NEAR EAST UNIVERSITY

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Department of Electrical and Electronic Engineering

DIGITAL SATELLITE COMMUNICATION

Graduation Project
EE- 400

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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. Digital Satellite Communication play a major role in telephone transmission, television and radio program distribution. There are several topic of this project; which are following:

- Historical of Satellite Communication.
- The concept of Satellite transponder.
- Digital, Earth Station, with different type of antennas.
- Dealing with details about orbit Satellite Communication, and understanding how to fix satellite in it's accurate orbit which is a constant distance from the earth. and finally studying frequency division multiple access (FDMA).

TABLE OF CONTENTS

1. HISTORY OF SATELLITE COMMUNICATION

1.1 INTRODUCTION

In less than 20 years communications satellites have become the dominant carriers of long distance communications.. From the first commercial launch of INTELSAT' (also called EARLY BIRD)on April 6, 1965, the satellite industry has grown until it handles most international telephone traffic, all international and almost all domestic long-distance television program distribution, and a rapidly growing proportion of new domestic voice and data channels. Direct satellite broadcasting will soon begin, and proposals for electronic mail and personal two way satellite radios are under discussion. Satellites have significantly improved the reliability and the accuracy of aviation and meantime communications and navigation, re-moving these. functions from the high-frequency (HF) portion of the spectrum. The International Telecommunication Satellite Organization *(Intelsat)* has grown at a rate of 20 percent per year since 1965 and, as of 1984, it operated over 35,OOO two-way traffic links.

These changes have occupied because the technology is now available to put large *spacecraft* into synchronous orbit where, to an observer on the ground, they rain permanently at the same place in the sky. At an altitude of about *35,870* km (22,291 miles). the satellites can receive, amplify, and retransmit radio signals for most of a hemisphere. Thus, with ore relay via a satellite, a single transmitter on the ground can reach nearly half the world. With three relays it can reach all of it.

1.2 HISTORY AND DEVELOPMENT

Some of the first communication satellite were designed to operate a passive mode Instead of actively, transmitting radio signals, they served merely to reflect signals that were becomes up to them by transmitting stations on the ground. Signals that were reflected in all direction, so they could be picked up by receiving stations around the world Echo 1,lanched by the United States in

1960,consisted of an aluminized plastic balloon 30 m in diameter. Launched in 964,Echo 2, was 41 m in (135 ft) in diameter. The capacity of such systems was severely limited by the need for powerful transmitters and large ground antennas.

Satellite communication currently make exclusive use of active system, in which each satellite carries it own equipment for reception and transmission. Source launched by the United States in 1958,was the first active communication satellite. It was equipped with a tape recorder that stored that messages received while passing over a transmitting ground station. These message were retransmitted when the satellite passed over a receiving station.Telstar 1, launched by American Telephone and Telegraph company in 192,provided direct television transmission between the United State. Europe and Japan and could also relay several hundred voice channels. Launched into an elliptical orbit inclined 45 to the equatorial plane.Teltar could only relay signals between two ground stations for a short period doing each revolution, when both stations were in its line of sight.

Hundreds of active communication satellite are now in orbit. They receive signals from one ground station, amplify them ,and then retransmit them at a different frequency to another station. One frequency band used,500 MHZ wide, is divided into repeater channels of various band widths (located at 6 GHZ for upward, or uplink, transmission and 4 GHZ for downward, or downlink, transmission).A band at 14 GHZ (uplink) and 11 or 12 GHZ (downlink) is also much in use, mostly with fixed (no Mobil) ground station. An 80 MHZ wide band at about 1.5 GHZ(up-and downlink) is used with small. Mobil ground stations (ships, land vehicles, and aircraft).Solar energy cells mounted on large panels attached to the satellite provide power for reception and transmission.

1.3 SATELLITE FREQUENCY BANDS

The satellite uses different frequencies for receiving and transmitting. The equipment which receive a signal freguency,ampolifier it and retransmits it in another frequency is called a transponder.

The most popular frequency band for satellite communication is 60 GHZ (c-band) for there uplink and 4 GHZ for the down link around 12 and 14 GHZ. The use of this frequency band offers the following advantages:

Relative inexpensive microwave equipment.

low attenuation due to rain fall: rain fall is the primary atmospheric cause of signal degradation.

In significant sky background noise: the sky background noise (due to the random noise emission from galactic, solar and terrestrial sources) reach its lowest 1 and 10 GHZ.

Additional satellite in this frequency bands are already precluded by the lack of suitable orbit slots.

Consideration is being given to higher frequency operation(around 29 to 30 GHZ)

Frequency band	Range(GHz)
L	1-2
C	2-4
S	4-8
X	8-12
Ku	12-18
K	18-27
Ka	27-40
Millimeters	40-300

2. SATELLITE TRANSPONDER

2.1 INTRODUCTION

The satellite transponder and associated antennas form the primary portion of the communications subsystem on a communication satellite. This transponders differs from some conventional microwave line-of-sight (LOS) repeaters in that many separate ground terminals access the satellite simultaneously at nearly the same instant from widely different points on earth. This chapter briefly describes some of the major elements and types of communication transponders. The discussion covers multichannel transponders, some of the advantages of transponder canalization, typical frequency plans and antenna assignments, and potential advantages of processing transponders The detailed effects of the transponder on different types of multiple-access techniques are described in later chapter on frequency division.

2-2 A TRANSPONDER MODEL

Most communication satellites contain several (four or more) parallel transponders often with several narrow beam antennas to aid in the multiple access problem, particularly where the received signal levels differ widely for different classes of users. A single channel of a typical transponder is modeled in Fig.2 -1. Only the most basic elements are shown: the channel separation band pass filter, the frequency converter, the various amplifiers, and a possible limiter amplifier. Multiple input sinusoids enter the transponder in frequency band, and exit in band f_d. The frequency bands are separated sufficiently *far* to prevent "ring around" oscillations in the transponder itself. This transponder uses a single frequency translation operation which converts the receive RF frequency directly to the transmit RF frequency. Other configurations first down-convert to a convenient IF frequency, for example,150 MHz, and then up-convert to the transmit frequency.

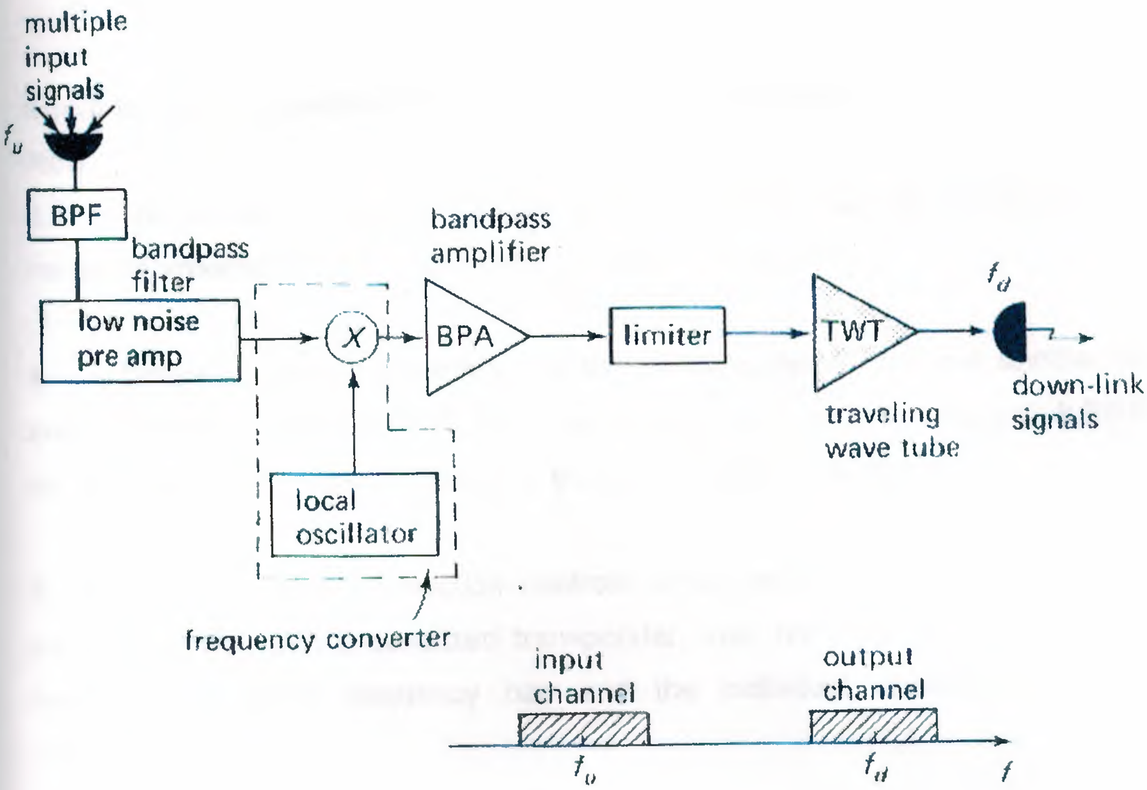


Fig 2.1 Simplified transponder block diagram shown a single channel transponder

2.3 TRANSPONDER CHANNELIZATION

Satellite transponders used for multiple access are often multichannel in configuration. That is, the transponder is canalized by frequency-selective to allow different frequency bands to be handled by separate amplifiers antennas. Transponder canalization has a variety of applications, including.:

1. The total downlink power can be increased by using parallel power amplifiers (usually Twits) in the satellite

Uplink frequency selection in the earth terminal can control which polarization or downlink satellite antenna (for example, a spot beam) is to be used. Thus, this approach can use a change in uplink frequency to switch the signal to different geographical areas and hence to different receive ground stations.

3. The number of signals handled by a single TWT can be decreased and hence intermediation (IM) product effects can be reduced.

4. Different classes of earth terminals can be isolated from one another by separate satellite channels—so that small mobile terminals of limited uplink ERP do not compete for. satellite power with large fixed ground stations.

5. Uplink frequency selection controls which downlink frequency is to be used. Note that with a canalized transponder, then need not be a fixed offset between the uplink frequency ban and the individual downlink frequency channels.

It is often convenient to set all transponder bandwidths equal. This bandwidth equality permits complete flexibility in the choice of transponder channel; network of earth terminals occupying one transponder can be transferred to another transponder with minimal impact other than a frequency offset Furthermore a spare unused transponder can provide a compatible redundant system element in the event of a transponder failure, thereby improving system reliability. Some of these potential uses of frequency canalization are illustrated in Fig .2.2. In the multichannel transponder shown, frequency channels 1 and 2 are separately filtered and amplified for each of the or hog anal polarizations RHP and LHP. Either earth-coverage or spot-beam antennas can be employed on the downlink by mechanical switching (SW).

The received signals in Fig. 2-2 enter the earth-coverage antenna/ diplexer, where they are band pass filtered to isolate the receive preamp from the transmitted downlink signals. The isolation provided by the product transmit and receive filters, and diplexer isolation must, of course, exceed the gain of the transponder by a significant amount to prevent runaround oscillations in the transponder which can occur for a loop gain of unity or more. After RF preamplification, the received carriers in channels I and 2 are separated by the channel filters. Additional AGC amplification or limiting can be used to bring the signals in each channel to the proper level. However it is common to have the gain adjustment of the transponder controlled by ground command. This approach is usually preferable to the use of AC in the satellite which would provide an additional element of uncertain in the earth terminal transmit power control problem. Thus, signal levels can be adjusted through the use of accurate uplink power control rather than hard limiting in the transponder.

The microwave carriers next are frequency converted to the transmit frequency channel, perhaps 750 MHz away, by a frequency generator containing a phase-locked frequency multiplier locked to a stable satellite frequency standard. A TWT or other amplifier then amplifies the output of one or more combined channels. The multiple carriers that may appear at the TWT input can cause significant intermediation products in the output channel bandwidth unless the power level is backed off. Other intermediation products can spread all the way to the receive channel of the same transponder. This effect is particularly important if the same antenna is used for both transmit and receive. For this reason, the TWT amplifier output must be heavily filtered to prevent cross products from falling in the receive band and saturating the preamp. The filter also must be designed for low loss in the transmit channel to provide efficient power utilization. Care must be given also in this filter design to minimize intermediation products that are generated in the passive (but slightly nonlinear) filter structure and enter the receive pass band.

An earth terminal can transmit uplink to the earth-coverage satellite receive antenna in either polarization and in either frequency channel, thereby selecting the downlink spot beam to be used. The TWT power-amplifier output is then fed to the spot-beam antenna or to dual-polarized earth-coverage antennas, depending on the setting of a mechanical switch. The mechanical switch is controlled by ground command. A ground station anywhere in the earth-coverage uplink pattern can direct its signals to any one of the four downlink spot-beam regions (3.5 beam width) of the transponder shown. Frequency reuse is provided here by the use of separate carriers of LHP and RHP or cross-polarized linear polarizations in the same frequency band. Cross-polarization isolation ratios as high as 40 dB have been demonstrated for cross-polarized linear polarization antennas.

Satellite beacon frequencies are inserted in each output channel usually outside of the communication channel. The beacon frequencies provide an easily identifiable and permanent signal for auto track receivers in the ground terminals to aid in satellite tracking. In addition, beacon frequency is often coherent with the stable local oscillator on board the satellite and can be used by the earth terminal to track long term drifts in the satellite translation frequency. It is possible to use an on-board atomic standard to improve this transfer oscillator stability. Finally, the beacon may be modulated to carry a satellite identification word and low-rate telemetry data on the satellite status. This direct satellite telemetry to a communications control earth station is sometimes used as an input to provide real time control the satellite and earth terminal network.

The filters in the various band pass amplifiers in the multiplexers are unallied in gain and group delay to reduce signal distortion. Each channel typically has its own set of equalizers. Both gain flatness and gain slope are ten compensated to reduce signal distortion effects.

Figure 2-3 gives a simplified block diagram of the 12-channel Intelsat IV spender. Each of the four receivers consists of a 6-GHz tunnel diode amplifier (TDA) low-noise preamplifier followed by a 4-GHz notch filter to provide out-of-band attenuation. The 500-MHz bandwidth receive signal band is then frequency translated to 4 GHz. The even and odd input multiplexers contain six band pass filters, each bandwidth 36 MHz, as shown in Fig. 2.3 Since adjacent channels are separated in center frequency by 40 MHz, there is then a 4-MHz guard band between adjacent channels.

Each of the input multiplex filters separates the signals into even and odd channels and is separately equalized. The channel filters in the input multiplexers are followed by redundant power TWT amplifiers, harmonic filters, and switches to direct the signals to the appropriate output antenna

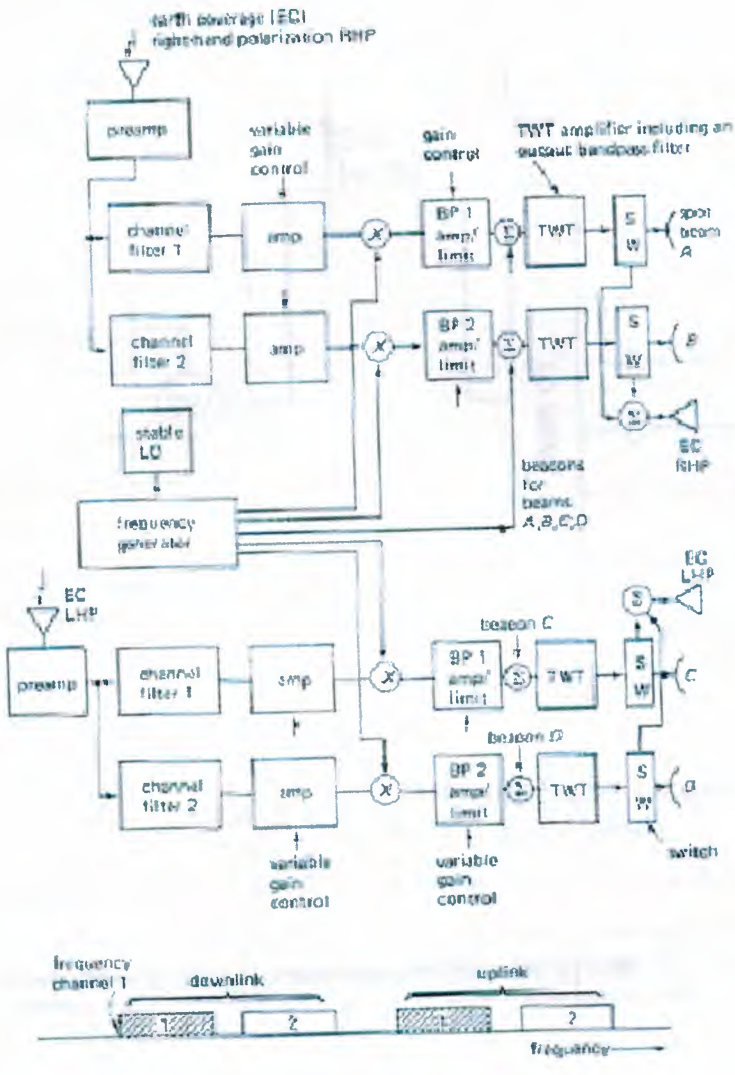


Fig 2.2 Examples of multi channel satellite transponder. The downlink has spot beams a,b,c,d available by switching

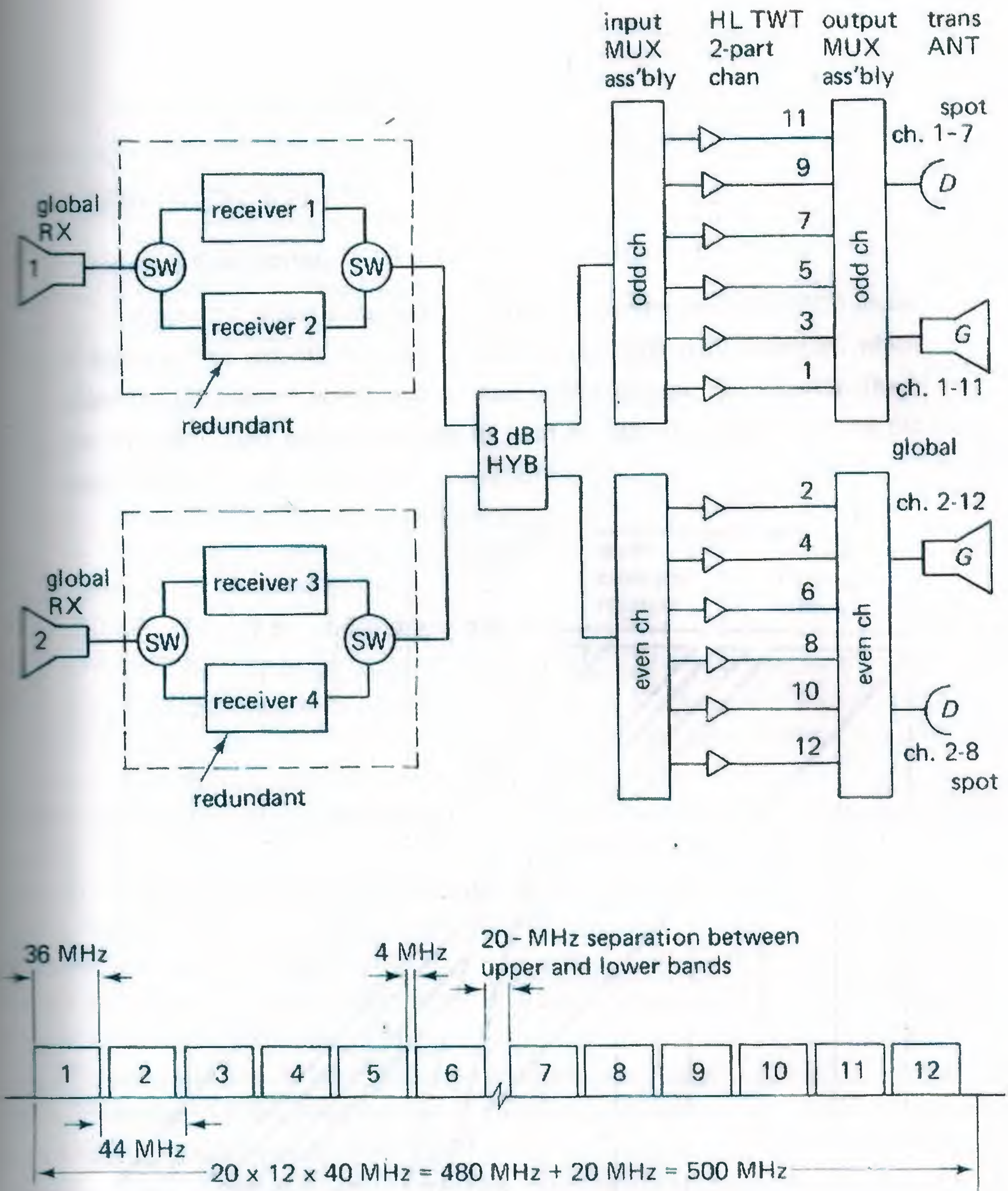


Fig 2.3 Simplified configuration of the INTELSAT satellite transponders (a) transponder block diagram, (b) transponder frequency plan

2.4 FREQUENCY PLANS

Frequency Canalization

Figure 2.4 shows a transponder frequency plan for the USA DSCS phase II Satellite. The satellite employs two narrow-coverage (NC) antennas, which share the NC transmit power, and a single earth-coverage (EC) antenna. There are redundant TWT power amplifiers for both NC out put channel and the EC output channel.

