Radiated Power •Effective Isotropic Radiated Power (EIRP), also known as Equivalent Isotropically Radiated Power

•It is the amount of power that would have to be emitted by an isotropic antenna (that evenly distributes power in all directions and is a theoretical construct) to produce the peak power density observed in the direction of maximum antenna gain

•EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna Basic Transmission Theory:

Rewrite the PFD now considering the transmit antenna gain

$$PFD = \frac{\text{EIRP}}{4\pi R^2} = \frac{P_t G_t}{4\pi R^2} [W/m^2]$$

**Basic Transmission Theory: Path Loss** 

The inverse of the term  $\left(\frac{\lambda}{4\pi R}\right)^2$  is called *path* loss or free space loss,  $L_p$ 

- Accounts for spherical spreading of wave
- Usually written as

$$L_{p} = \left(\frac{4\pi R}{\lambda}\right)^{2}$$
  
So, received power is  
$$P_{r} = \frac{P_{t}G_{t}G_{r}}{L_{p}}$$

- This is the basic link budget equation

Measurement of the G/T ratio with the aid of radio stars

# 1 Introduction

It is desirable to establish a practical method of measuring the G/T ratio with high accuracy, which will permit comparison of values measured at various stations. This Annex describes a method for the direct measurement of the G/T ratio using radio stars. It should be noted however, that the radio star method is not practical in certain cases (see § 5).

# 2 Method of measurement

By measuring the ratio, r, of the noise powers at the receiver output, the G/T ratio can be determined using the formula:

$$\frac{G}{T} = \frac{8\pi k (r-1)}{\lambda^2 \Phi(f)} \tag{1}$$

where:

- *k*: Boltzmann's constant  $(1.38 \times 10^{-23} \text{ J/K}^{-1})$
- $\lambda$ : wavelength (m)
- $\Phi(f)$ : radiation flux-density of the radio star as a function of f, frequency (W/(m<sup>2</sup> · Hz))
- $r = (P_n + P_{st}) / P_n$

 $P_n$ : noise power corresponding to the system noise temperature T

 $P_{st}$ : additional noise power when the antenna is in exact alignment with the radio star *G* (antenna gain) and *T* (system noise temperature) are referred to the receiver input.

In equation (1), account is taken of the fact that the radiation of the star is generally randomly polarized and only a portion corresponding to the received polarization is received. The radiation flux-density  $\Phi(f)$ is obtained by radio astronomical measurements.

This method has a basic advantage when compared with the calculation of G/T from G and T measured separately as only one relative measurement is necessary to determine the ratio, instead of two absolute measurements.

# 3 Suitable radio stars

The discrete radio sources Cassiopeia A, Cygnus A and Taurus A appear to be the most appropriate for measurements of G/T by earth stations in the Northern Hemisphere, while Orion, Virgo and Omega are similarly appropriate for earth stations in the Southern Hemisphere. The flux-densities of Cygnus A and Virgo, however, may not be sufficient in every case. Table 1 gives values of the flux-density of the radio stars indicated, where the frequency is between 1 and 20 GHz.

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#### TABLE 1

#### Flux-densities from radio sources

Radio source	Flux-density at $f$ GHz (W/(m <sup>2</sup> · Hz))
Cassiopeia A	$\Phi(f)_{Cass A} = 10^{-26} \times 10^{[5.745 - 0.770 \log_{10}(1000f)]^{(1)}}$
Taurus A	$\Phi(f)_{TauA} = 10^{-26} \times 10^{[3.794 - 0.278\log_{10}(1000f)]}$
Cygnus A	$\Phi(f)_{CygA} = 10^{-26} \times 10^{[7.256 - 1.279 \log_{10}(1000f)]}$
Orion	$\Phi(f)_{Orion} = 10^{-26} \times 10^{[3.317 - 0.204 \log_{10}(1000f)]}$
Virgo	$\Phi(f)_{Virgo} = 10^{-26} \times 10^{[6.541 - 1.289 \log_{10}(1000f)]}$
Omega	$\Phi(f)_{Omega} = 10^{-26} \times 10^{[4.056 - 0.378 \log_{10}(1000f)]}$

<sup>(1)</sup> Value of January 1980 (see § 4.2).

$$\Phi(f) = \frac{4 \pi k T b(f)}{\lambda^2} \left(1 - \cos \psi\right)$$

(2)

where:

Tb(f): brightness temperature of a planet (K)

 $\psi$ : semi-diameter.

The value of  $\Phi(f)$  derived from equation (2), is substituted in equation (1) to obtain the value of G/T of an earth station. The value of  $\psi$  can be found elsewhere in American Ephemeris and Nautical Almanac (US Government Printing Office, Washington DC 20402). In the case of the planet Venus, the values Tb(f)are thought to be about 580 K and 506 K at 15.5 and 31.6 GHz, respectively. Since the values of Tb(f) are based on a limited amount of measured data at the frequencies mentioned, and have not yet been determined for other frequencies, further study is required to confirm and extend the results given here.

## **4** Correction factors

The corrected value of G/T is given by:

(G/T)c ? G/T ? C1 ? C2 ? C3

(3)

where:

- C1: correction for atmospheric absorption
- C2: correction for angular extension of radio stars
- C3: correction for change of flux with time.

All factors to be given in decibels.

The value of atmospheric absorption C1 can be estimated using § 2.2 of Recommendation ITU-R P.676.

## 4.1 Angular extension of radio stars

If the angular extension of the radio star in the sky is significant compared with the antenna beamwidth, a correction must be applied. The following equations are close approximations for the angular extension correction factor, C2, also plotted in Fig. 1.

$$C_2 \approx -10 \log_{10} \left[ \frac{ABS(1 - e^{-\chi^2})}{\chi^2} \right]$$

where:

$$\chi_{Cass\ A} \approx \chi_{Tau\ A} \approx \chi_{Orion} \approx \chi_{Virgo} \approx \chi_{Omega} \approx \frac{4.6}{1.2012\theta_{3\,dB} \times 60}$$

$$\chi_{Cyg A} \approx \frac{2.5}{1.2012\theta_{3 dB} \times 60}$$

 $\theta_{3 \, dB} = \frac{62 \, \lambda}{D}$ 

: 3 dB beamwidth (degrees)

 $\lambda$  : wavelength (m)

D : antenna diameter (m).



### FIGURE 1 Correction factor for the angular extension of radio stars

## FIGURE 1/S.733...[D01] = 3 CM

The measured brightness distribution for Cygnus A can be adequately described by a dual columnar shape with 0.02 min of arc in each column's diameter and 2.06 min of arc in angular distance.

If the annular model for Cassiopeia A and the dual columnar model for Cygnus A are adopted, a convenient approximation is available for the correction factor. These models may also be useful to measure the half-power beamwidth of antennas by observing the half intensity width of the drift curve. This also means that the correction factor for the angular extension of radio stars can be determined from the observed drift curve itself without the knowledge of the half-power beamwidth of the antenna.

## 4.2 Change of flux with time

Cassiopeia A is subject to a frequency dependent reduction of flux with time. The correction may be obtained from:

$$C_3 = -10\log_{10} \left[ 1 - \frac{0.97 - 0.3\log_{10} f}{100} \right]^n \qquad \text{dB}$$
(4)

where:

n : number of years elapsed, with n 2 0 in January 1980

f: frequency (GHz).

System Configuration

The block diagrams of a two-link satellite communication system is shown in Fig. 9.1. Thetransmitted path form an earth station to the satellite is referred to as 'uplink' and the transmitted path from the satellite to an earth station as 'downlink'. The on-board repeater may contain one or more transponders (a transponder is asingle on-board RF channel). Uplink Downlink There are two types of transponders: transparent (amplifying) and regenerative types.

single on-board RF channel).



Fig. 9.1

There are two types of transponders: transparent (amplifying) and regenerative types.

Unit 5

Access Techniques

With the increase of channel demands and the number of earth stations, efficient use of a satellite transponder in conjunction with many stations has resulted in the development of multiple access techniques. Multiple access is a technique in which the satellite resource (bandwidth or time) is divided into a number of non overlapping segments and each segment is allocated exclusively to each of the large number of earth stations who seek to communicate with each other. There are threeknown multiple access techniques. They are:

(1) Frequency Division Multiple Access (FDMA)

(2) Time Division Multiple Access (TDMA)

(3) Code Division Multiple Access (CDMA)

9.5.1 Frequency Division Multiple Access (FDMA)

The most widely used of the multiple access techniques is FDMA. In FDMA,

the available satellite bandwidth is divided into portions of non-overlapping frequency slots which are assigned exclusively to individual earth stations. A basic diagram of an FDMA satellite system is shown in Fig. 9.22.



Examples of this technique are FDM/FM/FDMA used in INTELSAT II & III andSCPC satellite systems. Also, SPACE (signal-channel-per-carrier PCM multipleaccess demand assignment equipment) used in INTELSAT IV in which channels areassigned on demand to earth stations is considered as a FDMA system. In FDMA systems, multiple signals from the same or different earth stations with different carrier frequencies are simultaneously passed through a satellitetransponder. Because of the nonlinear mode of the transponder, FDMA signals with each other causing intermodulation products (intermodulation noise) which are signals at all combinations of sum and difference frequencies as shown in the example given in Fig. 9.23.Fig. 9.23The power of these intermodulation products represents a loss in the desired signalpower. In addition, if these intermodulation products appear within the bandwidth of the other signals, they act as interference for these signals and as a result the BER Nonlinear

#### Time Division Multiple Access (TDMA)

In search of an alternative multiple access technique; attention was focused on the possibilities afforded by TDMA. In TDMA, the sharing of the communicationresource by several earth stations is performed by

assigning a short time (time slot) toeach earth station in which they have exclusive use of the entire transnsponder bandwidth and communicate with each other by means of non-overlapping burst of signals. A basic TDMA system is shown in Fig. 9.24. In TDMA, the transmit timing of the bursts is accurately synchronized so that the transponder receives one burst at a time. Each earth station receives an entire burst stream and extracts the bursts intended for it. A frame consists of a number of bursts originating from a community of earth stations in a network. A TDMA frame structure is shown in Fig. 9.25. consists of two reference bursts RB1and RB2, traffic bursts and the guard time between bursts [10]. As can be seen, each TDMA frame has two reference bursts RB1and RB2. The primary reference burst (PRB), which can be either RB1 or RB2, istransmitted by one of the earth stations in the network designated as the primaryreference earth station. For reliability, a second reference burst (SRB) is transmittedby a secondary reference earth station. To ensure undisrupted service for the TDMA network, automatic switchover between these two reference stations is provided. Thereference bursts carry no traffic information and are used to provide synchronization for all earth stations in the network. The traffic bursts carry information from the traffic earth station. Each earthstation accessing a transponder may transmit one or two traffic bursts per TDMAframe and may position them anywhere in the frame according to a burst time planthat coordinates traffic between earth stations in the network. The Guard time between bursts ensures that the bursts never overlap at theinput to the





Multiple spot beam operation for the uplink and downlink transmissions. The interconnection between the uplink and downlink beams is performed by a high-speed switch matrix located at the heart of the satellite. An SS-TDMA scheme provides a full interconnection of TDMA signals among various coverage regions by means of interconnecting the corresponding uplink and downlink beams at a switching time. Figure 9.27 shows a three-beam (beams A, B and C) example of a SS-TDMA system Fig.



