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DIGITAL SATELLITE COMMUNICATION SYSTEM
(BASIC CONCEPTS. ARCHITECTURE)

GRADUATION PROJECT- "EE–400"

B.Sc. ENGINEERING PROJECT

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ACKNOWLEDGEMENT

One of the pleasures of authorship is acknowledging the many people whose names may not appear on the cover but without whose efforts; co-operation and encouragement a work of this scope never have been completed.

I am much indebted to

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For his kind supervision, generous advice, clarifying suggestions and support during the whole scope of this work.

In the end, I would like to thank my family for their support during my education.

ABSTRACT

DURING the past few years, the importance of Digital Satellite Communication, has increased rapidly. The accumulation of a vast body of engineering literature in the various technical journals has accompanied the design and development of digital system, and launch of satellite. There are several objectives of this project; which are as fellows :

- Realising in details all about the History Of Digital Satellite Communications.
- Understanding how to fix a satellite in its accurate orbit which is at a constant distance from the earth.
- Covering the concepts of multiple access techniques.
- Dealing with the whole systems of Satellite Communications, such as Earth Stations, Satellite Link, available antennas in this field and Satellite Transponders, ETC.
- Studying several Digital Communication Techniques.
- Studying Time Division Multiple Access in details.

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CHAPTER 4: SATELLITE TRANSPONDER

CHAPTER 5: EARTH STATION

CHAPTER 6: TDMA ACESS

CHAPTER 1 HISTORY OF SATELLITE COMMUNICATIONS

1.1 HISTORY

In 1945 ARTHUR CLARK wrote that satellite with a circular equatorial orbit at a correct altitude of 35,786 km would make one revolution every 24 hour ;that is, it would rotate at the same angular velocity as the earth. An observer looking at such a geostationary satellites powered by solar energy could provide world wide communications for all possible types of services. The "space race" and a sustained effort followed the 1957 launch of SPUTNIK 1 by the United States to catch up with the USSR. The first communications satellites to draw widespread popular interest (because on clear nights they were visible to the naked eye) were ECHO-I and II, launched by AT &T on August 12, 1960, and January 25,1964. These were orbiting balloons 100 ft in diameter, which served as passive reflectors. As such, they had no transponder batteries to run down, and they did not require a strict frequency channelling of up-link signals to accommodate transponder input bands. On the other hand, they operated like radar reflectors and incurred path losses that were proportional to the fourth power of path length rather than to the square of path length as is the case with active satellites. This as well as the available launch vehicles limited the ECHO's to very low orbits with periods of 118 min for ECHO 1 and 108.8 min for ECHO 11. Low orbits meant that an ECHO was in view of two widely separated earth stations for only a few minutes on each pass. Power and antenna requirements were severe; a typical ECHO link from Bell Laboratories in New Jersey to the Jet Propulsion Laboratory in California used 10 kW transmitter at ends, an 85 ft dish in California, and a 60 ft dish in New Jersey. Typical frequencies were 960 MHz westbound and 2390 MHz eastbound.

In 1963 Congress passed the Communications Satellite Act.; establishing the Communications Satellite Co-operation (Comsat) and barring the Bell System from further direct participation in satellite communications. While we will not go into the many conflicting reasons why this should or should not have been done (the authors have friends who are involved on all sides of matter), this caused considerable bitterness in the Bell

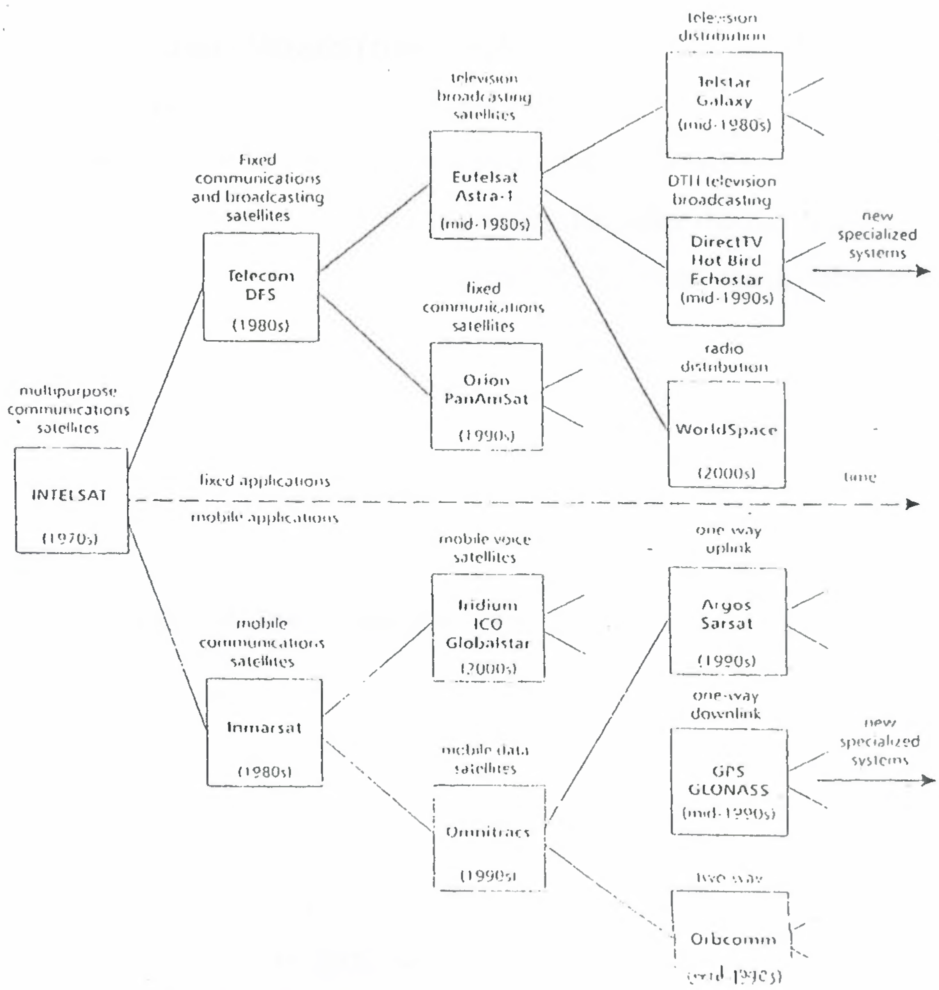
System. Which had invested substantial resources in the ECHO and TELSTAR programs. The Bell engineers involved felt that, once their company proved that communications satellites would work, the opportunity to profit by their investment was taken away and given to someone else. Unhappiness over this situation persisted well into 1970s and the restriction ultimately was lifted.

The first commercial geosynchronous satellite was INTELSAT 1 (first called EARLY BIRD), developed by Comsat for Intelsat. launched Apri16, 1965, it remained active until 1969. Routine operation between the United States and Europe began on June 28, 1965, a date that should be recognised as the birthday of commercial satellite communications. The spacecraft had two 25 MHz bandwidth transponders with up-links centered at 6301 MHz for Europe and 6390 MHz for the United States. U. S. receivers operated with a 4081 MHz center frequency and the European down-links band was centered at 4161 MHz . With this spacecraft the modern era of Satellite communications had begun.

1.2 SATELLITE COMMUNICATIONS EXPERIMENTS

Among other fields space activity at this time, the USA carried out a series of communication satellite experiments, involving NASA or the US Army, using passive reflectors in space, such as the Echo and West Ford projects, and active relaying satellites, such as Score and Courier. This programme, using active satellites, was continued by NASA with the six satellites of Applications Technology Satellites (ATS) series with launching running through the 1960s and was recently revived by the launch of Advanced Communications Technology Satellite (ACTS) in 1993.

Syncom was another important early project, designed primarily to develop and refine techniques for launching satellites into the GSO. The Hughes Aircraft Company supplied three satellites. Syncom1 was launched on 14 February 1963 into an orbit that was approximately geosynchronous, with an orbital inclination of 33.5^0 , but its communication system failed in the final stages of orbit adjustment. Syncom 2 was launched on 26 July 1963 into a more accurate geosynchronous orbit, its inclination was 33.1^0, and its communications system remained functional. Syncom 3 was highly successful being launched on 19 August 1994 into an almost geostationary orbit, approximately circular, its orbital period almost exactly equal to one Side real day and its inclination a mere 0. 1^0.



DTH = **direct to home**

FIGURE 1.1

CHAPTER 2 SATELLITE COMMUNICATIONS

2.1 INTRODUCTION

Satellites (spacecraft) which orbit the earth follow the same laws that govern the motion of the planets around the sun. From early times much has been learned about planetary motion through careful observations. From these observations Johannes Kepler (1571-1630) was able to derive empirically three laws describing planetary motion.

Later, in 1665, Sir Isaac Newton (1642-1727) was able to derive Kepler's laws from his own laws of mechanics and develop the theory of gravitation. Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The more massive of the bodies is referred to as the primary, the other the secondary, or satellite.

• Satellite Communications networks are one of the most major telecommunications system.

• Satellites have a unique capability for providing coverage over large geo-graphical areas.

• The resulting interconnectivity between communications sources provides major advantages in applications such as:

Telephone exchange , Mobile communications, Television and sound broadcasts directly to the public.

2.2 SATELLITE ORBITS

2.2.1 Geo-synchronous and Geo-stationary Orbits

a. Basic Orbital Characteristics

The Earth's sidereal period of rotation, that is, the time taken for one complete rotation about its center of mass relative to the stellar background, is one sidereal day, approximately 23 hours 6 minutes 4 seconds. If a satellite has a direct, circular orbit and its period of revolution measured as above, is equal to one sidereal day, it will keep pace with the turning Earth; that is, it is a geo-synchronous satellite. The radius of its orbit (r_g) will be 42164 km and its height above the earth's surface will be about 35786 km. If this satellites daily Earth track (that is, the locus of the points on the earth's surface that are vertically below the satellite at any instant) is traced, it will show a figure of eight pattern as sketched in Figure 2.1 (a).

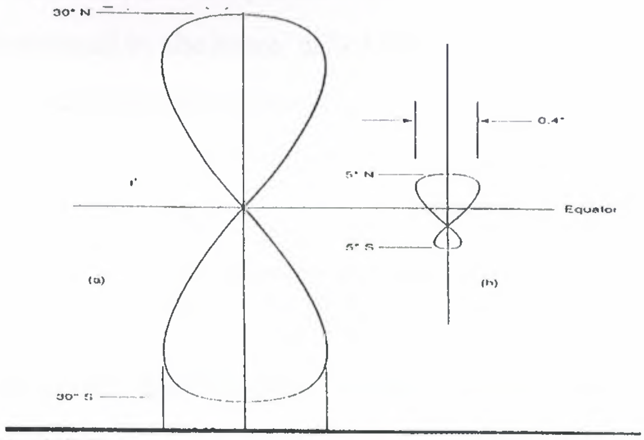


FIGURE 2.1

The maximum extent of the pattern in degrees of latitude, north and south of the equator, is equal to the angle of inclination of the orbit. Provided that the orbit is indeed circular, the north-going track crosses the equator at the same longitude as the south going track and the pattern is symmetrical about that central lino of longitude. However, if the orbit is elliptical, the cross- over point of the north-going and south-going tracks is no longer located in the equatorial plane and the pattern becomes asymmetrical; see for example, Figure 2.1 (b).

The maximum spread of the pattern, east and west of the central line of longitude is given by

Maximum spread = $\pm$ arcsine ($\sin^2 \frac{1}{2}i / \cos^2 \frac{1}{2}i$)

The Geo-stationary satellite orbit (GSO), like other orbits, is unstable. There are orbital perturbations that are tending all the time to change its period, inclination and shape from the Geo-stationary parameter set.

b. Advantages

The GSO is better for the most communication systems than any other orbit. The reasons for this are:

1. Above all, one satellite can provide continuous links between earth stations. An inclined geo-synchronous satellite can do this also, although the geo-graphical area that can be served is more limited if the angle of inclination is large.

The disadvantages of using satellites with an orbital period of less than one sidereal day for systems that are required to provide continuous connections.

2. The gain and radiation pattern of satellite antennas can be optimized, so that the geo-graphical area illuminated by the beam, called the footprint, can be matched accurately to the service area, yielding significant benefits .

3. The geo-graphical area visible from the satellite, and therefore potentially accessible for communication, is very large; see Figure 2.2 the diameter of the area with in which the angle of elevation σ of a geo-stationary satellite is greater than 5° is about 19960 km.

4. If the orbit is accurately geo-stationary, earth station antennas of considerable gain can be used without automatic satellite tracking reducing equipment cost and minimizing the operational attention required.

5. The frequency assignment used in different geo-stationary satellite networks can be coordinated efficiently, the satellite footprints can be matched to the service areas, and earth station antennas usually have high again.

c. Disadvantages

1. A satellite link from earth to station via a geo-stationary satellite is very long.

2. As can be seen from Figure 2.2 the angle of elevation of the satellite as seen from earth stations in high latitudes is quite low, leading at times to degraded radio propagation and possible obstruction by hills, buildings, and so on.

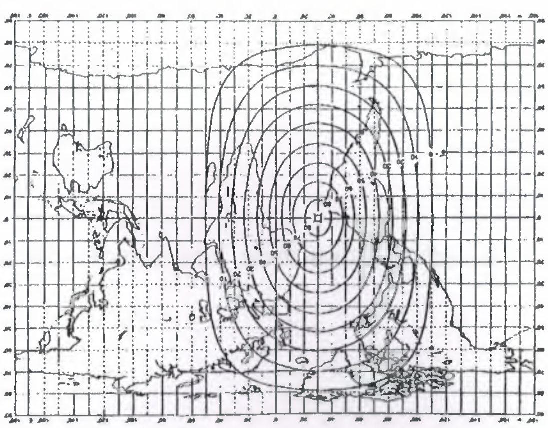


FIGURE 2.2

d. Perturbations Of Geo-stationary Orbits

The drag of the atmosphere on a satellite in a 24-hour circular orbit is negligible. However, there are three kinds of orbital perturbation, which tend to move the parameters of the orbit of geo-stationary satellite away from the nominal values. They are the gravitational effect of irregularities of the Earth's figure, the gravitational attraction of the Sun and Moon and solar radiation pressure.

2.2.2 Inclined Elliptical Orbits

a. Basic Orbital Characteristics

The shape of an ellipse is characterized by its eccentricity ϵ, where:

$$\epsilon = (1 - b^2 / a^2)^{1/2}$$

and a and b are the semi- major and semi-minor axes of the ellipse. There are two foci located on the major axis and separated from the origin of the ellipse by distance c, where

$$c = \epsilon a$$

For an Earth satellite with an elliptical orbit, one of the foci is located at Q, the center of mass of the Earth. The points on the orbit where the satellite is most and least distance from the Earth are called the apogee and the perigee respectively. The greatest and least distances from the surface of the earth, the altitudes of apogee and perigee ha and hp, are given by

$$h_a = a(1 + \epsilon) - R_E$$

and

$$h_p = a(1 - \epsilon) - R_E$$

$$\epsilon = (1 - b^2/a^2)^{1/2}$$

a, b are semi - major and semi-minor axes of the ellipse . These various terms are illustrated in Figure 2.3

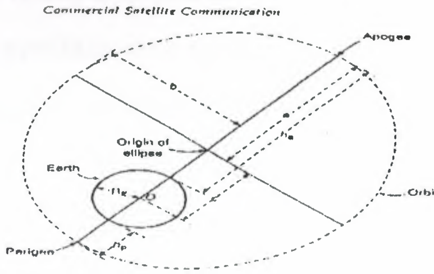


FIGURE 2.3

A satellite is perfectly circular orbit has uniform speed round that orbit, but the speed of motion of a satellite in an elliptical orbit varies. As the satellite moves from apogee to perigee its potential energy falls and its kinetic energy, as revealed by its speed, rises. Correspondingly, the potential energy rises and the speed fails as the satellite moves from perigee to apogee. This variation of speed is conventially expressed in the form of Kepler's second law of planetary motion. This states that each planetary motion. This states that each planet moves in such a way that a line joining it to the Sun would sweep out equal areas in equal periods of time. Thus in Figure (2.4), if the time taken by the satellite to move from N to M is the same as for the journey from K to J, then the sectors KOJ and NOM are equal in area and the ratio of the satellite speeds at the midpoints of the arcs NM and KJ (v_1, v_2) is related to the ratio of the distances of those midpoints to the center of mass of the Earth (I_1, I_2).

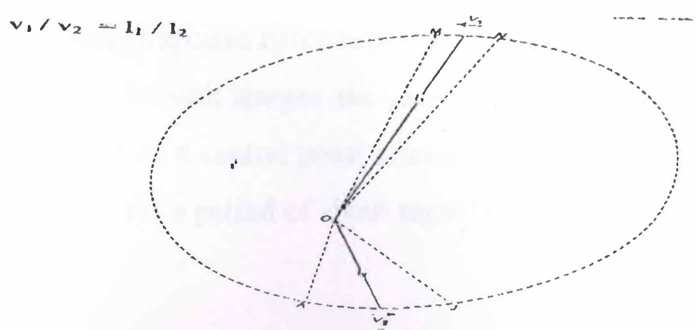


FIGURE 2.4

b. Perturbations Of Inclined Elliptical Orbits

The gravitational attraction of the Sun and the Moon and the pressure of solar radiation on the satellite body affect satellites with inclined elliptical orbits in much time the same way as they affect geo-stationary satellites. However, these effects are small compared with the effect of the oblateness of the Earth on the argument of perigee . Moreover, some elliptical orbits, having a quite small height at perigee, suffer considerable orbit modification through aerodynamic drag.

c. The Earth Coverage Of Satellites In Elliptical Orbits

Satellite in orbits of substantial eccentricity spend most of each orbital period at a high altitude, close to the height of their apogee, from which they can cover a large footprint. In general they are of little use at low altitude, near to perigee. The systems that might find such orbits of value are national or regional in coverage rather than global. Thus it is necessary to choose an orbital period and to control precession of the argument of perigee to stabilize the Earth track, to ensure that the point on the Earth directly beneath the apogee should be consistently located at an appropriate point in the service area.

d. High Latitude Coverage

A point on the surface of the Earth sweeps through right ascension at a constant rate of approximately 3600 /24 = 15^0 per hour. A satellite in a direct elliptical orbit with period of T (hours) sweeps through right ascension in the same direction as the earth and at an average rate of 360°/ T per hour, although the rate will be considerably less than the average near apogee and more than the average near perigee .The Earth track of the Molniya orbit, centered as an example on longitude 0°, is sketched in Figure 2.5 . The satellite passes through apogee twice each day, at about the same location in the celestial frame of reference. At each apogee the satellite is seen from the Earth's surface to be within a few degrees of a central point around latitude 60° N and, for this Example, at longitude 0° or 180° for a period of about eight hours.

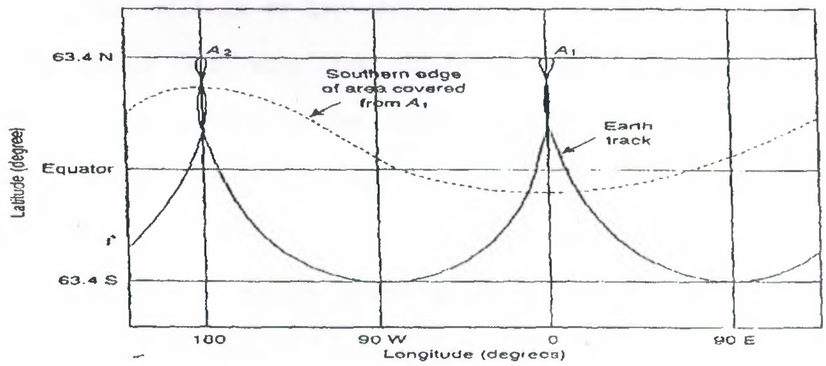


FIGURE 2.5

e. Short Orbital Period

Satellite in circular orbits with height above the Earth of 8000 km have an orbital period of 4.7 hours; 12 satellites in phased orbits might be needed to provide continuous coverage of a service area that is continental in extent. A satellite with an elliptical orbit having a period of two hours might also have a height above the Earth's surface at apogee of 8000 km, depending on the eccentricity of its orbits.

f. Medium- Altitude Orbits

Geo-stationary satellites have great advantages for communications applications where polar coverage is not required. In the early days of satellite communication, it was feared that one-way transmission times exceeding 250 ms might be an unacceptable impediment to telephone conversation. Geo-stationary satellite seems likely to continue to dominate satellite communications with high- capacity links between fixed points. However, there has recently been a revival of interest in using medium-altitude orbits for serving mobile Earth stations, because, compared with the GSO, the transmission loss is lower.

It is fortunate that the GSO has been found acceptable for trunk telecommunications. because tile use of lower orbits such as MEO's for this purpose would involve major additional problems and costs.

2.2.3 Orbital Perturbations For MEO's And LEO's

Satellite in medium-altitude or low circular orbits is, of course, subject to ORBITAL PERTURBATIONS. For very low orbits, the aerodynamic drag is likely to be significant. However, some of the other perturbations, such as precession of the argument of perigee, resolve to zero if the orbit is circular or polar. In general, a perturbation is unlikely to have a serious effect on the operation of a multi-satellite constellation since it will usually affect all the satellites of the constellation in equal measure .

2.2.4 Low Earth Orbits(LEO) Systems

Satellite with altitudes in the approximate range of 100–1000 miles is referred to as Low Earth Orbit (LEO). They circle the earth every few hours. In the following pages we are going to show two examples of satellite mobile service systems, Iridium and Global-Star systems, which are considered as LEO systems.

2.2.5 The Iridium System

Engineers at Motorola's satellite communication division in 1987 originated the iridium concept. Originally envisioned as consisting of 77 satellites in low earth orbit, the name Iridium was adopted by analogy with the element Iridium, which has 77 orbital electrons. Further studies led to a revised constellation plan requiring only 66 satellites. Because of the international character of satellite communications, an international consortium of telecommunications operator and industrial companies, called Iridium Inc., was formed to implement and manage the Iridium system .

Description Of The System

The system consists of six orbital planes, each containing 11 active satellite. The orbits are circular at height of 783 km. Pro-grade orbits are used, the inclination being 86°. The 11 satellites in any given plane are uniformly spaced, the normal spacing being 32.7°. An in-orbit spare is available for each plane at an orbit 130 km lower in orbital plane.

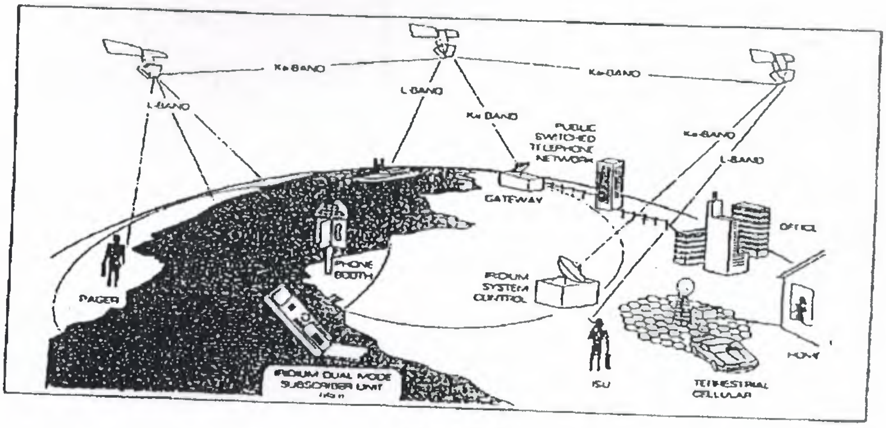


FIGURE 2.6

The satellite travels in co-rotating planes that they travel up one side of the earth cross over near the north pole, then travel down the other side . Since there are 11 equi-spaced satellites in each plane, it will be seen that the entire earth is continuously covered. The satellites in adjacent plane travel out of phase Figure (2.6), collision avoidance is built into the orbital planning, and the closest approach between satellites is 223 km. Satellites in planes 1,3 and 5 cross the equator in synchronization while satellites in plane 2,4 and 6 also cross in synchronization but of phase with those in planes 1.3 and 5. The separation between planes is 31.6^0, which allows 22^0 separation between the first and last planes. The closer separation is needed because the earth coverage under the counter rotating "seam" is not as efficient as it under the co-rotating seams. There are two-way communication links between satellites as shown in Figure (2.6), ahead and front, and to the satellites in adjacent planes. The up/down links between subscribers and satellites take place in the L-band. A 48-beam antenna pattern is used from each satellite. with each beam under separate control. The orbital period is approximately 100 min., and taking an average value of 6371 km for the earth's radius. the surface speed is 2x 6371x $\pi/100 \approx 400$ km/min or just over the 15,000 mile/hour. The 48 cell pattern and earth coverage is shown in Figure (2.8).

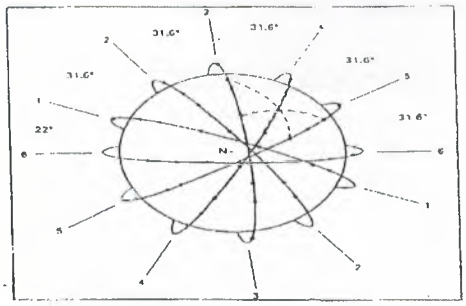


FIGURE 2.7

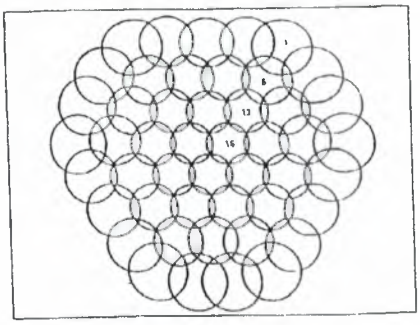


FIGURE 2.8

2.2.6 The Global Star System

Loral Qualcomm Satellite Services company develop the Global-Star system at 1944. The first group is supposed launched in mid 1997, service will begin in mid 1998, and full service will be in 1999. Global-Star use of MMA technology allows users to connect to multiple satellites, improves signal quality, eliminates interference, and disconnects cross talk and loss of data.

a. The Space Segment

A space segment consists of a constellation of 48 satellites in eight planes (6 satellites / plane plus 8 satellites on standby) inclined at 52^0 relative to the equator will be deployed as shown in figure (2.9). In this system the operating frequencies are 1. 6 GHz & 2.5 Hz instead of 800–900 grams used by terrestrial systems for mobiles & C-band for gateways. The frequency plan is shown in figure (2.10), which illustrates the link between the Mobil, and the gateway in both forward and return links. Satellites at a height of 1410 Km (750 nautical mile.), provide coverage areas as great as 5000 Km (2600 nautical mile) in diameter compared to 20 Km provided by terrestrial system employing 20 m high towers.

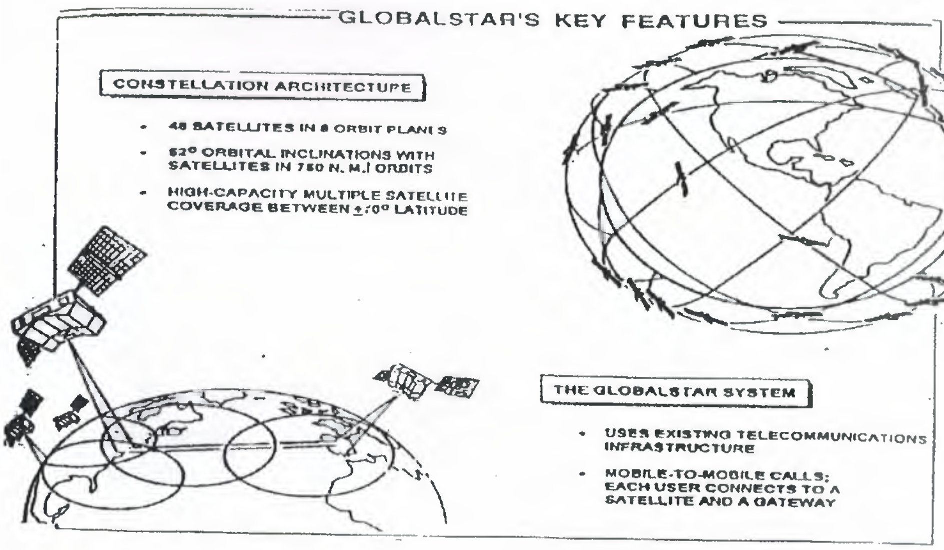


FIGURE 2.9

b. The User Segment

Handheld & mobile unites are similar to standard cellular telephones hut operate in dual mode with the local cellular system or through Global-Star. Dual mode means that some mobile terminals will be able to operate in a cellular network and in the Global-Star network, but single mode means that these operate only with the Global-Star system.

c. The Ground Segment

Global-Star system is comprised of gateways-earth terminals throughout the world that connect the Global-Star satellite constellation to the land-based switching equipment of terrestrial and cellular telecommunications service providers. Certain gateways also manage the Global-Star communication networks for call verification, billing as well as monitor and control each satellites performance.

d. Technical Details

i. Frequency Reuse

The satellites utilize simple frequency translating repeaters. The received signals from the users in the 1.6 GHz range are converted to the 7 GHz range for retransmission to the Gateways, and signals from the Gateways at about 5 GHz are converted to signals at about 2.5 GHz for retransmission to the users, see figure (2. 10).

