ACKNOWLEDGEMENT

The author is grateful to Dr. V.K. Bhargava for his guidance and help throughout the writing of this report. He also thanks Dr. V. Ramachandarn and Dr. A. Antonio for their encouragement and extends his sincere regards to Mr. Paul Tan for his support in the completion of the report. He is thankful to Cynthia and Nargis for typing and proof reading of the report.

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGEMENT ii

LIST OF ILLUSTRATIONS vi

LIST OF TABLE viii

LIST OF ABBREVIATIONS ix

CHAPTER 1

INTRODUCTION

1.1 General 1

1.2 Scope of the report

CHAPTER 2

MULTIPLE ACCESS TECHNIQUE

2.1 General 7

2.2 Frequency division multiple access 13

2.2.1 Single channel per carrier PCM multiple access demand assignment equipment 18

2.3 Time division multiple access 24

2.4 Time division multiple/switched spacecraft/space division multiple access 27

2.4.1 Realization of TDMA/SS/SDMA 27

2.5 Demand assignment multiple access 34

2.6 Comparison between FDMA and TDMA modes 40

CHAPTER 3

DESCRIPTION OF TDM SATELLITE SUBSYSTEMS

3.1	General	43
3.2	Signal processing subsystem	47
3.2.1	Burst format	47
3.2.2	Frame format	49
3.3	Radio link subsystem	54
3.3.1	Satellite motion	54
3.3.2	Path loss calculation	55
3.3.3	Attenuation due to rain	60
3.4	Transmitting and receiving earth station subsystem	64
3.4.1	PCM codec	66
3.4.2	Buffer memory	67
3.4.3	Multiplexer/demultiplexer	69
3.4.4	Scrambler and descrambler	70
3.4.5	Preamble generator and differential codec	75
3.4.6	PSK modulator-demodulator	78
3.4.7	Burst synchroniser and time slot acquisition unit	91
3.5	Spacecraft subsystem	100
3.5.1	Telemetry and command	100
3.5.2	Description of TDM/SS/SDMA spacecraft	102
3.5.3	Design of microwave switching matrix (MSM)	104

CHAPTER 4

SYNCHRONIZATION TECHNIQUE FOR THE TDM SATELLITE SYSTEM

4.1	General	107

4.2 Analysis of the open loop method for TDM satellite 110
4.3 Close loop method 118
4.3.1 Synchronization procedure for TDMA satellite system 117
4.3.2 Synchronization procedure for TDM/SS/SDMA system 122

CHAPTER 5

CONCLUSION

5.1 General 143
REFERENCES 148
BIBLIOGRAPHY 153

LIST OF ILLUSTRATIONS

Figure		Page number
2-1	Input-output characteristic of TWT amplifier	8
2-2	Intermodulation due to adjacent carrier	10
2-3	Frequency arrangement of frequency division multiplex (FDM) telephony	12
2-4	Spectrum in a frequency division multiple access satellite system	14
2-5	Frequency allocation in SPADE	17
2-6	Time division multiple access time slot assignment	23
2-7	TDM/SS/SDMA communication satellite system	26
2-8	Source-oriented system	28
2-9	Destination-oriented system	29
2-10(a)	Switching in satellite	31
2-10(b)	Earth station for burst switching satellite	33
3-1	A common TDM satellite subsystem	44
3-2(a)	Frame structure of a TDMA system	46
3-2(b)	TDM/SS/SDMA frame format	53
3-3	TDM satellite system block diagram for calculating C/N ratio	57
3-4	Rain rate vs BER	61
3-5	Block diagram of a TDM terminal	63
3-6	A PCM communication system	65

3-7	Scrambler and descrambler block diagram	72
3-8	Differential encoder block diagram	76
3-9(a)	PSK modulator functional diagram	79
3-9(b)	PSK demodulator functional block diagram	81
3-10	Block diagram of 4 PSK	83
3-11	Typical symbol clock recovery	85
3-12	Typical carrier recovery with AFC	88
3-13	Phase lock loop block diagram	92
3-14(a)	The process of initial acquisition in PLL	95
3-14(b)	Burst timing vs. BER	98
3-15	Distribution subsystem block diagram	101
3-16	Switching matrix operation	103
3-17	Transponder bandwidth vs. no. of PCM channel	105
4-1	Open loop synchronization diagram	109
4-2	PSK synchronization burst	124
4-3	Synchronization-signal and structure	128
4-4	Ground station with digital control	136
4-5	Ground station with analog control	138
4-6	Tracking mode	140

LIST OF TABLE

Table no.		Page no.
4-1	Comparison of PSK sync, burst method and coded search signal method	133

LIST OF ABBREVIATIONS

AFC	Automatic frequency control
BER	Bit error rate
BPSK	Binary phase shift keying
CCIR	International radio consultative committee
C/N	Carrier to noise ratio
CODEC	Encoder-decoder
CSC	Common signalling channel
DAMA	Demand assignment multiple access
DCU	Distribution control unit
DSI	Digital speech interpolation
FDM	Frequency division multiplexing
FDMA	Frequency division multiple access
FDM-FM	Frequency division multiplexing-frequency multiple
IF	Intermediate frequency
IM	Intermodulation
INTELSAT	International telecommunication satellite
LPF	Low pass filter
MAT	Multiple access technique
MODEM	Modulator-demodulator
MSK	Minimum phase shift keying
MSM	Microwave switching matrix
QPSK	Quaternary phase shift keying
PCM	Pulse code modulation
PLL	Phase lock loop

PSK	Phase shift keying
RF	Radio frequency
RUW	Reference unique word
SCPC	Single channel per carrier
SI	Speech interpolation
SS	Switched spacecraft
SPADE	Single channel per carrier PCM multiple access demand assignment equipment
TDM	Time division multiplexing
TDMA	Time division multiple access
TSAU	Time slot acquisition unit
TWT	Travelling wave tube
TDM/SS/SDMA	Time division multiple/switched spacecraft/space division multiple access
SIC	Station identification code
UW	Unique word

Dedicated to my Uncle and Aunt,

Mohmmed Hafiz and Hasibun Nessa.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the last decade numerous domestic and military satellite systems have mushroomed around the world. The evolution of the satellite and earth station in the last decade has been nothing less than phenomenal and provides on the most cost effective means to cope with sparse population, hostile terrain and long distances. Thus the satellite communication has become as much a part of our daily life as world-wide sports, news and telecommunications.

A communication satellite is an intermediate operator between transmitting and receiving earth stations. It receives messages from transmitting stations in any of the multiple access modes at its one end, and sends them through the other end in the same mode to the destined stations.

The choice for implementing one of the modes of multiple access in satellite has been the focus of research during the last two decades. In spite of several drawbacks in frequency division multiple access (FDMA), it has been employed by all the satellites so far except Earlybird (Intelsat 1). Some shortcomings of FDMA were obvious from the beginning and some were observed during the operation of the satellites. The observed demerits were due to the growth of traffic for communication via satellites and several other reasons.

Another obvious and available mode of multiple access is the transmission of messages in the time domain i.e. time division multiple access (TDMA). It has several advantages over FDMA. It is possible to eliminate intermodulation between two carriers to nil by using TDMA.

Another modified version of TDMA is time division multiple/switched spacecraft/space division multiple access (TDM/SS/SDMA), where on board switching was suggested. Switching in the satellite enables each earth station to transmit its bursts in sequence on one frequency and to receive its burst in sequence on another frequency. The sequence bursts arriving at and departing from the satellite must be rearranged by a switching matrix in the satellite. On reception all time frames are translated to a common intermediate frequency (I.F.) and fed to the input of the switching matrix, which has been previously programmed.

This report, besides the survey of the modes of multiple access techniques like FDMA, SPADE, DAMA, TDMA, TDM/SS/SDMA, presents comprehensive and illustrative summary on state of the art of operation and function of each equipment located at the transmit/receive earth station, together with some evident trends that both the systems (i.e. TDMA and TDM/SS/SDMA) look alike except some minor changes in the ground stations and major changes in the spacecraft. The report examines various factors that significantly influence the operation of the equipment of TDMA and TDM/SS/SDMA. Such examinations are done on burst length; buffer memory; PSK modem; and slot acquisition unit.

It is shown that the fundamental acquisition problem in TDMA and TDM/SS/SDMA is similar and it can be related to the behavior of the phase lock loop (PLL).

A decade of research on synchronisations and initial acquisition methods are classified into two groups: open loop method and closed loop method. An example of synchronisation and initial acquisition method has been described by implementing in a common TDMA and TDM/SS/SDMA. It is noticed that in TDMA the detection of unique words (UWs) are very important in order to achieve synchronisation and resynchronisation.

In order to achieve synchronisation between the transmitted bursts and the sequence of the preprogrammed switching sequence in TDM/SS/SDMA a new structure of "Superframe" is introduced. "Superframe" consists of a sync burst and conventional TDMA bursts. Three simple steps in acquiring synchronisation and initial acquisition in TDM/SS/SDMA are described in this report.

1.2 SCOPE OF THE REPORT

In this report, the author conducts a survey of the various multiple access techniques and to provide an all encompassing overview of the complete process of satellite communication. It was decided by the author after considerable search to provide the overview since most treatise and write-ups generally cover one specific topic of satellite communication. In this report, the author attempts to cover significant aspects of the modes of multiple access techniques, earth station, the satellite and their interrelationship. These are described as follow:

Chapter 1 of this report is a brief overview of a decade of research and development in the satellite\communication.

Chapter 2 contains the description and application of different modes of multiple access techniques and compares FDMA with TDMA.

Chapter 3 describes the subsystems of a satellite operating in time domain i.e. TDM satellite. Brief description on frame format, selection of frame length, satellite motion, effect of rain on propagation path and path loss calculation technique are identified.

Significant equipment at the transmit/receive earth stations such as PCM coder, buffer memory, scrambler/descrambler, PSK modem, time slot acquisition unit; along with consideration required for the selection of the size of microwave switching matrix for the spacecraft of TDM/SS/SDMA satellite are contained in this chapter.

Open loop and close loop method for synchronisation of TDMA and TDM/SS/SDMA are explained in chapter 4 of this report.

The conclusion has been made in chapter 5 where it has been stressed that the future generation will use TDMA and TDM/SS/SDMA Satellites.

CHAPTER 2

MULTIPLE ACCESS TECHNIQUE

2.1 GENERAL

Through multiple access technique (MAT), a satellite is able to receive one or multiple signals from one or multiple earth stations and transmit them accordingly. This operation of shared use of the transponder of a satellite by different earth stations located within the communication range [1] of a satellite is called multiple access technique.

Multiple access technique has been developed only recently and is widely used in the satellite communication. Two problems arise in implementing this technique in the satellite communication [1]:

a. There may be a number of earth stations within the communication range of the satellite and it may be possible that each earth station may differ from the other in its performance and also in the number of channel requirements.

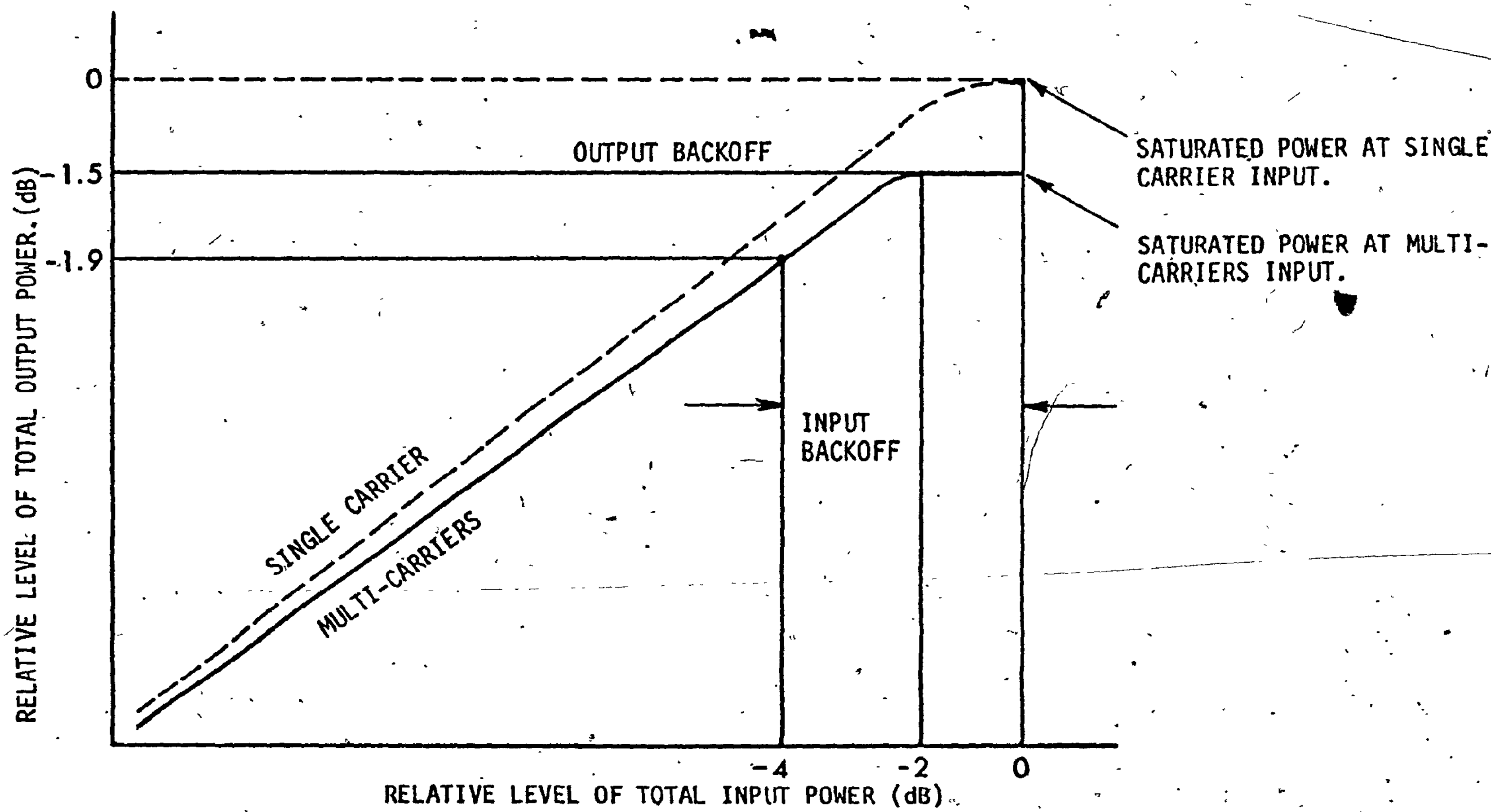


Figure 2.1: Input-Output Characteristics of TWT Amplifier

b. Each earth station has its own carrier and when multiple carriers from multiple earth stations are accessed together, the problem of intermodulation (IM) arises due to the non-linearity of the satellite's transponder. A satellite's transponder mainly consists of travelling wave tube (TWT) which is used for the amplification of the signals. The input-output characteristics of the TWT, shown in Figure 2.1, is non-linear [2]. In order to achieve maximum efficiency of a satellite, the TWT should be operated near saturated region. Unfortunately, when many carriers are amplified simultaneously through a TWT, due to the overlapping of a signal spectrum on some portion of adjacent signal spectrum, the problem of IM arises. The shaded area shown in Figure 2.2 represents the IM. In order to reduce the effect of IM, the "back-off" is required. That is, the TWT should be operated below the saturated region. Consequently the "back-off" causes degradation in the utilization of the satellite capacity..

The above two problems related to the MAT are too acute and more care is needed for using MAT in the satellite communication.

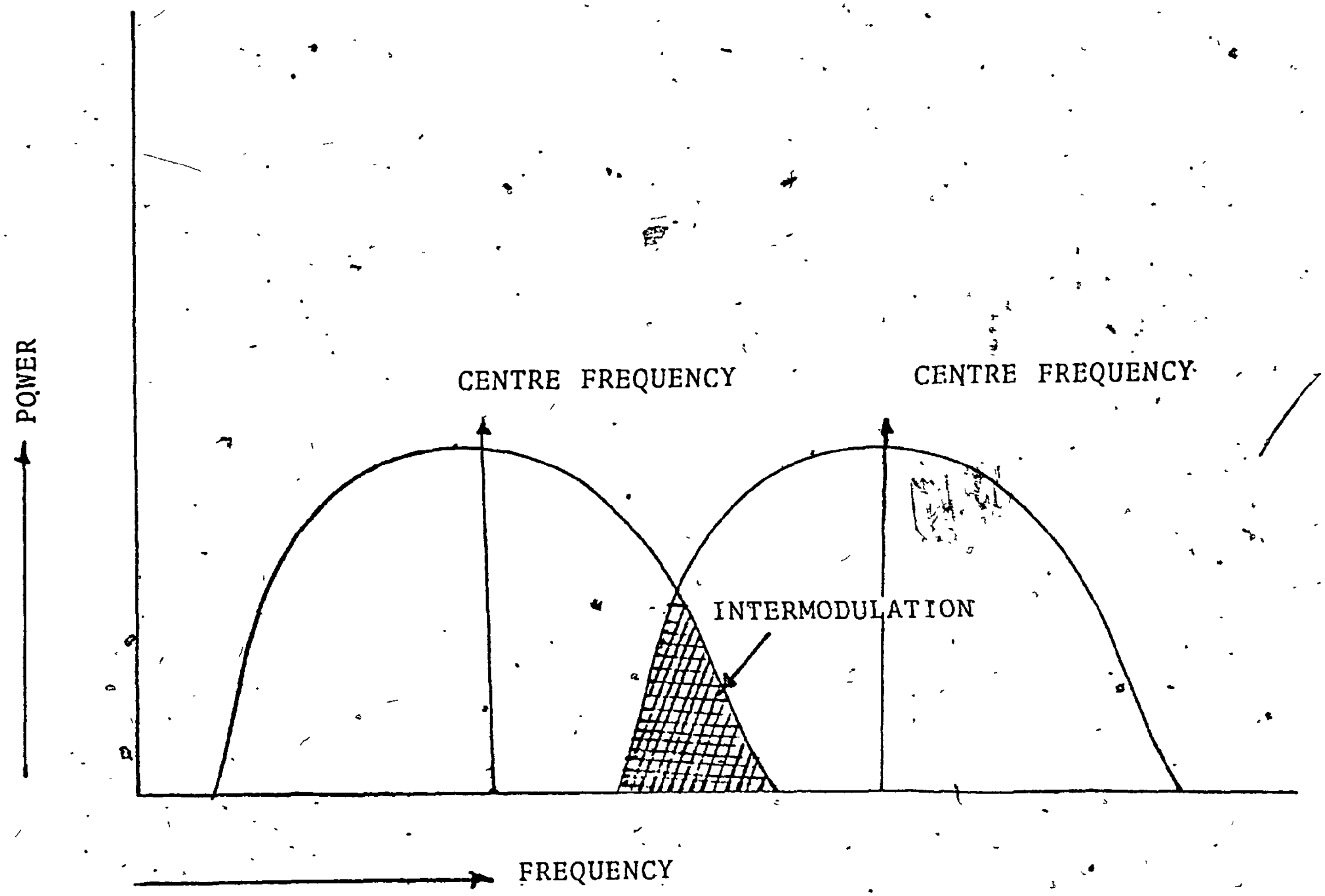


Figure 2-2: Intermodulation due to Adjacent Carriers

The application of MAT in a satellite system can be classified into two forms from the standpoint of (i) frequency utilization, and (ii) circuit utilization.

The frequency in the MAT can be utilized in two ways (i) in frequency domain called frequency division multiple access and (ii) in time domain called time division multiple access.

Similarly, the circuits in the MAT can also be utilized in two ways (i) on immediate demand called demand-assignment multiple-access and (ii) permanently assigned between two or more stations called pre-assigned multiple access technique.

These subclasses of the MAT are called the modes of multiple access technique and each of them is described hereinafter.

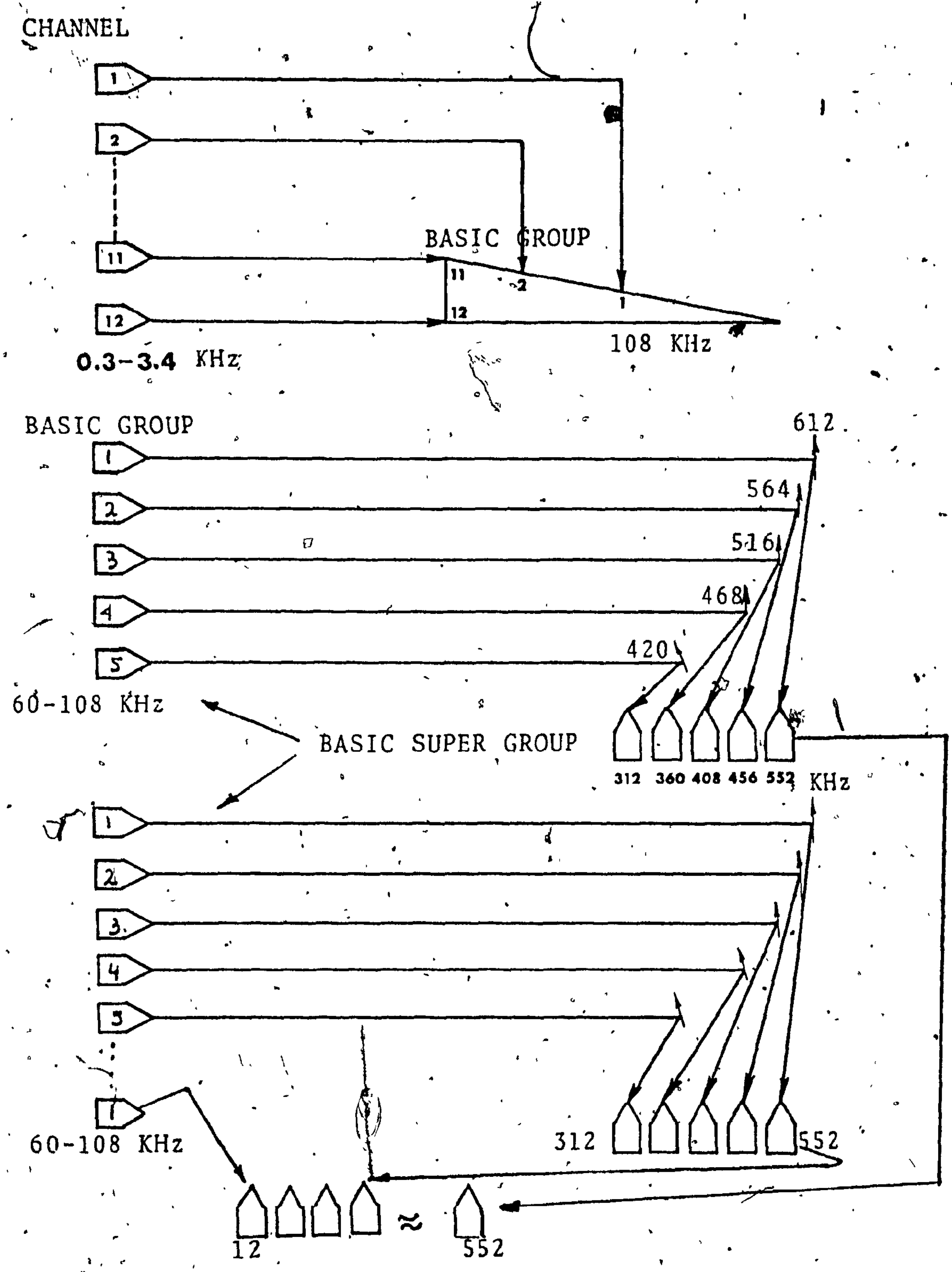


Figure 2.3: Frequency Arrangement of Frequency Division Multiplex (FDM) Telephony

2.2 FREQUENCY DIVISION MULTIPLE ACCESS

Many telephone chanels each having bandwidth of 4 KHz are multiplexed in frequency domain and this technique of multiplexing is called frequency division multiplexing (FDM) telephony. The actual multiplexing process, shown in Figure 2.3, is described herewith:

a. In this concept 12 telephone channels are frequency converted to compose a "basic group" in the frequency range (4KHz X 12) = 60KHz to 108KHz. The variation in the range depends upon the guard band between the two adjacent channels.

b. The five "basic groups" are again frequency converted to compose a "basic super group" in the frequency range from 312 to 552 KHz. The variation in the range depends upon the guard band between the two adjacent channels.

c. Frequency-conversion of this "basic super group" could be realized to multiplex further many telephone channels.

The frequency range assigned from FDM is lower than that of the requirement for the satellite communication. Hence this technique is not used in the satellite system.

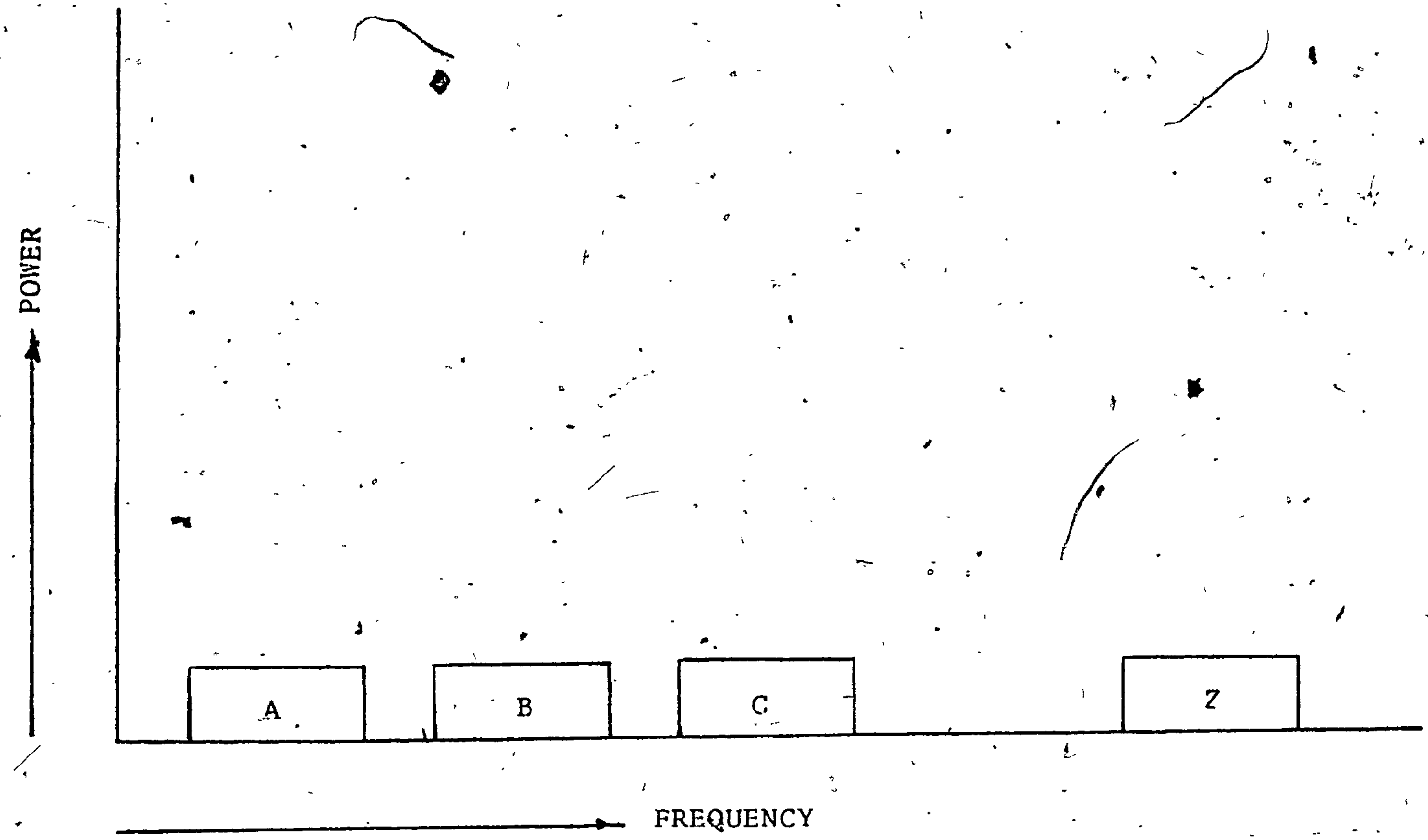


Figure 2-4: Spectrum in a Frequency Division Multiple Access Satellite System.

