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CHAPTER 2

MULTIPLE ACCESS TRADE STUDY

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2.0 INTRODUCTION

The Personal Access Satellite System (PASS) strawman design, as described in the PASS Concept Study Report[1], (hereafter referred to as the Strawman Design) utilizes a hybrid Time Division Multiple Access (TDMA)/ Frequency Division Multiple Access (FDMA) implementation. TDMA is used for the forward direction (from Suppliers to Users), and FDMA for the return direction (from Users to Suppliers). In the forward direction each transponder has a narrow band pilot channel plus two relatively high rate data and voice channels. In the return direction, access to the system by users is provided using narrow band Single Channel Per Carrier (SCPC), frequency division, Demand Assigned Multiple Access (DAMA). The channel assignment is done by a Network Management Center (NMC).

An alternative architecture is proposed that will require minimal real time coordination and yet provide a fast access method by employing random access Code Division Multiple Access (CDMA). This chapter addresses the CDMA system issues such as (1) connecting suppliers and users, both of whom may be located anywhere in the CONUS, when the user terminals are constrained in size and weight; and (2) providing efficient traffic routing under highly variable traffic requirements. It is assumed that bandwidth efficiency is not of paramount importance.

CDMA or Spread Spectrum Multiple Access (SSMA) communication is a method in which a group of carriers operate at the same nominal center frequency but are separable from each other by the low cross correlation of the spreading codes used[2]. Interference and multipath rejection capability, ease of selective addressing and message screening, low density power spectra for signal hiding and security, and high-resolution ranging are among the benefits of spread spectrum communications.

The problem of allowing multiple users to simultaneously access a channel without causing an undue amount of degradation in the performance of any individual user is a classical one in communications. Multiple access is the process by which a large number of stations interconnect their links. The two most common techniques, FDMA and TDMA, attempt to solve the problem by separating the signals in frequency and time, respectively. In CDMA architectures, stations use spread-spectrum transmissions with low cross correlating codes to share a channel with minimal interference. Each of these techniques has certain drawbacks associated with it.

For example, in FDMA, anytime the channel through which the signals are transmitted is nonlinear, intermodulation products will be generated. In TDMA, the intermodulation problem does not exist, but accurate synchronization of all users becomes important in system design. Furthermore, if interference such as jamming or multipath is present, large degradations in system performance can result in both FDMA and TDMA systems[3].

For such reasons, CDMA has become a competitive multiple access scheme in certain situations. Multiple access can be achieved by spread spectrum code division using direct pseudonoise sequences, frequency hopping, or combinations of these techniques. A primary necessity of such systems is the requirement for sets of spreading signals which have the two properties that 1) each signal can easily be distinguished from a time-shifted version of itself, and 2) each signal can easily be distinguished from every other signal in the set[4]. One of the major benefits of CDMA is the lack of central frequency and timing control. A CDMA system is usually operated in an asynchronous manner so that network timing problems do not exist. There is a penalty for this flexibility, of course, and that is a smaller capacity due to the imperfect orthogonality of the spreading sequences of the various users. The inter-modulation problem does not go away with CDMA, but the capability of rejecting external interference is invariably the crucial factor in deciding to implement a CDMA system.

In FDMA each uplink RF carrier occupies its own frequency channel. Guard bands between adjacent frequency channels allow for imperfect filters and oscillators. Receiving earth stations select a desired carrier by RF and IF filtering. No clocking control exists between channels. Other than remaining "on frequency," there is no coordination between accessing stations once a channel is assigned. FDMA requires stable sources for up- and down-conversions.

In CDMA all users operate at the same nominal frequency and simultaneously use the entire repeater bandwidth. The im-

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portant feature of CDMA is that unlike FDMA and TDMA, minimal dynamic (freq. and time) coordination is needed between the various transmitters in the system. In addition, CDMA techniques can provide substantial levels of antijam capability to combat deliberate or unintentional interference, and have a low probability of intercept to reduce the probability of reception by unauthorized users. Furthermore, CDMA allows a graceful degradation of performance as the number of simultaneous users increases. Conversely, when the system is underused, the extra capacity allowed for code noise is automatically realized as increased link margin.

Tables 2-1 and 2-2 summarize the advantages and disadvantages of using CDMA and FDMA respectively. The choice of a multiple access method depends on the application. For the purposes of this report Demand Access (DA) and Random Access (RA) are considered as viable methods for PASS. In general, when most of the users in a communications system do not transmit continuously, the channel need not be allocated permanently. Therefore it could be very advantageous to either dynamically assign the different channels according to the traffic requirements imposed on the system (DA) or allow random communications (RA). Systems requiring DA normally lead to utilization of FDMA whereas RA is more suited to CDMA. Some of the characteristics of systems employing RA or DA are shown in Table 2-3.

The complete CDMA architecture consisting of block diagrams of the user terminal, the supplier station, the Network Clock and Monitor Center (NCMC) and the satellite is provided along with the access methods and frequency/time plans. The complexity of developing the CDMA system is compared to the complexity of the DAMA system. The inherent advantages and disadvantages of the two architectures are noted and their respective throughput performance is discussed.

2.1 SPREAD SPECTRUM SYSTEM

The envisioned system using the properties of spread spectrum communications would give the users and suppliers of a personal communications system near complete freedom of access. Equipped with a user terminal, a subscriber could randomly access a host of voice and data services, similar to the ones described in the strawman design. The system contains a space segment, user equipment, and a ground segment that includes a NCMC and a number of supplier stations.

TABLE 2-1. ADVANTAGES AND DISADVANTAGES OF CDMA

ADVANTAGES	DISADVANTAGES
. MULTIPATH REJECTION . MINIMUM REAL TIME COORDINATION . LOW PROBABILITY OF INTERCEPT . GRACEFUL DEGRADATION IN PERFORMANCE AS NUMBER OF USERS INCREASE . REDUCED SPECTRAL DENSITY . PRECISE RANGE MEASUREMENT . CODE DIVERSITY & POLARIZATION DIVERSITY COMBINED, ENABLE ORBIT REUSE WITH OMNI ANTENNA . INCREASED CODING W/O INCREASED BANDWIDTH	. NEED OF SPREADING SEQUENCES WITH GOOD CORRELATION PROPERTIES . NEAR-FAR PROBLEM: UPLINK POWER CONTROL IS REQUIRED

TABLE 2-2. ADVANTAGES AND DISADVANTAGES OF FDMA

ADVANTAGES	DISADVANTAGES
. EACH UPLINK OCCUPIES OWN FREQUENCY CHANNEL . NO CENTRAL TIMING COORDINATION	. GUARD BANDS REQUIRED . NETWORK MONITORING AND CONTROL . REQUIRE STABLE FREQ. SOURCE . EXTENSIVE NMC SOFTWARE REQUIREMENT . NO VOICE ACTIVITY FACTOR BENEFIT IN A BANDWIDTH LIMITED SITUATION

TABLE 2-3. ADVANTAGES OF ACCESS METHODS

DEMAND ACCESS	RANDOM ACCESS
. VOLUMES, ORIGINS, AND DESTINATIONS HIGHLY VARIABLE . FULL CONTROL REQUIRED . TWO CHANNELS FULLY OCCUPIED FOR ONE CONVERSATION	. SHORT BURSTS OCCURRING AT RANDOM TIMES (USE ACTIVITY FACTOR IMPROVEMENT) . LIMITED SYSTEM CONTROL . SOME TRANSMISSIONS LOSS ACCEPTABLE (REPEATS ARE NECESSARY)

The communications link in the forward and return links follow the same format as the PASS strawman design, namely:

(a) Signals transmitted by the suppliers will be received by the satellite through the CONUS beam, filtered, routed to one of the spotbeams according to their destination, frequency converted, and subsequently transmitted to the intended user using the multibeam antenna.

(b) Signals originating from the user will be received via one of the spotbeams, filtered, frequency translated according to the channeling plan, and transmitted to the suppliers via the CONUS beam.

2.1.1 System Architecture

As previously mentioned, the satellite employs both CONUS and spotbeam antennas. The system has been designed for maximum flexibility, minimum coordination, and ease of operation. In this section a baseline architecture is provided to describe the operation of a CDMA system. In developing this architecture, it is assumed that bandwidth is available and that simplicity of operation is the most important factor.

2.1.2 Multiple Access Scheme

The multiple access property of spread spectrum communication is used in developing a scheme that would allow random access to users and suppliers. Taking advantage of spreading by nearly orthogonal codes, the transmissions in a given link can share the full allocated bandwidth in spreading their respective data. In the uplink of the user terminal this capability is provided by allowing all users transmissions to be at the same nominal frequency in a given spotbeam. Similarly, in the downlink to the user terminals all of the supplier transmissions are centered at a nominal frequency. Access to the system in the forward direction (from suppliers to users) is provided using a hybrid TDM/CDMA scheme, and in the return direction (from users to suppliers) using Random Access Code Division Multiple Access (RACDMA).

In the downlink to the user, the spotbeam signals share the full assigned bandwidth in relaying the suppliers spread signals to all the users. Each supplier can use any of a number of PN sequences that are preassigned to it by the organizers of the system, in spreading its data. As shown in

Fig. 2-1, the supplier forms its own TDM channel by packetizing the data or voice addressed to different users and sending it via a spotbeam. The data rate used is a multiple of the return rate, thus a number of users can be addressed simultaneously, however in order to communicate to multiple users in a spotbeam at the same instant in time, a second spreading sequence must be employed. It should be noted that this flexibility comes at the price of developing a method of informing the selected user of the change in its inbound spreading code. Furthermore, the number of simultaneous transmissions from a supplier should be set by the organizers of the system in order to limit the code noise in the channel.

In the return direction RACDMA is utilized in order to allow simultaneous communications by hundreds of users in a given spotbeam. The transmissions from a user terminal are via random bursts that are spread using pre-assigned supplier PN sequences, i.e. all of the users communicating with a supplier use the same PN code as their spreading sequence. A user terminal can spread its data using a code that is preassigned to it by the supplier or receive instructions to utilize one of many user resident codes. The proper selection of codes with low cross correlation and autocorrelation is essential.

The multiple access property of spread spectrum communication is also employed in developing a pilot reference for the full system. The pilots generated at the NCMC are transmitted and relayed to the spotbeams exactly in the same fashion as the supplier transmissions to the users.