The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time. In this figure, three different traffic patterns during time slot intervals T1, T2 and T3, with three different switch states s1, s2 ands3 are also shown. The switching sequence is programmed via a ground control so thatstates can be changed from time to time. The advantages of SS-TDMA systems over TDMA systems are:

(1) The possibility of frequency re-use by spot-beam spatial discrimination, i.e. the same frequency band can be spatially re-used manytimes. Hence, a considerable increase in satellite capacity ca which provides a high gain for the coverage region. Hence, a power saving can be obtained in both the uplink anddownlink. An SS-TDMA scheme has been planned for INTELSAT VI and Olympus satellites.9.5.3 Code division multiple access (CDMA)In CDMA satellite systems, each uplink earth station is identified by anaddress code imposed on its carrier. Each uplink earth station uses the entirebandwidth transmits through the satellite whenever desired. No bandwidth or timesharing is required in CDMA satellite systems. Signal identification is achieved at areceiving earth station by recognising the corresponding address code. There are three CDMA techniques as follows:

1. Direct sequence CDMA (DS-CDMA)

In this technique, an addressed pseudo-noise (PN) sequence generated by the PN code generator of an uplink earth station together with the information data are



Fig. 9.27





. The same PN sequence is used synchronously at the receiving earth station to despread the received signal inorder to receive the original data information (Fig. 9.28b). Information data

of the decimator is







The bits of the PN sequence are referred to as chips. The ratio between the chip rateand information rate is called the spreading factor. Phase-shift-keying modulationschemes are commonly used for these systems. The most widely used binary PN sequence is the maximum length linearfeedback shift register sequence (m-sequence) which is generated by an m-stage shiftregister. The m-sequence has a period of 2 m - 1. Table 2.3 gives the properties of thesequence sets which exhibit small peak cross-correlation values suitable for DSCDMAX There are two types of DS-CDMA techniques: synchronous and asynchronous. In a synchronous system, the entire system is synchronized in such a way that the PNsequence period (code period) or bit duration of all the uplink carriers in the systemare in time alignment at the satellite. This requires that all stations have the same PNsequence period and the same number of chips per PN sequence length. Hence, asynchronous DS-CDMA must have the type of network synchronization used in aTDMA system but in a much simpler form. However, in an asynchronous DS-CDMAsatellite no time alignment of the PN sequence period at the satellite is required andeach uplink carrier operates independently with no overall networksynchronization. Therefore, the system complexity is much simpler than a synchronous system.

#### 2. Frequency hopping CDMA (FH-CDMA)

The block diagram of an FH-CDMA transmitter/receiver is shown in Fig. 9.29 There are two types of DS-CDMA techniques: synchronous and asynchronous.In a synchronous system, the entire system is synchronized in such a way that the PNsequence period (code period) or bit duration of all the uplink carriers in the systemare in time alignment at the satellite. This requires that all stations have the same PNsequence period and the same number of chips per PN sequence length. Hence, asynchronous DSCDMA must have the type of network synchronization used in aTDMA system but in a much simpler form. However, in an asynchronous DS-CDMAsatellite no time alignment of the PN sequence period at the satellite is required andeach uplink carrier operates independently with no overall networksynchronization.Therefore, the system complexity is much simpler than a synchronous system. 2. Frequency hopping CDMA (FH-CDMA)

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#### UNIT6

e has always fascinated people on the carth and communication through space evolved as an offshoot of ideas for space travel. The earliest idea of using artificial satellites for communications is found in a science fiction Brick Moon by Edward Evert Hale, published in 1869-70. While the early fictional accounts of satellite and space communications bear little resemblance to the technology as it exists to day, they are of significance since they represent the origins of the idea from which the technology eventually evolved. In the area of satellite communications, the technology has been responsive to the imaginative dreams. Hence it is also expected that technological innovations will lead the evolution of satellite communications towards the visions of today.

## CONCEPT OF SATELLITE COMMUNICATIONS

Scientists from different countries conceived various ideas for communications through space along with the technological breakthroughs in different fields of science. The Russian scientist Konstantin Tsiolkovsky (1857-1935) was the first person to study space travel as a science and in 1879 formulated his Rocket Equation, which is still used in the design of modern rockets. He also wrote the first theoretical description of a man- made satellite and noted the existence of a geosynchronous orbit. But he did not identify any practical applications of geosynchronous orbit. The noted German Scientist and rocket expert, Hermann Oberth, in 1923 proposed that the crews of orbiting rockets could communicate with remote regions on earth by signaling with mirrors. In 1928, Austrian Scientist Hermann Noordung suggested that the geostationary orbit might be a good location for manned space vehicle. Russian Scientists in 1937 suggested that television images could be relayed by bouncing them off the space vehicles. During 1942-1943, a series of articles by George O Smith were published in Astounding Science Fictions concerning an artificial planet, Venus Equilateral, which functioned as relay station between Venus and Earth Station when direct communication was blocked by Sun. However, Arthur C. Clarke, an electronic engineer and the well-known science fiction writer is generally credited with originating the modern concept of Satellite Communications. In 1945, Clarke, in his article `Extra Terrestrial Relays: Can Rocket Stations give Worldwide Radio Coverage?' published in Wireless World outlined the basic technical considerations involved in the concept of satellite communications. Clarke proposed orbiting space stations, which could be provided with receiving and transmitting equipment and could act as a repeater to relay transmission between any two points of the hemisphere beneath. He calculated that at an orbital radius of 42,000 km. the space station's orbit would coincide with the earth's rotation on its axis and the space station would remain fixed as seen from any point on the earth. He also pointed out

that three such synchronous stations located 120 degrees apart above the equator could provide worldwide communications coverage. The concept was later considered to be generating a billion dollar business in the area of communications. However, Clarke did not patent the most commercially viable idea of twentieth century as he thought satellites would not be technically and economically viable until the next century.

## REALISATION OF CONCEPT TO REALITY

In October 1957, the first artificial satellite Sputnik -I was launched by former Soviet Russia in the earth's orbit and in 1963 Clark's idea became a reality when the first geosynchronous satellite SYNCOM was successfully launched by NASA.

The realization of the concept of satellite communications from an idea to reality has been possible due to a large number of technological breakthroughs and practical realization of devices and systems, which took place during and after the World War II. The pressures of international military rivalry during cold war period were also able to a great extent to push scientific and technological research and development far faster than it would have been possible if applied for peaceful purposes.

The successful launching of communications satellite in earth's orbit was possible because of keen interests shown by specific groups of people along with the developments in diverse areas of science and technology. Some of these factors, which are considered important in the realization of satellite communications, are:

- Development of high power rocket technology and propulsion systems capable of delivering satellites in high altitude orbits
- Scientific and military interests in Space Research
- Development of Transistors and miniaturization of electronic circuitry.
- Development of Solar Cells for providing sustained energy source for the satellite.
- Development of high-speed computers for calculating and tracking orbits.
- Government support in large-scale financial commitment to Space Technology Development for Military, Scientific Experiments and Civilian Applications.

- International military rivalry among super powers.
- The psychological impact of Sputnik Challenge leading to long range program of scientific research and development undertaken by US.

Before the transformation of the concept of communications by satellite to blue print and subsequent development of the hardware took place it was necessary to make the scientific communities convinced about the technical feasibility of such a system. In US J.R. Pierce, of Bell Laboratories initiated this by promoting the idea of transoceanic satellite communications within the scientific and technical communities. In 1955 Pierce in a paper entitled Orbital Radio Relays proposed detailed technical plan for passive communications satellites, disregarding the feasibility of constructing and placing satellites in orbit. He proposed three types of repeaters.

- Spheres at low altitudes
- A plane reflector
- An active repeater in 24 Hr. orbit

Pierce concluded his paper with a request to the scientific community to develop rockets capable of launching communications satellite. Fortunately, scientific and military interest in rocketry after World War II contributed in the development of a number of rockets like Atlas, Jupiter and Thor rockets in US and different multistage rockets in former USSR that ultimately made the launching of satellites in orbit possible.

On Oct. 4, 1957, Sputnik-1 was launched as part of Russia's program for International Geophysical Year. The launching of Sputnik marks the dawn of the space age and the world's introduction to artificial satellite. Mass of Sputnik was only 184 lbs. in an orbit of 560 miles above the earth. It carried two radio transmitters at 20.005 MHz and 40.002 MHz. However this space craft was far more than a scientific and technical achievement as it had a tremendous psychological and political impact particularly on United States resulting in a technological competition between United States and Russia, long term planning in Space Research and establishment of NASA.

Four months after the launch of Sputnik, US Explorer-1 was launched in January 1958 by a Jupiter rocket and the space race between Russia and US began.

### EVOLUTION OF COMMUNICATION SATELLITES

During early 1950s, both passive and active satellites were considered for the purpose of communications over a large distance. Passive satellites though successfully used in the early years of

satellite communications, with the advancement in technology active satellites have completely replaced the passive satellites.

**Passive Satellites** 

The principle of communication by passive satellite is based on the properties of scattering of electromagnetic waves from different surface areas. Thus an electromagnetic wave incident on a passive satellite is scattered back towards the earth and a receiving station can receive the scattered wave. The passive satellites used in the early years of satellite communications were both artificial as well as natural.

In 1954, the US Naval Research Laboratory successfully transmitted the first voice message through space by using the Moon to scatter radio signal. These experiments resulted in the development of Moon-Relay System, which became operational in 1959 for communications between Washington, DC and Hawaii and remained operational till 1963.

The first artificial passive satellite Echo-I of NASA was launched in August 1960. Echo-I was 100-ft. diameter inflatable plastic balloon with aluminum coating that reflected radio signals transmitted from huge earth station antennas. Echo-I had an orbital height of 1000 miles. Earth Stations across US and Europe picked up the signal and contributed a lot in motivating research in communication satellite.

Echo-I was followed by Echo-II in 1964. With Echo-II, Scientists of US and Soviet Russia collaborated for the first time on international space experiments. Signals were transmitted between University of Manchester for NASA and Gorki State University in Russia. The orbit of Echo-II was 600 to 800 miles.

In 1963, US Air Force under Project West Ford launched an orbital belt of small needles at 2000 miles height to act as a passive radio reflector. Speech in digitized form was transmitted intelligently via this belt of needles. However, further work in this area was discontinued due to strong protests from the astronomers.

Although passive satellites were simple, the communications between two distant places were successfully demonstrated only after overcoming many technical problems. The large attenuation of the signal while traveling the large distance between the transmitter and the receiver via the satellite was one of the most serious problems. The disadvantages of passive satellites for communications are:

- Earth Stations required high power (10 kW) to transmit signals strong enough to produce an adequate return echo.
- Large Earth Stations with tracking facilities were expensive.

- Communications via the Moon is limited by simultaneous visibility of the Moon by both the transmit and the receive stations along with the larger distance required to be covered compared to that of closer to earth satellite.
- A global system would have required a large number of passive satellites accessed randomly by different users.
- Control of satellites not possible from ground.

### **Active Satellites**

In active satellites, which amplify and retransmit the signal from the earth have several advantages over the passive satellites. The advantages of active satellites are:

- Require lower power earth station
- Less costly
- Not open to random use
- Directly controlled by operators from ground.

Disadvantages of active satellites are:

- Disruption of service due to failure of electronics components on-board the satellites
- Requirement of on-board power supply
- Requirement of larger and powerful rockets to launch heavier satellites in orbit

World's first active satellite SCORE (Satellite Communication by Orbiting Relay Equipment) was launched by US Airforce in 1958 at orbital height of 110 to 900 miles. It transmitted a pre-recorded message of Christmas Greetings from US President Eisenhower. However, the satellite did not function as a true repeater.

The first fully active satellite was Courier launched into an orbit of 600 - 700 mile, by Department of Defense in 1960. It accepted and stored upto 360,000 Teletype words as it passed overhead and rebroadcast them to ground station farther along its orbit. It operated with 3 watts of on-board output power and it was also the first satellite to use solar cells for generating electrical power.

