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STUDY OF REPEATER TECHNOLOGY FOR ADVANCED MULTIFUNCTIONAL COMMUNICATIONS SATELLITES

PHASE I AND II COMBINED FINAL REPORT

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

Contract No. NAS5-21695

November 1972

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COMPUTER SCIENCES CORPORATION

6565 Arlington Boulevard

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PREFACE

The objective of this study was to investigate design concepts and implementation approaches for the satellite communication repeater subsystems of advanced multifunctional satellites. In such systems the important concepts are the use of multiple antenna beams, repeater switching (routing), and efficient spectrum utilization through frequency reuse. The basic goals of this study were to develop an information base on these techniques and to perform tradeoff analyses of repeater design concepts, with the work "design" taken in a broad sense to include modulation beam coverage patterns, etc. However, the scope was not intended to be so broad as to comprise an overall system study including earth station parameters.

There were five major areas of study: requirements analysis and processing; study of interbeam interference in multibeam systems; characterization of multiple-beam switching repeaters; estimation of repeater weight and power for a number of alternatives; and tradeoff analyses based on these weight and power data.

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SECTION 1 - INTRODUCTION AND SUMMARY

1.1 BACKGROUND AND PURPOSE

As satellite technology has advanced over the past decade, there has developed increased incentive for "multifunctional" communication satellite applications. "Multifunctional" refers to the fact that these systems would be expected to serve communication requirements of a large and diverse group of civil (nonmilitary and noncommercial) users in the public sectors of education, health, civil defense, law enforcement, scientific research, weather, commerce, and transportation. Satellites serving the diversity in types of service, temporal utilization, and geographic distribution of such a collection of users would be expected to employ the advanced techniques of multiple-beam antennas and programmable signal routing and switching. The basic purpose of this study was to develop an information base on these advanced techniques and their technical problems, particularly as pertaining to the satellite repeaters. Parallel studies concentrating on (1) biomedical communications requirements modeling, and (2) multibeam satellite antennas were also initiated by NASA at about the same time as this study. The results of these three studies should provide a comprehensive data base for more detailed system design.

Although a certain degree of postulated system designing was necessary as a framework for repeater concept evaluation and design, overall system tradeoff and design was not a goal of this study. Therefore, tradeoffs between earth and space segments, or even between the various space subsystems (antenna, repeater, power, structure, etc.) were not germane. Instead, the general atmosphere or philosophy was one of conceptual and parametric tradeoff. Two very basic factors were found to be most important: interbeam interference, and requirements (needline) connectivity structure. These general factors are primary in determining the criteria of performance evaluation and the structural form of the repeaters.

1.2 METHOD OF APPROACH

The project which this report covers divided naturally into three broad areas of study: (1) requirements compilation and processing, (2) multibeam satellite antenna related topics, and (3) repeater structures, designs, and tradeoffs.

The requirements work was not intended to be an authoritative and definitive survey of actual user requirements. Instead, the purpose was to identify type requirements. It was also found useful to identify those parameters, or requirements-related factors, which were of most impact upon spacecraft system design. To more specifically determine the technical or engineering factors of most importance, a method for processing a given requirements base or set was also developed and applied to a hypothetical requirements data base.

The multibeam studies were not related to satellite antenna implementation. Instead, the system implications of operating a satellite repeater system with a number of contiguous narrowbeams were studied. This work included some consideration of optimum coverage arrangements. But the major emphasis was on the system implications of the beam-to-beam interference which is essentially unavoidable in such a system. Also studied were modulation and multiple access for such repeaters.

The requirements and multibeam topics were really inputs to the central tasks of the study, those pertaining to the repeaters themselves. A study of general multibeam, multichannel repeater structures or concepts was followed by specific tradeoffs and detailed designs applied to the hypothetical traffic model previously generated.

1.3 ORGANIZATION OF REPORT

This report is organized along the lines suggested by the three basic areas of study. Section 2 describes the traffic requirements modeling work, including:

- Collection and selection of needlines
- Establishment of the hypothetical traffic model

- Computerization of the needlines model.

Section 3 covers the modulation and multiple-beam studies, which included the related topics of multiple access, multiplexing, beam-coverage, and interbeam interference. Section 4 treats the processing or reduction of the requirements data base into technical terms, and presents a categorization of repeater concepts (structures) applicable to the multifunctional satellite system. Section 5 presents detailed designs of the baseline repeaters, weight and power consumption estimates for these baselines and for a number of alternatives, and tradeoffs based on these weight and power estimates. Section 6 presents observations, conclusions, and areas of possible future work.

1.4 SUMMARY

1.4.1 Traffic Requirements

1.4.1.1 Introduction

The requirements work consisted of three major areas: the collection and selection of potential needlines, the establishment of a hypothetical traffic and usage model, and computerization of the model. The model was not intended to be definitive or validated, but rather to serve as a framework or baseline.

1.4.1.2 Collection of Candidate Needlines

The basic sources for a listing of potential needlines were References 1 and 2. Through a process of successive screening, the list was narrowed to 21 demands in 10 functional categories. Biomedical demands inferred from Reference 2 were then added to this list.

To better define each demand, a set of categories of classification and specification was established. These factors are the column headings in the listing of demands which was finally established and appears in Table 2-3. To summarize, this listing includes:

1. Ten educational video broadcast demands

2. Two teleconferencing video demands

3. Four civil defense networks, video and data

4. Twelve data collection and dissemination demands (e.g., weather data)

5. Ten inquiry and response demands, including three medical diagnostic, two toxicology and epidemic control, other medical and welfare networks, and crime control networks

6. Two computer and library data transfer demands.

1.4.1.3 Hypothetical Traffic Model

1.4.1.3.1 Geographic Coordinates and Satellite Placement

The U.S. was reduced into a grid of 57 "cells," each 4° wide and high in longitude and latitude. Each such cell would be the smallest geographic increment to within which it was necessary to specify the location of users in the traffic model. The satellite was assumed to be located at 100° W longitude.

1.4.1.3.2 Traffic Model

Information from a variety of sources (documents and conference results) was applied to each of the candidate demands to derive hypothetical network configurations and parameter values. Descriptive parameters were specified for each network.

1.4.1.4 Computerized Data Base

Storing the traffic model information in a computer memory file permitted:

- Straightforward modification of data base entries
- Automation of analysis, compilation, and correlation
- Expedited trend and sensitivity analyses.

Also, a useful methodology for translating system needline requirements into satellite repeater requirements has been developed. The computerized data base is listed and described in Appendix A. A summary list of the networks appears in Table 2-5.

1.4.2 Modulation and Multiple Beam Studies

1.4.2.1 Introduction

The multifunctional satellite system is based on a multiple-beam satellite antenna concept. The signals radiated and received by these beams are not perfectly isolated from one another. Thus, in a multibeam environment the interference from the other beams is of fundamental importance. The ability of a system to operate in the face of such co-channel interference depends in part on the modulation technique used. Thus, it can be seen that signal format questions (modulation, multiplexing, multiple access) and multiple-beam antenna topics (coverage, interbeam isolation) are interrelated.

The emphasis in this study was on frequency divided concepts, that is, the use of frequency band separation between beams, frequency division multiplexing and multiple access, and appropriate implementation techniques (filters).

The constraining or driving influence of interbeam interference is one of the major factors identified and analyzed in this study. The demonstration that high interference resistance is not by itself a sufficient criterion for selecting a modulation technique in a constrained bandwidth environment is a major conclusion of great importance.

1.4.2.2 Modulation and Multiplexing

1.4.2.2.1 With Frequency Division Multiple Access (FDMA)

FDMA techniques were emphasized. A prime candidate for analog waveforms is frequency modulation. Multiplexing multiple baseband channels results in FDM/FM. Single sideband (SSB) modulation is also considered. Digital traffic is best (most efficiently) transmitted by the use of PSK. Thus three general techniques were considered: FM, VSB*/SSB, and PSK.

1.4.2.2.2 With Time Division Multiple Access (TDMA)

Time-divided systems apply only to digital or digitized signals. Therefore, the applicable modulation techniques are those for digital basebands, and of these the most efficient in both power and bandwidth is phase shift keying (PSK).

1.4.2.3 Beam Coverage Studies

Multiple-beam coverage was not studied from the hardware implementation point of view. Instead, the system implications of various coverage patterns, beam isolation models, and changes in the number of beams were of interest. A number of coverage models was created to relate the needline requirements to repeater structure constraints.

The coverage models were designed to provide relatively uniform distribution. Emphasis was placed on the 12/14 GHz frequency bands. Coverage models ranging from "time zone" coverage (four beams for CONUS plus three for extracontinental areas) to a 30-beam model. It was shown that a triangular or billiard ball arrangement of multiple circular beams provides the best (most uniform) coverage.