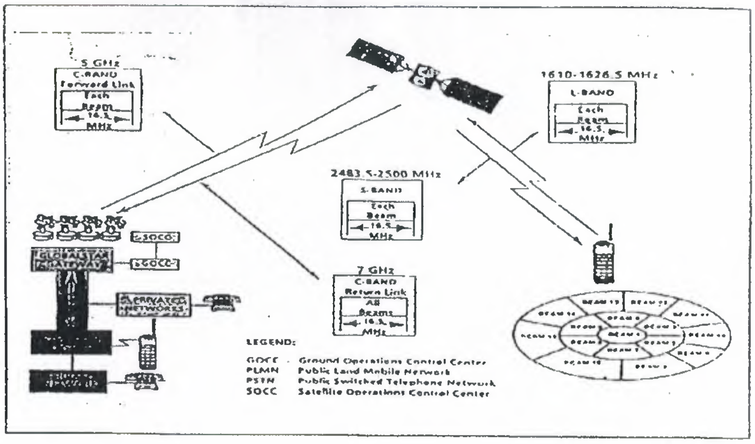


FIGURE 2.10

ii. Active phased Array Satellites Antennas

Active phased array satellite antenna have been developed for Global-Star which use LNA's for the receive and use HPA's for every antenna elements as shown in figure (2.11). Global-Star satellite payload block diagram consists of 2 parts as shown in figure (2.1 1) the first of figure (2 .11) contains the return link between the mobile and the gateways where the relevant beam forming network (1) contains the phased array antenna. Where the second part contains the forward link between the mobile and the gateways. The relevant beam forming network (2) contains the phased array antenna and also the LAN's. The receiver antenna is identical to the transmiter one except that LAN's are substituted by HPA's beam. The total power consumption of each satellite varies from 600 W to 2000 W.

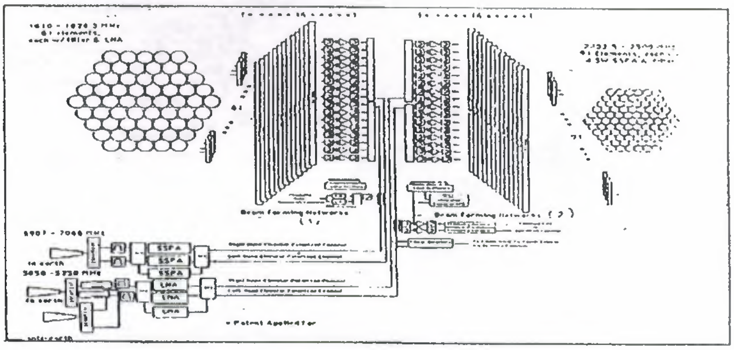


FIGURE 2.11

2.2.7 The Orboccomm System

The orbital communication co-operation (ORBOCCOMM) is a law earth orbital (LEO) satellite system intended to provide two way message and data communication services and position determination. The first two satellite of ORBOCCOMM launched at April 1995. October 1995 was the time to make the service available to customers. In Feb. 1996 the production subscriber communication equipment became available. Orboccomm covers 67 countries and about two-third of the earth's population. This is served by a total of 36 satellites in the Orboccomm constellation, 26 of which will be launched by the end of 1997. During the interval until the constellation is completed, the licenses will be building their own ground stations, and beginning their own service. Offered in Europe and most of Latin American beginning in 1997. Full global availability is projected for 1999. Figure(2.12) illustrates a map of service planned and underdevelopment.

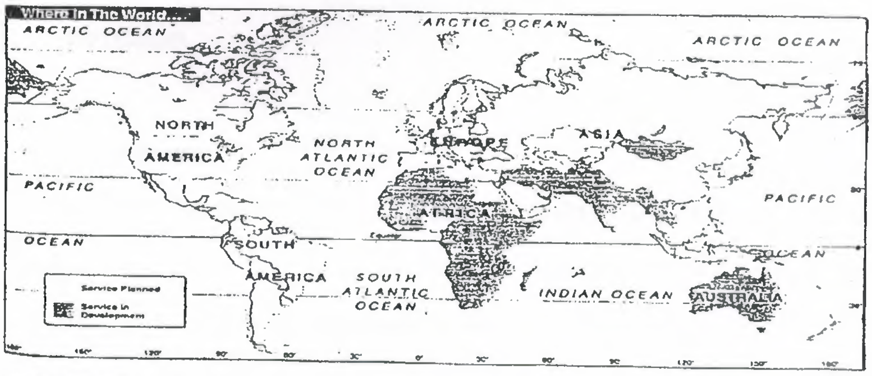


FIGURE 2.12

2.3 ANTENNAS

Type of Antennas

1- Wire Antennas

2- Aperture Antennas

3- Array Antennas

4- Reflector Antennas (Parabolic Reflector)

5- Lens Antennas

2.3.1 Wire Antennas:

Wire Antennas are familiar to the Layman because they are seen vertically everywhere. In automobiles, building, ships aircraft, and so on. There are various shapes of wire Antennas such as a straight wire (dipole), loop, and helix, which are like the below figure:

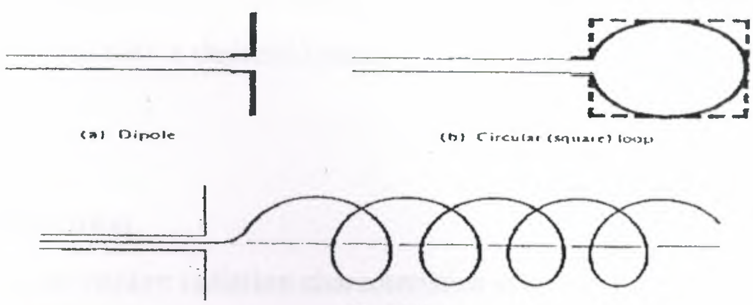


FIGURE 2.13

Loop Antennas need not only be circular. They may take the form of rectangular, square, ellipse, or any other configuration. The circular loop is the most common because of its simplicity in construction.

2.3.2 Aperture Antennas

Aperture Antennas may be more familiar to layman today than in the past because of the increasing demand for most sophisticated forms of antennas and utilization of higher frequencies. Some forms of aperture antennas are shown as in Figure 2.14:

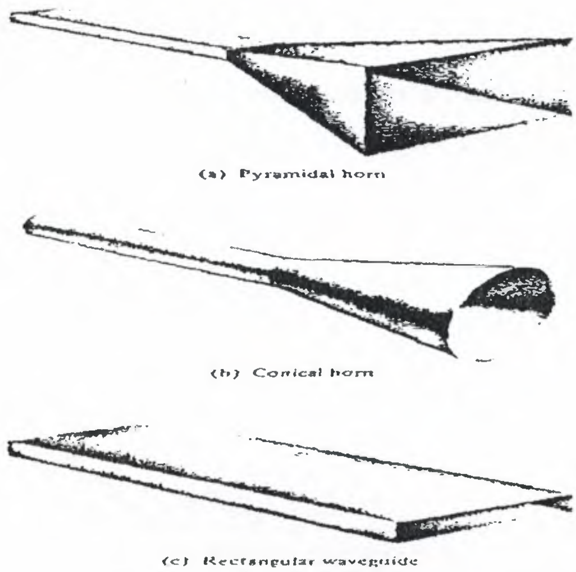


FIGURE 2.14

Antennas of this type are very useful for aircraft or spacecraft applications, because they can be very conveniently flush mounted on the skin of aircraft or spacecraft. In addition, they can be covered with a dielectric material to protect them from hazardous conditions of environment.

2.3.3 Array Antennas

Many applications require radiation characteristics that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geo-metrical arrangement (an array) will result in the desired radiation characteristics. The arrangement of the array may be such that the radiation from the element adds up to give a radiation maximum a particular directions, minimum in others, or other wise as desired. Typical examples of arrays are shown in Figure 2.15:

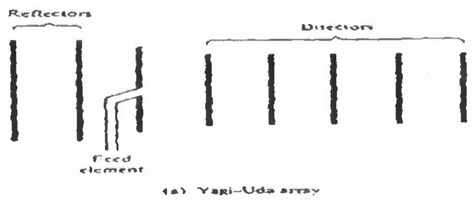


FIGURE 2.15 (a)

Usually the term array is reserved for an arrangement in which the individual radiators are separate as shown in Figures 2.15 (a) and b). However the same term is also used to describe an assembly of radiators mounted on a continuous structure shown in Figure 2.16(c):

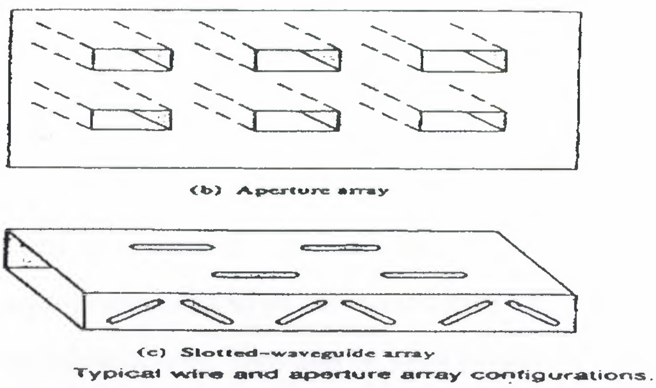


FIGURE 2.15 (b),(c)

2.3.4 Reflector Antennas

The success in the exploration of outer space has resulted in advancement of antenna theory, because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles. A very common antenna form such in application is a parabolic reflector shown in below (a) and (b). Antennas of this type have been built with diameter as large as 305 m. Such large dimensions are needed to achieve the high gain required to transmit or receive signals after million of miles of travel.

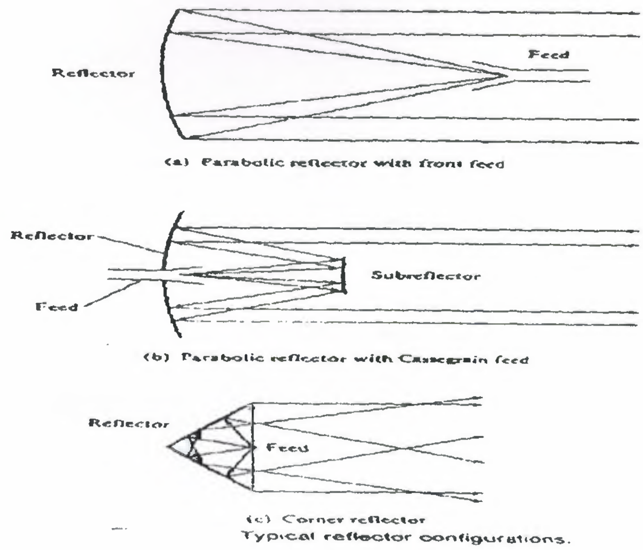


FIGURE 2.16

2.3.5 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geo-metrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they constructed, or according to their geo-metrical shape. Some forms are shown in Figure bellows. In summary, an ideal antenna is one that will radiate all the power delivered to it from the transmitter in a desired direction or directions. In Practice, however, such ideal performances cannot be achieved but may be closely approached. Various types of antennas are available and each type can take different forms in order too achieve the desired radiation characteristics for the particular application.

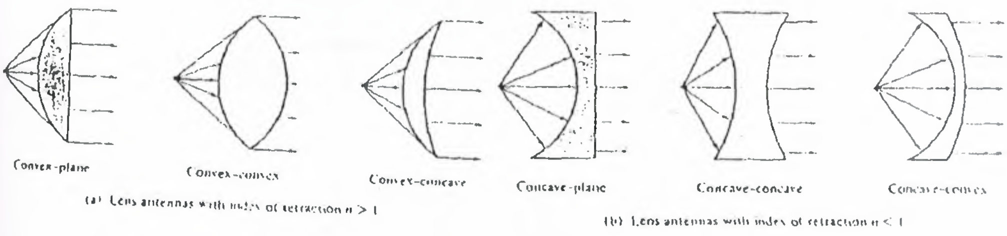


FIGURE 2.17

2.4 LAUNCHERS AND LAUNCHING

2.4.1 Introduction

A satellite may be launched into orbit by either a multi-stage expendable launch vehicle or a manned or unmanned reusable launcher. Additional rocket motors (perigee and apogee kick motors) nay also be required. The process of launching a satellite is based mainly on launching into equatorial circular orbits, and in particular he GSO, but broadly similar processes are used for other orbits. There we two techniques for launching a satellite into an orbit of the desired altitude, namely by direct ascent or by a Hohmann transfer ellipse. In the direct ascent method. the thrust of the launch vehicle is used to place the satellite in a trajectory, the turning point of which is marginally above the altitude of the direct orbit. Apogee kick motor (AKM) is often incorporated into the satellite itself, where other thrusters are also installed for adjusting the orbit or the satellites attitude throughout its operating lifetime in space. The Hohmann transfer ellipse method enables a satellite to be laced in an orbit at the desired altitude using the trajectory that quires the least energy. In practice it is usual for the direct ascent method to be used to inject a satellite into a LEO and for the Hohmann transfer ellipse method to be used for higher orbits.

2.4.2 Expandable Launch Vehicle:

a. Description And Capabilities:

Launch vehicle and their nose fairing impose mass and dimensional constraints on the satellites that can be launched. However, a number of different types of launcher are available for commercial use and the satellite designer ensures that the satellite will meet the constraints and capabilities of one of them, or preferably more than one.

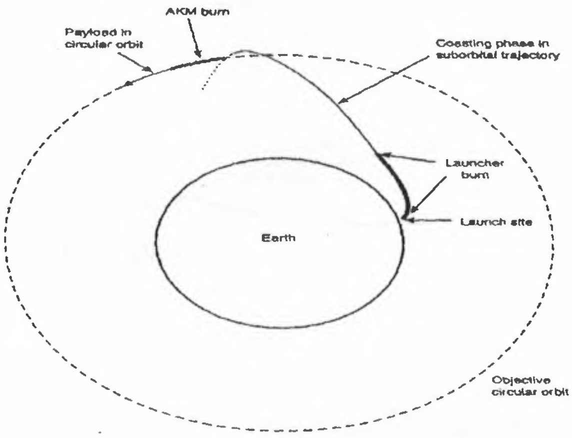


FIGURE 2.18

A brief description of the major expendable currently used for launching commercial satellite follows in this section. It should be noted that a few of them have the capability off placing satellite directly into a high circular orbit; with the others, use is made of a Hohmann transfer elliptical orbit. When the objective is the GSO, the transfer orbit is called a Geo-synchronous or Geo-stationary Transfer Orbit (GTO). All of these vehicles consist of several stages, mostly fuelled by bi-properlane liquids, and solid racket boosters strapped on to the first stage assist some of them. The dimensional constraint on the launcher payload, consisting of one or more satellites, is determined by the size and shape of the nose fairing which protects the payload while the launcher is within the atmosphere. Several different fairing are available for most launchers, accommodating satellites of different sizes and shapes after they have been prepared for launching by folding back such structures as solar arrays and large antennas.

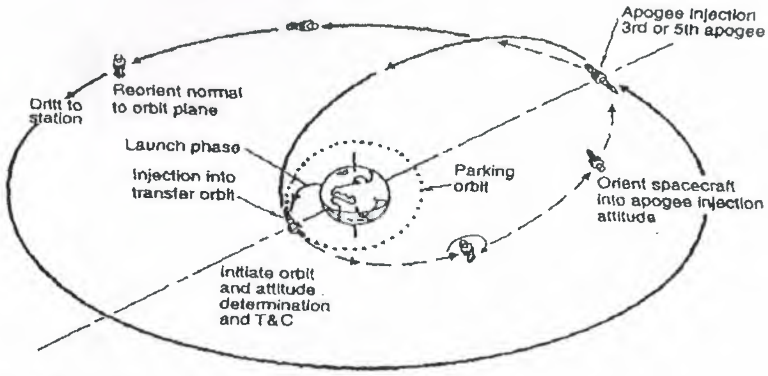


FIGURE 2.19

b. Satellite launch industry

According to a study 0f Euro consult entitled launch service market survey worldwide prospects, 1996-2006, the launch service industry are currently undergoing a radical change in size. Structure and operations. Between 1987 and 1996, an average of 36 satellites were launched each year worldwide (excluding the Commonwealth of Independent States CIS). At least three times more are scheduled Per year over the next ten years. Similarly the annual average mass launched into various orbits is expected to double from 69000 to 150000 kg while demand for both the Geo-stationary Satellite Orbit (GEO) and Medium Earth Orbit (MEO) Low Earth Orbit (LEO) will peak over the next five years, potentially saturating launch capacities. This period will also see the

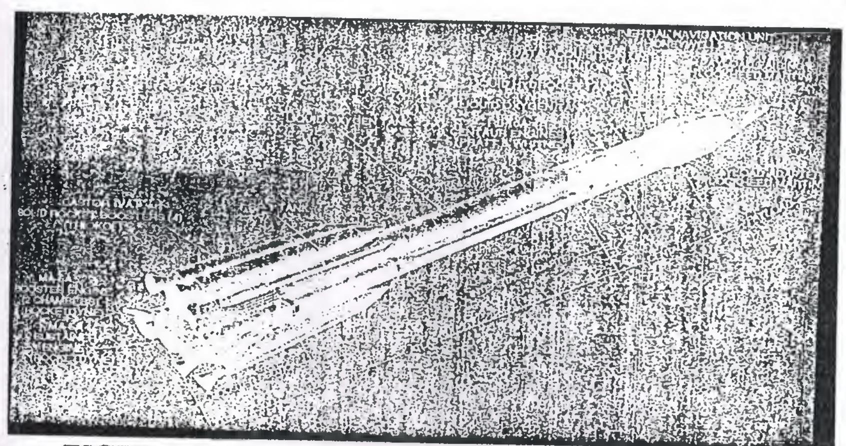


FIGURE 2.20

commercial introduction of several new vehicles, therefore enlarging competition in the different market segments. As a result of growing competition and decreasing launch demand, anticipated around 2005, a buyer's market could well develop.

Distribution Of Launch Market By Orbit and Type Of Satellite Operator, 1997-2006.

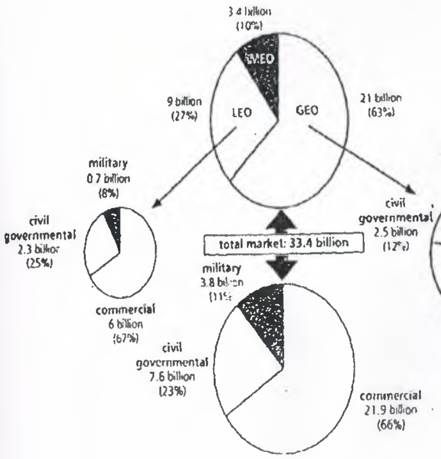
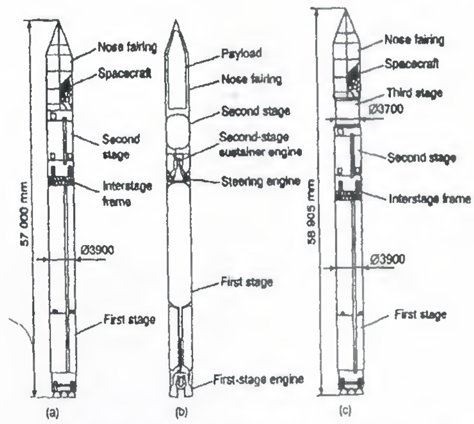


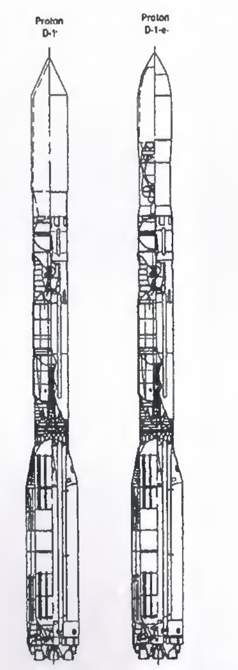
FIGURE 2.21



General views of the (a) Zenit 2 and (c) Zenit 3 launchers and, at

FIGURE 2.22

cutaway view of the commercial Titan launcher.



A comparative cut-away view of the Proton D-1 and D-1-E

FIGURE 2.23 **FIGURE 2.24**

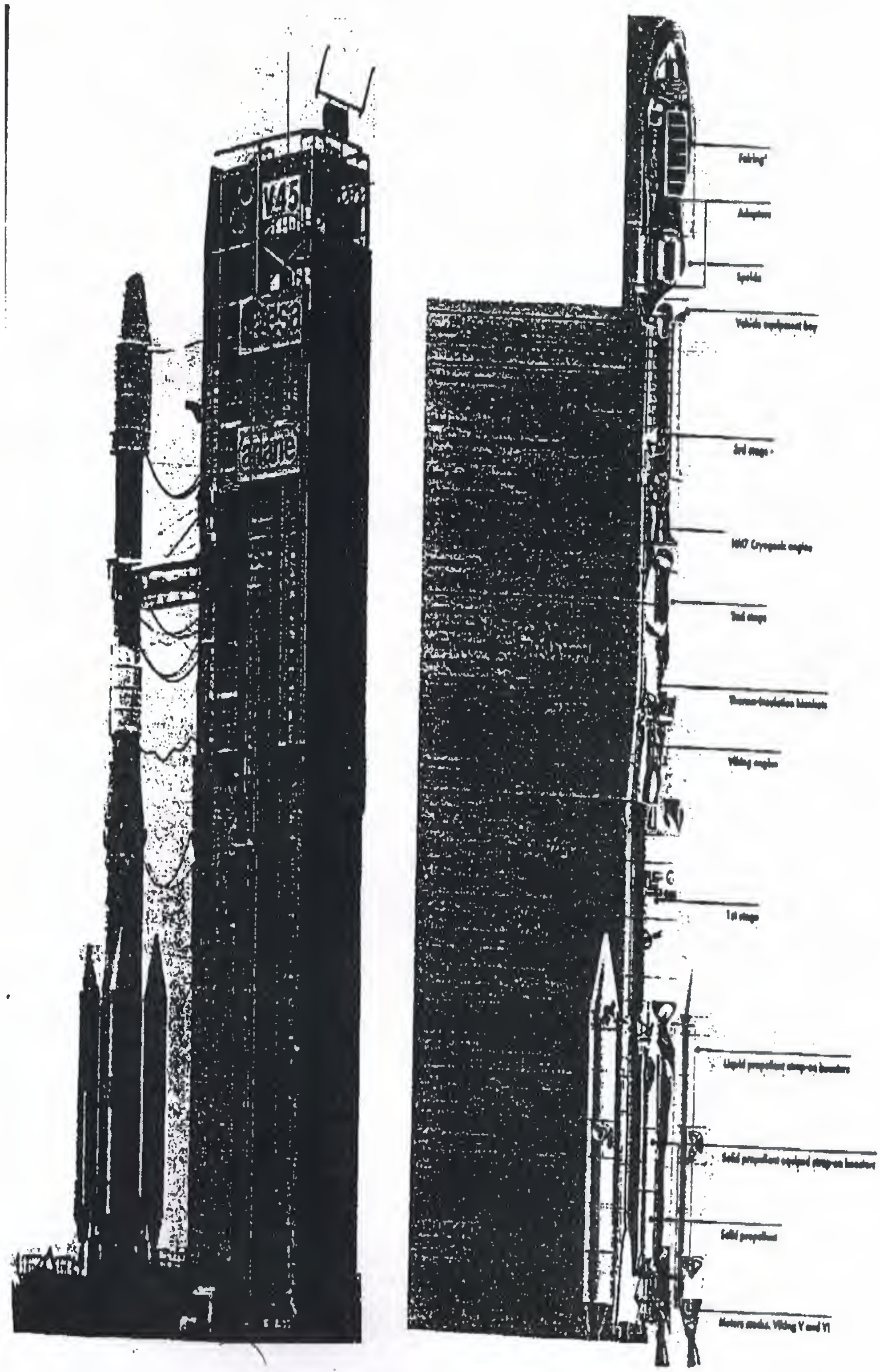

Fairing
Adaptors
Vehicle equipment bay
3rd stage
HM7 Cryogenic engine
2nd stage
Thermal-insulation blankets
Viking engine
1st stage
Liquid propellant strap-on boosters
Solid propellant equipped strap-on boosters
Solid propellant

FIGURE 2.25

CHAPTER 3 DIGITAL COMMUNICATIONS & MULIPLE ACCESS

3.1 Introduction

The term digital communications covers a broad area of communications techniques, including digital transmission and digital radio. Digital transmission is the transmittal of digital pulses between two or more points in a communications system. Digital radio is the transmittal of digitally modulated analog carriers between two or more points in a communications system. Digital transmission systems require a physical facility between the transmitter and receiver. such as a metallic wire pair, a coaxial cable, or an optical fiber cable. In digital radio systems, the transmission medium is free space or the earth's atmosphere.

Figure 3.1 shows simplified block diagrams of both a digital transmission system and a digital radio system.

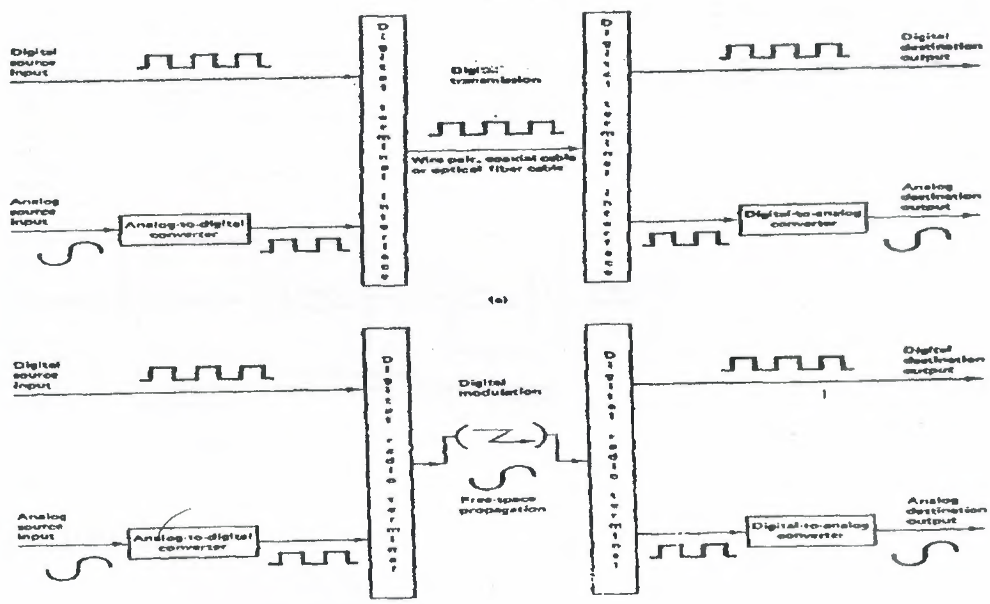


FIGURE 3.1

3.2 Digital Radio

The property that distinguishes a digital radio system from a conventional AM, FM, or PM radio system is that in a digital radio system the modulating and demodulated signals are digital pulses rather than analog waveforms.Digital radio uses analog carriers just as conventional systems do. Essentially, there are three digital modulation techniques that are commonly used in digital radio system

Frequency shift keying (FSK), phase shift keying (PSK), and quadrature amplitude modulation (QAM).

3.3 FREQUENCY AND TIME DIVISION MULTIPLEXING

3.3.1 FDM Systems

Much of the earlier development and usage of a satellite links was concerned with telephony in which the analogue voice channels were multiplied using FDM techniques. FDM is still very widely used and Figure (3.2) shows the basic blocks making up the earth station transmitter and receiver circuits when employing FDM.