In July 1962 AT&T's active satellite Telstar was developed and launched. Telstar was placed in an elliptical orbit with orbital height of 682 to 4030 miles circling the earth in 2 hours and 40 min. Through Telstar, the first live transatlantic television was transmitted. Voice, television, fax and data were transmitted between various sites in UK, France, Brazil Italy and US at 6/4 GHz frequency range.

Relay-I satellite of RCA & NASA, was the first satellite to carry redundant system for increasing the reliability. Telephone & Television signals were transmitted to Europe, South America and Japan. Frequency bands of 4.2/1.7 GHz and orbit heights of 942 to 5303 miles were used.

Syncom, the first geosynchronous satellite of NASA was built by Hughes Aircraft Co. and was launched in July 1963 and was used for conducting many experiments. Most famous of the series Syncom-III was

launched in 1963 and was used to transmit Tokyo Olympic games to United States, demonstrating the commercial market for space technology. Syncom-I and-II were used by Department of Defense for military purpose. The Syncom Satellites marked a turning point in the development of Satellite Communications as most of the commercial satellites that followed were designed to operate from geosynchronous orbit.

Table-1 gives the major milestones of Space Radio Communications events, prior to the start of commercial satellite communications service by INTELSAT. **TABLE - 1** 

Category	Year	Activity	Person/Agency/ Country.
Geostationary	1945	Suggestion of Geostationary satellite	A. Clark ( U.K )
concept		communication feasibility.	
	1946	Detection of Lunar Echo by Radar	J. Mofenson
Moon Reflection			(U.S.A.)
	1954	Passive relaying of voice by moon	J.H. Trexler
		reflection.	( U.S.A. )
	1960	Hawaii-Washington, D.C.	U.S.A. Navy.
		Communication by Moon Reflection.	
	1957	Observation of signals from Sputnik -1	U.S.S.R., Japan and
		Satellite.	others.
	1958	Tape-recorded voice transmission by	U.S.A. Air Force.
		Satellite SCORE.	
	1960	Meteorological facsimile Trans mission	U.S.A. NASA
		by Satellite Tiros-1.	
Low altitude			
orbit.			
	1960	Passive relaying of telephone and	U.S.A. Army.
		television by Satellite Echo-1.	

### MAJOR MILESTONES OF SPACE RADIO COMMUNICATIONS

	1960	Delayed relaying of recorded voice by	U.S.A. Army.
		Satellite Courier-1B.	
	1962	Active transatlantic relaying of	U.S.A., U.K.,
		communication by Satellite Telstar-1.	France.
	1962	Communication between manned	U.S.S.R.
		Satellites Vostok-3 and 4; Space	
		television transmission.	
	1963	Scatter communication by tiny needles in Orbit.	U.S.A. MIT.
		( West Ford Project 6 )	
	1963	Active transpacific relaying of	U.S.A. NASA, Japan.
		communication by Satellite Relay 1.	
	1963	USA-Europe-Africa communication by	U.S.A. NASA
		Satellite Syncom 2.	
Synchronous Satellite.			
	1964	Olympic Games television relaying by	U.S.A., NASA
		Satellite Syncom 3	Japan.
	1965	Commercial Communication (Semi- experimental) by Satellite Early Bird.	INTELSAT.

## SATELLITE COMMUNICATIONS SYSTEMS

Historically, commercial operational satellite communications systems were developed after having working experience with a large number of experimental satellite systems launched to demonstrate the various aspects of satellite communications. Initially the commercial satellite communications systems were meant for meeting the needs of international transoceanic communications. The trend was for establishing only a few large earth stations in any country for overseas communications. In the early years of satellite communications, the earth stations were large due to low transmit power available from the satellites. Over the years the trend has been reversed as with the advancement of technology, higher transmitted power is available from the satellites. This has reduced the size and the cost of the

earth stations. Thus the trend is now on the use of thousands of small earth stations and portable hand held terminals, for meeting the various specialized communications needs. Moreover, apart from international system a number of Regional, Domestic, and military systems are now in operations worldwide. From the traffic point of view, emphasis was initially more on point-to-point telephone, telex etc, and to some extent on Television broadcasting. The present trends however are on Direct To Home television broadcasting and VSAT based data communications using small antenna systems deployed on rooftops or on one's backyards. Finally, it is expected that the satellite communications will meet the ultimate goal of hand held personal communications of voice and data for anyone from anywhere and anytime.

Different types of Satellite Communications Systems are:

- Experimental
- International
- Regional
- Domestic
- Military
- Navigational and Radio Determination
- Personal Communications System
- Broadband Satellite System

Experimental Satellite Communications Systems

For the purpose of test and evaluation of new technologies a number of satellites have been designed and operated for technical experiments. Various experiments have also been conducted using these satellites for demonstrating different applications of communications satellites. Prominent among these experimental satellites are:

- Applications Technology Satellite Series (ATS-1, ATS-3, ATS-5 & ATS-6) of NASA.
- Joint Canadian US Communications Technology Satellite (CTS or Hermes)
- Advanced Communications Technology Satellite (ACTS) of NASA.
- APPLE (Ariane Passenger Payload Experiment) Satellite of India.
- Symphonie Satellite (France & Germany).
- SIRIO (Italy)
- LES (US military)
- OTS (ESA)
- JBS, CS (Japan)

International Satellite Systems

Currently only a part of the world's long distance telecom traffic is handled by different international satellite communications systems. However, for international broadcasting of television there is no alternative to satellite communications. Examples of various international satellite systems are:

- INTELSAT
- New Skies Satellites
- PanAmSaT
- INTERSPUTNIK
- INMARSAT
- COSPAS-SARSAT

INTELSAT: Recognizing that Satellite Communications would be an important means for international cooperation, in July 1961, President Kennedy of US invited all nations to participate in a communication satellite system in the interest of world peace and brotherhood among peoples throughout the world.

In Dec. 1961, UN endorsed the US proposal regarding the desirability of a global system of communication satellites because it could

- Forge new bonds of mutual knowledge and understanding between people everywhere
- Offer a powerful tool to improve literacy and education in developing areas
- Support world weather services by speedy transmittal of data
- Enable leaders of nations to talk face to face on a convenient and reliable basis

The UN unanimously adopted General Assembly Resolution, which stated that:

`Communications by means of satellite should be available to the nations of the world as soon as practicable on a global and nondiscriminatory basis'.

In August 1962, US Government passed Communications Satellite Act. Its purpose was to establish a commercial communications system utilizing satellites, which would serve the needs of the US and other countries and contribute to world peace and understanding. The significance of the choice of a single system for international communications is economic, technical and political.

In August 1964, the final negotiations for the international satellite system were completed and nineteen nations became the founding members of International Telecommunications Satellite Organization (INTELSAT) with Headquarters in Washington D.C, USA. These nineteen nations are Australia, Austria, Belgium, Canada, Denmark, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, United States and Vatican City. Over the years the number of member governments grew to 144.

In April 1965, Early Bird (INTELSAT-I) was launched starting the commercial international satellite services. Within four years the INTELSAT system grew from the single transatlantic link to the global network with high capacity INTELSAT satellites positioned over the Atlantic, Pacific and Indian Ocean Regions. The 240 voice circuit capacity of the Early Bird is miniscule in comparison to the channel capacity of the latest INTELSAT satellites which caters to tens of thousands of telephone channels in addition to providing TV, data, fax, telex and Internet services to more than 200 countries and territories.

With the improvement in life of the satellites, introduction of latest communication techniques, and the availability of more channel capacity, the tariff of Intelsat has also been reduced considerably over the years.

In the 1960's at the time of establishment of Intelsat, the satellite Communication Industry was not well developed. The international telecommunications was also not considered suitable for handling by private companies. However, the skepticism changed after successful privatization of telecommunications departments in many countries during the last few decades of the twentieth century. Since in highly competitive telecommunications market, private enterprises are in a position to provide better and cheaper services compared to the international organizational set up of Intelsat, ideas for privatization of Intelsat were mooted. Privatization places Intelsat on a level playing field to better address opportunities of the telecommunications marketplace. Streamlined decision-making is expected to make it easier to expand the business and introduce new services. Considering these, in November 2000, the representatives of all member governments of Intelsat unanimously approved a plan to privatize Intelsat.

The approved plan endorses the transfer of all assets, liabilities and operations to a private Bermuda based company known as Intelsat Ltd., and its 100 % subsidiaries. In accordance with its heritage as a

global satellite communications services provider to all countries, Intelsat Ltd. will continue to honour a clear set of public service commitments on a commercial basis. These include

- Global coverage and global connectivity
- Service to "lifeline" customers around the world according to specific Lifeline Connectivity Obligation Contracts
- Non-discriminatory access to the Intelsat Ltd. Satellite fleet

A small separate and independent inter governmental office will monitor the private company's implementation of these public service commitments. Privatization of INTELSAT is expected to be completed in 2001.

New Skies Satellites N.V (New Skies) is formed through the partial privatization of Intelsat. It is a wholly independent satellite service provider starting its services through five in orbit satellites transferred from Intelsat fleet. New Skies, with headquarters at The Hague, Netherlands, began operations as a commercial spin off from Intelsat in November 1998, with three satellites in Atlantic Ocean Region, one each in the Indian & Pacific Ocean Region and appropriate ground facilities around the world. These satellite and the ground facilities provide complete global coverage at C band and high powered Ku band spot beams over most of the world's principal population centers. It offers video, voice, data and Internet communications links for broadcast networks, telephone carriers, enterprise customers and ISPs.

PanAmSat Corporation, based in Greenwich, Conn. / USA, is a leading provider of global video and data broadcasting services via satellites. The company builds, owns and operated networks that deliver entertainment and information to cable television systems, TV broadcast affiliates, telecommunications companies and corporations with a large fleet of 21 satellites in orbit as on 2001.

INTERSPUTNIK: The Intersputnik International Organization of Space Communications with headquarters at Moscow was established in 1971, according to an intergovernmental agreement submitted to UN, for operating a global satellite communication system. However, Intersputnik became operational only in 1974 with Molniya and Statsionar Satellites for providing telephony, telegraph, radio, data, telex and direct broadcasting of television. Initially Intersputnik had nine member countries, which has grown to twenty-three over the years. These are Afghanistan, Belarus, Bulgaria, Cuba, Czech Republic, Georgia, Germany, Hungary, Kazakhstan, Kyrghizstan, DPR Korea, Laos, Mongolia, Nicaragua, Poland, Tajikistan, Turkmenistan, Romania, Russia, Syria, Ukraine, Yemen, Vietnam. Intersputnik's user base exceeds 100 state run and private companies.

Due to the changes in the geopolitical conditions in the 1990's and rapid development of telecommunications market with the introduction of new services created severe competitions among the telecom service providers. Under the changed circumstances, Intersputnik reviewed its strategy to get adapted to the dynamically developing environment. In order to keep the competitive edge, Intersputnik established strategic alliances with different satellite communications operators, manufactures, launch vehicle service providers, ground equipment manufacturers and international entities. One of these alliances is the joint venture Lockheed Martin Intersputnik (LMI) established in 1997. First LMI satellite with 44 high power C and Ku band transponders and lifetime of 15 years was launched at 75 deg E. in September 1999. With strategic alliance with Lockheed Martin corporation, Intersputnik is able to provide high quality services, which include digital video, high bit rate access to Internet, use of VSATs, Telemedicine, Tele-education, banking on a global scale etc.

INMARSAT: INMARSAT was established as an international cooperative organization similar to INTELSAT, for providing satellite communications for ships and offshore industries. INMARSAT, a specialized agency of UN, was established in 1979 and became operational in 1982 as a maritime focused intergovernmental organization with headquarters located at London. INMARSAT has forty-four members and also provides services to nonmember countries.