The 12-beam model uses nine elliptical beams over CONUS for better coverage. Multiple circular beams, 17 to 30 in number, were also investigated. In each case the beam overlay was arranged over CONUS so as to yield the best compromise between absolute gain and coverage of critical high density areas. In each case three beams are added for service to Alaska, Hawaii, and Puerto Rico. Thus, the antenna beam models selected have seven (time zone), 12, 23, and 30 beams, with the following parameters:

*Vestigial sideband, a hybrid modulation form better suited to video than pure SSB.

Model	Typical Gain Range (dB)
7	35 to 40
12	36 to 42
23	40 to 45
30	41 to 46

These selected models can be seen in Figures 3-3, 3-5, 3-7, and 3-8.

1.4.2.4 Interbeam Interference Studies

1.4.2.4.1 Introduction

One of the justifications for adopting multiple beams on communication satellites is the ability to reuse spectrum, i.e., to use the same frequency allocation in more than one beam simultaneously, the reuse contingent upon the pattern and polarization isolation between beams. One of the more surprising results of this study was that although multiple beams do allow frequency reuse, this reuse does not always result in an increase in overall system capacity, depending on the nature of the requirements and the exact definition of system capacity used as a measure of system performance. A theoretical analysis of the relationships between modulation and frequency reuse was conducted.

The basic problem is that of maximizing the total satellite capacity through the application of frequency reuse (reassignment) on multiple downlink (and uplink) beams. It has often been assumed that techniques such as FM, because of their superior resistance to interference, would be better than narrow bandwidth techniques such as SSB. It was shown that in a system with constrained bandwidth and reasonable number of beams this may not be true. It was also shown that for achievable antenna pattern models, increasing the number (therefore decreasing the beamwidth) of beams covering a given fixed area may be somewhat beneficial in terms of satellite RF power savings, but does not help and may actually reduce the total system capacity.

1.4.2.4.2 Theoretical Analysis Results

The theoretical analysis treated in Paragraph 3.4.2 assumed a commonly accepted exponentially declining antenna sidelobe envelope model. An infinitely extended field of closely packed such beams was assumed.

It is shown in Paragraph 3.4.2.2 that the normalized number of channels per unit solid angle, which is equivalent within a multiplicative factor to the average number of channels per beam, is given by:

$$\dot{n}_j = \frac{A}{R_j \left(\frac{C}{I}\right)_j^{2/m}}$$

where A = A constant within which were absorbed geometric factors, system bandwidth factors, and other terms which do not change as a function of modulation

R_j = The bandwidth expansion of the jth modulation technique

$(C/I)_j$ = The permissible carrier to interference ratio for modulation scheme j

m = Sidelobe taper parameter

The system tradeoff illustrated by this equation is the bandwidth expansion versus modulation hardness one. SSB can be taken as a reference, relative to which other modulation techniques are compared. This is done in this report (see Figure 3-14). The following conclusions are drawn:

1. FM outperforms SSB only under appropriate operating conditions
2. Digitized voice (PCM-PSK) performs approximately the same as FM.

In conclusion, the theoretical analysis showed that, in terms of system capacity under constrained bandwidth conditions, narrow bandwidth techniques, especially SSB (or VSB for video), should be further considered as well as FM for multiple-beam systems.

1.4.2.4.3 Finite Beam and Actual Beam Model Considerations

The analysis summarized above was for an infinite beam model. With a finite number of beams, the interference experienced by a given beam is lower, so that even less benefit is obtained from applying interference resistant techniques.

The theory was applied to practical models. In particular, system operation was assumed with each of the four (seven, 12, 23, and 30) beam models chosen previously, under two system assumptions: FM video and VSB video. A total bandwidth of 500 MHz was assumed, along with a sidelobe taper exponent of 3. Frequency reuse plans were then prepared for each of the beam models. Combining the modulation performance parameters and the beam interference/frequency reuse plans, the results shown in Table 1-1 were obtained. It can be seen that FM does not allow nearly as many channels as VSB, despite its 20 dB lower protection ratio.

The same data can be used to draw some interesting conclusions about the "optimum" beam number. These are tersely described in Paragraph 3.4.3.5. Here, we mention only that:

1. For broadcast (large coverage area) requirements, large beam numbers are not desirable.

2. The number of beam-channels* is bounded by about 200 with VSB and less than 100 for FM, regardless of the beam model. Therefore, the optimum beam number is related to the requirements structure, and the greater frequency reuse of smaller beams does not lead to capacity advantages in multibeam systems.

1.4.2.4.4 Extension to TDMA

The interbeam interference concepts can be extended to TDMA systems by utilizing the duality of time and frequency. In Paragraph 3.4.4.3 this is done for digitized video, and it is shown that the high bandwidth of this type of transmission leads to very low capacities. Therefore, digital and TDMA concepts are excluded from consideration for video transmission.

*One channel in a beam is one beam channel

Table 1-1. Power and Bandwidth for Viable Systems

Model	Average Beam Channels	Modulation	RF Power** W	Code	Frequency Reuse Plan* (Bands)	Maximum Number of Channels Per Beam*	Comments
7	75	VSB	160	B	7	14	
			190	A	4	25	
		FM	200	B	2	10	
12	140	VSB	100	B	12	8	
			150	B	9	11	
			180	A	6	16	Marginal C/I of 40 dB
		FM	140	B	3	6	Marginal C/I of 20 dB
23	210	VSB	100	B	12	8	
			150	B	10	10	Marginal C/I of 40 dB
		FM	70	B	6	3	Marginal C/I of 20 dB
30	260	VSB	70	B	15	6	Marginal C/I of 40 dB
		FM	30	B	9	2	

*Assuming equal loading in all beams, and G/T of 30 dB/^{o}K for FM, 42 dB/°K for VSB.

**The lower of the powers necessary either to meet the requirements approximately or achieve the bandwidth limited capacity with all beams equally loaded.

Code A = Requirements met

B = BW limited value met

On the other hand, the lower bandwidth requirements (voice and data) of MFR do not require the careful optimization of bandwidth utilization that video does, so that the implementation advantages (switches are simpler than filters) of TDMA concepts make them attractive possibilities for these requirements.

1.4.3 Requirements Processing and Repeater Categorization

1.4.3.1 Introduction

Section 4 of this report covers two areas of concern in the study which at first do not seem to be closely related: processing or reduction of the requirements data base, and categorization of repeater types. However, qualitative and quantitative information on the requirements is necessary to select those repeater concepts of greatest applicability to the MFR system. Thus, Section 4 presents the results or outputs of processing the data base, characterizes FDMA and TDMA repeaters, and selects baseline and alternate concepts for the more detailed analysis and design treated in Section 5.

1.4.3.2 Data Base Processing

The computerized data base or file, described in Section 2, contained too great a volume and detail of information to be of direct use in repeater design or even of interest in estimating gross system performance. Thus, there were two reasons for processing the data base: (1) to compile the specific parameters necessary for repeater design and tradeoff, and (2) to derive simplified data in tabular and graphic form which would have inherent value in presenting system operating parameters and magnitudes.

Specific counting rules were established whereby descriptive parameters previously established could be used to specify how many channels a given needline actually involved, in terms of peak, average, and minimum values for uplink, downlink, and repeater internal channels. These counting rules are summarized in Tables 4-1 and 4-2.

Two downlink-oriented sizing parameters were of interest: the range in number of channels for each beam, and the total beam-channel demand as a function of time. The first parameter is listed in Table 4-4 for the 12-beam model. The second is shown in Figure 4-2 for the 12-beam model.

The uplink and internal parameters of most interest were the overall satellite total channel (and trunk) loading as a function of time, shown for the 12-beam model in Figure 4-6; and the largest value (over the 24-hour period) of channels and trunks in each uplink beam, shown in Table 4-9 for 12 beams.

Specific values of satellite capacity were then selected as input information to the repeater design and tradeoff tasks. The channel and trunk numbers which would approximately meet requirements are shown in Table 1-2.

The EIRP and bandwidth required to serve voice and medium/low rate data are so small compared with video that the same detail in requirements analysis was not justified. Nevertheless, the following data was obtained:

1. Range in number of channels for each downlink beam (for each beam model)

2. Peak total beam-channel demand

3. Range in number of channels in each uplink beam (for each beam model).

These can be found in Paragraph 4.1.3. The peak total beam channel demand is also shoen in Table 1-3 for the beam models used in this study.

1.4.3.3 Repeater Structure Categorization

The general problem was the categorization and evaluation of alternative repeater configurations. The emphasis was on frequency-divided techniques. Mixing traffic categories within one repeater system was not permitted.* Categorization of repeaters could be done along signal-structure or functional lines. The signal-structure categorization had to do with the organization and structure of the signals

*Except that categories were combined as video/high rate data and voice/medium rate data. Low rate data could also be included in the latter.