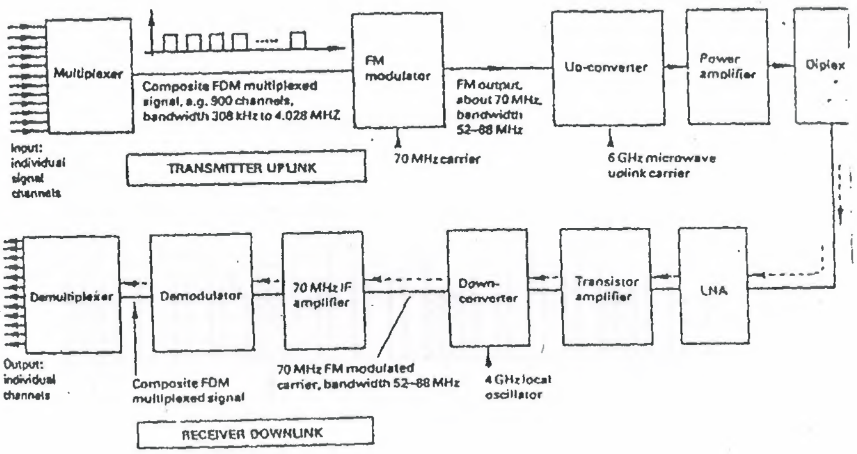


FIGURE 3.2

3.3.2 TDM Systems

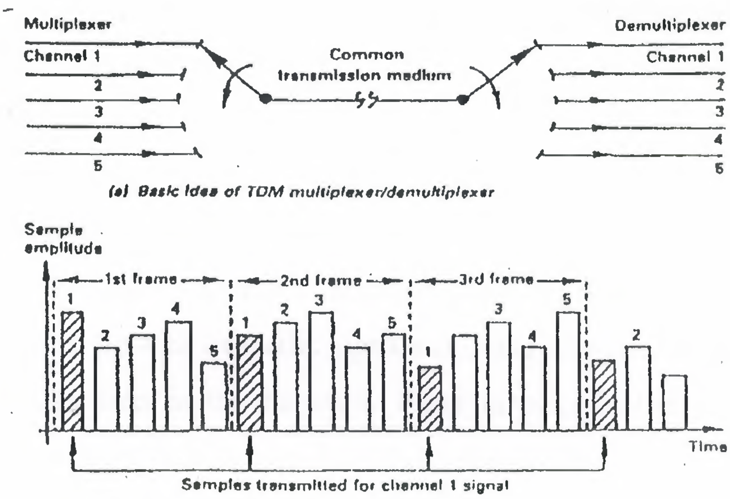
Figure (3.3) illustrates the basic principle of the time division multiplexing of signals. The channels carrying different signals are sampled in turn on a regular respective basis and only during the sampling instants is given channel connected to the common transmission medium. In this way the channel samples can share the common medium on a time basis . The channel samples are interleaved and transmitted as a sequence of pulses-each pulse representing the signal of a given channel at instant of sampling.

For successful operation of a TDM system, exactly the same criterion applies as in PCM/PAM. 'The number of samples per second for all channel signals must be at least twice the maximum frequency contained in the signal, i. e.

- Sampling frequency = 2x maximum frequency in signal. - For example, for voice channel band limited to 4 kHz Sampling frequency = 2x4=8 kHz
- For video Channel, band width 5 MHz, Sampling frequency 2x 5 =10 MHz

The samples are organized into frames, one complete frame containing one sample from each channel.

In a practical system a frame would also contain synchronizing pulses to ensure that multiplexers remain synchronized so that the samples, after propagating through the common medium are routed



(b) Each channel sampled in turn on regular basis. Samples share common transmission medium on time basis. Multiplexer/demultiplexer must be synchronised to ensure samples are tracked to their respective channel destination

Simple TDM system

FIGURE 3.3

to their respective channels outputs. The frame time T_f and the sampling frequency f_S are related:

T_f= I/f_S

For example , for speech where f_S 8 kHz, the frame time:

T_f= 118000 = 125 msec.

3.4 MULTIPLE ACCESSES

3.4.1 Introduction

Multiple access is the ability for a large number of earth stations to simultaneously interconnect their respective communication channels, e.g. voice, data, or TV, using a given satellite, Multiple access provides the means by which the very wide geographical coverage capability of a satellite may be more fully exploited and its capacity optimized for a much greater and wider variety of different users.

There are essentially three multiple access techniques:

1- Frequency Division Multiple Access (FDMA).

2- Time Division Multiple Access (TDMA).

3- Code Division Multiple Access (CDMA).

FDMA and TDMA systems are widely employed by commercial users; CDMA is almost exclusively used by the military.

In FDMA, all users may utilize the satellite at the same time, but access it using different frequency carriers. In an FDMA network, see Figure 3.4, each station is assigned at least one carrier frequency and a specialized bandwidth may be allocated several carriers whilst light traffic stations may employ only one. Each station modulates its carrier (s) with its traffic signals and this information is transmitted via the satellite to every station in the network. Filter circuits in the earth station receiver circuits select the wanted carrier signals and reject all others.

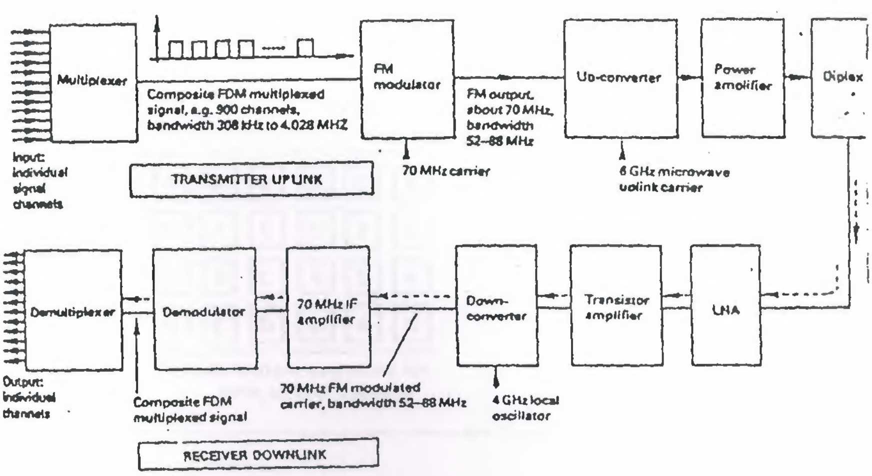


FIGURE 3.4

Each TDMA frame contains a reference burst to establish an absolute time reference for the network and a series of traffic bursts. One for each station. Each of the individual traffic bursts contains a preamble. Which contains synchronization and signalling information and identifies the transmitter. And this is followed by the message bits. The individual bursts are amplified by the satellite transponder and retransmitted in the down link beam, which is received by all stations in the network. The stations can then select and extract the signal information destined for them.

In code Division Multiple Access, also referred to as Spread Spectrum. Multiple Access, the earth stations in the network transmit continuously encoded signals, spread in frequency, but occupying the same frequency band. Each station is allocated its own transmission code, and transmission between any pair is effected by the transmitter station modulating its carrier with the correct code allocated to the destination station. After stations receive the combined coded transmissions from the satellite and use decoding techniques to extract the signal addressed to them. For example, Figure 3.5 demonstrates a frequency hopping CDMA scheme. Each station in the network transmits with a given pseudo-random frequency pattern, maintaining a carrier frequency for only a very short time, normally the order of a bit time before hopping to another one in the coded sequence..

At present CDMA is not being used in commercial satellite links, but is employed by the military for interconnecting small groups of mobile stations.

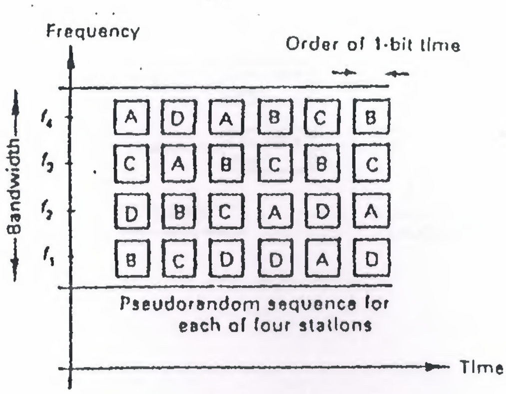
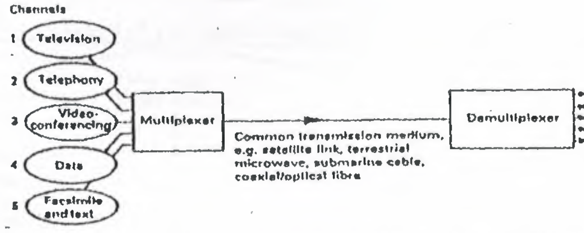


FIGURE 3.5

3.5.2 BLOCK DIAGRAM OF FDM AND TDM



Principle of multiplexing: use of a common medium to transmit several signal channels simultaneously

Figure 3.31

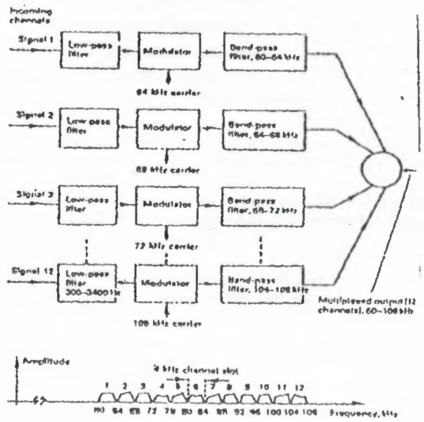
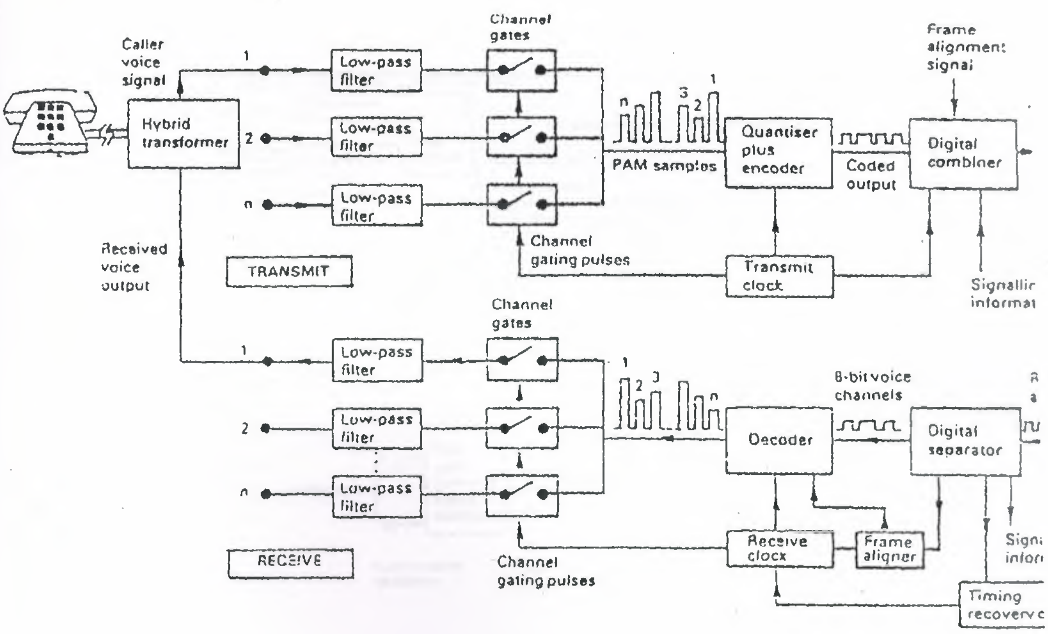
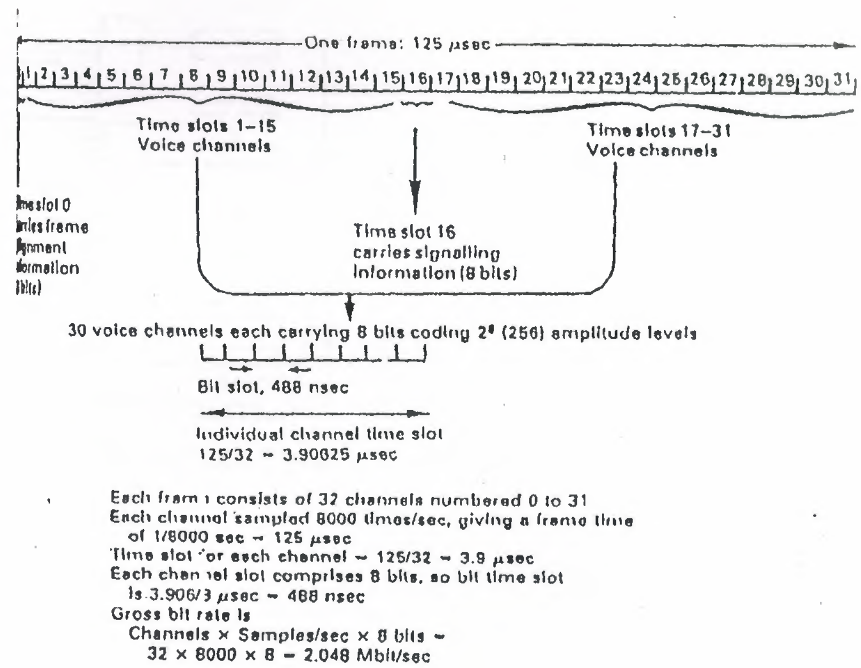


Figure 3.32

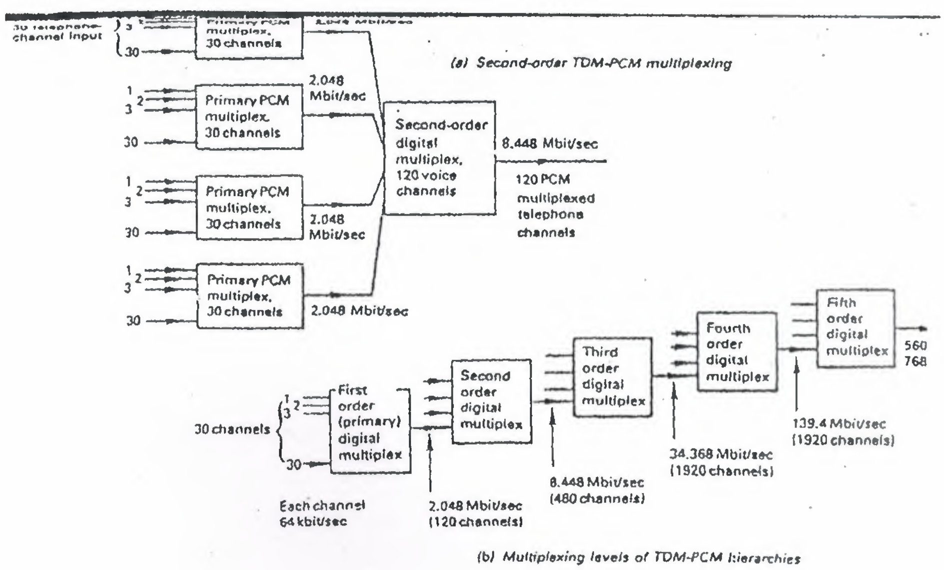


FIGURES 3.6 & 3.7



· Frame structure for 30-channel TDM-PCM system (CCITT A-low ystem, recommendation G732.

FIGURE 3.8



(a) Second-order TDM-PCM multiplexing

(b) Multiplexing levels of TDM-PCM hierarchies

FIGURE 3.9

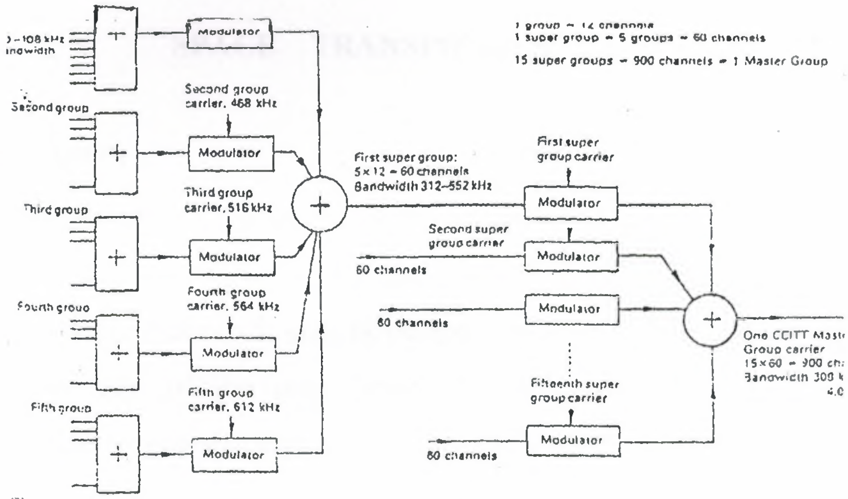

1 super group = 5 groups = 60 channels
15 super groups = 900 channels = 1 Master Group
Modulator
Second group
Second group carrier, 468 kHz
Modulator
Third group
Third group carrier, 516 kHz
Modulator
Fourth group
Fourth group carrier, 564 kHz
Modulator
Fifth group
Fifth group carrier, 612 kHz
Modulator
First super group:
5 × 12 = 60 channels
Bandwidth 312–552 kHz
First super group carrier
Modulator
Second super group carrier
Modulator
60 channels
Modulator
60 channels
Fifteenth super group carrier
Modulator
60 channels
One CCITT Master
Group carrier

FIGURE 3.10

CHAPTER 4 SPACE TRANSPONDER

4.1 INTRODUCTION

Communications satellites are designed to have an operating life time of 5 to 10 years. The operator of the system hopes to recover the initial and operating costs well within the expected life time of the spacecraft, and the designer must provide a satellite that can survive the hostile environment of the outer space for that long. In order to support the communications system, the spacecraft must provide a stable platform on which to mount the antennas, be capable of station keeping, provide the required electrical power for the communication system and also provide a controlled temperature environment for the communications electronics. In this chapter we discuss the sub-systems needed on spacecraft to support its primary mission of communications. We also discuss the communications sub-system it self in some detail, and other problems such as reliability.

4.2 SPACECRAFT SUBSYSTEMS

The major sub-systems for spacecraft are as following:

4.2.1 Attitude and Orbit Control System (AOSC)

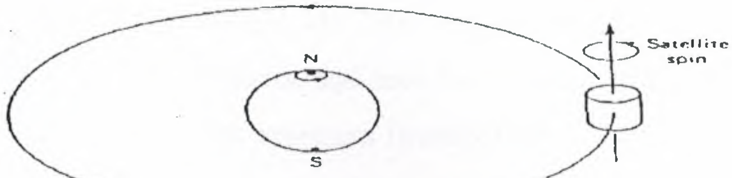
This sub-system consists of rocket motors that are used to move the satellite back to the correct orbit when external forces cause it to drift off station and gas jets or inertial devices that control the attitude of the spacecraft.

a. Attitude Control

The attitude of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is necessary, for the purpose of controlling its attitude. Attitude control is necessary, for example, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellites, the earth - sensing instruments must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as disturbance torque's, can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts. Attitude control must not be confused with station keeping, which is the term used for maintaining a satellite in its correct orbital position, although the two are closely related. Controlling torque's may be generated in a number of ways. Passive attitude control refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite's energy supplies; at most, infrequent use is made of these supplies, for example when thruster jets are impulses to provide corrective torque. Examples of passive attitude control are spin stabilization and gravity gradient stabilization. The other form of attitude control is active control. With active attitude control there is no overall stabilizing torque present to resist the disturbance torque's. Instead, corrective torque's are applied as required in response to disturbance torque's. Methods used to generate active control torque's include momentum wheels, electromagnetic coils, and mass expulsion devices such as gas jets and ion thrusters. The electromagnetic coil works on the principle that the earth's magnetic field exerts a torque on a current carrying coil, and that this torque can be controlled through control of the current. However, the method is of use only for satellites relatively close to the earth.

b. Spin stabilization

Spin stabilization is used with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis. For satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth as illustrated in Figure 4.1. Spin rate is typically in the range of 50 to 100 rev/min.



Spin stabilization in the geostationary orbit. The spin axis lies along the pitch axis, parallel to the earth's N-S axis.

FIGURE 4. 1

In the absence of disturbance torque's, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torque's are generated in a number of ways, both external and internal to satellite. Solar radiation gravitational gradients and meteorite, impacts are all examples of external forces, which can give, rise to disturbance torque's. The overall effect is that the spin rate will decrease and the direction of the angular spin axis will change. Nutation, which is a form of wobbling can occur as result of; the disturbance torque's and / or from misalignment or unbalance of the control jets. This Nutation must be damped out by means of energy absorbers known as Nutation dampers.

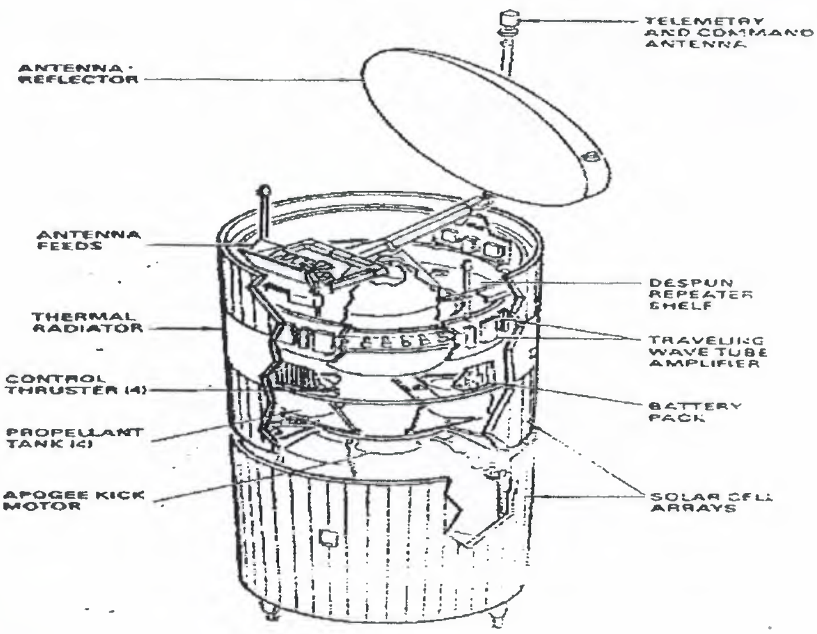


FIGURE 4.2

Figure 4.2 shows the Hughes Hs 376 satellite in more detail. The antenna sub-system consists of a parabolic reflector and feed horns mounted on the despun itself, which also carries the communications repeaters (transponders). The antenna feeds can therefore be connected directly to the transponders without the need for radio-frequency (RF) rotary joints. While the complete platform is despun.

c. Three-axis Stabilization(Body Stabilization)

In three-axis stabilization. as the name suggests, there are stabilizing elements for each of the three axes, roll, pitch, and yaw. Because the body of the satellite remains fixed relative to the earth, three-axis stabilization is also known as body stabilization. Active attitude control is used with three-axis stabilization. This may take the form of control jets (mass-expulsion controllers) fired to correct the attitude of the satellite. Reaction wheels can also be used. A reaction wheel is a fly wheel which is normally stationary but reacts when a disturbance torque tend to shift the spacecraft orientation, by gathering momentum until it absorbs the effect off the disturbance torque. In practice various combinations of wheels and mass-expulsion. devices are used Figure (4.3).

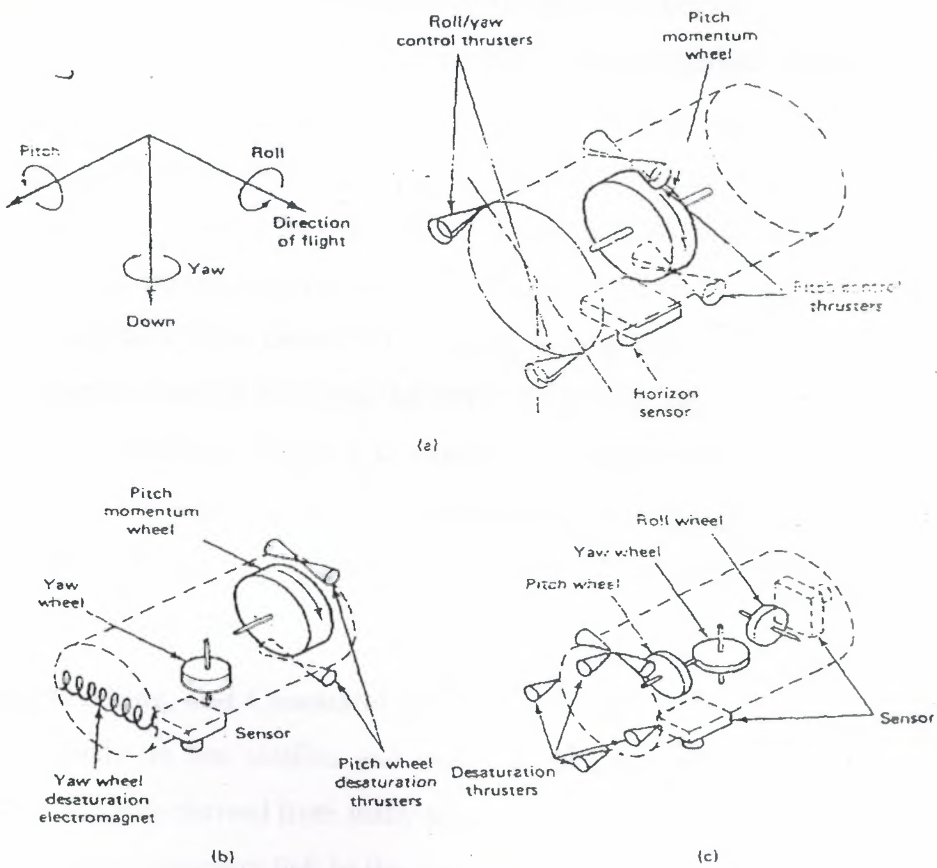


FIGURE 4.3

d. Orbit Control

For communications satellite to accomplish its mission, it must first acquire and then maintain its specified orbit with in close limits. The orbital perturbations which make subsequent corrections of the parameters of the orbit necessary. The final stages of the launching process and all of the in service orbital corrections are carried out by firing thrusters on board the satellite in appropriate directions to obtain the desired incremental velocity vectors. While the satellite is on station and operating, it must also be correctly oriented, so that its antennas and its solar arrays can function as intended; this orientation of the satellite attitude in space also facilities the adjustment of the orbital parameters. In order to maintain the satellite orbit inclination at zero, the gravitational forces due to the Sun and the Moon should be counteracted by the North-South Station- Keeping (NSSK) propulsion system, which provides thrust to the north or the south at the appropriate phase of the orbit. The inclusion of the NSSK system and its fuel on board a satellite carries a mass penalty, which can be as high as 15 percent of the spacecraft mass when conventional hydrazine technology is used; the penalty may be even larger if a very long life time in orbit is foreseen. Utilization of an electric propulsion system can reduce the mass penalty to about 7 percent for a 7-year geo-stationary orbit mission. The forces arising due to the triaxiality of the Earth and solar radiation pressure act along the plane of the orbit, resulting in a relative east-west satellite motion. operating thrusters in easterly or westerly direction can provide a correction. The propellant mass required for east-west station keeping is normally in range of 3 to 10 percent of the mass of the satellite, depending on the satellite configuration and the correction strategy employed.

4.2.2 Telemetry, Tracking, and Command (TT&C)

This systems are partly on the satellite and partly at the controlling earth station. The telemetry system sends data derived from many sensors on the spacecraft, which monitor the spacecraft's "health" via a telemetry link to the controlling earth station. The tracking system is located at this earth station and provides information on the range and the elevation and azimuth angles of the satellite. Repeated measurement of these three parameters permits computation of orbital elements, from which changes in the orbit of the satellite can be detected. Based on telemetry data received from the satellite and orbital data obtained from the tracking system, the control system is used to correct the position and attitude of the spacecraft. It is also used to control the antenna pointing and communication system configuration to suit current traffic requirements, and to operate switches on the spacecraft. Telemetry, tracking and command (TT&C) systems support the function of spacecraft management. These functions are vital for successful operation of all satellites and are treated separately from communication management. In communication satellites the TT&C system is normal independent of the payload. An Omni-directional antenna provides the necessary coverage for telemetry and command information to be exchanged between the ground and the satellite irrespective of the attitude of the latter.

