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GRADUATION PROJECT

"SATELLITE COMMUNICATION"

SUBMITTED BY:-

MUTASEM ABDELHADI

SHADI AL SHAAR

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CONTENTS

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PREFACE

Satellite communication has evolved into an every day, common place thing. Most television coverage travels by satellite, even reaching directly to the home from space. The bulk of transoceanic telephone and data communication also travels by satellite.

Because of these and more, we prefer to choose our project's subject as 'Satellite Communication.'.

However, the word 'Satellite' used in this project means the spacecraft in outer space providing linking between earth stations.

Satellite communication is very wide field, and it can not be covered even by one book. So, you can find a lot of books talking about this subject and each book has its own point of view.

One of the mean objectives of this project is to give the reader enough of understanding to allow him or her to ask the right question.

As we are doing this project to cover the important subject for a student studying such a vital field, we have found that the following chapters are most commonly useful and helpful for satellite communication student.

Chapter 1 'Introduction to satellite communication' identifies the key feature of satellite communication and reviews the origins and history of it. Chapter 2 'Link analysis' determine the signal-to-noise ratio at the input. This ratio depends on characteristics of the transmitter, transmission medium, and receiver. Chapter 3 'Transmission techniques for a satellite channel', it deals with techniques which enable signals to be sent from one user to another. Chapter 4 'Application of satellite network', the ways in which satellite links can be applied to practical communication problems are described in some detail. Chapter 5 'Reliability of satellite communications systems', investigate the reliability of complete satellite communication system which consist of two principle constituents; the satellite and the ground station. Chapter 6 'Future directions of satellite communication' makes a reasonable projection into the future, using today's technologies and applications as base. Therefore chapter 6 is quite conservative, since we have not yet thought of some of the important uses to come. Chapter 7 'Special problems in satellite communications' is an especially interesting chapter dealing with some problems unique to satellite communication. Attention is given to the problems inherent in echo control and coding that are aggravated by the long time delay. This earth-station-to-earth-station delay is an undesirable feature of satellites at geostationary altitude. It gives rise to interesting and important difficulties, notably in data transmission and echo control.

Finally, we should mention that we include the figures, photos and, tables in separates appendixes. Consequently they are:

Appendix A for Figures, Appendix B for Photos, and Appendix C for Tables.

CHAPTER 1

INTRODUCTION TO SATELLITE COMMUNICATION

Satellite telecommunication are now part of our environment. Every day we receive and transmit information by satellite, often without knowing it. The availability of the service is high and can be as high as 99.5%. The difficulty of the enterprise should not be forgotten; failure of the launcher and failure of the satellite are formidable and much feared dangers in this context. Satellite telecommunication will have to face the increasing competition of fiber optic ground network in the next 10 to 20 years. Installation of these networks has started and, in time, the most industrialized countries will be entirely cabled. Such networks offer both wide bandwidth and high capacity; these features have so far been characteristic of satellites. In this context, one could imagine that the satellites will be integrated into such networks and will appear as supporting elements to improve security within the ground network of wide area network links. However, one can also imagine that competition will force the operators of satellite systems to offer specialized services which will use the characteristics of satellite communication more specifically; examples are broadcasting and data collection, access to mobile vehicles, radio location and so on.

Whatever, the assumption, one can be assured that satellite will continue to occupy an important place as a means of communication.

1.1 THE BIRTH OF SATELLITE COMMUNICATION SYSTEMS

Radio communication by satellite is the outcome of research in the area of communications whose objectives is to achieve ever increasing ranges and capacities with the lowest possible costs. The Second World War favored the expansion of two very distinct technologies-missiles and microwaves. The expertise eventually gained in the combined use of these two techniques opened up the era of satellite communication. The service provided in this way usefully complements that previously provided exclusively by ground networks using radio and cables. The space era started in 1957 with the launching of the first artificial satellite (Sputnik). Subsequent years have been marked by various experiments including the following:-

Christmas greetings from President Eisenhower broadcast by **SCORE** (1958), the reflecting satellite **ECHO** (1960), wideband repeater satellite (**TELSTAR** and **RELAY** in 1962) and the first geostationary satellite **SYNCOM** (1963). In 1965, the first commercial geostationery satellite **INTELSAT I** (or **Early Bird**) inaugurated the long series of INTELSATs; in the same year, the Soviet communication satellite of the **MOLNYA** series was launched.

1.2 GEOSTATIONARY SATELLITES

1.2.1 SYNCOM:

In 1959, Harlod A.Rosen and his two colleagues at Hughes Aircraft Company, Tom Hudspeth and late Don Williams, identified the key technologies for a simple and lightweight active repeater communication satellite for launch into **GEO**. The basic concept used a drum-shaped spinning body for stability with tiny gas jets to alter the attitude in space, as shown in photo 1.1 in appendix B . This team, working at Hughes Laboratories in Los Angeles, California, built a working prototype in 1960 which demonstrated the feasibility of spin stabilization and microwave communication. Supported by Allen Puckett, then Vice President and now retired Chairman of the Broad of Hughes Aircraft, they convinced **NASA** and the Department of Defense to go ahead with the launch of **SYNCOM**, an acronym meaning 'synchronous orbit communication satellite'. On the second attempt launch of the Delta rocket in July 1963, **SYNCOM II** became the first operational geosynchronous satellite providing intercontinental communication. The first transoceanic live T.V broadcasts ever were carried on **SYNCOM**, because undersea cables did not have the bandwidth to pass a T.V signal in real time.

1.2.2 COMSAT:

The idea of going into the commercial communication business based on the use of satellite can be attributed to the administration of President John F.Kennedy, which issued ground rules in 1961 for the US operation of an international communication satellite system. President Kennedy favored private ownership and operation of the US portion of an international system which would be benefit all nations of the world, large and small. The communication Satellite Act of 1962 resulted from this initiative, establishing the character for the Communication Satellite corporation (**COMSAT**). This company developed a workable satellite system and helped to encourage worldwide expansion.

COMSAT raised money through the sale of common stock both to the public and to the US common carriers, particularly **AT&T**. At the time, it was assumed that sub-synchronous satellite would be used for basically two reasons.

First, the US communication companies felt that the time delay associated with the propagation of radio waves which travel at the speed of light (approximately one-quarter second for the uplink and downlink combined) would prove to be unacceptable to a significant percentage of telephone subscribes; and, second there existed a lingering doubt about the viability of the technology necessary solved when **SYNCOM** demonstrated the feasibility and quality of synchronous orbit satellite communications.

1.3 DEVELOPMENT

1.3.1 OVERLOOK:

The first satellite system provided a low capacity at a relative high cost; for example, **INTELSAT I** weighed 68Kg at launch for a capacity of 480 telephone channels and an annual cost of $32,500 per channel at the time. This cost resulted from a combination of the cost of the launcher, that of the satellite, the short life time of the satellite (1.5 years) and its low capacity. The reduction in cost is the result of much effort which has led to the production of reliable launchers which can put heavier and heavier satellites into orbit (3750Kg at launch for **INTELSAT VI**). In addition, increasing expertise in microwave techniques has enabled realization of contoured multibeam antennas whose beams adapt to the shape of continents, reuse of the same band of frequencies from one beam to the other and incorporation of higher power transmission amplifiers. Increased satellite capacity has led to a reduced cost per telephone channel (80000 channels on **INTELSAT VI** for an estimated annual cost per channel of $380 in 1989).

In addition to the reduction in the cost of communication, the most outstanding feature in the diversity of services offered by satellite telecommunication systems. Originally these were designed to carry communications from one point to another, as with cables, and the extended coverage of the satellite was used to advantage to establish long distance links; hence **Early Bird** enabled stations on opposite sides of the Atlantic ocean to be connected. As a consequence of the limited performance of the satellite, it was necessary to use earth station equipped with large antennas and therefore of high-cost (around $10 millions for a station equipped with a 30m diameter antenna). The increasing size and power of satellite has permitted a consequent reduction in the size of earth station, and hence the cost, with a consequent increase in number. In this way it has been possible to exploit another feature of the satellite which is its ability to collect or broad cast signals or to several locations. Instead of transmitting signals from one point to another, transmission can be from a signal transmitter to a large number of receivers distributed over a wide area or, conversely transmission to a large number of station often called a hub. In this way multipoint data transmission networks, satellite broadcast networks and data collection networks have been developed. Broadcasting can be either to relay transmitters (or cable heds)or directly to the privet consumer (the latter are commonly called direct broad cast by satellite television systems).These network operate with small earth stations having antennas with a diameter between 0.6 and 3.5 m at a coast between $500 and $50 000.

1.3.2 *EVOLUTION OF INTERNATIONAL SATELLITE SYSTEM:*

Clearly the first and most demonstrable need for the commercial satellite was to provide international communication links. The term 'telecommunication' is used internationally in reference to communication services offered to the public using electrical and radio means. Telecommunication companies in various countries can be privately owned or government controlled (which is usually the case as with the domestic postal service). The following paragraphs outline the evolution of the now well established international satellite system.

1.3.2.1 Early Bird:

In march of 1964, **COMSAT** contracted with Hughes Aircraft Company for the construction of two spin *stabilized satellites* using **C** band (**SYNCOM** used **S** band which was authorized only for **NASA** experimentation). **Early Bird**, the well recognized name for this first commercial satellite, launched in the spring of 1965, worked perfectly for six years, well past its design life of two years. The second spacecraft was never launched and now resides in the Air and Space Museum of the Smithsonian Institution in Washington, D.C. **Early bird** was positioned over the Atlantic Ocean and was first used to link stations in Andover, Maine, and Goonhilly Downs, England, providing voice, telex, and T.V service.

1.3.2.2 INTELSAT:

The intended international nature of the system led to **COMSAT** establishing a new organization called the International Telecommunications Satellite Consortium (**INTELSAT**). Later, the word 'Consortium' was change to 'Organization', and **INTELSAT** grew to become the preeminent satellite operator in the world. In the discussion of generations of **INTELSAT's** satellites, only the first letter is capitalized to distinguish the name of a satellite series from the name of the organization.

Intelsat I, II, and III:

The formal name adopted for Early Bird was Intelsat I, being the first generation of satellite employed by **INTELSAT**. Generations II through VI are reviewed in the following paragraph and Fig 1.1 in Appendix A illustrates the relative size of each design. Intelsat II and III were precursors to the establishment of satellite as the primary means of international communication.

The design of the spacecraft was similar to Early Bird with the exception that transmitter power was increased by supporting it with more solar cells and batteries. Intelsat I and II employed a simple antenna which radiated the signal 360° around the satellite as it spun.

An innovation in the Intelsat III spacecraft, built by **TRW** of Redondo Beach, California, was the despinning of a directional antenna abroad the satellite so as to maintain a more intense beam on the earth. This type of global coverage beam allows access to the satellite repeater by any earth station which lies within the hemisphere facing the satellite orbital position. A common characteristic of these three types was their limited capacity in terms of the number of individual transmitter, since electrical power generated by their small solar panels could only support one or two power amplifiers.

Intelsat IV:

The big setup in satellite capability happened with the introduction of the Hughes Aircraft built Intelsat IV, a spacecraft many times larger than its commercial forerunners. A photograph of the assembled Intelsat IV spacecraft is shown photo 1.2. Intelsat IV employed the same basic spacecraft configuration as a military satellite called Tacsat. A major innovation came in the way the repeater and antenna were attached. Instead of spinning the repeater with the spacecraft and despinning the antenna, the repeater with antenna were despun as a package. With considerably more power and communication equipment, the **C-band** repeater on Intelsat IV contained 12 individual channel of approximately 36MHz each. The selection of the now standard 36MHz **RF** bandwidth resulted from the technical tradeoff involving the bandwidth required for a single TV channel using frequency modulation and the maximum number of amplifiers that could be carried and powered.

The first Intelsat IV was launched in 1971, and a total of seven have each provided ten or more years of service, only one Intelsat IV was lost and that was due to failure in 1975 of the Atlas Centaur rocket to reach orbit.

INTELSAT saw the need to go beyond the design of Intelsat IV to match network growth in the Atlantic Ocean Region (**AOR**). The 1970 traffic requirements of 50 earth stations which exceed the capability of one Intelsat IV. The solution was the frequency reuse which doubles the 500MHz of allocated bandwidth at the satellite by directing two independent beams towards the visible face of the earth. The re designated Intelsat IV-A spacecraft design contained nearly 24 transponders of equivalent capability, with half connected to each of two hemispherical beams - one directed at North America and the other at Europe and Africa.

Intelsat V:

Because of continued expansion of the **INTELSAT** system, both in terms of the number of member-users and of the traffic demands, Intelsat found that the problem of traffic overload in the **AOR** and also the Pacific Operation Region (**POR**) required another doubling of capacity per satellite. The 14/11 Ghz portion of **Ku** band was selected as the means of carrying heavy links in the two regions, freeing up the **C**-band for general connectivity among countries.

The first Intelsat V was launched in 1980. The **C**-band repeater on Intelsat V is very similar to that of Intelsat IV-A with the exception that frequency reuse was taken to another dimension with the use of polarization discrimination. A modification to Intelsat V, called the V-A, added a payload package for maritime communication similar to that provided by the Marisat. Altogether, 12 Intelsat V/V-A satellite were constructed, and these satellite have taken over the bulk of international satellite communication during the 1980s.

Intelsat VI:

Presented in photo 1.3 is a photograph of Intelsat VI, the largest commercial satellite ever built. Conceived in the late 1970s to provide for the widest possible expansion of international satellite services, the massive Intelsat VI spacecraft promises to continue the monotonic decline in cost per circuit. As Intelsat V, Intelsat VI is hybrid design (**C** and **Ku** bands), but frequency reuse has been carried to an even greater stage in order to triple the capacity of the satellite as compared to Intelsat V/V-A. A new feature in the form of on board switching of traffic is incorporated; this increases the efficiency of providing high capacity links to allow their configuration with minimal effect on the earth stations. The Intelsat VI program is the means for continued expansions of **INTELSAT** through the 1990s.

1.3.2.3 Alternatives to INTELSAT:

The Soviet Union has used subsynchronous Molnoya satellite since late 1960s for domestic communication and during 1970s began to promote an international system called Inter Sputnik. Membership has nearly been limited to countries in the eastern block, and, over time, synchronous satellite named Statsionar have come into usage. Direct competition with **INTELSAT** is on the horizon in the form of private US companies which wish to offer trans-Atlantic and transpacific services. As of 1987, none of these potential new entrants have begun operation, but some form of competition with **INTELSAT** is expected to appear.

1.4 THE ARCHITECTURE OF A SATELLITE COMMUNICATIONS SYSTEM

Fig 1.2 shows the various components of a satellite communication system. It comprises a ground segment and a space segment.

1.4.1 the space segment:

The space segment contains the satellite and all terrestrial facilities for the control and monitoring of the satellite. This includes the tracing, telemetry and command stations (TT&C) together with the satellite control center where all the operations associated with station-keeping and checking the vital functions of the satellite are performed.

The radio waves transmitted by the earth stations are received by the satellite; this is called the uplink. The satellite in turn transmits to the receiving earth stations; this is the downlink. The quality of a radio link is specified by its carrier-to-noise ratio. The parameters involved are discussed in Chapter 2 which is devoted to link analysis. The important factor is the quality of the total link, from station to station, and this is determined by the quality of the up link and that of the downlink. The quality of the total link determines the quality of the signals delivered to the end user in accordance with the type of modulation and coding used. These aspects are discussed in Chapter 3 which deals with transmission techniques over a satellite channel.

The satellites forms a mandatory point of passage of a group of simultaneous links. In this sense, it can be considered as the nodel point of the network. access to the satellite, and to a satellite transponder, by several carriers implies the use of specific techniques, called multiple access techniques. The mode of operations of these techniques differ between a satellite with beam (monobeam satellite) and one of several beams (multibeam satellite).

The satellite consists of payload load and platform. The play load consists of the receiving and transmitting antennas and all the electronic equipment which supports the transmission of the carriers. The platform consists of all subsystems which permit the payload to operate. These includes:-

1. Structure.
2. Electric power supply.
3. Temperature control.
4. Attitude and orbit control.
5. Propulsion equipment.
6. Tracking, telemetry and command (**TT & C**) equipment.

The satellite has a dual role:-

1. To amplify the received carriers for retransmission on the downlink. The carrier power at the input of the satellite receiver is of the order of 100pW to 1nW. The carrier power at the output of the transmission amplifier is of the order of 10 to 100W. The power gain is thus of the order of 100 to 130dB.
2. To change the frequency of the carrier to avoid reinjection of a fraction of the transmitted power into the receiver; the reinjection capability of the input filters at the downlink frequency combines with the low antenna gains between the transmitting output and the receiving input to ensure isolation of the order of 150dB.

To fulfill its function the satellite can operates as a simply relay. The change in frequency is achieved by means of a frequency converters. This is the case with all currently operational commercial satellites. One speaks of 'transparent' or ' conventional' satellites. However a new generation of satellites (starting with **ACTS** and **ITALSAT**) is emerging. They called 'regenerative' satellites and are equipped with demodulators; baseband signals are, therefore, available on board. The change in frequency is achieved by modulating a new carrier for the downlink. The dual operation of modulation and demodulation can be accompanied by processing of the baseband signal with varying levels of complexity.

To ensure a service with a specified availability, a satellite communication system must make use of several satellite in order to ensure redundancy. A satellite can cease to be available due to a failure or because it has reached the end of its lifetime. In this respect it is necessary to distinguish between the reliability and the lifetime of a satellite. reliability is a measure of the probability of a breakdown and depends on the reliability of the equipment and any schemes to provide redundancy. The lifetime is conditioned by the ability to maintain the satellite on station in the nominal attitude, that is the quantity of fuel available for the propulsion system and attitude and orbit control. In a system provision is generally made for an operational satellite, a backup satellite in orbit and a backup satellite on the ground. *We will discuss this problems in chapter 5 .*

1.4.2 The ground segment:

The ground segment consists of all the earth stations; these are most often connected to the end-user's equipment by a terrestrial network or, in the case of small stations (Very Small Aperture Terminal, **VSAT**), directly connected to the end-user's equipment. Stations are distinguished by their size which varies according to the volume of traffic to be carried on the space link and the type of traffic (telephone, television, or data). The largest are equipped with antennas of 30m diameter *(Standard A of the* ***INTELSAT*** *network). The* smallest have 0.6m antennas (direct television receiving station). Fixed, transportable and mobile stations can also be distinguished. Some stations are both transmitters and receivers. Others are only receivers; this the case, for example with receiving stations for a satellite broadcast system or a distribution system for television or data signals. Fig 1.3 shows the typical architecture of an earth station for both transmission and reception.

1.5 TYPES OF ORBIT

The orbit is the trajectory followed by the satellite in equilibrium of two opposing forces fig 1.4. These are the force of attraction, due to the earth's gravitation, directed towards the center of the earth and the centrifugal force associated with curvature of the satellite's trajectory. The trajectory is within a plane and shaped as an ellipse with a maximum extension at the apogee and a minimum at aperigee. The satellite moves more slowly in its trajectory as the distance from the earth increases.

The most favorable orbits are follows :

1. Elliptical orbits inclined at angle of 64° with respect to the equatorial plane, This type of orbit is particularly stable with respect to irregularities in terrestrial gravitational potential and, owing to its inclination, enables the satellite to cover regions of high latitude for a large fraction of the orbital period as it passes to the apogee. This type of orbit is particularly useful for satellite systems for communication with mobile where the masking effect caused by surrounding obstacles such as buildings and trees and multiple path effects are pronounced at low elevation angle (less than 30°). In fact, inclined elliptic orbits can provide the possibility of links at medium latitudes when the satellite is close to the apogee with elevation angle close to 90°; these favorable conditions cannot be provided at the same latitudes be geostationery satellite. This type of orbit has been adopted by the USSR for the satellite of the **MOLNYA** system with a period of 12 hours.

2. Circular inclined orbits, The altitude of the satellite is constant and equal to several hundreds of kilometers. The period of the order of 1.5 hours. With near 90° inclination, this type of orbits guarantees that the satellite will pass over every region of the earth. This the reason for choosing this type of orbits for observation satellites. Several systems with worldwide coverage using constellations of satellite carriers in low altitude circular orbits have been proposed recently such as (**GLOBAL STAR**, **ARIES**, **STARNET**,etc).
3. Circular orbits with zero inclination (equatorial orbits), The most popular is the geostationary satellite orbit, the satellite orbits around the earth at an altitude of 35,786 km. and in the same direction as the earth. The period is equal to that of the rotation of the earth and in the same direction. The satellite thus appears as a point fixed in the sky and ensures continuous operation as a radio relay in real time for the area of visibility of the satellite (43% of the earth's surface).

The choice of orbit depends on the nature of the mission, the acceptable interference and the performance of the launchers briefly is:-

1) The extent and latitude of the area to be covered, the altitude of the satellite is not a determining factor in the link budget for a given earth coverage. The geostationary satellite thus appears to be particularly useful for continuous coverage of extensive regions. However, it does not permit coverage of the polar regions which are accessible by satellite in inclined elliptical orbits or polar orbits.
2) The elevation angle of earth stations, with a geostationary satellite, the angle of elevation decreases as the difference in latitude or longitude between the earth station and the satellite increases.
3) Transmission duration and delay, the transmission time is low between station which are close and simultaneously visible to the satellite, but it can become long for several hours for distant stations if only store-and-forward transmission is considered.
4) Interference, geostationary satellite occupy fixed positions in the sky with respect to the station with which they communicate. Protection against interference between systems is ensured by planning the frequency bands and orbital positions.
5) The performance of launchers, the mass which can be launched decreases as the altitude increases.

1.6 DEVELOPMENT OF SERVICES

Three classes of services can now be distinguished as follows:-

1. Trunking telephony and television program exchange, this is a continuation of the original service. The traffic is collected and distributed by the ground network on a scale appropriate to the country concerned. Examples are **INTELSAT** and **EUTELSAT** (**TDMA** network); the earth stations are equipped with 15 to 30m diameter antennas.
2. 'Multiservices' systems, telephone and data for user groups who are geographically dispersed. Each group shares an earth station and accesses it through a ground network whose extent is limited to one district of a town or an industrial area. Examples are **TELECOM 1**, **SBS**, **TELE-X**; the earth station are equipped with antennas of 3 to 10m diameter.
3. Very Small Aperture Terminal **(VSAT)** systems, low capacity data transmission (uni or bi-directional), T.V or digital sound program broadcasting. Most often, the user is directly connected to the station. Examples of such networks are: **EQUATORIAL**, **INTELNET** and so on; the earth station are equipped with antennas of 0.6 to 1.2m diameter. Mobile users can also be included in this category.

CHAPTER 2

LINK ANALYSIS

This chapter deals with the transmission of radio waves between two earth stations, one transmitting and one receiving, via a satellite. In this context, the link consists of two sections, the uplink from the station to the satellite and the downlink from the satellite to the receiving earth station.

The aim of the chapter is to determine the signal-to-noise ratio at the receiver input. This ratio depends on the characteristics of the transmitter, the transmission medium and the receiver. The uplink and downlink are first considered separately. Then the expression for the signal-to-noise ratio for the complete link between the two earth stations established.

In this chapter, the term '**signal**' relates to the carrier modulated by the information content. It will be assumed that the frequency of the carrier is between 1Ghz and 30Ghz since this corresponds to the majority of present and future applications to the end of this century.

2.1 THE CHARACTERISTIC PARAMETERS OF AN ANTENNA

2.1.1. *Gain:*

The gain of an antenna is the ratio of power radiated per unit solid angel by the antenna in a given direction to the power radiated per unit solid angle by an isotropic antenna fed with the same power. The gain is maximum in the direction of maximum radiation and has a value given by:

$$G_{\max} = \left(4\pi/\lambda^2\right) A_{eff} \tag{2.1}$$

where λ =c/f and c is the velocity of light and f is the frequency of the electromagnetic wave. A_{eff} is the equivalent electromagnetic surface area of the antenna. For an antenna with a circular aperture or reflector of diameter D and geometric surface $A = \pi D^2/4$, $A_{eff} = \eta A$, where η is the efficiency of the antenna. Hence:

$$G_{\max} = \eta\,(\pi D/\lambda)^2 = \eta\,(\pi\, Df/c)^2 \tag{2.2}$$

The actual antenna gain in dB can be expressed as:

$$G_{\max,dB_i} = 10\log\eta\,(\pi D/\lambda)^2 = 20\log\eta\,(\pi Df/c) \quad (dB)$$

The global efficiency η of the antenna is the product of several factors which take account of the illumination law, spill-over loss, surface impairments, resistive and mismatch losses etc.:

$$\eta = \eta_i \times \eta_s \times \eta_f \times \eta_z \ldots\ldots \tag{2.3}$$

The illumination efficiency hi specifies the illumination law of the reflector with respect to uniform illumination ($\eta_i = 1$) leads to a high level of secondary lobes. A compromise is achieved by attenuating the illumination at the reflector boundaries (aperture edge taper).

The spill-over efficiency hs is defined as the ratio of the energy radiated by the primary source which is intercepted by the reflector to the total energy radiated by the primary source. The difference constitutes the spill-over energy. The larger the angle under which the reflector is viewed from the source, the greater the spill-over efficiency. However, for a given source radiation pattern, the illumination level at the boundaries becomes less with large values of view angle and the illumination efficiency collapses.

The surface finish efficiency η_f takes account of the effect of surface impairments on the gain of the antenna. The actual parabolic profile differs from the theoretical one.

2.1.2 *The radiation pattern:*

The radiation pattern indicates the variation of gain with direction. For an antenna with a circular aperture or reflector this pattern has rotational symmetry and is completely represented within a plane in polar co-ordinate form Fig 2.1a or Cartesian co-ordinate form Fig 2.1b. The main lobe which contains the direction of maximum radiation and the side lobes can be identified.

2.1.3 *The angular beamwidth:*

This is the angle defined by the directions corresponding to a given gain on Fig 2.1a by θ_{3dB} is very often used. The 3dB beamwidth corresponds to the angle between the directions in which the gain falls to half its maximum value. The 3dB beamwidth is related to the ratio l/D by a coefficient whose value depends on the chosen illumination law. For uniform illumination, the coefficient has a value of 58.5°. With non-uniform illumination laws, which lead to attenuation at the reflector boundaries, the 3dB beamwidth increases and the value of the coefficient depends on the particular characteristics of the law. The value currently used is 70° which leads to the following expression:

$$\theta_{3dB} = 70(\lambda/D) = 70(c/fD) \qquad \text{(degree)} \qquad (2.4)$$

In direction α with respect to the boresight, the value of gain is given by:

$$G(\alpha)_{dB} = G_{\max,dB} - 12(\alpha/\theta_{3dB})^2 \quad (dB) \qquad (2.5)$$

This expression is valid only for sufficiently small angles (between 0 and $\theta_{3dB}/2$). Combining expression 2.2 and 2.4, it can be seen that the maximum gain of an antenna is a function of the 3-dB beamwidth and this relation is independent of frequency:

$$G_{\max} = \eta\,(\pi Df/c)^2 = \eta\,(\pi\, 70/\theta_{3dB})^2 \qquad (2.6)$$

2.2.4 Polarization:

The wave radiated by an antenna consists of an electric field component and a magnetic field component. These two components are orthogonal and perpendicular to the direction of propagation of the wave. They vary with the frequency of the wave. By convention, the polarization of the wave is defined by the direction of the electric field. In general, the direction of the electric field is not fixed and its amplitude is not constant. During one period, the projection of the extremity of the vector representing the electric field onto a plane perpendicular to the direction of propagation of the wave describes an ellipse; the polarization is said to be elliptical (Fig 2.2).

Polarization is characterized by the following parameters:

- Direction of rotation with respect to the direction of propagation, clockwise or counter-clockwise.
- Axial ratio AR: AR = E_{max}/E_{min}, that is the ratio of the major and minor axes of the ellipse.
- Inclination τ of the ellipse.

Two waves are in orthogonal polarization if their electric fields describe identical ellipses in opposite directions. In particular, the following can be obtained:

- Two orthogonal circular polarizations described as clockwise circular and counter-clockwise circular.
- Two orthogonal linear polarizations described as horizontal and vertical.

An antenna designed to transmit or receive a wave of given polarization can neither transmit nor receive in the orthogonal polarizations. This property enables two simultaneous links to be established at the same frequency between the same two location; this is described as frequency re-use by orthogonal polarization. To achieve this either two polarized antennas must be provided at each end or, preferably, one antenna which operates with the two specified polarizations may be used. This practice must, however, take account of imperfections of the antennas and the possible depolarization of the waves by the transmission medium. These effects lead to mutual interference of the two links.

2.2 THE POWER EMITTED IN A GIVEN DIRECTION

2.2.1 Equivalent isotropic radiated power (EIRP):

The power radiated per unit solid angle by an isotropic antenna fed from a radio-frequency source of power P_T is given by:

$P_T/4\pi$ (W/steradian)

In a direction where the value of transmission gain is G_T, any antenna radiates a power per unit solid angle equal to :

$G_T P_T/4\pi$ (W/steradian)

The product $P_T G_T$ is called the 'equivalent isotropic radiated power' (EIRP). It is expressed in W.

2.2.2 Power flux density (Fig 2.3):

A surface of effective area A situated at a distance R from the transmitting antenna subtends a solid angle A/R^2 at the transmitting antenna. It receives a power equal to :

$$P_R = \left(P_T G_T/4\pi\right)\left(A/R^2\right) = \Phi A \quad \text{(W)} \tag{2.7}$$

The magnitude $F = P_T G_T/4\pi R^2$ is called the ' power flux density'. It is expressed in W/m^2.

2.3 RECEIVED SIGNAL POWER

2.3.1 Power received by the receiving antenna (Fig2.4):

A receiving antenna of effective area A_{eff} located at a distance R from the transmitting antenna receives a power equal to :

$$P_R = \Phi A_{Reff} = \left(P_T G_T / \pi R^2\right) A_{Reff} \quad \text{(W)} \qquad (2.8)$$

The equivalent area of an antenna is expressed as a function of its receiving gain G_R by the expression:

$$A_{Reff} = G_R / \left(4\pi / \lambda^2\right) \quad (m^2) \qquad (2.9)$$

Hence an expression for the received power:

$$\begin{aligned} P_R &= \left(P_T G_T / 4\pi R^2\right)\left(\lambda^2 / 4\pi\right) G_R \\ &= \left(P_T G_T\right)\left(\lambda / 4\pi R\right)^2 G_R \\ &= \left(P_T G_T\right)\left(1/L_{FS}\right) G_R \quad (W) \end{aligned} \qquad (2.10)$$

where $L_{FS} = (4\pi R/\lambda)^2$ is called the free space loss represents the ratio of the received and transmitted powers in a link between two isotropic antennas.

Example: The uplink:

Consider the transmitting antenna of an earth station equipped with an antenna of diameter D=4m. This antenna is fed with a power P_T of 100W, that is 20dB(W), at a frequency f_U = 14 GHz. It radiates this power towards a geostationary satellite situated at a distance of 40,000km from the station on the axis of the antenna. The beam of the satellite receiving antenna has a width $\theta_{dB} = 2°$. It is assumed that the earth station is at the center of the region covered by the satellite antenna and consequently benefits from the maximum gain of the antenna. The efficiency of the satellite antenna is assumed to be $\eta = 0.55$ and that of the earth station to be $\eta = 0.6$. The power flux density at the satellite and the power received by it will be calculated.

- Power flux density at the satellite:

From equation (2.2),

$$G_{Tmax} = \eta(\pi D f_U/c)^2$$
$$= 0.6(\pi*4*14*10^9/(3*10^8)$$
$$= 206,340 = 53.1 \text{ dB}$$

The equivalent isotropic radiated power of the earth station on the axis is given by:

$$P_T G_{Tmax} = 53.1 \text{ dB} + 20 \text{ dB(W)} = 73.1 \text{ dB(W)}$$

The power flux density is given by:

$$F = P_T G_{Tmax}/4\pi R^2 = 73.1\text{-}10\log(4\pi(4*10^7)^2) = -89.9\text{dB(W/m}^2)$$

- The power received by the satellite antenna is obtained using equation (2.10) :

PR = EIRP - attenuation of free space + gain of receiving antenna.

The attenuation of free space $L_{FS} = 207.4$dB

The gain of the satellite receiving antenna $G_R = G_{Rmax} = \eta(70\pi/\theta_{3dB})^2$,

$G_{Rmax} = 6650 = 38.2$ dB.

Notice that the antenna gain does not depend on frequency when the beamwidth, and hence the area covered by the satellite antenna, is imposed.

In total :

$$PR = 73.1 - 207.4 + 38.2 = -96.1 \text{ dB(W)} \text{ that is } 250\text{pW}$$

The practical case:

In practice, it is necessary to take account of additional losses due to various causes:

- Losses associated with attenuation of waves as they propagate through the atmosphere.
- Losses in the transmitting and receiving equipment
- Losses due to imperfect alignment of the antenna.
- Polarization mismatch losses.

2.4 NOISE POWER AT THE RECEIVER INPUT

2.4.1 The origin of noise:

Noise is a signal without information content which adds itself to the useful signal. It reduces the ability of the receiver to produce the information content of the useful signal correctly.

The origins of noise are as follows:

- The noise emitted by natural sources of radiation located within the antenna reception area.
- The noise generated by electronic components in the equipment.

Signals from transmitters other than those which it is wished to receive are also as noise. This noise is described as interference.

2.4.2 Characterization and definition of noise:

Harmful noise power is that which occurs in the bandwidth of the useful signal. Normally this is that of the receiver. A very much used noise model is that of white noise for which the power spectral density No(W/Hz) is constant in the frequency band involved (Fig 2.5). The equivalent noise power N(W) measured in a bandwidth B_N (Hz) has a value:

$$N = NoB_N \qquad (W) \qquad (2.11)$$

Real noise sources do not always have a constant power spectral density, but the model is convenient for representation of real noise observed over a limited bandwidth.

(A) Noise temperature of a two-port noise source

It is given by :

$$T = N/kB = No/k \qquad (K) \qquad (2.12)$$

where :

k : Boltzmann's constant $= 1.379*10^{-23}$ (W/Hz K),

T : represents the thermodynamic temperature of a resistance

(B) Noise temperature of a four-port element

The noise figure of this four-port element is given by:

$$F = \{Gk(Te + To)B\} / (GkToB) = (Te + To) / To = 1 + Te/To \quad (2.13)$$

Where:

Te : thermodynamic temperature of a resistance placed at the input and

assumed to be noise-free.

To : reference temperature = 290K

F : ratio of the total available noise power at the output of the element to the

component of this power engendered by a source at the input of the element with a

noise temperature equal to To.

<u>2.4.3 Noise temperature of an antenna:</u>

An antenna picks up noise from radiating bodies within the radiation of the antenna. The noise output from the antenna is a function of the direction in which it is pointing, its radiation pattern and the state of the surrounding environment. The antenna is assumed to be a noise source characterized by a noise temperature called the noise temperature of the antenna T_A (K). The noise temperature of the antenna is obtained by integrating the contributions of all the radiating bodies within the radiation pattern of the antenna:

$$T_A = (1/4\pi)\iint T_b(\theta,\varphi)G(\theta,\varphi)d\Omega \quad (2.14)$$

where:

$T_b(\theta,\varphi)$: is the brightness temperature of a radiating body located in a direction (θ,φ).

$G(\theta,\varphi)$: is the gain of the antenna.

2.4.4 *Noise temperature of an attenuator:*

An attenuator is a four-port element containing only passive components such as resistances, all at temperature T_F, the noise temperature of attenuator can be given as :

$$Te = (L_F - 1)T_F \tag{2.15}$$

where

T_F : is generally the ambient temperature.

L_F : is the attenuation caused by the attenuator.

2.5 SIGNAL-TO-NOISE RATIO AT THE RECEIVER INPUT

2.5.1 Definitions:

The signal-to-noise ratio enables the relative magnitude of the received signal to be specified with respect to the noise present at the receiver input. Several ratios for specifying this relative magnitude can be envisaged:

- The ratio of signal power to noise power; this approach seems to be the most natural since two magnitudes of the same kind are being compared. It is usual to designate the power of the modulated carrier by **C**. As the noise power is **N**, the ratio is written **C/N**.
- The ratio of signal power to the spectral density of the noise; this is written **C/No** and expressed in Hz. It has the advantage, with respect to the ratio **C/N**, of not in any way presupposing the bandwidth used. In fact, the latter implies knowledge of the equivalent noise bandwidth B_N of the receiver which is adjusted to the bandwidth B occupied by the modulated carrier. In the course of the design, one can require to evaluate the link quality before the nature of the transmitted signals is specified. The bandwidth occupied by the carrier is then unknown and this prevents further insight into the **C/N** value.
- The ratio of the signal power to the noise temperature; this ratio is derived from the ratio **C/No** by multiplication by Boltzmann's constant k. It is written **C/T** and is expressed in W/K.