INMARSAT has become a limited company since 1999. INMARSAT Ltd is a subsidiary of the INMARSAT Ventures plc holding company, which operates a constellation of geosynchronous satellites for worldwide mobile communications. The satellites are controlled from INMARSAT headquarters at London, which is also home to INMARSAT ventures and a small Intergovernmental office created to supervise the company's public service duties for the maritime community i.e. Global Maritime Distress and Safety System and Air traffic Control communications for the aviation industry.

Starting with a user base of about 900 ships in early 1980's, the user base of INMARSAT grew to 210,000 ships, vehicles, aircrafts and portable terminals in 2001. INMARSAT Type A mobile terminals meant for installation in large ships are quite expensive, whereas, portable INMARSAT mini-M terminals are small, cost effective and easy to operate. The services provided by INMARSAT include telephone, fax and data communications up to 64 kbps. Other services include videotext, navigation, weather information and Search & Rescue. INMARSAT Satellites can also be used for emergency Land Mobile Communications for relief work and to re-establish communications or to provide basic service where there is no alternative. INMARSAT can also be used to alert people on shore for coordination of rescue activities. Apart from maritime and Land Mobile Satellite Service, INMARSAT also provide aeronautical satellite service for passenger communications.

INMARSAT system operates at C-band and L-band frequencies. The INMARSAT system uses allocations in the 6 GHz band for the ground station to satellite link, 1.5 GHz for satellite terminal downlink, 1.6 GHz for terminal to satellite uplink and 4 GHz for the satellite to ground station down link.

COSPAS-SARSAT: COSPAS-SARSAT is a joint venture of Canada, France, Russia and US. It is a satellite based international Search and Rescue, alert and location system using different low earth orbit satellites operating in the frequency of 120 MHz and 406 MHz. Local Users Terminals operating in different parts of the world pick-up the alert signals from Emergency Location Beacons carried by ships and airplanes and pass on the information regarding the location of accident to the nearest rescue centres for carrying out the rescue operations. Since the operationalisation of the satellite based Search and Rescue System, hundreds of lives have been saved due to timely deployment of prompt rescue operations.

Domestic Satellite Communications Systems

In the initial years of implementation of commercial Satellite Communications the emphasis was mainly on the transoceanic and international communications. However use of satellite communications for improvement of domestic communications also emerged as a distinct possibility. Countries like, USSR, Canada, Indonesia took initiatives in implementing domestic satellite communications systems for the respective countries. Satellite Communications System for domestic communications is cost effective compared to the conventional terrestrial systems under the following conditions.

- A large country without basic terrestrial communications
- Population is spread over mountains, deserts and a large number of islands
- Thinly populated remote areas

Former USSR was the first country to adopt satellite communications for its domestic use. However, because of its geographic location, where large landmass was in the high latitude region, the geosynchronous satellite systems were not found to be suitable. Thus a system with a series of Molniya Satellites operating in highly elliptical non-geosynchronous inclined orbits was introduced in 1965 to meet the country's domestic requirement of telecommunications and television transmission.

Canada became the first country to use a geosynchronous satellite for domestic communications with the launching of Anik-1 in 1972. With the advent of Anik Satellite it was possible to cover for the first time the whole of Canada particularly thinly populated northern region under the live TV coverage. Apart from TV, Anik Satellites are also used for radio broadcasting to remote locations and interactive distance education.

Indonesia is the first developing country to have its own domestic satellite system. Because of its limited infrastructure and widely scattered population dispersed over more than 13,600 islands, a satellite communications system is an ideal technology to deliver telecommunications and broadcasting throughout the country. Telecommunications services using PALAPA-A, the first Indonesian domestic satellite started in 1976.

Some of the other countries with their own domestic satellite communications systems are:

- United States of America (Wester, SBS, Etc.)
- India (INSAT)
- Brazil (Brazilsat)
- Mexico (Morelos)
- China (Chinasat)
- Japan (CS, BS)

Many countries where operating an exclusive domestic satellite communications system is not economical, the domestic requirements of communications can be met by leasing capacity from Intelsat or other satellites.

Regional Satellite Communications Systems

Regional Satellite Communications Systems have been an ideal means to deliver telecommunications and broadcasting services to a number of countries in a region for meeting their domestic and regional telecommunications and broadcasting requirements rather than having separate domestic system for each of these countries. A number of regional satellite communications systems are presently in operations and quite a few of them are in the planning stages.

Some of the regional Satellite Communications Systems are:

- EUTELSAT
- ARABSAT
- AUSSAT
- PALAPA

Eutelsat is a consortium of twenty-six European nations, established for operations and maintenance of space segment of the Eutelsat Satellite System, and providing its members with the space segment capacity necessary for meeting their telecommunications services requirements. Eutelsat provides services that are not available via Intelsat in Europe. These include:

- Transmission of television networks to eighteen countries for cable distribution and transmission of Eurovision programs
- Intra-European telephony and telegraphy
- Multi-service data communications for computer networking, facsimile, remote printing of newspapers, teleconferencing etc.

Eutelsats' space segment is coordinated by the European Space Agency (ESA) which procures spacecraft from European manufactures.

Arabsat evolved from 1953 Arab league agreement to develop regional telephone, telex and telegraph communications. Arab Space Communication Organization was established in 1976 and had twenty-two members. However, by the time two Arabsat Satellites were launched in 1985, Egypt, a leader in the System's planning had been expelled from Arab league. Each Arabsat Satellite has twenty-five C-band transponders and one C/S band transponder for community television reception. However, the Arabsat Satellites are extremely under utilized as only six countries have earth stations. Several countries are still working with Intelsat lease rather than switch to Arabsat.

AUSSAT systems of Australia designed for meeting domestic communications needs of Australia for Radio, TV broadcasting and long distance Telephony is also used by Papua New Guinea for telecommunications and broadcasting services.

Since 1979, PALAPA system of Indonesia became a regional satellite system, after Philippines, Thailand and Malaysia signed agreement to use PALAPA.

#### Military Satellite System

For military communications Army, Air force and Navy use both fixed and mobile satellite systems. In addition to the normal communications, military communications are also required for tactical communications from remote and inhospitable locations.

The special requirements of military communication terminals are high reliability, ruggedness, compact, operations under hostile environment, immunity to jamming, ease of portability and transportation, etc. Examples of military satellite communications systems are:

- DSCS (US AF)
- SKYNET (UK)
- NATO (NATO)
- FLTSATCOM (US NAVY)
- MILSTAR

Because of the special frequency band used in Military satellite system and other special requirements, Military satellite Systems are always much costlier and it takes longer time to design and develop compared to commercial satellite communications systems. Realizing that not all communications are strategic in nature, there is a trend now to use commercial communications system as far as possible. US Department of Defense is one of the major users of commercial Iridium satellite system with their own gateway.

#### Navigational System

Satellites have now replaced the stars and terrestrial systems for the purpose of navigation and radiolocation. The Transit Satellite system of US Navy was the first satellite navigational system with satellites orbiting in low polar orbits. By means of triangulation, the crews could establish the location of the ship and submarine by picking up the signals transmitted by different Transit satellites. US agreed to allow civilian use of Transit Navigational System for use by merchant marine shipping industry throughout the world.

Transit system is now replaced by the Global Positioning System (GPS) of US Navstar Satellite System consisting of eighteen low earth orbiting satellites operating at L-band. GPS receiver calculates the position (latitude, longitude, height) with extremely high accuracy by receiving signals from at least three-satellite passes. Apart from its use in ships, the miniaturized GPS receiver has also found many applications related to land based fleet monitoring.

The Russian Glonass system is the other navigational satellite system. However, the system is not being maintained properly by timely replacement of the satellites.

of the decimator is Personal Communications System

Introduction of terrestrial personal communications in many countries since1980's saw a very rapid growth of wireless telecommunications. Considering that the terrestrial cellular telephone systems are limited only to urban and sub-urban areas, the business potential in providing global satellite based personal communications system was realized by many. It was thought that a satellite based personal communication system would provide not only communications to remote locations from anywhere, it would also provide a seamless roaming system integrating the scattered pockets of terrestrial system. A large number of global and regional personal satellite were planned during the 1990's. Most of these proposed systems were for voice communications with non-geosynchronous satellites in order to avoid the long delay associated with geosynchronous satellites. However, quite a few of these proposed systems, never took off and a few ran into financial problems at the implementation stage casting serious doubts about the commercial viability of satellite based personal communications system using non geosynchronous satellites.

Examples of regional satellite based personal communications systems providing voice and data services through geosynchronous satellites are

- Thuraya
- Asia Cellular Satellite (ACeS)

Both these systems use satellites with large antenna systems and cover a large area of Asia and Europe.

Thuraya: Thuraya Satellite Company is a regional satellite system that provides satellite telephone services to a region covering 99 countries through a dynamic mobile phone that combines satellite, GSM cellular system and GPS. Thuraya was established in 1997 in UAE as a private joint venture with shareholders from 18 national telecommunications operators and investment houses. Thuraya meets the demand for seamless coverage of mobile communications to 2.3 billion people residing in India, Middle East, Central Asia, North & central Africa and Europe. Thuraya handsets offer voice, data, fax messaging and position location. It enables the user to use GSM service in local networks and automatically switch on to satellite mode whenever out of local terrestrial reach. The first Thuraya satellite operating in L band has been launched in Oct 2000 and commercial service started from 2001.

ACeS is another regional geo-mobile personal satellite communications system providing digital voice, fax and data communications using small dual mode (satellite and GSM) handsets. Users of ACeS are able to roam between terrestrial GSM cellular and satellite networks and can interface with public

switched telephone networks. ACeS is jointly owned by PT Pacifik Satelit Nusantara of Indonesia, Lockheed Martin Global Telecommunications of USA, Philippines Long Distance Telephone Company and Jasmine International of Thailand. ACeS coverage area extends from Pakistan & India in the west to Philippines & Papua New Guinea in the east and from China & Japan in the north to Indonesia in the south. ACeS started its operations from November 2000.

Examples of a few Personal Satellite communications Systems providing services or planning to provide services using non-geosynchronous satellite constellations are:

- Iridium (66 Satellites)
- Globalstar (48 satellites)
- Orbcomm (35 satellites)
- New ICO (10 satellites)

Non-geosynchronous satellites in low and medium earth orbits need a large number of satellites in a constellation to provide global coverage and the number of satellites in the constellation increases with decreasing orbital height. The non-geosynchronous low earth orbit satellites appear to be attractive for providing two-way voice and data communications and location positioning to small handheld terminals from the points of view of higher available power from the satellite, low time delay etc. However, launching and maintaining a large number of satellites on orbit and operations of corresponding ground system pose technical as well as operational problems. Financial problems faced by a few of these systems in providing services at the early stages of operations, have made people rethinking on the commercial viability of such systems. The frequency allocations for personal communications systems are in the VHF, L band and S band.

Iridium: The Iridium system was the first satellite based Personal communications system to start commercial global wireless digital voice communications operations in November 1998 with its 66 Low Earth Orbit satellite constellation. But the infamous original Iridium service did not pick up and it failed in its attempt to attract the target subscriber base. This caused financial problems and bankruptcy of the company within a few months of starting the operational service. Iridium's failure despite a sophisticated on board technology and compatibility of hand sets with different terrestrial mobile telephone standards, is considered largely due to poor marketing and a service that was too costly. Moreover, by the time Iridium system was launched the cellular phone coverage also improved worldwide, thus reducing the target service area of Iridium that was uncovered by terrestrial cellular service.

After acquiring the assets of the bankrupt Iridium LLC, a privately held corporation Iridium Satellite LLC, launched its commercial global satellite communications service in March 2001. Iridium Satellite

provides voice, paging, and messaging services to mobile subscribers using handheld user terminals. Frequency of operations of Iridium system is L band.

