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Chapter 3
Antenna Beam Coverage Concepts

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3.1 Introduction

The strawman PASS design calls for the use of a CONUS beam for transmission between the supplier and the satellite and for fixed beams for transmission between the basic personal terminal (BPT) and the satellite. The satellite uses a 3m main reflector for transmission at 20 GHz and a 2m main reflector for reception at 30 GHz. The beamwidth of the reflector is 0.35°. To cover CONUS 142 fixed beams are needed. A sample fixed beam coverage plan for CONUS is shown in Figure 3.1. In the strawman design, suppliers transmit to the users on a 100 Kbps TDMA carrier for the low rate channel and on a 300 Kbps TDMA carrier for the high rate channel. The uplink frequency of this TDMA carrier is chosen according to the coverage area - or beam location - in which the user is located. Users with Basic Personal Terminals (BPTs) transmit a SCPC signal at 4.8 Kbps in the frequency band assigned to their coverage area. The time and duration of supplier transmissions are determined by the network management center (NMC) as are the specific transmit frequencies for the users [1].

The decision to employ spot beams to link users to the satellite was motivated by several factors. Major differences in beam characteristics are listed in Table 3.1; the entries are based on various satellite descriptions [2,3,4,5]. The use of spot beams, whether fixed, switched or scanning, allows users to operate with satellites having higher $EIRP$ and G/T than possible with CONUS beams. Operation with small terminals is therefore possible. Spot beams also allow spectral reuse through assignment of the same frequency to geographically separated beams. Connecting users via spot beams rather than with a CONUS beam brings about two problems: difficulty in providing a broadcast channel and the necessity for the satellite transponder to be designed specifically to connect users in various spot beams. The importance of the latter is reduced in the strawman design by the use of CONUS and spot beams, the drawback then being that user to user communication requires a two hop satellite link. For PASS, the advantages of spot beam use – primarily the ability to work with small terminals – outweigh the disadvantages and motivate their use over designs employing only

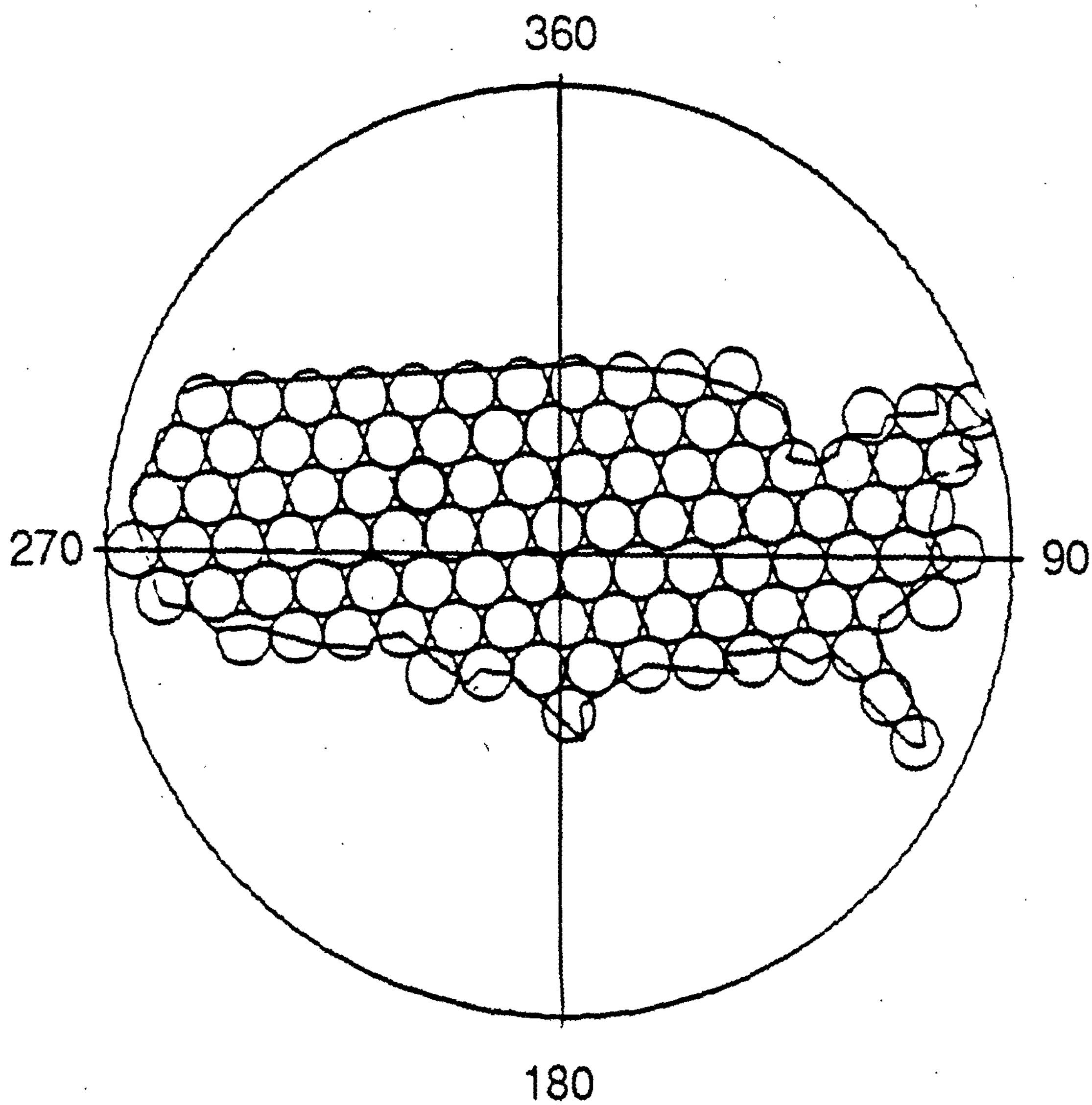

Figure 3.1: Fixed beam CONUS coverage (from [1]).

CONUS beams.

There are several types of spot beams under consideration for the PASS system besides fixed beams. The beam pattern of a CONUS coverage switched beam is shown in Figure 3.2: that of a scanning beam is illustrated in Figure 3.3. Here a switched beam refers to one in which the signal from the satellite is connected alternatively to various feed horns, each of which create a beam focused on a different geographical region. In Figure 3.2 the coverage pattern of four switched beams is identified. Each beam is shown as illuminating five areas, all identified by the same fill pattern. For example, the hatched beam is shown as capable of illuminating either an area on the West Coast, or one of three Mid-Western locations or an area on the East Coast. In the satellite transponder the output signals (in the forward direction, these signals are on a TDMA carrier; in the return direction, they are SCPC carriers) bound for any of these five areas are connected to a switch which alternatively connects to one of five possible antenna feeds (see Section 3.2.2). Scanning beams are here taken to mean beams whose footprints are moved between contiguous regions in the beam's coverage area. In Figure 3.3 CONUS coverage is achieved by dividing the US into 16 North-South sections. Other types of spot beams can be considered for PASS such as the hopping beam configuration used by ACTS [2]. For the purposes of this chapter, switched beams and scanning beams are considered to share similar characteristics.

Table 3.2 lists the advantages and disadvantages of switched/scanning beams relative to fixed beams. The advantages of fixed beams are that less centralized control over the network is necessary to coordinate communication between supplier and user and that they possess greater capacity for frequency reuse. The main advantage of switched/scanning beams is their ability to match the satellite's capacity to variable traffic needs.

The difference in the ability of these two beam types to effectively match current traffic requirements to satellite capacity can be understood as follows. Because the envisaged spot beams, whether fixed, switched, or scanning, handle traffic from a small area (about 135 mile diameter for a 0.35° beamwidth), the number of users or traffic demands within a beam will be fluctuate rapidly depending on the time of day, the season, etc. In addition the traffic requirements will vary greatly from beam to beam. Although the bandwidth given to each fixed beam and the size of satellite power amplifier associated with it can be pre-set prior to satellite launch according to the expected traffic per beam, this static solution can not efficiently match the satellite power and bandwidth to the traffic. Some techniques for distributing satellite power according to traffic variations when fixed beams are used are discussed in Chapter 5.

In contrast, scanning or switched beams have the advantage that they transmit and collect data from several coverage areas. Thus the time distribution of the traffic is averaged over several coverage areas. Futhermore switched/scanning beams are capable of picking up or delivering traffic to each of their coverage areas within one TDMA frame. The beam's dwell time is dynamically adjusted to match the traffic needs of a particular coverage area. In this way the time-varying distribution of the traffic can be smoothed. This results in a better match of the satellite's capacity to network traffic, or a reduced probability of users in one beam being queued up to use the satellite while other beams have no traffic. Although

Table 3.1: Comparison of CONUS and Spot Beam Characteristics

	CONUS Beam	Spot Beam
<u>System:</u>		
Broadcast Channel	Yes	Possible; but may require satellite processing and switching
Potential for small E/S	Limited	Yes
Match satellite capacity to traffic requirements	Good (depending on access tech.)	Some (depending on spot beam type)
Frequency Reuse	No	Yes
<u>Transponder Complexity:</u>	Simple	Complexity depends on comm. link: 1. Somewhat complex if unsymmetric link † 2. More complex if spectral reuse used (eg. PASS strawman design) 3. Very complex if interbeam connection is required (i.e. certain advanced satellite designs)
<u>Satellite Antenna Complexity:</u>	Simple	Complex BFN required
<u>User Terminal Complexity:</u>	Low May require higher gain ant. & higher EIRPs	Higher

† An unsymmetrical link is used to mean one where the CONUS beam used to RX/TX from hub and spot beams used to TX/RX to the user terminals.

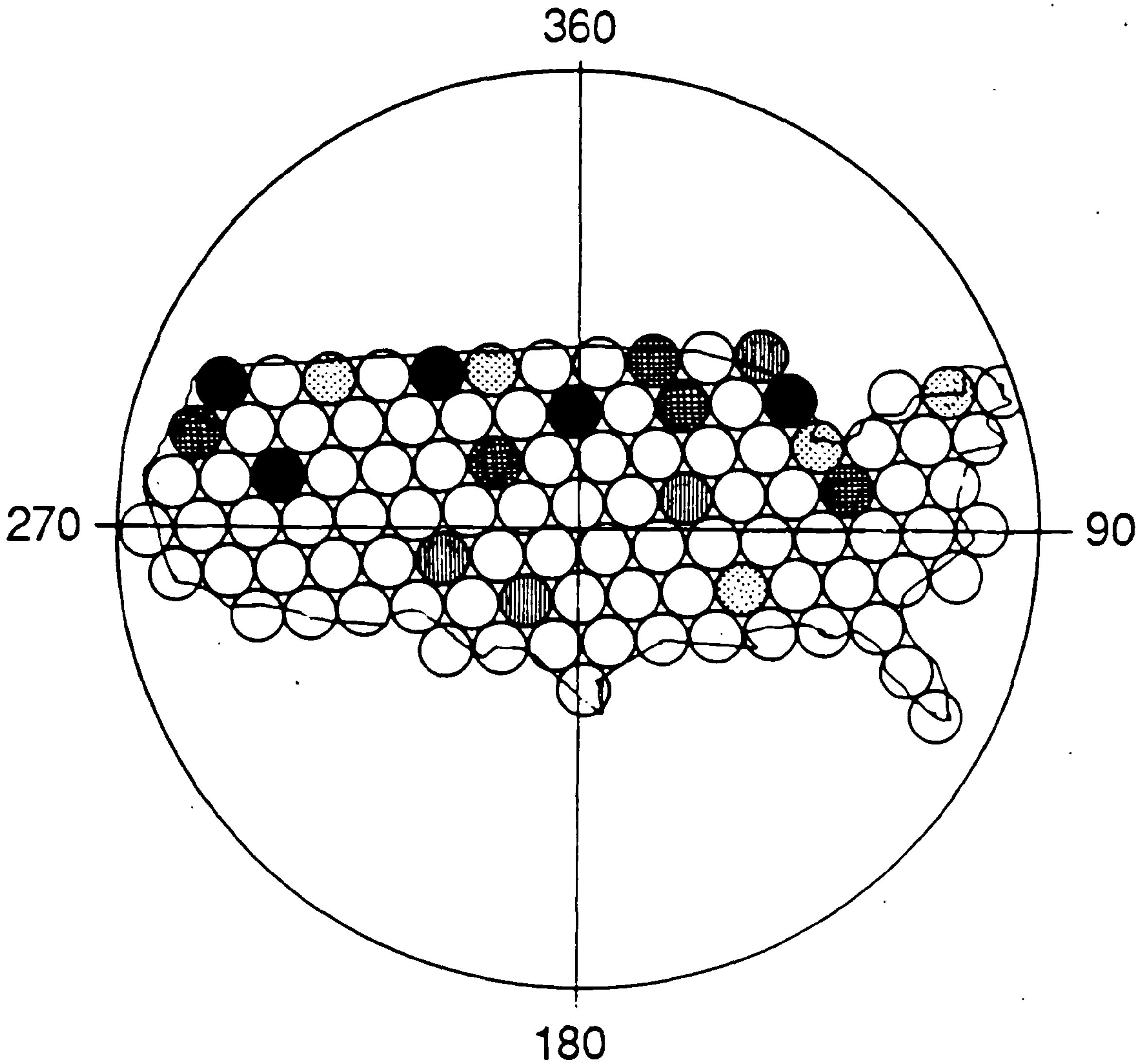

Figure 3.2: Switched beam CONUS coverage.

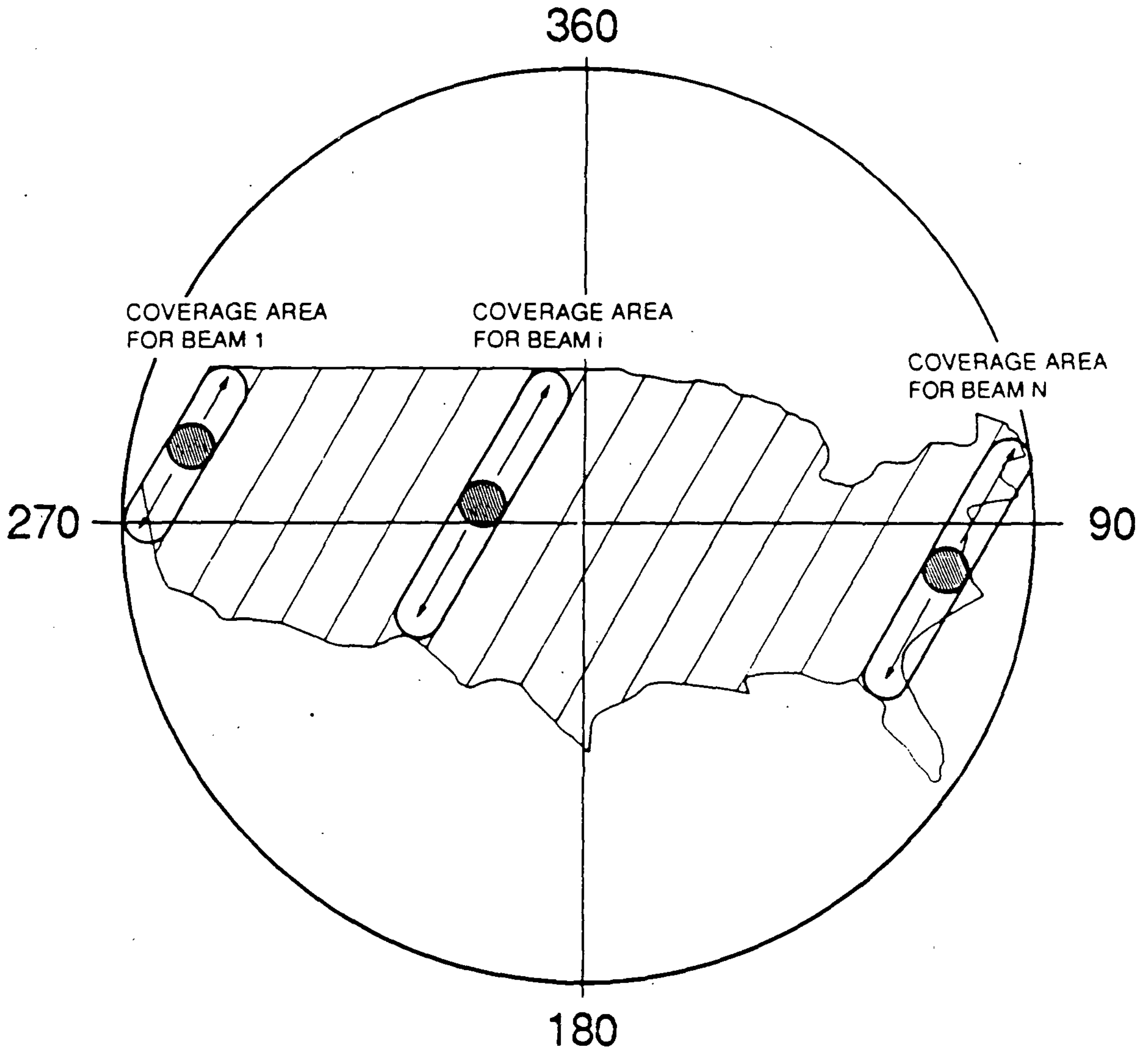

Figure 3.3: Scanning beam CONUS coverage.