2.6 INFLUENCE OF THE PROPAGATING MEDIUM

On both the uplink and downlink, the carrier passes through the atmosphere. Recall that the range of frequencies concerned is from 1 to 30GHz. From the point of view of wave propagation at these frequencies, only two regions of the atmosphere have an influence the troposphere and the ionosphere. The troposphere extends practically from the ground to an altitude of 15km. The ionosphere is situated between around 70 and 1000km. The regions where their influence is maximum are in the vicinity of the ground for the troposphere and at an altitude of the order of 400km for the ionosphere.

The predominant effects are those caused by absorption and depolarization due to tropospheric precipitation (rain & snow). These are particularly significant for frequencies greater than 10GHz. The occurrence of precipitation is defined by the percentage of time during which a given intensity level is exceeded. Low intensities with negligible effects correspond to high percentage of time (typically 20%); these are described as 'clear sky' conditions. High intensities, which significant effects, correspond to small percentage of time (typically 0.01%); these are described as 'rain' conditions. These effects can degrade the quality of the link below an acceptable threshold. The availability of a link is thus directly related to the temporal precipitation statistics. In view of their importance, the effect of precipitation will be presented first.

2.6.1 The effects of the precipitation:

The intensity of precipitation is measured by the rainfall rate R expressed in mm/h. The temporal precipitation statistic is given by the cumulative probability distribution which indicates the annual percentage $p(\%)$ during which a given value of rainfall rate R_p (mm/h) is exceeded. In the absence of precise precipitation data for the location of the earth station involved in the link, the data of **CCIR** Report 563 can be used. To be more specific, in Europe a rainfall rate of $R_{0.01}$ (p=0.01% is the annual percentage most used to analyze systems, it corresponds to 53 minutes per year) is around 30mm/h.

Precipitation causes two effects which will be explained in the next two sections:

2.6.2 Attenuation:

The value of attenuation due to rain A_{RAIN} is given by the product of the specific attenuation g_R (dB/km) and the effective path length of the wave in the rain L_e (km), that is:

$$A_{RAIN} = g_R \, L_e \quad \text{(dB)} \qquad (2.16)$$

The value of g_R depends on the frequency and intensity R_p (mm/h) of the rain. The result is a value of attenuation which exceeded during a percentage of time p. This equation can be used for attenuation due to rain exceeded for 0.01% of an average year.

The value of attenuation exceeded for a percentage p between 0.001% and 1% is:

$$A_{RAIN} = A_{RAIN}(p = 0.01) \times 0.12\,p^{-(0.546+0.043\log p)} \quad \text{(dB)} \qquad (2.17)$$

It is sometimes required to estimate the attenuation exceeded during a percentage p_w of any month. The corresponding annual percentage is given by:

$$p = 0.3(p_w)^{1.15} \quad (\%) \qquad (2.18)$$

The specific attenuation g_C is calculated as :

$$g_C = KM \quad \text{(dB/km)} \qquad (2.19)$$

where

$K = 1.1*10^{-3} f^{1.8}$

f is expressed in GHz (1GHz to 30GHz), K in (dB/km)/(g/m³) and M= water concentration of the cloud (g/m³).

Attenuation due to clouds and fog is small compared with that due to precipitation except for clouds and fog with a high water concentration. For an elevation angle E=20°, one can expect 0.5 to 1.5 dB at 15 GHz and 2 to 4.5 dB at 30GHz. This attenuation, however, is observed for a greater percentage of the time.

Attenuation due to ice clouds is smaller still. Dry snow has little effect. Although wet snowfalls can cause greater attenuation than the equivalent rainfall rate, this situation is very rare and has little effect on attenuation statistics. The degradation of antenna characteristics due to accumulation of snow and ice may be more significant than the effect of snow along the path.

2.6.3 Cross-polarization:

Part of the energy transmitted in one polarization is transferred to the orthogonal polarization state. Cross polarization occurs as a result of differential attenuation and differential phase shift between two orthogonal characteristic polarizations. These effects originate in the non-spherical shape of raindrops. A commonly accepted model for a falling raindrop is an oblate spheroid with its major axis canted to the horizontal and with deformating dependent upon the radius of a sphere of equal volume. It is commonly accepted that canting angles vary randomly in space and time. The angle of the characteristic polarizations to the horizontal and vertical is often termed the effective canting angle.

The relationship between cross-polarization discrimination XPD and the copolarized path attenuation A_{RAIN} is of importance for predictions based on attenuation statistics. The following relationship is in approximate agreement with log-term measurements in the frequency range between about 3 and 37GHz :

$$XPD = U = 20\log(A_{RAIN}) \quad (dB) \qquad (2.20)$$

where:

$$U = 30\log(f) - D(E) + \kappa^2 + I(\tau) \quad (dB).$$

f is the frequency in GHz, E the elevation in degrees and τ the polarization tilt angle (for linear polarization) relative to the horizontal.

The term D(E) varies approximately with elevation angle E as given by:

$$D(E) = 40\log(\cos E) \quad (dB).$$

However it is recognized that this term does not predict the elevation dependence for elevation angle close to 90°.

The term k^2 is believed to depend primarily on the degree of random spread of the raindrop canting angles averaged over the path. For a Gaussian model of the raindrop canting angle distribution, $\kappa^2 = 0.0053\sigma^2$, where σ (in degrees) has been termed the effective standard deviation of the inclination of the raindrop canting angle distribution. Because κ^2 depends on several factors, σ cannot necessarily be interpreted solely in terms of the canting angle distribution.

The factor $I(\tau)$ can be omitted for circular polarization. It represents approximately the improvement of linear polarization with respect to circular polarization. If the effective canting angle is assumed to vary randomly within a rainstorm and from storm to storm and to have a Gaussian distribution with zero mean and standard deviation sm , then $I(\tau)$ can be expressed by:

$$I(\tau) = -10\log\left\{0.5\left[1 - \cos(4\tau)\exp\left(-\kappa_m^2\right)\right]\right\} \quad (dB)$$

where $\kappa_m^2 = 0.0024\sigma m$.

Values of σ can be taken as 0° , 5° , 10° and 15° for time percentage of 1, 0.1, 0.01, and 0.001 respectively at 14/11 GHz. A value of $\sigma_m = 5°$ would appear to give a sufficiently conservative maximum improvement of $I = 15$ dB for $\tau = 0°$ or 90°.

Typically one can expect a value of XPD less than 20dB for 0.01% of the time. Snow (dry or wet) causes similar phenomena.

2.6.4 Other effects:

- Attenuation by atmospheric gases.
- Attenuation by sandstorms.
- Refraction.
- The Faraday effect.
- Cross-polarization due to ice crystal.
- Influence of the ground-multipath effects.

2.7 COMPENSATION FOR THE EFFECTS OF THE PROPAGATION MEDIUM

2.7.1 Cross polarization:

The method of compensation relies on modification of the polarization characteristics of the earth station. Compensation is achieved as follows:

- For the uplink, by correcting the polarization of the transmitting antenna by anticipation so that the wave arrives matched to the satellite antenna.
- For the downlink, by matching the antenna polarization to that of the received wave. Compensation can be automatic; the signals transmitted by the satellite must be made available (as beacons) so that the effects of the propagation medium can be detected and the required control signal deduced.

2.7.2 Attenuation:

The mission specifies a value of the ratio **C/No** greater than or equal to $\mathbf{(C/No)}_{require}$ during a given percentage of the time, equal to (100-p)%. For example, 99.99% of the time implies p=0.01%. The attenuation A_{RAIN} due to rain causes a reduction of the ratio **C/No** given by:

$$(C/No)_{rain} = (C/No)_{clear\ sky} - A_{RAIN}\ (dB) \qquad ((dB)(Hz)) \qquad (2.21)$$

for an uplink and:

$$(C/No)_{rain} = (C/No)_{clear\ sky} - A_{RAIN}(dB) - \Delta(G/T)\ (dB(Hz)) \qquad (2.22)$$

for a downlink.

$\Delta(G/T) = (G/T) - (G/T)_{rain}$ represents the reduction (in dB) of the figure of merit of the earth station due to the increase of noise temperature.

For successful mission, one must have $(C/No)_{rain} = (C/No)_{required}$; this can be achieved by including a margin M(*p*) in the clear sky link budget with M(*p*) defined by :

$$\begin{aligned} M(p) &= (C/No)_{clear\ sky} - (C/No)_{required} \\ &= (C/No)_{clear\ sky} - (C/No)_{rain} \quad (dB) \end{aligned} \qquad (2.23)$$

The value of A_{RAIN} to be used is a function of the time percentage p. It increases as p decreases. Making provision for a margin M(*p*) in the clear sky link requirement implies an increase of the EIRP which requires a higher transmitting power.

For high attenuations which are encountered for a small percentage of the time and at the highest frequencies, the extra power necessary can exceed the capabilities of the transmitting equipment.

Other solutions must be considered as follows:

- Site diversity.
- Adaptivity.

2.7.3 Site diversity:

High attenuations are due to regions of rain of small geographical extent. Tow earth stations at two distinct locations 1 and 2 can establish links with the satellite which, at a given time t, suffer attenuations $A_1(t)$ and $A_2(t)$ respectively. $A_1(t)$ is different from $A_2(t)$ as long as the geographical separation is sufficient. The signals are thus routed to the link less affected by attenuation. On this link the attenuation is $A_D(t) = \min\{A_1(t), A_2(t)\}$. The mean attenuation for a single location is defined as $A_M(t) = \{A_1(t) + A_2(t)\}/2$; all values in dB.

Two concepts are useful to quantify the improvement provided by location diversity as follows

- The diversity gain.
- The diversity improvement factor.

2.7.3.1 Diversity gain $G_D(p)$:

This is the difference (in dB) between the mean attenuation at a single location $A_M(p)$, exceeded for a time percentage p, and the attenuation with diversity $A_D(p)$ exceeded for the same time percentage p. Hence, for a downlink for example, the required margin M(*p*) at a given location is obtained from (2.22) and (2.23)

$$M(p) = A_{RAIN} + \Delta\,(G/T) \qquad \text{(dB)} \qquad (2.24)$$

With site diversity, the required margin becomes:

$$M(p) = A_{RAIN} + \Delta(G/T) - G_D(p) \quad (dB) \tag{2.25}$$

2.7.3.2 Diversity improvement factor F_D:

This is the ratio between the percentage of time p_1 during which the mean attenuation at a single site exceeds the value A dB and the percentage of time p_2 during which the attenuation with diversity exceeds the same value A(dB).

The relation between p_1 and p_2 can be given by :

$$p_2 = (p_1)^2\left(1+\beta^2\right)/\left(p_1 + 100\beta^2\right) \tag{2.26}$$

with $b^2 = 2*10^{-4}\, d$, when $d > 5$ km.

Site diversity also provides protection against scintillation and cross-polarization.

2.7.4 *Adaptivity*

Adaptivity involves variation of certain parameters of the link for the duration of the attenuation in such a way to maintain the required value for the ratio **C/No**.

Several approaches can be envisaged as follows:

⇒ Assignment of an additional resource, which is normally kept in reserve, to the link affected by attenuation. This additional resource can be:

- An increase of transmission time with or without the use of error correcting codes.
- Use of a frequency band at a lower frequency which is less affected by the attenuation.
- Use of higher EIRP on the uplink.

⇒ Reduction of capacity; the link affected by the attenuation has its capacity reduced. In the case of digital transmission (chapter 3), the reduction in information rate enables an error correcting code to be used for a constant transmission rate.

2.8 CONSTRAINTS

The constraints in choosing the parameters of the link are in three categories:

- Regulations.
- Operational constraints.
- Propagation conditions.

As propagation conditions have been discussed above, the first two items will be considered below:

2.8.1 *Regulatory aspects:*

2.8.1.1 Administrative organization:

The International Telecommunication Union (**ITU**) is the Untied Nation organization for telecommunications. One of the objectives of the **ITU** is to ensure compatible radio networking by avoiding 'harmful interference' between different systems. To this end it has established the following:

1. Committees to examine technical and operational matters to produce reports and Recommendation such as **CCIR** and **CCITT**.
2. World and Regional Administrative Radio Conferences which are convened to discuss particular telecommunications topics and to carry out total or partial revision of the administrative regulations, particularly the Radiocommunication Regulation (**RR**).
3. The International Frequency Registration Board(**IFRB**) which is responsible for registration of the frequency assignments made by countries to their radio stations and verification that they conform to the assignment rules.

Every Radiocommunication system must conform to the provisions contained in the **RR**. These regulations divide satellite telecommunication into various space Radiocommunication services.

2.8.1.2 Space Radiocommunication services:

The **RR** distinguish the following services:

⇒ Fixed Satellite service (**FSS**).

⇒ Mobile Satellite Service (**MSS**) with three particular services:

- Maritime Mobile Satellite Service (**MMS**),
- Aeronautical Mobile Satellite Service (**AMS**),
- Land Mobile Satellite Service (**LMS**).

⇒ Broadcasting Satellite Services (**BSS**).

⇒ Earth Exploration Satellite Service (**ESS**).

⇒ Space Research Service (**SRS**).

⇒ Space Operation Service (**SOS**).

⇒ Inter-Satellite Service (**ISS**).

⇒ Amateur Satellite Service (**ASS**).

2.8.1.3 Frequency allocation:

The concept of a Radiocommunication service is applied to the allocation of frequency bands and analysis of the conditions for sharing a given band among compatible services. To this end the world has been divided into three regions as follows:

- Region 1: Europe, Africa, the Middle East and the USSR.
- Region 2: The Americas.
- Region 3: Asia except The Middle East and USSR, Oceania.

Frequency allocations to a given service can depend on the region. According to region, the bands allocated can be exclusive or shared. To be more precise:

⇒ Fixed satellite service links use the following bands:

- Around 6GHz for the uplink and around 4GHz downlink (**C** band). These bands are occupied by the oldest systems such as **INTELSAT** and tend to be saturated.
- Around 8GHz for the uplink and around 7GHz for the downlink (**X** band). These bands are reserved, by agreement between administrations, for government use.
- Around 14GHz for the uplink and around 12GHz for the downlink (**Ku** band). This corresponds to current operational developments such as **EUTELSAT**.

* Around 30GHz for the uplink and around 20GHz for the downlink (**Ka** band); this is currently used for experimental and pre-operational purposes.
* The bands above 30GHz will be used eventually in accordance with developing requirements and technology.

⇒ Mobile satellite service links currently use the bands around 1.6GHz for the uplink and 1.5GHz for the downlink (**L** band).

⇒ Broadcasting Satellite Service links contain only downlinks using bands around 12GHz. The uplink appertains to the Fixed-Satellite Service and is called a feeder link.

2.8.1.4 Fixed-Satellite Service allotment plan:

The world Radio Administrative Conferences 1985 and 1988 have retained the principle of a plan which guarantees every country equal access to the geostationary satellite orbit and to the frequency bands alloted to space services using this orbit. The plan adapted concerns fixed satellite services in the **C**, **Ku**, and **Ka** bands. This plan contain two parts as follows:

⇒ An allotment plan which enables each administration to satisfy the hardware requirements of national services for at last on orbital position on an arc and in one or more predetermined bands. The allotment plan relates to the following bands:

4500-4800 MHz (downlink),

6725-7025 MHz (uplink),

10.7-10.95 GHz and 11.2-11.45GHz (downlink),

12.15-13.25 GHz (uplink).

⇒ Procedure which permit requirements other than those appearing in the allotment plan to be satisfied.

Each allotment consists of :

⇒ An orbital position on a predetermined arc.

⇒ A bandwidth in the bands mentioned.

⇒ A service area.

procedures associated with the plan permit an orbital position to be modified within the limits of the predetermined are in such a way as to give more flexibility to the plan. They include the possibility of using a national allotment for a regional system (serving several neighboring countries).

2.8.1.5 Interference with terrestrial systems:

Most of the frequency bands allocated to space Radiocommunication are also allocated on a shared basis to terrestrial Radiocommunication. To facilitate this sharing, a number of provisions has been introduced into **RR** (Articles 27and 28) and a co-ordination procedure has been instituted between earth and terrestrial stations (**RR**, Articles 11).

Four types of interference between systems can be distinguished:

- A satellite interfering with a terrestrial station.
- A terrestrial station interfering with a satellite.
- An earth station interfering with a terrestrial station.
- A terrestrial station with an earth station.

Fig 2.6 illustrates the geometry associated with these forms of interference. The provisions intended to reduce them are numerous. The most evident are as follows:

1. Limitation of the power flux density produced on the Earth's surface by satellite .
2. Limitation of the EIRP emitted by terrestrial stations in the direction of the orbit of geostationary satellites.
3. Limitation of the minimum elevation angle of an earth station antenna.
4. Limitation of the EIRP of the earth station on the horizon.
5. Limitation of off-axis EIRP density levels from earth stations.
6. Use of energy dispersion techniques for analogue transmission using angular modulation and digital transmission in the fixed satellite service.
7. The co-ordination procedure which governs every earth and terrestrial station installation.
8. The station-keeping conditions and the orbital spacing between satellites.
9. The specifications of the radiation diagram of earth station antennas and those of the satellite.

2.8.2 *Operational constraints:*

These constraints relate to :

- Realization of a **C/No** ratio greater than or equal to a specified value for a given percentage of the link of the time.
- Provision of an adequate satellite antenna beam for coverage of the service area; this imposes the value of the satellite antenna gain.
- The level of interference between satellite systems; orbital separation between satellites operating in identical frequency bands may be as low as a few degrees. Under these conditions it is important that the earth station antenna produces a beam of sufficiently small angular width and with sufficiently small secondary lobes. This avoids emission of excessively large signals towards an adjacent satellite or reception of signals from this satellite which interfere excessively with the required signal. However, the size of the antenna should not be too large, otherwise, considering the station-keeping tolerances of the satellite, the satellite will move significantly within the principle lobe. In the absence of a costly tracking system this would involve large variations in antenna gain.
- The total cost should be minimal.

The first of these constraints implies a minimum value of the product EIRP*G/T for each link (up and down). The two following constraints limit the degree of exchange between EIRP and G/T for all pairs of values giving the minimum value of their product:

- On the uplink, the noise temperature of the satellite is influenced to a large extent by the high noise temperature of the earth and, taking account of the constraint on coverage, the G/T of the satellite can hardly be significant. It is up to the ground station to ensure a sufficient EIRP and, taking account of antenna constraints, design flexibility resides above all in the output power of the transmitting amplifier.
- On the downlink, the output power of the amplifier used is generally limited by amplifier technology and by the size of the platform which limits primary power generation. Taking account of the coverage constraint on the satellite antenna, the EIRP of the satellite is limited. It is necessary to compensate with a high ground station G/T and, taking account of the antenna constraint, design flexibility resides above all in the receiver noise temperature.

At this stage the various constraints remain sufficiently flexible for several technical solutions to be envisaged. An attempt is made to choose the most economic solution in order to satisfy the last constraint to be stated, that is the cost.

CHAPTER 3

TRANSMISSION TECHNIQUES FOR A SATELLITE CHANNEL

This chapter deals with techniques which enable signals to be sent from one user to another.

In this chapter, the term '**signal**' relates to the voltage representing the information transmitted from one user to another (such a telephone, television, telex, and so on). Such a signal is called a 'baseband' signal. If the signal is analogue, the voltage which represents it can take any value within a given range. If the signal is digital, the voltage takes discrete values, of which there are a finite number, within a given range.

In all cases, the baseband signal modulates the carrier in order to access the radio-frequency channel for routing via the satellite. Before modulating the carrier, the signal is generally subjected to specific processing.

The following will be examined in succession:

- Analogue transmission of telephone and television signals by satellite.
- Digital transmission of telephone signals by satellite.

3.1 SIGNAL CHARACTERISTICS

The following baseband signals will be considered:

- Speech on a telephone channel.
- Television.

3.1.1 Telephone channel signals:

A telephone channel signal occupies a band from 300Hz to 3400Hz. The test tone for the channel is a pure sinusoid at a frequency of 800Hz (**CCITT**) or 1000Hz (USA). Its power at the point of zero relative level in any telephone channel with a reference impedance of 600W is 1mW or 0dBm0 (the suffix 0 indicates that the value expressed in dBm is referenced to the zero relative level point). the maximum energy of a signal representing speech is in the region of 800Hz and 99% of the energy is situated below 3000Hz. The signal power of an 'average talker' relative to the zero relative level point is given by:

$$P_m = P_a + 0.115\sigma^2 + 10\log\tau \qquad \text{(dBm0)} \qquad (3.1)$$

where P_a= -12.9dBm0 represents the average power of the speech signal, σ =5.8dB is the standard deviation of the normal distribution of active speech power, τ=0.25 is the activity factor of a talker (this factor takes account of the periods of silence reserved for listening to the correspondent and pauses in the discussion). In total P_m=-15dBm0.

3.1.2 Television signals:

The television standards are as follows: **NTSC** (Japan, USA, Canada, Mexico, some South American countries, and Asia), **PAL** (Europe except France, Australia, other South American countries and some African countries) and **SECAM** (France, USSR, Eastern countries and other African countries). Recently, anew standard called **MAC** (Multiplexed Analogue Components) has been proposed for satellite broadcasting (direct broadcast television).

3.2 A MODEL OF THE CHANNEL

Fig 3.1 shows the transmission channel from one user terminal to another. If the terminal is located at some distance from the station, it will be connected to it through a terrestrial network as shown in Fig 3.1a. This is the case for large stations which are connected to the terrestrial network by means of a station/network interference. For small stations (**VSAT**), it can be expected that the station and terminal will be at the same location. There is, therefore, only a station/terminal interface (Fig 3.1b). Between the station/network or station/terminal interface and the transmitting antenna is the earth station equipment which provides the baseband signal processing functions, intermediate frequency (**IF**) modulation and conversion to radio frequency (**IF/RF**). The inverse operations take place at the receiving station.

3.3 PERFORMANCE OBJECTIVES

According to the nature of the transmitted signal, the performance objectives have been fixed by the **CCIR**. The quality of the signals delivered to the user is defined at the station/network interface level (Fig 3.1a) or the station/terminal (Fig 3.1b) by:

- The ratio S/N=baseband signal power / baseband noise power when the signal is analogue.
- The bit error rate (**BER**) when the signal is digital.

3.3.1 Telephone:

3.3.1.1 Analogue transmission:

CCIR Recommendation 353 stipulates that the noise power at a zero relative level point in any telephone channel must not exceed:

- 10000pW0p psophometrically weighted one minute mean power, for more than 20% of any month,
- 50000pW0p psophometrically weighted one minute mean power, for more than 0.3% of any month,
- 1000000pW0p unweighted (with an integration time of 5ms) for more than 0.01% of any year.

The noise power mentioned above is defined at a zero transmission level point where the test signal power has a value of 1mW. The ratio S/N of the test signal to the noise power is thus given by:

$$S/N = 10^9 / N_{pW0p} \qquad (3.2)$$

where N_{pW0p} is the power mentioned in the above Recommendation. Consequently, the value 10000pW0p corresponds to a S/N ratio=50dB.

The psophometrically weighted power (identified by the suffix p in pW0p) is that measured at the output of a psophometric filter whose gain is intended to reproduce the curve of ear sensitivity as a function of frequency. Fig 3.2 shows the gain of the psophometric filter and its effect on the noise. The established improvement in the S/N ratio is w=2.5dB.

3.3.1.2 Digital transmission:

CCIR Recommendation 522 stipulates that the bit error rate must not exceed:

- One part in 10^6, 10-minutes mean value for more than 20% of any month.
- One part in 10^4, 1-minute mean value for more than 0.3% of any month.
- One part in 10^3, 1-second mean value for more than 0.05% of any month.

3.3.2 Television:

CCIR Recommendation 567 stipulates that the ratio of the nominal luminance signal amplitude to the mean square weighted noise in the 0.01 to 5MHz band must be not less than 53dB during more than 1% of any month and not less than 45 dB during more than 0.1% of any month. The weighting used takes account of the sensitivity of the average viewer to the noise frequency components.

3.4 AVAILABILITY OBJECTIVES

Availability is the fraction of time during which a service conforming to the specifications is provided. It is affected by both equipment breakdowns and propagation phenomena.

CCIR Recommendation 579 stipulates that the unavailability must not exceed:

- 0.2% of the year in the case of breakdown or in other word, interruption of the service must be less than 18 hours per year.
- 0.2% of any month if the service interruption is due to propagation.

The effects of propagation on the quality of the link have been examined in Chapter 2. Breakdown involves the earth station and satellite equipment. For earth stations, service interruption due to the conjunction of the station, the satellite and the sun is regarded as a breakdown. As far as the satellite is concerned , it is necessary to consider its reliability, which is determined by breakdowns of on-board equipment, breaks during an eclipse when the only source of on-board energy is solar and the life time of the satellite. In general an operational satellite, a back-up satellite in orbit and a back-up satellite on the ground are provided. Finally, availability depends also on the reliability of the launchers which are indispensable for replacement of satellite at the end of their life.

3.5 PROPAGATION TIME

Referring to Fig 3.1, it can be seen that the propagation time of signals from one terminal to another is the sum of the propagation times on the space link (station-to-station) tss and propagation times t_N on the network at departure and arrival.

3.5.1 *Propagation time on the space link:*

The propagation time on the space link depends on the satellite orbit. It is least with satellites in low orbit, but the relative variations of propagation time are much greater than in the case of a geostationary satellite for which the variations are small although the propagation time is relatively long.

The propagation time on a space link is given by the following relation:

$$t_{ss} = (R_U + R_D)/c \qquad (3.3)$$

where R_U and R_D are the distances from the earth station to the satellite on the up and down links respectively and c is the velocity of the light. A range of propagation times can be determined by considering two extreme cases:

- a vertical trajectory: $R_U = R_D = R_o$, where R_o is the altitude of the satellite (R_o=35786km). In this case t_{ss}=238ms.
- an oblique trajectory corresponding to stations at the limit of visibility (elevation angle=0°): $R_U = R_D = (R_o+R_E)\cos(17.4°/2)/c$, where RE is the radius of the earth (R_E=6738km). In this case t_{ss}=278ms.

3.5.2 *Propagation time on the network:*

The terrestrial propagation time on the network can be calculated using the following expression:

$$t_N = 12 + (0.004 * \text{distance in km}) \text{ (ms)} \qquad (3.4)$$

It is reasonable to take a mean value of 30ms for the sum of the propagation times on each network.

3.5.3 The case of the telephone:

Fig 3.3a shows the path followed by telephone signals during a conversation. A high value of propagation time causes an unpleasant effect known as an echo in telephone circuits. The origin of this phenomenon is the interface between the subscriber lines which are bi-directional (2-wire circuit) to reduce the cost and the long distance links between switching centers where the two directions of transmission are generally separate (4-wire circuit). This interface is realized with a differential coupler which can be seen in Fig 3.3a and in more detailed from Fig 3.3b. When the impedance Z_1 of the subscriber line is equal to the load impedance Z_2, every signal received on the link from B to A is transmitted to subscriber A and every signal emitted by subscriber A is transmitted on the link from A to B. In general the impedances Z_1 and Z_2 are not equal, since Z_2 is fixed and Z_1 depends on the line in service. Under these conditions, part of the received signal power passes directly from the B to A link to the A to B link. Subscriber B thus hears his own voice with a delay equal to the round trip return time, this is the phenomenon of echo. It is more noticeable when the propagation time is high. we are going to discuss this phenomenon in chapter 7 in more details.

CCITT recommendation G114 stipulates that the propagation time $t_{ss}+t_N$ between subscribers must not exceed 400ms. It recommends that the use of echo suppressers or echo cancelers when this time is between 150ms and 400ms. No particular precaution is to be taken when it is less than 150ms.

For links between subscribers established with geostationary satellites this leads to the following:

- The need to install echo suppressers or cancelers.
- The need to avoid a 'double hop', that is establishment of a link through two satellites without an intersatellite link. If the system contains an intersatellite link, the propagation time tISL between the two satellites must remain less than 90ms. The orbital separation between the two satellites for a propagation time $t_{ISL} = R_{ISL}/c$ is given by the following expression:

$$\theta = 2 \text{ arc sin } ct_{ISL}/\ 2(R_E + R_o) \qquad (3.5)$$

With R_E=6378 km, R_o=35786 km and t_{ISL}<90ms, this gives θ<37°.

2.6 ANALOGUE TRANSMISSION

Analogue transmission is characterized by the following:

- Processing performed on the baseband signal before modulation and after demodulation in order to improve the quality of the link.
- The number of channels supported by the carrier. In the case of a single channel one refers to single channel per carrier (**SCPC**) transmission. In the case of several channels transmitted by frequency division multiplexing, one refers to **FDM** transmission.
- The type of modulation used. The most widely used is frequency modulation FM. as the modulation envelope is constant (the carrier amplitude is not affected by the modulating signal), it is robust with respect to the non-linearities of the satellite channel. On the other hand, for a given quality of link, it offers the useful possibility of a trade-off between the signal-to noise ratio and the bandwidth occupied by the carrier. In view of the use on some recent satellites of field effect transistors which are more linear than the traveling wave tubes which they replace, experiments have been performed in the realization of signal sideband amplitude modulation (**SSB-AM**).

The station-to-station space link is generally identified by the multiplexing/modulation combination. After reviewing baseband processing, frequency division multiplexing and modulation techniques, the following will be examined successively:

Telephone and Television transmission using **SCPC/FM**.

2.6.1 Baseband processing:

The purpose is to improve the quality of the space link using methods whose realization cost is less than that arising from modification of one of the parameters involved in the link budget. The principal methods used are:

- For telephony:
  - Speech activation.
  - Pre- and de-emphasis.
  - Compression and expansion (companding).
- For television:
  - Pre- and de-emphasis.

3.6.1.1 Speech activation:

The principle is to establish the space link only when the subscriber is actually speaking. As the activity factor is 0.25, its application to multicarrier **SCPC** systems should permit a reduction of the power required on the satellite by about 6dB.

In practice, allowing guard times for activation and deactivation of the carrier and the sensitivity of the system-to-noise spikes, the reduction is only of the order of 4dB. The parameters to be taken into account are:

- The activation threshold (-30 to -40dBm0).
- The carrier activation time (6 to 10ms).
- The carrier deactivation time (150 to 200ms).

3.6.1.2 Pre- and de-emphasis:

The noise at the output of the demodulator of a frequency modulation transmission has a parabolic spectral density; the high frequency components of the signal are more affected by noise than the low frequencies. Fig 3.4 shows the principle of pre- and de-emphasis. The pre-emphasis filter before modulation increases the amplitude of the high frequency components. The cross-over frequency is the frequency for which the gain of the pre-emphasis filter is 0dB. After demodulation, the de-emphasis filter, whose gain follows a law which is the inverse of that of pre-emphasis, reduces the amplitude of the high frequency signal components and the noise. The signal is restored without spectral distortion. The noise power in the band is reduced. In this way the signal-to-noise ratio S/N is improved. The improvement is of the order of 4 to 5 dB for telephony and around 13 dB for television.

3.6.1.3 Compression and expansion (Companding):

The improvement in the signal-to-noise ratio S/N at the output of the demodulator is obtained by reducing the dynamic range of the signal before modulation (compression) and performing the inverse operation after demodulation. Fig 3.5 illustrates the principle. When control of the device gain is adapted to the power of syllables, the technique is called syllabic companding. Compression in general reduces the dynamic range by half and expansion by a factor of two restores the original dynamic range. On expansion, the noise at the demodulator output is subjected to attenuation since it is at a low power level. For

...e, if the noise level at the receiver input between syllables, words and phrases, is -25 ...respect to the zero reference level, the corresponding noise level after expansion is ...B. The improvement is subjective since it is associated with the absence of perceived ...uring silences in the conversation. It is considered to be of the order of 15dB.

...2 *Multiplexing:*

...exing consists of combining the signals from several users into a single signal which ...s the signal which modulates the carrier. After demodulation the individual signals ...rated by an operation called demultiplexing. For analogue telephone transmission, ...exing is by **FDM**; the subscriber signal spectra are translated in frequency and ...adjacent to each other in the frequency spectrum with a space of 4kHz reserved for ...annel. Fig 3.6 illustrates the principle of multiplexing and demultiplexing.

...3 *Amplitude modulation (AM):*

3.6.3.1 The principle:

... be the voltage representing the modulating signal and F_c the carrier frequency. ...ude modulation associates a variation of carrier amplitude with the voltage *v(t)* whose ...plitude is V_{max}. The expression for the carrier is:

$$c(t) = A\left[1 + m_{AM}\, v(t)/V_{\max}\right]\cos(\omega_c t) \tag{3.6}$$

... m_{AM} is the amplitude modulation index, assumed to be between 0 and 1.

3.6.3.2 Spectral occupation:

...form of 3.6 the spectrum of the modulated carrier contains a component at a ... f_c (that the unmodulated carrier) and two sideband on each side of this component ...plicate the spectrum of the modulating signal. If f_{max} is the maximum frequency of ...trum of the modulating signal, the bandwidth occupied by the carrier is:

$$B = 2f_{max} \text{ (Hz)} \quad (3.7)$$

Transmission of one of the two sidebands can be suppressed by filtering. A single sideband amplitude modulated signal is thus generated (**SSB-AM**). under these conditions, spectral occupancy by half and becomes:

$$B = f_{max} \quad \text{(Hz)} \quad (3.8)$$

3.6.4 Demodulation of an amplitude modulated wave:

3.6.4.1 The principle:

For amplitude modulation with two sidebands, demodulation can be non-coherent. In satellite transmission, amplitude modulation is considered only in cases where bandwidth constraints are severe. It is then better to use single sideband modulation and coherent demodulation. The principle of coherent demodulation is to multiply the received modulated carrier by an unmodulated carrier, generated locally, which has the same frequency and phase as the received carrier. Low-pass filtering at the output of the multiplier restores the modulating signal.

3.6.4.2 Signal-to-noise ratio at the demodulator output:

With single sideband amplitude modulation, the signal-to-noise ratio at the demodulator output is given by:

$$S/N = (C/No)_T/f_{max} \quad (3.9)$$

3.6.5 Frequency modulation (FM):

3.6.5.1 The principle:

Let *v(t)* be the voltage representing the modulating signal and *fc* be the nominal carrier frequency. Frequency modulation associates a frequency deviation of the carrier $\Delta F(t) = f(t) - f_c$, which is proportional to *v(t)*, with the voltage *v(t)*:

$$\Delta F(t) = f(t) - fc = k_{FM}v(t) \qquad \text{(Hz)} \qquad (3.10)$$

k_{FM}(Hz/V) characterizes the modulator.

3.6.5.2 Modulation index:

If the modulating signal is sinusoidal of frequency f_m and amplitude A, it causes a peak frequency deviation of the carrier of value $\Delta F_{max} = k_{FM}A$. The modulation index m_{FM} is defined as:

$$m_{FM} = \Delta F_{max}/f_m \qquad (3.11)$$

3.6.5.3 Spectral occupation:

The spectrum of a carrier modulated by a sinusoidal signal of frequency fm occupies a bandwidth given by Carson's formula:

$$B = 2(m_{FM} + 1)f_{max} \qquad \text{(Hz)} \qquad (3.12)$$

In practice, Carson's formula is used even when the modulating signal is not sinusoidal. Hence, assuming that the non-sinusoidal modulating signal occupies a band (0-f_{max}), f_m in (3.10) and (3.11) is replaced by the maximum frequency f_{max} of the modulating signal:

$$B = 2(m_{FM} + 1)f_{max} \qquad \text{(Hz)} \qquad (3.13)$$

with $m_{FM} = Df_{max}/f_{max}$.

3.6.6 Demodulation of a frequency modulated wave:

3.6.6.1 The principle:

The carrier at the demodulator input has a carrier-to-noise ratio $(C/No)_T$. The demodulator identifies the instantaneous frequency deviation $\Delta F(t)$ of the carrier and recovers a voltage $u(t)$ such that:

$$u(t) = \sigma_{FM}\, \Delta F(t) \qquad \text{(V)} \qquad (3.14)$$

(V/Hz) characterizes the demodulator.

3.6.6.2 Noise spectral density at the demodulator output:

The noise spectral density at the demodulator output is given by:

$$N_0(f) = N_0(\sigma_{FM}/A)^2(2\pi f)^2 \quad (W/Hz) \tag{3.15}$$

where A is the amplitude of the carrier and No the noise spectral density at the demodulator input, assumed to be constant. The noise spectral density at the demodulator output is not constant; it increases parabolically with frequency.