Globalstar: Globalstar is a consortium of leading international telecommunications companies originally established in 1991 to deliver satellite telephony services through a network of exclusive service providers. Globalstar system designed with a constellation of 48 low-earth orbiting satellites, started its commercial phone service using multimode handsets from October 1999. Other Globalstar services include voice mail, short messaging service, fax and supporting terrestrial IS 41 and GSM systems.

Calls from a Globalstar wireless handsets are transmitted in L band to the satellite and the receive frequency is in S band. Calls via satellites are routed through the appropriate gateway, from where they are passed on to existing fixed and cellular telephone network. The service is available in more than 100 countries in 6 continents.

Orbcomm: Orbcomm Global LP is the first commercial provider of global low earth orbit satellite data and messaging communications system. Globalstar started its commercial service in November 1998 with 28 out of a constellation of 35 low earth orbit satellites and 14 gateway Earth stations in 5 countries. Orbcomm provides two-way monitoring, tracking and messaging services to both fixed and mobile terminals. The system is capable of sending and receiving two-way alphanumeric packets, similar to two-way paging and e-mail.

VHF frequency bands are used for providing two-way messaging services at low data rates. The orbiting satellites pick up small data packets from sensors in vehicles, containers, vessels or remote fixed sites and relay these to the destination through a tracking Earth Station and Gateway Control Centre.

Orbcomm was originally formed as a partnership company owned by Orbital Sciences Corp (USA), Teleglobe Inc (Canada) and Technology Resources Industries Bhd (Malaysia). In April 2001, International Licensees, a consortium of Orbcomm licensees and other investors purchased all the assets of Orbcomm Global LP and its other entities that were under protection of bankruptcy since September 2000.

New ICO: New ICO, formerly of ICO global communications is working on a Medium Earth Orbit(MEO)/ Intermediate Circular Orbit (ICO) satellite system designed for both fixed and mobile operations around the world. ICO Global Communications was founded in 1995 and contracts for satellites launch services and ICO network were awarded. In August 1999, due to financial problems, the company was declared bankrupt. However, with fresh investment from a group of international investors New ICO emerged
from the bankruptcy. New ICO system consists of a constellation of 10 on-orbit ICO satellites, 2 on orbit spares at an orbit of 10,390 km. Target launch of service of New ICO system is 2003.

New ICO is based in London with offices in different countries. The goal of New ICO is to provide global Internet protocol services, including Internet connectivity, data, voice and fax services. The system operates in both circuit switched mode based on GSM standard and packet switched Internet protocol mode. New ICO plans to target markets like maritime, transportation Government, oil, gas, construction & other industries, individuals and small & medium size businesses.

**Broadband Satellite System** 

Broadband satellite service is an emerging service which has caught the fancy of many for meeting the demand of worldwide fiber like access to telecommunications services such as computer networking, broadband Internet access, interactive multimedia and high quality voice. These systems use advanced satellite technology at Ka band or Ku band frequencies to achieve the high bandwidth requirements.

Examples of proposed Broadband Satellite systems are:

- Teledesic
- SkyBridge
- Spaceway

Teledesic satellite network is designed with 288 plus spare satellites at low earth orbits. The operating frequency is in the Ka band of the frequency spectrum with 30 GHz uplink and 20 GHz downlink. The network will enable millions of simultaneous users to access the two-way network using standard user equipment providing up to 64 Mbps on the down link and up to 2 Mbps on the up link. The fixed user equipment will be mounted out door and connect inside to a computer network or PC.

Teledesic is a private company based in Bellevue, Washington (USA) attracting investment from many reputed companies and individuals. The ambitious Teledesic service targeted to begin in 2005 will enable broadband connectivity for businesses, schools and individuals everywhere on the planet and expected to facilitate improvements in education, healthcare and other crucial global issues.

SkyBridge is a satellite-based broadband global telecommunications system designed to provide business and residential users with interactive multimedia applications as well as LAN interconnection or ISDN applications, thus allowing services such as high speed Internet access and video conferencing to take place anywhere in the world. The system is based on a constellation of 80 low earth orbiting satellites, which link professional and residential users equipped with low cost terminals and terrestrial gateways. The satellite network operates at Ku band and will deliver asymmetric broadband connection to fixed network at up to 60 Mbps (in steps of 16 kbps) to the user and up to 2 Mbps (in increments of 16 kbps) on the return link via a gateway.

SkyBridge LP was formed in Delaware, USA in 1997. The partners of SkyBridge LP are Alcatel and leading industries from North America, Europe and Asia.

Spaceway is another advanced broadband satellite system offered by Hughes Network system of USA that will make high-speed broadband applications available on demand to the businesses and to consumers around the world. Operating in the Ka band spectrum, SPACEWAY will consist of interconnected regional satellite systems providing service to nearly all of the world's population. The first North American regional service will start in 2002 with two geosynchronous satellites plus an on orbit spare. Using a globally deployed system of satellites in conjunction with a ground-based infrastructure, users will transmit and receive video, audio, multimedia and other digital data at uplink rates between 16 kbps to 16 Mbps. The access to the system will be provided through a family of low cost easily installed 66 cm terminals.

## **ORBITS FOR COMMUNICATION SATELLITE**

The path a Satellite or a planet follows around a planet or a star is defined as an orbit. In general the shape of an orbit of a satellite is an ellipse with the planet located at one of the two foci of the ellipse. The circular orbit may also be considered as an ellipse where the two foci of the ellipse coincide at the center of the circle. Satellite Orbits are classified in two broad categories i.e.

- Non-Geostationary Orbit (NGSO)
- Geo Stationary Orbit (GSO)

Non-Geostationary Orbit (NGSO)

Early ventures with satellite communications used satellites in Non-geostationary low earth orbits due to the technical limitations of the launch vehicles in placing satellites in higher orbits. With the

advancement of launch vehicles and satellite technologies, once the Geo Stationary Orbit (GSO) was achieved, majority of the satellites for telecommunications started using GSO due to its many advantages. During 1990s the interests in NGSOs were rekindled due to several advantages of NGSO in providing global personal communications in spite of its many disadvantages.

Advantages of NGSO are:

- Less booster power required to put a satellite in lower orbit
- Less space loss for signal propagation at lower altitudes (<10,000 km) leading to lower on board power requirement
- Less delay in transmission path reduced problem of echo in voice communications
- Suitability for providing service at higher latitude
- Lower cost to build and launch satellites at NGSO
- Use of VHF and UHF frequency bands at NGSO permits low cost antennas for hand-held terminals

Disadvantages of NGSO are:

- Requirement of a large number of orbiting satellites for global coverage as each low earth orbit satellite covers a small portion of the earth's surface for a short time.
- Complex hand over problem of transferring signal from one satellite to another
- Less expected life of satellites at NGSO requires more frequent replacement of satellites compared to satellite in GSO
- Compensation of Doppler shift is necessary
- Satellites at NGSO undergoes eclipse several times a day necessitates the requirement of robust on board battery system for the satellite for operations without solar power during eclipse
- Complex network management for a constellation of satellites and corresponding ground system
- Problem of increasing space debris in the outer space

There are different types of Non Geostationary Orbits (NGSO), depending on the orbital height and the inclination of the orbital plane. Inclination is the angle that the orbital plane makes with the equatorial plane at the time of crossing the equator moving from south to north of the earth and is measured from

0 to 180 degrees. NGSOs are classified in the following three types as per the inclinations of the orbital plane

- Polar Orbit
- Equatorial Orbit
- Inclined Orbit

In polar orbit the satellite moves from pole to pole and the inclination is equal to 90 degrees. In equatorial orbit the orbital plane lies in the equatorial plane of the earth and the inclination is zero or very small. All orbits other than polar orbit and equatorial orbit are called inclined orbit.

A satellite orbit with inclination of less than 90 degrees is called a prograde orbit. The satellite in prograde orbit moves in the same direction as the rotation of the earth on its axis. Satellite orbit with inclination of more than 90 degrees is called retrograde orbit when the satellite moves in a direction opposite to the rotational motion of the earth. Orbits of almost all communication satellites are prograde orbits, as it takes less propellant to achieve the final velocity of the satellite in prograde orbit by taking advantage of the earth's rotational speed. Example of retrograde orbit is the sun synchronous orbit where the orbital parameters are such that that the satellite crosses the same latitude at the same local time. This type of orbit is used for earth observation satellites where repeated observations are required to be made under the same sun angle. It needs more propellant to launch a satellite in retrograde orbit as it is launched in a direction opposite to the direction of the earth's rotation.

## UNIT-7

Satellite orbits are also classified in terms of the orbital height. These are:

- Low Earth Orbit (LEO)
- Medium Earth Orbit (MEO) / Intermediate Circular Orbit (ICO)
- Highly Elliptical Orbit (HEO)
- Geosynchronous Earth Orbit (GEO)

Satellite orbits with orbital height of approximately 1000 km or less are known as Low Earth Orbit (LEO). LEOs tend to be in general circular in shape. Satellite orbits with orbital heights of typically in the range of 5000 km to about 25,000 km are known as Medium Earth Orbit (MEO) / Intermediate Circular orbit (ICO). MEO and ICO are often used synonymously, but MEO classification is not restricted to circular orbits. Satellites in Highly Elliptical Orbit (HEO) are suitable for communications in the higher latitudes. Russian Molnya satellites have highly inclined elliptical orbits with a perigee of about 1000 km, apogee of 40,000 km, inclination of 63.435 deg and orbital period of 12 hours. In Geosynchronous Earth Orbit

(GEO) the satellite is in equatorial circular orbit with an altitude of 35,786 km and orbital period of 24 hours. Three satellites in GEO placed 1200 apart over equator cover most of the world for communications purposes.

Fig.1 shows different types of orbits.



Geostationary Orbit (GSO)

There is only one geostationary orbit possible around the earth, lying on the earth's equatorial plane and the satellite orbiting at the same speed as the rotational speed of the earth on its axis. For a Satellite to have an orbital period equal to that of earth's rotation i.e. a sidereal day (23 Hrs 56 min. 4.09 sec.) an altitude of 35,786 km is required. Such a satellite orbiting at a velocity of 3.075 km/sec remains fixed relative to any point on earth or geostationary. With the idealized assumptions that the geostationary satellite is at rest relative to the earth the conditions required to be satisfied for geostationary orbit are:

- The orbit shall be circular
- The period of the orbit shall be equal to the period of rotation of the earth about itself
- The plane of the orbit shall be the same as the equatorial plane but the sub-satellite longitude, i.e. the longitude of the projection of the satellite on the Earth's surface can be selected arbitrarily.

The principle of satellite communications based on this concept of geostationary orbit was originated by Arthur C Clarke. Main advantage of geostationary satellite being the permanent contact between the ground segment and the satellite with fixed directional antennas at both the earth station and the satellite.

The ITU (International Telecommunications Union), recognizing the importance of the GSO along with the frequency spectrum as limited natural resources available on the earth, set out the procedures for all radio communications services, regarding the use of GSO/spectrum through ITU Radio Regulations, a binding international treaty. With respect to the use of the GSO and frequency spectrum, the ITU space regulations laid down in the ITU Constitution is as follows:

In using frequency bands for radio services, Member states shall bear in mind that radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources and they must be used rationally, efficiently and economically, in conformity with the provisions of Radio Regulations, so that countries or groups of countries may have equitable access to those orbits and frequencies, taking into account the special needs of developing countries and the geographical situation of particular countries.

Table-3 outlines the salient features, advantages and disadvantages of Geostationary Satellite Orbit (GSO).