Table 1-2. Channel and Trunk Quantities
(Uplink or Internal Routing Capability)

30 Beams	
Single channels	66
Two-channel trunks	24
23 Beams	
Single channels	57
Two-channel trunks	21
12 Beams	
Single channels	51
Three-channel trunks	9
Four-channel trunks	3
Seven Beams	
Single channels	28
Two-channel trunks	8
Four-channel trunks	2

Table 1-3. Peak Total Beam-Channel Demands, Voice and Medium Data

Beam Model	Uplink	Downlink
7	41	43
12	65	70
23	119	125
30	150	162

appearing in the satellite's uplink and downlink beams. The functional categorization has to do with identifying the various signal routing functions performed in a multibeam multichannel satellite. The five basic functions identified were:

- Separation
- Fanout Branching
- Switching/Routing
- Fanin Routing
- Combining

There are two fundamentally different ways of organizing the repeater: either subsystems such as the separator (and its filters) are common to and shared by all beams, or each beam has a dedicated hardware subsystem. The shared approach is called "pooling." Other implementation questions have to do with:

1. Demodulation
2. Demultiplexing
3. Frequency at which routing performed
4. Multiplexing
5. Remodulation.

After screening nonviable combinations of selections and techniques, and considering relative benefits, three kinds of repeaters were found to be most applicable to further analysis. These three concepts were found to have many similarities in implementation.

The duality of time and frequency was used to expedite categorization of time switched repeaters. Two basic concepts were found to be the most applicable, one with and one without on-board storage (memory) of data. It is possible to combine more than one repeater of either type on the same spacecraft, however. The simplest concept is, if course, the use of only one (single repeater path), its input and output switched rapidly among the uplink and downlink beam ports. A second concept is to have as many independent repeater paths as there are beams, but with the internal routing switched during each frame to connect each uplink beam (or satellite receiver) with the required downlink beams (transmitters). The third concept uses time separation between beams, thereby ganging or switching synchronously several repeater paths. This concept requires on-board storage, because, in general, it is impossible to achieve arbitrary connectivity while having both the uplink and downlink beams ganged. The various TDMA alternatives are shown in Table 4-27 ("R" stands for re-transmit immediately, i.e., no storage; "S" means there is memory storage in the repeater).

1.4.3.4 Baseline Selection

1.4.3.4.1 Introduction

The video/high rate data requirements are so large as to be the pacing or defining item in system design. Therefore, the philosophy adopted was to consider repeater structures for these requirements first, and then consider how subsystems could be added to handle the "on-demand" voice and data needlines. The video repeater was FDMA-based, while time switched concepts were applied for the voice/data add-on subsystem.

1.4.3.4.2 Video System Baselines

The baseline description should specify the number of beams, the signaling (modulation, multiplexing, multiple access), the system capacity or capability, and perhaps the repeater structure. To place the baseline near the middle of the range, the 12-beam model was chosen. FM was limited by bandwidth constraints to six channels per beam. Therefore, a second baseline using VSB was selected, with a nominal 16 channels per beam, thus meeting the 163 beam-channels specified by the requirements. Both baselines required about 2 watts RF power per channel in the repeater, but it should be noted that the FM systems operate with earth terminal G/T of 30 dB/°K, while VSB requires terminals 12 dB better.

The various system alternatives also selected for tradeoff analysis are shown in Table 4-28.

1.4.3.4.3 Voice and Medium Rate Data Subsystem

To form a basis for comparison, the single switched path repeater concept was a candidate for analysis. The n-path concept (with n equal to the number of beams) also seemed applicable, while the ganged-switch approach was not considered to offer advantages to offset the complexity of the memory required. For all cases, a capacity of 10 channels per beam (nominal 50-kbps data rate channels), both up- and downlink, met requirements. Emphasis would be on applying the concepts as add-ons to the video baseline repeaters, both the FM and VSB versions.

1.4.4 Repeater Designs and Tradeoffs

1.4.4.1 Introduction

Repeater design and the tradeoff studies were performed in an iterative fashion. It was necessary to design two baselines, one for an FM-based system and the other using VSB. These baselines were for the video/high rate data needlines. Included as part of the design process were detailed weight and power consumption estimates, so it was straightforward to extrapolate to the weight and power values of the alternate system concepts which differed from the baselines in number of beams and in system capacity. Tradeoffs were then performed using these values. Finally, the design of the added-on subsystems for voice and medium rate data transmission was considered.

1.4.4.2 Baseline Designs

1.4.4.2.1 FM Baseline

The FM baseline was designed first and in greater detail then the VSB baseline. Prior to actual design, a number of preliminary tradeoffs also had to be made. The FM baseline is a 12-beam repeater with a nominal capacity of six channels per beam, and using a three-band frequency reuse plan. A diagram of this repeater appears in Figure 1-1. The beam coverages and band plan correspond to Figure 3-18 with three bands. It has the following features:

- Tunnel diode amplifier receivers.
- Single receiver L.O. which translates to the 300- to 800-MHz IF range.
- Channel separation accomplished using active filters.
- Frequency band channelization into three bands. Each uplink beam operates only in its assigned band, while downlink beams operate primarily in their assigned band, but can have some channels in other bands when necessary.
- Two watts per baseband channel or a total of 12 watts RF output in each transmitter. TWT operated at less than saturated to achieve intermodulation level 23 dB down.

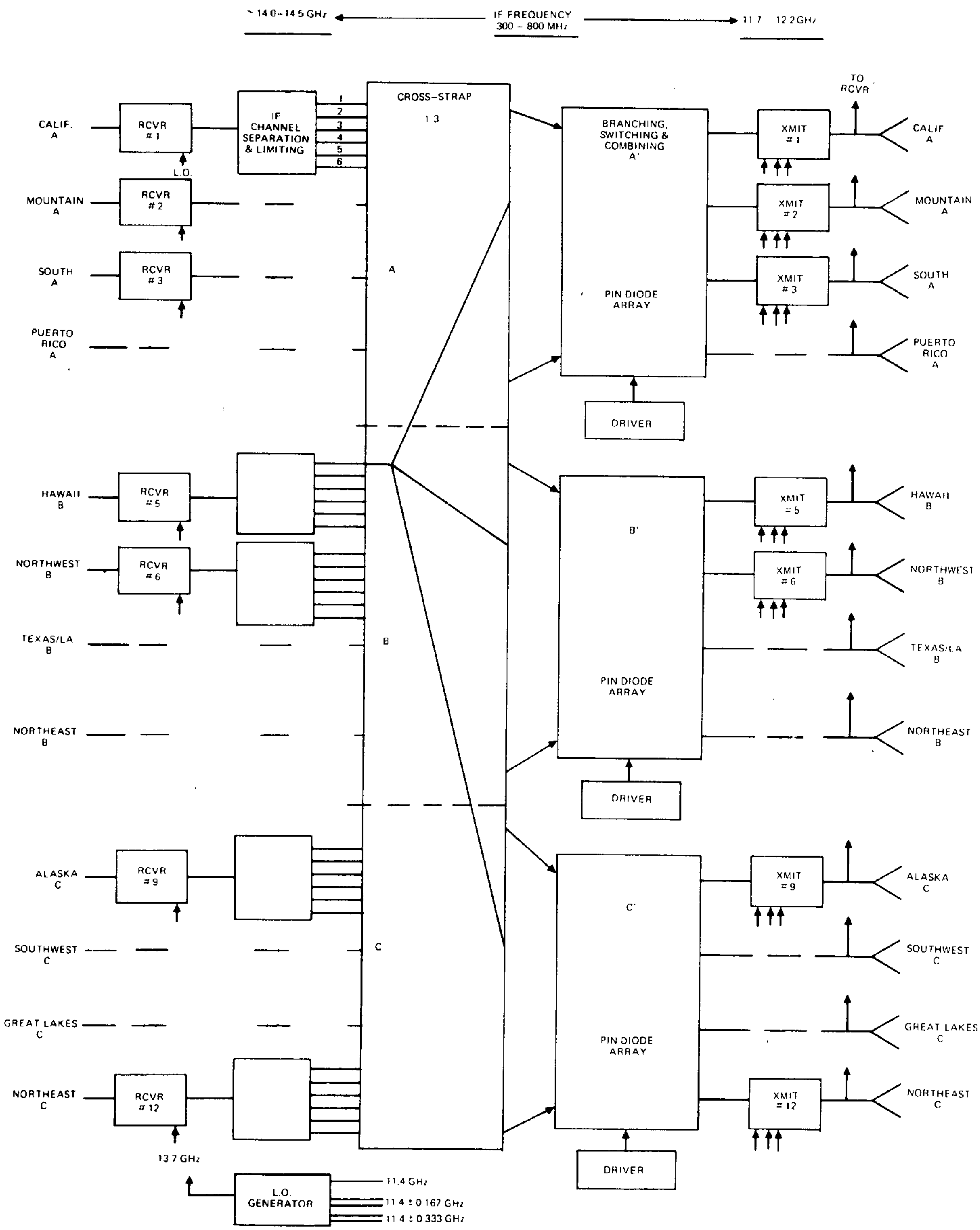


Figure 1-1. Switching and Routing Repeater (12 Beams, Three Frequency Bands)

The baseline weight is 897 pounds, of which 456 are in the transmitters and 240 are in the branching, switching, and combining networks. The power consumption is 1716 watts, of which 1440 are for the transmitters.