Another system of FDM is called frequency division multiplexing - frequency multiple (FDM-FM), where the radio-carrier is frequency modulated by the FDM signal. This system has wide application in communication satellite system. The MAT can be realized by the FDM-FM-FDMA, generally referred to as FDMA.

FDMA, is a common and conventional technique, used in the satellite system and this mode of MAT is being used in almost all the satellites which are presently in service.

FDMA is analogous to frequency division multiplex in which each user is assigned a unique frequency band. In FDMA, each transmitting or receiving earth station has its own frequency bandwidth. The idea of FDMA is pictorially illustrated in Figure 2.4, where the various blocks A, B, C, etc. signify the different users and there is a guard band between two consecutive channels in order to reduce overlapping of the adjacent channels.

There are many ways to realize FDMA system in the satellite communications. For instance there are, say, 'n' earth stations and each earth station would transmit (n-1) carriers to the rest of the (n-1) stations, then the transponder of the satellite have to amplify n(n-1) carriers, resulting in the problem of the IM for both the power amplifiers (i.e. TWTs) of the earth stations and the transponders of the satellite. This realization of FDMA can be called multi-destination carrier system.

The effect of IM on the FDMA multi-destination carrier system can be reduced by minor modification in the signal processing. That is, one carrier accumulates all the telephone channels to be transmitted from one earth station to the satellite and at the receiving stations, after all carriers are received and demodulated, only the channels which are destined for it are picked up. Consequently, the problem of IM for each earth station's transmitter, is solved as one station, transmits only one carrier. Thus the IM in the satellite's transponder is lessened since the number of carriers to be amplified by it would be only n. However, the problem with this method is that a carrier accommodating many channels would require more power. So a small level carrier is more affected by IM. Hence, the number of channels per carrier must be limited.

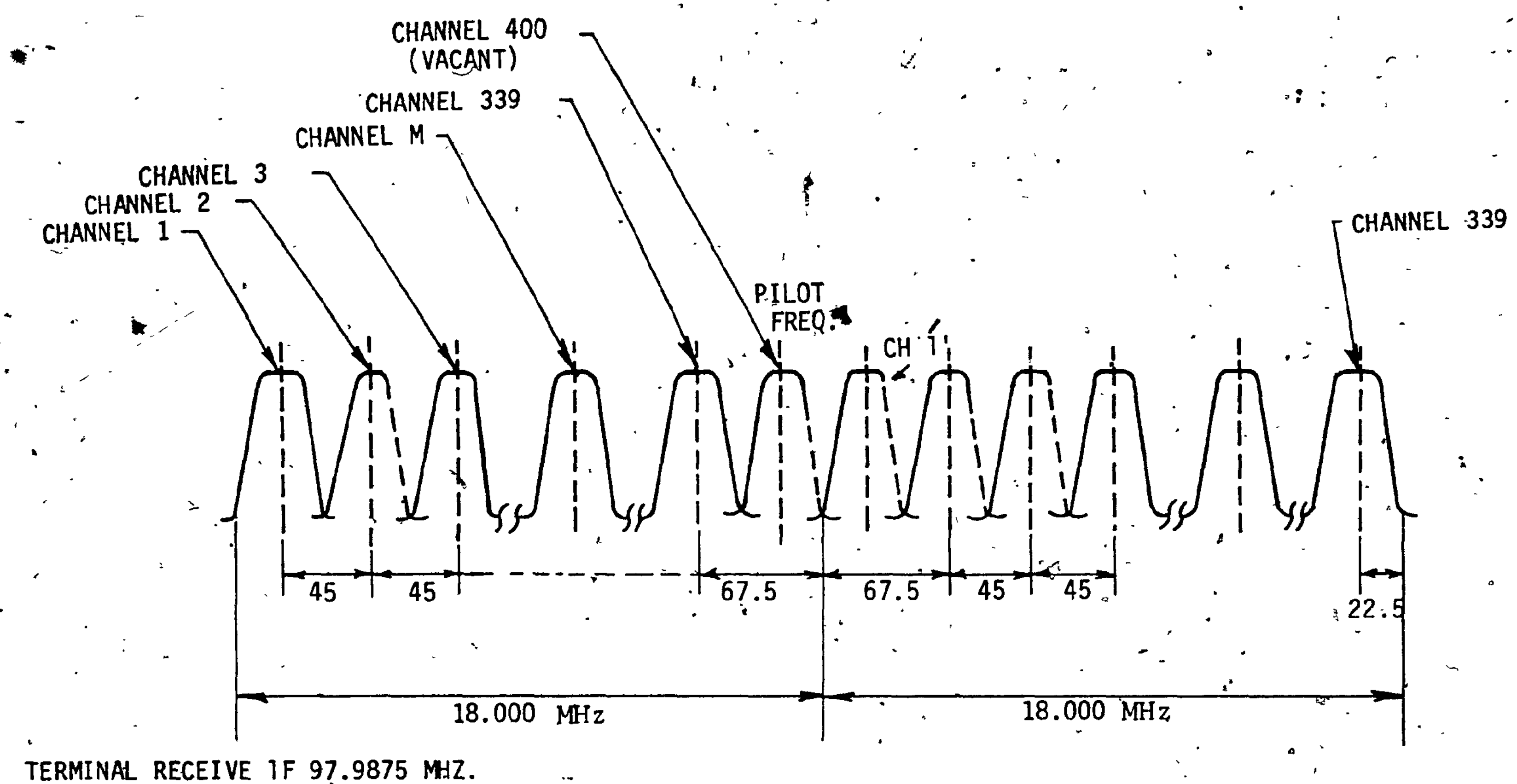


Figure 2.5: Frequency Allocation in SPADE

The technique has been utilized in one of the transponder of the INTELSAT IV.

Another way of realizing FDMA technique in the communication satellite is called single channel per carrier (SCPC), where one channel is assigned to only one carrier. This technique was developed by the COMSAT Corporation for low density routes (i.e. low density traffic). The modified version of SCPC is called single channel per carrier PCM multiple access demand assignment equipment (SPADE) and is described next.

2.2.1 SINGLE CHANNEL PER CARRIER PCM MULTIPLE ACCESS DEMAND ASSIGNMENT EQUIPMENT

The technique of transmission of signals through SPADE is similar to that of the FDMA where each carrier is assigned none or one or many signals depending upon the traffic demand. That is, it is operated in variable mode and it is economical for those earth stations where the circuit requirements are minimal.

The frequency allocations for the respective carriers in the SPADE system is shown in Figure 2.5. Each channel in SPADE is a single channel pulse code modulated-phase shift-keyed (PCM-PSK) carrier. The voice channels are divided into the higher and the lower channel groups, with pilot frequency at the centre. A matched pair (1-1' as shown in the Figure 2.5) of higher and lower channels constitute one telephone channel. This is done because SPADE has two way traffic.

The frequency division in SPADE and related mathematical formulations are given below;

The bit rate of a voice channel

= 64 kbits ----- (2-1)

The channel bandwidth, using 4-PSK as modulation, according to Nyquist

= 32KHz - - - - (2-2)

Since, practically it is not possible to recoupe the signal at Nyquist rate without distortion, the channel bandwidth for transmission purposes would be 20% more than the Nyquist bandwidth.

Thus total channel bandwidth required to transmit 64K bits data

$$= 32KHz + 0.2X32KHz$$

$$\simeq 38KHz \quad ---- \quad (2 - 3)$$

The guard band required between two channels

$$= 7KHz \quad ---- \quad (2 - 4)$$

Thus the distance, between two carriers of two adjacent channels, in frequency domain as shown in Figure 2.5

$$= 45KHz \quad ---- \quad (2 - 5)$$

The bandwidth of a transponder of INTELSAT IV is,

$$= 36\ MHz \quad ---- \quad (2 - 6)$$

The number of channel with the bandwidth of 36 MHz can occupy '.

$$= \frac{36 \times 10^6}{45 \times 10^3}$$

$$= 800 \text{ channels} \quad ---- \quad (2-7)$$

The number of pair channels

$$= \frac{800}{2}$$

$$= 400 \quad ---- \quad (2\text{-}8)$$

One pair channel is used by the reference station for synchronization of the system, the remaining number of channels are 399. Thus the separation between the carriers of each pair is equal to 18.045 MHz.

The SPADE system uses a common signalling channel (CSC) in order to send and receive the telephone exchange signals. That is, CSC is used by all the earth stations in time domain. The 2ΦPSK modulation is used for CSC.

The SPADE has the following features from the standpoint of operation:

a. It enables the interconnection between the stations having different signalling systems of domestic network.

b. Every channel in the SPADE system is independent, hence, a malfunction in any of the stations does not affect the entire system.

c. Increase or decrease in the number of circuits can easily be made.

d. The overflow calls from the system like FM-FDMA can easily be accomodated in the SPADE system.

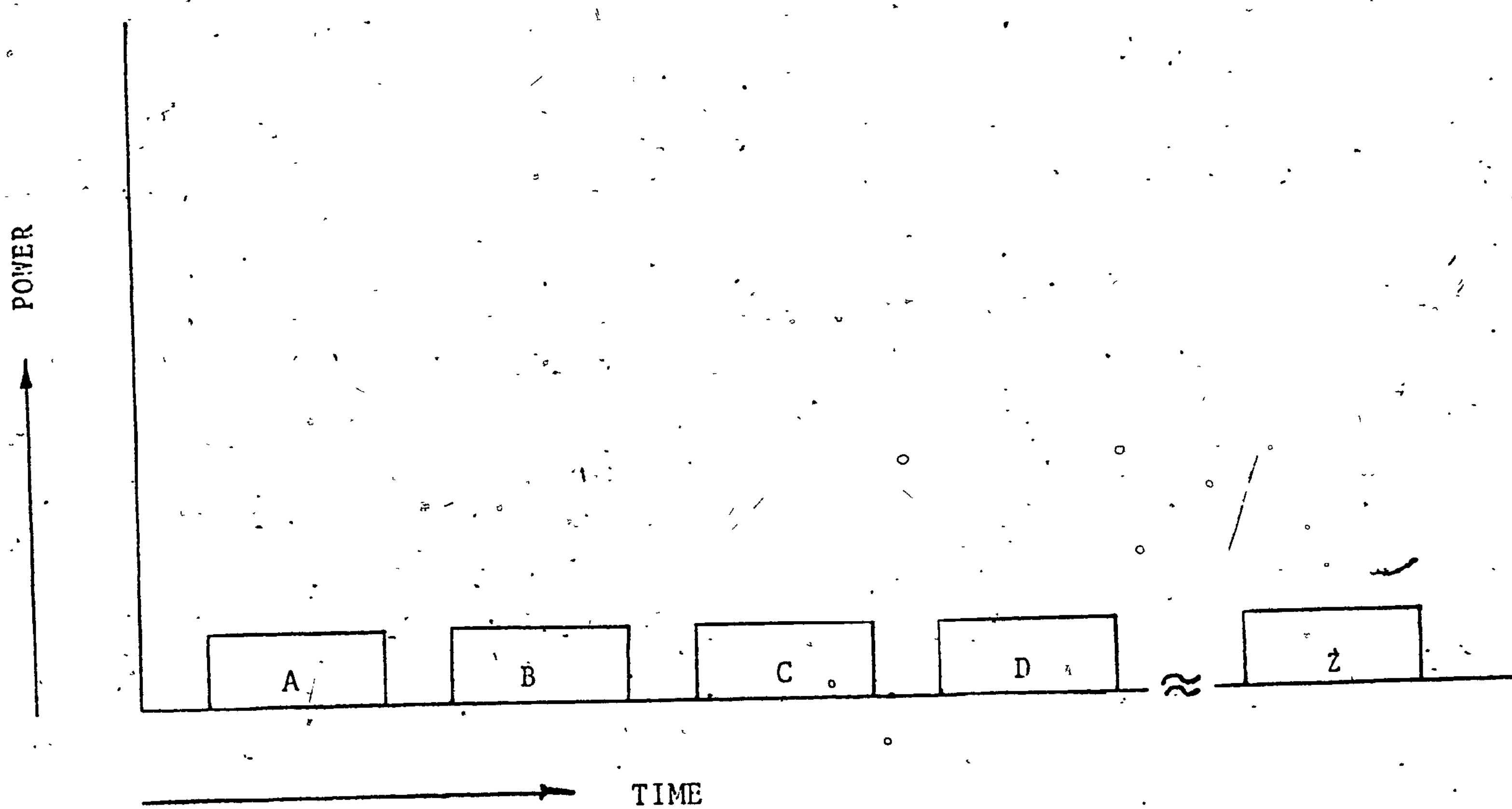


Figure 2.6: Time Division Multiple Access Time Slot Assignment

2.3 TIME DIVISION MULTIPLE ACCESS

One of the modes of the MAT is time division multiple access (TDMA) where many analog input signals are pulse coded by the pulse code modulator (PCM) and then multiplexed in time domain. Since PCM is generally used in the satellite communication, so other technique will not be discussed. The pulse coded bits are again upconverted to radio frequency (RF) with the help of the phase shift keying (PSK) for transmission to the satellite. The complete operation on the analog input signal is referred as PCM-PSK-TDMA. Different aspects of PCM and PSK are discussed in Chapter 3.

In TDMA, all the stations generate the same carrier frequency and the transmitting time slot for the respective stations are alloted. That is, the digitized burst carriers are intermittently transmitted by the respective stations and are arranged in time domain. The time slot assignment of TDMA system is shown in Figure 2.6, where A, B, C, etc., represent different bursts coming out of different earth stations.

TDMA system increases the number of channels compared to FDMA because there is no chance or zero probability of intermodulation's occurence [2].

Extensive research has been done on TDMA in order to increase the number of channels in the satellite. One of the results has been quite successful and it is discussed next.

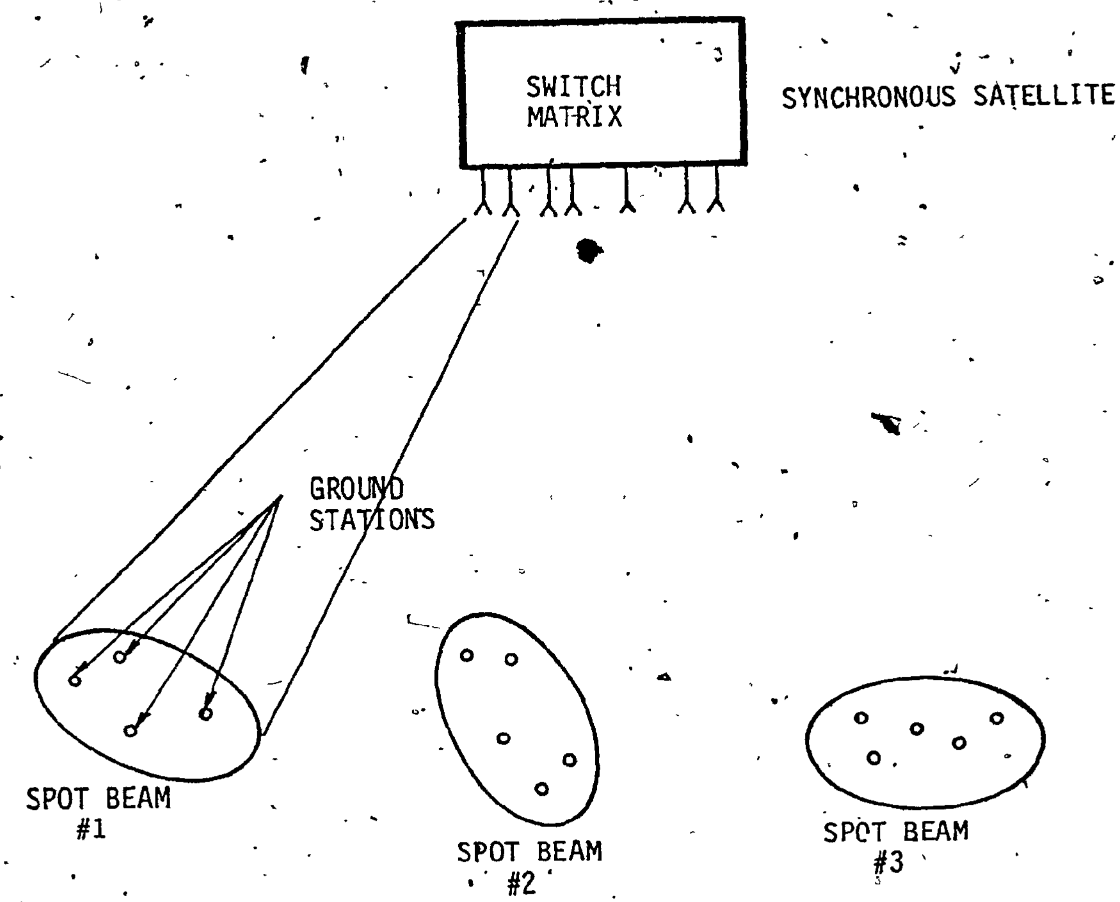


Figure 2.7: TDM/SS/SDMA Communications Satellite System

2.4 TIME DIVISION MULTIPLE/SWITCHED SPACECRAFT/SPACE DIVISION MULTIPLE ACCESS

In future, as traffic requirements increase, it will become necessary to introduce new high capacity satellites employing the frequency re-use [2] features through implementation of spot-beam zones as shown in Figure 2.7. In this arrangement, called time division multiple/switched spacecraft/space division multiple access which is an outgrowth of TDMA, each earth station in one beam might communicate with the other station in another beam. The beams are cyclically interconnected in a rapid sequence by a satellite borne distribution centre called spacecraft switching (SS), which is controlled by an onboard timing device of high stability. The highest acheivable capacity and great flexibility is provided by using time division multiple access, thus producing the TDM/SS/SDMA combination.

2.4.1 REALIZATION OF TDM/SS/SDMA

The analysis of a TDM/SS/SDMA becomes unweildy without a clear overview of the model. There are three means of realizing a TDM/SS/SDMA system, given below [3].

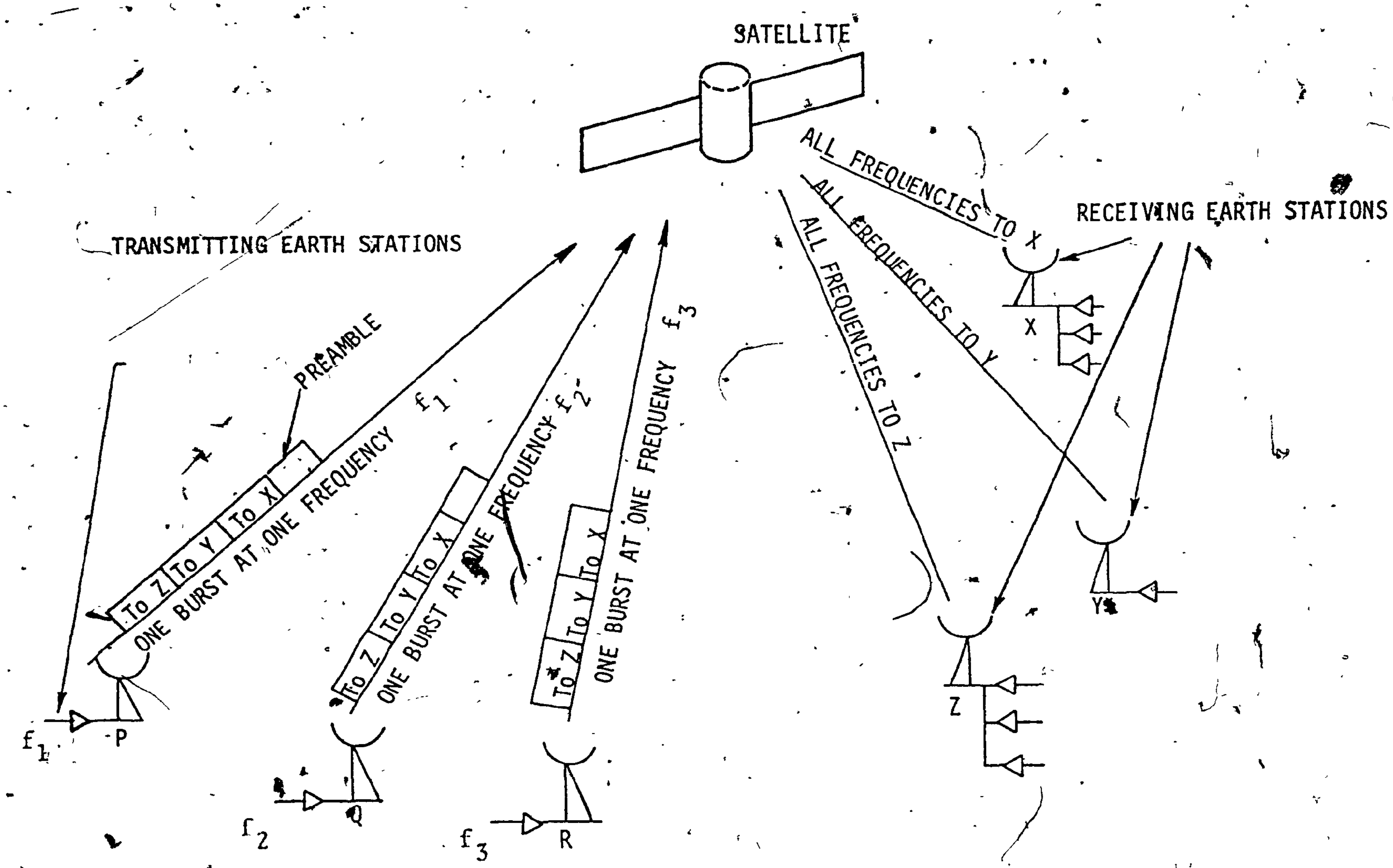


Figure 2.8: Source-Oriented System

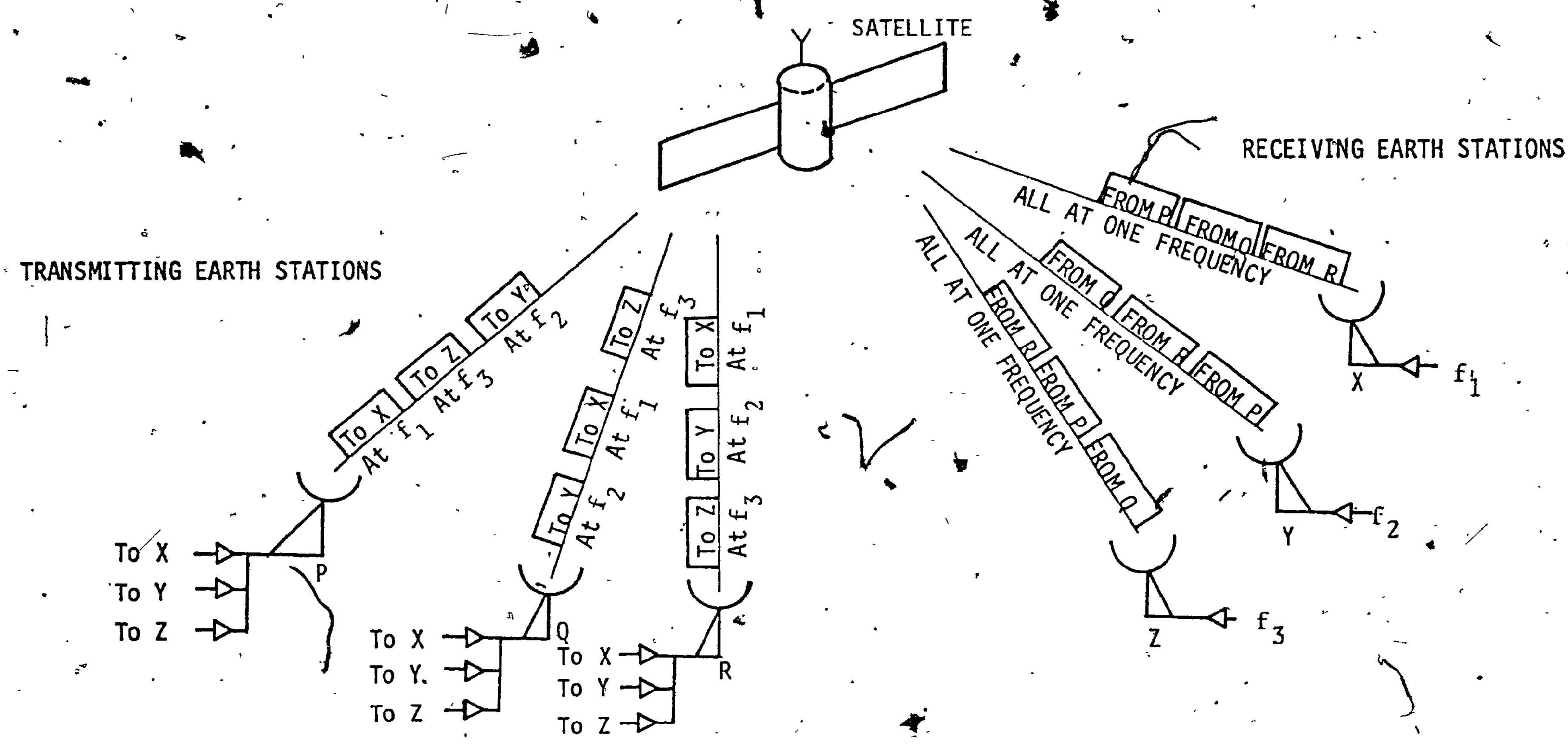


Figure 2.9: Destination - Oriented System

a. Source oriented system

Source oriented system of TDM/SS/SDMA model is presented in Figure 2.8 where each transmitting station has only one carrier. When the transmitted bursts from different transmitting earth stations arrive at the satellite, the switching matrix arranges them according to their destinations and sends them to the respective ground stations.