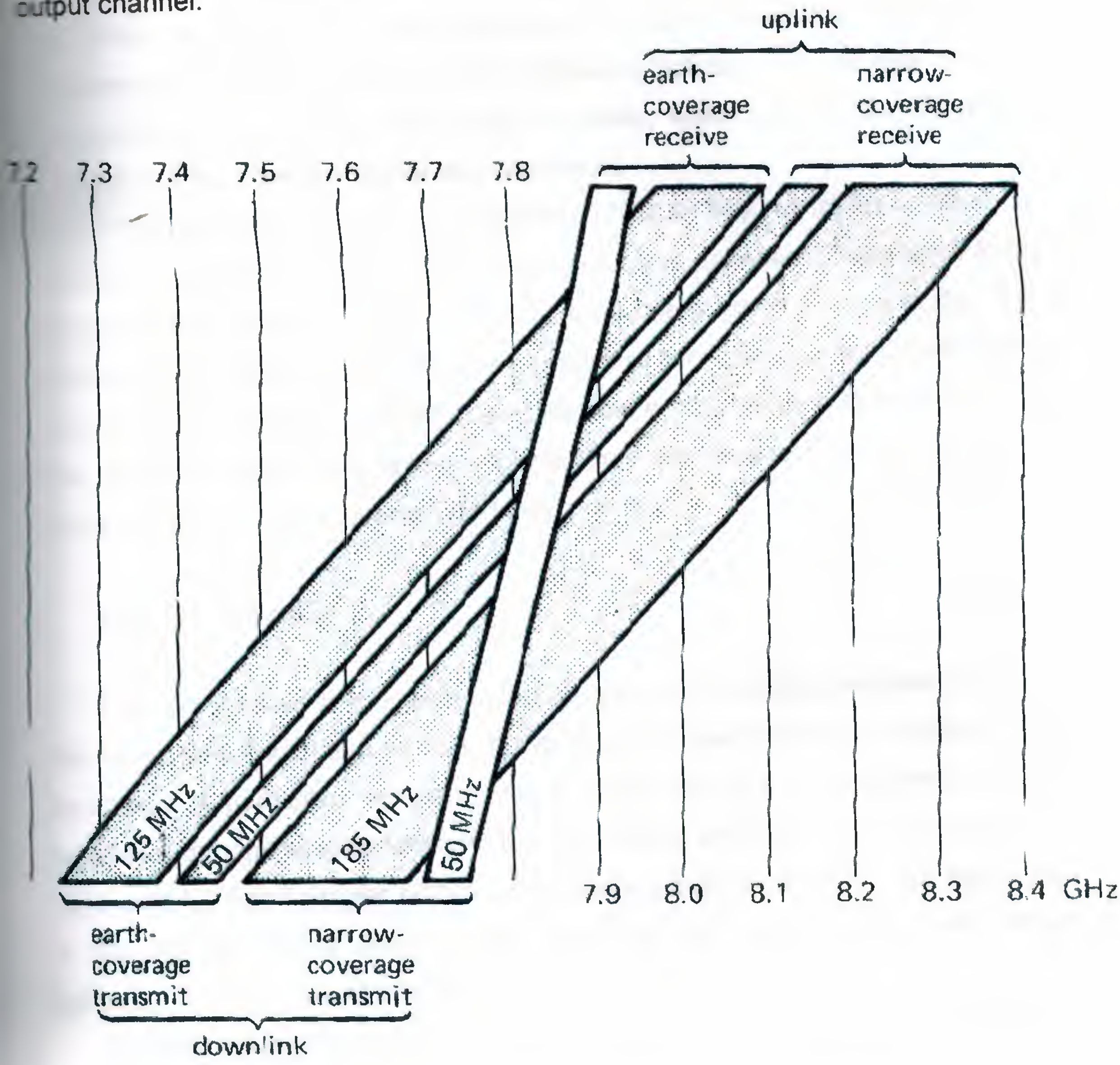


Fig 2.4 DSCS phase II satellite frequency plan for the uplink and down link

In this transponder, uplink power from a user in the narrow-coverage beam of the satellite can be transmitted by either the earth-coverage or narrow-beam downlink antennas. The power is split to each of two narrow beam antennas. Similarly, carriers in the earth-coverage uplink channel are directed to either downlink narrow coverage or earth coverage antennas, depending on the frequency of the uplink carriers. Thus an earth terminal situated in the beam width (~ 1000 nm diameter) of the NC antenna can transmit up to the satellite in either the NC or EC uplink bands and by proper frequency selection can transmit down in either NC or EC channels. Notice that the two 50-MHz channels in Fig. 2.4 are cross-strap channels, which convert an EC uplink signal to a NC downlink signal and vice versa.

The earth-coverage transmit channels *(7250* to 7450 MHz) for a.200 M Hz band are separated from the earth-coverage receive channels (7900- 8100 MHz) by 450 MHz. Therefore, if there were not adequate transmit filtering in the TWT outputs, the seventh-order (4, 3) cross-product of two uplink carriers could fall as high as 7450 +3(200) = 8050 MHz and into the earth-coverage receive channel. The third- and fifth-order cross-products, however, cannot fall into a receive channel from the earth coverage transmit channel.

Frequency Reuse

Frequency reuse is the technique for transmission of two separate signal in the same frequency band by use of two separate types of antenna beams. The technique of particular importance here is the use of two coincident antenna beams of orthogonal polarizations, that is, vertical and horizontal polarization or right- and left-hand circular polarization. Figure 2.5 show an artist's conception of a satellite employing vertical and horizontal polarizations, and employing polarizer in front of the antennas.

It appears feasible to obtain polarization isolation on the order of 30dB.The polarization isolation of circularly polarized antennas depends on the axial ratios of the wave incident to the earth terminal receive antenna on the receiving antenna axial ratio itself. For coincident elliptically polarized waves incident on the dual beam receive antenna, the coupling to the orthogonal port is given by

$$\mathfrak{F} = \frac{(1 + r_1^2)(1 + r_2^2) - 4r_1 r_2 \pm (1 - r_1^2)(1 - r_2^2)}{2(1 + r_1^2)(1 + r_2^2)} \qquad 2.1$$

where r_1 is the axial ratio of the incident wave and r_2 is the axial ratio orthogonal port antenna beam.

The plus sign in (2.1) yields the minimum coupling loss (coincident ellipse axes), and the minus sign yields the maximum coupling loss (orthogonal ellipse axes). Figure 2.5 illustrates the coupling loss for an incident wave axial ratio of 0.5 dB. If the receive antenna axial ratio is *0.5* dB, the minimum coupling loss is F=25 dB.

Rainfall not only affects the attenuation of the received wave, as described in but also depolarizes the incident wave. This rainfall can significantly reduce the cross-polarization isolation needed for reuse, particularly at frequencies above 10 GHz. Measured data illustrating this effect taken by Simple show the effect of rain on 18-GHz signals of both vertical and horizontal polarization over a 1ine of sight microwave link of 2.6 km. As can be seen in Fig. 2.6 the cross-polarization isolation for little or no rainfall was approximately 30 dB for both linearly and circularly polarized signals. At periods of high rainfall, the difference between the desired and depolarized component was only 8 dB for circularly polarized signals, but was about 18.5 dB for linear polarization. Thus linear polarization would appear to be the better choice with respect to rainfall depolarization's effects.

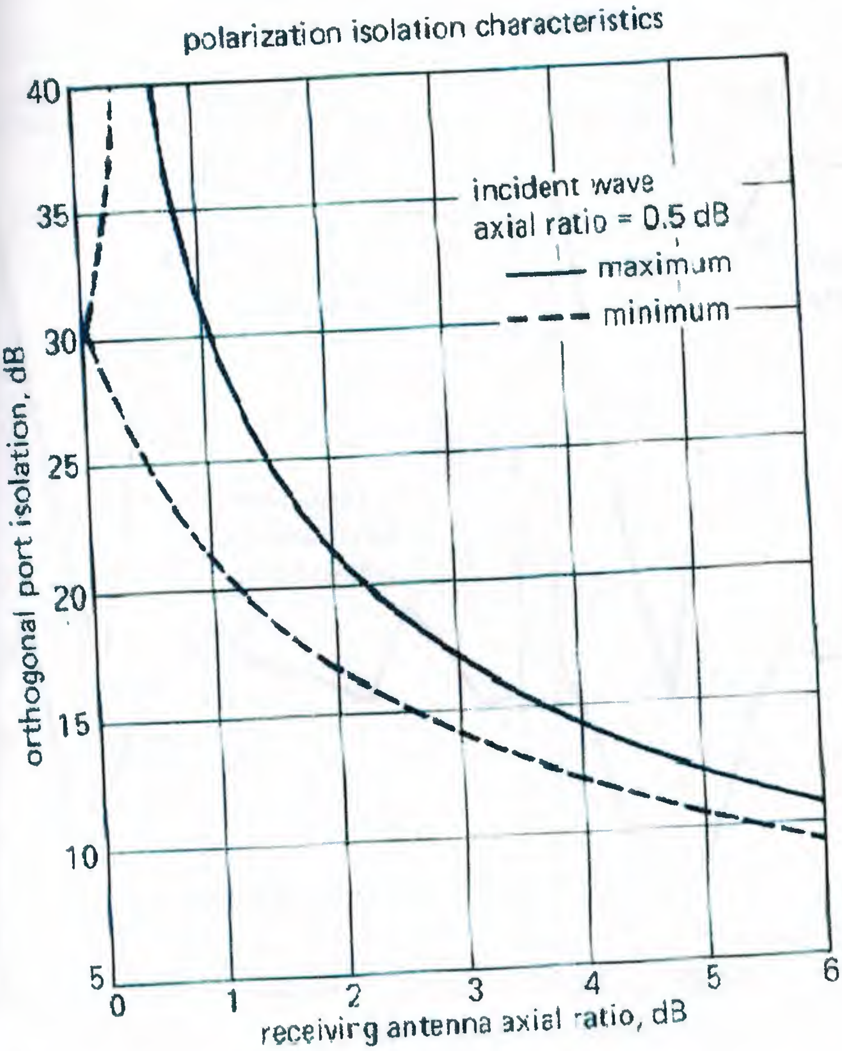


FIGURE 2.5 Orthogonal port isolation versus antenna axial ratio

Multibeam Satellite Antennas

Multibeam satellite antennas can increase both the power bandwidth efficiency of the satellite link. The multiple narrow-beam provide higher gain to localized areas of high density traffic thereby producing higher capacity for the same satellite RF power, relative to a 17.3 earth coverage antenna. Furthermore, with a multibeam antenna (MBA) the transponder channel can be connected with a multipole -multithrow switch to any of a number of geographical regions on earth. High-gain multiyear antennas can be employed to reduce ground station cost at nodal connection points centered in the narrow beam.

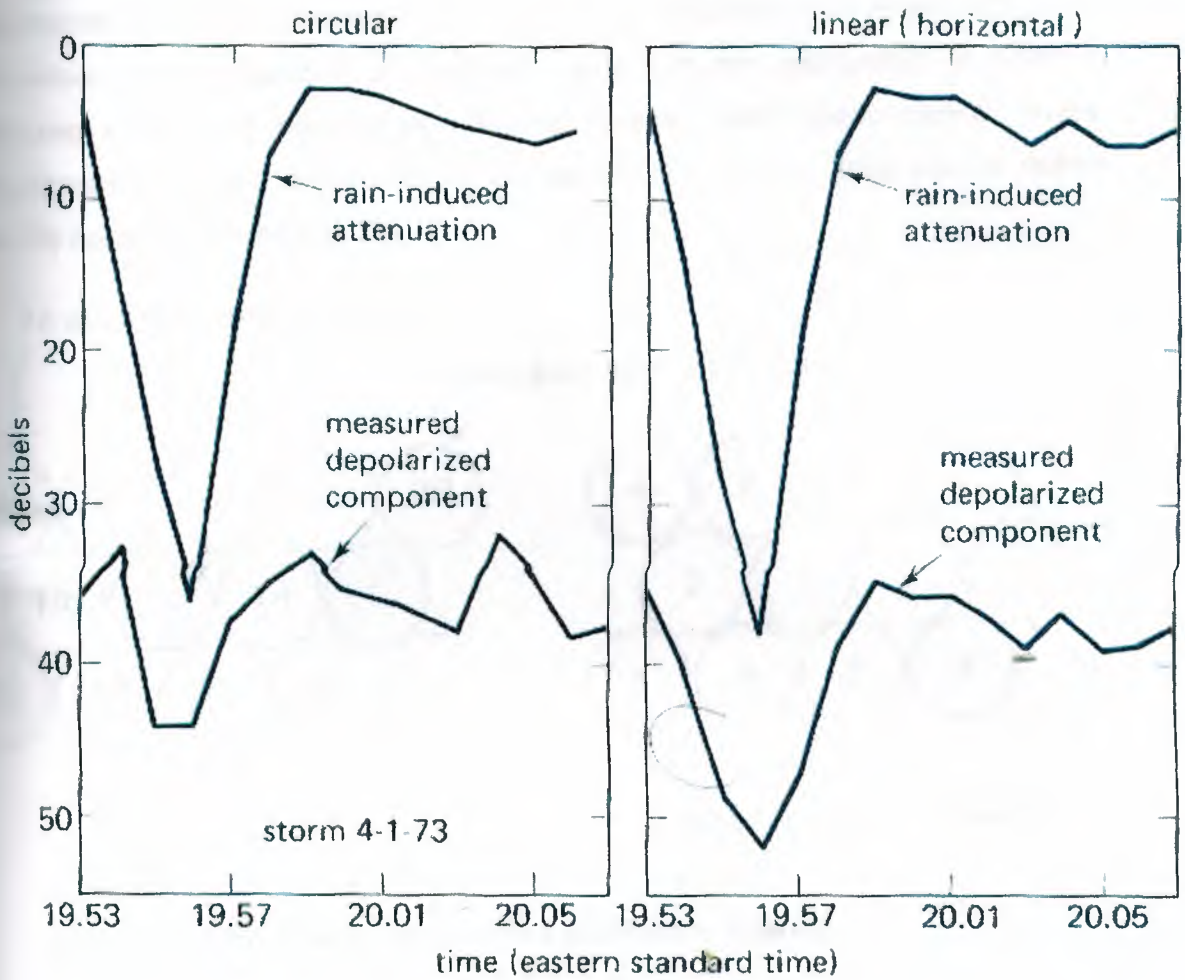


FIGURE 2.6

The frequency reuse concept employing orthogonal polarizations can be generalized to provide many simultaneous uses of the same downlink frequency band by using a multibeam antenna , if the frequency band is subdivided into two frequency sub bands 1 and 2, right-R and left-L hand circular polarizations are used for alternate beam, then contiguous beam coverage of earth's surface is provided with these four types of beams. Each type of beam is separated by one complete bandwidth from the same beam type appearing elsewhere.

As described in the previous paragraph on frequency reuse, the isolation between individual narrow beams can provide additional frequency efficiency by using smaller guard bands between transponder channels. This ability to improve bandwidth utilization becomes more important as satellite power levels increase. However, some examples of multibeam antennas are appropriate in order to discuss some their parameters affecting communication performance. These multibeam antennas require only a single reflector or lens, thus can be rather easily deployed on the satellite.

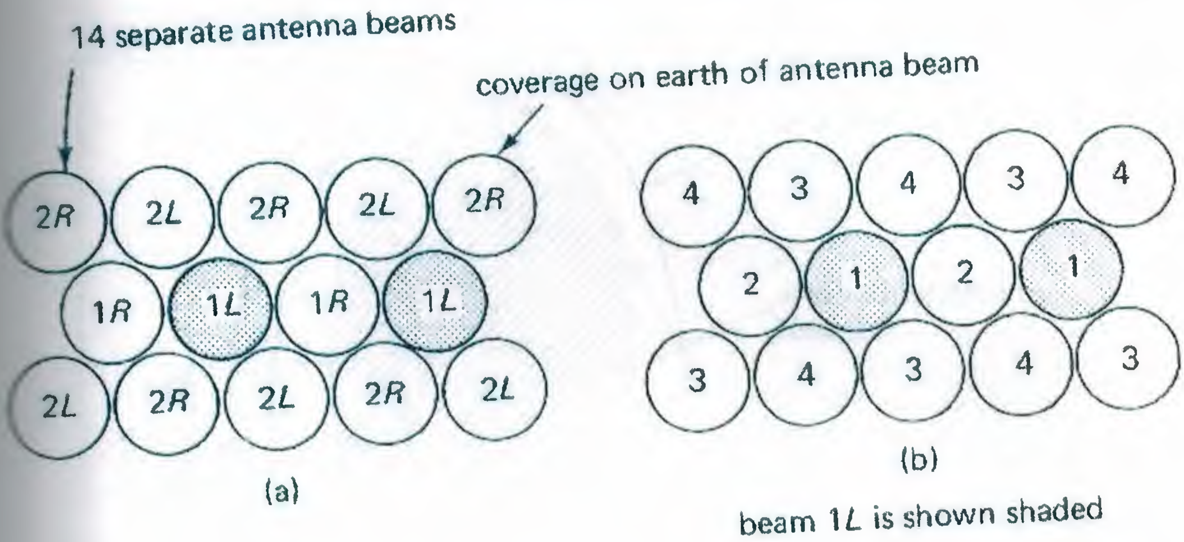


FIGURE 2.7 Frequency reuse with a multibeam antenna.

Figure 2.8 depicts one of the simplest forms of multibeam antennas visualize. The antenna shown is a multibeam spherical reflector with multiple feeds to illuminate somewhat different sections of the reflector. It is desirable to be able to scan +/- 8.60 relative to the center horn pointed at the sub satellite point, that is, to be able to scan over any section of the earth in view. From the geometry of the global scanning, the spherical reflector must have diameter L relative to the effective diameter of the reflector.

$$L \simeq 1.4D \tag{2.2}$$

For a focal length-to-diameter ratio F/D = 0.7 the physical surface area~ the reflector is

$$A = 0.837L^2 \cong 1.64D^2 \qquad 2.3$$

The antenna gain is

$$G = \frac{\eta_a \pi^2 D^2}{\lambda^2} = 10\eta_a f^2 D^2 \qquad 2.4$$

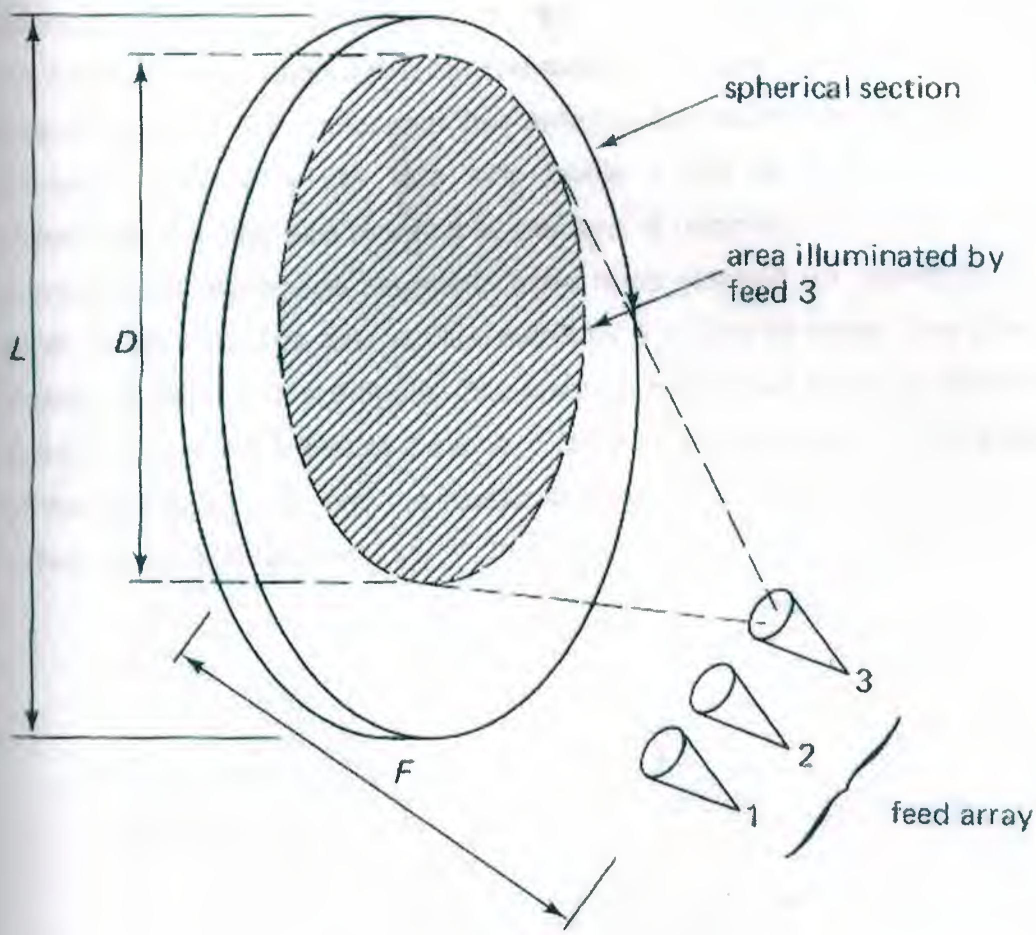
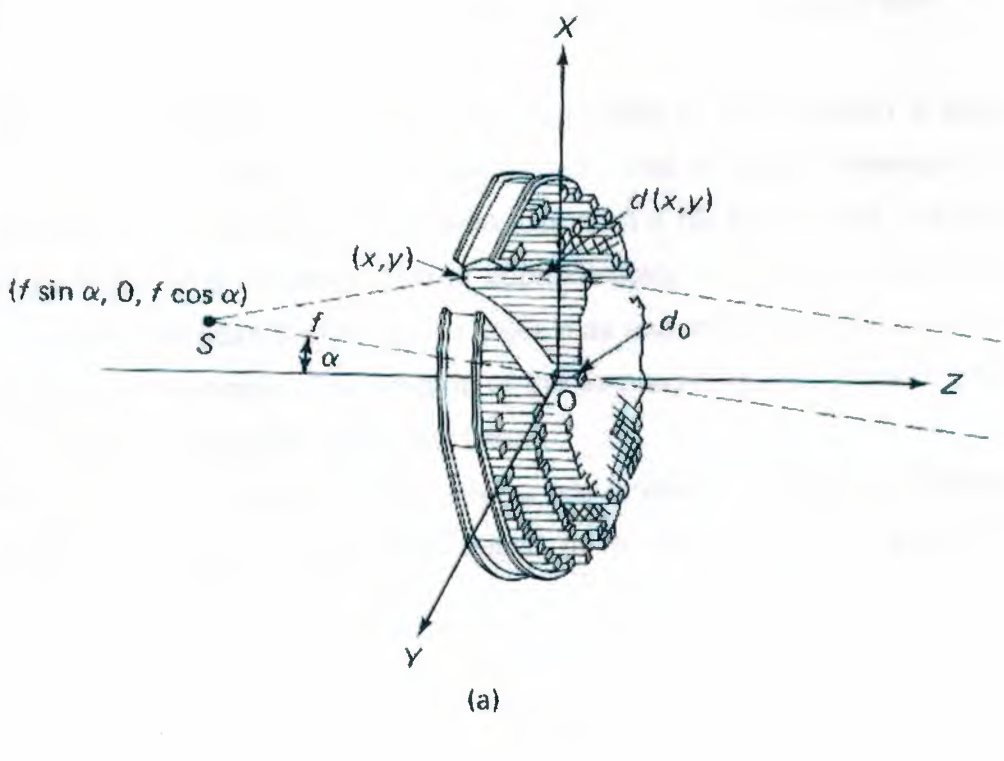


FIGURE 2.8 Multibeam spherical reflector antenna.