1.4.4.2.2 VSB Baseline

The VSB baseline design was performed in less detail, since there is much commonality with the FM design. However:

1. The larger number of channels than with FM forces one to adopt full frequency agility, accomplished by translating all channels to the same IF frequency.

2. Despite the 12-dB better earth terminals assumed, the VSB repeater nevertheless requires far greater prime power than with FM, because the capacity is higher and amplifier overall efficiencies are lower to meet the more stringent C/IM requirement (40 dB).

The baseline provides 192 downlink beam channels, and was designed to allow certain beams with a large uplink potential (program source locations) to accommodate 24 or 36 channels, while others (e.g., Alaska) would have a capability on the uplink for only six channels. This repeater is shown in Figure 1-2. The weight is 1587 pounds and the power required 8452 watts, of which 90 percent is in the transmitters. A great premium is therefore placed on development of greater efficiency while meeting the C/IM specifications.

1.4.4.3 Alternate Repeaters, and Tradeoff Analyses

1.4.4.3.1 Alternates - Weight and Power

The weight and power consumption values for the alternate systems were obtained from an estimated repeater parts count, based on the baseline structures and estimates. These appear in Tables 5-4 and 5-5.

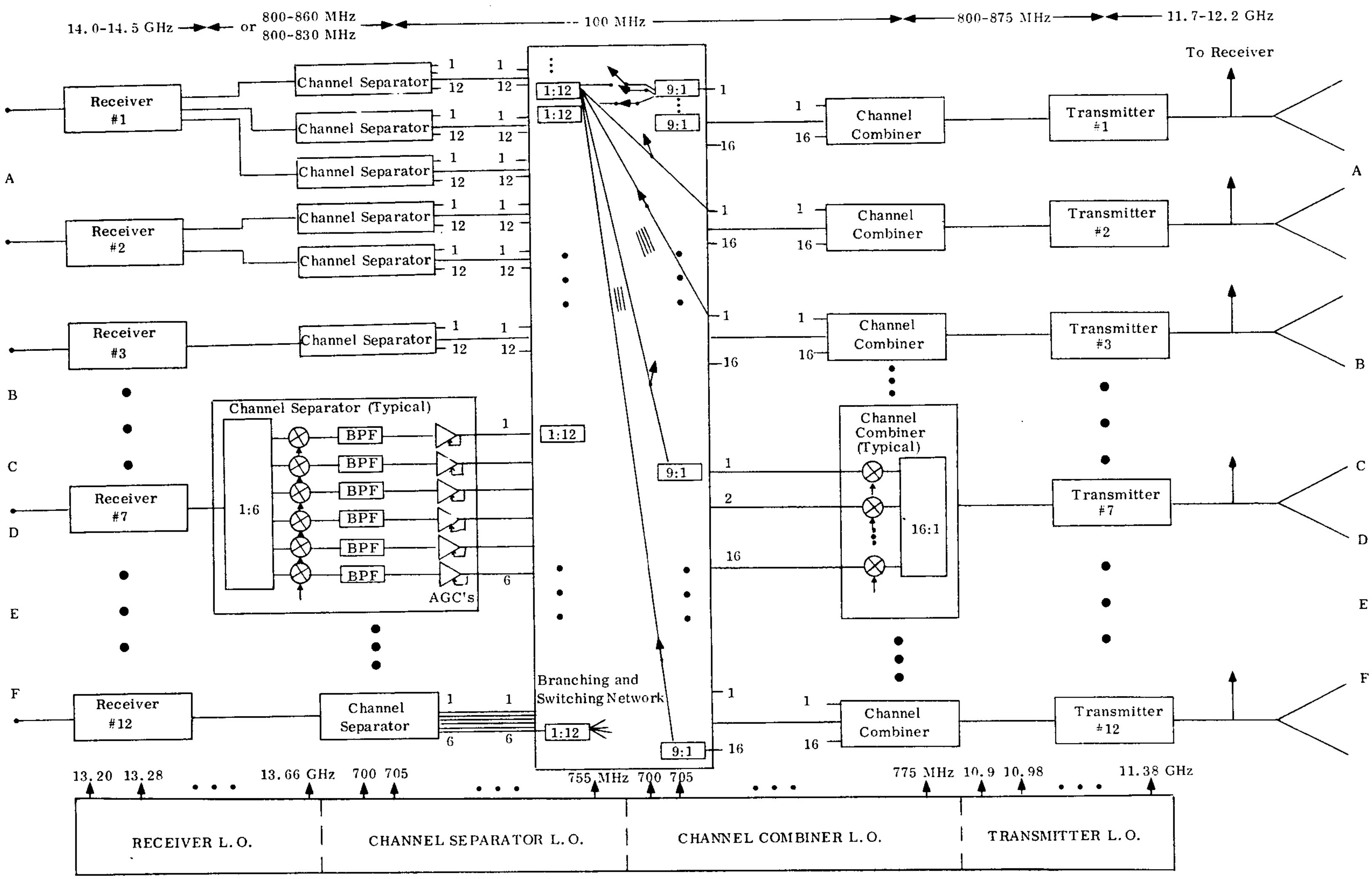


Figure 1-2. Diagram of SSB AM Multifunctional Repeater

1.4.4.3.2 Parametric Tradeoffs

The fundamental driving parameters (or independent variables) in the MFR characterization are the number of beams and the number of channels. More accurately in the case of the latter, one can specify the number of channels per beam or the total number of beam channels. The parametric impact of repeater weight and power of varying these parameters was examined.

The number of channels per beam is an appropriate measure of system performance when wide-area broadcast requirements predominate, such that the actual beam size does not affect the number of channels required in each beam. The variation in repeater weight and power as the number of channels per beam varied was plotted in Figure 5-10 for the seven-beam* FM model. The power not only rises linearly with the number of channels but would, if extrapolated to 0 channels, intersect at close to 0 watts. This reflects the fact that the transmitters use most of the prime power. The weight is monotonic but the slope decreases at small channel numbers since there is an irreducible minimum overhead component even with very few channels (e.g., the receivers).

Since channels/beam is a useful criterion when the system serves wide-area broadcast, it is of interest to hold this number constant and vary the beam model. Whereas the weight increases linearly with large slope as the number of beams increases (see Figure 5-12), since the parts count rises rapidly, there is very little change in the power (see Figure 5-11), since the increased number of beams is essentially offset by the increased beam antenna gain. As a result, there is no net benefit in increasing the number of beams if wide-area broadcast applications are served. However, if even a small proportion of the needlines is for small area or point-to-point application, the greater number of beams offers much greater flexibility, allowing separate channels in the different beams.

*This model was used instead of one of the others because the greatest amount of data is available for this number of beams.

In systems where all the needlines are of a point-to-point nature, the total number of beam-channels is equal to the total number of channels handled in the system. Therefore, this is also a good parameter for characterizing system capability. The repeater weight versus number of beams, with total beam channels held constant, shows the expected monotonic increase (see Figure 5-14). However, it is the power curve which is more interesting. It is reproduced here as Figure 1-3. With a fixed total of beam channels, it is clear that increasing the number of beams (therefore the beam gain) should lead to reduced power requirements. However, as the beams become very small, the transmitters' proportion of total power becomes insignificant and diminishing returns set it - the curve flattens out. This point appears to be approached in the FM case somewhere between 20 and 30 beams. The relative shapes of the weight and power curves also mean that an "optimum" number of beams can be found by applying a power subsystem power to weight conversion ratio. This is shown in Figures 5-15 and 5-16, assuming solar array power at 15 watts per pound and batteries at 5 watt-hours per pound. The FM system with 70 beam - channels total reaches minimum weight at about 12 beams when this tradeoff is performed. A total satellite tradeoff could also be performed by adding the satellite antenna weight data available in the companion multibeam antenna study and satellite structure/overhead weight information.

1.4.4.4 Provision for Other Services

Add-on TDMA repeater concepts were investigated. These would provide a nominal 10-voice or data channel (at 50 kbps) per beam capability when added to the baseline repeaters. A single path switched repeater capability was estimated to require 28 pounds and 10 watts when added to the FM baseline, or 2 pounds and 0.4 watts when included in the VSB baseline (but preempting one video channel in each beam). The n-path repeater would involve 54 pounds and 17 watts added to the FM baseline, or 27 pounds and 7 watts to the VSB. The n-path has much better growth potential for expansion to more beams and/or greater capacities, up to 100 channels per beam.