3.6.6.3 Signal-to-noise ratio at the demodulator output:

For a modulating signal with a spectral width (0-f_{max}) the signal-to-noise ratio S/N at the demodulator output, when the noise power is measured in a bandwidth $B_N = f_{max}$ is given by:

$$S/N = \{3/(2f_{max})\}(\Delta F_{max}/f_{max})^2 (C/N_0)_T \tag{3.16}$$

3.6.6.4 Demodulation gain:

The modulated carrier occupies a bandwidth B at the demodulator input where B is given by Carson's formula. It is assumed that the receiver has an equivalent noise bandwidth B_N equal to the spectral occupation of the carrier, hence $B_N=B$. The noise power at the demodulator input is $N=N_0B_0$ and the carrier power-to-noise power ratio has a value $C/N=(C/N_0)_T B_N$.

Equation (3.16) becomes:

$$\begin{aligned} S/N &= (3/2)(B_N/f_{max})(\Delta F_{max}/f_{max})^2\, C/N \\ &= 3(1+m_{FM})m_{FM}^2\, C/N \end{aligned} \tag{3.17}$$

is sufficiently large, S/N$=3m_{FM}^3$ C/N. The value of S/N is greater than that of demodulation of a frequency modulated wave provides a 'demodulation gain' in terms signal-to-noise ratio. Notice that this advantage implies providing the satellite link with a bandwidth greater than that of modulating signal. Since demodulation gain increases with bandwidth, a low value of C/N can be compensated by an increase in the bandwidth used in the case where the satellite link is limited in power. It is this principle of bandwidth C/N exchange, for a given S/N, which makes frequency modulation very well suited to analogue signal transmission by satellite.

3.6.6.5 Demodulator threshold:

(3.17) is valid only for values of C/N greater than a minimum value called the 'demodulator threshold'. Below this threshold, noise of an impulse type appears at the demodulator output and this degrades the signal-to-noise ratio S/N with respect to the value given by (3.17). The demodulator threshold depends on the type of demodulator. It is close to dB for conventional demodulators and can be 5 to 6dB with 'improved threshold' demodulators.

Telephone transmission on SCPC/FM:

The carrier is modulated by the signal of a single telephone channel (**SCPC**=Single Channel Per Carrier). There is , therefore, no multiplexing.

3.6.7.1 Signal-to-noise ratio at the demodulator output:

The ratio of signal power-to-noise power at the demodulator output is given by:

$$S/N = 3\left[(\Delta F_r)^2/(f_{\max})^3\right]pw(C/N_o)_T \qquad (3.18)$$

where

ΔF_r= r.m.s. frequency deviation due to the test signal.

f_{max}= maximum frequency of the telephone channel = 3400Hz.

p =improvement factor due to pre-emphasis and de-emphasis (6.3dB) and companding (17dB), if any.

w = psophometric weighting factor (2.5dB)

$(C/N_0)_T$ = carrier power-to-noise spectral density ratio at the receiver input (Hz).

3.6.7.2 Required bandwidth:

The receiver must have a bandwidth equal to the bandwidth B occupied by the carrier. The equivalent noise bandwidth of the receiver B_N is taken equal to B:

$$B_N = B = 2(\Delta F_p + f_{max}) \qquad \text{(Hz)} \tag{3.19}$$

where:

ΔF_p = peak frequency deviation (Hz) = $gL\Delta F_r$

The expression for ΔF_p is derived as follows; the peak frequency deviation due to an active speech signal is related to the effective frequency deviation by a factor g which is a function of the acceptable clipping. If clipping is defined by the r.m.s. deviation due to an active speech signal exceeding a level of 15dB below the peak deviation, then g=12.6. Furthermore, the r.m.s. frequency deviation due to an active speech signal and the r.m.s. frequency deviation due to the test signal are in a ratio, called the load factor L, which is that of the r.m.s. signal amplitudes. The ratio of the amplitudes is equal to the square root of the powers. Hence, from expression (3.1) where the activity factor is omitted since an active speech signal is considered:

$$\begin{aligned} L &= 10^{\left(P_a + 0.115\sigma^2\right)/20} = 0.35 \quad \textit{without companding} \\ L &= 10^{\left(P_a/2 + 0.002875\sigma^2\right)/20} = 0.53 \quad \textit{with companding} \end{aligned} \tag{3.20}$$

3.6.7.3 Example 1: **SCPC/FM** transmission (without companding):

A satellite link between two stations occupying a bandwidth of 25kHz is considered. The quality target is S/N=50dB. Calculate the required value of $(C/N)_T$.

Taking account of (3.18), the peak frequency deviation must not exceed

$\Delta F_p = B_N/2 - f_{max}$ = 25000/2 - 3400 = 9100 Hz.

$\Delta F_r = \Delta F_p/gL \quad = 9100/(12.6*0.35) \quad = 2063.5$ Hz.

$(C/N_o)_T = (S/N)/\{3*((DF_r)^2/(f_{max})^3)pw\} = 76.1$dB (Hz).

The corresponding value required for $(C/No)_T$ is:

$(C/N)_T = (C/N_o)_T/B_N = 32.1$dB.

3.6.7.4 Example 2: **SCPC/FM** transmission (with companding):

Consider the previous example to find required $(C/N)_T$:

L=0.53 and p=17+6.3 = 23.3dB.

This gives:

$\Delta F_r \quad = 1362.7$ Hz

$(C/N_o)_T = 62.7$ dB(Hz) and

$(C/N)_T \; = 18.7$ dB.

The gain due to companding is thus 13.4dB.

The other techniques which used in telephone transmission are:

- **FDM/FM**
- **FDM/SSB-AM**

3.6.8 Television transmission in SCPC/FM:

The carrier is modulated by the television signal after passing through the pre-emphasis filter. After demodulation the signal is de-emphasis.

3.6.8.1 Signal-to-noise ratio at the demodulator output:

The quality target for a television transmission is stipulated in terms of the weighted signal-to-noise ratio. This is given by:

$$S/N = (3/2)(\Delta F_{Tpp}/B_n)^2(1/B_n)pw(C/N_o)_T \qquad (3.21)$$

where ΔF_{Tpp} is the peak-tp-peak frequency deviation for a signal at the input of the transmission chain of frequency equal to the cross-over frequency f_r of pre- and de-emphasis(f_r=1.512MHz for 625/50 systems and 0.762MHz for 525/60 systems) and peak-to-peak amplitude V_{Tpp} equal to the peak-to-peak amplitude of the video signal including the synchronizing pulses. B_n is the bandwidth of noise measurement at the receiver output and is equal to the maximum spectral frequency of the video signal f_{max} or 5MHz when the noise measurement is made with the unified weighting filter recommended in **CCIR** Recommendation 568. The product pw represents the combined effect of pre- and de-emphasis and the weighting.

3.6.8.2 Required bandwidth :

The receiver must have a bandwidth equal to the bandwidth B occupied by the carrier. The equivalent noise bandwidth of the receiver B_N must be equal to:

$$B_N = B = \Delta F_{Tpp} + 2f_{max} \quad \text{(Hz)} \tag{3.22}$$

where f_{max} is the maximum frequency in the spectrum of the video signal.

3.6.8.3 Example 1: Transmission of 625/50 television by **INTELSAT**:

Data:

ΔF_{Tpp}=15MHz, f_{max}=6MHz, B_n=5MHz, pw=13.2dB.

so, $S/N = 5.6*10^{-5}(C/N_0)_T = -42.5 + (C/N_0)_T$ (dB)

The bandwidth occupied by the modulated carrier is B = 15+ (2*6)= 27MHz.

However, **INTELSAT** uses only 15.75MHz of bandwidth in order to be able to transmit two television carriers simultaneously on the same 36MHz bandwidth repeater. Therefore frequency over deviation occurs. Taking B_N=15.75MHz, this gives:

$S/N = 5.6*10^{-5}(C/N)_T*B_N = 29.5 + (C/N)_T$ (dB)

To obtain a value of 45dB, it is necessary to have $(C/N)_T$=15.5dB.

3.6.9 Energy dispersion:

The **CCIR** Recommendation 446 recommend the use of energy dispersion techniques in radio-frequency transmission in order to limit interference between radio communication systems sharing the same frequency bands.

When the modulation index of a frequency modulated carrier is low, the power of the modulated carrier is concentrated in a narrow band in the vicinity of the carrier and the risk of interference in increased. This the case, for example, An **SCPC/FM** television transmission when the image contains large portions of constant luminance.

The principle of energy dispersion is to superimpose a low frequency triangular signal on the modulating signal before modulation. This signal is subtracted from the demodulated signal or reception. For telephone transmission, a dispersion signal with a frequency between 20 and 150Hz is used. For television transmission, the dispersion signal must be synchronized to the field frequency (50 or 60Hz according to the system).

3.7 DIGITAL TRANSMISSION

gital transmission relates to links for which the user's terminals produce digital signals mputer for example). But it is also possible to transmit signals of analogue origin lephone for example) in digital form. Although this choice implies an increased baseband, permits signals from diverse origins to be transmitted on the same satellite channel and e satellite link to be incorporated in the Integrated Services Digital Network. This implies e use of Time Division Multiple (**TDM**) techniques. Fig 3.7 shows the element of the gital transmission chain. These will now be described in succession.

7.1 *Digitization of analogue signals:*

gitization of analogue signals implies three stages :

Sampling.
Quantisation.
Source coding

3.7.1.1 Sampling:

mpling must be performed at a frequency Fs equal to at least twice the maximum quency f_{max} of the spectrum of the analogue signal. The signal at the sampler output is a quence of amplitude modulated pulses (Pulse Amplitude Modulation (**PAM**)). For the ice on a telephone channel f_{max}=3400Hz and F_S=8kHz. For a radio program, $_{max}$=15kHz and F_S=32kHz.

3.7.1.2 Quantisation:

ch sample is then quantized into a finite number M of discrete levels. This quantization n be either uniform or non-uniform according to the quantization step which may be dependent of, or a function of, the sample magnitude. In the case of non-uniform antization it is possible to adapt the quantization law to the amplitude distribution of the mples in order to maintain a constant signal-to-quantization noise ratio for all sample mplitudes. This operation is called compression. For speech samples, two types of mpression are currently used; these are '*m* law' and 'A law' compression.

3.7.1.3 Source encoding:

Quantized samples have a finite number M of levels which can represented by a finite alphabet of signals which will be transmitted on the link. This operation is called source encoding (**PCM**, Pulse Code Modulation) in order to distinguish it from channel encoding which provides protection against transmission errors. Most often the element of the alphabet is a binary signal and it is necessary to transmit $m=\log_2 M$ bits per sample and this determines the bit rate:

$$R_q = F_s \log_2 M \tag{3.23}$$

For example, for the telephone, if $M=2^8=256$(Europe), 8-bits per sample are required. With $F_S=8kHz$, this gives $R_q=64kbit/s$. For a radio program, source encoding with compression is used which provide a bit rate of 384kbit/s.

Various techniques have been used to reduce the bit rate. These techniques take advantage of the existence of redundancy between successive samples. In this way a bit rate $R_b \leq R_q$ is achieved and this is the information rate to be transmitted. These techniques, called low rate encoding (**LRE**). They are applicable for speech and vision. For telephony the most widely used equipment uses adaptive differential encoding (**ADPCM**, Adaptive Differential **PCM**) which provides a value $R_q=32kbit/s$.

3.7.2 Time Division Multiplexing (TDM):

Time division multiplexing (**TDM**) consists of interleaving in time the bits relating to different signals. For multiplexing digital telephone channels two recommended by the CCITT are widespread- the European standard of the **CEPT** (European Conference Post and Telecommunications) and the 'T-carrier' standard used in Japan and North America (USA and Canada).

3.7.2.1 The **CEPT** hierarchy:

The **CEPT** standard is based on a frame of 256 binary elements. The frame duration is 125ms. The bit rate is 2.048Mbit/s. The multiplex capacity is 30 telephone channel, 16 bits per frame being used for signaling and the frame synchronization signal. The highest capacities are obtained by successive multiplexing of multiplexers of equal capacity. In this way a multiplexing hierarchy is established which contains several levels; each level is constructed by multiplexing 4 multiplexed channels with a capacity equal to the capacity of the immediately lower level.

3.7.2.2 The 'T-carrier' hierarchy:

This standard is based on a frame of 192 bits obtained by multiplexing 24 samples each of 8-bits to which one frame alignment bit is added. Each frame thus contains 193 bits. The frame duration is 125ms. The bit rate is 1.544Mbit/s. The multiplex capacity is 24 channel (23+1 for signaling). The multiplexing hierarchy differs between Japan and North America.

3.7.3 Digital speech concentration and channel multiplication:

Systems for digital speech concentration (Digital Speech Interpolation (**DSI**)) use the nag activity factor of telephone channels in order to reduce the number of satellite channels required to transmit a given number of terrestrial channels. The speech interpolation technique is based on the fact that in a normal telephone conversation each participant monopolizes the circuit for only around half the time . As the silence between syllables, words the phrases increase so does the unoccupied time, Hence on average the activity time of a circuit is from 35 to 40% of the connection time. By making use of the actual activity of the channels, several users can permitted to share the same telephone circuit. Fig 3.8 shows this principle. The gain of the digital concentrator is given by the ratio m/n. In the **INTELSAT/EUTELSAT** system, 240 terrestrial channels require only 127 satellite channels plus one assignment channel and the gain is 240/127=1.9. The preceding gain assumes satellite telephone channels at 64kbit/s. By adding a low rate encoder (**LRE**) to the digital speech concentrator, the gain can be further increased. For example, with encoding at 32kbit/s a gain increase by a factor of 2 can be obtained. These techniques are used in digital circuit multiplication equipment (**DCME**).

3.7.4 Synchronism between networks:

Due to movement of the satellite in its orbit, even it is a geostationary satellite for which this movement is small but not zero, a Doppler effect is observed and the received binary rate is not always equal to the transmitted binary rate. Furthermore, the terrestrial networks at the end of the satellite link (see Fig 3.1a), when digital, do not always have strictly synchronous clocks. To compensate for these variations, buffer memories are provided at the station/network interfaces. In choosing the size of these memories account must be taken of the station-keeping specification and use can be made of **CCITT** Recommendation G811 which recommends plesiochronism between digital interfaces. Plesiochronism exists when the clocks of each network have a discrepancy of at most $\pm 10^{-11}$. This leads to a frame slip for a multiplex frame of 125ms once every 72days.

3.7.5 Encryption:

Encryption is used when it is wished to prevent exploitation of, or tampering with, transmitted messages by unauthorized users. It consists of performing an algorithmic operation in real time bit-by-bit on the binary stream. The set of parameters which defines the transformation is called the 'key'. Although the use of encryption is often associated with military communications, commercial satellite systems are increasingly induced by the customers to propose encrypted links particularly for commercial and administrative networks. In fact, due to the extended coverage of satellites and the easy access to them by small stations, eavesdropping and message falsification are potentially within the reach of a large number of agent of reduced means.

Fig 3.9 illustrates the principle of encrypted transmission. The encryption and de-encryption units operate with a key provided by the key generation units. Acquisition of a common key implies a secure method for key distribution.

Encryption consists of two aspects:

1. That of confidentiality- avoiding exploitation of the message by unauthorized persons.
2. That of authenticity-providing protection against any modification of the message by an intruder.

Two techniques are used:

- On-line encryption (stream cipher)-each bit of the original binary stream (plain text) is combined using a simple operation with each bit of a binary stream (the keystream) generated by a key device. The latter, for example, could be a pseudorandom sequence generator whose structure is defined by the key.

- Encryption by block (block ciphering)-the transformation of the original binary stream into an encrypted stream is performed block-by-block according to logic defined by the key.

3.7.6 Channel encoding:

Fig 3.10 illustrates the principle of channel encoding. It has the objective of adding redundant bits to the information bits; the former will be used at the receiver to detect and correct errors. The addition of these bits is performed in blocks or by convolution. The code rate is defined as:

$$r = n/n(n+r) \qquad (3.24a)$$

where r is the number of bits added for n information bits.

The bit rate at the encoder input is R_b. At the output it is greater, and equal to R_c. Hence:

$$R_c = R_b/r \quad \text{(bit/s)} \qquad (3.24b)$$

3.7.7 Digital modulation:

Fig 3.11 shows the principle of a modulator. It consists of:

1. A symbol; generator.
2. An encoder.
3. A radio-frequency signal (carrier) generator.

The symbol generator generates symbols with M states, where $M=2^m$, from m consecutive bits of the binary input stream. The encoder establishes a correspondence between M states of these symbols and M possible states of the transmitted carrier. Two types of coding are practiced:

- Direct encoding-one state of the symbol defines one state of the carrier.
- Encoding of transitions (differential encoding)-one state of the symbol defines a transition between two consecutive states of the carrier.

For a bit rate Rc(bit/s) at the modulator input, the modulation rate Rs at the demodulator output (the number of changes of state of the carrier per second) is given by:

$$R_s = R_c/m = R_c/\log_2 M \quad \text{(baud)} \qquad (3.25)$$

The modulation (phase shift keying (**PSK**)) is particularly well suited to satellite links. In fact it has the advantage of a constant envelope and in comparison with frequency shift keying (*FSK*) it provides better spectral efficiency (number of bit/s transmitted per unit of radio-frequency bandwidth). We mention two types of phase shift keying, they are :

a- Two-state modulation (M=2), (Fig 3.12) :

- With direct encoding- Binary Phase Shift Keying (**BPSK**).
- With different encoding-Differentially Encoded **BPSK (DE-BPSK)**.

b- Four-state modulation (M=4), (Fig 3.13) :

- With direct encoding-Quadrature Phase Shift Keying (**QPSK**).
- With differential encoding-Differentially Encoded **QPSK (DE-QPSK)**.

3.7.7.4 Spectral efficiency:

Fig 3.14 shows the form of the spectrum of the digital carriers presented in this section. An important parameters in the choice of modulation type for a link is the spectral occupancy of the carrier in the satellite repeater. In fact, the link operator pays for the bandwidth occupied and is reimbursed at the user's expense. His benefit increases as spectral occupation decreases and the number of paying users increases, that is the throughput is high. This leads to the concept of spectral efficiency which is defined as the ratio of the capacity R_c(bit/s) of a carrier to the bandwidth occupied B(Hz), hence :

$$G = R_c/B \qquad \text{(bit/sHz)} \tag{3.26}$$

It can be shown that for **BPSK** modulation, the theoretical spectral efficiency is 1bit/sHz. For **QPSK** modulation, it is 2bit/sHz. In practice taking account of the imperfections of the transmission channel (such as non-optimal filtering and non-linearities), the spectral efficiency is of the order of 0.7-0.8 bit/sHz for **BPSK** and 1.4-1.6bit/sHz for **QPSK**.

3.7.8 *Demodulation:*

The role of the demodulator is to identify the phase (or phase shift) of the received carrier and to deduce from it the value of the bits of the transmitted stream. Demodulation can be:

- Coherent: the demodulator makes use of a local sinusoidal reference signal having the same frequency and phase as the modulated wave at the transmitter. The demodulator interprets the phase of the received carrier by comparing it with the phase of the reference signal. Coherent demodulation enables the binary stream to be reconstructed for both cases of transmission encoding-direct and differential.
- Differential: the demodulator compares the phase of the received carrier for the duration of transmission of a symbol and its phase for the duration of the preceding symbol. The demodulator thus detects phase changes. The transmitted information can be recovered only if it is contained in phase changes; differential demodulation is always associated with differential encoding on transmission. This type of modulation and demodulation is identified by the initials **D-BPSK** or **D-QPSK.**

Coherent demodulator of BPSK and DE-BPSK is shown in Fig 3.15, and differential one is shown in Fig 3.16.

On the other hand; coherent demodulator of **QPSK** and **DE-QPSK** is shown in Fig 3.17 and differential one is shown in Fig 3.18.

3.7.8.1 Performance:

Phase identification errors under the influence of noise lead to errors in identification of the received symbol and hence the received bit. The measure of demodulator performance is the bit error (**BER**). The error rate can be estimated from the theoretical error probability (**EP**). This error probability is always less than the measured error rate. Nevertheless it permits the various demodulation techniques to be compared and the degradation of a real system to be quantified.

For two-state modulation where association of the symbol is identified as the bit. The symbol error probability **SEP** represents the bit error probability BEP:

$$BEP = SEP \tag{3.27}$$

For four-state modulation, the bit error probability **BEP** is given by:

$$BEP = SEP/2 \tag{3.28}$$

More generally:

$$BEP = SEP/\log_2 M \qquad \text{for } M \geq 2 \tag{3.29}$$

3.7.9 Decoding and error correction:

The decoder uses the redundancy introduced at the encoder in order to detect and correct errors. In this respect, we mention briefly two techniques which can be used independently or simultaneously:

- Forward-acting error correction (**FEC**).
- Automatic repeat request (**ARQ**).

This two techniques will be discussed in more detail in chapter 7.

3.7.10 Energy dispersion:

The recommendation made by **CCIR** 446 for the use of energy dispersion techniques in order to limit interference between radio communication systems sharing the same frequency bands has been recalled in section 3.6.9. In digital transmission when the binary stream is random the carrier energy is spread throughout the spectrum of the modulating signal. By limiting the transmitted EIRP of the satellite, one can remain below the limit on surface power density at ground level. In contrast, if the binary stream contains a repeated fixed pattern, lines appear in the spectrum of the modulated carrier and their amplitude can lead to the limit on surface power density at ground level being exceeded. The principle of energy dispersion is to generate a modulating binary stream which has random properties regardless of the structure of the binary stream containing the information. This operation which is performed at the transmitter before modulation is called scrambling. On reception the inverse operation, performed after demodulation, is called descrambling. Fig 3.19 shows an example of scrambler and descrambler realization. Each bit of the binary stream carrying information is combined by modulo 2 addition with each bit generated by a pseudorandom sequence generator. The pseudorandom sequence generator consists of a shift register with various feedback paths. The descrambler contains the same pseudorandom sequence generator and, by virtue of the properties of modulo 2 addition, the combination by modulo addition of the bits of the bits of the demodulated binary stream with those of the random sequence provides recovery of the information content. This implies synchronism of the two pseudorandom sequence generators. The arrangement of Fig 3.17 automatically ensures synchronism; after r bits transmitted without error the r stages of the scrambling and descrambling shift registers are in the same state. However, an error in one bit produces as many errors in an interval of r bits as there are non-zero coefficient a_i in the feedback paths. An additional advantage provided by scrambling is suppression of sequence of logical 0's and 1's which, in **NRZ-L** coding, can lead to a loss of synchronization of the the timing recovery circuit and introduce detection errors at the demodulator output as a result of a timing error in the instant of decision.

CHAPTER 4

APPLICATION OF SATELLITE NETWORKS

The purpose of operating satellites in orbit is clearly to provide connections between earth stations which in turn deliver or originate various types of communication services. Applications of satellite networks are broken down into the board categories of video, telephone, and data. The first part of this chapter reviews the features and generic arrangements of networks independent of the specific use. This provides a cross reference with regard to the applications which are reviewed in detail at the end of this chapter.

4.1 GENERAL FEATURES

4.1.1 Connectivity:

The manners in which points on the earth are linked between each other is called "connectivity." There are three generic forms of connectivity: point-to-point, point-to-multipoint, and multipoint-to-point. Each of these connectivities, reviewed in the following paragraphs, can be established through one satellite and two or more earth stations. Comparisons are made with implementations of the same connectivities using the same terrestrial communication technology. It is shown that while terrestrial systems compete favorably on a point-to-point basis, satellite communication has a decided advantage whenever a multipoint connectivity is needed.

4.1.1.1 point-to-point:

The simplest type of connectivity is point-to-point, illustrated in Fig 4.1 with two earth stations both transmitting simultaneously to the satellite. A pair of earth stations transmits RF carriers one to another (and receive each other's carriers), creating what is called a duplex link. The parties being served can thereby talk or transmit information in both directions at the same time. The uplink section of the satellite repeater receives both transmissions and after translation to the down frequency range, transmits them back toward the ground. Reception by an earth station of the opposite end's transmission completes the link. In most cases, transmissions between earth stations through the satellite repeater are continuous in time. If the satellite provides a single footprint covering both earth stations, then a given station can receive in the down link its own as well as that of its communicating partner. This supplementary ability provides a unique way for stations to verify the content and quality of satellite transmission. A typical of several earth stations a satellite provides many duplex point-to-point links to interconnect the locations on the ground. There are many possible circuit routings between the locations. In fully interconnected "mesh" network, the maximum number of possible links between N earth stations is equal to $N(N-1)/2$. To prevent harmful interference, all stations cannot be on the same frequency at the same time. The technology which allows the needed simultaneous transmission without **RFI** through the satellite repeater is called *multiple access*.

4.1.1.2 point-to-multipoint:

While point -to-point links are easily achieved by satellite, it is the point-to-multipoint link which takes full advantage of the wide area coverage of the satellite's footprint. Fig 4.2 indicates how satellite broadcasting is accomplished with transmitting earth station (called the *uplink* in common practice) and many *receive-only* (**RO**) earth stations. The satellite repeater retransmits the single RF carrier containing the information to be distributed. It is usually advantageous to use the highest satellite transmit power possible, because this allows the use of smaller diameter (less expensive) **RO** antennas on the ground.

4.1.1.3 multipoint-to-point:

A multipoint-to-point satellite network complements the broadcast approach by allowing remote stations to send information back to the central station As shown in Fig 4.3, this type of connectivity provides two-way communication because the remotes receive the broadcast from the central station and can transmit back over the same satellite. It is different from a point-to-point network because the remote the remote stations cannot communicate directly with one another but must do so through the central station, to as the hub. In Fig 4.3, the remotes efficiently transmit packets of data toward the satellite on the same frequency but timed the packets such that do not overlap when they enter the satellite repeater. Multipoint-to-point networks are an important extension of point-to-point because of the relativity small antenna size and simplicity of the remote stations. These are afforded by using a more sophisticated hub station with a large-diameter antenna.

4.1.2 *Flexibility:*

A satellite-based network is inherently very flexible from a number of the following perspectives:

1. *Implementation of Satellite Network*
2. *Expansion of the Network*
3. *Simplification of Network Rout*

4.1.3 *Quality:*

The following headlines can be considered while measuring quality of transmission:

1. *Signal reproduction*
2. *Voice Quality and Echo*
3. *Data Communication and Protocols*
4. *Quality appraisal*

4.1.4 *Reliability:*

The reliability of satellite communication is enhanced by the fact that virtually all the ground the facility can be under the direct control of one using organization and this subject will be discussed in details in chapter 5.

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4.2 SATELLITE VIDEO APPLICATIONS

Television or video service, which are one and the same, is perhaps the most popular source of entertainment and information for the public. The broadcast industry has embraced satellite communication as the primary means of carrying programming from the program originator (TV Networks, cable TV programmers, and program syndicators) to the point of distribution (broadcast TV stations, cable TV system operators, and home dishes).

4.2.1 *TV Broadcasting:*

Broadcasting is the commonplace medium whereby local TV stations employ VHF or UHF frequencies to transmit programming to the community. The range of reception is usually limited by line-of-sight propagation to approximately 50 to 100 miles. To conserve frequency channels, the same channel is assigned by the government to another station some safe distance away. Individuals use directional antennas (yogis and reflector dipoles) to maximize signal strength and to suppress reception of unwanted distant stations operating on the same adjacent channels. A given station only transmits a signal channel and hence is constrained to offer only one program at a time.

4.2.1.1 Networks, affiliates, and Independent Stations:

There are national television Networks to provide programs to affiliated TV stations for broadcast over their assigned frequency channel either in real time or replay from video tape. Independent stations can also obtain programming from the out side from syndication companies which sell programs either individually or as packages. Network affiliates also obtain much of their programming from syndicators.

4.2.1.2 Satellite Program Distribution:

This then brings us to the importance of satellites in providing the needed low cost and highly reliable means of delivering the programming. A single satellite can employ point-to-multipoint connectivity to perform this function on a routing basis. To receive programming, every TV station in the United States owns and operates at least one receiving earth stations and many own earth stations usable as uplinks. To achieve very high reliability during an extremely high value (in terms of advertising dollars) event such as the Olympics or the Super Bowl, a Network will "double feed" the program on two different satellites at the same time.

4.2.1.3 Backhaul of Event Coverage:

All sports events and much news coverage are brought back to the studio over a separate point-to-point satellite link called a "backhaul." "In the case of football games, for example, stadiums in North America have access via terrestrial microwave to a local earth station which can uplink telecast to the backhaul satellite, illustrated in Fig 4.4. The Network or stations pay for the use of the satellite, and uplink earth station by the minute or hour. The galaxy satellite system, owned and operated by hughes Communications, Inc., is used extensively for this purpose and calls its occasional use business the video Timesharing Services. Anyone with a receiving earth station can pick up the backhaul, which does not yet include the "commentary" and advertising spots that are inserted at the studio prior to reuplinking to the program distribution satellite.

4.2.1.4 Ground Antenna Utilization:

A network affiliated TV station will use one fixed-mounted earth station antenna to receive full-time Network programming from the point-to-multipoint program distribution satellite. In addition, some "roving" a among other satellites can be done with a movable antenna to pick up special programs provided by syndicators and to receive live coverage of sports events of interest only to the local community (for example, when the local baseball team is playing an away from-home game in another city). Antennas used by the Network in backhaul services would therefore need to be movable, since events and satellites change from time to time.

4.3 TELEPHONE SERVICES

Telecommunication facilities used to provide telephone service can be divided essentially into three parts: subscriber loops, switching, and transmission. A telephone subscriber has on his or her premises one or more subscriber units, which can consist of telephones, facsimile equipment, data terminals, and video teleconferencing equipment. The common denominator is that any of these instruments can send and receive via a telephone line with three kilohertz of bandwidth (300 to 3400 Hz frequency range). The subscriber is connected to the local telephone switched by a single pair of wires called a subscriber loop. In specialized cases requiring maximum transmission performance, the loop can be provided over four wire lines (two for send and two for receive). The telephone switch access other local subscriber which is not directly connected to the same local switching office. Transmission facilities provide the point-to-point links (trunks) which are used to carry the calls between switches.

Public telephone systems connect the switches together according to a five level hierarchy to allow a subscriber to place to any destination in the region, country, or the world. The smallest local switch is designated level 1, while the toll switches are designated 2 through 5, depending on their capacity and location (level 5 being reserved for the largest long distance switching offices). In contrast to this, private line service is implemented by fixed point-to-point circuits which do not pass through switches. The implications of switched *versus* private line services are very important both to the user and to the service provider Satellite communication can and has been applied to both applications, The basic arrangements for switched and private lines are shown in Fig 4.5.

4.3.1 <u>*Switched Telephone Services:*</u>

Switched telephone service is an effective and economical means of allowing individual subscriber to communicate by telephone or other voice bandwidth techniques over a single subscriber loop. As shown at the top of Fig 4.5, a telephone instrument is connected to the local switch which provides access to the national telephone network. Other local subscriber can be called typically with only seven digits because of the limited number of separate loops served by the same or other nearby switching offices. To place a long distance call, another series of digits is required to indicate the region of the country or the country to be called. These "area code" digits are passed to the toll switch which has available to it dedicated point-to-point transmission facilities called trunk reaching a variety of distant toll switches. By interpreting the area code, the toll switch can connect the through on the proper trunk and notify the toll switch on the other end that a circuit is to be established. The call may be routed through more than one toll office. The distance local switch receives the seven dialing digits and rings the telephone of the subscriber being called. The end-to-end circuit is established and maintained until either party hangs up, at which time the local loops and trunks are made available to provide other service.

The long distance trunks between toll officer use either terrestrial or satellite link. Terrestrial facilities predominate in all developed countries, particularly in populated regions such as the eastern United States. Satellite trunks are attractive for economic reasons when covering distances greater than 500 to 1000 miles or if larger bodies of water must be spanned. When properly engineered, satellite trunks cannot be distinguished from long distance terrestrial trunks by most telephone subscribers. When the circuit is to pass voice band data both directions, the delay from satellite transmission can disrupt the performance of the connection, unless an appropriate protocol is used.

Essentially every long distance service provider in the United States has used or is using satellite trunks to interconnect their most distant toll switches. The advent of digital fiber optic links between major cities, however, has reduced the attractiveness of satellite trunks for the heaviest routes. The future use of satellite trunks will probably be limited to what are called thin routes, Where it is not economically attractive to install fiber.

4.3.2 Very Small Aperture Terminal:

The feature of satellite network outlined at the beginning of this chapter can be used to the fullest advantage in telephone services with very small aperture terminals (**VSATs**). The type of the earth station called a **VSAT** is typically inexpensive and easy to operate, justifying its use on the customer's premises. Fig 4.3 shows how a **VSAT** is used in a multipoint-to-point network. With typical antenna size of 1.8 meters and a purchase price comparable to that of a small business computer system, a **VSAT** gives full access to private switched network involving hundreds or thousands of locations. Such networks would be prohibitively expensive if implemented with dedicated point-to point private lines, whether terrestrial or satellite. In a **VSAT** network, a user can view the satellite as a toll switch in the sky, eliminating the needed for local loops, toll switching, or even **PBXs** in some cases.

The key to the effectiveness of a **VSAT** network is its interactive nature, allowing two-way communication from remote locations in the same manner as the terrestrial telephone network.

4.4 DATA COMMUNICATION

The purpose of data communication is to link computers and other centralized data processing facilities with remote users or with other computers. Among the very first data communication network was the **SAGE** system developed for US air force by IBM in the 1950s. Its purpose was to gather radar tracking data from remote early warning radar sites, process the data to identify friendly and possibly unfriendly aircraft, and display the results on **CRT** screens for use by aircraft control personnel. Another such early network was American Airlines' first computerized reservation system called SABER. In the 1980s, data communication networks have been applied in nearly every business imaginable, from grocery store inventory control systems to automated teller machines at banks.

The volume of data along a given path is measured in kilobits per second (kb/s). Low speeds ranging among 1.2 and 9.6 kb/s can pass through a telephone circuit and have generally been served by booth the public switched network and by privet lines. The special circuits which are required to conduct medium speed up to 56 kb/s have been difficult to obtain even in North America. Analog transmission systems, which currently predominant, where designed to carry voice band frequencies which are too narrow for data rates higher than 9.6 kb/s. Satellite links, however, can support any speed, including rates of 1000 kb/s and higher. Terrestrial networks are being upgraded around the world to provide direct digital connections which are capable of the highest rates, also. With the increasing number of alternatives, it becomes a complex task to identify the specific data communication needs of the particular application and the compare the approaches offered by satellite and terrestrial networks

In using the terrestrial telephone network, data communication users find that they are forced to pay high monthly lease rates of private lines. Organization such as brokerage houses, air lines, department store chains, oil companies, and car rental agencies must maintain nearly continuous datalinks with hundreds or thousands of branch offices and stores, even though a small amount of data is being sent to one specific site at one time. In addition to cost, the critical problems in making a data communication system work properly have been the reliability and throughput capability of the interconnecting telephone lines. Satellite links are attractive for data communication because of recognized strengths in all of these areas. Because of high performance to cost rations, a great deal of emphasis is now being placed on using **VSAT** networks.

As was stated earlier in this chapter, modern data protocols allow satellite links to achieve the efficiency formerly possible only on high-grade terrestrial lines. The star network using **VSAT** technology has proven particularly valuable for thin-route data communication. As performances and cost of digital ground equipment improve and as **Ku-band** satellite with advanced features become available, interactive **VSAT** data networks will become widespread. To provide back ground for this evolution, the following paragraphs explain satellite data communication applications in terms of the three generic connectivities.

4.4.1 One-Way Data Broadcast:

The common data communication application implemented by satellite is data broadcasting, illustrated in Fig 4.6. Point-to-multipoint connectivity is used to deliver information in digital form (numbers and characters) to numerous receiving ground antennas. The data are typically transmitted in fixed blocks called packets, since customers can segregate their own data to be delivered like letters. Each packet is "addressed" to certain receivers and even coded so that only authorized users can gain access to the information. Full access to all information in the broadcast is provided in the case of news wire service such as the associated press.

4.4.1.1 Data Broadcast Network Arrangement:

A central hub earth station, shown at the upper left of Fig 4.6, uplinks a nearly continuous stream of packets to the satellite. Information to be transmitted as packets originate from a central database located at the hub or connected to it by a private line. A data packet assembler is a digital processing device that takes the information to be sent, organizes into packets, and places appropriate address bits at the beginning of each packet. Since each packet is self-contained with source and destination address, it can be routed in any way over the satellite and ultimately through a terrestrial packet switched network.

The data broadcast reaches receive-only terminals, shown as sites A, B, and C in Fig 4.6 which are all within the satellite footprint. Receiver C, for example, contains digital processing electronics which can identify the packets addressed to it and recover the data for delivery to the user terminal or storage device. In the illustration, the user at site C has a personal computer to view the data and store it for analysis or later use. Also, the modem and telephone instrument allow the user to reach the hub station or data base to request that certain additional data be transmitted over the satellite. With this dial-up capability, the broadcast network can perform as if it were a multipoint-to-point network.