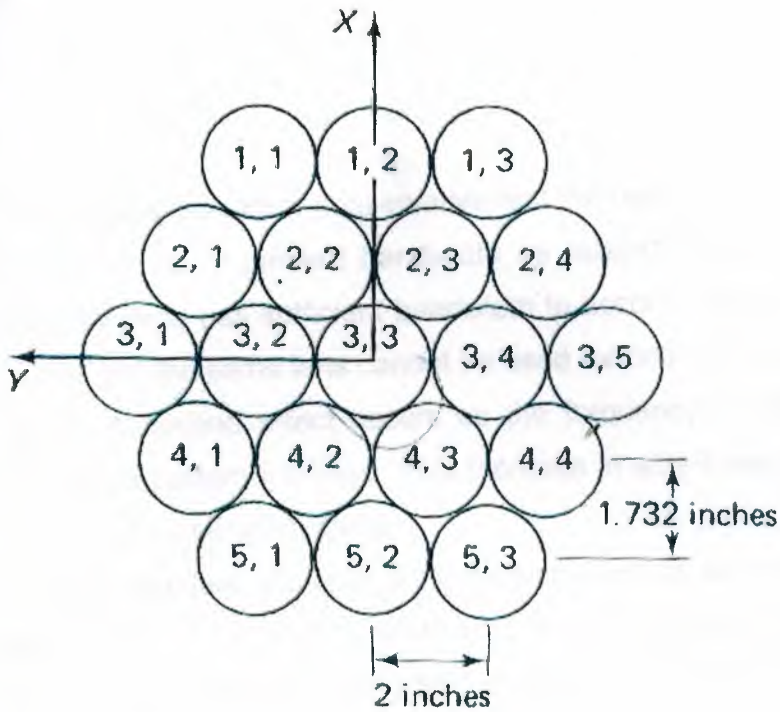
where n_a is the antenna efficiency, λ is the wavelength in the same units as D and f is in GHz if *D* is in feet. The antenna 3-dB beam width in degrees is

$$\theta_{3\,dB} = \frac{69^\circ}{fD}$$

spherical reflectors have the advantage of being insensitive to beam steering because the illuminated region is always a section of a sphere. However, the side lobe level is typically rather high next to the main beam, and the antenna aperture efficiency Na is rather low on the order of 25 percent. At frequencies in the millimeter waveband; there may be sufficient excess gain to permit use of this type of antenna The multibeam lens antenna has been described as means for achieving reasonably low side lobe levels < -20 dB. A photograph of an experimental model lens antenna is. the lens is basically a double concave lens composed of waveguide segments have been stepped (or zoned) to limit the width of the Len. The lens is illuminated by a cluster of feeds, one of which is located at point S in the figure. The antenna beam then points in direction, the line the feed to the center of the lens.: For earth coverage at X-band the diameter of the lens is 20 inch. and the cluster of feed horns is as shown in Fig. 2.9 (b). When all nineteen of these



(a)



(b)

FIGURE 2.9a lens geometry and (b) feed cluster for the multibeam lens.

feed horns are excited by RF power, the composite of the nineteen 3 beams produces a circular beam of 17.3 beam width, that is, earth coverage. The antenna gain is approximately 20 dB with less than 2 dB peak ripple. Excitation of a single feedhorn produces a gain of approximately 30 dB with a beam width of 3^0. A feedhorn at point S offset by an angle o as shown in Fig. 2.10 produces a beam aligned at an angle . The lengths of the lens wave-guides properly phase all the contributing components for that beam.

The waveguide elements of the lenses are limited in bandwidth, however. The effects of waveguide dispersion based on a maximum phase error of /4 radian is B/f0 = 25/(2 + k) percent, where k is one more than the number of steps in the lens. For this lens k = 3, and the bandwidth is then related to the center frequency by

$$\frac{B}{f_0} = \left(\frac{25}{2 + k}\right) 5 \text{ percent}$$

However, this bandwidth is rather conservative and the use of a 0.5-dB decrease in efficiency leads to a 10 percent bandwidth as related to center frequency. Thus, at X-band the lens has sufficient bandwidth to accommodate the 500-MHz downlink channel, but the same lens cannot be used for both uplink and downlink frequency bands. A second effect occurs as the frequency is offset: the side lobes of the antenna pattern increase. This increase in side-lobes must also be considered in the communication design.

Variable power dividers are connected to each feed to adjust the effective radiated power (ERP) P in each of the M spot beams to give the desired MBA antenna patterns. The gain and hence ERP is subject to the constraint

$$\sum P_i = P_{max}$$

if all beams are weighted equally then each gain corresponds to that of an earth converge antenna minus any power divider loss.(Power divider loss is approximately 0.3dB per divider)

In general the number of beams in a nested set of circles in a 6-sided cluster is

$$M = \sum_{i=1}^{n} 6(i - 1) + 1,$$

where there are n layers in the nest. thus M takes on values 1, 7, 19, 37, 61,..........

2.5 PROCESSING TRANSPONDERS

Onboard satellite processing can take a number of forms. Among these processing functions are: (1) active switching to distribute various up1ink signals to the appropriate downlink amplifier and antenna; and (2) detection, of the digital signals on the uplink and their regeneration for the downlink See Fig. 2.12. The use of switching includes a "switchboard in the sky" concept, wherein different transponder input channels are switched by ground command to the appropriate downlink channel. An alternative

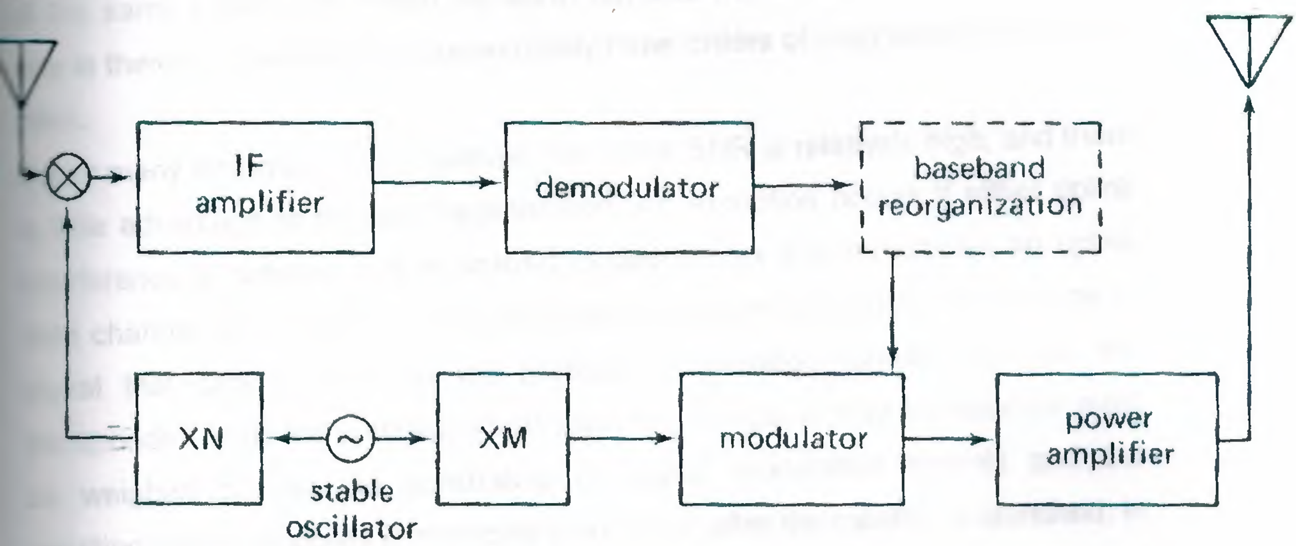


Fig. 2.10 Simplified block diagram of a demodulating-remodulating processing transponder

concept employs a preprogrammed switching sequence to provide satellite-switched time-division-multiple-access (SS-TDMA). The use of active time-division switching in a satellite transponder offers improved bandwidth and power efficiency compared with, for example, an FDMA technique.

Onboard demodulation of the uplink signals can improve the link performance. For example where up- and downlink SNRs are equal, this regeneration provides almost 2.6-dB improvement in performance relative to a linear transponder; while the error rate at the output of the ground terminal remains the same. *Hence, if the SNR is the same* at the regenerative satellite as at the receiving earth terminal, the error rates at the satellite and earth terminals are identical. Since these errors are independent, the total error rate at the earth terminal output includes those errors generated by the satellite as well as those generated by earth terminal demodulation. Since these error rates are equal, the total error rate is double that of the satellite itself. This tandem error effect corresponds to <O.5-dB loss in signal power. On the other hand, a 3-dB performance degradation occurs in a conventional linear transponder operating at the same power level when the earth terminal noise is added, and the error rate is thereby increased by approximately three orders of magnitude at low error rates.

Under many circumstances, however, the uplink SNR is relatively high, and there is little advantage to onboard regeneration. An exception occurs if either uplink interference is present or it is desired to demultiplex and remultiplex an uplink data channel in the satellite. The processing transponder constrains the type of signal that can be used to the particular modulation format built into the transponder. Thus the potential advantages of the regenerative transponder must be weighed against the constraints on signal modulation formats and the resulting lack of flexibility in changing modulation after the satellite is launched. In spite of these limitations, the potential for onboard processing, switching, and multiplexing of signals remains high.

3. EARTH STATION

3.1 Introduction

For each an every satellite in the space needs a earth station. The concept of earth station any transmitting or receiving system that sends signal to or receive signal from a satellite. The earth station may have located on a chip at sea or on an air craft. The most visible part of an earth station is usually the antenna, which may be as large as 30-m diameter in the Intelast network , or as small as 0.7m for reception of direct broadcast satellite television (DBS-TV). The one feature that all earth station have in common is need to achieve a low system noise temperature in the receiving channel .In fig3.1Earth station is basically divided into tow parts:

1-A RF terminal, which consists of an up converter and a down converter. a high power amplifier, a low noise amplifiers and an antenna.2-A base band terminal, which consists of base band equipment, an encoder and decoder and a modulator and demodulator.

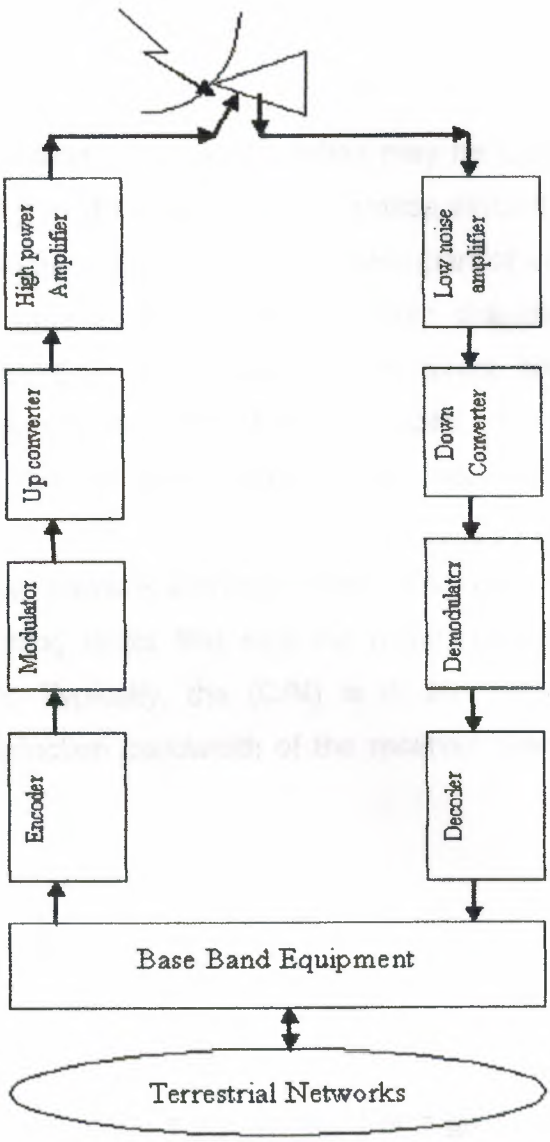


Fig 3.1 Functional block diagrame of a digital earth station

3.2EARTH STATION DESIGN

Earth Station Design for Low System Noise Temperature

An *earth* station is any transmitting or receiving system that sends signals to or receives signals from a satellite. The earth station may be located on a ship at sea or on an aircraft, but it is still called an earth station since it forms the earth-based end of the earth—space link. The most visible part of an earth station is usually the antenna, which may be as large as 30m diameter in the Lintels network, or as small as 0.7 m for reception of direct broadcast satellite television(DBS-TV). The one feature that all earth stations have in common is the need to achieve a low system noise temperature in the receiving channel.

.We showed that the downlink carrier-to-noise ratio in the receiving channel is nearly always the limiting factor that sets the communications capacity and performance of the link. Typically, the (C/N) is in the range of 5 to 25dB, measured in the IF predilection bandwidth of the receiver. Recalling Eq. (4.20), (C/N) is. found from

$$(C/N) = \frac{P_t G_t}{kB}\left[\frac{\lambda}{4\pi R}\right]^2 \frac{G_r}{T_s} \tag{3.1}$$

where G_r/T_s is the ***G/T** ratio* of the earth station. For a given satellite and signal transmission, the only parameters of the earth station that affect the (C/N) are G_r, ***the*** antenna gain when receiving the wanted transmission, and T_s, the system noise temperature at the frequency of the transmission. (G_r and T_s are not necessarily constant with frequency.) Since (C/N) is directly proportional to ***G/T,*** this is a useful parameter with which to characterize earth stations.

Earth station *G/T* ratios are usually expressed in dBK, obtained verting system noise temperature into dBK (dBKelvins, or dB greater perature of 1 K). Thus

$$G/T = G_r \text{ in dB} - 10\log_{10}(T_s \text{ in Kelvins})\ \text{dBK}^{-1}$$

GMay have a value from as low as —10 dBK up to 46 dBK.Most satellite communication systems are designed around a specified earth station there may be a minimum earth station *G/T* that can be used in the s example, Intelsat Standard A earth stations are required by Intelsat to of 40.7 dH or greater at 4000 MHz and **5** elevation angle [1]. An e owner must prove to Intclsat that this G/T is achieved before the is permitted to join the network.

The specified G/T can be obtained from an infinite number of corn of G and 1'. In practice, however, the range of values of T_s the sys temperature, is somewhat limited. Where it is desirable to reduce T_s, so that G/Becomes large, this cannot he done in practice. External it such as the atmosphere, the receiving system waveguides, and the lawn ficr of the receiver all contribute to $T_s$and set a lower limit to its value. T_s is rarely below 70 K, and may be as high as 2000 K. The gain of the antenna can be increased by using a larger aperture area, with an upper of about 65 dB. This limits *G/T* to about 46 dl with the largest practice and the lowest practical noise temperature.

The optimum *G/T* for a given application is invariably a compromise between the cost of a large antenna, to increase G, and the cost of lower system noise to decrease *T*. Once the antenna becomes large, increasing G becomes extremely expensive, making it worthwhile to minimize *T*. Thus, large antenna earth station may use cryogenically cooled low noise amplifiers in an attempt to obtain the lowest possible system noise temperature. With a small earth station antennas, it is usually more cost effective to increase the antenna aperture area than the lower system noise temperature.

The high cost of large-aperture antennas (several million dollars for a 25-m diameter steer able dish) led to a great deal of research into design techniques aimed at improving the efficiency of large antennas during the period from 1960 to 1980.Some notable advances in antenna technology stemmed from the requirements of large earth stations—the shaped CASs grain antenna, beam waveguide feed, corrugated horn, and low cross-polarization design methods can all be attribute to this research effort. Similar advances have occurred in low-noise amplifiers.1962 when the first TELSTAR experiment was tried, the low-noise amplifiers used at the earth stations were masers immersed in liquid helium. The need for more practical LAN's led to the development of GaAsFET amplifiers at 4 and 11GHZ with noise temperatures down to 70 K without cooling

In this chapter we discuss the design of large and small earth station, and how the antenna gain can be traded for system noise temperature to obtain specified *G/T*. There are significant differences in approach depending on the number of voice or data channels an earth station is to carry, and the flux density the satellite achieves at the earth's surface. The system noise temperature is made up of contribution from many sources; minimizing Ts requires considerable care in the design of the earth station antenna, as well as the selection of a suitable LNA or receiver.

Large antennas invariably produce narrow beams with the result that satellites that move their position by more than a fraction of a degree must be tracked. Most large antennas are equipped with automatic tracking (called *auto track) facilities* so that the motion of the satellite can be followed. Smaller antennas with broader beams may require only a reposition capability.

The antenna of an earth station is its most visible part, but receivers are needed at all earth stations and many also need transmitters. Earth stations that multiplex many telephone or data signals together and provide links to many countries simultaneously require extensive base band and IF equipment to implement the required multiplexing and may also have a great many transmitters receivers.

3.3Large Earth Station Antennas

Large antennas are used at earth stations that require a high *G/T* ratio, and capable of carrying large numbers of telephone, television, or data channels simulltaneously. A high volume of traffic is needed to recover the cost of a large earth station antenna, which implies operation with wideband carriers.

As an example, consider the case of an earth station designed to operate within a zone coverage region of an INTELSAT V satellite. The satellite is designed for operation with Standard A earth stations having a minimum *G/T* of 40.7 dBK using FDM/FM/FDMA. The satellite cannot he used with earth stations having G/T much below 40 dBK as illustrated by the following calculations. Supposewe send just one FM carrier from a 4-GHz transponder of an INTELSAT V satellite so that it occupies the full 72 MHz of a wideband transponder and has an EIRP of 26 dBW in the direction of the receiving earth station. The received (C/N) is given by Eq. (3.1) (ignoring any interference or uplink noise contribution)

$$(C/N) = (26 + 228.6 - 78.6) - 196 + G/T \text{ dB} \tag{3.2}$$
$$= G/T - 20 dB$$

INIELSAT V links operate with a 7-dB margin over a minimum (C/N) of 11dB,so for an 18dB (C/N) we must have a *G/T* of 38 dB. This is the minimum G/T that can be used for any earth station to communicate via an INTELSAT V zone beam transponder, when the transponder is fully loaded. Even if we use several narrower bandwidth FM carriers, the transponder transmitter power must be shared among the carriers in proportion to their bandwidth, and the incident flux density at the earth's surface remains the same. Thus only Standard A earth ns can join the Intelsat global network using the standard FM/FDMA carriers even when the earth station wants to send only one or two voice signals.This makes small-capacity systems very costly and has led to the establishment of different standards for such applications.

Intelsat has made provision for smaller earth stations *(Standard B)* in its network by using some transponders on its satellites in a TDMA mode (I)These transponders can be operated in or close to saturation, increasing the transmitted and allowing a reduction in antenna diameter. Typical Standard B earth station have 19-m diameter antennas, but achieve the same low noise temperatures as standard A antennas. compares the specification of Intelsat Standard and C earth stations. Standard C earth stations use smaller antennas and in the 14/11 GHz band using the spot beams of INTELSAT V and VI spacecraft.

3.4:Basic antenna theory

Earth station antennas are required to supply gains in excess of 25 dB in nearly. This requires the use of an *aperture antenna* that has a significant gain and Examples of aperture antennas are waveguide horns and reflector antennas. In this section we review the basic theory of aperture antennas before proceeding to discuss the special requirements imposed b the earth station application. We concentrate on reflector antennas because that is the most widely used configiguration earth station. the theory is equally applicable to antennas used on spacecraft although there are different requirements related to need for area coverage in that case that lead to difference in antenna design. Many spacecraft antennas have array feeds to create shaped beam patterens,and some UK phased arrays. We concentrate on the earth station antenna that is optimized for G/T ratio and is pointed at a single source of radiation, the satellite.