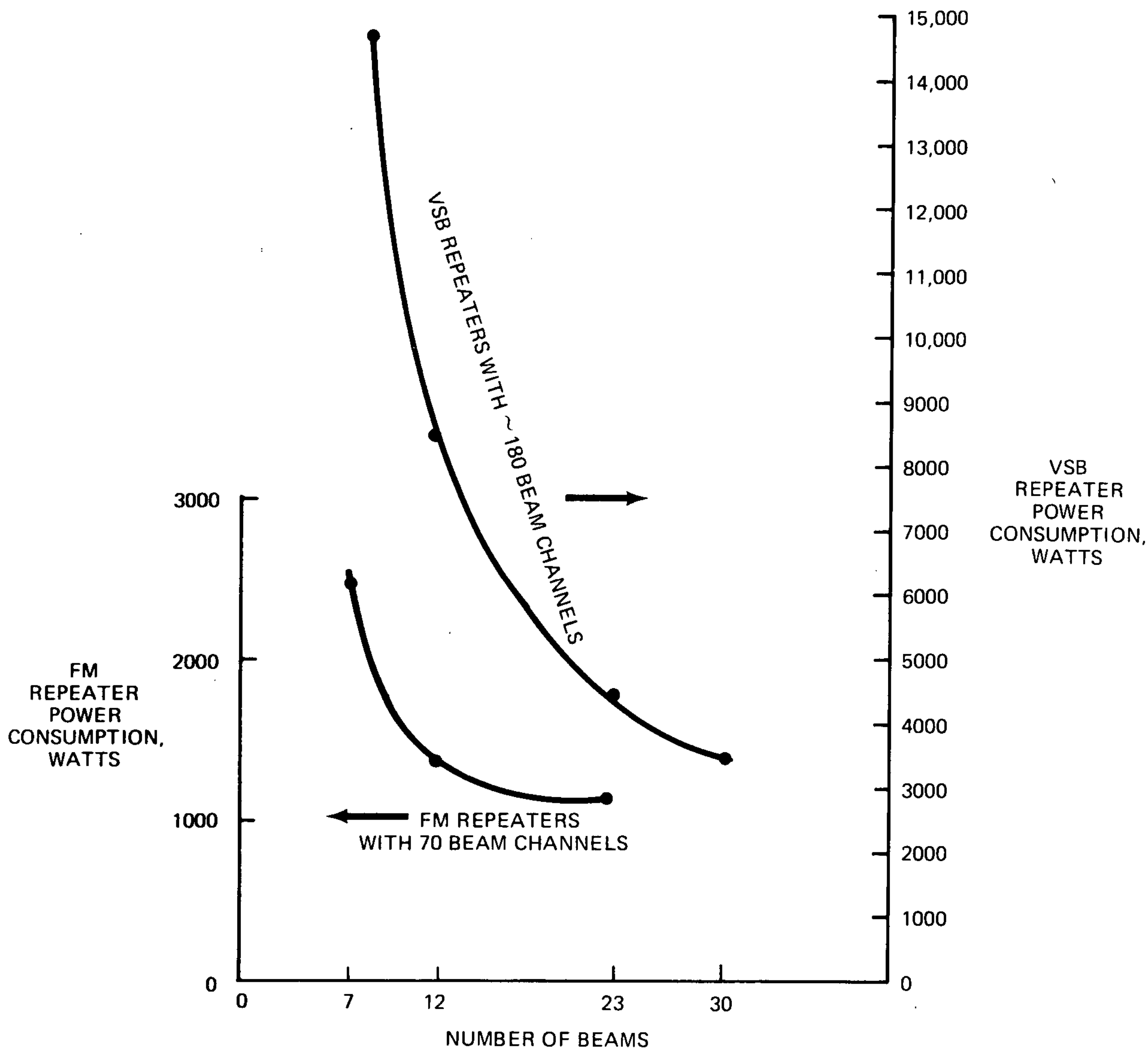


Figure 1-3. Power Consumption Versus Beam Model With Total Beam-Channels Held Constant

1.4.5 Accomplishments, Conclusions, and Areas for Future Work

1.4.5.1 Accomplishments

The study yielded many accomplishments which will be of value in future study of this type of system. Some of the most significant ones are:

1. A computer-assisted methodology for compiling, specifying, and processing complex sets of user requirements was developed.

2. The analysis of interbeam interference was extended beyond that previously published.

3. Frequency and time-division oriented repeater concepts were classified and categorized, and primary candidates for the MFR applications were selected.

4. The baseline and alternate repeaters were sized in weight and power consumption.

1.4.5.2 Observations and Conclusions

Significant observations, based on analysis and on the data, and conclusions are listed as follows:

1. The bandwidth expansion versus power saving (C/kT reduction) plot is the fundamental output of an interbeam interference analysis and can be used to perform several important system tradeoffs.

2. For infinitely extended beam models, the superior interference resistance of FM video and PCM-PSK voice, for example, result in greater system capacity than with VSB and SSB. However, with finite beam models, including the actual models investigated, the opposite is true: VSB transmission of video, in particular, provides greater capacity than FM.

3. With systems which relay to wide areas, channels per beam is the fundamental performance criterion. In these cases, increasing the number of beams beyond a small value is not advantageous in terms of overall system capacity.

4. If the needlines are all point to point, on the other hand, the total number of beam-channels is the best criterion of system performance. This criterion does allow optimization of the number of beams, since repeater power and satellite subsystems' weights move in opposite directions with changes in number of beams.

5. Despite the regionalized nature of most of the networks in the MFR system, the channels-per-beam criterion was found to be a better indicator of capacity than total beam-channels.

6. The maximum number of beam-channels from a single satellite system appears to be limited to a fixed maximum regardless of the number of beams, and depends only on the antenna beam sidelobe characteristics and the modulation techniques.

1.4.5.2 Future Work

A continuing process of user information and edification is necessary. A full-scale requirements study prior to some preliminary hands-on experience by the users will not be fruitful.

A great premium exists on improvements in the overall DC to RF conversion efficiency of power amplifiers for multiple carrier, low intermodulation level applications.

The data in this report can be combined with that in the companion antenna study and well-developed system tradeoff routines to obtain an overall system optimization.

SECTION 2 - TRAFFIC REQUIREMENTS MODELING

2.1 INTRODUCTION

The purpose of the traffic modeling work in this study was to provide a general framework of type requirements, connectivities, and orders of magnitude for the technical tradeoff tasks which followed, rather than to establish a definitive or validated set of actual user requirements, which would be premature. Therefore, the requirements have no validity of their own, and results which are sensitive to the assumed structures or magnitudes should be identified as such, rather than being considered as definite conclusions.

The requirements work actually consisted of three major areas:

- The collection and selection of potential needlines.
- The establishment of a hypothetical traffic and usage model, in terms as specific as possible or reasonable, with both temporal and geographic details given.
- Computerization of the needlines model. Initially, this meant simply the compilation of the traffic model in punched card form, suitable for subsequent processing.

These three areas, plus certain other incidental analyses and assumptions, are covered in detail in this section. Once again it is emphasized that the model described herein is entirely hypothetical and does not describe any actual or specifically planned system.

2.2 COLLECTION OF NEEDLINES AND BASIC DATA

2.2.1 Introduction

The intention of this study was to deal with repeater techniques; an extensive requirement collecting activity was not intended. Besides, several studies have concentrated on detailed requirements tabulation for the types of activities MFR would serve. However, in its review of these studies, CSC found numerous deficiencies, both of a general nature and of specific kinds, which did not make the data useful for direct application to a multibeam, multifunctional satellite. As a result, the recommended sources (References 1 and 2) were primarily used as descriptions or listings of potential uses or "needlines," while relatively critical judgment was applied to the quantitative factors contained in these references. It was also necessary to apply some judgment with regard to the necessary additional information which would be required. In summary, the list of highest ranked demands of Reference 1 was screened, supplemented by type-demands implied in References 2 and 3, discussions with potential users, and general information of both an informal and documented form, on domestic (U.S.) satellites, ongoing NASA programs, etc. Quantitative information available from these sources was used, when available, in revised form; otherwise, estimates of usage and similar factors were made. CSC is confident that the demand listing thus obtained is quite comprehensive, even though quantitative estimates may be subject to very large changes.

2.2.2 Initial Demands Listing

The Information Transfer Systems Requirement Study (Reference 1) was an extensive survey and study of potential demands for systems similar to the MFR satellite. While the final data can be faulted in some ways, it is probably correct to say that the list of "all conceivable demands for transfer of information," initially totaling 322 demand types, was complete. These were screened by a variety of criteria, leaving a still quite comprehensive list of 134 demands.