The Inmarsat 2 satellite, a second-generation three-axis stabilized satellite, showing (a) a general view, (b) the communications floor, exploded away from the main body, and (c) the central structure, withdrawn from the main body and inverted to reveal areas not visible in (a). (Reproduced by permission of Inmarsat.) Key: 1, Earth-facing wall structure. 2, North-facing wall structure. 3, South-facing wall structure. (Most payload and TTC&C sub-system components are mounted on these three walls.) 4, Solar array drive mechanisms. 5, Solar panels. 6, Solar array sun sensors. 7, Batteries. 8, Infrared two-axes Earth sensors. 9,
Sun acquisition sensor. l0, Earth sun sensor .11, Fixed momentum wheels. 12, Gyro. 13, Thruster modules. 14, Pressurant (helium) tanks. 15, Fuel (mono-methyl-hydrazine) tanks. 16, Oxidant (nitrogen tetroxide) tanks. 17, Apogee kick motor. 18, L band transmit antenna. l9, L band receive antenna. 20, C band transmit antenna. 21, C band receive antenna, 22, TTC&C Omni-directional antenna

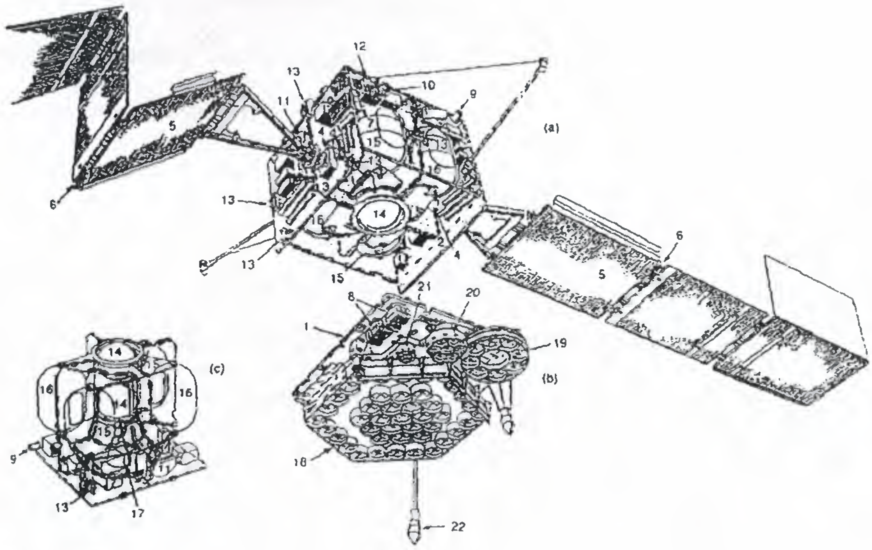


FIGURE 4.4

The Main Function Of a TT& C System are to

a. Monitor the performance of all satellite sub-systems and transmit the monitored data to the satellite control center;

b. Support the determination of orbital parameters;

c. Provide a source to earth stations for tracking ;

d. Receive commands from the control center for performing various functions of the satellite .

a. Telemetry Sub-System

The function is to monitor various spacecraft parameters such as voltage, current, emperature and equipment status and to transmit the measured values to the satellite control center. The telemetered data are analyzed at the control and used for routine operational and failure diagnostic purpose. For example, the data can be used to provide nformation about the amount of fuel remaining on the satellite. A need to switch to a edundant chain or an HPA overload. The parameters most commonly monitored are:

. Voltage, current and temperature of all major sub-system;
. Switch status of communication transponders;
. Pressure of propulsion tanks;
. Outputs from attitude sensors;
. Reaction wheel speed.

igure 4.5 shows the main elements of a telemetry sub-system. The monitored signals are all ıultiplexed and transmitted as a continuous digital stream. Several sensors provide analog gnals whereas others give digital signals. Analog signals are digitally encoded and ıultiplexed with other digital signals.

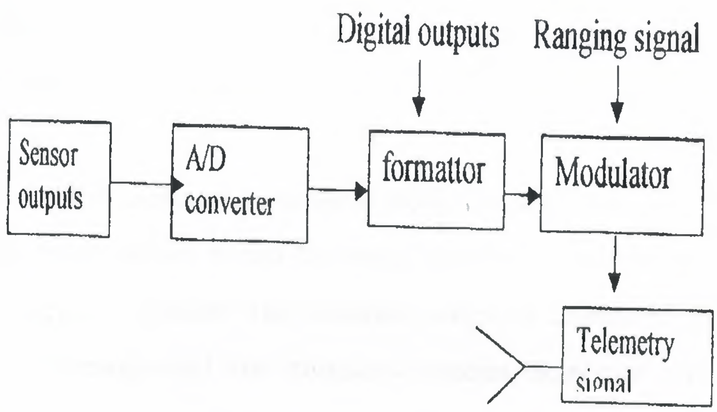


FIGURE 4.5

ypical telemetry data rates are in the range 150 –100 bps. For low- bit rate telemetry a sub-ırrier modulated with PSK or FSK is used before RF modulation. PSK is the most ommonly used at RF. The telemetry signal is commonly used as a beacon by ground ations for tracking. Distributed telemetry systems are increasingly being, favored. In this onfiguration, digital encoders are located in each sub-system of all the satellite and data om each encoder are sent to a central encoder via a common, time-shared bus. This heme reduces the number of wire connections considerably. This type of modulator design also permits easy expansion of the initial design and facilities testing during assembly of the satellite.

b. Command Sub-System

The command system receives commands transmitted from the satellite control center, verifies reception and executes these commands. Example of common commands are:

- Transponder switching
- Switch matrix configuration
- Antenna pointing control
- Controlling direction speed of solar array drive
- Battery reconditioning
- Thruster firing
- Switching heaters of the various sub-system

Typically, over 300 different commands could be used on a communication satellite. From the example listed above, it can be noted that it is vital that commands be decoded and executed correctly. Consider the situation where a command for switching off an active thruster is mis-interpreted the thruster remains activated the consequence would be depletion of station keeping fuel and possibly loss of the satellite as the satellite drifts away from its nominal position. A fail- safe has to be achieved under low carrier-to- noise conditions (typically 78 dB). A commonly used safety feature demands verification of each command by the satellite control center be execution. To reduce the impact of high bit error rate, coding and repetition of data are employed . further improvements can be obtained by combining the outputs of two receive chains. The message is accepted only when both outputs are identical.

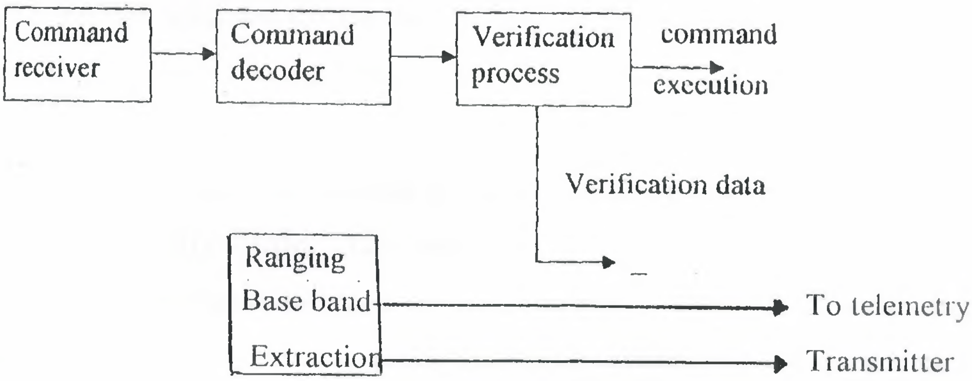


FIGURE 4.6

Figure (4.6) shows the block diagram of a typical command system. The antennas used during the orbit-raising phase are near Omni-directional to maintain contact for possible orientations of the sat. During critical maneuvers. The receiver converts RF signals to base band. Typical bit rate are 100 bps. A command decoder decodes commands. This is followed by a verification process which usually involves the transmitter of the decoded commands back too the sat. control center via the telemetry carrier. The command system hardware is duplicated to improve the reliability . The command is stored in a memory and is executed only, after verification. The Tele-command receiver also provides the base-band output of ranging tone. This base band is modulated on the telemetry beacon and transmitted back to the satellite control system.

c. Tracking Satellite Position

To maintain a sat. In it's assigned orbital slot and provide look angle information to earth stations in the network it is necessary to estimate the orbital parameters of a sat. regularly. These parameters can be obtained by tracking the communication sat. from the ground and measuring the angular position and range of the sat. During orbit raising when the sat. is a non-geo-stationary orbit, a network of ground stations distributed through out the globe is used for obtaining the orbital parameters. The most commonly used method far angular tracking is the mono-pulse technique. Angular positions measured though a single station taken over a day are adequate for the determination of orbital parameters. The range of a sat. can be obtained by measuring the roundtrip time delay of a signal. This is achieved by transmitting a signal modulated with a tone. The signal is received at the spacecraft and modulated in command receiver, the tone is then re-modulated and transmitted back to the ground on the telemetry carrier. The time delay is obtained by measuring the phase difference between the transmitted and received tones shows the main blocks of a multi-tone ranging system. In practice, the phase difference between the transmitted & received tones can be more than 360^0, leading to errors in multiple tones of tone time period. To resolve the ambiguity, multiple tones are transmitted . Lower frequencies resolve the ambiguity and the high tone frequencies provide the desired accuracy. Consider a total phase shift in degrees $\Phi>360^0$:

$\Phi = 360\, n + \Delta\Phi$ where n= unkown integer

$\Delta\Phi$ = measured phase shift

- The range of R is then given by

$R = \lambda\, n + (\Delta\Phi / 360^o).\lambda$, where λ= wave length

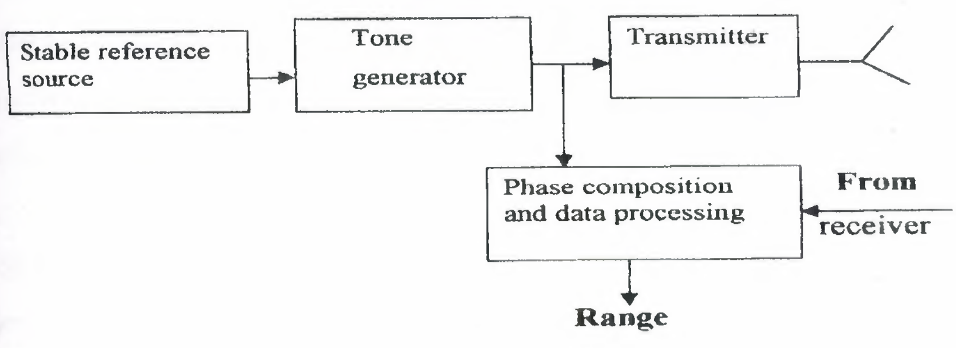


FIGURE 4.7

d. Low -Noise Amplifiers (LNA)

The satellite and the earth station receivers are handling very low level signals. We have to put a (LNA) low noise amplifier to do amplification for signal without amplifying the noise.

e. High-Power Amplifiers (HPA)

The high amplifier is a wide band device (500 MHZ to 6 GHZ) and it can be used to amplify a number of carriers within that bandwidth although if more than one carrier is used the output power must be reduced in order to inter-modulation effects.

Table 4.1 noise temperatures of low-noise amplifiers

Low noise amplifier	Frequency range (GHz)	Typical noise temp. (K)	Comments
Parametric amplifier cooled	3.7-4.2 11-12	30 90	Thermo-electric cooling
Parametric amplifier uncooled	3.7-4.2 11-12	40 100	Temperature of enclosure controlled Thermo electrically
GaAs FET cooled	3.7-4.2 11-12	50 125	Typically, first stage GaAs FET cooled Thermo- electrically
GaAs FET uncooled	3.7-4.2 11-12	75 170	

f. Down-Converter

It is change High frequency to Low value. In our transponders we use down converter to reduce the output frequency from LNA to Suitable frequency.

g. Up-Converter

It does the opposite function of down converter. It convert Low frequency to High frequency.

h. Band Pass Filter

This filter used for limits the signal and it's characteristics diagram Frequency Bandpass Filter characteristics as shown in figure.

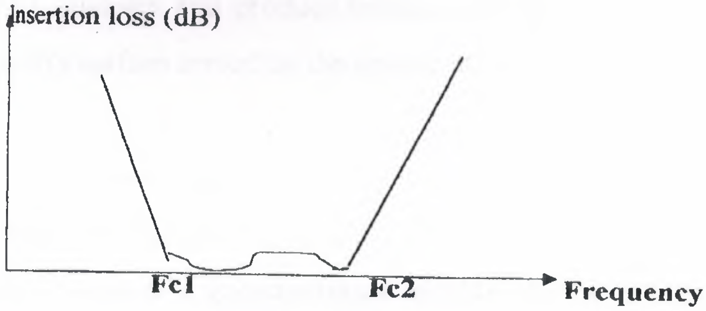


FIGURE 4.7 B.P.F

4.2.3 Power System

All communications satellites derive their electrical power from solar cells. The power is used by the communication system, mainly in its transmitters. and also by all other electrical systems on the spacecraft. The latter use is termed housekeeping, since these sub-systems serve to support the communications system.

4.2.4 Communications Sub-Systems

The Communications Sub-Systems is the major component of a communications satellite, and the remainder of the spacecraft is there solely to support it. Frequently, the communications equipment is only a small part of the weight and volume of the whole spacecraft. It is usually composed of one or more antennas, which receive and transmit over wide bandwidth at microwave frequencies, and a set of receivers and transmitters that amplify and transmit the incoming signals. The receiver-transmitter units are known as transponders.

4.2.5 Spacecraft Antennas

Although these form part of the complete communication system, they can be considered separately from the transponders. On advanced satellites such as INTELSATV, the antenna systems are very complex and produce beams with shapes carefully tailored to match the areas on the earth's surface served by the spacecraft.

4.3 The Electrical Power Supply

4.3.1 Energy Sources And Power Systems

The power requirement of a geo-stationary satellite may be as high as 5 kW. most of the communications payload. The supply of electric power in a spacecraft involves several basic elements. There must be a primary source of energy and means for converting that energy into electrical energy. A device is needed for storing the electrical energy to meet peak demands and to provide power during eclipses. Finally a system is required for conditioning, regulating and distributing the electrical energy at the required levels.

Only two primary sources are suitable for missions with life times in space measured in years, namely radiation from the sun and the spontaneous decay of radioactive material. The radioactivity option is preferred where the power requirement is high, perhaps 10 kW or more, or when an interplanetary mission takes the spacecraft too far from the sun. But solar radiation, converted to electrical power by an array of photo voltaic cells, is always chosen for Earth satellites used for telecommunications. Rechargeable batteries are used for storing electrical power during the sunlit portion of the orbit., to provide power during eclipses and at peak demand periods. A simplified diagram of a typical satellite power sub-system is shown in Figure 4.8. primary electrical power is generated by the main solar panel and it is supplied to the power utilization loads through the main distribution bus. Bus voltage limiters ensure that bus voltages do not exceed the maximum voltage rating of the consuming sub-systems. Limiter resistors energized by the bus load limiters provide variable shunt loads to stabilize the bus voltage when the solar panel output voltage rises or the power utilization loading decrease. The spacecraft batteries charge / discharge control functions are provided by a battery controller device. When the distribution bus voltage is reduced to a predetermined level due to decreased solar panel output, the battery discharge regulator is activated to provide a minimum regulated bus voltage from the battery. The battery voltage needs to be greater that the bus voltage for two main reasons. The discharge regulator has certain impedance, causing a voltage drop across its terminals. And the maximum battery voltage required for full recharge is considerably higher than the battery discharge output voltage. Usually a small area of solar panel connected in series with the main panel provides the required recharging voltage boost and limits the maximum recharge current. This simplifies the charge control functions of the controller to the simple on- off and rate change switching shown in Figure 4.8

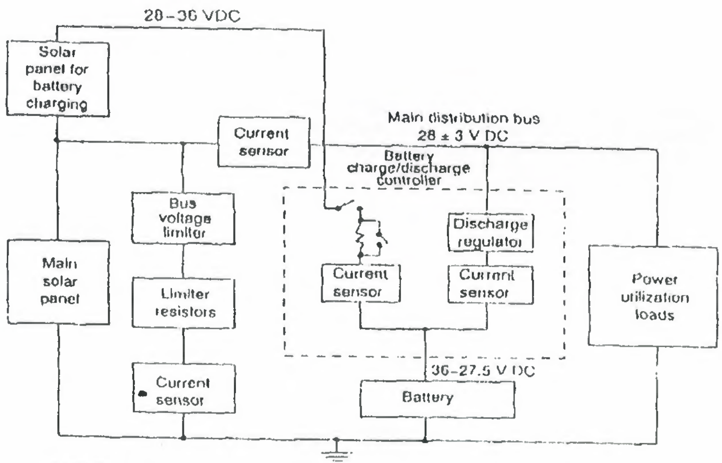


FIGURE 4.8

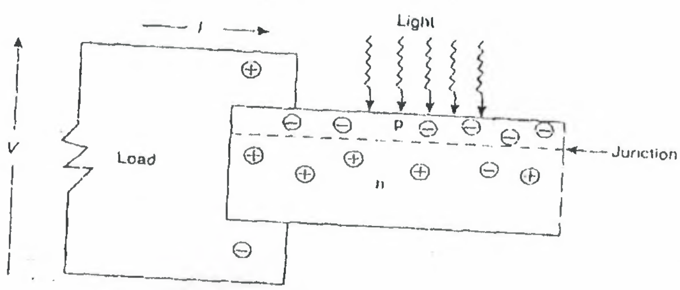


FIGURE 4.9

4.3.2 Solar Cells

A solar or photo-voltaic cell converts incident solar radiation into electric energy by the photo-voltaic as illustrated in Figure 4.9. The current versus Voltage characteristics of a solar cell. When it is dark is shown in Figure 4.10. The curve of the non- illuminated solar cell indicates that it behaves as a power sink like any other semiconductor diode; its resistance is low when the current flows in the forward direction and high when if flows in the reverse direction. When the solar cell is illuminated, incident photons are absorbed, ionizing the atoms of the semiconductor material and producing electrons / hole pairs. Electric current is generated when the electrons & holes reach the junction before recombining.

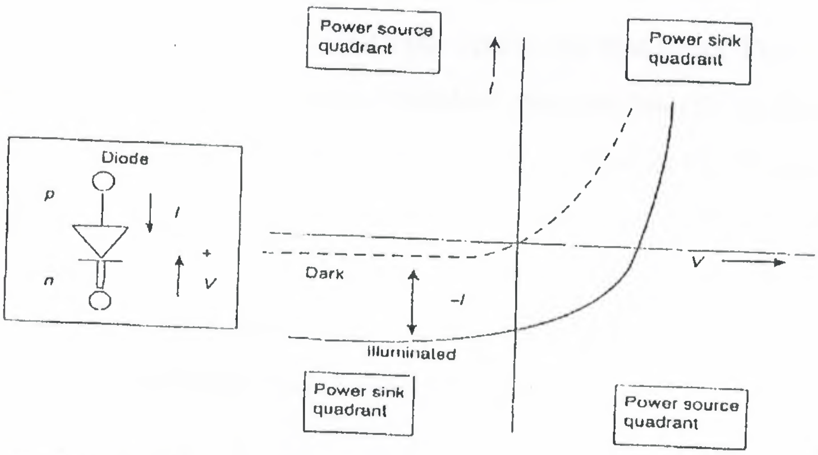


FIGURE 4.10

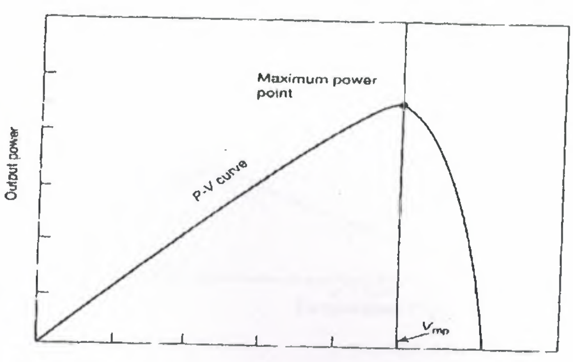


FIGURE 4.11

Illumination results in the voltage / current curve being shifted in the minus-current direction in proportion to the strength of the incident illumination. The characteristic I /V output graph shown in Figure 4. 11 is obtained by inverting the power source quadrant of Figure 3. 10. The output voltage of a silicon cell under typical load conditions is about 0.5V.

The solar cells of a geo-stationary satellite may be cycled in temperature between 110 and 340 K. The efficiency of solar cells reduces with increasing temperature, so their temperature has to be kept as low as possible in order to obtain the maximum power output. The variation of efficiency with temperature for gallium arsenate, germanium and silicon solar cells is shown in Figure 4.12. The efficiency of solar cells in space also decreases with the passage of time. This is due to the damage caused to the cell semiconductor material, due mainly to solar flare protons and the trapped electrons of the Van Allen radiation belts. Typically, the power output is reduced by 10 per cent in the first years. Placing a glass cover over each solar cell considerably reduces radiation damage caused by the lower- energy particles. The amount of radiation failing on the cell is reduced as the thickness of the glass employed is increased. However, the cover glass also acts as a filter, which reduces the total energy absorbed by the cell, thus reducing its operating temperature and diminishing somewhat the loss of power output caused by the presence of the cover. The cover glass is usually made of quartz, sapphire, or silica doped with cerium.

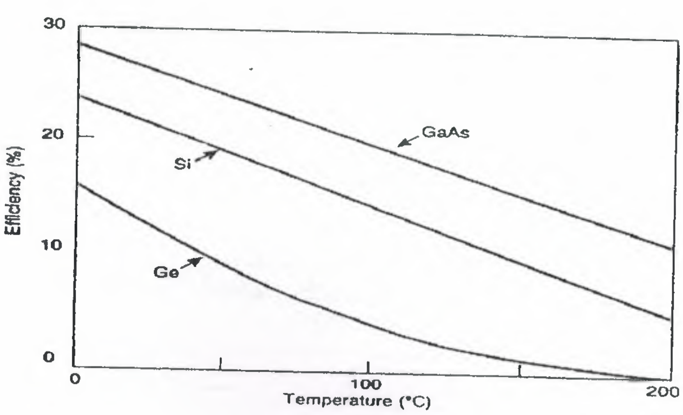


FIGURE 4.12

4.3.3 Solar Arrays

The power output of a single solar cell is very low and the individual cells must be connected in a series- parallel matrix as shown in fig. 4-13 to satisfy the voltage, current & power requirements of the space-craft. The solar cell matrices are mounted on light weight honey comb or fibre-glass substrates to form solar arrays. Satellites utilize either dual-spin or three-axis attitude stabilization. In the dual-spin configuration the spinning drumis covered with solar cells. In the three-axis stabilized configuration cells are mounted on deployable flat panel appendages which are continuously oriented to obtain maximum exposure to solar radiation. Inspin-stabilized satellites the individual cells are usually arranged in a series-parallel configuration of which the series strain can typically vary from 66 to 71 cells. Modules are constructed with three strings in parallel connected together in series- parallel network as shown in figure 4.13(ii). This arrangement minimizes the power loss resulting from the failure of a single sell.

A solar array drive mechanism is employed, first to acquire an orbit and then to track the sun, maintaining the face of the array approximately normal to the solar radiation as the satellite moves around its orbit. The drive mechanism also includes means for transmitting power from the rotating arrays(one revolution per orbit) to the equipment in the spacecraft body. The deployable solar arrays of the Intelsat VIII satellite. in the launch and the deployed configuration, are shown in Figure 4.14.

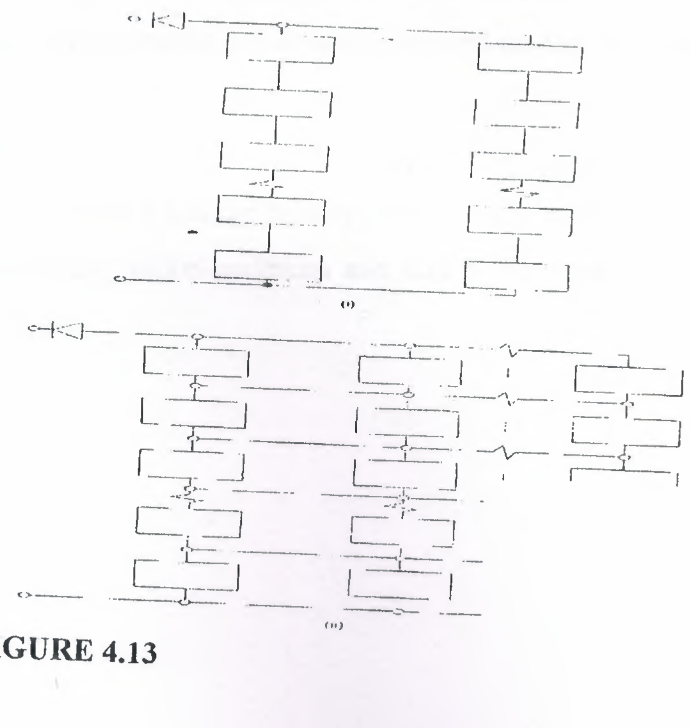


FIGURE 4.13

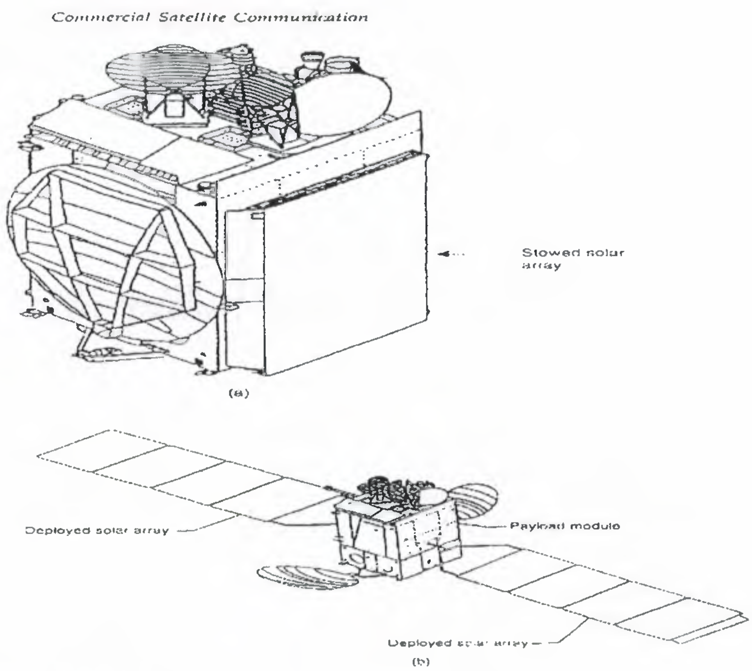


FIGURE 4.14

4.3.4 Energy Storage

Storage batteries are used to provide power during eclipse and to satisfy peak power demands, which may be much greater than the average available solar power. In the GS there are two eclipse seasons per annum, centered on the vernal and autumnal respectively; each eclipse period lasts for 45 days with a maximum shadow time of 1.2 hours as shown in Figure 4.15 . For satellites in lower orbits, the number of eclipses is greater .

There are many types of storage battery commercially available but only four namely silver-zinc, silver-cadmium, nickel-cadmium and nickel-hydrogen, have been qualified for space applications to date.

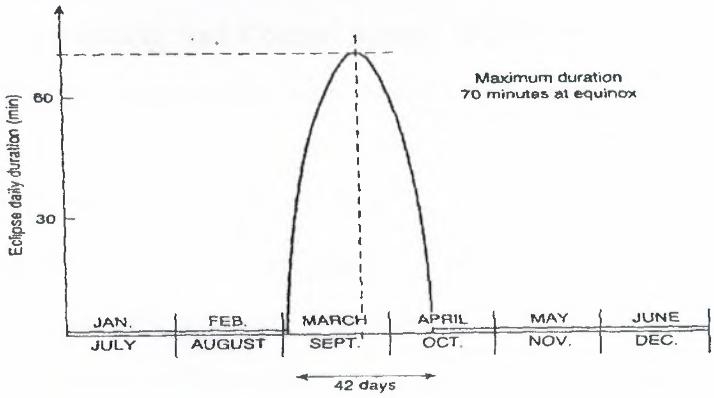


FIGURE 4.15

In general the main requirements of the storage batteries for space application are:

1. To receive and deliver power at high rates. These enables the spacecraft to utilize the extra power delivered by the solar cells when the satellite comes out of eclipse and to provide the extra power needed at peak periods.
2. To survive a large number of charge-discharge cycles under various conditions. There are 90 charge-discharge cycles per year in the GSO where the battery is being charged during the orbital day and discharge during the orbital night.
3. High recharge efficiency.
4. Leakage-free seals, able to withstand a large number of extreme thermal and pressure changes.
5. Capability of operating in a gravity- free environment in all positions.
6. High usable energy capacity for low per-unit weight and volume.
7. Stability under long-term overcharge conditions.
8. Ability to withstand the stresses of the launch and in -orbit environments
9. High reliability.
10. Long life.

4.3.5 Power Conditioning And Control

The Power Conditioning And Control System (PCCS.) ensures that the output of the solar array and the storage battery satisfy the power requirements of the various sub-systems. The PCCS also controls the battery charge-discharge function. which is essential in order to maximize the battery life time. In essence. the PCCS is an assembly of various types of regulators, DC-to-DC or DC-to-AC converters and control circuits.

PCCSs can be classified into two main categories; dissipative and non-dissipative systems the power requirement of the satellite is less than the output of the solar arrays, the unused power being dissipated by the system. In non-dissipative systems almost all the power provided by the solar arrays is used to satisfy the operational needs of the spacecraft.