It is common practice to analyze apertures antennas in the transmitting mode, and then use reciprocity to equate the receiving characteristics to those calculated for the antenna when transmitting. We will follow this approach in reviewing the basic theory of apertures antennas and in calculating the gain and radiation patteren.When considering tracking antennas, it is useful to examine their operation receiving mode, since tracking is usually accomplished on reception rather than transmission. An apertures antenna achieves gain and a narrow beam by creating an electro-magnetic field over the aperture that has uniform phase plane wavefront.It is necessary to control the amplitude distribution of the aperture field,both to maximize gain and to minimize losses the aperture field distribution determines the radiation pattern in the far field and also affect the gain, so we first examine the relationship between the aperture field and the far field radiation pattern for several cases.

3.5 DESIGN OF LARGE ANTENNAS

Large antennas are expensive to construct and install, with costs exceeding \$1 M for 30-m diameter fully steer able antennas. This makes it worthwhile to highest possible aperture efficiency and the lowest possible noise temperature so that G/T is maximized. The cost of large fully steer able antennas has been quoted as (5)

$$\text{cost} = \gamma(D)^{2.7} \tag{3.3}$$

The constant y in Eq. (3.3) depends on the currency used and inflation, but might typically he around five U.S. dollars in the early 1980s. This gives a figure of S1.25M for a 100-ft diameter steer able antenna using Eq. (3.3) and a figure of \$2,26M using Eq. (3.4), which lie within the range of expected values for100-ft earth station antennas. The power 2.7 reflects the fact that an antenna grows in three dimensions as the dish diameter increases. The need for a stronger support structure as the reflector size is increased forces up the cost more nearly as D than D

Taking our 100-ft diameter reflector as a baseline, consider the cost of increasing the antenna gain by I dB, or a factor of 1.258. Since G $\alpha\, 4\pi$ A/. λ ,we need to increase the reflector diameter by 1.258 to 11 cost of a 112-ft antenna is $1.7M with y = 5, an increase of $450,000 to obtain just 1 dB extra gain. Antennas of this size must therefore achieve very high efficiency and low system noise temperature to keep the diameter of the reflector as low as possible for a given *G/T*.

The earliest earth station antennas used with the TELSTAR satellite experiment had apertures of about 25-rn diameters. Bell Labs built a large *horn-reflector antenna* allocated at Andover, Maine, which was a scaled-up version of the 6/4 GHz ins used in microwave line of sight links [7]. The horn-reflector or *hog horn* very low far-out side lobes and provides better rejection of interference than reflector antennas by virtue of the screening around the aperture. Andover was chosen as the location to minimize interference from microwave links operating in the 4-GHZ band, because of concerns about potential interference levels. Experience showed that provided the earth station site was chosen with care, interference was not a severe problem and the very high cost of the hog horn was not justified. The French PT&T authority built a hog horn similar to the Bell Labs design at Plateau -Bodeau in northwest France for the TELSTAR experiment.

The British Post Office constructed a 26-rn diameter *front-fed* paraboloidal antenna at Goon hilly Downs, in the southwest corner of England, using a design developed from the large aperture antennas used for radio astronomy [8]. This is the only front-fed antenna that has ever been used for a Standard A earth station, has the notable distinction of still being in service in 1984, 23 years after it was built for one experiment with TELSTAR. Standard A Cass grain antennas replaced the hog horns at Maine and Plateau.

The front-fed parabolic is widely used as a configuration for smaller earth station, but has an excessively long wave guide run from the rear of the reflector out the feed at the focus of the dish in a large antenna. The loss in this wave guide a major contribution to the system noise temperature, reducing the ratio. The preferred design for all large earth station antennas built since the nal TELSTAR experiment has been the *Cass grain* configuration, which iires much shorter waveguide runs than the corresponding front-fed figuration. The Gregorian configuration is also used by some manufacturers. geometry of front-fed ,Cass grain and Gregorian configurations is illustrated Figure3.1.. The names Cass grain and Gregorian are derived from the enteenth-century astronomers William Cass grain and James Gregory, who signed optical reflecting telescopes using these geometries. Isaac Newton also structed reflecting telescopes using a flat plate for the secondary reflector, this configuration has not widely adopted for microwave antennas.

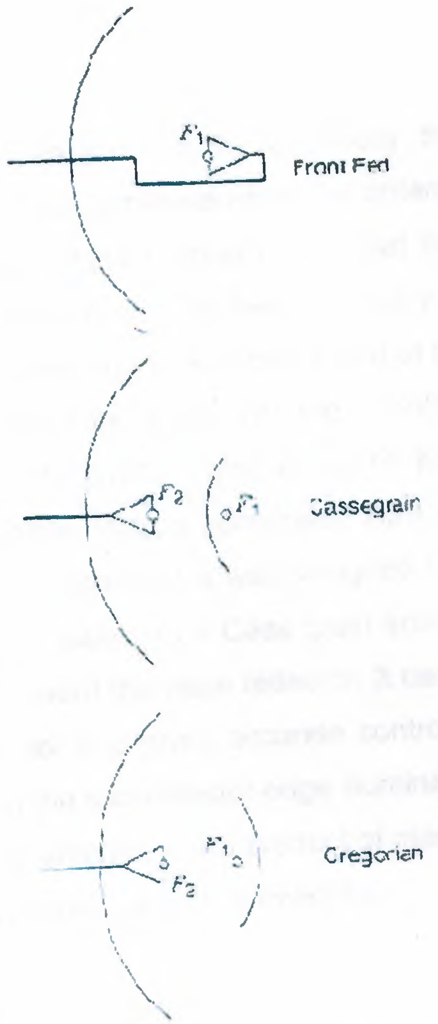
The Cass grain antenna is popular for large earth stations for several asons:

The gain can be increased by approximately 1 dB, relative to a front-fed flector, by *shaping* of the dual reflector system.

Low antenna noise temperatures can be achieved by controlling *spillover* d using short waveguide runs or *beam wave guide* feeds.

Beam waveguide feeds place the low noise amplifier of the receiver, and other complex feed components, in a convenient, stationary position.

he design procedure for a Cass grain antenna is discussed in the next section.



F_1=pimar focus
F_2=secondary focus

Figure 3.2 front fed, Cass grain, and Gregorian configuration of reflector antennas.

3.5.1: Large Cass grain Antennas

The basic geometry of the Cass grain antenna is shown in Figure 3.3.The main reflector is a parabolic, which reflects incoming radiation toward the prime focus. The hyperboloid secondary reflector, often called a *sub reflector* or has one focus coincident with the parabolic reflector's focus, and a feed system is placed at the second focus, such that the phase center of the feed coincides the hyperboloid's second focus. The parabolic converts an incoming plane to a spherical wave converging toward the prime focus, which is then reflected the sub reflector to form a spherical wave converging on the feed, as illustrated Figure3.3

The design of a Cass grain antenna is conventionally carried out by assuming that the feed is transmitting. By reciprocity, the same antenna pattern and aperture efficiency will be achieved when the antenna is receiving. Thus we need feed system with a radiation pattern such that the subrefiector intercepts most of the energy transmitted by the feed. Typically, the subreflector edge is illuminated with a power level 10 to 15dB below that at the center. This keeps the spillover from the feed, past the edge of the Sub reflector, to a low level. Spillover reduces the of the antenna and increases its noise temperature, so it must be kept as possible. With a *corrugated horn* as the feed, spillover can be reduced the around 3 percent in a well-designed Cass grain antenna Figure 3.2 illustrates spillover losses in a Cass grain antenna. Spillover also occurs when the sub reflector toward the main reflector. It can be kept to a minimum by using a large sub reflector that gives accurate control of the sub dish radiation pattern, and by keeping the sub reflector edge illumination low.

The gain of the antenna is the product of many factors that contribute to its efficiency. In general. the gain is given by

$$G = \eta \cdot \frac{4\pi A}{\lambda^2} \qquad (3.5)$$

where A is the aperture area of the antenna and n is the aperture efficiency. Aperture efficiency can be computed from efficiencies of various parts of the antenna. Major contributors to this factor are the *illumination efficiency* of the main aperture. N the spillover *efficiency* (1 — spillover loss) for the subreflector and the main reflector n_{ss} and n_{ms} *blockage efficiency,* $n_b$which accounts for radiation lost by from the subrefleetor and its support legs after reflection by the main dish

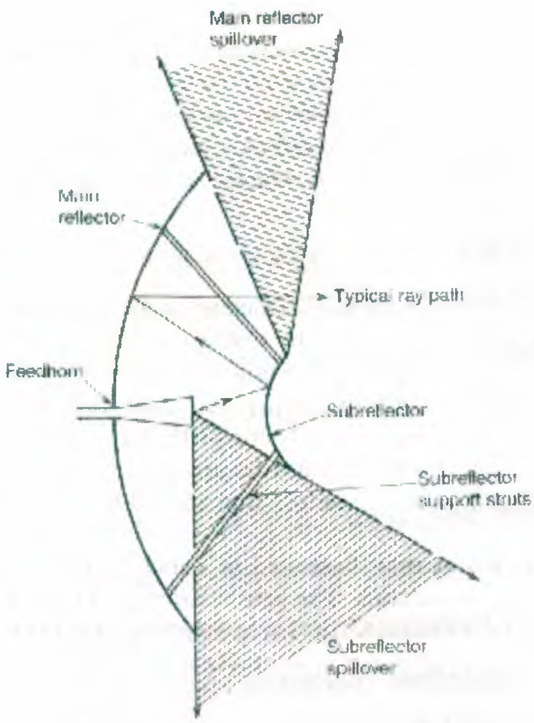


Fig 3.3 Geometry of the Cass grain antenna.

Other losses contribute to aperture efficiency to a lesser degree. The most important ones are *comic losses* in the feed and waveguide components and surface *errors* on the main reflector.

Many other losses such as polarization loss, reflections at the feed, errors across the feed, gaps between reflector panels, and so on can be introduced to refine the calculation of aperture efficiency. For the efficiency factors above we have

$$\eta = \eta_I \times \eta_{ss} \times \eta_{ms} \times \eta_h \times \ldots \tag{3.6}$$

Typical values for each of these efficiencies arc given in Table 3.1 for the 27.4-m Cass grain antenna operated by Cable and Wireless at Bahrain [1O].The overall efficiency is 70.8 percent, including 8.81 percent losses due to phase errors in the aperture resulting from horn phase error, reflector surface error, and misalignments of the feed and sub reflector [10]. Any radiation in the polarization orthogonal to that desired will not be accepted by the distant receiving antenna and represents a polarization loss that should be included in the efficiency calculation.

culation.

A calculation such as that illustrated in Table 3.1 is an essential part design process of a large antenna. The gain is calculated from Eq. (3.6) using aperture efficiency factor derived in Table 3.1.For this example, the gain 27.4-in diameter circular aperture at 4.0 GHz with an aperture efficiency of percent is 59.7 dB

The efficiency factors used in this calculation cannot be found by the application of simple geometric optics to the antenna. Diffraction losses around the sub reflector, phase-error losses, and polarization losses can be calculated only with a wave analysis using numerical techniques. A suite of computer programs is required derive the factors in Table3.1, each factor being found by the procedure described below.

The first step in the process of computing antenna gain and efficiency factors is two establish two-dimensional pattern of the feed system. This pattern may be measured on an antenna range or generated from an algorithm that models the feed radiation. The pattern should be known in amplitude, phase, and polarization, in polar coordinates with origin at the nominal phase center of the feed. The feed pattern is used to calculate the current induced on the surface of the sub reflector using the geometric optic approximation

$$K \quad 2 \quad H \tag{3.7}$$

Where K is the vector surface current density, n is a unit normal to the reflector surface, and H is the incident magnetic field. The current must be calculated at large number of points on the sub reflector surface in order to obtain an accurate predication of the radiation pattern of the sub reflector. If the sub reflector and feed are close together, the feed pattern will have to be corrected for near-field effects.

The radiation pattern from the sub reflector is then calculated at a large number of point on the main reflector, so that Eq. (3.7) can be used to establish the surface current distribution on the main reflector. Finally, the radiation pattern of main reflector can be calculated. The spillover efficiency factors in Table 3.1 obtained by comparison of the total power radiated b the feed with the power incident on the sub reflector surface and the main reflector surface, in the wanted polarization. Blockage loss is calculated by assuming an approximate blocking pattern and computing the energy lost from the main aperture by scatter from blocked areas [9]. Surface error losses can he computed by introducing random errors across the reflector surface, with a given rms value, and calculating the reduction in the on-axis field strength.

Efficiency Calculation for a Large Cassegrain Antenna

Efficiency Factor	Symbol	Loss (%)	Loss (dB)	Efficiency (%)
Illumination efficiency	η_i	1.34	0.059	98.66
Subreflector spillover	η_{ss}	11.73	0.542	88.27
Main reflector spillover	η_{ms}	4.00	0.177	96.00
Blockage losses	η_b	7.40	0.334	92.60
Phase errors and surface errors	η_{pe}	7.56	0.340	92.44
Polarization loss	η_{xp}	1.15	0.050	98.85
Aperture efficiency, %	η			70.74
Total of losses, dB			1.502	

Source: Reproduced from N. Lockett, "The Electrical Performance of the Marconi 900 Space Communication Aerials," Marconi Review, 34, 50–80 (1971), by permission of the editor, GEC Journal of Technology.

As an example of what can be achieved by these techniques, Figure 3.3.shows a typical calculated pattern for the sub reflector of a Cass grain antenna and the corresponding antenna pattern assuming no surface errors. The pattern calculated when surface errors on the main reflector included in this case, the main reflector surface and these data were were used in the calculation. measured azimuth plane tern of this antenna, which shows close agreement to the calculated pattern to the seventh side lobe peak. Note that inclusion of reflector surface errors in oscillation of the far-field pattern fills in the nulls of the theoretical pattern It ~s the side lobe peaks away from the main beam. Null-filling is heuristic to phase errors in the antenna aperture. A null results from ant phasing margay from different parts of the aperture to achieve total cancellation. Canation will occur only with a constant-phase aperture distribution. If phase errors, or curvature of the phase front are present in the aperture field, complete cancellation of field contributions at a far field point cannot occur. This is easily understood by separating the aperture field into in-phase and quadrate quos nets. When the in-phase components cancel, there will be residual qua* components preventing the field from, falling to zero.

In the procedure described here, the surface currents in the sub reflector main reflector were calculated using the incident magnetic field. An alter analysis procedure that leads to equivalent results uses the electric field ret from a conducting surface according to the equation

$$\mathbf{n} \times (\mathbf{E}_i + \mathbf{E}_r) = 0 \qquad (3.8)$$

where Er is the reflected electric field just above the surface and E_1 is the incident electric field, with n a unit vector normal to the surface at the point of reflection

Both techniques assume that the surface is fiat in the ion flections point, and both lead to errors at the edges of the reflector wnp current flow is assumed to terminate abruptly, whereas in practice it c to improve the accuracy of pattern calculations by including e in a large antenna,

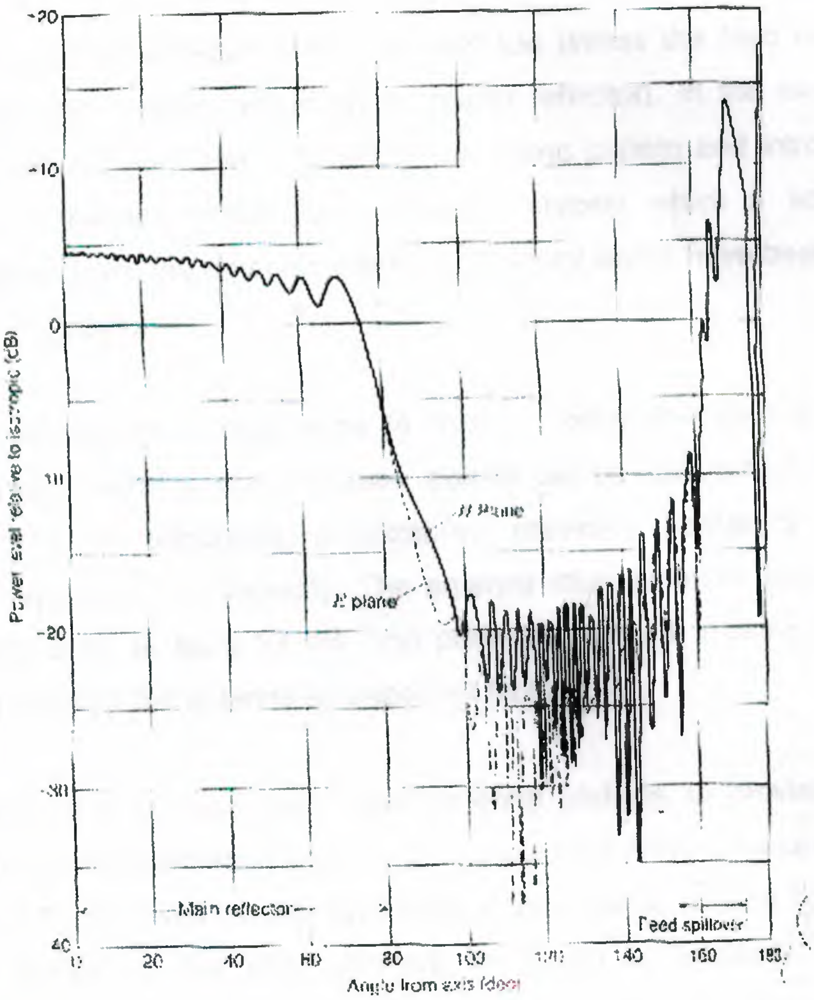


Fig 3.4 far field pattern of sub reflector

3.5.2: Optimizing the Gain of Large Antennas

The importance of achieving maximum efficiency in a large antenna has already been discussed. To achieve maximum efficiency, we must reduce far as possible and increase efficiencies whenever possible. Two powerful techniques have been used in Cass grain antennas, both of which resulted from research aimed at improving the efficiency of large antennas used in satellite communication earth stations. The first technique is the use of feed systems with symmetrical radiation patterns; the second technique is shaping of the dual reflector of a Cass grain antenna to improve the illumination efficiency.

Feed-pattern symmetry is important in reflector antennas for two reasons.

The spillover past the reflector cannot be kept low unless the feed radiates a circularly symmetric pattern (assuming a circular reflector). In the example in Table3.1the feed did not have a circularly symmetric pattern and introduced a over loss of 11.7 percent. If this loss had been 3 percent, which is achievable with a corrugated horn, the antenna aperture efficiency would have been 79 and the gain 0.48 dB greater.

Feed-pattern symmetry also helps to control cross-polarization in antenna [12]. In most large earth station antennas, signals can be transmitted and at the same frequency on orthogonal polarizations providing frequency reuse to increase the system traffic capacity. The antenna must maintain separation of two polarizations by at least 27 dB. and preferably *35* dB, making control of cross-polar pattern of the antenna an important factor.

Two types of feed have been used in earth stations to provide circular. Symmetry of the feed-radiation pattern. The *multimode horn,* as exemplified by Potter horn LI 3], achieves circular symmetry of the radiated pattern by summing waveguide modes in the horn aperture to obtain a circularly symmetric distribution in the horn aperture. The Potter horn adds TE_{11} and TE_{31} in ci waveguide. The TE_1 and TE_{11} modes do-not propagate at the same velocity the horn and will arrive at the aperture in the correct relative phase only o narrow band of frequencies. This makes the design of a Potter horn for *500*-bandwidths at 6 and 4 G1-Iz simultaneously very difficult.

The corrugated horn uses hybrid modes to obtain a circularly symmetric field distribution in the horn aperture. The hybrid mode is effectively a combination of TE_1 and TM_{11} modes in circular waveguide excited and maintained in horn by slots cut into the internal wall of the horn. The slots are typically about $\lambda/4$ deep and $\lambda/3$ apart. They cause the wall of the horn to present a reactive impedance surface field and prevent termination of the E field vector on The corrugated horn can provide excellent circular symmetry, good cross polarization performance, and wide bandwidth. It is widely used for Caesarian antenna feeds [14].