The demands were partially organized and described by assignment into groups termed networks and functional categories. There were five networks, of which only these four were ultimately retained:

1. I - Information Dissemination and Broadcast Network
2. II - Data Collection and Distribution Network

3. III - Inquiry and Response Network

4. IV - Computer Information Network.

The ten functional categories were:

1. Education
2. Teleconferencing
3. Civil defense
4. Earth sciences
5. Weather data
6. Space programs
7. Aircraft
8. Welfare
9. Medical
10. Computer services.

The 134 demands were then ranked according to the following socioeconomic benefit ranking parameters:

1. Trend rate
2. Technical availability
3. Ease of implementation
4. Social acceptance
5. Number of users
6. Potential beneficiaries
7. Social benefits
8. Scientific benefits.

CSC's approach to this list was to retain those demands which seemed applicable to a domestic U.S. multifunctional satellite, reject those not applicable, eliminate a few of the relatively noncontroversial minor demands,* and use the quantitative data in the reference only as a guide. Table 2-1 shows the retained demands. Although it is relevant to observe that the successive screenings, from the original 322 to the remaining 21, may have eliminated many useful demand categories, the list contains a good representative sampling of the types of services envisioned. The subsequent work supplemented and expanded this list substantially.

2.2.3 Biomedical Communication Demands

The screened list (Table 2-1) contained only one biomedical demand, the diagnostic and consulting one. Even the data on this demand, in Reference 1, is subject to criticism:

1. Only one video channel is assumed (though a discrepancy exists, in the 20,000 channel hours per year estimate).
2. Only 350,000 bits per year of data transfer was assumed.

Therefore, Reference 1 was restudied to find those biomedical communication demands which may have been dropped during the screening process. Reference 2 was also consulted. It became evident that a number of important biomedical demands were missing.

Potential biomedical demands were not explicitly listed in Reference 2. However, they may be readily inferred from scrutiny of the service components:

1. Library - Concerned with acquisition, indexing, cataloging, and classifying of literature; provides bibliographic access and dissemination.
2. Specialized Information Services - An organizer and disseminator of knowledge in specialized, narrow fields, such as biomedical analysis centers and toxicology information.

*For example, fish migration data. In addition, several demands which severely biased the net balance of service toward aerospace-oriented services were discarded.

Table 2-1. Demands Retained From Reference 1

Network	Functional Category	Demand
I Information Dissemination and Broadcast Network	1 (Education)	Education, Preschool Education, Grade School Education, Adult Education, Ailing at Home Education, Criminal Rehabilitation Education, Rural Communities
	2 (Teleconferencing)	Meeting, Legislative Session Meeting, Political Presentations
	3 (Civil Defense)	Civil Defense Emergency Communication Civil Defense Emergency Warning
II Data Collection and Distribution Network	4 (Earth Sciences)	Earth Resources Satellite
	5 (Weather Data)	Weather Satellite Data
	6 (Space Programs)	Manned Orbit Support Data Astronomy Data Relay Satellite Control Data Deep Space Exploration Data Relay
	7 (Aircraft)	Enroute Air Traffic Control, Commercial
III Inquiry and Response Network	8 (Welfare)	Centralizing and Relaying of Employment Records
	9 (Medical)	Medical Diagnostic and Consulting
IV Computer Information Network	10 (Computer Services)	Computational Information Services

3. Specialized Education Services - Concerned with continuing education of professionals, education for students, and basic health education for the medically uninformed.

4. Audio and Audiovisual - films and audio lectures.

In particular, the following possibilities are postulated:

1. Library related - Bulk data transfer

2. Special Information - Communications of an inquiry-and-response type, primarily voice and data but with perhaps some video, related to such time-value functions as poison control, specialist consultation, epidemic control, etc.

3. Special Education - Educational broadcasts, mostly video but perhaps some audio-lecture, for continuing education of professionals and for medical education for the layman.

4. Medical Education - Specifically oriented toward classroom consumption. This would be almost all video (plus sound) with broadcast-type, one-way, connectivity. Some two-way requirements might exist in interactive electronic classroom applications or teleconferencing of specialists during operations, etc.

Using this information and the unscreened demand list from Reference 1, a list of potential biomedical demands was established as shown in Table 2-2.

2.2.4 Demands and Functional Categorization

2.2.4.1 Introduction and Approach

It was deemed necessary to establish categories of classification of communication demands which differentiated on the basis of repeater design impact so that the demands could then be organized according to these categories. Besides the very obvious and previously determined characteristic of service type (video, voice, or data), the criteria of interest are geographical (spatial) and temporal.

Table 2-2. Biomedical Communication Demands

Demand	Network[1]	Service
Education, Medical Schools	I	Video
Education, Medical Professionals	I	Video
Education, Medical for Laymen	I	Video
Library Data Transfer	IV[2]	Data
Medical Diagnostic and Consulting[3]	III	Video Audio Data
Toxicology Control	III	Data
Blood, serum, and organ banks	III	Data
Medical Records Transfer	III	Data

[1]See Table 2-1 for description.

[2]Library data transfer is considered to be closer in function to computer-to-computer links than to any of the other three networks.

[3]This demand existed in Reference 1 but has been augmented in capacity and type of service.

2.2.4.2 List of Demands

Table 2-3 is a consolidated list of demands. The following paragraphs explain the headings.

2.2.4.3 Geographic Factors

Short of specifying in detail the precise location of each and every user and/or earth terminal, an adequate general description of the geographic structure of each demand can be obtained using the following parameters:

1. Connectivity
   a. Point-to-Point (P-P)
   b. Point-to-Multipoint (e.g., broadcast) (P-M)
   c. Conferencing - at any instant of time, the connectivity is point-to-multipoint, but the origination point is continually shifting.
   d. Multipoint-to-Multipoint (M-M) - can be thought of as an overlay of several point-to-multipoint networks.
2. Dispersion
   a. Continental - essentially complete coverage over most of the U.S.
   b. Mixed - extensive coverage, but not to all areas
   c. Regional - coverage of several, usually contiguous, areas
   d. Area - within a single area (or connecting one area to another single area)
3. Clustering

   High clustering implies that many users are located within one (or each) beam coverage area. Low clustering means that only one or a very few users are located within one area.

Table 2-3. List of Demands (Sheet 1 of 3)

Network	Demand	Service (Signal Type)	Connec-tivity	Disper-sion	Clus-tering	Time Blocks	Estimated Range of Use (ch-hrs/day)	Duration of Con-nection	Peaking	Simul-taneity	Predict-ability
I INFORMATION DISSEMINATION AND BROADCAST	1. Education, Preschool	Video	P-M (Brcst)	Mixed	High	2, 3, 4	1 - 10	Hours	Medium	High	Yes
	2. Education, Grade School	Video	P-M (Brcst)	Regional	High	2, 3	2 - 20	Hours	Medium	High	Yes
	3. Education, Adult	Video	P-M (Brcst)	Mixed	Med.	3	1 - 4	Hours	High	Medium	Yes
	4. Education, Ailing at home	Video	P-M (Brcst)	Cont.	Med.	2, 3	2 - 4	Hours	Medium	High	Yes
	5. Education, High School	Video	P-M (Brcst)	Regional	High	2, 3	2 - 20	Hours	Medium	High	Yes
	6. Education, Criminal Rehabilitation	Video	P-M (Brcst)	Mixed	Low	3	1 - 2	Hours	High	Medium	Yes
	7. Education, Rural	Video	P-M (Brcst)	Mixed	Low	3	1 - 4	Hours	High	Medium	Yes
	8. Education, Medical Schools	Video	P-M (Brcst)	Mixed	Med.	2, 3, 4	2 - 20	Hours	Medium	Medium	Yes
	9. Education, Medical Professionals	Video	P-M (Brcst)	Cont.	Med.	2, 4	1 - 10	Hours	Medium	Medium	Yes
	10. Education, Medical for Laymen	Video	P-M (Brcst)	Mixed	Med.	3	1 - 2	Hours	High	Medium	Yes
	11. Meeting, Legislative	Video	Conf.	Mixed	Low	2, 3, 4	2 - 30	Hours	High	Low	Part.
	12. Meeting, Political	Video	Conf.	Cont.	Med.	2, 3, 4	1 - 30	Hours	High	Low	Part.
	13. Civil Defense Comm. 1	Video	P-M	Mixed	High	1 - 4	0 - 24	Minutes	High	Low	No
	14. Civil Defense Comm. 2	Data-low	P-M	Mixed	High	1 - 4	75 bps	Minutes	High	Low	No
	15. Civil Defense Warning 1	Video	P-M	Mixed	High	1 - 4	0 - 24	Minutes	High	Low	No
	16. Civil Defense Warning 2	Data-low	P-M	Mixed	High	1 - 4	75 bps	Minutes	High	Low	No

Cont. = Continental

Part. = Partial

Table 2-3. List of Demands (Sheet 2 of 3)