b. Destination oriented system

Destination oriented system of TDM/SS/SDMA model is shown in Figure 2.9 where each transmitting station has more than one carrier and they send data burst at different carriers. When the transmitted bursts from different earth stations arrive at the satellite, the switching matrix arranges them according to their destinations and sends them to the respective ground stations. Each ground receiving station can receive at only one frequency. This is just the opposite of the model a.

c. Satellite switched system

This model is less complicated compared to the above two models. Here, each earth station

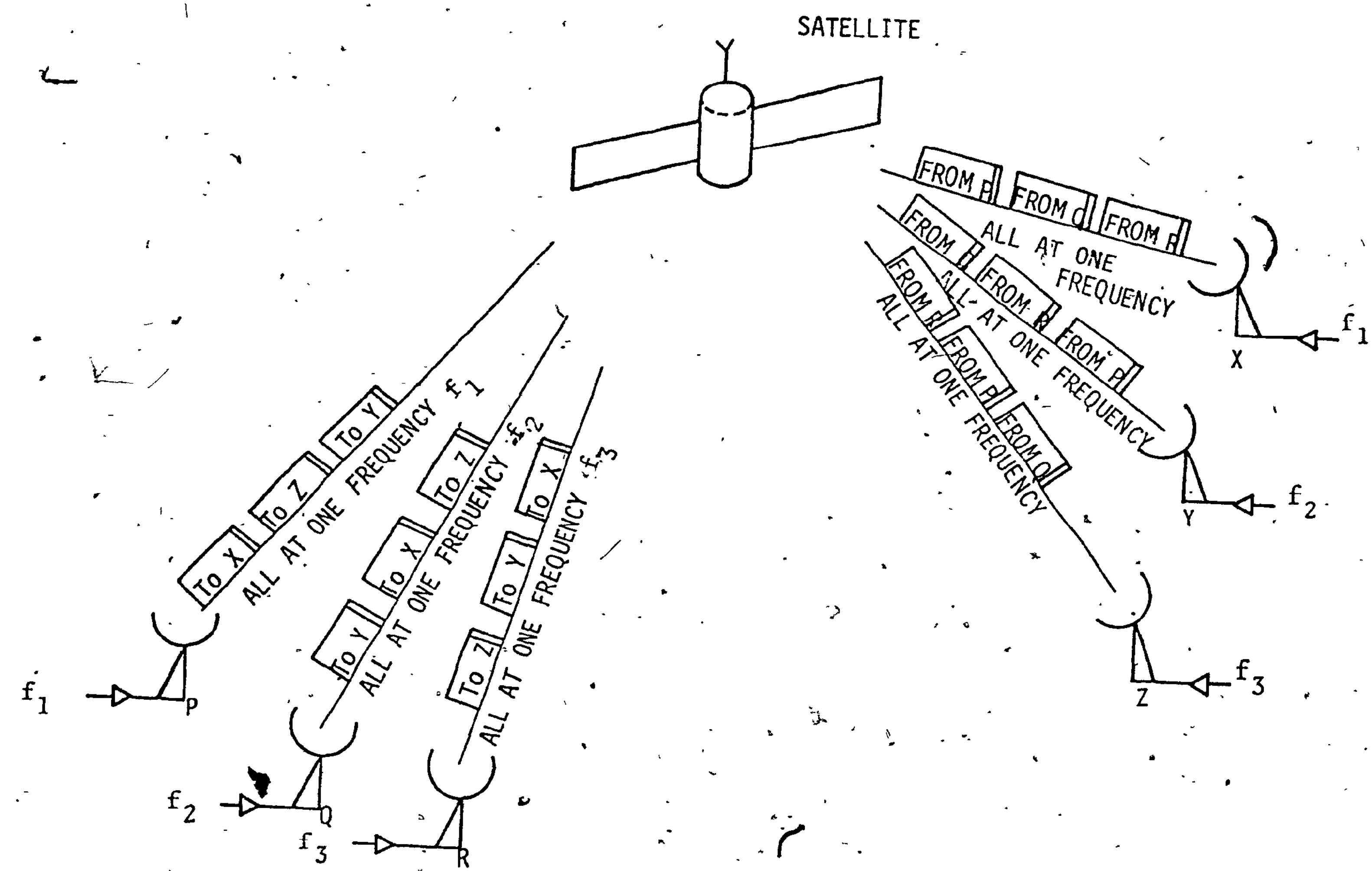


Figure 2.10 (a): Switching Satellite

transmits its bursts in sequence on one frequency and the receiving station receives its bursts in sequence on one frequency. This model simplifies both the transmission and reception side of the earth station. The model is shown in figure 2 - 10a, -b. The sequence of the bursts arriving at and departing from the satellite must be re-arranged by a switching matrix located in the satellite.

Different aspects of the satellite switched system are discussed in Chapter 3 and 4.

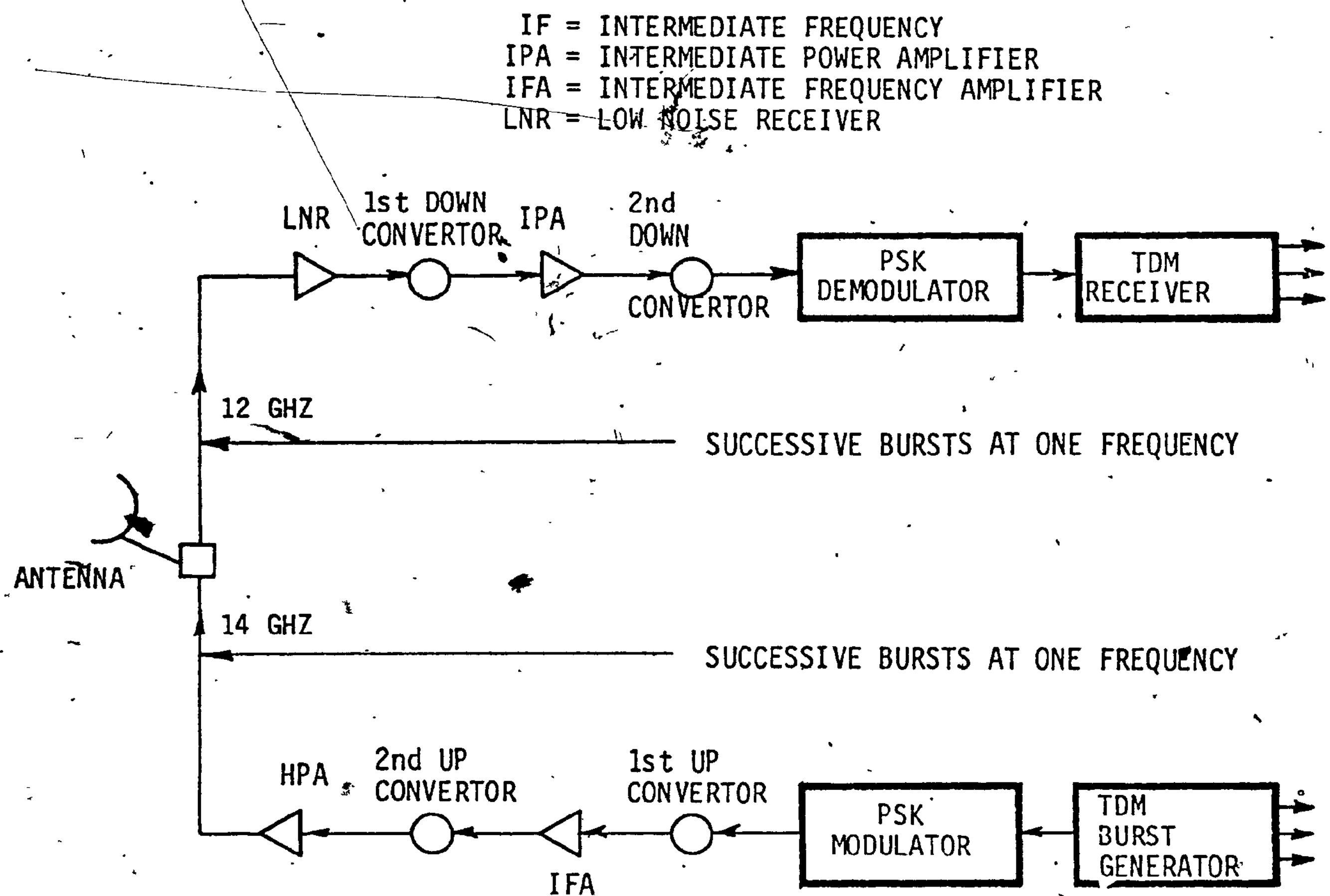


Figure 2.10 (b): Earth-Station for Burst-Switching Satellite

2.5 DEMAND ASSIGNMENT MULTIPLE ACCESS

COMSAT corporation has developed a demand assignment multiple-access (DAMA) system which can be used with SCPC and SPADE. The purpose of the DAMA is to facilitate a greater network operating efficiency for switched messages (voice or data) over low density trunk. It accomplishes this goal by facilitating the operation of entire resources of the multiple access network as a single trunk and by incrementally allocating messages for the use on a pre-call basis to meet the actual service demand.

The DAMA may be realized by (i) centrally controlled or (ii) locally controlled techniques. The choice of the control techniques depend upon the following:

a. Mean call holding time
b. Post dialing delay
c. Relative cost to implement

The choice between the two control techniques can be decided as follows:

a. Mean call holding time

Mean call holding time is the average sum of the three times i.e. (i) the operating time (ii) the ringing time and (iii) the conversation time or paid time. Thus for a given grade of the service in any communication network, a change in the mean call holding time within that network may increase or allow a decrease in the total amount of channel equipment required. Thus, it is important to minimize mean call holding time.

For the centrally controlled DAMA system, it will be seen that the mean call holding time is lesser [4] than that of locally controlled technique.

If a TDMA channel is used, the operating time contributed by the DAMA network for a centrally controlled call is given by [4]

$$A_{ct} = P_c + 1.5U(\frac{b_k}{2} + t + q) \quad . . . (2.9)$$

Where

A_{ct} = Average operating time for a centrally controlled TDMA network using a TDMA CSC.

P_c = Processing time required by a central controlled facility.

U = Average number of signal unit per call.

b = Burst time per terminal.

K = Maximum number of terminals per network.

t = Transmission delay via the satellite link ($\simeq$270ms).

q = Average queing delay of a signal unit.

From the above equation 2.9, it is apparent that all the signalling unit parameters are multiplied by 1.5 because almost one and half of the information must be first transmitted [4] to the central controlled facilities for processing and then returned to the DAMA terminals for selective control.

In case of locally controlled DAMA, only the signalling information must be communicated to the outgoing terminals, so the operating time contributed by the DAMA common signalling channel is given by

$$A_{1t} = P_1 + U\left(\frac{b_k}{2} + t + q\right) \quad . \; . \; . \; . \; (2.10)$$

Where

A_{1t} = Average operating time for a locally controlled DAMA network using a TDMA signalling channel.

P_1 = Processing time for a locally controlled facility.

From equation (2.10) it is clear that the average operating time for a locally controlled DAMA network using a TDMA signalling channel is less compared to that of the centrally controlled DAMA network.

The DAMA system is used in variable mode i.e. on demand, so it is important to know that what would be the traffic demand and accordingly how many channel would be required to meet the traffic growth at a certain time period. This can be understood as follows:

The traffic density of any trunk is a function of the call arrival rate and the mean of the holding time and is given below;

$$a = \frac{N*h}{3,600} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2.11)$$

Where

a = busy hour traffic density, Erlang

N = average number of calls offered during busy hours

h = mean call holding time in seconds

To calculate the amount of channel equipment required per trunk to serve a given traffic density may be found from the Erlang Table [4].

The increased in Erlang Load for a trunk having an increase in the mean call holding time is given by

$$\Delta a = \frac{\Delta h \; (a)}{h} = \zeta \cdot a \quad . \; . \; . \; . \; . \quad (2-12)$$

Where

h = increase in mean call holding time caused by an increase in operating time.

Δa = increase in traffic density, in Erlangs.

$$r = \frac{\Delta h}{h}$$

so the new traffic density is given by

$$a_{new} = a(1+r) \quad \ldots\ldots\ldots (2\text{-}13)$$

b. Post-dialing delay

Post-dialing delay is equal to the sum of the operating time and ringing time. If any of the parameters in the equation (2-10, -11) become sufficiently large, then the post-dialing delay may become more than 60 seconds [4]. This indicates the design alone is not poor but it is unacceptable to the customer.

c. Relative implementation cost

The relative cost to implement a system is very difficult to determine because it involves the lifetime of the system, the operational cost, the management cost and the processing time of the signal. Besides that there are many other factors to be determined in the implementation of DAMA network.

2.6 COMPARISON BETWEEN FDMA AND TDMA MODES

To bring out the merits and demerits of the two systems (FDMA and TDMA), the various characteristics of both the systems are described and compared.

a. Modulated signal

The nature of modulated signals in FDMA mode are analog while in the case of TDMA, they are digital.

b. Channel capacity

Almost all the satellites use travelling wave tubes (TWT) as the final amplifier which are operated nearly at their saturation point for maximum efficiency. This causes intermodulation due to the non-linear amplification of the TWT.

In FDMA, the TWT is operated below its saturation output power level to keep the IM produced by simultaneous amplification of multiple carriers within the permissible values. The larger the number of carriers the greater the "back-off" required. This results in the decrease of total channel capacity of a satellite.

In case of TDMA, the carrier, that passes through the transponder, is limited to one at a time. So in this system, the TWT can be operated nearly at its saturated output level without producing much intermodulation.

c. Speech interpolation

Speech interpolation (SI) is a technique used to increase the number of usable channels in the link. In FDMA system, this technique is almost impossible to implement because it is done in time domain, where as FDMA operates in frequency domain. In TDMA, it is possible to implement it by merely changing the time position of channels and of voice detection. This technique in TDMA is called digital speech interpolation (DSI).

d. Synchronization

In FDMA mode, the carrier frequency transmitted from the respective earth station, must be detected coherently and accurately controlled.

For TDMA system, transmitted digital bits must remain in the assigned time slot and should not spill over the adjacent slot to avoid asynchronization of the system.

e. Implementation cost

FDMA, the well developed technique, is used in the present satellite systems. Yet TDMA, a new technique, is not realized by the INTELSAT. An attempt to switch from FDMA to TDMA system, requires a complete change in the system. This will be expensive. The merits of TDMA over FDMA mode show that future generation of the satellites will use TDMA mode and possibly the more powerful method of TDM/SS/SDMA.

CHAPTER 3

DESCRIPTION OF TDM SATELLITE SUBSYSTEM

3.1 GENERAL

Time division multiple access (TDMA) or the time division multiple/switched spacecraft/space division multiple access (TDM/SS/SDMA) when operating in time division mode (TDM) constitute a TDM satellite system.

This chapter contains a general and functional description of each equipment of the sub-systems which comprise a TDM satellite system. Additionally a brief survey of the major equipment and the operational parameters affecting the quality transmission are presented.

It should be noted that due to international acceptance of INTELSAT IV which utilizes a TDM transponder; this application of the TDM concepts are frequently referred to for comparative and analytical usage or as an example.

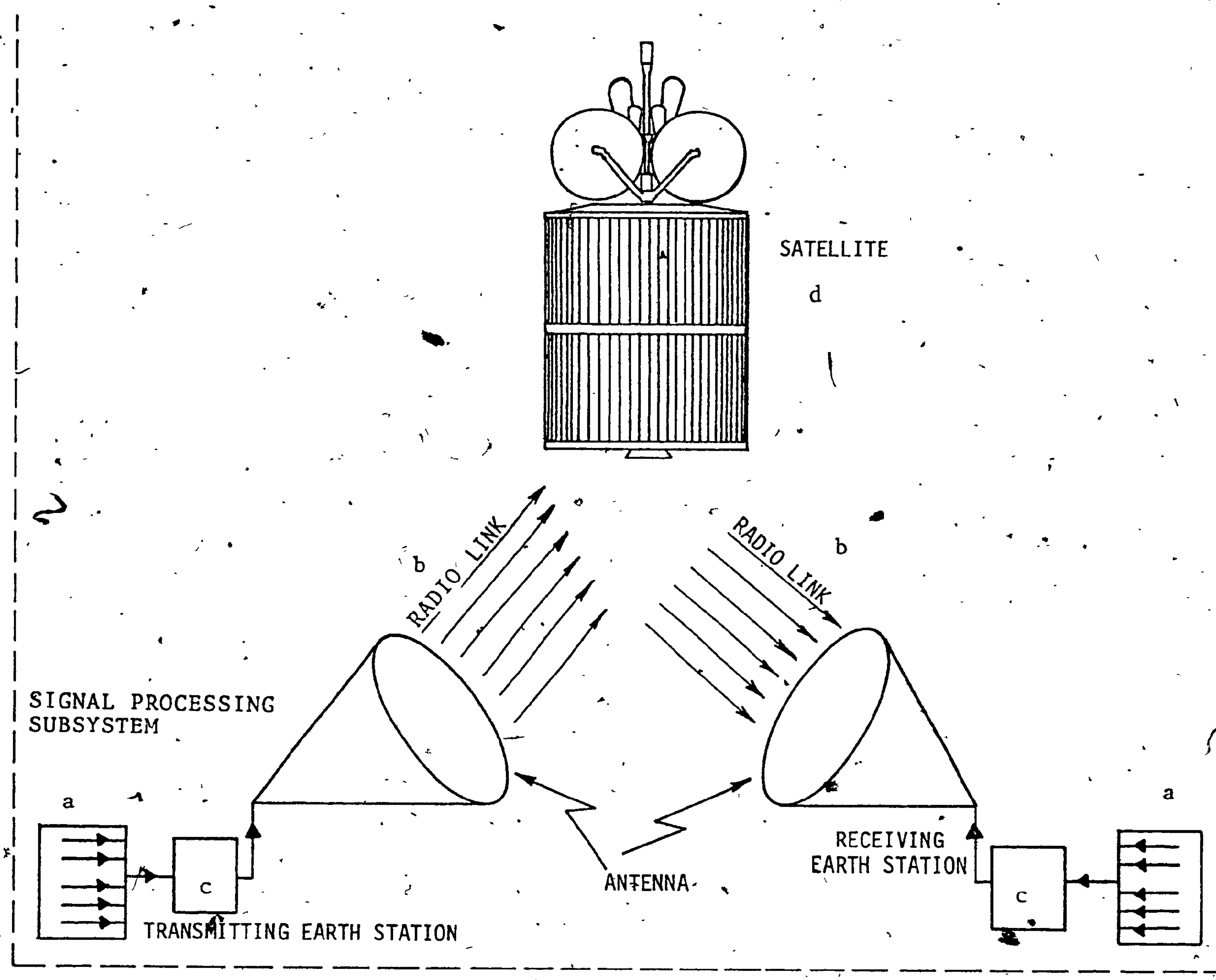


Figure 3.1: A Common TDM Satellite Subsystem

Whereas different workers [5], [6], [7] have proposed various models of TDM satellite configurations for future applications; in general, the common TDM satellites consist of four subsystems (shown in figure 3-1), given below.

a. Signal processing subsystem

b. Radio link (i.e. the space between the ground station and the spacecraft) subsystem.

c. Transmitting and receiving earth station subsystem.

d. Spacecraft subsystem.

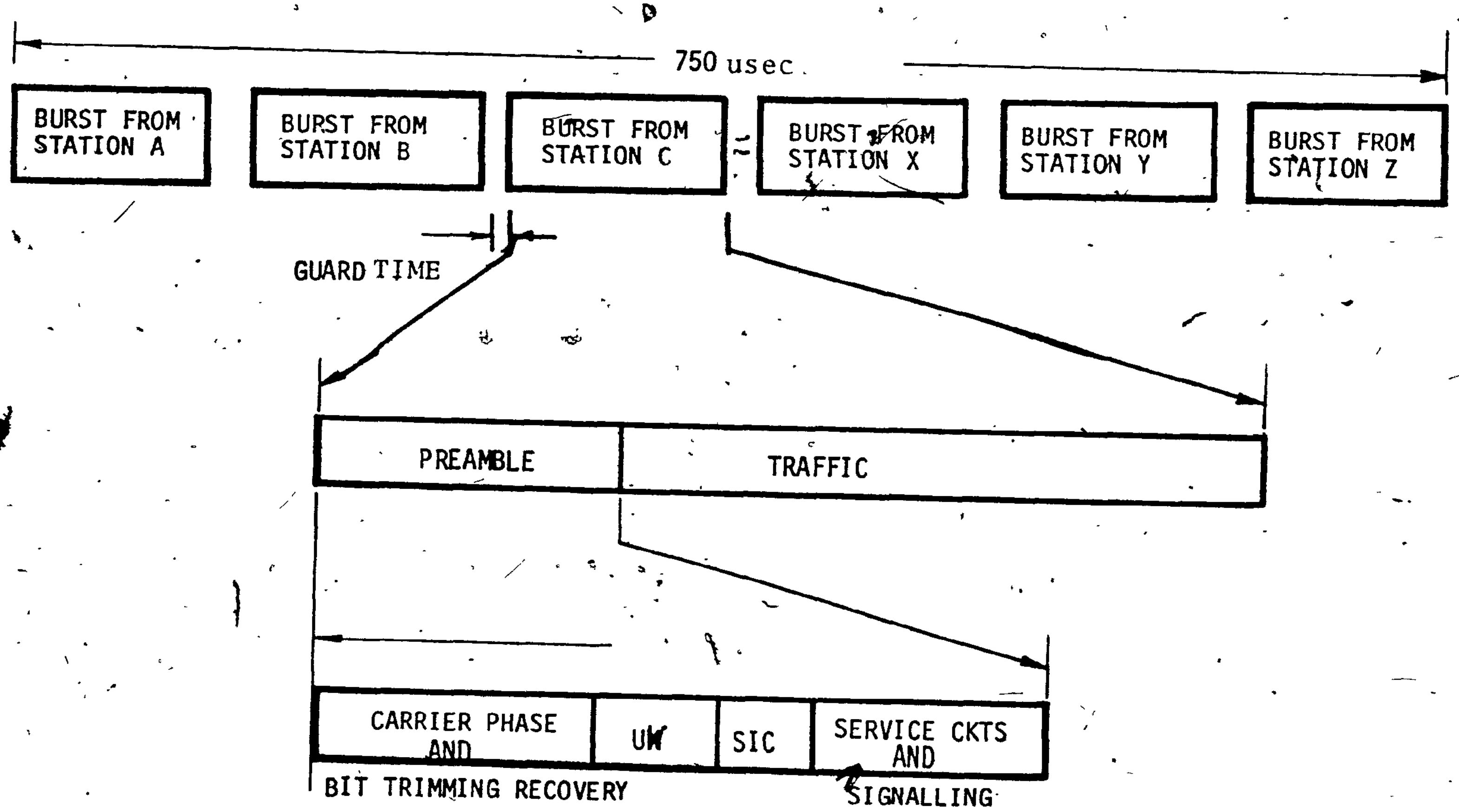


Figure 3.2a: Frame Structure of a TDMA System

3.2 SIGNAL PROCESSING SUBSYSTEM

The signal processing subsystem comprises the processing of message data into digital format, and then these digital bits are assembled into bursts which are subsequently grouped into frame. Each burst contains the preamble and the traffic, and a frame comprise several bursts.

The burst and the frame format are discussed below.

3.2.1 BURST FORMAT

The burst format, shown in Figure 3-2a, comprises of the following elements:

a. The traffic in a burst is the digitized message. The number of bits in a traffic portion of a burst depends on the system and its bit rate.

b. Each traffic portion of a burst is headed by a short preamble of several segments. These segments have different lenghts and different functions. The segments of the preamble as used in INTELSAT IV, are discussed next.

(1) The first 60 bits of the preamble, of a burst, are called carrier and bit timing recovery, and are used for correct detection of the received information at the receiving earth station. When these bits are received, the demodulator in the receiving station, detects these bits and compares with the bits which are supposed to be there. This comparison shows the phase difference, between the received bits and the transmitted bits.

(2) In a TDM satellite system, the burst of different stations must be consecutively interleaved in a frame without overlap, and separately distinguishable during reception. Specific groups of bits with selected code patterns are contained in each burst for this purpose. The code patterns are referred to as unique word (UW) patterns. In the INTELSAT IV, UWs are subdivided in order to achieve the following two different functions:

(i) 20 bits (10 symbols) are used as a time reference for the transmission of each burst so that it does not overlap on the adjacent burst and each burst in the frame can be detected at the receiving end of the satellite system. These unique words are used for the burst synchronization.

(ii) 8 bits (4 symbols) are used to identify the origin of the received burst and they are called station identification code (SIC).

(iii) In some TDM satellite system, a sequence of symbols (e.g. telephony signalling voice, orderwire) are used to provide service circuits and various house keeping signalling functions.

3.2.2 FRAME FORMAT

A frame in a common TDM satellite comprises of a sequence of bursts. These bursts are interleaved by a duration, called guard time, to avoid overlapping between two consecutive bursts. The guard time is variable and depends upon transmission rate. The greater the guard time, the better the transmission quality but lesser the communication system efficiency. The shorter the guard time the higher the bit error rate in the transmission of data.

The transmission rate is decided on the frame length. The TDM satellite system uses a minimum frame length of 125 usec $(=\frac{1}{8\ KHz})$, therefore, each frame can be sampled at the sampling frequency rate of 8KHz. The TMD satellite system either utilizes the minimum frame length or a multiple of 125usec. The selection between the minimum frame length or a multiple of it can be demonstrated by the example of the INTELSAT IV system, given below.

In the INTELSAT IV system:

Bit rate = 60 Mbits

Preamble length including guard time (12 bits) in each burst called the overhead = 100 bits

Assuming there are 20 access in the INTELSAT IV system, then the total number of bits in the overhead 'b' = 2,000 bits

For the transmission rate of 60 Mbits, the number of bits in a 125 usec frame are

$$'b_{125}' = \frac{125usec}{\frac{1}{60 \times 10^6}}$$

$$= 7,530 \text{ bits}$$

The ratio 'R' between the overhead bits 'b_o' and the number of bits in the 125usec frame 'b_{125}' is given by

$$R_{125} = \frac{b_o}{b_{125}}$$

$$= \frac{2000}{7,530}$$

$$= 0.2656 \quad \ldots\ldots(3.1)$$

That is, for each frame of 125usec, the number of overhead bits constitute approximately 27% of the total frame length. This can be reduced if the frame length is increased to 750usec and it is shown below.