Shaping the reflectors of a Cass grain or Gregorian antenna can increase the gain by 1dB by improving the illumination efficiency [9, *15]*. In a front-fed reflector antenna, or a conventional Cass grain, there are conflicting requirements feed pattern. We want near-uniform illumination of the main reflector to aperture efficiency, hut low edge illumination to achieve low spillover. hom aperture is only a few wavelengths in diameter, such precise con-radiation pattern is not possible. However, if we change the shape of the sub reflector in a dual-reflector antenna, we can redistribute the energy radiated

By the feed so that more energy is directed toward the outer edge of the main are Figure 3.4 illustrates the way in which this is done. A feed system that has a high taper at the sub dish edge is used to give low spillover loss, edge illumination of 15 to -20dB being typical. Reshaping the sub reflector produces on in the main reflector aperture that is uniform in the center and

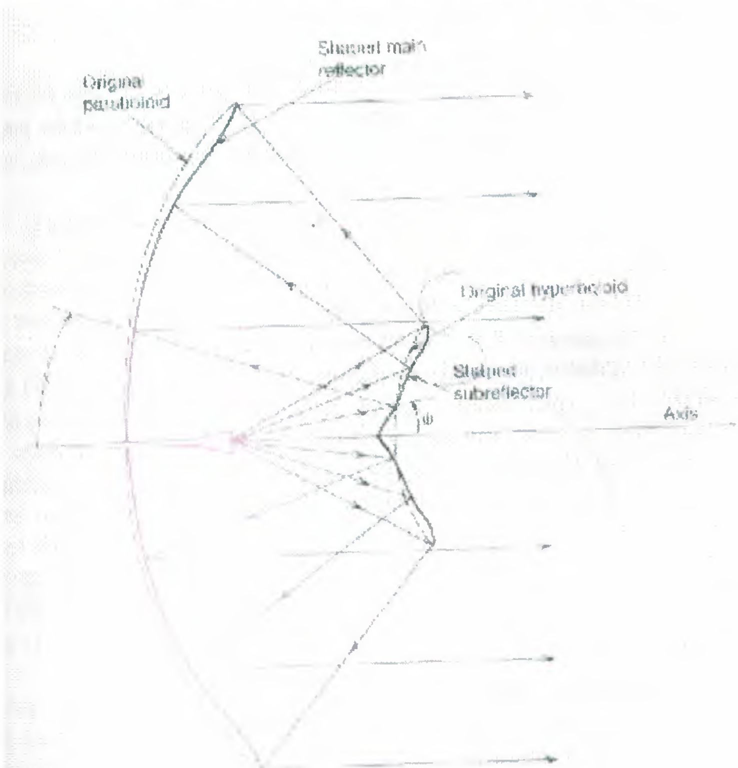
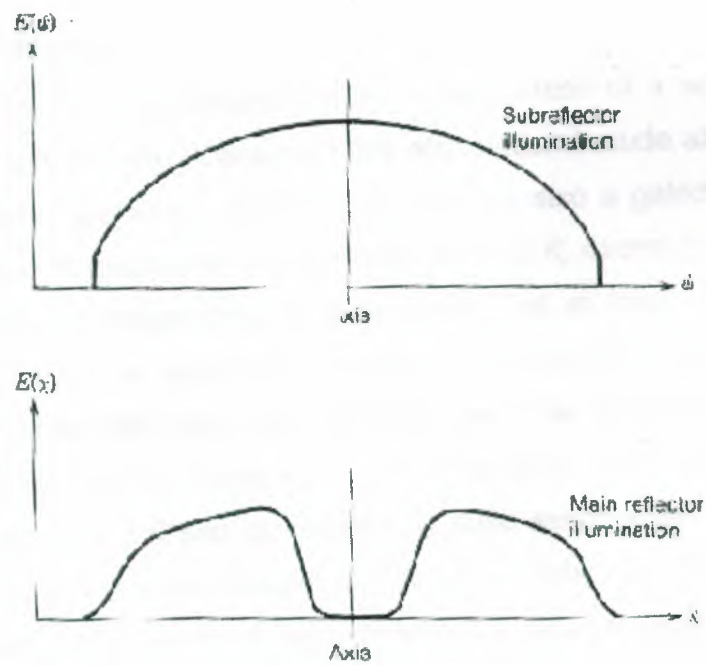


Fig 3.5 Geometry of a shaped Cass grain antenna, redistribution of the energy

radiated by the feed across the main reflector aperture.
in. The corrugated horn can be designed to give near-constant beam width a wide frequency range by tapering the slot depth and spacing, which makes a popular choice for shaped Cass grains.

The choice of sub reflector diameter influences the main reflector spillover loss the blocking loss in a Cass grain antenna. We need a large sub reflector to accurate illumination of the main reflector and reduce diffraction losses at sub reflector edge. but a large sub reflector causes high blockage losses and heavy support legs. In a large Cass grain antenna, a sub reflector diameter 20 to 40 wavelengths is commonly used. If the main reflector diameter is 25 m, blockage introduced by a 40 λ sub reflector at 4 GHz is 1.44 percent of the aperture area. The sub reflector diameter is 3 m in this example. Because the sub reflector blocks the central region of the antenna aperture, the loss in gain is slightly greater than 1.44 percent. Some reduction in this loss can be achieved by age a "pip" in the center of the sub reflector to direct radiation away from natural part of the main aperture, as illustrated in Figure 3.5. Sub reflector king invariably increases side lobe levels.



3.5.3Antenna Noise Temperature

Large Cass grain antennas operating in the 6/4-GHz band must have low noise temperatures to meet stringent *G/T* specifications. Two items contribute most of the noise that makes up the system noise temperature: the low noise amplifier (LNA) and the antenna. Prediction of the antenna noise temperature under operating is an conditions is an essential part of the design process of a large station antenna.

The calculation of antenna noise temperature is straightforward. It involves addition of noise temperatures, representing thermal noise contributions, for each of the losses in Table 9.4 plus a contribution from the sky. Sky noise is not constant it depends on elevation angle and atmospheric conditions, so the antenna noise temperature must be calculated at a specified elevation angle in clear-sky conditions. An increase in antenna noise temperature will occur when attenuation in the atmosphere is present due to rain, which must be taken into account when calculating the (C/N) at the receiver for small percentages of time when rain attenuation is present.

3.5.4 Sky Noise

Sky noise arises because there is attenuation of a wave as it passes through atmosphere. Causes of this attenuation include atmospheric gases and hydro-mirrors(rain, snow, etc.). There is also a galactic contribution to sky noise. At microwave frequencies this is 3 *K,* except for those directions in the sky corresponding to radio stars, but at lower frequenow 1GHz) galactic noise is significant. Figure 3.2.shows the variation of average galactic noise with frequency. Mapping sky noise temperature at microwave frequencies is the basis of radio astronomy. The galactic background temperature of *3* K was discovered by radio astronomers when they tried to cal- vibrate the noise temperature of their antennas. The residual 3 K is attributed to hot matter at large distances in galactic space and gave rise to e Big Bang theory. [17]. For most practical purposes, galactic noise is ignored in the calculation of earth station noise temperatures.

Although sky noise can be calculated from atmospheric attenuation, it is usually determined from graphs or tables tinder clear-sky conditions. Figure shows the variation in sky noise with elevation angle for two frequencies, 4GHZ and 11 GHz. The higher noise temperatures at 11GHz are caused by the increased attenuation experiments at higher microwave frequencies, especially at low elevation angles where the path in the atmosphere is long. Sky noise increase's at low elevation angles, so antenna noise temperature is calculated for the lowest working elevation angle of the antenna, usually 5 for 4GHZ system and 10 for 11-GHZ.

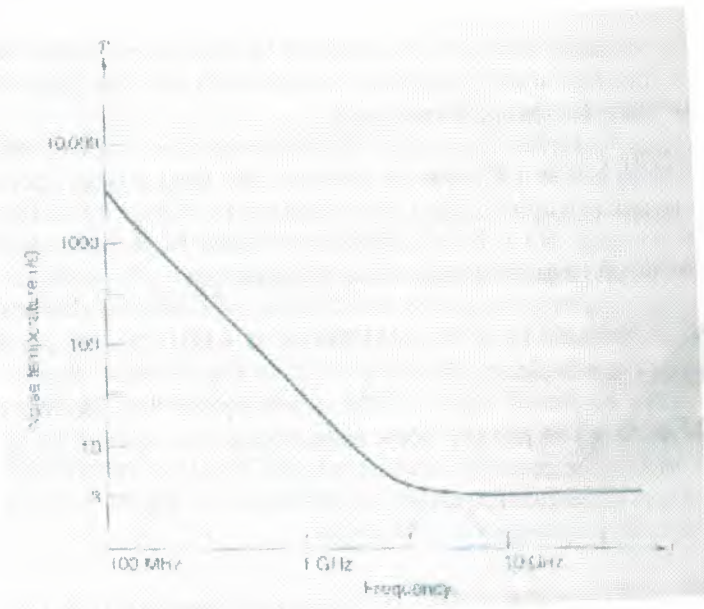


Figure 3.7 Galactic background noise as a function of frequency.

3.5.5 Small Earth Station Antennas

Small earth stations escape many of the problems encountered with large antennas and cost a small fraction of their larger counterparts. The broader beam width of a small antenna allows fixed pointing of the antenna when the satellite is held within $\pm$ 0.1 of its nominal position, eliminating the need for expensive auto track equipment, dual-axis drives, and servo systems. Thus, the fixed-pointing, aperture antenna is an attractive design where the lower *G/T* can be compensated for by any increase in satellite transmitted power or a reduction in RF bandwidth

Small earth stations have been constructed in large numbers for domestic *TVRO* reception of cable TV signals distributed at 4GHz by U.S. domestic satellites. In 1984, these earth stations could be purchased for $1300, with a10-ft diameter antenna and feed costing as little as $300. The introduction of direct broadcast satellites (DBS) will see a further reduction in earth station size and as satellite power is increased and production quantities move from thousands to millions.

The Cass grain and Gregorian antenna configurations cannot be used the main reflector diameter is less than 50 wavelengths without a considerable loss in efficiency. This is because the sub reflector must have a diameter of at least 8 wavelengths to prevent diffraction of waves round it. Smaller subreflectors do not act as good reflectors and cannot control the illumination of the main reflector adequately. If a large sub reflector is used, blockage loss becomes severe and antenna pattern side lobes rise significantly due to blocking of the aperture

Below a main reflector diameter of 50 wavelengths, front-fed parabolic antennas are used. The *scalar feed* has been developed to provide good illumination of front -fed reflectors [20]. Aperture efficiency with a scalar feed can be up to 65 percent in a typical antenna, but cannot be as high as in a shaped Cass grain antenna. Figure 3.6 shows an example of a scalar feed, and its radiation pattern.

Control of the antenna pattern side lobes becomes increasingly important as antenna aperture size is reduced and the pattern broadens.

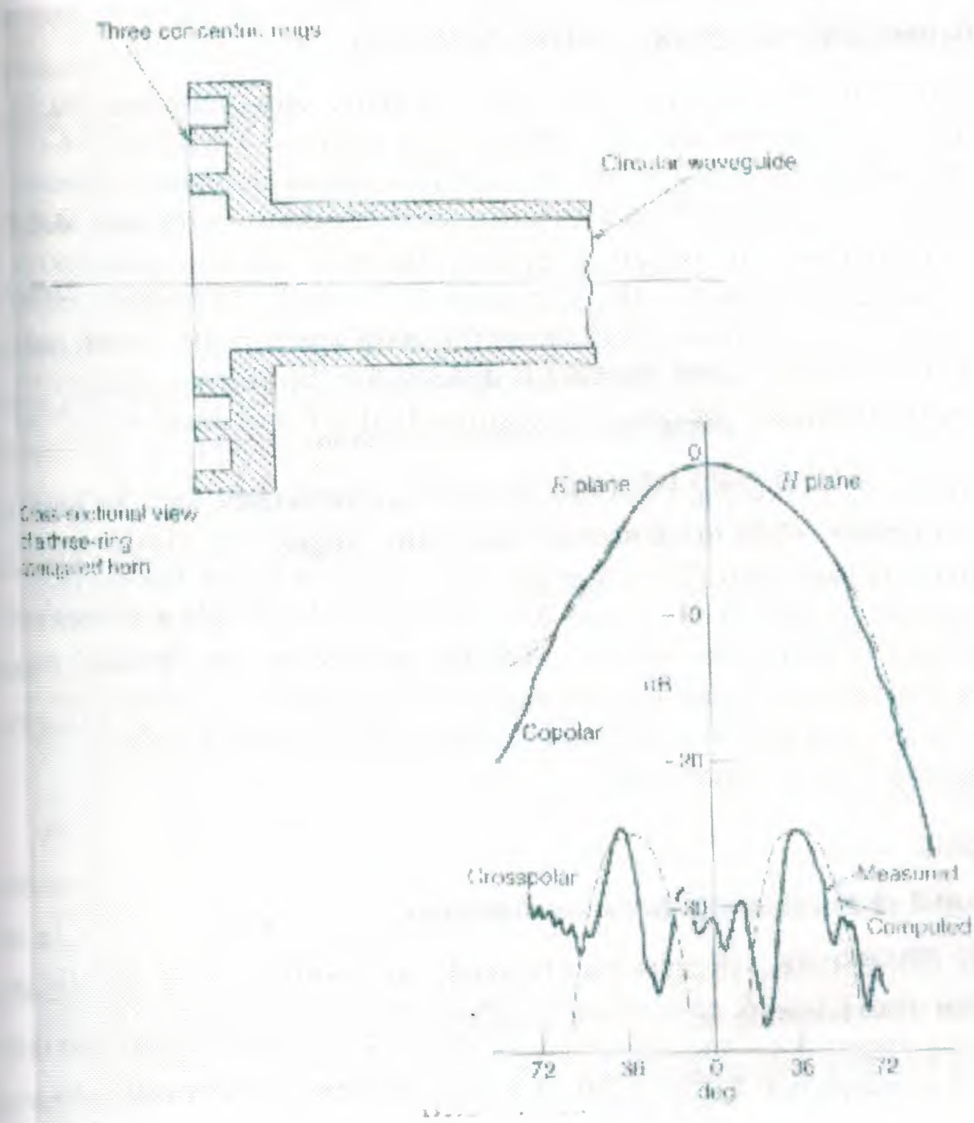


Figure 3.8 Measured and theoretical copular radiation pattern for a three-ring corrugated horns.

Satellite spacing in geostationary orbit is being reduced from 3 to 2,which will increase interference from adjacent satellites on reception and also lead to increased uplink interference when a small earth station transmits. The latter problem places a lower n the antenna size used by transmitting earth stations. However, for small diameter reflectors, the cost of a larger reflector is not very great especially when compared to high-power microwave transmitters. It is the transmitter that is often the most costly item in small earth stations that transmit and receive.

3.5.6 Design of Small Earth Station Antennas

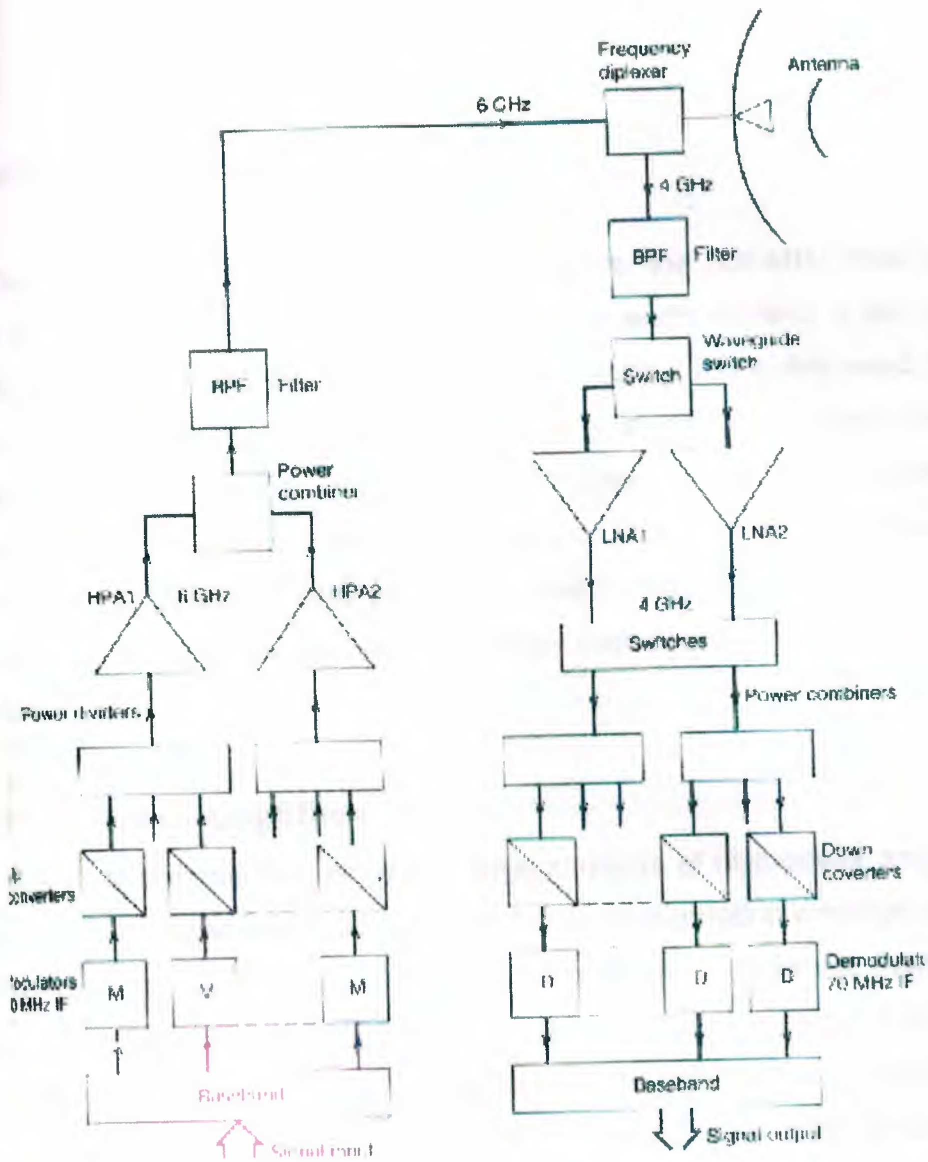
Small earth stations are defined here as those using antennas less 60 wavelengths in diameter, corresponding to 5-m dishes at 4 GHz and 1.6-m dishes at 11GHZ, with gains below about 44 dB. Most of these antennas are symmetrical, front-fed paraboloidal reflectors with scalar feeds. Blockage losses b in symmetrical dual-reflector antennas when the main reflector diameter is l 602, because the sub reflector diameter must be 8). or 10 to obtain good control of the aperture illumination. Blockage of the main aperture also causes high side lobes in the far-field pattern, making it difficult for the antenna designer to the stringent side lobe envelope specifications that are mandated with 20. spacing.

Although symmetrical front-fed paraholoids are widely used for station antennas, *offset-fed antennas* employing single- and dual-reflector configurations are also used. The offset feed lies above or below the ray path fom the main reflector, which eliminates the blockage problem. We will discuss offset- fed antennas later in this section. Multiple beams can be obtained with. reflector if a *spherical reflector* or *parabolic tours reflector allowing one antenna to be* used with several closely spaced satellites simultaneously..

3.6 EQUIPMENT FOR EARTH STATIONS

Figure 3.9 shows a simplified diagram of the major items of equipment at an earth station that receives and transmits. In a large earth station there will be many receivers and transmitters multiplexed together onto one antenna to. provide canalized communication through separate transponders. In a TVRO earth station, for example, there will be only one receive channel and only one receive channel and no transmitting equipment. Transmitters are very much more expensive than receivers, and the cost increases rapidly as the transmitter power increases; this is partly because receivers are made in much larger quantities than transmitters, leading to economies of scales, and partly because of the tight specifications on out-of-band emission, frequency stability, and power control that are necessary to avoid interference with other channels and satellites. Microwave transmitters are expensive devices that employ costly high-power amplifiers such as traveling wave tubes and multifamily klystron.

Base band equipment (modulators, demodulators, and multiplex equipment) is considered in the next section. The major RF components in an earth station the low noise amplifier (LNA) of the receiver and the high-power amplifier (HPA) of the transmitter. Also required are up and down converters to translate signals from (or to) VHF intermediate frequencies (usually 70 or 140 MHz) to(or from) microwave carriers.



IG 3.9 Simplified diagram of earth station's equipment using FDM/FM/FDMA

3.6.1 Low Noise Amplifiers

Large earth stations need very low noise amplifiers. Cryogenically cooled parametric amplifiers are widely used, with liquid helium cooling at 40 K above absolute zero to achieve noise temperatures of 20 to 40 K at 4GHz, Medium and small earth stations use GaAsFET amplifiers with no cooling or electron thermal (Pelletier) cooling. These achieve noise temperatures in the range 50 to 120 K at 4GHZ and 120 to 300 K at 11GHz.The FET amplifier is much simpler than the cooled parametric amplifier and is particularly attractive for unattended and TVRO earth stations, especially wise cost is an important factor. Development of 20- and 44-6Hz GaAsFET amplifier is in progress, although noise temperatures tend to be much higher than those achieved at 4 and 11 6Hz.

The LNAs used in earth stations usually cover the 500-MHz fixed service bud at 4 GHz and 750 MHz at 11 GHz. In large earth stations a one-for-one redundancy arrangement such as that shown in Figure 3.7 is widely used. Failure of one LNA, indicated by loss of a pilot signal at the receiver output, result in immediate switchover to the second LNA. The spare (unused) LNA is often kept on test with a pilot signal or noise source input so that its state of readiness can be monitored continuously. Dual polarization earth stations need two RF receive channels and may use *one-for-two redundancy (one spare for two operational)in* their LNAs.

3.5.2 High-Power Amplifiers

Large earth stations frequently use large numbers of high-power amplifier (H PA) with output power levels up to 8.5 kW. The configuration employs depends on the number of carriers to be transmitted and whether these are Femur TDM signals. The most common configuration employs one HPA for each Tran ponder to be used. At 60Hz, HPAs having bandwidths of 40 or 80 MHz are used in large earth stations, using either air-cooled TWT (traveling wave tube) amplifiers or *water-cooled klystrons. TWTAs have wider operating* bandwidths to klystrons and can cover the full 500-MHz bandwidth at 6 0Hz [29], allowing flu TWT to he tuned to any transponder band.

FDM transmission of several carriers to one or more transponders require, a linear high-power amplifier if intermediation is to be avoided. At an earth station neither input power nor efficiency are prime concerns, so considerable input baè. off can be used with the HPA to achieve near-linear operation and low intermodulation. Typically, a 3-kW HPA will be operated with 12 or 14dB input bee. off giving an output power in the 300 to 500 W range.

Although QPSK and other digital modulations are often represented as cog stint-envelope signals, this condition is present only in an infinite bandwidth QPSK signal. Out-of-band emissions and inter symbol interference are controlled by careful filtering of the PSK signal with SyQuest-type filters (see Chapter *5).* The filtering of the signal results in a noneonstant envelope signal with amplitude as well as phase variation. When the filtered signal is hard limited by a saturating amplifier, the signal is returned to a constant envelope form, which broadens its spectrum considerably, increasing the level of out-of-band emissions. Consequently, HPAs used at earth stations carrying digital traffic are often run with input back off of 10 to 14 dB.

When several HPAs are used with one antenna, a combining network is needed to sum their outputs into a single transmit waveguide. Frequency-selective networks and waveguide hybrid junctions are used to couple the HPAs, with a typical loss of 4 dB per HPA [29]. As a result, a 3-kW 1-IPA run with an output back off of 10 dB might actually deliver only 120 W to the earth station antenna.