Network	Demand	Service (Signal Type)	Connec-tivity	Disper-sion	Clus-tering	Time Blocks	Estimated Range of Use (ch-hrs/day)	Duration of Con-nection	Peaking	Simul-taneity	Predict-ability
II DATA COLLECTION AND DISTRIBUTION	1. Earth Resources Satellite 1	Data-med.	M-M	Mixed	Low	1 - 4	Continuous		---	---	Yes
	2. Earth Resources Satellite 2	Video	M-M	Mixed	Low	1 - 4	3 Channels	Continuous	High	Medium	Yes
	3. Weather Satellite Data	Video	M-M	Cont.	Med.	1 - 4	3 Channels	Continuous	---	---	Yes
	4. Weather Data	Data-med.	M-M	Regional	Med.	1 - 4	20 kbps	Minutes	Low	Low	No
	5. Manned Orbit Support 1	Video	M-M	Mixed	Med.	1 - 4	2-48	Hours	High	Low	Yes
	6. Manned Orbit Support 3	Data-high	M-M	Mixed	Low	1 - 4	.3-5Mbps	Minutes	High	Low	Yes
	7. Astronomy Data Relay 1	Video	M-M	Mixed	Low	1 - 4	Continuous		---	---	Part.
	8. Astronomy Data Relay 2	Data-low	M-M	Mixed	Low	1 - 4	20 bps	Continuous	---	---	Part.
	9. Satellite Control Data	Data-high	M-M	Regional	High	1 - 4	10^5 bps	Continuous	Medium	Medium	Part.
	10. Deep Space Data 1	Video	M-M	Regional	Low	1 - 4	.1-24	Hours	High	Medium	Yes
	11. Deep Space Data 2	Data-low	M-M	Regional	Low	1 - 4	75 bps	Minutes	High	Low	Part.
	12. Air Traffic Control	Data-	M-M	Regional	Med.	1 - 4	Continuous		---	---	Yes

Cont. = Continental

Part. = Partial

Table 2-3. List of Demands (Sheet 3 of 3)

Network	Demand	Service (Signal Type)	Connec-tivity	Disper-sion	Clus-tering	Time Blocks	Estimated Range of Use (ch-hrs/day)	Duration of Con-nection	Peaking	Simul-taneity	Predict-ability
III INQUIRY AND RESPONSE	1. Welfare (Employment) Data	Data-med.	P-P	Area	Med.	4	.1-10 kbps	Hours	High	Low	Part.
	2. Medical Diagnostic 1	Video	P-P	Area	Low	1 - 4	0 - 10	Minutes	Medium	Medium	No
	3. Medical Diagnostic 2	Data-low	P-P	Area	Low	1 - 4	2400 bps	Minutes	Medium	Medium	No
	4. Medical Diagnostic 3	Voice	P-P	Area	Low	1 - 4	10-1000	Minutes	Medium	Medium	No
	5. Toxicology & Epidemic Control 1	Data-low	P-P	Area	Low	1 - 4	75 bps	Minutes	High	Low	No
	6. Toxicology & Epidemic Control 2	Voice	P-P	Area	Low	1 - 4	0 - 10	Minutes	High	Low	No
	7. Blood, Serum, Organ Banks	Data-low	P-P	Regional	Med.	1 - 4	2400 bps	Minutes	High	Low	No
	8. Medical Records	Data-med.	P-P	Mixed	Low	1 - 4	20,000 bps	Minutes	Medium	Low	No
	9. Welfare & Employment Data	Data-med.	P-P	Cont.	Low	4	20,000 bps	Hours	High	Low	Part
	10. Crime control nets	Data-med.	P-P	Cont.	Low	1 - 4	24,000 bps	Minutes	Medium	Medium	No
IV COMPUTER INFORMATION NETWORK	1. Computer Data	Data-high	P-P	Mixed	Low	1 - 4	2.4k-1Mbps	Minutes	Medium	Medium	Part.
	2. Library Data	Data-high	P-P	Area	Med.	1 - 4	2.4k-1Mbps	Minutes	Medium	Low	Part.

Cont. = Continental

Part. = Partial

Geographic categorization and differentiation are necessary to properly consider the possibilities of space division and frequency reuse.

2.2.4.4 Temporal Factors

Consideration of the time structure of the demands is important because it is the temporal nonuniformity of most requirements which allows sharing of resources (power and bandwidth). This sharing might be thought of as a time division, although not of the TDMA kind in most cases.

1. <u>Time Blocks</u>

   a. 0000 to 0600 local time*

   b. 0600 to 1200

   c. 1200 to 1800

   d. 1800 to 2400

2. <u>Estimated Range of Use</u>

   For video and voice channels, the number of channel hours per day is estimated. For data links, the approximate data rate while the link is in operation is estimated.

3. <u>Duration of Connection</u>

   Only the general distinction between hours and minutes is made. Scheduled links, especially broadcast, tend to be hours in duration, while on-demand type demands are generally shorter lived.

4. <u>Peaking</u>

   High peaking means that the short-term duty cycle is not stationary (in a statistical sense) and is much higher than the long-term duty cycle.

---

*Later referenced to eastern standard time for the sake of uniformity.

5. Simultaneity

Does this demand tend to occur at the same time as many other demands of a similar type?

6. Predictability

Predictability in both time and location is highest with scheduled demands.

2.2.4.5 Other Modifications

The demand list was also supplemented during the course of the study to include such demands as regional weather networks, welfare and employment data, and crime control information. These have been included in Table 2-3. In addition, the categorization criteria were expanded and made more precise when the hypothetical traffic model and data base were established (Paragraph 2.5).

2.3 GEOGRAPHIC COORDINATE SYSTEM AND ASSUMED SATELLITE PLACEMENT

2.3.1 Introduction

To correlate a hypothetical traffic model with possible locations of users and earth terminals, and then to translate this to satellite-beam related terms, it was necessary to establish a system of organizing potential user needlines according to location and to postulate a baseline satellite location.* Considerations entering into these decisions are described in this paragraph.

2.3.2 Reduction of U.S. Into Coverage Cells

2.3.2.1 Approach

It was desired to establish a flexible location system which could be used with any and all beam-coverage schemes. Specifically, the fundamental geographic locating system would be derived independently of the beam coverage plots. Since available maps had convenient latitude/longitude grids, that coordinate system was

*For purposes of analysis, it was assumed that there would be only one satellite, though a system would more likely have several at various orbital locations.

chosen. This had the additional feature that known locations such as metropolitan areas could be readily pinpointed, and also that CSC's modified orthographic projection computer program, used subsequently to develop the beam coverage models, also identifies points on a latitude/longitude coordinate system.

2.3.2.2 Geographic Cells

Initially, a grid of 1° x 1° rectangles was placed over the U.S. These 1° square "cells" were, of course, much too small and too numerous. After some consideration, 4° x 4° rectangular cells were chosen for two reasons:

1. The center-to-corner distance is about 100 miles, a distance appropriate for nonsatellite end connections, i.e., one could assume an earth terminal at the center of the cell serving the entire cell without incurring unreasonable end connection expenses.
2. The resulting cell size is on the same order of magnitude as the smallest reasonable antenna-beam coverage footprint, so that it would never be necessary to quantize (specify with greater accuracy) the location of a given requirement.

It was then necessary to select the best positioning of the set of adjacent and contiguous 4° x 4° rectangular cells. Two criteria were used:

1. The total number of cells necessary had to be kept to a minimum.
2. The best possible coverage, especially of heavily populated areas, had to be achieved.

The cell overlay illustrated in Figure 2-1 was selected. The cells are defined by odd-numbered latitude and even-numbered longitude lines with 4° spacing, resulting in a total of 57 cells. (Additional cells for Alaska, Hawaii, and Puerto Rico should also be included.)