2.1.3 Frequency Plan and Channelization

The frequency plan is driven by the simplicity requirement of the system architecture and multiple access scheme. For the baseline design, the available uplink and downlink spectra are divided into two parts for the CONUS beams and the spotbeams. In both the uplink and downlink spotbeams, frequency reuse is employed in order to reduce spectrum requirement. Thus, as depicted in Fig. 2-2, in the forward and return links of the CONUS beams, the allocated bandwidths are divided to N subbands where N is the number of spotbeams utilized (for the current design N=142 beams). In the downlink the N subbands are frequency converted to one of nine center frequencies and are transmitted via the N spotbeams. In the return direction the exact reverse process occurs whereby all the users transmit at the center frequencies of the spotbeams that they are in and N downlink subbands are used to relay these signals. This channelization will require [2*N*Forward Chip Rate] of bandwidth for the CONUS uplink and [2*N*Return Chip Rate] for its downlink; using opposite polarization, the bandwidth requirement is lowered by a factor of two.

Contrary to the CONUS beams using such a wide bandwidth (assuming high chip rates), the spotbeams will only require 9*2*Forward Chip Rate in the downlink and 9*2*Return Chip Rate in the uplink.

Overall bandwidth requirements for the uplink and downlink are:

Up: (N*Forward Chip Rate)+(18* Return Chip Rate) Eq. 2-1

Down: (N* Return Chip Rate)+(18*Forward Chip Rate) Eq. 2-2.

2.1.4 System Operation

2.1.4.1 SATELLITE TRANSPONDER

The satellite transponder, as shown in Fig. 2-3, can be regarded as a bent pipe that achieves signal routing to spotbeams by frequency translation. The signal from a spotbeam is frequency shifted per the frequency plan shown in Fig. 2-2 and sent with the signals of the other spotbeams to the CONUS transmitter for transmission to all of the suppliers and the NCMC. The forward direction of the satellite transponder is basically the reverse of the return link where all of the incoming frequencies are down-converted to one of nine downlink frequencies and are sent to the corresponding spotbeams. One oscillator is used as the reference for both the uplink and downlink conversions so that the automatic frequency control, performed by the NCMC, on the pilot is simplified.

2.1.4.2 USER TERMINAL

A block diagram of the user terminal is shown in Figure 2-4a. The received RF signal is down converted and is filtered by a channel filter with a bandwidth equal to twice the chip rate. After being level controlled by an Automatic Gain Controller (AGC), the signal is divided and provided to three elements that operate as follows (refer to Fig. 2-4b for the flow diagram of the receiver operation):

1. An acquisition unit or better known as the "correlator" performs the rough code acquisition. The unit

initially searches for the pilot chip sequence in all nine frequency subbands in order to initialize carrier and chip recovery. Upon completion of this function and indication of lock from the "carrier and chip recovery" unit, it starts the search for transmissions from a supplier station. The performance of this element is a function of the frequency offset therefore a sweep controller is required.

2. A carrier and chip recovery that locks to the incoming pilot and thereby corrects the Voltage Controlled Oscillator (VCO) frequency for proper up and down conversion. Note that the unit also controls a sweep control circuitry which performs the function of searching the range of frequency uncertainty. Once the recovery unit has correctly locked to the pilot, it sends the "LOCK" signal to the acquisition unit to initiate the search for an acquisition sequence from a supplier. Furthermore, the unit provides the chip clock and functions as the local reference to all other parts of the terminal thus locking the full terminal to the stabilized oscillator at the NCMC.

3. A data correlator channel that processes the input signal to produce a full-amplitude despread signal for data demodulation. Due to the recovery of carrier and chip clocks of the reference pilot, there is no need for any elaborate demodulation scheme at this point.

In the transmit portion the following functions can be performed by the user:

- Insert messages to be sent to the supplier
- Start a voice conversation or data
- Select a code for his reply, and
- Initiate an emergency message.

The user terminal will form the sequence of data words that make up the transmitted burst. This burst consists of:

a. A synchronization sequence that allows the supplier to detect the presence of the burst, identify the spreading code that is being used, and establish coarse timing,

b. A header, that includes the user's address and a small amount of control information; and

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c. Message bits possibly followed by redundant bits for error detection/correction.

This serial binary sequence is modulo-2 added to the PN sequence corresponding to the receiving supplier and is then supplied to the modulator. Figure 2-4a gives an example of the format of a voice conversation.

2.1.4.3 Ground Stations

Network Clock & Monitor Center

The NCMC as shown in Fig. 2-5 consists of a pilot generating circuit, a pilot recovery unit, and a billing station.

The pilot generator or the network reference clock modulates a PN code on N carriers and transmits them to the satellite. The pilot generator is locked to a very accurate clock and is constantly updated by the control line from the pilot recovery unit. The recovery unit tracks the return pilot from the satellite so that the drifts in the satellite Local Oscillator (LO) are compensated.

The billing station will need the capability of recognizing the start and stop times of all communication both in forward and return directions. Since this information is available at supplier stations, one could envision a central billing that gets its information from all of the supplier stations rather than receiving all of the communication. An on-line billing station such as the one shown in Fig. 2-5 requires the same receiving circuitry of the suppliers and numerous receivers similar to the one used in a user terminal.

Supplier Stations

The supplier stations in the CDMA baseline design have full control in communicating with their users. Each supplier has a spreading code assigned to it by the system coordinator. Using this code a supplier can simultaneously communicate to users scattered over CONUS without any coordination with the NCMC or any other supplier. Figure 2-6 shows the block diagram of a supplier station. As seen in the figure, the forward portion of a supplier station consist of M processor, spreader, and frequency shift chains, where M is a function of the number of users and the number of beams. Each processor time division multiplexes the data to users in a beam prior to sending it to a spreader. The frequency reference for the synthesizer and the up converter used is locked to the pilot received from the satellite. LO_1 to LO_M may be set by the Processor for any of N different frequencies corresponding to the destination beams.

In the return portion, the station must monitor the downlink transmissions, lock its reference to the pilot, and detect, acquire and track all incoming transmissions addressed to it. Due to the asynchronous nature of the system, all of the N beams have to be monitored simultaneously leading to requirements for a down converter and N frequency translators that feed N acquisition units. The output of the acquisition units feed a controller that can select any of the available demodulator-decoder chains. Once synchronization is obtained, the data portion of the transmissions must be demodulated and decoded. The responses from users will be spread by the same PN code thus all the filters and PN code generators used at a supplier station are identical. Figure 2-6 also shows the option of having multiple incoming codes by adding the appropriate acquisition units. It should be noted that there are only a few codes that a supplier may use and these can be generated by or stored in the user terminals. Furthermore, it is possible for a supplier to command a user terminal to use a second spreading sequence by communicating to the user on the first code and requesting a change of code. This process is also followed when a second supplier needs to talk to a user that is not assigned to it. In the second case the change of code (to the code of the second supplier) command is sent by the first supplier after receiving a request to transmit by the second supplier.

The key parts of a supplier station are the acquisition (ACQ) units that monitor the RF spectrum coming from each spotbeam. The ACQs utilize devices that are matched to the first part of the chip sequences that spread the user's replies. These devices will serve the dual purpose of detecting the presence of return signals, and identifying the code being used by that user. Because of possible frequency uncertainty on the incoming burst transmissions, multiple filters may have to be used in parallel.

2.1.5 PERFORMANCE CONSIDERATIONS

In developing a criterion for the performance of a multiple access system, the number of users supported is of the most importance. The number of users is a function of the traffic model used. Market survey is required before a realistic model is developed thus for the purposes of this report, instead of basing the study on an arbitrary traffic model, the maximum number of simultaneous channels is considered.

The PASS FDMA design requires 142 spotbeams to cover CONUS, and provides an equivalent of two thousand 4.8 Kbps channels (9.6 Mbps) in each of the forward and return directions. Therefore the same total data rate and number of channels are used as the required capacity in the case of CDMA. Taking from the strawman design case a 1 dB modem implementation loss, and a 3 dB margin, and taking an E_b/N_o of 4.5 dB as the required level in providing a 10^{-5} bit error rate using K=7, rate 1/2 convolutional coding and Viterbi decoding, then the total required E_b/N_o at the input to the receivers is 8.5 dB.

Weber, Huth, and Batson in a paper titled "Performance Consideration of Code Division Multiple-Access Systems"[5] discuss the number of users that can be accommodated in a direct-sequence spread spectrum multiple access system. As opposed to the operation of acquisition and tracking, they consider only communication performance and use the probability of bit error as the performance measure. For a randomly accessed CDMA system consisting of a number of users transmitting at equal powers, the above mentioned paper gives the means of calculating the degradation in bit error rate as a function of the number of simultaneous users for both coded and uncoded data to be:

$$DF = \frac{1}{1-(n-1)(R_b/R_c)(E_b/N_o)} \qquad \text{Eq. 2-3}$$

where DF is the Degradation Factor, n is the number of simultaneous users accessing the channel, R_b is the bit rate, and R_c is the spread rate or chip rate.

In the forward direction of the CDMA system there are 142 frequency subbands each including transmissions to a particular spotbeam. On the average each subband should be capable of handling 67.6 Kbps (9.6 Mbps/142) of data or equivalently four 19.2 Kbps channels. Substituting in Eq. 2-3,

$$DF = \frac{1}{1-(4-1)(19200/R_c)(E_b/N_o)}$$

gives the degradation in bit error as a function of R_c and E_b/N_o. Figure 2-7 shows the total one-direction bandwidth (assuming same chip rate for forward and return directions) and the degradation in BER performance as a function of the chip rate and the required E_b/N_o. As seen from the plots, the degradation and its slope approach zero as chip rate increases. In order to avoid near-far problems inherent to a non-power controlled CDMA system, the operating point should be selected at a high chip rate (>10 Mcps) and thus a high bandwidth requirement. For PASS, assuming power control is applied, a chip rate of 2.88 Mcps is selected. This leads to a degradation of ≈0.7 dB with a bandwidth requirement of 460 MHz. Figure 2-8 gives the degradation as a function of the number of simultaneous supplier channels for the 2.88 Mcps operating point. Note that if an extra 0.3 dB of degradation is allowed, the capacity will increase by 50%. In order to provide the extra margin, the E_b/N_o should remain the same and either the front end or the coding gain has to improve.