The number of bits in 750usec frame, for 60 Mbits transmission rate is given by

$$= \frac{750}{\left(\frac{1}{60X10^6}\right)}$$

$$b_{750} = 45,180 \text{ bits}$$

The ratio $R_{750} = \dfrac{2000}{45,180}$

$$= 0.04426 \quad \ldots\ldots\ldots(3.2)$$

The computed in equation (3.1) and equation (3.2) show that the ratio between the overhead bits and the frame length is decreased by increasing the frame length. Thus, the frame efficiency can be increased by increasing the frame length. The frame efficiency is defined as the ratio of the potentially usable portion to the total frame length. In its general form, it is given by

frame efficiency

$$\eta = \frac{F-n(G+P)-S}{F}$$

Where F = frame length

G = guard time

P = preamble length

S = sync. burst length

n = number of accesses

Clearly, frame efficiency is higher if the guard time and/or the preamble can be made short.

The TDMA satellite system utilizes the frame format, shown in figure 3-2a. For TDM/SS/SDMA, each frame, shown in figure 3-2b, is headed by a 1usec (for the minimum length i.e. 125usec) or 6usec (for the six multiple of the minimum frame length i.e. 6 X 125usec) burst, called "Sync Burst" and is discussed in Chapter 4.

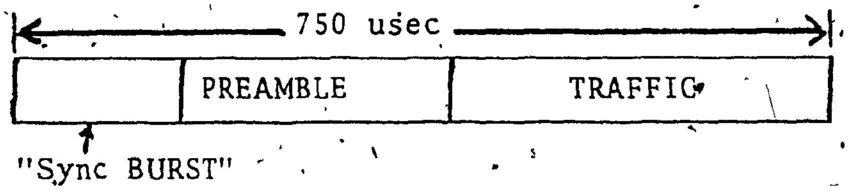


FIGURE 3-2b TDM/SS/SDMA Frame Format

3.3 RADIO LINK SUBSYSTEM

When a frame containing digitized information is transmitted from the earth station through space to the satellite, it may not be coherently detected by the receiving station due to the satellite motion in relation to the earth station, the attenuation due to rain and/or power loss in the path. These problems of satellite motion and propagation are analysed and the path loss calculation technique is identified in the following paragraphs.

3.3.1 SATELLITE MOTION

The most significant effect of the motion (relative to the earth) occurs during the rising and setting of the low altitude satellite. In order to provide the nearly continuous link for commercial communications, not one but an orbiting fleet of satellites system is required. The ground station portion of this satellite system is also complicated by the motion, large tracking antennas with high performances over virtually an entire hemisphere are required, which are far more expensive than antennas with fixed reflectors.

Another factor which effects both signal amplitude and frequency is the Doppler effect.

Thus a new orbit was chosen which is called synchronous orbit [8].

3.3.2 PATH LOSS CALCULATION TECHNIQUE

The most significant parameter in the design of a TDM satellite system is the carrier to noise (C/N) ratio. The carrier to noise ratio, depends upon the level of the radio waves and the noise level due to different sources.

Radiowaves for satellite communications pass through the earth's atmosphere and the iononsphere. Generally a low frequency wave fades due to ionospheric absorption and the one below the critical frequency is reflected at the ionosphere [9].

The International Radio Consulative Committee (CCIR) recommends that the frequency range of 1 to 10 GHz is the most practical for satellite communications and radio signals of this range can be dealt with under free-space propagation conditions. The receiving power 'P_R' of the satellite or the ground station under free-space propagation is given by:

$$'P_R' = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \quad \ldots\ldots (3\text{-}3)$$

Where

P_R = Receiving power of the satellite or the ground station in db.

P_T = Transmitting power

G_T = Transmitting antenna gain

G_R = Receiving antenna gain

d = Propagation distance

λ = wavelength

Under free-space propagation, the noise power 'P_N', due to various sources, at the receiving system, can be calculated as follows:

$$P_N = K \ T_S \ B \quad \ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}4)$$

$$P_N = 10 \log_{10} KT_SB \text{ (dBW)} \quad \ldots\ldots (3\text{-}5)$$

Where

P_N = Noise power at the receiving system

K = Boltzman constant (1.38×10^{-23} joule/Kelvin)

T_S = Equivalent noise temperature (K^o)

B = Frequency Bandwidth (Hz)

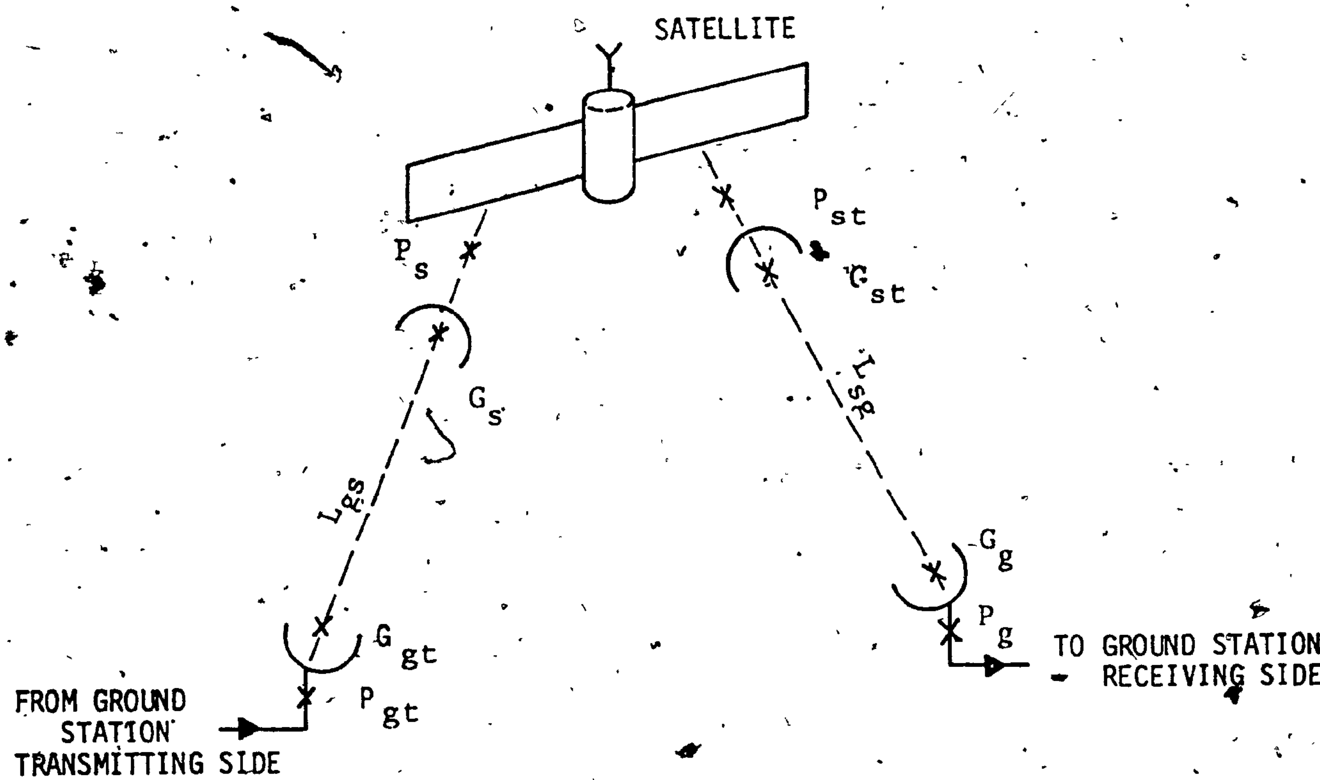


Figure 3-3: The TDM Satellite System Block Diagram for Calculating C/N Ratio

From equation (3-3) and (3-4), the carrier to noise (C/N) ratio can be calculated as follows:

$$C/N = \frac{P_R}{P_N}$$

$$= \frac{P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2}{K T_S B} \qquad \ldots .(3\text{-}6)$$

Another method for calculating the carrier to noise ratio is given below and shown in the figure 3-3.

$$P_s = P_{gt} + G_{gt} - L_{gs} + G_s \text{ (dBW)} \qquad \ldots .(3\text{-}7)$$

Between satellite to ground station, the power available,

$$P_g = P_{st} + G_{st} - L_{sg} + G_g \text{ (dbw)} \qquad \ldots .(3\text{-}8)$$

Where

P_s = Power available at the satellite receiver

P_g = Power available at the ground receiver

P_{gt} = Ground transmitter power

P_{st} = Satellite transmitter power

G_{gt} = Gain of the ground transmitting aerial

G_{st} = Gain of satellite transmitter aerial

L_{gs} = Transmission loss between ground station and the satellite

L_{sg} = Transmission loss between satellite and the ground station

G_s = Gain of satellite receiver

G_g = Gain of the ground receiver aerial

The gain/loss parameters are expressed in decibels (dB) and powers in decibels relative to 1 watt (dBW).

Associated equation for carrier to noise ratio is:

$$C/N = P_g - P_n \quad \ldots\ldots (3\text{-}9)$$

Where P_n = Noise power as given in equation (3-4)

= $10 \log_{10} KT_S B$ (dBW) as given in equation (3-5)

and transmission loss in either direction is given by $'L' = 20 \log_{10} \frac{4\pi d}{\lambda}$

Equations presented in (3-6) and (3-9) provide an important tool to measure C/N ratio which significantly determines the fade margin for the propagation path.

3.3.3 ATTENUATION DUE TO RAIN

Satellite communication systems utilising 4 and 6 GHz common carrier bands are now fairly commonplace. Suitable care must be taken to reserve the quality of the earth station antennas and selection of sites to avoid interference with terrestrial systems sharing the same frequency bands. However, to overcome this saturation, the use of higher frequency bands was proposed and new common carrier bands, more than 2 GHz wide were subsequently allocated at 19 and 20 GHz. Unfortunately, it was determined that rain becomes a much more serious factor at these higher frequencies than 4 GHz [10].

The noise level increases significantly when it is raining in the vicinity of the receiving station. This increase stems primarily from two sources: "black body" radiation from water drops in the sky; additionally emission and reflection from water layers that formed on the randomes used to protect the earth-station antennas.

The attenuation effect due to fog, snow, trosposphere and ionophere are small compared to

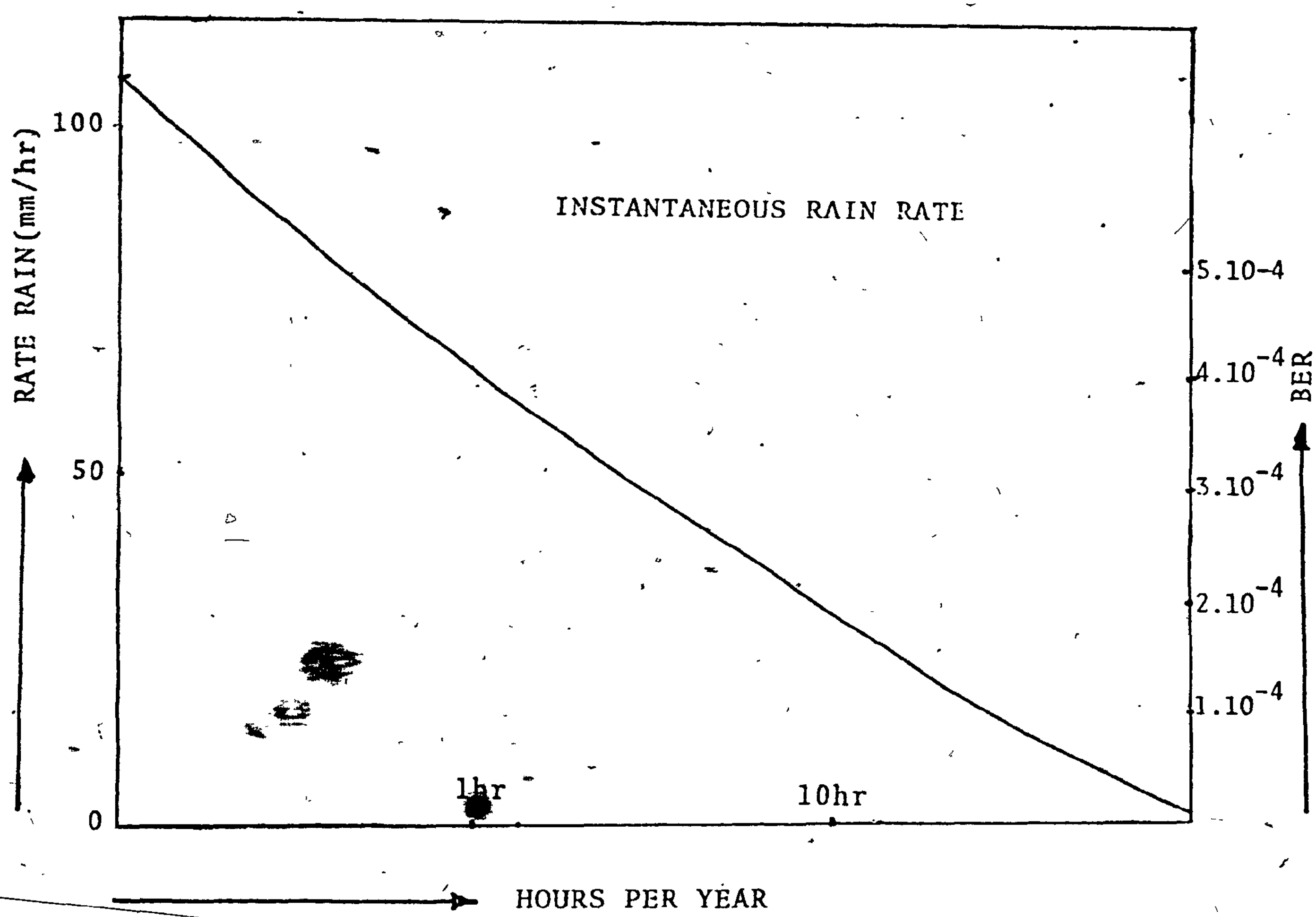


Figure 3.4: Rain Rate VS BER

rain. Rain effects have been calculated, using the annual statistics for Washington, D.C. on the basis of assumed deterministic near worst-case link parameters being considered for the Intelsat IV satellite and 4 phase PSK-TDMA terminal. Figure 3-4 shows the commulative bit-error rate (BER) occurence for links that are affected by rain.

Due to the above problem, considerable improvement in the transmission system can be obtained by switching between two earth stations separated by a distance [11] . This arrangement called "path diversity", requires a broadband terrestrial link between the two earth stations and appropriate switching circuitry. The diversity improvement clearly increases as the separation between antennas are increased.

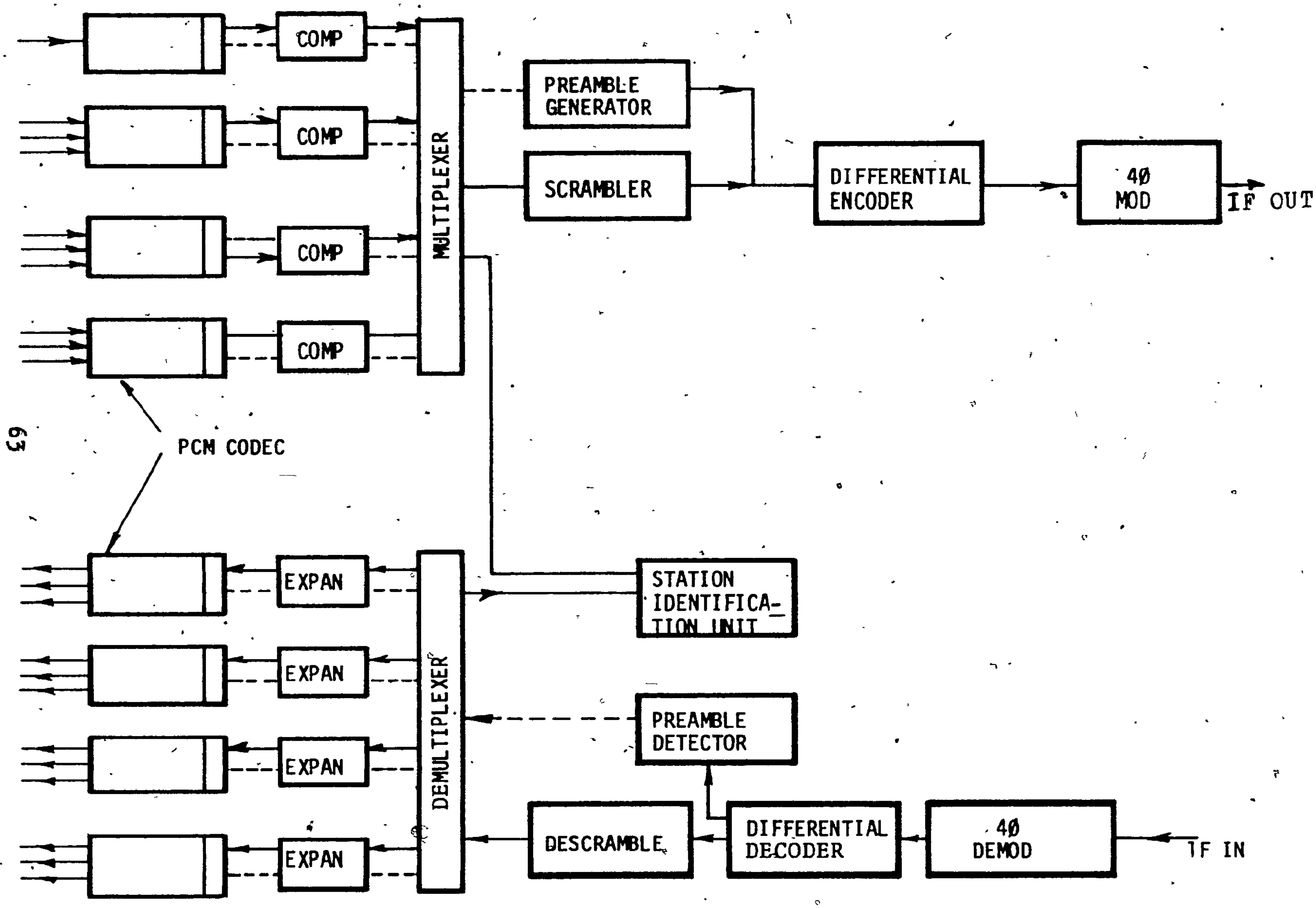


Figure 3.5: Block Diagram of a TDM Terminal

3.4 TRANSMITTING AND RECEIVING EARTH STATION SUBSYSTEM

Examining domestic and defence satellites, it is concluded that the basic equipment at the ground stations are the same in configuration [12].

The transmit side of the ground station performs the information processing which is appropriate for the transmission to the satellite. This includes time division multiplexing of the transmit bursts, preamble generation, the application of digital energy dispersal sequence to the data portion of the burst, the premodulator conversion to a differential encoding format, and modulation.

The receive side performs the inverse operations on the received signal.

The independent functional principles and the specific criteria of each equipment and explicit performance limits to the subsystem (shown in Figure 3.5) compatibility. These equipments are described briefly in the following paragraphs.

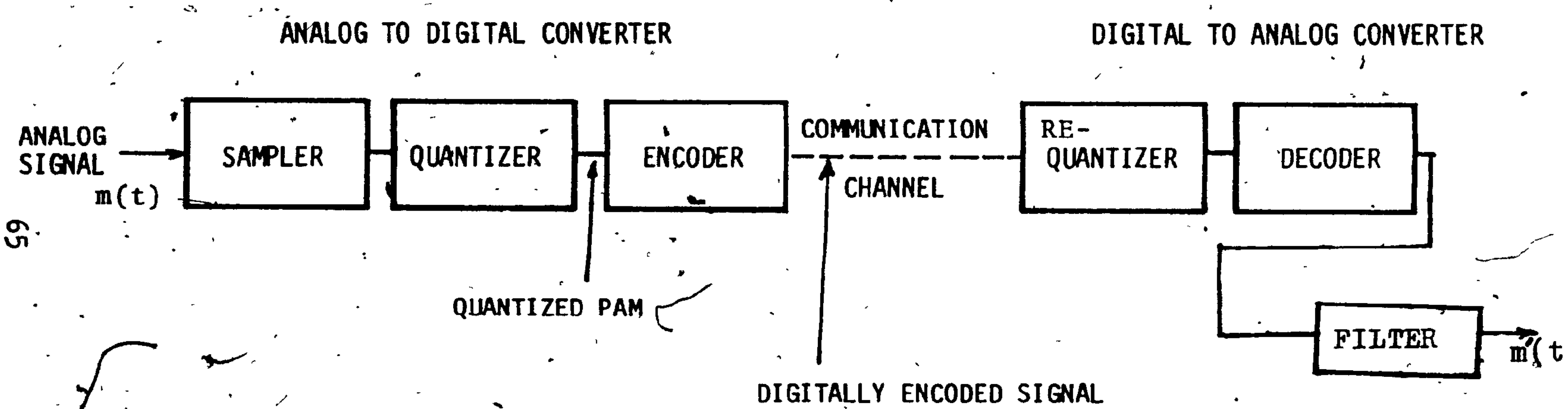


Figure 3.6: A PCM Communication System

3.4.1. PCM CODEC

The PCM codec is designed to meet the interface between the analog input signal and the digital data requirement of the TDM satellite system. A PCM communication system is represented in Figure 3.6. The analog signal m (t) is sampled. These samples are quantized and applied to an encoder which responds to each such sample by generating a unique and identifiable binary pulse (or binary level) pattern. At the receive side of the earth station, these digitally encoded signals are requantized to determine whether a positive or a negative pulse was received. The requantizer transmits its decision, in the form of a constituted or regenerated pulse train to the decoder. The decoder performs the inverse operation of the encoder. The decoder output is the sequence of quantized multilevel sample pulses. The final output signal m′ (t) is identical with the input signal m (t) except for quantization noise and the occassional error in the binary level.

The general specifications of this equipment used in INTELSAT IV include:

Modulation	pulse code
Sampling	8,000 samples per second channel
Clock frequency	1.544 MHz
No. of bits/sample ..	7 bits for voice, plus 1 bit for signalling
No. of bits for 125 usec frame	= 8 X 24+1 = 193 bits

3.4.2 BUFFER MEMORY

The basis function of a buffer memory is to convert the continuous data from the PCM encoder into a burst form and to covert the TDM bursts into a continuous stream. The buffer memory performing the continuous to burst conversion is called the compression memory and it is located at the transmitting side of the earth station. The buffer memory, performing the bursts to continuous conversion is called the expansion memory, located at the receiving side of the earth station. The expansion memory configuration is similar to that of a compression memory.

The important feature of buffer memory is the storage capacity of the input data. The storage capacity is decided upon the transmission rate of the system. If the transmission rate is high, the storage capacity should be less and vice versa. This is explained through the example, given below:

In case of INTELSAT IV, the bit rate is 60 Mbit/sec.

Each bit duration for 60 Mbit transmission is

= 16 nsec .... (3-10)

The number of bits in 750 usec frame

= 45,180 bits...... (3-11)

If the bit rate of the encoder is 2.048 Mbits, then each bit duration for 2.048 Mbit is

= 488 ns .... (3-12)

The number of bits in 750 usec frame when the bit rate is 2.048 Mbit

= 1536 bits .... (3-13)

Since the buffer memory is connected after the coder, its storage capacity is based upon the bit rate of the coder.

The ratio between equations (3-12) and (3-10) is given by = 30.5 .... (3.14)

The multiplication between equation (3-14) and (3-13) will yield 45,180 bits.

Thus, the storage capacity of a buffer memory is almost equal to 1536 bits for 2.048 Mbit i.e. the rate of the encoder. From above result, the storage capacity is given by:

= Frame lenght * bit rate of the encoder (3-15)

= 750 usec * 2.08 Mbit/sec

= 1536 bits

The above result is the same as one presented in equation (3-13).

3.4.3 MULTIPLEXER/DEMULTIPLEXER

The purpose of a synchronous multiplexer is to assemble the various elements of burst together into one or more time contiguous frame. The output of the buffer memory is multiplexed by a multiplexing combiner which produces a code train of bursts. It also causes the preamble unit, the control signal unit and each of the terresterial interface units in turn to read out the contents of their buffers to the modulator.

The demultiplexer unit, located at the receiving side of the earth station, performs the equivalent receiving function opposite to that of the multiplexer. This involves the selection of the traffic portion of the received burst and channeling it to the appropriate interface module for the destined station.

The feasibility of asynchronous time division multiplexers has also been studied in the TDM satellite system[13]. Synchronization problem arises due to the application of asynchronous time division multiplexer, this makes it less reliable for the TDM satellite system application.

3.4.4 SCRAMBLER AND DESCRAMBLER [14]

In a TDM system the used PCM channels, or slots associated with idle equipment, tend to generate fixed bit patterns which, when repeated at the frame rate, generate spectral components which may exceed the maximum power flux density allowance (i.e. as per Radio Regulation, Geneva, April 1972, Art. 7, Section VIII, Para 470 P).

The energy spectrum associated with normal TDM bit streams can be made more uniform by combining with the data bit stream another bit stream which has pseudo-random properties. This energy dispersal bit stream can be generated by means of a feedback shift register.

The scrambler and descrambler are located at the transmitting and receiving earth station respectively.

The multiplexer output is fed to the scrambler which disperses the spectral energy of the bit stream. This is because, the discrete frequencies appear in the transmitted signal as a result of repetitive sequence of the data. The scrambling, therefore, produces a nearly white noise frequency spectrum at the output of the PSK modulator (Section 3.4.6), thus keeping the radiated satellite energy per 4KHz (voice channel) of bandwidth low to avoid interference with the terrestrial microwave systems, operating in the same frequency band.

A scrambler is defined as a digital machine which accepts a data sequence with known statistic and produces a channel sequence whose statistics approach those of white Gaussian noise.