## TABLE – 3

Attitude	35,786 km.					
Period	23 Hr. 56 min. 4.091 sec. (One sidereal day)					
Orbit inclination.	00					
Velocity	3.075 km per sec.					
Coverage	42.5% of earth's surface.					
Sub satellite point	On equator.					
Area of no coverage	Beyond 810 North and South latitude.					
	(77º if angle of elevation below 5º are eliminated )					
Advantages	- Simple ground station tracking.					
	- No hand over problem					
	- Nearly constant range					
	- Very small doppler shift					
Disadvantages	- Transmission delay of the order of 250 msec.					
	- Large free space loss					
	- No polar coverage					

## GEOSTATIONARY SATELLITE ORBIT

A perfect geostationary orbit is a mathematical abstraction that could be achieved only by a spacecraft orbiting around a perfectly symmetric earth and no other forces are acting on the spacecraft other than the central gravitational attraction from the earth. The abstraction is however, useful as an approximate description of real case, since all other forces or perturbations due to attractive forces of the Moon and the Sun and the non-sphericity of the Earth's gravity are small.

In real life due to gravitational pull of the Moon & the Sun, the equatorial orbital plane of the satellite makes an angle of inclination with respect to the equatorial orbital plane. For a satellite with orbital period equal to a sidereal day and non-zero inclination, the footprint of the satellite will move in North-

South direction over its sub satellite point instead of remaining stationary. The non-spherical shape of the earth also causes movement of the satellite in the east-west direction. Thus the trace of the satellite on earth appears to roam in both North-South and East-West direction around the sub-satellite point.

The inclination of the satellite can be corrected by firing appropriate thrusters on-board the satellite and is known as North-South station keeping. Similarly the correction of East-West drift of the satellite is called East-West Station keeping. Without any station keeping the inclination plane drifts to about 0.86 deg per year. Thus the satellite orbital position is required to be corrected periodically to keep the drift from the desired location within a certain limit. Considering the drift in the satellite position in North-South and East-West direction around the sub-satellite point, it is more appropriate to designate such an orbit as geosynchronous orbit.

## GEOSYNCHRONOUS COMMUNICATION SATELLITE

Geosynchronous Satellites have now become almost synonymous for communications satellites, because of its wide use in telecommunications due to the advantages over non-geosynchronous satellites. Because of the availability of a number of communication satellites over the geosynchronous arc, the communications between different parts of the world have become possible and affordable. The communication satellites have played a significant role in converting the world into a global village.

Salient features of Geosynchronous Communications Satellite

Salient features of Geosynchronous Satellite are:

- Wide Coverage
- Stationary Position
- Multiple Access
- Suitability for transcontinental telecommunications, broadcasting, mobile and thin route communications.
- Frequency reuse capability
- Very low Doppler Shift
- Reliability.
- Cost effectiveness.

Brief description of each of these features are given below:

Wide Coverage: From the geosynchronous orbit the satellite can cover an area equal to about 42% of the area of the earth (38% if angles of elevation below 5° are not used). Thus three satellites placed 120° apart can cover almost the whole world for the purpose of communications. INTELSAT Satellites strategically placed over Atlantic Ocean Region (AOR), Indian Ocean Region (IOR) and Pacific Ocean Region (POR) covers the whole world for International Telecommunications. With worldwide satellite TV coverage, any incidence happening in any part of the world can now be viewed live in the TV throughout the world.

Stationary Position: The orbital velocity of the geosynchronous satellite being equal to the rotational velocity of the earth on its own axis, the satellite in the geosynchronous orbit appears to be stationary with respect to any location from the earth. Thus the satellite is always visible from any earth station situated in its coverage region and the tracking of the satellite is simple and there is no hand over problem of transferring signal from one satellite to another as in the case of satellites in NGSO. The constant visibility of the satellite also enables both the satellite and the earth station to use highly directive antennas. High gain of the antennas on-board the satellite and the earth station, enhances the transmit and receive capabilities.

Multiple Access: Multiple Access is the ability of a large number of users to simultaneously interconnect their respective voice, data and television links through a satellite. The wide geographic coverage and broadcast nature of satellite channel are exploited by means of multiple access. Multiple access also helps in optimum use of satellite capacity, satellite power, spectrum utilization and interconnectivity among different users at reduced cost.

A satellite in geosynchronous orbit can link multiple earth stations within its coverage area and separated by great circle distances up to 17,000 Km. Multiple access is the unique feature of satellite communications not possible to get by any other means. For m earth stations visible from a Satellite, the number of potential available communication circuits is given by

n = m (m-1)/2

compared to non flexible 2-port network of conventional cable or land based networks.

Suitability for Transcontinental Telecommunications, Broadcasting, Mobile and Thin Route Communications: TV Broadcasting via Satellite is perhaps the most common use of geosynchronous satellite. In developing countries where the terrestrial TV distribution is very limited, the communications satellites can be very effectively utilized for TV distribution. Geosynchronous satellites handle a large portion of transcontinental telecommunications traffic.

Geosynchronous Satellites along with other NGSO satellites are found to be suitable for reliable mobile communications for ships and aircrafts, as the ship and the aircraft can continuously maintain the communication link with the satellites while moving. However, GEO based satellite systems are much simpler to operate and maintain compared to other system.

Geosynchronous Satellites are also the most suitable means of providing reliable and cost effective communications to thin route rural areas, interconnecting small islands, and providing communications to hilly and difficult terrain.

Frequency Reuse: The frequency bands of a geosynchronous satellite can be reused by different methods for increasing the channel capacities of the communications satellite. By using specially designed spatially separated shaped beams the same frequency and polarizations can be reused. By using orthogonal polarizations the same frequency bands can be reused for the same coverage area of the satellite. By using orthogonal linear and circular polarizations and shaped beams covering different regions, the same frequency band can be reused many folds thus increasing the communication capacity of geosynchronous satellite. Different techniques of frequency reuse of the same frequency band are found in INTELSAT series of satellite.

Very Low Doppler Shift: Compared to low earth orbit satellites, in geosynchronous satellite there is almost no Doppler Shift i.e. change in the apparent frequency of operations to and from Satellite, caused by the relative motion of the Satellite and the earth station. Satellites in elliptical orbits have different Doppler shifts for different earth stations and this increases the complexities of the receivers especially when a large number of earth stations intercommunicate.

Reliability: The reliability of long distance telecommunication links improves considerably when geosynchronous satellites are used. The path loss in the satellite links although very high; these remain almost constant, thus maintaining the performance quality of the link.

Cost effectiveness: The geosynchronous satellite because of its long life of twelve to fifteen years and wide-band operations shared by a large number of users, makes the point to point service very cost effective compared to the service provided by land based terrestrial system. No viable alternatives to geosynchronous satellites are presently available, so far as the broadcasting and mobile services are concerned.

of the decimator is Problems of Geosynchronous Satellite Communications Systems

The problems of geosynchronous satellite communications systems are:

- No coverage of polar region.
- Long time delay.
- Echo.
- Eclipse due to the earth and the sun.
- Sun Transit outage

No Coverage Region: The geosynchronous satellite from its location of 35,786-Km altitude above equator is not found suitable for communications beyond the latitude of 81 deg. Thus the polar region of the earth cannot be properly covered by geosynchronous satellite. Time Delay: In Satellite Communications System using geosynchronous satellite, the signal has to travel a long distance while travelling from the transmit earth station to the receive earth station via satellite. From the geometry of the geosynchronous satellite orbit it is found that the single hop time required for the signal to travel from one point to another varies from 230 m sec. (90 deg. elevation) to 278 m sec. (0 deg. elevation). This time delay does not pose any problem in data and broadcasting services, but this delay is quite perceptible in two-way telephone conversations. ITU-T specifies a delay of less than 400 msec to prevent echo effects and delay variation of upto 3 msec. Although the propagation and intersatellite delays of LEOs are lower, LEO systems exhibit high delay variation due to connection handovers, satellite and orbital dynamics and adoptive routing.

Echo: Generally a long distance telephone circuit is accompanied by echo due to mismatch at the terminal point where circuits are converted from four wire to two wire system. As the delay of the echo is increased, the effect of the echo becomes increasingly disagreeable to the talker. The echo can be attenuated by using echo suppressor or echo canceller. By using echo suppressor of excellent quality, a two hop satellite link can be utilized for practical communications, provided the delay is acceptable.

Eclipse of Satellite: A Satellite is said to be in eclipse when the positions of the earth, the Sun and the Satellite are such that the earth prevents sun light from reaching the satellite i.e when the satellite is in the shadow of the earth. For geosynchronous satellites, eclipses occur for 46 days around equinox (March 21 and September 23). During full eclipse, a satellite does not receive any power from solar array and it must operate entirely from batteries. In case the power available from battery is not enough, some of the transponders may be required to be shut down during the eclipse period. The satellite passes through severe thermal stress during its passage into and out of the earth's shadow. The solar power also fluctuates sharply at the beginning and end of an eclipse. For these reasons the probability of failure of satellite is more during eclipse than at any other time.

Sun Transit Outage: Sun transit outage takes place when the sun passes through the beam of an earth station. During vernal and autumnal equinox, the sun approaches toward a geosynchronous satellite as seen from an earth station and this increases the receiver noise level of the earth station very significantly and prevent normal operations. This effect is predictable and can cause outage for as much as 10 min. a day for several days. The sun transit outage is about 0.02 percent in an average year. A receiving earth station cannot do anything about it except wait for the sun to move out of the main lobe.

## ELEMENTS OF SATELLITE COMMUNICATIONS SYSTEM

Two major elements of Satellite Communications Systems are

- Space Segment
- Ground Segment

The Space Segment includes

- Satellite
- Means for launching satellite
- Satellite control centre for station keeping of the satellite

The functions of the ground segment are to transmit the signal to the satellite and receive the signal from the satellite. The ground segment consists of

- Earth Stations
- Rear Ward Communication links
- User terminals and interfaces

• Network control centre

Schematic block diagram showing the elements of Satellite Communications System is shown in fig. 2.



## Communication Satellite

Communication satellites are very complex and extremely expensive to procure & launch.

The communication satellites are now designed for 12 to 15 years of life during which the communication capability of the satellite earns revenue, to recover the initial and operating costs. Since

the satellite has to operate over a long period out in the space the subsystems of the satellite are required to be very reliable. Major subsystems of a satellite are:

- Satellite Bus Subsystems
- Satellite Payloads

Satellite Bus subsystems:

- Mechanical structure
- Attitude and orbit control system
- Propulsion System
- Electrical Power System
- Tracking Telemetry and Command System
- Thermal Control System

Satellite Payloads

- Communication transponders
- Communication Antennas

Since the communications capacity earns revenue, the satellite must carry as many communications channels as possible. However, the large communications channel capacity requires large electrical power from large solar arrays and battery, resulting in large mass and volume. Putting a heavy satellite in geosynchronous orbit being very expensive, it is logical to keep the size and mass of the satellite small. Lightweight material optimally designed to carry the load and withstand vibration & large temperature cycles are selected for the structure of the satellite.

Attitude and orbit control system maintains the orbital location of the satellite and controls the attitude of the satellite by using different sensors and firing small thrusters located in different sides of the satellite.

Liquid fuel and oxidizer are carried in the satellite as part of the propulsion system for firing the thrusters in order to maintain the satellite attitude and orbit. The amount of fuel and oxidizer carried by the satellite also determines the effective life of te satellite.

The electrical power in the satellite is derived mainly from the solar cells. The power is used by the communications payloads and also by all other electrical subsystems in the satellite for house keeping. Rechargeable battery is used for supplying electrical power during ellipse of the satellite.

Telemetry, Tracking and Command system of the satellite works along with its counterparts located in the satellite control earth station. The telemetry system collects data from sensors on board the satellite and sends these data via telemetry link to the satellite control centre which monitors the health of the satellite. Tracking and ranging system located in the earth station provides the information related to the range and location of the satellite in its orbit. The command system is used for switching on/off of different subsystems in the satellite based on the telemetry and tracking data.