4.4.1.2 Spread Spectrum Features:

Equatorial Communications Company of Mountain View, California (now a subsidiary of CONTEL/ASC), was the first to offer data broadcasting with receive-only **VSATs** approximately two feet in diameter. An antenna of this size has a beamwidth of nine degrees, which is broad enough to allow **RF** signals from several to enter the ground receiver. To visualize this situation, examine Fig 4.7, which shows closely spaced satellites and a large ground antenna with an appropriately narrow beam. Imagine how the situation would look if the broader ground antenna beam of Fig 4.8 were employed with these closely spaced satellites. With multiple satellites transmitting signals potentially on the same frequency, the ground receiver must have some means of selecting the signal from the right satellite and suppressing the rest. The technique exploited by Equatorial is called *spread spectrum*. With spread spectrum, the digital demodulator of the **VSAT** is able to separate the desired data broadcast from the adjacent satellite interference (and terrestrial microwave interference as well).

Spread spectrum, which inefficient in its use of transponder bandwidth, is not needed if ground receiving antennas of sufficiently narrow bandwidth are used. A C-band antenna approximately 12 feet (not exactly a **VSAT**) would discriminate adequately against adjacent satellite signals. On the other hand, Ku-band **VSATs** of four to six feet can also perform adequately without spread spectrum, because the band width is approximately one-third that at C-band for the same diameter of receiving antenna. A data broadcast on an **RF** carrier without spread spectrum modulation is said to employ the signal channel per carrier (SCPS) technique, which is also used to distribute audio services as discussed at the conclusion of this chapter.

4.4.1.3 Data Broadcasting with Video:

Data broadcasting has also been applied as an adjunct to video transmission, which is convenient to do because the video signal requires a lot of power and bandwidth, while the data requires very little (assuming a data rate of 56 kb/s or less). The cost of reception is relatively low, because the data terminal can use conventional video receiving equipment of the type in mass production for industrial and consumer markets. In one common technique, a low-speed data stream is interested into the vertical blanking interval of the video transmission. (The vertical blanking interval is the horizontal black band which is visible in a gently rolling television picture.) The data is removed from the video signal by a special decoder unit to which the display terminal or data recorder is connected. Another approach employs a separate baseband "subscriber" onto which is modulated a low or medium-speed data stream. The receiving earth station will require a separate subscriber receiver and decoder to recover the data; the subscriber approach can potentially carry much higher data rate, however, and does not interfere with the video signal in any way. For these reasons, data subscriber can be found on a large percentage of video carriers used for full-time delivery of cable TV programming. Alternatively, broadcast data service is being provided to subscribers without the video as a means to optimize the link for reception by the smallest possible receive-only antenna.

4.4.2 *Interactive Data:*

While data broadcast has a variety of uses, most data communication applications require that the remote terminals be able to respond back to the central site. Also, remotes may need to transmit information between another.

4.4.2.1 Network Architecture for Interactive Data:

Fig 4.9 shows an interactive data network where the remote stations can transmit information to the hub over the same satellite that delivers the data broadcast. This is obviously more convenient for the remote station than using the dial-up line as suggested in the previous section. However, there is a significant trade-off between the money saved by using the same satellite transponder and the money spent to add the transmitting capability to every remote station. In cases where the remote stations transmit infrequently (once per day, for example) but need to receive data continuously, the point-to-multipoint broadcast network will be the lowest in cost.

The principle advantage of an interactive **VSAT** network is that no terrestrial facilities of any kind are required, as is shown in Fig 4.9. The hub's large antenna allows remote stations to uplink with the lowest **RF** Possible, usually less than ten watts. Even well, transmissions from remotes will be at significantly lower data rates than originate from the hub. It is usually advantageous to share a **VSAT** among several users, such as would be the case at an airline reservation office. The data concentrator shown at the lower right of Fig 4.9 combines (multiplexes) the data inputs from the three terminals and inputs a signal stream of bits to the **VSAT** indoor electronic unit. Conversely, the data broadcast from the hub is demultiplexed by the **VSAT** for the delivery to the individual user terminals. To maximize the efficiency satellite transmissions, the **RF** mounted in close proximity to the VSAT antenna feed horn.

4.4.2.2 Network Management:

The hub station has many of the same elements as shown for the broadcast application. The necessity of controlling the transmission from numerous remote stations, however, adds another level of complexity. This function is accomplished by a *network management system* (NMS), which is incorporated into one of the hub stations in the **VSAT** network. Since VSATs are usually unnamed (in the same sense as a **PBX** or minicomputer), the **NMS** automatically interrogates each **VSAT** on a routine basis to determine its operating status and past history of usage. A given **VSAT** which has failed and cannot transmit to the satellite could still reach the **NMS** over a dial-up telephone line. This result in a powerful and resilient network where faults in remote **VSATs** can be isolated and even corrected. If human intervention is required to restore service at the remote location, then the operator on duty at the **NMS** can notify the appropriate field maintenance person. The integrity of the interactive satellite network is particularly strong, because the failures are limited to accessible sources within the hub, the **VSAT**, the satellite transponder, and possibly the NMS itself. As was mentioned previously, satellite links are extremely reliable and yield error rates which are lower than those achievable with terrestrial private lines. The earth stations in the network are subject to equipment failures and software problems, which will cause outages on occasion. Experience has shown that such out gates can be minimized in frequency by using field-proven electronics and in duration by providing standby (redundant) equipment which can be activated by remote control from the **NMS.**

4.5 INTEGRATED DIGITAL SERVICES

The expansion of high capacity digital communication system is causing the dividing lines between telephone, data, and video transmission to blur. In fact, as discussed bellow, it is possible to convert any and all of these services into a digital format and thereafter utilize common terrestrial and satellites links. New standards and equipment are being developed under the name of *integrated services digital networks* (**ISDN**), by which many applications would be digitized essentially at the source and combined together (integrated) for efficient routing and transmission. When implemented on the user side of typical local loop, **ISDN** is expected to provide such capability as tow separate telephone lines plus an independent digital data line. This refereed to as 2B+D, which stands for two bearers (channels) plus data.

Advances in digital bandwidth compression are allowing the multiple channels of voice, data, or video to be carried over a link which could previously only carry a single channel. This is accomplished by high speed programmable digital processors which remove dark time and redundancy from the signal information coming from the source. Users cannot usually detect compression, because the equipment at the distant and reconstructs the signal adequately for its intended purpose. A rather fundamental way of combining digital signals together is called *time division multiplexing* (or simply *multiplexing*), the reverse process of splitting out the individual data channels is called *demultiplexing*.

In major advancement of the last decade called *statistical multiplexing*, the combining of input data channels is done in response to the time varying (*dynamic*) demand for transmission. The sum of data rates of input channels would exceed the capacity of the output transmission link, except that only those channels with data to be sent are passed through. From the user perspective, a full-time data link is provided and the dynamic switching of the statistical multipliers at both ends is transparent, i.e, it can be totally ignored by the user. Blockage of users when the outbound link is overloaded is automatically signaled to terminal equipment through the data transmission interface.

As a precursor to full implementation of **ISDN,** the *time division multiple access* (TDMA) networks pioneered by **COMSAT** laboratories of the communications Satellite Corporation required digitization and multiplexing of voice and data channels before uplinking to the satellite. This technology, proven out in the early 1970s, became the driving force for developing signal processing techniques and for proving that digital systems can work reliably. Digital transmission facilities did not become commonplace however, until the mid-1980s, delaying commercial development and marketing of associated equipment.

4.5.1 *Digital Hierarchy:*

Once the user information in whatever form is digitized and multiplexed, it can be viewed as a signal stream of data. It is a common practice to classify data streams according to the amount of transmission capacity or bandwidth that is required. The digital hierarchy established in the 1960s for the bell system uses standard levels designated by **DS-0**, **DS-1**, DS-2, . . ., **DS-*n***, *et cetera* ("T" can be substituted for "**DS**" in the naming convention). TABLE 4.1 summarizes the basic transmission rates and applications for the levels of the hierarchy currently in use. Perhaps the most common transmission speed for integrated digital services is **DS-1** (1.544 Mb/s), because a link of this capacity can support a variety of different services even at the same time. Levels of the hierarchy above **DS-3** (45 Mb/s) carry such large amounts of information that they are not generally available for resale. In terms of **IDSN** (mentioned at the beginning of this section), **DS-0** (64 Kb/s) is seen as the basic user interface rate on the local loop and **DS-1** link, there are 23 bearer channels plus one data channel, i.e., **23B+d**. There is currently some difficulty in reconciling **ISDN** standards with the digital hierarchies in North America, Europe, and Japan. This is because European countries have adopted different digital rates for their hierarchy, making it somewhat inconvenient for them to interface with North America and Japanese digital transmission facilities.

4.5.2 *Combining of Digital Services:*

The multiplexing and transmission of integrated digital services are illustrated in Fig 4.10. On the user side (shown at the left) are three possible applications: telephone, video teleconferencing, and high speed data. A high level multiplexer is located at a point of service aggregation to combine and route traffic to the digital transmission network. On the right, high-speed digital streams (typically **DS-1**)reach other locations over various point-to-point transmission systems, which can consist of satellite links, terrestrial microwave systems, and fiber optic cables. An **IDNX** would be located at each major user location to establish a network node. Traffic routing between nodes is programmed in a routing pattern which can be altered at any time by an operator using a computer terminal connected to any

NDX in the network. Another important feature for this equipment is that it provides stical multiplexing efficiently to squeeze together smaller streams of data traffic.

4.5.2.1 Digital Telephone Services:

r telephone services, modern local switches and **PBXs** digitize the incoming voice quency information (including voice band data and facsimile) and connect users to each er and to those at distant locations. The trunk side of the switch would be at the **DS-1** el. With digital compression, the number of voice channels that can be carried by a **DS-1** nnel is the range of 44 to 99, depending on the mathematical process (algorithm) ployed. This increased telephone capacity shows the effectiveness of digital compression maximizing the use of the transmission facility.

The digital switch shown at the top of Fig 4.10 provides access to a private or blic long distance network utilizing digital transmission at a high level of hierarchy. sers are connected to the switch by local loops within the same building or by terrestrial e lines. The inter face device at the switch which determines the type of subscriber rvices is called a "port." A standard telephone instrument or voice band data modem cesses the switch through a two-wire along voice port. Analog four-wire trunks can be nnected to the switch through a tandem port. Some switches allow direct digital nnections at 9.6 Kb/s and even 56 Kb/s through a digital data port. Lower-speed devices n be combined together using a static multiplexer, as discussed in previous paragraphs. nally, in the case of **ISDN**, digital switches will be modified to provide greater capability d accommodate **DS-0** ports and other port configurations which result from current efforts standardized the user interface.

4.5.2.2 Compressed Video Teleconferencing:

e video teleconferencing system shown in Fig 4.10 can establish a two-day video link th one or more distant locations. A full-motion color **TV** signal with sound can be ansmitted at the **DS-1** rate or even lower. The device which digitized and compresses the deo signal from the camera is called a video *codec* (coder-decoder). Devices of this type ve existed for ten or more years, but companies have caused the cost and size of codecs decrease greatly. The quality of this type of video adequate for business meeting showing alking heads" and presentations consisting of color slides or computer graphic images. It common to operate the video teleconferencing system at one-half the **DS-1** rate (called

T-1) and use a high-level digital multiplexer to introduce other services in to the out and DS-1 stream. When 56 Kb/s compression produces picture quality comparable to current T-1 codecs, it is expected the there will be a significant rise in the use of the requires a rate of 90 Mb/s or greater with exciting equipment. However, broadcast-quality TV at the DS-3 (45Mb/s) rate is gradually being adopted for point-to-point links via fiber optic cable systems.

4.5.2.3 Digital Data Services:

The last type of user access shown in Fig 4.10 is high-speed data on point-to-point basis. This type of services could be required to interconnect two or more large computer systems, each capable of transmitting at 56 Kb/s, 256 Kb/s, or even **DS-1**. These high rates would be required when a large file of data must be transferred. Another application for such high speeds is for digital facsimile such as that used to reproduce newspaper or magazine pages. With rates up to **T-1**, an entire newspaper can be transmitted with absolute clarity in under one our. In general, high-speed digital access can be required in special access, and, therefore, it is difficult to establish standards. The advantage of using digital integration is that such unusual requirements can be easily accommodated with a more conventional network composed of **DS-1** transmission facilities and high-level digital multipliers. Port configurations for any of these rates are available from the suppliers of high-level digital multipliers.

4.5.3 Digital Integration with TDMA:

Modern **TDMA** equipment can perform the function of the high-level multiplexer, making **TDMA** particularly attractive for private digital networks with large and divers service requirements. An important benefit of **TDMA** is that it can make use of the point-to-multipoint capability of the satellite and thereby reduce the number of individual transmission links that would otherwise be required with point-to-point **DS-1** channels.

4.6 HIGH FIDELITY AUDIO SERVICES

The delivery of high fidelity audio services by satellite to broadcast radio stations represents an effective although relatively small niche in the telecommunication business. Sound quality is excellent because of the wide audio bandwidth (specified anywhere between 5 and 15 KHz, depending on the application)and low noise provide over the satellite link. Using point-to-multipoint connectivity, either monaural or stereo sound is uplinked to the satellite typically with single channel per carrier technique. The audio information can be sent in either analog or digital form, with the receive-only station performing the necessary conversion. One audio **SCPC** occupies only a narrow slice of bandwidth in a transponder; therefore, a given transponder can carry one hundred or more audio signals. In another approach, several high fidelity audio channels are digitized and multiplexed together into a high speed stream of data. This transmission is uplinked to the satellite on a signal carrier, and received at the radio station where the desired audio channel is demultiplexed.

4.6.1 Audio Network Arrangement:

The network arrangement is nearly identical to that shown in Fig 4.4 for broadcast **TV**. An affiliated radio station would use one antenna to receive a continuous or scheduled network feed containing music, news, and national commercials. Local commercial and information are inserted at the radio station in the same way a **TV** broadcast station adds to its network feed. A second, roving antenna is used for sports events and for syndicating programming such as a nationwide talk show. Uplinks at every Major League baseball stadium in the USA are operated by **IDB** communications Group of Culver city, California, offering local radio stations convenient access to the away games at home teams.

4.6.2 Alternative Delivery Concept:

Using satellite, it is possible to have private radio network which is never actually broadcast over the air. The supermarket Radio Network (**SRN**) of Atlanta, Georgia, provides individualized "radio stations" for supermarket chains. As shoppers stroll through the aisles, the specific **SRN** station is played over the store's audio system. The signal, received by a rooftop **C**-band antenna, contains popular music with a disk jockey who reads commercials targeted towards products which are already in the store. Rather that using **SCPC**, the radio

...nels are uplinked as subscriber on a wideband carrier similar to the type used for video ...mission. Satellite transmission is particularly valuable for this application, because the ...-to-multipoint transmissions go directly from the studio to the store without passing ...gh any (uncontrollable) terrestrial lines or tie points.

CHAPTER 5

RELIABILITY OF SATELLITE COMMUNICATIONS SYSTEMS

The reliability of a system is defined by the probability of correct operation of the system during a given lifetime. The reliability of a complete satellite communication system depends on the reliability of two principle constituents, the satellite and the ground stations. The availability is the ratio of the actual period of correct operation of the system to the required period of correct operation. The availability of a complete satellite communication system depends not only on the reliability of the constituents of the system but also on the probability of successful launching, the replacement time and the number of operational and back-up satellite (in orbit and on the ground).

Availability of the ground station depends not only on their reliability but also on their maintainability. For the satellite, availability depends only on reliability since maintenance is not envisaged with current techniques.

5.1 INTRODUCTION OF RELIABILITY

5.1.1 Failure rate:

For complex equipment such as that of a satellite, two types of breakdown occur:

- Coincidental breakdown.
- Breakdowns resulting from usage, and exhaustion of energy sources (such as the propellant reserves required for station keeping and attitude control).

The instantaneous failure rate $\lambda(t)$ of a given piece of equipment is defined as the limit, as the time interval tends to zero, of the ratio of the number of pieces of equipment in correct operating state at the start of the time interval (a large number of identical pieces of equipment is assumed to operate at the same time).

The curve illustrating the variation of failure rate with time often has the form shown in Fig 5.1 (the 'bath-tub' curve), particularly for electronic equipment. Initially, the failure rate decreases rapidly with time. This is the period of early or infant failure. Subsequently, the failure rate is more or less constant. Finally, the failure rate increases rapidly with time, this the wear-out period.

For space equipment, failures due to 'infant maladies' are eliminated before launching be means of special preparation producers (burn-in). Hence, during the period of useful life, most of the electronic and mechanical equipment has constant failure rate l. The instantaneous failure rate is thus often expressed in **Fit** (the number of failures in 10^9 h).

5.1.2 The probability of survival or reliability:

If a piece of equipment has a failure rate $\lambda(t)$, its probability from time 0 to t, or reliability R(t), is given by :

$$R(t) = \exp\left(-\int_0^t \lambda(u)\,du\right) \tag{5.1}$$

This expression is of a general form which is independent of the law of variation of failure rate $\lambda(t)$ with time.

If the failure rate λ is constant, the expression for the reliability reduces to:

$$R(t) = \exp\{-\lambda t\} \tag{5.2}$$

For a satellite, the maximum mission life U can be defined at the end of which the service is no longer provided, usually due to exhaustion of the propellants. After time U, the probability of survival is zero. The curve of 5.2 illustrates the variation of satellite reliability; the reliability is high when l is small.

5.1.3 *Probability of death or unreliability:*

5.1.3.1 Unreliability D(t):

The unreliability of probability of having the system in a dead state at time t is the complement of the reliability:

$$R(t) + D(t) = 1 \tag{5.3}$$

5.1.3.1 Death probability density *f*(t):

The instantaneous probability of death is the derivative with respect to time of the unreliability. A death probability density $f(t)$ can thus be defined as:

$$F(t) = dD(t)/dt = -dR(t)/dt \tag{5.4}$$

The probability of death occurring during a time interval t is thus

$$D(t) = \int_0^t f(u)\, d(u) \tag{5.5}$$

The failure rate $\lambda(t)$ is related to the death probability density $f(t)$ by:

$$\lambda(t) = f(t) / R(t) \tag{5.6}$$

If the failure rate is constant,

$f(t) = l \exp(-\lambda t)$.

5.1.4 *MTTF-mean lifetime:*

The mean lifetime or Mean Time To Failure (**MTTF**) is the mean time T of the occurrence of the first failure after entering service.

5.1.4.1 Definition:

The mean time of occurrence of the first failure is obtained from the instantaneous probability of failure using :

$$T = \int_0^\infty tf(t)\, d(t) = \int_0^\infty R(t) d(t) \tag{5.7}$$

If the failure rate l is constant, $T = 1/\lambda$.

5.1.4.2 The case of a satellite of limited lifetime:

The mean lifetime t can be written as follows:

$$\tau = \int_0^U t\lambda\, e^{-\lambda t}\, dt + e^{-U/T} \int_U^\infty t\delta(t-U)\, dt \tag{5.8}$$

Hence:

$$t = T\{ 1- \exp(-U/T)\}. \tag{5.9}$$

The ratio t/T is the probability of death during maximum mission life U.

5.1.5 *Reliability during the wear-out period*

Components prone to wear-out, such as bearings, thrusters and vacuum tube cathodes, have failure at the end of life whose probability density can be modeled by a normal distribution. The instantaneous probability of failure is thus of the form:

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t-\gamma}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t-\gamma}{\alpha}\right)^{\beta}\right] \tag{5.10}$$

where m is the mean lifetime and s the standard deviation. The reliability becomes

$$R(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}}\int_t^{\infty} \exp\left[-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2\right]dt \tag{5.11}$$

A hybrid reliability can be defined as the product of the reliability considering only wear-out and the reliability which characterizes accidental failure. Equipment is generally designed in such a way that the lifetime determined by wear-out is long compared with the duration of the mission.

For components prone to wear-out, probability laws other than the normal distribution, such as the Weibull distribution for example, are also used to model the occurrence of failures.

The Weibull distribution, the expression for death probability density $f(t)$ and reliability R(t) are given by:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2\right] \tag{5.12}$$

and:

$$R = \exp\left[-\left(\frac{t-\gamma}{\alpha}\right)^{\beta}\right] \tag{5.13}$$

where α, β, γ are fitting parameters.

To model failure due to wear-out, the rate of which increases with time, the parameter β will be greater than 1.

5.2 SATELLITE SYSTEM AVAILABILITY

Availability A is defined as A = (required time - down time)/ required time where required time is the period of time for which the system is required to operate and down time is the cumulative time the system is out of order within the required time.

To provide a given system availability A for a given required time L, it is necessary to determine the number of satellite to be launched will affect the cost of the service.

The required number of satellites n and the availability A of the system will be evaluated for two typical cases for which t_R is the time required to replace a satellite in orbit and p is the probability of a successful launch.

5.2.1 No back-up satellite in orbit:

5.2.1.1 Number of satellite required:

By defining S = L/τ satellites into orbit on average during L years. As the probability of success of each launch is p, it will be necessary to attempt n=S/p launches and the number of satellite n required is thus:

$$n = \frac{L}{pT\left[1 - \exp(-U/T)\right]} \qquad (5.14)$$

5.2.1.2 System availability:

If it is assumed that satellite close to their end of mission life U are replaced sufficiently in advance so that , even in the case of a launch failure, another launch can be attempted in time, the unavailability of the system at this time is small compared with the unavailability due to accidental failures.

During its lifetime U, the probability that a satellite fails in an accidental manner is P_a =1- exp(-UT). In L years, there are S replacements to be performed of which P_a*S are for accidental failures. Each replacement requires a time t_r if it succeeds and, on average, a time t_r/p. The mean duration of unavailability during L years is $P_aSt_r/p = Lt_r/pT$. The mean unavailability (breakdown) rate is :

$$B = t_r/pT \qquad (5.15)$$

and the availability $A = 1\text{-}B$ of the system is thus :

$$A = 1-(t_r/pT) \tag{5.16}$$

5.2.2 *Back-up satellite in orbit:*

By admitting, pessimistically but wisely, that a back-up satellite has a failure rate λ and a lifetime U equal to that of an active satellite, it is necessary to launch twice as many satellites during L years than in the previous case:

$$n = \frac{2L}{pT[1 - \exp(-U/T)]} \tag{5.17}$$

Taking account of the fact that t_r/T is small, the availability of the system becomes:

$$A = 1 - \{(2t_r^{\,2})/(pT)^2\} \tag{5.18}$$

5.3 SUB-SYSTEM RELIABILITY

Calculation of the reliability of a system is performed from the reliability of the elements which constitute the system. As far as the satellite is concerned, except in the special case where elements in parallel can independently fulfill a particular mission, most sub-systems are essentially in series from the point of view of reliability. This indicates that correct operation of each sub-system is indispensable for correct operation of the system.

5.3.1 Elements in series:

5.3.1.1 reliability:

$$R = R_1 * R_2 * R_3 * \ldots\ldots\ldots\ldots * R_n \tag{5.19}$$

5.3.1.1 Failure rate:

$$\lambda = \Sigma \lambda_i \tag{5.20}$$

$$MTTF = 1/\lambda \tag{5.21}$$

5.3.2 Elements in parallel (static redundancy)

5.3.2.1 Probability of death is defined as :

$$D = D_1 * D_2 * D_3 * \ldots\ldots * D_n \tag{5.22}$$

where

$$R = 1\text{-}D.$$

5.3.2.2 Failure rate :

Is obtained from the ratio $f(t)/R$, and its found that the overall failure rate is a function of time and hence the overall failure rate is not constant.

5.3.2.3 MTTF:

$$MTTF = \Sigma\,(MTTF_{i}/n) \tag{5.23}$$

where $MTTF_i = 1/\lambda_i$

5.3.3 Dynamic redundancy (with switching)

5.3.3.1 Poisson distribution:

$$R = e^{-m\lambda_i t}\left[1 + m\lambda_i t + (m\lambda_i t)^2/2! + \ldots + (m\lambda_i t)^n/n!\right] \tag{5.24}$$

where:

m are active elements in parallel that the system is constituted of.

n are elements can, in turn, be placed in parallel to replace a failed main element.

and;

λ_i is the failure rate of each of the elements ant it is constant and same for each.

$$MTTF = \{(n+1)/m\} * MTTF_i \tag{5.25}$$

where

$MTTF_i = 1/\lambda_i$ is characteristic of one element.

5.3.3.2 Redundancy with different failure rates which depends on the operational state

A sub-system consists of a principle elements and a back-up element which can replace it. The failure rate of the principle element is λ_p; the failure rate of the back-up element is λ_r when the element is inactive and l_s when its operating.

The reliability R is equal to $R_p + R_s$ with:

$R_p = \exp(-\lambda_p t)$, and;

$$R_s = \int_0^t \left[\left(\lambda_i e^{-\lambda_p tf}\right)\left(e^{-\lambda_r tf}\right)\left(e^{-\lambda_s (t-tf)}\right)\right] dt_f$$

The reliability R of the system with redundancy is then given by:

$$R = \exp(-\lambda_p t) + \{\lambda_p/(\lambda_p+\lambda_r+\lambda_s)\}*\{\exp(-\lambda_s t) - \exp(-(\lambda_p+\lambda_t)t)\} \quad (5.26)$$

and

$$T = \text{MTTF} = (1/\lambda_p) + \lambda_p/\lambda_s(\lambda_p+\lambda_r) = T_p+\{(T_s+T_r)/(T_p+T_r)\} \quad (5.27)$$

where

T_p, T_s, T_r are the mean times of occurrence of failure MTTF of the principle equipment, the back-up equipment when inactive and the back-up equipment when operating respectively.

5.3.4 *Equipment having several failure modes:*

Some equipment and elements have several modes of failure, for example short circuit and open circuit for diodes, capacitors and so on. The consequences of a failure on the operation of the system concerned are not the same following a failure of one type or the other. The consequences also depend on the system architecture.

With a structure containing n elements in series, a failure of the open circuit type, characterized by a probability of death Do for one element, involves death of the ensemble. The probability of death of ensemble is thus $1-(1 - Do)^n$.

On the other hand, with a failure of the short-circuit type, characterized by a probability of death D_c, death of the ensemble requires failure of all the elements. The corresponding probability of death of the ensemble is thus $(Dc)^n$.

The reliability R of the series structure is thus $R = (1-Do)^n - (Dc)^n$ and the series structure is robust with respect to failures of the short-circuit type.

When n elements in parallel are associated with failures of the open circuit type, characterized by a probability of death D_o for one element, death of the ensemble requires failure of all the elements. The probability of death of the ensemble is thus $(Do)^n$. On the other hand, failure of the short-circuit type, characterized by a probability of death Dc, involves that of the ensemble. The probability of death of the ensemble is thus $1-(1 - D_c)^n$. The reliability R of the parallel structure is thus, $R = (1- D_c)^n - (D_o)^n$, and the parallel structure is robust with respect to failure of the open circuit type.

For each of these structures, there is an optimum number of elements which enables maximum reliability to be achieved. If protection against both types of failure is required simultaneously, more complex structures must be used such as series-parallel or parallel-series types. These procedures are used for wiring the solar cells of the power generator for example.

5.4 COMPONENT RELIABILITY

Certain sub-systems, such as the payload, contain several hundreds of components. To obtain failure rates of one or two per 100,000h, each component must not exceed a failure rate of the order of 1 per 10 million hours.

During the design of the satellite, after the constraints have been analyzed, provisional examination of the reliability enables redundancy arrangement to be defined together with the quality level of components and equipment.

5.4.1 Component reliability:

Information on the failure rates of various types of component is available from the manufacturers who have the results of component tests under particular environmental conditions. The least reliable components are traveling wave tubes and components with moving parts such as rotating bearings, relays and potentiometers). The most reliable components are passive ones such as resistors, capacitors, switching diodes and connectors.

The failure rate of a component can be greatly reduced by an appropriate choice of loading ratio (derating). The mean power dissipated by components is chosen to be a small percentage of the nominal power specified by the manufacturer. For example; a resistor capable of dissipating 1W would be chosen for a resistance which must dissipate 300mW. The junction temperature of transistors must not exceed a specified value (typically 105° C).

The same principle is applied to the maximum values of voltages, current, etc, which components and equipments must be capable of withstanding. Wear-out of elements is thus reduced according to a power law as a function of reduced loading. Applicable loading ratios appear in the preferential lists of components to be used in priority.

5.4.2 Component selection:

Component are chosen after a functional examination of the equipment on preferential lists established by space agencies such as the European Space Agency (**ESA/SCCG** Space Component Coordination Group), **NASA**, etc. Special procedures are followed to ensure the manufacturing quality of the component chosen, the constancy of its properties from one sample to another and with time (these include purchase and acceptances specifications, qualifications of batches and component acceptance).

When a component which does not appear in the preferential lists is necessary, qualification of the component is performed using the same specifications as those which are supplied.

It includes two main phases:

- The evaluation phase.
- The qualification phase.

5.4.2.1 Evaluation:

This phase includes the following :

1. Inspection of the manufacturing facilities.
2. Detailed examination of the production line of the component concerned.
3. Evaluation tests to the limits of the components.
4. Examination of the manufacturing and monitoring documentation (the Process Identification Document (**PID**)).

When this phase is completed in a satisfactory manner, the qualification phase is entered.

5.4.2.2 Qualification:

This phase includes the following activities:

1. Manufacture of the components which constitute the qualified batch.
2. 100% testing at the end of production and selection.
3. Qualification testing of a sample of the batch.

If the results are satisfactory qualification is declared and a qualification certificate is delivered to the manufacturer. The qualified product is then entered in the preferential list such as the Qualified Product List (**QPL**) of the **ESA**.

Qualification is valid for a fixed period, after this period the validity could be extended on condition that batch tests are, or have been, performed and the process identification document has been not been changed.

5.4.3 Manufacture:

Having selected the components, the equipment manufacturing specifications must be defined. Technical design takes account of the constraints of performance, weight, volume, etc. and the constraints specific to the space environment. The manufacturing specifications includes the choice of wiring process, the type of solder, the form of enclosure or protective padding, etc.

Manufacturing quality control has the particular goal of verifying that manufacturing specifications are actually observed during the various stages and the components used are actually those which have been specified.

5.4.4 Quality assurance:

Quality assurance is indispensable and complementary to security and reliability. More precisely, quality assurance ensures a number of objectives and tasks relating to the requirements of the space project become facts.

The main elements of a quality assurance program are as follows:

1. Quality of the pre-project studies and definition.
2. Design quality.
3. Supply quality.
4. Quality of manufacture.
5. Quality of testing.
6. Control of the configuration.
7. Non-conformity, failures, exemptions.
8. Development program of the models and mock-ups.
9. Storage, packaging, transport and handling.

CHAPTER 6

FUTURE DIRECTION FOR SATELLITE COMMUNICATION

Advances of satellite communication systems and applications have always been evolutionary in nature. the beginning of the industry was technology driven, with the development of the space craft design and the proving of its feasibility in the early 1960s. Favorable economics in comparison to terrestrial alternatives gave satellite a needed boosts to get them literally off the ground and to expand. More recent innovations in fiber optic transmission, discussed later in this chapter ,are seen in some ways as a response to the advances made by satellite communication in reducing transmission cost. The versatility of satellites should allow them to fill important and even vital needs, even as long distance fiber optic networks become widespread. At the same time that satellite applications are evolving in response to competition from terrestrial systems, the technology base undergoing evolutionary change. There is very reason to expect that the capability versatility of satellites and earth stations will improve significantly over the coming years. This provides a technology push all over again allowing system designer and operators to approach the new applications and markets with powerful hardware and software capabilities.

In the following paragraphs, an attempt is made to project into the future using the current shape of the industry as a starting point. Much of this should be viewed as conceptual and possible, since the prices makeup of the applications and technology is impossible to predict. Even the most conservative projection would show a satellites having a significant role in the future telecommunication picture. since unpredictable advances will occur, the future for the satellites will probably be even brighter than is painted here.

6.1 EVOLUTION OF NEW SATELLITE APPLICATION

The changing nature of the uses to which communication satellites have been economically put is reviewed in TABLE 6-1. Prior to and during 1970s the pre dominant applications were in telephone communication, a use which employed 80 to 90% of the available capacity on domestic and international satellites. Video applications were primarily in point-to-point transmission across oceans and continents. At the time, the TV Networks continued their reliance on terrestrial microwave to distribute programming to their affiliates. Towards the end of the decade, point-to-multipoint point distribution of cable TV and radio programming grew rapidly.

During the 1980s the combined mass of all video transmission consumed approximately one-half of total domestic satellite capacity serving the UNITED STATES. This occurred because the cable TV programmers were joined by the TV Networks to take advantage of low cost and reliable satellite signal distribution .The 1980s also saw the explosive growth of private communication Networks which use satellite transmission as an integral part. The quality and reliability of the satellite link made data transmission attractive for both point-to point and point -to multipoint-point (broadcast) transmission.

Projecting this into the 1990s, it seems reasonable to expect a continuation of the heavy dependence of the satellite delivery of TV and radio programming. The advent of the high power **DBS** systems should greatly increase the quality of **TVRO** dishes found at homes, principally because of diminished size and cost. Mobile satellite services are also on the horizon, wherein users vehicles and remote locations can access the public network for voice and data services.

6.1.1 Emphasis of broadcast applications:

The point frequently made is that one of the satellite's principle advantages is its wide area coverage capability. In broadcasting, the down link signal is available everywhere within the footprint. This capability would continue to be attractive for video, audio, and data delivery proposes, as discussed in the following paragraphs.

6.1.1.1 Direct Broadcast satellite:

The decade of the 1980s has not really seen the introduction of **DBS** services, although a number of experiments and trails are underway. Problems in the past have had less to do with technology than with market confusion. Current C-band direct-to-home service offerings from the cable TV programmers could be the precursor to similar services offered from high powered direct broadcast satellite. The type of home receiver required will use a dish between one and two in diameter, permitting the homeowner to locate the dish conveniently. The **DBS** will never be successful without programming, which is the most costly element of such an endeavor. One aspect of **DBS** that could prove useful is its ability to reach a segment of users dispersed throughout a nation. Programs in a particular foreign language such as Spanish, or Chinese can be sent directly to the home for convenient viewing by families. This greatly simplifies the logistics of delivering the programming which otherwise would have to come by way of the local cable TV system or UHF station, both of which may be unavailable due to limited channel capacity

Another possibility for **DBS** is the delivery of high definition TV (**HDTV**)programming. There is currently no means of broad casting **HDTV** to the home. The DBS satellite can easily transmit such a signal, which also happens to occupy approximately twice the baseband bandwidth of a standard color TV signal. Probably the most encouraging tend for **DBS** is the growth in the number of backyard c-band dishes, reaching in to the millions.

6.1.1.2 Broadcast Data:

The broadcast of low and medium data very small antennas is based on existing technology and should continue as an important satellite application. Data broadcasting is currently available at reasonable cost through local FM radio stations using the **SCA** subcarrier technique and some services are offered over cable TV systems. Another data broadcast services called videotex provides consumer with information in graphic and character form through the video channel for display on their TV sets. As more Videotex services become available and begin to prove themselves as viable businesses, the ground work will come firmly established for the direct delivery of the same types of information from the satellite.

Increasing the data rate from a few thousand bits per second to perhaps a million bits per second would greatly improve the visual quality of digitized images. Also, such high data rates would increase the amount of information that could down loaded into an internal database within the receiving equipment, allowing to subscript to select for viewing only the portion of interest. This application is similar in concept to the use of laser discs which hold information for access to computer terminal, although the satellite version has the important of being able to provide information in real time. If access is to be controlled, the use of digital information can be restricted by addressing packets of data for specific terminals.

6.1.2 *Paralleling the Terrestrial Network:*

The evolution of satellite applications illustrated in TABLE 6-1 clearly shows that while satellite transmission was at first attractive for long-distance links, the situation has shifted significantly since the advent of fiber optics. Satellite links, however, will continue to be useful as divers and alternate routes. Private networks employ satellites because of flexibility of the services offered and the ability of the user to own the ground equipment and exercises nearly total control of the network.

6.1.2.1 Interplay Of Terrestrial and satellite communication:

In Fig 6.1, the shifting nature of the competition between terrestrial communication and satellite communication is illustrated. The first innovations in high capacity long distance transmission were in the terrestrial area. These developments included analog frequency division multiplex (**FDM**) and microwave radio satellite became well established and new technology in digital processing and transmission, notably (**TDMA**),began to bleed over to the terrestrial side. This provided some of the basis for advances in terrestrial communication such as digital switching and high speed digital transmission. These digital technologies are essential to the effective use of fiber optic cables, and now the terrestrial part of Fig 6.1 is becoming dominant again. Quite logically, forthcoming innovations on the terrestrial side will aid in the redefinition of telecommunication services that can be provided conveniently by the next generations of satellites.