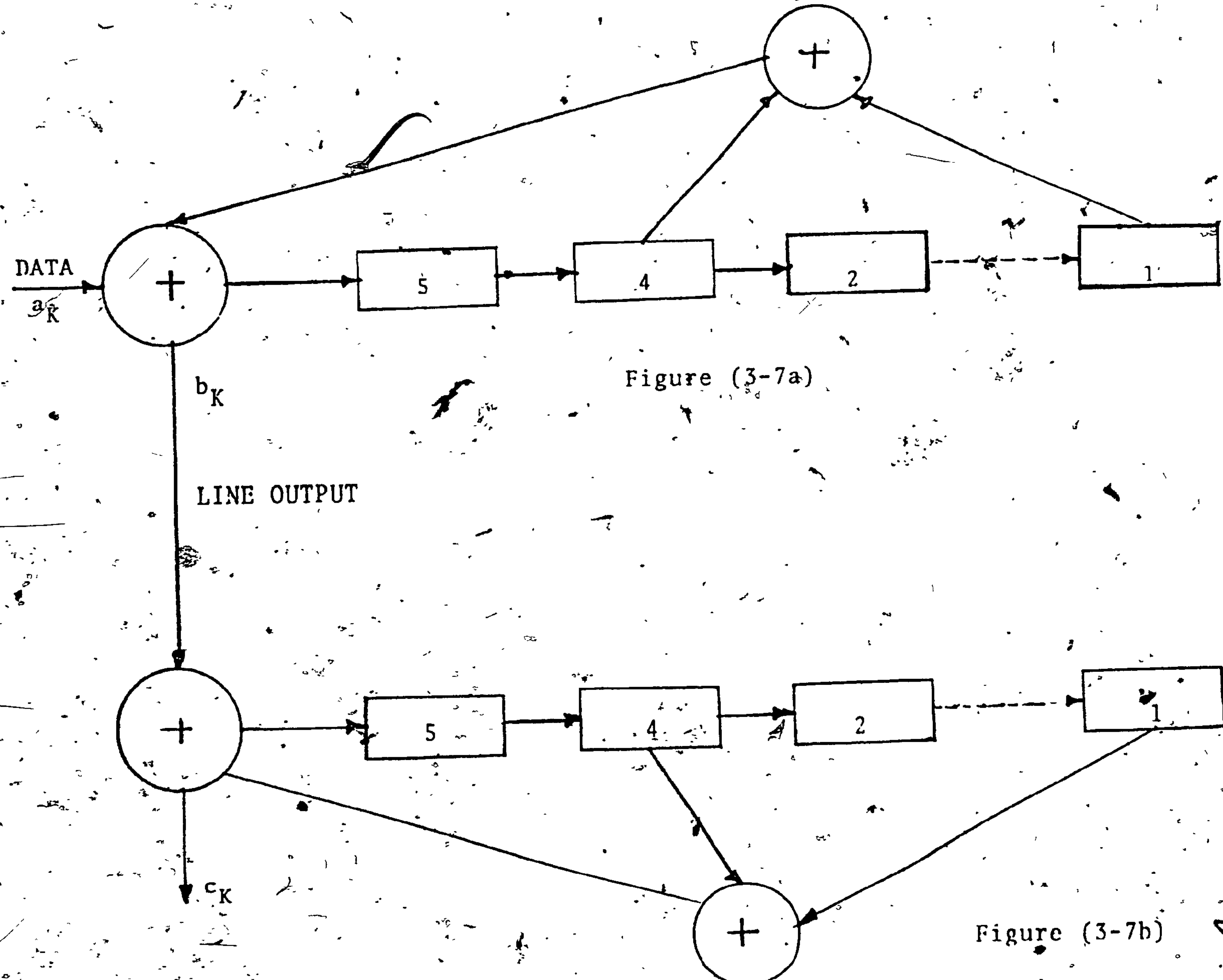


Figure (3-7a)

Figure (3-7b)

Figure 3.7: Scrambler and Descrambler Block Diagram

The descrambler is defined as a unit which accepts the scrambled output and produces the initial input sequence of the scrambler.

The digital filter utilizing feedback paths, shown in figute 3-7a is the general configuration of a basic scrambler. It consists of three elements, unit delays, summers and multipliers. It can operate on any modular field of data sequence as long as summers and multipliers operate on the same modular field. The most common case is, when the data sequence is binary (0,1) then summations and multiplications are taken modulo-2 while the unit delays are formed from a shift register. For instant (refer to the figure 3-7a) if

a_K = Data sequence input to the scrambler

then b_K = Line output from the scrambler or,

$$b_K = a_K \oplus b_{K-3} \oplus b_{K-5} \cdots\cdots \quad (3\text{-}16)$$

One of the characteristics of a scrambler is that if there is no input to the scrambler, then the scrambler acts as a sequence generator whose output becomes periodic because the future states of the registers are completely determined by the present state of the register. The possible number of states are finite i.e. 2^M when M equals the number of stages. The longest possible period from the generator is equal to (2^M-1) bits.

The basic descrambler, shown in figure (3-7b), utilizes feed forward paths in contrast to the basic scrambler and the corresponding output of the descrambler is given by:

$$c_K = b_K \oplus b_{K-3} \oplus b_{K-5} = a_K \quad \ldots\ldots \text{(3-17)}$$

$=$ Data input to the scrambler.

Each station starts its scrambling sequence at a unique state within the overall energy dispersal sequence available. The descrambler must be reset so that the initial contents in its feedback shift register are correct for each burst being received. Hence the descrambling of the dual data channel can begin. The basic descrambler is identical to the scrambler; the modulo-2 addition of the energy dispersal bit stream to the dual channel output of the differential decoder will yield the original unscrambled sequence.

One of the input characteristics of the descrambler is that it is a self-synchronizing unit since the effect of the channel error (insertion or delection of a bit) lasts only as long as the total delay of the shift register i.e. 2^M-1.

3.4.5 PREAMBLE GENERATOR AND DIFFERENTIAL CODEC

The TDM data burst preamble is a symbol sequence preceding the data transmission symbol sequence of the burst. The preamble sequence format is shown in figure 3.2.a. The preamble bits like station identification, unique word sequence, etc. do not vary from frame to frame for a particular terminal. The control signalling, telegraphy and voice orderwire sequence do vary from frame to frame. The control signalling sequence provides a signalling channel to control and monitor TDM network operations. This channel also performs the following functions:

a. Reference station control and sync. burst handover signalling.

b. Steady-state burst position feedback

c. Voice and telegraphy orderwire signalling. Generally one voice channel is provided per TDM terminal for orderwire service. On the

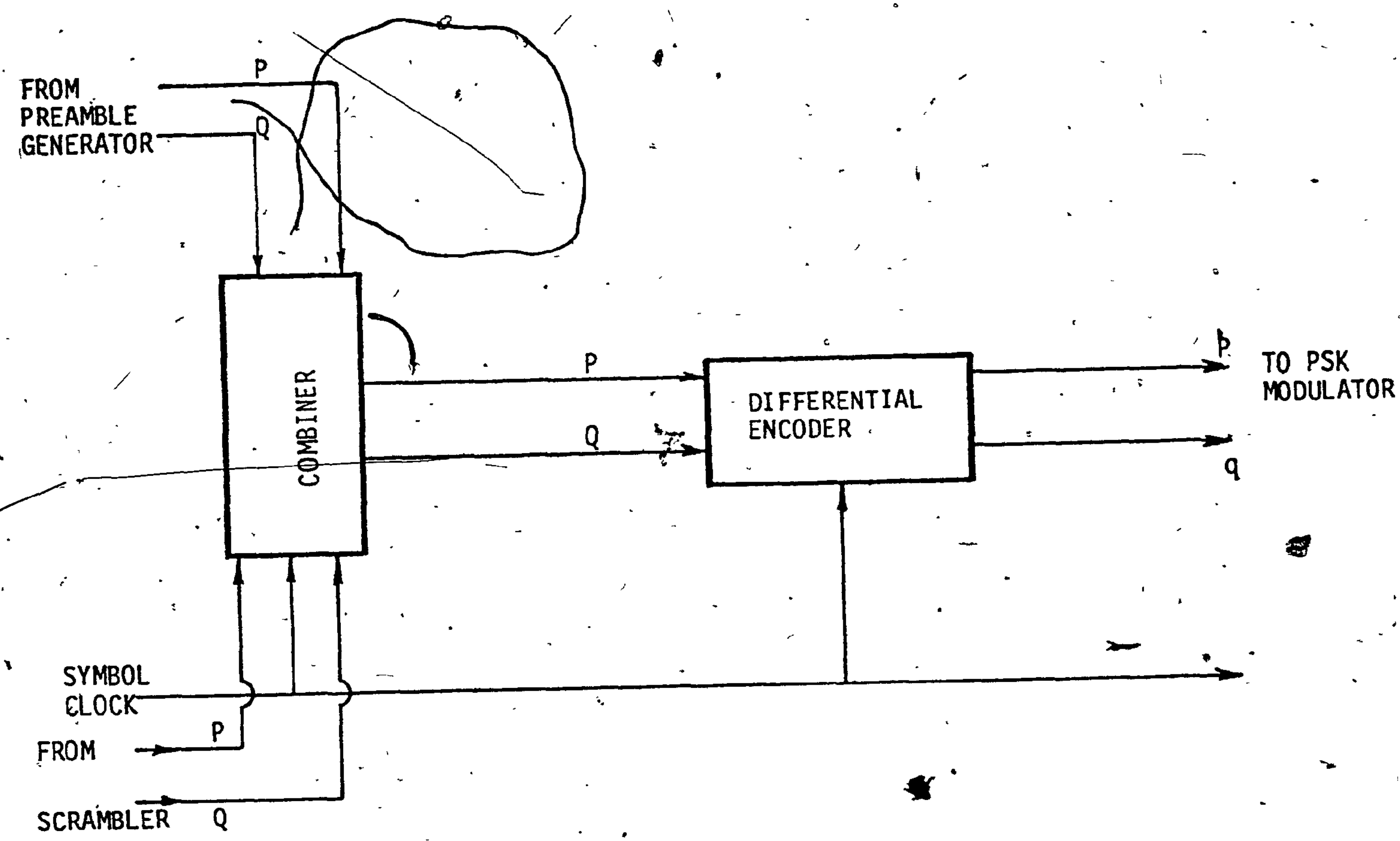


Figure 3.8: Differential Encoder Block Diagram

receive earth station, the function of a preamble detector is to detect the various unique words being received and to demultiplex the remainder of the received preamble i.e. identification signalling, orderwire segments, etc. and distribute these segments to the appropriate equipment. Differential encoding is used to resolve carrier phase and channel ambiguity after demodulation at the receiver. A functional block diagram of the unit is shown in figure 3.8. To avoid confusion, the dual input channels to the encoder logic have been labelled P and Q; the output channels to the modulator are labelled p and q.

All input data channels to the modulator are differentially encoded in accordance with the Boolean expression.

$$p_n = p_{n-1}\,\overline{P}_n\overline{Q}_n + \overline{p_{n-1}}\,P_nQ_n + q_{n-1}\,P_n\,\overline{Q}_n + \overline{q_{n-1}}\,P_n\,\overline{Q}_n \tag{3-18}$$

$$q_n = p_{n-1}\,\overline{P}_n\,Q_n + \overline{p_{n-1}}\,P_n\overline{Q}_n + q_{n-1}\,\overline{P}_n\,\overline{Q}_n + \overline{q_{n-1}}\,P_n\,Q_n \tag{3-19}$$

where the subscript n applies to the present value of the particular symbol slot and n-1 refers to the previous value of that particular symbol slot.

The differential decoder which is part of the modem receives two differentially encoded data channels, as well as the symbol timing, from the demodulator. Because of the carrier phase and channel ambiguity in the demodulator, the bit streams which were transmitted as channels p and q may be received, respectively, as P and Q, $\overline{P}$ and Q, $\overline{Q}$ and P, or $\overline{Q}$ and $\overline{P}$. Upon passing any of these combinations through a differential decoder, the original P and Q channels of the transmission are recovered at the decoder outputs.

3.4.6 PSK MODULATOR-DEMODULATOR

In general phase shift keying (PSK) and frequency shift keying (FSK) modem have been considered for the TDM satellite system. It is seen that for equal probability of error for FSK and PSK, the signal energy in the case of PSK is 0.6 times as large as that of FSK. Therefore a 2 dB increase in the transmitted signal power is required for FSK to provide equal probability of error when compared to PSK. The significance of 2 dB is ex-

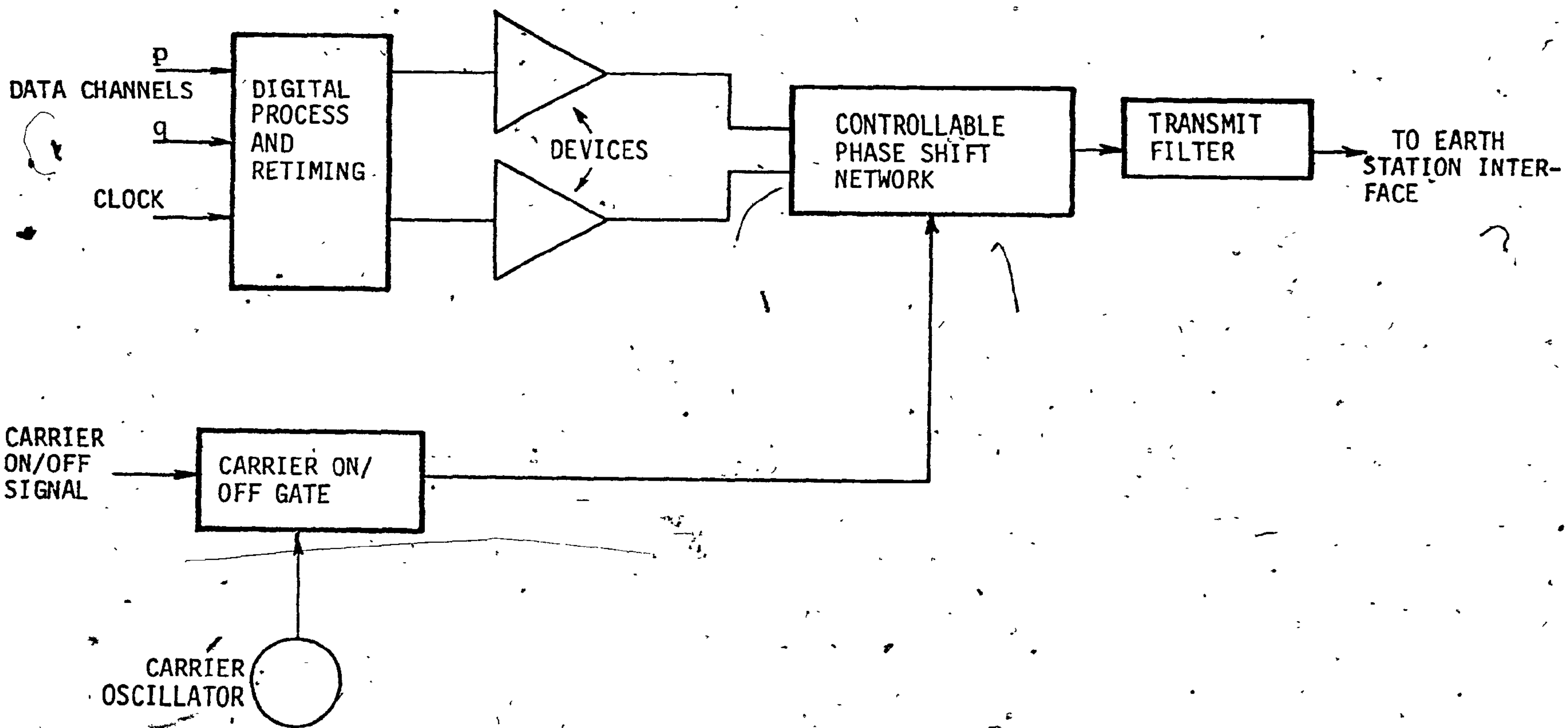


Figure 3.9a: PSK Modulator Functional Diagram

tremely costly in satellite communication.

Additionally, comparing binary phase shift keying (BPSK) and quan-tenary phase shift keying (QPSK), it has been found that QPSK can transmit twice the bit rate than that of BPSK within a constant bandwidth (or for the same bandwidth).

Therefore the 4 phase PSK as shown in figure 3.9a, - 9b has been considered for the TDMA satellite system and performs the following functions:

a. The modulator accepts two parallel data streams in bursts at the symbol rate of 60 Mbit/sec (for INTELSAT IV), symbol timing, as well as a carrier ON/OFF signal in synchronism with the data; and provides a burst of modulated carrier at an intermediate frequency to be up converted by the transmit subsystem to some higher frequency.

b. The demodulator receives TDM bursts in the IF bandwidth. It recovers a coherent reference carrier and symbol timing for each burst. It has an output of two parallel data channels

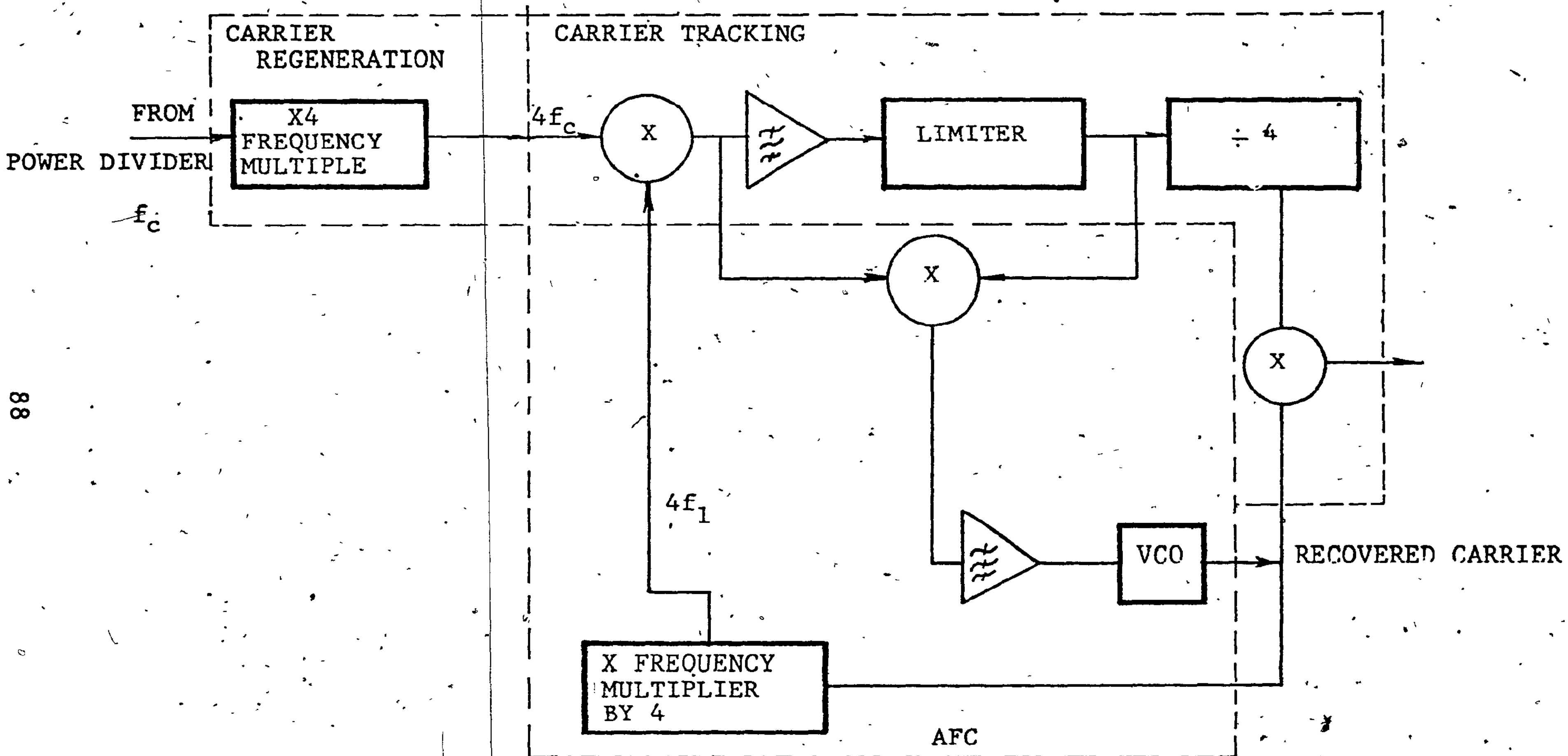


Figure 3-12: Typical Carrier Recovery With AFC

The modulated carrier enters at frequency f_c (refer to figure 3-12). The modulation is removed by frequency multiplication of 4, resulting in a desired discrete component at $4f_c$. This component is translated using a frequency $4f_1$ from AFC voltage-controlled oscillator (VCO). The resulting component at $4(f_c - f_1)$ is filtered by a suitable bandpass filter whose design parameters are based on the acquisition requirements of the system and the signal-to-noise ratio of the recovered carrier required to meet the bit error rate performance specification. The filter is followed by an amplifier/hard limiter circuit; frequency division by 4 (a two-stage recirculation shift register is recommended because four output phases are available if single side band mixer is needed) and translation by frequency f_1 to produce the desired coherent carrier at frequency f_c. A variable phase shifter compensates for phase shifts introduced in the signal path so that demodulation can be optimized and the desired carrier frequency f_c is produced. Because frequency division is necessary; the frequency at which the recovered carrier is filtered $4(f_c - f_1)$, should be restricted to a value no higher than the operating capability of the components used in division. Different models of QPSK carrier regenerator circuits for TDM satellite have been identified but significant progress does not deviate from what has been described [15].

The PSK modem filter are designed to achieve an optimum pulse response while minimizing the inter-symbol interference at the sampling point. The PSK modem has to achieve three additional tasks:

a. Prevent IF - modulated spectrum foldover.
b. Reject baseband components in IF spectrum.
c. Minimize interference to adjacent channel.

Different modems have been identified for TDM satellite system but QPSK has provided better performance in the presence of phase noise [16].

However, the function of a PSK modem, as discussed above, is important for the TDM satellite system. Extensive research is also being done on offset QPSK and minimum phase shift keying (MSK) for future use in the satellite communication systems.

3.4.7 BURST SYNCHRONIZER AND TIME SLOT ACQUISITION UNIT (TSAU)

The burst synchronizer and TSAU performs two distinct functions. Time slot acquisition and normal or steady state synchronization.

In particular, burst synchronizer, is required to control the time of burst transmission such that burst overlap does not occur and maintain the burst typically within the guard time duration presented for normal operation. This unit also maintains the phase of the burst relative to the reference phase.

The TSAU places a burst in the TDM frame. The entering burst must not interfere with other bursts in the TDM frame and must also be able to be positioned in the frame within the accuracy requirements.

Any discrepancy between the receive burst and the reference burst is measured every 1/3 seconds which is equivalent to twice the time taken by the signal to travel between the ground station and the spacecraft. This discrepancy is measured by PLL. A brief description of phase lock

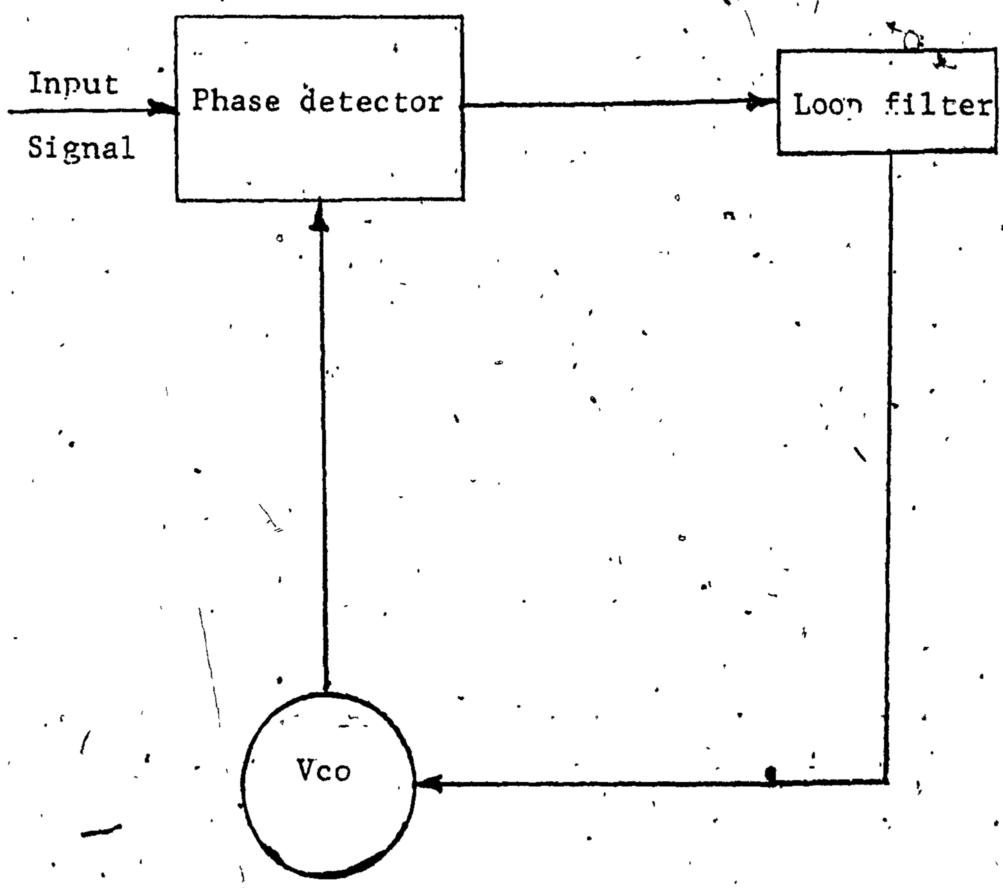


Figure 3-13: Phase Lock Loop Block Diagram.

loop and the initial acquisition behaviour which is similar to the performance of the TSAU , is presented in the following subparagraphs.

a. Phase lock loop (PLL)

Many communications and control systems requires the acquisition and tracking of the carrier frequency.

Several methods have been developed to solve this acute problem by using PLL. One of the methods is to sweep the oscillator frequency of the PLL (with a narrow loop bandwidth) across the frequency band of interest until the signal is acquired [17]. The PLL, shown in figure (3-13), consists of (i) phase detector (ii) lowpass filter (LPF) and (iii) a voltage controlled oscillator (VCO).