In the return direction, the link is to support two thousand 4.8 Kbps channels transmitted via the spotbeams. These channels affect the performance of the receivers at every supplier station. Taking the 2000 as the total number of simultaneous users and without including the increased capacity due to the voice activity factor, each beam will have to support an average of 14 users at an E_b/N_o of 8.5 dB at any instant of time. Plots of degradation as a function of chip rate for E_b/N_os of 8.5, 9, and 10 dB are shown in Fig. 2-9. Assuming the same chip rates are to be used in both forward and return directions, the plot of 8.5 dB gives a degradation of 0.8 dB. Figure 2-10 depicts the effect of increasing the number of simultaneous transmissions on the link performance, namely a 25% increase in capacity for a 0.2 dB extra degradation in code noise.

In order to increase the margin to compensate for the degradation due to code noise, a more effective coding scheme without any increase in the required bandwidth, or on-board processing could be considered. Figure 2-11 depicts the amount of extra margin required as a function of the uplink and downlink bandwidths. These plots can be used in determining a suitable operating point based on the complexity of the coding algorithm used.

2.1.6 CHALLENGES

The key feature of a spread spectrum system is the pseudo-noise (PN) transmission that allows for CDMA. Acquisition and synchronization to the PN are the problems in employing CDMA. Rapid acquisition implies short sequences, while longer sequences with ever-increasing time-bandwidth products are required to decrease cross correlation of multiple user systems. In any spread spectrum system, the purpose of the acquisition subsystem is to establish coarse (i.e., to within one chip duration) time alignment of the transmitted PN sequence and a locally generated replica of it. There are several available techniques for establishing coarse synchronization.

The acquisition subsystem can be thought of as a correlator that is matched to the incoming code. A matched filter can either operate at IF or can be a digital device that operates on data decisions. Due to discrete sampling, the digital devices have slightly inferior performance as compared to analog devices, however they provide the flexibility of automatic changing of the spreading code and chip rate.

The candidate technologies for implementing matched filters are charged couple devices (CCDs), digital correlators, and surface acoustic wave (SAW) filters. CCDs perform many of the same functions as SAW devices except in a different range of bandwidth. Most practical CCDs are limited to a bandwidth of 10 MHz whereas SAW filters can be much wider. For matched filter applications in systems requiring high chip rates and fixed matching codes SAWs are recommended (programmable SAWs are available but not widely used). CCD is a clocked device that samples the signal appearing at its input. Because in neither the user terminals nor the supplier stations a synchronous chip-rate clock is available in the receiver prior to pilot acquisition, it is necessary to sample the input signal at some multiple of the chip rate or use a SAW matched filter.

In a user terminal, the acquisition unit is initially searching for a continuously running pilot. Thus a serial search of the incoming PN sequence, using discrete integrated circuits, can be performed. This requires a longer acquisition time than using a SAW matched filter, however it can be developed very simply and cost effectively by using VLSI technologies. For the supplier station it is recommended that SAW filters be used. It should be noted that SAW filters will require temperature compensation in order to stay at their nominal center frequency. The development of acquisition methods, providing high processing gain at negative signal-to-noise ratios in the presence of wide frequency shifts, is the only challenge of using CDMA beyond those listed in the strawman design.

2.1.7 BASELINE ADVANTAGES AND DISADVANTAGES

The CDMA system will provide random and unrestricted access to suppliers by the users and to the users by suppliers. The task of the network management center has been minimized

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to a pilot generating and correcting center by decentralizing its functions to the supplier stations. Two thousand simultaneous channels are provided as the baseline capacity, however in a full-duplex two-way voice conversation the typical duty cycle for each side of the channel is less than 50%. Accordingly using a voice activity factor of 40% the number of channels increases to approximately 5000 voice-only channels. Figure 2-12 is a good example of the tradeoff between simultaneous data and voice channels.

These advantages come with a large bandwidth requirement, and 0.7 dB extra coding gain in each link. As was calculated in the previous section, the bandwidth required for the uplink and downlink of the CONUS beam is very high. In order to alleviate this shortcoming, some possible alternatives are discussed shortly.

As a result of a simplified network management center the problem of unauthorized use is one that enters into any spread spectrum system design. Although it is not easy to restrict the use of a wideband transponder, it is possible to monitor it at all times. In the case of a bent pipe transponder one could envision monitoring the average levels of the uplinks and downlinks and comparing them with samples of the total traffic as reported by the supplier stations. Based on the statistics and user distribution model, it is possible to detect the presence of unauthorized users. Of course one should keep in mind that the cost of building a supplier station from scratch is an expensive way of getting channel capacity. Fortunately, if one of the alternatives of the next section is implemented, this problem automatically disappears.

2.1.7.1 Bandwidth Efficient Alternatives

There are several methods that can be explored for use in PASS. Two possible solutions are:

Onboard Multi-carrier Spreading

The high bandwidth requirement is due to the one subband per spotbeam allocation as received or transmitted by the CONUS beams. The excess bandwidth in the forward direction can be minimized by utilizing a satellite switched TDMA format. This is accomplished by assigning a narrowband portion of the available spectrum to each supplier in order to allow a high rate TDM channel to transmit all of the spotbeam data to the satellite. Upon demodulation of the data, at the satellite, the transponder can encode, spread and transmit

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the data through appropriate spotbeams. It is possible to implement a number of code generators onboard the satellite and assign different codes to suppliers.

In the return direction due to the high number of users and codes being utilized, onboard processing is much more complicated. It may be possible to implement the reverse process, however, an in depth tradeoff study between bandwidth efficiency and satellite complexity is required.

Note that if this alternative is implemented, the spread pilots will be generated onboard the satellite, thus simplifying the design of the NCMC. Furthermore, the hardware requirement of the supplier station is drastically reduced by transferring some of the hardware to the satellite.

Onboard Spreading and Despreading

The second option is related to the first one. The difference is that the full bandwidth available for the uplink and the downlink of the CONUS beam is assigned to a spread channel. A supplier station spreads the signal using a PN code preassigned for a spotbeam (N codes will be used). The satellite transponder will in this case consist of N receiver chains that acquire and demodulate the signals and based on the supplier ID respread the data for transmission by the spotbeam.

The onboard processing in the return direction consists of acquisition and demodulation of simultaneous signals originating from users all around CONUS. The transmissions from user terminals will all start with a known acquisition sequence followed by a destination address. The spread sequence would be used to do the initial detection of an incoming signal. The destination address would then be used to send the signal to the appropriate supplier. The receivers onboard the satellite continuously search for the PN acquisition code and upon detection of one start a demodulator/decoder chain similar to the one presented for the supplier station. The recovered signal is then respread and transmitted via the CONUS beam in conjunction with all other signals. This method would require a single code acquisition chain along with multiple demodulator chains.

As compared to the previous option, this alternative solution is more favorable because all communication is spread over the same bandwidth instead of dividing it among different suppliers. Furthermore onboard processing increases the available link margin in both forward and return directions.

However, the design of the return link of the transponder is not trivial.

2.2 FDMA SYSTEM

As previously mentioned, the PASS strawman design calls for TDMA channels in the forward direction and DA/FDMA in the return direction. Figure 2-13 describes the strawman frequency plan in which the NMC transmits the pilot for all of the spotbeams. Each beam has at least a TDM high rate channel (HRC) and a low rate channel (LRC) on which all suppliers can communicate to their respective users. These channels along with the pilot form a frequency segment per spotbeam, i.e, N frequency segments are transmitted to the satellite via the CONUS beam. In the downlink of the forward direction frequency reuse is employed in converting the N uplink segments to nine frequency subbands for transmissions by the spotbeams.

In the return direction once again frequency reuse is used in transmitting a number of HRCs and LRCs via spotbeams to the suppliers. The downlink in this case consists of N distinct frequency segments.

In order for a user (or a supplier) to gain access to a channel, it sends a request to the NMC in order to be assigned either a frequency slot (or a time). Upon reception of the channel assignment, the user terminal automatically will tune its synthesizer to the appropriate frequency. Meanwhile the supplier will synchronize its TDM clock to the appropriate interval. Note that because of the single channel per carrier (SCPC) nature of the transmissions from the user, wide guard bands may have to be included in the frequency plan to avoid interference if Doppler shifts are present.

Figures 2-14 to 2-17 show the block diagrams of the transponder, a user terminal, the NMC, and a supplier station respectively.

2.3 COMPARISON

The strawman design and the CDMA option are functionally the same, however from an operational point of view and system complexity there are pronounced differences.

The satellite transponder follows a bent-pipe architecture with frequency shifting in accordance with the frequency plan. Except for the bandwidth of filters and the change in local oscillators, the transponder is very similar to the one described in the CDMA baseline design.

The user terminal is different in the sense that the initial search is for one of nine narrowband pilot frequencies rather than spread ones. The user terminal's phase locked loop (PLL) in conjunction with the sweep controller searches and locks to the pilot. Upon locking to the pilot, the synthesizer sets the appropriate up conversion and down conversion frequencies. The shaded blocks in Fig. 2-15 give an indication of the areas of difference between this design and the CDMA one. Due to the large number of channels, the synthesizer required for the FDMA design may be very complicated.

The most pronounced difference between the two systems shows up in the design of the NMC. The NMC is the central controller of the PASS strawman design. The role of this portion of the system is to listen for requests from suppliers and users, assign channels, and wait for the end of conversations. Furthermore, it includes pilot generation and recovery along with the billing functions. The NMC of the FDMA architecture is by far the most complicated portion of the ground segment. The CDMA architecture simplifies the design of the NMC by allowing random access in both forward and return directions, however the option exists for a supplier to control the users communications by virtue of start and stop commands. This function can be beneficial for system peak hours where control is required. Note that this option is distributed among all suppliers therefore an elaborate network management center will not be required.

From a hardware point of view, the supplier station depicted in the strawman design is less complicated than the CDMA one. Due to the demand access nature of the architecture, there are far less on-line receiver chains required to support the users. Upon receiving authorization from the NMC, the request channel can set a transmit chain and a receive chain to the assigned frequency and commence communication with its user. In conclusion, the difference in the hardware is due to the real time assignment of frequency compared to the preassigned codes of the suppliers.