6.1.2.2 Satellites Versus Fiber Optics:

It is anticipated that while fiber optic networks will become firmly established in the developed world, satellite communication will play a complementary and therefore important role. Conceptually, a fiber optic network in a given country provides the backbone of transmission between major cities and user locations. The economics of fiber optic are very favorable as long as the fibers and digital transmission groups within them can be adequately loaded with paying traffic. An unloaded loaded fiber optic cable is not attractive economically, compounded by the fact that once the link is installed between two points it cannot conveniently be moved for deployment elsewhere.

The obvious role of satellite transmission is to provide the flexibility that point-to-point cables cannot. Thin-route applications will always be attractive by satellite. A highbred network of heavily loaded fiber and divers satellite links can produce the lowest cost per call where services is to be provided on a widespread basis. the type of satellite that is called for would operate in the **FSS** portion of The **Ku** band, taking advantage of the ability to locate uplinks any where in the satellite footprint. A high capacity **Ku** band satellite can achieve cost per call for thin-route service which is competitive with conventional services over the public network, even with low cost fiber optic transmission between major nodes.

6.1.2.3 International Communication:

Satellites will continue to provide a cost effective means of spanning oceans and continental distance between countries. A high capacity satellite operated by **INTELSAT** provides a valuable point of central inter connectivity for the widest variety of traffic between dozens of international gateway stations within a hemisphere. The other hand, it is possible that a specifically designed heavy trunking satellite can be effectively parallel fiber optic cables in the heavy route marketplace. This will permit satellite to continue to play the role of provider of alternate routes and backup. An important implications of this is that the **ISDN** and **OSI** standards being developed must tolerate satellite time delay so that circuits and message can take either terrestrial or satellite routing. The use of international satellites to provide telecommunication services within domestic borders should continue to be viable into the future. A developing country which wishes to upgrade the quality and reliability of domestic television and telephone services by installing a satellite network would find that transponder leasing is an economical way of getting started. This type of business is attracting organization than **INTELSAT** who intend to aggregate several such customers and operate the satellite on a condominium basis.

6.1.2.4 Expansion of Business Video:

The development of video communication for private and business uses has largely been made possible by advances in satellite transmission. Whether the signal is transmitted in analog or digital form, the applications represents a new development in business communication *.Point-to-multipoint broadcast as well as point-to-point teleconferencing are* both growing quickly in use within the develop world. The services is easily added to VSAT networks operating at **Ku** band since the relatively high power of the satellite permits the direct reception of the video signal. An interactive service is possible with transmit capability of the **VSAT**.

6.1.3 Mobile Communication Services:

Communication with and between vehicles, ships, and aircraft has been an important facet of radio. The uses of satellites for such purposes has developed somewhat slowly because of the cost of providing the satellite capacity in orbit and the lack of sufficiently advanced signal processing technology for the mobile terminals. During the 1990s, these technical deficiencies in all likelihood will be overcome.

6.1.3.1 Maritime And Aeronautical Mobile:

Building upon Marisat, the inmarsat system is establishing a long-term maritime mobile capability world wide and operating well into the next century. A similar is being planned for aeronautical communication.

6.1.3.2 Land Mobile:

Land mobile satellite communication represents significant opportunity within the developed and developing worlds. From a technical standpoint, the system operates similarly to marisat. Mobile terminals communicate with the satellite at **L** band, while either C or **Ku** band (**FSS**) links the satellite to fixed hub stations. The later provided access to the public telephone and data networks. The associated mobile antennas will be mounted directly on vehicles and therefore must be extremely compact. In addition, the coverage will be limited to a signal orbit position within a geographical region because the vichular ennas will not be able to discriminate between satellites. The types of services that are ntemplated are illustrated in Fig 6.2. Two way voice communication (D)represents the st attractive applications, because much of the interior of a large country is often does ot have ready access to mobile cellular telephone services. From business and economy andpoint, commercial vehicles represents one of the best market for **MSS**. AS illustrated t (C),contact can be maintained with heavy trucks which carry cargoes between cities. rivers could report their position and receive instructions their disparture along the route. truck which is lost (or high jaked) can be located. The same principle would apply to named railcars (B).

6.2 EVOLUTION OF TECHNOLOGY

While satellite communication began through the technology push of the space program, satellite application and markets have motivated the expansion of the industry. The decade of the 1990s should witness the introduction of new technologies which can again play a leading role. The paragraphs that flow review a number through these evolving technologies, many of which have been applied in government and commercial programs. What can not be discussed are those technologies which are yet to be proven feasible. As a matter of convenience, the following discussion is divided into separate sections on the space and ground segments.

6.2.1 Space Segment Technology Development:

Significant advances in spacecraft design and manufacturing technology will have a profound impact in satellites of the coming decades. Fig 6.3 presents an over view of the evolving technologies for three axis (body stabilized) and dual spin configurations, where both are expected to play appropriate roles into the future.

6.2.1.1 Advanced Spacecraft Antenna Designs:

The high gain antenna system strongly influences the capacity and versatility of a communication satellite. Coming generation will employed highly shaped beams and sophisticated **RF** to increase bandwidth through frequency reuse techniques. Fig 6.4 illustrates frequency reuse from scanning and addressable spot beams. The technology is best applied in the **Ku** band, because the higher frequencies generate smaller spots for the same size of spacecraft antenna reflector. Each vertical slice of the coverage is tied to a selected of the total frequency band ; the segment of each portion repeats according to the sequence of shading. In this example at Ku band; the signal allocation of 500 MHz is used a total of four times, yielding an effective band width of 2000 MHz. Because of the narrowness of the spot beams, cross-polarization need to isolate beams on the same frequency. hence, the second can be reserved for another service entirely or to permit collection of a second satellite at the same orbital longitude.

The physical antenna which produces this capability would consist of very complex feed system and large diameter reflectors deployable or unfurable reflector is shown mounted on the body stabilized satellite in the figure. This approach has demonstrated on once in space on of a number of US-government satellite.

6.2.1.2 Spacecraft Bus Technologies:

One of the most apparent trends in the spacecraft buss has been towards greater capability and larger size. The objectives, of course, is to be able to support the more powerful payloads demand by **Ku**-band applications. with its ability to dipole and maintain large sun-oriented solar panels, the three axis or body stabilized configuration continues to play a leading role in the future. Spinning satellites, being simpler in design and operation than body stabilized, should find an important place in small-to-medium class satellites, particularly at **C** band.

Since the satellite s of the future will provide more **RF** and dc power, the demands on the electrical system will increase. Until some new technology for prime power generation is proven out for long term use in space, solar cells will be relied upon .The final category of the buss technology improvements is refereed to as technology streaming, indicating that many divers innovations often combine in a beneficial ways. As new spacecraft are designed and built, numerous small weight reductions are introduced in the various subsystems. A lighter weight material might be found for the thermal blankets, the wiring might be simplified by using remote digital multiplexers, and advanced composites containing graphite might be used in parts of the structure to add strength at the same time that weight is reduced. The individual weight saving per item would be small (a few pounds here or there) but aggregate, the reduction can represent several percentage points of the total spacecraft weight.

6.2.1.3 Future Launch System Technology:

It is difficult to make projections of major innovative technology before the next century. A significant problem is the escalating cost per pound of spacecraft mass into **GTO**. The space shuttle was to have greatly reduced this cost by employing are useable vehicle with the capability to place several spacecraft into parking orbit at the same time. with much of the true cost of operating the **STS** now accountable, however, the shuttle seems no more cost effective than current expendable **LVs**.

A concept on the drawing boards (but not as heavily funded) is **NASA'S** space plane, which would take off and land like a commercial jet liner. The European space agency and the soviet government are also working on space plane concepts. It will take more than a decade before the true capability of any such advanced system is comprehended by potential users and several years thereafter before the launch capability would be available. In the meantime, implements of commercial satellite system must proceed with what they know, that is, that expandable **LVs** are the best available means.

One of the benefits of the space shuttle is its ability to support servicing of satellites in low earth orbit. This was tried successfully on an **STS** mission in 1984 when a scientific satellite was actually repaired .In 1985 shuttle astronauts revived the least at 3 satellite which had failed to activate after deployment from a previous shuttle mission. Recovery of the Waster 6 and palapa B2 satellites, as also performed successfully. These activities have raised the question of whether satellites in **GEO** might be serviced to extend their useful lives. A previous international space development project was to have created the space tug, an unnamed vehicles capable of carrying payloads between the arbiter's parking orbit and **GEO** .The project has not as yet gotten past the conceptual stage.

There is an extremely efficient propulsion technology which has been around for several years and has been demonstrated in orbit in an experimental basis .Called *ion propulsion* or *electric propulsion,* it uses the impulse of electrically charged particles ejected at very high velocity from an ion thruster. Electrical power from a solar array provides the energy to accelerate the particles of a liquid material which is brought up by the satellite much like fuel. Unlike the normal fuel, however, the total mass of the material is a small fraction of that required with conventional propulsion. A 10-year mission would only require a few pounds of material, leaving ample margin for other functions. The difficulty of using ion propulsion is that thrust levels are so low that the thruster would need to operate nearly continuously. Lifetime is also question, since the thruster uses technology similar to that of the traveling wave tube and is therefore subject to wearing out.

A final possibility for launch operations in the future is the space station or platform, which is under active study in the UNITED STATES. It would be extremely costly and probably unattractive to attempt to put a space station into **GEO**. A space station at the altitude of the parking orbit, however, could prove useful as a staging area for subsequent unnamed missions. It has been suggested that large spacecraft can be brought to the space station for final assembly and test in space under realistic conditions. Then, a space tug or other propulsion system would move the satellite out to the desired orbit. Assembly in space represents an interesting possibility for communication satellites of the next century.

6.2.2 Ground Segment Technology Development:

The direction of technology innovation in earth stations and networks will almost certainly involve miniaturization and cost reduction. This tends to push **VSAT** and **DBS** applications downward towards individual users. On the other hand, the network, which has grown in size and diversity, must be managed effectively. This will demand advanced network management *systems*, such as are under development for terrestrial data communication networks which interconnect terminals, mainframes, and personal computers. The technology of digital signal processing and compression will continue to advance, making possible the integration of voice, data, and video communication. The following paragraphs review these possibilities more detail.

6.2.2.1 VSAT Technology Extension:

The impressive gains in the price and capability of small computers will in all likelihood be transferred to the **VSAT** of the future. The principle benefit of **VSAT** networks is that can bypass the terrestrial network, particularly the expensive local loops normally provided by the local telephone company. The first **VSAT** networks to appear were designed primarily for data communication and applied the star architecture, shown in Fig 6.5(a). With the hub station collocated with the central computer to be accessed, the star provides sufficient benefit to be competitive with multidrop private line telephone service. Telephone traffic could also has over the link from VSAT to hub; it is not advisable, however, to use another satellite hop to reach the final destination. The star architecture, therefore, precludes VSAT to VSAT telephone communications, an application which on its own could pay for network. Point-to-point connections are also beneficial for high-speed data transmission between mainframe computers. The only other practical way to include point-to-point service for voice or dates to use the hub as a gateway to the terrestrial network, provided that adequate terrestrial transmission is available to the hub. The coast of the call would rise because of the charge for using the terrestrial network (canceling much of the advantage of having the satellite network available in the first place).

Point-to-point satellite links between VSATs require that each VSAT have the capability to transmute sufficient uplink power to be received with a small diameter antenna. Current VSAT separate with low power because the receiving antenna at a hub is typically considerable larger. Therefore, a critical technology is the reliable solid states-power amplifiers which is part of the VSAT outdoor equipment. Amplifiers with sufficient output power are currently available, although the cost of these units will have to come down *substantially before this type of VSAT would* be affordable. Operation at Ku band places the additional burden that high rain attenuation on the up link should be overall reliability. A useful feature of the VSAT would be to include automatic uplink power *control to boost* the level when the uplink is experiencing heavy rain fall.

6.2.2.2 *Inexpensive* **TVROs** *for* Antenna Technology:

The importance of reducing the cost of the terminal in broadcast receiving is just as vital as it is in two way **VSAT** applications. Fortunately, the simplicity of the video receive function make cost reduction more a matter of manufacturing volume than technology innovation. The emphasis now is on using the smallest possible receiving dish to reduce cost and simplify installation, as illustrated in Fig 6-1.

The first way to reduce electronics costs is to put as many functions as possible into one unit. For example, the integrated receiver-descrambler (**IRD**) has already appeared on the market for use with the US domestic **C**-band satellites. As production quantities increase, the price of one **IRD** will nearly equal to that of a consumer **VCR**. From that point, emphasis will be on the antenna and **LNC**.

6.3 SATELLITE COMMUNICATION INTO THE TWENTY-FIRST CENTURY

In approximately 25 years the satellite communication industry has clearly come along way. Once seen as technical feat and curiosity, the geostationary communication satellite is now commonplace and indispensable in many sectors. there has been a maturation prosecute work: first the technology had to be made economical, and, second, the applications for satellite communication had to prove themselves in a competitive market place. Clearly these have been accomplished with greater rapidity than any one could have imagined.

Satellite communication is the foundation for, and now defines, certain industries. Cable TV in North America could never have become an $8 billion industry without satellites' reliable and low cost delivery of programming. Transoceanic communication would still be limited to only those heavy routes which would justify The investment in undersea cable. Numerous other uses, which are yet to become industries in themselves, are establishing themselves through access to **C-Ku**-band space segment. Whether it be video shopping at home, broadcasting of financial news directly to stock brokers' offices, or the possibility of mobile communication by satellite with vehicles on the go anywhere in the nation, this development and evolution process is constantly going on.

The technology of the satellite it self also advancing, although the changes tend to be less dramatic .Essentially, the applications now drive the design of the satellites to be launched in the future. It is not uncommon for a technology to be developed specifically to provide a certain capability required for an application.

Satellite communication at the end of this century and in that coming will provide many services currently available. For example, the distribution of TV programming will certainly be by of satellites. It is the new applications, not yet introduced, which will be the most exciting, providing the base for expansion of the industry in new directions. Satellite communication will be an important part of the evolving picture of the twenty-first century.

CHAPTER 7

SPECIAL PROBLEMS IN SATELLITE COMMUNICATION

7.0 BACKGROUND

The development of modern satellite communications technology using satellites in geostationary orbit has spawned many new services and capabilities not practically previously when using terrestrial systems. The unique geometric advantage of satellite in stationary orbit allows multiple access by many earth stations on the earth's surface through a signal satellite repeater. This high altitude repeater instantly creates long-distance, wideband network facilities at low cost copared to other media. Unfortunately, the high altitude of 23 000 miles above the earth of the geostationary orbit also creates a relatively long transmission-time delay of about one-quarter second, which can accentuate undesirable subjective effects of echo on voice circuits, may cause reduced throughput efficiency on data circuit, and may create synchronization problems for digital transmission. This delay is approximately 10 times that of the longest delays of modern domestic terrestrial circuits. Up to 15 years ago, the echo control devices, modems, and protocols developed for terrestrial transmission were not suitable for this long delay variation in delay due to durnal variations in the satellite orbit. Thus delay variation creates a doppler-type effect that must be accounted for in digital transmission between synchronous networks. In this chapter we examine the effects of the long time delay and its variability on various satellite communication services.

7.1 ECHO CONTROL

Telephone sets and the local loop circuits that connect them to their serving central offices operate on a *two-wire* basis. That is, a signal bi-directional medium (ordinarily a cable pair) carriers the voice signals in both directions. some 15 years ago, the same was true for the trunk circuits interconnecting central-offices in the same serving area. In the early days of telephony, even long distance circuits were of this type, up to a few hundred miles.

Multiplex systems, used today to derive most long distance circuits, and an increasing portion of intracity, inter office circuits, inherently utilize separate transmission paths for the two directions. The link is called a *four-wire* circuit, a term that was introduced when the two directions of transmission were first separated using two separate conductor pairs.

The four-wire and two-wire circuits are interfaced by means of a four-port transformer circuit called a ***hybrid coil***, shown in Fig 7.1. One port is connected to the two-wire telephone circuit, or line. To the opposite port is connecting a ***balancing*** network that simulates, over the range of voice frequencies, the impedance expected, looking into the line. The other two ports are connected to the sending and receiving ports of the four-wire circuit. Assuming that the impedance of the balancing network is precisely that of the two-wire circuit, all the energy coming from the receiving from the receiving port of the four-wire circuit divides between the line and the network. None passes "across" the hybrid to the sending port. thus a circulating path, which would lead to echo and, if duplicated at the other end, to self-oscillation, is avoided. Signals arriving from the line divide evenly between the two four-wire ports. The energy that enters the receiving port is just lost in the output impedance of some amplifier.

The division of power when a signal passes through the hybrid represents a **3-dB** loss, and dissipative loss in the transformer used in the hybrid adds about another **1/2 dB**. Since the four-wire transmission system contains active devices, this loss is readily compensated.

The two-wire line may of course pass through switching system and then to a wide range of telephone stations and associated loop circuits, or interface with an interconnecting trunk. Hence its impedance may be quite variable and cannot always be matched by the fixed balancing network. Therefore, in practice, the balancing network is a design compromise usually consisting only of a resistance and capacitance in series, with a parallel capacitance as "built-out" network. As a result of the imperfect balance between line and network impedences in any particular case, some of the signal power arriving from the four-wire receiving port will cross the hybrid to the transmission port, constituting a potential source of echo.

A measure of the balance of the hybrid in a particular connection is given by the *return loss*. [This is the apparent loss encountered by a signal introduced into one four-wire port of a hybrid which emerges from the conjugate four-wire port, corrected for *twice* the inherent loss of a pass through the hybrid (**7 dB**).] this definition in effect treats the signal as though it passed through the hybrid to the line, was reflected, dimensioned by the return loss, and passed back through the hybrid on the conjugate port. ***Echo return** loss* is the weighted average value over the voice band spectrum corrected for **TLP** values of receive and transmit sides. It varies in value depending on where in the network it is defined, with a median value of between **18 dB** and **22 dB** and turn down values **7 dB** below these.

The level of echo (relative to the talker's speech) that can be tolerated by a talker depends on the time delay with which the echo returns. The more an echo is delayed, the more it is perceived, and so the lower in level it must be tolerable.

Based on this relationship, the basic method of echo control in the analog telephone network depends on controlling the end-to-end loss of a connection, since that loss, doubled, attenuates any echo. This represents a necessary compromise with the desire for low transmission loss. The scheme by which this is accomplished is called the *via net loss* (VNL) plan. In effect, each link of a connection must contribute a component of loss proportional to its round-trip transmission delay. The overall connection loss (**OCL**) between end offices is given by the following expression:

$$\mathbf{OCL} = 0.1\mathbf{D} + 0.4\mathbf{N} + 5 \quad \text{dB}$$

where **D** is the interconnecting trunk's delay in milliseconds, and **N** the number of the trunks in tandem. It should be mentioned that this expression holds for the analog network primarily. With digital trunks having come into the networks, the **EO-to-EO** losses limited to 6 **dB**, regardless of distance. This has implications that we shall discuss next.

For round-trip delays greater than about 45 ms, the required loss increment starts to cause the **OCL** to become such that an unacceptable number of customers would complain about low received volume on their connections. Thus, for such circuits, *echo* control is applied allowing lower loss without echo. most long-haul terrestrial telephone circuits today use transmission media whose high propagation velocities keep round-trip delay below the 45 ms threshold. However, the emergence of satellite communication circuits, with round-trip delays easily reaching 540 ms, renewed the interest in these devices. In today's networks, two types of echo control devices are employed, an echo supressor and an echo canceler. The latter is actually the superior of the two techniques and we developed only in the past 15 years as a result of the order of magnitude increase in delay due to synchronous orbit satellites.

Fig 7.2 shows a simplified block diagram of an echo control device is required on both ends of the four-wire circuit, preferably close to the location of the hybrid. Whenever speech from the distance telephone set is present in the receive part of the four-wire connection, a comparator compares the speech level to a preset threshold. If the threshold is exceeded, the echo suppressor inserts a high loss (>60 **dB**) in the transmit path, thus blocking the receive-side speech from returning via the echo path through the hybrid to the distance telephone set. While blocking the transmission path in this manner, speech signal that may transmitted from the near end (the east side) telephone set will also be blocked to the distant end. Therefore, an echo suppressor must have a second operating mode that allows the transmission path to be reenabled whenever the near-end talker is speaking. The near-end talker must exceed the relative level of the far-end talker to reenable the transmission path during this occurrence of double talk. When transmission path is reenabled, the echo path is also reenabled, so that during a double-talk condition not only are the speakers hearing each other but they are also likely to hear their respective echoes. Some echo suppressors insert modest loss in both directions during double-talk. When that happens, the suppressor tends to insert and remove the loss rapidly, some times causing some speech to be blocked or clipped and, in some cases, creating confusion to the talkers.

On domestic terrestrial circuits the round-trip delay is rarely over 60ms, and well-designed echo suppressors on properly maintained circuits can adequately control the echo problem. However, the undesirable, subjective effects of echo are enhanced the longer the delay, particularly in the environment of satellite communications. In fact , subjective studies at Bell Laboratories and elsewhere (Helder et al., 1977) have shown conclusively that echo suppressors do not provide satisfactory performance in the long delay environment of satellite circuits, whereas the canceler does provide it. Thus the more sophisticated echo canceler has emerged as a commercial reality, and is applied in most modern networks.

Fig 7.3 shows a simplified block diagram of an echo by rapidly and adaptively developing a replica of the echo signal and subtracting it from the unwanted returned signal (comprising echo plus rear-end speech), leaving only the desired near-end speech signal. In effect, the echo canceler contains a close replica of the true echo path in terms of delay, amplitude, and phase response. The arriving inbound signal is passed through the circuitry, and the resulting signal is subtracted, selectively removing the echo.

the echo canceler consists of an adaptive linear filter, implemented with digital techniques. A convolution processor monitors the discrepancy between the actual echo and the echo repilca and uses that information to refine the parameters of the filter's impulse response. This beings at the start of conversation with an arbitrary impulse response and typically converges within about 200 ms. The entire device is available in a signal **IC**.

Typically, the cancellation process enhances the inherent echo return loss by more than 20dB so long as that inherent return loss is greater than 6dB.

To improve the subjective quality, particularly during single talk, a nonlinear processor consisting of a center clipper follows to the echo cancler output to reduce any residual echo to zero. This nonlinear clipping device may produce some minor distortion, but it's effect is imperceptible as long as the echo return loss is in excess of 6dB. during double-talk mode, the center clipper is removed to prevent any distortion of the near-end talker's speech. Detection of double talk also stops the adaptive control processor to prevent misinterpretation by the adaptive control in the canceler.

In satellite applications, the echo canceler must often be located at the interface between the satellite circuit and the general telephone network. This is not usually the end of the four-wire portion of the connection. Thus the delay in the echo path, as seen by the echo canceler, may be substantial, that is, 10 ms to 15 ms. Inturn, this implies that the adaptive filter in the echo canceler must have a significant delay storage capability. The use of **VLSI** technology makes the achievement of such delays with digital technique quite feasible. This "end delay" accommodation is unimportant specification when selecting an echo canceler from vendors.

Echo cancelers have been accepted as the preferred method of echo control on satellite circuits. In fact, a great deal of development using a digital implementation of the echo canceler has been performed over the past decade and, at present, echo cancelers implemented in **VLSI** technology are available at prices much lower than those of echo suppressors. This is the reason that cancelers are now used not only on satellite circuits but also on terrestrial circuits requiring active echo control because of their high performance and affordable price.

For some time many people doubted the ability of satellite circuits to provide adequate voice communications because of the echo problem. However, because of the development of the echo canceler and its evolution into a commercial reality, the problem of echo control on satellite voice circuits is solved in prenciple. As we will see in the next section, data communication via satellite may also be impaired because of the long time delay, and good echo control similarly helps improve performance on data communication circuits.

It should be mentioned that in the end-to-end connections of global networks, including satellite links, the probability of encountering tandem trunks with echo control devices in each trunk is not be ignored. Although this problem is not peculiar to satellites, it is likely to be more damaging to satellites than to terrestrial links, in terms of perceived degradation. In principle, links in random and switched on a four-wire basis should have only two echo control devices, one at each end of the entire connection. Almost all switching of tandem connections, both nationally and internationally, is now performed by four-wire switches. The **CCITT** has nevertheless established rules and conditions for having tandem echo control devices that may exist on multi link connections, but these rules clearly indicate that is generally unfavorable to have more than two echo control devices in an otherwise four-wire end-to-end connection. The critical function component of the echo control device in such cases is the double-talk detector and the built-in memory is related to the sum of the inherent propagation delay in, and the impulse response dispersion of the echo path. If, due to tandem switching and erroneous, mutilated echo and other undesirable effects will be experienced, possibly degrading performance. Thus it behooves the satellite operators to be on guard for such occurrences and to take remedial steps to prevent it from happening on their connections.

7.2 DELAY AND DATA COMMUNICATIONS

The economics of the satellite environment has also created opportunities for data communications users. However, The protocols that govern data communications, both for data exchange and foe error control, have largely been developed for connections that have very little or almost no delay (from a few to less than 100ms). The one-way satellite link alone has delays somewhere between 250ms and 350ms, which is an order of magnitude larger than most terrestrial delays. Since data communications operate on the premise that the arrival of data at their destination needs to be acknowledged by return messages, transit delay between user terminals becomes a critical element for the efficient use of the transport medium. The impact of the delay may be expressed in terms of throughput efficiency or potential modem or protocol malfunctioning due to conflict with inherent timing requirements.

Fig 7.4 illustrates new applications for data communications available via satellite. Typical applications include resource sharing and load leveling, backbone networking, distributed processing, data base broadcast, and system backup and recovery. To accommodate these services, much development effort has been expended in recent years to ensure that the satellite time delay and echo problem are properly accounted for in the development of these applications.

7.2.1 Data Transmission Protocols:

A set of rules that govern the exchange of data between information systems is called a *protocol*. A large number of protocols are in use, many of which have been tailored to particular computer communications installations. Data are exchanged between business machines in block formats. That is, the data are grouped into blocks ranging in size from 1000 bits to 100 000 bits. Three basic classes of protocols are in use today. The first class of protocol is the **block-by-block** transmission type illustrated in Fig 7.5. This class includes **IBM's** binary synchronous communications (**BISYNC**) protocol, which is by far the most common system in use today . In **block-by-block** protocols, data are transmitted on contiguous blocks, with each block comprising a fixed number of bits. The **block-by-block** protocols employs a transmit, stop-end-wait error control technique with an automatic request for retransmission, also indicated by **ARQ**. As each block is transmitted to the distant end, it is checked for errors. If it is error free, the reverse channel is used to acknowledge the receipt of an error-free block by transmitting an **ACK**. if an error is found in the block, the reverse cannel transmits a **NAK** signal, indicating detection of an error and requesting retransmission of the block. As illustrated in Fig 7.5, waiting for the reverse channel acknowledgments (**ACK/NAK** signals) creates a large amount of idle channel time, which reduces throughput efficiency dramatically as the time delay increases. Throughput efficiency is defined as :

$$efficiency = \frac{number\ of\ bits\ received\ without\ error}{total\ number\ of\ bits\ transmitted}$$

As shown in Cohen and Germano (1970) the transmission efficiency can be improved by optimizing the block size as the error rate is not too high. Fig 7.6 shows a plot of transmission efficiency versus block size for the block transmission protocol for various error rates. Note that as long as the error rate is 10^{-6} we can achieve fairly high efficiencies by optimizing block size. However, if the block size decreases, even at low error rates, even at low error rates, the waiting time is too large a percentage of the total transmission time. If the block is too large, the loss of a signal block becomes a significant part of the total transmission time. However, as the data rate increases, the optimum block size may become impractically large, so that achieving high efficiency by simply selecting block size will work mostly for lower-speed applications.

A second class of protocols is illustrated in Fig 7.7. In this approach, blocks are transmitted contiguously and a high efficiency is achieved. Whenever a block is found in error (*B1* in fig 7.7) a **NAK** is received some times after the end of that block. In this case the protocol simply completes the transmission of the block in process, stops transmitting, returns to the beginning of the block in error, and transmits that block plus all succeeding blocks. This approach, called **ARQ** with *continuous block transmission and restart after error detection*, can be implemented within the high-level data link control (**HDLC**) family of protocols. A typical example of such a protocol is the advanced data communication control protocol (**ADCCP**). As illustrated in Fig 7.7, the amount of idle channel time is substantially reduced compared to the **block-by-block** approach. In fact, the plot of transmission efficiency versus block size shown in Fig 7.8 shows that high efficiency can be achieved even at relatively short block lengths. However, if the block length is too short (< 100 000 bits), the amount of overhead information contained in the block becomes a significant portion of the total block, thus reducing efficiency significantly.

Another variant of **ARQ** protocols uses continuous block transmission with selection block repeat, and is called , and is called selective repeat **ARQ**. The **HDLC** protocols can also be modified for this technique. As illustrated in Fig 7.9, this method also transmits blocks contiguously without waiting for the acknowledgment signal. As long as blocks are error-free, block transmission continues with virtually no idle time. Whenever an error occurs, a **NAK** signal is received on the reverse channel. However, the protocol continues to transmit blocks one after another until the end of that particular sequence of blocks. At the end of the block sequence, only the block(s) in error are repeated and a new sequence of block transmission begins. This protocol requires a block sequence numbering system which is usually included in the **HDLC** family protocols. This selective repeat protocol is need the most efficient, as illustrated in Fig 7.10. At virtually any error rate less than 10^{-5}, very high efficiencies are achieved with relatively short block lengths. Again, if the block size is too short, the block overhead becomes a significant portion of the block and reduces efficiency. Typical block sizes for this class of protocol are in the range of 10 100 bits.

Special protocols for broadcast satellite data transmission have been developed over the years. a data channel as part of a multichannel **TDMA** system can have various forms of implementation. Assignment of a data port in this **TDMA** environment may be on a *fixed* or *random* basis, and the source messages can be either of the same length or variable. Among the random-access protocols, a well- known technique is that described by the **ALOHA** protocol (named by the University of Hawaii), which sends a packet whenever it is ready for transmission. A conflict may occur when more than one station transmits, whereupon a packet may be lost. However, due to the broadcast mode of transmission, the receiver will be able to detect the error (loss) and request a transmission of that packet. By assigning a random waiting time to the transmitting stations, a occurrence of the same error is generally avoided.

If traffic consists of fixed lengths, a slotted **ALOHA** system has been developed, using global timing but without the need of having a frame reference. A peculiar effect exhibits itself with **ALOHA** systems, in that efficiency increases with increasing delay, up to some maximum, after which an *unstable* condition sets in which the efficiency decreases as delay further increases. This is demonstrated in Fig 7.11. This will occur as transmission intervals are becoming small relative to the traffic rate.

7.2.2 *Data Communications Efficiency:*

The achievable transmission efficiency of a data communications circuit is probably its most important attribute. However, the other factors must be considered when evaluating its overall quality. In Owings (1983), results on efficiencies are provided for all three classes of data communications protocols for various data rates and error rates. These result based on the following assumptions:

- Physical file size = 10^{10} bits: Physical file size on disk or tape are now in the range 10^{8} or 10^{10}bits. In the near future even larger sizes will be common place.
- Data range = 2.4 *kb/s* to 1.544 *Mb/s*: Although data rates are clustered toward the low end, there is a trend toward the higher rates.
- One way satellite transmission time delay =320ms (include terrestrial delay).
- Threshold bit error rate = 10^{-5} . Typical satellite circuits deliver error rates less than 10^{-6} more than 95% of the time. Typical observed are 10^{-7} or 10^{-8}. However, under worst-case conditions, error rates can drop as low as 10^{-5}.
- Block overhead less than 1%: In each of the protocols in use today, there is a minimum amount of overhead data for housekeeping functions, such as block number identification, parity checks, and other error control bits. To achieve the 1% objective, block sizes greater than about 8000 bits are required.

1. *Probability that the entire physical file (10^{10} bits) is received with an undetected error must be less than 0.01.*
2. *Transmission efficiency must be at least 90%.*
3. *The efficiency must be independent of data rate.*
4. *Minimum sensitivity to error rate.*

TABLES 7.1 and 7.2 compare the three protocols relative to these performance objectives. Results are provided for three different data rates and two error rates. For voiceband rates (for example, 4.8kbit/s) fairly high efficiencies are achievable even with the **block-by-block** protocol by optimizing the block size. However, as the data rate increases, the block size must also increase dramatically and the efficiency degrades accordingly. The continuous transmission with restart-after error protocol does a much better job than block-by-block transmission but still does not achieve the 90% efficiency objective, particularly at the higher data rates. Only the continuous block transmission system with selective repeat achieves at least 90% efficiency at an error rate of 10^{-5} over the full data-rate range.

7.2.3 Implementation:

In the long term, the implementation and development of these protocols will be accomplished by software modification of existing protocols. However, in the interim there may also be a need to provide an external hardware solution in some cases, particularly in those older installations in which it is difficult to make major software changes in the protocol to accommodate satellite service. In the these cases, a satellite delay compensator, illustrated in Fig 7.12, may solve the problem. This device is inserted between the terrestrial interface to the information system and the satellite data channel. In effect, it is a store-and-forward data processor that interacts with the near-end information system, using the existing protocol (such a **BSC**), but with its counterpart at the distant end of the satellite circuit using a selective repeat or restart after error protocol. The device receives data from the information system and organize them in blocks of the correct size. A multiple-block buffer stores transmitted blocks until the reverse channel indicates that a block was received in error. Whenever a request for retransmission occurs, the controller interrupts transmission from the information system and returns to multiple-block buffer to retransmit either all the previous blocks from the time the error occurred or a selected block, depending on which protocol is being implemented. This approach has the advantage of not disrupting the software and still solving the efficiency problem.

7.2.4 Forward error correction:

Besides **ARQ** techniques for controlling errors effectively in satellite communications, it is sometimes more suitable or even mandatory to control errors without having to signal on the return path that errors have occurred. An example of such a condition is when in **TDMA** the traffic burst from a station arrives at its destination and an error is detected in the data. At that instant of time, a decision must be made as to the validity of the data and a correction applied, without having to wait for signals to be transmitted back and forth over the link. Forward error correction, or **FEC**, is the answer in this case. it is not our intention to discuss **FEC** in detail, as that could occupy several chapters. We will only sketch the general aspects of it, and discuss the consequences in the applications for satellite transmission engineering.

Forward error correction is a channel coding technique, whereby the information bit sequence is enhanced by adding redundancy bits that will allow us to detect if certain of the information bits are in error, and thus to correct those errors. Clearly, the additional bits needed for protection require that the original information rate after decoding. That is the price to be paid for this capability. **FEC** codes are generally classified as either block or convolution codes. With block codes, data are accepted in blocks of k symbol (binary bits mostly), and delivered in blocks of n symbols, where $n>k$. The ratio k/n is called the code rate, usually indicated by **R**. Thus the output of the block coder delivers a transmission rate which is **1/R** larger than the data bit rate. One of the characteristics of block coding is that the code blocks are independent of each other; that is each k input bit is independently treated and decoded at the receiver, and then decided upon. A class of block codes is known as linear, and is very popular for its implementation in practical systems such as that of the satellite.

Convolution codes also provide n output bit for each k input (data) bits ($n>k$), but the method by which this comes about is quite different from that of block coding. The difference is that the ***n*-bit** convolution decoder output depends not only on the last k input bits at the encoder, but also on several previous sets of k input data bits. In addition, n and k are much smaller than is the case with block codes. However, the same $k/n=$**R** coding rate concept applies as with block codes, and similarly the **1/R** increased channel rate is required.

When applying **FEC**, the term rate k/n is used to indicate the inverse of rate increase that is required. Well known coding techniques with different properties are rate 1/2, rate 3/4, or rate 7/8, just to name a few. Quite often, the term coding gain is used, as follows.

FEC is an effective method for improving link performance to the degree generally required. It is also considerably more complex than, say, **ARQ** methods, and thus more expensive to implement, because of the extensive to implement, because of the extensive and high-speed processing at the decoder for deciding which bit or bits were in error. It is, on the other hand, an indispensable component in the design of digital satellite systems, and must be included in its overall engineering aspects.

Fig 7.13a shows the effect of rate 7/8 coding on transmission efficiency, using a restart-after-error detection protocol. Notice that is **FEC** provides an enhancement of efficiency as long as the error rate is lees than 10^{-7} compared to the use of the protocol alone. Fig 7.13b shows the effect of the same rate 7/8 **FEC** using the continuous protocol with selective repeat. In this case, use of coding provides no substantive advantage unless the error rate is less than 10^{-5}. This is true for all transmission rates and shows that the use of **FEC** may not always improve efficiency, depending on the desired rate.

7.2.5 Impact of echo control devices and data modems:

Uncontrolled echo on voice circuits can also be disruptive to data communications on voiceband circuits. However, special echo cancelers for data transmission can substantially mitigate the degrading effects of echo. A malfunctioning echo suppressor, for example, can cause clipping and chopping of the speech. This, in turn, may cause a data modem to misinterpret delayed echoes as data and produce malfunctions such as shutdowns or impaired data. Modems designed for the typical delays of the terrestrial plant can also cause difficulty because of the long time delay. Such devices can trigger early time-outs because of expectations of return signals that do not arrive within the prescribed time period. In general, the introduction of echo cancelers on satellite circuits solves many of the problems produced by echo on data communication circuits. Improved modem design with more accurate accounts for delay also enhances performance on satellites circuits.

7.3 ORBITAL VARIATIONS AND DIGITAL NETWORK SYNCHRONIZATION

Orbital variations have no impact on analog transmission may be dramatically affected by these time variations, which cause the data rate at the receiving station to vary over the period of the sidereal day about the nominal data rate. For example, at a data rate of 65 kb/s, a 1.1ms transmission path-length variation results in a peak-to-peak variation in data rate of 61.6 bits. Since terrestrial networks, using synchronous transmission, cannot accommodate data-rate variations of this magnitude, an elastic buffer must be inserted between the satellite facilities and the terrestrial network, as illustrated in Fig. 7.14. An elastic buffer is essentially a first-in-first-out (**FIFO**) random-access memory, which can be thought of as a water bucket with a hole in its bottom. The rate at which (bits) is poured into the bucket changes over the period of the sidereal day. However, the rate at which water (bits) leaves the bucket remains constant, independent of the fullness of the bucket. As the pouring rate increase, the bucket tends to fill, but the water output remains constant. When the pouring rate decreases, the bucket tends to empty, but again analogously, and the primary design consideration is to choose a buffer that is large enough to absorb the peak-to-peak variations in data rate. Memory devices are generally built in size that are powers of 2. Since the use of these buffer memories inherently adds additional delay to the satellite link, it is important to choose the smallest memory consistent with the maximum expected range variation.

In addition to accounting for the range variations due to satellite position movement as illustrated in Fig 7.15, the elastic buffer shown in the digital interface of Fig 7.14 can also be used to perform a second function. The necessity for it arises when the satellite is used to communicate between two separate digital networks, each operating with its own clock. Three methods have been proposed to accommodate this problem. This first is an synchronous solution using bit stuffing and justification. The second is a synchronous method involving locking all clocks together. The third is the plesiochronous solution, in which the two clocks have almost the same frequency but are not actually synchronized. As shown in Fig 7.14, if the ***S*** clock and ***T*** clock are independent clocks at the same nominal rate, the interface is said to be *asynchronous*. If the ***S*** clock and ***T*** clock are located together or are, in fact, the same clock, the interface the inter face called *synchronous*. If the ***S*** clock and the ***T*** clock are almost the same but not actually synchronized, the interface is referred to as *plesiochronous*. The plesiochronous solution to synchronization of two independent networks is the solution recommended by the **CCITT**. For example, assume that two independent networks are to be connected via the satellite and each network has a clock derived from an independent cesium beam oscillator with an accuracy of 10^{-11}, as recommended by the **CCITT**. Assuming nominal clock rates of 2.048 Mb/s (the first level in the European digital hierarchy) and the clock of one network is high by 10^{-11} in frequency and the other is low by 10^{-11}, a time-displacement error of 1 bit will accumulate in just under 7 hours. As recommended in **CCITT** recommendation **G..703** , **PCM** multiplex system slips will be made in integral frame increments to avoid loss of frame in the multiplex equipment. With a frame size of 256 bits, slips will occur about every 72 days. Since the bit slips can occur in either direction, the function to be accomplished by the elastic buffer of Fig 7.14 in addition to its orbit satellite range absorption function, as long as the buffer is of sufficient size.

CONCLUSION

Advances in satellite communication systems and applications 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 its feasibility in the early 1960s. In approximately 15 years the satellite communication industry has clearly come along way. Once seen as technical feat and curiosity, the geostationary communication satellite is now common place and indispensable in many sectors. There has been a maturation process at work: first the technology had to be made economical, and, second the applications for satellite communication had to prove themselves in a competitive.

Transmission delay can be good further research topic, since data communications operate on the premise that the arrival of data at their destination needs to be acknowledged by return messages, transit delay between user terminals becomes a critical element for the efficient use of the transport medium.

Satellite communication at the end of this century and in that coming will provide many services currently available. For example, the distribution of **TV** programming will certainly be by way of satellites. It is the new applications, not yet introduce, which will be the most exciting, providing the base for expansion of the industry in new directions. Satellite communication will be an important part of the evolving picture of the twenty-first century.

APPENDIX A

"FIGURES"

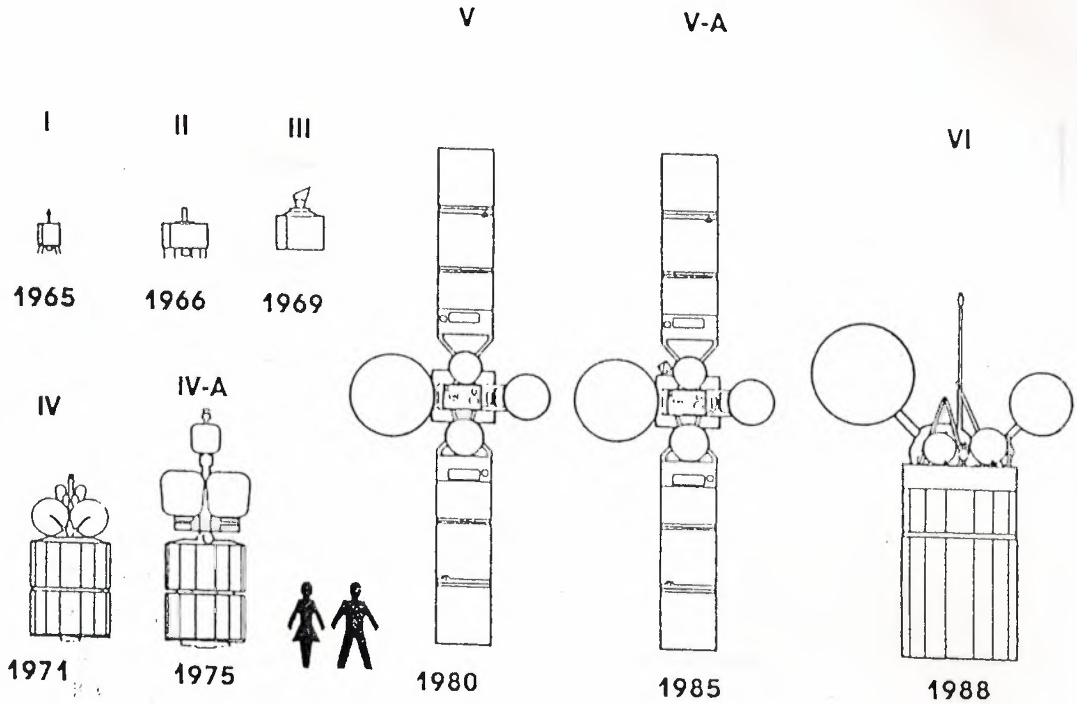
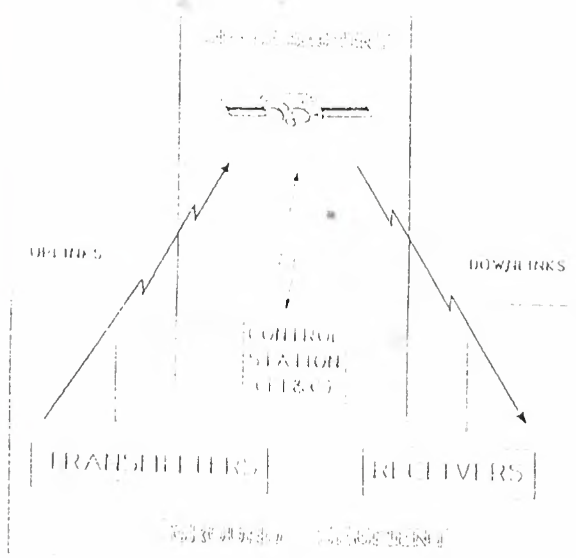


Fig. 1.1 Six Generations of INTELSAT Spacecraft



1.2 The elements of a satellite communication system

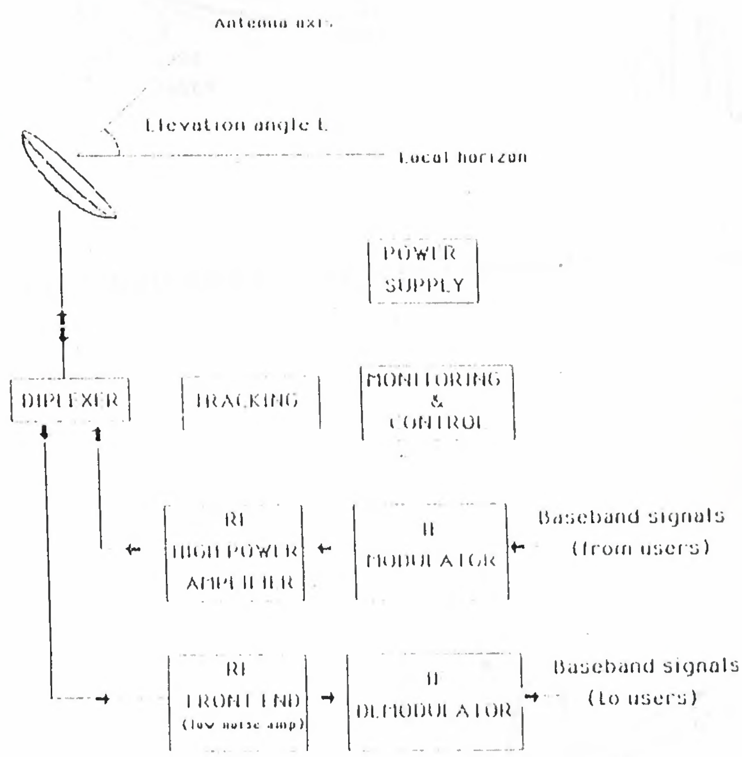


Fig 1.3 The architecture of an earth station

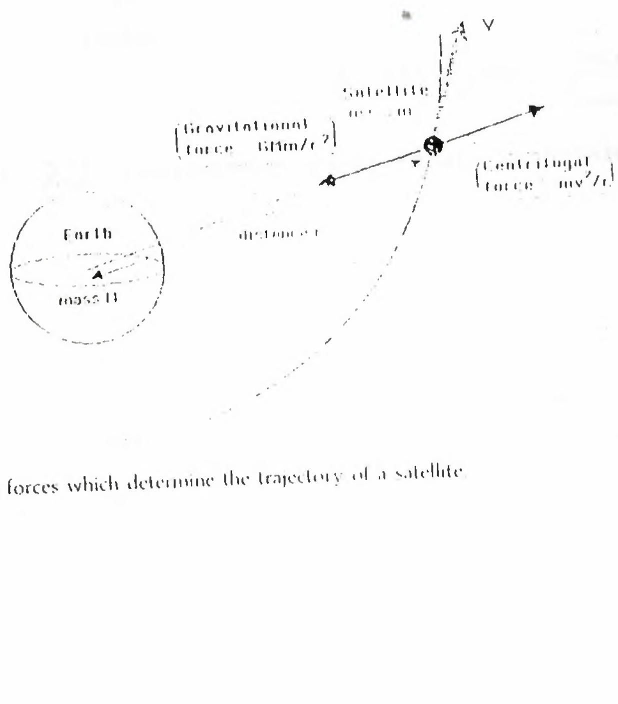


Fig 1.4 The forces which determine the trajectory of a satellite

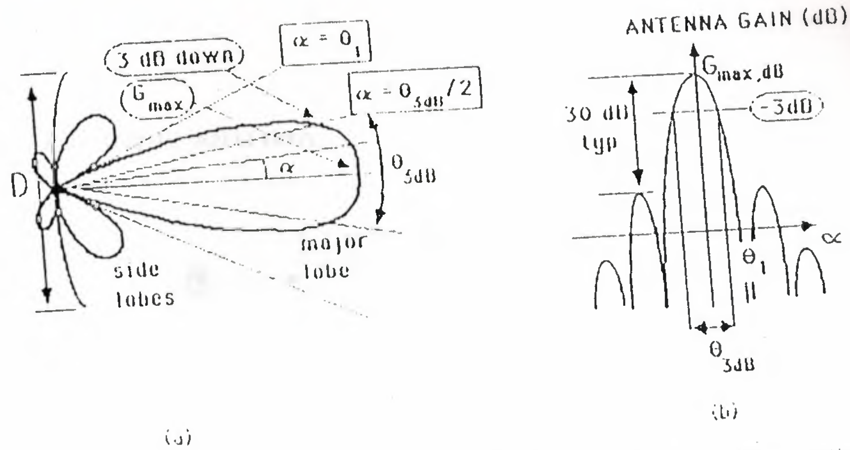


Fig. 2.1 Antenna radiation pattern. (a) Polar representation. (b) Cartesian representation.

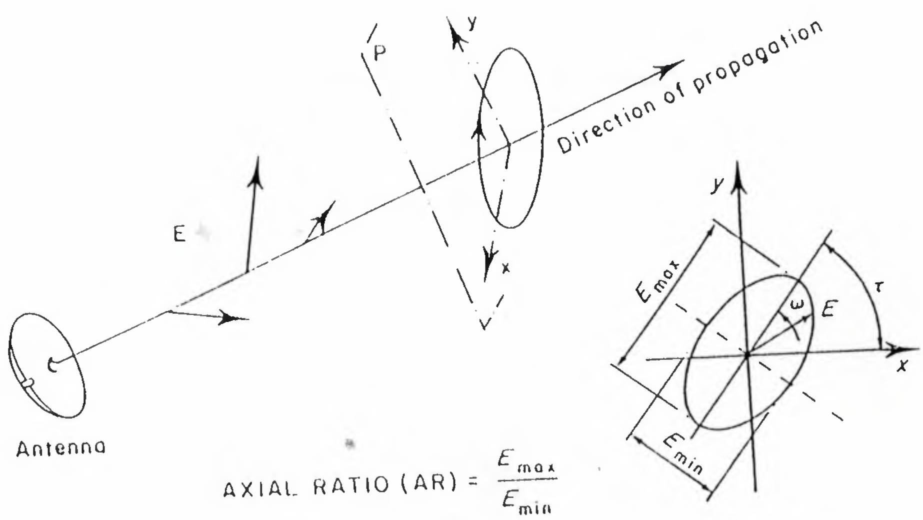
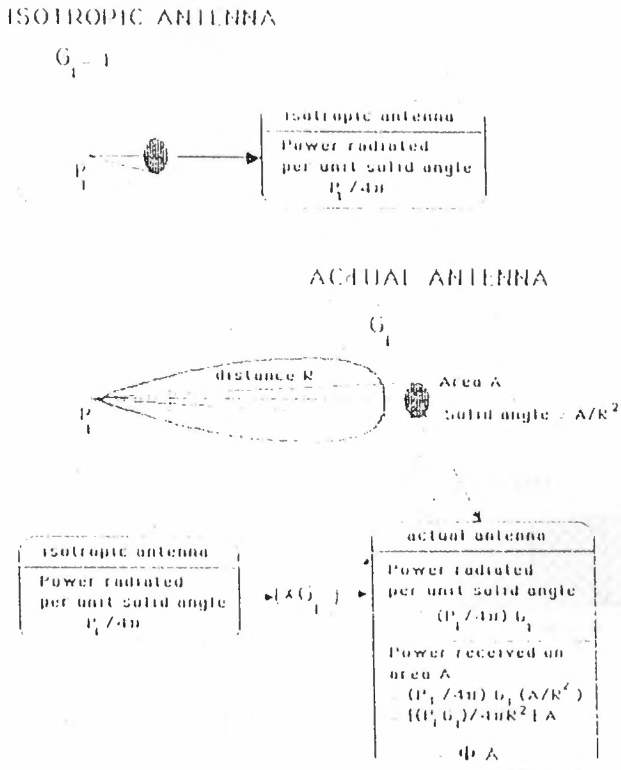


Fig. 2.2 Characterisation of the polarisation of an electromagnetic wave.



$\Phi = P_tG_t/4\pi R^2$ = Flux density at distance R (W/m^2)

Fig 2.3 Power flux density

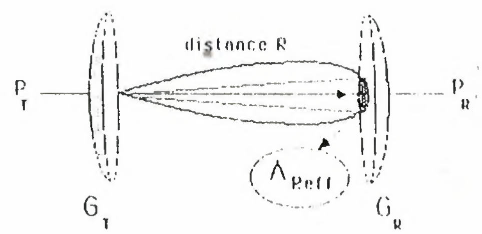


Fig 2.4 The power received by a receiving antenna

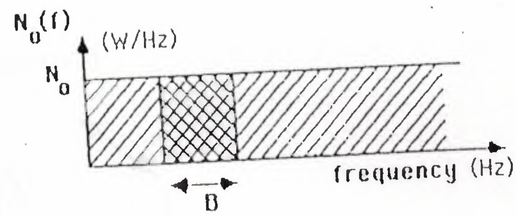


Fig2.5 Spectral density of white noise.

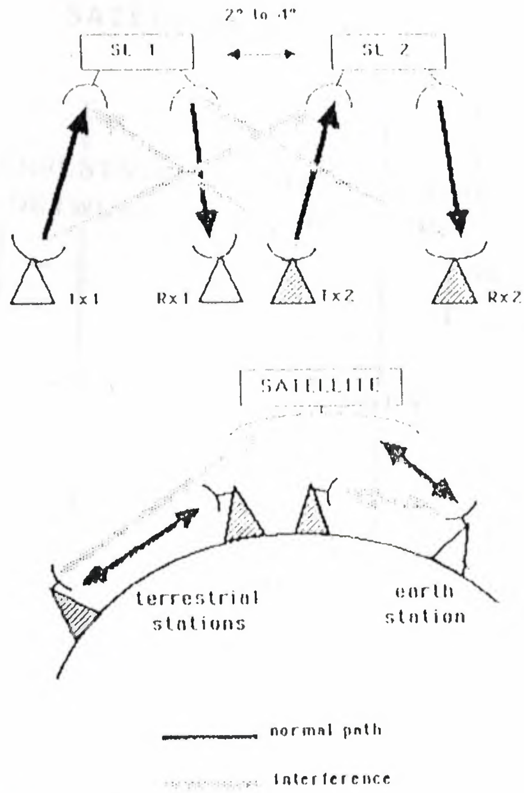
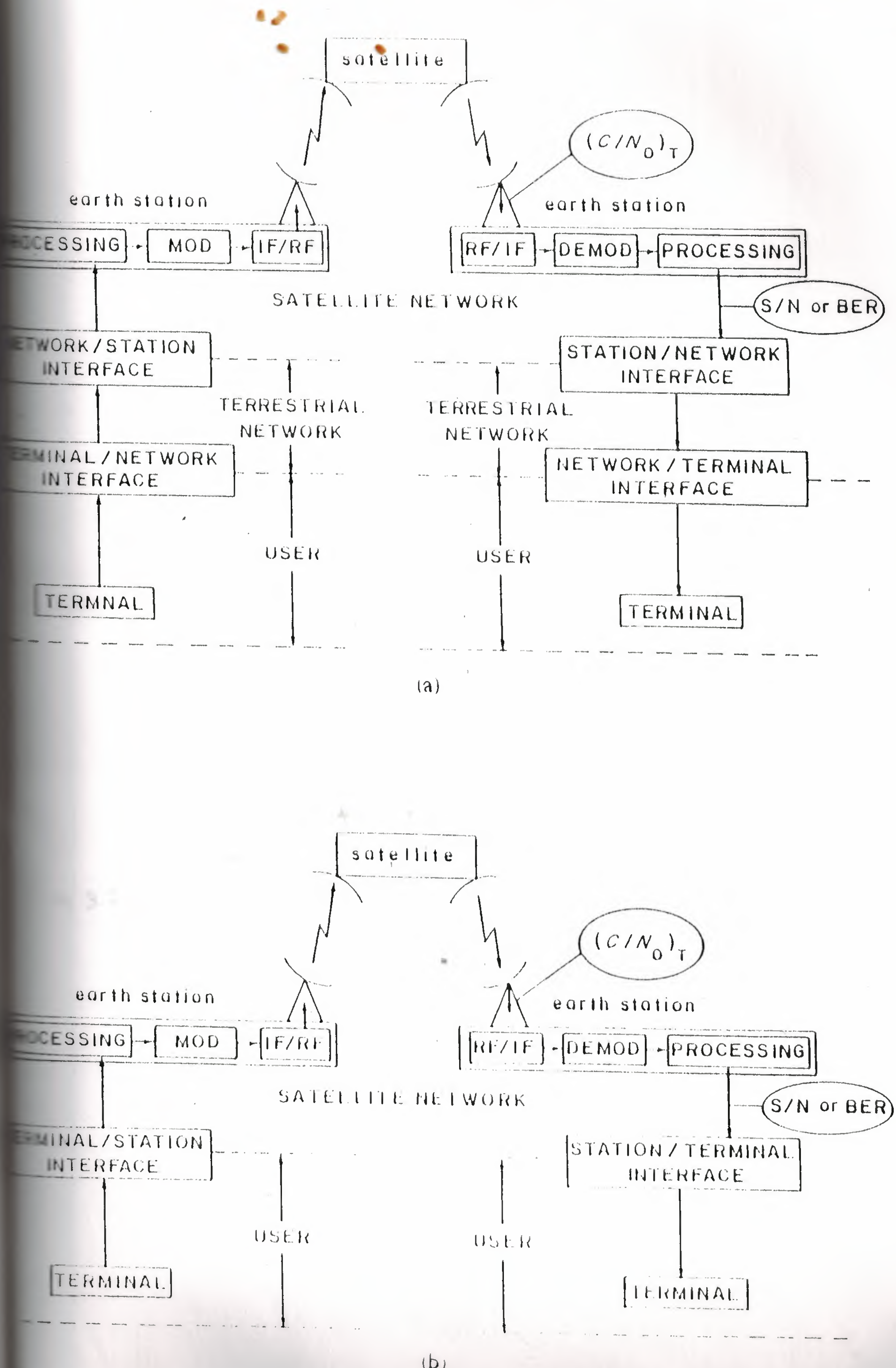


Fig 2.6 The geometry of interference between systems.



3.1 Model of a transmission channel from one terminal to another. (a) Connection by terrestrial link. (b) Direct connection (VSAT).

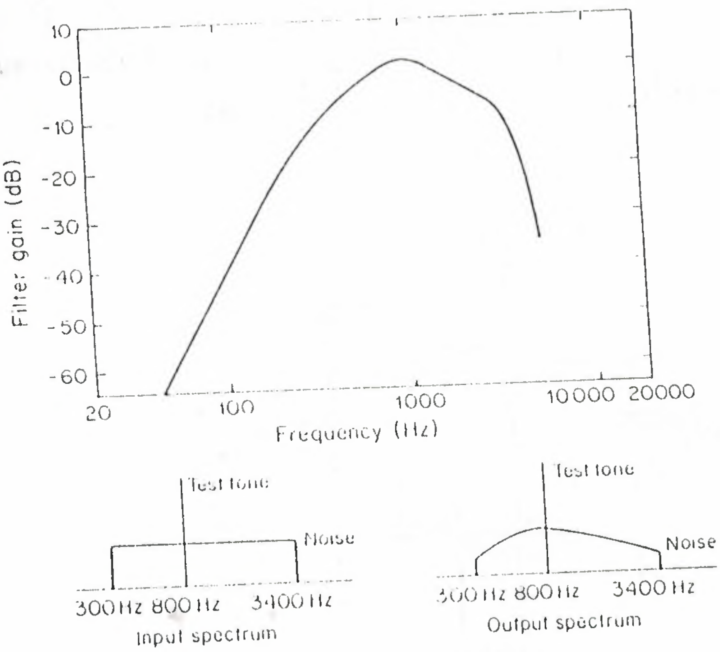
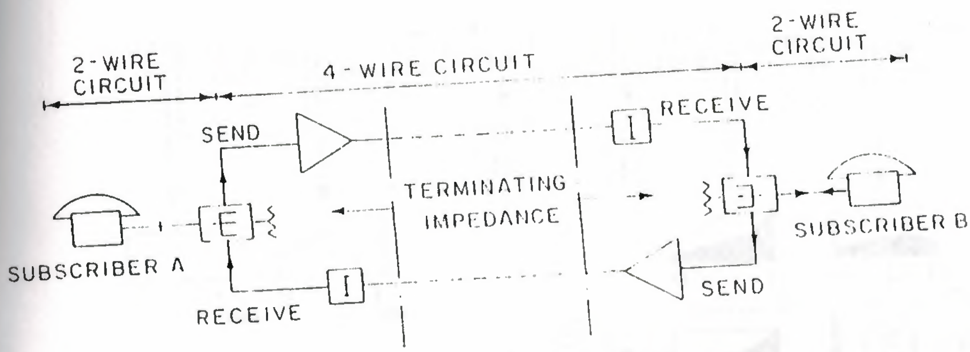
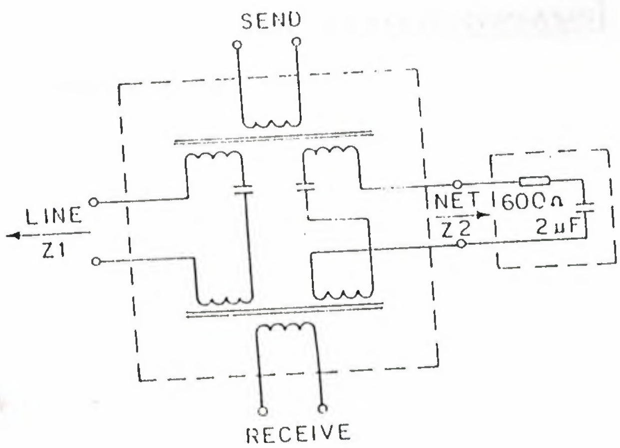


Fig 3.2 The gain of a psophometric filter and its effect on noise.



(a)



(b)

Fig 3.3 Routing of telephone signals between two subscribers. (a) Two-wire links, four-wire links and the location of differential couplers. (b) The principle of the differential coupler.

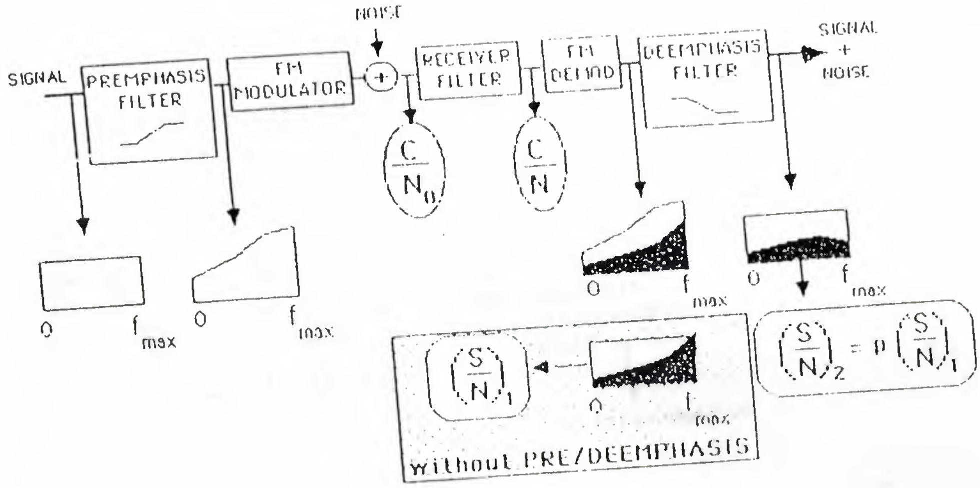


Fig: 3.4 The principle of pre- and de-emphasis.

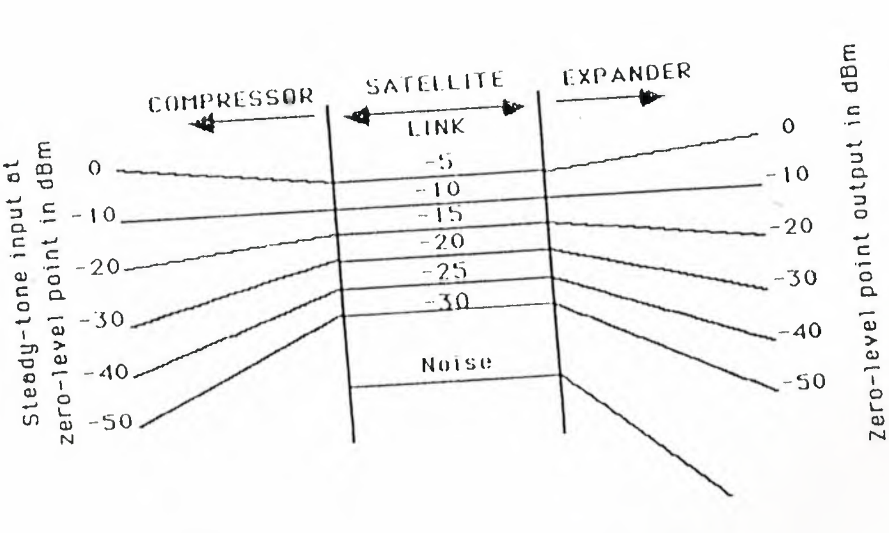


Fig: 3.5 The principle of companding.

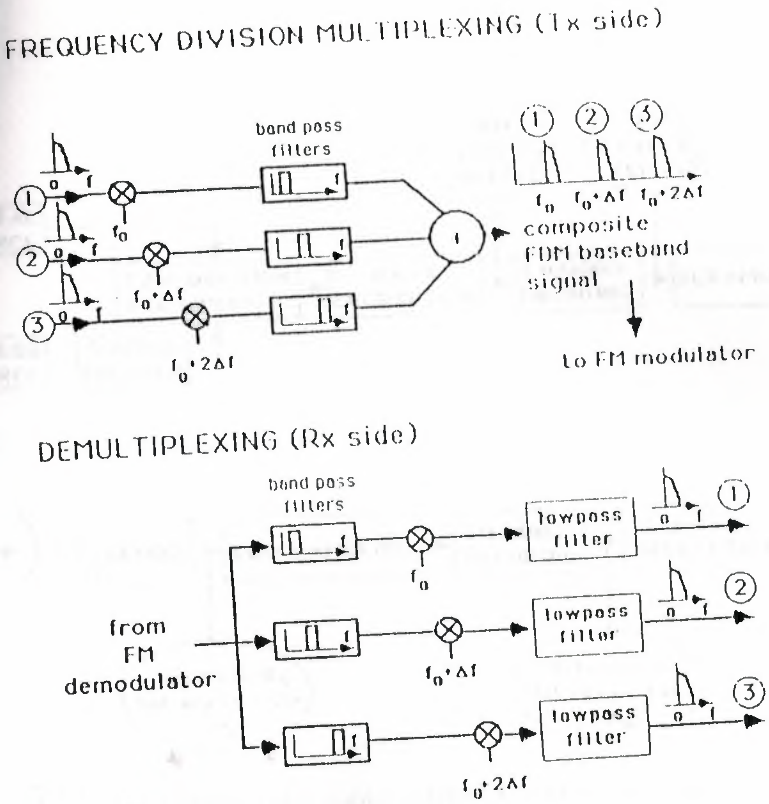


Fig 3.6 The principle of FDM multiplexing and demultiplexing.

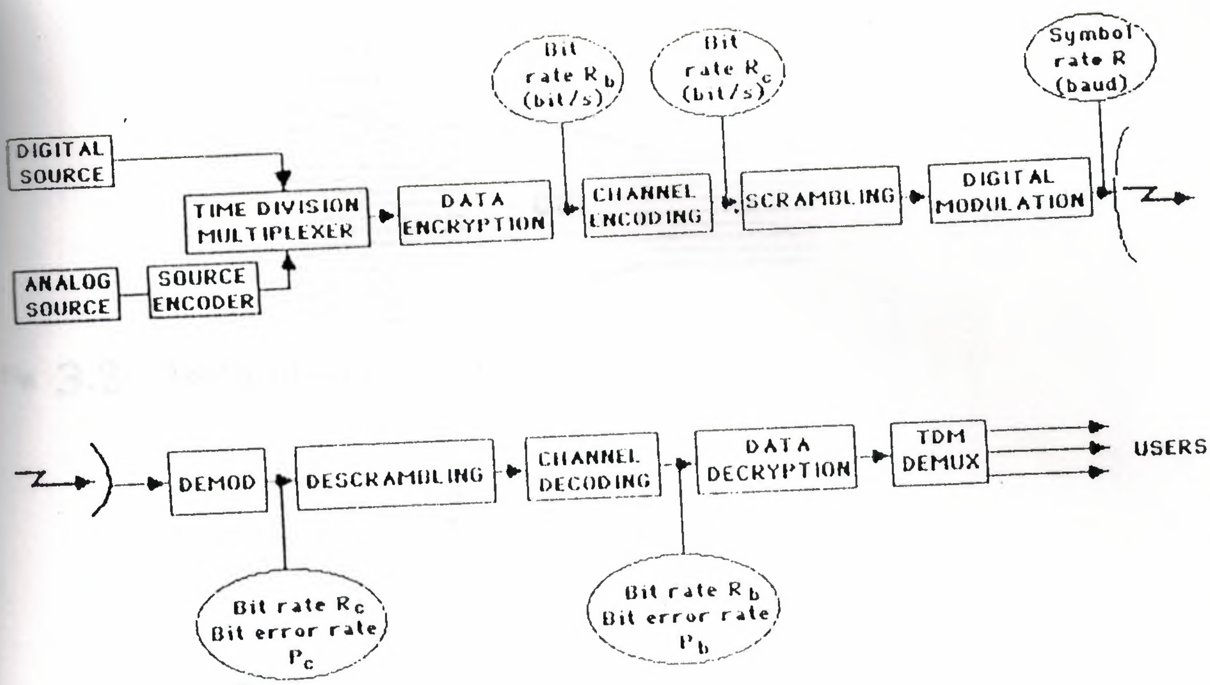


Fig 3.7 The elements of a digital satellite transmission chain.

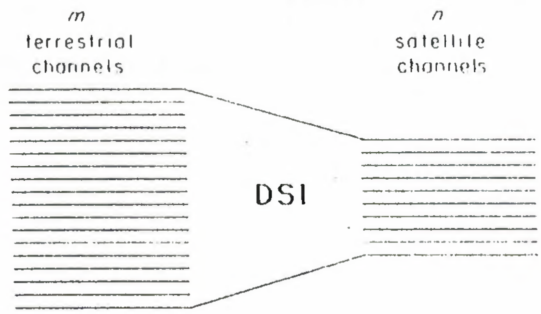


Fig 3.8 Digital speech interpolation (DSI).

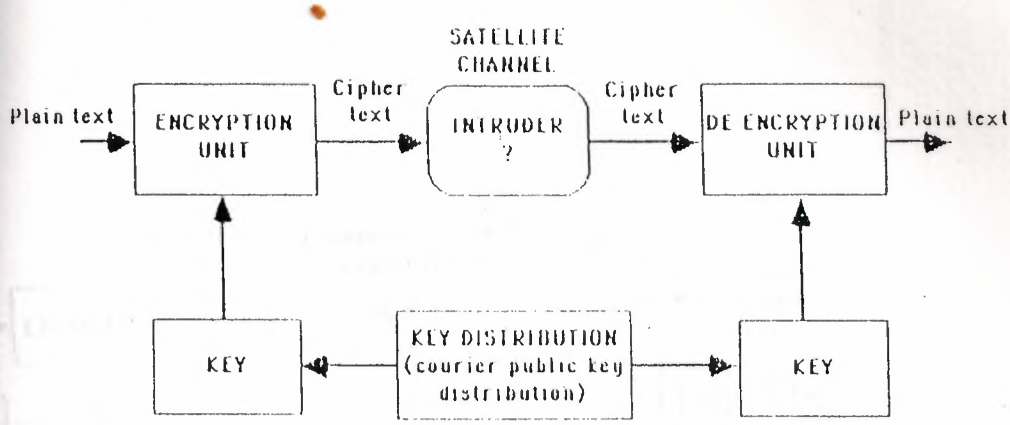


Fig. 3.9 The principle of encrypted transmission.

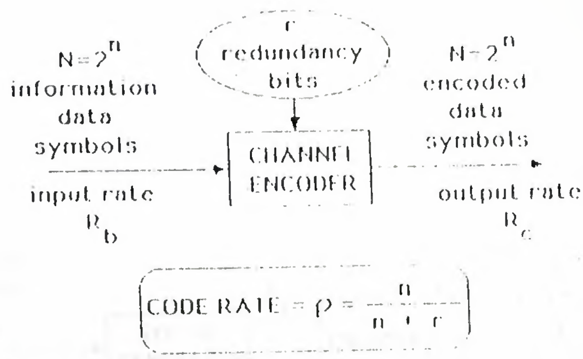


Fig. 3.10 The principle of channel encoding.

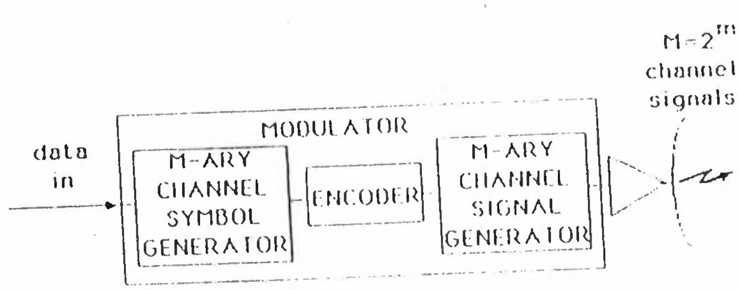


Fig. 3.11 The principle of a modulator for digital transmission.

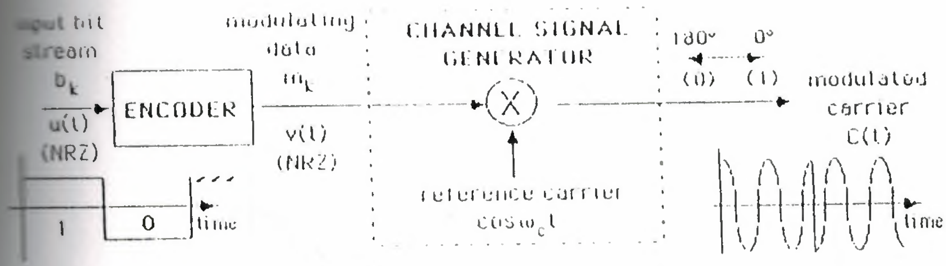


Fig 3.12 Two state phase modulator (BPSK)

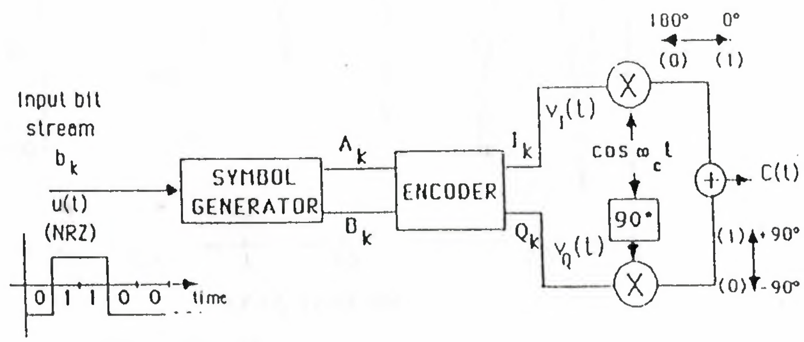


Fig: 3.13 Four-state phase modulator (QPSK).

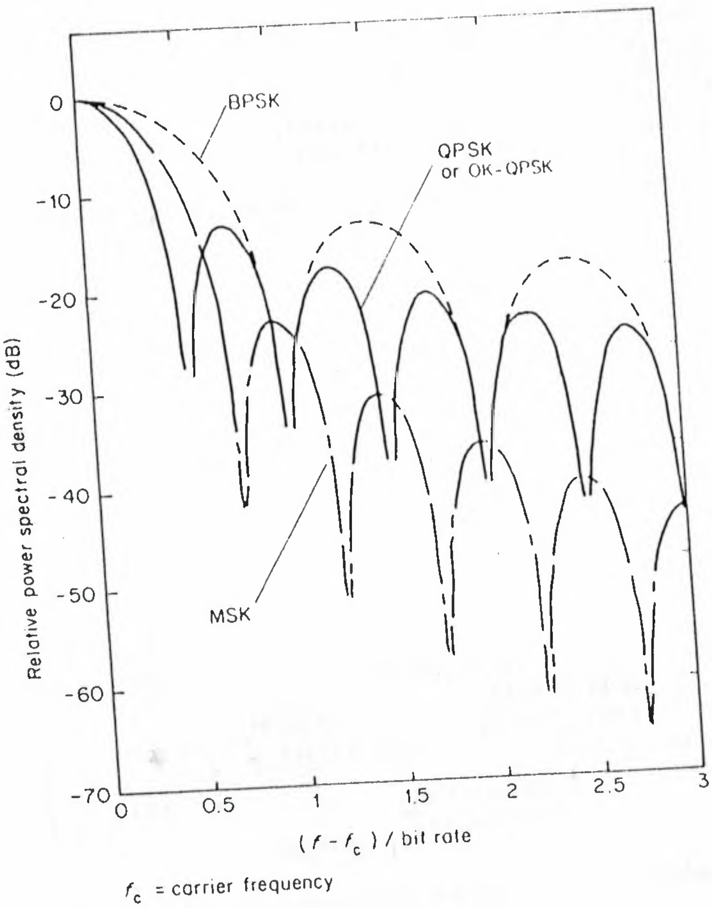


Fig 3.14 The spectrum of digital carriers.

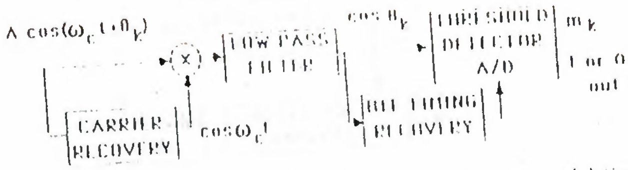


Fig 3.15 The structure of a coherent demodulator for two state phase modulation.

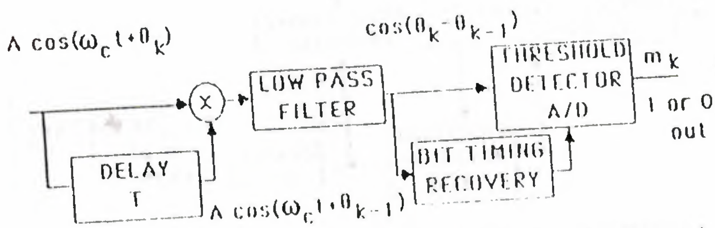


Fig 3.16 The structure of a differential demodulator for two state phase modulation.

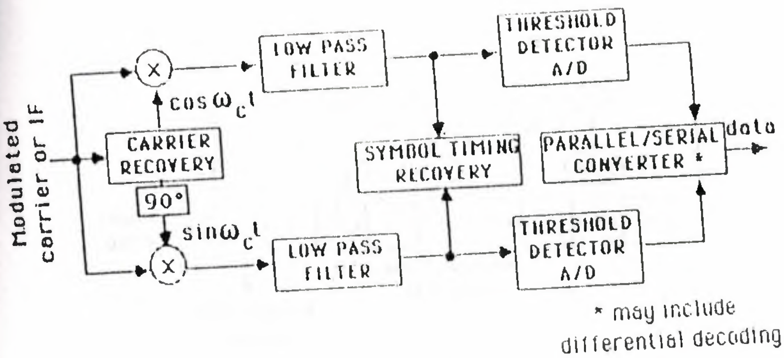


Fig 3.17 The structure of a coherent demodulator for four state phase modulation.

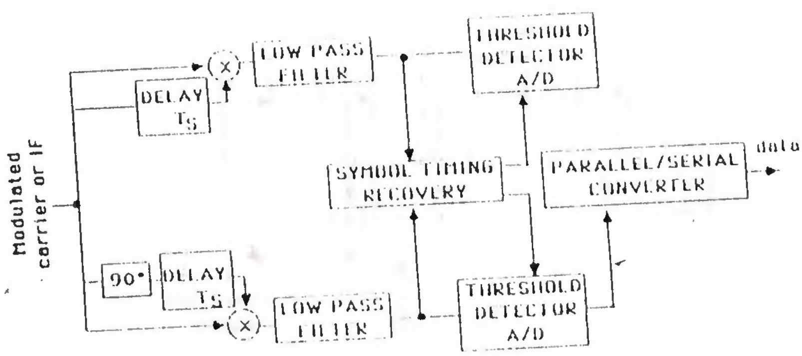


Fig 3.18 The structure of a differential demodulator for four state phase modulation.

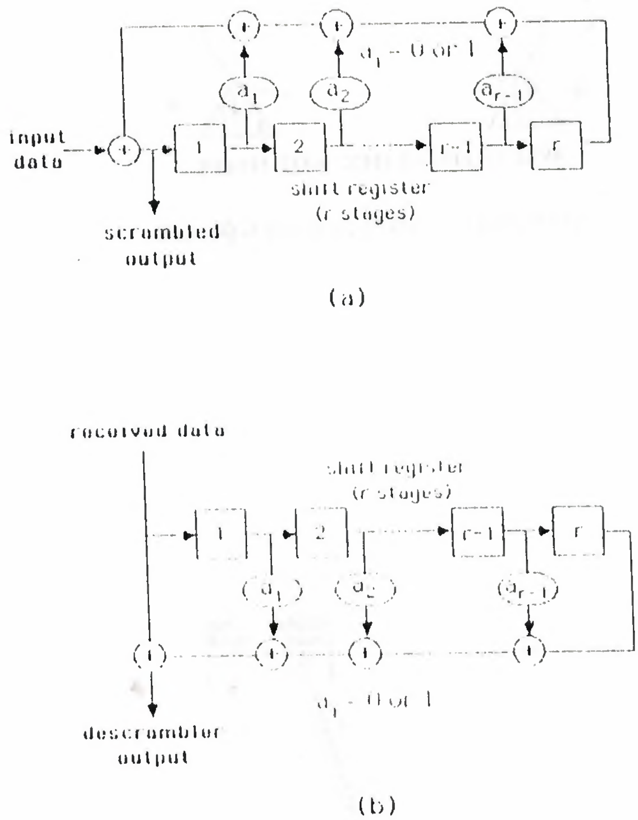


Fig. 3.19 (a) A scrambler. (b) A descrambler.

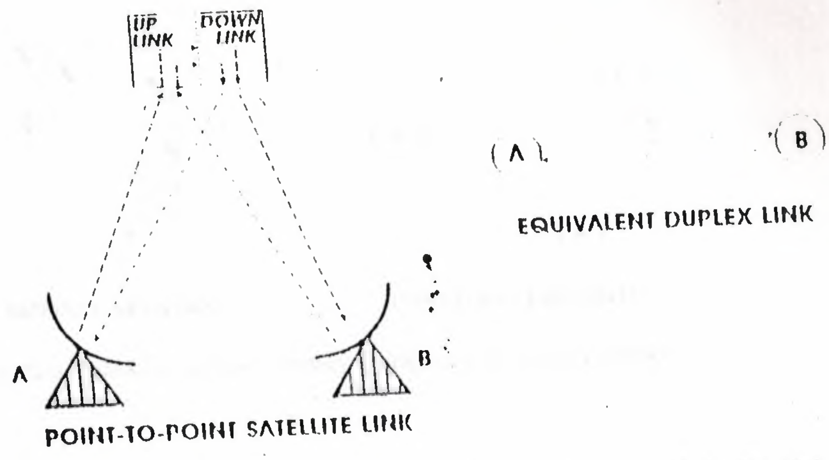


Fig. 4.1 Point-to-Point Connectivity Using a Full Duplex Satellite Link

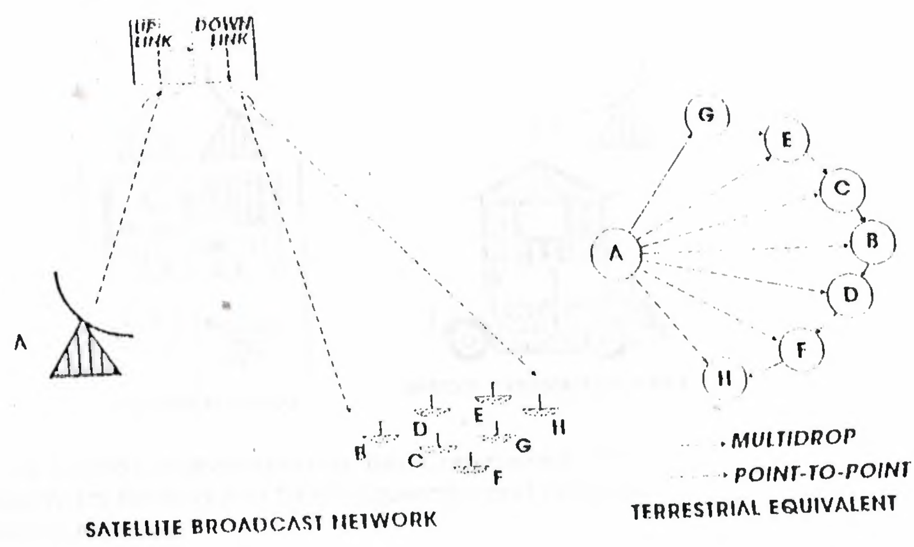


Fig. 4.2 Point-to-Multipoint Connectivity Providing a One-Way Broadcast Capability

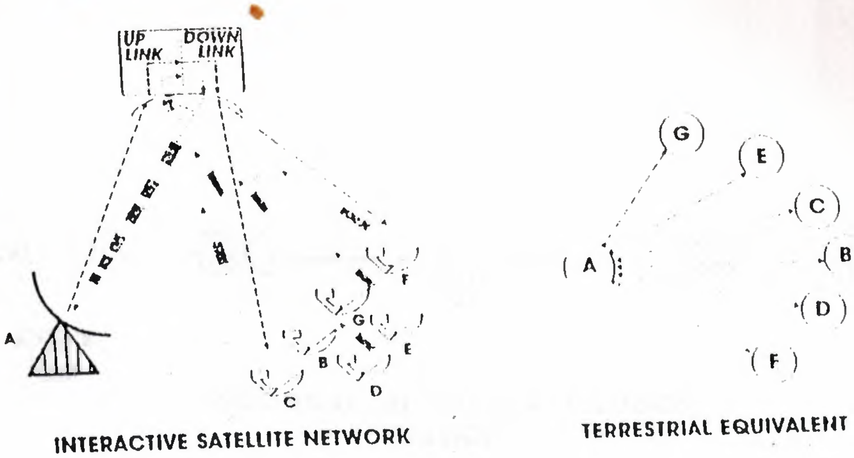


Fig. 4.3 Interactive Satellite Network Using Multipoint-to-Point Connectivity

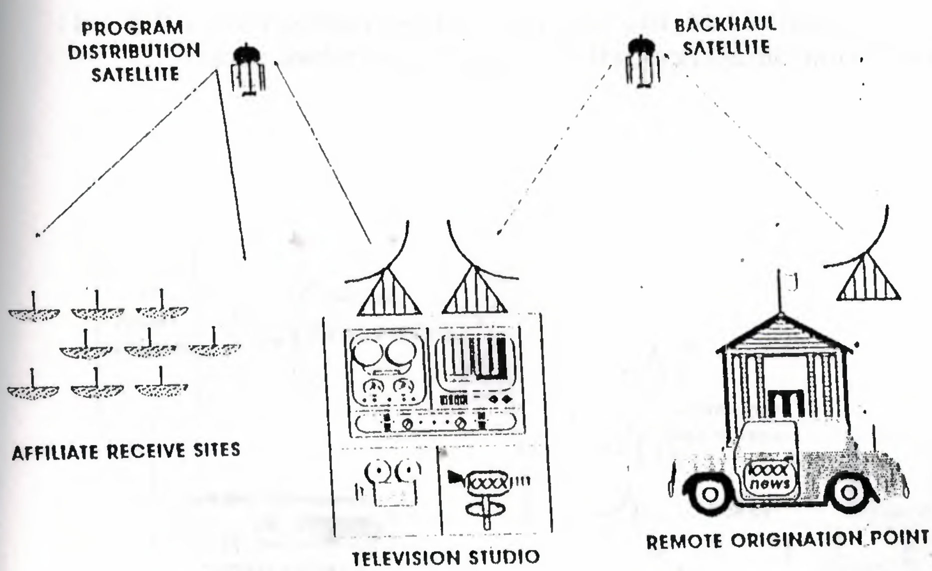


Fig. 4.4 The Use of Satellite Transmission in the Commercial Television Industry for Backhaul of Event Coverage and Program Distribution to Affiliates

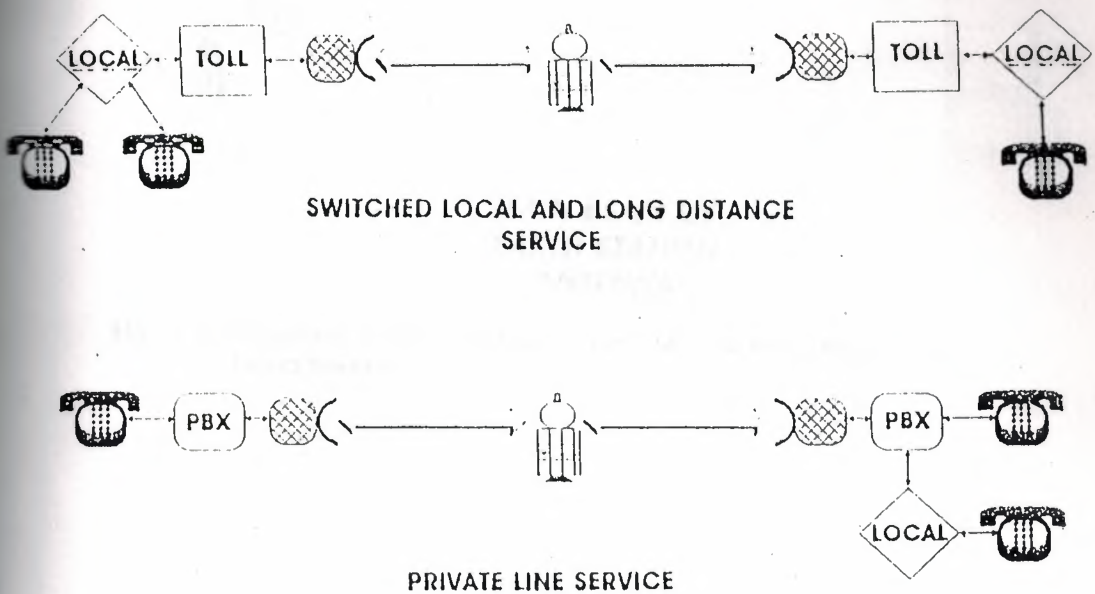


Fig. 4·5 Commercial Telephone Service Can Be Obtained Either Through Public Switching Facilities or Through Dedicated Private Lines

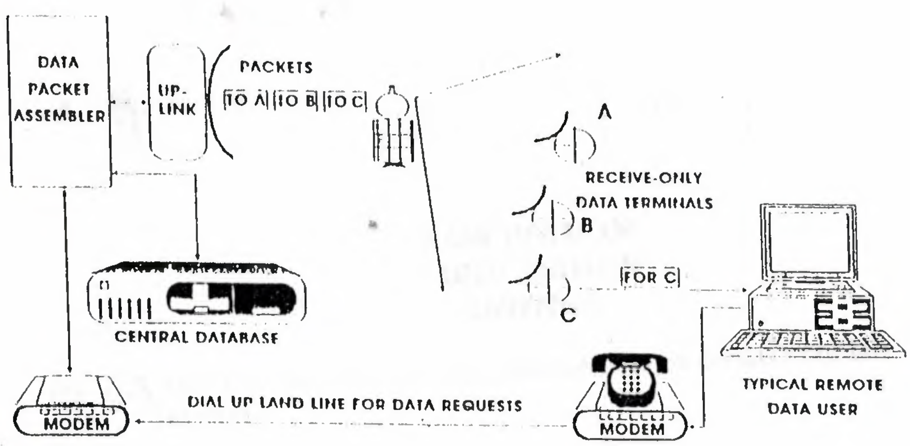


Fig. 4·6 One-Way Data Broadcasting to Low Cost Receive-Only Terminals, Illustrating Terrestrial "Dial-Up" Response

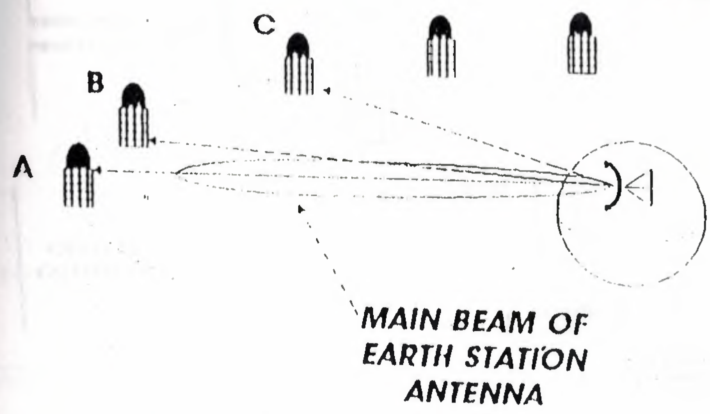


Fig. 4.7. Improved GEO Arc Utilization from Narrow Earth Station Antenna Beams

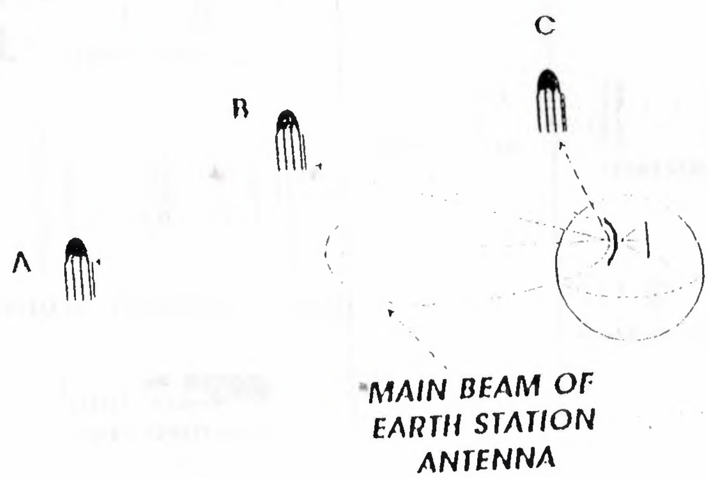


Fig. 4.8 Effect of Wide Beam Earth Station Antennas on GEO Arc Utilization

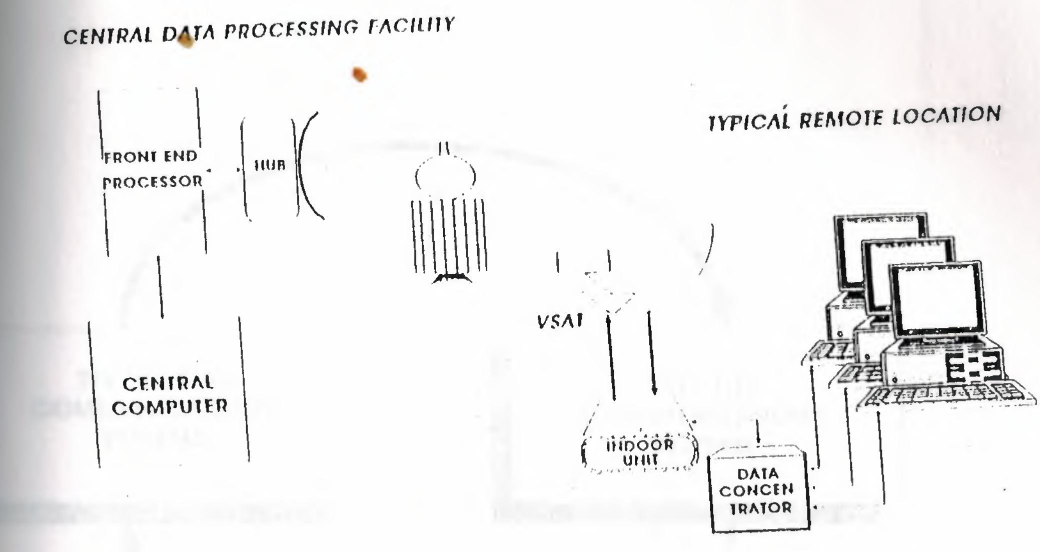


Fig. 4.9 Interactive Data Communications from a Shared Very Small Aperture Terminal

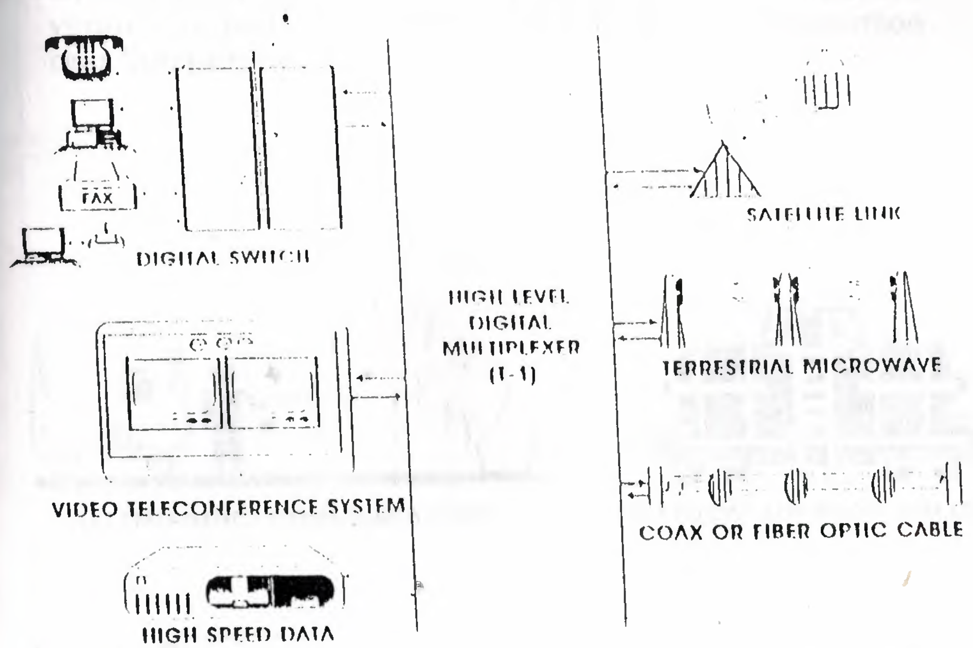


Fig. 4.10 Integrated Digital Services Using a High Level Multiplexer with Connections to Satellite and Terrestrial T-1 Transmission Facilities

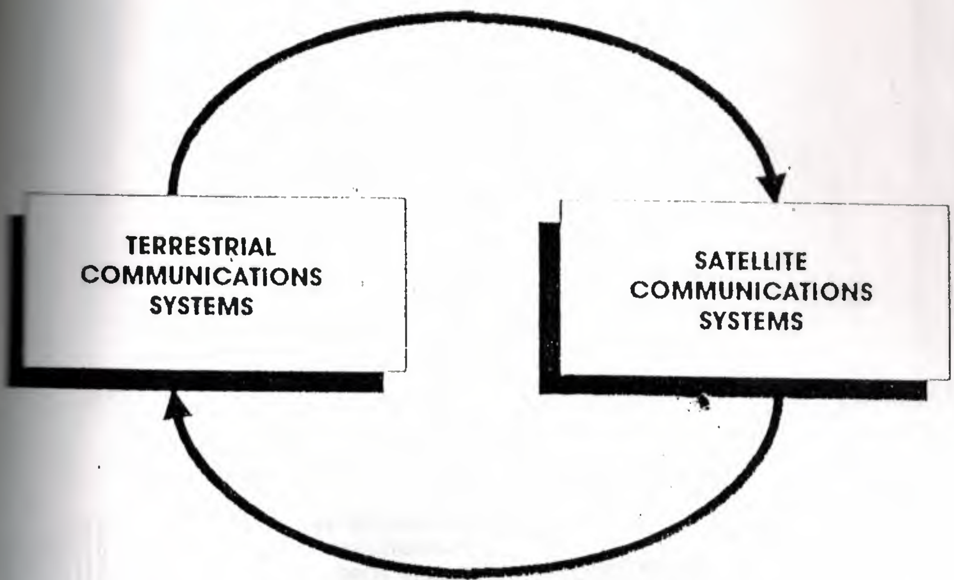


Fig. 6-1 Cyclical Nature of the Dominance of Satellite Communications versus Terrestrial Communications due to Technical Innovation and Competition

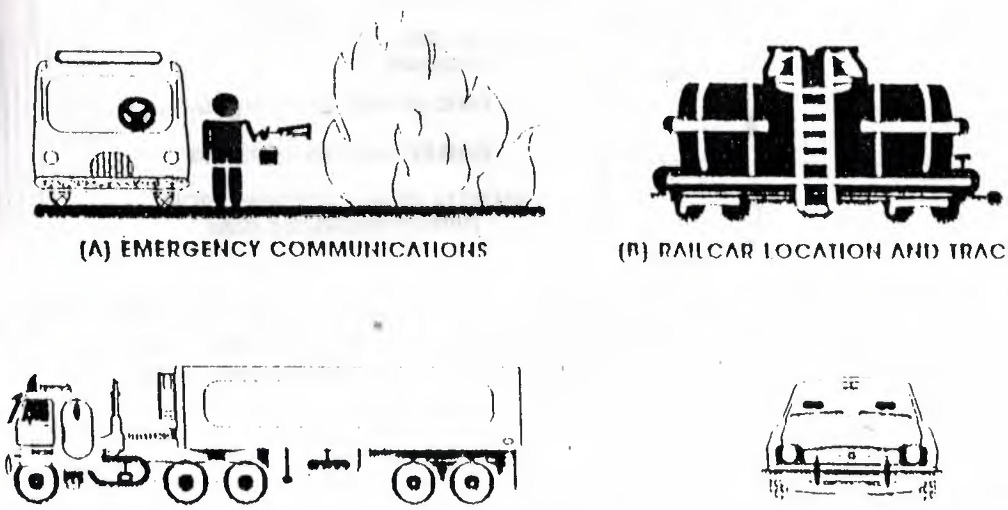


Fig. 6-2 A Mobile Satellite Communication System Will Provide New Services for Vehicles and Remote Locations

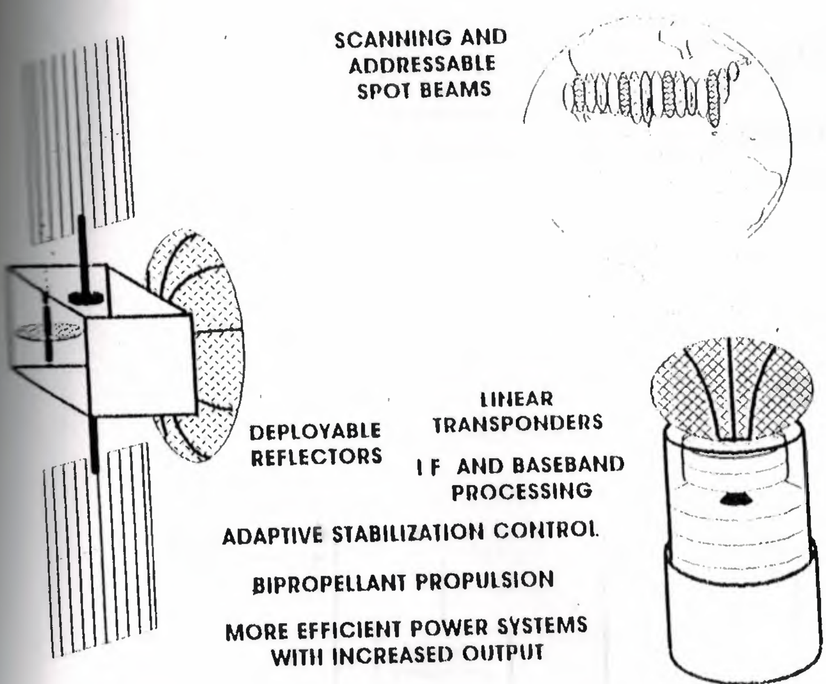


Fig. 6.3 Examples of Evolving Technologies for Commercial Communications Satellites with the Three-Axis (Body Stabilized) and Dual Spin Configurations

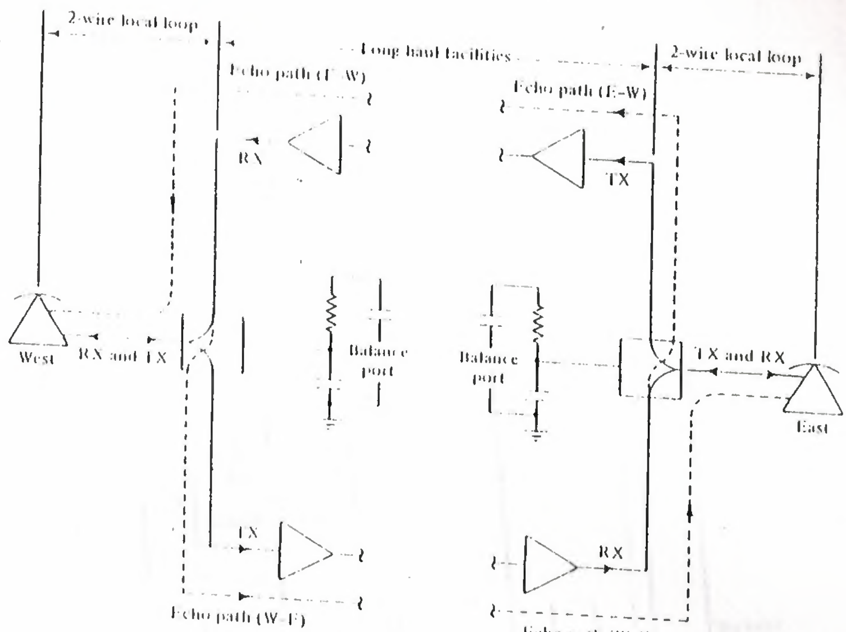


Fig 7.1 Full duplex long distance voiceband circuit.

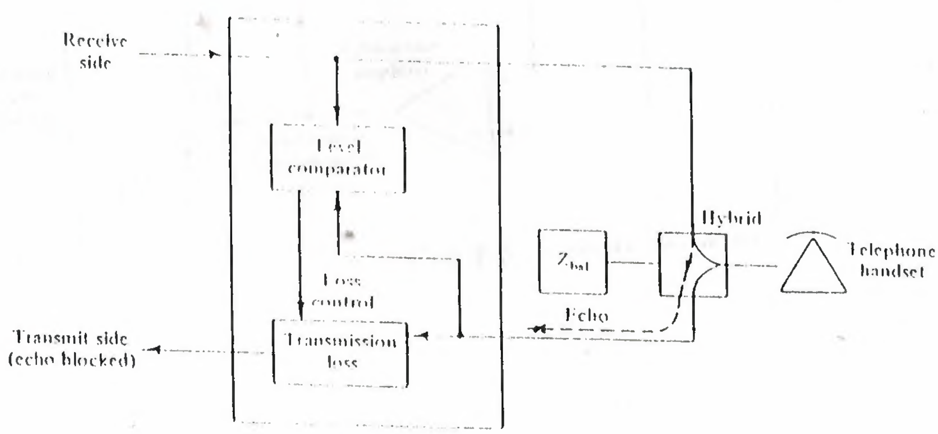


Fig 7.2 Simplified echo suppressor.

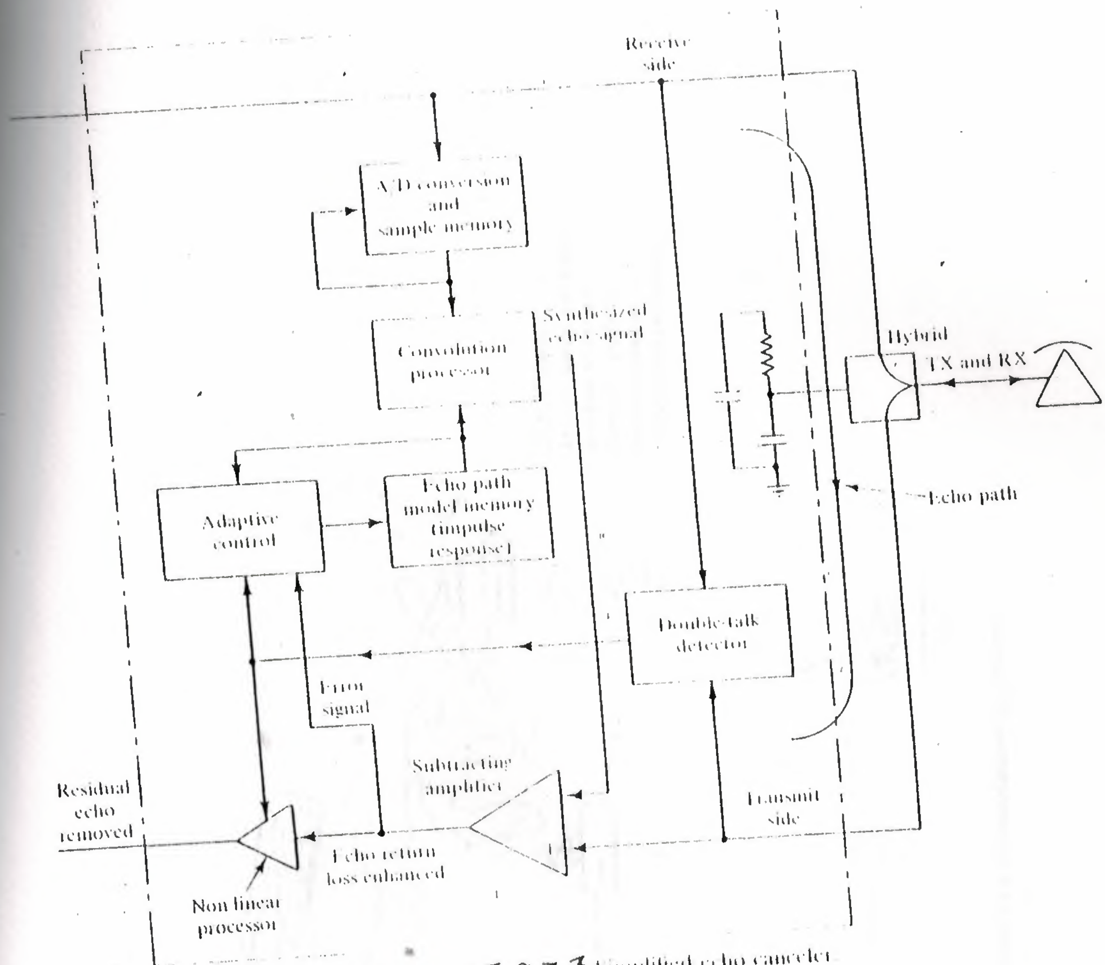


Fig 7.3 Simplified echo canceler.

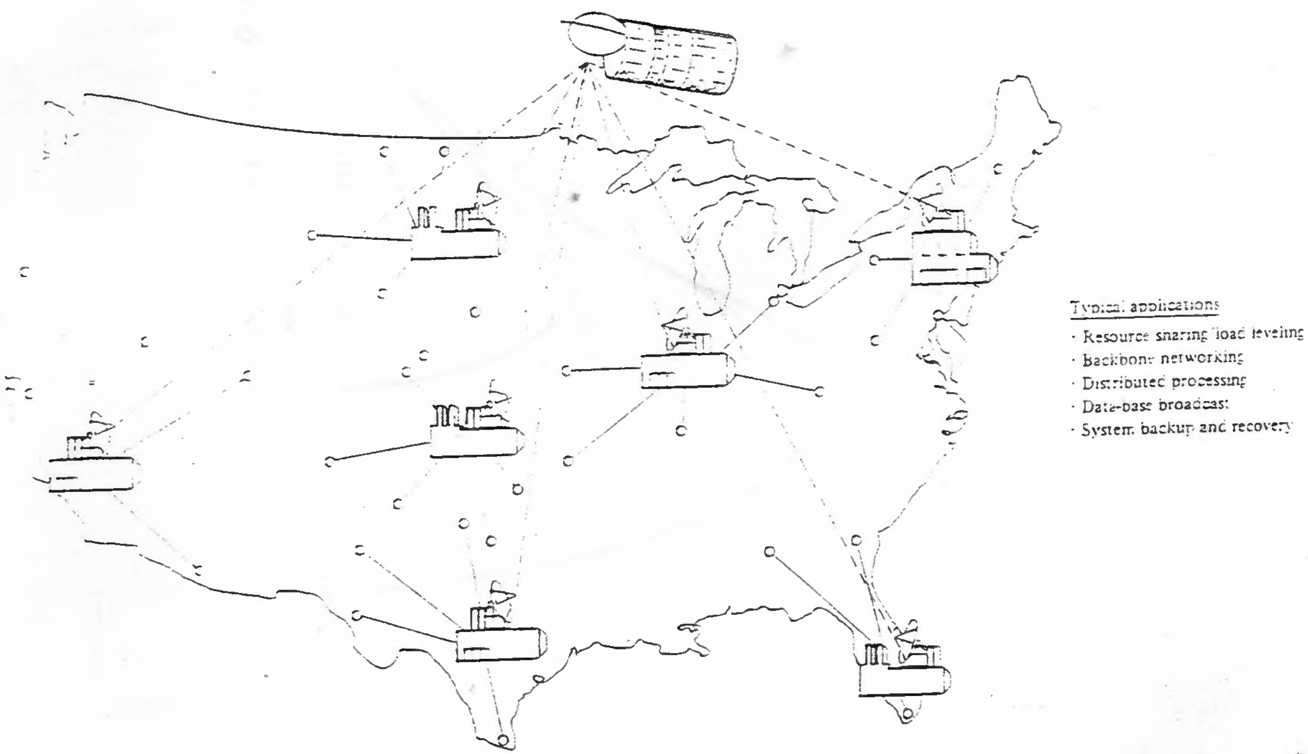


Fig 7.4 Satellite data communications applications.

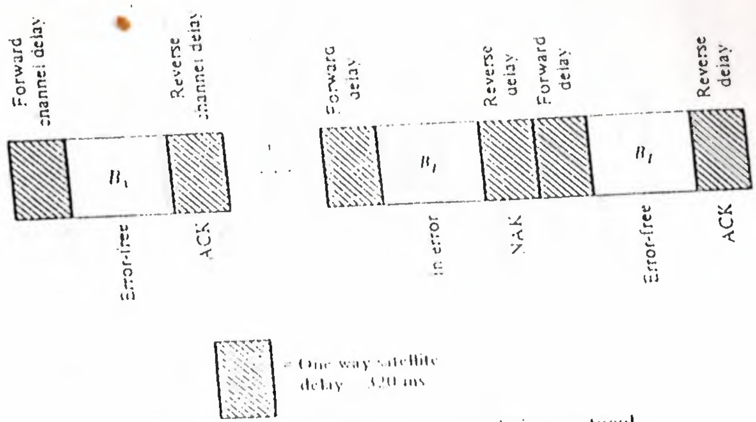


Fig. 7.5 Block-by-block transmission protocol.

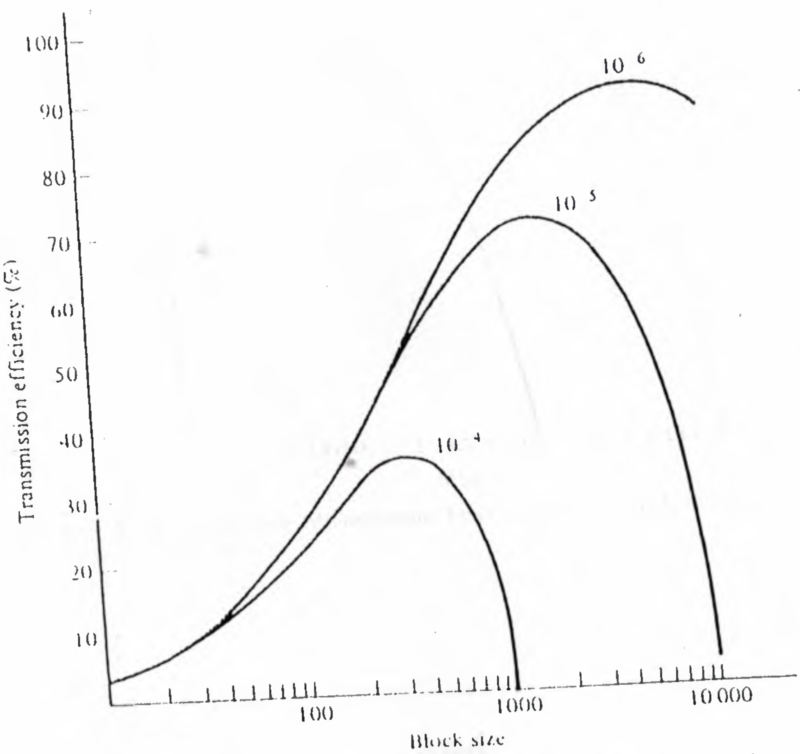


Fig. 7.6 Efficiency of block-by-block transmission protocol.

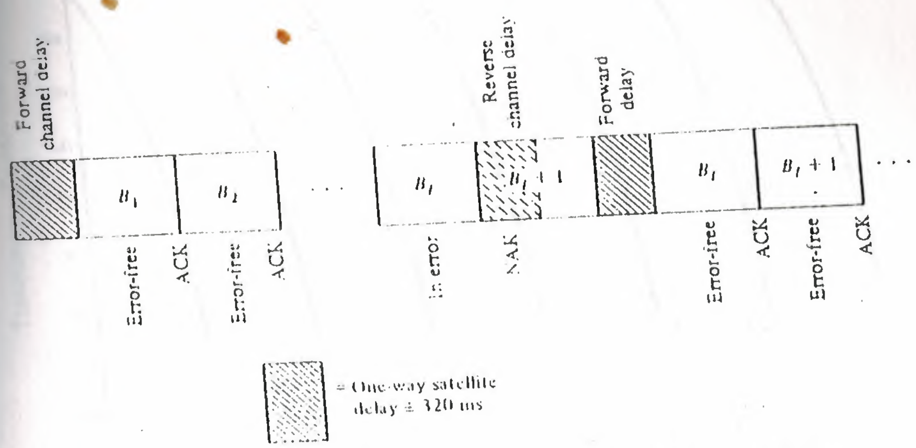


Fig 7.7 Continuous block transmission with restart after error detection.

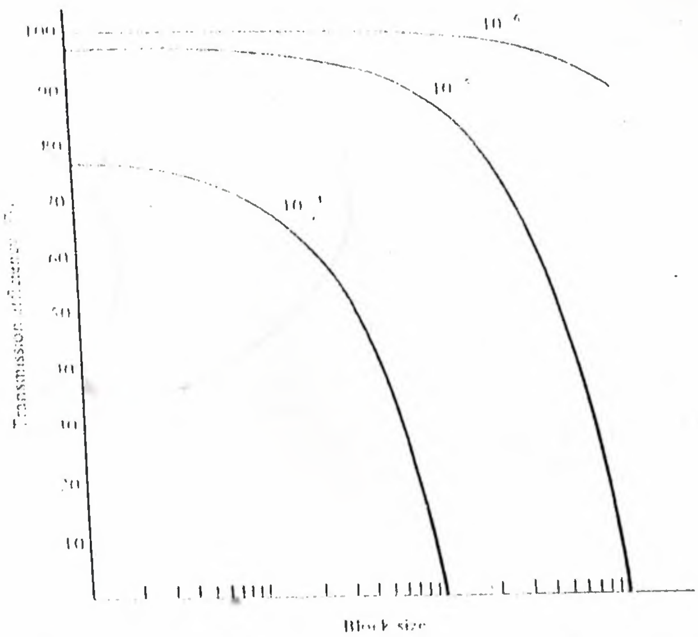


Fig 7.8 Efficiency of continuous block transmission protocol with restart after error detection.

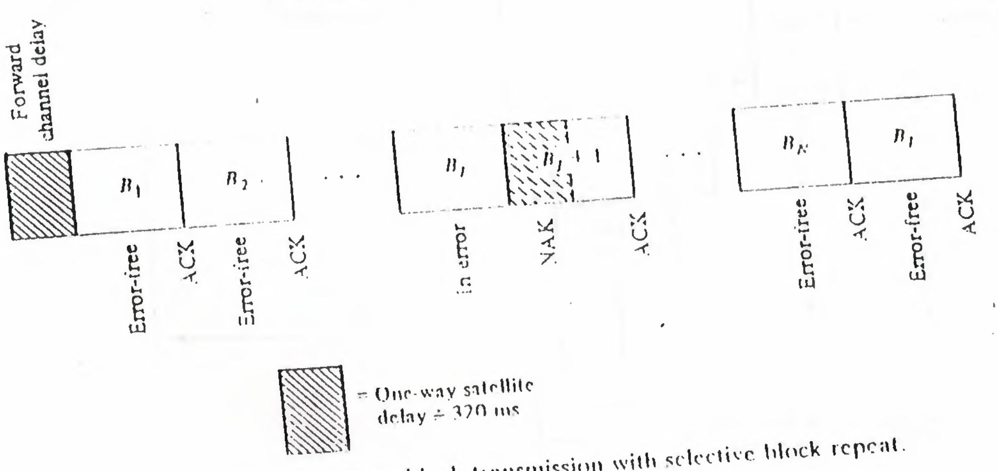


Fig 7.9 Continuous block transmission with selective block repeat.

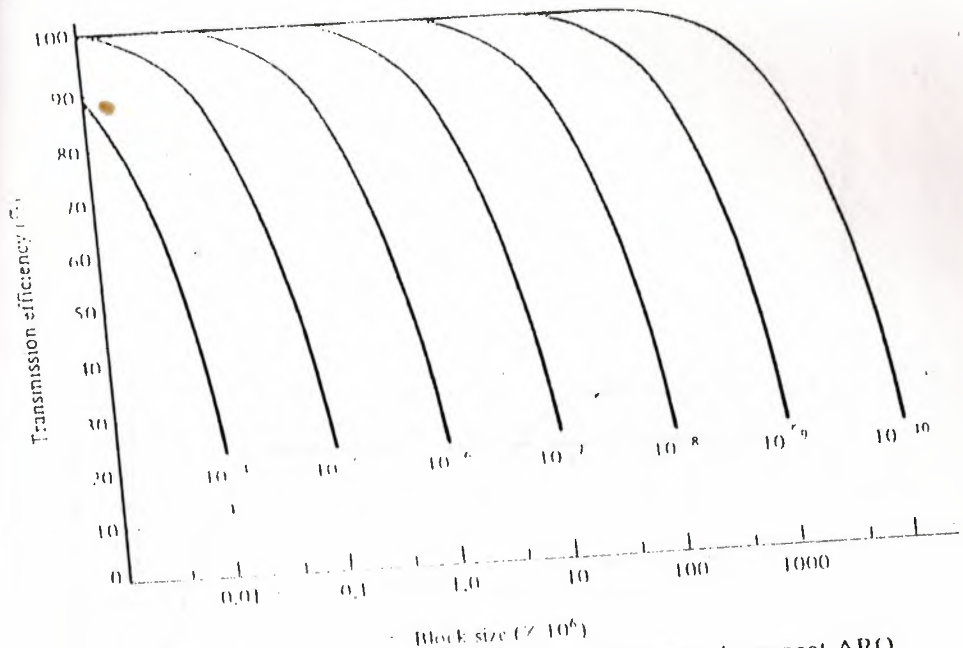


Fig. 7.10 Continuous block transmission with selective repeat ARQ.

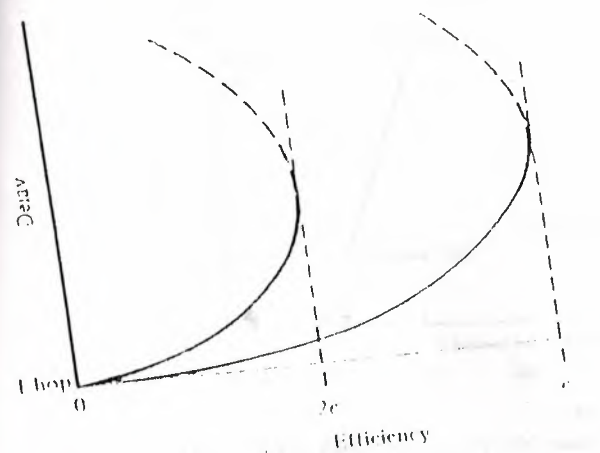


Fig. 7.11 ALOHA channel efficiency.

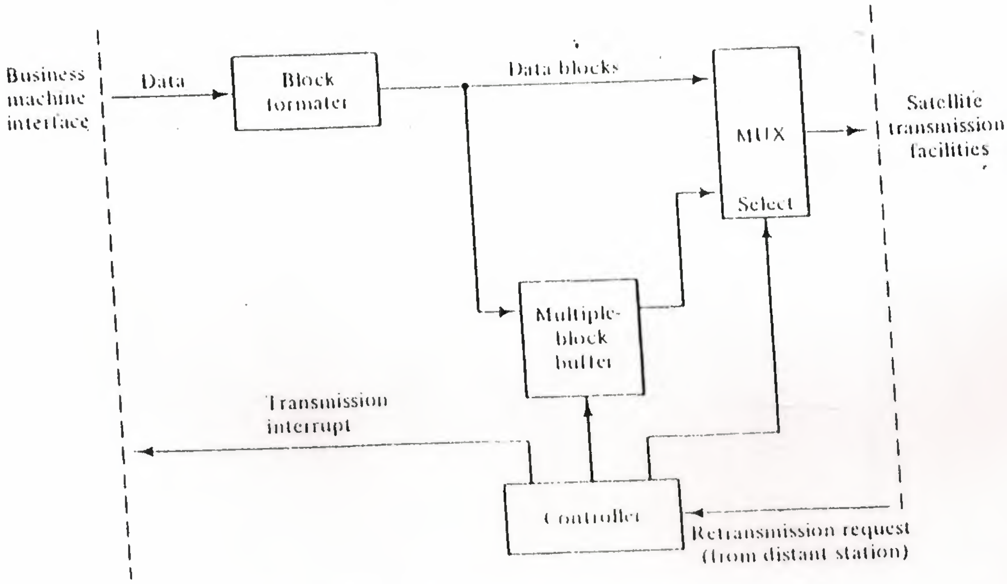
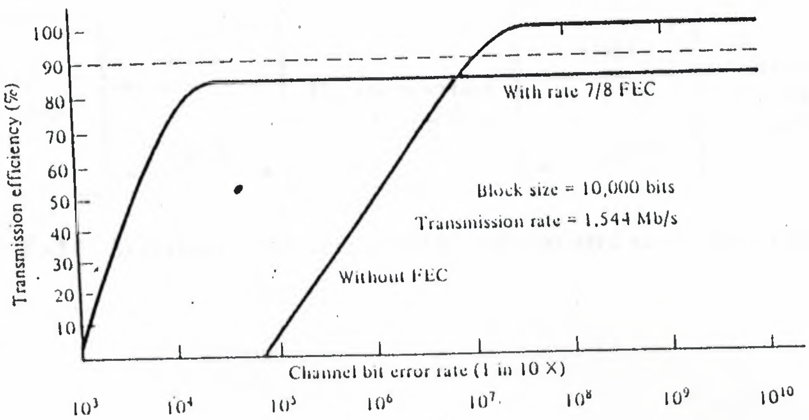
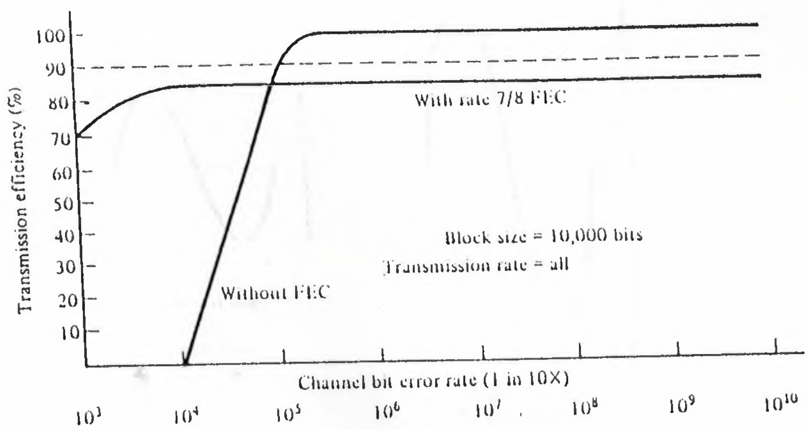


Fig. 7.12 Simplified satellite delay compensator.



(a)



(b)

Fig. 7·13 Effect of rate 7/8 FEC code on transmission efficiency: (a) with restart-after-error detection protocol; (b) with continuous protocol with selective repeat.

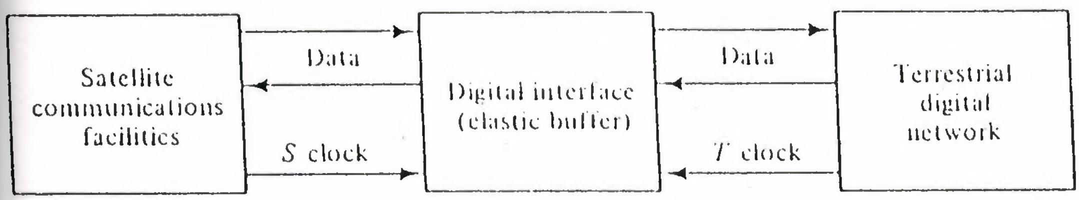


Fig. 7.14 Interface between satellite system and terrestrial facilities.

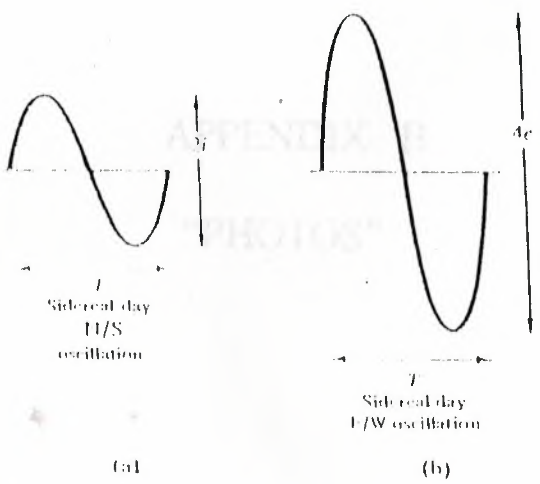


Fig. 7.15 Effects of orbital inclination i and eccentricity e on the angular position of a nominally geostationary satellite.

APPENDIX B

"PHOTOS"

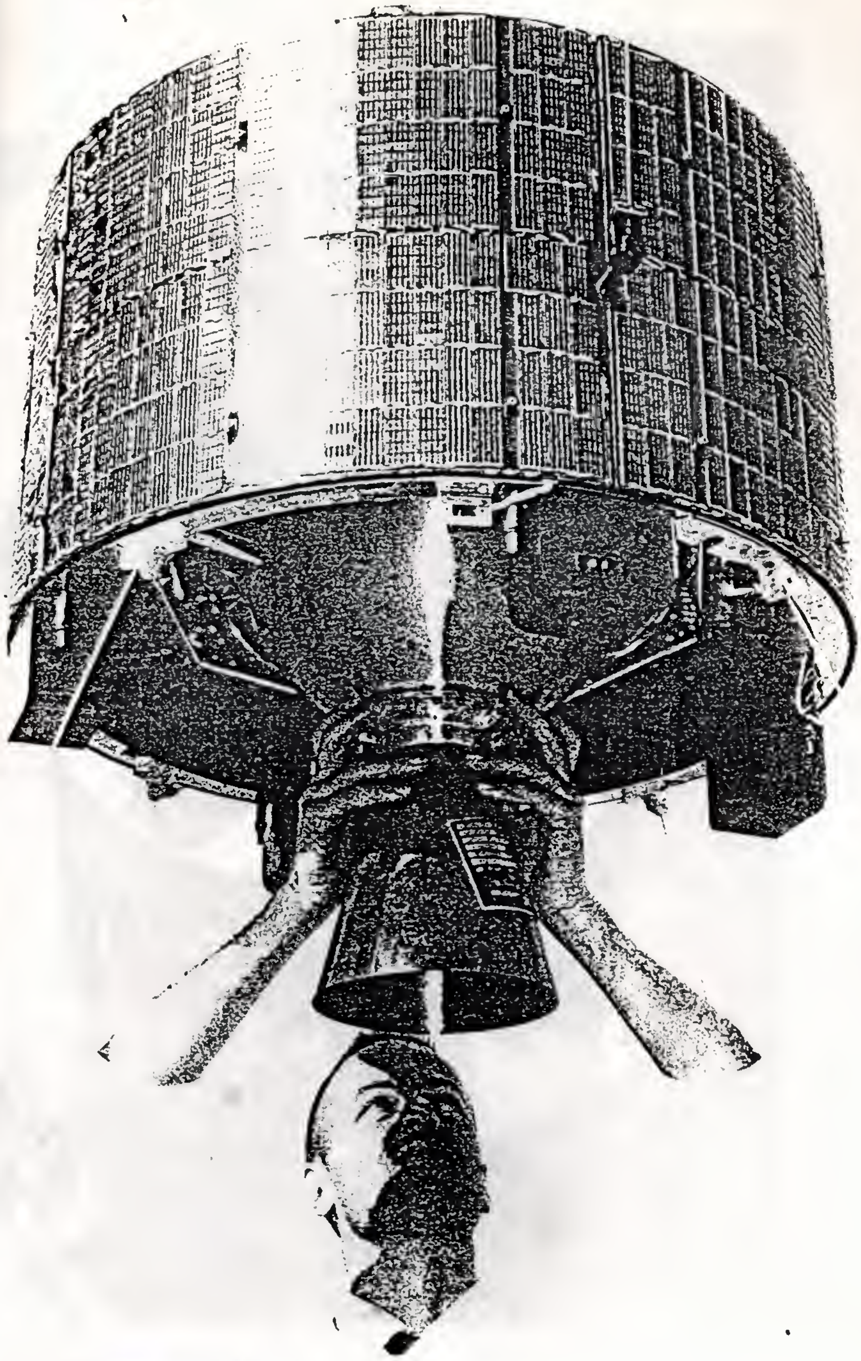


Photo 1.1

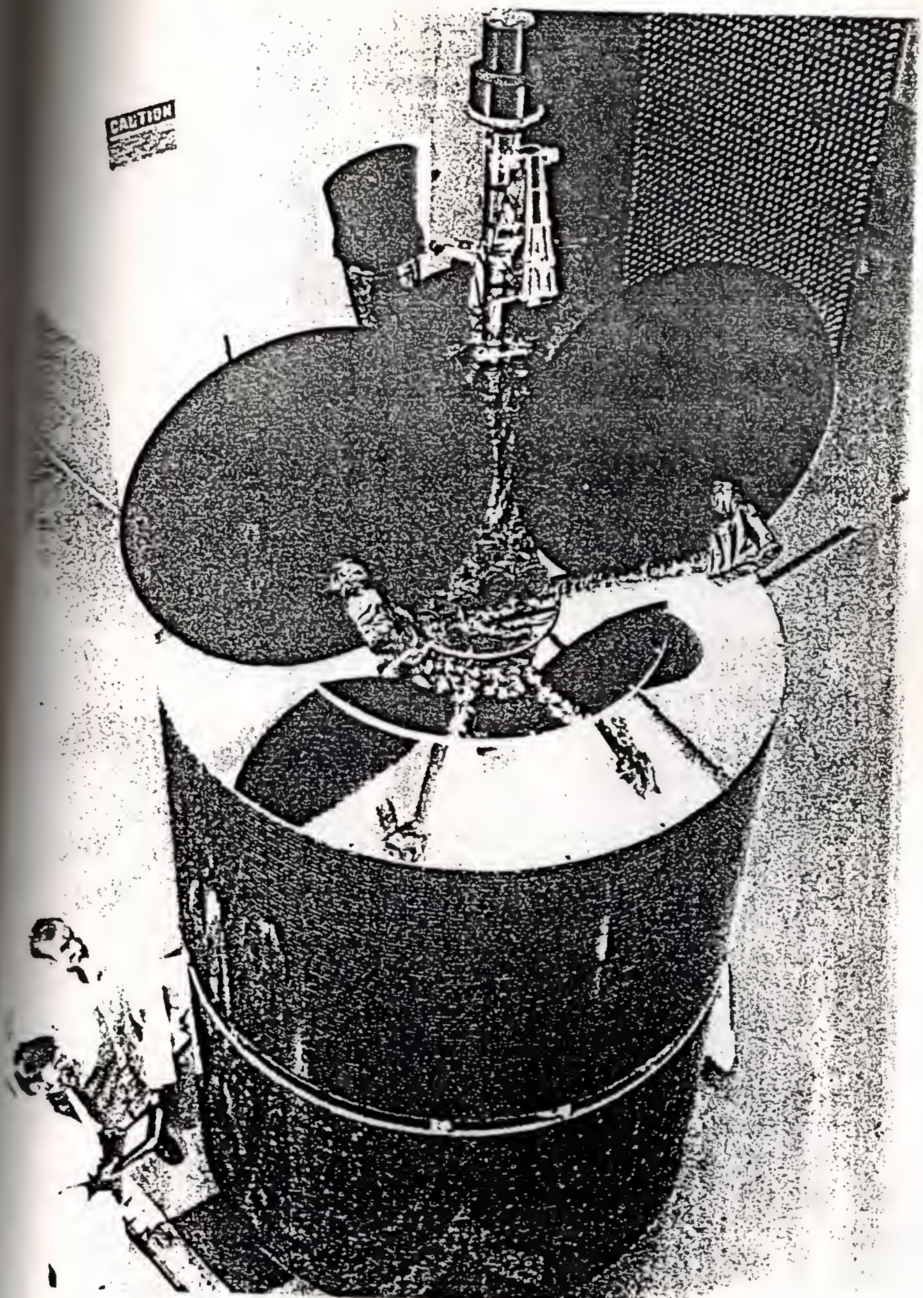


Photo 1.2

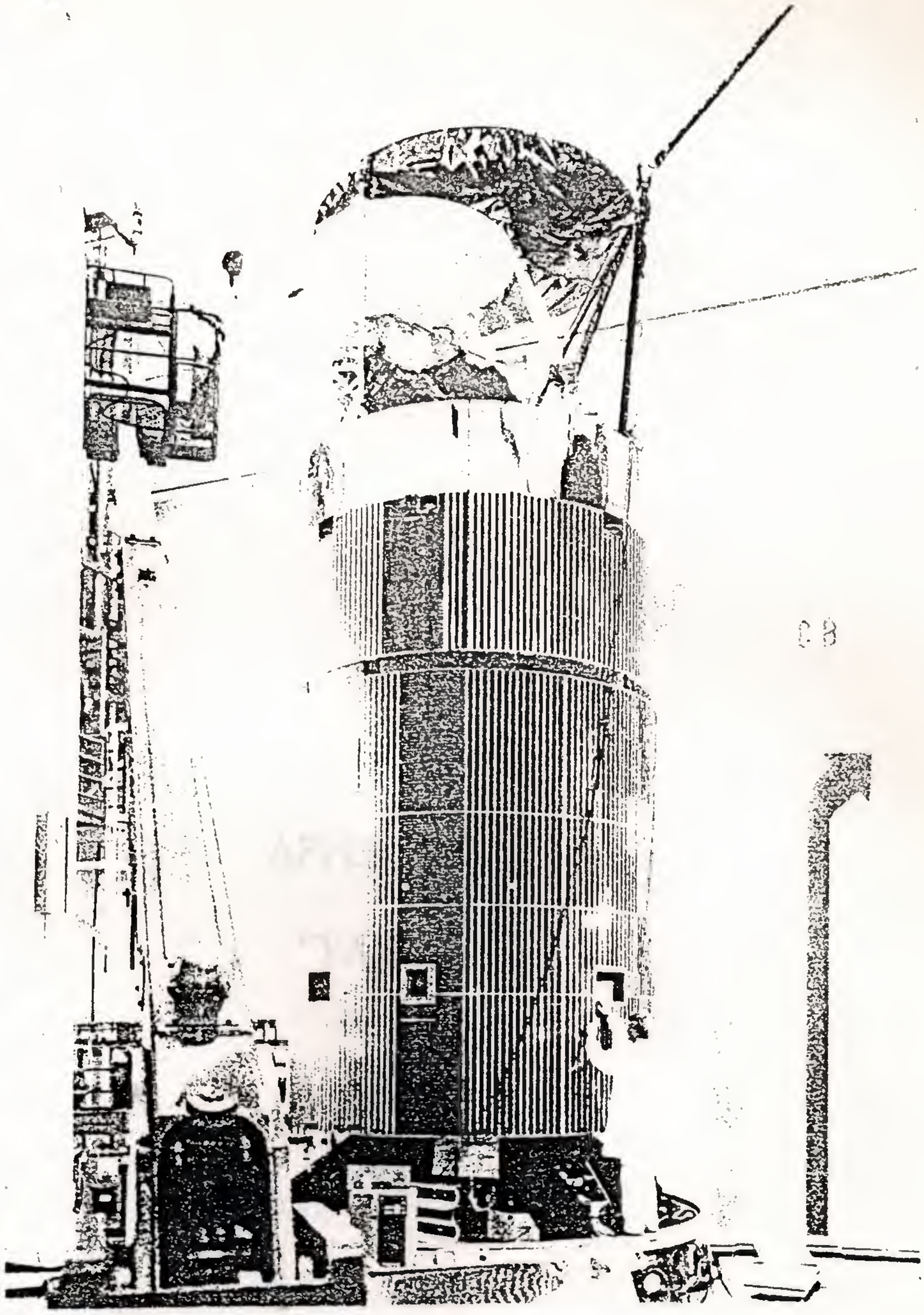


Photo 1.3

APPENDIX C

"TABLES"

TABLE 7.1 PROTOCOL EFFICIENCY COMPARISON

Protocol / Data rate (kb/s)	Block by Block		Continuous with restart after error		Continuous with selective repeat	
Error rate	10^{-5}	10^{-6}	10^{-5}	10^{-6}	10^{-5}	10^{-6}
4.8	72%	90%	97%	99%	90%	99%
56	40%	70%	72%	97%	90%	99%
1 544	5%	25%	10%	50%	90%	99%

TABLE I-2 PROTOCOL PERFORMANCE COMPARISON

Criteria / Protocol	Block by Block	Restart After Block Error	Continuous With Selective repeat
$P = 0.01$ for 10^{10} bits without error	No	Yes	Yes
Efficiency > 90% at BER = 10^{-5}	No	No	Yes
Efficiency independent of rate	No	No	Yes
Efficiency insensitive to error rate	No	No	Yes

APPENDIX D

"GLOSSARY"

APPENDIX D:

GLOSSARY

ACK : Acknowledgment of Error-Free Reception.

ADCCP : Advance Data Communication Control Protocol.

AMS : Aeronational Mobile Satellite Service.

AOR : Atlantic Ocean Region.

ARQ : Automatic Repeat Request.

ASS : Amateur Satellite Service.

BEP : Bit Error Probability.

BN : Band width.

BPSK : Binary Phase Shift Keying.

BSS : Broadcasting satellite Service.

CCIR : International Consultative Committee of the International Telecommunication Union

CCITT : International Consultative Committee on Telegraph and Telephone of the

CEPT : European Conference Post & Telecommunication.

DBS : Direct Broadcast Satellite.

DCME : Digital Circuit Multiplication Equipment.

DE-BPSK: Differential Encoded BPSK.

DSI : Digital Speech Interpolation.

EIRP : Equivalent Isotropic Radiated Power.

EP : Error Probability.

ESA : European Space Agency.

ESS : Earth Exploration Satellite Service.

FDM : Frequency Division Multiplexing.

FEC : Forward Error Correction.

FIFO : First-In-First-Out

FM : Frequency Modulation.

FSK : Frequency Shift Keying.

FSS : Fixed satellite Service.

GEO : Geostationary.

HDLC : High-level Data Link Control.

HDTV : High Definition TV.

IFRB : International Frequency Registration Board.

International Telecommunication Union.

IRD : Integrated receive-Descrambler.

ISDN : Integrated Services Digital Network.

ISS : Inter-Satellite Service.

ITU : International Telecommunication Union.

LMS : Land Mobile Satellite Service.

LNC : Low Noise Converter.

LRE : Low Rate Encoding.

LV : Launch-Vehicle.

MMS : Maritime Mobile Satellite Service.

MSS : Mobile Satellite Service.

MTTF : Mean Time To Failure.

NAK : Negative Acknowledgment.

NMS : Network Management System.

OCL : Overall Connection Loss.

OSI : Open System Inter-connection.

PAM : Pulse Amplitude Modulation.

PBX : Private Branch Exchange.

PCM : Pulse Code Modulation.

PID : Process Identification Document.

POR : Pacific Operating Region.

PSK : Phase Shift Keying.

QPL : Qualified Product List.

QPSK : Quadrature Phase Shift Keying.

RF : Radio Frequency.

RFI : Radio Frequency Interference.

RO : Receive Only.

RR : Radio communication Regulation.

SCA : Subcarrier Channel Authorization.

SCCG : Space Component Coordinate Group.

SCPC : Single Channel Per Carrier.

SOS : Space Operation Service

SRN : Supermarket Radio Network.

SRS : Space Research Service.

SSB-AM : Single Sideband Amplitude Modulation.

STS : Space Transportation System.

TDM : Time Division Multiplexing.

TDMA : Time Division Multiple Access.

TLP : Transmission Level Point.

TTFC : Tracing, telemetry and command station.

TVRO : Television Read-Only.

UHF : Ultra High Frequency.

VHF : Very High Frequency.

VSAT : Very Small Apreture Terminal.

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