Dissipative systems can be categorized according to whether the bus voltage is regulated or unregulated. In general, the different voltage levels and regulation profiles, which are required at different points of the spacecraft sub-systems differ from the ones, provided by the bus. The bus voltage therefore needs to be further regulated, increased, decreased or inverted by utilizing regulators and DC-to-DC and DC-to-AC converters.

4.4 Antenna Sub-System

Directional beams are usually produced by means of reflector type antennas, the paraboloidal reflector being the most common. As the gain of the paraboloidal reflector, relative to an isotropic radiator. is given by

$$G = \eta_I (\pi D/\lambda)^2$$

Where λ is the wavelength of the signal, D is the reflector diameter, and η_I is the aperture efficiency A typical value for η_I is 0.55. The -3 dB beam-width is given approximately by:

$$\Theta_{3dB} = 70\ \lambda / D \text{ degrees}$$

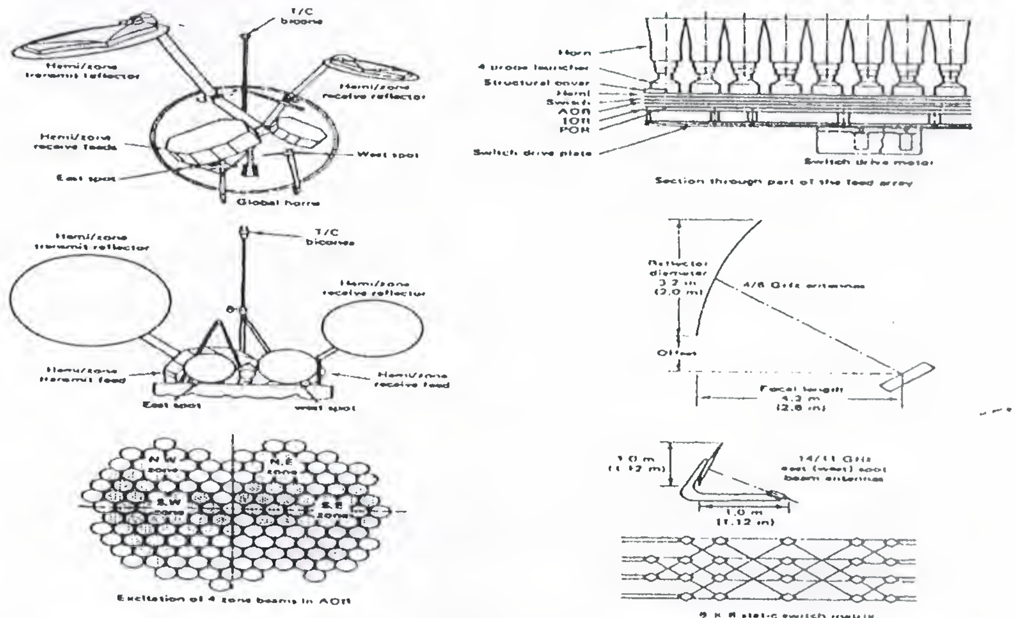
The ratio D/λ is seen to be the key factor in these equations, the gain being directly proportional to $(D/\lambda)^2$ and the beam width inversely proportional to D/λ. Hence the gain can be increased, and the beam-width made narrower. by increasing the reflector size or decreasing the wavelength. The largest reflectors are those for the 6/4GHz band.

Comparable performance can be obtained with considerably smaller reflectors in the 14112-GHz band.

Figure 4.16 shows the antenna sub-system for the Intelsat V1 satellite . This provides a good llustration of the level of complexity, which has been reached in large communications satellites. The largest reflectors are for the 6/4 GHz hemisphere and zone coverages as llustrated in Fig. 4.17. These are fed from horn arrays, and various groups of horns can be excited to produce the beam shape required. As can be seen, separate arrays are used for transmit and receive. Each array has 146 dual-polarization horns. In the 14/11 GHz band, circular reflectors are used to provide spot beams, one for east and one for west. These beams are fully steerable. Each spot is fed by a single horn which is used for both transmit and receive.

Wide beams for global coverage are produced by simple horn antenna at 6/4 GHz.. These horns beam the signal directly to the earth without the use of reflectors. A simple bi-conical dipole antenna platform and the communications payload are despun to keep the antennas pointing to the correct locations on earth.

The same feed horn may be used to transmit and receive carriers with the same polarization. The transmit and receive signals are separated by means of frequency filtering. Polarization discrimination may also be used to separate the transmit and receive signals using the same feed horn. For example, the horn may be used to transmit horizontally polarized waves in the down-link frequency band, while simultaneously receiving vertically polarized waves in the up-link frequency band. The polarization separation takes place in a device known as an ortho-coupler, or orthogonal mode transducer (OMT). Separate horns may also be used for the transmit and receive function.



The antenna subsystem for the Intelsat VI satellite.

FIGURE 4.16

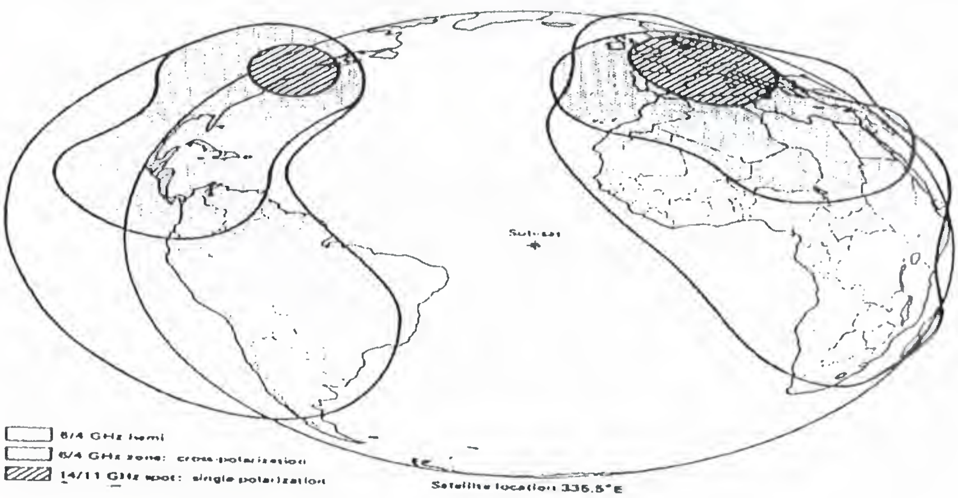


FIGURE 4.17

The satellite uses three types of antennas

i. Spot beams dish antennas, steerable antennas to adjust the area the beam cover on earth.

ii. Receiving and transmitting earth coverage antennas fixed position, where horn antennas are used for global coverage.

iii. A non-directional antenna for receiving commands to the satellite and transmitting telemetry data to earth. The data rate use with this antenna is very low, and so its low gain is acceptable. Wire antennas, which are monopoles and dipoles are used. Figure (4-18) shows three types of antennas mounted on INTELSAT IV satellites: There are two types of beams, spot beams & global beams as shown in Figure (4.19)

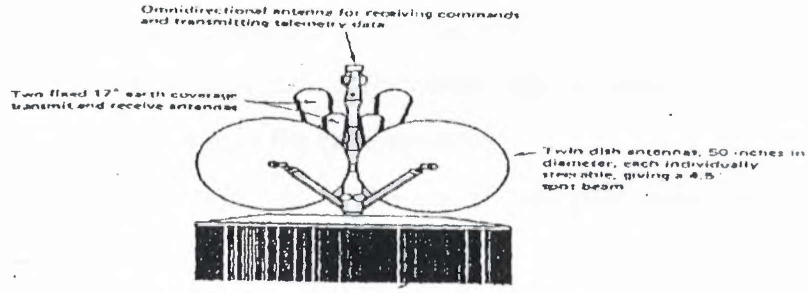


FIGURE 4.18

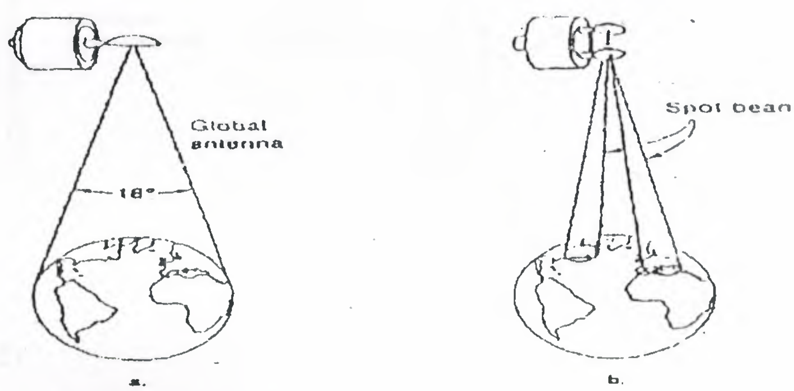


FIGURE 4.19

4.4.1 Global Beam in Satellite Down-link

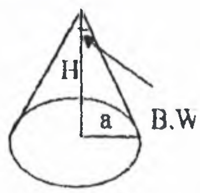
Figure (4-20) shows the parameters used to calculate the beam-width for a certain coverage area .

'or a global beam of a satellite at a geo-stationary orbit, H=36000Km
ınd a= 63 70 Km . The global Beamwidth can calculated as follows :

$$3.W/2 = \tan^{-1} (a/ H+a)$$

$$= \tan^{-1} (6370/42370) = 9°$$

$$3.W = 18°$$



. Spot Beams in Satellite Down-link:

ipot beams increasing satellite EIRP by using narrower beams, so as to concentrate power ıto areas smaller than covered by global beams. In this way the reception of wide band ıformation in small earth stations with low g/T° values will be improved. Spot beams ıcrease CNR within the beam, but reduce the coverage area .

'he transmission technique can be separated by the use of dual polarization within a spot eam as shown in figure (4.21)

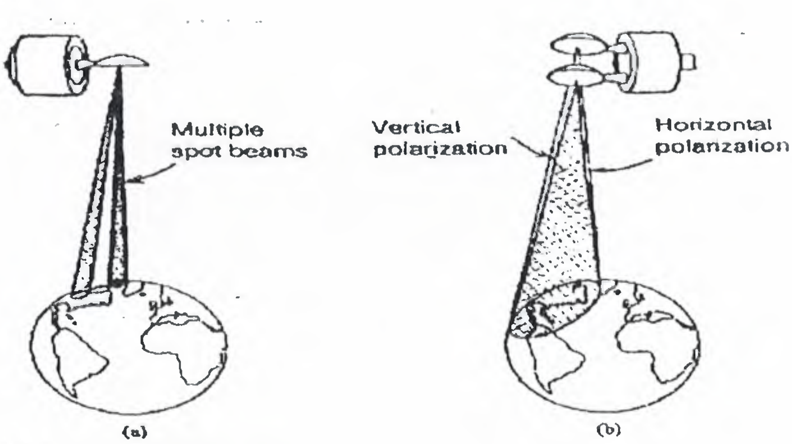


FIGURE 4.21

ome earth stations use only horizontal polarization others use vertical polarization .Some eamwidth, earth coverage diameter of the beam footprint & effective EIRP (effective otropic radiation power) are the spot beam parameters where :

$IRP = 10 \log(P_T G_T)$

P_T = transmitter power

G_T = Gain of the transmitting antenna

t is noted that the ELRP per beam increases as the spot is reduced, but number of spots needed to cover a fixed area also increases. This have the disadvantage of using multiple antenna beams from the satellite, increase the complexity & structure of the spacecraft & beam pointing is more critical with the narrower beams. This can be shown in table (3- 1) using the following relation:

an (B.W/2)=(a/H+ a)

Where, H = 36000 Km.

A = Earth coverage diameter.

Table4.2 : Spot Beam Parameters

Spot Beamwidth	**Earth coverage Diameter**	EIRP (dB)
0^0	3921	5.1
$.7^0$	2235	9.9
$.8^0$	1117	16.1
$.0^0$	392	25.0
$.57^0$	223	29.9

. Multiple Beams:

There are basic ways to produce multiple beams from a satellite :

. Using of separates antennas for each beam.

. Single reflector or microwave lens using multiple feeds.

. Phased antenna arrays.

. Disadvantage In Forming Spot Beams With Arrays

The size of the array (number of elements) becomes large when it is forming a small spot.

. The Beam width decreases with the number of elements of the array. (Narrow spot beam arrays require an increase in both the array size and the numbers of phase-shift feeder elements at the Satellite).

d. Advantage of Spot Beam

To achieve the advantage of spot beams is by using hopping beams as follows and sketched figure (4.22). A single spot can be moved in sequence from one point to another. The wide coverage is achieved with a single beam, but only on a shared time basis. Only one spot antenna assembly is needed, but must repositioning sequentially, which is achieved by gimbals control where the antenna assembly is mechanical re-pointed in each desired direction.

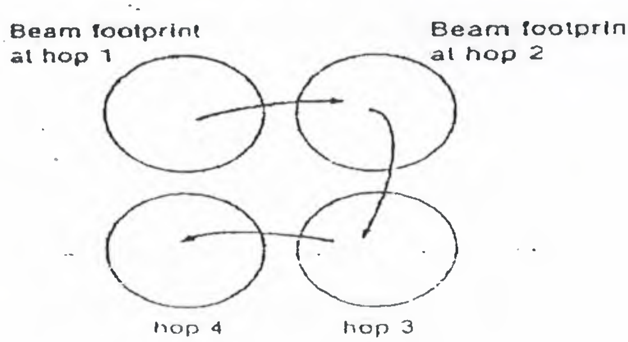


FIGURE 4.22

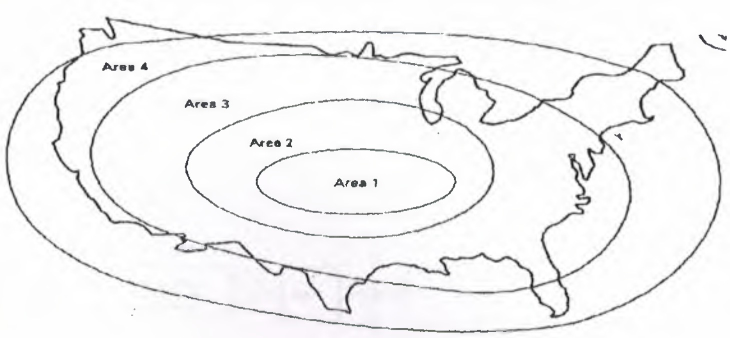
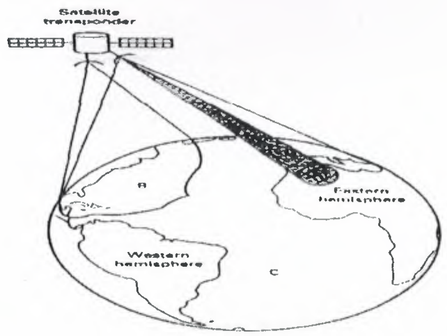


FIGURE 4.23



Beams: (a) spot; (b) zonal; (c) earth

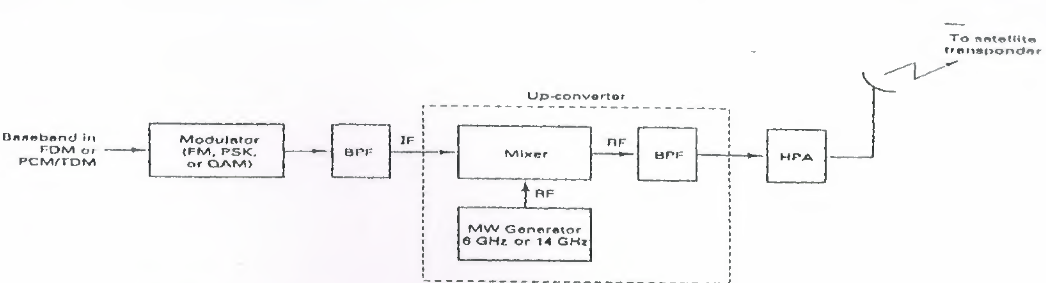
FIGURE 4.24

4.5 SATELLITE SYSTEM LINK MODELS

Essentially, a satellite system consists of three basic sections: an up-link, a satellite transponder, and a Down- link.

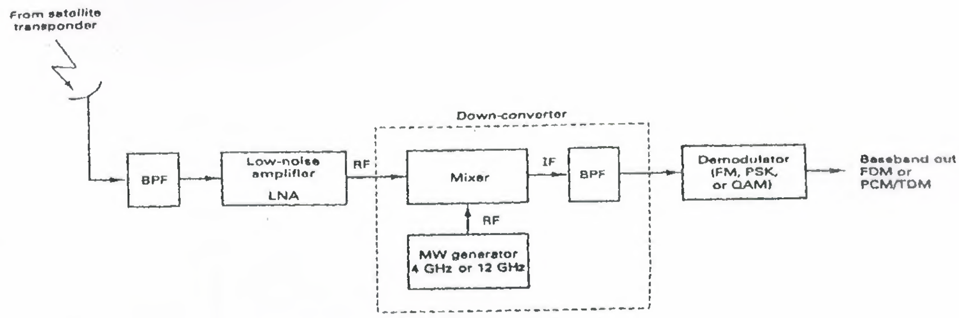
4.5.1 Up-Link Model

The primary component within the up-link section of a satellite system is the earth station transmitter. A typical earth station transmitter consists of an IF modulator, an IF-to-RF microwave up-converter, a high power amplifier (HPA), and some means of band limiting the final output spectrum (i.e. an output bandpass filter). Figure 4.25 shows the block diagram of a satellite earth station transmitter. The IF modulator converts the input baseband signals to either an FM, a PSK, or QAM modulated intermediate frequency. The up-converter (mixer and band-pass filter) convert the IF to an appropriate RF carrier frequency .The HPA provides adequate input sensitivity and output power to propagate the signal to satellite transponder. HPAs commonly used are klystons and traveling-wave tubes.



Satellite up-link model

FIGURE 4.25



Satellite down-link model

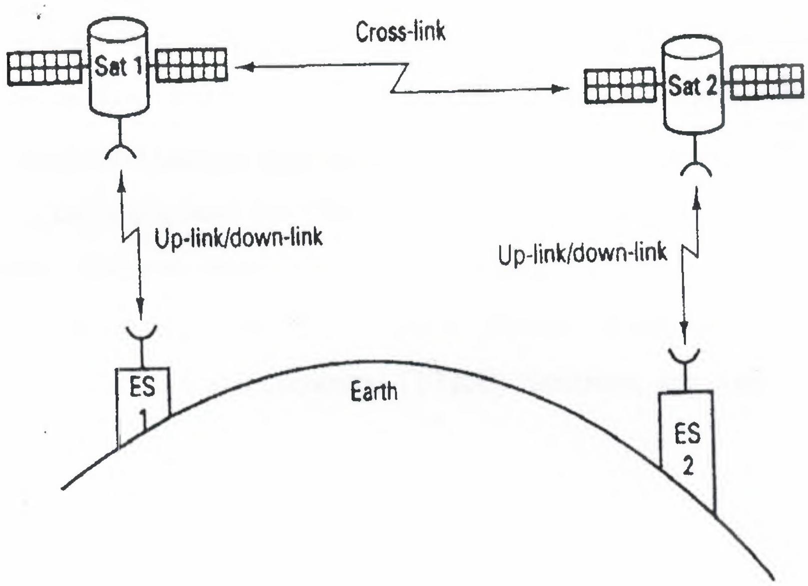
FIGURE 4.26

4.5.2 Down-link Model

An earth station receiver includes an input BPF, an LNA, and an Rf –to- IF down converter. Figure 4.26 shows a block diagram of a typical earth station receiver. Again the BPF limits the input noise power to the LNA. The LNA is a highly sensitive, low-noise device such as a tunnel diode amplifier or a parametric amplifier. The RF-to-IF down- converter is a mixer / bandpass filter combination which converts the received RF signal to an IF frequency.

4.5.3 Cross-Links

Occasionally, there is an application where it is necessary to communicate between satellites. This is done using satellite crosslinks or satellite links (ISLs), shown in Figure 4.27. A disadvantage of using an ISL is that both transmitter and receiver are space-bound. Consequently, both the transmitter's output power and receiver's input sensitivity are limited



Intersatellite link

FIGURE 4.27

CHAPTER 5 EARTH STATION

5.1 INTRODUCTION

The earth segment of a satellite communication system consists of the transmit and receive stations. The simplest of these are the home TV Receiver-Only (TVRO) systems, and the most complex are the terminal stations used for international communication networks.

Also included in the earth segment are those stations, which are on ships at sea, and commercial and military land and aeronautical mobile stations.

Earth stations, which are used exclusively for logistic support of satellites, such as those providing the telemetry, tracking, and command (TT&C) functions, are considered as part of the space segment.

Definitions

Earth - Orbiting Satellites

· **Apogee** The point farthest from earth. Apogee height is shown as h_a in Fig. 5 .1

· **Perigee** The point of closest approach to earth. The perigee height is shown as h_p in Fig. 5. 1

· **Line of upsides** The line joining the perigee and apogee through the center of the earth.

· **Ascending node** The point where the orbit crosses the equatorial plane going from south to north.

· **Descending node** The point where the orbit crosses the equatorial plane going from north to south.

· **Line of nodes** The line joining the ascending and descending nodes through the center of the earth.

· **Inclination** The angle between the orbital plane and earth's equatorial plane. It is measured at the ascending node from the equator to the orbit, going from east to north. The inclination is shown as in Fig. 5.2 . It will be seen that greatest latitude, north or south, is equal to the inclination.

· **Pro-grade orbit** As orbit in which the satellite moves in the same direction as the earth, s rotation, as shown in Fig 5.2. The pro-grade orbit is also known 90°. Most satellites are

Launched in a pro-grade orbit because the earth's rotational velocity provides part of the orbital velocity with a consequent saving in launch energy.

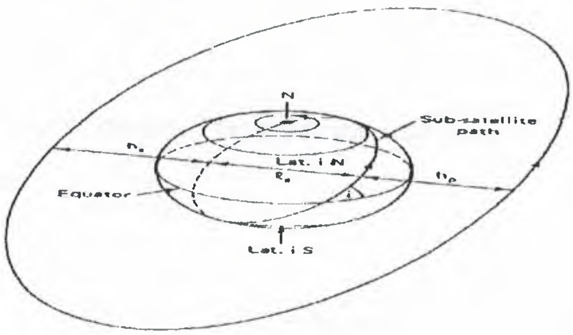
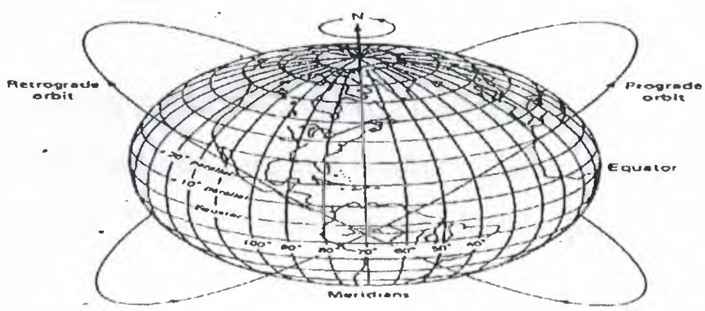


FIGURE 5.1



Prograde and retrograde orbits

FIGURE 5.2

· **Rectrograde orbit** As orbit in the satellite moves in the direction counter to the earth's rotation, as shown in Fig 5.2. The inclination of a retrograde orbit always lies between 90° and 180°.

· **Argument of perigee** The angle from ascending node to perigee, measured in the orbital plane at the earth's center, in the direction of satellite motion. The argument of perigee is shown in Fig. 5.3

.Mean anomaly Mean anomaly M gives an average value of the angular position of the satellite with reference to the perigee . For a circular orbit, M gives the angular position of the satellite in the orbit. For an elliptical orbit, the position is much more difficult to calculate, and M is used as an intermediate step in the calculation.

.True anomaly The true anomaly is the angle from perigee to the satellite position, measured at the earth's center. This gives the true angular position of the satellite in orbit as a function of time.

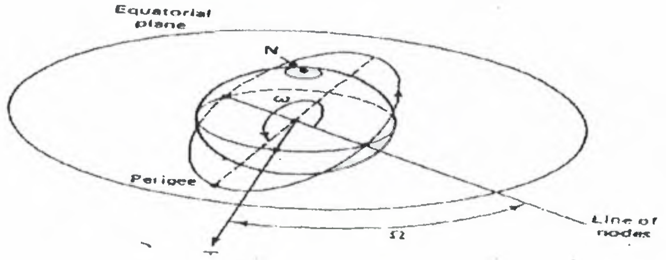


FIGURE 5.3

5.2 EARTH STATIONS DESIGN CONSIDERATION

The design of an earth station depends on a number of factors. Some of these are:

5.2.1 Type of service: Fixed Satellite Service, Mobile Satellite Service or Broadcast Satellite Service.

5.2.2 Type of communication requirements: telephony , data, television, etc.

5.2.3 Required base-band signal quality at the destination.

5.2.4 Traffic requirements: number of channels, type of traffic continuous or bursty.

5.2.5 Cost reliability: Two broad stages may be identified in the design process. The first stage is based on the overall system requirements from which the required earth station parameters such as G/T, transmit power, access scheme, etc, and emerge. An earth station designer then engineers the most cost-effective configuration to achieve these specifications.

5.3 General Configuration:

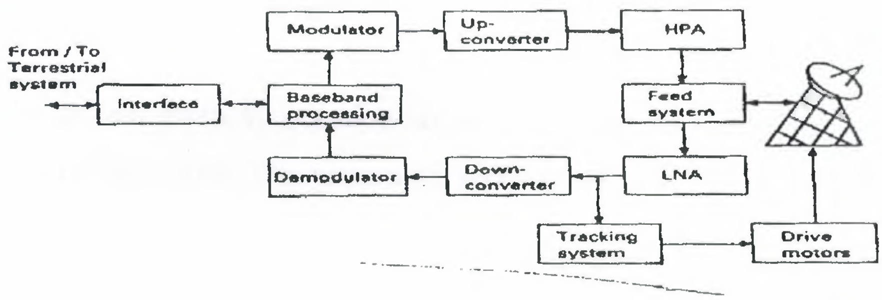


FIGURE 5.4

.3.1 Antenna system

Most earth stations use reflector antennas since such antennas can readily provide, high gain nd the desirable side lobe characteristics. A reflector antenna consists of a parabolic eflector, which is illuminated by a primary radiator usually a horn. The reflector diameter an vary from around 30 m for an INTELSAT standard-A earth station to less than 60 cm or direct broadcast satellite receiver. A high efficiency is essential because an antennas cost sensitive then the size of its diameter. Additionally, the radiation pattern of antennas must ave low side lobes to minimize interference from and to other radio systems. The efficient tilization of two natural resources; the radio spectrum and the geo-stationary orbit are ffected by the side lobe characteristics of an earth station antenna. Hence the CCIR has laid own guidelines m the form of a reference radiation pattern. All system designers follow nese guidelines. For example. It has been recommended that the gain G, of 90% of the side obe peaks of an FSS earth station antenna of more than 100 wavelengths (λ) diameter and or a frequency range of 2- 10 GHz must not exceed

$$= 32- 25 \log(\theta) \, dB_I$$

Vhere θ = off-axis angle with respect to the antenna bore-sight (off-axis angle is limited to vithin 3^0 of the geo-stationary arc)

$^0 \leq \theta \leq 200$

'he reference pattern given by equation above was based on the available data of earth ation antennas of the 1960s. This pattern has recently been modified to (CCIR), 1986)

$= 29- 25 \log(\theta)\ dB_I$

'he effect of this change is a reduction in interference caused or received by an earth station. 'he main purpose of the change was to increase the effective utilization of the geo-ationary orbit, effected by a reduction in the interference caused/ received to /from djacent satellite systems. Thus the improved specification has permitted adjacent spacing to e reduced from about 3^0 to $\approx 2^0$

or practical reasons the CCIR reference antenna pattern for antenna diameters D , less than 00% is modified to

$= 52- 10 \log (D/\lambda) - 25 \log (\theta)\ dBi$

imilar reference patterns have been suggested for other services such as BSS. Earth ations can have either axi-symmetric or asymmetric (also called offset) antenna onfigurations based on their geometry.

Satellite Communications Systems

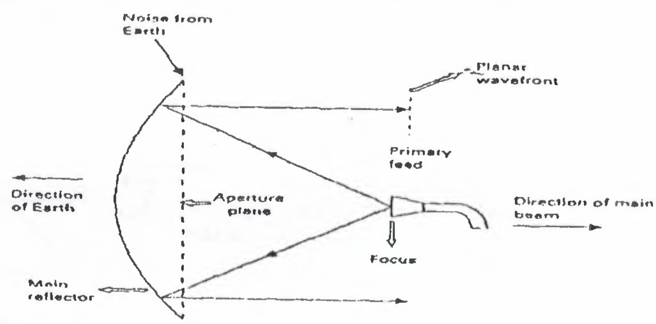


FIGURE 5.5

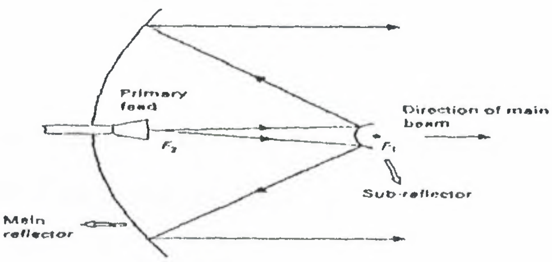
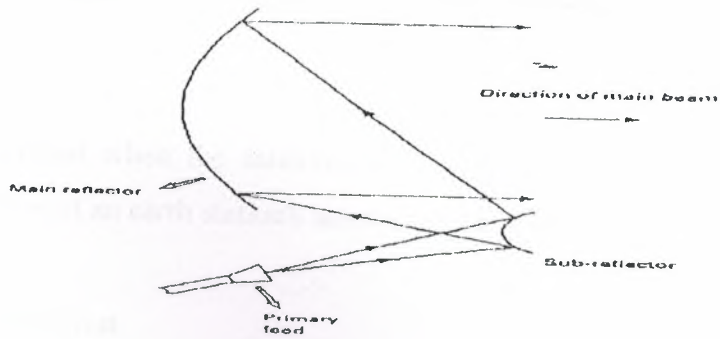
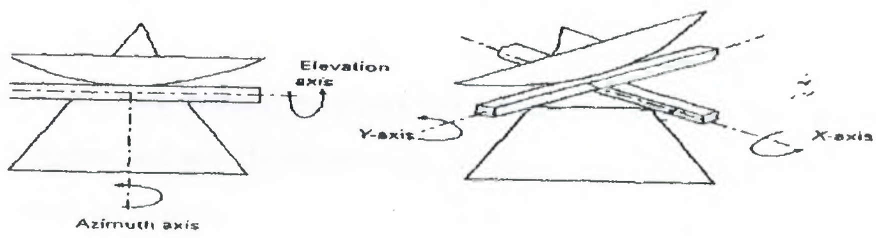


FIGURE 5.6



An offset feed arrangement.

FIGURE 5.7



(a) An azimuth–elevation mount. (b) An X–Y mount.

FIGURE 5.8

5.3.2 Feed System

The primary feed system used in existing earth stations performs a number of functions. Depending on the type of earth station, these functions may be:

i. to illuminate the main reflector;

ii. to separate the transmit and receive band;

iii. to separate and combine polarization in a dual polarized system;

iv. to provide error signals for some types of satellite tracking system .

5.3.3 Tracking System

Tracking is essential when the satellite drift, as seen by an earth station antenna, is a significant fraction of an earth station's antenna beam-width.

. Satellite Acquisition

Before communication can be established it is necessary to "acquire" a satellite. One method is to program the antenna to perform a scan around the predicted position of satellite. The automatic tracking system is switched on when the received signal strength is sufficient to

:k the tracking receiver to the beacon. In simplest form, a satellite can be acquired by ›ving the antenna manually around the expected satellite position.

Automatic Tracking

:er acquisition a satellite needs to be tracked continuously. The automatic tracking system en called an auto-track system) performs this function. Auto-track systems are closed - p control systems and are therefore highly accurate. This tracking mode is preferred ıfiguration when accuracy is the dominant criterion. The most commonly used techniques discussed in a subsequent sections.

Manual Track

avoid a total loss of communication due to a failure in tracking system, earth stations :erally also have a manual mode. In this mode an antenna is moved through manual ımands.

Program Track

his tracking mode the antenna is driven to the predicted satellite position by a computer. satellite position predictions are usually supplied by the satellite operators. In earlier s of satellite communications this method was used commonly, but now this facility is fined to expensive earth stations and satellite control stations. It may be noted that since ogram track system is an open-loop control system, its accuracy is mainly governed by prediction data.

4 Main Functional Elements

ıre 5.9 shows the main functional elements of a satellite tracking system

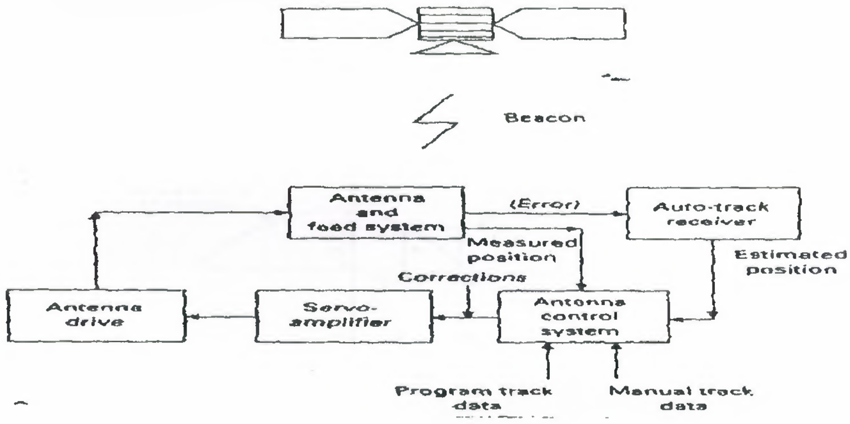


FIGURE 5.9

n the manual mode, An operator sets the desired angles for each axis on a control console. his position is compared with the actual antenna position, obtained through shaft encoders, nd the difference: signal is used to drive the antenna. In the program track mode the desired ntenna position is obtained from a computer . The difference in the actual and the desired ntenna positions constitutes the error md is used to drive the antenna.

3.5 Auto- Track System

here are three main types of auto-track system which have been commonly used for tellite tracking:

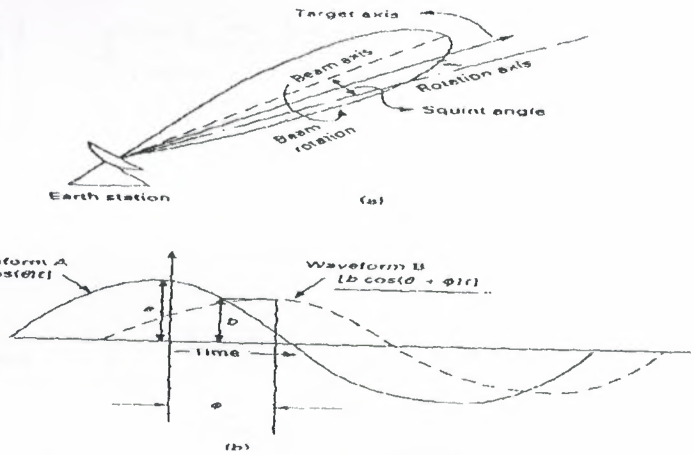


FIGURE 5.10

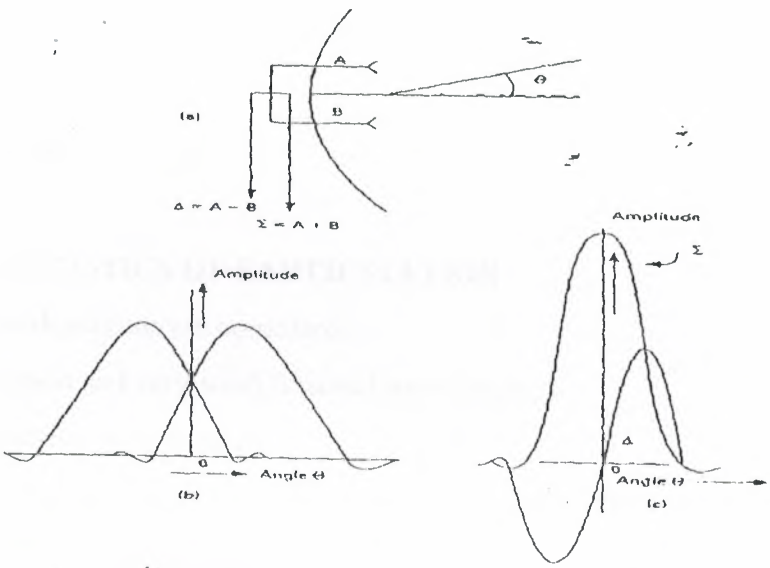


FIGURE 5.11

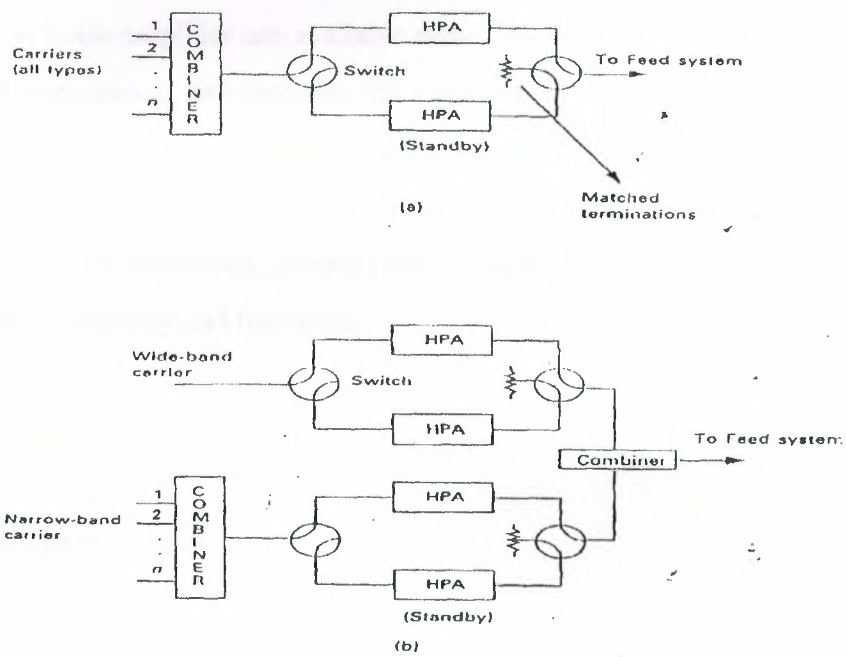


FIGURE 5.12

5.4 CHARACTERISTICS OF EARTH STATION

Two types of earth stations are considered :

A large earth station and very small terminal earth station .

Fixed satellite service earth stations

Two types of FSS earth station are described- a large earth station of INTELSAT standard-A type and a VSAT.

a. Large Earth Stations

The antennas used in large earth stations are of the reflector type. Various types of Case grain antenna systems have been used. Because of the advantages offered by the Beam wave guide feed Case grain system, this type of configuration is being used increasingly. An attempt is made to choose a low noise amplifier having a noise temperature of at least equal to or less than the antenna noise temperature. It is of interest to note that sky noise nperature above 10 GHz are higher than at 4 GHz because of atmospheric effects. Several pes of low noise amplifier are available now. The function of the transmit communication uipment is to process and modulate the base band and convert the IF signal to an RF level itable for amplification and subsequent transmission. In the receive path, the output from e LNA is , amplified, down converted and demodulated to the base band. Depending on e transmission requirements, several types of communication equipment are possible:

FM/FDM telephony and television

SCPC

a. fixed assigned

b. demand assigned

. **TDMA IDST or DNI**

Very small aperture terminal (VSAT)

SATs dispersed throughout a coverage region access the satellite through a random access otocol. The earliest VSATs were operated in the C band and employed the spread ectrum technique to counter interference in this heavily congested band. The current trend to utilize the less congest Ku band which also permits the use of small antennas. Mobile tellite service earth station: The main features in design optimization of an MSS earth ation are :

limited mounting space implies that the antenna size on mobiles is severely restricted;

minimization of earth station cost is important for service uptake since the terminal cost is ared by relatively few users-especially in land mobiles;

traffic flow through the earth station is low (typically, a single channel is equate).Typical examples of mobile earth station are standard-A and standard C terminals r use in the Ti-TMARSAT network.

ble 5. Primary characteristics of INMARST standard-A earth station

Parameter	Value	Comments
Receive band	1535.0-1543.5 MHz	
Receive G/T	>-4 dB/K	Clear sky conditions 5o elevation
EIRP (nominal)	36 dBW	
Telephony	1 channel (multi-channel versions available)	FM/SCPC
Telegraphy (receive)	1200 bit/s BPSK	TDM stream
Telegraphy (transmit)	1 channel 4800 bit/s BPSK	TDMA
Request	2 channels	Either one selected Via random access

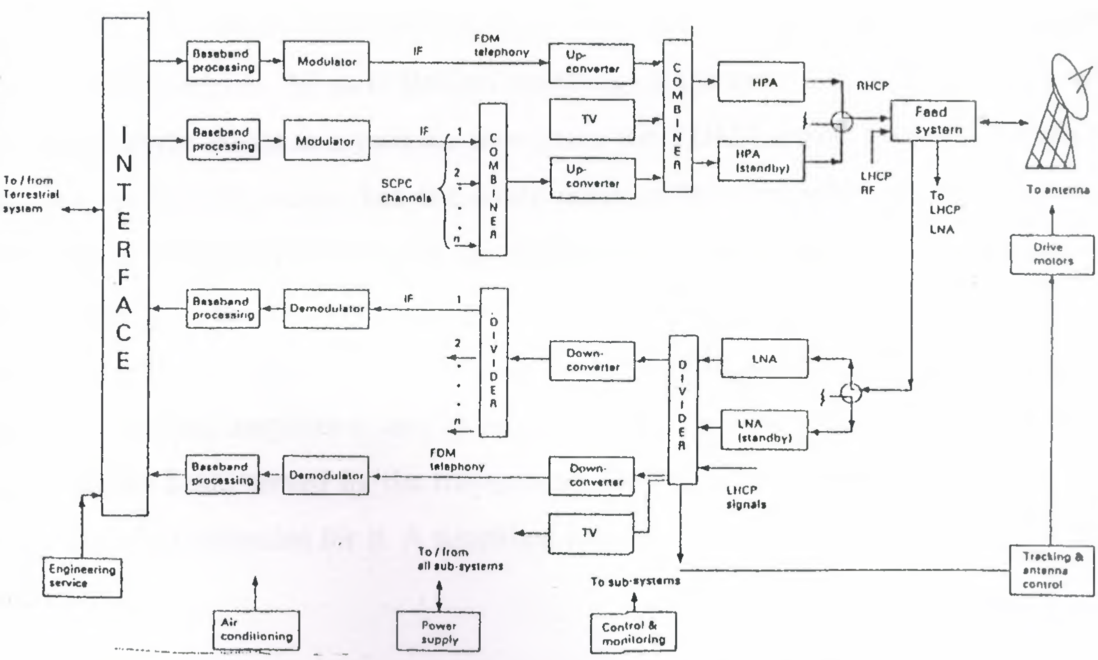


Figure 5.13 A general configuration of a large FSS earth station

FIGURE 5.13

CHAPTER 6 TIME DIVISION MULTIPLE ACCESS

6.1 INTRODUCTION

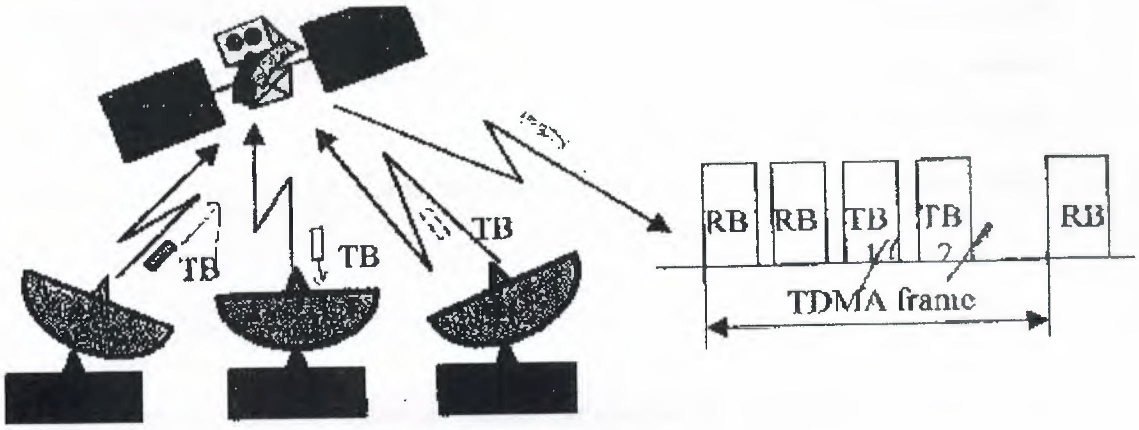


FIGURE 6.1

Time Division Multiple Access (TDMA) is a multiple access protocol in which many earth station in a satellite communications for transmission via each satellite transponder on a time division basis. All earth stations operating on the same transponder are allowed to transmit traffic bursts in a periodic time frame-the TDMA frame. Over the length of the burst, each earth station has the entire transponder bandwidth available to it for transmission. Transmit the timing of the bursts is carefully synchronized so that all the bursts arriving at the satellite transponder from a community of earth stations in the network are closely spaced in time but do not overlap. The satellite transponder receives one burst at a time, amplifies it, and retransmits it back to earth. Thus every earth station in the satellite beam served by the transponder can receive the entire burst stream and extract the bursts intended for it. A simplified diagram of a TDMA operation is shown in Figure 6.1.

6.1.1 Traffic Burst

The traffic bursts (TBs) transmitted by the traffic stations carry digital information. Each station accessing a transponder may transmit one or more traffic bursts per TDMA frame and may position them anywhere in the frame according to a burst time plan that coordinates traffic between stations. The length of the traffic burst depends on the amount of information it carries and can be changed if required. The location of the traffic bursts in a frame is referenced to the time of occurrence of the primary reference burst. By detecting the primary reference burst, a traffic station can locate and extract the traffic bursts or portions of traffic bursts intended to it. Also, it can derive the transmit timing of its bursts precisely, so that they arrive at the satellite transponder within their allocated positions in the TDMA frame and avoid overlapping with bursts from other stations.

6.1.2 Guard Time

A short guard time is required between bursts originating from several stations that access a common transponder to ensure that the bursts never overlap when they arrive at the transponder. The guard time must be long enough to allow differences in transmit timing accuracy and in the range rate variation of the satellite. The guard time is normally equal to the time interval used to detect receive the timing pulse marking the start of receive a TDMA frame at a station. There is no transmission of information during the guard time.

6.2 THE SYSTEM CONCEPT AND CONFIGURATION

Time-division multiple access (TDMA) is a multiple-access technique that permits individual earth terminal transmissions to be received by the satellite in separate non-overlapping time slots, thereby avoiding the generation of inter-modulation products in a nonlinear transponder. Each ground terminal must determine satellite system time and range so that the transmitted signals are timed to arrive at the satellite in the proper time slots. Signal timing and details of signal formats are discussed later.

Figure 6.2 illustrates the typical configuration of a TDMA network in which each high velocity burst of RF energy, typically quadriphase modulated, arrives at the satellite in its assigned time slot. There is little or no inter-modulation caused by instantaneous non-linearity, because only one signal enters the satellite transponder at a time. Note that the bit rates of the transmitted bursts are generally many times higher than that of the continuous input bit streams to the ground terminal.

Time-division multiple access permits the output amplifier to be operated in full saturation, often resulting in a significant increase in useful power-output. IM-product degradation is largely avoided by transmitting each signal with sufficient guard time between time slots to accommodate any timing inaccuracies, while preventing the "tails" of the pulsed previous and next signal from causing significant interference in the present time slot. The amplitude of these tails depends, of course, on the transient response and, in turn, on the amplitude , and phase response of the filters, both in the satellite transponder receive section and in the earth-terminal transmit filters.

If the transponder is operated in the "hard-limiting" mode and limits on noise input alone, the output envelope is essentially constant, even during the guard-time interval (Fig. 6.3). Typically, guard times can be made sufficiently small that the total guard-time frame consumes less than 10 percent of the useable signal power and the transponder is utilized to greater than 90 % efficiency.

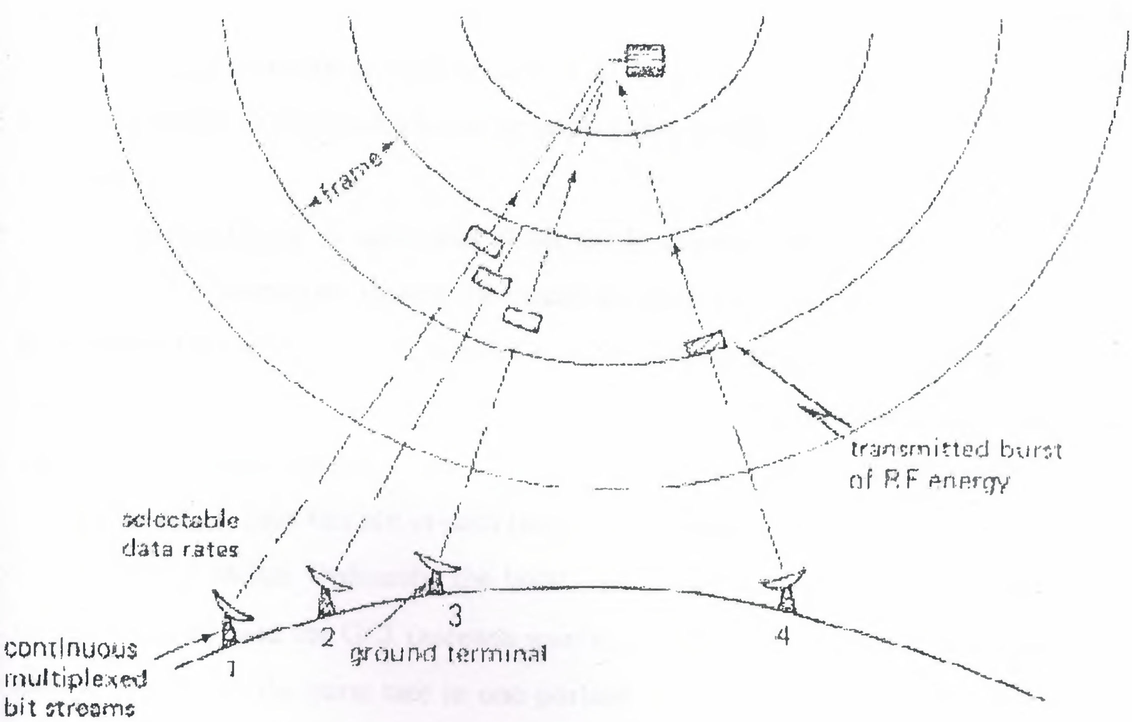


FIGURE 6.2

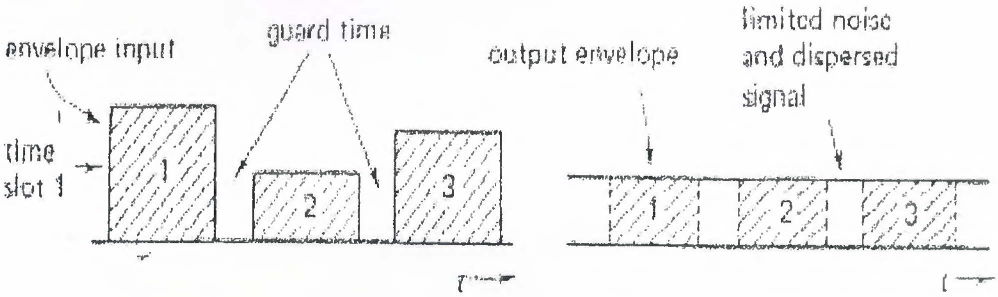


FIGURE 6.3

6.3 SYSTEM TIMING

Each TDMA earth station has parallel input digital bit streams, or analog streams that are digitized at the earth station, which are addressed to separate receiving earth stations (Figs. 6.4 and 6.5). The signals addressed to separate receive terminals are allocated separate portions of the transmit TDMA burst following the TDMA burst preamble. The TDMA receiver demodulates each of the TDMA bursts from separate transmit terminals and multiplexers, then demultiplexes the appropriate portions of them into separate serial bit streams.

TDMA system timing is such that if all earth stations transmitted at the beginning (epoch) of their respective frames, all signals would arrive simultaneously at the satellite. If the frame rate is $f_f = 1/T_F$, all input data rates f_{di} must be exact integral multiples of f_f that is, $f_{di} = \eta_i f_f$. Otherwise, an integral number of bits could not be transmitted during each frame (or super-frame) - The burst rate f_{bi} is usually integrally related to the frame rate because f_{di} T_f data bits are in each burst, and each burst duration is a natural fraction of the frame duration. Ordinarily, the burst rate should be the largest rate permitted by the satellite ERP and the G/ℑ (antenna gain/noise temperature) of the receiving ground station. If desired, the burst rate in one portion of the burst from a given terminal can differ from that used in other portions by some multiple of the frame rate.

Figure 6.6 is a simplified block diagram of a TDMA earth-station terminal. Parallel voice channels are PCM encoded at a clock rate synchronous with the TDMA frame rate. If there is a multiplicity of voice channels at the particular terminal, then this PCM

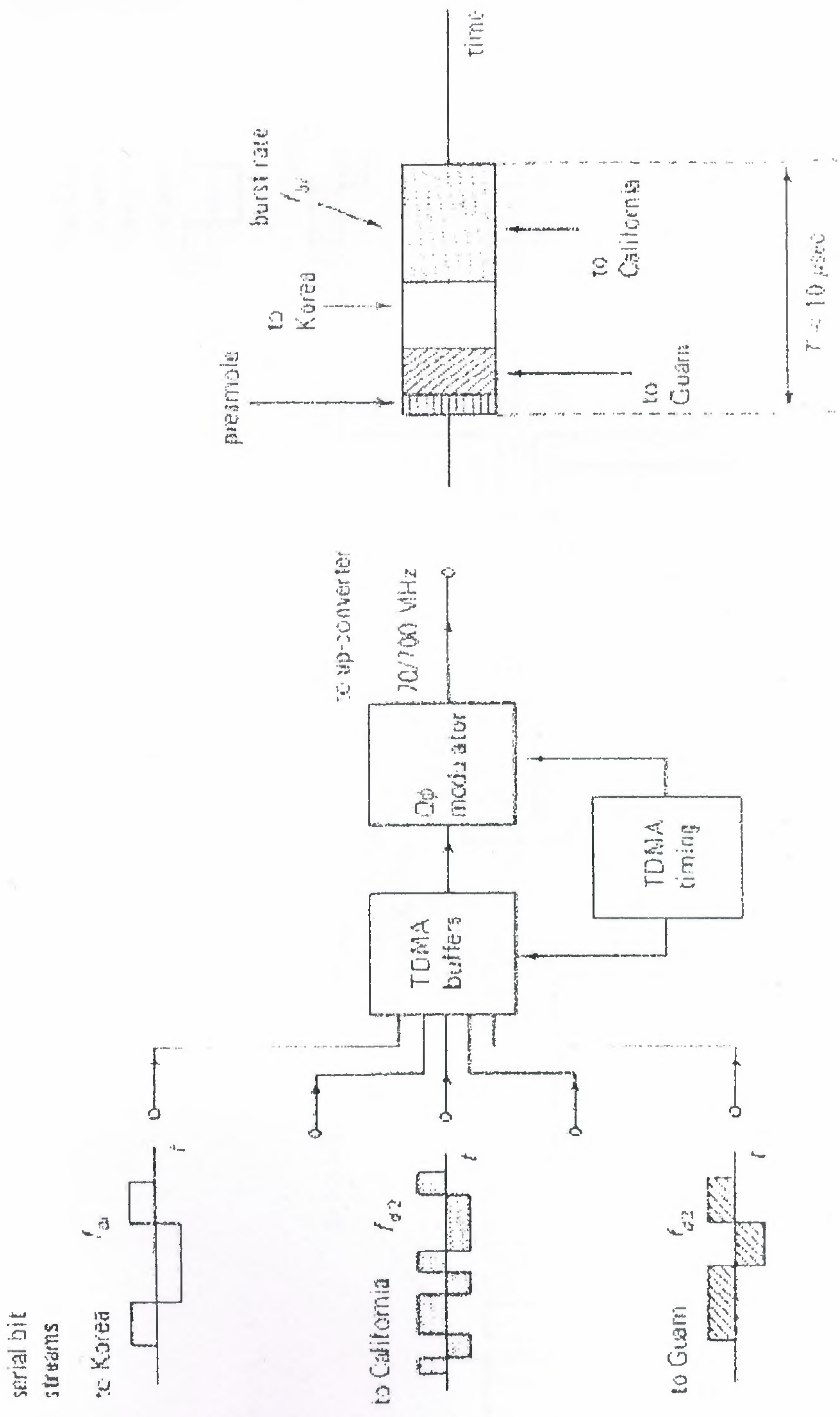

serial bit streams
to Korea
to California
to Guam
TDMA buffers
TDMA timing
modulator
to up-converter
preamble
to Korea
burst rate
to California
to Guam
time

FIGURE 6.4

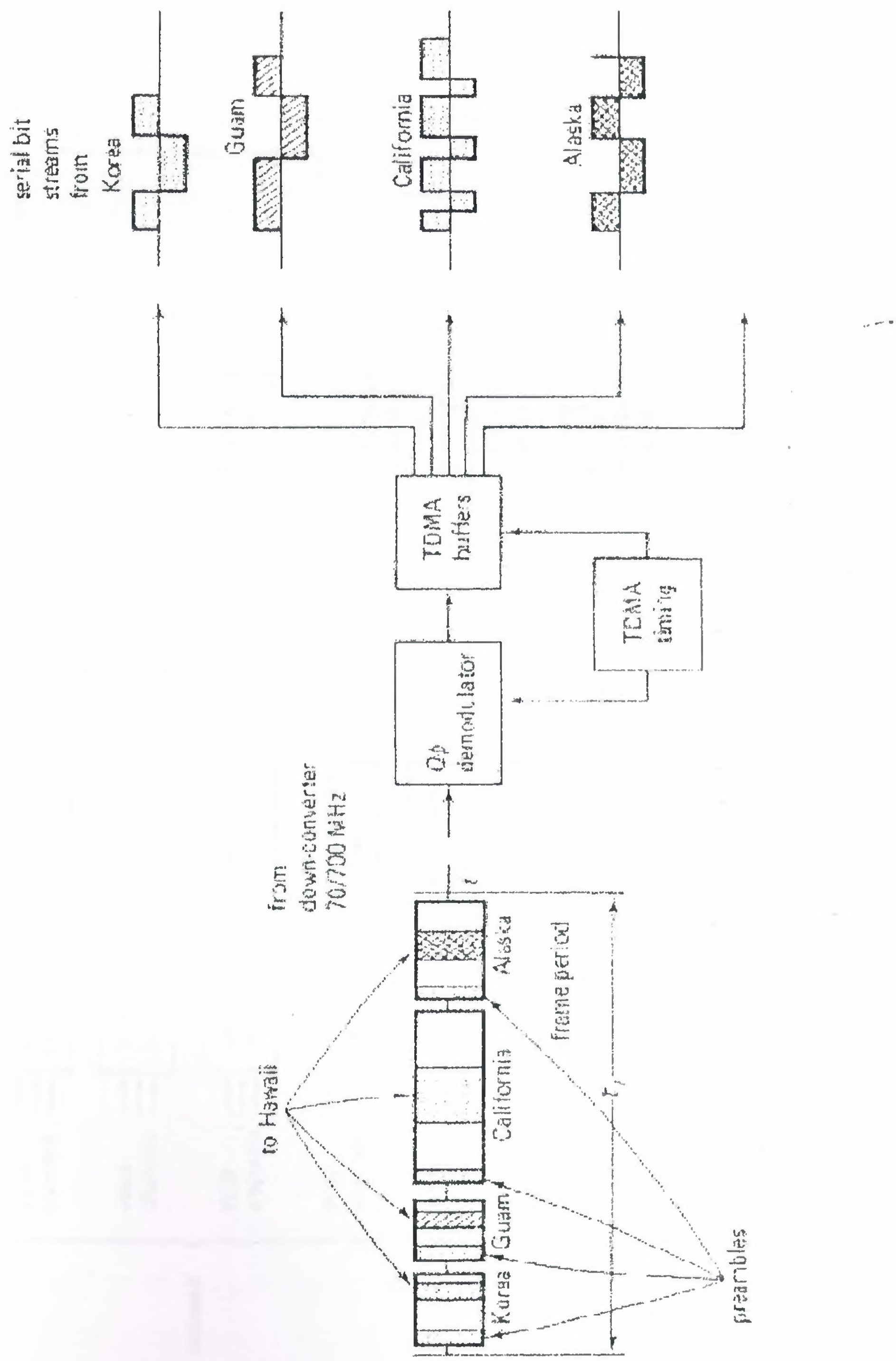

serial bit streams from Korea
Guam
California
Alaska
TDMA buffers
TDMA timing
QP demodulator
from down-converter 70/700 MHz
to Hawaii
Korea
Guam
California
Alaska
frame period
preambles

FIGURE 6.5

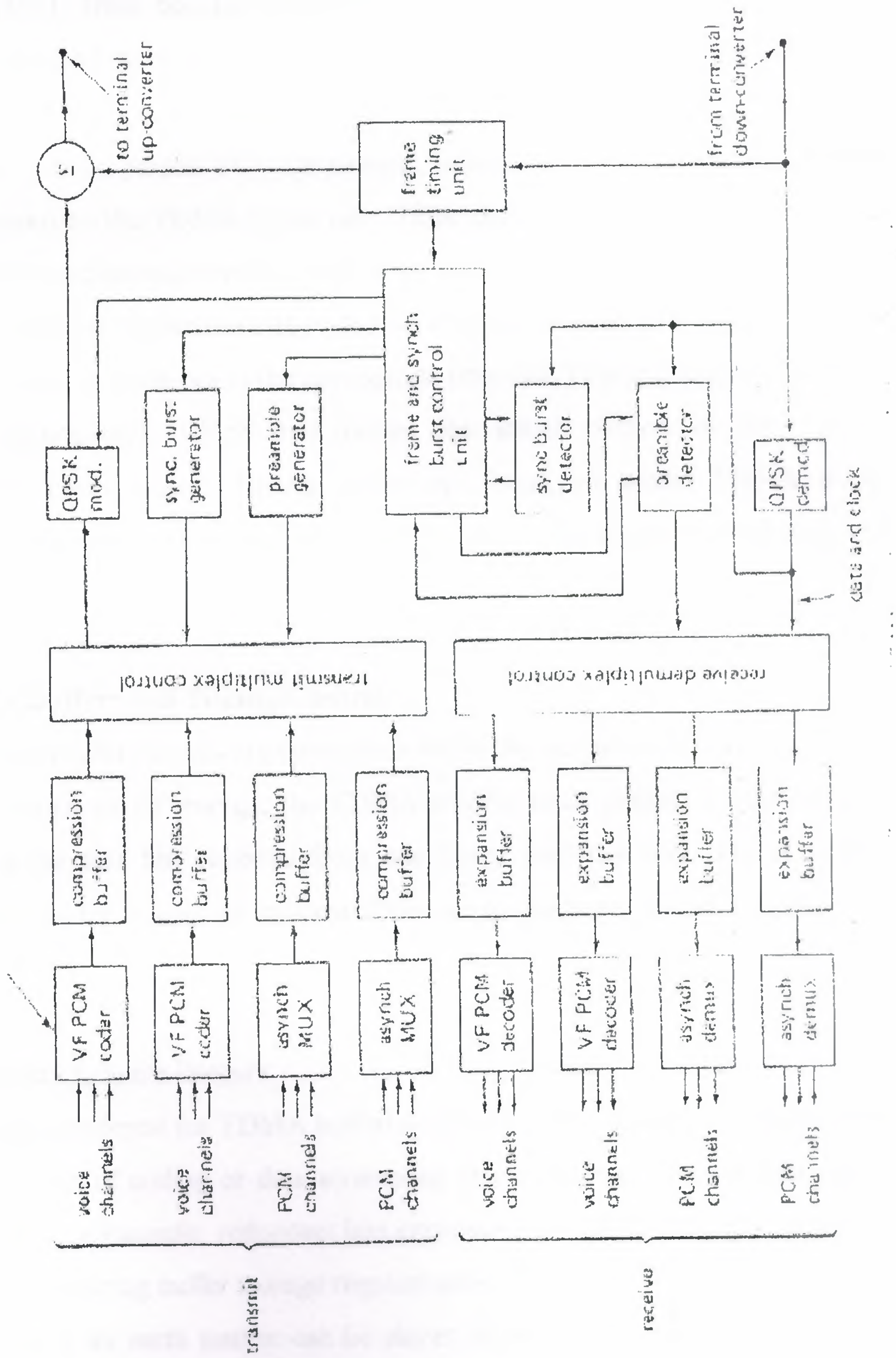

to terminal up-converter
frame timing unit
from terminal down-converter
QPSK mod.
sync. burst generator
preamble generator
frame and synch burst control unit
sync burst detector
preamble detector
QPSK demod
data and clock
transmit multiplex control
receive demultiplex control
compression buffer
compression buffer
compression buffer
compression buffer
expansion buffer
expansion buffer
expansion buffer
expansion buffer
VF PCM coder
VF PCM coder
asynch MUX
asynch MUX
VF PCM decoder
VF PCM decoder
asynch demux
asynch demux
voice channels
voice channels
PCM channels
PCM channels
voice channels
voice channels
PCM channels
PCM channels
transmit
receive

FIGURE 6.6

technique can take advantage of the loading factor of voice, which is less than 50 percent because of pauses in speech. Voice activity can he sensed and channel sharing used for the active channels as in the Time-Assigned Speech Interpolation [TASI; Fraser et al., 1962,1439-1454]. Thus, benefits similar to those described earlier for single Channel-Per-Carrier Demand-Assigned-Multiple-Access (SCPC-DAMA) can be obtained in addition to the other TDMA advantages.

Figure 6.6 also shows parallel PCM bit streams, which must be multiplexed together at a rate synchronous to the TDMA frame rate. Thus, pulse-stuffing multiplexing or elastic buffers usually must be employed to synchronize the bit streams.

The coded serial bit streams are then fed to compression buffers, where hits stored during one frame are burst out in the appropriate time slot. Frame timing is controlled by a separate timing unit, which may utilize the initial portion of the frame for ranging/timing transmissions. Timing within the frame, or within TDMA burst, is controlled by the synchronization burst generator and synch-burst control unit in Fig. 6.6.

6.3.1 TDMA Buffers and Timing Control

Since the incoming bit streams are continuous while the output of the TDMA modulator is a periodic burst of RF energy, the TDMA modem must contain a data buffer This buffer stores the data hits received from one frame until the next. The total storage required is M bits for N input bit streams of bit rate f_{di} and frame period τ_f where

$$M = \sum_{i=1}^{N} f_{di}\tau_f \qquad (6.1)$$

and the products f_{di} τ_f are integers

The techniques employed for TDMA buffering depend on the formats of received signals (Fig. 6.5), the use of coding or data scrambling at the terminal, and the data and burst rates required. F or example, redundant bits introduced by coding can be introduced after buffering, thus reducing buffer storage requirements.

TDMA timing at an earth station can be slaved either to an actual clock onboard the satellite or to an earth terminal clock at a terminal designated as the master. The master earth station generates a clock signal which is relayed by the satellite appears as if generated by the satellite.

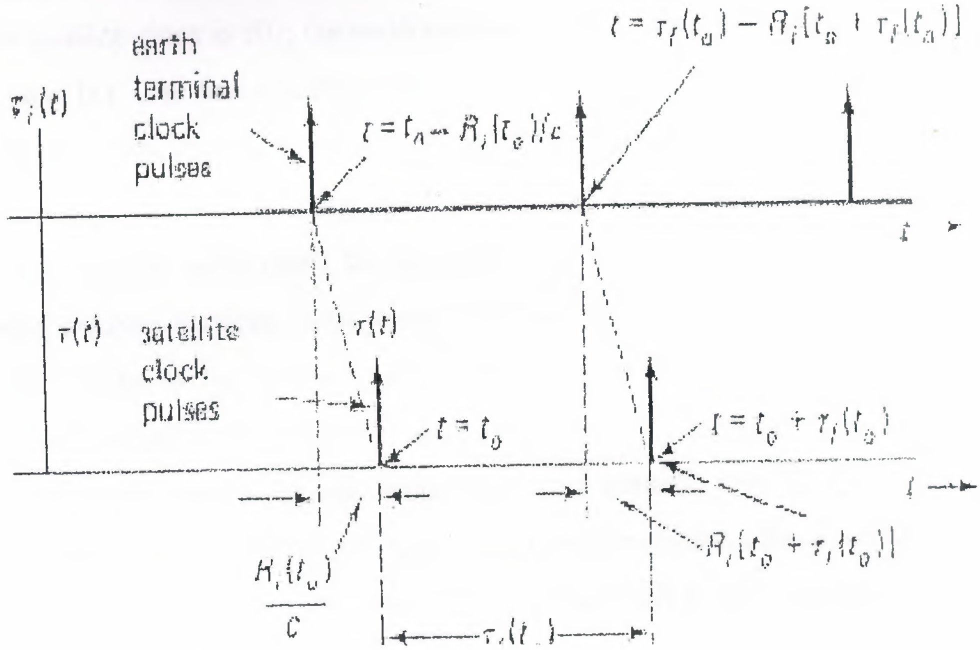


FIGURE 6.7

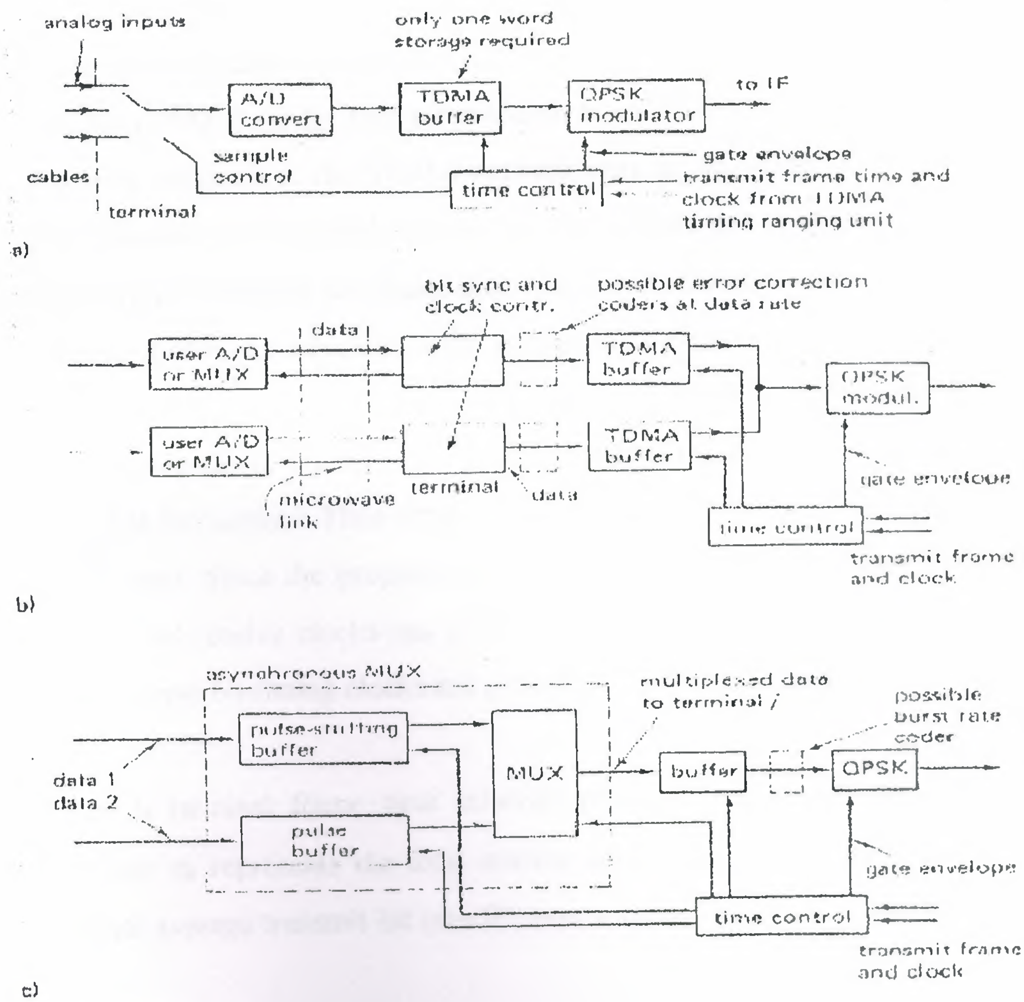


FIGURE 6.8

Figure 6.7 illustrates the timing at the satellite and at the earth station slaved to the satellite clock where the earth terminal is assumed to be precisely slaved to the satellite clock. The satellite clock is $\tau(t)$, the earth terminal clock at station i is 1 (t), and "true" or universal time is t. The first satellite clock pulse shown in Fig. 6.7 occurs at t = to. The earth terminal slaves its clock and transmissions so that they arrive at the satellite in synchronism with the satellite frame clock pulses spaced by i τ_f (t) sec. Thus, the earth terminal clock pulses must really be transmitted earlier by Ri(t)/c, where Ri(t) is the propagation distance between earth terminal and satellite, and c is the velocity of light. Thus the first pulse in Fig. 6.6 is emitted from the earth terminal at true time t = to-Ri(to)/ c since the pulse arrival time at the satellite is t = to. The earth terminal clock is slaved to the satellite and since the range Ri(t) is, in general, varying with time, *Ti* (t) cannot be a fixed constant frequency pulse rate. Thus the second pulse is emitted at time t = to +Tf (to) - Ri[to + Tf(to)]/c. Hence the frame duration at each earth terminal varies with time.

After one has assured that an integer number of bits arrive in each frame one must also store these data bits and transmit them to the TDMA modulator for transmission to the satellite at the burst rate f_{ij} (t) for that transmission from terminal i to terminal j. Note that not all receive terminals in the TDMA network may be the same size. Hence, the burst rate for transmission to terminal j may not be the same as that to terminal k because the G/$\Im$ of the receive terminals, and hence their receive bit rate capabilities, may differ.

TDMA transmit and receive timing may differ in phase as well as rate. The earth terminal TDMA transmit clock is slaved to arrive in synchronism with the satellite clock. The earth terminal receive clock, on the other hand, is slaved to the arrival time of clock pulses generated at the satellite. Thus these two earth terminal clocks differ by the round trip propagation time. Since the propagation path may be varying with time, the earth terminal transmit and receive clocks can differ in both phase and frequency. The more precise TDMA receive bit-timing clocks are generated from the TDMA demodulator bit synchronizer.

During this earth terminal frame time interval, precisely η_i bits of data must be transmitted, where η_i represents the total number of data bits to be transmitted in a frame. The actual average transmit bit rate fi* over a frame varies with time by a small fractional amount (< 10), and there must be some means for accommodating the difference between this rate and the actual input rate fi(t) received at the terminal by the user. Possible techniques for this purpose include:

1. Place a non-synchronous multiplexer or pulse-stuffing buffer at the earth terminal to increase the actual input rate $f_i(t)$ to the TDMA transmit rate- f_i *(t): then f_i (t) - $f_i(t)$ is the pulse stuffing rate of the buffer

2. Transmit the TDMA clock f_i*(t) or a clock-correction signal back to the users, or to the user multiplexers, so that received user bit streams arrive at the earth terminal TDMA transmitter in synchronism with the T DMA transmit clock.

3. Sample input analog waveforms at the earth terminal in synchronism with the TDMA transmit clock.

This approach, of course, assumes that the analog signals are in fact available at the earth terminal and that the sampling and quantizing are part of the TDMA equipment operation. This approach places only minimal requirements on the TDMA buffers if the TDMA frame rate is a multiple of or equal to the desired sampling rate. In this situation one can sample and quantize each of the analog input waveforms at the time that the TDMA transmit burst is to contain the bits from that input channel. The slight non-uniformity in sampling rate has negligible impact on the analog quantizing and reconstruction operation.

The three TDMA user interface techniques described above are illustrated in the simplified block diagrams of Fig. 6.8. In Fig. 6.8a, the analog waveform itself is used essentially to store information (for example, analog voice) until the time arrives in the frame for those data bits to be transmitted. If necessary, a sample-hold circuit can be employed to store the analog waveform. Variations in the sampling rate $\approx$ 1 in 10^3 do not usually affect quality of the analog transmission when thc transmit clock rate slowly changes because of satellite motion and clock drifts.

In Fig. 6.8b the transmit data streams arrive at the earth terminal in digital form, perhaps in a bipolar form. In many cases, this data stream can be phase locked to a multiple of the TDMA transmit frame rate by comparing the phase of the received bit stream with that of the TDMA transmit clock at the earth terminal. Any timing error can be fed back to the data clock at the source as a frequency or phase correction. Thus we have a remote phase-locked oscillator. If data streams to and from the users are in bipolar format, the clock or clock correction can be transmitted as a modulated carrier in the spectral null at the clock frequency of a bipolar waveform.

In Fig. 6.8c the received data streams are at some nominal value less than the TDMA data rate for that channel. The data streams are multiplexed together using pulse suturing or word stuffing. Forward error-correction coding at the TDMA earth terminal can be used with TDMA buffers in at least three different forms:

1. Each data channel can be independently coded and decoded at the data channel level. (See Fig. 6.8(b).) If rate 1/2 coding is used, the data buffers must then double in size compared to those with no coding. Also, a separate coder/decoder is required for each data channel. For example, if there are N = 10 channels of 64 kbps each, then 10 coder/ decoders are required, and ($10 \times 64 \times 10^3$) x 2 =1.28×10^5 bits must be stored in high-speed burst buffers. Clearly a rate 3/4 code

2. The coder/decoder operates at burst rate and is placed between the burst buffer and the modulator/demodulator. It must operate at a high speed (perhaps 40 Mbps to 100 Mbps), and the TDMA burst may have to transmit the preamble and tail of the code (or the complete block) in addition to coded data bits. Only a single coder/decoder is required here, and the TDMA buffer storage is no greater than that for no coding. Only the burst rate and burst timing must change when coding is introduced. For some types of decoders, however, the required burst rate speed may be beyond the state of the art or too costly.

3. The coder can also be operated at the average or aggregate rate of n bits/frame. Low-rate buffering is used to insert each separate data channel at a separate non-overlapping time interval in each TDMA frame into a coder/decoder operating at the average or aggregate rate (Fig. 6.9). The aggregate coded output is then increased to the TDMA burst rate by a burst rate buffer. This aggregate-rate approach was first discussed by Jacobs [1971].

The aggregate rate coder/decoder operates at a duty factor much higher than the duty factor of the TDMA burst transmissions from this terminal. In fact, the coder/decoder duty factor can approach 100 percent, and the coder operating speed therefore can be substantially less than the TDMA burst rate and approaches a rate as low as the sum total input data rate. If there are 10 channels at 64 kbps data rate each, the coder operates at an output rate just above $10 \times 64 \times 10^3 \times 2 = 128$ kbps for rate ½ coding. Note that a second TDMA buffer is needed at the coder output to increase the coder output rate from the aggregate rate to the burst rate.

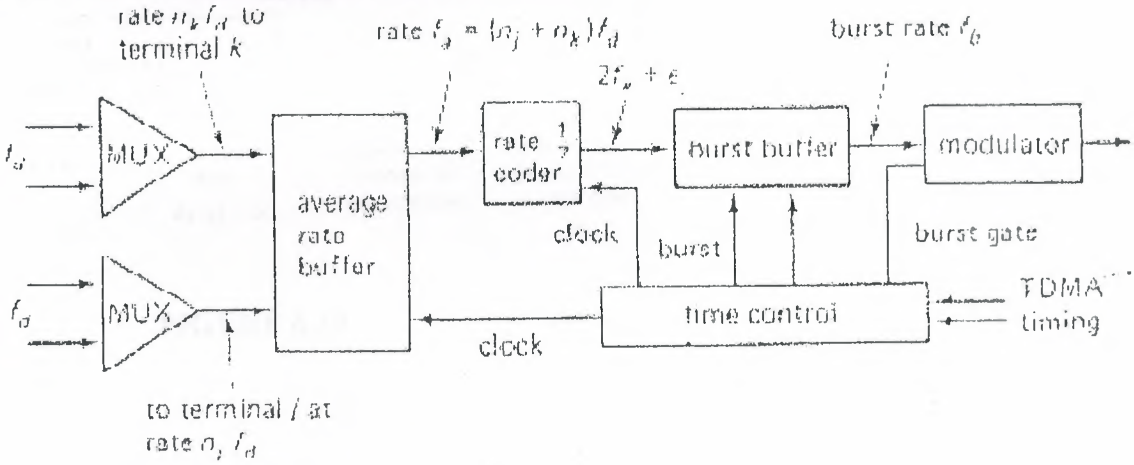


FIGURE 6.9

6.3.2 Elastic Buffers

If stable clocks are used for the data sources and sinks at each terminal in a TDMA network and the frame rate at the synchronous satellite transponder is held constant, it is possible to avoid the use of pulse-stuffing buffers altogether. An elastic buffer of varying fullness level can be used to accommodate the finite changes in the path delay caused by satellite motion. The path delay is in essence a variable length bit storage delay line. An elastic buffer simply stores data bits as they enter until they are called for by the transmit clock; hence, there are no pulse-stuffing inefficiencies. However, buffer size must be sufficient to prevent overflow or underflow. Typically, an elastic buffer must be reset periodically to accommodate clock drifts in imperfect earth terminal
clocks.

A synchronous satellite is not perfectly stable relative to earth terminals , since there is a nonzero eccentricity* and nonzero orbital inclination in any realistic orbit. Thus, the number of bits in transit varies diurnally with time. The elastic buffer is fed by a constant bit stream, and fills and empties relative to a nominal halt' filled state, depending on the number of bits stored in transit (Fig. 6.10). The number of bits in transit appears in effect as a "piston" storage buffer, which always fills and empties at a constant hit rate that corresponds to the frame rate at the satellite transponder. Figure 6.11 shows alternate frame timing techniques: the frame rate is

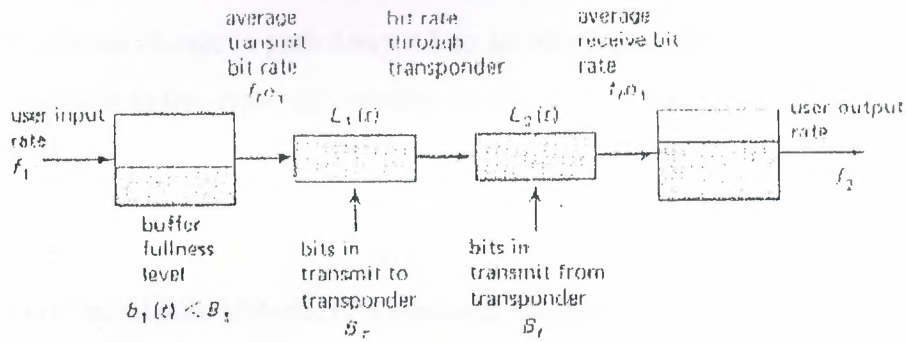


FIGURE 6.10

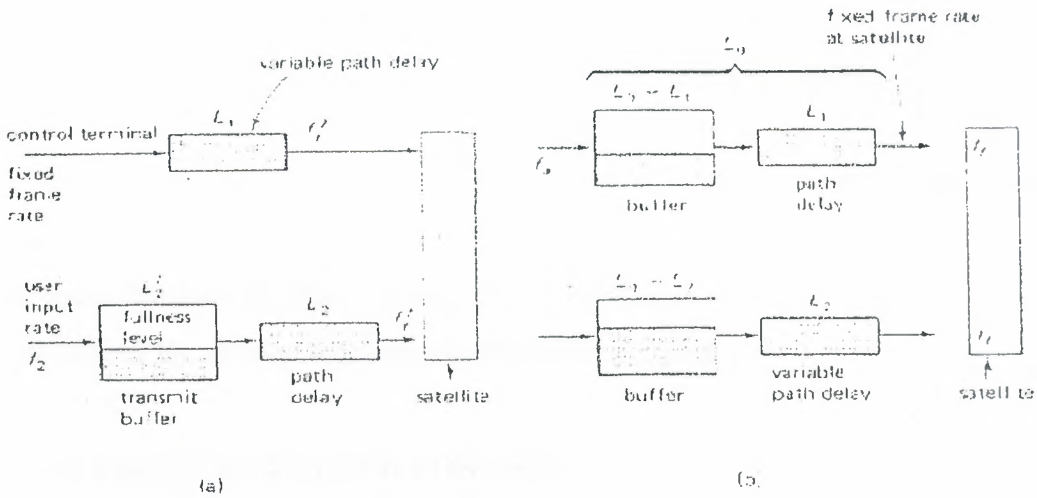


FIGURE 6.11

An equatorial station observes a ±e (H + re) change in path delay for an orbit of eccentricity e and altitude H. For e = 0.01 and H =19,300 nm, the variation is ±228 nm. constant at the control terminal (Fig. 6.11a), and all other terminals are slaved to that rate; or the frame rate is held constant at the satellite itself (Fig. 6.11b), and all other terminals are slave to that rate.