Considering both the ground and space segments, the design complexity of the CDMA and FDMA systems are comparable. Although the bandwidth requirement driven by the use of CDMA is approximately ten times that of FDMA, it is anticipated that with the advent of more powerful error correcting codes and higher output satellite power systems, the number of users per unit bandwidth will increase beyond that of FDMA[6]. This is because the transmitted bandwidth of the FDMA channel is proportional to the amount of coding that is applied to the data, hence, for a given channel bandwidth the more coding that is applied, the lower the number of user channels that can be accommodated. In the case of CDMA the data is spread over the total bandwidth of the channel, thus the increase in coding bits required by the more powerful error correcting codes does not decrease the available user bandwidth and furthermore could conceivably allow for an increase in the number of users due to increased channel coding and satellite power system performance.

The following table summarizes these differences:

Table 2-4 **DESIGN COMPARISON**

	CDMA BASELINE	PASS STRAWMAN
Hardware Complexity:		
- Transponder	Simple	Simple
- User Terminal	Moderate	Moderate
- NMC	Simple	Complex
- Supplier	Complex	Moderate
Operation:	Simple	Moderate
Bandwidth: (Using Dual Polarization)	460 MHz Uplink 460 MHz Downlink	27 MHz Uplink 27 MHz Downlink
Capacity:	2000 4.8 Kbps DATA 5000 VOICE w/ VAF of 0.4	2000 4.8 Kbps Chs.
Margin:	≈2.3 dB Each Link	≈3 dB Each Link
Coding:	No effect on BW	Effects BW

2.4 CONCLUSION

The design of a CDMA architecture for the Personal Access Satellite System has been presented. Employing the properties of spread spectrum communication, the architecture calls for unrestricted access to suppliers by users and vice versa. As compared to the FDMA strawman design, the CDMA baseline provides a more flexible access method, comparable hardware complexity, and the possibility of more voice channels (by virtue of the voice activity factor) at the expense of 0.7 dB degradation in each link and a ten time increase in the bandwidth required. The degradation can be compensated for by some additional error-correction-coding without increasing the overall bandwidth. Alternative methods are required in order to decrease the bandwidth requirement.

The random access spread spectrum architecture provides an alternate method for implementing the PASS concept. It is believed that unrestricted access, without capacity and time consuming channel assignment, are required for a personal satellite system at the turn of the century.

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[6] K. Dessouky, and Masoud Motamedi, "FDMA and CDMA PASS Design Tradeoffs, Comparison of Results, and Conclusions," JPL Interoffice Memorandum No. 3392-90-001, January 1990.

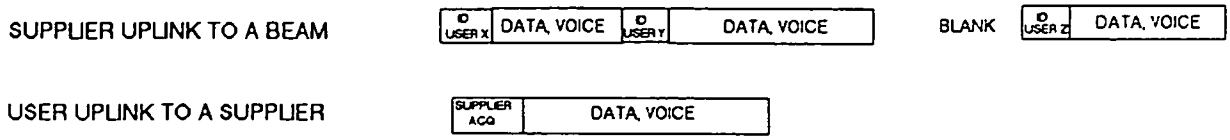


Figure 2-1 SAMPLE TIME PLAN

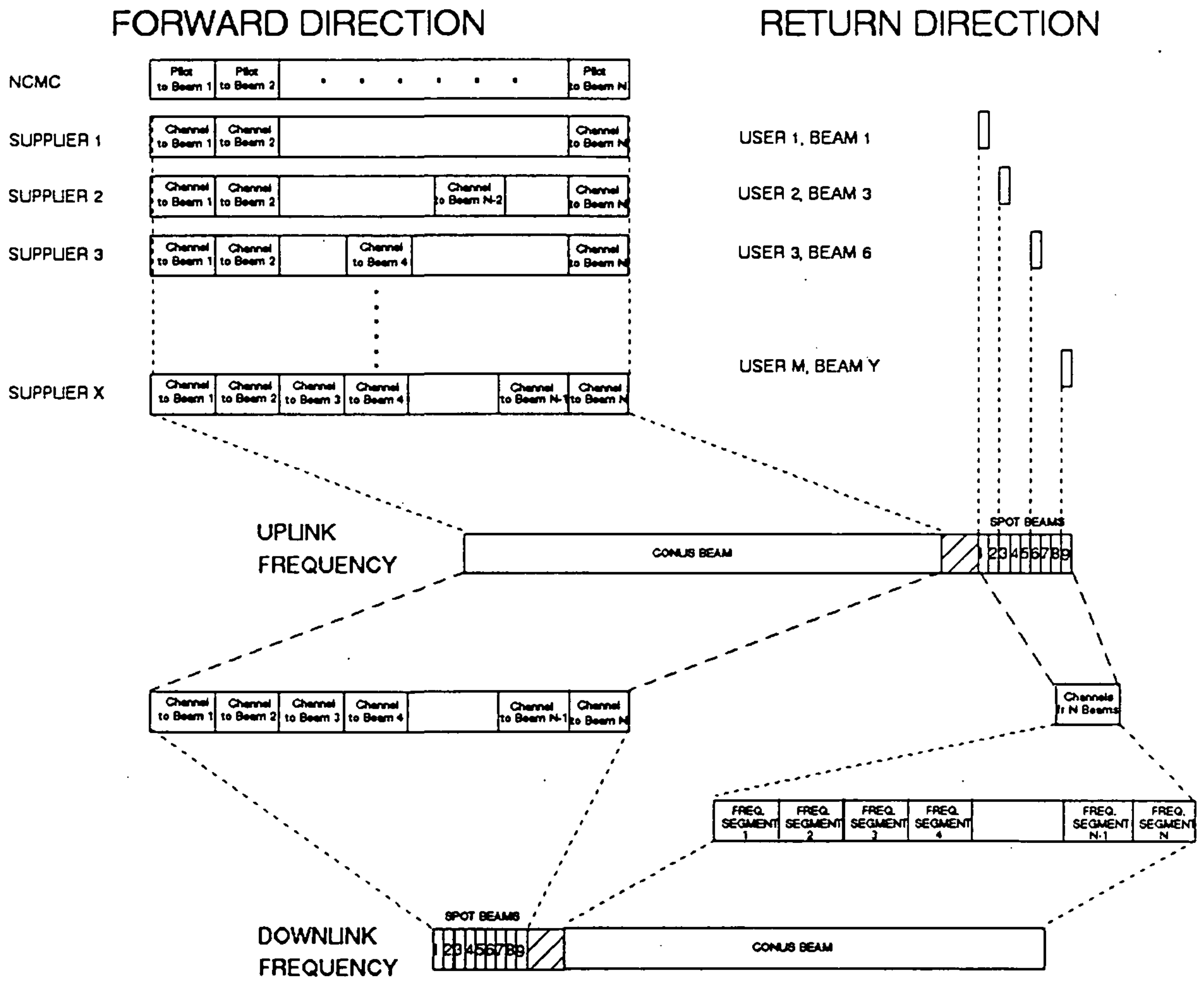
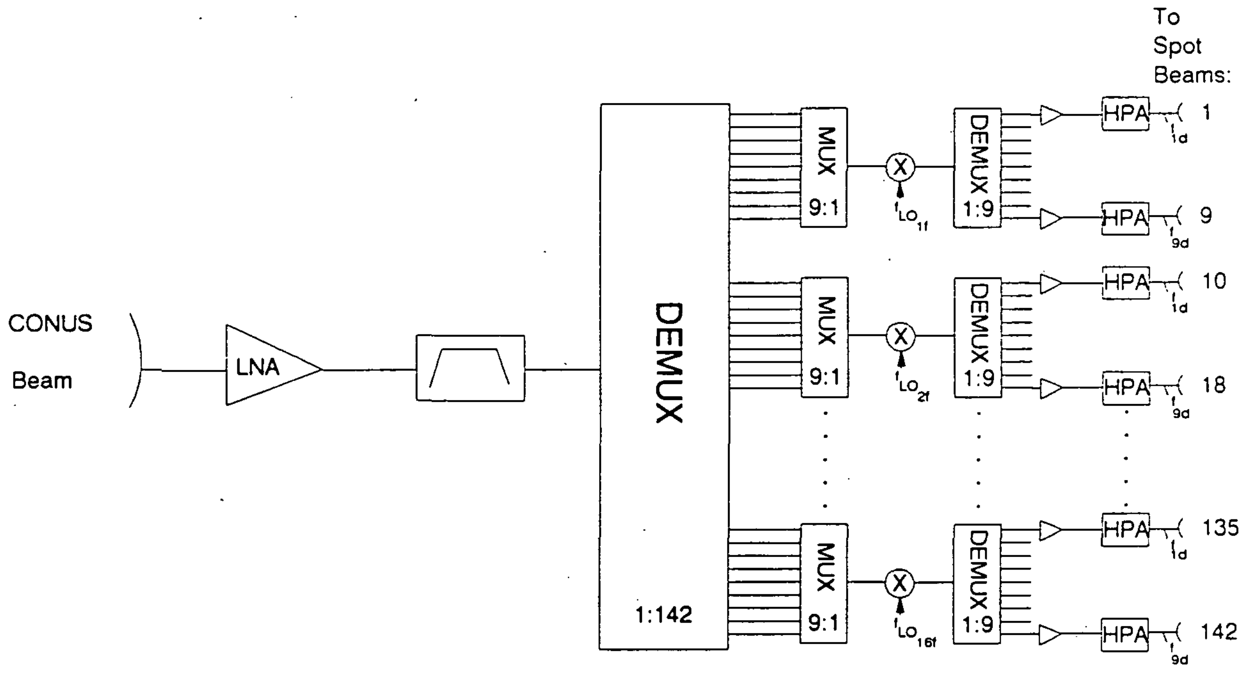
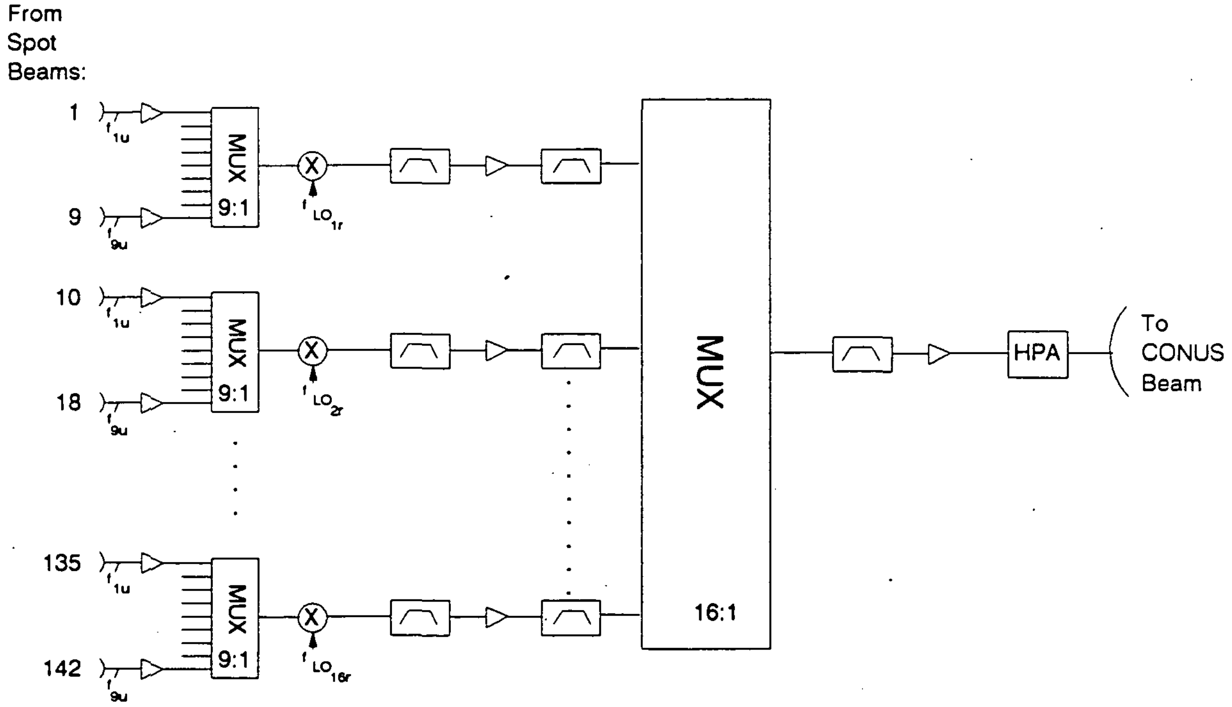