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Table 3.2: Pro's and Con's of Switched/Scanning Beams Relative to Fixed Beams

Advantages	Disadvantages
System Design:	
Better traffic match achieved by dynamically varying dwell time	Non-continuous coverage of CONUS Higher link data rate required Higher level of control over network req'd to synchronize transmissions.
Possible component and weight reduction in transponder	Reduced frequency reuse capability Increase in signal delay (Tradeoff between voice delay and supplier overhead for choice of scan rate)
User Communication:	
	Burst modem with variable duration due to variable dwell time Special acquisition equipment
Multibeam Antenna Design:	
Possible simplification of beam forming network	Increase in insertion loss between HPA and feed

this plan does not simplify bandwidth or power allocation between switched/scanning beams it does reduce the need for these measures. Beam dwell time is calculated by the NMC and dispersed by the NMC to the satellite and user terminals.

Operation with switched/scanning beams instead of fixed beams changes the system in other ways as well. First, users are not guaranteed a constant connection with the satellite, e.g. they will not receive the satellite beacon all of the time, nor can they request a channel at any time. Although this may be transparent to the user, their receiver must be able to transmit and receive in prescribed time windows and for variable lengths of time, must be instructed on how to find these times. Second, users must possess burst modems with variable burst duration times to work with beams having variable dwell times. In addition the data rate of the burst modems must be higher than that needed when fixed beams are used. Assuming that the beam accesses a particular coverage area once every T_{period} sec and that it remains in contact for, on the average, $T_{duration}$ sec, then the user data rate with the switched or scanning beam, R_s, must be increased by a factor inversely proportional to the coverage duty cycle:

$$R_s = R_f \cdot \frac{T_{period}}{T_{duration}} \tag{3.1}$$

where R_f is the 4.8 Kbps data rate used with fixed beams. The number of scan sites/beam, N_P, is therefore

$$N_P = \frac{T_{period}}{T_{duration}}. \tag{3.2}$$

These differences effect system design and performance. They result in greater delay for voice transmission. They require higher data rates on both the forward and return links to be supported. They necessitate changes in user terminal hardware so that frequency and time synchronization with the satellite can be maintained.

This chapter examines the consequences of using switched/scanning in lieu of fixed beams in the PASS design and attempts to evaluate the advantages and disadvantages listed in Table 3.2. Two uses of switched/scanning beams are examined. The first scenario calls for replacing the fixed beams used for communication between the user terminals and the satellite with switched/scanning beams, i.e. on the user terminal uplinks and downlinks. The second scenario utilizes switched/scanning beams for the downlink from the satellite to the user terminal and fixed beams for the uplink from the user terminal to the satellite. It is referred to as the hybrid beam concept. Using switched/scanning beams on both the user terminal's uplinks and downlinks will maximize the system advantages brought by the use of these beams at the price of system complexity. The hybrid beam concept seeks to reduce the system complexity and variety of requirements on the user terminal by using fixed beams for the satellite uplink.

To illustrate the implications of switched beams use on PASS system design, operation at two beam scan rates is explored. Scan rate is defined as $1/T_{period}$. For both switched beam examples, each beam is taken to access 10 coverage areas. The low scan rate, corresponding

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to T_{period} of 2 sec and $T_{duration}$ of 200 msec, was chosen to minimize the supplier overhead per transmission and to illustrate the case where complete spatial acquisition can be performed during one access time. The fast scan rate, corresponding to T_{period} of 20 msec and $T_{duration}$ of 2 msec, was set so as to minimize voice signal delay.

The use of switched/scanning beams on the user terminal uplinks and downlink is examined in Section 3.2. The implications of the hybrid beam concept are studied in Section 3.2.6.

An important issue, relevant to both beam scenarios, is the pilot acquisition and the implications of rapid acquisition on pilot power and user terminal local oscillator stability. This is detailed in Section 3.3. Conclusions are presented in Section 3.4.

3.2 Switched/Scanning Beams for User Terminal Uplinks and Downlinks

First the system performance obtained with these beam types is investigated, then the ensuing transponder complexity is discussed, and finally the user terminal and supplier station complexity is detailed. Performance advantages and disadvantages with both multibeam antenna approaches are tabulated and summarized in Section 3.2.5. The hybrid beam scenario is discussed in Section 3.2.6.

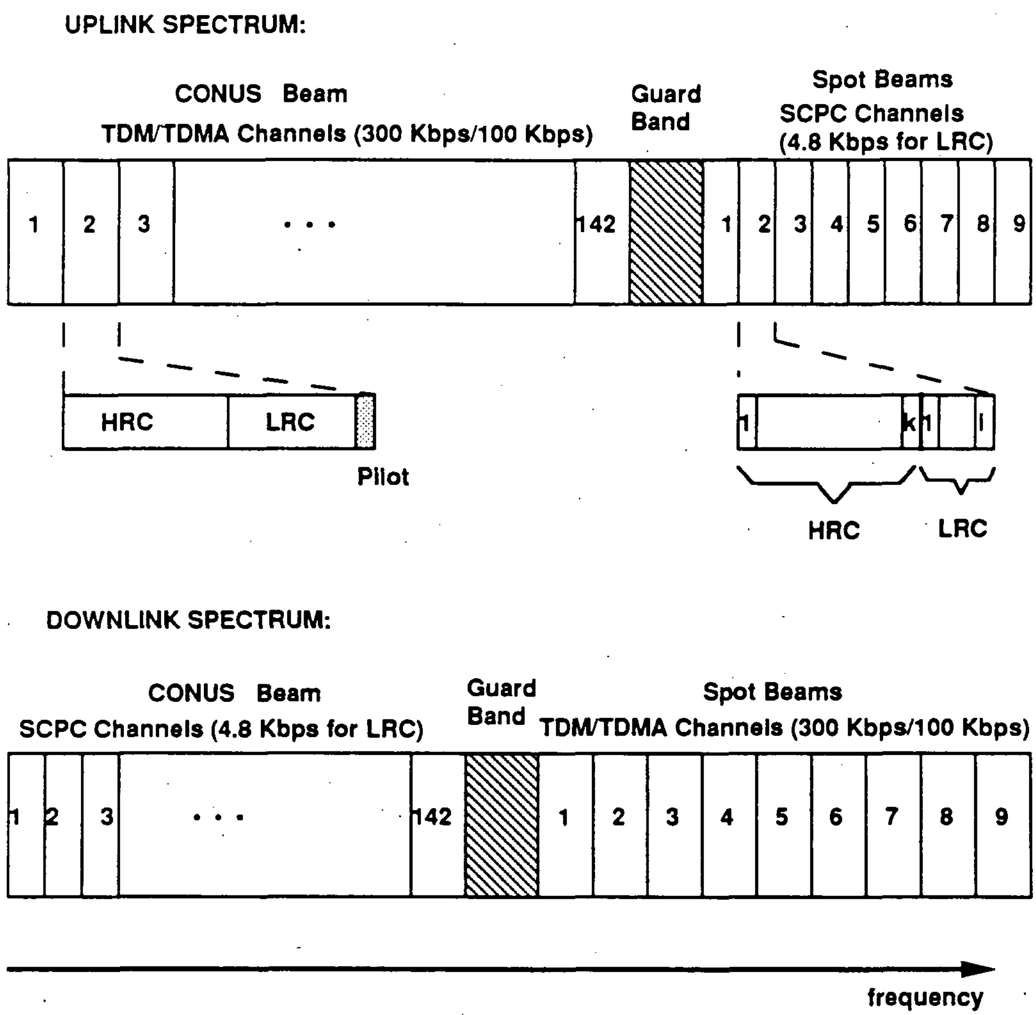
3.2.1 System Performance

In this section the system performance is quantized by various parameters and the communication link between user terminal and supplier station is reexamined to determine which components must be changed for operation with switched/scanning beams. The parameters used to quantize performance are: the spectrum requirement, the tradeoff of voice delay vs. supplier overhead per transmission, and the efficiencies of the fixed and switched beams.

Spectrum Requirement

The spectrum required for the forward and return links resulting from the strawman design are shown in Figure 3.4 (the high rate channels between suppliers and enhanced personal terminals are denoted by HRC; the low rate channels between suppliers and basic personal terminals are labelled by LRC). A possible frequency plan for the switched/scanning beam scenario (that corresponding to the transponder design discussed in Section 3.2.2) is shown in Figure 3.5. In this figure, N_P is taken to be 10, the number of switched/scanning beams is then 14. Five frequency bands are estimated as necessary for these 14 beams, assuming frequency reuse.

Defining frequency reuse as in the PASS Concept Study [1], Table 3.3 lists the overall frequency reuse factor for switched/scanning beams when the number of beam positions per beam, N_P, is varied from 1 (equivalent to a fixed beam) to 15. The number of output frequencies required to address the 142 coverage areas, N_{F_s}, cannot be determined exactly without knowledge of the coverage areas addressed by each switched beam. In fact the value



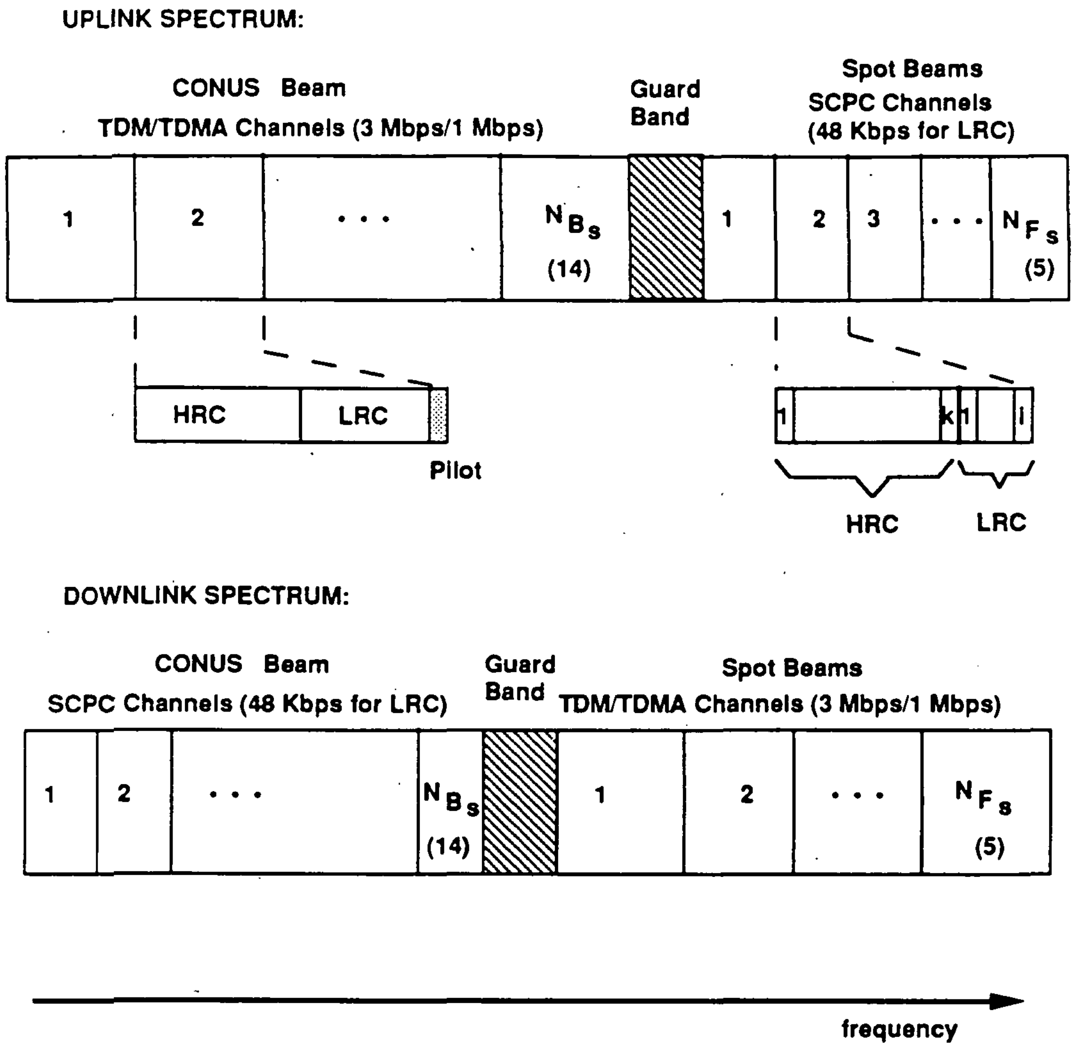
CONUS Beam:

142 uplink frequency bands for 142 fixed beams. Each beam is addressed by a specific frequency, ie. uplink band j is for j th Beam.

Spot Beams:

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

Figure 3.4: Frequency plan for the fixed beam coverage concept.



CONUS Beam:
N_{B_s} uplink frequency bands for N_{B_s} switched beams. Each beam is addressed by a specific frequency, i.e. band j is for the jth switched beam.

Switched/scanning Beam:
Users in the N_{B_s} switched beams use N_{F_s} uplink channels to transmit their SCPC uplink signals to the suppliers.

Figure 3.5: Frequency plan for the switched/scanning beam coverage concept ($N_P = 10$).

of N_{F_s} for a given N_P is probably not the same for switched and scanning beams because it may be possible to reuse these spot beam frequencies more often with scanning beams. The values for N_{F_s} listed in the table are best-case estimates. From Table 3.3 it is seen that the overall frequency reuse factor drops from 1.88 achieved with the fixed beam scenario to 1.43 with the switched/scanning beams when N_P is 15.

Table 3.3: Overall Frequency Reuse as the number of beam positions per beam, N_P, is varied.

N_P	Number of Switched/ Scanning Beams N_{B_s}	Number of Output Frequencies N_{F_s}	Net Equiv. Frequency Reuse
1	142	9	$\frac{284}{151} = 1.88$
5	28	6	$\frac{56}{34} = 1.65$
8	18	5	$\frac{36}{23} = 1.57$
10	14	5	$\frac{28}{19} = 1.47$
15	10	4	$\frac{20}{14} = 1.43$

Another way to gauge the spectral requirement of the switched/scanning beam scenario relative to the fixed beam design can be accomplished by assuming values for certain parameters and calculating the required bandwidth. From Figure 3.4 the uplink and downlink bandwidths can be written as:

$$BW_{up_f} = 142 \cdot \Delta f_{TDMA} + N_{F_f} \cdot \Delta f_{SCPC} \tag{3.3}$$

$$BW_{down_f} = 142 \cdot \Delta f_{SCPC} + N_{F_f} \cdot \Delta f_{TDMA} \tag{3.4}$$

where Δf_{TDMA} is the bandwidth of the two TDMA carriers (HRC and LRC) and the pilot in each beam, Δf_{SCPC} is the bandwidth allocated to all the SCPC channels in each beam, and N_{F_f} is the number of frequency bands necessary to address the 142 fixed beams. In the strawman design N_{F_f} is 9. The assumption here is that all beams are accorded the same bandwidth.