The phase detector compares the phase of a periodic input signal with the phase of the VCO. The phase detector's output is a measure of the phase difference between the two signals. The phase difference is then filtered by the loop filter and applied to the VCO. The frequency of the VCO changes in the direction that reduces the phase difference between the input signal and the local oscillator waveform. When the loop is locked, the control voltage is such that the frequency of the VCO is exactly equal to the average frequency of the input signal. This means one cycle of input is exactly equal to one cycle of output waveform. This function is expressed by the following equations:

Let the input signal to the comparator of PLL, is given by

$$V_i(t) = V_s \, Sin \, (W_i(t)+\theta_i) \ldots\ldots (3\text{-}20)$$

and the VCO waveform be

$$V_o(t) = V_o \, Cos \, (W_i(t)+\theta_o) \ldots\ldots (3\text{-}21)$$

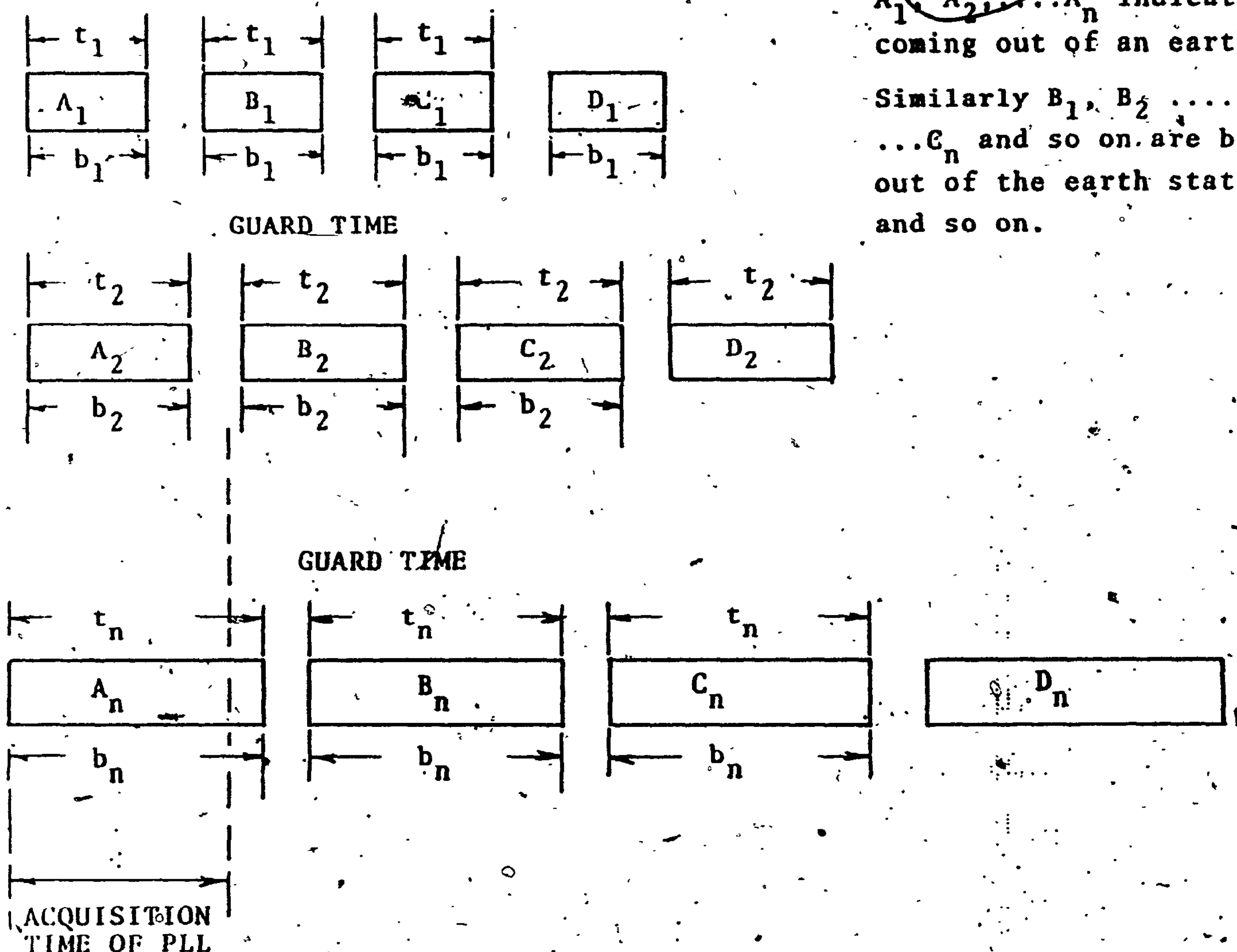
Equations (3-20) and (3-21) show that the input signal $V_i(t)$ and the VCO waveform are 90^o apart when $\theta_i = \theta_o$

The comparator which receives the signals presented in (3-20) and (3-16) multiplies them. The output V_d of the comparator is given by:

$$V_d = V_i(t) * V_o(t) \; V_s \; V_o \; Sin \, (W_i(t)+\theta_i) \; Cos \, (W_i(t)+\theta_o)$$

$$\text{or,} \quad V_d = K_m \frac{V_s \; V_o}{2} \; Sin \, (2W_i(t)+\theta_i+\theta_o) \; Sin \, (\theta_i-\theta_o) \ldots\ldots\ldots (3\text{-}22)$$

$$V_d = K_m \frac{V_s \; V_o}{2} \; Sin \, (\theta_i-\theta_o) \ldots\ldots (3\text{-}23)$$



$A_1, A_2, \ldots A_n$ indicate the burst coming out of an earth station A

Similarly $B_1, B_2, \ldots B_n$; $C_1, C_2, \ldots C_n$ and so on are burst coming out of the earth stations B, C... and so on.

Figure 3.14a: The Process of Initial Acquisition of a PLL

The signal represented in (3-22) is fed to the LPF which filters out the term $(2W_i(t)+\theta_i+\theta_o)$ because the frequency component of the above term is out of band. Equation (3-23) represents the output of the LPF fed to the VCO, which is operating at a set frequency called free running frequency 'f_o'. If the input frequency 'f_s' is sufficiently close to f_o, then the two signals are aligned or locked together. The process of locking, called initial acquisition behaviour of the PLL and the time taken by the PLL to lock these two signals is called initial acquisition time, which is discussed next.

b. Acquisition time of the PLL

The process of initial acquisition of the PLL is illustrated through figure 3-14a.

When a transmitting earth station attempt to acquire initial acquisition with the spacecraft, the earth station transmits a small burst A_1 at frequency f_1 and it contains b_1 number of digital bits. The length of burst A_1 in time domain is t_1. Suppose that this burst A_1 arrives at the satellite (spacecraft) and does not get lock with the VCO's frequency f_o. Then all the bits b_1 of the burst A_1 are found to be in error at the receiving station. The probability of receiving the correct bits is significantly low and the BER is very high and let us assume that it is e_1. During the second trial, the ground station transmits another burst A_2 at frequency f_2 and it contains b_2 number of bits. The length of the burst A_2 in time domain is t_2. Assuming that the burst A_2 arrives at the satellite; the two frequency f_2 and f_o could not lock on to each other. This can be explained as follow: the difference between the two frequency (f_2-f_o) is lesser than that of (f_1-f_o). However, it has been found that the difference between the input frequency (i.e. f_i i.e. i = 1,2,3.) is narrowing or gradually decreasing as the burst time (i.e. t_1, t_2, t_3) is being increased. In other words it can be said that the number of bits b_2 are not sufficient to be locked, and bits received at the receiving earth station are found to be error. But this time it may be possible that the BER e_2 is lesser than that of e_1.

Similarly, if the earth station continues relaying the bursts A_3, A_4, A_5 ....A_n respectively at 3rd, 4th, ...nth trial at the frequency f_3, f_4, f_5......f_n such as $(f_3-f_o) > (f_4-f_o) > \ldots\ldots >$

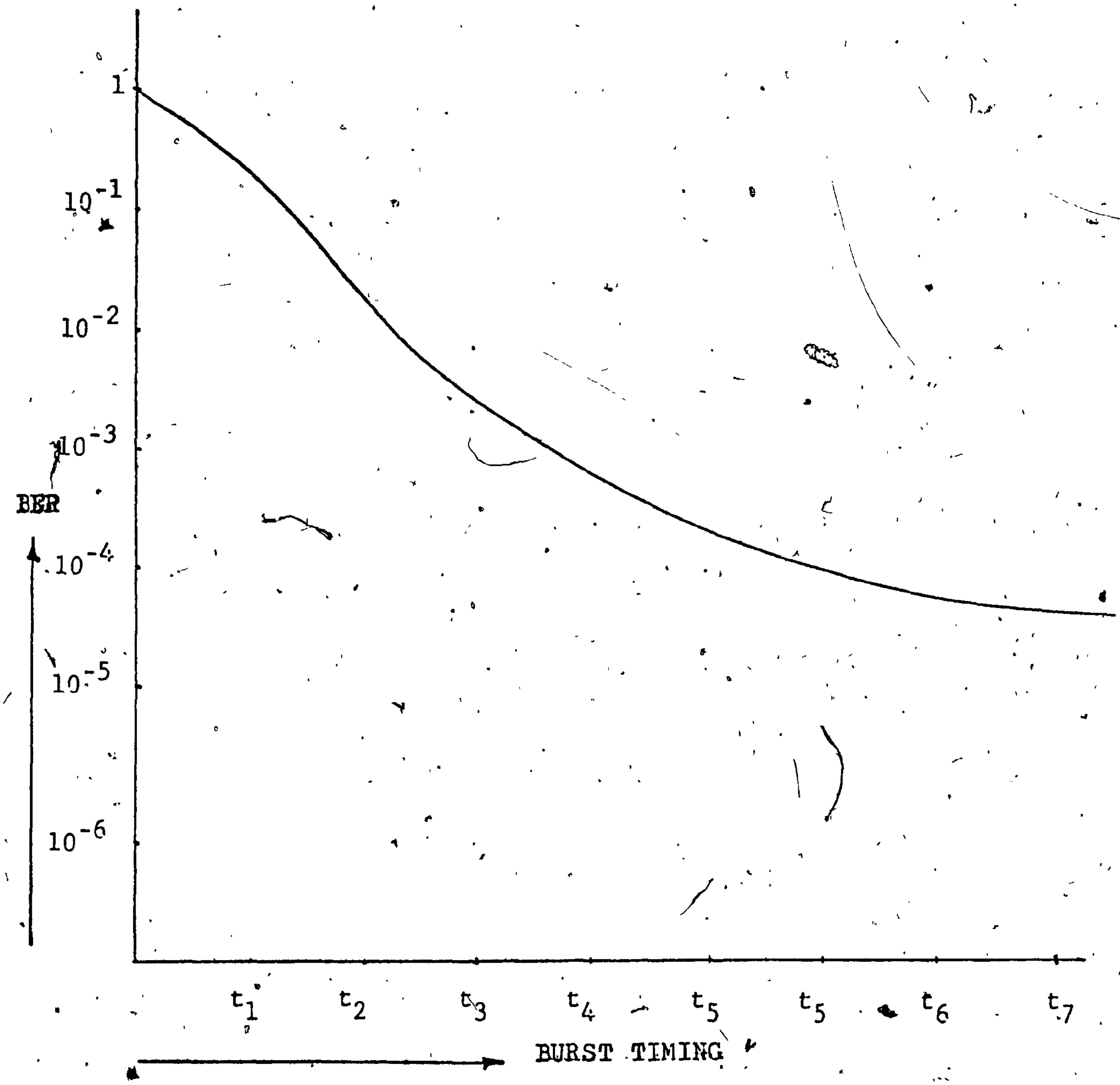


Figure 4-14: Burst timing vs BER

$(f_n - f_o)$ which is approximately equivalent to zero. The corresponding burst time t_3, t_4, $t_5 \ldots t_n$ for the bursts A_3 up to A_n are in such a way that $t_3 < t_4 < t_5 < \ldots < t_n$. During each trial the BER obtained for the above bursts at the ground stations are e_3, e_4, $e_5 \ldots e_n$. On the analysis of the data, it is noticed that as the difference frequency between the input frequency and free running frequency i.e. $f_{input} - f_o$ is decreasing, the BER is also decreasing. In other words it can be said that as the burst timing is increasing, the BER is decreasing. This result is ploted in the figure 3-14b. This process illustrates the behaviour of the PLL which is equivalent to the initial acquisition behaviour of the satellite system.

3.5 SPACECRAFT SUBSYSTEM

A common TDM satellite system spacecraft consists of several significant assemblies; a transponder, antennas, power supply, telemetry and command units.

The transponder in the spacecraft is associated with the antenna which receives the up-link frequency carriers from the earth stations, amplifies and converts them to down-link carrier and then retransmits back to the ground stations [18]. Generally, the dual conversion system which performs the amplification in the IF stages is used. The amplified signal is further amplified by a high power TWT and transmitted back to ground stations.

Prime spacecraft power is provided by a solar panel during noneclipse periods and the spacecraft batteries during eclipse.

3.5.1 TELEMETRY AND COMMAND

a. Telemetry

Two independent telemetry channels are included. Transducers, redundant digital encoders, and a cross-strap switch are provided. Diagnostic data, received from transducers and other data sources, are fed to the encoders before phase

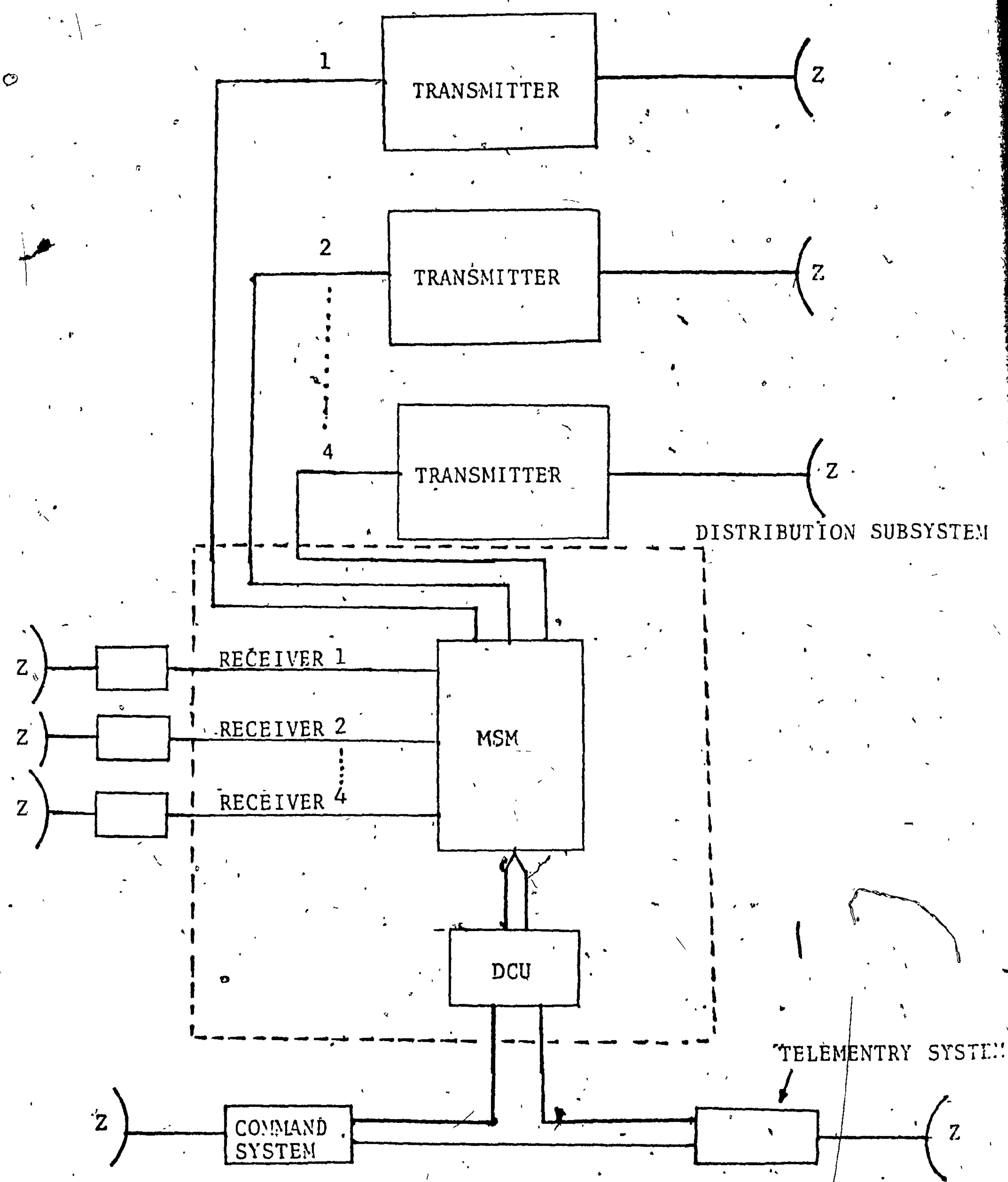


Figure 3-15: Distribution Subsystem Block Diagram

modulating the beacon oscillators via the cross-strap switch. Three selectable modes of data processing are used in each encoder; PCM, and two real-time FM modes [19]. The PCM mode is used for all altitude, thermal power and status information, including command verification. The two FM real-time modes are used for attitude pulses or altitude-related signals.

b. Command.

Two command receivers and two digital decoders are cross-strapped for redundancy. Command transmission consists of a microwave carrier modulated by a sequence of tone bursts at three discrete freouencies. The decoders provide command output lines. The command format consists of an introduction portion which clears and resets the decoder registers and logic, an address portion which provides the necessary digital encoding, and the comand itself consists of eight bits.

3.5.2 DESCRIPTION OF TDM/SS/SDMA SPACECRAFT [20]

The distribution subsystem of TDM/SS/SDMA system, shown in figure 3-15 consists of a micro-

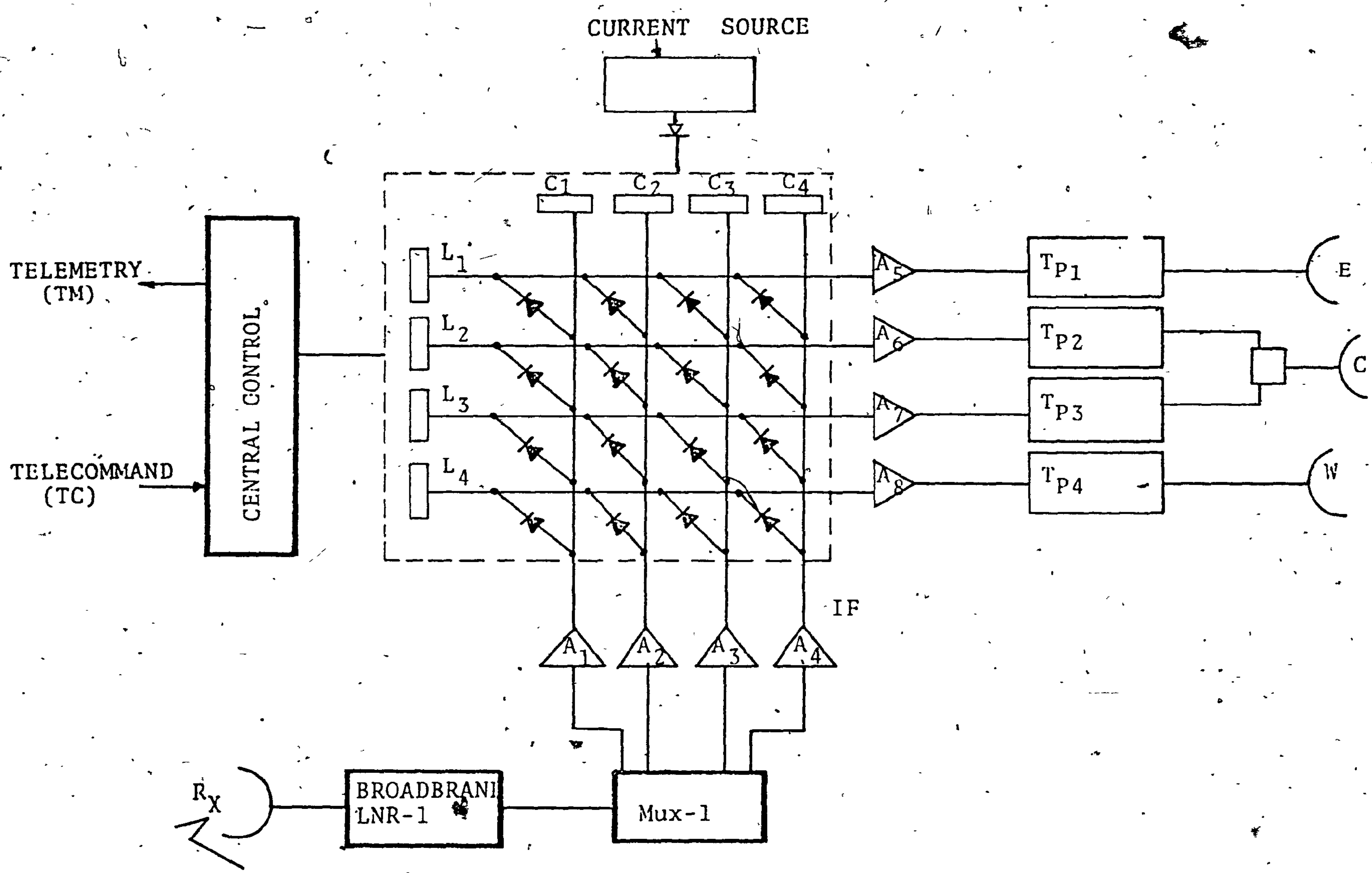


Figure 3.16: Switching Matrix Operation

wave switching matrix (MSM) and a distribution control unit (DCU). These two elements while operating together perform the programmed switching operations necessary to interconnect the communications beams accessing the TDM/SS/SDMA satellite system.

The space-borne distribution subsystem is introduced into the conventional transponder equipment prior to the output power amplifiers. In system operation, the n-uplink beams and n down-link beams are interconnected in a programmable frame by the MSM under the control of the DCU. Re-routing of circuits in a satellite can be acheived through the appropriate TDM burst of the circuit to be switched to the transponder associated with the earth station to be served.

3.5.3 DESIGN OF MICROWAVE SWITCHING MATRIX

In TDM/SS/SDMA satellite system, any of the up coming beam groups can be connected to any of the downgoing beam groups by means of a dynamic, high speed satellite switch which can be programmed to distribute the bursts among all the beams in a desired periodic pattern in a common frequency band (say 40 MHz which is the bandwidth of the

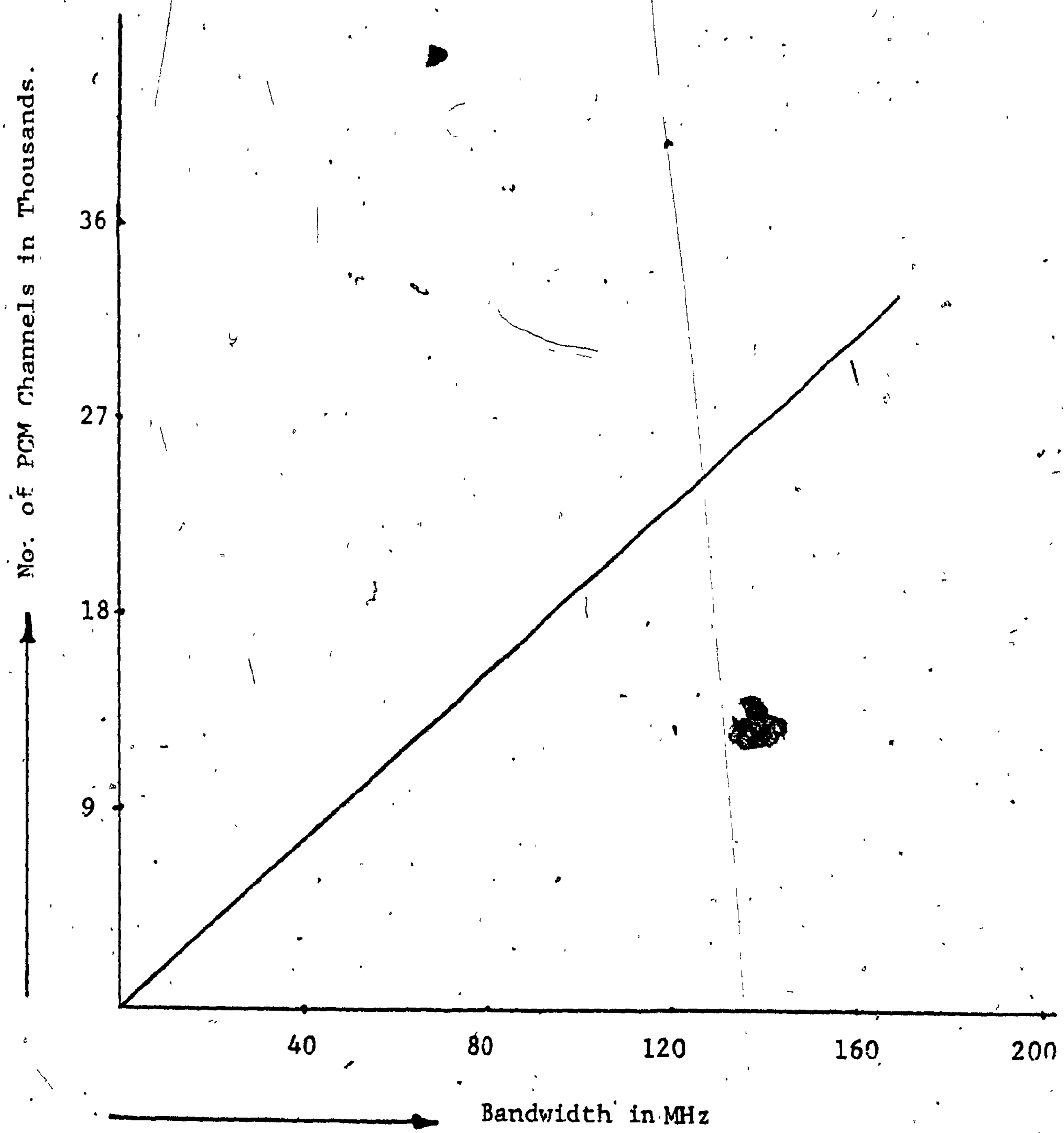


Figure 3-17:. Transponder Bandwidth VS No. of PCM Channels

transponder for Intelsat IV). For 4 X 4 matrix of beam group interconnections, a 4 fold frequency reuse could be established [20]. The switching matrix, shown in figure 3-16 and determined by the number of transponders required for the TDM/SS/SDMA system, are made of PIN diode and operated nearly at 10 nano seconds. The speed of the switch significantly is determined from the transmission rate of the system. These switches can operate either at baseband, IF or RF (Radio frequency), as per requirement.

The bit rate is mainly determines the number of the transponders. It has been found that there exist a linear relation between the transponder's bandwidth and the number of PCM channels.

The linear relationships, shown in figure 3-17, is obtained due to the fact that TDM/SS/SDMA operates in time demain.

CHAPTER 4

SYNCHRONIZATION TECHNIQUE FOR THE TDM SATELLITE SYSTEM

4.1 GENERAL

With the acceptance of TDMA and TDM/SS/SDMA as the most feasible multiple access techniques for multi-channel satellite communications; increasing attention is directed to the special problems encountered with synchronization aspects affecting satellite communication systems.

In a satellite communication system it is required that the commutation at the transmitting end and the decommutation at the receiving end must be in step, this requirement is commonly referred to as synchronization.

A brief survey on different methods of synchronization shows that two broad classes have been divised which are called open loop synchronization and closed loop synchronization [21]. Other workers have also identified synchronization in comparison with packet switching [22]; however this comparison falls in the category of open loop synchronization.

This chapter contains a brief description by open loop method and close loop method of the synchronization procedures for TDM satellites.