Figure 2-2 BASELINE FREQUENCY PLAN



(a) FORWARD LINK



(b) RETURN LINK

Figure 2-3 CDMA SATELLITE TRANSPONDER

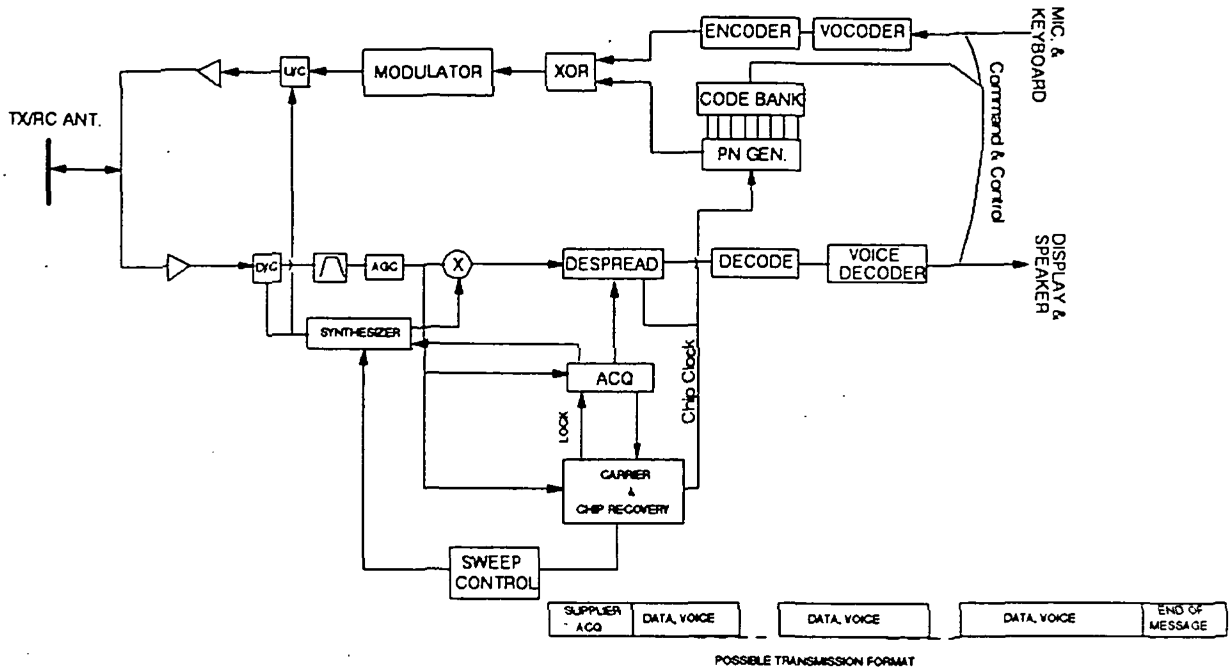


Figure 2-4a CDMA USER TERMINAL

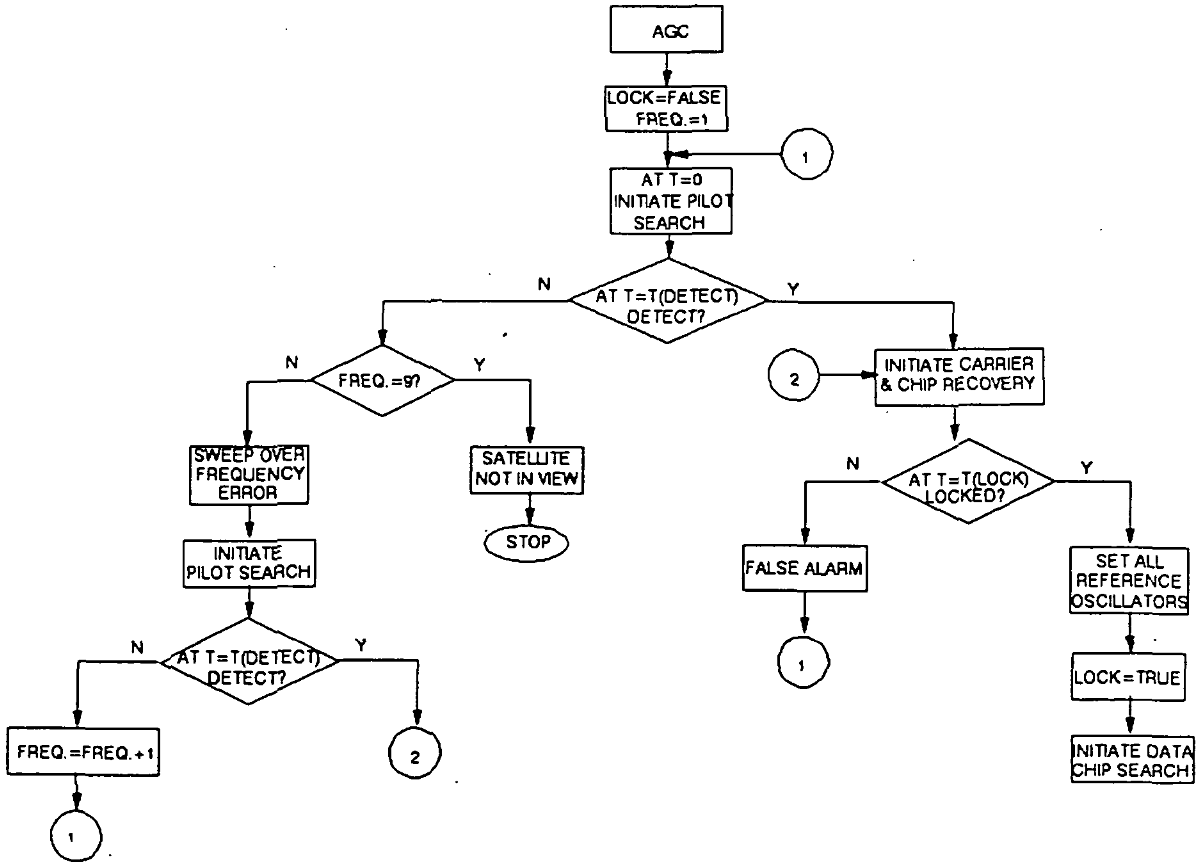


Figure 2-4b ACQUISITION FLOW DIAGRAM

D-7382

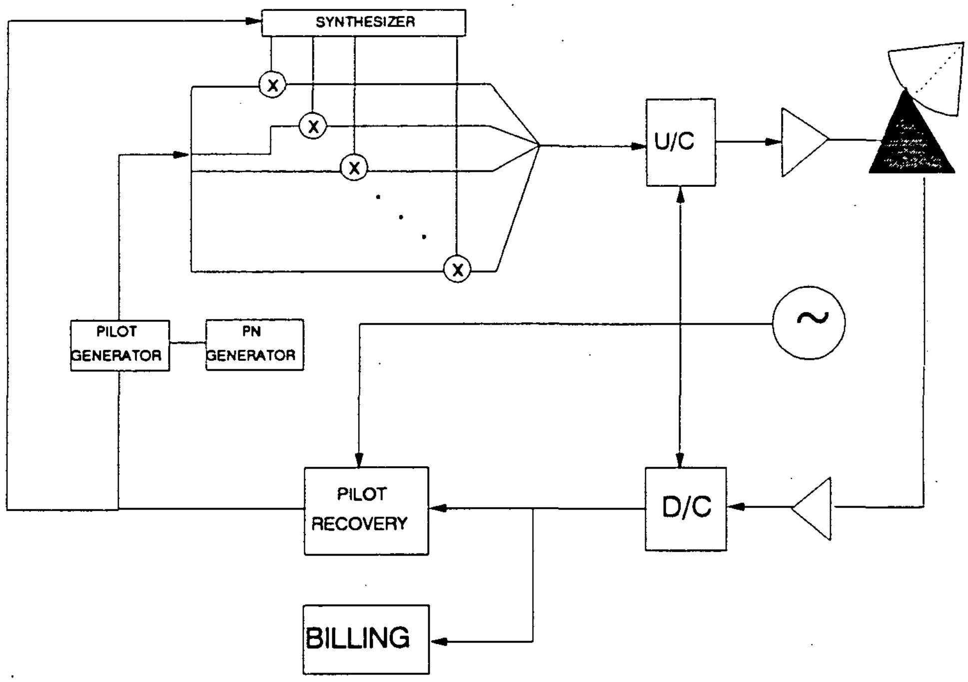


Figure 2-5 NCMC BLOCK DIAGRAM (CDMA)