The thermal control system maintains the temperature of different parts of the satellite within the operating temperature limits and thus protects the satellite subsystems from the extreme temperature conditions of the outer space.

The communications subsystems are the major elements of a communication satellite and the rest of the space craft is there solely to support it. Quite often it is only a small part of the mass and volume of the satellite. The communications subsystem consists of one or more antennas and communications receiver - transmitter units known as transponders. Transponders are of two types, Repeater or Bent pipe and processing or regenerative. In Repeater type, communications transponder receives the signals at microwave frequencies and amplifies the RF carrier after frequency conversion, whereas in processing type of transponder in addition to frequency translation and amplification, the RF carrier is demodulated to baseband and the signals are regenerated and modulated in the transponder. Analog communication systems are exclusively repeater type. Digital communication system may use either variety. Fig. 3(a) and 3(b) show the schematic diagrams of repeater type and regenerative type transponders respectively.







The actual reception and retransmission of the signals are however, accomplished by the antennas on board the satellite. The communications antennas on board the satellite maintain the link with the ground segment and the communications transponder. The size and shape of the communications antenna depend on the coverage requirements and the antenna system can be tailor made to meet the specific coverage requirements of the system.

## Launch Vehicle

The function of the launch vehicle is to place the communication satellite in the desired orbit. The size and mass of the satellite to be launched is limited by the capability of the launch vehicle selected for launching the satellite. The satellite launch vehicle interface is also required to be provided as per the launch vehicle selected. Satellite launch vehicles are classified in two types i.e.

- Expendable
- Reusable

In expendable type the launch vehicle can be used only once and most of the launch vehicles are expendable type. Space Transportation System (STS) or Space Shuttle of NASA, USA is the only available operational reusable launch vehicle. Although most of the launches take place from ground, Sea Launch has embarked on the launching of satellites from off shore platforms and Peagasus launch vehicles can launch small satellites from aircrafts. Launching of a satellite in orbit being a costly affair a number of programs have been undertaken by NASA to make the future launching of satellites in orbit as cost effective and routine as commercial air travel.

Satellite Control Centre

Satellite Control Centre performs the following function.

- Tracking of the satellite
- Receiving Telemetry data
- Determining Orbital parameters from Tracking and Ranging data
- Commanding the Satellite for station keeping
- Switching ON/OFF of different subsystems as per the operational requirements
- Thermal management of satellite.
- Eclipse management of satellite
- Communications subsystems configuration management.
- Satellite Bus subsystems configuration management etc.

## **GROUND SEGMENT**

The ground segment of satellite communications system establishes the communications links with the satellite and the user. In large and medium systems the terrestrial microwave link interfaces with the user and the earth station. However, in the case of small systems, this interface is eliminated and the user interface can be located at the earth station. The earth station consists of

Transmit equipment.

- Receive equipment.
- Antenna system.

Fig. 4 shows the schematic block diagram of an earth station.



In the earth station the base band signal received directly from users' premises or from terrestrial network are appropriately modulated and then transmitted at RF frequency to the satellite. The receiving earth station after demodulating the carrier transmits the base band signal to the user directly or through the terrestrial link.

The baseband signals received at the earth stations are mostly of the following types.

- Groups of voice band analog or digital signals
- Analog or digital video signals
- Single channel analog or digital signal
- Wide band digital signal.

In satellite communications, in early days FM modulation scheme was most frequently used for analog voice and video signal transmission. However, the trnd is now to use digital signals for both voice and video. Various digital modulation schemes like Phase Shift Keying (PSK) and Frequency Shift Keying (FSK) are adopted for transmission of digital signals.

The network operations and control centre for the communications network monitors the network operations by different users, distribution of different carriers within a transponder and allocation of bandwidth & EIRP of different carriers. Proper functioning of Network operations and control centre is essential where the number of users in the network is large. Network operations & control centre is also responsible for giving clearance to the ground system in respect of antenna radiation pattern, EIRP etc.

## SATELLITE COMMUNICATIONS SERVICES

Different Satellite Communications services are classified as one way link and two way link. One way link from transmitter Tx to receiver Rx on earth's surface is shown in fig.5.



Examples of satellite services where the transfer of information takes place through one way link are:

- Broadcast Satellite Service (Radio, TV, Data broadcasting)
- Data Collection Service (Hydro meteorological data collection)
- Space operations service, (Tracking, Telemetry, Command)
- Safety services (Search & Rescue, Disaster Warning)
- Earth Exploration Satellite Service (Remote Sensing)
- Meteorological Satellite Service (Meteorological data dissemination)
- Radio Determination Satellite Service (Position location)
- Reporting Service (fleet monitoring)
- Standard frequency and time signal satellite service
- Space Research Service.

In two-way Satellite Communications link the exchange of information between two distant users takes place through a pair of transmit and receive earth stations and a satellite. Fig.6 shows the elements of two-way link



#### Examples of two-way satellite services are

- Fixed Satellite Service (Telephone, telex, fax, high bit rate data etc.)
- Mobile Satellite Service (Land mobile, Maritime, Aero-mobile, personal communications)

## UNIT-8

Satellite navigation systems has become integral part of all applications where mobility plays a important role (Heinrichs et al., 2005). These functions will be at the heart of the mobile phone thirdgeneration (3G) networks such as the UMTS. In transportation systems, the presence of receivers will become as common as seat belts or airbags, with all car manufacturers equipping their entry-level vehicles with these devices. As for the past developments, GPS launched a variety of techniques, products and, consequently, applications and services. The milestone of satellitenavigation is the real timepositioning and time synchronization. For that reason the implementation of wide-area augmentation systems should be highlighted, because they allow asignificant improvement of accuracy and integrity performance. WAAS, EGNOS and MSAS provide over US, Europe, Japan a useful augmentation to GPS, GLONASS and Galileo services

## **GNSS COMPONENTS**

The GNSS consist of three main satellite technologies:GPS, Glonass and Galileo. Each of them consists mainly of three segments: (a) space segment, (b) control segment and (c) user segment. These segments are almost similar in the three satellite technologies, which are all together make up the GNSS. As of today, the complete satellite technology is the GPS technology and most of the existing worldwide applications related to the GPS technology. The GNSS technology will become clearer after the operation of Galileo and the reconstruction of Glonass in the next few years. Global Positioning System:

- The United States Department of Defense (DoD)
- has developed the Navsta
- r GPS, which is an all-weather, space based navigation system to meet the needs of the USA military forces and accurately determine their position, velocity, and time in a common reference system, any where on or near the Earth on a continuous basis (Wooden, 1985). GPS has made a

considerable impact on almost all positioning, navigation, timing and monitoring applications. It provides particularly coded satellite signals that can be processed in a GPS receiver, allowing the receiver to estimate position, velocity and time (Hofmann-Wellenhof et al., 2001). There are four GPS satellite signals that are used to compute positions in threedimensions and the time offset in the receiver clock. GPS comprises three main components: Space segment: The Space Segment of the system

- consists of the GPS satellites;
- 1. These space vehicles (SVs) send radio signals from space as Control segment: The Control Segment consists of a system of tracking stations located round the world. The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in the State of Colorado, USA.
- User segment: The GPS User Segment consists of the GPS receivers and the user
- community. GPS receivers convert space vehicle (SV) signals into position, velocity, and time estimates.

GPS Constellation. GPS Satellite Signals The satellites are dispersed in six or

- bital planes on almost circular orbits with an altitude of about 20,200 km above the surface of the Earth, inclined by 55 degree with respect to the equator and with orbital periods of approximately 11 hours 58 minutes (half a sidereal day). The categories are Block I, Block II, Block IIR (R for replenishment) and Block IIA (A foradvanced) and a further follow-on category
- GPS Signals

The generated signals on board the satellites are based or derived from generation of a fundamental frequency fo=10.23 MHZ (Hofmann-Wellenhof eal., 2001). The signal iscontrolled by atomic clock and has stability in the range over one day. Two carrier signals in the L-band, denoted L1 and L2, are generated by integer multiplications of f. The carriers L1 and L2 are biphase modulated by codes to provide satellite clock readings to the receiver and transmit information such as the orbital parameters. The codes consist of a sequence with the states +1 or -1, corresponding to the binary values 0 or 1. The biphase modulation is performed by a 180° shift in the carrier phase whenever a change in the code state occurs; see clear/access code (C/A-code) and precision code (P-code) are used for the satellite clock reading, both are characterized by a pseudorandom noise (PRN) sequence. The W-code is employed to encrypt the P-code to the Y-code when Anti Spoofing (A-S) is applied. The navigation message is modulated using the two carrers (L1 and L2) at a chipping rate of 50 bpsk IIF has also been planned (ICD-GPS, 2003). the main GPS segments. Modernized GPS Due to the vast civil applications of GPS technology during the past decade or so and due to the new technologies used in the satellite and receivers, the U.S government has decided to extend the capabilities of GPS to give more benefits to the civilcommunity. In addition to the existing GPS signals, new signals will be transmitted by GPS satellite; see Figure 5. Moreover, this will increase the robustness in the signals and improve the resistance to signal interference. This definitely will lead to a better quality of service (QoS). The new signals added to the GPS (Fontana et al., 2001), are: (i) a new L5 frequency in an aeronautical radio navigation service (ARNS) band with a signal structure designed to mprove aviation applications, (ii) C/A code to L2C carrier (L2 civil signal ), and (iii) a newmilitary (M) code on L1 and L2 frequency for the DoD has been added. It has the potential to tracksignal even in poor conditions where the C/A code tracking on L1 would not be possible. The new military code will be transmitted from the Block IIR-M and IIF satellites (Betz, 2002).

The GPS Standard Positioning ServiceThe Global Positioning System (GPS) is a space-based radionavigation system which ismanaged for the Government of the United States by the U.S. Air Force (USAF), the systemoperator. GPS was originally developed as a military force enhancement system and will continue to play this role. However, GPS has also demonstrated a significant potential to benefit the civilcommunity in an increasingly large variety of applications. In an effort to make this beneficialservice available to the greatest number of users while ensuring that the national security interestsof the United States are observed, two GPS services are provided. The Precise PositioningService (PPS) is available

primarily to the military of the United States and its allies for usersproperly equipped with PPS receivers. The Standard Positioning Service (SPS) is designed toprovide a less accurate positioning capability than PPS for civil and all other users throughout the

## **Global Positioning System Overview**

Sufficient information is provided below to promote a common understanding of the minimum GPS baseline configuration. The GPS baseline system is comprised of two segments, whose purpose is to provide a reliable and continuous positioning and timing service to the GPS user community. These two segments are known as the Space Segment and the Control Segment. The GPS Space Segment

The GPS Block II/IIA satellite constellation normally consists of 24 operational satellites.