Define the TDMA signal frame rate as f_f frames/sec. Each earth terminal transmits (or receives) η_i bits/frame. If the path delay then changes by ± ΔTi sec, the elastic buffer capacity for that terminal must exceed

$2f_f\eta_i \quad \Delta T_i$ bits when $f_f = 1/T_f$ (6.2)

If the satellite orbital inclination drifts to an angle I rad relative to the equatorial plane, then the diurnal change in path delay ΔT to an observer at the pole (worst case) at the same longitude as the mean sub-satellite longitude is given by

$$(\Delta T) = \frac{1}{c}\left[(h+r_e)^2 + r^2 - 2r_e(h+r_e)\cos\left(\frac{\pi}{2}+1\right)\right] - \frac{1}{c}\left[(h+r_e)^2 + r_e^{\,2} + 2r_e(h+r_e)\cos\left(\frac{\pi}{2}\right)\right]$$

where h is the satellite altitude, r_e is the earth's radius, and c is the velocity of light. The satellite is assumed to have a circular orbit in this calculation. Then

$$(\Delta T) = \frac{2r_e}{c}(h+r_e)[2\sin \mathrm{I}] = \frac{4r_e}{c}(h+r_e) \qquad (6.4.)$$

and if << I

$$(\Delta T) \cong \frac{4I(h+r_e)r_e/c}{\sqrt{(h+r_e)^2 + r_e^{\,2}}} \cong 4Ir_e/c \qquad (6.5)$$

Thus if 4I= 0.1 rad, then (ΔT)c ≅ 344 nm ≅ 2.09 x 10^6 ft, or ΔT ≅ 2.1 msec peak-to-peak variation.

For any frame duration less than 2 msec, the storage-capacity requirement of this elastic buffer dominates the storage requirements of the burst buffer.

6.4 TDMA FRAME RATES AND FORMATS

6.4.1 Frame Format

The format of a TDMA transmission can have many variations within the basic structure shown in Fig. 6.12. A superframe of N (perhaps 2) frames can be used to allow for some very iow data-rate users desiring to transmit at a rate below the frame rate. The frame rate, for example, might be 1200 frames/sec, and a user at terminal i who desires to transmit at 150 bits/sec would transmit on the average of one bit per 8 frames- or 8 bits per superframe of 64 frames. However, most users transmit one data burst per frame plus perhaps a timing burst used for synchronization.

Each TDMA burst is subdivided into a preamble for receiver synchronization followed by data bits addressed to various receive earth stations. The TDMA burst concludes with a postamble that identifies the end of the burst, and can be used to resolve carrier phase and frequency ambiguities.

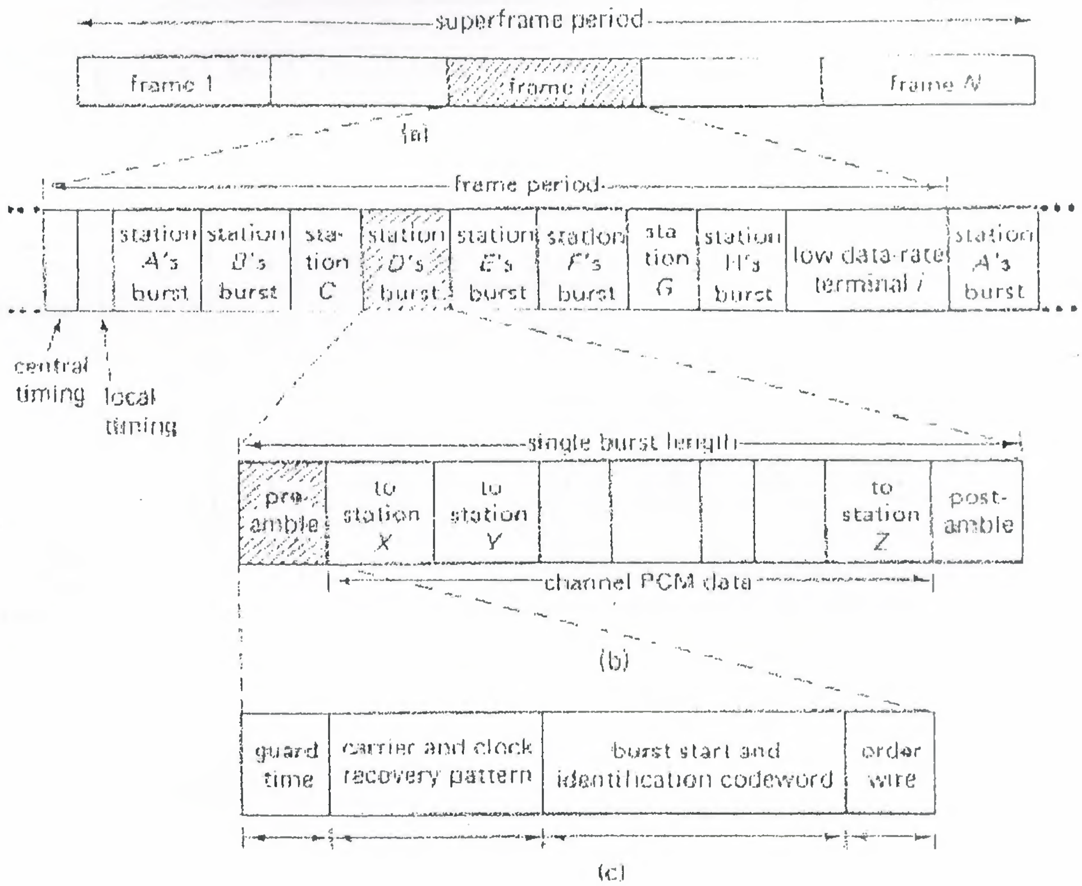


FIGURE 6.12

The time slots shown for central and local timing represent one method of obtaining TDMA timing. In this method, one station is assigned as a central timing reference for each satellite. The "local" stations transmit their own timing signal in the adjacent time slot and receive both central timing and their own timing signal as relayed from the satellite. Each timing signal can be a time-gated PN-coded signal. Timing is successfully accomplished when the terminals have properly placed the timing of their own signals so that the two signals (central and local) arrive in relative synchronism.

Each TDMA frame is subdivided typically into unit intervals, perhaps $2^{13} = 8192$ unit intervals, so that the time slot allocated to a given user can be identified by two integers, the start and stop times as measured in unit intervals. Table 6-2 lists the number of unit intervals needed for various input data bit rates and output burst rates.

TABLE 6.1 NUMBER OF UNIT INTERVALS

Burst Rate (Mbps) 75×2^m	Data Rate (Kbps) — $75 \times 2^n/1000$							
	38.4	76.8	153.6	307.2	614.4	1228.8	2457.6	4915.2
	$n = 9$	10	11	12	13	14	15	16
2.4576 $m = 15$	64	128	256	512	1024	2048	CW 4096	--
4.9152 $m = 16$	32	64	128	256	512	1024	2048	CW 4096
9.8304 $m = 17$	16	32	64	128	256	512	1024	2048
19.6608 $m = 18$	8	16	32	64	128	256	512	1024
39.3216 $m = 19$	4	8	16	32	64	128	256	512
78.6432 $m = 20$	2	4	8	16	32	64	128	256

N = Length of time slot required (in unit intervals) for $4096 = 2^{12}$ subintervals, or specifically N = Number of unit intervals required $= \left(\frac{\text{Data rate}}{\text{Burst rate}}\right) 4096 = \frac{75 \times 2^n}{75 \times 2^m} 2^{12}$.

The preamble interval comprises a number of elements that accomplish functions listed in Table 6-3. The postamble identifies the end of the message and is used also to assure that the carrier recovered is the correct carrier frequency, not a sideband of the carrier that has been offset by an odd multiple of the frame rate. Periodic time gating of the carrier of course generates spectral lines spaced at odd multiples of the frame rate. Transponder filter transient response affects TDMA guard-time requirements in that the tail of the previous time slot postamble can overlap the preamble and even

Table 6-2 FUNCTIONS OF THE TDMA PREAMBLE

Preamble Element	Function
Guard time Tg	Prevent overlap of adjacent bursts from different ground terminals. This guard time* must be sufficient to account for system timing inaccuracies and tails from adjacent bursts caused by finite filter-response times.
Carrier recovery	Provide a preamble sequence of consecutive "1s" or an alternate pattern to permit coherent carrier recovery for a synchronous demodulator. Carrier recovery can be accomplished either by rapidity acquiring carrier on each new carrier burst, or by using the frame-frame coherence in consecutive bursts from the same transmit terminal in a narrow bandwidth carrier recovery loop.
Bit timing	This bit synchronization function can be accomplished with one or more transitions in the preamble bit stream. This function is accomplished after and during carrier synchronization.
Burst start and identification	The burst start symbol identifies the last bit in the preamble or the first bit of actual data. The identification symbol identifies the address of the data and the transmitting terminal. In some applications, this address information is redundant because the users know by way of parallel order wires which time slots are allocated to which users-that is, the time slots are, in effect, the addresses.
Order wire	This order wire is for terminal-terminal communications-for example, for setting up the TDMA time slots power levels.

the data bits of the present time slot. This effect is accentuated if the previous burst is significantly larger in amplitude than the present burst and can cause data bit errors in the initial portion of the time slot.

6.4.2 Frame Rate Selection

The TDMA frame rate affects several important system parameters and should be selected with care. Some specific factors bearing on frame-rate selection are :

1. Primary data rates are limited to integral multiples of the frame rate (unless superframe multiplexing is used). Thus, the lower the frame rate, the greater the flexibility in data rates.
2. Long frame periods lead to greater efficiency relative to a given guard time Tg and a fixed preamble duration.
3. An increase in the frame period decreases the frame-frame coherence o f the carrier. This decrease in coherence introduces added phase noise in the demodulation process when frame-frame coherent carrier recovery is used. This efficient method of carrier recovery is degraded by too large a frame period or too much carrier phase noise.
4. Increasing the frame period Tf causes the buffer storage requirement to increase since buffer storage memory is directly proportional to frame period (with the exception of overhead functions). Hence, increasing the frame period adds to the memory cost.
5. Increasing the frame period beyond 125 μsec (8 kHz sampling rate) makes it more difficult to use analog storage-that is, let the waveform remain analog until needed, then sample the analog waveform at the burst transmission time and transmit the quantized samples as described in Sec. 6-3.
6. An increase in the frame period beyond 0.1 sec introduces a significant added delay to the transmission in addition to the satellite round trip delay of 025 sec. Nevertheless, the use of long frame times may have advantages for some applications where data are being transmitted at low rate rather than voice, and the simplifications in system timing associated with longer frame times outweigh the increased buffer storage costs.

6.5 TDMA SYSTEM EFFICIENCY

The power efficiency of the satellite transponder with TDMA inputs and hard limiting depends on the guard times between the transmissions Tgi of each terminal, the preamble and postamble time, used for example to provide addressing and carrier recovery, the addressing time required for each transmit/receive terminal pair Taij the time utilized for the timing-ranging function TR- and the frame duration Tf . The maximum efficiency for all terminals fully occupying the frame is

$$\eta_{\max} = \left(\frac{T_f \left(T_R + \sum_j \left(T_{gi} + \sum_j T_{aij} \right) \right)}{T_f} \right) \qquad (6.6)$$

where i is summed over all N terminals in the network and j is summed over all N-1 which can be addressed by terminal. The preamble and postamble are included in Taij. If all guard times and address times are identical then the efficiency is

$$\eta_{\max} = \frac{T_{fF} - [NT_R + N(N-1)T_A]}{T_f}$$

where it is assumed that all terminals are communicating with all other terminals and the frame is fully utilized. Since TR and Tg tend to be approximately constant for a given channel bandwidth, efficiency increases as Tf increases.

Increasing T f improves efficiency, but beyond a certain point it causes other difficulties as described in the preceding section. An example efficiency for a 125 μsec frame and N = 5 users is

$$\eta_{\max} = \frac{125 - [2 + 5(0,1) + 20(0,025)]}{125} = \frac{125 - 3}{125} = 97,6 \quad \text{percent}$$

for T_R = 2 μsec, Tg = 0.1 μsec, Ta = 0.01 μsec. Clearly, the actual efficiency is less than this because the data to be transmitted rarely just fill the total frame space available. A data channel to be transmitted may require more space than available, and it may be impossible to transmit only a fraction of that data channel. Hence a portion of the frame may go unused. In addition there are the possible inefficiencies of time division multiplexing the data channels together prior to entering the TDMA modulator

6.6 TDMA CARRIER RECOVERY USING FRAME-FRAME COHERENCE

The TDMA carrier bursts destined for a given receive terminal during one frame are received from many transmit terminals (Fig. 6.13). Each of these carrier bursts received from separate terminals has an independent carrier phase since the carrier phase at the satellite is not synchronized from one transmitting terminal to another.

Carrier recovery of these TDMA bursts of PS K signal can proceed in at least two different ways:

1. Use a rapid-acquisition carrier recovery phase-locked loop or narrow-band filter which is able to respond accurately to burst-to-burst phase transients. One carrier recovery loop can then handle bursts from all earth terminals. However, the carrier recovery noise bandwidth must be relatively wide to provide a rapid transient response within the preamble time.

2. Use multiple time-gated carrier recovery loops or a single time-multiplexed phase-locked loop with phase memory from frame to frame. This approach permits the use of relatively narrow bandwidth carrier recovery loops which operate on the main spectral line component of a time-gated carrier.

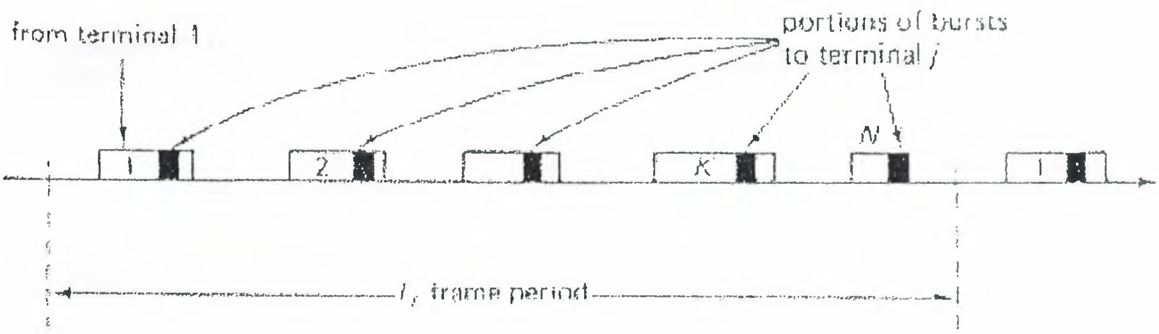


FIGURE 6.13

In method (2) one must avoid the potential false lock on to a sideband line component Fig. 6.14) in the periodically time-gated carrier preamble spectrum. In addition, the carrier phase stability must be sufficiently good to provide phase coherence from frame to frame. Otherwise the phase stored in memory during the previous frame may differ substantially from that in the next frame even though it has been linearly extrapolated using the frequency estimate as a basis for extrapolation. The frame-frame coherent approach operates as shown in the simplified carrier recovery loop of Fig. 6.14. One carrier recovery loop can be used for each received carrier burst, or a single loop with n loop filter/VCOs can be time multiplexed for each carrier burst as shown. (There is a simple digital filter/NCO equivalent of Fig. 6.14)

In order fur the frame-frame coherent carrier recovery loop to operate satisfactorily, the carrier phase difference for a single transmit terminal caused by oscillator phase noise from one frame to the next must be small; that is,

$$|\phi(t)-\phi(t-T_f)| \stackrel{\Delta}{=} |\Delta\phi(t)| << \pi / N$$

for N phase PS K and where the constant frequency part of the phase has been removed from $\phi(t)$. Satellite accelerations are usually negligible over these short frame durations and satellite doppler is tracked. The relationship $\Delta\phi$ to oscillator phase-noise statistics is discussed.

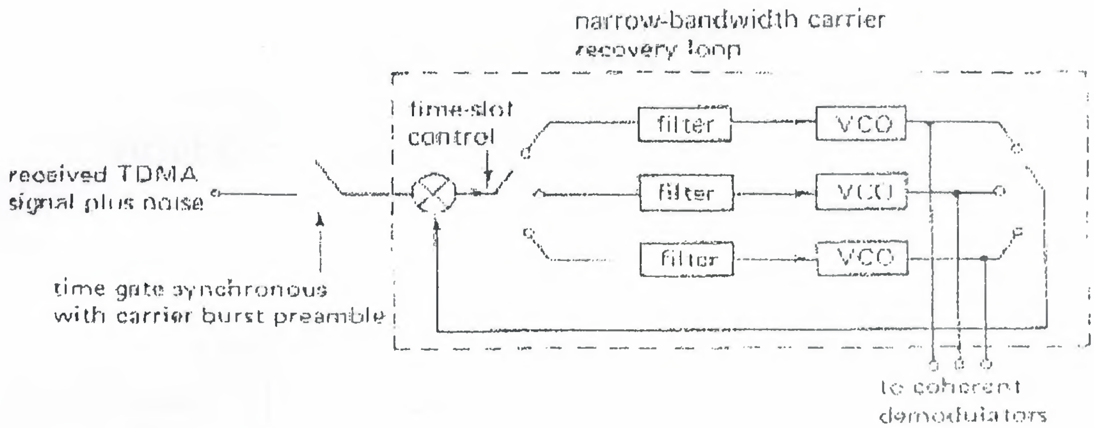


FIGURE 6.14

The side bands of a pulsed preamble of pure carrier used for carrier tracking are shown in Fig. 6.15. If a carrier tracking loop attempts to track the fundamental frequency of the carrier but instead tracks the carrier sideband at $1/\tau_f$ f frequency offset, the carrier will be in phase at the middle of the carrier preamble Tc 12 sec after the beginning of the carrier (Fig. 6.16). A k-th order offset carrier causes the cross correlation between reference and actual carrier to decrease at the edge of the burst to

$$\cos\left[\left(\frac{2\pi k}{\tau_f}\right)\left(T_s-\frac{T_c}{2}\right)\right] \cong 1-\frac{1}{2}\left(\frac{2\pi k}{\tau_f}T_s\right)^2 \quad \text{for Tc <<Ts, kTs<<Tf} \qquad (6.10)$$

where Ts is the total width of the time slot of RF energy and Tc is the duration of the TDMA preamble. The frequency offset is k/T_f and the time offset at the end of the signal burst is Ts – Tc/2. Clearly, if the order k of the sideband is sufficiently large for a given

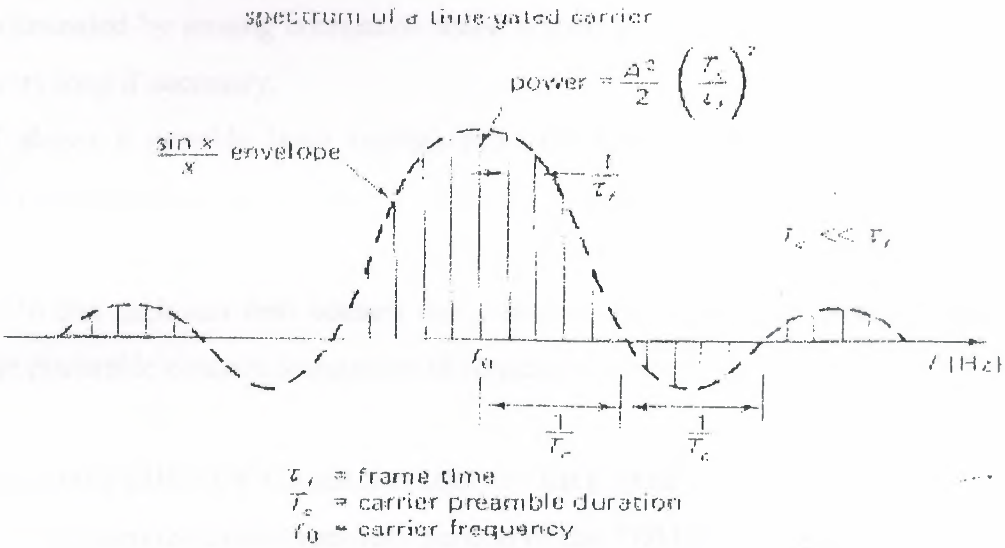


FIGURE 6.15

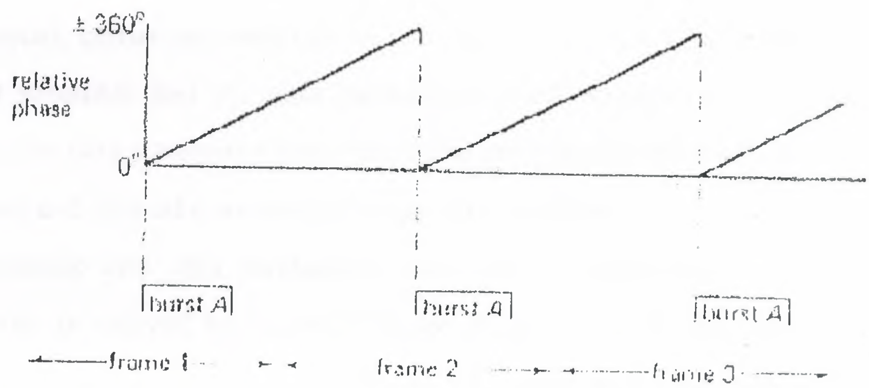


FIGURE 6.16

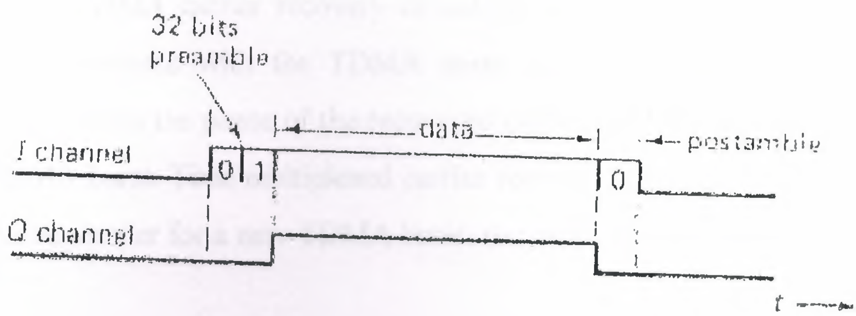


FIGURE 6.17

Ts, sideband lock can cause a substantial degradation in performance which could be reduced or eliminated by sensing correlation using a burst postamble and returning the carrier recovery loop if necessary.

Figure 6.17 shows a possible burst configuration for the in phase and quadrature channels of a quadri-phase burst. The "0" represents a sequence of 16 serial zeros followed by a,1 representing 16 “ones”. Multiplication in the receiver by an alternate b,1 sequence of 16 bits each can then convert the preamble into a pure carrier of 32 bits duration. The postamble contains a sequence of consecutive zeros.

6.7 DELAYED REFERENCE CARRIER RECOVERY FOR TDMA

It is possible to shorten the carrier recovery portion of the TDMA burst preamble while still performing the carrier recovery on a burst-to-burst basis [Nosaki, 1970, 425-434]. Suppose that carrier recovery requires 02 μsec and that ordinarily a 0.2 μsec preamble is required just for carrier acquisition in addition to the other portions of the preamble used for station addressing and bit synchronization. If the first 0.2 μsec, portion of the preamble is deleted, carrier recovery can still be obtained by operating on the remaining portion of the preamble and the data modulation itself Because pure carrier is not available during the data transmittal time, the carrier recovery circuit must operate on the modulated signal and may take somewhat longer, say, 0.3 μsec.

The entire preamble and data modulation can still be recovered, however, if the modulated carrier is delayed by TΔ = 0.3 μsec in parallel with the carrier recovery operation as shown in Fig. 6.8. The cable delay TΔ corresponds to the carrier recovery acquisition time. When a TDMA burst begins, one of the two alternating carrier recovery loops is switched to that burst and the acquisition operation begins. The TDMA burst at IF frequency is being stored in a delay cable during that acquisition interval. At the end of TΔ sec, the TDMA carrier recovery circuit for that burst switches to the coherent detector in coincidence with the TDMA burst exiting the delay cable. The carrier recovery circuit holds the phase of the recovered carrier until To sec after the end of the received TDMA burst. Time multiplexed carrier recovery loops are shown so that while one is acquiring carrier for a new TDMA burst. the other can be holding the phase of the previous burst. The alternate carrier recovery loop then is switched to the coherent phase detector, and the demodulation of the next TDMA burst begins.

In principle, therefore, no preamble is required for TDMA acquisition. In practice. however, one must also account for several other effects, including:

1. The delay $T\Delta$ of the delay cable must be an integer number of IF cycles and must remain constant over the expected temperature fluctuations of the environment. Phase-stabilized cable may be required to hold the carrier phase shift to less than $\pm\varepsilon°$ over the expected temperature range.

2. Doppler frequency changes or long-term frequency drifts must be sufficiently small that the phase change is also small from that cause. If the frequency drift is $\Delta f \pm 10^4$ Hz and the delay is $T\Delta = 0.3$ μsec, then the phase shift is $\Delta f\, T\Delta = \pm 10^4 \times 0.3 \times 10^{-6} = \pm 3 \times 10^3$ cycles, or $\Delta\phi = \Delta f T\Delta \times 360° = \pm 1.08°$, an effect which would usually be negligible.

3. The delay cable itself must be sufficiently distortion-less to the IF modulated carrier that it does not degrade performance. If T is large compared to the inverse RF bandwidth W, and TW >>1, then this effect can be a problem.

This reduction in preamble duration requires the use of additional circuitry, an additional carrier recovery loop, and the delay cable and driver amplifiers. For some applications, however, it may be a desirable approach.

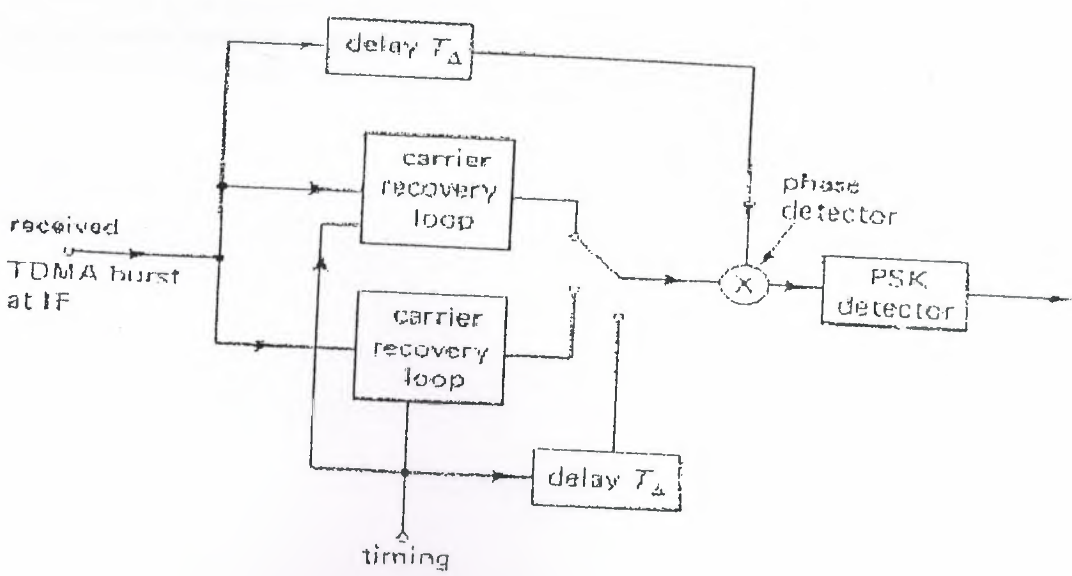


FIGURE 6.18

CONCLUSION:

1. Digital Satellite Communication networks are one of the most major Telecommunication system.

2. Satellite have a unique capability for providing coverage over large geographical areas. The resulting interconnectivity between Communication sources provide major advantage in Telephone Exchange, Mobile Communications, Television & sound broadcasts directly to the public.

3. Multiplexing is sending more than one signal over a single channel. At receiving end, the signals are demultiplexed, or separated & sent on to separate terminals. A multiplexer acts as a electronic switch. We can send two signals together, in short time.

4. Time Division Multiple Access is a primary alternate to Frequency Division Multiple Access. TDMA can achieve efficiencies in satellite power utilization of 90 percent or more compared to 3 to 6 dB loss in power efficiency in FDMA.

5. TDMA permits the output amplifier to be operated in full saturation, often resulting in a significant increase in useful power output. Forward Error Correction Coding at TDMA earth terminal can be used with TDMA Buffers in at least 3 different forms

6. Each TDMA frame contain a reference burst to establish an absolute time reference for network & a series of traffic burst. One for each station . Each of the Individual traffic bursts contains a preamble. Which are amplified by satellite transponder & received in down-link beam, which is received by all stations.

7. Which means that TDMA is a protocol in which among earth station in a Satellite Communications for transmission via each satellite transponder on a Time Division basis .

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