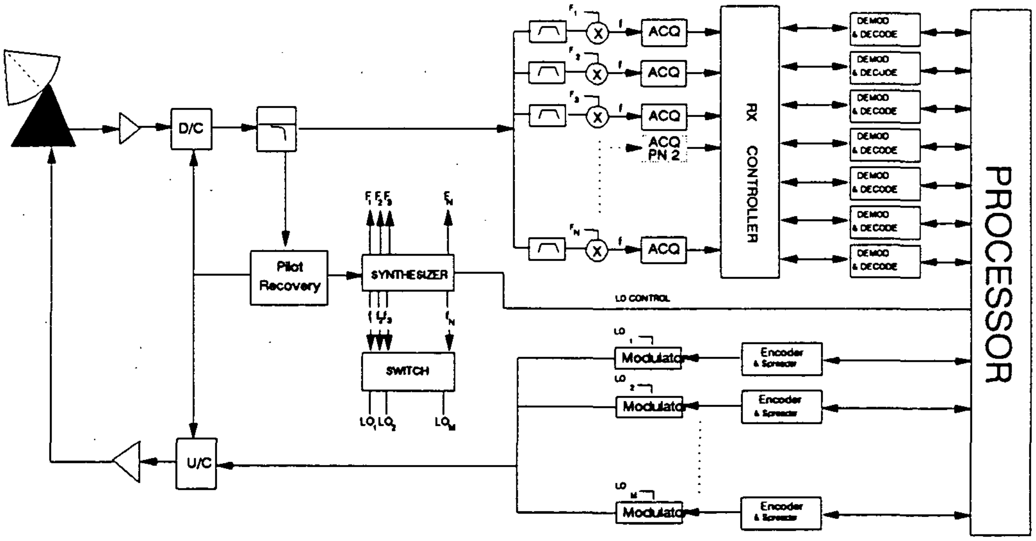


Figure 2-6 CDMA SUPPLIER STATION

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FIGURE 2-7 DEGRADATION AS A FUNCTION OF CHIP RATE FOR THE FORWARD LINK
(FOUR SIMULTANEOUS SUPPLIERS, 19.2 KBPS EACH)

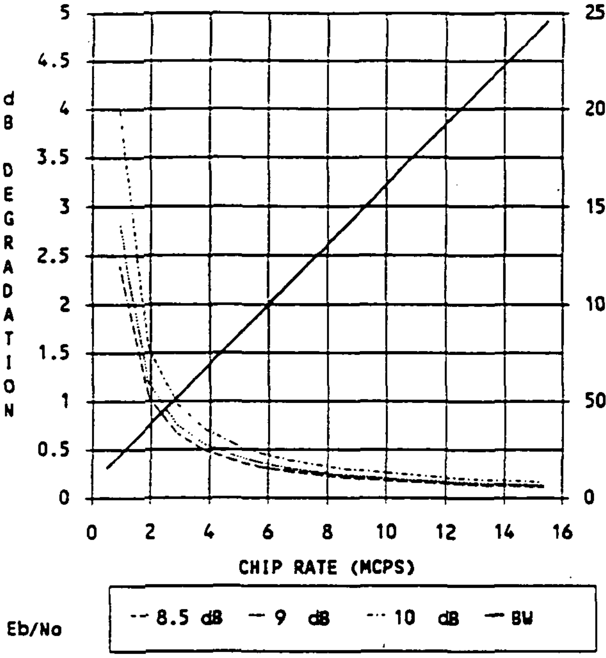


FIGURE 2-8 DEGRADATION AS A FUNCTION OF SIMULTANEOUS SUPPLIERS, Eb/No=8.5 dB

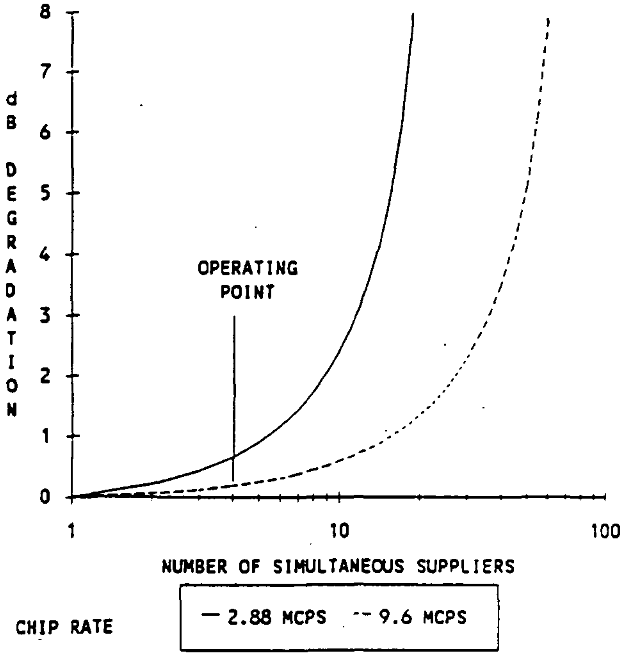


FIGURE 2-9 DEGRADATION AS A FUNCTION OF CHIP RATE FOR THE RETURN LINK
(FOURTEEN SIMULTANEOUS USERS, 4.8 KBPS EACH)

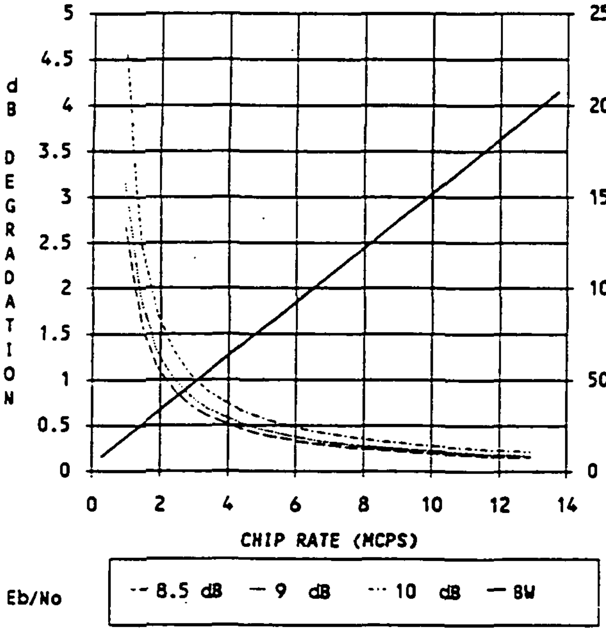


FIGURE 2-10 DEGRADATION AS A FUNCTION OF SIMULTANEOUS USERS, Eb/No=8.5 dB

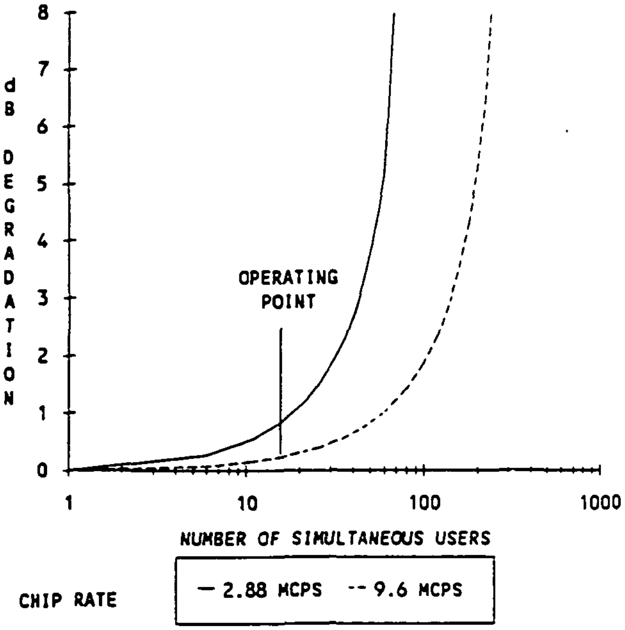


FIGURE 2-11 DEGRADATION AS A FUNCTION OF TOTAL BANDWIDTH, FOURTEEN 4.8 KBPS USERS & FOUR 19.2 KBPS SUPPLIERS PER BEAM, Eb/No = 8.5 dB

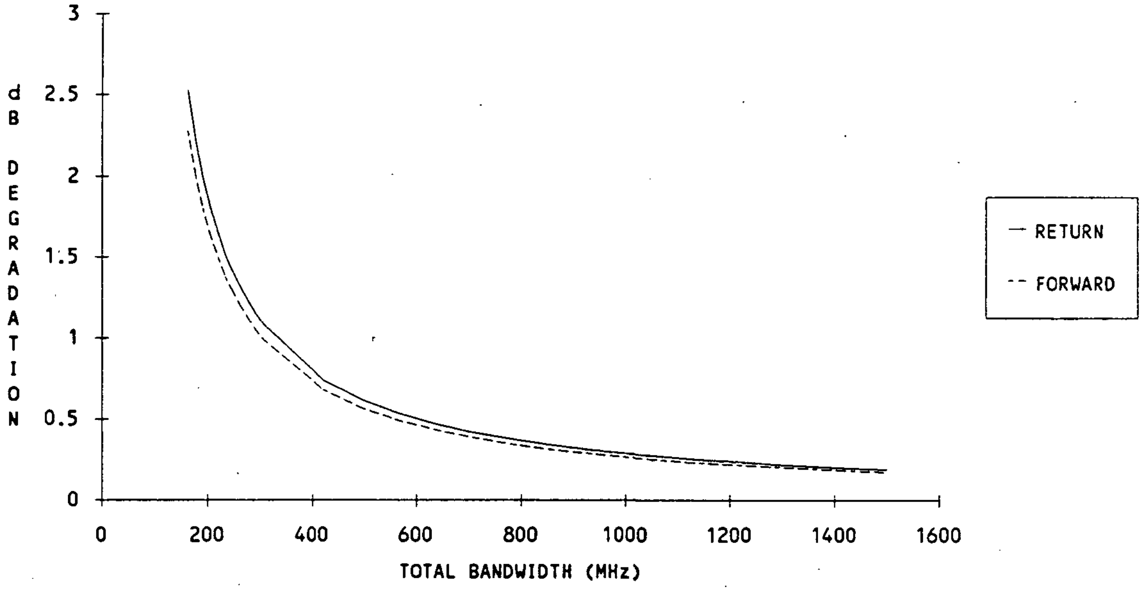
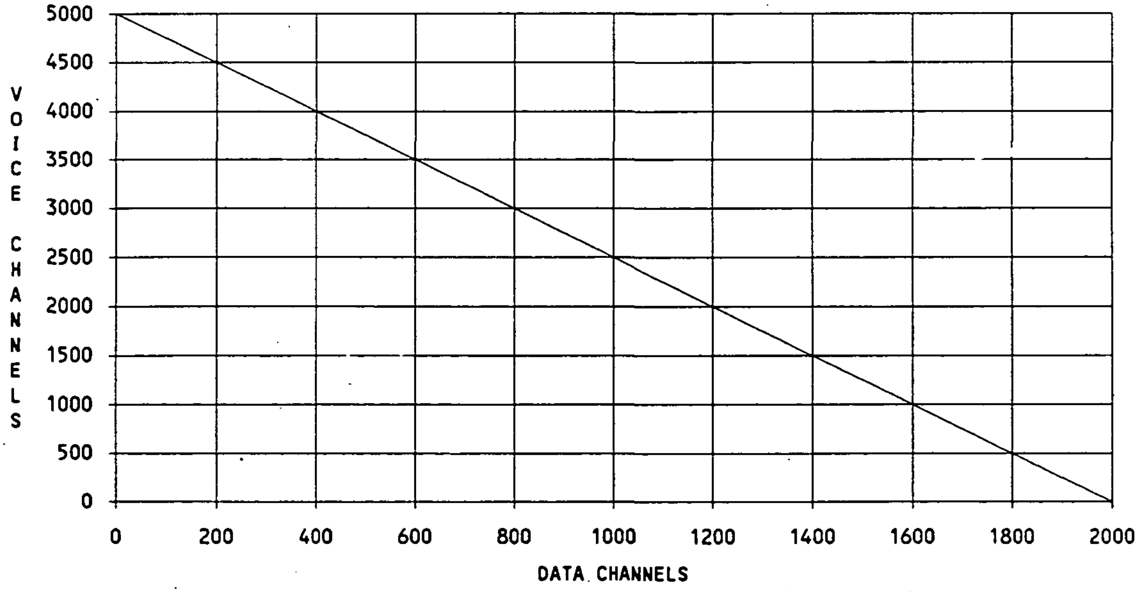
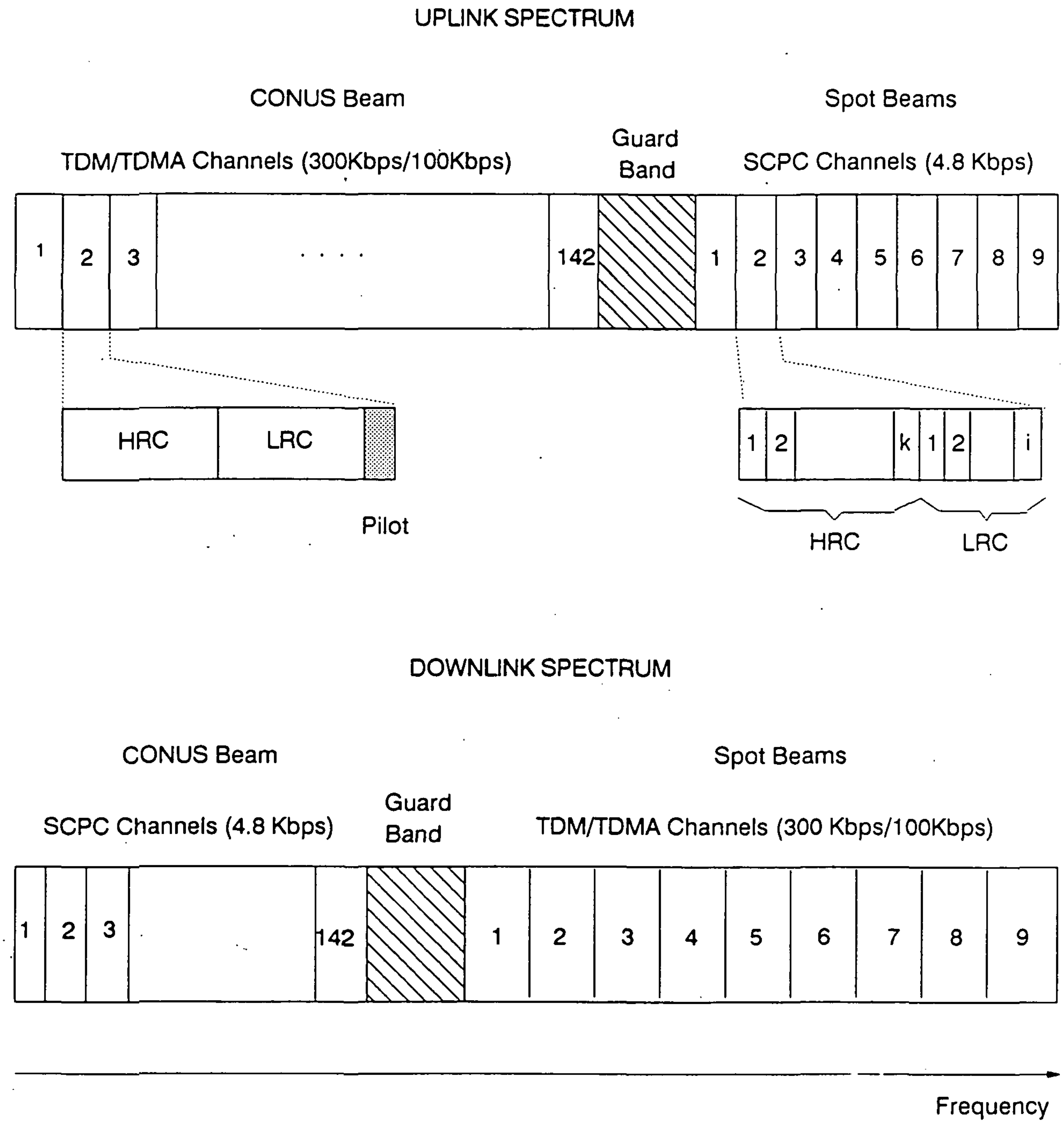


FIGURE 2-12 TRADEOFF BETWEEN VOICE CHANNELS & DATA CHANNELS, VOICE ACTIVITY FACTOR = 0.40





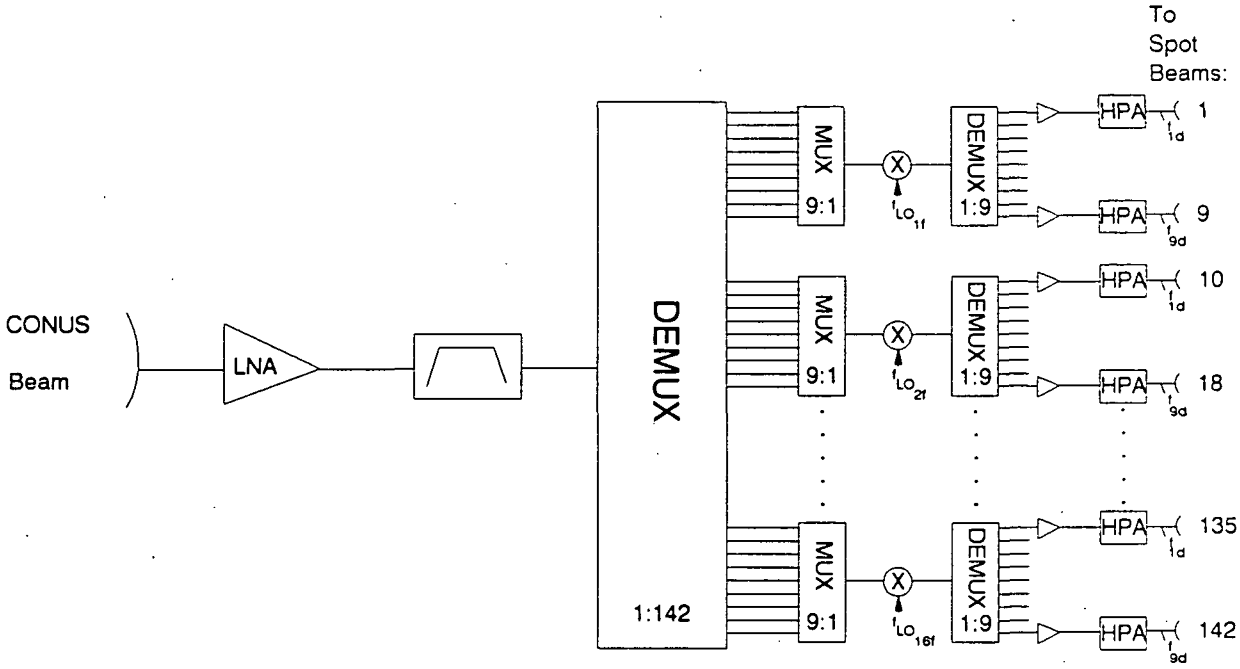
CONUS Beam:

142 uplink frequency bands for 142 fixed beams. Each Beam is addresses by a specific frequency, i.e. uplink band j is for the j th beam.