When a switched/scanning beam is used the bandwidth requirements can be written by replacing the 142 fixed beams by $(142/N_P)$ switched beams. The bandwidth requirements become:

$$BW_{up_{s/s}} = N_{B_s} \cdot \Delta f'_{TDMA} + N_{F_s} \cdot \Delta f'_{SCPC} \quad (3.5)$$

$$BW_{down_{s/s}} = N_{B_s} \cdot \Delta f'_{SCPC} + N_{F_s} \cdot \Delta f'_{TDMA} \quad (3.6)$$

where $\Delta f'_{TDMA}$ is the bandwidth of the two TDMA carriers (HRC and LRC) per beam, and, N_{B_s} is the number of switched/scanning beams, equal to $\frac{142}{N_P}$. Values for N_{B_s} and N_{F_s} for a given N_P can be found from Table 3.3. $\Delta f'_{TDMA}$ and $\Delta f'_{SCPC}$ for the switched/scanning beams have N_P higher data rates than their fixed beam counterparts. They can be written as:

$$\Delta f'_{TDMA} = N_P \cdot \Delta f_{TDMA}, \quad (3.7)$$

and

$$\Delta f'_{SCPC} = N_P \cdot \Delta f_{SCPC}. \quad (3.8)$$

Substituting Eqns. 3.7 and 3.8 into Eqns. 3.5 and 3.6, we find:

$$BW_{up_{s/s}} = 142 \cdot \Delta f_{TDMA} + N_{F_s} \cdot N_P \cdot \Delta f_{SCPC} \quad (3.9)$$

$$BW_{down_{s/s}} = 142 \cdot \Delta f_{SCPC} + N_{F_s} \cdot N_P \cdot \Delta f_{TDMA}. \quad (3.10)$$

The ratio of total bandwidth required for both uplink and downlink in the switched/scanning beam scenario to that required in the fixed beam case is then expressed as:

$$BW_{total_{s/s\text{-fixed}}} = \frac{142 + N_{F_s} \cdot N_P}{142 + N_{F_f}}. \quad (3.11)$$

Eq. 3.11 shows that the bandwidth expansion factor in the switched/scanning beam scenario is not a function of Δf_{TDMA} or Δf_{SCPC}. $BW_{total_{s/s\text{-fixed}}}$ varies from 1.14 for $N_P = 5$ to 1.34 for $N_P = 15$.

It is also of interest to compare the bandwidth expansion factors for uplink and downlink beams separately. To do so, values for Δf_{TDMA} and Δf_{SCPC} must be assumed. Let us then consider the simple case where there are no HRCs in either forward or return link. We also consider the bandwidth required by the pilot to be far less than that of the low rate TDMA channel. The null-to-null bandwidth requirements for the coherent BPSK modulation with $r = 1/2$, $K = 7$ convolutional coding assumed in the strawman design can then be written as:

$$\Delta f_{TDMA} \simeq 4 * 96\text{Kbps} \simeq 400\text{KHz} \quad (3.12)$$

and

$$\Delta f_{SCPC} \simeq i \cdot 4.8\text{Kbps} \simeq i \cdot 19.2\text{KHz} \quad (3.13)$$

where i is the maximum number of SCPC 4.8 Kbps channels allotted to each beam. Note that all areas covered by the same switched or scanning beam utilize the same SCPC band (see Figure 3.5).

To calculate the switched beam bandwidth requirement for comparison with the bandwidth required in the fixed beam scenario, the signal bandwidth given by Eqns. 3.12 and 3.13 is taken to represent both the signal bandwidth plus pilot bandwidth, for the TDMA case, and the signal bandwidth plus guard band for the SCPC case. Bandwidth requirements are calculated by substituting Eqns. 3.12 and 3.13 into Eqns. 3.9 and 3.10 and assuming two values of i, the maximum number of SCPC channels per beam. The results are listed in Table 3.4. The first case, $i = 14$, corresponds to the present strawman design. As discussed in Appendix A, the system is power limited by the satellite to 2000 duplex channels at 4.8 Kbps. If these channels are distributed evenly among the 142 spot beams then there would be $\approx$ 14 channels/beam. The second case, $i = 100$, is given for comparison. It represents operation with a more powerful satellite or with a more power efficient modulation technique.

From Eqns. 3.9 and 3.10 and Table 3.4 it can be seen that the uplink bandwidth is determined principally by the TDMA signal and that the relative bandwidth required by the SCPC signals becomes important for large i or large N_P. The downlink signal bandwidth is principally determined by the SCPC channels requirement, thus the effect of the TDMA channels is more obvious for lower values of i.

Tradeoff of Voice Delay and Supplier Overhead/Transmission

Operation with both fixed and switched beams permits the supplier to tradeoff the desire to achieve low transmission delay against the need to maintain a low number of overhead bits per transmission. However in the switched/scanning beam scenario the period of the beam sets the tradeoff, whereas in the fixed beam case it can be set at the operator's discretion. This tradeoff is particularly important for voice signals where delay must be minimized.

In the fixed beam case, a supplier with voice traffic for user A in Beam j can either place each vocoder packet as it is output from the vocoder in the outbound TDMA frame with the user's address or the supplier can store up several packets and transmit them in one TDMA frame with one address message. The former case minimizes voice delay time and the latter minimizes overhead per message. To calculate the minimum delay and overhead in the switched/scanning beam case, performance with two values for beam period is considered.

Voice Delay The voice delay calculation is based on the MSAT-X vocoder performance. This 5 Kbps vocoder produces a 100 bit frame every 20 msec, creating therefore 50 frames per sec. The communication system for the forward link, from supplier to user, is depicted in Figure 3.6. If the signal delay in a component is significant it is listed above the component. These delay values are worst case estimates, but should be accurate enough to permit valid beam comparisons. The return link signal delay is equivalent to the forward link delay as it is determined by the delay in the codex, the encoder/decoder, the burst modem wait period, the uplink and downlink propagation paths, and the satellite. The transceiver components

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Table 3.4: Bandwidth Requirements for the Switched/Scanning Beam Scenario

N_P	BW_{up}	BW Expansion Ratio	BW_{down} Ratio	BW Expansion
	$i = 14$			
1	59.22 MHz	1	41.77 MHz	1
5	64.86 MHz	1.10	50.17 MHz	1.20
8	67.55 MHz	1.14	54.17 MHz	1.30
10	70.24 MHz	1.19	58.17 MHz	1.39
15	72.93 MHz	1.23	62.17 MHz	1.49
	$i = 100$			
1	74.08 MHz	1	276.24 MHz	1
5	114.40 MHz	1.54	284.64 MHz	1.03
8	133.60 MHz	1.80	288.64 MHz	1.04
10	152.80 MHz	2.06	292.64 MHz	1.06
15	172.00 MHz	2.32	296.64 MHz	1.07

Note: The assumptions made for these calculations are (1) no HRCs on either the forward or return link; (2) equal sized TDMA carriers and SCPC bandwidths per beam; (3) low rate TDMA carrier and pilot bandwidth is 400 KHz; (4) SCPC channel and guard band bandwidth is 19.2 KHz.

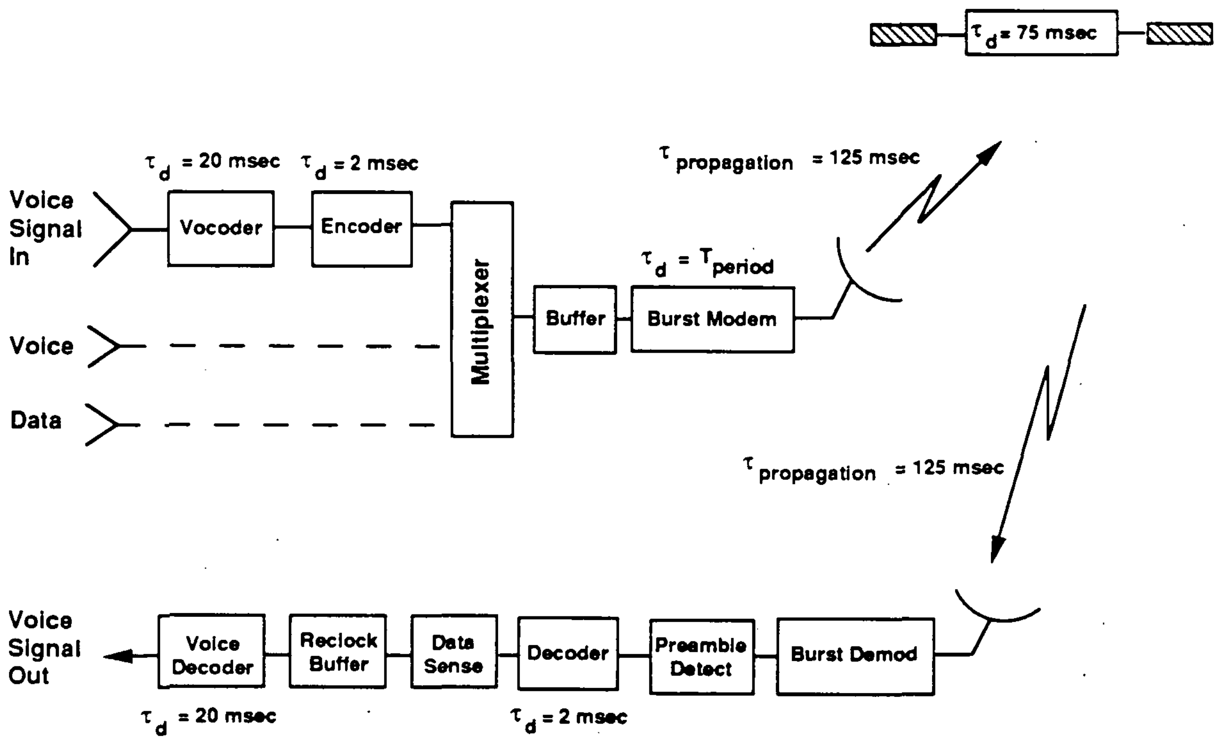

Figure 3.6: Communication system components and associated delay used for voice delay calculation.

at the user terminal and supplier terminal differ from those shown in Fig. 3.6.

In the fixed beam situation, one voice packet is sent every 20 msec, similar to the case when the switched/scanning beam is operated in the fast scan mode. The one way voice delay (supplier → user) is then 369 msec according to Fig. 3.6 (with no wait time for the burst modem). The round trip voice delay (supplier → user → supplier) is then ~ 0.74 sec. If a switched/scanning beam is used, vocoder packets are stored in the burst modulator prior to transmission once every T_{period} sec (100 vocoder packets are queued up in the slow scan mode, 1 packet in the fast scan mode). Thus the round trip transmission takes:

$$\tau_{\text{rd trip}} = 2\left(T_{period} + T_{satellite} + \sum_{\text{all delays}} \tau_d + 2\tau_{\text{propagation}}\right). \tag{3.14}$$

For the fast scan rate (T_{period} = 20 msec, $T_{duration}$ = 2 msec) $\tau_{\text{rd trip}}$ = 0.78 sec; for the slow scan rate (T_{period} = 2 sec) $\tau_{\text{rd trip}}$ = 4.74 sec. The fast scan rate produces a voice delay that is nearly identical to the fixed beam delay as the scan rate has been chosen to match the vocoder output rate. The difference in fixed and fast scan delay is due mostly to the use of burst modems, which add a delay of 20 msec to the round trip scan delay. Table 3.5

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Table 3.5: Round Trip Voice Delay for Various Switched Beam Periods

T_{period}	Rnd Trip Delay (user to supplier to user)
Fixed Beam	0.74 sec
20 msec	0.78 sec
500 msec	1.74 sec
1.0 sec	2.74 sec
1.5 sec	3.74 sec
2.0 sec	4.74 sec

gives the round trip delay, from supplier to user to supplier for the fixed beam and for the switched/scanning beam with various beam periods.

Information Throughput – Supplier Overhead per Transmission Supplier overhead per transmission for different spot beams can be roughly estimated by assuming a TDMA frame structure and taking the offered traffic to be of voice origin. A generic TDMA frame is shown in Figure 3.7. Obviously the greater the data transmitted from supplier to user in one TDMA frame the lower the transmission overhead. Usage of a switched/scanning beam with a slow scan rate results in more data transmitted per preamble bit worth of overhead and therefore results in a lower overhead/transmission. Using voice packets as the message unit, the overhead/transmission can be estimated as T_{period} is increased.

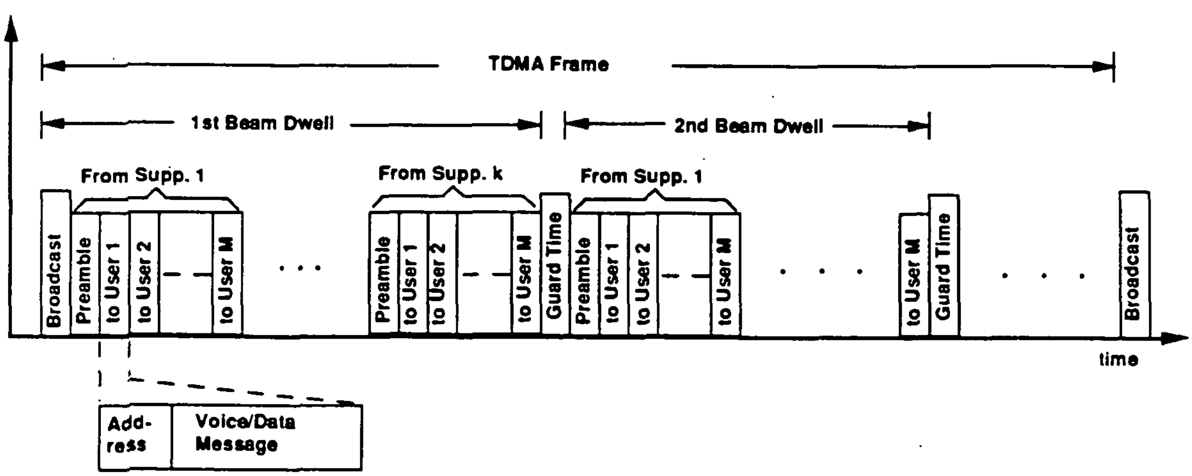

Figure 3.7: Generic TDMA frame format used for overhead calculation.

Let

P_P denote the preamble bit packet,
P_A denote the address bit packet,
and, P_V denote the 100 bit vocoder packet length,

then the supplier overhead/transmission can be written as follows:

$$\text{Overhead/transmission}_{\text{ jth supplier}} = \frac{N_j \cdot P_A + P_P}{N_j \cdot M \cdot P_V}$$

where N_j is the number of users addressed by the jth supplier and M is the number of vocoder packets per transmission,

$$M = \frac{T_{period}}{T_{vocoder}};$$

$T_{vocoder}$ being the time between subsequent vocoder packets, i.e. 20 msec.

This expression can be simplified by assuming that the 100 bit vocoder packet length is long enough to accomodate a preamble or an address, i.e. $P_A \leq P_V$ and $P_P \leq P_V$. Then the supplier overhead/transmission can be written as:

$$\begin{aligned}\text{Overhead/transmission}_{\text{ jth supplier}} &= \frac{N_j \cdot P_V + P_V}{N_j \cdot M \cdot P_V} \\ &= \frac{N_j + 1}{N_j \cdot M}.\end{aligned}$$

When one supplier communicates with several (>10) users, the above equation can be reduced simply to

$$\begin{aligned}\text{Overhead/transmission}_{\text{ jth supplier}} &\approx \frac{1}{M} \\ &= \frac{T_{vocoder}}{T_{period}}.\end{aligned}$$

The above equation is plotted in Figure 3.8 for the MSAT-X vocoder frame rate of 20 msec. For the slow and fast scan beams assumed here, the supplier overhead/transmission is found to be

$$\text{Overhead/transmission}_{\text{ jth supplier}} = \begin{cases} \frac{N_j \cdot P_V + P_V}{N_j \cdot 100 \cdot P_V} \rightarrow \frac{1}{100} & \text{Slow scan} \\ \frac{N_j \cdot P_V + P_V}{N_j \cdot P_V} \rightarrow 1 & \text{Fast scan.} \end{cases}$$

The overhead/transmission for the jth supplier can be estimated for the fixed beam by assuming again that all N_j users being addressed are sent signals of voice origin. Since each supplier transmits to the BPT's at a rate of 100 Kbps, a maximum of 20 voice signals can

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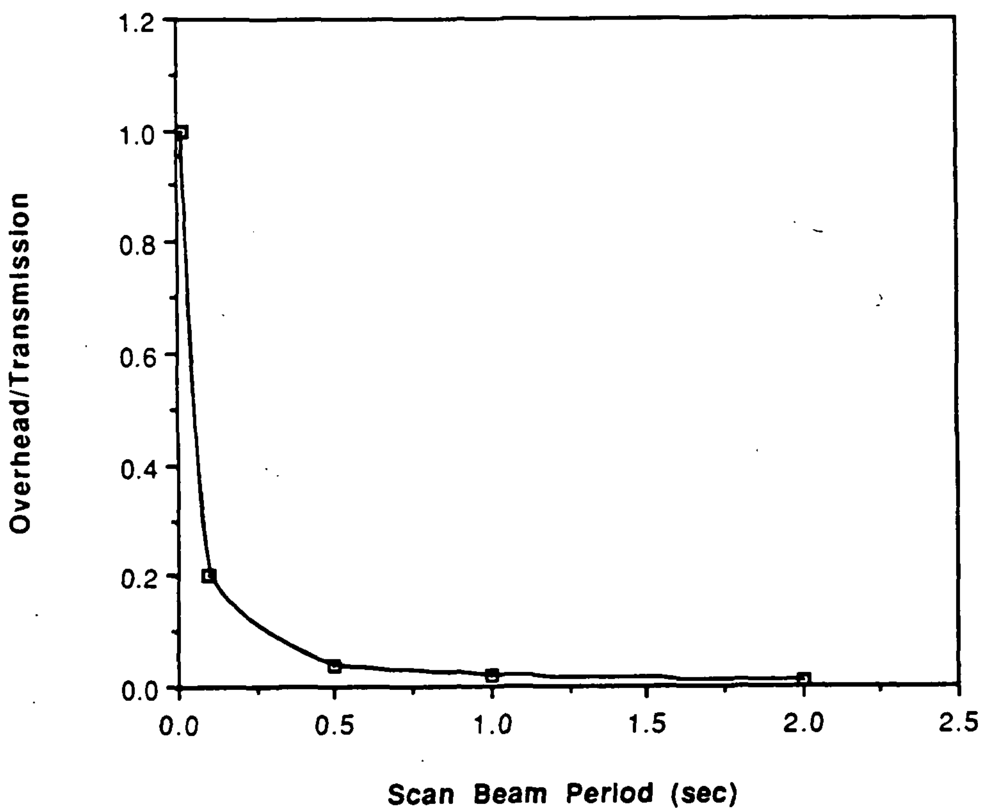


Figure 3.8: Overhead/transmission vs. scan beam period.

be sent in one TDMA frame (for a 5 Kbps vocoder). If this traffic requirement is assumed, then only one vocoder packet can be sent to each BPT in a TDMA frame, hence $M = 1$ and $N_j = 20$. The overhead/transmission can then be estimated to be ≈ 1, or one overhead packet required for every vocoder packet. If not all users addressed by that supplier are voice users then the supplier can choose between sending more than one vocoder packet per TDMA frame, thus lowering the overhead/transmission at the expense of an increase in voice delay, or sending one vocoder packet/TDMA frame, thereby operating with a high overhead/transmission but with the minimum voice delay of 0.74 sec.