Single-channel-per-carrier (SCPC) systems allocate a separate transmitter frequency to each channel (usually FM or P5K voice). The channel frequencies are generated by a programmable synthesizer and then used to up convert the modulated signals to the transmit frequency. In a large earth station, the outputs of the up converter are then summed with hybrid couplers and a single broadband FDM signal is applied to the HPA. In small earth stations carrying only a few voice channels, it is possible to use solid-state amplifiers for the HPAs, by having one amplifier for each voice channel. The transmitted power of a single SCPC voice channel is typically below 1 W for medium-sized earth stations; GaAsFET amplifiers at 6 GHz can produce up to 20 W output power in saturation. At the time of writing (1984), the cost of these amplifiers and the combining losses for a large number of HPAs make it uneconomical to use solid-state HPAs when more than a few voice channels are to be combined.

Solid-state HPAs have the additional benefit that they do not require the very high voltages needed by TWT and klystron amplifiers (typically 10—50 kV). High voltage equipment tends to suffer more failures than lower voltage equipment, and is also bulky and heavy. In transportable earth stations, or mobile systems, solid-state HPAs are attractive. However, reducing the size of the antenna demands more transmitter power for a given EIRP, and small earth stations often require relatively high transmitter power levels.

Bipolar transistor HPAs with up to 50-W saturated output are widely used in maritime satellite communication systems for shipboard transmitters operating at 1.6 GHz.

An earth station serves as an interface between the RF carriers sent to and from a satellite and the base band voice, data, or video signals sent via the terrestrial network or provided by the user. A great deal of signal processing is required when many voice or data channels are multiplexed together into single carriers. The multiplexing and modulation demodulation operations are almost always carried out at base band and intermediate frequencies, which can be handled more easily than microwave frequencies. The up- and down converters form an interface between the RF and IF portions of transmitters and receivers; the only operations that are normally carried out on RF signals are amplification and filtering, with minimal combining and splitting. This part of the earth station is known as *grot4 control equipment (GCE).*

There are significant differences between equipment designed for FDM operation and that designed for TDM, so we will discuss them separately. The up converter and down converter are similar in each case, although bandwidth may differ.

3.6.3FDM Systems

FDM systems transmit and receive many voice or data signals by allocating separate frequencies to each signal, at either base band or RF, or both. At an earth station that operates in an FDM mode, a terrestrial link is used send and receive FDM or TDM groups of channels. The link may be microwave; coax cable, or an optical fiber. The terrestrial interface may separate incoming channels back to base band for reassembly as new FDM groups for transmission via the satellite link, or it may assemble incoming FDM groups. When the terrestrial, link uses TDM (e.g., optical fiber links), the channels must be converted back to base band and then reassembled in FDM groups for satellite transmission. Tb reverse process must be performed on received FDM groups.

Large earth stations using FDM/FDMA operation, such as Standard. A stations in the Intelsat network and many domestic satellite system stations, may carry several thousand 4-kHz voice channels. The voice channels are collected from a wide geographic area and sent via a *gateway.* In international systems, the gateway is usually located in a major city, and all international traffic from the whole country may be routed through this one point. Voice channels that are to be routed to each country, or each earth station, are assembled into groups at the international exchange and then sent to the earth station. Similar receive path are established to complete the two-way link.

It is not essential that both the go and return paths be via satellite. Undersea or terrestrial cable or terrestrial microwave links can be used for one path, and; satellite link for the other. [his reduces the round-trip delay in a long telephone circuit and also allows maintenance of parts of the earth station equipment. An advantage of the international gateway arrangement is that all international circuits satellite, cable, and optical fiber terminate at one point, allowing traffic to be distributed between the available transmission paths

. Figure3.8 shows a typical arrangement for a FDM/FDMA earth station ground control equipment, corresponding to the IF and base band equipment M Figure 3.7The transmitting section, shown in Figure3.8a, accepts basement signals from the terrestrial interface and assembles these into FDM groups far different destinations. In an FDM/FDMA system, each route from one earth station. to another earth station has an allocated frequency. Destinations are associated with RF frequencies at a transmitting station, so base band channels must be -translated to specific RF frequencies determined by their eventual destination. The system shown in figure 3.8a uses a double frequency conversion with two IF frequencies,70MHZ and 770MHZ.Each 70MHZ channel leads to a separates RF carrier in the transmitted spectrum. The FDM signal, consisting of as few as 12 telephone channels or as many as 1872, is frequency modulated onto a 70 MHZ IF carrier.

The 70 MHZ IF filter defines the bandwidth of the FM signals very accurately and is the major bandwidth control element in the transmit chain. Its bandwidth lies between 1.25 and 36 MHZ depending on the carriers size, and a variable group delay equalizer may be included to compensate for group delay in the up link .The 70 MHZ IF carrier is then unconverted to a 770 MHZ IF band, where other carriers are added to form a composite FM/FDMA signal. The 770 MHZ broadband signal is finally unconverted to .6 GHZ for amplification .Not shown in figure 3.8a are power control devices needed to set the level of the 6 GHZ carrier.FDMA requires very accurate power sharing when more than one carriers accesses a single transponders, to avoid excessive intermodulation on any one downlink carrier is monitored at the transmitting station using a spectrum analyzer, and the levels of the uplink carrier is set accordignaly.This cannot be done when a satellite such as INTELSAT V is used and the transmitting and receiving station are in separate zone beams.In this case ,the absolute levels of the transmitted carriers must be correctly set as the transmitter. Monitoring of the transponders carrier power distribution is then carried out by a station within the receive zone beam region ,which reports back to each transmitting earth station via a telex or voice channel allocated for this purpose. A considerable amount of monitoring and supervisory equipment is also required at each stage of the GCE, and energy dispersal waveform generators are needed in the uplink equipment to add triangular wave form to the transmitted signals when traffic volume on any carrier is low

The downlink GCE complement that of the uplink and contain almost the same equipment except that frequency conversion is down rather than up. Figure 3.8b shown an arrangements to complement the transmit equipment of the Figure 3.8a.Carriers at 4 GHZ are amplified in a broadband LNA and then down converted to 770 MHZ IF using appropriate local oscillators. The local oscillators separate the received 4 GHZ carriers into individual 770 MHZ receivers with 40 MHZ bandwidth so that each reciver corresponds to one transponder. A second down conversion to 70 MHZ allows accurate filtering and group delay equalization to be performed before demodulation. The bandwidth of the 70 MHZ IF stages is set between 1.25 and 36 MHZ depending on the number of channels carried by the transponders. The FM demodulators used in the GCE usually employ threshold extension techniques to achieve a low threshold in (C/N) for carriers with up to 252 channels. Threshold extension may not be needed with the higher carriers these usually have much higher(C/N) and originate only in larger earth stations served by higher gain zone beams. After demodulation, the voice channel signals are translated to base band to 3.1 or 3.4 KHZ, continuity are extracted, and the signal is passed to the terrestrial interface for onward transmission.Deemphasis filters are required in the base band equipment, as well as noise pilot level monitoring equipment. The 70 MHZ IF incorporates automatic gain control(AGC) to ensure that a constant levels signal is applied to the demodulators

4. SATELLITE ORBITS

4.1 Introduction

The orbit machine of communication satellite, together with their construction specially in relation to a geostationary satellite. That appears to an observe on earth to be hanging prefatory still at one spot in the sky. But this is all related an observer in space sees a geostationary satellite orbiting. The earth at a sped of 11,068.8 km/h.At this velocity satellite makes one revolution around the earth in exactly the same amount of time it takes the earth to rotate it once on its axes. Since the only great circle that is moving exactly parallel to the direction of the earth rotation is the quarter, the geostationary stationary orbit lies in the equatorial at the distance of approximately 42, 164km from the earth's center. A satellite that has a 24h none equatorial orbit is called a synchronize satellite.

The term geosynchronous satellite is also used to refer to a synchronous satellite, but it is also used in the literature to refer geostationary satellite. To avoid confusion the term geostationary satellite is employed through this project Why use a geostationary satellite? Because it is stationary relative to a point on the earth, their no requirement for a tracking antenna and the cost of the space and earth segments is much less then for lower altitude satellite system. This is principal advantage.

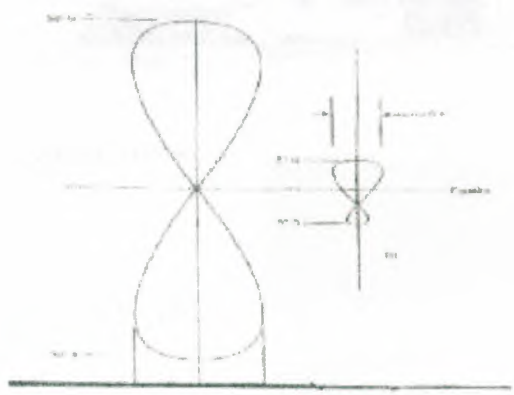
4.2 Basic orbit characteristics

The earth sidereal period of rotation. That is , the time taking for one complete rotation about its center of masse relative to the stellar back ground, 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 geo-synchronous satellite. The radius of its orbit will be 42164 km and its height above the earth's surface will be about 35786 km. If this satellites daily earthtrack is traced , it will show figure of eight pattern as sketched in figure 4.1.

The maximum extent of the pattern in degrees of latitude, north arid 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 the central 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.

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

Maximum spread= ±arcsine (sin2 1/2i / cos 1/2i)



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.

There are three type of satellite orbit is shown in figure. 4. 2

1. Geostationary Earth orbits (GEO)

2. Medium earth orbit (MEO)

3. Low earth orbits (LEO)

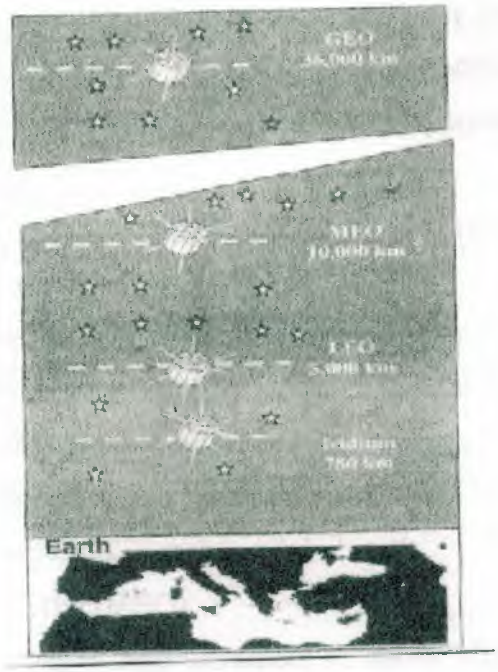


Figure 4.2:satellite orbit.

I .Geostationary Earth Orbit (GEO):

Most of the current satellites in operation fall into the category. This orbit is approximately 35,786 km above the earth. The terms geosynchronous are often used by interchangeably, but there is an important difference between them.
Geosynchronous satellites have an orbit whose period is one sidereal day or 24 hours. However due to the earth's revolution around the sun the actual period is slightly shorter: 23 hour, 56minute, and 4.1 second. The satellite must also be in a direct orbit that is the satellite must move n the same direction as rotation of the earth. The inclination of geosynchronous satellite's orbit may be at any angle with respect to the earth's equatorial plane.
A truly geostationary satellite also has the same period and the same direction of rotation as the earth. However, it must have an orbit that is close to the equatorial plane of the earth it must have a zero inclination. An observer looking at such a

geostationary satellite would see it hanging perfectly fixed spot in the sky. But this is all relative. An observer in space sees a geostationary satellite orbiting earth at a speed of 11.068 km/h. the round trip propagation delay for GEO link is about 260 ins.

The geostationary orbit is now employed for most commercial satellites because of the following advantages:

I. The satellite remains stationary with respect to one point on earth. That is the earth station antenna is not required to track the satellite periodically.

2. The Doppler shift caused by a satellite drifting in orbit is small for the earth stations within the geostationary satellite coverage. This is desirable for many synchronous digital systems.

2. Medium Earth Orbit (MEO):

The medium earth orbits is approximately at about 10,000 km above the earth. Their space earth transmission loss is much less then for geostationary satellites and the route trip transmission is reduced to l00-l5Oms. Circular MW orbits have periods in the range of 8-12h. as a result of the lower orbit they do not principle advantage travel at the same speed relative to the earth. This introduces to the need of several MFO satellites in order to provide continuous coverage.

Although geostationary satellites seem likely to dominate satellite communication with high speed link between fixed points lower transmission loss of MEO satellites make them particularly attractive for mobile satellite system because hand held terminals with much lower power and simple omni directional antennas can be used.

3.Low earth orbit (LEO):

A low earth orbit would provide a further reduction space earth transmission loss relative to the geostationary orbit and transmission times of 20-25ms. This allows to use even more low power handheld terminals in MSS.

Altitude between 780 and 1400 km are favored corresponding with orbital periods between 100 and 113minutes. Thus LEO systems require slightly more satellites then MEO systems to provide continuous coverage. For example 66 satellites are used in Iridium system.

4.3 Effects of orbital inclination:

The maximum drift in both latitude and longitude due to orbit inclination can be determined by considering the fig 4.3. Let R be the satellite's instantaneous projection on the earth's surface and let λ and ψ denote the instantaneous latitude and relative longitude of R. considering the spherical triangle PRQ and non rotating earth we obtain.

$$\text{Sin}\ \Psi - \tan\lambda / \tan$$

The are *PR* is the trace of the orbit and subtends n angle u given by

Sin u= sin λ /tan i

. Now consider a rotating earth. Let t_p be the time at which the satellite passes the ascending node *P:* then when the satellite reaches the latitude λ in the time t he earth has rotated east ward through the angle u. Therefore if the relative longitude of the satellite projection R is Ψ ,it become Ψ -u.Thus the relative Longitud of the satellite for any given latitude is equal to

$$\Psi = \sin(\tan\lambda / \tan i) - \sin(\sin\lambda / \sin I) \quad (4.1)$$

The trace of a synchronous satellite with inclination i is plotted in fig 4.4. It is seen that this inclination in effect gives the satellite in apparent movement in the form of a figure eight. The maximum latitude deviation from the equator is given by

$\lambda_{max} = i$ (4.2)

And the maximum longitude deviation from the ascending node Ψ max and the corresponding latitude λ when I < 5 can be small

Ψ max= i/228 (4.3a)

λ =.707i (4.3b)

Where i is in degrees from (4.2) and (4.3) it is seen that the displacement in latitude is more pronounced then the displacement in longitude for a synchronous satellite with small inclination. In this case displacement Dλ and DΨ can be calculated as follows

Dλ/Reλ max=a/Re

DΨ/Dλ= Ψmax/ λmax= i/228

Where a is the orbital radius (a=42,164.2km) and Re is earth's radius. Therefore,

Dλ=aλmax=42,164.2i/360/2π=735.9(km) (4.5)

DΨ=i Dλ/228=3.23i(km) (4.6)

Where i in (4.5) and (4.6) is in degree. As in example consider the case when i=1; then Dλ=735.9(km) and DΨ=3.23(km).

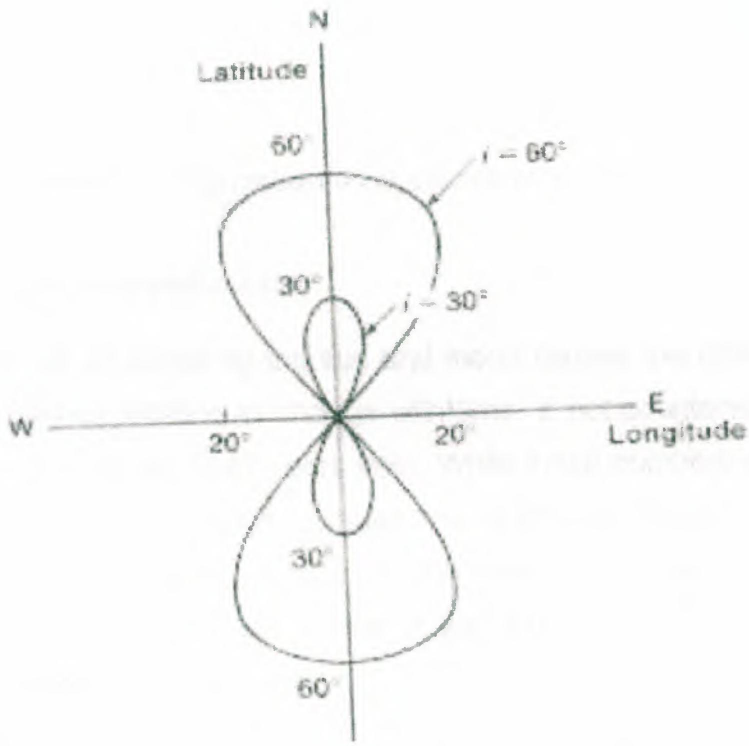


Figure 4.4; Apparent movement of a satellite in an inclined and synchronous orbit with respect to the ascending

To correct the orbital inclination it is necessary apply a velocity impulse perpendicular to the orbital plane when the satellite passes through the node as shown in fig *4.5.* for the given I the impulse amplitude is given by:

$$\Delta V = V \tan i$$

$$= \sqrt{\mu / a} \tan i \qquad (4.7)$$

where $V = \sqrt{\mu / a} = 3074.7$m/s and is the orbital velocity. For I = 1°,

$\Delta V = 3074.7 \tan 1° = 53.7$ m/s.

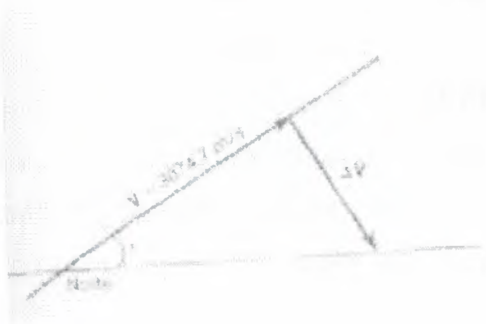


figure 4.5: Correction of the inclination of a synchronous orbit.

4-4:-Effect of the sun and moon

Gravitational attraction by the sun and moon causes the orbital inclination of a geosynchronous satellite to change with time. If not countered by north — south 0degree at lunch to 14,67 years later. While these numbers are academic in the sense that no commercial satellite has a 26-years useful lifetime, they indicate the magnitude of the problem. The rate of change varies with the inclination of the moons orbit, but values of about 0.86/ year are quoted for the 1970-1980 time period.

4.4.1: eclipse:

For a geostationary satellite that utilizes solar energy, the duration and periodicity of solar eclipses are important because no solar energy is available during eclipses. The earth equatorial plane is inclined at an angle Ie(t) with respect to the direction of the sun. This annual sinusoidal variation.

$$i_e(t) = 23.4 \sin 2\pi t / T \qquad (4.8)$$

Where the annual period T=365 days and the maximum inclination is $i_e=23.4^0$. The time t_a and t_s when the inclination angle Ie is zero are called the autumn equinox and the *spring equinox* and occur about September 2 1 and March 21, respectively. The time t_w and t_{su} when the inclination angle Ie is at its maximum are called the *winter solstice* and the *summer solstice* and occur about December21 and June21 ; respectively.

To find the eclipse duration consider (fig4.6) where the finite diameter of the sun is ignored (the sun is assumed to be at infinity with respect to the earth), hence the earth shadow is considered to be cylinder of content diameter. The maximum shadow angle occurs at the equinoxes and is given by:

$$\Phi_{max} = 180^\circ - 2\cos^{-1}(R_e/a)$$

$$= 180^\circ - 2\cos^{-1}(6378.155/42,164.2)$$

$$= 17.4^\circ \qquad (4.9)$$

because a geostationary satellite period is 24 h, this maximum shadow angle is equivalent to a maximum daily eclipse duration:

$$t_{max} = 17.4^\circ / 360^\circ * 24 = 1.16\ h \qquad (4.10)$$

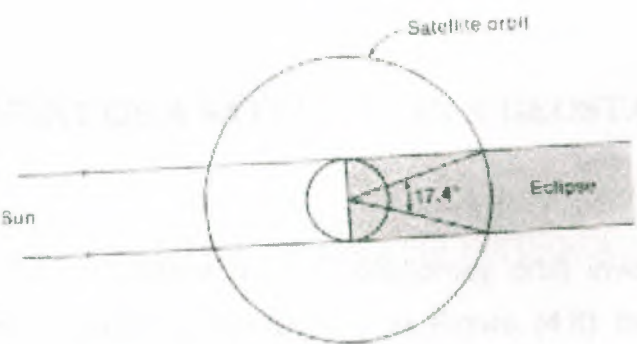
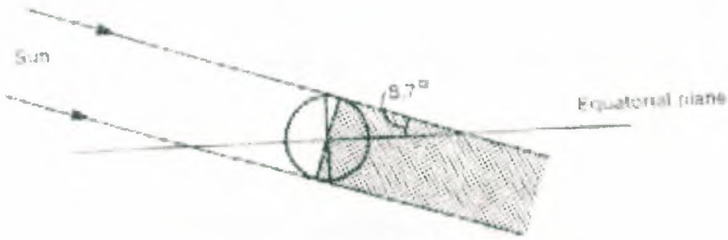


fig 4.6 : Eclipse when the sun is at equinox

The first day of eclipse before an equinox and the last day of eclipse after an equinox correspond to the relative position of the sun such that the sun rays tangent to the earth pass through the satellite orbit. Thus the inclination angle of the equatorial plane with respect to the direction of the sun in these cases (fig 4.7) is



$$i_e = 1/2\ \phi_{max} = 8.7^\circ \quad (4.11)$$

Fig 4.7: Earth inclination at first day of eclipse before equinox.