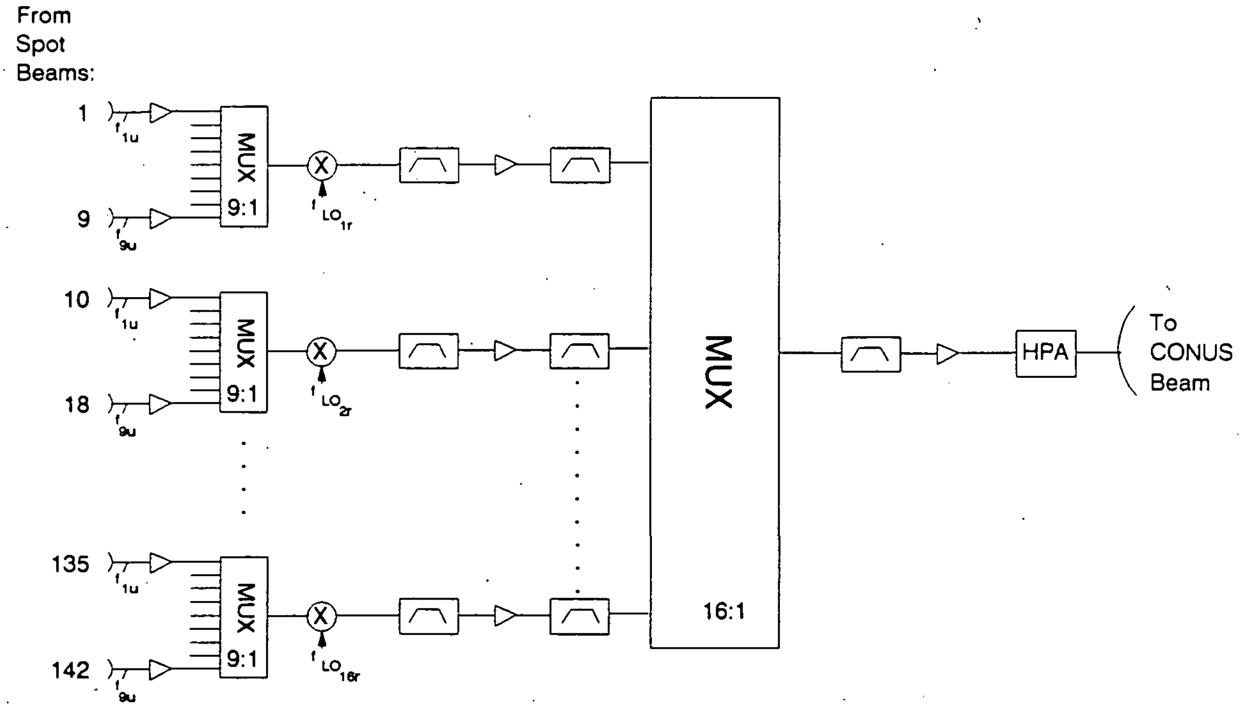
Spot Beams:

User in the 142 fixed beams use 9 uplink channels to transmit their SCPC uplink signals to the suppliers.

Figure 2-13 FDMA FREQUENCY PLAN



(a) FORWARD LINK



(b) RETURN LINK

Figure 2-14 FDMA SATELLITE TRANSPONDER

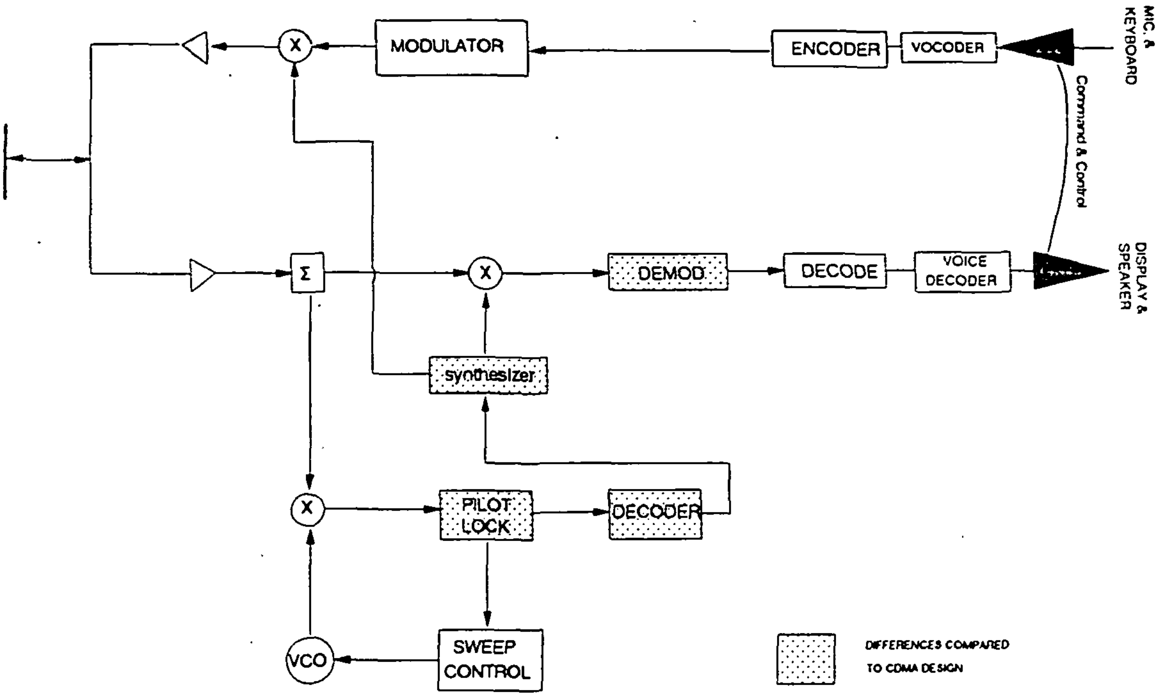


Figure 2-15 FDMA USER TERMINAL

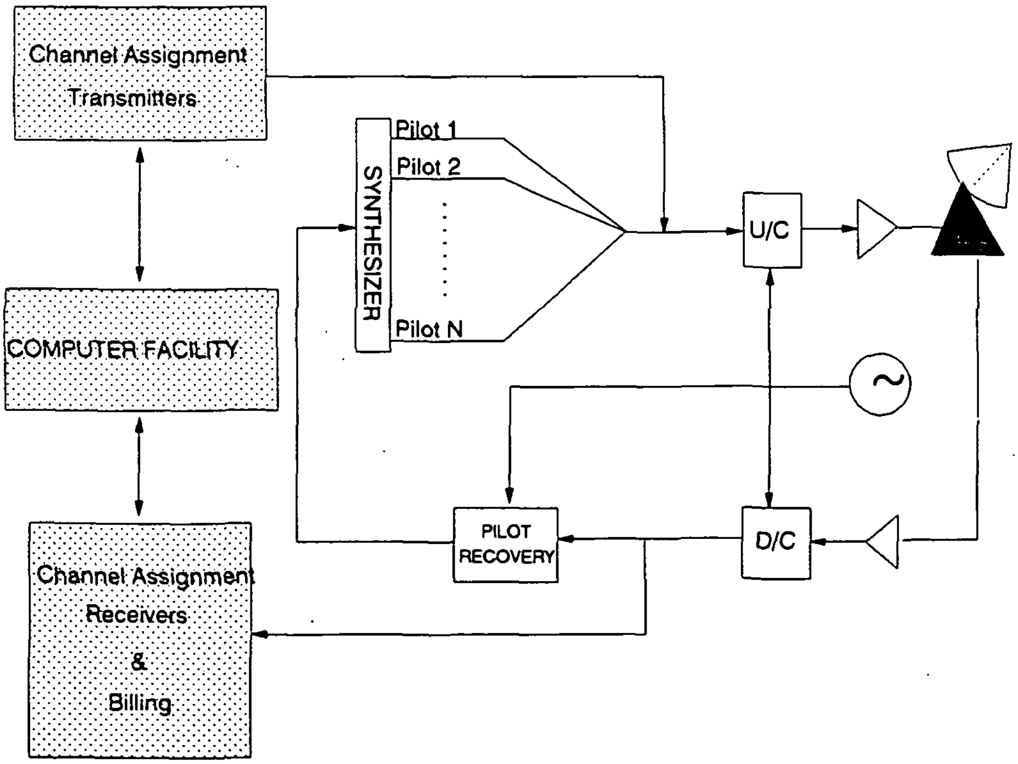


Figure 2-16 FDMA- NMC BLOCK DIAGRAM

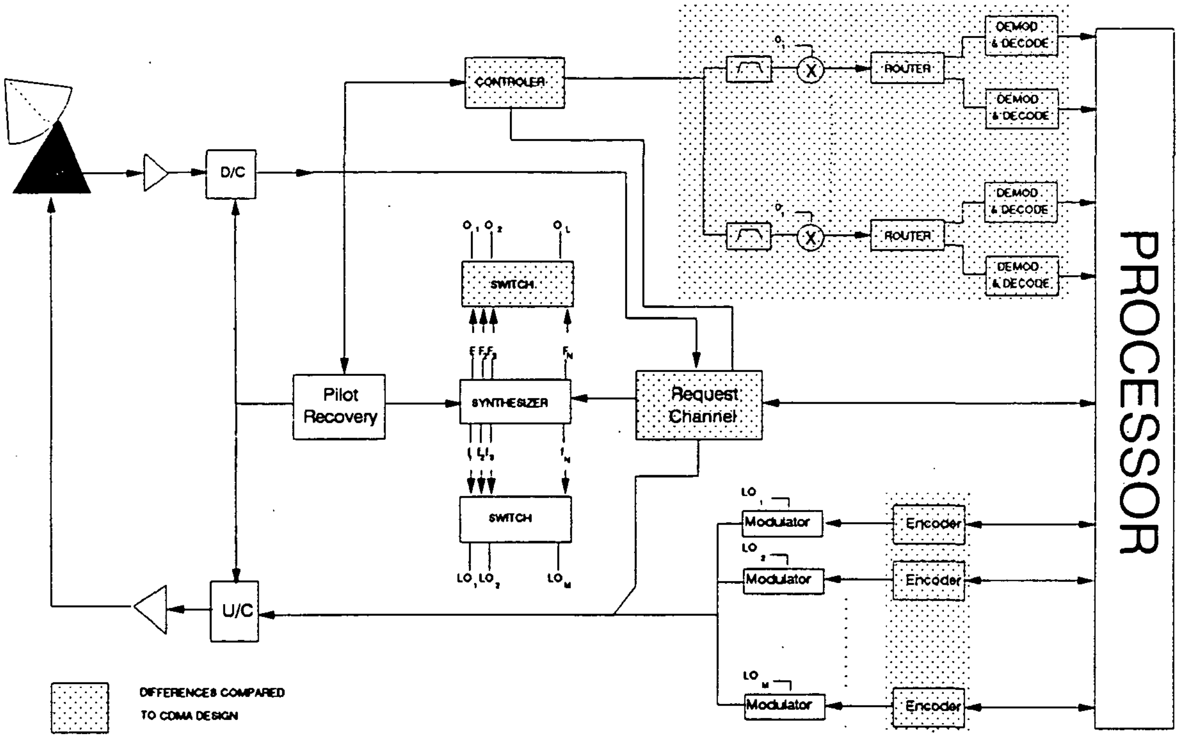


Figure 2-17 FDMA- SUPPLIER STATION