Fixed and Switched Beam Efficiencies

As discussed in the introduction, fixed beams have the disadvantage that the satellite capacity can not be easily reconfigured so as to match the traffic requirements. Thus, in general, fixed satellite power and bandwidth are allocated to each beam irrespective of the number of users. Although methods for sharing the high power amplifier's power between beams do exist, switched/scanning beams still remain more efficient at matching traffic requirement with satellite capacity due to their variable dwell time. This is particularly true if the traffic possesses large geographical and temporal variations.

No precise calculation of the relative efficiencies between beam types has been performed. However a rough value for fixed beam efficiency is thought to be 50%; the switched/scanning beam is thought to be about 95% efficient. The high efficiency of the latter reflects the fact that the probability that none of the users in the N_P coverage areas need to use the beam is low. A more accurate means of gauging the relative beam type efficiencies is necessary. For this chapter, they have been taken to be:

$$\eta_{Traffic} = \begin{cases} 1.0 & \text{Switched Beam with non-adaptive power,} \\ 0.5 & \text{Fixed Beam with non-adaptive power.} \end{cases}$$

A disadvantage arising from the use of switched beams is the need for guard time between transmissions from each coverage area to allow for the switching time of the beam. This reduces the efficiency of the TDMA and the SCPC signals. For ACTS, the ferrite switches in the beam forming network are specified to have a switching time of less than 75 μsec in order to allow the beam to hop to many locations within the 1ms TDMA frame period [2]. Assuming the total wasted transmission time could take 5% to 20% of the transmission time, the time usage efficiencies of the two beam types can be written as,

$$\eta_{TXtime} = \begin{cases} 0.75 - 0.90 & \text{Switched Beam} \\ 1.0 & \text{Fixed Beam.} \end{cases}$$

The overall efficiencies of switched and fixed beams can now be compared.

$$\eta_{overall} = \eta_{Traffic} \cdot \eta_{TXtime}$$

$$\eta_{overall} = \begin{cases} 0.75 - 0.90 & \text{Switched Beam} \\ 0.5 & \text{Fixed Beam.} \end{cases}$$

As the switched beam's scan rate increases, the guard time required between transmissions occupies a greater fraction of the total transmission time. The beam's efficiency drops. Therefore the 90% beam efficiency is associated with the slow scan beam and the 75% estimate is associated with the fast scan. Under these assumptions the efficiency of a switched beam is higher than that of a fixed beam.

Link Calculation

The communication links detailed in the strawman design must be reanalyzed to evaluate which components may be changed in order to support the N_P higher data rate required by the use of switched/scanning beams. The uplink and downlink C/N_0 values for the forward and return link in the strawman design are given in Table 3.6. It can be seen that the overall C/N_0 is determined principally by the link between the BPT and the satellite.

Table 3.6: C/N_0 Values for Strawman Design

	Forward Link Supp. → User	Return Link User → Supp.
C/No_{up}	69.9 dB/K	46.9 dB/K
C/No_{down}	58.8 dB/K	50.3 dB/K
$C/No_{overall}$	57.4 dB/K	44.2 dB/K
$C/No_{required}$	54.5 dB/K	41.3 dB/K

Forward Link The higher data rate on the forward link can be accommodated by increasing the transmit power from the supplier stations slightly and by increasing the transmit power per TDMA channel on the downlink from its current 4W per low rate TDMA data channel. Using a switched/scanning beam with N_P coverage areas per beam means that (1) the outgoing bit rate will be increased by N_P and (2) the number of outgoing TDMA channels will be reduced by N_P. This occurs because the data from N_P fixed beams is being handled by one switched/scanning beam. If, for example, N_P is 10, then the 100 kbps bit rate of the TDMA channel carrying information for the basic personal terminals (the low rate channel) will be increased to 1 Mbps. As before, there will be one low rate TDMA channel (now 1Mbps) per beam, however now the 142 fixed beams will be replaced by 14 switched/scanning beams. If we allow the power of the TDMA beam to increase to compensate for the 10 times higher data rate, then the satellite transmit power per low data rate TDMA carrier will increase from its current 4W to 40W. The availability of 40W solid state high power amplifiers (SS-HPA) is poor as typical SS-HPAs at 30 GHz provide 1-5 Watts. Hence travelling wave tube amplifiers (TWTA) would have to be used. The latter weigh more and have a greater volume but their efficiency is greater than that of solid state amplifiers. This one positive side effect is important because the channel capacity is limited by the DC power generation capability of the satellite in the strawman PASS design (see Appendix A).

Return Link To accomodate the higher data rate on the return link from BPT to satellite, the most possible changes in the communication components are to 1) increase BPT transmit power from current 0.3 W/channel; or 2) increase the satellite receive antenna gain (current antenna has 2m diameter). The BPT's power can easily be upgraded from 0.3 W/channel and still be accomplished with SS-HPA's. The penalty then will be increased radiation from the BPT antenna. Increasing the satellite's antenna size increases transponder complexity dramatically as discussed in Appendix B and should be avoided if possible.

3.2.2 Transponder Complexity

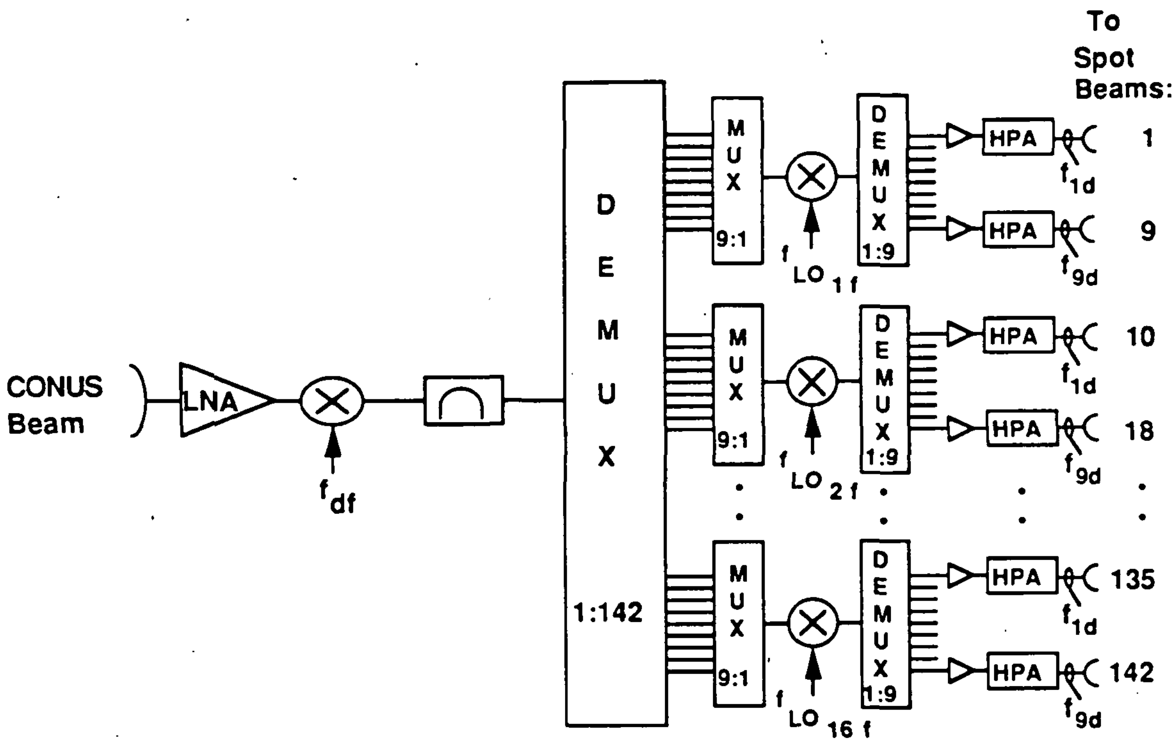
Connectivity between fixed and CONUS beams is achieved in the strawman design by the transponder as depicted in Figure 3.9. 142 4W HPA's are required to produce the 142 antenna feed signals. The 9:1 multiplexers and demultiplexers and the 16 different local oscillators and mixers are required to obtain the frequency reuse factor of 9 on the downlink.

A possible transponder design is depicted in Figure 3.10 for a switched/scanning beam design. A CONUS beam is still used to link the suppliers and the satellite; the switched or scanning beams are used to link the BPT's and the satellite. If each beam is taken to have 10 scan sectors, then the 142 fixed beams can be replaced by $\approx$ 14 switched beams. The number of output frequency bands needed for the 14 switched beams, N_{F_s}, is taken to be 5. Although the transponder design may seem more complex at first glance, a significant number of expensive or heavy components have been eliminated: the number of HPA's required drops from 142 to 14 and the number of local oscillators required is reduced from 16 to 3.

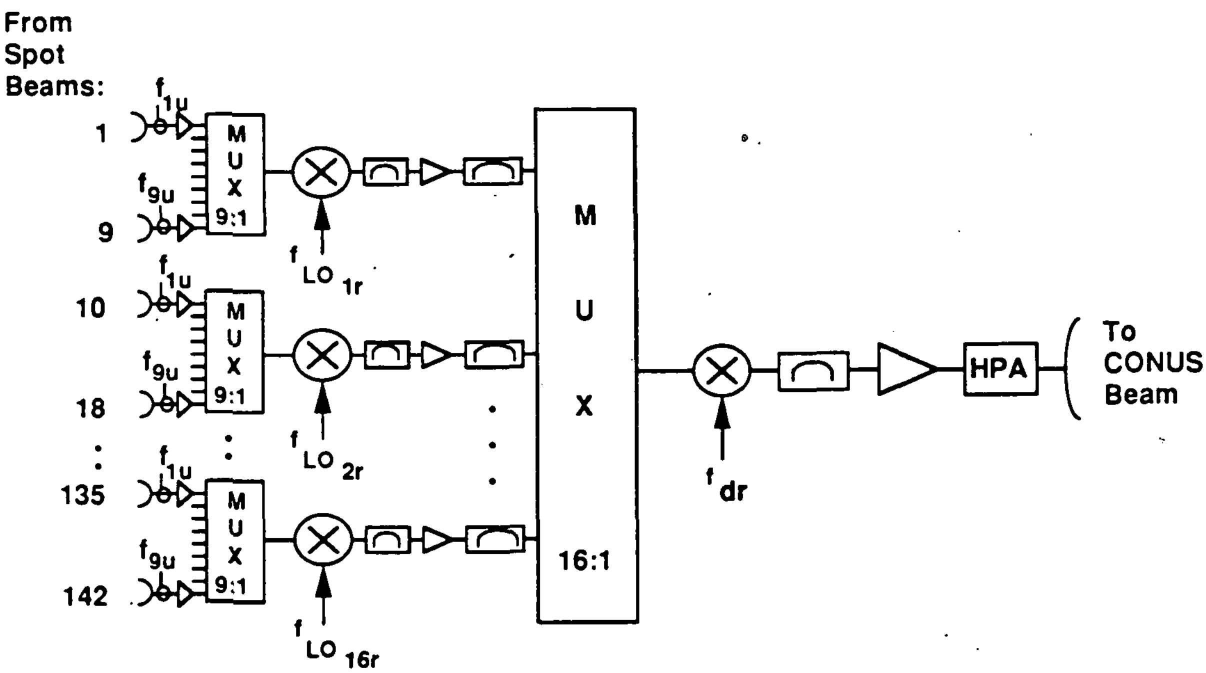
However, in the forward link, the signal from each of the HPA's are passed to a switch that connects the signal to one of the N_P feeds for that switched beam. One of the possible disadvantages of switched beams is the increased insertion loss in the signal path presented by this switch. Because a fixed switched beam design is considered here, the number of feeds and gain modules associated with each feed is not reduced through the use of switched beams. However if a hopping beam scenario is employed, such as that used by ACTS, it would be possible that the beam forming network would also be simplified.

3.2.3 User Terminal Complexity

When a scanning beam is used, the user terminal will differ from that in the strawman design in that it must transmit a burst signal and receive a burst TDMA signal. The terminal must

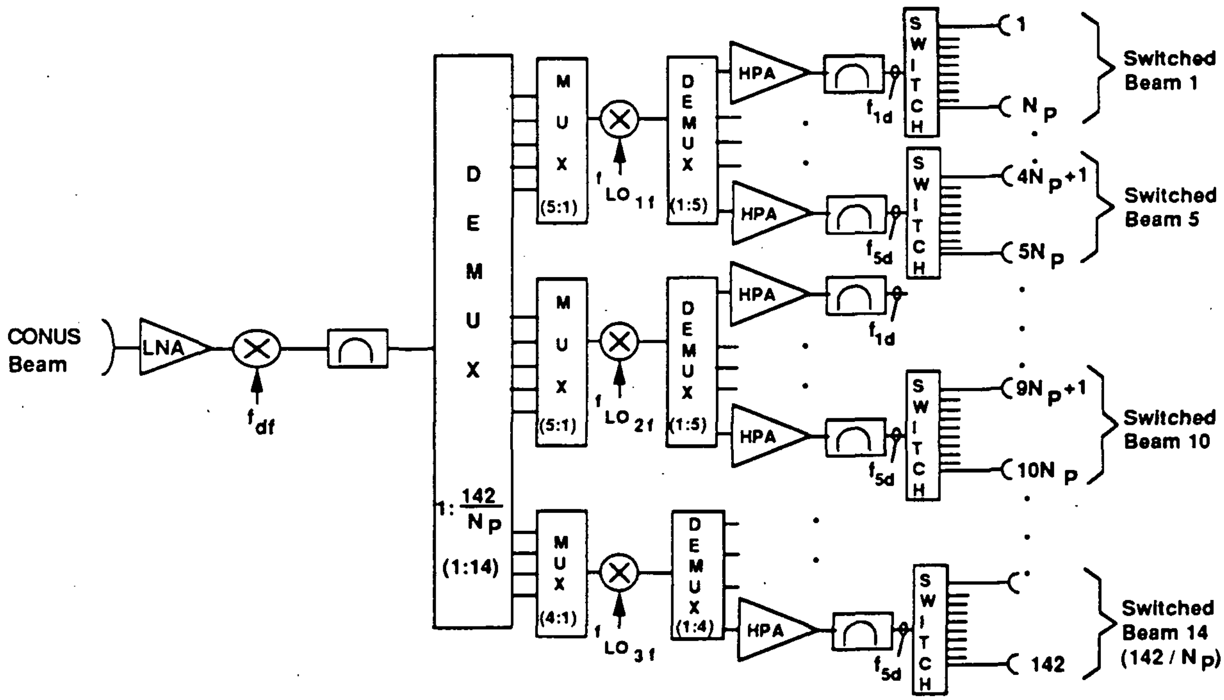


(a) forward link

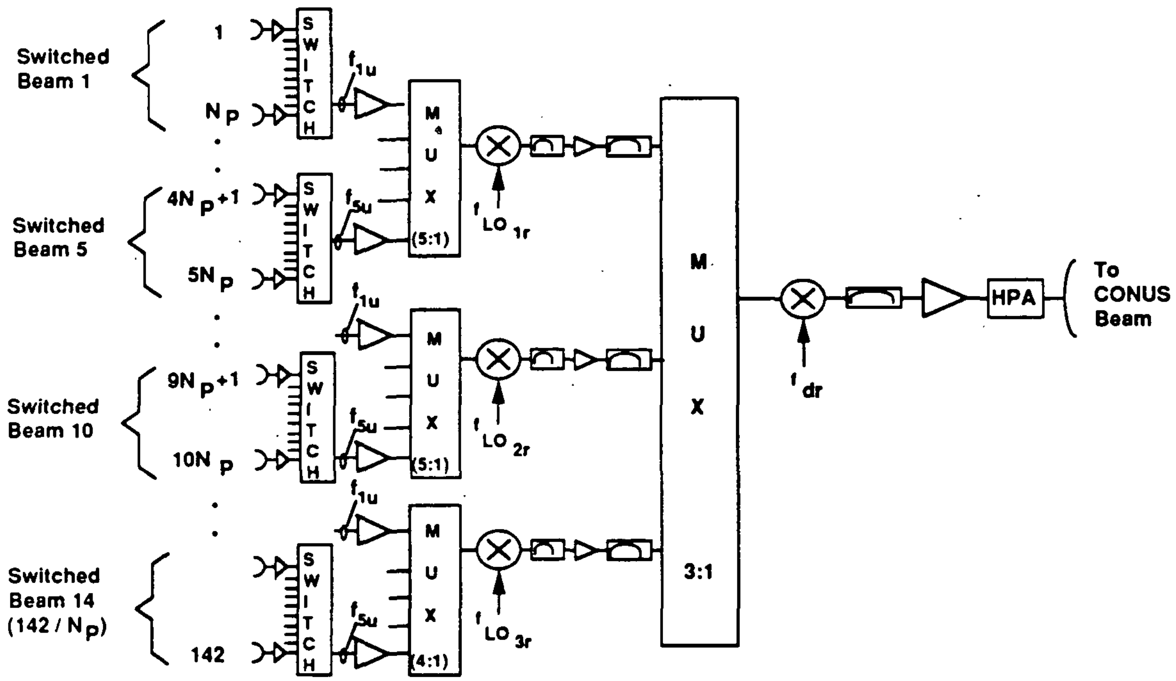


(b) return link

Figure 3.9: Strawman transponder design for CONUS and fixed beams.



(a) forward link ($N_p = 10$)



(b) return link ($N_p = 10$)

Figure 3.10: Possible transponder design for CONUS and scanning beams.

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possess a receiver that can acquire and process the incoming signal quickly. The operation of the receiver is done in two stages. The first phase is the initial acquisition of the pilot whereby a spatial and frequency acquisition are performed. In the second phase time and frequency synchronization with the incoming scanning or switched beam is maintained and the data is demodulated. The first phase is discussed in detail in Section 3.3. The second phase is discussed below.

The pilot frequency must be within the bandwidth of the acquisition loop when the switched beam returns to a given coverage area. Acquisition time depends on input C/N_0, loop BW and frequency deviation since last lock. The short term stability for two types of crystal oscillators is given in Table 3.7 and is plotted in Fig. 3.11 for various switched/scanning beam periods at 20 GHz and 30 GHz. The data in Table 3.7 is taken from the Vectron catalog [6]. From this figure, the maximum deviation between satellite passes of a 20 GHz local oscillator in the BPT can be seen to be 400 Hz or 600 Hz for the 30 GHz transmit signal assuming the satellite antennas use the slow beam rate corresponding to $T_{period} = 2$ sec.

Two methods can be used to compensate for transmit signal frequency offset at 30 GHz:

1. Use $f_{REFERENCE}$ from last satellite pass. At most the 30 GHz signal will be off by 30 - 600 Hz. The $f_{REFERENCE}$ from the last satellite pass is locked to the received pilot at 20 GHz.

2. Acquire pilot and receive preamble before transmit - i.e. stagger RX and TX beams. Then the TX signal will be locked to the NMC generated pilot and thus precisely on frequency.

Frequency deviation for the TX and RX signals should be designed to be well within the loop bandwidth at the BPT and the supplier. Using a VCXO these frequency offsets seem to be within allowable loop bandwidths. As shown in Table 3.7 higher stabilities are achievable using TC-VCXO's or OC-VCXO's although at a higher cost.

3.2.4 Supplier Station Complexity

In the strawman design, the supplier stations receive continuous signals from each user. In the switched/scanning beam scenario currently envisaged, users covered by the same beam would share the uplink SCPC channel, thus f_1 might be used by User 1 in Coverage Area 1 of Beam 1, by User 5 in Coverage Area 2 of Beam 1, ..., and finally by User m in the N_Pth coverage area of this beam. The supplier (and the NMC) station then have to rapidly acquire the bursty transmissions from various users with slightly different carrier frequencies. The use of switched/scanning beams with variable dwell times requires supplier stations to have for burst demodulators. Variable data rate modems are required in the strawman design to compensate for rain fade. Currently variable rate burst modems are used for high speed computer communications (19.2 Kbps modems). They should not be difficult to develop for this application.

Table 3.7: Stability and Price of Voltage Controlled Crystal Oscillator Sources

	Short Term Stability	Long Term Stability	Prices Quant. 1-2	Quant. 10,000
OC-VCXO	$1 \cdot 10^{-10}$ Hz/sec	$1 \cdot 10^{-7}$ Hz/sec	\$ 600 - 700	\$ 100 - 150
TC-VCXO	$5 \cdot 10^{-9}$ Hz/sec	$3.2 \cdot 10^{-6}$ Hz/sec	\$ 500 - 550	\$ 50 - 100
TC-VCXO	$5 \cdot 10^{-9}$ Hz/sec	$1 \cdot 10^{-6}$ Hz/sec	\$ 450 - 500	\$ 40 - 80
VCXO	$1 \cdot 10^{-8}$ Hz/sec	$1 \cdot 10^{-5}$ Hz/sec	\$ 200 - 300	\$ 10 - 12

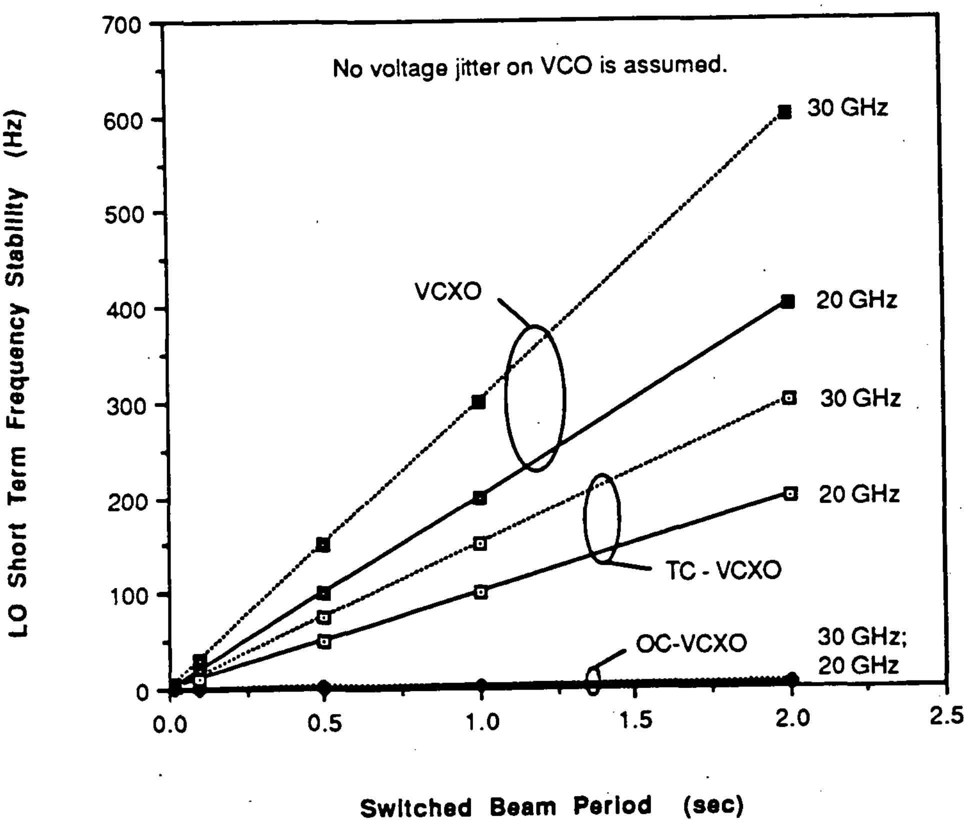

Figure 3.11: LO short term frequency stability vs. switched beam period.

3.2.5 Relative Advantages and Disadvantages

The implications of replacing the 142 fixed beams (of 0.35° beamwidth) with a reduced number of switched/scanning beams have been examined. Conclusions are summarized in Tables 3.8 and 3.9 where the characteristics of slow and fast scan switched beams are compared with those of the current fixed beam PASS design. System operation can be characterized by several parameters, beam efficiency or match of satellite capacity with traffic needs, spectrum requirements, voice signal delay, supplier overhead/transmission, and required burst data rate that must be supported by the communication link. From the user's point of view, rapid acquisition of the beam at the onset of the communication link is of importance, and to a lesser degree the time required for spatial beam location is of interest.

Table 3.8: Switched and Fixed Beam Characteristics from the System Point-of-View

	Slow Scan	Fast Scan	Fixed Beam
T_{period}	2 sec	20 msec	
$T_{duration}$	200 msec	2 msec	
N_P	10 cov. areas/beam	10 cov. areas/beam	1 cov. area/beam
Beam Efficiency w.r.t. Traffic Variations	90 %	75 %	50 %
Req'd Burst Data Rate			
From BPT	50 Kbps	50 Kbps	5 Kbps
From Supplier	1 Mbps	1 Mbps	100 Kbps
Net Equiv. Frequency Reuse	1.5	1.5	1.9
Normalized Overall BW Requirements	≈ 1.3	≈ 1.3	1.0
Min. Conversation Delay	4.74 sec	0.78 sec	0.74 sec
Supplier Overhead per Transmission	Low	High	High
NMC Overhead to Broadcast Beam Dwell Time	High	High	Nonexistent

Table 3.9: Switched and Fixed Beam Characteristics from the User Point-of-View

	Slow Scan	Fast Scan	Fixed Beam
T_{period}	2 sec	20 msec	
$T_{duration}$	200 msec	2 msec	
N_P	10 cov. areas/beam	10 cov. areas/beam	1 cov. area/beam
Frequency Stability between Sat. Passes			
RX at 20 GHz	4 - 400 Hz	0.04 - 4 Hz	N/A
TX at 30 GHz	6 - 600 Hz	0.06 - 6 Hz	N/A
Need to restart acquisition loop	Low	Low	N/A
Spatial Acquisition	All 108 essays performed in one satellite pass	At 1 essay per satellite pass: 2.16 sec	216 msec

Switched/scanning beams have been found to allow a better match between traffic requirements with large geographic and temporal variations and satellite capacity. Their use reduces the number of local oscillators and high power amplifiers required on-board the satellite and hence may reduce payload weight and size. No additional equipment is thought to be necessary in the user and supplier terminals to acquire the non-continuous satellite signal. Reacquisition of the satellite pilot can be accomplished without reentering into the receiver's acquisition mode as the pilot will be within the loop's tracking bandwidth.

The cost of using switched/scanning beams lies in the four areas. First, higher EIRP user terminals will be necessary to support the higher burst data rates. This can be achieved by increasing the size of the HPA in the user terminals at the cost of higher radiated power from the terminals. Second, burst modems will be needed at the user terminals and supplier stations instead of non-burst modems. Third, the NMC will have more functions to perform and more precise control of the network will be necessary. Four, spectral efficiency, accomplished in the strawman design through frequency reuse, will be slightly reduced by the use of switched/scanning beams, the total required bandwidth (uplink and downlink) being 1.2 to 1.4 times that required with fixed beams.

Optimum beam scan rate is determined by tradeoffs in various parameters. As the beam scan rate decreases (its period and duration over one coverage area increases) the following occur: the round trip delay incurred by signal of voice origin increases; information throughput at the supplier station increases; and, the need to restart signal acquisition process at user terminal between satellite beam accesses increases. Operation with a slow

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scan beam, such as exemplified in Tables 3.8 and 3.9, is most likely impossible due to its poor delay performance: 4.7 sec for voice communications. Scan rates closer to that typified by the fast scan beam will have to be used.

Enhanced match of satellite capacity usage and the possibility of reduced transponder complexity make consideration of switched/scanning beams of interest for PASS although their system price is high. To reduce this price, a satellite design employing multibeam antennas with switched/scanning beams on the downlink to the user terminals and with fixed beams on the uplink from the user terminals will be examined next.

3.2.6 Hybrid Beam Concept

Another possibility for the design of the satellite is to use multibeam antennas with switched/scanning beams on the downlink to the user terminals and with fixed beams on the uplink from the user terminals. This hybrid design would eliminate the need to transmit from the user terminals with the higher EIRP necessary to support the higher burst rate from the terminals. In addition no burst modems would be required at the user terminal - although burst demodulators would still be necessary. However the advantages of using a fully switched/scanned beam system, ie. the enhanced match of satellite capacity to user traffic and the possibility of reduced transponder complexity, would then not be fully realized.

3.3 Pilot Acquisition and Detection Time

The detection of a pilot from a satellite that employes scanning or switching beams is very similar to the detection of bursty radar signals in presence of clutter. In order for a user terminal using a scanning antenna to lock to the incoming TDMA type pilot, it has to scan in azimuth and elevation until it detects the incoming energy, to synchronize to the scanning beam scan rate, and then perform a fine tuning both in frequency and phase. A fast detection mechanism must be used if the time duration of a beam in a given geographic area is to be minimized.

A great amount of effort has been expended over the past twenty years on the subject of the properties, configurations, performance, and implementation of signal detectors and many reports and papers are available which delineate basic detector topology and optimum configurations and methods for performance analysis [7,8,9]. The results produced lay the necessary foundation and provide bounding criteria for detectability as a function the principal parameters. Several possible ways are available in performing the frequency search; eg. swept IF, wide-open, or multi-channel configurations. The swept-IF receiver mixes the incoming signal with an oscillator signal whose frequency varies as periodic sawtooth. A relatively narrow-band IF filter which follows looks at successively different portions of frequency uncertainty. The wide-open receiver employs an IF filter which is sufficiently wide to accommodate the entire frequency uncertainty and thus, no actual sweep is performed. The multi-channel receiver employs parallel sweep in which a bank of IF filters simultaneously "looks" at different portions of the frequency uncertainty. All publications report that if certain requirements are fulfilled, the wide-open receiver has the fastest detection time and is the easiest to implement. For this study it is assumed that a wide-open receiver with an envelope detection scheme using an accurate threshold is employed; data from the references cited above is applied to evaluate the performance of the proposed PASS architecture.

3.3.1 Detection Mechanism

The detection of a pilot from a switching beam by a scanning user beam can be looked at as a three dimensional problem where the receiver has to search in the space, frequency, and time domains until a predetermined energy level is detected. The block diagram of such a receiver is shown in Figure 3.12. The receiver's task is to detect the presence of a TDMA pilot by moving the antenna beam, either mechanically or physically, to different locations in azimuth and elevation. At each location (or direction) a frequency search in a set of predetermined bandwidths is performed. Once the detection is obtained a fine tracking loop is activated to synchronize the receiver with the scanning rate of the satellite antenna and lock to frequency and phase of the pilot. Figure 3.13 shows a simplified flow diagram of this process.

Spatial Search

A user terminal, without any prior history of its position, when turned on has to initiate a search in both azimuth and elevation. In order to detect the pilot, the user antenna has to move to a maximum of M directions where:

$$M = \frac{360^\circ}{W_{azimuth}} \cdot \frac{90^\circ}{W_{elev}} \tag{3.15}$$

and $W_{azimuth}$, W_{elev} are the beamwidths of the user antenna in azimuth and elevation, respectively. The antenna beam moves to one azimuth-elevation cell at a time and stays there until the frequency search is completed thus requiring a maximum of $M-1$ direction changes for a maximum possible switch time of:

$$T_{switch} = (M-1)T_{dir} \tag{3.16}$$

where T_{dir} (sec) is the antenna direction switch time.[1]

Frequency Search

Assuming a constant carrier pilot is employed, for a system such as PASS that employs frequency reuse techniques, the frequency search consists of observing N different frequency regions each having a bandwidth equal to the frequency uncertainty at the input of the matched filter.

[1] In deriving the equations in this report, it is assumed that the satellite is in direct view of the user antenna.

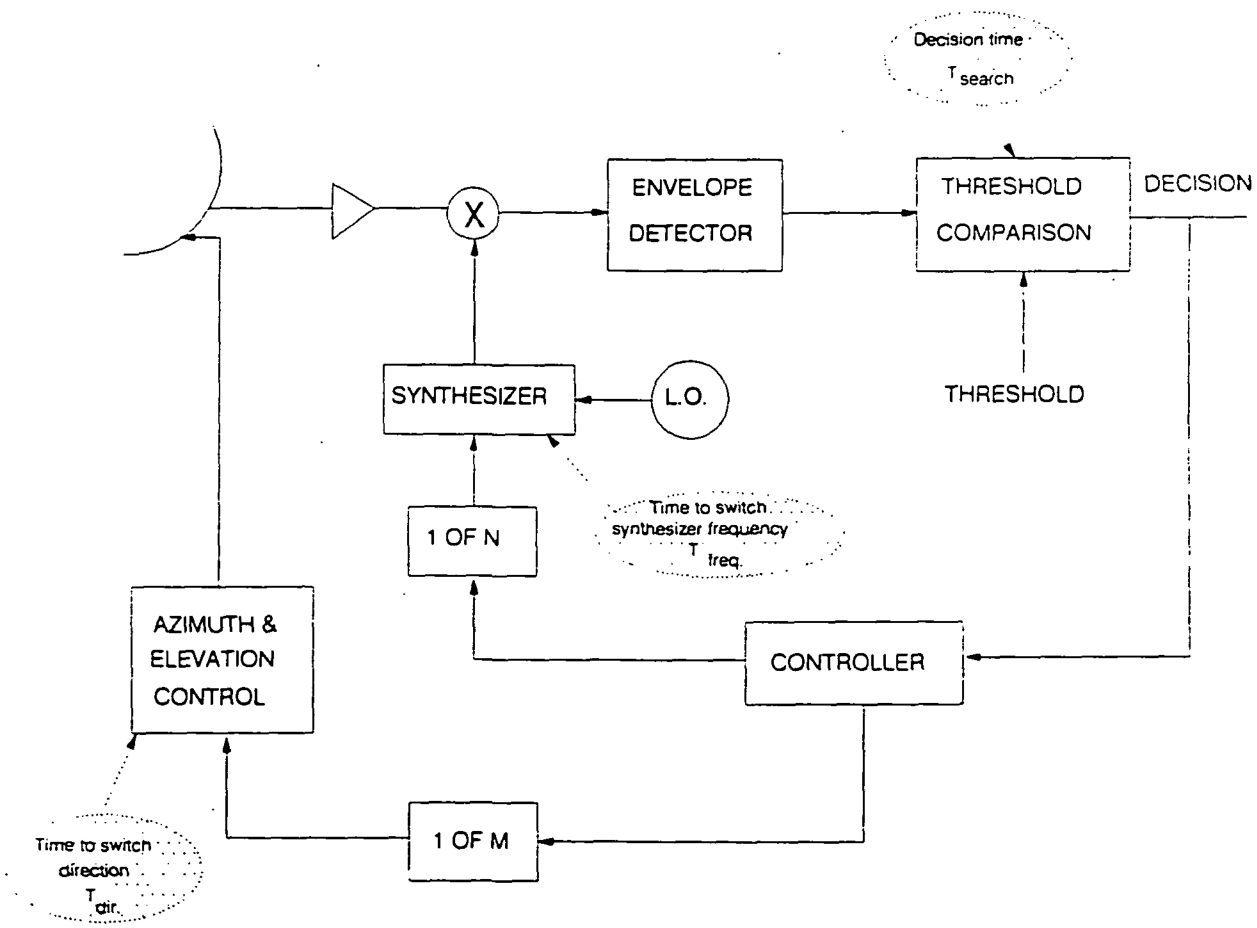

Figure 3.12: Receiver block diagram.

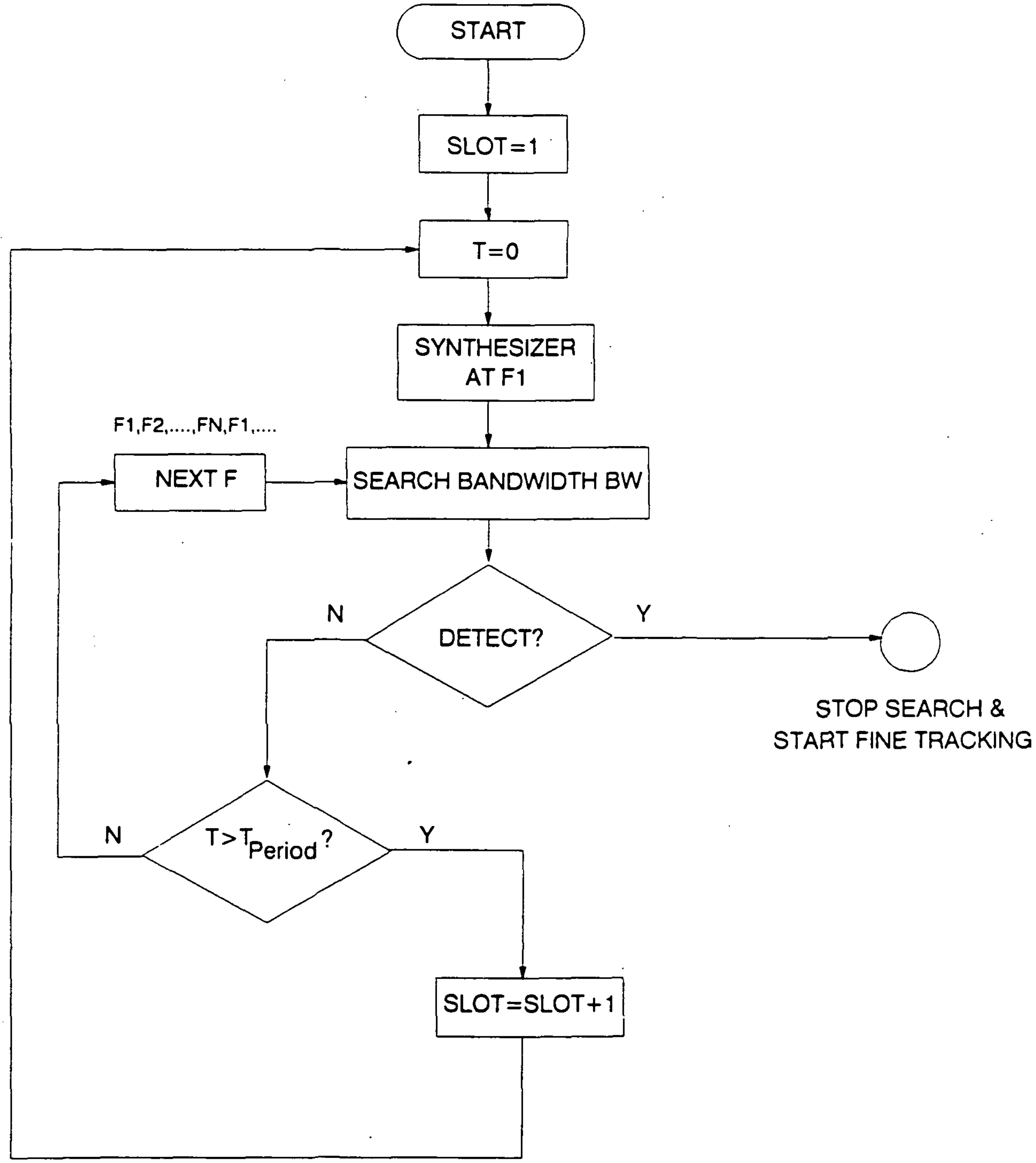

Figure 3.13: Detection flow diagram.

The frequency uncertainty is due to downconversion error (δf) and possibly some Doppler shift (δF). At each spatial cell N frequency regions, each being a maximum of $\pm(\delta f + \delta F)$ off from the expected value, have to be searched. The total search bandwidth at each frequency is:

$$BW_{IF} = 2(\delta f_{max} + \delta F_{max}). \tag{3.17}$$

The receiver's downconversion error is a function of the local oscillator drift and the center frequency of the incoming pilot, that is:

$$\delta f_{max} = F_{down} \cdot \text{Oscillator long term accuracy} \tag{3.18}$$

where F_{down} is the down link frequency from the satellite hereafter assumed to be 20 GHz. The Doppler shift for stationary applications consists of only the satellite Doppler which is ideally compensated for by the NMC so that only residual Doppler shift is present at the input of the receiver, thus,

$$\delta F \approx 0.$$

To ensure proper detection a small detection bandwidth is required and thus instead of sweeping the full bandwidth of the N pilots, it is assumed that the synthesizer frequency is switched to one pilot frequency at a time leading to a maximum synthesizer switch time of:

$$T_{synth} = (N-1)T_{freq} \tag{3.19}$$

where T_{freq} is the synthesizer frequency switch time.

At each frequency region an integration of the energy in a bandwidth $2\delta f_{max}$ is done by the matched filter for a period of time T_{search} that depends on the nominal link conditions. The output of the matched filter is envelope detected and is then compared to a predetermined threshold that ideally ensures the detection of the pilot. This scheme, because of its preset threshold will occasionally detect noise pulses that are sometimes as high as the actual signal thus causing what is known as a false alarm. Numerous studies have shown the tradeoffs between probability of detection (P_d) and false alarm rate (FAR) as a function of the channel C/N_0. The results of [7] will be applied in Section 3.3.2 in conjunction with the parameters of the PASS strawman design.

When the user terminal antenna is pointed towards the satellite, there must be a reasonably high probability that the receiver will detect the pilot. This is difficult as the pilot and the user terminal receiver are initially asynchronous and because, as viewed from the user terminal, the pilot occupies only a brief interval. Thus the probability of detection must be very close to unity and that false alarms must occur infrequently. Given that frequency reuse techniques are used, and assuming that an envelope detection scheme with an accurate threshold is employed, the initial detection time (T) of the receiver depends on δf, δF, N, P_d, FAR, T_{freq}, T_{search}, and C/N_0 of the link. These parameters will be applied in Section 3.3.2.

Time Search

Time search is not a function of the detector characteristics, however it sets the system requirements that have to be met in order to ensure that both spatial and frequency searches conclude with a true detection. These requirements are on the selection of the satellite scan period (T_{period}), and duration ($T_{duration}$) of the beam at a given location.

For proper spatial acquisition to occur, assuming that the time to switch a synthesizer is less than the time to switch to a new spatial cell, the minimum $T_{duration}$ should be selected such that:

$$T_{duration} = T_{synth} + (N+1)T_{search} \tag{3.20}$$

that is the scanning beam should be pointed to a given geographic region at least long enough for the receiver to search all N frequency regions. The second term in the right side of the equation is the total search time of all of the $N+1$ bandwidths where the extra search time is to compensate for possible race conditions. Furthermore, it should be ensured that the total time the user antenna is oriented in one of M directions (T_{dd}) meets the following requirement:

$$T_{dd} \geq T_{period}, \tag{3.21}$$

thus resulting in a maximum detection time of:

$$\begin{aligned} T_{detect} &= MT_{period} + T_{switch} \\ &= MN_P T_{duration} + T_{switch}. \end{aligned} \tag{3.22}$$

where N_P is the scan factor defined as the ratio of the scan period of the satellite beam to its $T_{duration}$. It is obvious from Equations 3.20 to 3.22 that the scanning rate of the satellite beams is a function of the search time of the user receiver. The overall search time T_{search} is basically a function of the link condition C/N_0 and the expected P_d.

3.3.2 Numerical Example

In order to minimize T_{search}, it is vital that the probability of detecting energy in the detection bandwidth be very high and that the number of false alarms be very low. For a given bandwidth, a specific S/N is required to meet the desired probability of detection and false alarm rate. The probability that the signal will be detected, P_d, is given by Skolnik to be [7]:

$$P_d = \frac{1}{2}\left(1 - \text{erf}\left[\frac{v_T - A}{\sqrt{2\Psi_0}}\right]\right) + \left(\frac{\exp\left[\frac{-(v_T-A)^2}{2\Psi_0}\right]}{2\sqrt{2\pi}\frac{A}{\sqrt{\Psi_0}}}\right)\left(1 - \frac{v_T - A}{4A} + \frac{1 + \frac{(v_T-A)^2}{\Psi_0}}{\frac{8A^2}{\Psi_0}} - \cdots\right) \tag{3.23}$$

where the error function, erf, is defined as:

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Table 3.10: Bandwidth vs. Oscillator Long Term Drift

Oscillator Long Term Drift	Bandwidth BW_{IF}
± 1 PPM	40000 Hz
± 0.1 PPM	4000 Hz
± 0.01 PPM	400 Hz
± 0.001 PPM	40 Hz

$$\operatorname{erf} Z = \frac{2}{\sqrt{\pi}} \int_0^Z e^{-u^2} du,$$

v_T is the detector threshold voltage, A is the signal amplitude, and Ψ_0 is the mean-square value of the noise voltage. He furthermore shows that the probability of false alarms, P_{FA}, is:

$$P_{FA} = \exp\left(-\frac{v_T^2}{2\Psi_0}\right) = \frac{1}{TBFA \cdot BW_{IF}}$$

and

$$\frac{A}{\Psi^{\frac{1}{2}}} = \left(\frac{2S}{N}\right)^{\frac{1}{2}}$$

where $TBFA$ is the average Time Between False Alarms. The results of the above equations are plotted in Figs. 3.14 and 3.15. Fig. 3.14 plots the required signal-to-noise ratio as a function of the probability of false alarm for a number of detection probabilities, namely 90%, 95% and 99%. As is evident from the plots, for a given P_d, higher P_{FA} result in lower requirements for S/N. The time between false alarms is plotted as a function of the false alarm rate in Fig. 3.15 for four oscillator stabilities. The relationship between oscillator stability and IF bandwidth is given by Eqns. 3.17 and 3.18; this trade-off is quantified in Table 3.10. For a given TBFA, Fig. 3.15 shows that the higher the accuracy of the oscillator the higher P_{FA}, and, thus the lower the required S/N. For example, in order to get a P_d of 99% at a $TBFA$ of 1 minute, a SNR of 14.8, 14.4, 13.8, and 13 dB is required for an oscillator accuracy of 1, 0.1, 0.01, and 0.001 PPM, respectively.

The signal-to-noise ratio at the input of the detector is given as a function of C/N_0 and BW_{IF}:

$$\frac{S}{N} = \frac{C}{N_0} - 10\log(BW_{IF})$$

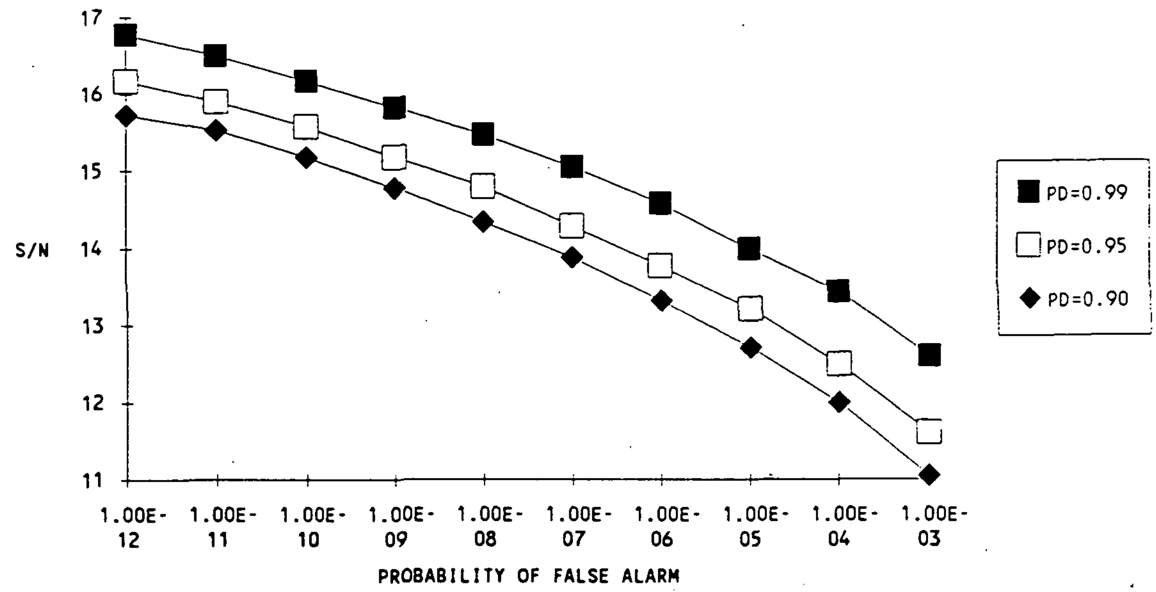

Figure 3.14: Required signal-to-noise ratio vs. probability of false alarm as a function of detection probability.

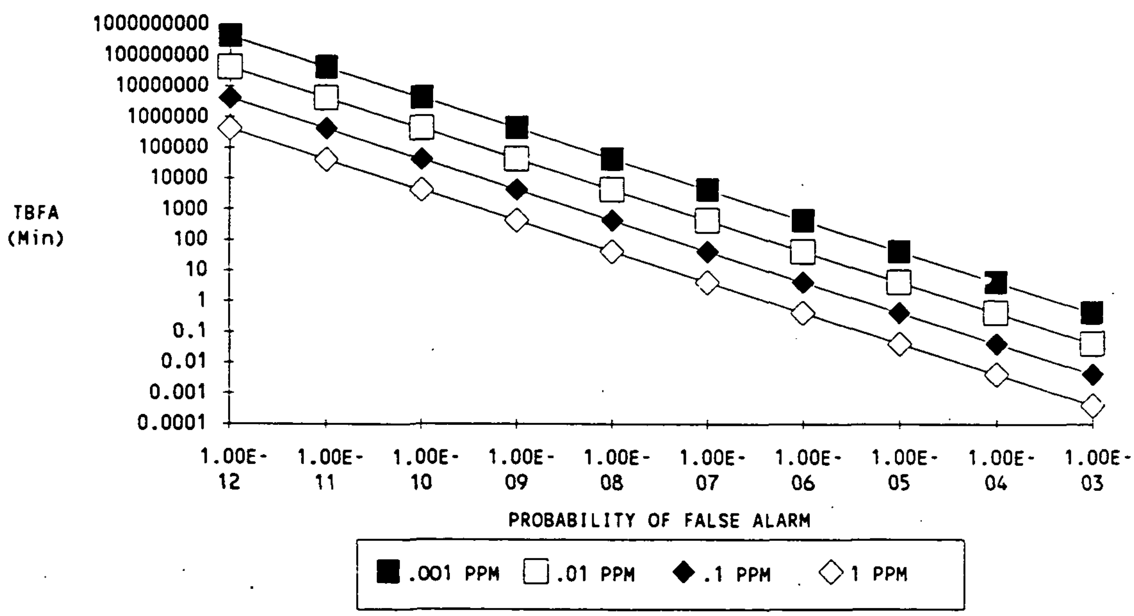

Figure 3.15: Mean time between false alarms vs. probability of false alarm as a function of oscillator accuracy.

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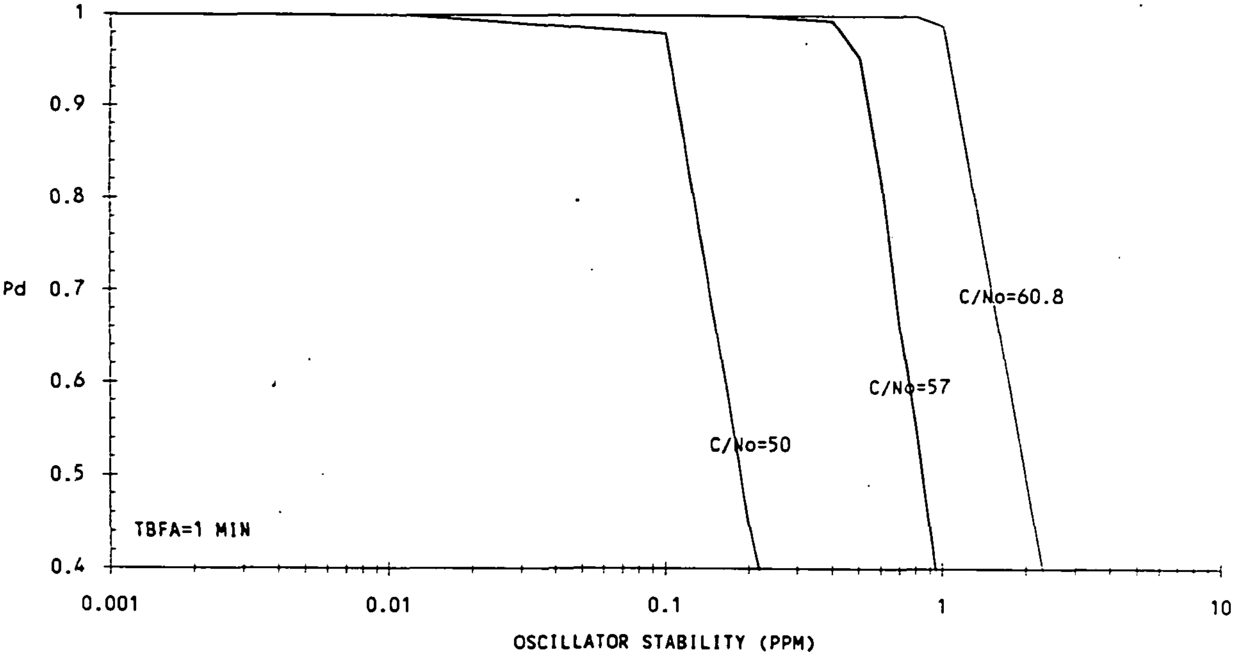

Figure 3.16: Probability of detection as a function of oscillator stability for different C/N_0 values.

For a TBFA of 1 minute, the probability of detection as a function of oscillator drift for C/N_0 of 50, 57 and 60.8 dB-Hz is plotted in Fig. 3.16. Note that a probability of detection of 99% corresponds to an oscillator stability of 0.02, 0.32, and 1 ppm for C/N_0 of 50, 57, and 60.8 dB-Hz, respectively.

The PASS strawman design supports a C/N_0 of 57 dB-Hz at the input to the user terminal receiver for the low rate 100 Kbps TDMA carrier and calls for a pilot channel whose C/N_O is much less than that of the TDMA carrier. A scanning beam covering N_P regions will require the forward link data rate to increase N_P times. The higher data rate will necessitate an increase of $10\log(N_P)$ in the effective radiated power of the satellite. Assuming N_P is 10, the received C/N_0 will increase to 67 dB-Hz for the same class of satellite as the strawman design. Table 3.11 gives the pilot power as a percentage of the LRC TDMA carrier power for various oscillator stabilities for a $TBFA$ of 1 minute and a P_d of 0.99. The data for the table is taken from Fig. 3.16. For $N_P = 10$, assuming that the pilot power should be no more than 10% of the power in the low data rate channel, an oscillator stability of better than 0.32 ppm is needed to perform the initial acquisition.

Once the required C/N_0 has been set, the minimum switched/scanning beam duration time, i.e. that required for the receiver to search all N pilots, can be determined from Eq. 3.20 for the operational system values listed in Table 3.12. Given that there are 9 pilots bands which the receiver must search at a given spatial direction, and assuming that the synthesizer frequency switch time, T_{freq}, is 10 μsec, T_{synth} can be found from Eq. 3.19 to be:

Table 3.11: Required Pilot Power at the Satellite for Pilot Acquisition

Oscillator Stability (ppm)	Required Pilot C/N_0 (dB-Hz)	Pilot Power as a % of the low rate TDMA channel power)
1.00	60.8	24
0.32	57.0	10
0.10	50.4	2
0.01	39.8	0.2

$$T_{synth} = (9 - 1)\, 10 \cdot 10^{-6} = 80\ \mu\text{sec}. \tag{3.24}$$

If only a short time is allowed for observation, determination, and processing of a given bandwidth, then T_{search} can be assumed to be 1msec. T_{search} depends on the signal-to-noise of the pilot. Assuming 9 pilots ($N = 9$) and ten scan regions per beam ($N_P = 10$), $T_{duration}$ can be calculated from Eq. 3.20 to be:

$$T_{duration} = 80\ \mu\text{sec}\ +\ (9+1) \cdot 1\ \text{msec} = 10.08\ \text{msec}. \tag{3.25}$$

Under the operational assumptions shown in Table 3.12, the minimum beam dwell time over a particular area must then be 10.08 msec in order for the receiver to search for the 9 possible pilots at a given spatial location. This minimum beam duration time has been computed assuming an oscillator with long term stability of 0.32 ppm is used and that the pilot C/N_0 is 57 dB-Hz. From Table 3.7, a VCXO could be used at a cost of \$10 - \$12 in 1000 unit quantities. Operation with more stable oscillators or with higher pilot C/N_O's will reduce the minimum beam duration time at the expense of using a higher cost LO or more satellite power.

In order to find the time required to search all spatial locations M for the presence of the satellite pilot, T_{detect}, the number of spatial locations and the time for the antenna to move from direction to direction, T_{dir}, must be given. The former can be calculated from Eq. 3.15 given $W_{azimuth}$ and W_{elev} and the latter can be found from Eq. 3.16 given T_{dir}. Values for $W_{azimuth}$, W_{elev}, and T_{dir} are given in Table 3.12 and used to find:

$$T_{switch} = (100 - 1)\, 20 \cdot 10^{-6} = 1.98\ \text{msec}. \tag{3.26}$$

Using Eqs. 3.22, 3.25 and 3.26, T_{detect} is found to be:

$$T_{detect} = 100 \cdot 10 \cdot 10.08\ +\ 1.98 = 1082\ \text{msec} = 1.082\ \text{sec}.$$

These results are meant to identify the dependency of $T_{duration}$ and T_{detect} on oscillator stability and pilot C/N_O. Under the conditions stated above, an oscillator with 0.32 ppm

Table 3.12: Operational Values

PARAMETER	Assumed value
F_{down}	20 GHz
Oscillator Long Term Drift	1, 0.1, 0.01, 0.001 ppm
δF (Doppler Compensation by the NMC)	0
N	9
P_d	99%
$TBFA$	1 min
N_P	10
T_{freq}	10 μsecs ‡
T_{search}	1 msec
$W_{azimuth}$	18°
W_{elev}	18°
T_{dir}	20 μsecs †

† Estimated value for the switch time of phase shifter.
‡ Derived from current low cost synthesizer specification.

long term stability can be used to detect the pilot if its C/N_O is 57 dB-Hz; alternatively an oscillator with 1 ppm long term stability can be used if the pilot C/N_O is 60.8 dB-Hz. However these results, based on the data provided in Table 3.11, assume a perfect receiver and no margin has been left for errors. In practice there will be other factors that will influence these results and careful consideration should be made to ensure perfect detection. Some of these factors are presented in the next section.

3.3.3 Practical Considerations

Threshold Setting

Many wideband detectors have been built to operate in different frequency bands, and have been used extensively for different applications. As a result, the technology needed for this type of detector is fairly well in hand. From a functional standpoint, the most difficult problem is that of setting and maintaining the receiver threshold value. Proper setting of this value is essential to meeting the specified P_d and P_{fa}. If the threshold is too low, an excessive false alarm rate is obtained while, if it is too high, detection of the actual signal may be missed. Even if the threshold is set properly initially, time, temperature, and voltage variations, and other dynamic conditions, will affect the overall detector such that the initial setting will become incorrect. Further, the receiver effective noise temperature will change as the receiving antenna is subject to varying background temperature due to changing angles and fields of view. For example, a 1 dB change in the threshold can result in three orders of magnitude change in false alarm probability. Thus, some precise, automatic, periodically updating method of threshold termination is needed. Devices that accomplish this purpose are called $CFAR$ (CONSTANT-FALSE-ALARM-RATE).

$CFAR$ complexity varies based on the application. A $CFAR$ may be obtained by observing the noise in the vicinity of the pilot and adjusting the threshold in accordance with the measured background. Figure 3.17 illustrates the cell-averaging $CFAR$ which utilizes a tapped delay-line to sample the bandwidths in either side of the bandwidth of interest i.e. the frequency bandwidths of Section 3.3.1 can be used as the sample points. (For a detailed description of this method please see Chapter 10 of [7].) For the purposes of this study it should be noted that a loss of about 1 dB in performance will be added to the required SNR.

There are several other methods for achieving $CFAR$ at the output of the low-pass filter. These methods are complex and all result in some loss of performance. It is obvious that some method is required to be able to perform this detection, however for a hand held terminal, requiring ease of implementation and low cost components, this may be formidable.

Voice Delay

In the switched beam scenario the period of the beam sets the voice delay and it is extremely important to minimize this delay. From Eq. 3.20 it is clear that the minimum delay is a function of the overall detection time of the user terminal. Table 3.5 plots the round trip

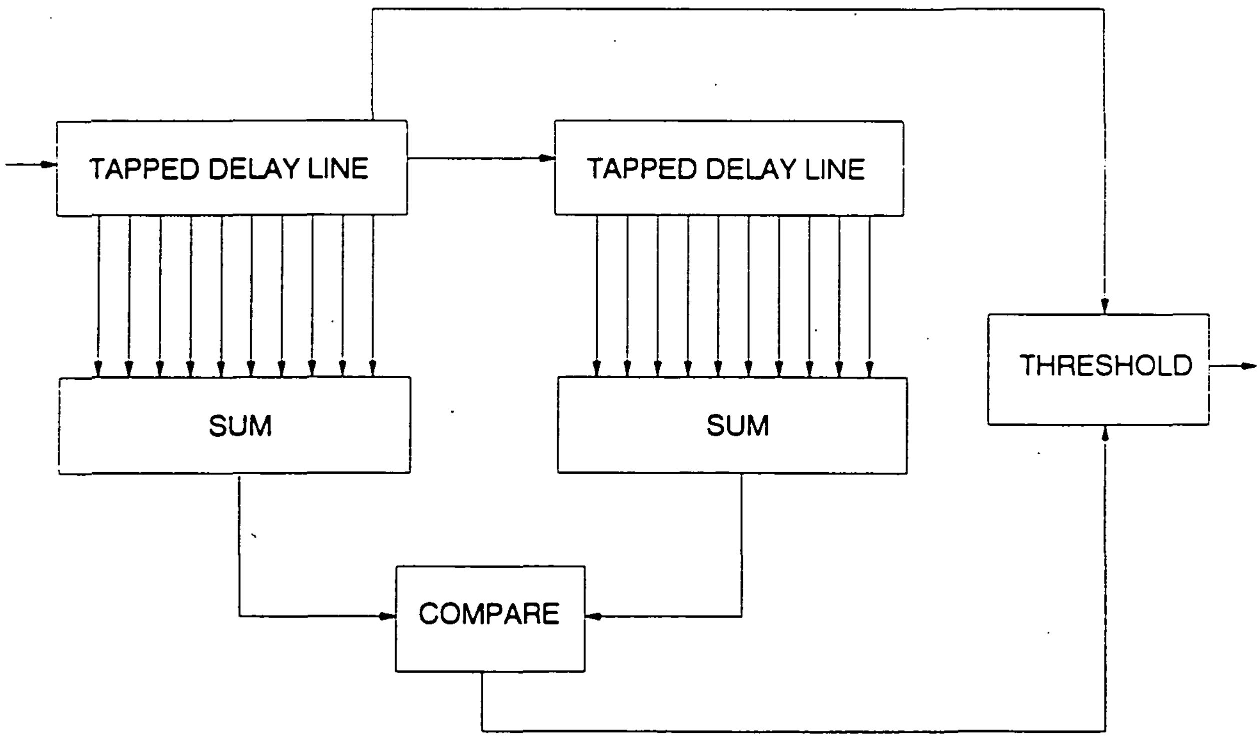

Figure 3.17: Cell averaging $CFAR$.

voice delay for the switched beam vs. T_{period} for various values of N_P. Applying the results of the example, namely,

$$T_{period} = 10T_{duration} = 100.8\text{msecs},$$

to Eq. 3.14, the minimum roundtrip delay achievable is 0.274 sec, which is a minimal impact as compared to the fixed beam case. However, this number increases exponentially with the decrease in pilot transmit power.

3.3.4 System Impact

The equations determining pilot acquistion have been presented. The interrelationship between pilot C/N_O, P_d, $TBFA$, and user terminal oscillator stability has been quantified. Examples of the tradeoff between long term oscillator stability and pilot C/N_O in determining the minimum beam duration time required - or time necessary for the receiver to check all possible pilot bands when the user antenna is pointed in a given direction - have been given for the specific case where P_d is 0.99 and $TBFA$ is 1 minute. Oscillators with stabilities of 0.32 ppm and 1 ppm can be used with pilot C/N_O's of 57 dB-Hz and 60.8 dB-Hz to achieve a $T_{duration}$ of 10 msec, assuming a P_d of 0.99 and a $TBFA$ of 1 minute. Lower beam duration times can be arrived at if oscillators with higher stabilities, and higher costs, or higher power pilots are utilized. The pilot powers listed above represent 10% and 24% of the power of the TDMA low rate channels, respectively. This is the minimum acceptable power for these oscillator stabilities. However detection in fading environment will require even greater power. Furthermore, there are manufacturing and aging tolerances that need to be considered. If one allows a 3 dB margin to compensate for all of the possible errors i.e. noise fluctuations, threshold settings, aging tolerances, etc., then an overall increase of 7 dB of power will be required to acquire the pilot. This will either put a big burden on the satellite or decrease the capacity of the system. The 7 dB power increase can be minimized by permitting longer integration time in the pilot acquistion circuit. However this will increase $T_{duration}$ and hence lead to a greater round trip voice delay.

3.4 Conclusion

The PASS strawman design calls for the use of a CONUS beam for transmission between the supplier and the satellite and for fixed spot beams for transmission between the basic personal terminal (BPT) and the satellite. 142 such beams, of 0.35° beamwidth, are necessary to cover CONUS. This chapter explores the consequences of replacing these 142 fixed beams by a number of switched or scanning beams, each of which would address N_P coverage areas. Several advantages are gained through the use of satellite switched/scanning spot beams instead of fixed spot beams. They lie primarily in improved system operation and enhanced ease of satellite hardware and implementation. First, the use of switched beams on-board the satellite provides a method to efficiently match satellite capacity with traffic needs particularly if the traffic is non-uniformly distributed in time and geographical location. Second, the transponder design may be simplified and component weight reduced. Third, replacing the 142 fixed beams by $142/N_P$ switched, or scanning, beams may simplify the overall beam forming network design on-board the satellite.

Several drawbacks arise through the use of switched beams. As continuous communication with each coverage area is no longer possible as with fixed spot beams, communication to and from the switched/scanning beams must occur at higher data rates if the average data rate achieved with fixed beams is to be sustained. Thus the communication links must be modified to support these higher data rates and a higher level of control over the system will be necessary to maximize system throughput. The network management center will also have more tasks to perform. In addition to those duties required in the strawman design – notifying users of their start-of-transmission times, transmission duration, and frequency assignment – it will have to distribute to suppliers and users information about the beam's dwell time over their coverage area to insure the correct orchestration of all transmissions and calculate an efficient switch plan for the satellite switched beam (i.e. the duration and sequence of the switch's states). User communication will be effected in two ways: (1) all users must possess variable data rate burst modems to accommodate the variable beam dwell time, and, (2) fast acquisition mechanisms may be necessary in order to rapidly lock onto the satellite beacon at the onset of every connection period with the satellite. Furthermore the use of switched beams instead of fixed beams will reduce frequency reuse capability slightly.

To illustrate the implications of switched beams use on PASS system design, operation at two beam scan rates is explored. Beam scan rate denotes the frequency with which the beam accesses the same coverage area. Scan rate is defined in terms of the period of the beam and is equal to $1/T_{period}$. Each beam is taken to dwell over each coverage area for, on the average, $T_{duration}$ and has the capability of addressing N_P coverage areas ($N_P = T_{period}/T_{duration}$). For both switched beam examples, each beam is assumed capable of accessing 10 coverage areas. The low scan rate, corresponding to T_{period} of 2 sec and $T_{duration}$ of 200 msec, was chosen to minimize the supplier overhead per transmission and to illustrate the case where complete spatial acquisition can be performed during one access time. The fast scan rate, corresponding to T_{period} of 20 msec and $T_{duration}$ of 2 msec, was set so as to minimize voice signal delay.

The requirement of a fast acquisition mechanism was explored. It was shown that the user terminal oscillator stability sets the lower limit of the receiver's front-end C/N_0. Table 3.11 shows the required pilot C/N_0 in dB-Hz and in terms of the low data rate channel C/N_0 as a function of the oscillator long-term stability. The data obtained indicates that, under perfect conditions, i.e. no noise fluctuations, optimum detector setting, etc., an oscillator stability of 0.32 ppm is necessary to keep the pilot channel power at 10% of the data channel level. Including some margin for these tolerances would require a better oscillator and hence a more expensive user terminal. Given that the right combination of oscillator stability and C/N_0 is selected then, for a ten area scanning beam ($N_P = 10$), the voice delay achievable is close to that of the strawman design, however this number increases exponentially as the received pilot power decreases.

Conclusions are summarized in Tables 3.8 and 3.9 where the characteristics of slow and fast scan switched beams are compared against those of the strawman fixed beam PASS design. System operation can be characterized by several parameters, beam efficiency or match of satellite capacity with traffic needs, spectrum requirements, voice signal delay, supplier overhead/transmission, and required burst data rate that must be supported by the communication link. From the user's point of view, rapid acquisition of the beam at the onset of the communication link is of importance, and to a lesser degree the time required for spatial beam location is of interest.

Optimum beam scan rate is determined by tradeoffs in various parameters. As the beam scan rate decreases (its period and duration over one coverage area increases) the following occur: the round trip delay incurred by signal of voice origin increases; information throughput at the supplier station increases; and, the need to restart signal acquisition process at user terminal between satellite beam accesses increases. Operation with a slow scan beam, such as examplified in Tables 3.8 and 3.9, is probably not practical due to its poor delay performance: 4.7 sec for voice communications. Scan rates closer to that typified by the fast scan beam will have to be used.

Switched/scanning beams have been found to allow a better match between traffic requirements with large geographic and temporal variations and satellite capacity. Their use reduces the number of local oscillators and high power amplifiers required on-board the satellite. No additional equipment is thought to be necessary in the user and supplier terminals to acquire the non-continuous satellite signal. Reacquisition of the satellite pilot can be accomplished without reentering into the receiver's acquisition mode as the pilot will be within the loop's tracking bandwidth.

The cost of using switched/scanning beams can be divided into four categories. First, higher EIRP user terminals and satellites will be necessary to support the higher burst data rates. The former can be achieved by increasing the size of the HPA in the user terminals at the price of increased radiated flux. The latter can be accomplished by using TWTs in place of solid state high power amplifiers at the cost of greater weight and volume. Second, burst modems will be needed at the user terminals and supplier stations instead of non-burst modems. Acquisition of the pilot when the user terminals are pointed in one spatial direction in $\simeq 10$ msec implies that oscillator stabilities of better than 0.32 ppm with a pilot C/N_O of 57 dB-Hz, or 10% of the low rate TDMA channel power, or of better than 1 ppm with a pilot C/N_O of 60.8 dB-Hz, or 24% of the data channel power, is necessary to achieve a P_d of 0.99 with a $TBFA$ of 1 minute. Third, the NMC will have the additional function of dynamically varying the beam duration time depending on the user traffic, thus a more precise control of the network will be necessary. The overhead in the forward link will increase as the NMC will have to distribute the variable dwell time of the beam for each pass to all the users within that beam. Four, this system will not be able to service mobile terminals as they would not be able to continuously track the satellite during motion of the mobile. Spatial and frequency acquisition would have to be performed prior to the reception or transmission of any data and would thus require very slow scan beams with the ensuing long signal delay times. Lastly, spectral efficiency, accomplished in the strawman design through frequency reuse, will be slightly reduced by the use of switched/scanning beams, the total required bandwidth (uplink and downlink) being 1.2 to 1.4 times that required with fixed beams. The use of a hybrid system, employing switched/scanning beams on the downlink to the user terminal and fixed beams on the uplink from the user terminal would alleviate some of these problems but also reduce the incentive to use switched/scanning beams.

If the use of these beams are further explored two topics deserve deeper analysis: the evaluation of a more precise range for beam efficiency, this being the main advantage for switched/scanning beam use; and a quantitative study of the acquisition scheme employed to assess their operation with spread spectrum multiple access techniques.

Appendix A

Channel Capacity of the Strawman PASS Design

System capacity of the strawman design is limited to the equivalent of 2000 duplex voice channels. This is determined by the RF power in the satellite. The currently conceived PASS satellite should be capable of generating 2.5 KW of DC power from solar wings. It is expected that this will translate to greater than 400 W of RF power. Currently the link from satellite to users requires 4W per 100 Kbps TDMA channel or 0.19W per 4.8 Kbps portion of the channel. Thus 2000 4.8Kbps channels would utilize 384 Watts. The link from satellite to suppliers calls for a maximum of 0.01W per SCPC channel; 2000 channels would then require 20 Watts. The strawman bandwidth requirements for communications to the BPT's can be taken from Table 3.4. The uplink bandwidth required is $\approx$ 60 MHz, the downlink bandwidth would be 42 MHz, assuming no high rate TDMA carriers are used, that the bandwidth required for the low rate TDMA carrier and the pilot is 400 KHz, and that the bandwidth required for a 4.8Kbps SCPC carrier with guard band is 19.2 KHz.

Appendix B

Beam Concept Impact on Satellite Antenna

The use of switched beams with N_P coverage areas/beam will require that the users transmit at a higher data rate, R_s, if the average data rate from the users is to remain constant:

$$R_s = N_P \cdot R_f$$

where R_f is the data rate supported by the fixed beam design. Consequently the link must be modified to support an N_P higher data rate. Here we consider the return link from BPT to supplier. In the preliminary PASS design, the C/N_0 of this link is set by the uplink from the BPT.

B.1 Return Link Assumptions

The communications link must be modified to support the higher data rate. If we want to use a solid state HPA at the BPT, then we cannot assume that running the HPA in burst mode will increase either the available output power or the HPA's efficiency as would be the case with a TWT [1]. If we stipulate that the transmit power and the antenna size of the BPT must remain constant so that the flux density emitted from the BPT is not increased, then we can vary only the G/T of the satellite to accomodate the higher data rate. If we further assume that no improvements can be made in the satellite system temperature, then we are left making up the required link change of N_P by increasing the antenna gain by a factor of N_P.

[1]This is based on a discussion with Dick Reis of Varian's Electron Device and Systems Group.

B.2 Antenna Size and Beam Number for CONUS Coverage

Denoting the fixed satellite antenna gain by G_f, its diameter by d_f, and its 1/2 power beamwidth by ϕ_{b_f} and the new switched satellite antenna gain by G_s, its diameter by d_s, and its 1/2 power beamwidth by ϕ_{b_s}, we wish to calculate the impact that increasing the satellite antenna gain from G_f to G_s will have on the number of beams coverage areas required to cover CONUS and thereby calculate the number of switched beams necessary given our initial assumption of N_p coverage areas/switched beam.

The following equations give the relationship between antenna gain, G, 1/2 power beamwidth, ϕ_b, beam coverage area, A_{beam}, and number of beam covering areas in CONUS, N_{cov}:

$$\begin{aligned} G &= \rho_a \cdot \frac{4\pi}{\lambda^2} \cdot Area \\ &= \rho_a \cdot \pi^2 \cdot \left(\frac{d}{\lambda}\right)^2 \end{aligned}$$

$$\begin{aligned} \phi_b &= \frac{\lambda}{d\sqrt{\rho_a}} \\ &\propto \frac{1}{\sqrt{G}} \end{aligned}$$

$$\begin{aligned} A_{beam} &= \pi\left(\frac{h sin 2\phi_b}{2}\right)^2 \\ &\simeq \pi h^2 {\phi_b}^2 \end{aligned}$$

The number of coverage areas required for CONUS is,

$$\begin{aligned} N_{cov} &= \frac{A_{CONUS}}{A_{beam}} \\ &\propto \frac{1}{{\phi_b}^2} \\ &\propto G. \end{aligned}$$

Let N_{B_f} be the number of fixed beams required for the initial case of fixed beam CONUS coverage and let N_{B_s} be the commensurate number of switched beams with N_p areas/beam necessary to cover CONUS. Then for the fixed beam case,

$$N_{B_f} = N_{cov};$$

whereas for the switched beam case,

$$N_{B_s} = \frac{N_{cov}}{N_p}.$$

If we force the satellite antenna to increase in size to make up the required power in the link, the following will occur:

$$\begin{aligned} R_s &= N_p \cdot R_f \\ G_s &= N_p \cdot G_f \\ d_s &= \sqrt{N_p} \cdot d_f \\ \phi_{b_s} &= \frac{1}{\sqrt{N_p}} \cdot \phi_{b_f} \\ N_{cov_s} &= N_p \cdot N_{cov} \end{aligned}$$

Increasing the satellite antenna's gain by N_p translates into increasing the number of coverage areas in CONUS by N_p which means that the number of switched beams that will be necessary to cover CONUS is:

$$\begin{aligned} N_{B_s} &= \frac{N_{cov_s}}{N_p} \\ &= N_{B_f} \end{aligned}$$

B.3 Example

Let the fixed beam scenario be as follows:

$$\begin{aligned} R_f &= 5 \text{ Kbps} \\ G_f &= 52.5 \text{ dBi} \\ d_f &= 3 \text{ meters} \\ \phi_{b_f} &= 0.35^\circ \\ N_{B_f} &= 142 \text{ beams.} \end{aligned}$$

If a scanning beam is used with $N_p = 10$, or 10 coverage areas/beam, then

$$\begin{aligned} R_s &= 50 \text{ Kbps} \\ G_s &= 62.5 \text{ dBi} \\ d_s &= 9.5 \text{ meters} \\ \phi_{b_s} &= 0.11^\circ \\ N_{B_s} &= 142 \text{ beams} \\ & \quad \text{with 10 areas/beam.} \end{aligned}$$

The satellite's antenna is far larger than in the fixed beam case and the beam forming network is far more complex, 142 beams with 10 areas/beam.

Of course, the conclusions would be different if the BPT HPA and antenna gain were permitted to increase.

B.4 Discussion

If instead of covering CONUS with N_{B_f} fixed beams we try to cover CONUS with N_{B_s} switched beams, where each switched beam must alternate between N_p areas, we find that the transmit and receive data rates at the BPT must increase by N_p to keep the average data rate/user constant.

Here we consider the impact of the higher transmit data rate on the BPT, i.e. on the PASS return link. We assume that the transmit power and the antenna size at the BPT are not permitted to increase to support the N_P times higher data rate. Only the size of the satellite receive antenna may grow to support the higher data rate. We then arrive at the conclusion that $N_{B_s} = N_{B_f}$.

For the preliminary PASS design, assuming each switched/scanning beam scans 10 areas, this means that the 142 fixed beams required to cover CONUS will be replaced by 142 switched/scanning beams each of which covers 10 areas. CONUS will then be covered by 1420 areas and serviced by 142 beams. The complexity of the beam forming network for the switched/scanning beam scenario is far higher than that of the fixed beam scenario.

Bibliography

[1] Miles K. Sue, editor. *Personal Access Satellite System Concept Study.* Jet Propulsion Laboratory, JPL D-5990 Edition, Feb. 1989.

[2] F. M. Naderi and S. J. Campanella. NASA's Advanced Communications Technology Satellite (ACTS): An Overview of the Satellite, the Network, and the Underlying Technologies. In *AIAA 12th International Communications Satellite Systems Conference*, pages 204 – 224, March 13-17 1988.

[3] G. Morelli and T. Matitti. The Italsat Satellite Program. In *AIAA 12th International Communications Satellite Systems Conference*, pages 112 – 121, March 13-17 1988.

[4] F. T. Assal, A. I. Zaghloul, and R. M. Sorbello. Multiple Spot-Beam Systems for Satellite Communications. In *AIAA 12th International Communications Satellite Systems Conference*, pages 322 – 331, March 13-17 1988.

[5] S. Joseph Campanella, Benjamin A. Pontano, and Harvey Chalmers. Future Switching Satellites. In *AIAA 12th International Communications Satellite Systems Conference*, pages 264 – 273, March 13-17 1988.

[6] Vectron Laboratories, Inc. *Vectron Catalog*, 1987.

[7] M. I. Skolnik. *Introduction to Radar Systems.* McGraw-Hill Book Co., New York, 1980.

[8] S. J. Erst. *Receiving Systems Design.* Artech House, Inc., Massachussetts, 1984.

[9] A. R. Martin and R. F. Cobb. A Guide to Acquisition Receiver Selection and Performance. *Microwave Journal*, 1968.

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