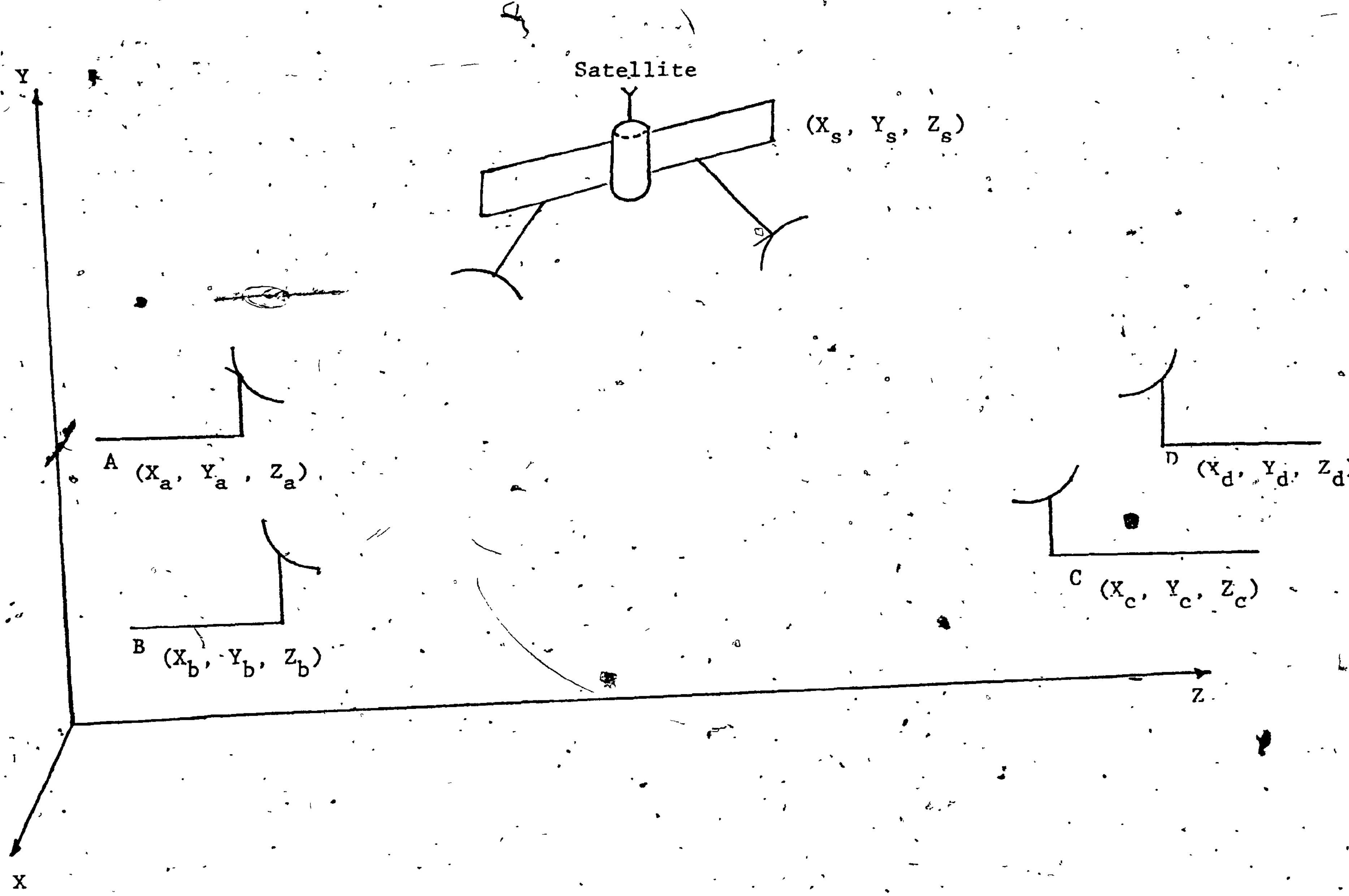


Figure 4-1: Open Loop Synchronization Diagram

4.2 ANALYSIS OF THE OPEN LOOP METHOD FOR TDM SATELLITE

In open loop mode of synchronization for TDM satellite, a burst is transmitted from an earth station with a preassigned time delay relative to the burst which is already synchronized by the closed loop method.

Three aspects of open loop analysis are presented in the following paragraphs:

Let us consider that there are A, B and C three ranging stations [23] and D is the station under open-loop control (refer to figure 4-1).

The range of the satellite from a particular earth station, A for example, is given by the following expression:

$$P_a^2 = (X_s - X_a)^2 + (Y_s - Y_a)^2 + (Z_s - Z_a)^2 \quad \text{--- (4-1)}$$

where, P_a = satellite range from A

X_s, Y_s, Z_s = satellite coordinates

X_a, Y_a, Z_a = coordinates for earth station A

Two further equations can be defined for stations B and C respectively so that the unknowns X_s, Y_s and Z_s can be calculated. Having defined the satellite's coordinates, the satellite range from station D can be calculated from an equation similar to (4-1).

$$P_d^2 = (X_s - X_d)^2 + (Y_s - Y_d)^2 + (Z_s - Z_d)^2 \qquad (4\text{-}2)$$

where P_d = satellite range from D

X_d, Y_d, Z_d = coordinates for earth station D

Equation (4-2) is an exact solution for the parameter P_d, but it involves the solution of three simultaneous second-order equations. The complication of solving three such equations can be reduced by describing the position of the satellite in terms of small displacements from a nominal position. In this manner the satellite's coordinates can be deduced from three linear simultaneous equations having made the assumption that second order terms in the small displacements can be ignored. However, it demonstrates that this assumption can lead to intolerable errors for a satellite with station-keeping limits of the Intelsat IV-A and V series of satellites.

The solution adopted for the open-loop experiment is to use a linearised solution for the co-ordinates of the satellite but with a 'nominal' satellite position which is refreshed so that in essence it follows the drift of the satellite. This displacement of the actual satellite position from the 'nominal' is always small enough for the linear approximation to be applied with confidence.

This approach presents the simplicity of the linearised solution and gives almost the same accuracy as the exact solution. However, the coefficients of the linearised solution have to be evaluated anew for each calculation.

In the form of the quasi-linear solution, the differences between nominal and actual delay to the satellite and back in symbol periods for stations A, B and C are denoted by ΔA, ΔB and ΔC respectively and are given by the following equations:

$$\Delta A = K_{ax} \Delta X + K_{ay} \Delta Y + K_{az} \Delta Z \quad \text{----} \quad (4\text{-}3)$$

$$\Delta B = K_{bx} \Delta X + K_{by} \Delta Y + K_{bz} \Delta Z \quad \text{----} \quad (4\text{-}4)$$

$$\Delta C = K_{cx} \Delta X + K_{cy} \Delta Y + K_{cz} \Delta Z \quad \text{----} \quad (4\text{-}5)$$

where $\Delta X, \Delta Y, \Delta Z$ = differences between actual and nominal satellite position.

K_{ax}, thru K_{cz} = constants depending on, among other parameters, earth station location and nominal satellite position.

Typically,

$$K_{ax} = \frac{2f\ (X_s - X_a)}{CP_a}$$

where f = symbol frequency; C = velocity of light

X_s, X_a = nominal satellite and earth station coordinates

Pa = range of earth station A from satellite

Equations (4-1), (4-2) and (4-3) can be rearranged to give:

$$\frac{\Delta X}{D_1} = \frac{\Delta Y}{D_2} = \frac{\Delta Z}{D_3} = \frac{1}{D_0} \quad \ldots\ldots\ldots\ldots \quad (4-6)$$

where D_0, D_1, D_2 and D_3 are third-order determinants given by:

$$D_0 = \begin{bmatrix} K_{ax} & K_{ay} & K_{az} \\ K_{bx} & K_{by} & K_{bz} \\ K_{cx} & K_{cy} & K_{cz} \end{bmatrix}$$

$$D_1 = \begin{bmatrix} \Delta A & K_{ay} & K_{az} \\ \Delta B & K_{by} & K_{bz} \\ \Delta C & K_{cy} & K_{cz} \end{bmatrix}$$

$$D_2 = \begin{bmatrix} K_{ax} & \Delta A & K_{az} \\ K_{bx} & \Delta B & K_{bz} \\ K_{cx} & \Delta C & K_{cz} \end{bmatrix}$$

$$D_3 = \begin{bmatrix} K_{ax} & K_{ay} & \Delta A \\ K_{bx} & K_{by} & \Delta B \\ K_{cx} & K_{cx} & \Delta C \end{bmatrix}$$

The solution for ΔX, ΔY, and ΔZ can be applied to the following equation:

$$R_d = \sqrt{\Big[(X_s - X_d)^2 + (Y_s - Y_d)^2 + (Z_s - Z_d)^2 + \Big\{2(X_s - X_d) + \Delta X\Big\}\Delta X + \Big\{2(Y_s - Y_d) + \Delta Y\Big\}\Delta Y + 2(Z_s - Z_d) + \Delta Z\Big\}\Delta Z\Big]} \quad (4-7)$$

Equation (4-7) is exact and holds for all values of ΔX, ΔY, ΔZ and X_s, Y_s and Z_s. The solution of equations (4-3), (4-4) and (4-5), however, depend on the difference between actual and nominal satellite position. For this reason at the end of each cycle of the calculation the nominal satellite position is refreshed according to the following:

$$X_s = X_s + \Delta X$$

$$Y_s = Y_s + \Delta Y \qquad \ldots\ldots \quad (4\text{-}8)$$

$$Z_s = Z_s + \Delta Z$$

$$P_a = \sqrt{\left[(X_s - X_a)^2 + (Y_s - Y_a)^2 + (Z_s - Z_a)^2\right]}$$

Similarly, this calculation is repeated for stations B and D. In addition, coefficients K_{ax} through K_{cz} are recalculated with the new satellite range and co-ordinate values.

To obtain a sufficiently accurate nominal satellite position to start range determination for station D, an arbitary satellite position will be defined in line with the incoming range data ΔA, ΔB and ΔC.

The minimum number of four open-loop participants in an open-loop acquisition and synchronization experiment. Station D could derive a number ΔD, the difference between actual and nominal range in symbol periods, using a linearized approximation by the following equation:

$$\Delta D = K_{dx} \cdot \Delta X + K_{dy} \cdot \Delta Y + K_{dz} \cdot \Delta Z \quad \text{.... (4-10)}$$

where coefficients K_{dx} through K_{dz} are defined in a manner consistant with coefficients K_{ax} through K_{cz}.

Equation (4-6) and (4-10) can be combined to give:

$$\Delta D = K_{dx} \cdot \frac{D_1}{D_0} + K_{dy} \cdot \frac{D_2}{D_0} + K_{dz} \cdot \frac{D_3}{D_0} \quad \text{.... (4-11)}$$

Equation (4-11) can be rearranged to yield:

$$\Delta D = \frac{D_4}{D_0} \cdot \Delta A + \frac{D_5}{D_0} \cdot \Delta B + \frac{D_6}{D_0} \cdot \Delta C \quad \text{.... (4-12)}$$

where

$$D_4 = \begin{bmatrix} K_{dx} & K_{dy} & K_{dz} \\ K_{bx} & K_{by} & K_{bz} \\ K_{cx} & K_{cy} & K_{cz} \end{bmatrix}$$

$$D_5 = \begin{bmatrix} K_{ax} & K_{ay} & K_{az} \\ K_{dx} & K_{dy} & K_{dz} \\ K_{cx} & K_{cy} & K_{cz} \end{bmatrix}$$

$$D_6 = \begin{bmatrix} K_{ax} & K_{ay} & K_{az} \\ K_{bx} & K_{by} & K_{bz} \\ K_{dx} & K_{dy} & K_{dz} \end{bmatrix}$$

If station D were made coincident with station A to reduce the complexity of the experimental open loop network, then $D_4 = D_0$, and $D_5 = D_6 = 0$

Equation (4-12) reduces to $\Delta_D = \Delta_A$

In other words, the solution of the range for station D (or A) is independent of measurements taken at stations B and C. To obtain meaningful results from the open loop experiment, four physically seperated stations must constitute the open loop network.

The accuracy to which the satellite can be determined from measurements made at station A, B, and C, and the subsequent calculation of satellite range from station D, depends on the accuracy to which the coordinate of earth station A through D can be determined.

The latitutde and longitude of earth station antennas are documented to the nearest second of arc so that their Cartesian coordinates can be determined from the parameters of the international spheroid. Therefore the coordinate of the antenna must be modified to take the difference into account.

The way this modification is transformed is as follows: station D provides the output of its range counter to A which also receives the range numbers from stations B and C, as well as its own for portions of the daily movement of the satellite. All these numbers are time indexed and recorded. The satellite position is determined by the quasi-linear solution and the exact solution of satellite range of station D is determined. Initial values of earth station coordinates are those of the respective antenna. Thus, the differences between measured range and calculated range for station D can be observed for the day. The coordinate of station B, C and D can now be refined in accordance with the distance of the TDM terminals from the antenna and the mean square error between measured and calculated error observed. A selection of coordinates for stations B, C and D can be evaluated and the set which gives the least mean square error can be chosen. The selection must be strictly limited and chosen judiciously, otherwise the scope of the problem becomes unmanageable.

4.3 CLOSE LOOP METHOD

In closed loop method of synchronization for TDM satellite system, the burst coming from an earth station is synchronized on reception at the same earth station. That means an earth station, operating in TDM mode, using close loop mode of synchronization, transmits unique word for initial acquisition and a reference burst to the satellite and loops back to the same earth station. However, an earth station, operating in TDM/SS/SDMA, transmits a synchronization burst to the satellite and the synchronization window of the synchronization burst is looped back to the same earth station. Therefore, initial acquisition and synchronization procedure for TDMA and TDM/SS/SDMA by using unique word and reference burst plus self locking method and window method are described here respectively.

4.3.1 SYNCHRONIZATION PROCEDURE FOR TDMA [24]

Unique words, which are a unique set of symbols in the preamble serving to establish a known position in the burst, establishes approximate transmission timing. Therefore, a station transmits only the preamble, which is monitored by its receiver.

For synchronization, a single ground station utilizing reference burst plus self locking method transmits a reference bursts which passes through the transponder of the satellite and they are received by all other ground stations. Relative to this time base, the ground stations establishes the time slot for its transmission to the satellite. An elaborate description of initial acquisition and synchronization method by using unique words and reference burst plus self locking is presented as follows:

The TDMA system clocks are free-running and have an accuracy in the order of 1 part in 10^9. With a perfectly geosynchronous satellite, the transmitted burst position could, drift relative to the reference burst at the rate of one symbol duration every 15 seconds. This bursts error can be overcome by each station itself by comparing the timing of its own unique word (UW) with the reference unique word (RUW). If the two unique words (i.e. UW and RUW) are not coincident, the time difference will be measured and used to advance or retard the timing pulse. The timing pulse determines the start of the transmit burst at the rate of one symbol per frame for the appropriate number of frames. This is called synchronization of transmitted and received bursts. Once the correct timing between the transmit and receive has been established, normal transmission can begin.

The synchronization method described above relies on reception by each earth station of its own transmitted burst after retransmission by the satellite. Such satellites use global beam. However, the above method cannot be used in satellites which are using spot beam.

The above method of synchronization is easy to implement. Since, it can be applied to a TDMA network using many ground stations, it is proposed that the common frame timing shall be used for all the TDMA signals passing through one satellite, controlled by a single reference station. A reference burst would be transmitted through one global beam transponder and all other earth stations would use this burst to acquire system burst timing. This can be achieved with the help of a PSK demodulator. The PSK demodulator is designed to receive the preamble and acquire the phase of the carrier during the first part of the preamble and to maintain it throughout the burst, with sufficient accuracy to give a very low error rate at the operating C/N ratio. Similarly, the demodulator will rapidly acquire the clock phase and retain it throughout the burst. Consequently, correct detection of incoming bits should be taking place before the start of unique word. The differences between the phases of the received burst and the reference burst may take little time to be reduced to zero and this is called acquisition time.

After overcoming the phase difference and unique word detection, the remainder of the preamble is routed to the station identification unit which informs the demultiplexer of the origin of the burst. The control signal unit, which extracts the order wire, (i.e. service channel) from the circuit routes them to the order wire unit. A station which looses synchronization during its operation must inform another station about a synchronization loss by transmitting an alarm signal. Two different alarm signals are used, one indicating the loss of UW and the other indicating the loss of RUW, then these alarm signals can be used to determine a failure in the system.

Usually a so-called rapid re-entry procedure is desired, in which the station starts transmitting its UW directly without any need of initial acquisition.

4.3.2 SYNCHRONIZATION PROCEDURE FOR TDM/SS/SDMA SYSTEM

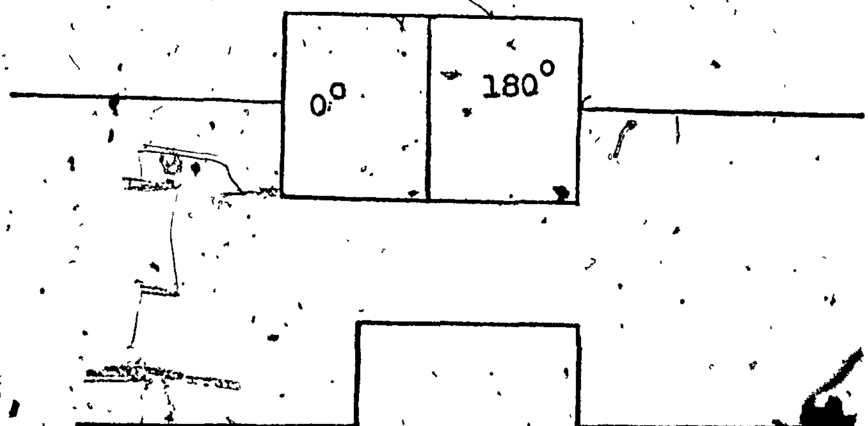
A ground station operating in TDM/SS/SDMA mode achieves synchronization when the sync burst of the super frame looped back to it by a switch connection interval i.e. "Sync. Window". The use of the synch window only to synchronize each earth station to the autonomous satellite distribution centre eliminates the concept of a reference station. The satellite becomes a reference station for all users. Synchronization using window method is separated into three distinct phases. These are called the coarse search mode, the fine search mode and the tracking mode. Each of the modes are described in detail.

a. Coarse search mode

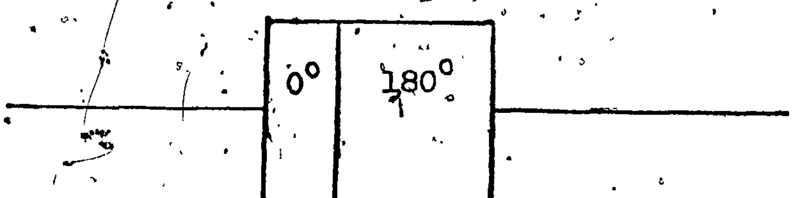
In start up, a ground station does not have synchronization. This means that the timing relationship between the ground station time base and the occurence of sync. window satellite is not known at the ground station. Therefore, the first operation which to be performed must be to obtain an estimate of the time at which a sync. burst should be transmitted in order to reach the satellite at the correct time. Passage through the sync. window and its return to the ground station is dependent on the assumption of the initial estimate. Two possible methods described here, which can be implemented with the PSK signals, are first the sync burst technique and, second, the coded search signal technique.

(1) Course search mode using PSK Sync. bursts:

Any station in the system achieves synchronization by transmitting a train of sync. bursts having a unique frequency identified with that station.



a. PSK Sync. Burst



Sync Window modulated Sync burst.

Figure 4-2: PSK Sync. Burst

There are three possibilities:

(i) The sync. burst arrives at the satellite when a sync. window occurs.

(ii) The sync. burst arrives at the satellite after the occurrence of sync. window.

(iii) The sync. burst arrives at the satellite midway during the occurrence of the sync. window.

In the first case, the sync. burst is modulated by the window as shown in figure 4.2 and returned to the ground station one round trip time delay after transmission (270 ms). The probability of occurrence of this case is 0.024 i.e $\left(\frac{\text{sync window length}}{\text{frame length}} * 3\right)$

If the other two cases occur, then the ground station increments a clock by a small amount equal to approximately the sync. window duration 6 μsec.

for 750 μs frame or 1 μs for 125 μs frame) and repeats the procedure until the entire frame length which required to vary over the entire frame length. This requires approximately 40 sec.

An estimate of the bandwidth required for the PSK burst for the two different sync. window durations of 1 us and 6 us can be obtained by considering the bit rates. For the former, the requirement is 2 Mb/s while for the latter the value is 0.33 Mb/s. There is a possibility of interference due to sync. bursts falling in data windows during the search. On the average, the interference duration is $\frac{1}{2}$ N* T_F where N is the numbers of pulses in each transmitted train, and T_F is the frame of the satellite switched sequence.

(2) Coarse search mode using coded search signals

Coarse search synchronization can be achieved in only one round trip time of approximately 270 ms [25]. Synchronisation is independent of the ratio of frame length to window duration. The use of a PSK coded search signal provides a sufficiently good estimate of the relationship between the sync. window and the ground station time base so that a PSK sync. burst could be transmitted. The timing relationship can be found by considering the following three parameters:

i) The transmission time delay T_A between the earth station and the satellite.

ii) The time difference T_S between the arrival of the leading edge of a transmitted signal from an earth station at the satellite and the occurence of the first subsequent synchronization window.

iii) The frame T_F of the satellite switch sequence.

Typically, T_A is in the order of 135 ms, T_S may fall anywhere between Zero and T_F. T_F is determined by a highly stable oscillator on board the satellite and has a frequency that is assumed to be known at the earth station.

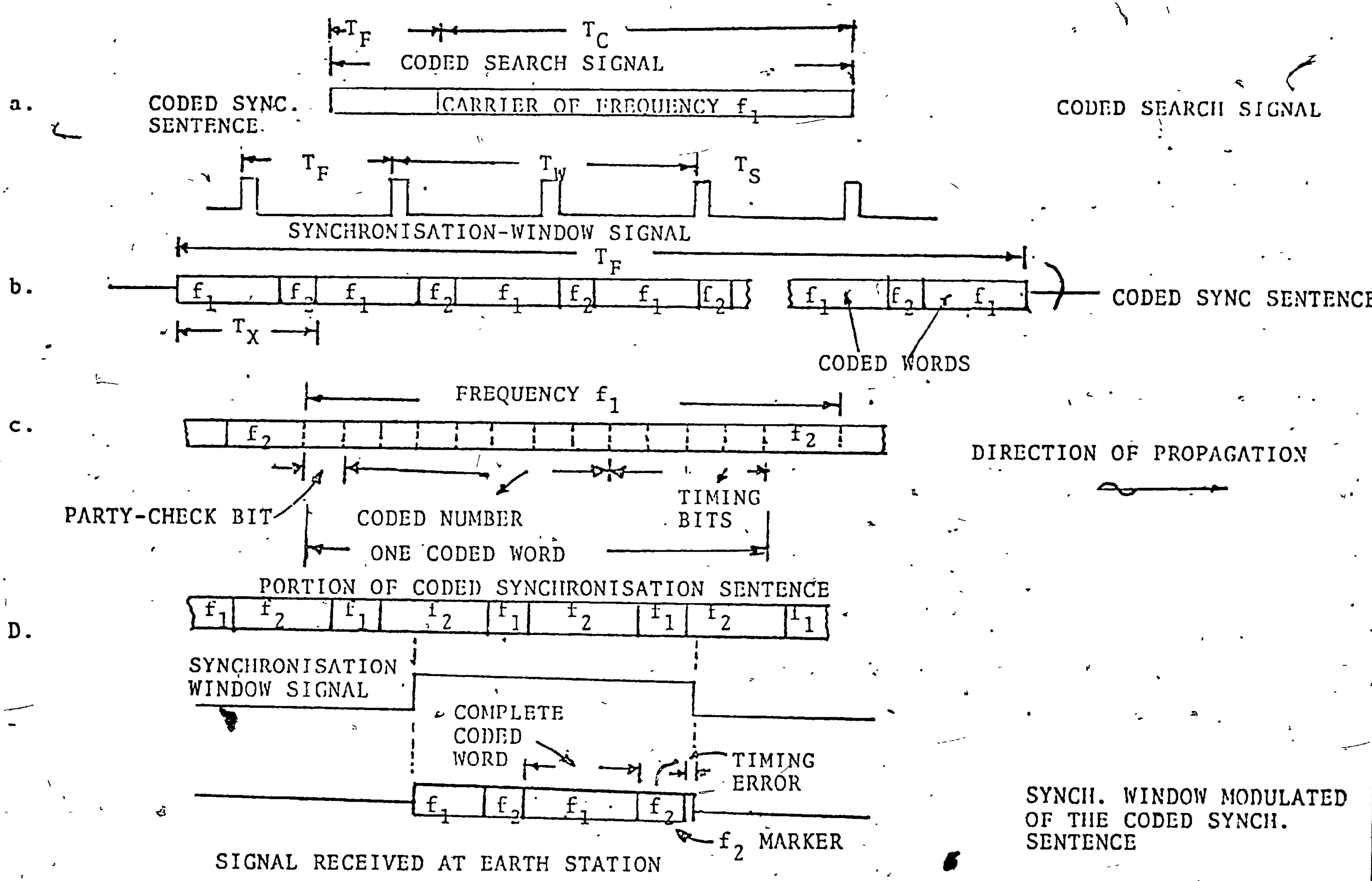


Figure 4.3: Synchronisation-Signal and Structure

The coded search signal, illustrated in figure 4-3a consists of two parts, the first being carrier of duration $T_C \gg T_F$ and the second a coded Synchronization sentence structure of duration T_F that is used to provide an estimate of T_S. Synchronization window modulates the carrier portion to produce pulses from the carriers that are used by the earth station receiver for the purpose of carrier lock.

Let us assume that, at the earth station, there is a high-stability oscillator driving a counter, a decoder having a reset feature, and an interpulse spacing of the output pulses is T_F. When the leading edge of the coded synchronization sentence is transmitted, the counter is reset. Now, the leading edge of the coded synchronization sentence, is transmitted, at time T_1 reaches the satellite at time $T_1 + T_A$, and, at a later time T_S, the synchronization window modulates the coded synchronization sentence portion of the signal, producing a pulse. At the time $T_2 \approx T_1 + 2T_A + T_S$, this pulse reaches the earth station, where the time difference between T_1 and T_2 is given by

$$T_R = T_2 - T_1 = 2T_A - T_S \quad .... \quad (4-13)$$

or $$T_A = \frac{1}{2} (T_R - T_S) \quad .... \quad (4-14)$$

An other way to determine T_S is by considering the coded synchronization sentence, also shown in figure 4-3b, which uses two different frequencies f_1 and f_2 and a set of coded words. The frequency f_2 is used solely to provide a marker to indicate the beginning of each coded word, so that a simple decoding procedure would be possible. Each coded word has a structure, illustrated in figure 4-3c that comprises several bits at the beginning (to provide bit timing), a coded number and a parity-check bit and the end. Carriers lock to f_1 is obtained from the pulses of the carrier, as previously mentioned. The coded numbers (in binary form) would run in consecutive order from zero to some integer K that is the smallest integer satisfying:

$$K \geqslant \frac{2 T_F}{T_W} - 1 \quad .... \quad (4-15)$$

where T_W is the synchronization-window length.

Having determined K from this relation, the duration T_X that defines the length of one code word plus one burst of frequency f_2 as shown in figure 4-3c can be next determined by using

$$T_X = \frac{T_F}{K + 1} \qquad \ldots. \quad (4\text{-}16)$$

The synchronization window produces a pulse length T_W of the coded synchronization sentence (figure 4-3d) and returns the signal to the earth station. Since the frequency f_2 marks the beginning of a coded word, it it possible for the earth station to identify, the portion of the synchronization sentence modulated by decoding word immediately following the f_2 frequency burst. The received signal would always contain at least one full length f_2 frequency burst and code word, since the coded words and the f_2 burst would have a time period. Hence, T_S and T_A could be calculated by using equation (4-14)

Finally, it is possible to determine the time at which a train of earth station's synchronization bursts should be transmitted. This predicted time can be related to the transmission time T_1 given by:

$$T = T_1 + T_S + PT_F; \quad P = 1, 2, 3 \ldots \quad (4\text{-}17)$$

But the values of $T' = T_1 + PT_F$ for different P, are just the times at which pulses are appearing out of the decoder fed by the earth station oscillator and counter. Thus, if the counter is fed to one side of a comparator, and T_S is loaded into the other side of the comparator, the required predicted time T will occur on equality in the comparator. This output pulse can be used to reset the counter, and pulse from the decoder will hence mark the times at which synchronization bursts should be transmitted. Therefore, coarse search synchronization is achieved in one round-trip time of approximately 270 ms independent of the time frame length [26].

Method	Sync Acquisition Time	Bit Rate
PSK Sync burst		
1 μs Sync Window	270 ms to 40 s	2 Mb/s
6 μs Sync Window	270 ms to 40 s	0.33 Mb/s
Coded Search Signals		
1 μs Sync Window	270 ms	2 Mb/s
6 μs Sync Window	270 ms	0.33 Mb/s

Table 4-1 Comparison of PSK Sync burst method and coded search signal method.

An estimate of bandwidth required for the coded synch. sentence can be obtained by considering the bit rates assuming 1 us and 6 us synch. window. The coded sync. sentence uses a bit rate of 2 Mbit/s for the forme and 0.33 Mbits for the latter. The amount of interference caused by a coded search signal falling into data windows can be determined by considering the length of the signal. Since only one transmission is required for synchronization, the total interference time for a coded search signal is just its duration.

The sync burst method and the coded search signal method can now be compared, as shown in Table 4.1. From the standpoint of fast acquisition, narrow bandwidth and short interference time, the coded search signal using PSK sync sentence appears to be supperior to the other techniques.

b. Fine search mode using the PSK sync. burst

Fine search synchronization can be initiated once the coarse search mode is completed. The objective in this case is to reduce the initial timing error due to the inaccuracies in the coarse search mode. In this mode, burst trains of sync. bursts are transmitted and after one way trip time, the train reaches the satellite. Next, the signals are modulated by the sync window, as shown in figure 4-2 and transmitted back to the ground station. By comparing the modulation and the built-in timing reference of the sync burst, it is possible to measure a timing error and adjust the ground station time base. Further trains of sync bursts can then be transmitted at intervals of one round trip time with the adjustment performed after each train is received. Hence, a feedback control loop results. Two different techniques for providing fine search described here are the fine search system with digital control and the fine search system with analog control.

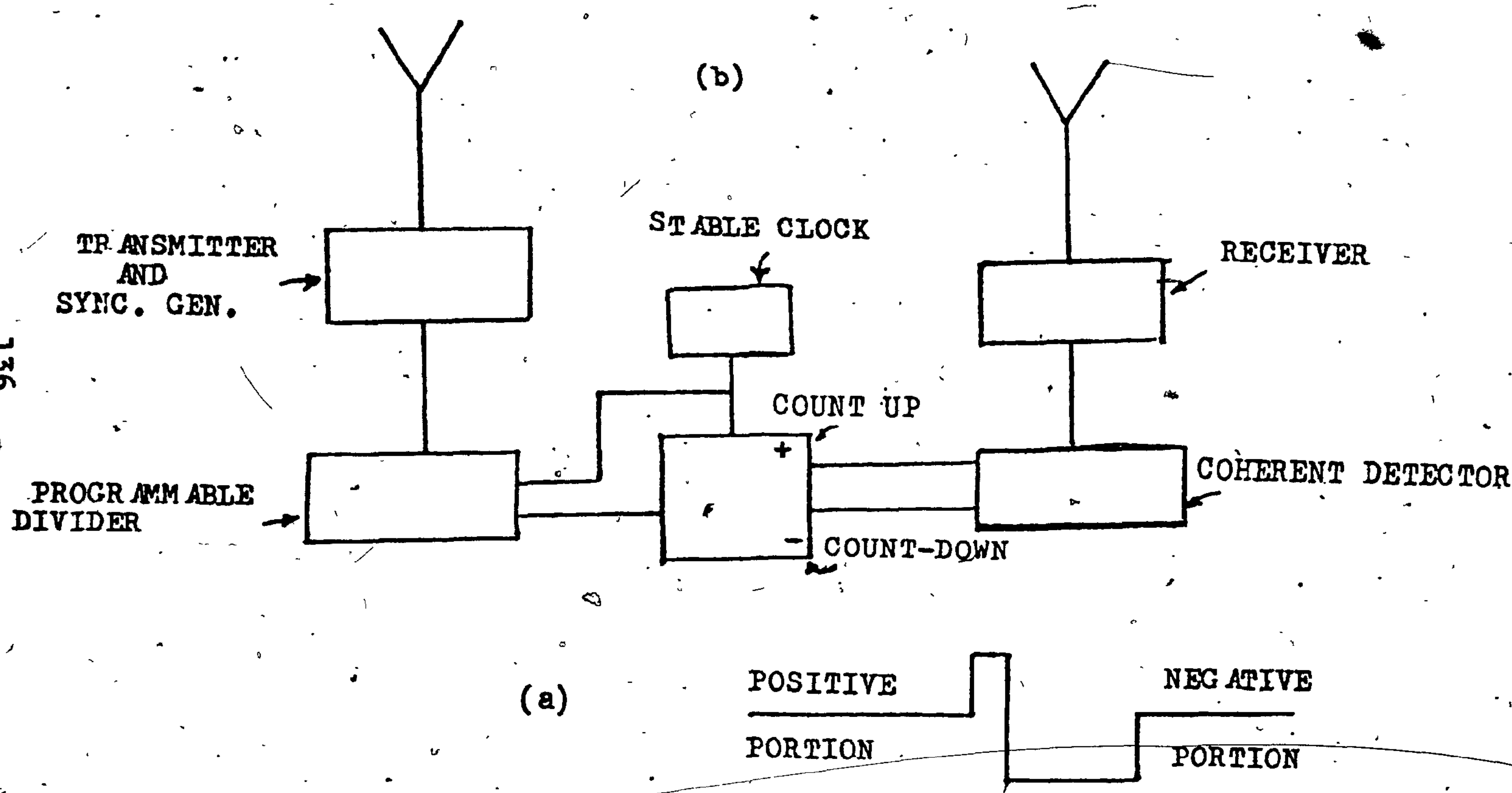


Figure 4-4: Ground Station with Digital Control

(1) Fine search using digital control

PSK sync brusts, transmitted by the ground station are modulated at the satellite and arrive back at the ground station after one round trip time. The sync bursts are detected coherently producing a video wave form consisting of a positive portion and a negative portion, as shown in figure 4-4a. Figure 4-4b shows the digital control system. Each portion of the video burst is used to gate clock pulses into a counter. The positive portion would count-up and the negative portion would count-down.

The remainder is, then, a measure of the timing error. By advancing or retarding the ground station time base by a number of clock pulses equal to half the error, the time base error can be reduced. Precision is restricted to the basic resolution which is a clock pulse period of approximately 30 ms and accuracy is limited mainly by satellite motion.

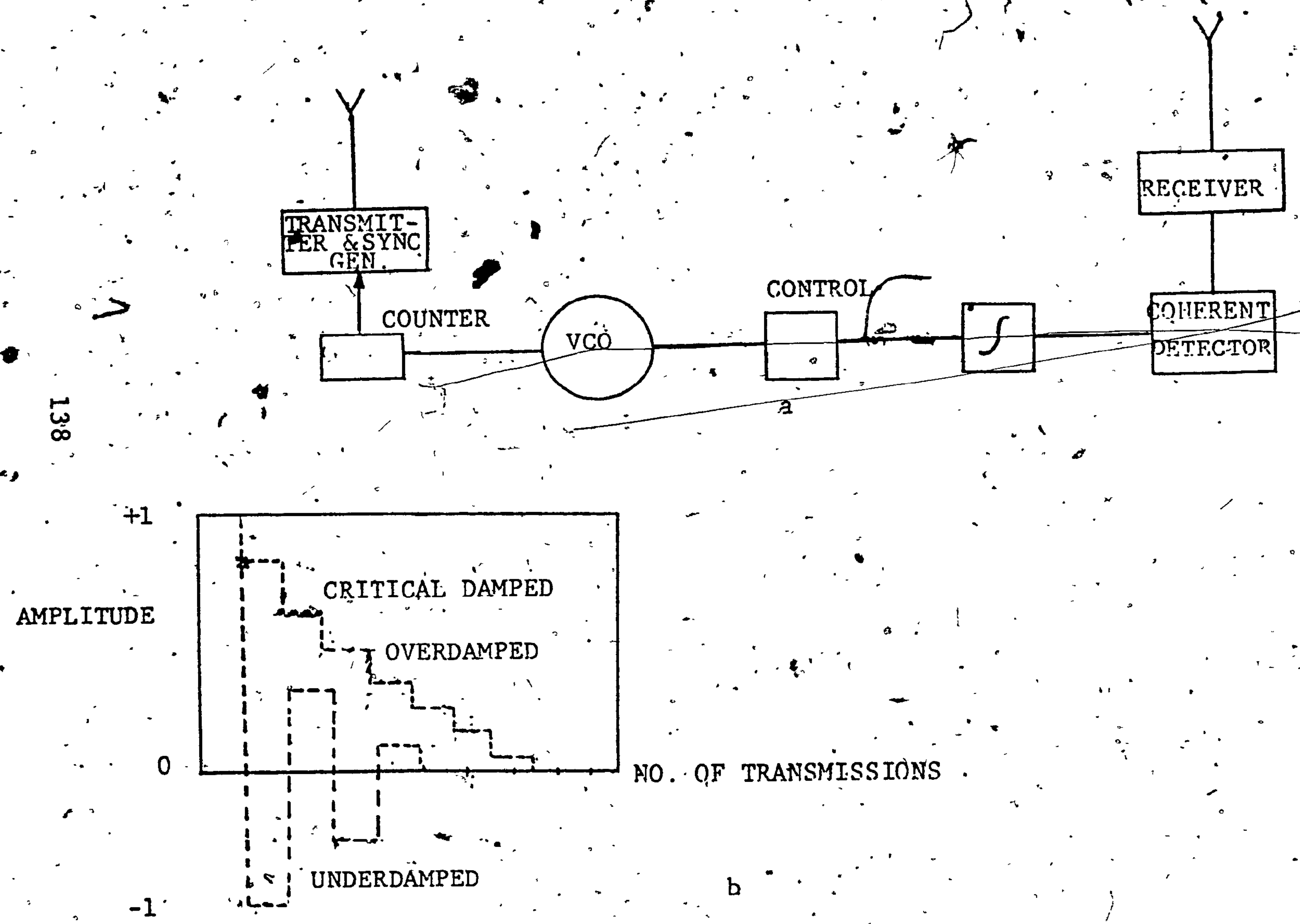


Figure 4-5: Ground Station With Analog Control

(2) Fine search mode using analog control

The analog fine search system is not as restricted severely be accuracy problems as in the digital case. The essential features of the system are as follows: The sync. bursts, transmitted by the ground station, are modulated at the satellite and arrive back at the ground station after one round trip time. The sync. bursts are detected coherently producing the video waveform shown in figure 4.4a, as in the digital case. However, error voltage is produced by integrating the pulses, as shown in figure 4.5a. Zero timing error gives zero integrated voltage and positive and negative timing errors give positive and negative integrated voltage, respectively. The integrated error voltage is used to adjust the frequency of a voltage-controlled oscillator (VCO) over a short period and in effect producing a phase shift. After the shift, another train is transmitted and the same procedure is repeated. It is possible to show that this series of steps leades to progressively smaller timing error, as in figures 4.5b and the

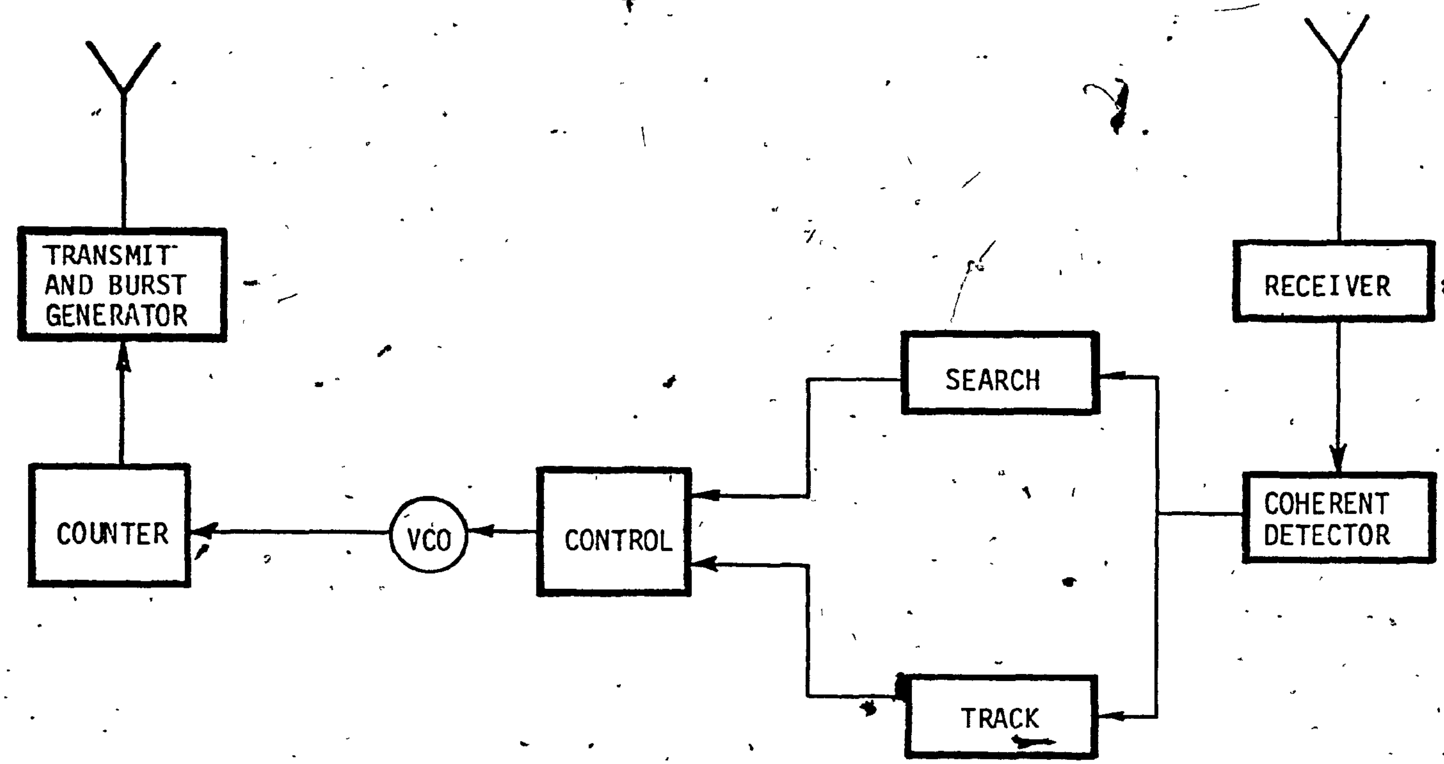


Figure 4.6: Tracking Mode

limit is dependent on the number of pulses integrated and the signal-to-noise ratio. Thus the measurement of the time error can be improved simply by integrating more pulses.

Three possible cases arise using this loop. If the loop constant is small, overdamping occurs. If the loop constant is large, underdamping results. Critical damping is also possible. Assuming a high stability oscillator on-board the satellite and high stability VCO at the ground station, the main source of error is due to the satellite motion and elimination of this error is considered next.

c. Tracking mode using the PSK Sync Burst

Errors due to satellite motion can be reduced by using a tracking network in conjunction with the analog fine search control as shown in figure 4.6. Since the VCO has two adjustable parameters, (namely, the phase and the frequency). It is possible to use the latter to reduce the timing error due to satellite motion. At all times, the tracking network applies a small correction voltage to the VCO. This corrective voltage causes the frequency of the VCO to be different from the center frequency whenever there is satellite motion. Thus, provided the acceleration is small, the sync window of a switching satellite can be accurately tracked by a ground station. It is estimated that the timing error can be reduced to several nanoseconds even for a satellite moving at constant velocity.

CHAPTER 5

C O N C L U S I O N

5.1 GENERAL

An overview of the multiple access techniques, used in satellite communication, has been presented. In different modes of multiple access techniques like FDMA, SPADE, DAMA, TDMA and TDM/SS/SDMA, the following are to be noted:

a. SPADE is suitable for light taffic.

b. FDMA cannot be operated in full capacity because of intermodulation between two channels which is due to the non-linearity of TWT.

c. DAMA is suitable for light traffic. Locally controlled DAMA offers better results over centrally controlled DAMA.

d. TDMA offers efficient utilisation of satellite power and bandwidth. Also there is no intermodulation since one carrier is transmitted at a time to TWT.

e. TDM/SS/SDMA has essentially the same principle as that of TDMA and it offers more capacity than TDMA due to the introduction of microwave switching on-board.

f. Comparison between FDMA and TDMA shows that TDMA is attractive but expensive to implement in the satellite communication.

Chapter 3 describes the subsystems of the satellite communication systems and the following significant points have been noted:

a. The lesser the guard time between the two consecutive burst, the better the efficiency. The frame length of 750 μsec found to be more efficient than 125 μsec.

b. The effect of satellite motion is analysed.

c. The technique to calculate the path loss is identified.

d. The rain causes severe attenuation on the propagation path. Site diversity is suggested to avoid fading due to rain.

e. The transmit and receive earth station have same configuration but opposite function. The assemblies on earth stations were described as follows:

(1) The PCM technique is identified.

(2) The buffer memory function is discussed and the method to calculate the storage capacity is described and it depends on the frame length.

(3) The function of multiplexes/demultiplexes are important to divert the proper burst into proper channel.

(4) Scramblers and descramblers can be used to avoid interference between the satellite systems and the terresterial microwave systems operating in the same frequency band.

(5) The process of synchronization and acquisition looks similar to the acquisition behaviour of phase Lock Loop. Hence PLL is used in measuring the discrepancy in the phases of the reference burst and the burst containing data.

f. The size of switching matrix on board depends upon the traffic density.

Finally, in chapter 4, the following points are described:

a. Synchronization and initial acquisition are grouped in two i.e. (i) open loop method and (ii) close loop method.

b. Open loop method is based upon the approximation of the satellite range.

c. In TDMA system, the burst of each participating station must contain station identification code and time references which help in acquiring re-synchronization without the need for initial acquisition.

d. Synchronizations can be maintained among many ground stations by implementing a common frame timing.

e. The technique described for synchronization, in TDM/SS/SDMA, between the ground stations to a switching satellite, uses three steps called the coarse search mode, the fine search mode and the tracking mode.

f. It is shown that coarse search synchronization could be achieved using two different methods and that in particular the coded search signal using frame sync. sentence offers advantages in faster acquisition time and less interference.

g. In the fine search mode, an anlaog technique is described and a brief description of the loop behavior is presented.

h. Finally a technique for providing a tracking mode is described using analog control which accounts for satellite motion.

It may be concluded that TDMA technology is well developed due to many advances made by numerous researchers throughout the world. At present, TDMA development is at a plateau, waiting for operational experience. Then TDMA systems of various designs tailored to specific requirements are expected to prosper in domestic, international, and special purpose applications.

The results and ideas presented in the study of TDM/SS/SDMA have not yet been fully complemented and laboratory measurements as well as practical test will be required to confirm its feasibility for operational satellite systems.

This report has attempted to give a conceptual grasp of the system and to indicate areas where further research is necessary. It is hoped that the TDM/SS/SDMA system will be the most promising technique for future spot beam satellite communication.

REFERENCES

(1) K.Miya, Global Satellite Communication, Lattice Company, Japan, 1975.

(2) J.J.Spilker, Digital Communications by Satellite, Printice-Hall, New Jersey, 1977.

(3) Dinwiddy, "Advance Techniques for the ECS Systems", STL Research Contract No. 1433/71 SL 1972.

(4) G.T.Alderich, "An Operational Single Channel-Per Carrier Demand-Assignment-Multiple Access Satellite Telephone Network using Centralized Control", Nat. Telecommun. Conf. Vol. 2, pp 25-13 to 25-16, New Orleans,Louisiana, December 1-3, 1973.

(5) J.R.Allen, "TDMA System Design for small Satellite Terminals" Int., Conf. Commun, Vol. 2, pp 49-11 to 49-14, Seattle Cen~~tre~~, Seattle, Washington D.C., June 11-13, 1973.

(6) O.G.Gabbard, P.Kaul, A.Walker, J.Hangen and Pradeep Kaul, "The Common TDMA Terminal Equipment for the Telesat TDMA System", Int. Conf. Commun, pp 44-16 to 44-21, San Francisco, CA, 1975.

(7) J.Dicks and M.Brown, "Intelsat IV-A Transmission System Design", COMSAT Tech. Rev. Vol 5, Number 1, pp 73-103, Spring 1975.

(8) J.P.Houssin, "The Planning of Satellite Systems for efficient use of the Geostationary Satellite Orbit", Int. Conf. Digital Satellite Systems Technology, pp 8-11, Savoy Place, London, April 7-10, 1975.

(9) C.E.Mahle, V.E.Rigionos and I.G. Atohoun, "In-Orbit Testing of Communications Satellite", COMSAT Tech. Rev. Vol 7, Number 1, pp 197-226, Spring 1977.

(10) D.C.Hogg and TA-Shing Chu", The Role of Rain in Satellite Communications", Proc IEEE, Vol 63, No. 9, pp 1308-1331, September 1975.

(11) R.R.Taur and J.Mass, "Rain Depolarisation and its effects upon Satellite Communications Systems", in Inter. Conf. Comm. Philadelphia, Pennsylvania, June 14-16, 1976.

(12) M.H.A.Schulke and J.Rose, "Defense Communications and its Technology - Past, Present and Future", Int. Conf. Comm., Vol 2, pp 45-1 to 45-6, Seattle Centre, Seattle, Washington D.C., June 11-13, 1973.

(13) N.T.Keyes and D.J.Muller, "Multiplexing" in Int. Conf. Commun, pp 2B-1 to 2B-5, Minneapolis, Minnesota, June 17-19, 1974.

(14) D.G.Leeper, "A Universal Digital Data Scrambler, "Bell System Tech.", Vol 52; No. 10, December 1973.

(15) F.M.Gardner, "Comparison of QPSK Carrier Regenerator Circuits for TDMA Application", Int. Conf. Commun, pp 43-1 to 43-5, Minneapolis, Minnesota, June 17-19, 1974.

(16) P.A.Kullstam, "Differentially Coherent Demodulator of BPSK and QPSK signals in the presence of Doppler and Phase Noise", Nat. Telecommunications Conf. pp. 221-227, San Diego, California, December 2-4, 1974.

(17) R.H.Ryle and J.Way, "An Adaptive Discrete Phase Lock Loop Acquisition Behaviour", Int. Conf. Comm. pp.43-1 to 44-5, Minneapolis, Minnesota, June 17-19, 1974.

(18) S.A.Butman and J.R.Lesh, "The Effects of Bandpass Limiters on n-phase, Tracking systems", Int. Conf. Commu., pp 21.5-100 to 21.5-103, Chicago, Illinois, June 12-15, 1977.

(19) Wright and McLellan, "Defense Satellite Communication System - An Operational System", Int. Conf. Commun., pp 31.1-281 to 31.1-285, Chicago, Illinois, June 12-15, 1975.

(20) W.G. Schmidt and R.S.Cooperman, "A Satellite Switched SDMA/TDMA System for a Wideband Multibeam Satellite", Int. Conf. Commun., pp 12-7 to 12-12, Seattle Centre, Seattle, Washington, D.C., June 11-13, 1975.

(21) P.P.Nuspel, K.E.Brown, W.Steenaart and G.Chieopoulos, "Synchronization Methods for TDMA", Proc. IEEE Vol 5, Number 3, March 3, 1977.

(22) C.R.Carter, "Packet Switching using a Regenerative Switching Satellite", 18th. Midwest Symposium on Circuits and Systems, pp 42 to 46, Montreal, August 11-12, 1975.

(23) P.P.Nuspl , N.G.Davies and R.L.Olsen, "Ranging and Synchronization Accuracies in a Regional TDMA Experiment", 3rd Int. Conf. Digital Satellite Communications, Koyto, Japan, November 1975.

(24) H.Ganssmantel and B.Ekstram, "TDMA Synchronization for Future Multitransponder Satellite Communication", Int. Conf. Commun., pp 430-1 to 430-5, Minneapolis, Minnesota, June 17-19, 1974.

(25) R.A.Rapuano and N.Shimmaski, "Synchronization of Earth Station to Satellite-Switched Sequence", Proc. of AIAA, 4th, comm. Sat. System Conf., Vol 33, pp 411-429, Washington, 1972.

(26) C.R.Carter and S.S.Haykin, "Fast Synchronization of an Earth Station to a Switching Satellite", Electronics Letters, Vol 9, pp 513-514, November, 1973.

(27) M.Asahara, Y.Samamoto, Y.Sohma, M.Fukui and T.Hara, "Synchronization and Acquisition problems for SDMA/SS-TDMA Results of Hardware Studies", Int. Conf. on Satellite Communications Technology, pp 43E-1 to 43-5, Savoy Place, London, April 1-10, 1975.