TheBlock II satellite and a slightly modified version, the Block IIA satellite, will be the mainstays of theconstellation over the next decade. From a civil user's perspective, the Block II and Block IIAsatellites provide an identical service. Each satellite generates a navigation message based upon data periodically uploaded from theControl Segment and adds the message to a 1.023 MHz Pseudo Random Noise



Surface area of sphere enclosing

 $P_t = 4\pi R^2$ 

**Power Flux Density:** 

 $PFD = \frac{P_t}{4\pi R^2} \left[ W / m^2 \right]$ 

Question papers Time: 3 hours Max Marks: 80 Answer any FIVE Questions All Questions carry equal marks

1. Discuss the Performance Characteristics of different Altitude Satellites. [16] 2. Discuss in detail the effects of Earth Gravitational Force on Satellite. [16]

3. (a) Explain about 6/4 GHz Communication Subsystem in detail with neat schematics.
(b) The earth subtends an angle of 170 when viewed from geostationary orbit. What are the dimensions and gain of horn antenna that will provide global coverage at 4 GHz. [8+8]

## 4. (a) Discuss the uplink design.

(b) A Transponder of a Ku band satellite has linear gain of 127 dB and a nominal output power at saturation of 5W. The satellite's 14GHz receiving antenna has a gain of 26 dB on axis and the beam covers western Europe. Calculate the power output of an uplink transmitter that gives an output power

of 1W from the satellite transponder at frequency of 14.45GHz. when the earth station antenna has a gain of 50 dB and there is a 1.5 dB loss in the waveguide run between the transmitter and antenna. Assume that the atmosphere introduces a loss of 0.5dB under clear sky conditions and that the earth station is located on the -2dB contour of the satellite receiving antenna. If the rain in the path causes attenuation of 7 dB for 0.01% of the year. What output power rating is required for the transmitter to guarantee that a 1 W output can be obtained from the satellite transponder for 99.9% of the year if the uplink power control is used. [8+8]

5. (a) Define multiple access techniques? Mention the types of multiple access techniques?(b) Give in detail about the comparisons of multiple access techniques? [4+12]

## 6. (a) What are the different types of antenna mounts?

(b) Suppose the receiver antenna is a parabolic dish antenna with diameter of 1.75m and is operation with a horn at 5.956GHz. Calculate the antenna operation and the gain in db. The efficiency of receiving antenna is 80%?[6+10]

- 6. Explain the delay and throughput Explain how optimum orbital altitude is determined?
  - 8. Explain about:(a) GPS receiver(b) GPS codes

## **17. QUESTION BANK:**

## **18. ASSIGNMENT TOPICS:**

Assignment Questions UNIT-I

- 1.a) Define Satellite communicationb) Explain Aryabhatta
- 2.a) Write short notes Frequency allocations
- 3.a) Discuss various types of satellities.
- b) Give the Basic block diagram of Communication.

## 4.a) Define Earth Station.

b) What is perigee

5. List out various applications of satellities.

UNIT-II

- 1.a) Define orbits.
  - b) Find the the expression for look angle.
- 2. Define orbital perturbations

3.(a) Design a high pass filter using hamming window with a cut-off frequency 1.2 radians/second and N=9

- (b) Compare FIR and IIR filters.
- 4.a) Define DFS. State any Four properties of DFS.
- b) Find the IDFT of the given sequence  $x(K) = \{2, 2-3j, 2+3j, -2\}$ .
- 5.a) Define DFT and IDFT. State any Four properties of DFT.

b) Find 8-Point DFT of the given time domain sequence  $x(n) = \{1, 2, 3, 4\}$ .

UNIT-III

- 1.a) Find IFFT of the given X(K) = { 1,2,3,4,4,3,2,1}using DIF algorithm
  - b) Bring out the relationship between DFT and Z-transform.
- 2.a) Develop DIT-FFT algorithm and draw signal flow graphs for decomposing the DFT for N=6 by considering the factors for N = 6 = 2.3.
- b) Bring out the relationship between DFT and Z-transform.
  - 3. (a) For each of the following systems, determine whether or not the system is i.
    - stable
    - ii. causal
    - iii. linear
    - iv. shift-invariant.

A. T [x(n)] = x(n – n0) B. T [x(n)] = ex(n) C. T[x(n)] = a x(n) + b. Justify your answer.

(b) A system is described by the difference equation y(n)-y(n-1)-y(n-2) = x(n-1). Assuming that the system is initially relaxed, determine its unit sample response h(n).

- 4.a) Derive the expressions for computing the FFT using DIT algorithm and hence draw the standard butterfly structure.
  - b) Compare the computational complexity of FFT and DFT.

3.a) Find X(K) of the given sequence  $x(n) = \{1,2,3,4,4,3,2,1\}$ using DIT- FFT

algorithm.

b) Compare the computational complexity of FFT and DFT.

#### UNIT-IV

- 1.a) Define Z-Transform and List out its properties.
  - b) Discuss Direct form, Cascade and Linear phase realization structures of FIR filters.
- 2.a) Discuss transposed form structures with an example.
  - b) Discuss Direct form, Cascade realization structures of FIR filters.
- 3. Discuss and draw various IIR realization structures like Direct form I, Direct

form-II, Parallel and cascade forms for the difference equation given by y(n) = -3/8 Y(n-1) + 3/32 y(n-2) + 1/64 y(n-3) + x(n) + 3 x(n-1)

4. What are the various basic building blocks in realization of Digital Systems and hence discuss transposed form realization structures.
(a) Implement the decimation in time FFT algorithm for N=16.

(b) In the above Question how many non - trivial multiplications are Required.

## UNIT-V

- 1.a) Discuss digital and analog frequency transformation techniques.
  - b) Discuss IIR filter design using Bilinear transformation and hence discuss frequency warping effect.
- 2.a) Discuss digital and analog frequency transformation techniques.
- b) Discuss IIR filter design using Impulse Invariant transformation and list out its advantages and Limitations.
  - 3. (a) Discuss the frequency-domain representation of discrete-time systems and signals by deriving the necessary relation.
    - (b) Draw the frequency response of LSI system with impulse response
    - h(n) = an u(-n) (|a| < 1)
- 4.a) Compare Butterworth and Chebyshev approximation techniques.
- b) Design a Digital Butterworth LPF using Bilinear transformation technique for the following specifications

 $0.707 \le | H(w) | \le 1$ ; 0  $\le w \le 0.2\pi$ 

#### $| H(w) | \le 0.08$ ; 0.4 $\pi \le w \le \pi$

- 5.a) Compare Impulse Invariant and Bilinear transformation techniques.
  - b) Compute the poles of an Analog Chebyshev filter TF that satisfies the

#### Constraints

 $0.707 \le |H(j\Omega)| \le 1$ ;  $0 \le \Omega \le 2$ 

## $| H(j\Omega) | \le 0.1$ ; $\Omega \ge 4$

and determine Ha(s) and hence obtain H(z) using Bilinear transformation.

UNIT-VI

1.a) Derive the conditions to achieve Linear Phase characteristics of FIR filters

b) Design an FIR Digital Low pass filter using Hanning window whose cut 1ff freq is 2 rad/s and length of window N=9.

- 2.a) Compare FIR and IIR filters
- b) Design an FIR Digital High pass filter using Hamming window whose cut off freq is 1.2 rad/s and length of window N=9.

- a) Compare various windowing functions
- b) Design an FIR Digital Band pass filter using rectangular window whose upper and lower cut off freq.'s are 1 & 2 rad/s and length of window N = 9.
- 3.a) Compare various windowing functions.
  - b) Design an FIR Digital Low pass filter using rectangular window whose cut off freq is 2 rad/s and length of window N=9.
  - 4. (a) Describe how targets can be decided using RADAR
    - (b) Give an expression for the following parameters relative to RADAR

## i. Beam width

- ii. Maximum unambiguous range
- (c) Discuss signal processing in a RADAR system.

## UNIT-VII

- 1. a) Discuss the implementation of Polyphase filters for Interpolators with an example
- b) Discuss the sampling rate conversion by a factor I/D with the help of a Neat block Diagram.
- 2. a) Define Interpolation and Decimation.
  - b) Discuss the sampling rate conversion by a factor I/D with the help of aNeat block Diagram.
- 3.a) Define Interpolation and Decimation. List out the advantages of Sampling rate conversion.

b) Discuss the sampling rate conversion by a factor I with the help of a Neat block Diagram.

4. a) Define Multirate systems and Sampling rate conversion

b) Discuss the process of n Decimation by a factor D and explain how the aliasing effect can be eliminated

5.(a) An LTI system is described by the equation

y(n)=x(n)+0.81x(n-1)-0.81x(n-2)-0.45y(n-2).

Determine the transfer function of the system. Sketch the poles and zeroes on the Z-plane.

(b) Define stable and unstable systems. Test the condition for stability of the first-order IIR filter governed by the equation y(n)=x(n)+bx(n-1).

UNIT-VIII

1. Discuss various Modified Bus structures of Programmable DSP Processors.

Write short notes on:

- 2. a) VLIW Architecture of Programmable Digital Signal Processors
- b) Multiplier and Multiplier Accumulator
- 3. a) Discuss Various Addressing modes of Programmable Digital Signal Processors.
  - b) Give the Internal Architecture of TMS320C5X 16 bit fixed point processor
- 4. a) Write a short notes on On-Chip peripherals of Programmable DSP's.b)Give the Internal Architecture of TMS320C5X 16 bit fixed point processor
- 5. (a) Compute Discrete Fourier transform of the following finite length sequence considered to be of length N.

i.  $x(n) = \delta(n + n0)$  where 0 < n0 < N

ii. x(n) = an where 0 < a < 1.

(b) If x(n) denotes a finite length sequence of length N, show that x((-n))N = x((N - n))N

19. UNIT WISE QUIZ QUESTIONS AND LONG ANSWER QUESTIONS:

UNIT-I: INTRODUCTION

.

UNIT II: DISCRETE FOURIER SERIES

UNIT III: FAST FOURIER TRANSFORMS

UNIT IV: REALIZATION OF DIGITAL FILTERS

UNIT V: IIR DIGITAL FILTERS and

UNIT VI: FIR DIGITAL FILTERS

#### PART - B

UNIT VII: MULTIRATE DIGITAL SIGNAL PROCESSING

2. Define multi channel and multi dimensional signals. (2)

3. Define symmetric and anti symmetric signals. (2)

4. Differentiate recursive and non recursive difference equations. (2)

5. What is meant by impulse response? (2)

6. What is meant by LTI system? (2)

UN IT-II :

UNIT – III

PART B

PART B

PART A (2marks)

PART B

20. TUTORIAL PROBLEMS:

# 21. KNOWN GAPS, IF ANY AND INCLUSION OF THE SAME IN LECTURE SCHEDULE:

## **Known Gaps:**

1. Comparison of received signal with the reference signal (not just by cross correlation but by using time shift parameter).

2. Transponders characteristics should be known

3. To differentiate between the signals based on geographical position of the signal source in order to find real time applications

4. To study the GPS .

5. To support much wider range of representing satellites

## **DISCUSSION TOPICS, IF ANY:**

GEO, LEO, MEO and GNNS

## 22.REFERENCESS, JOURNALS, WEBSITES AND E-LINKS IF ANY:

References

- 1. Satellite Communications: Design Principles M. Richharia, BS Publications, 2nd Edition, 2003.
- 2. Satellite Communication D.C Agarwal, Khanna Publications, 5th Ed.
- 3. Fundamentals of Satellite Communications K.N. Raja Rao, PHI, 2004
- 4. Satellite Communications Dennis Roddy, McGraw Hill, 2nd Edition, 1996.

## **WEBSITES:**

1.www.pearsoned.co.in/johngproakis

2.www.google.com

3.www.wikipedia.com

4.www.satellite communications.com

5.www.dspguru.com

## **23.Quality Control Sheets**

## **24. STUDENTS LIST:**

No.Admin/B.Tech/SR/15		Rev. No. 00
Academic Year: 2015-16		Date

Class / Se	ection: ECE 4-1C				
S.No	Roll No	Student Name	S.No	Roll No	Student Name
1			34		
2			35		
3			36		
4			37		
5			38		
6			39		
7			40		
8			41		
9			42		
10			43		
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21			54		
22			55		

23		56	
24		57	
25		58	
26		59	-
27		60	
28		61	
29		62	
30		63	
31		64	
32		65	
33			
Total: 65	Males: Females:		

25.QUALITY MEASUREMENT SHEETS

- 1. COURSE END SUREY
- 2. TEACHING EVALUATION

26.GROUP- WISE STUDENTS LIST FOR DISCUSSION TOPICS:
