NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

SATELLITE TRANSPONDERS

Graduation Project
EE- 400

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ABSTRACT

In daily life satellite communication has a great importance and used in every important field like in official work, army field and field of science.

A satellite communication system can take many different forms. As associated antennas and satellite transponder forms the primary portion of the communication as a sub-system on a communication satellite. These transponders differ from conventional microwave and ordinary communication system, which access the satellite simultaneously as nearly the same instant from widely different points on earth, so we can say multiple carriers arrive at and must be relayed by, the satellite transponder and its opens the new sought of light on human.

Chapter one deals with the details of satellite communication, types of communication devices, system, and controlling of different kinds of antennas and transponders.

In chapter two there is a discussion about multi-channel transponders, some of the advantage of transponder canalization, typical frequency plans and potential advantages of processing transponders. Frequency division multiple access (FDMA) protocols have the potential to provide simple but effective broadcast bus communication for embedded systems in described in chapter third. However bus master based protocol such as TDMA can be undesirable in practice because the bus master node constitutes single point failure vulnerability and adds to system expense. It presents the FDMA protocol, which eliminates the need of having bus master use of nondestructive jamming signal fro frame synchronization. This can be critical for low-cost implementations. FDMA reaps the benefit of protocols without suffering the reliability and system complexity drawbacks of FDMA methods.

Chapter four covers the detail effect of the TDMA multiple access techniques, and also describe the fundamental properties of frequency division multiple access (FDMA).

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1. INTRODUCTION TO SATELLITE COMMUNICATIONS

1.1 Introduction

The use of orbiting satellites is an integral part of today's worldwide communication systems. As the technology and hardware of such systems continue to advance significantly, it is expected that satellites will continue to play an ever-increasing role in the future of long-range communications. Each new generation of satellites has been more technologically sophisticated than its predecessors, and each has had a significant impact on the development and capabilities of military, domestic, and international communication systems. This progress is expected to continue into the next century, and the capability to transfer information via satellites may well surpass our present-day expectations.

To the communication engineer, satellite communications has presented a special type of communication link, complete with its own design formats, analysis procedures, and performance characterizations. In one sense, a satellite system is simply an amalgamation of basic communication systems, with slightly more complicated subsystem interfacing. On the other hand, the severe constraints imposed on system design by the presence of a space borne vehicle makes the satellite communication channel somewhat special in its overall fabrication.

1.2 Historical Developments of Satellite

Long-range communications via modulated microwave electromagnetic fields were first introduced in the 1920s. With the rapid development of microwave technology, these systems quickly became an important part of our terrestrial (ground-to-ground) and near-earth (aircraft) communication systems. However, these systems were, for the most part, restricted to line-of-sight links. This meant that two stations on Earth, located over the horizon from each other, could not communicate directly, unless by ground transmission relay methods. The use of troposphere and ionosphere scatter to generate reflected sky waves for the horizon links tends to be far too unreliable for establishing a continuous system.

In the 1950s a concept was proposed for using orbiting space vehicles for relaying carrier waveforms to maintain long-range over-the-horizon communications. The first version of this idea appeared in 1956 as the Echo satellite a metallic reflecting balloon placed in orbit to act as a passive reflector of ground transmissions to complete long-range links. Communications across the United States and across the Atlantic Ocean were successfully demonstrated in this way. In the late 1950s new proposals were presented for using active satellites (satellites with power amplification) to aid in relaying long-range transmissions. Early satellites such as Score, Telstar, and Relay verified these concepts. The successful implementation of the early Syncom vehicles proved further that these relays could be placed in fixed (geostationary) orbit locations. These initial vehicle launchings were then followed by a succession of new generation vehicles, each bigger and more improved than its predecessors.

Today satellites of all sizes and capabilities have been launched to serve almost all the countries of the world. Satellites now exist for performing many operations, and present development is toward further increase in their role.

1.3 Communication Satellite Systems

A satellite communication system can take on several different forms; Figure 1.1 summarizes the basic types. System I shows an uplink from a ground-based earth station to satellite, and a downlink from satellite back to ground. Modulated carriers in the form of electromagnetic fields are propagated up to the satellite. The satellite collects the impinging electromagnetic field and retransmits the modulated carrier as a downlink to specified earth stations. A satellite that merely relays the uplink carrier as a downlink is referred to as a relay satellite or repeater satellite, more commonly, since the satellite transmits the downlink by responding to the uplink, it is also called a transponder. A satellite that electronically operates on the received uplink to reformat it in some way prior to retransmission is called a processing satellite.

System II shows a satellite crosslink between two satellites prior to downlink transmission. Such systems allow communication between earth stations not visible to the same satellite. By spacing multiple satellites in proper orbits around the Earth, worldwide communications between remote earth stations in different hemispheres can be performed via such crosslink.

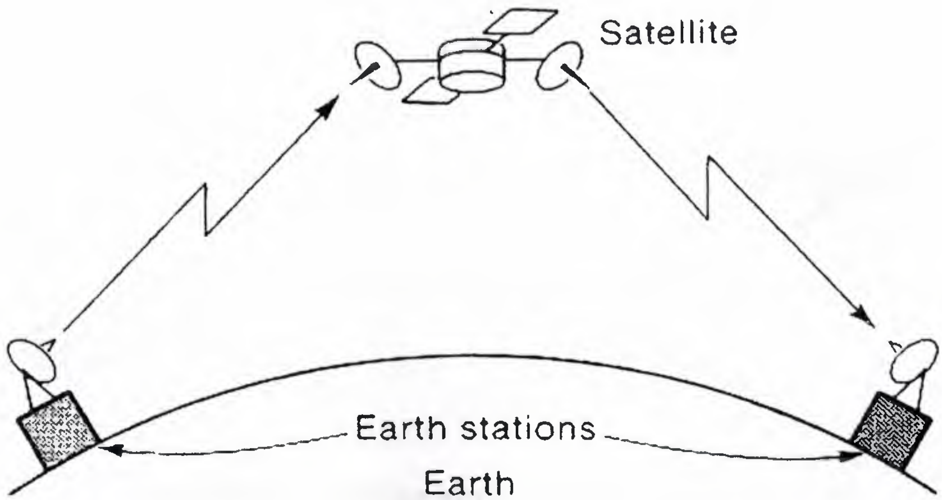


FIGURE1.1 satellite system (I) ground-ground

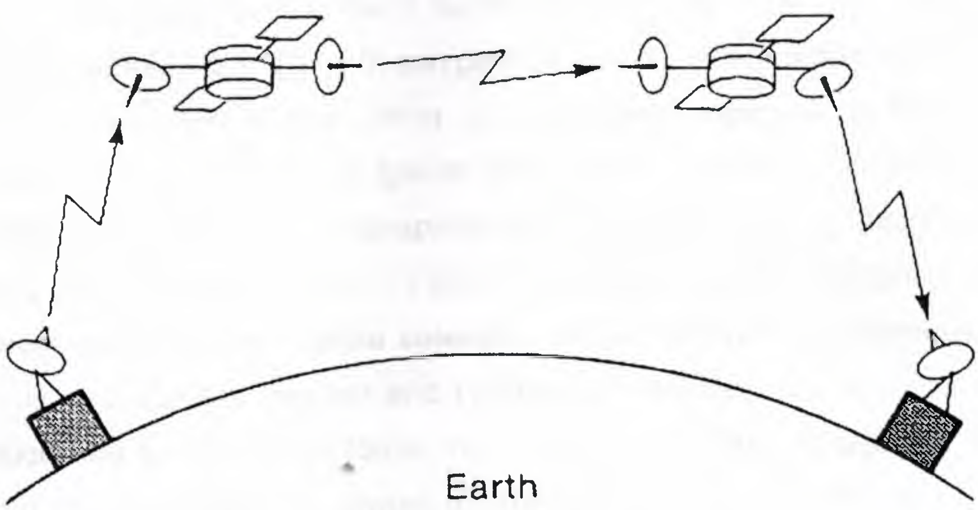


FIGURE1.2 satellite system (II) ground-cross-link-ground

System III shows a satellite relay system involving earth stations, near-earth users (aircraft, ships, etc.), and satellites. An earth station communicates to another earth station or to a user by transmitting to a relay satellite, which relays the modulated carrier to the user. Since an orbiting satellite will have larger near-earth visibility than the transmitting earth station, a relay satellite allows communications to a wider range of users. The user responds by retransmitting through the satellite to the earth station.

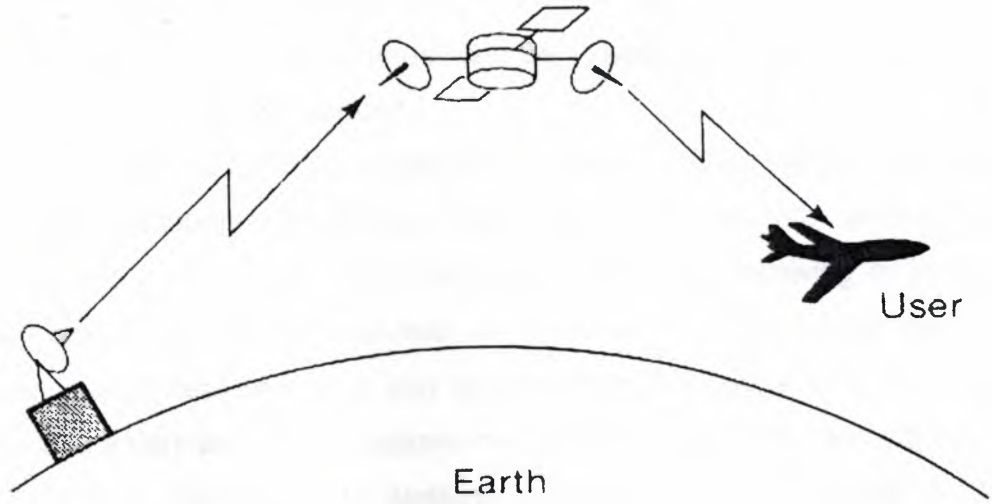


FIGURE1.3 satellite systems (III) ground-user relay

The link from earth station to relay to user is called the forward link, while the link from user to satellite to Earth is called the return link. The satellite systems of Figure 1.1, 1.2, 1.3, can perform a wide variety of functions, besides the basic operation of completing a long-range communication link. Today's satellites are also used for navigation and position location, terrain observations, weather monitoring, and deep-space exploration, and are an integral part of wide area distribution networks. Figure 1.4 shows a satellite navigation system, in which signals from multiple satellites can be received simultaneously by a moving or stationary receiver and processed instantaneously to determine its location and velocity. This forms the basis of the Global Positioning Satellite (GPS) system in which a network of orbiting satellites are continually available to provide the ranging signals for authorized users anywhere in the world. The figure shows a satellite serving as a terrestrial observation vehicle in which weather, terrain, or agricultural information can be collected by cameras and monitors and transmitted to earth-based locations. It also shows a satellite as a primary interconnection between a vast network of moving vehicles and fixed-point earth stations, with voice, data, or command information being exchanged, the use of space vehicles to probe the outer universe by returning television and scientific data has been carried out successfully for several decades. Although simpler in structure and limited in communication capability, these vehicles represent, again, a form of communication satellite whose design principles are similar to those of Figure 1.1, 1.2, 1.3. After deriving the key satellite link equations, the deep-space channel can be viewed as a special case to which the basic analysis can be applied.

Earth stations form a vital part of the overall satellite system, and their cost and implementation restrictions must be integrated into system design. Basically, an earth station is simply a transmitting or receiving or both power station operating in conjunction with an antenna subsystem. Earth stations are usually categorized into large and small stations by the size of their radiated power and antennas. Larger stations may use antenna dishes as large as 10-60 m in diameter, while smaller stations may use antennas of only 3-10 m in diameter, which can be roof-mounted. The current trend is toward very small aperture terminals (VSATs), using 1-3 ft (0.3-0.9 m) antennas that can be attached to land vehicles or even man packs. Large stations may often require antenna tracking and pointing subsystems continually to point at the satellite during its orbit, thereby ensuring maximum power transmission and reception. A given earth station may be designed to operate as a transmitting station only, as a receiving station only, or as both. An earth station may transmit or receive single or multiple television signals, voice, or data (teletype, commands, telemetry, etc.) information, as well as ranging (navigation) waveforms, or perhaps a combination of all these items, the internal electronics of an earth station is generally conceptually quite simple. In a transmitting station the base band information signals (telephone, television, telegraph, etc.) are brought in on cable or microwave link from the various sources. The base band information is then multiplexed (combined) and modulated onto intermediate-frequency (IF) carriers to form the station transmissions, either, as a single carrier or perhaps a multiple of contiguous carriers. If the information from a single source is placed on a carrier, the format is called single channel per carrier (SCPC). More typically, a carrier will contain the multiplexed information from many sources, as in telephone systems. The entire set of station carriers is then translated to radio frequencies (RF) for power amplification and transmission. A receiving earth station corresponds to a low-noise wideband (RF) front end followed by a translator to (IF). At the (IF), the specific uplink carriers wishing to be received,

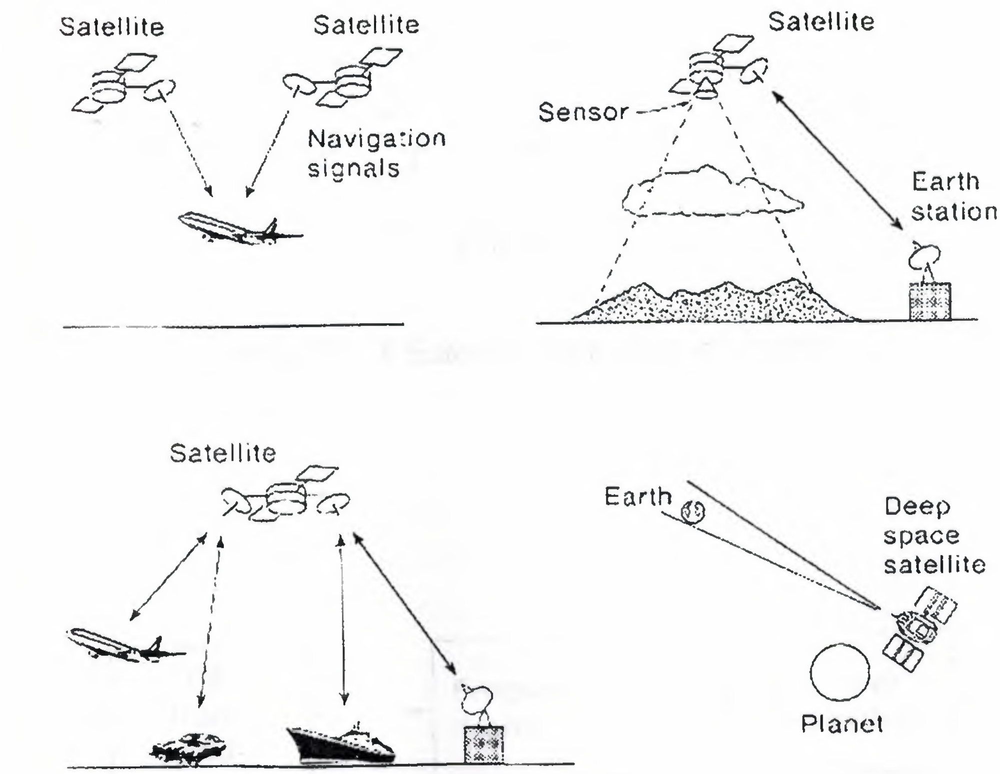


FIGURE 1.4 Satellite uses

are first separated, then demodulated to base band. The base band is then de-multiplexed (if necessary) and transferred to the destination. In some applications an earth station may itself operate in a transponding mode, in which received satellite signals are used to initiate a retransmission from the station to the satellite.

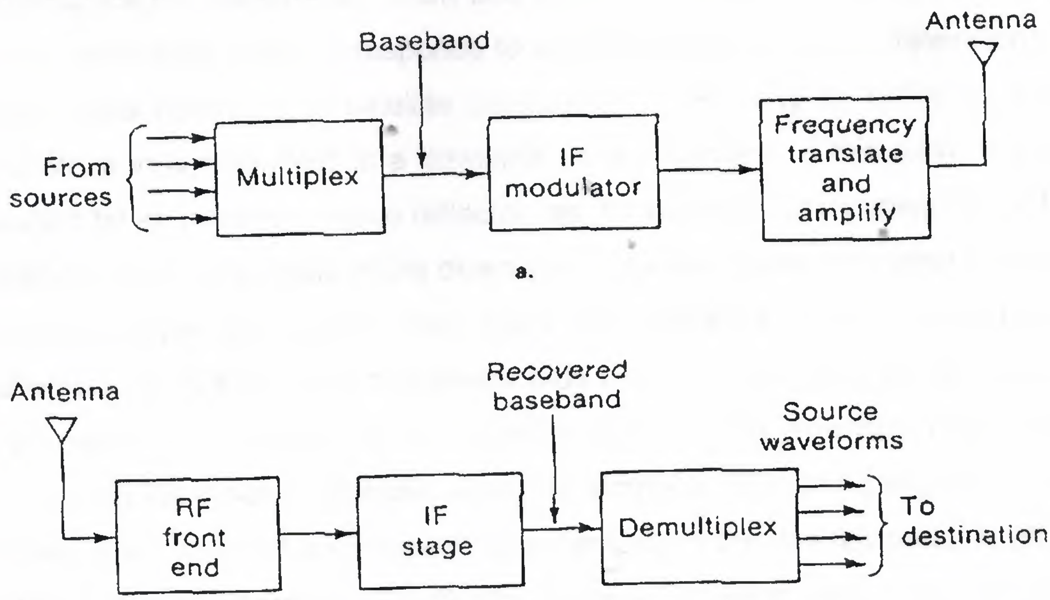


FIGURE 1.5 Earth-station block diagrams (Transmitting and receiving)

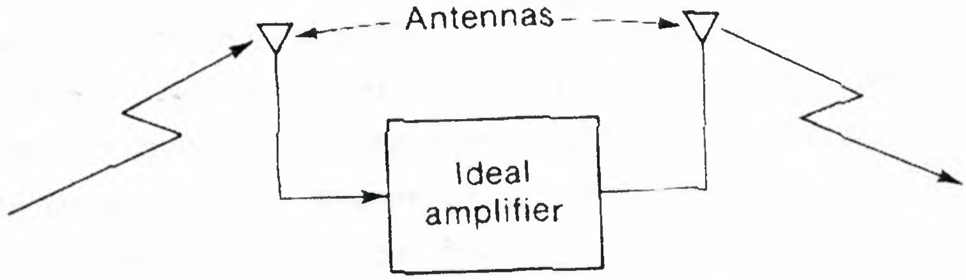


FIGURE 1.6 Satellite block diagram (Ideal)

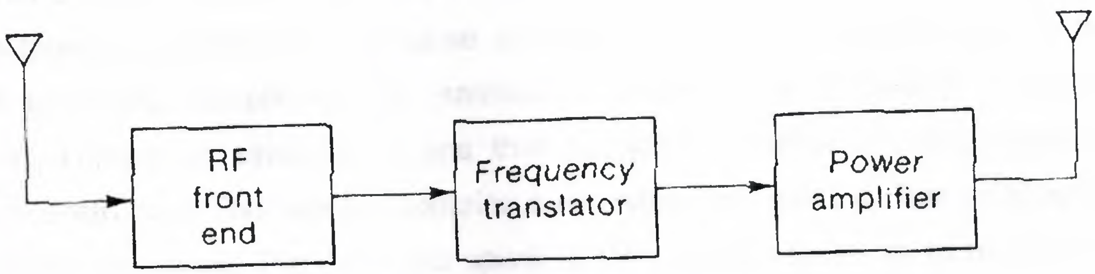


FIGURE 1.7 Satellite diagram (Repeater)

1.4 Communication Satellites

A communication satellite is basically an electronic communication package placed in orbit. The prime objective of the satellite is to initiate or aid communication transmission from one point to another. In modern systems this information most often corresponds to voice (telephone), video (television), and digital data (teletype). A satellite transponder must relay an uplink or forward link electromagnetic field to a downlink, or a return link. If this relay is accomplished by an orbiting passive reflector, as, for example, in the case of the Echo satellite, the power levels of the downlink will be extremely low owing to the total uplink-downlink propagation loss (plus the additional loss of a non-perfect reflector). An active satellite repeater aids the relay operation by being able to add power amplification at the satellite prior to the downlink transmission. Hence, an ideal active repeater would be simply an electronic amplifier in orbit. Ideally, it would receive the uplink cater, amplify to the desired power level, and retransmit in the downlink. Practically, however, trying to receive and retransmit an amplified version of the same uplink waveform at the same satellite will cause unwanted feedback, or ring around, from the downlink antenna into the receiver. For this reason satellite repeaters must involve some form of frequency translation prior to the power amplification. The translation shifts the uplink frequencies to a different set of downlink frequencies so that some separation exists between the frequency bands. This separation allows frequency filtering at the satellite uplink antenna to prevent ring around from the transmitting (downlink) frequency band. In more sophisticated processing satellites the uplink carrier waveforms are actually reformatted or restructured, rather than merely frequency-translated, to form downlink. Frequency-band separation also allows the same antenna to be used for both receiving and transmitting, simplifying the satellite hardware. The frequency translation requirement in satellites means that the ideal amplifier should instead be reconstructed. The satellite contains a receiving front end that first collects and filters the uplink. The collected uplink is then processed so as to translate or reformat to the downlink frequencies. The downlink carrier is then power-amplified to provide the retransmitted carrier. As more sophisticated satellites have evolved, the basic transponder model has been modified and extended to more complicated forms.

In addition to the uplink repeating operation, communication satellites may involve other important communication subsystems as well (Figure 1.8). Since satellites may have to be monitored for position location, a turnaround ranging subsystem is often required on board. This allows the satellite to return instantaneously an uplink ranging waveform for tracking from an earth station, in addition, communication satellites must have the capability of receiving and decoding command words from ground-control stations. These commands are used for processing adjustments or satellite orientation and orbit control. Most satellites utilize a separate satellite downlink to specific ground-control points for transmitting command verification, telemetry, and engineering "housekeeping" data. These uplink and downlink subsystems used for tracking, telemetry, and command (TT&C) are usually combined with the uplink processing channels in some manner. This means that, although they are not part of the mainline communication link, their design and performance does impact on the overall communication capability of the entire system.

Primary power supply for all the communication electronics is generally provided by solar panels and storage batteries. The amount of primary power determines the usable satellite power levels for processing and transmission through the conversion efficiency of the electronic devices. The higher the primary power, the more power is available for the downlink retransmissions. However, increased solar panel and battery size adds additional weight to the space vehicle. Thus, there is an inherent limit to the power capability of the communication system.

Another important requirement in any orbiting satellite is attitude stabilization. A satellite must be fabricated so it can be stabilized (oriented) in space with its antennas pointed in the proper uplink and downlink directions. Satellite stabilization is achieved in one of two basic ways. Early satellites were stabilized by physically spinning the entire satellite (spin-stabilized) in order to maintain a fixed attitude axis. This means all points in space will be at a fixed direction relative to that axis. However, if the entire satellite is spinning, the antennas and solar panel must be de-spun so they continually point in the desired direction. This de-spinning can be accomplished either by placing the antennas and panels on platforms that are spun in the opposite direction to counteract the spacecraft spin or by using multiple elements that are phased so that only the element in the proper direction is activated at any time. Again an inherent limitation to both antenna and solar panel (power) size.

The second stabilization method is carded out via internal gyros, through which changes in orientation with respect to three different axes can be sensed and corrected by jet thrusters (three-axis stabilization). As requirements on satellite antennas and solar panels increased in size, it became correspondingly more difficult to de-spin, and three-axis stabilization became the preferred method. Spin stabilization has the advantage of being simpler and providing better attitude stiffness. However, spinning is vulnerable to bearing failures, cannot be made redundant, and favors wide diameter vehicles, which may be precluded by launch vehicle size. Also, when de-spinning multiple-element antennas and solar panels, only a fraction of each can be used at any one time, thus reducing power efficiency. Three-axis stabilization tends to favor vehicles with larger antennas and panels, and favors operation where stabilization redundancy is important.

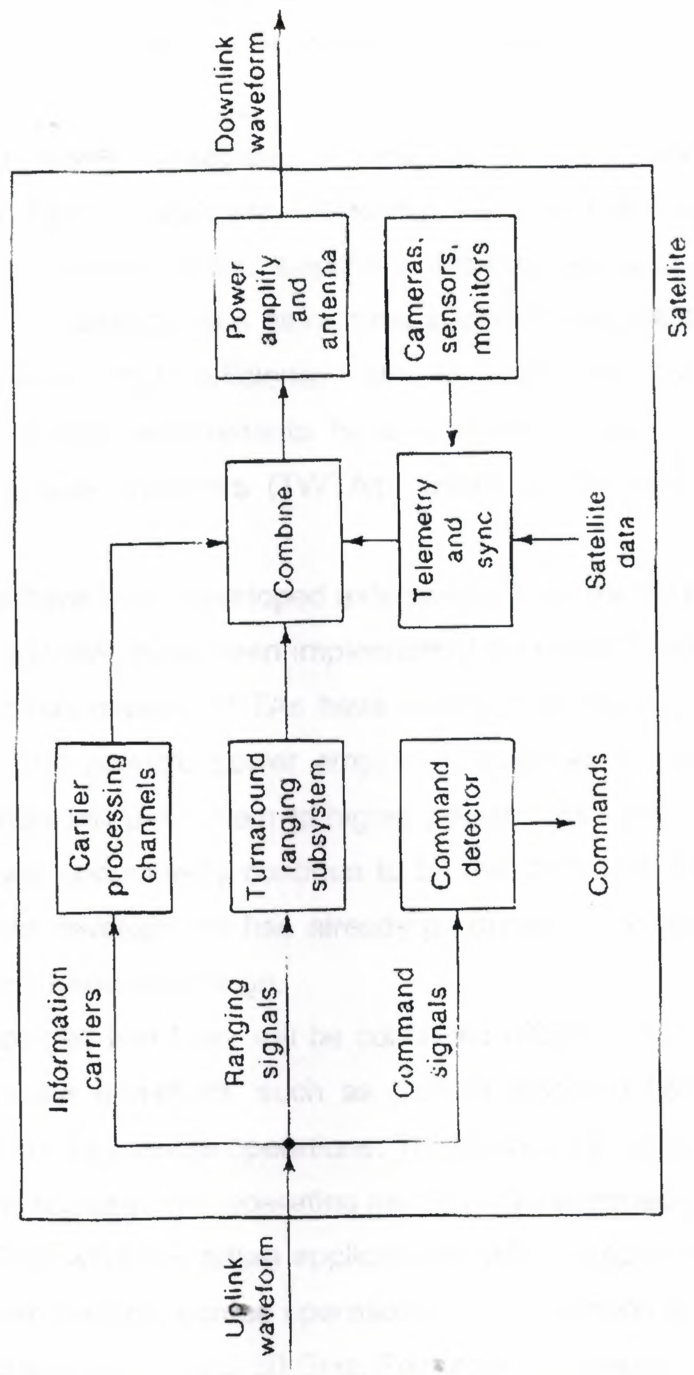


FIGURE 1.8 Satellite sub-systems

Attitude stabilization also determines the degree of orientation control, and therefore the amount of error in the ability of the satellite to point in a given direction. Satellite downlink pointing errors are therefore determined by the stabilization method used. Both methods previously described can be made to produce about the same pointing accuracy, generally about a fraction of a degree. The pointing errors directly affect antenna design and system performance, especially in the more sophisticated satellite models being developed.

Satellite power amplifiers provide the primary amplification for the retransmitted carrier, and are obviously one of the key elements in a communication satellite. Power amplifiers, besides having to generate sufficient power levels and amplification gain, have additional requirements for reliability, long life, stability, high efficiency, and suitability for the space (orbiting) environment. These requirements have sufficiently been met by the use of traveling-wave-tube amplifiers (TWTAs), either of the cavity-coupled or helix type.

TWTAs have been developed extensively, their theory of operation is well understood, and they have been implemented successfully in all types of space missions. For this reason TWTAs have emerged as the universal form of both earth-station and satellite power amplifiers. Even as increased demands on power amplifiers will push them to higher power levels and higher frequencies, the TWTAs will undoubtedly continue to be the dominant amplification device. Their continual development has already produced sufficient power levels well into the 30-0Hz frequency range.

It is expected that there will be continued effort to develop smaller lighter-weight solid-state amplifiers, such as gallium arsenide field-effect transistors (GA FET) for future satellite operations. These devices, however, have not been established in higher-power operating modes with reasonably sized bandwidths. They most likely will have future applications with appropriate power-combining, or lower-power, multiple-source operations. FET operation is generally confined to upper frequencies of about 30 GHz. For projected amplification above 300Hz, impact avalanche transit time (IMPATT) diode amplifiers are rapidly developing as a capable medium-power amplifier. Such diodes have been developed at frequencies up to about 60 GHz, and it appears they will become extendable to 100 GHz operation in the near future.

1.5 Satellite frequency Bands

The electromagnetic frequency spectrum is shown in Figure 1.9 along with designated frequency bands. The frequencies used for satellite communications are selected from bands that are most favorable in terms of power efficiencies, minimal propagation distortions, and reduced noise and interference effects. These conditions tend to force operation into particular frequency regions that provide the best trade-offs of these factors. Unfortunately, terrestrial systems (ground-to-ground) tend to favor these same bands. Hence, there must be concern for interference effects between satellite and terrestrial systems. In addition, space itself is an international domain; just as are airline airways and the oceans, and satellite use from space must be shared and regulated on a worldwide basis. For this reason, frequencies to be used by satellites are established by a world body known as the International Telecommunications Union (ITU), with broadcast regulations controlled by a subgroup known as the World Administrative Radio Conference (WARC). An international consultative technical committee (CCIR) provides specific recommendations on satellite frequencies under consideration by WARC. The basic objective of these agencies is to allocate particular frequency bands for different types of satellite services and also to provide international regulations in the areas of maximum radiation levels from space, coordination with terrestrial systems, and the use of specific satellite locations in a given orbit. Within these allotments and regulations, an individual country operating its own domestic satellite system, or perhaps a consortium of countries operating a common international satellite system (e.g., Intelsat), can make its own specific frequency selections based on intended uses and desired satellite services.

Most of the early satellite technology was developed for UHF, C-band, and X-band, which required minimal conversion from existing microwave hardware. Major problems have been projected in these areas, however, because of the worldwide proliferation of satellite systems in these bands. The foremost problem is that the available bandwidth in these bands is now inadequate to meet present and future traffic demands. Furthermore, interference among various independent satellite systems, and between satellite and existing terrestrial systems, will become more severe as additional satellites are put into use. Coordination among independent systems will be difficult to maintain. There can also be serious orbital congestion in the most favorable orbits for systems operating at C- and X-bands.

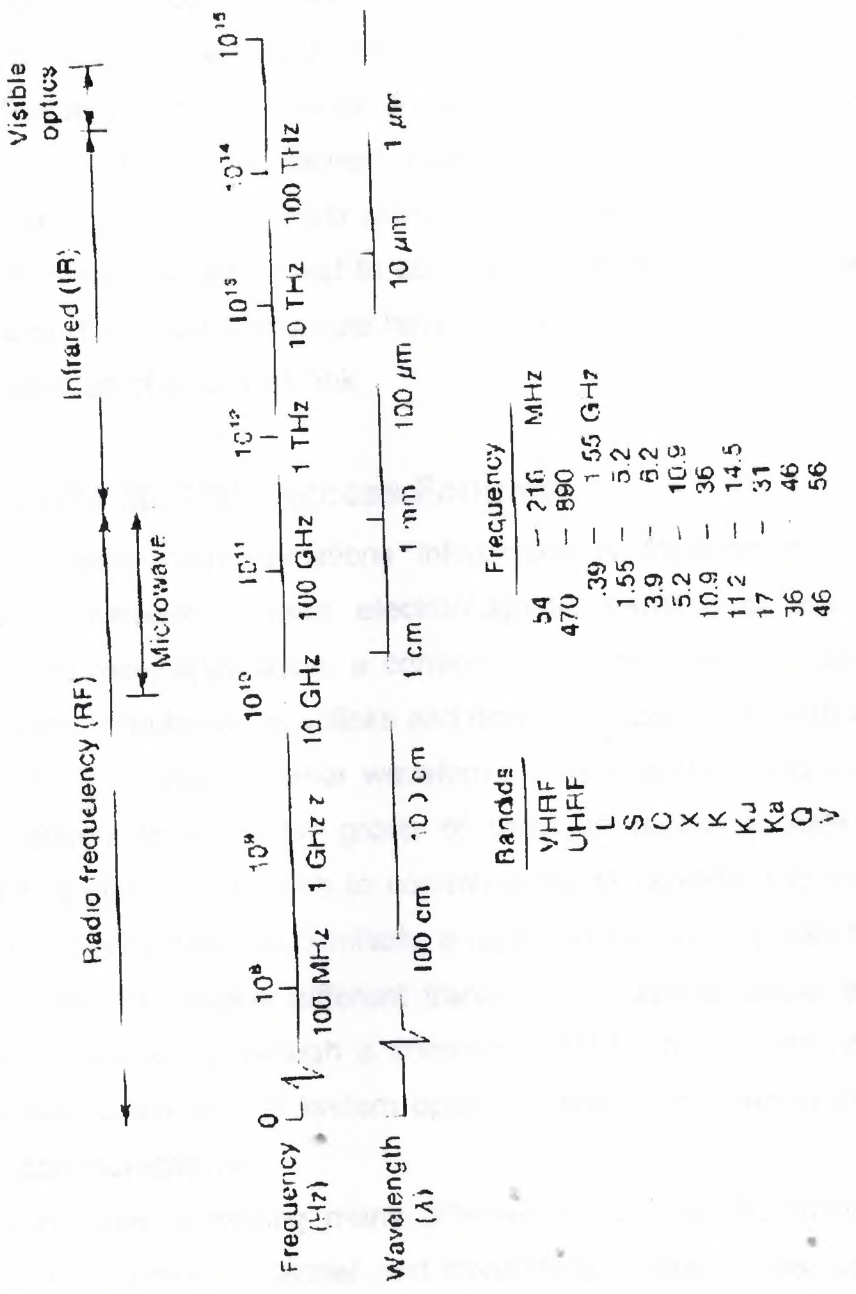


FIGURE 1.9 Electromagnetic frequency spectrums and designated bands

For these reasons there is continued interest in extending operation to the higher K-band and V-band frequencies. In most cases this means further development of technology and hardware, and expanded research on atmospheric propagation at these frequencies, but the extended operation has the advantages of more spectral bandwidth, negligible terrestrial interference, and closer orbital spacing.

An immediate, obvious advantage of using a carrier at a higher frequency is the ability to modulate more information (wider bandwidths) on it. If the bandwidth that can be modulated onto a carrier is a fixed percentage of that carrier frequency, then a carrier at 30 GHz can carry roughly five times the information of a C-band carrier. Thus, while C-band satellite systems can provide bandwidths of 500 MHz (about 10% of the carrier frequency), a K-band carrier frequency would project to about 2.5 GHz of modulation bandwidth. An increase of this proportion would have significant impact on the cost efficiency and capabilities of a satellite link.

1.6 Satellite Multiple-Access Formats

In satellite communications information is transmitted by modulating information waveforms onto electromagnetic carriers at the frequencies. However, in most application, a communication satellite must be designed to handle many simultaneous uplinks and downlinks. Separate earth stations each transmit their individual carrier waveforms to the satellite, and all are relayed simultaneously to a similar group of separate receiving stations. A given transmitting station may wish to communicate its waveform to one or several different receiving stations. Similarly, a receiving station may wish to receive the transmissions of several different transmitting stations. Since all the uplink carriers must access through a common satellite to complete their downlink transmissions, the overall system operation has been referred to as multiple-access communications.

In multiple accessing many different carriers are transmitted simultaneously over a common channel, and therefore a multiple-access operation must permit the separability of the carriers at the receiver. That is, multiple accessing must allow a receiver to separate out a desired carrier while tuning out undesired carriers.

This separability is achieved by requiring the carriers to conform to a specific multiple-access format. The multiple-access format is simply a form of carrier-wave multiplexing that allows many carriers, even when emitted from remotely located stations, to remain separable after channel transmission.

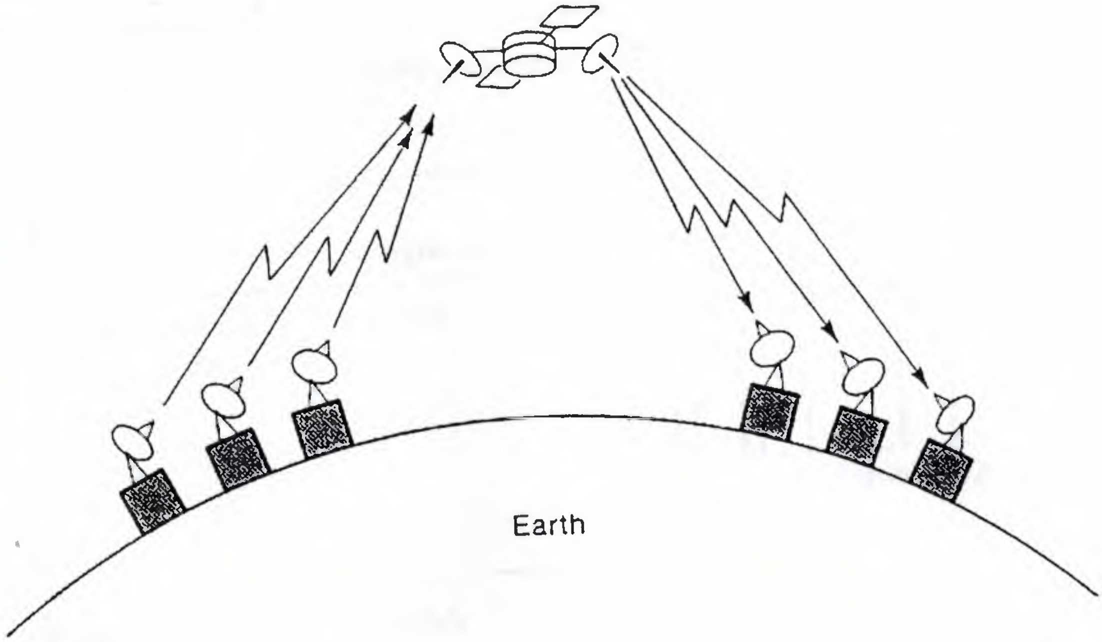


Figure 1.10 Multiple accessing satellites links

A satellite system generally has both uplink and downlinks multiple accessing. The uplink accessing format allows many different ground stations to transmit up to the satellite at the same time. Likewise, a satellite downlink must have multiple accessing to allow a ground receiver of the satellite to separate out any (or all) of the downlink carriers. In a transponding satellite the uplink and downlink multiple-accessing format is the same, with all uplink carriers passing through the satellite to complete the downlink. In processing satellites the uplink format may be revised at the satellite prior to the downlink transmission.

The three most common forms of multiple-accessing formats are summarized in Table 1.1. In frequency-division multiple accesses (FDMA), earth stations using the satellite are assigned specific uplink and downlink carrier frequency bands within the allotted satellite bandwidth. Station separability is therefore achieved by separation in frequency. After retransmission through the satellite, a receiving station can receive the transmitted waveform of an uplink station by simply tuning to the proper frequency band. FDMA is the simplest and most basic format to implement, since it requires earth-station configurations most compatible with existing hardware. FDMA formats are also the most popular, and were used almost exclusively in all early satellite systems. The primary disadvantage of FDMA is its susceptibility to station crosstalk and inter-carrier interference from nearby carriers while all are passing through the satellite.

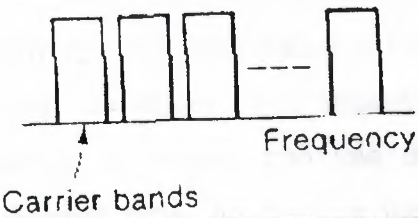
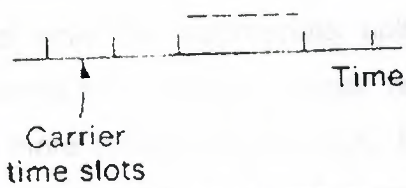
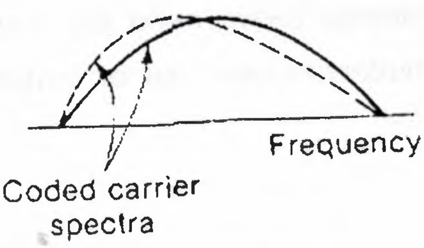
Multiple-access Format	*Designation*	*Characteristic*
Frequency-division multiple access	FDMA	Frequency separation 
Time-division multiple access	TDMA	Time separation 
Code-division multiple access (spread-spectrum multiple access)	CDMA (SSMA)	Waveform separation 

Table1.1 Multiple-access formats

In time-division multiple access (TDMA), each uplink station is assigned a specific time slot in which to use the satellite. Each station must carefully ensure that its waveform passes through the satellite during its prescribed interval only. Receiving stations receive an uplink station by receiving the downlink only at the proper time period. TDMA involves more complicated station operations, including some form of precise time synchronization among all users. Frequency crosstalk between users is no longer a problem, since, theoretically, only one station uses the satellite at a time. Since each station uses the satellite for intermittent time periods, TDMA systems require short-burst communications. This type of communication allows each station to transmit a burst of information on its carrier waveform, during its allotted time interval. An operation like this makes TDMA primarily applicable to special-purpose systems involving relatively few earth stations.

In code-division multiple access (CDMA), carriers are separated by assigning a specific coded address waveform to each. Information is transmitted by superimposing it onto the addressing waveform, and modulating the combined waveform onto the station carrier. A station can use the entire satellite bandwidth and transmit at any desired time. All stations transmitting simultaneously therefore overlap their carrier waveforms on top of each other. Receiving the entire satellite transmission, and demodulating with the proper address waveform, allows reception of only the appropriate uplink carrier. Accurate frequency and time-interval separation are no longer needed, but station receiver equipment tends to be more complicated in order to carry out the address selection required.

Since addressing waveforms tend to produce cater spectra over a relatively wide bandwidth, CDMA signals are often called spread-spectrum signals, and CDMA is alternatively referred to as spread-spectrum multiple access (SSMA).

2. INTRODUCTION TO TRANSPONDERS

2.1 Introduction

An electronic device carried on board a communication satellite that picks up signals from the ground on one frequency and immediately rebroadcasts then on a different frequency.

In the last few years the world has witnessed an enormous evolution in communications services telephony, cellular, cable, microwave terrestrial internet and satellite. Successful design, planning, coordination, management, and financing of global communications networks requires a broad understanding of its segments, their costs, advantages and interfaces with other segments within the network. Satellite transponders, which are built and tested over many months under extremely rigorous conditions, are designed to function well beyond the normal lifetime of a spacecraft. That's why most geo-synchronous birds can continue to provide service for some customers even after they exhaust their fuel supply and can no longer maintain their stationary orbital position. Transponder complexity varies from the simple 'bent pipe" approach to on-board processing (OBP) and on-board switching (OBS) transponders. Common elements include receivers, mixers, oscillators, channel amplifiers, and RF switches. OBP transponders may include additional elements of demodulators, de-multipliers, demodulators, and base band switches.

2.2 A Transponder Model

A satellite transponder receives and retransmits the RF carrier. A detailed diagram is shown in Figure shown below. The RF front end receives and amplifies the uplink carrier, while filtering off as much receiver noise as possible. The received carrier is then processed so as to prepare the retransmitted waveform for the return link. Carrier processing involves either some form of direct spectral translation or some form of re-modulation. In spectral translation, the entire uplink spectrum is simply shifted in frequency to the desired downlink frequency. In re-modulation processors, the uplink waveforms are demodulated at the satellite, and then re- modulated onto the downlink carrier.

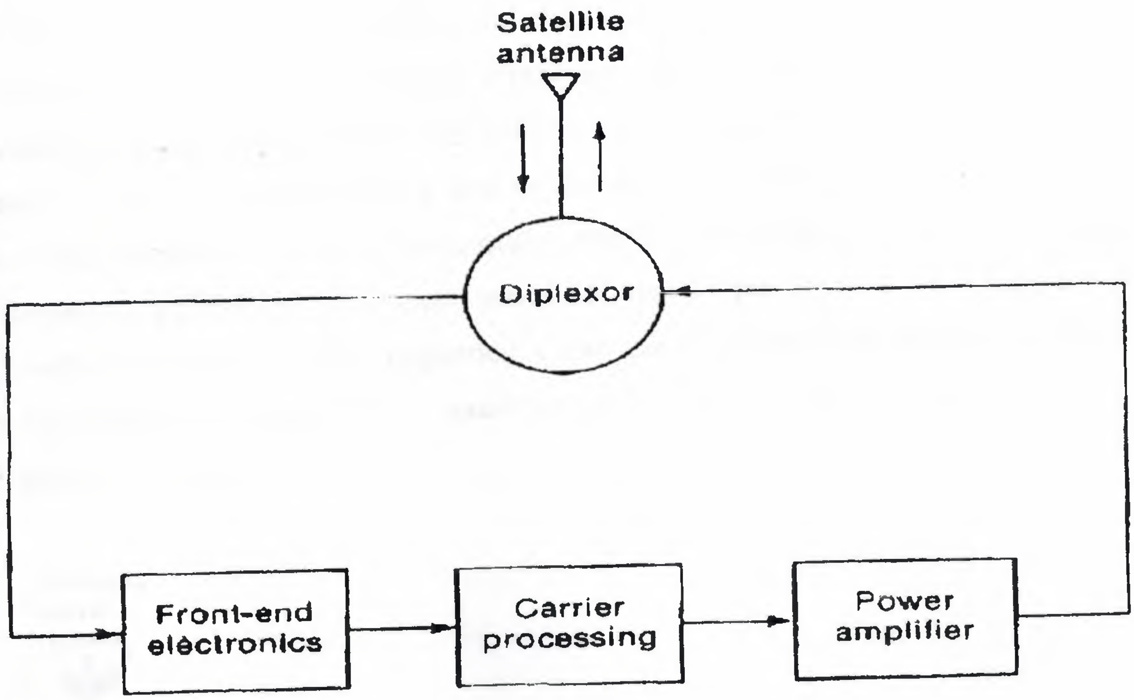


FIGURE 2.1 Transponder block diagram

Re-modulation processors involve more complex circuitry, but provide for changeover of the modulation format between uplink and downlink. This restructuring of the downlink can provide advantages in decoding, power concentration (e.g., spot beams), and interference rejection. While the earlier transponder diagram showed a separate antenna for uplink receiving and downlink transmission, the same antenna could actually be used for both. This is possible since the uplink and downlink frequency bands are separated. A diplexer is used in the front end to allow simultaneous transmission and reception. The diplexer is a two-way microwave gate that permits received carrier signals from the antenna and transmitted carrier signals to the antenna to be independently coupled into and out of the antenna cabling. The carriers, being at different frequency bands, can flow in the same cabling and antenna feeds without interfering.

After front-end filtering and signal processing, the downlink carrier is power-amplified to provide the required level for the downlink receiver. Most communication satellites contain several (four or more) parallel transponders, often with several narrow beam antennas to aid in the multiple-access problem, particularly where the received signal levels differ widely for different classes of users. A single channel of a typical transponder is shown in Fig2.1. Only the most basic elements are shown, the channel separation band pass filter, the frequency converter, the various amplifiers, and a possible limiter amplifier. Multiple input sinusoids enter the transponder in frequency band f_u and exit in band f_d. The frequency bands are separated sufficiently far to prevent "ring around" oscillations in the transponder itself, this transponder uses a single frequency translation operation which converts the receive RF frequency directly to the transmit RF frequency. Other configurations first down-convert to a convenient, if frequency, for example, 150 MHz, and then up-convert to the transmit frequency.

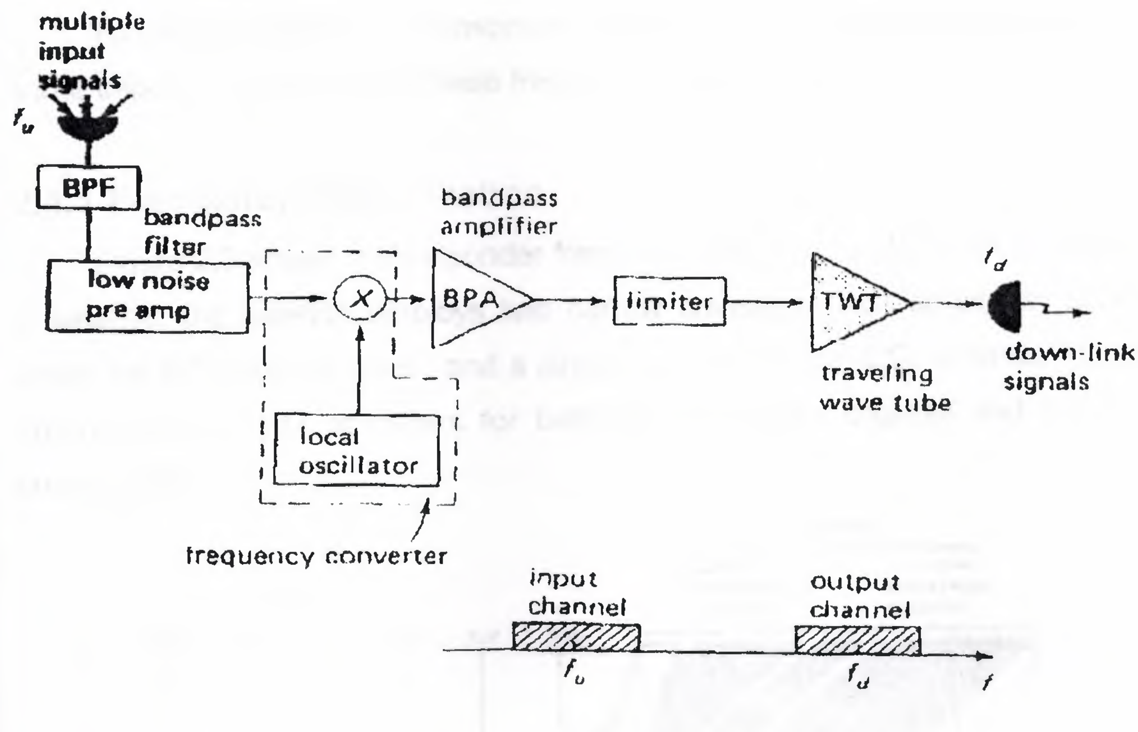


FIGURE 2.2 Simplified transponder block diagram

2.3 Purpose of Transponders

It is for the ATC controller to locate and identify transponder-equipped aircraft. Most ground stations have the capability to track both primary and secondary targets. The primary and secondary radar systems are synchronized together. The primary targets are aircraft (or flying saucers) that are not equipped with transponders. What we are referring to here is the reflection off the aircraft skin. Secondary targets are aircraft with working transponders, when the controller sees the Secondary target; they see the code selected in the transponder window along with Mode "C" altitude if present. Composite aircraft may not reflect the radar back so without a transponder system ATC may not see them at all. The controller also has the option to select only certain codes or aircraft with mode "C" only. Often in busy areas, the 1200-VFR code is blocked off the screen, so to get a clearer picture of the aircraft showing the codes the controller wants to see. That is why it is important to always have your eyes outside in VFR conditions.

2.4 Frequency Plans

To transmit signals by transponder, different kind of frequencies required, some important properties of these frequencies are given below:

2.4.1 Frequency Chanalization

Figure 2.3 shows a transponder frequency plan for the USA DSCS phase-II satellite, the satellite employs two narrow coverage (NC) antennas, which share the NC transmit power, and a single earth-coverage (EC) antenna. There are redundant TWT amplifiers for both the NC output channel and the EC output channel (I).

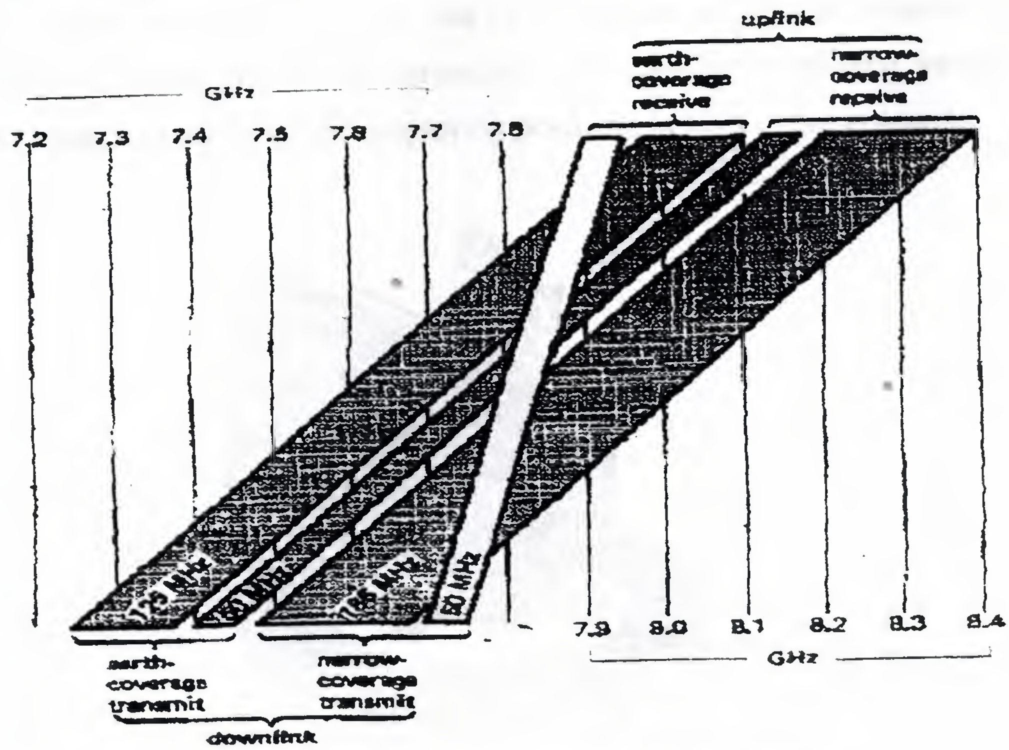


FIGURE 2.3 Transponder Frequencies

In this transponder, uplink power from a user in the narrow-coverage beam of the satellite can be transmitted either the earth-coverage or narrow-beam downlink antennas. The power is split to each of two narrow-beam antennas. Similarly, carriers in the earth-coverage uplink channel are directed to either downlink narrow-coverage or earth-coverage antenna, depending on the frequency of the uplink earners. Thus an earth terminal situated in the beam width (1000 nm diameter) of the NC antenna can transmit lip to the satellite in either the NC or EC uplink bands and by proper frequency selection can transmit down in either NC or EC channels.

The earth-coverage transmits channels (7250 to 7450-MHz) for a 200-MHz band arc separated from the earth-coverage receives channels (7900-8100 MHz) by 450 MHz. Therefore, if there were not adequate transmit filtering in the TWT outputs, the seventh order (4, 3) cross-product of two uplink carriers could fall as high as $74503 \approx 3(200)$ =8050 MHz and into the earth-coverage receive channel. The third and fifth-order cross products, however, cannot fall into a receive channel from the earth coverage transmit channel.

2.4.2 Frequency Reuse

Frequency reuse is the technique for transmission of two separate signals in the same frequency band by use of two separate types of antenna beams. Figure 2.4 shows an artist's conception of a satellite employing vertical and horizontal polarizations, and employing polarizes in front of the antennas.

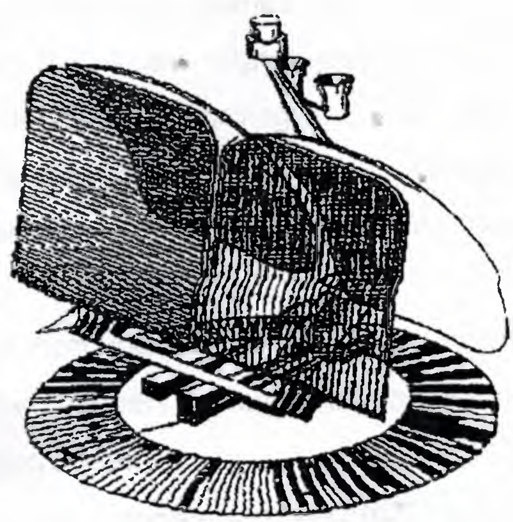


FIGURE 2.4 Artist's conception of a satellite

The technique of particular importance here is the use of two coincident antenna beams of orthogonal polarizations, that is, vertical and horizontal polarization or right-and left-hand circular polarization. Conception of a satellite employing frequency reuse through transmission of vertical and horizontal polarizations is shown below.

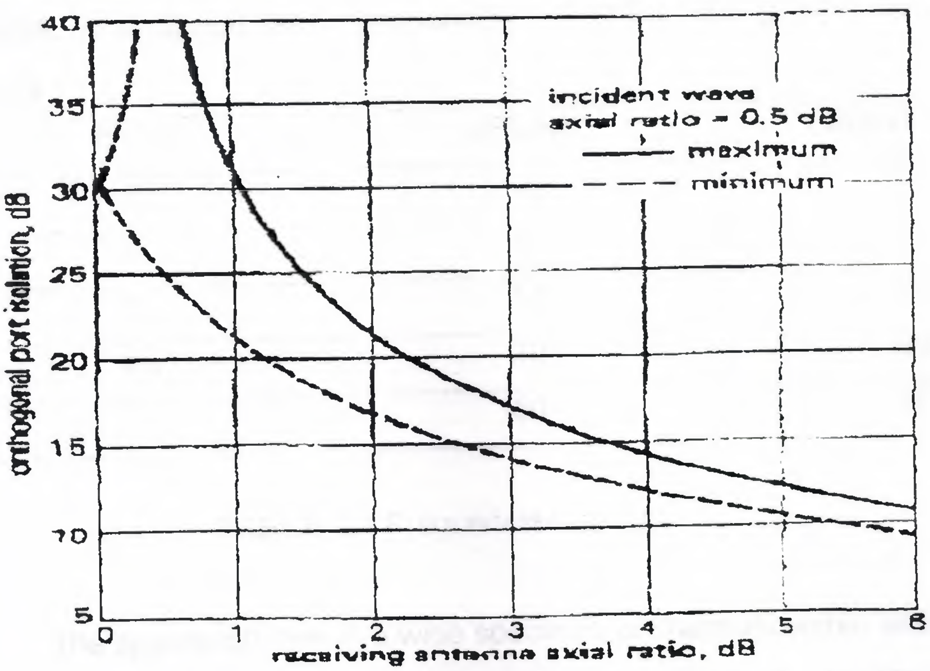


FIGURE 2.5 Polarization isolation characteristics

2.5 Reception of Transponders

Satellite Transponders are good listeners as they receive process and transmit signals from a far Picture floating in space 22.300 miles from earth, not for satellite transponders, so named because they transmit and respond to signals automatically. Their signal-relaying function is the heart of a communications satellite, according to Andy Kopito, operation leader for Payload System Engineering at Boeing Satellite Systems. A typical transponder consists of various components that perform four basic functions:

- Amplify' the incoming broadband signal and filter out noise.
- Separate the channels contained within the broadband signal.
- Amplifier each channel.
- Recombine the channels into one broadband signal for retransmission.

Almost all transponders currently in orbit relay signals without changing them. But that role is about to expand in new satellite systems offering advanced global mobile telecommunications services. The transponders on these birds will perform on-hoard signal processing and switching, redirecting signals among a large number of narrow spot beams. A typical geo-stationary satellite is equipped with transponders for one of the given below frequency bands.

BAND	UPLINK	DOWNLINK
L	2	1
C	6	4
Ku	14	12
Ka	30	20
V	50	40

TABLE 2.1 Frequencies (G-Hz)

The spacecraft "sees" a wide spectrum of channels within each band from one or many sources on the ground. Its receivers initially amplify all channels together by about 60 decibels (dB), using special low-noise amplifiers and additional filters to remove signal noise. (Satellites designed to perform on-board processing would manipulate incoming signals at this point.). Multiplexes then separate the channels a step called "Channelization" and route each one to its own high-power amplifier. A second set of multiplexes recombines the amplified channels for broadcast as a single broadband signal back to earth. To prevent the powerful downlink signal from overpowering the weak uplink signal, the satellite's transponder receivers perform an automatic frequency shift within their assigned operating hand. Downlink frequencies are typically lower than uplink frequencies.

There are two types of high-power transponder amplifiers and many geostationary satellites carry both solid-state power amplifiers (SSPAs) are all-electronic devices that operate on the same principle as a home stereo, albeit at vastly higher frequencies and power levels. Traveling wave tube amplifiers (TWTAs) use foot-long vacuum tubes to do their amplifying. SSPAs are compact, light-weight and relatively inexpensive. But as frequency and output power requirements rise. Kopito says, TWTAs are used due to their superior power efficiency. SSPAs are generally used in all L-band transponders, in moderately powered C-band transponders and in low-power Ku-band devices. TWTAs are usually specified for C-band systems over 30 watts, Ku-band systems over 20 watts and transponders operating in Ka-band or above. The breakpoint, Kopito notes, may be different for medium and low earth satellites because their lower altitudes mean they can rebroadcast at relatively lower power levels.

Determining where to mount transponder components inside a satellite depends upon their function. Thus the high-power power amps go near the satellite's output antennas to maximize efficiency. To avoid the heat these big amps generate, the sensitive electronics of low-noise amplifiers and receivers are placed at some distance away in a special "low-temperature" zone. Packaging also varies from one satellite design to another. In "spinner" satellites such as the Boeing 376, for example, the high-power amps have always been located near the outer surface of the bird for easier heat dissipation. There's more choice in body-stabilized spacecraft such as the company's popular Boeing 601, Boeing 601-HP and new Boeing 702 series which use heat pipes to move heat to radiators. Since repairing problems in a geostationary communications spacecraft is impossible in the usual sense, these satellites carry backups for critical components such as the broadband receivers that handle all incoming signals. They also carry devices that permit ground controllers to adjust the gain or amplification level for each channel. When the satellite performs as expected, redundant equipment is never used. But if needed, it literally can he "rewired" into a satellite's circuitry by commands from the earth.

2.6 Processing Transponders

Onboard satellite processing can take a number of forms. Among these processing functions are: (1) active switching to distribute various uplink signals to the appropriate downlink amplifier and antenna: and (2) detection of the digital signals on the uplink and their regeneration for the downlink. An example of this kind of transponder is shown below in figure 2.6.

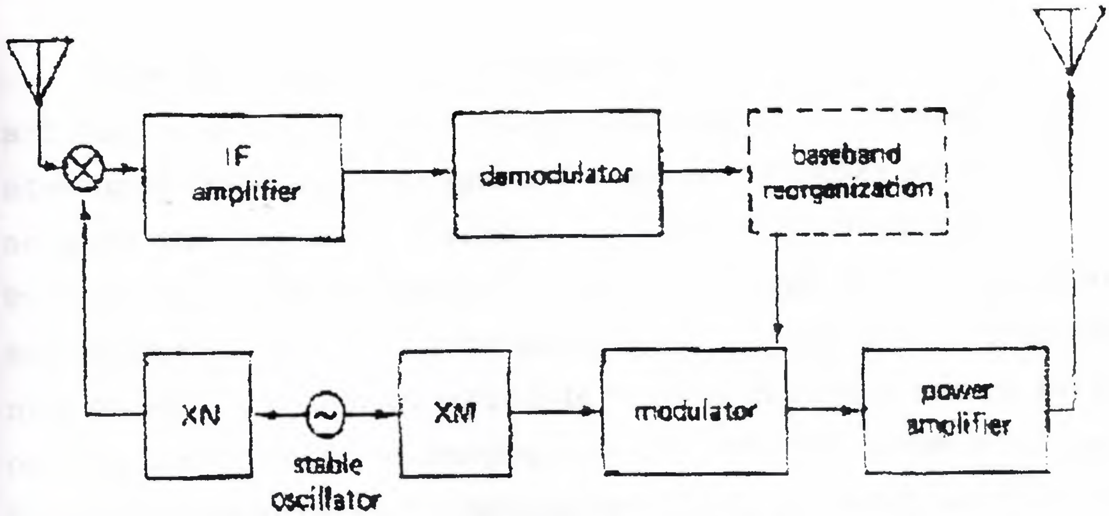


FIGURE 2.6 Modulation and de-modulating transponder

The use of switching includes a "switchboard in the sky" concept. Where in different transponder input channels are switched by ground command to the appropriate downlink channel an alternative switching Concept employs a preprogrammed switching sequence to provide satellite-switched time-division-multiple-access (SS-TDMA). The use of active time-division switching in a satellite transponder offers improved bandwidth and power efficiency compared with, for example, an FDMA technique. Onboard demodulation of the uplink signals can improve the link performance, for example where up and downlink SNRs are equal, this regeneration provides almost 2.6-dB improvement in performance relative to a linear transponder, while the error rate at the output of the ground terminal remains the same. Hence, if the SNR is the same at the regenerative satellite as at the receiving earth terminal, the error rates at the satellite and earth terminals are identical. Since these errors are independent, the total error rate at the earth terminal output includes those errors generated by the satellite as well as those generated by earth terminal demodulation. Since these error rates are equal, the total error rate is double that of the satellite itself. This tandem error effect corresponds to <0.5-dB loss in signal power. On the other hand 3-dB performance degradation occurs in a conventional linear transponder operating at the same power level when the earth terminal noise is added and the error rate is thereby increased by approximately three orders of magnitude at low error rates.

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

2.7 Multiple Accesses

One advantage of communications satellites over other transmission media is their ability to link all earth stations together, thereby providing point-to-multipoint communications, a satellite transponder can be accessed by many earth stations, and therefore it is necessary to have techniques for allocating transponder capacity to each of them. If the transponder capacity is 120-Mbps, this can handle about 3562 voice channels at 32 kbps, assuming the transponder efficiency is 95%. It is the unlikely that a single earth station would have this much traffic, there fore the transponders capacity must be wisely allocated to other earth station.

Further more, to avoid the chaos, the earth stations has to gain access to the transponders capacity allocated to them in an orderly session, this called multiple accesses. The most commonly used multiple schemes are:

1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)

FDMA has been used since the inception of satellite communication, each earth station in the community of earth station that shares the transponders capacity transmits one or more carriers to the satellite transponders at different center frequencies. Each carrier is assigned a frequency band in the transponder bandwidth, along with a small guard band to avoid interference between adjacent carriers. The satellite transponder receives all the carriers in its bandwidth, amplifies them, and retransmits back to earth The earth station in the satellite antenna beam served by the transponder can select the carrier that contains the messages intended for it. The carrier modulation used in FDMA is FM or PSK. In TDMA the earth stations that share the satellite transmission use a carrier at the same center frequency for transmission on a time division basis. Earth stations are allowed to transmit traffic bursts in a period time frame called the TDMA frame.

The transmit timing of the bursts is carefully synchronized so that all the bursts arriving at the satellite transponder are closely spaced in time but don't overlap. The satellite transponder receive one burst at a time, amplifies it re-transmit it back to earth. Thus every earth station in the satellite beam served by the transponder can receive the entire burst stream and extract the bursts intended for it. The carrier modulation used in TDMA is always a digital modulation scheme. TDMA possesses many advantages over FDMA, especially in medium to have traffic networks, because there are number of efficient techniques such as demand assignments and digital speech interpolation that are inherently suitable for TDMA and can maximize the amount of terrestrial traffic that can be handling by a satellite transponder, for example, a 72- MHz transponder can handle about 1781 satellite PCM voice channels or 356232 –kbps adaptive differential PCM channels, with a digital speech interpolation technique it can handle about twice this number 3562 terrestrial PCM voice channels or 712432 - kbps adaptive differential PCM voice channels. In many TDMA networks employing demand assignments the amount of terrestrial traffic handled by the transponder can be increase many times. Of-course these efficient techniques depend on the terrestrial traffic distribution in the network and must be used in situation that are suited to characteristics of the technique. Although TDMA has many advantages, these don't mean that FDMA has no advantages over TDMA. Indeed, in networks with many links of load traffic. FDMA with demand assignments, as overwhelmingly preferred to TDMA because of the low cost of equipment.

2.8 Hamming Distance

The following analysis is under the assumption of a noiseless channel can be done by using hamming distance. The information binary digits 01011010 are encoded by the systematic rate 2 / 3-trellis code. The figure 2.7 illustrates the case where the codeword, which correspond to the signal points, are decoded and used within the Viterbi decoder to decode the information sequence. Instead of decoding each codeword as it arrives, the Viterbi decoder utilizes the code structure embedded across several codeword by using cumulative metrics. Indeed, the Viterbi algorithm compares the received codeword sequence with all possible valid codeword sequences within the trellis, and selects the closest path. The use of code words is only a means to compare the sequence of encoder state transitions that are possible with the state transitions represented by the received codeword sequence.

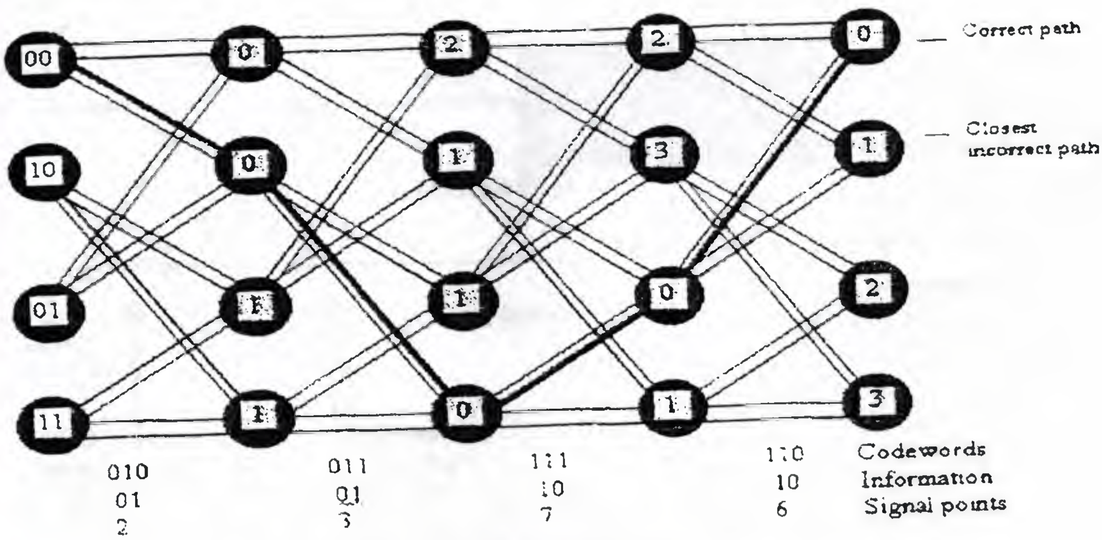


FIGURE 2.7 Example of hamming coding

By first demodulating a signal point to its corresponding codeword, vital soft-decision information has been lost that would otherwise have helped to improve the comparison of valid encoder state transitions with those represented by the received signal points.

2.9 Telemetry Tracking and Command (T T&C) Subsystem

The T-T&C Subsystem contains Radio Frequency (RF) components, working in S-band, which provides the necessary functions to ensure Satellite access from the Ground Station for commanding and telemetry data transmission. The T-T&C Subsystem includes:

1. Two S-band Transponders.
2. Two S-band antennas.
3. One Radio Frequency Distribution Unit (RFDU).

The Transponders are connected through the RFDU and RF coaxial cables to the two antennas that provide full spherical coverage with an overlap of at least ten degrees. The nominal operation scenario foresees that the receiver sections of both transponders are always switched on as shown in figure 2.8

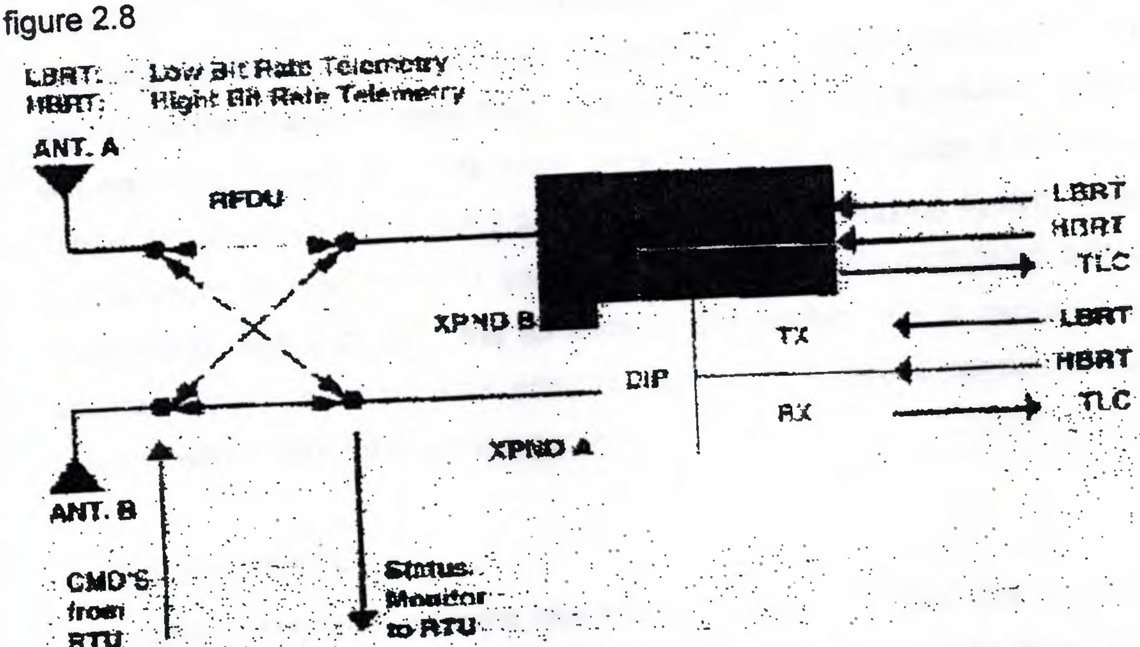


FIGURE 2.8 T-T&C block diagram

Depending on the satellite attitude during the ground station contact, only the transmitter section of the transponder connected to the ground-linked antenna is switch on. A transponder failure can be recovered through a cross coupling in the RFDU to allow the connection of the still working transponder with both the antennas.

2.10 Modulation Techniques

There are many kinds of modulation like frequency modulation, and amplitude modulation. Both terms apply to techniques for imposing a meaningful pattern of variations on an otherwise unvaried stream of energy during transmission, but they have also come to be applied to whole categories of broadcast radio, AM modulates the carrier radio wave by varying the amplitude (strength of the wave) in accordance with the variations of frequency and intensity of a sound signal, such as a musical note. Such modulation is vulnerable to electrical interference, and the sound quality is variable. FM works by varying the frequency of the carrier wave within a narrowly fixed range at a rate corresponding to the frequency of a sound signal. It is used within the VHF band, so that the terms "VHF" and "FM" have become synonymous for most radio listeners. FM reaches only to the horizon, so a transmitter's remit is local rather than national in scale. This geographical restriction has the advantage of reducing interference, and coverage is therefore more stable, day or night. The signal itself is inherently static-free, unlike that for AM, and a suitable receiving set can take advantage of its more generous frequency range and dynamic range to reproduce high-fidelity sound. The prototype tagging system uses a frequency modulated 100-KHz carriers that are amplitude modulated onto the radar return signal to carry the ID back to the reader. This is decidedly sub optimal, though; all indications point to the use of a spread spectrum-coding scheme with CDMA for several reasons.

2.10.1 Reliability

Spread spectrum systems can have a "processing gain" this processing gain applies in the numerator of the radar equation along with increases in transmit power and antenna gain. This directly contributes to a better detection distance or improved reliability at a given distance.

2.10.2 Multiple Accesses

A satellite's power could be concentrated on small regions of the Earth, making possible smaller-aperture (coverage area), lower-cost ground stations. A lintels 5 satellite can typically carry 12,000 voice circuits. The lintels 6 satellites, which entered service in 1989, can carry 24.000 circuits and feature dynamic on-board switching of telephone capacity among six beams, using a technique called SS-TDMA (satellite-switched time division multiple access), the present system can handle only one tag in the beam at a given time severe inter symbol interference between two visible tags at the same time renders the tagging system useless when presented with more than one tag at a time. A spread spectrum system could be designed using code division multiple access (CDMA) to decode many tags at the same time.

2.10.3 Security

The use of a spread spectrum system with a concealed synchronization method and spreading code renders the tag very difficult to pirate or hijack read. These benefits apply to both passive scattering tags and transponder tags, even more security is possible with a transponder tag as the transponder controller could be programmed to receive a challenge in one spreading code and transmit the response in another entirely different code.

2.11 Transponder Landing System

Airplanes are supposed to take people where they want to go. If where they want to go is in a small town and under the weather, airplanes can't get there. That situation is changing rapidly; there are at least two schemes around. GPS or Differential Global Positioning System (DGPS) is one idea that uses celestial radio navigation system. Coupled with new and exotic gear in the cockpit it can make a near CAT 1 (or better) approach into remote locations.

The system is the Transponder Landing System, developed by Advanced Navigation and Positioning Corp. of Hood River, Ore. The concept is simple, the ground installation easy, and the potential applications are endless. The conventional Instrument Landing System has been around for a very long time. ILS was developed in 1946, and was finally deemed completely developed in 1973, when the solid-state systems were deployed; the current ILS transmits a VHF localizer and UHF glide slope signal, modulated with 150 and 90-Hz audio tones. The modulation of these tones provides a measure of the deviation from the extended centerline of the runway, and a 3-degree sloped beam ending at about the runway threshold.

The Transponder Landing System is so very simple. Ground stations interrogate the standard ATCRBS Transponder. The replies are received by an antenna array that processes the signals and determines the position and altitude of the aircraft within the airport traffic area (actually out to about 22 nm).

Altitude is independent of Mode C the 3-D position is derived from the received signals much like a DF. Once the TLS has the position information, it transmits a signal to the aircraft that provides steering on the localizer and glide slope to touchdown, the ultimate goal is to steer the aircraft from where it is to the runway. Where a conventional ILS send out a fixed beam that the pilot aligns himself with, TLS actually adjusts the beam to bring in the airplane.

There are few components in the TLS system. The most visible are four units mounted in a 50-meter radius alongside the runway. There is a base station unit, a Calibration/Built-in-Test (BIT) unit that monitors station accuracy and integrity, and two angles of arrival antennas. The localizer and glide slope angle of arrival AOA sensors are used to define the flight path from the transponder system as it nears the runway. A central processor in the base station computes the aircraft position in three dimensions; it should be in relation to the approach, and transmits corrections to the aircraft over the localizer and glide slope transmitter. Because the system can be programmed precisely for the location, the approach can be curves, segmented, dogleg, or whatever is necessary to avoid any obstacle along the approach path. These obstacles can be political, too. Some airports are considering TLS as a way to avoid noise sensitive areas on the approach. The glide slope is adjustable as well, some airports, like Aspen, want a steep glide path. For helicopters even steeper approaches are possible. The basic TLS can provide guidance in an area that extends 45 degrees from the runway centerline. The system is capable of tracking 25 aircraft (or even equipped ground vehicles as a way to prevent runway incursion accidents). One of the limitations of a single TLS system is that only one aircraft could be "on the beam" at a time, because the TLS generates a correction based on its position. However, the system is not intended to replace the ILS at Denver International or DFW, the TLS is a low traffic volume system.

2.12 Kinds of Transponder

2.12.1 Deep Space Transponder

The small deep space transponder combines the many separate functions that other spacecraft telecommunications systems perform into one unit. This unit has less than half the mass than would be required without this new technology. It contains several innovations that will help it meet the needs of many future missions.

The small deep space transponder has the ability to generate the beacon signals in Beacon Monitor Operations. Space projects that use the transponder will be saved the burden of designing their own telecommunications systems, and will be able to take advantage of the transponder's modern components and design techniques to save mass. The transponder has built into it the ability to use the new Ka-band radio frequency, which will improve the effect Telemetry Tracking, and Command (T-T&C) Subsystem.

2.12.2 Telephony Transponder

The Telephony Transponder is a program that is designed to indicate if a person is present by monitoring their telephone usage. At its simplest one can assume that if a telephone is currently in use then the owner of the telephone is present. On the obverse one can assume that the owner is not present if the telephone has not been used for a long period or if incoming calls to the telephone have not been answered. The Telephony Transponder is an application, written in Visual Basic, which runs on a PC under Windows. It communicates with a PABX (telephone exchange in a private network) using a Computer-Telephony Interface (CTI). This CTI is a special protocol, which has been developed to allow computer applications to get involved with the handling of telephone, calls by the PABX. The CTI link, which uses TCP/IP, allows the Telephony Transponder to monitor the activity of telephones on the PABX. The Telephony Transponder uses this monitor information to build up a picture of the usage of each telephone over time.

The Telephony Transponder is also linked, via TCP/IP, to the Rich Finger server called AP-IA and being developed by BT. This pulls together information from the Telephony Transponder and other transponders (such as for screen savers, Mail system access, diary etc.) developed for Virtu-Osi to provide a better picture of the users availability.

The Telephony Transponder responds to availability requests from the server by providing an intelligent assessment of the user's availability based on their telephone usage. For security reasons the information that the Telephony Transponder provides is carefully restricted so that the Big Brother syndrome is not invoked. In practice the Telephony Transponder provides no more information than could be gleaned by someone within earshot of a target telephone. The power of the Telephony Transponder lies in that the enquirer may be remote from the target telephone.

The Telephony Transponder has been developed as part of the Virtu-Osi project's research into how Virtual Reality could be used to support distributed business applications. The concept has been to provide a link from cyberspace to real space so that remote locations (potentially on the other side of the world) could be investigated from cyberspace. A typical example is visiting a remote office, which is modeled in cyberspace, to determine who is available to be consulted etc.

However the use of the Telephony Transponder is not limited to cyberspace and it is planned to be implemented by another Virtu-Osi partner, BICC, as part of the Virtu-Osi Factory pilot and accessed from specially developed PC console applications.

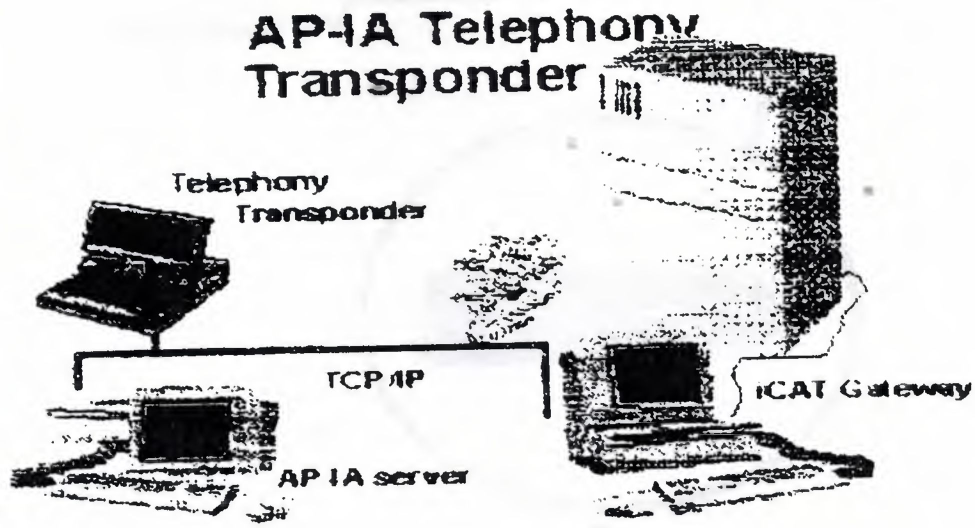


FIGURE 2.8 Telephony transponder

2.12.3 Transponders, TWTAs, and SSPAs

In a communication satellite serving the earth, the transponder transforms the received signals into forms appropriate for the transmission from space to earth. The transponder may be simply a repeater (a "bent pipe") that merely amplifies and frequency shifts the signals, or it may be much more complex, performing additional functions including signal detection, demodulation, de-multiplexing, re-modulation and message routing.

In this section the technologies of the major transponder elements are presented with major emphases on the transmitters and amplifying devices, i.e. the traveling wave tube amplifiers (TWTAs) and the solid state power amplifiers (SSPAs).

2.12.4 ID 100-Implantable transponder

- Designed especially for animal identification.
- Biocompatible glass encapsulation.
- Pre-sterilized, and ready-to-use.
- Individually packaged in a disposable syringe.
- Small size is suitable for use in even the smallest species.

This kind of transponder is shown in below

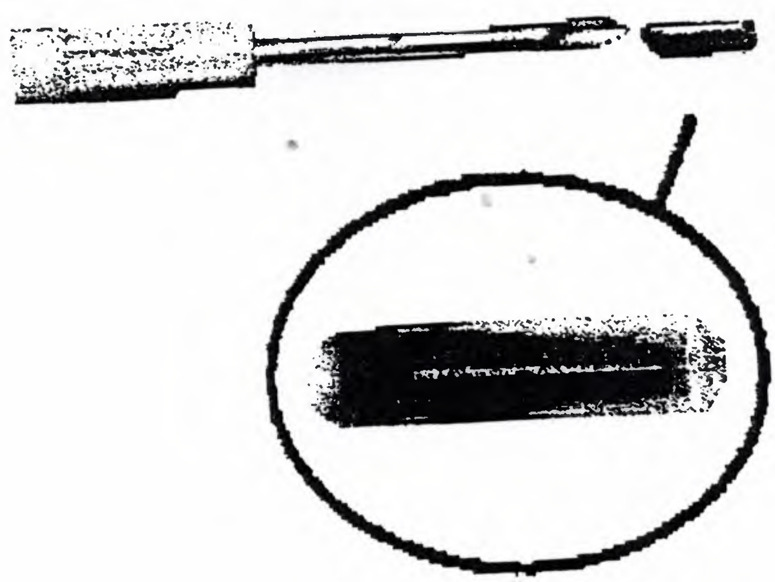


FIGURE 2.10 ID-100 Implantable transponder

1. Endorsed by the Captive Breeding Specialist Group (C.B.S.G.), of the International Union for Conservation of Nature.

2. Used in over 300 zoos worldwide.

3. Used by over 80 government agencies in 20 countries.

4. Longest read range in any micro-transponder available today enhances safety of shelter personnel and ensures transponder detection.

5. Only micro-transponder that can be read using a walk-by reader.

6. Typical read range:

180 mm (7 inch.) w/ LID-500 reader.

380 mm (149 inch.) W/ LID-504 reader.

Dimensions: 2.12 x 11.5 mm (0.08 x 0.45 inch.).

3. FREQUENCY DIVISION MULTIPLE ACCESS

3.1 Introduction

Frequency division multiplexing access (FDMA) is the simultaneous transmission of multiple separate signals through a shared medium such as a wire, optical fiber or light beam by modulating, at the transmitter, the separate signals into separable frequency bands and adding those results linearly before transmission or within the medium. While thus combined, all the signals may be amplified conducted, translated in frequency and routed toward a destination as a single, resulting in economies, which are the motivation for multiplexing. Apparatus at the receiver separates the multiplexed signals by means of frequency passing or rejecting filters, and demodulates the result individually each in the manner appropriate for the modulation scheme used for that band or group.

Bands are joined to form groups, and groups may then be joined into larger groups this process may be considered recursively, but such technique is common only in large and sophisticated system and is not necessary part of FDMA.

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

Neither the transmitter nor the receiver need to be close to each other ordinary radio, television and cable service are the examples of FDMA. It was once the mainstay of the long distance telephone system. The more recently developed time division multiplexing in its several forms lends itself to the handling of digital data, but the low cost and high quality of available FDMA equipment, especially that intended for television signals make it a reasonable choice for many purposes.

3.2 The FDMA System

The basic model of an FDMA satellite system is shown in Figure 3.1. A set of earth stations transmit uplink carriers to be relayed simultaneously by the satellite to various downlink earth stations. Each uplink carrier is assigned a frequency band within the available RF bandwidth of the satellite. In the basic satellite transponder, the entire RF frequency spectrum appearing at the satellite input is frequency translated to form the downlink. A receiving station receives a particular uplink station by tuning to, and filtering off, the proper band in downlink spectrum.

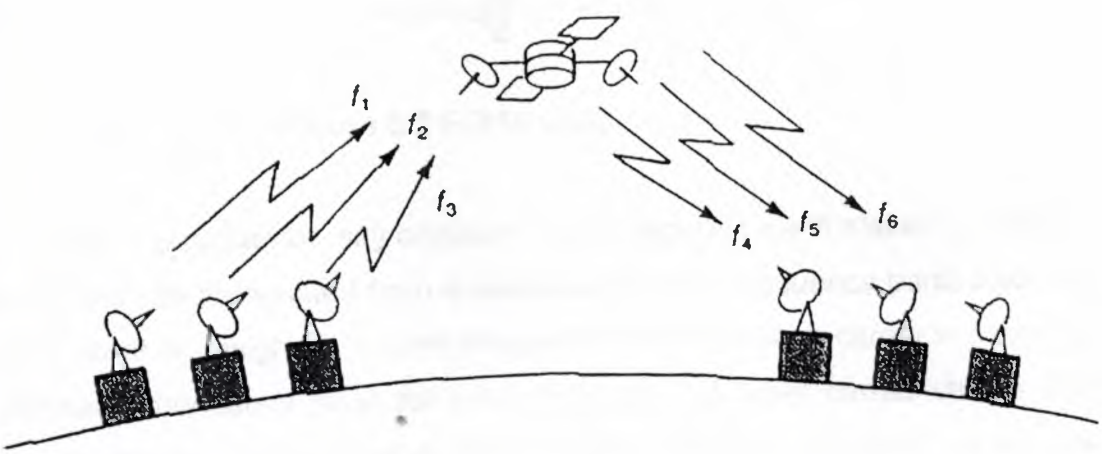


Figure 3.1 FDMA system model **(a)** block diagram

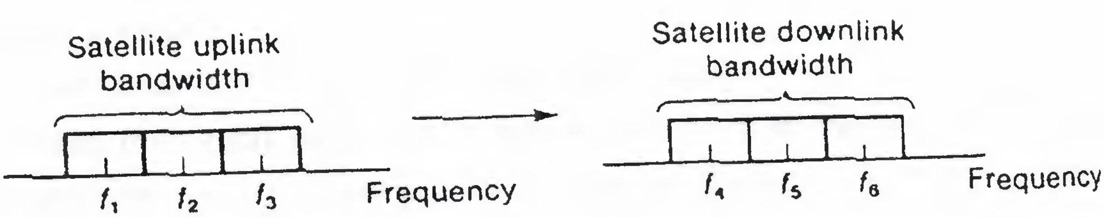


Figure 3.1 FDMA system model **(b)** frequency plan

Each carrier can independently be modulated, either analog or digital, from all others. With digital carriers, only synchronization between the desired carrier and the receiving station must established without regard to other carriers at other frequency bands. FDMA represents the simplest form of multiple accessing, and required system technology and hardware are almost all readily available in today's communication market.

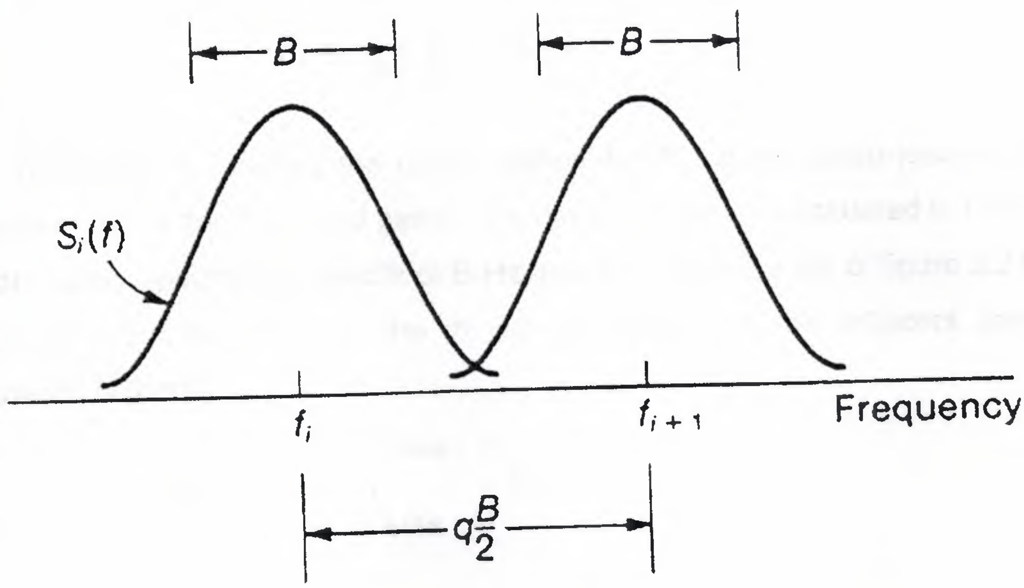


Figure 3.2 FDMA adjacent spectra

Each uplink carrier may originate from a separate earth station, or several carriers may be transmitted from a particular station. Frequency band selection may be fixed or assigned. In fixed-frequency operation each carrier is assigned a dedicated frequency band for the uplink, and no other carrier utilizes that band. In demand-assignment multiple access (DAMA) frequency bands are shared by several carriers, with a particular band assigned at time of need, depending on availability. DAMA systems can serve a larger number of carriers if the usage time of each is relatively low, but may require more complex ground routing hardware.

Individual carrier spectra in an FDMA system must be sufficiently separated from each other both to allow filtering off of the carriers at the downlink stations and to prevent carrier crosstalk (frequencies of one carrier spectrum falling into the band of another carrier, as shown in Figure 3.2). This is why spectral tails associated with digital carriers. However, excessive separation causes needless waste of satellite bandwidth. To determine the proper spacing between FDMA carrier spectra, crosstalk power must be calculated. Spacing can then be selected for any acceptable crosstalk level desired. Let the "ith "carrier have a center frequency ω_i, and a one-sided power spectrum given by $S_i(\omega)$. The power of the carrier, referred to the satellite uplink receiver, is then

$$P_i = \frac{1}{2\pi}\int_0^{\infty} S_i(\omega)dx \tag{3.1}$$

Note that P_i includes the uplink station EIRP, uplink space losses, and satellite antenna and front-end gains. The spectrum $S_i(\omega)$ is assumed to occupy a 3-dB carrier spectral bandwidth of B-Hz about ω_i. With the aid of figure 3.2 the fractional crosstalk power of the ith carrier falling into the adjacent carrier bandwidth is then,

$$C_i = \frac{1}{2\pi P_i}\int_{\pi B(q-1)}^{\pi B(q+1)} S_i(\omega_i + x)dx \tag{3.2}$$

Where the carrier center frequency spacing is denoted qB/2. Equation (3.2) is plotted in Figure 3.3 for the case of a Butterworth-shaped carrier spectrum,

$$S_i(\omega) = \frac{P_i(\mu/\pi B)\sin(\pi/2\mu)}{1 + [(\omega - \omega_i)/2\pi B]^{2\mu}} \tag{3.3}$$

Where the bandwidths and power of both adjacent carriers are assumed to be equal. Also included is the corresponding result for several types of digital carrier. The result shows the carrier-to-crosstalk power ratio, as a function of the spacing between center frequencies. Note that a spacing of approximately three bandwidths is needed to obtain a crosstalk ratio of more than 20 dB with a μ = 2. Butterworth spectrum, but little more than one bandwidth is needed when $\mu \geq 10$.

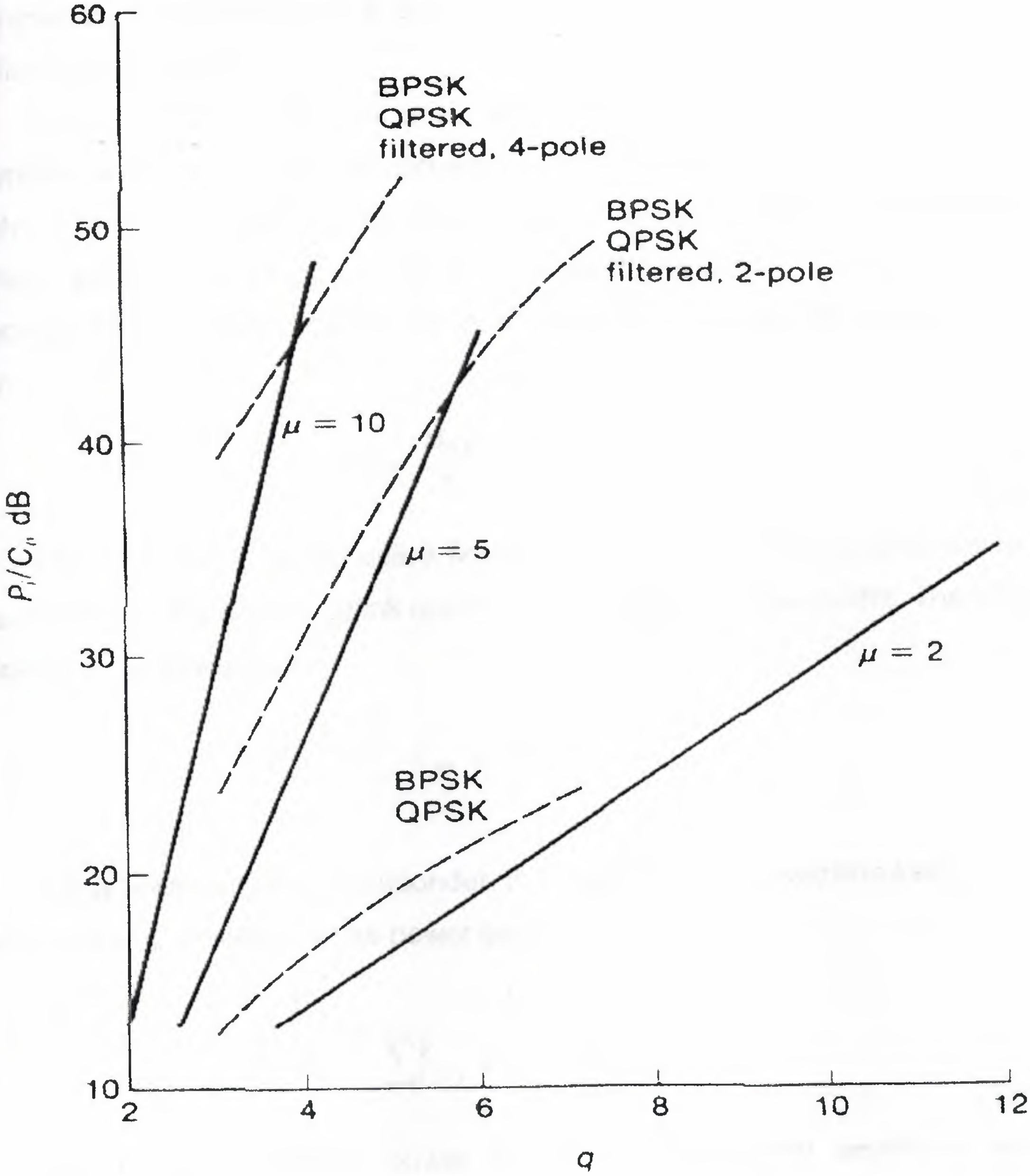


Figure 3.3 Signal to crosstalk ratio for adjacent carriers

This latter case corresponds to only a slight separation between carrier spectra. The crosstalk power level should be small enough to produce an interference level significantly smaller than the acceptable receiver noise level.

For digital carriers, separation is plotted in terms of main lobe bandwidths. Crosstalk is computed based on peak spectral levels falling into adjacent bandwidths. If crosstalk is too high, either carrier separation must be increased, or spectral filtering must be applied (usually at the transmitting earth station) to reduce spectral tails. The latter leads to possible carrier distortion and decoding degradation, it is susceptible to the tail-regeneration problem associated with nonlinear amplification.

When an FDMA format is used with a linear transponding channel, the downlink performance can be determined by extending the single-channel analysis. Let an RF satellite bandwidth B_{RF} be available to the earth-station carriers, each carrier using an individual bandwidth of B-Hz (including spectral spacing). The number of FDMA carriers allowed by the satellite bandwidth is then

$$K = \frac{B_{RF}}{B} \tag{3.4}$$

Let P_{ui} be the ith carrier uplink power at the satellite amplifier input, and let P_{UN} be the corresponding uplink noise in the same carrier bandwidth. The total amplifier input power is then

$$P_u = \sum_{i=1}^{K} P_{ui} + KP_{un} \tag{3.5}$$

For a linear amplifier transponder, the satellite RF bandwidth is frequency-translated and amplified by the power gain,

$$G = \frac{P_T}{P_u} = \frac{P_T}{\sum_{i=1}^{K} P_{ui} + KP_{un}} \tag{3.6}$$

The downlink receiver power of the ith carrier after amplifying and downlink transmission is then

$$P_{di} = LGP_{ui} = LP_T\left[\frac{P_{ui}}{\sum_{i=1}^{K} P_{ui} + KP_{un}}\right] \tag{3.7}$$

Where L is again the combined downlink power losses and gains from satellite amplifier output to earth-station receiver input. Note that the power robbing on the downlink carrier that was caused in the single carrier case only by the noise is now increased by the additional power robbing of the other carriers. The total receiver noise is the sum of the transponder uplink noise and the receiver noise. Hence, the downlink CNR of a single carrier in its own bandwidth B is then

$$\mathrm{CNR}_d = \frac{P_{di}}{LGP_{un} + N_{0d}B} \tag{3.8}$$

Where N_{0d} is the receiver noise spectral level, so the equation becomes,

$$(\mathrm{CNR}_d)^{-1} = (\mathrm{CNR}_u)^{-1} + (\mathrm{CNR}_r)^{-1} \tag{3.9}$$

Where

$$\mathrm{CNR}_u = \frac{P_{di}}{LGP_{un}} = \frac{P_{ui}}{P_{un}} \tag{3.10}$$

$$\mathrm{CNR}_r = \frac{P_{di}}{N_{0d}B} = \frac{P_T L}{N_{0d}B}\left(\frac{P_{ui}}{P_u}\right) \tag{3.11}$$

Here CNR_U, is the uplink CNR of a single carrier. The receiver CNR_r is that which the satellite power P_T can produce at the receiver, reduced by the power-robbing loss of the uplink. If the system is power-balanced (all carrier have some uplink power) and if the uplink CNR_U is high $(\mathrm{CNR}_u \gg 1)$, then $\mathrm{CNR}_r \approx P_T L / K N_{0d}B$. That is, the available satellite P_T is equally divided among the FDMA downlink carriers, and by solving the equation, the required satellite power to support and FDMA system with K carriers' yields

$$P_T = \frac{KN_{0d}B}{L}\left[\frac{\mathrm{CNR}_d}{1-(\mathrm{CNR}_d/\mathrm{CNR}_u)}\right] \tag{3.12}$$

With a specified value of CNR_d and CNR_u it concludes that P_T increases linearly with the number of carriers. Also superimposed is the relation between the satellite bandwidth and the number of carriers. The figure can also be used to balance the number of carriers allowed by the satellite power against that allowed by the satellite bandwidth.

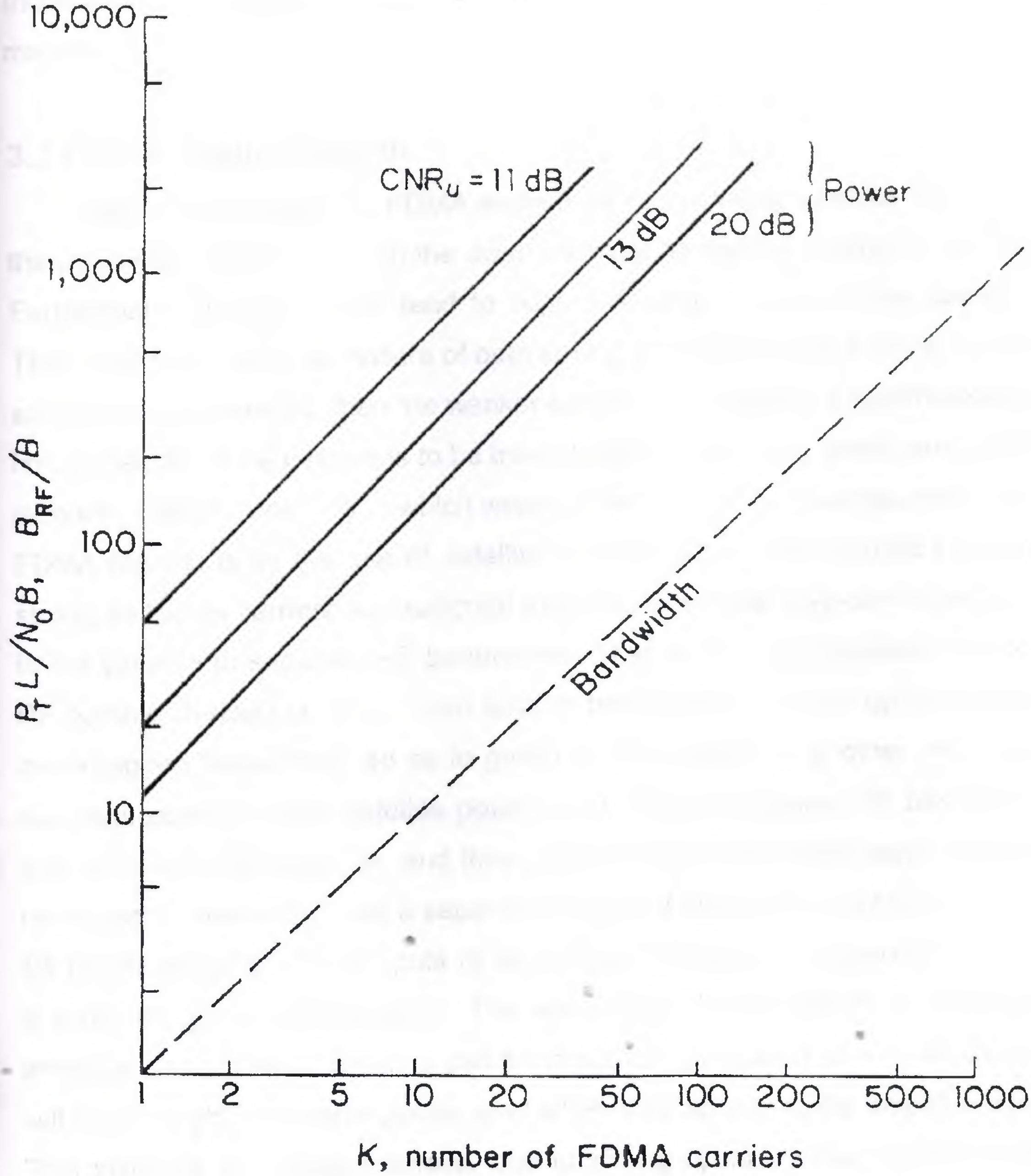


Figure 3.4 Required satellite power and satellite bandwidth to support K-FDMA

By entering the ordinate at the proper value of P_T and B_{RF}, it can read off the number of FDMA carriers that can be separately supported by each. The smaller of the two then determines the available FDMA system capacity. Hence, an FDMA system may be either power-limited or bandwidth-limited, in terms of the number of carriers that can be simultaneously supported. In any FDMA design tradeoff, it is always important to know which is the limiting factor, since any techniques to increase power levels or bandwidth will not necessarily increase multiple access capacity if the other parameter determines performance.

3.3 FDMA Channelization

While dealing with an FDMA system using nonlinear satellite amplifiers, the available satellite power in the downlink must be divided among all carriers. Furthermore, strong carriers tend to suppress weak carriers in the downlink. This means that, when a mixture of both strong and weak carriers are to use the satellite simultaneously, then the weaker carriers can maintain a communication link, especially if the mixture is to be transmitted to a relatively small (small g/T^0) receiving station. One way in which weak carrier suppression can be reduced in FDMA formats is by the use of satellite channelization. In channelization, the strong and weak carriers are assigned frequencies so that they can be received in the satellite in separate RF bandwidths. That is, the total available satellite RF bandwidth (B_{RF}) is divided into smaller bandwidths, and the uplink carriers are assigned frequencies so as to group in a bandwidth with other carriers of the (approximate) same satellite power level. These individual RF bandwidths are called satellite channels, and they can be used in two basic ways. One is to permit each channel to have a separate RF filter and amplifier, but to use only a sill power amplifier. The outputs of all channel amplifiers are summed prior to limiting and power amplification. The advantage of channelization is that the amplifier gains in each channel can be individually adjusted so that all carriers will have roughly the same power level when they appear at the amplifier input. This prevents suppression effects due to strong uplink carriers, although the total number of carriers and the total amount of noise remains the same. In essence, uplink power control is obtained at the satellite instead of at the earth stations.

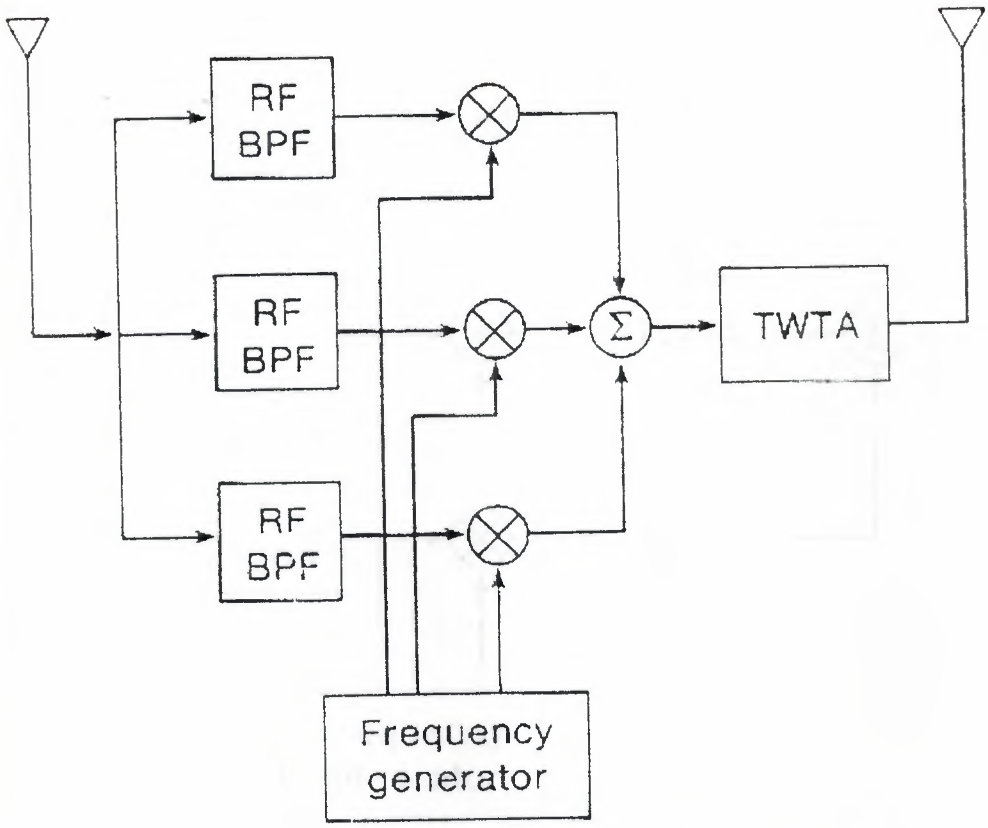


Figure 3.5(a) Channelized satellite –single TWTA

The second channelization method is to use separate power amplifiers for each channel. Each satellite channel then becomes an independent transponder. Only carriers of the same power are used in the same channel. The power of each amplifier is therefore divided only among the carriers in its own bandwidth. The uplink noise per channel is reduced because of the smaller bandwidths, thus leading to improved CNR for the downlink. In addition, the inter-modulation and power suppression effects are reduced since there are fewer carriers in each transponder. The limit of course, is when each uplink carrier is assigned its own transponder channel, which is the so-called SCPC (single channel per carrier) format and all nonlinear effects are removed. The advantages of channelization are achieved, of course, at the expense of a more complex satellite, since the weight of not only the additional power amplifiers and filters must be included but also that of the supporting auxiliary primary power. The advantages in performance of the increased number of independent transponders must be carefully weighed against the additional satellite cost.

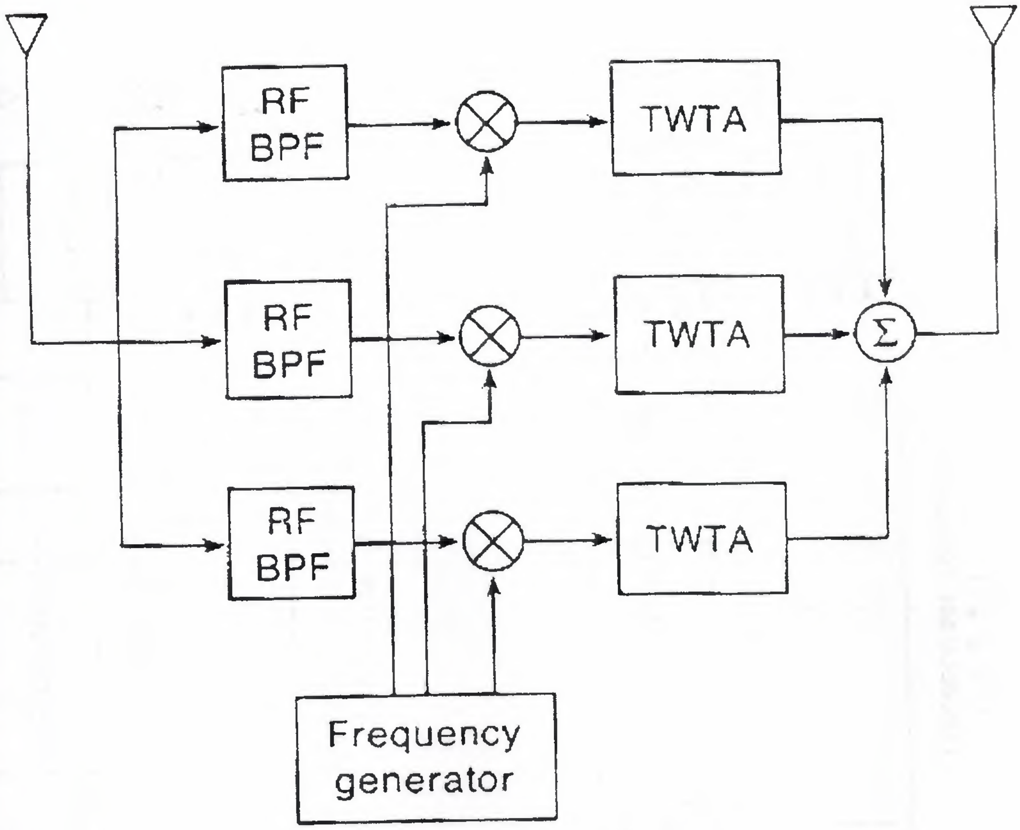


Figure 3.5 (b) Channelized satellites- multiple transponders

The use of increasing numbers of satellite transponders is an obvious trend in modern satellite design. Figure 3.6(a) shows the processing block diagram for the 12-transponder Intelsat satellite. The uplink and downlink RF bandwidth is divided, as shown in Figure 3.6(b). Each individual transponder has a 36-MHz bandwidth, with each channel center frequency separated by 40-MHz. The 12 transponders therefore utilize the entire 500-MHz RF bandwidth. Satellites may employ additional channels by making use of antenna beam separation or antenna polarization separation in the uplink and the downlink. Recall that this allows frequency reuse, in which the RF bandwidth can be used simultaneously by two separate carriers at the same uplink and downlink frequencies.

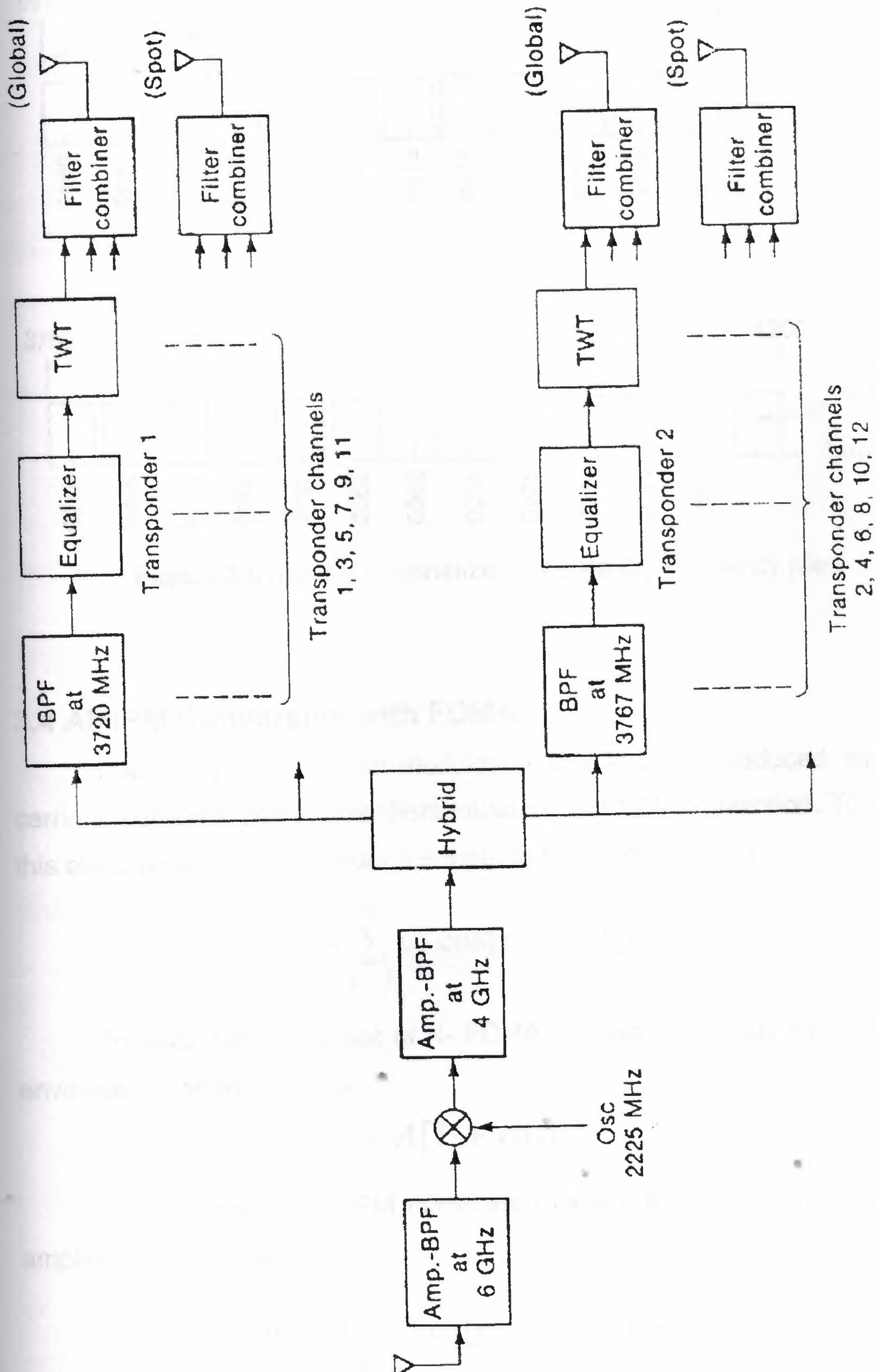


Figure 3.6 Intelsat channelized satellite **(a)** block diagram

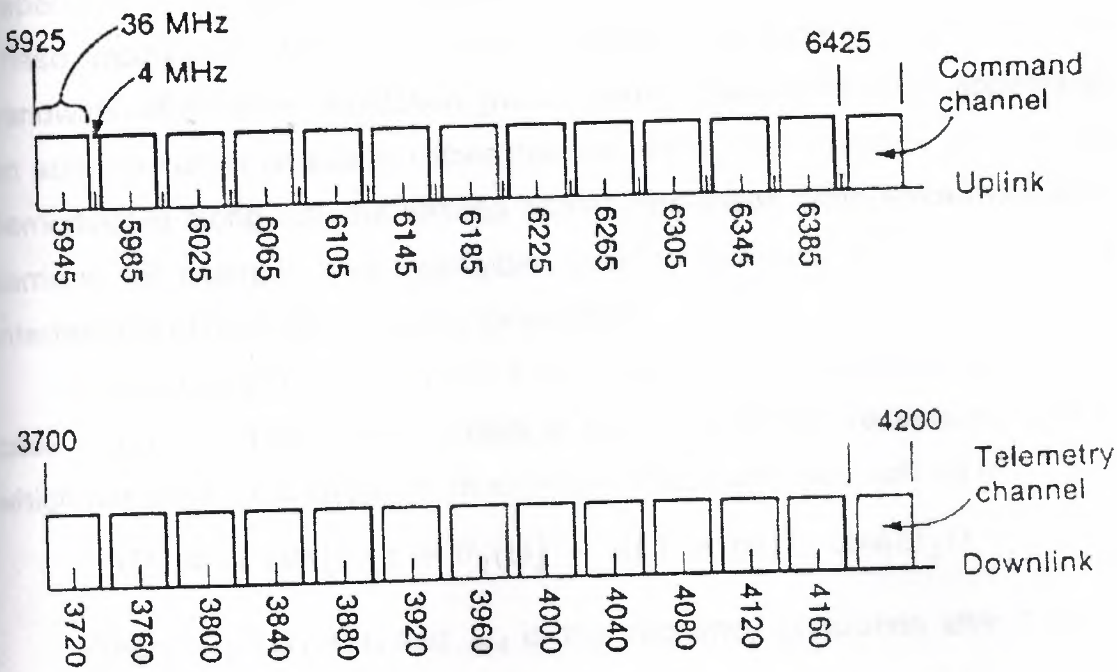


Figure 3.6 Intelsat channelized satellite **(b)** frequency plan

3.4 AM/PM Conversion with FDMA

In addition to the inter-modulation interference produced by FDMA carriers, nonlinear power amplifiers introduce AM / PM conversion. To examine this effect analytically, consider the input to the amplifier to be

$$x(t) = A \sum_{q=1}^{K} a_q \cos[\omega_q t + \theta_q(t)] \tag{3.13}$$

Corresponding to a set of K- FDMA carriers of various forms, the total envelope variation of x (t) is,

$$\alpha(t) = A[1 + e(t)] \tag{3.14}$$

Using a linear AM / PM conversion model, the conversion causes the amplifier output to be

$$y(t) = g[\alpha(t)] \sum_{q=1}^{K} a_q \cos[\omega_q t + \theta_q(t) + \eta A e(t)] \tag{3.15}$$

Where η is the AM / PM conversion coefficient. Note that the amplitude modulation is coupled into the phase of each carrier, with the value of η

dependent on the degree of amplifier nonlinearity (back off). Since this is itself phase modulation, typically having frequency components directly in the bandwidth of all other modulation, the converted phase modulation appears as an additive carrier crosstalk, rather than as noise. This crosstalk can then be demodulated along with the desired carrier modulation. With voice-modulated carriers, for example, this intelligible crosstalk corresponds to direct voice interference of one voice circuit onto another.

As an example of the AM / PM conversion effect, consider the simplified case of two equal amplitude carriers at two separate RF frequencies, one of which has base band amplitude modulation. The waveform simplifies to.

$$x(t) = A\cos[\omega_1 t + \theta_1(t)] + A[1 + m(t)]\cos(\omega_2 t) \tag{3.16}$$

Where $\omega_2 = \omega_1 + \omega_d$ and ω_d is the frequency separation after trigonometrically expanding,

$$\begin{aligned} x(t) = {} & A\{1 + [1 + m(t)]\cos[\omega_d t - \theta_1(t)]\}\cos[\omega_1 t + \theta_1(t)] \\ & + A\{[1 + m(t)]\sin[\omega_d t - \theta_1(t)]\}\sin[\omega_1 t + \theta_1(t)] \end{aligned} \tag{3.17}$$

The envelope of x (t) expands out as

$$\alpha(t) = \sqrt{2}A[1 + f(t)]^{1/2} \tag{3.18}$$

Where

$$f(t) = [1 + m(t)]\cos[\omega_d t - \theta_1(t) + \tfrac{1}{2}m^2(t) + m(t)] \tag{3.19}$$

The amplifier output is then

$$\begin{aligned} y(t) = {} & g[\alpha(t)]\cos[\omega_1 t + \theta_1(t) + 2A\eta e(t)] \\ & + g[\alpha(t)]\cos[\omega_2 t + 2A\eta e(t)] \end{aligned} \tag{3.20}$$

Since e(t) has a component due to the modulation m(t), e(t) introduces intelligible crosstalk onto the phase of the angle-modulated carrier, the strength of which depends on the coefficient η. It is for precisely this reason that amplitude-modulated carriers are usually not used in multiple-carrier FDMA satellite systems having TWT amplification.

Often the undesired amplitude modulation m(t) appears unintentionally. In FDMA formats with channelization, FM carriers of the uplink are filtered and combined for downlink amplification. During the filtering, if the RF filters are somewhat narrow, the filter gain characteristics cause the FM to be converted to undesired AM. For example, if $|H(\omega)|$ has a constant slope of V_ω V/ rps (called the filter gain slope) in the vicinity of carrier center frequency, then an FM carrier with frequency variation $\Delta\omega m(t)$ produces an amplitude variation on this carrier of,

$$e(t) = V_\omega \Delta_\omega m(t) \tag{3.21}$$

This envelope variation is then coupled into the phase of all other channelized carriers using the same transponder. Hence, the frequency modulation of one carrier is transferred to all other carriers through the filter gain slope and amplifier AM / PM effect. The strength of this FM crosstalk depends on the filter gain slope and the AM / PM coefficient. The former is reduced by better control of the filter functions, while the latter is reduced by backing off the amplifier.

3.5 Satellite-Switched FDMA

A channelized FDMA format is particularly suited for operation with multiple spot beams. Consider the multiple-beam model in Figure 3.7. Each spot beam illuminates a particular set of earth stations, and within each beam FDMA is used. The frequency separation of the carriers in each uplink beam can be used to channelize each beam, with a separate carrier filter at the satellite for each carrier within a beam. An uplink carrier designated for a downlink earth station is then routed to the particular spot beam covering that station.

Hence, each uplink channel filter output must be switched to the proper downlink beam channel. Since all uplinks must be switched simultaneously, an onboard switching matrix is needed to provide all possible routing directions. This switching can be suitably provided by a microwave diode gate matrix that allows signal flow in only specified directions. An FDMA satellite system of this type is referred to as satellite-switched FDMA (SS-FDMA). Figure 3.8 shows a simplified channelized diode switch matrix implementation for a three-beam SS-FDMA satellite. Each beam uses the same frequency bands, and an uplink carrier to be routed to a particular downlink spot beam is assigned a specific frequency band in each uplink beam.

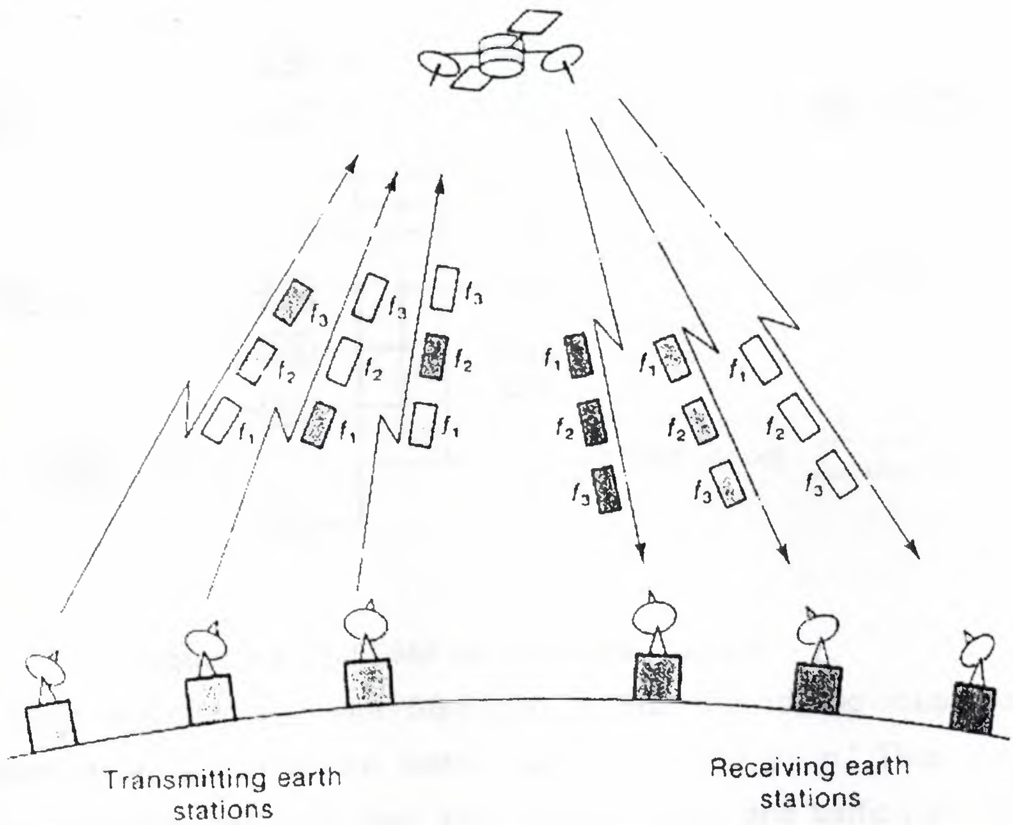


Figure 3.7 Satellite–switched FDMA model

This band is different for every uplink beam. The uplink beams are then channelized, and each band filtered off. The diode switch matrix connects each band to a different downlink. In other uplink beams, the same bands are switched to different downlinks. In this way, the same frequency bands from different beams are never superimposed on the same downlink. An uplink earth station need only select the appropriate band for the desired downlink earth-station beam. Thus, at any one time each uplink in any beam has connectivity to any downlink earth station in any beam. Note that the system utilizes complete frequency reuse, with the same bands being used in each uplink beam. In addition, channelization of the uplinks in SS-FDMA allows the filters to include gain adjustment as well, providing power control over the downlink carriers in the same beam. This reduces suppression effects on weaker carriers being routed to the same beam as stronger carriers

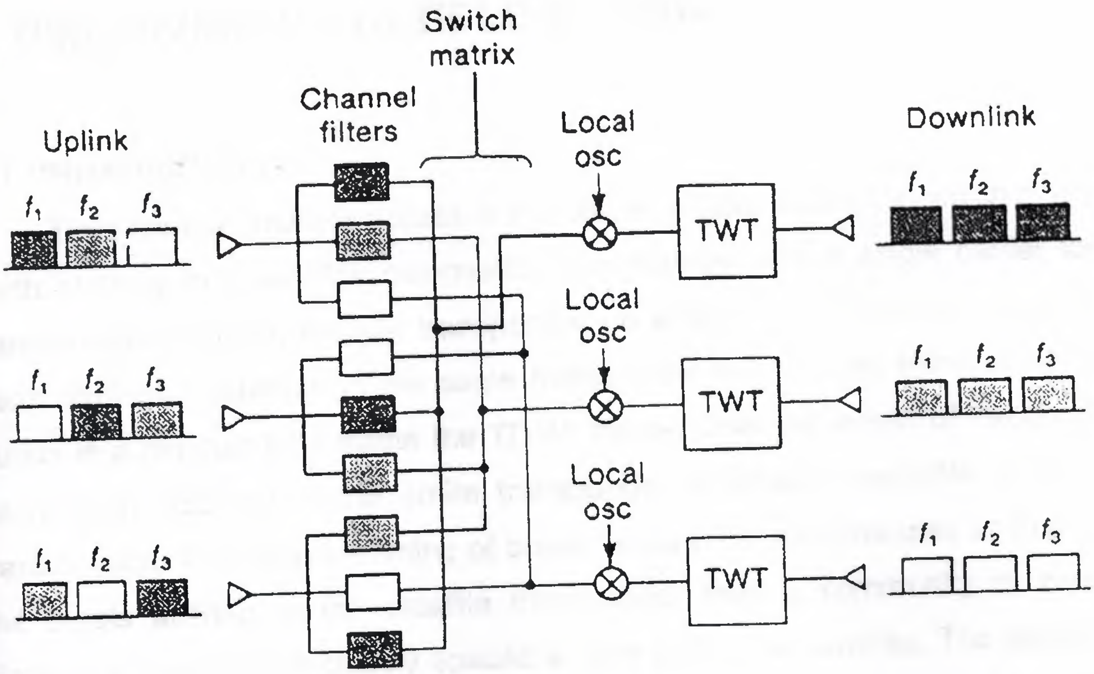


Figure 3.8 SS-FDMA satellite block diagram

A basic disadvantage with SS-FDMA is that the routing must be incorporated a priori; that is, the switch matrix is "hardwired in." Thus, the frequency distribution pattern is then fixed for that matrix, and traffic patterns cannot be altered. In addition, care must be used to prevent the same frequency band in two different beams from appearing in the same downlink and causing crosstalk. Preventing this crosstalk interference requires a significant isolation from the channel filters, and negligible leakage in the diode matrix. Isolation as high as 60 dB is possible with microwave switches. Another disadvantage is that the number of filters increases directly with the product of the number of one-way beams and frequency bands. Hence, if 3 bands are used with 4 uplink and downlink beams, a total of 12 carrier filters is required in the satellite.

4. TIME DIVISION MULTIPLE ACCESS

4.1 Introduction

Time division multiple access is a multiple access protocol in which many earth stations in a satellite communications network use a single carrier for transmission via each satellite transponder on a time division basis that is, all earth stations operating on the same transponder are allowed transmit traffic bursts in a periodic time frame the TDMA frame. Over the length of the burst, each earth station has the entire transponder bandwidth available to it for transmission. The transmit timing of bursts is carefully synchronized so that all the bursts arriving at the satellite transponder from a community of earth stations in the network closely spaced in time but do not overlap. The satellite transponder receives one burst at a time, amplifies it, and retransmits it back to earth. Thus every earth station in the satellite beam served by the transponder can receive the entire burst stream and extract the bursts intended for it. A simplified diagram of a TDMA operation is shown in Fig. 4.1.

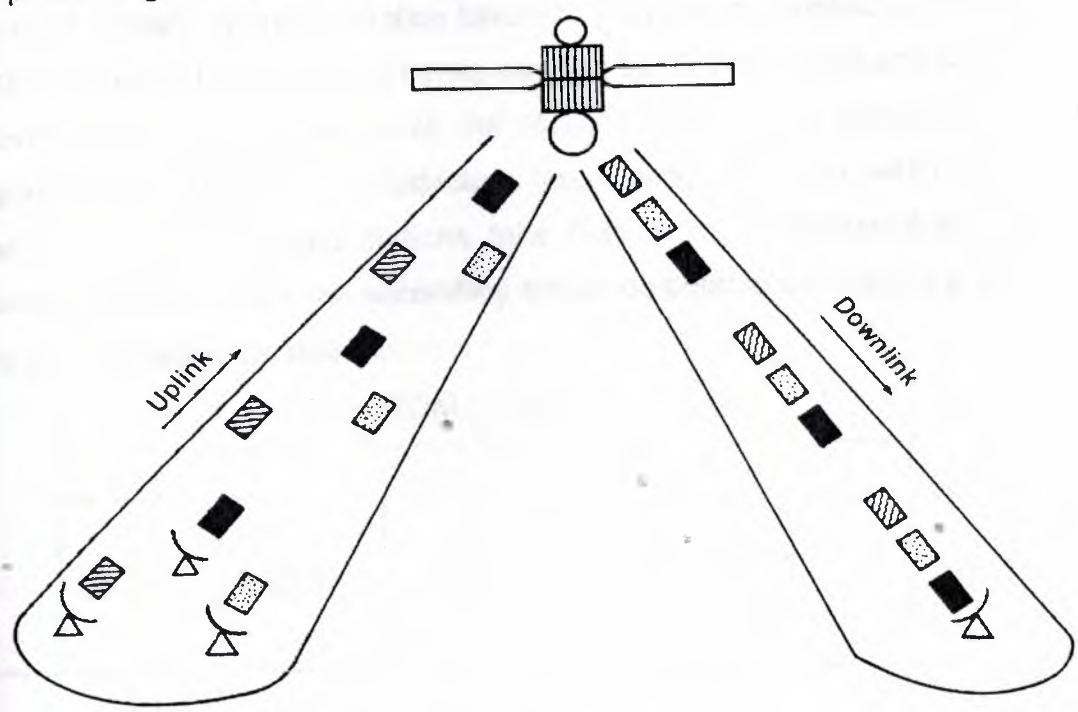


Figure 4.1 Time division multiple accesses

4.2 TDMA Frame Structure

In a TDMA network each earth station periodically transmits one or more bursts to the satellite. The input signal to the satellite transponder carrying TDMA traffic thus consists of a set of bursts originating from a number of earth stations. This set of bursts is referred to as a TDMA frame and is shown in figure 4.2. It consists of two references bursts RB1 and RB2, traffic bursts and the guard time between bursts. The TDMA frame is the period between RB1 references and bursts.

4.2.1 Reference Frame

Each TDMA frame normally consists of two reference bursts RB1 and RB2 for reliability .The primary reference burst(PRB),which can be either RB1 or RB2, is transmitted by one of the stations in the network designated as the primary reference station (PRS).A secondary reference burst (SRB), which also can be either RB1 (if PRB = RB2) or RB2 (if PRB = RB1), is transmitted by a secondary reference station(SRS) which allows automatic switchover in the event of primary reference station failure to provide undisrupted service for the TDMA network. The reference bursts carry no traffic information and are used to provide timing references for all the stations accessing a particular satellite transponder. This allows satisfactory interleaving of bursts within a TDMA frame. The TDMA traffic stations take their timing reference from primary reference burst or from the secondary reference burst when there is a failure of the primary reference station.

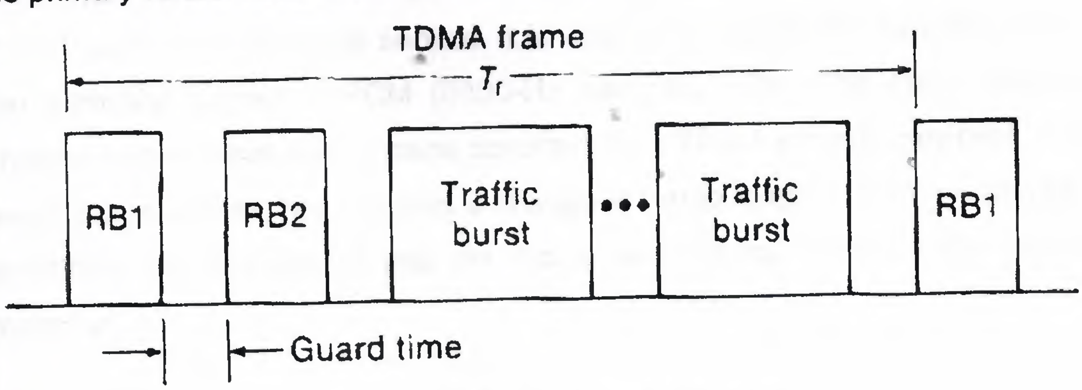


Figure 4.2 TDMA frame structure

4.2.2 Traffic Burst

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

4.2.3 Guard Time

A short guard time is required between bursts originating from several stations that access a common transponder to ensure that the bursts overlap when they arrive at the transponder. The guard time must be long enough to allow differences in transmit timing accuracy and in the range rate variation of the satellite. The guard time is normally equal to the interval used to detect the receive timing pulse marking the start of receive TDMA frame at a station. There is no transmission of information during the guard time.

The TDMA frame length is normally selected to be in the range $0.75 \leq T_f \leq 20.0$ ms for voice service. It is usually a multiple of 0.125 ms, which is the sampling period of PCM (8000-Hz sampling rate). The frame length is chosen at the outset and remains constant for a TDMA system. However, in the event that a new service requires a change in frame length, it may be altered by redefining the number of bits per frame and storing count in the network memory.

4.3 TDMA Burst Structure

In general the structure of the reference burst and the traffic burst are as shown schematically in fig4.3.In the traffic burst, information bits are precede by a group of bits referred to as a preamble that is used to a synchronize the burst and to carry management and control information.

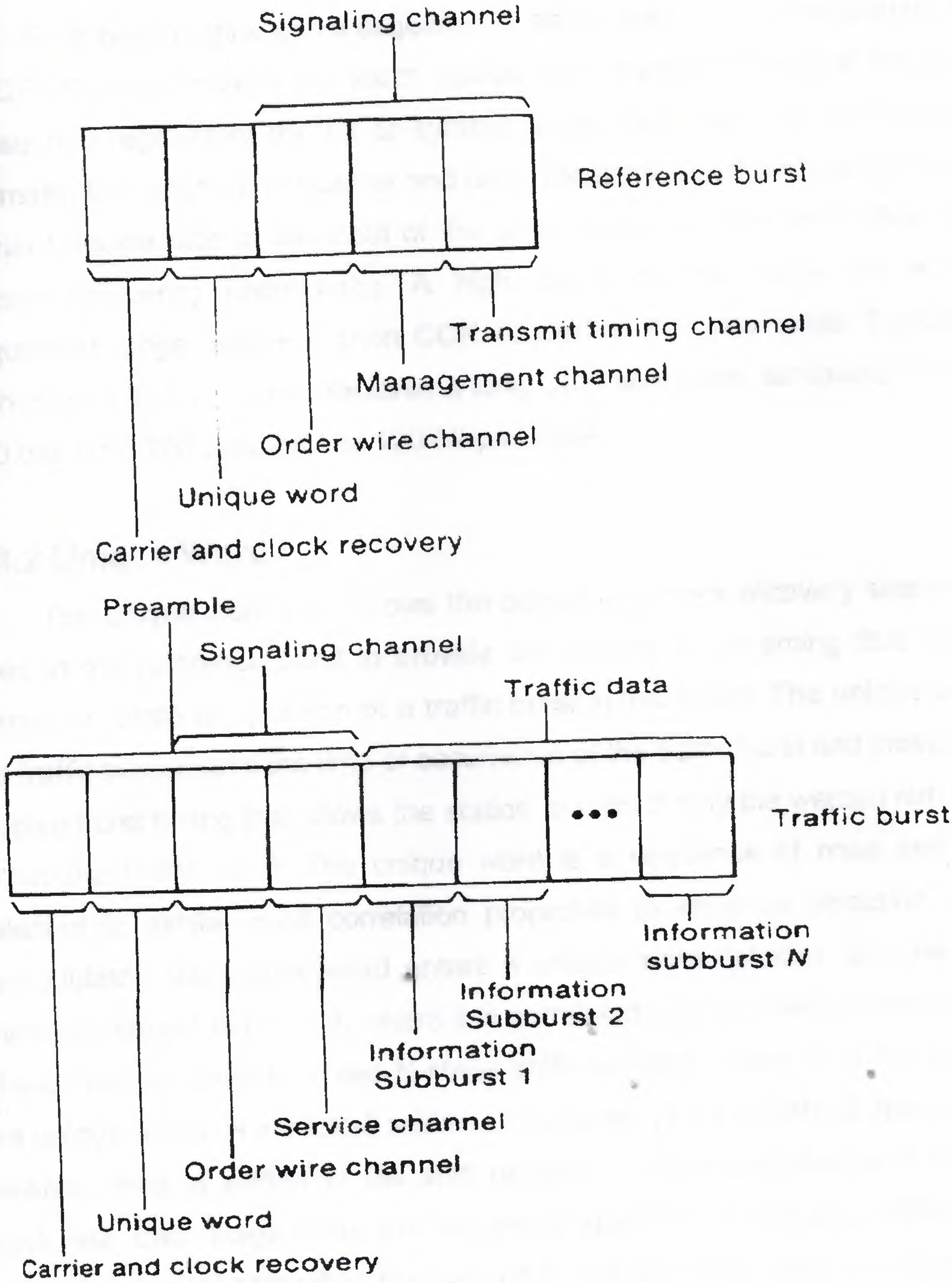


Figure 4.3 TDMA burst structure

The reference burst contains only the preamble, that is, no traffic data. Normally the preamble consists of three contiguous parts the carrier and clock recovery sequence (CCR), the unique word (UW), and the signaling channel.

4.3.1 Carrier and Clock Recovery Sequence

Each burst begins with a sequence of bits or symbols (for modulation such as QPSK) which enable the earth station demodulator to recover the carrier phase and regenerate the bit or symbol timing clock for data demodulation. Normally, the length of the carrier and clock recovery sequence depends on the carrier-to-noise ratio at the input of the demodulator and the acquisition range (carrier frequency uncertainty). A high carrier-to-noise ratio and a small acquisition range require a short CCR sequence, and vice versa. Typically, a high-bit-rate TDMA system requires a long CCR sequence, for example, 300 to 400 bits (150-200 symbols) for 120-Mbps TDMA.

4.3.2 Unique Word

The unique word that follows the carrier and clock recovery sequence is used in the reference burst to provide the receive frame timing that allows a station to locate the position of a traffic burst in the frame. The unique word in the traffic burst marks the time of occurrence of the traffic burst and provides the receive burst timing that allows the station to extract only the wanted sub bursts within the traffic burst. The unique word is a sequence of ones and zeros selected to exhibit good correlation properties to enhance detection. At the demodulator, the unique word enters a unique word detector, like the digital correlator shown in Fig. 4.4, where it is correlated with a stored pattern of itself. The correlator consists of two N-stage shift registers (where N is the length of the unique word), N modulo-2 adders, a summer, and a threshold detector. The received data is shifted in the shift register in synchronization with the data clock rate. Each stage in the shift register is applied to a modulo-2 adder whose output is a logical zero when the data bit or symbol in the stage is in agreement with the stored unique word bit or symbol in the same position. All the modulo-2 adder outputs are summed, and the sum is compared to a preset threshold by the threshold detector. The output of the summer is thus a step function representing the number of agreements or disagreements between the input data and the stored unique word pattern. The maximum number of errors allowed in the unique word detection is called the detection threshold **€.** When the correlation errors are equal to or below **€**, the detection of the unique word is declared. The unique word detection occurs at the instant of reception of the last bit or symbol of the unique word and is used to mark the receive frame timing.

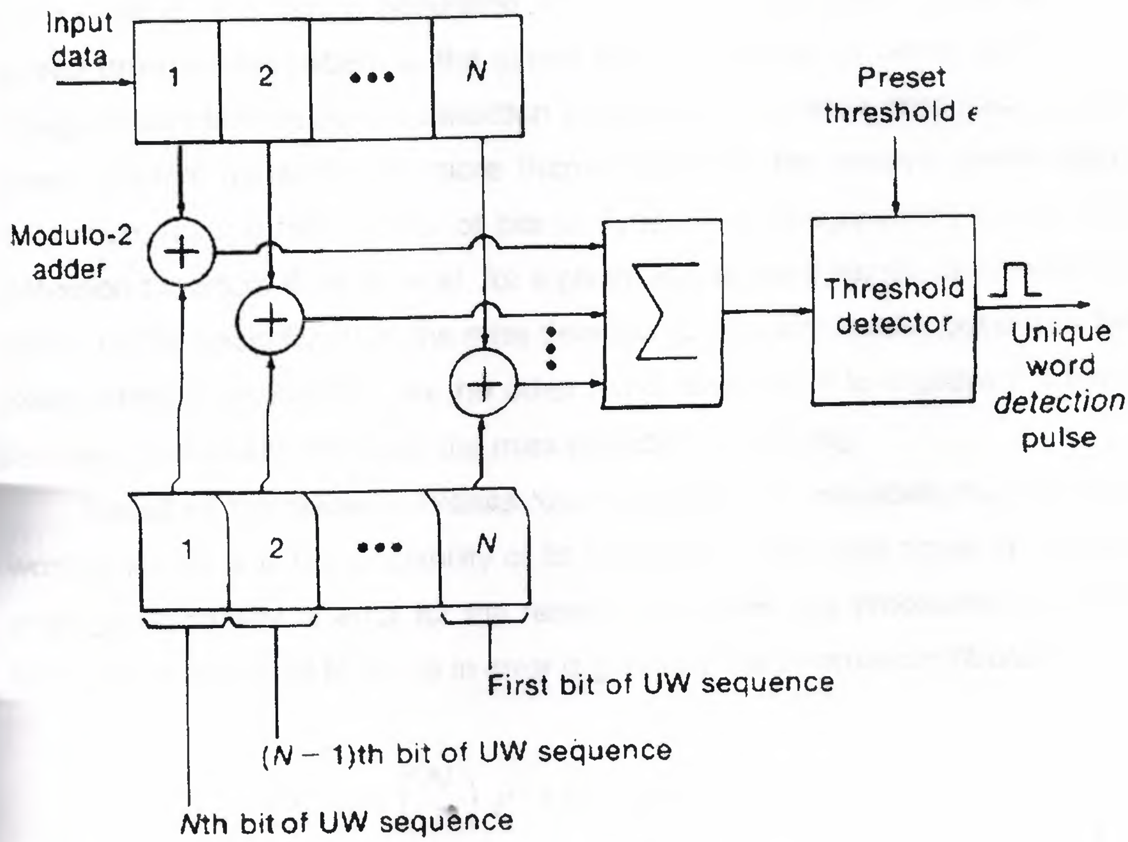


Figure 4.4 unique word detectors

If the unique word belongs to the primary reference burst, or to mark the receive traffic burst timing if the unique word belongs to the traffic burst. The position of every burst in the frame is defined with respect to the receive frame timing, and the position of every sub burst in a traffic burst is defined with respect to the burst's receive burst timing. It is seen that accurate detection of the unique word is of utmost importance in a TDMA system. For example, when the unique word of a traffic burst is missed, the entire traffic is lost. This causes impulses or clicks in voice transmission. In data transmission, a block is lost and consequently the bit error rate is increased. A false detection of the primary reference burst unique word generates the wrong receive frame timing and consequently incorrect transmit frame timing, causing the earth station to transmit out of synchronization and resulting in overlapping with other bursts at the satellite.

A false detection is generated whenever data or noise agrees with the stored unique word pattern to the extent that the number of bits or symbols in disagreement falls below the detection threshold €. A unique word miss occurs when channel noise causes more than € errors in the receive unique word sequence, making the number of bits or symbols in disagreement exceed the detection threshold €. In general, for a given unique word length, increasing the detection threshold € makes the miss detection probability smaller but raises the false detection probability. On the other hand, lowering € to improve the false detection probability increases the miss detection probability.

Based on the above discussion the miss detection probability for a unique word of length N is the probability of its having € + 1 or more errors. If P is the average probability of error for the receive data, then the probability P_i that "i" bits or symbols out of N will be in error is given by the binomial distribution.

$$P(i) = \binom{N}{i} p^i (1-p)^{N-i} \qquad (4.1)$$

Where

$$\binom{N}{i} = \frac{N!}{i!\,(N-i)!}$$

The probability of a correct detection is thus the sum of the probabilities of 0, 1, 2... € errors:

$$P_C = \sum_{i=0}^{\epsilon} \binom{N}{i} p^i (1-p)^{N-i} \tag{4.2}$$

Consequently the miss detection probability P_M is simply $P_M = 1 - P_C$ or

$$P_M = \sum_{i=\epsilon-1}^{N} \binom{N}{i} p^i (1-p)^{N-i} \tag{4.3}$$

The miss detection probability P_M is plotted in Fig. 4.5 for P = 0.01 which is the typical threshold error probability for link data. It is seen that, for a given link error probability, the unique word miss detection probability P_M can be reduced by decreasing the unique word length N or by increasing the detection threshold value €. In any case, N and € should be selected such that P_M<<P, the false detection probability P_F is given by the probability that random data (the data bits 1 and 0 are assumed to be generated with equal probability) accidentally corresponds to the stored unique word pattern to the extent that the number of bits or symbols in disagreement does not exceed the detection threshold €. For a unique word of length N, there are 2^N combinations in which random data can occur, hence the probability of the occurrence of one unique combination that corresponds to the stored unique word pattern is $1/2^N$, which is also the false detection probability when €=0. For a given value of €, the total number of possible combinations in which € or fewer errors can occur is $\sum_{i=0}^{\epsilon} \binom{N}{i}$. Thus the probability that N random data bits or symbols will be decoded as the unique word, or the false detection probability P_F, is and is independent of the link error probability.

$$P_F = \frac{1}{2^N} \sum_{i=0}^{\epsilon} \binom{N}{i} \tag{4.4}$$

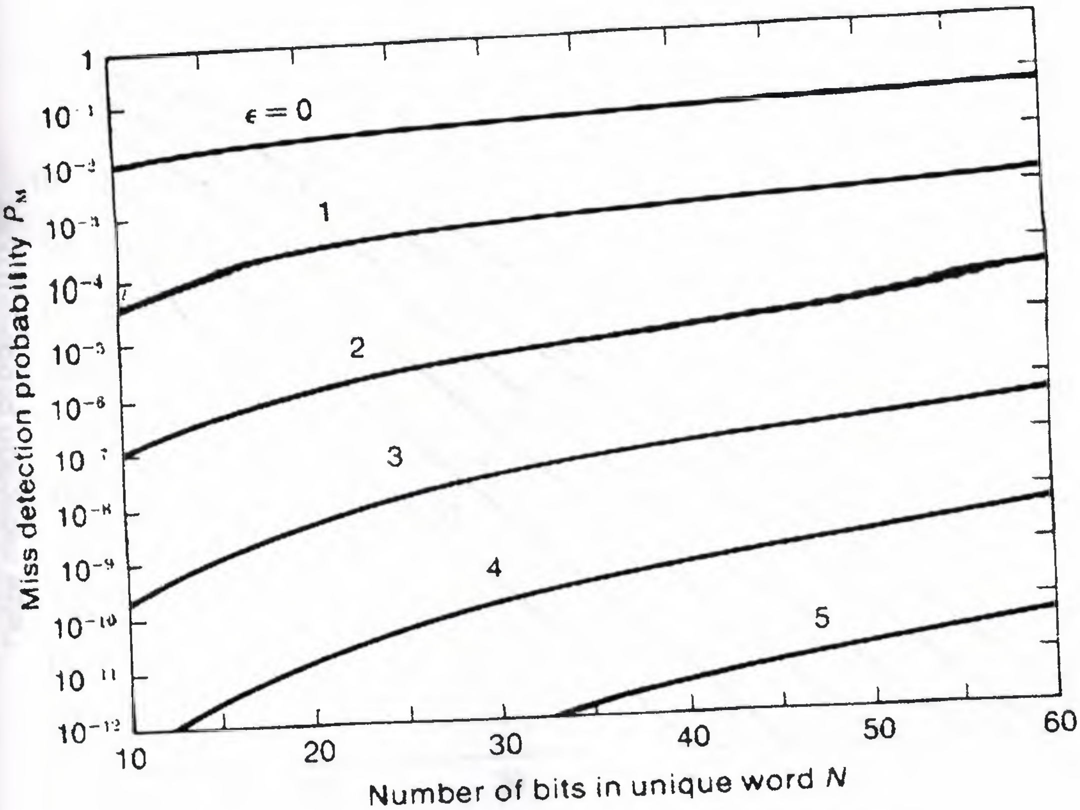


Figure 4.5 Unique words miss detection probability

The false detection probability is plotted in figure4.6 .It is seen that P_F can be reduced by increasing the unique word length N or decreasing the detection threshold **€.**

As an example, consider a unique word of length N= 40 and a detection threshold of **€**=5. The miss detection probability P_M for a given link error probability of P = 0.01 is given in Fig. 4.5 as

$$P_M \approx 5 \times 10^{-12}$$

If the data rate is R = 60 Mbps, then a miss detection will occur once every 3333 s. The corresponding false detection probability P_F is given in Fig. 4.6 as

$$P_F \approx 10^{-6}$$

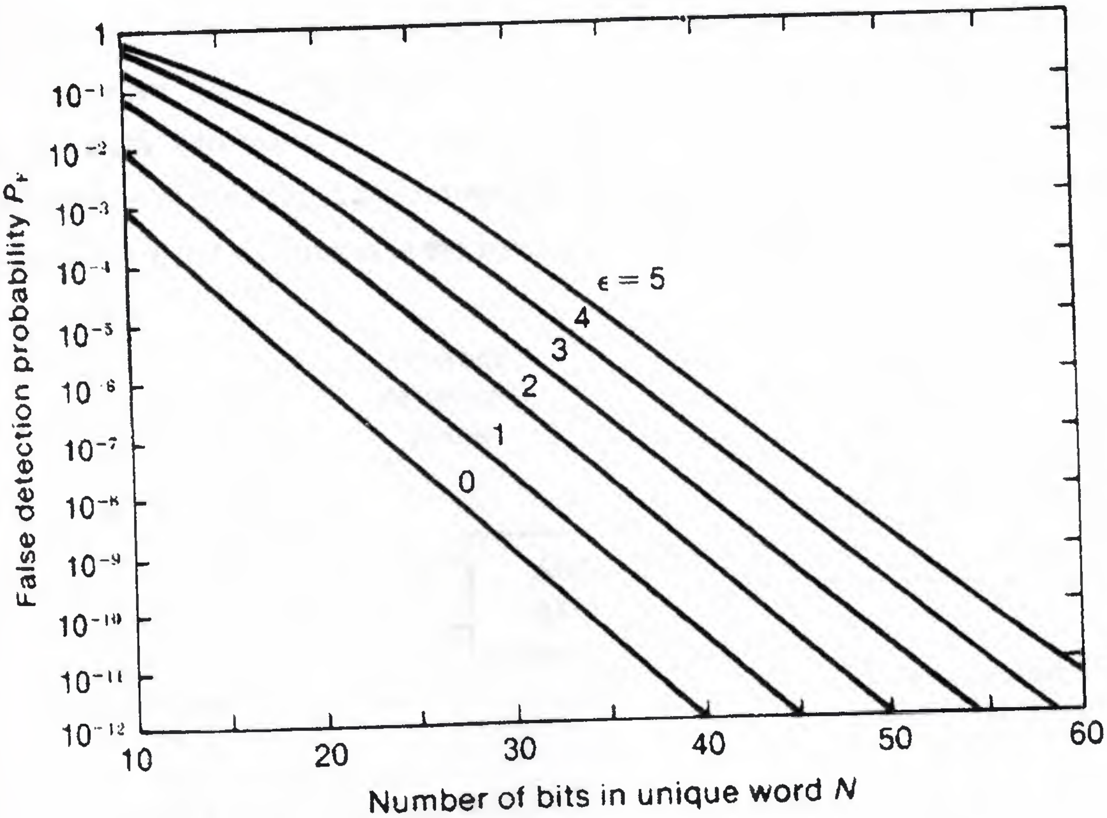


Figure 4.6 unique word false detection probabilities

If the data rate is R = 60 Mbps, then a false detection can be expected to occur at least 60 times every second. The above example shows that a unique word miss occurs very infrequently, in contrast to a false detection. To avoid this problem, the aperture technique is employed to suppress false detections. The aperture timing period is started by the unique word detection pulse, and one TDMA frame later an aperture window is formed at the expected occurrence of the unique word detection pulse, as shown in Fig. 4.7. All correlation pulses which do not occur within the aperture are suppressed. The aperture window allows detection of the unique word within the specified time interval. The length of the aperture window must be sufficient to compensate for drift of the unique word from its expected position as a result of timing uncertainty in the TDMA system resulting from satellite motion. Figure 4.8 shows the position of the aperture window relative to the detection pulse resulting from correlation of the carrier and clock recovery sequence that precedes the unique word and the unique word itself with the stored unique word pattern as they are shifted sequentially into the shift register. The aperture window is W bits, and the occurrence of the unique word detection relative to the end of the aperture is X bits. If X = 0, the aperture is in the most advanced position.

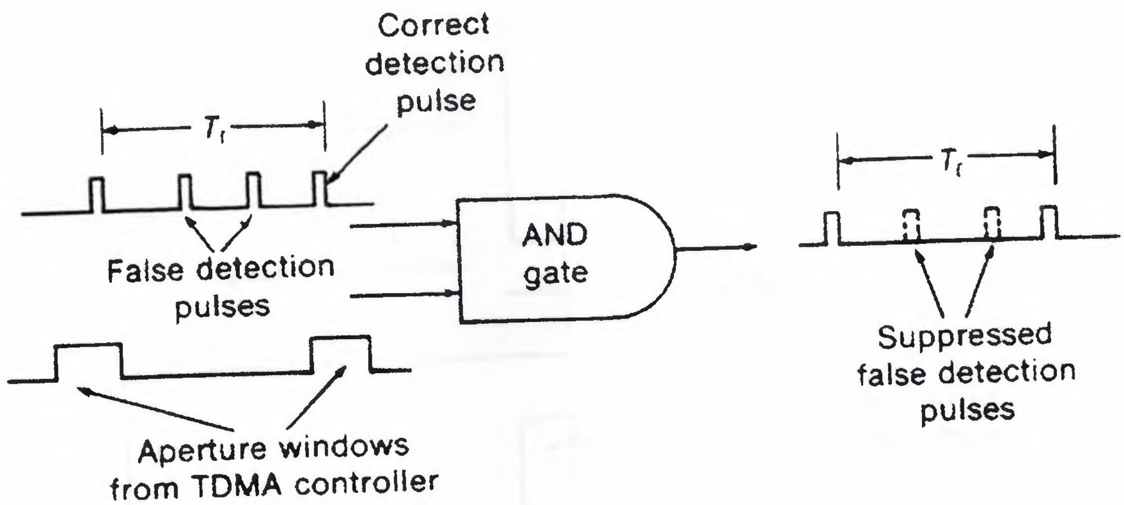


Figure 4.7 Aperture techniques for reducing false detection

Further advancing, the aperture to the left will cause the unique word detection to be missed. For X = W - 1, the aperture window is in the least advanced position. If the aperture is set back further, the unique word detection will be missed. In practice X = W/2 is the nominal position for the aperture relative to the occurrence of the unique word detection. Note that the occurrence of the unique word detection completes the unique word detection process, hence the bit or symbol pattern of the preamble that follows the unique word sequence does not play a role in the correlation process and only the carrier and clock recovery sequence takes part in the correlation. Note that in the worst case, when the aperture is

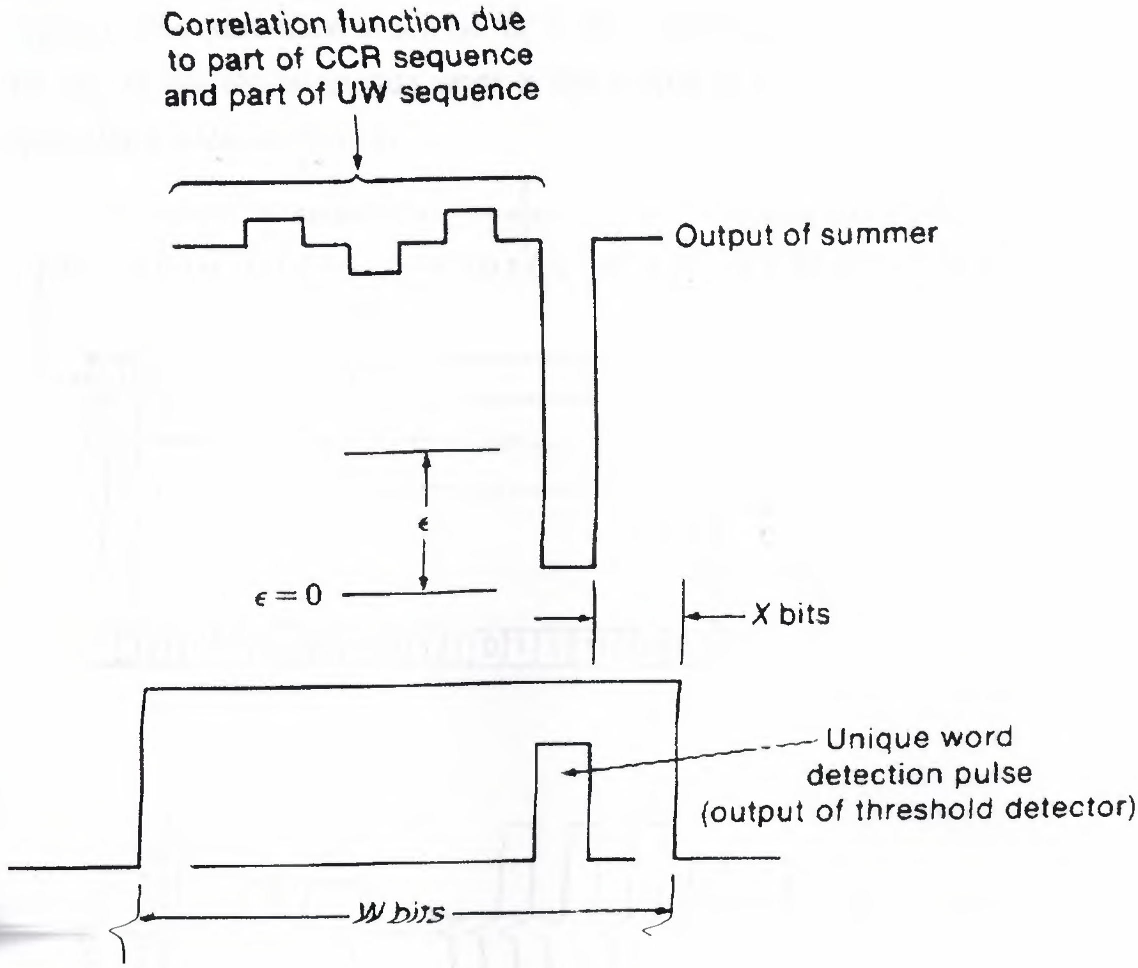


Figure 4.8 Positioning of aperture window

in the most advanced position, that is, X = 0, the correlation function at the output of the summer in the interval W - 1 bits before the unique word detection can cause a false detection if the number of bits in disagreement during any 1-bit correlation interval happen to be less than the threshold level €.Therefore it is important to select the last W-1 bits of the carrier and clock recovery sequence in such a way that they do not exhibit a strong correlation with the unique word pattern. An example of such a selection is illustrated in Fig. 4.9, where the correlation function within the aperture window W =23 bits and X = 2 bits is shown. The amplitude of the correlation functions depends on the number of bits in the carrier and clock recovery sequence that reside in the shift register. The correlation of any bit "b_i" in the shift register with the corresponding bit "b_i'" of the stored unique word is the output of the modulo-2 adder and is given by the following rules.

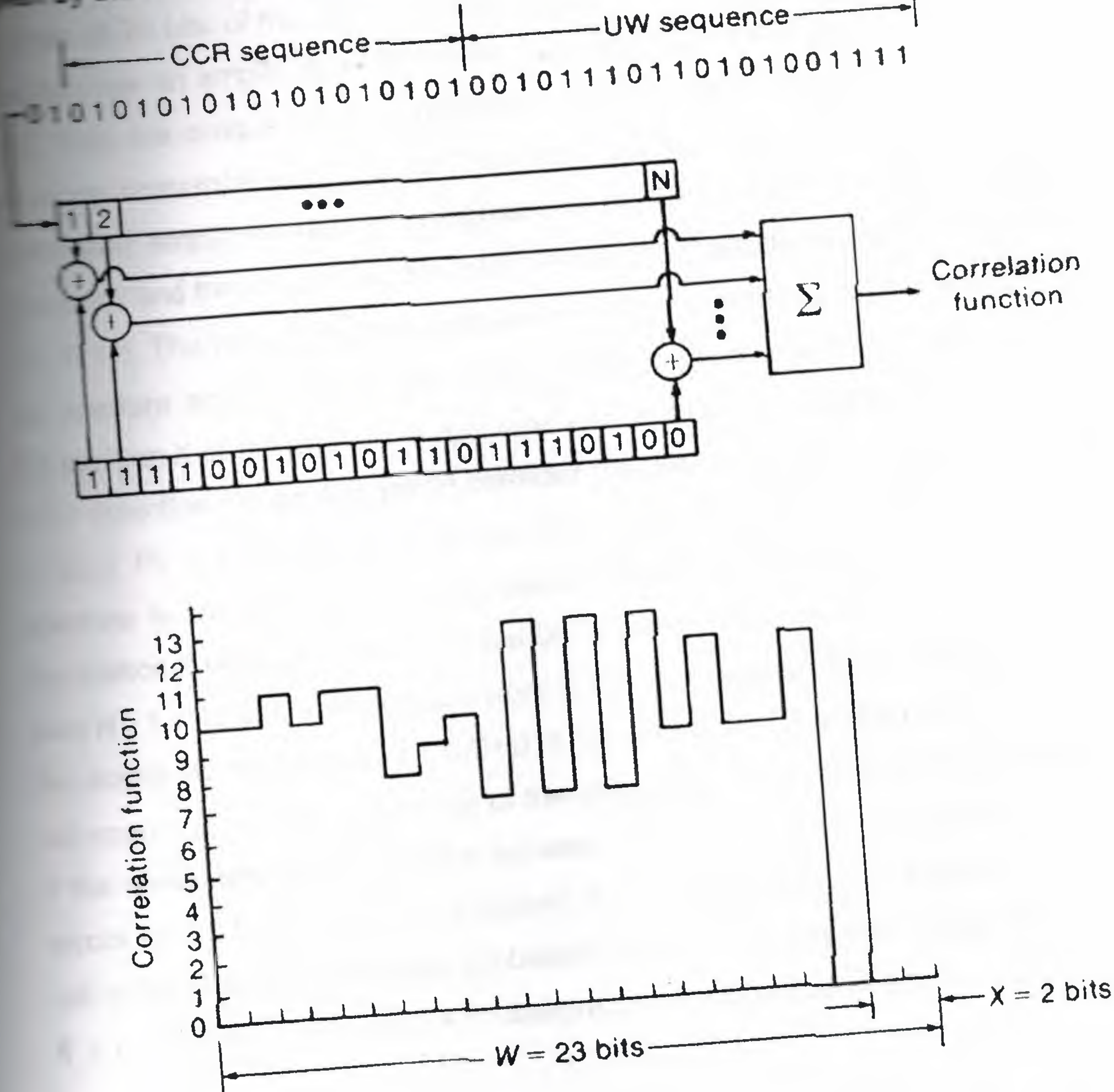


Figure 4.9 Correlation functions of CCR, UW, and stored UW sequence

$b_i \oplus b_i'$	0	1
0	0	1
1	1	0

Table 4.1

It is seen that, when the last 10, 8, and 6-bits of the carrier and clock recovery sequence and the first 10, 12 and 14 bits of the unique word reside in the shift register, the correlation functions have the next lowest amplitude of 7.when all 20 bits of the unique word reside in the shift register, the correlation function has an amplitude of "0". If the detection threshold € is selected to be € < 7, then the unique word is detected. For this particular carrier and clock recovery sequence and this particular unique word, the mean value of the correlation amplitude due to combinations of the carrier and clock recovery sequence and the unique word is N/2=10 with δ amplitude fluctuations, where $-3 \leq \delta \leq 3$. The false detection probability P_F clearly depends on the width W of the aperture and the amplitude of the correlation function. It also depends on the position X of the end of the aperture relative to the occurrence of the unique word detection. As an illustration consider the case in Fig. 4.9 with X = 0. If W = 1, then P_F = 0, since the only correlation function that appears within the aperture is the unique word correlation. When W=2, there is an additional correlation function involving the last bit of carrier and clock recovery sequence plus N - 1 = 19 bits of the unique word in the shift register. If there are no errors, the amplitude of pulse will be $N/2+\delta$ = 12, where δ = 2, and no false detection will occur before the occurrence of the unique word correlation pulse. However if the above sequence contains between $N/2+\delta$ - € = 12- € and $N/2+\delta$ = 12 errors (€<7), the correlation threshold € will be reached and a false detection will occur. The false detection probability is the probability that "i" bits, $N/2+\delta$ - € $\leq$ i $\leq$ $N/2+\delta$, out of $N/2+\delta$ disagreement bits will be in error:

$$P_{N/2+\delta} = \sum_{i=N/2-\delta-\epsilon}^{N/2+\delta} \binom{N/2+\delta}{i} p^i (1-p)^{N/2-\delta-i} \tag{4.5}$$

Where P is the link error probability. In the case W = 2 the false probability $P_{N/2+2}$. Now consider the case W = 3; there are two correlation functions that exist before the occurrence of the unique word detection. This yields two opportunities for a false detection. The total probability of a false detection is the sum of the individual probabilities. The probability of a false detection of the first correlation (the last bit in the CCR sequence and the first N - I bits in the UW sequence) is just $P_{N/2+\delta}$. The probability of a false detection of the second correlation (the last 2 bits in the CCR sequence and the first N - 2 bits in the UW sequence) is the joint probability that the first bit is correct, which is I - P, and that the second correlation contains between N/2+δ - € = 9 - € and N/2+δ = 9 errors (δ = -1), which is $P_{N/2+\delta}$ with δ = - 1. Thus the joint probability is (1 - P) $P_{N/2-1}$. The total false detection probability is

$$P_2 = P_{N/2-2} + (1-p)P_{N/2-1} \tag{4.6}$$

Proceeding in a similar manner, the overall probability of false detection is,

$$\begin{aligned} P_F = {} & P_{N/2+2} + (1-p)P_{N/2-1} + (1-p)^2 P_{N/2-1} + (1-p)^3 P_{N/2+2} \\ & + (1-p)^4 P_{N/2-1} + (1-p)^5 P_{N/2-3} + (1-p)^6 P_{N/2-3} \\ & + (1-p)^7 P_{N/2+3} + (1-p)^8 P_{N/2-3} + (1-p)^9 P_{N/2+3} \\ & + (1-p)^{10} P_{N/2-1} + (1-p)^{11} P_{N/2} + (1-p)^{12} P_{N/2-1} \\ & + (1-p)^{13} P_{N/2-2} + (1-p)^{14} P_{N/2} + (1-p)^{15} P_{N/2+1} \\ & + (1-p)^{16} P_{N/2} + (1-p)^{17} P_{N/2+1} + (1-p)^{18} P_{N/2} \\ & + (1-p)^{19} P_{N/2} \end{aligned} \tag{4.7}$$

For $p < 10^{-3}$, $P_{N/2+\delta} = P_{N/2}$ $(-3 \le \delta \le 3)$ and

$$P_F = \frac{1-(1+p)^{W-X-1}}{p} P_{N/2} \qquad W = 23,\ X = 2 \tag{4.8}$$

The above false detection probability will be reduced even more when the aperture window is positioned such that X = W/2. The selection of the aperture window W directly determines the guard time between bursts. Even though the satellite is said to be stationary in a geostationary orbit, the situation is approximate because of the attraction of the moon and sun. Analysis of the departure from geostationary orbit reveals that, for the worst case, the round trip range rate variation (Doppler shift) is approximately 40 ns/s. For a TDMA system with a burst bit rate of R bits per second, the Doppler shift is equivalent to 40 x IO^{-9}R bits per second. Since the aperture window is W bits centered on the expected unique word detection pulse, the time required for it to drift out of its aperture is approximately W / (80 x IO^{-9}R) seconds. Therefore each station must correct it's transmit timing at least once every W / (80 X IO^{-9}R) seconds. Also, the guard time between bursts must be at least as long as the aperture width to guarantee non overlapping bursts if the unique word detection pulses of two adjacent bursts drift to the opposite extremes of their respective apertures. To provide an additional degree of protection against the possibility of overlapping bursts, the guard time can be selected to be longer than the aperture window.

4.3.3 Signaling Channel

In general the signaling channel of the reference burst consists of the following sub-bursts:

1. An order wire channel carrying voice (telephone), and data (teletype) traffic via which instructions are passed to and from earth stations. Order wire is a term used in manual telephone switching to describe a circuit on which operators and maintenance personnel can talk to one another. Operators use the order wire for placing calls.
2. A management channel which is sent by the reference stations to all traffic stations carrying frame management instructions such as burst time plan changes. The burst time plan describes the coordination of traffic between stations. It identifies the boundaries of the time slots of the frame allocated to the stations, that is, burst positions. It also identifies the position, length, and source or destination stations corresponding to sub bursts in the bursts. This channel also carries monitoring and control messages to the traffic stations

when the reference station wants to obtain a status report (monitoring) and/or to control the switchover of subsystems at the traffic stations remotely.

3. A transmit timing channel carrying acquisition and synchronization information to the traffic stations which enables them to adjust their transmit burst timing so that transmitted bursts arrive at the satellite transponder within the correct time slots in the TDMA frame. It also carries the status codes which allow the traffic stations to identify the primary reference burst and the secondary reference burst from RBI and RB2.

The signaling channel of the traffic burst consists of the following sub bursts:

1. An order wire channel which is the same as the reference burst order wire channel.

2. A service channel carrying the traffic station's status to the reference station, or other information such as the high bit error rate and unique word loss alarms to other traffic stations.

Besides these sub bursts in the preamble, both reference and traffic bursts can carry additional sub bursts containing the frame identification number (for frame management purposes), station identification number, and type of transmitting bursts (primary reference burst, secondary reference bursts, traffic burst). Different types of unique words can be employed to provide burst identification.

4.3.4 Traffic Data

Traffic information is carried by the traffic burst immediately following the preamble. The length of a traffic sub burst depends primarily on the type of services and the total number of channels required for each service being supported in the burst. This portion contains information from the calling user being communicated to the called user, whether it be voice, data, video, or facsimile signals. The information for each channel is transmitted as a continuous sub burst. The size of each sub burst may be selected to be any number of bits to specifically accommodate the actual speed of the voice, data, video, or facsimile signal. For example, one PCM voice channel is equivalent to 64 kbps; if the frame length T_f = 2 ms, the resulting sub-burst of one PCM voice channel is 128 bits long. Each station in the TDMA network normally can transmit many traffic bursts containing different numbers of sub bursts per frame and is also capable of receiving many traffic bursts or sub bursts per frame.

4.4 TDMA Frame Efficiency

The TDMA frame efficiency depends on the percentage of the frame length T_f allocated to traffic data. The higher this percentage, the higher the system's efficiency. In order to achieve this goal, the overhead portion of the frame (e.g., guard times and preambles) has to be lowered, but not to the point of making the design of the system difficult. The carrier and clock recovery sequence must be long enough to provide enough time for stable acquisition of the carrier and to minimize the effect of inter burst interference (the tail of the preceding burst interfering with the head of the succeeding burst, hence degrading the carrier-to-noise ratio of the latter) caused by a finite filter response in the demodulator. Furthermore, the guard time between bursts must be long enough to allow synchronization tolerance due to the uncertainty of the satellite position and the method of frame synchronization employed. Therefore, trade-offs between TDMA efficiency and system implementation must be carefully considered in any TDMA design. The TDMA frame efficiency η is usually defined as,

$$\eta = 1 - \frac{T_x}{T_f} \tag{4.9}$$

Where T_X is the overhead portion of the frame. If there are n bursts in a frame, then T_X can be expressed as

$$T_x = nT_g + \sum_{i=0}^{n} T_{p,i} \tag{4.10}$$

Where T_g = guard time between bursts and $T_{P,i}$ = preamble of burst "i". It is obvious that the frame efficiency can be increased without lowering the overhead simply by increasing the frame length. But this in turn increases the amount of memory needed to store the incoming terrestrial data at a continuous rate for one frame, to transmit the data at a much higher burst bit rate to the satellite, and to store the receive traffic bursts and convert them to lower continuous outgoing terrestrial data. Furthermore, the frame length has to be kept small compared to the maximum satellite roundtrip delay of about 274 ms (5 degree elevation angle) to avoid adding significant delay to the transmission of voice traffic. For voice traffic frame length is normally selected to be less than 20 ms.

As an example, consider a TDMA system with the frame and burst structures, calculation of the frame efficiency is based on the following parameters:

1. The TDMA frame length is 15 ms.
2. The TDMA burst bit rate is 90 Mbps.
3. Each of the 10 stations transmits 2 traffic bursts for a total of 20 traffic bursts in the frame plus 2 reference bursts.
4. The length of the carrier and clock recovery sequence is 352 bits.
5. The length of the unique word is 48 bits.
6. The order wire channel has 510 bits.
7. The management channel has 256 bits.
8. The transmit timing channel has 320 bits.
9. The service channel has 24 bits.
10. The guard time is assumed to be 64 bits.

From the above assumptions, it concluded that

Number of bits in the reference burst preamble: 1486

Number of bits in the traffic burst preamble: 934

Total number of overhead bits: 23,060

Total number of bits in a frame (15 ms X 90 Mbps): 1.35 X 1000000

Frame efficiency: 98.29%

Assume that all the traffic data is PCM-encoded voice. Each voice channel data rate is 64 kbps and each channel is carried by a sub burst in traffic burst.

The number of bits in a 15-ms frame for a voice sub burst 64kbps x 15 ms= 960. The maximum number of PCM voice channels carried in a frame is 0.9829 x 1.35 x 1000000/960 = 1382.

4.5 TDMA Super Frame Structure

The two most critical functions in a TDMA network are control of the burst position in the frame and coordination of the traffic between stations such a way that any rearrangement of the position and length of bursts does not cause service disruption or burst overlapping. Control of the position of bursts may be carried out by the reference station using the transmit timing channel, while coordination of traffic is achieved through e management channel of the reference burst.

To provide control and coordination, the reference station has to address all the traffic stations in the network. If there are N stations to be addressed in the network, there will be N messages in the transmit timing channel and N messages in the management channel of the reference burst. Furthermore, to provide almost error-free communication for these critical control and coordination messages, some form of coding is normally employed. The most commonly used coding for these channels is the 8:1 redundancy coding algorithm where an information bit is repeated eight times according to a predetermined pattern and then decoded using majority decision logic at the receive end. This effectively increases the time slot allocated to each message eight times and further reduces the frame efficiency. The same reasoning applies to the service channel of the traffic bursts.

In order to reduce the length of the preamble of the reference bursts and the traffic bursts, the reference station can send one message to one station per frame instead of N messages to N stations per frame. To address N stations in the network, the process takes N frames. For example, station 1 is addressed by the reference station in frame 1, station 2 by the one in frame 2, so on, and finally station N by the one in frame N. The procedure is repeated in the same fashion for the next N frames until completion. Similarly, if the status report sent by the traffic station to the reference station, or other information sent to other traffic stations, is sent over N frames and repeated until completion, the length of the traffic burst preamble will also be reduced; hence the frame efficiency will be increased.

In this way, N frames can be put into one group called a super frame, where N is the number of stations addressed by the reference station as shown in Fig. 4.10. To identify the frames in a super frame, a frame identification number may be carried in the management channel or in a separate channel in the reference burst for each frame. Normally the identification number of frame 1 serves as the super frame marker. Alternatively, different unique words can be employed by the reference bursts and the traffic bursts to distinguish the super frame marker from the frame markers.

When the number of stations N in the network is fixed or its maximum is known, it is easy to design the service channel of the traffic bursts so that its message can be transmitted over N frames. For example, any message transmitted by the service channel of the traffic bursts is limited to a maximum of 40 bits. If the 8:1 redundancy coding algorithm is used for the message, it will take 320 bits to transmit it. Suppose N = 10 (i.e., a super frame consists of 10 frames): then a super frame would be needed to transmit the 320-bit message with 32 bits per frame. That is, the service channel occupies a time slot of only 32 bits. Although the rate of message data transmission is now only 4 bits per frame, the frame efficiency is increased significantly as compared to transmitting 320 bits per frame (40 bits of message data per frame).

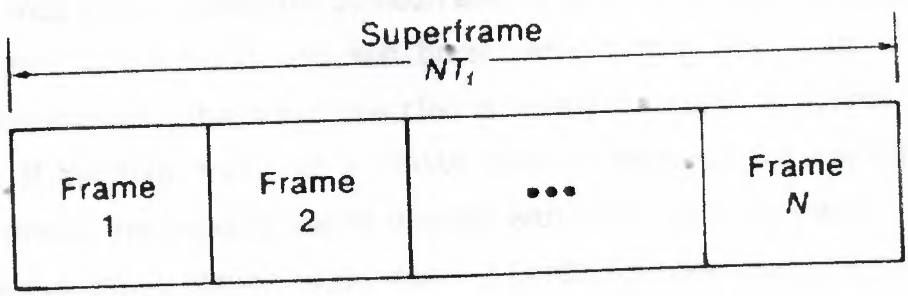


Figure 4.10 Super frame

When the number of stations N in the network is variable, that is, the network can grow, and if demand assignment is employed, it might be appropriate to transmit the messages in the service channel of the traffic bursts and demand assignment messages in a separate super frame short burst (SSB) at the super frame rate. That is, each of the N stations in the network transmits a super frame short burst once per super frame. In other words, each frame of a super frame contains a super frame short burst from a designated station. For the above example, the super frame short burst would be allocated a time slot of 320 bits for a 40-bit message with 8:1 redundancy coding. Note that message data rate is still 40 bits per super frame, as in the case where a service channel with 4 bits of message data per frame is used in a traffic burst. The advantage of putting the service channel in the super frame short burst instead of in the traffic burst is to increase the frame efficiency when a station transmits more than one traffic burst per frame.

Since the messages in the service channel of all the traffic bursts in same frame that originate from the same station are normally identical for ease of design, the redundancy of messages reduces the frame efficiency.

4.6 Burst Time Plan

In a TDMA network a traffic station transmits its bursts on time to their allocated positions in the frame at the satellite transponder according to a transmit burst time plan and receives bursts in the frame returned by the satellite transponder according to receive burst time plan .The burst time plan is thus a map that indicates the position and length of information sub burst within the burst Since burst and sub burst carry traffic(voice, data, and video) between stations , the burst time plan is simply the traffic assignment within a frame. If the total traffic of a TDMA network exceeds the capacity of one transponder, the network has to operate with more than one transponder. This means that traffic station might transmit bursts to more than one transponder (transponder hopping). In such a multiple-transponder operation, the burst time plan is the assignment of traffic to transponders and time ordering of the assigned traffic within a frame. A typical burst time plan format is shown below:

- Message data
  1. Burst time plan identification
  2. Traffic station identification
  3. Number of transmit bursts
  4. Number of receive bursts
- Burst data
  1. Burst identification
  2. Transmit-receive flag
  3. Transponder identification
  4. Burst position
  5. Number of transmit-receive sub burst
- Sub burst data
  1. Transmit receive sub burst identification
  2. Sub burst position
  3. Sub burst length

4.7 Burst Position Control

Consider the dual-polarized satellite communication network shown in Fig. 4.11 where the continental United States, Alaska, and Hawaii are illuminated by four downlink satellite beams: the east beam, the west beam, the CONUS beam, and the global beam over the frequency band 11.7 to 12.2 GHz; and by two uplink satellite beams: the CONUS beam and the global beam over the frequency band 14 to 14.5 GHz. The satellite transponder based on the downlink beams may be grouped as:

- East transponders
- West transponders
- CONUS transponders
- Global transponders

In order to control the burst positions and to update D_N for a traffic station in this type of TDMA network, two reference stations are required: a primary reference station (PRS) in the east beam and a secondary reference station (SRS) in the west beam. The roles of the PRS and SRS can be interchanged.

The PRS and SRS transmit primary reference bursts and secondary reference bursts, respectively, to the satellite transponders using the uplink global beam on the vertical polarization (two transponders), the uplink CONUS beam on the vertical polarization (six transponders), and the uplink CONUS beam on the horizontal polarization (eight transponders). All the PRBs are staggered in time by a fixed offset relative to a PRB in a transponder designated as timing and reference transponder (TRT). The SRB in a transponder is separated by a fixed offset relative to its corresponding PRB. This arrangement permits all 16 transponders of the satellite to be synchronized for transponder hopping. When feedback control is employed, it is administered by the PRS and SRS independently in the following manner:

1. For traffic stations that transmit their traffic bursts into east transponders.

a. Control is administered at the PRS by observing the traffic burst position relative to the PRB to correct D_N.

b. For the SRS to be able to administer control, each traffic station must be capable of transmitting a short burst (preamble only) to a designated west transponder or, alternatively, to a designated CONUS or global transponder. An acquisition time slot must also be allocated in this designated transponder for sequential acquisition of the traffic stations. Control is administered at the SRS by observing the short burst position relative to the SRS to correct D_N.

2. For traffic stations that transmit traffic bursts to the west transponders.

a. Each must be capable of transmitting a short burst to a designated east transponder or, alternatively, to a CONUS or a global transponder. An acquisition time slot must be allocated in the designated transponder for sequential acquisition of the traffic stations. Control is administered at the PRS by observing the short burst position relative to the PRB to correct D_N.

b. The SRS administers control by observing the traffic burst position relative to the SRB to correct D_N.

3. For traffic stations that transmit traffic bursts to both east and west transponders,

a. Control is administered at the PRS by observing the traffic burst positions relative to the PRB in the east transponders to correct D_N.

b. Control is administered at the SRS by observing the traffic burst positions relative to the SRB in the west transponders to correct D_N.

The transmission of short bursts by traffic stations whenever necessary enables the PRS and SRS to initiate feedback control acquisition and synchronization for all the traffic stations in the network independently. If the PRS fails, the SRS can take over control immediately. In this type of network, the satellite may consist of many local synchronized communities of transponders (LSCTs), each serving a number of traffic stations, and these may constitute sub-networks whose control and coordination are independent of each other. The reference burst in each transponder of a LSCT may contain identical information in its signaling channel. Each traffic station in a LSCT obeys the control and coordination exerted by the reference burst in a designated transponder. All the traffic bursts from a traffic station that access a LSCT contains identical information in their signaling channel.

Another way to control the burst positions of traffic stations in this type of network, besides the above-mentioned feedback control method involving the PRS and SRS, is the loop back control method. This is possible because a traffic station in the east beam (west beam) that does not transmit its traffic bursts to the east transponders (west transponders) always has the ability to transmit a short burst to a designated east transponder (west transponder), so that it can receive its own short burst and perform loop back synchronization. Other traffic stations that transmit their traffic bursts to their own beam can receive their own traffic bursts and need not transmit short bursts. In this way loop back synchronization can be performed by each individual traffic station employing a burst synchronizer. Acquisition may be carried out using feedback control from the PRS and SRS.

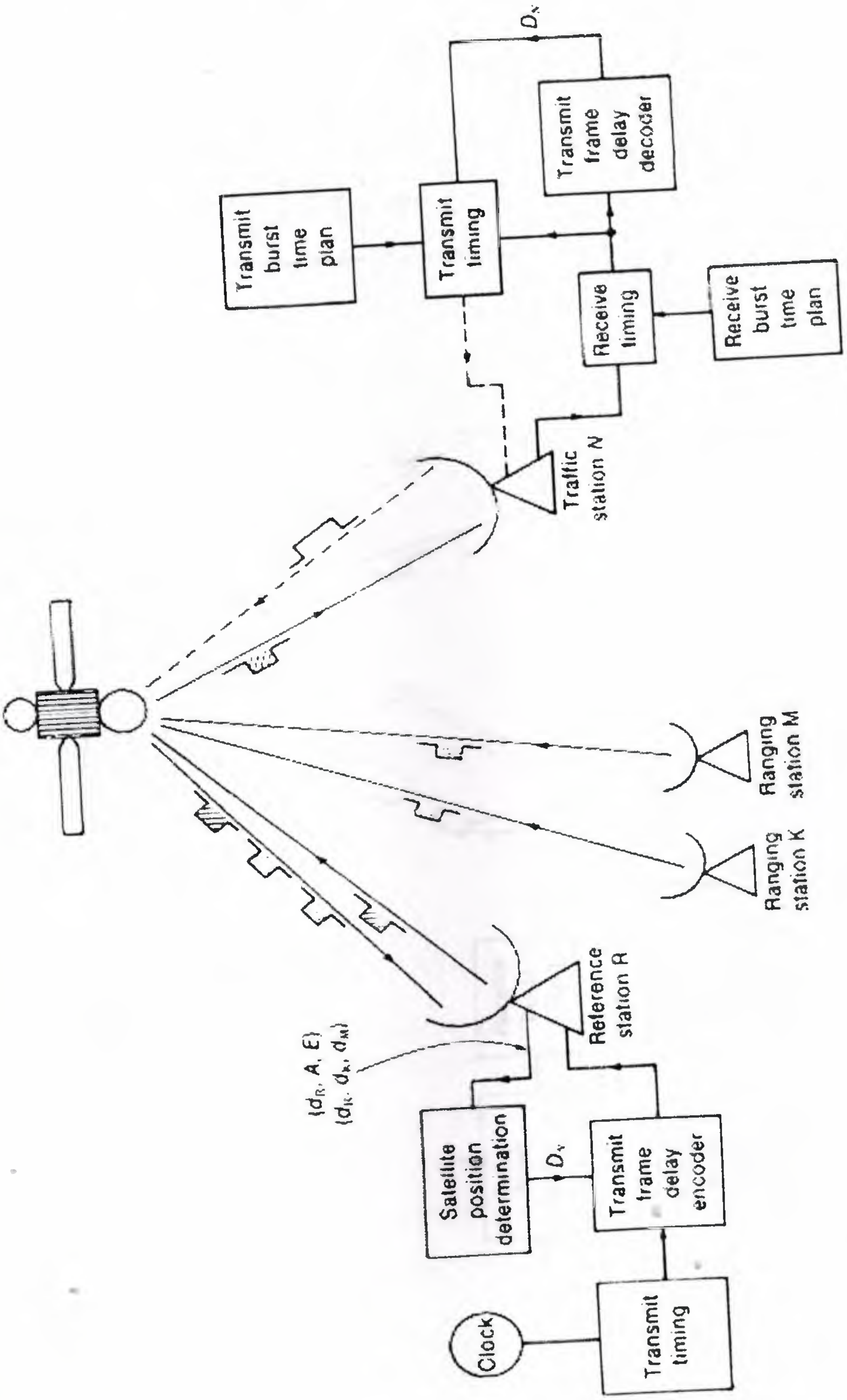


Figure 4.11 satellite position determination for transmit frame acquisition

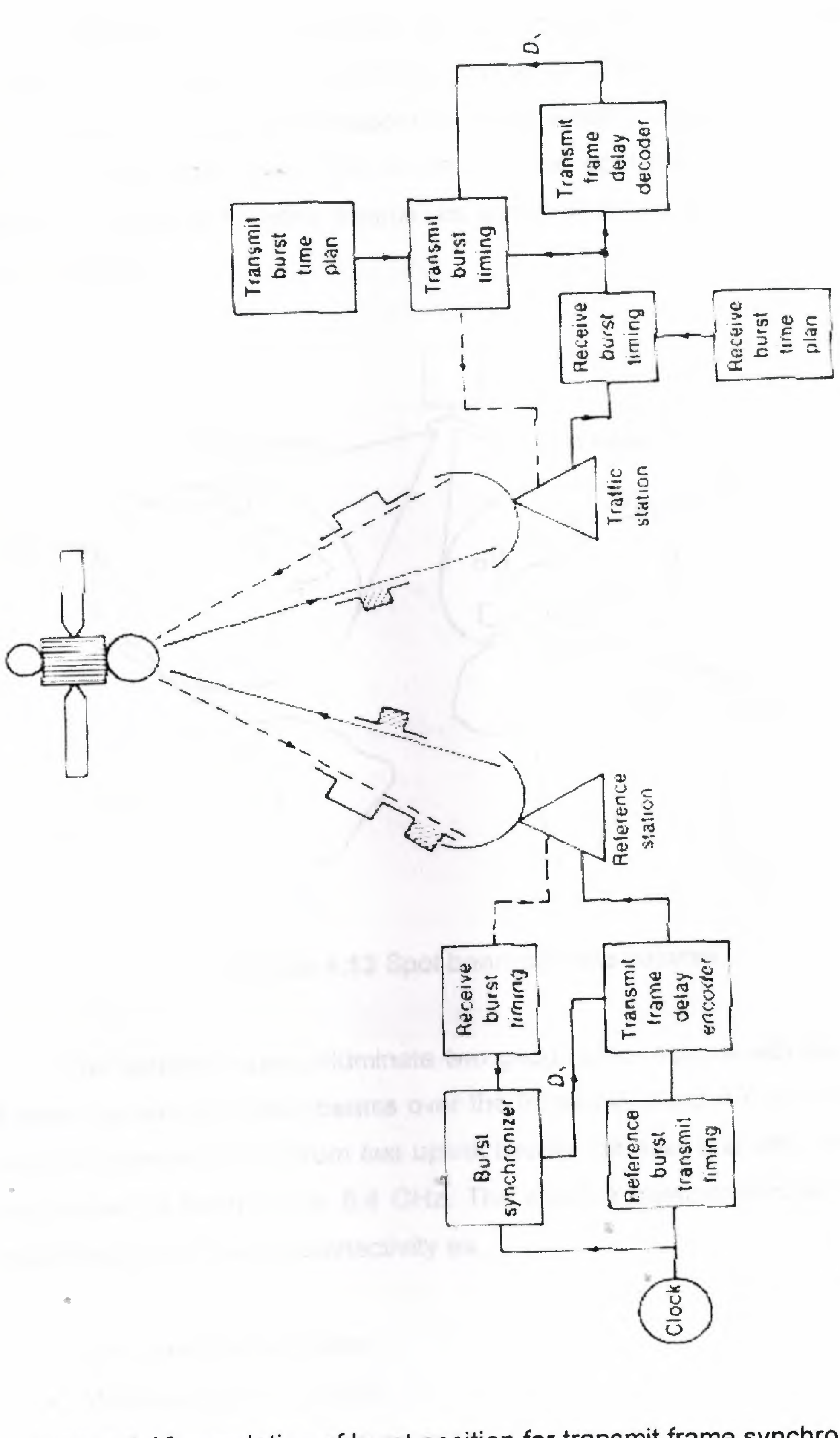


Figure 4.12 correlation of burst position for transmit frame synchronization

A TDMA network where only two reference stations are needed, a PRS and a backup SRS, this is possible because the PRS and SRS can transmit their reference bursts to all transponders in the satellite using the uplink CONUS beam or the global beam. For a network that operates with downlink spot beams and also with uplink beams, as shown in figure 4.13, the situation is much different.

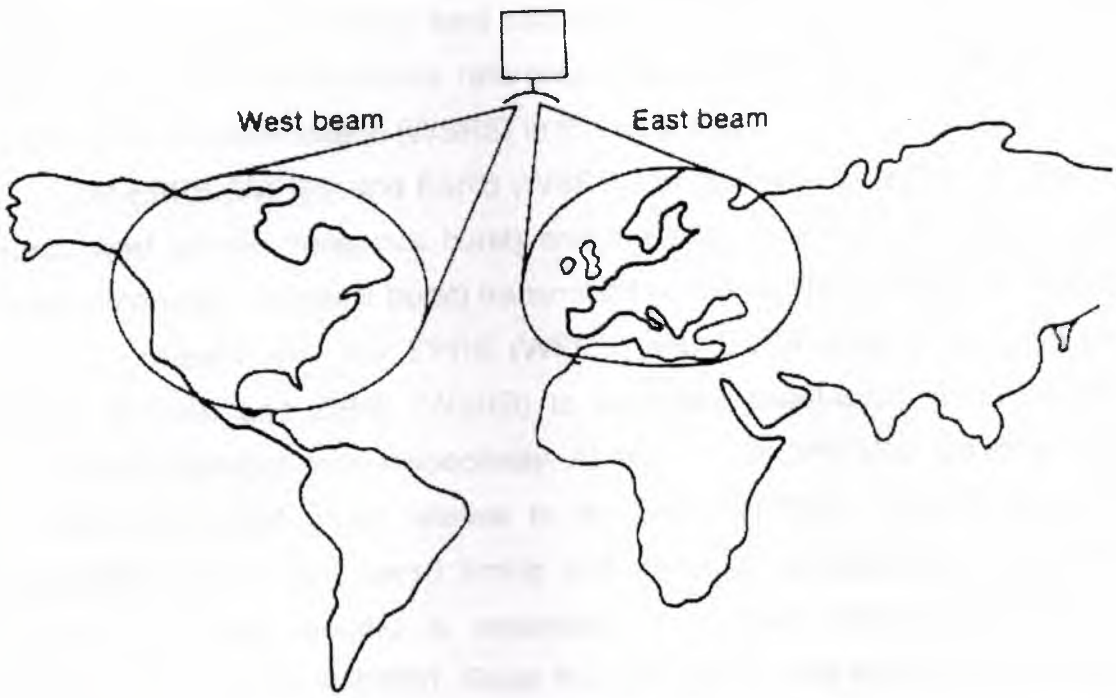


Figure 4.13 Spot beam satellite network

The satellite beams illuminate two geographic regions with two downlink beams the east and west beams over the frequency band 3.7 to 4.2 GHz. The satellite receives traffic from two uplink beams the east and west beams over the frequency band 5.9 to 6.4 GHz. The satellite transponders are arranged according to their beam connectivity as,

- East-west transponders
- West-east transponders
- East-east transponders

- West-west transponders

Earth stations in the east (west) beam can transmit their bursts only to east-west (west-east) transponders and east-east (west-west) transponders and can receive bursts only from west-east (east-west) transponders and east-east (west-west) transponders. This type of beam connectivity necessitates the use of a pair of reference stations in each beam, namely, an east primary reference station (EPRS) and a backup east secondary reference station (ESRS) in the east beam, and a west primary reference station (WPRS) and a backup west secondary reference station (WSRS) in the west beam.

Let EPRB (WPRB) and ESRB (WSRB) denote the east primary reference burst (west primary reference burst) and the east secondary reference burst (west secondary reference burst) transmitted by the EPRS (WPRS) and ESRS (WSRS), respectively. The EPRS (WPRS) and ESRS (WSRS) transmit the EPRB (WPRB) and ESRB (WSRB) to east-west (west-east) and east-east (west-west) transponders, respectively. All the EPRBs (WPRBs) are staggered in time by a fixed offset relative to an EPRB (WPRB) in a transponder designated as the east (west) timing and reference transponder. The ESRB (WSRB) in a transponder is separated by a fixed offset relative to its corresponding EPRB (WPRB). Since the east-west (west-east) and east-east (west-west) transponders are synchronized with a single set of EPRBs (WPRBs) and ESRBs (WSRBs), transmit transponder hopping between them is possible. In order to achieve receive transponder hopping between west-east (east-west) transponders using the WPRB (EPRB) and WSRB (ESRB) as timing references and east-east (west-west) transponders using the EPRB (WPRB) and ESRB (WSRB) as timing references, the WPRB must be synchronized with the EPRB to provide a common timing reference for all the transponders. This can be carried out by either the EPRS or the WPRS using feedback control. Let the EPRS be selected to perform reference burst synchronization. Since the EPRS can receive its own EPRB from the east-east transponder, it can observe the position of the WPRB received from the west-east transponders relative to its EPRB and corrects the transmit frame delay D_{WPRS} that it sends to the WPRS for synchronization. In this manner all the WPRBs and EPRBs can be synchronized to a common timing reference (the EPRB in the east timing and reference transponder) and both transmit and receive transponder hopping is possible. When feedback control is employed, it is administered by the reference stations as follows:

1. For traffic stations that transmit their traffic bursts to east-west (west-east) transponders, control is administered by the WPRS (EPRS) by observing the traffic burst positions relative to the EPRB (WPRB) to correct D_N. The WPRS (EPRS) then sends the updated D_N to the traffic stations in its WPRB (EPRB) via west-east (east-west) transponders.

2. For traffic stations that transmit their traffic bursts to east-east (west-west) transponders, control is administered by the EPRS (WPRS) by observing the traffic burst positions relative to the EPRB (WPRB) to correct D_N. The EPRS (WPRS) then sends the updated D_N to the traffic stations in its EPRB (WPRB) via east-east (west-west) transponders.

3. For traffic stations that transmit their traffic bursts to both east-west (west-east) and east-east (west-west) transponders, control is administered in the same way as in case 1. This is possible because the WPRB and EPRB are synchronized.

4.8 Asynchronous Interfaces

In this type of connection no special frequency relationship between the TDMA system and the terrestrial networks is assumed. Slip-free operation can be achieved through the use of pulse stuffing on the transmit side to account for the difference between the TDMA clock and the terrestrial clock, and pulse de-stuffing on the receive side to restore the original data rate. Doppler buffers must again be employed on both transmit and receive sides to account for the effects of satellite motion. Figure 4.14 illustrates asynchronous interfaces. Each of these interfaces contains a stuffer and a de-stuffer as shown in Fig. 4.15.

On the transmit side, the incoming terrestrial data stream is asynchronous; that is, its bit rate fluctuates around the nominal bit rate R_k. The clock frequency is recovered by the clock recovery circuit. To make the data stream synchronous with the TDMA clock at frequency f_0, (or a sub-multiple of f_0, namely fo/m, where m is an integer), an elastic buffer is employed. Asynchronous data is written into the elastic buffer by the write clock at a frequency of $f_k = R_k$, and synchronous data is read out of the elastic buffer by means of the TDMA clock. Since data must be written into the elastic buffer before it can be read out, the read clock must operate at a faster rate than the write clock; that is, the TDMA clock rate f_0 is set higher than data clock rate f_k, the frequency difference $f_0 - f_k$ is the stuffing rate. The read clock cannot be allowed to overtake the write clock to the extent that it attempts to read a bit that is not yet in the buffer.

To prevent this situation, the phase difference between the write and read clocks is determined by a phase comparator. When the phase difference between the clocks reaches a certain threshold, the stuff decision circuit generates a stuff request to make the read clock dwell for one additional time slot. As a result, one bit in the elastic buffer is read twice or, in effect, a dummy bit is stuffed into the data stream.

Also, the stuff control bits are multiplexed to the data stream at precise intervals according to a framing scheme which allows identification of the stuffing bits on the receive side so that they can be removed from the data stream. The output of the stuffer is a data stream operated at the TDMA clock rate f_0 or at a bit rate of $R_0 = f_0$ bits per second.

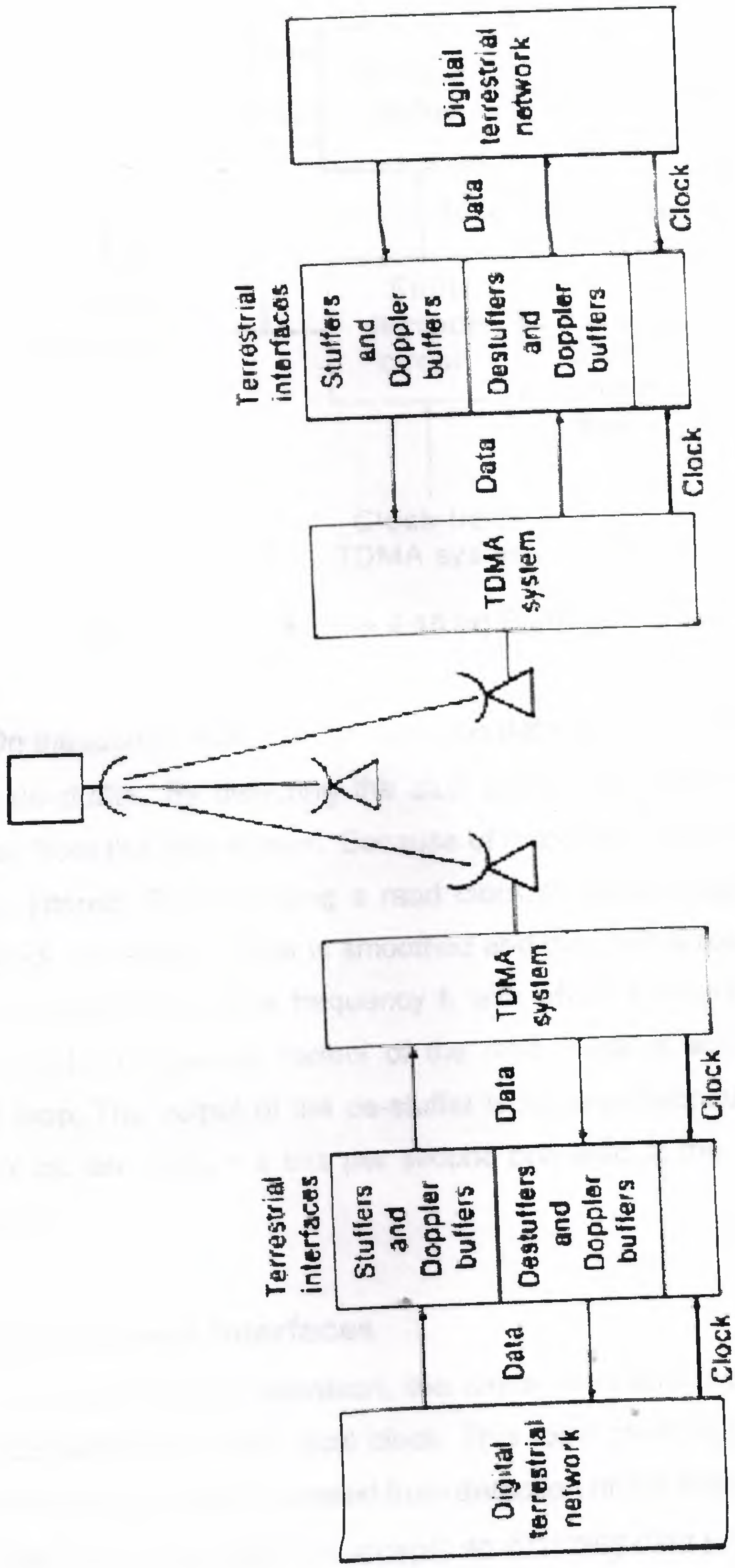


Figure 4.14 Asynchronous interfaces

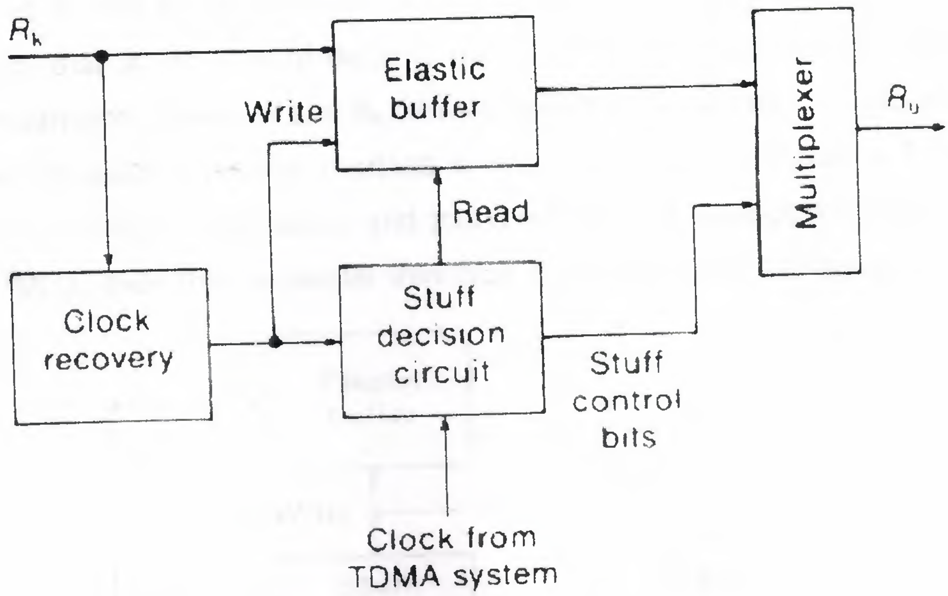


Figure 4.15 (a) Stuffing

On the receive side, the synchronous data stream at bit rate R_0 is received by the de-stuffer. By detecting the stuff control bits, the stuffed bits can be removed from the data stream. Because of removal of the stuffed bits the write clock is jittered. By generating a read clock at the average frequency of the write clock, the effect of jitter is smoothed and the data is read out of the elastic buffer with the same clock frequency f_k with which it enters the stuffer on the transmit side. Frequency control of the read clock is achieved by a phase-locked loop. The output of the de-stuffer is an asynchronous data stream at a nominal bit rate of $R_k = f_k$ bits per second operated at the nominal read clock frequency f_k.

4.9 Synchronous Interfaces

In a synchronous operation, the digital terrestrial network clock is synchronized with the TDMA local clock. This local clock is phase-locked to the reference station clock recovered from detection of the reference burst's unique word. Each terrestrial interface accepts an incoming data stream from the digital terrestrial network at a rate of R_k bits per second and delivers an outgoing data stream at a rate of R_k bits per second to the terrestrial network. Slip-free operation, that is, no loss of data, is achieved by synchronizing the outgoing data stream with a clock of $f_k = R_k$ derived from the TDMA clock at frequency f_0, assume that each terrestrial interface is designed to accommodate a T_1 carrier at a bit rate of R_k = 1.544 Mbps and that the TDMA local clock frequency is f_0 = 44.776 MHz; then the terrestrial interface clock can be obtained as $f_k = f_0/29$

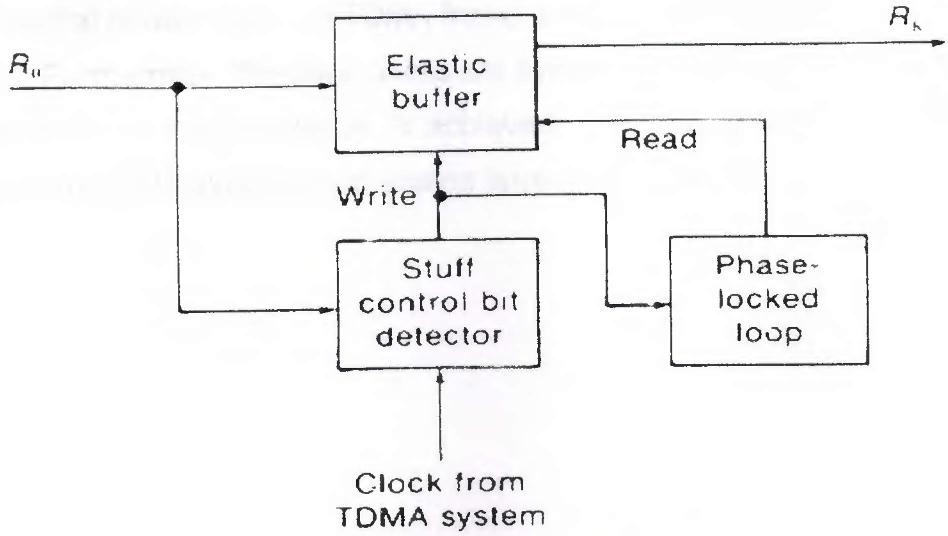


Figure 4.15(b) De-stuffing

1.544 MHz. The terrestrial interface multiplexes the data stream and the clock and transmits them to the digital terrestrial network where the clock f_k is extracted from the data stream and used to generate the incoming data stream (from the terrestrial network to the TDMA system). Thus the incoming data stream is also synchronized with the TDMA clock. Because the outgoing data stream at the terrestrial interface is synchronized with the TDMA local clock phase-locked to the reference station clock no Doppler buffer is needed on the receive side of the terrestrial interface.

However, because of periodic modifications of the transmit frame using the transmit frame delay D_N, Doppler buffers are needed on the transmit it side. Figure 4.16 illustrates synchronous interfaces for a TDMA system. Note that in this mode of operation the PCM frame (125 μs) in the digital terrestrial network and the TDMA frame may not be synchronized, although the data clocks are synchronized with the receive TDMA clock. That is why Doppler buffers are employed on the transmit side.

If the terrestrial network operates with analog signals and when the timing for the PCM encoding of the analog signal is derived from the transmit frame timing and timing for the PCM decoding is derived from the receive frame timing, no Doppler buffer is required. This is because the PCM frames in the terrestrial network and the TDMA frame are fully synchronized.

Furthermore, the data clocks are synchronized with the TDMA clocks, and therefore slip-free operation is achieved. Figure fully synchronous interfaces between TDMA systems and analog terrestrial networks.

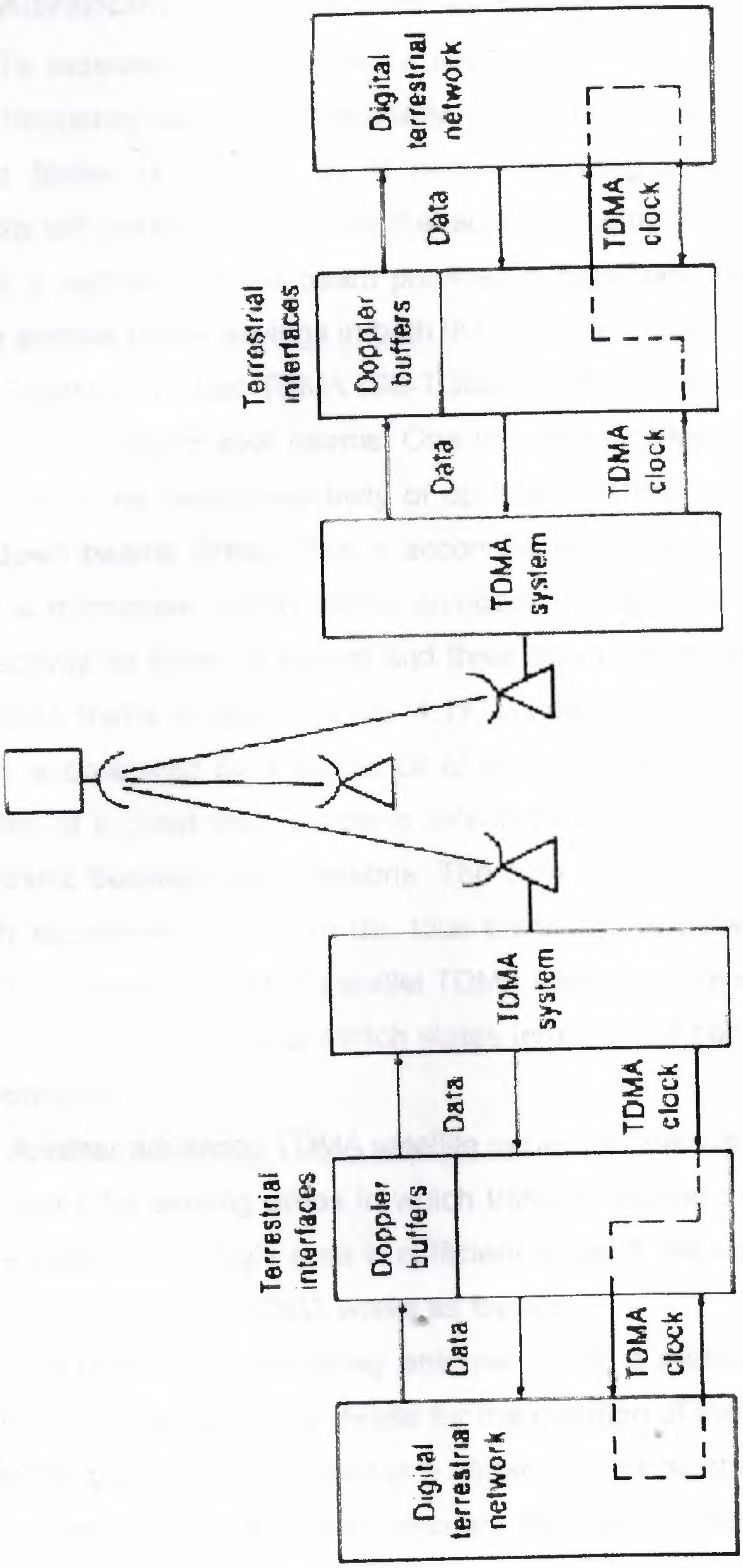


Figure 4.16 Synchronous interfaces for digital terrestrial networks

4.10 Advanced TDMA Satellite Systems

To increase satellite capacity, spot beams must be employed so that the same frequency band can be spatially reused many times. Theoretically, if the United States is covered by N non-overlapping spot beams, the satellite capacity will increase N-fold over that achieved using one beam. In addition, the use of a narrow antenna beam provides a high gain for the coverage area, hence permits power savings in both the uplink and downlink channels.

Satellite-switched TDMA (SS-TDMA) such as that planned for INTELSAT VI employs multiple spot beams. One inherent problem in multiple spot beam operation is the interconnectivity of up beams (UBs) with down beams (DBs) with down beams (DBs). This is accomplished by dynamic satellite switching using a microwave switch matrix on-board the satellite. An illustration of the connectivity for three up beams and three down beams and the corresponding SS-TDMA frame is shown in Fig. 4.17. During a SS-TDMA frame the satellite switch is controlled by a sequence of switch states of various durations. The duration of a given switch state is selected to accommodate a segment of the total traffic between earth stations. The sum of the segments provided by the switch sequence is equal to the total traffic of the network. In essence, SS-TDMA operates as a set of parallel TDMA frames on the uplink, which are then switched by a sequence of switch states into a set of parallel TDMA frames on the downlink.

Another advanced TDMA satellite system is beam-hopping TDMA which is very useful for serving areas in which traffic is spread out geographically and where traffic in no single area is sufficient to justify the use of a stationary spot beam. Beam hopping TDMA works as follows:

The on-board phase-away antenna points a particular spot beam in the direction of a new burst and dwells for the duration of the burst plus guard time needed for burst position uncertainty. After the first burst in the frame has been received and stored in the uplink memory, the beam is steered in the direction of the second burst, the second burst is stored, and so on until all the bursts in the TDMA frame are stored; then the hopping sequence is repeated for a new TDMA frame. The stored uplink bursts are then processed by an on-board processor which performs demodulation of the uplink carriers followed by reconfiguration of the uplink bursts into new downlink bursts each for a particular down-beam dwell, followed by re-modulation on downlink carriers. On-board demodulation and re-modulation decouple the uplink noise and interference from the downlink noise and interference to improve the bit error rate. Reconfiguration of bursts allows the grouping of all traffic into one burst destined for a particular region, thus avoiding the inter-burst interference associated with conventional TDMA.

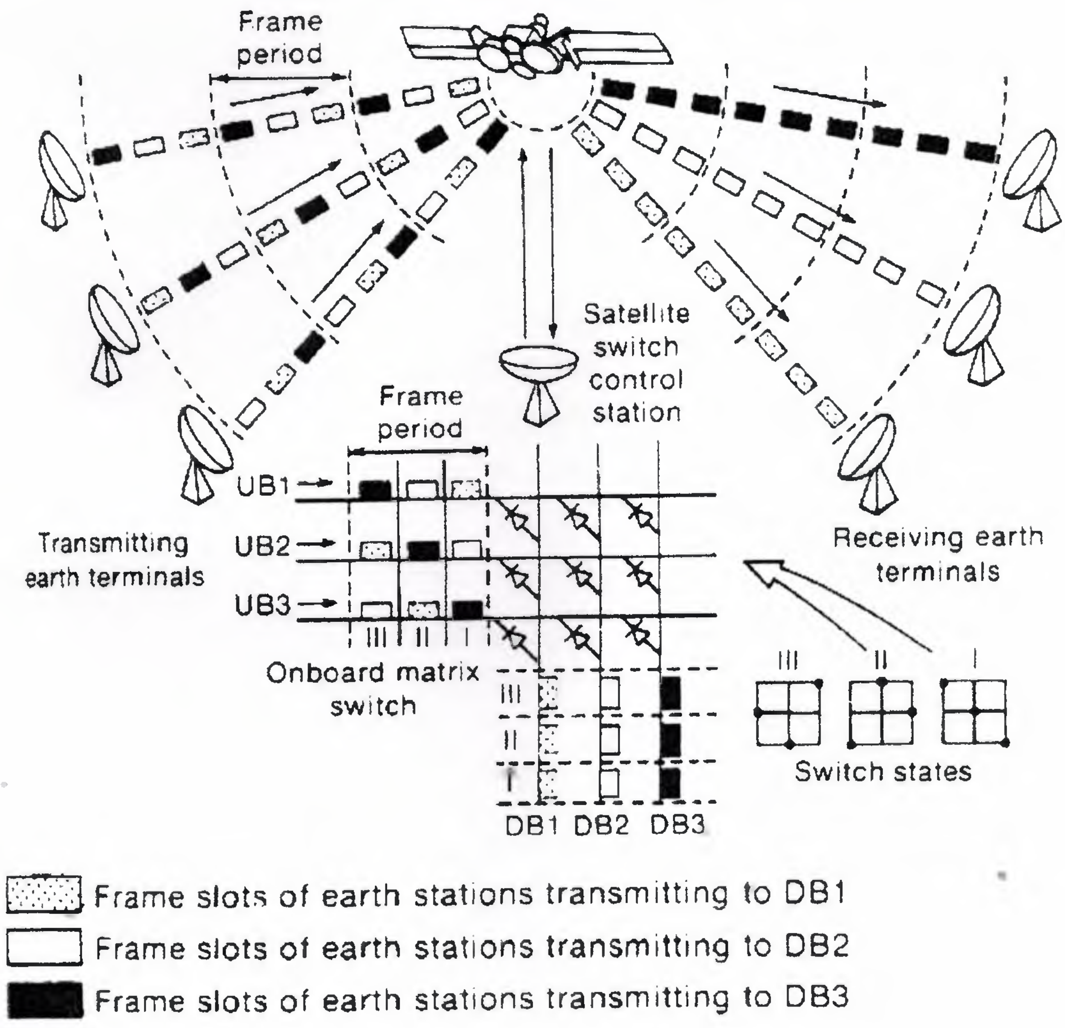


Figure 4.17 Satellite Switched TDMA

A combination of beam-hopping TDMA and SS-TDMA permits a mixture of low, medium and high bit rates. The planned NASA Advanced Communication Technology Satellite (ACTS) will employ on-board switching with beam hopping and may set a future trend for satellite communications.

CONCLUSION

A satellite communication system can take on several different forms it is know that an uplink from a ground-base station to the satellite, and a downlink from satellite back to ground modulated carriers in the form of electromagnetic field are propagated up to the satellite .The satellite collects the impinging electromagnetic field and retransmits the modulated carrier as a downlink to specified earth stations. A satellite that merely relays the uplink carrier as a downlink is referred to as a relay satellite or repeater satellite. More commonly, since the satellite transmits the downlink by responding to the uplink, it is also called a transponder.

If we interpret the transponder as an ideal "amplifier in the sky " the entire transponder must provide the required overall gain needed to multiply the uplink power level to that of the downlink. Taking into account the power losses of filters and cabling the required gain is generally far above that which can provide by TWTA alone. Hence, transponders require intermediate amplification to achieve the power level suitably matched to the capability of the high power downlink amplifier.

Transponder output power levels are directly related to available primary power the load the efficiency the less the carrier power for the given amount of primary power, or conversely the more primary power to achieve desire downlink carrier power.

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