Substituting i_e 8.7° into (4.8) yield the time from the first day of eclipse to the equinox and also the time from the equinox to the last day of eclipse:

$$T = 365 / 2\pi \sin\ (8.7 / 23.4)$$
$$= 22.13 \text{ days} \quad (4.12)$$

where the angle is in radians.

4.5 PLACEMENT OF A SATELLITE IN A GEOSTATIONARY ORBIT

The placement of a satellite in a geostationary orbit involves many complex sequences and is shown schematically in Figure (4.8) the launch vehicle (a rocket or a space shuttle) places the satellite in an elliptical transfer orbit whose apogee distance is equal to the radius of the geosynchronous orbit (42,164.2 km). The perigee distance of the elliptical transfer orbit is in general about 6678.2 km (about 300 km above the earth's surface). The satellite is then spin-stabilized in the transfer orbit so that the ground control can communicate with its telemetry system. When the orbit and attitude of the satellite have been determined exactly and when the satellite is at the apogee of the transfer orbit, the apogee kick motor is fired to circularize the orbit. This circular orbit, with a radius of 42,164.2 km. is a geostationary orbit if the launch is carried out at O~ latitude (i.e., at the equator). What happens if the satellite is launched from, say, Cape Kennedy at 28^0N latitude? Then the orbit will be a synchronous orbit with an inclination i greater than or equal to the latitude O~ when the injection at the perigee is horizontal.

The velocity at the perigee and apogee of the transfer orbit can be calculated from (4.12):

$$V = \sqrt{\mu (2/r - 1/a)}$$

At the perigee r =6678.2 km. a = (6678.2 + 42.164.2)/2 = 24,521.2 km. And the velocity is

$$V_p = 10.15km$$

At the apogee r = 42,164.2 km. hence the velocity is

$$V_a = 1.61 \text{ km/s}$$

Since the velocity in a synchronous orbit (r = a = 42,164.2 km) is

$$V_c = 3.07 \text{ km / s}$$

In incremental velocity required to circularize the orbit at the apogee of the Transfer orbit must be

$$\Delta V_c = V_c - V_a$$
$$= 3.07 - 1.61 = 1.46 \text{ km/s} \qquad (4.13)$$

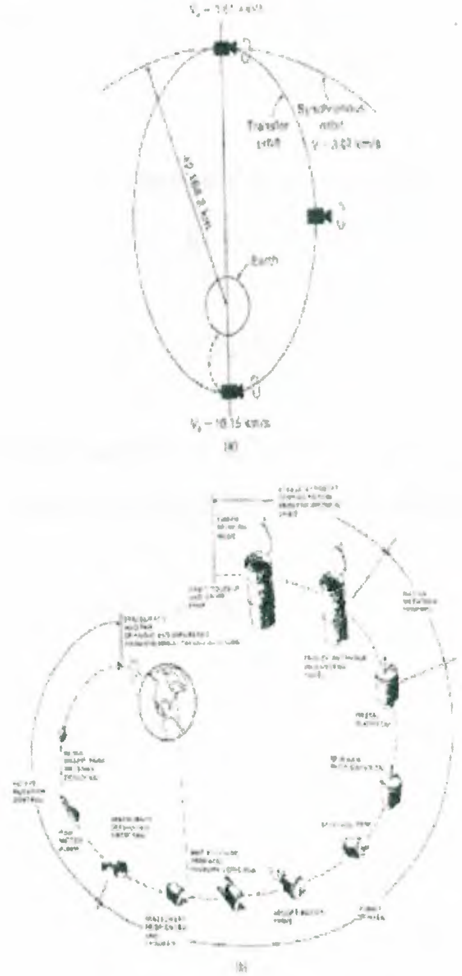


figure 4.8:Placement of a satellite in a geostationary orbit . (a) Concept. (b) Actual launch.

Since the plane of the transfer orbit is formed by the position vector r and the velocity vector **V** of the satellite at a given instant in time, the inclination correction can be **made** at the ascending or descending node where the orbit intersects the *equatorial plane at an incremental velocity vector* ΔV s *such a way that the sum of* the node velocity vector **V"** and the incremental velocity vector ΔV is a vector *V* in the equatorial plane. The inclination correction is shown schematically in Fig. 4.9 where the magnitude of ΔV required to correct the inclination is

$$\Delta V = \sqrt{V_n^2 + V_c^2 - 2V_n V_c \cos i}$$

If the line connecting the apogee and perigee is the node line, and the inclination correction is made at the apogee in conjunction with orbit circularization then.

$$\Delta V = \sqrt{V_a^2 + V_c^2 - 2V_a V_c \cos i}$$

For i = 280, V_a 1.61 kmls. and V_c = 3.07 kmls, the incremental velocity required to correct the orbit inclination and to achieve orbit circularization

$$\Delta V = 1.81 \text{ km/s}$$

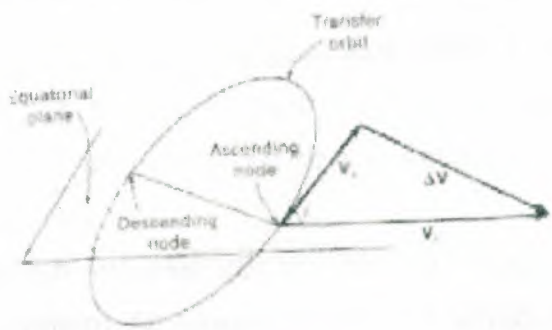


figure:4.9 Sirnulataneous orbit circularization and inclination correction.

Satellites are now being placed in geostationary orbits by two major organizations the *National Aeronautics and Space Administration* (NASA) and the *European Space Agency* (ESA). NASA uses a space *transportation system* (STS) or .*space shuttle* to take the satellite to a circular parking orbit between 300 and 500 km with an inclination of 28 The propulsion requirements for establishing the final geostationary orbit are satisfied by two impulsive maneuvers. The first maneuver imparts a velocity increment of approximately

2.42 km/s for a 300-km parking orbit (in this orbit the satellite velocity is about 7.73 kmls. while the velocity at the perigee of the transfer orbit is 10.15 km/s) at the first equatorial crossing of the parking orbit. This establishes the elliptical transfer orbit with the perigee at the equatorial crossing where the maneuver is executed (r = 6678.2 km) and the apogee at the geostationary radius (r =42,164.2 km). The second maneuver has been described previously. ESA uses the Arian rocket to carry the satellite directly to the elliptical transfer orbit. Since the transfer orbit established from the Arian launch site in French Guiana is inclined only 5•30 to the geostationary orbit, less fuel is required in the second maneuver for the Arian launch. The Arian is also capable of placing a satellite directly in a geostationary transfer orbit. NASA also uses the Atlas-Centaur and Delta rockets to complement the space shuttle.

4.6 LAUNCHES AND LAUNCH VEHICLES

For a spacecraft to achieve synchronous orbit, it must be accelerated to a velocity of 3070 m/s in a zero-inclination orbit and raised to a distance 42.242 km from the center of the earth an of the earth(11). There are two competing technologies for doing this:
expendable launch vehicles *(ELV)* and the space shuttle (STS. for space transportation system) At present (1984) the situation is fluid , and long-term developments are difficult to predict. U.S. government policy is to phase out ELV launches for its own satellites and to rely exclusively on STS. If this happens a number of private firms would like to pick up the ELV programs and offer ELV launch for sale to non movement users. At the same time European company Arianespace is marketing ELV launches in competition with U.S industry and with STS. There are also rumors of a forthcoming Japanese entry into the commercia launch market .in this section we will try to summarize the problem of launching a synchronous satellite and to describe the system that are currently available fo solving them , warning the reader to situation may change drastically in the nex few years.

The Mechanics of Launching a Synchronous Satellite

While theoretically a satellite could be placed into geosynchronous orbit in one operation, practical considerations of cost and launch vehicle capability dictate **a** two- or three-step process, as depicted in Figure (4.10). Most ELV launchers like Delta and Arian (Figure 4.11) put the satellite in an inclined elliptical orbit called a transfer orbit with an apogee at geosynchronous altitude and a 185 to 370 km (100 to 200 nautical mile) perigee [12]. At the transfer orbit apogee, a rocket engine called the apogee kick motor *(AKM)* puts the satellite into a circular geosynchronous orbit with (ideally) zero inclination. The AKM is an integral part of the satellite except in some Titan IIIC launches where the last stage of that rocket both places the satellite into transfer orbit and serves as an AKM [13].

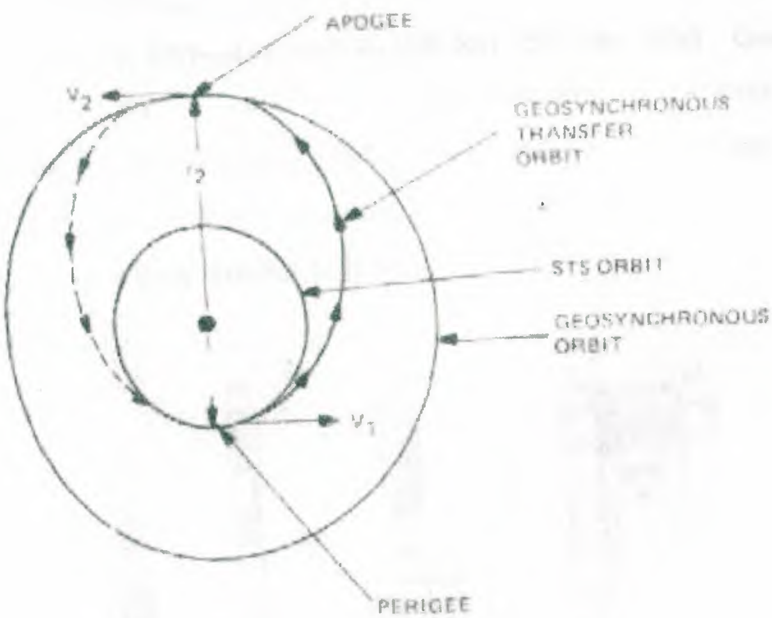
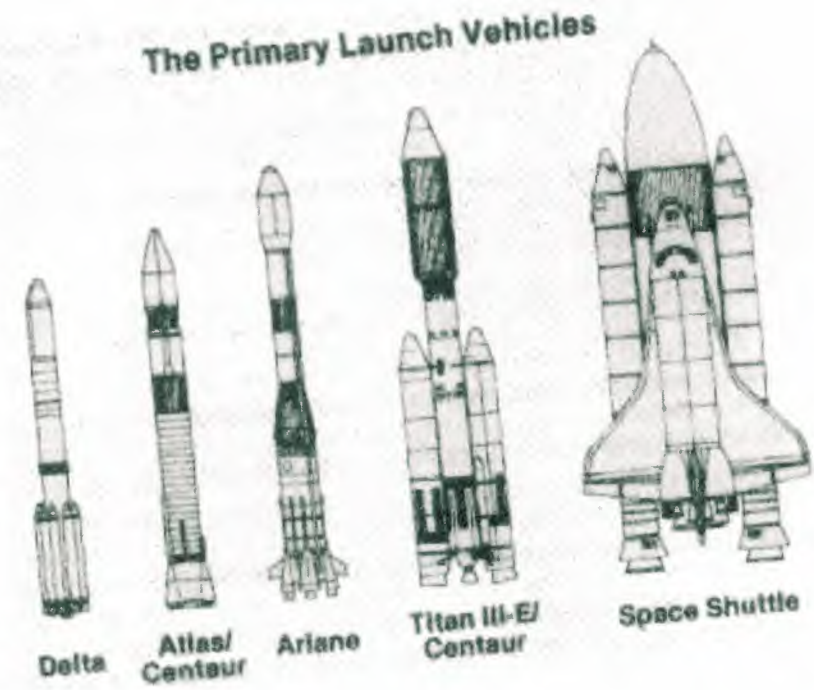


FIG 4.10: The step in launching a communication satellite V1 and V2 are the velocity

Increments that move the spacecraft into and out of the transfer orbit. The AKM must be capable of increasing the satellite velocity from *1585m* /s in the transfer orbit to about 3048 m/s in geosynchronous orbit while simultaneously reducing the orbital inclination to zero. The bigger the inclination, the more energy this requires. Rocket engineers express required energy in terms of an equivalent velocity change of the spacecraft in level flight. The minimum inclination that the transfer orbit can have is equal to the latitude of the launching pad. For Cape Canaveral this is 28.30, and the energy required to overcome this inclination corresponds to a velocity change of 366m/s. Hence, for a Cape Canaveral launch the AKM must be able to deliver a total velocity change of 1463 + 366 or 1829*m/s*.. Arian rockets launched from the Guiana Space Center (French initials *CGS)* in French Guiana have a transfer orbit inclination of about **50.** thus' an Arian launch requires less energy from the AKM for inclination correction and can deliver a bigger payload to synchronous orbit than a rocket of the same size launched from Florida..

The Space Shuttle flies a nominal 296-km circular orbit. Geosynchronous satellites launched by STS are moved from this orbit to a transfer orbit by an additional stage frequently called a PAM (for payload assist module) or a perigee



motor. An AKM injects the satellites from trans orbit in the same way as with ELV launches. Approximately 30 min elapse between. ELV ill lift off into the transfer orbit. With STS the time may the rest of the Shuttle's mission. After transfer orbit the launching agency to the satellite owner, who spacecraft into geosynchronous orbit. Factors transfer orbit include how long it takes to verify the transfer orbit, required visibility of the satellite from earth stations, and the like [13).RCA SATCOM example, go into geosynchronous orbit at their seventh apogee passage(14).

5. FREQUENCY DIVISION MULTIPLE ACESS

1. INTRODUCTION

This chapter describes the fundamental properties of frequency division multiple access (FDMA) whereby multiple signals from the same or different earth terminals are transmitted on carriers at different RF center frequencies.

The FDMA class of signals includes many variations in the number and bandwidth of carriers transmitted by a given earth station. For example, we might transmit only one carrier per earth station, where the data to all receive terminals are multiplexed on that single carrier. Alternatively, each terminal might transmit separate carriers for each receive earth terminal being addressed. This latter approach has the advantage that it requires the receive earth terminal to demodulate only the data intended for it, but this technique may not have any power or efficiency advantage. Finally, one can provide a separate carrier for each voice channel. This single-channel per carrier (SCPC) system has the advantage that it can be used in a demand-assigned mode and can there by improve the system efficiency. These SCPC carriers can also be voice-activated such that carrier power is turned on only during time intervals when the voice envelope exceeds a threshold level.

The transponder and other amplifier nonlinearities have a significant effect on the FDMA signals. causing signal suppression and intermediation products. An analysis is given of both of these effects.

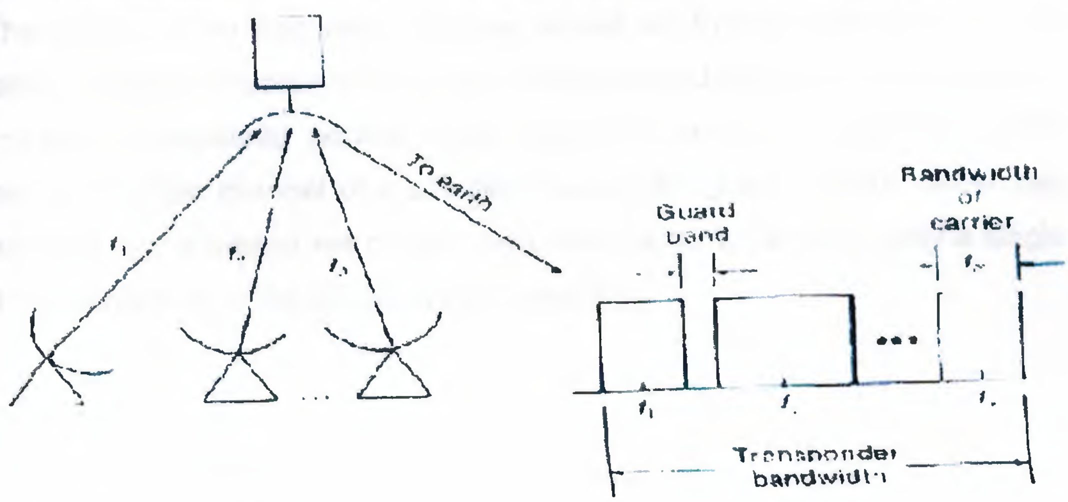


Figure 5.1 Concept of a FDMA system.

5-2 PRINCIPLES OF FREQUENCY DIVISION MULTIPLE ACCESS

Here we address the simplest form of multiple access wherein each carrier is transmitted at a different frequency. In FDMA, each signal is assigned a separate no overlapping frequency channel, and power amplifier inter modulation products are either accepted or minimized by appropriate frequency selection and/or reduction of input power levels to permit quasi-linear operation (Fig.5 -2). Attention is focused on the satellite transponder effects since this power is more critical and costly than earth terminal power. Typically, one might reduce the satellite average output power by 50 percent or more to reduce IM products to an acceptable level with a high density of input signals. Oscillators with good long-term stabilization are employed to keep the signals properly centered in n on overlapping frequency bands.

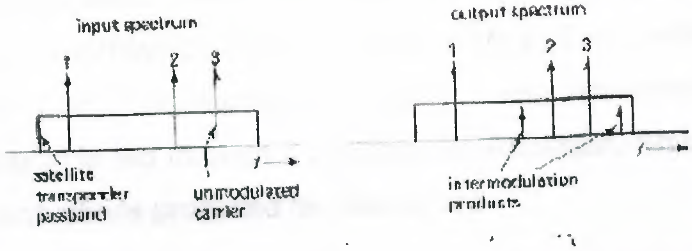


Fig 5.2 Typical input and output spectra for FDMA.Inter modulation products are shown corresponding to nonlinear repeaters and un modulated carriers.

FDMA Channel Formats

The format of the frequency channel utilized for FDMA depends on signal distortion, adjacent channel interference, and inter modulation effects caused by the satellite transponder nonlinearities. Figure 5.3 shows a simplified FDMA format for a single channel of a satellite transponder. Each FDMA carrier can either carry a multiplexed set of user data streams, or it can carry only a single user's bit stream as in the SCOC system described

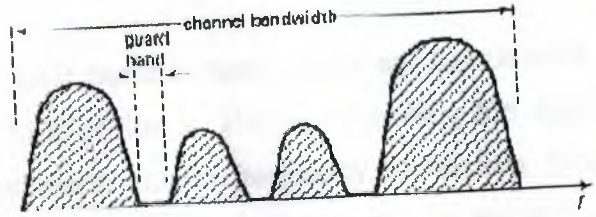


Fig 5.3 Simplified format for FDMA single in a single satellite channel.

The carrier can either be destination oriented or a signal carrier can carry data destined for several receive earth station.

Guard bands must be used between adjacent frequency channels to minimize adjacent channel interference and these, of course, reduce the frequency utilization efficiency of the transponder channel. The required size of the guard hand depends in part on the residual sidebands in each transmitted signal. Figure 5-3 shows the power spectral density of a QPSK signal at IM symbol/sec (2M bps). Transmission filters can be employed to cut off the signal spectrum at IF bandwidths between I and 2 MHz. The smaller bandwidths must utilize some form of equalization. However, these sidebands can build back up when the signal is fed through a nonlinearity [Robinson, Shinto, Fang, 1973] and envelope fluctuations produced by filtering are

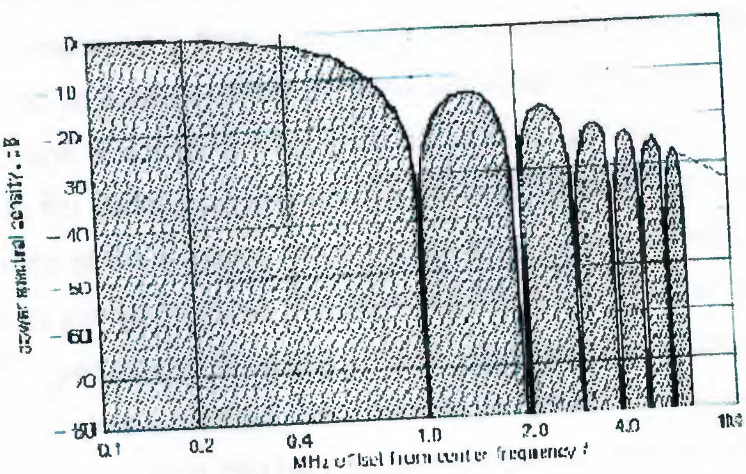


Fig 5.4 Power spectrum of QPDK AT 1.0 M symbol/sec shown on lograthmic

frequency scale

reduced. The guard band between adjacent frequencies must also account for the frequency drifts of the oscillators controlling the signal center frequencies at the satellite and earth station frequency translators. Doppler shifts of satellites that are not perfectly synchronized can also be significant for very low data rate transmissions. Satellite beacons used for antenna tracking or pilot signals can be used to reduce this frequency uncertainty if the beacon frequency is coherently related to the translation frequency.

Computations of the effects of inter modulation products created by satellite and earth-station nonlinearities must account for changes is the relative signal strength received at the satellite. These signal levels can change because of ground-station transmit ERP fluctuation, localized rain losses that can significantly attenuate the signal received from one earth station and not another, and antenna pointing losses at both the ground station and the satellite.

5.3 FM-FDMA TELEVISION

Televisions broadcasting via satellite in the United States is among the most highly developed in the world. TV programming is distributed on the *fixed satellite service* portion of the C and Ku bands. In 1983 the *Federal Communications Commission* approved a frequency band for domestic *direct broadcast satellite* services (DBS) to provide direct-to-home television: an uplink frequency of 17.3 to 17.8 6Hz and a downlink frequency of 12.2 to 12.7 6Hz. The DBS downlink portion of the Ku band is adjacent to the 11.7- to 12.2-6Hz downlink frequency of the P55 portion of the Ku band. High-power direct broadcast satellites have many characteristics similar to those of communications satellites, except that the DBS downlink radiated power is about 10 d13 more per transponder. The powerful television signal lets individual users receive programs with antennas as small as 0.7 m in diameter, which can be mounted on the roof of an average house. The nominal carrier-to-noise ratio is about 14 to 15 dB when used with an earth station *Gil* of 10 *dBIK*. The television receive-only terminal employs an offset-fed antenna with an efficiency in the range of 70 to *75%* and a receiver using a GaAs FET low-noise amplifier with noise figures ranging from 2.5 to 3.2 dB.

The performance of a FM-FDMA television channel is expressed in terms of the peak-to-peak luminance signal-to-noise ratio. For a sinusoidal wave, the peak-to-peak power is (2V1)2 times the rms power. Also, the peak-to-peak value of the luminance signal is I/V2 times the peak-to-peak value of the composite television signal. Therefore the *peak-to-peak luminance signal-to-noise ruth)* for a FM-FDMA television signal is

$$\left(\frac{S}{N}\right)_{p-p} = (2\sqrt{2})^2\left(\frac{1}{\sqrt{2}}\right)^2\frac{3}{2}\left(\frac{C}{N}\right)\left(\frac{B}{f_m}\right)\left(\frac{f_\Delta}{f_m}\right)^2 PW$$

$$= 6\left(\frac{C}{N}\right)\left(\frac{B}{f_m}\right)\left(\frac{f_\Delta}{f_m}\right)^2 PW$$

where C/N = carrier-to-noise ratio
P = preemphasis-deemphasis factor
W = noise weighting factor
f_Δ = peak frequency deviation
f_m = maximum frequency
$B = 2(f_\Delta + f_m)$ = Carson's rule bandwidth

Typical FM-FDMA television parameters in fixed satellite service are *B*= 36 MHz, *fm* = 4.2 MHz, *f*Δ = *B/2 —fin* = 13.8 MHz, and *PW*= 12.8 dB. For DBS television channels, typical parameters are *B* = 24 MHz,f_m= 4.2 MHz,iL = *B/2 -fm*= 7.8 MHz, and *PW* = 12.8dB. Using these parameters we can express *(S/N)p-p* in terms of *C/N* as

$$\left(\frac{S}{N}\right)_{p-p} = 40.24 + \frac{C}{N}\ (\text{dB}) \qquad \text{FSS}$$

$$\left(\frac{S}{N}\right)_{p-p} = 33.53 + \frac{C}{N}\ (\text{dB}) \qquad \text{DBS}$$

With a clear-sky carrier-to-noise ratio of 14 dB, the receiver signal-to-noise ratio for a DBS television channel is *47.5* dB. A more detailed calculation which allows for an audio sub carrier above the video base band yields a 2-dB reduction in the video *S/N.* A 45.5-dB *S/N* indicates a subjective impairment grade of approximately *4* (perceptible impairment but not annoying).

5.4COMPANDED FDM-FM-FDMA AND SSB-AM-FDMA

The transponder capacity in FDM-FM-FDMA operations can be improved by the use *of syllabic compandors.* The traditional use of syllabic compandors has been to improve the quality of signal transmission over poor channel.. A compandor consists of a compressor at the transmit side satellite channel and an expandor at the receive side. The compressor is a variable-gain amplifier that gives more gain to weak signals than to strong signals. This results in an improved overall signal-to-noise ratio because the low-level speech signals are increased in power above the aid noise. On the receive side, the expandor restores the signal's level by attenuating the low-level speech signals. During pauses in the speech signal, channel noise is reduced by the expandor, giving further improvement in the overall subjective signal-to-noise ratio. A 36-MHz transponder can accommodate a single FDM-FM-FDMA carrier of 1100..uncompaned channels. On companding the channels, the capacity is increased to about 2100 channels. With overdeviation beyond its allocated bandwidth (with no loss in the quality of the channels), such a transponder can carry about 2900 channels.

Recent use of solid-state power amplifiers with sufficiently linear characteristics to replace nonlinear TWTAs allows the use of companded single -sideband—amplitude modulation—frequency division multiple(SSB-AM-FDMA) to achieve 6000 channels per transponder of 36-MHZ bandwidth for a single carrier. Besides the high capacity, SSB-AM-FDMA offers another major advantage over FDM-FM-FDMA from a multiple access point of view. The capacity of a satellite transponder using SSB-AM-FDMA is not decreased by multiple access, unlike FDM-FM-FDMA. Also, the capacity of small FDM-FM-FDMA in cannot be increased by over deviation, because of the crosstalk among the carriers. A transponder carrying 6000 SSB-AM-FDMA channels can be accessed, say, by four earth stations with 1500 channels, each with no loss in capacity. On the other hand, a four-carrier companded FDM-FM-FDMA transponder can carry a total of about 1500 channels.

5.5 SINGLE-CHANNEL DEMAND-ASSIGNMENT TECHNIQUE

An important variation of the FDMA transmission technique is Single-Channel Per Carrier Demand-Assigned Multiple-Access (SCPC-DAMA) [Puente et al., 1972, 218—229]. The terminology refers to the fact that each carrier is modulated by a bit stream representing a single user's voice channel (Fig. 9-4). One form of SCPC. is the SPADE* system devised by COMSAT Corporation. A given earth station may transmit either none, one, or many of these single-channel carriers, depending on its traffic demand at a given time and equipment capability.

The transmit center at each terminal provides signaling information from the user interfaces to SPADE for purposes of establishing the link. The demand-assigned switching subsystem at each terminal responds to these requests for service and allocates an unused frequency to the user and notifies other terminals of its use through the common signaling channel. The voice detector gates on and off the individual PSK or QPSK carrier used for the voice channel, depending on whether the talker is active or silent. This voice detector can operate by sensing the harmonic content in voiced sounds as opposed to the more random nature of some background noise.

SPADE utilizes a single RF carrier for each 64-kbps digitized voice channel (which corresponds to a single 4-kHz voice channel sampled at 8000 samples/sec at 8 bits/sample) rather than multiplexing a large number of voice channels to form one large-bandwidth signal. QPSK at 32k symbols/sec

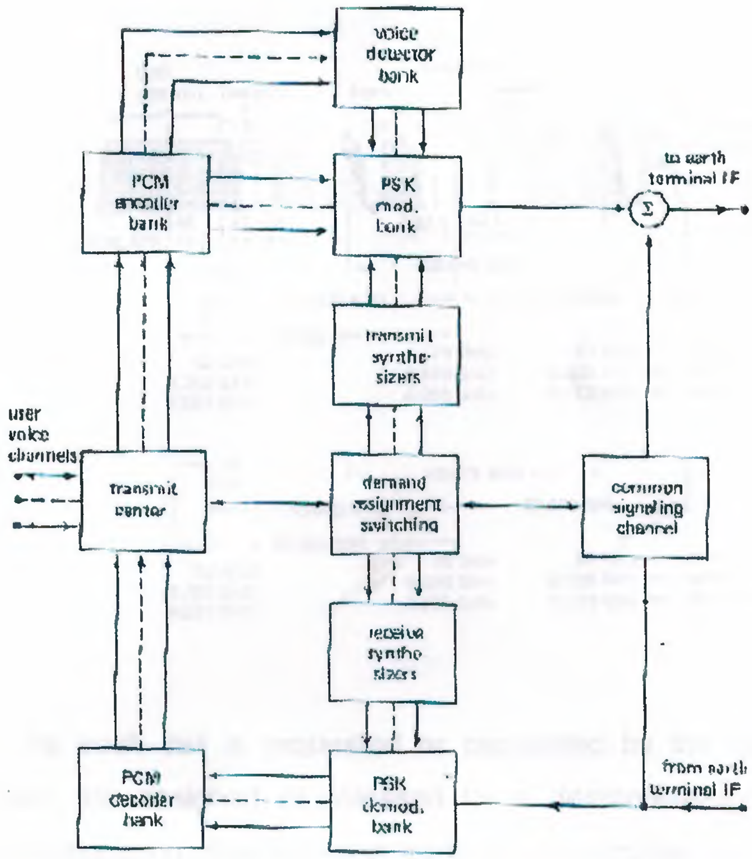
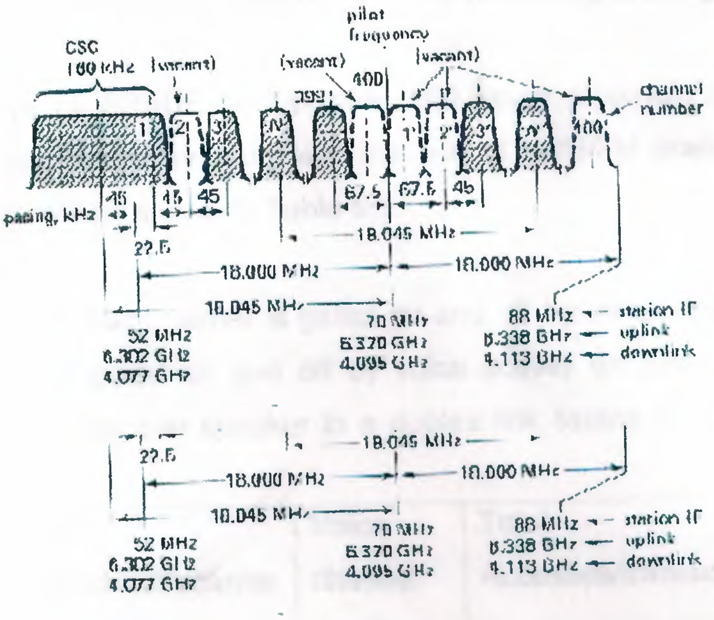


fig 5.5 simplified diagram of SPADE demand assigned multiple-access system

is used with a signal bandwidth of 38 kHz. A channel spacing of 45 kHz allows for a 7-kHz guard band between channels. The channel spacing allows for possible drifts in the satellite transponder frequency translators; however, pilot tones generated in an earth terminal provide a frequency reference that can be used by another terminal's receiver in an AFC loop to compensate for these drifts. Figure 5.5 depicts the SPADE frequency spectrum for one of the Intelsat IV 36-MHz transponders. The figure shows a total of 800 channels (400 channel pairs transmit and receive) plus a common signaling channel (CSC) at 128 kbps which is time-shared among users and is used to assign frequencies and to request channel usage.



ectrum for a 36

As each call is requested or completed by the user earth station and channels are assigned or released by a demand-assignment unit using the common signaling channel, each earth station updates a current log of available frequencies. This log is updated continually by each terminal, which monitors the common signaling channel (CSC) to determine which channels are being utilized by other terminals. The CSC is a 128 kbps PSK channel which is time-shared among all terminals by using Time Division Multiple Access (TDMA). SPADE utilizes a 50-msee frame and a l-msec access time. Thus each of the terminals in a 50-terminal network can request a channel once every 50 msec.

The earth terminal initialing the request must wait the roundtrip propagation time of 0.24 sec before the channel request is received by the destination terminal. The initiating terminal has requested at random a frequency pair of those remaining unassigned in the frequency log. If during the propagation time of the channel request another terminal requests the same frequency, the channel is considered busy and the transmitting terminal must initiate another frequency request. The random selection of a frequency channel makes it unlikely that two terminal will simultaneously request. the same channel twice in a row unless there are very few frequencies remaining unassigned.

The use of SPADE can provide 800 voice channels in a 36-MHZ. This capability compares favorably with the use of FDM/FM analog transmission for multiple carriers as shown in Table 5.1.

In addition, each carrier is gated on and off by voice activity on. In addition, each carrier is gated on and off by voice activity on each channel. Thus, the carrier is off while one speaker in a duplex link listens to the other speaker, or

Multiple access	RF bandwidth/carrier	Voice channel Carrier	Total Accesses/transponder	Total Voice channels Transponder
FDM/FM	2.5 MHZ	24	14	336
FDM/FM	5MHZ	60	7	420
SPADE	0.0045 MHZ	1	800	800

during pauses between words. This gating is accomplished by a separate voice-activity detector. For a large number of simultaneous conversations, fewer than

40 percent of the voice channels arc active at any one instant. Hence, one achieves at least a 4-dB average power advantage. The time activation by each voice signal also time gates the inter modulation products in this random manner and significantly reduces their effect. Mcclure [1970] has shown that the worst inter modulation noise is reduced by 3 dB.

To accommodate the voice activation of the carrier, each PSK or QPSK demodulator must reacquire rapidly at the beginning of each speech segment or a large initial portion of the segment will be lost. Hence, the carrier recovery must be relatively rapid, that is, within the first 10 bits.

5.6 FREQUENCY SELECTION TO REDUCE INTERMODULATION DISTORTION EFFECT

We have **dealt** primarily with the power levels in each order TM product and the total IM power in the entire fundamental zone. However, the input spectral density and input frequency selection have a substantial impact on the TM power levels falling on each signal. Frequency selection can reduce IM effects substantially.

Effects of Input Spectral Characteristics

For a large number of equally spaced carriers, the hard-limiter inter-modulation power is essentially. That is for large N,the value of the signal out put line components .are 0.78 *5P/N,* and the inter modulaticn power at the center channel is 0.1 28P/N and at the edge channel it is 0.09 12P/N. Hence, the signal-power-to-inter modulation-power ratios Ps/Pim are 7.8 and 9.35 dB for the center and edge channels, respectively, when the input signals are so closely spaced that they are essentially *continuous.* These results are valid to within 1 dB for values of *N* > *7.*A more generalized set of inputs is shown in Fig. 5.7.

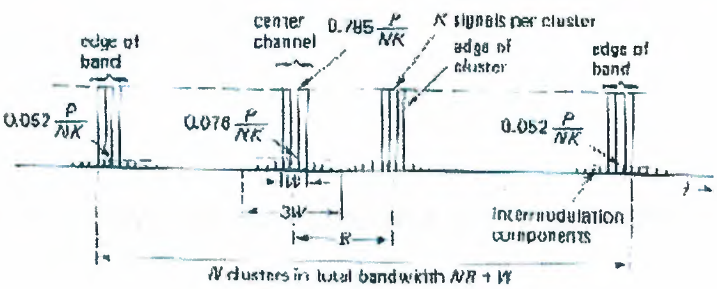


Fig 5.7 Inter modulation spectrum for N cluster of K carrier each. The spacing

between cluster is B HZ,each cluster has bandwidth W,and a cluster spacing of $B \geq 3W$ is assumed

More generally, the inter modulation spectrum can be computed by recalling that the dominant inter modulation products of each order are all of the form

IM_3 =A+B-C

OR

IM_3 =A+B+C-D-E, ETC **(5.1)**

for all possible permutations of input frequencies if substituted for A, B, C, D, E. If input frequencies are translated from IF to base band, the same relationships apply and the frequencies now occupy the positive and negative frequency range —(NB + W)/2 to +(NB +W)/2. Dominant inter modulation products can be expressed now as A + B+C+D+E, where both positive and negative frequencies $f1,f2,f3.......f_{nk}$ $f_i \leq (NB+W)/2$ are selected without replacement .(sincc A =B = C) and substituted for A,B,C,D,E

Thus, determination of the spectral distribution of inter modulation products of each order **M** for equal-amplitude inputs is reduced to exactly the same problem as calculating the amplitude probability distribution of the sum of M random inputs taken from *NK* locations without replacement.

For *N* uniformly spaced equal-amplitude signals within a cluster, the discrete inter modulation spectrum of order *M* at frequency $f_n = n$, *for* $n < NM/2$ and unity frequency spacing, is

$$Q_M(n) = \sum_{i=0}^{I(y)} (-1)^i \frac{M!}{(M-i)!(i!)} \frac{(y-i)^{M-1}}{N(M-1)!}$$

where $y \; \Delta (M/2 - n/N)$ and the upper limit of the summation $I(y)$ is the largest integer< y.

Define $Q_c(x)$ as the input cluster distribution for *N* clusters of discrete line components. If each cluster is spaced by *B* Hz, then the total input spectral distribution for N odd at frequency n is

$$Q_T(n) = \frac{1}{N}\sum_{k=-(N-1)/2}^{(N-1)/2} Q_c(n - kB)$$

The resulting discrete line spectrum of inter modulation components of order M *for* this set of signal clusters is obtained using the characteristic function method,

$$Q_{MT}(n) = \frac{1}{N^M}\sum_{k=-M(N-1)/2}^{M(N-1)/2} A_{Mk} Q_{cM}(n - kB)$$

wherc Q~M is the Mth-order inter modulation component distribution of an individual clusterwherc Q~M is the Mth-order inter modulation component distribution of an individual cluster. The coefficients .4 ~ are derived from the generating functions

$$\left[\sum_{i=-(N-1)/2}^{(N-1)/2} x^i\right]^M = \sum_{k=-M(N-1)/2}^{M(N-1)/2} A_{Mk} x^k$$

—

and

$$\sum_{k=-M(N-1)/2}^{M(N-1)/2} A_{Mk} = N^M$$

The distribution of inter modulation products thus obtained from (9-85) is the weighted sum of the cluster inter modulation products each offset by B Hz from the others.

Figure 5.8 shows the 'variation of total inter modulation power at the center *frequency channel in the central cluster as a function of cluster frequency* spacing *B*. The cluster frequency spacing is uniform. This central channel is the worst channel in the band. The power in units of PINK varies from 0.128 for equal spacing *B* =W and no guard space between channels, to 0.077 for large spacing *B* <*W* between channels. Spacing of *B* = *2W* yields nearly full improvement with a 2-to-l increase in bandwidth. Thus, as channel spacing increases above *B* = W, the inland signal-to-total inter-modulation-power ratio increases from 8.9 dB to a maximum of 11.19dB at the center channel.

Almost all of the 2.29-dB improvement comes by increasing *B* to 1Wvery little further improvement is gained by larger increases in the frequency spacing *B*.Consider now a set of contiguous channels of bandwidth *B*. If the clusters are of bandwidth selected in center frequency from one edge of the B-Hz channel to the other, the inter modulation spectrum remains exactly the same as above for a sufficiently large number of clusters *N*. However, only a fraction *W/B* of the inter modulation power is passed through the receive channel band pass filter (bandwidth W). Hence, by increasing the total bandwidth of each channel *B* above *W* Hz and randomly selecting the position within the channel the center channel signal to IM power ratio increases by the factor B/W to

$$\frac{P_1}{P_{IM}} = 7.8\ \text{dB} \quad 10 \log\left(\frac{B}{W}\right) \text{dB}$$

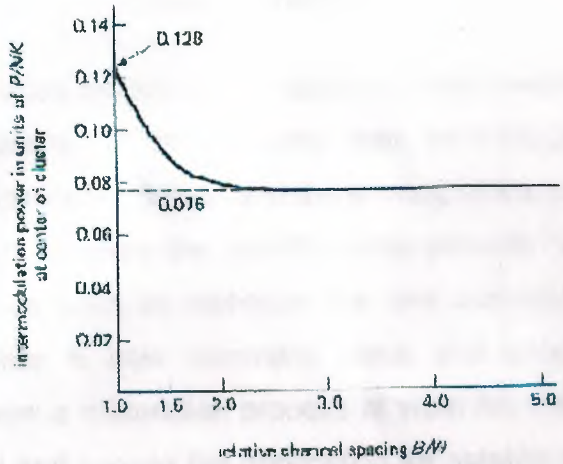


Fig 5.8 Inter modulation power at the central in the center cluster for a hard limter.Channel spacing is B,the cluster bandwidth is W,and there are a total of NK equal amplitude input sinusoids.

for a total transmission bandwidth of *NB* Hz and a total input information bandwidth of NWHZ,As an example, if *B/W* = *4.* then **Ps/Pin=**13.8 dB. Thus this approach gives a valuable improvement in performance.

Deterministic Frequency Assignments

Suppose that *N* fixed-frequency sinusoids are to be packed in a channel of bandwidth *MB* where *B* Hz is assigned to each signal channel. By neglecting IM-product spreading and testing all input frequency choices, one can compute the minimum bandwidth required to avoid completely third- or third- and fifth-order cross products. These results for the minimum bandwidth required were obtained by Babcock [1953, 63—73], who also determined the frequency spacing required. The results are plotted. Note that for ten channels to be free of third-order cross products one requires an RF bandwidth 60B,even when IM product spreading is neglected. Thus for a transponders channel occupied by a large number of carriers, complete avoidance of third order IM product is often im-practical.

Conclusion

In satellite communication system and application have always been evolutionary in nature. The beginning of the industry was technology driven, with the development of the spacecraft design and the proving of it's feasibility in the early 1960.In approximation 15 years the satellite communication industry has clearly come along way. Once seen as technical feat and curiosity, the geostationary communication satellite is now command place and indispensable in many sector. There has been a maturation process at work firs the technology had to be made economical and second the application for satellite communication had to prove themselves in a competitive.

Satellite communication at the end of the century and in that coming will provide many services currently available most television coverage travels by satellite, even reaching directly to the home space.

Satellite has a unique capability for providing coverage over large geographicalareas.The resulting interconnectivity between communication source provides major advantage in Telephone Exchange, Mobil Communication, Television and sound broadcast directly to the public.

Frequency Division Multiple Access (FDMA) first generation telecommunication system such as advanced Mobil phone service only provided voice communication. They also suffered from low user capacity and security problems due to the simple radio interface used.

Multiple accesses is the process by which a large number of earth station interconnect their links through a satellite. In frequency division multiple access (FDMA) stations are separated by frequency, while in Time Division Multiple Access (TDMA), they are separated in time.

FDMA with frequency division multiplexing and FM modulation (FDM/FM/FDMA) is oldest and currently the most widely used multiple accesses.

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