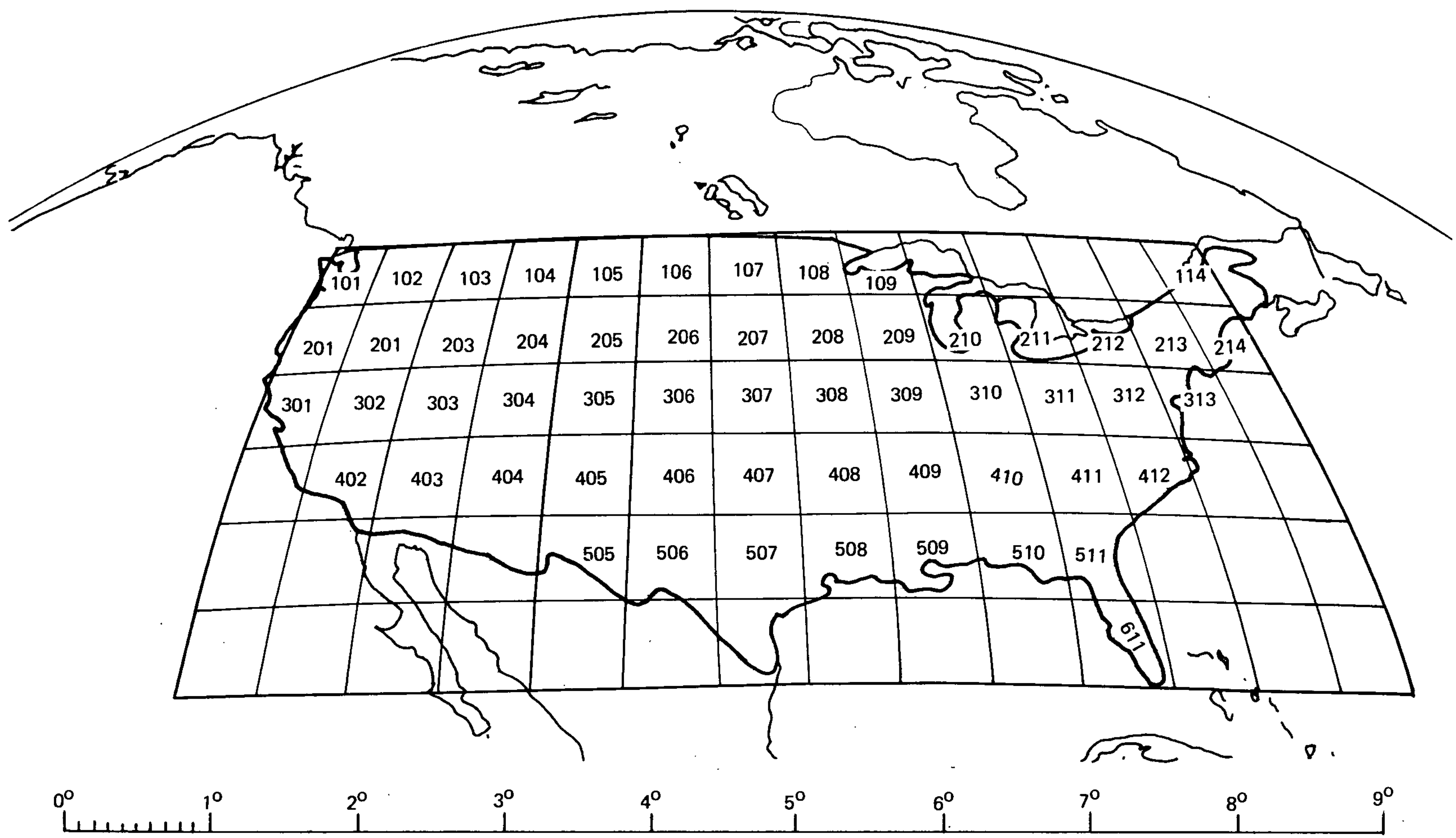


Figure 2-1. Cell Assignment Seen From 100° W Longitude

These cells were then numbered as shown in the figure. Hypothetical requirements locations could then be described in terms of cell numbers, and ultimately beam coverages could also be described by their assigned cells (see Paragraph 3.3.4).

2.3.3 Satellite Location and Projection Maps

To perform the beam overlays necessary in Task 2, a hypothetical satellite location (longitude) had to be chosen. Considerations in this regard are coverage, symmetry, and orbital sharing.

1. Coverage suggests that the satellite be placed far enough west to allow Hawaii and Alaska to view the satellite with reasonable elevation angles. This would actually favor 110 to 120° W longitude.

2. Symmetry is important because the emphasis is on those multiple-beam antennas which reuse the aperture. Therefore, the beams are more or less identical in beamwidth and are best arranged in a symmetrical cluster. Furthermore, the best match between symmetrical, equal-width beams, and the geographic cell model occurs for cell locations near in longitude to that of the satellite. Horizontal offsets in beam steering are thus minimized, on the average, by locating the satellite at a geographic median longitude (center of U.S.) of about 96 to 102° W.

3. Orbital sharing would be an important consideration in actual system design and planning, but in the present techniques tradeoff study, should be considered only parametrically as an intersystem interference factor.

The 100° W longitude placement was selected because it offers a symmetrical view of the continental U.S., and also covers Alaska, at least theoretically. Admittedly, an actual satellite would be placed further west for better coverage. It should be stressed, however, that the symmetry requirement itself is somewhat ficticious, since it occurs only in attempting to match the arbitrary geographic grid arrangement to feasible multiple-beam packing models. Nevertheless, since the population densities on the east and west coasts are approximately analogous, a satellite location roughly central would be optimum to provide equivalent service to both coasts, if only one satellite were to be used. For the techniques tradeoffs, the somewhat unrealistic coverage provided to central Alaska is not judged to be serious, and the 100° W location will be assumed.

The projection shown in Figure 2-1 actually applies to the U. S. as seen from a 100° W location. This projection map was subsequently used in the beam-coverage work (Paragraph 2.   ). The particular projection is unique in that circular (or other shapes) beam patterns can be directly drawn (overlaid) onto the map regardless of where the center of the particular beam lies. In other words, the coverage footprints of circular beams themselves appear circular.

2.4 HYPOTHETICAL TRAFFIC MODEL

2.4.1 Introduction

A hypothetical traffic model or scenario was considered to be a useful tool in examining the sensitivity of results to requirements, scoping the alternative solutions, and assisting the engineers studying the technical problems in visualizing the various operational factors involved. An actual listing of requirements would, of course, be preferable, but is not available, since not only the satellite system but even most of the corresponding conventional systems are not presently in operation. One may question the validity of performing systems analyses based on a totally hypothetical traffic model. But the utility of results thus obtained is not in their specific conclusions and numerical values, but rather in the parametric dependence on changes in requirements. There is also the advantage in using a well-defined model of having a framework or baseline upon which the engineering decisions can be made. For example, there is no absolute validity to the numerical channel requirement values obtained from processing the requirements model data. Furthermore, these numbers themselves could have been estimated without establishing the complete model. Nevertheless, once the model had in fact been established, deriving this and many other parameters was straightforward. The general magnitude and routing structure of these channel requirements then influenced the modulation and multiple-access study decisions.

2.4.2 Approach

The approach used in establishing the traffic model was to apply information available from the sources shown in Table 2-4, along with the knowledge and experience of engineers with a background in satellite and conventional communication systems engineering, to each of the candidate demands as listed in Table 2-3, and thereby derive hypothetical network configurations and parameter values. In some cases detailed network information was available, especially where conventional systems have already been adopted for the purpose. In other cases, where the conjectured usage was quite new and different, less definitive and direct information had to be used, such as the type of data which could be exchanged, the relative distribution of potential users, etc. The nature of the information which needed to be specified can be inferred from the descriptive parameters listing in Paragraph 2.4.3. In addition, the locations of network members were specified in terms of geographic cell number, and the time block or hour under consideration was specified. The nature of this data can best be ascertained by examining the data base, described in Paragraph 2.5, and listed, with information on its arrangement, in Appendix A.

2.4.3 Descriptive Parameters

Each demand had a set of descriptive parameter values associated with it characterizing the demand according to temporal and geographic considerations.

The descriptive parameters used in the data base were somewhat more detailed and explicit than the general temporal and geographic factors used in the demand listing (Paragraph 2.2.4). The traffic model data base included time block descriptions in some cases; in others it was considered feasible to state the exact particular hours of assumed network operation. The time pattern was broken into the following factors:

1. Duty cycle of network operation
2. Duration of connection
3. Toggling of network, e.g., fixed, back and forth (half duplex), or conference (roundtable)

Table 2-4. Information Sources

Information Transfer Systems Requirements Study (Reference 1).
"Communications for the Medical Community - A Prototype of a Special Interest Audience" (Reference 2).
Program on Application of Communication Satellites to Educational Development and related reports by Washington University.
Dr. Lawrence G. Roberts, "A Forward Look," SIGNAL, August 1971; a paper describing the ARPA computer network.
Rossi et al, "A Telephone Access Biomedical Information Center," Rand RM-6205-NLM, April 1970 (Reference 3).
Conference with Lister Hill National Center for Biomedical Communications, March 23, 1972
Meeting with participants of study on Phase 1 Requirements for Communications in Alaska.
The National Aviation System Plan 1973-1982, Federal Aviation Administration, March 1972.

4. Predictability (of network operation), e.g., scheduled, generally predictable (to within a time block), or unpredictable.

The geographic pattern was described as follows:

1. Dispersion (see Paragraph 2.2.4.3)

2. Connectivity (see Paragraph 2.2.4.3)

3. Specificity: variability of the network connectivity, e.g., fixed, unchanging configuration from day to day, temporarily fixed and specified 24 hours in advance, and fixed source locations but random sink locations.

The utility of these factors was confirmed during the data base processing (Paragraph 4.1). For example, only networks with fixed or predictable connectivities could be counted for trunking (paralleling) of channels.

As an example, here are the descriptive parameters for the medical records transfer network during time block 1:

1. Medium rate data

2. 50 percent duty cycle (during the time block)

3. 10-minute duration of connection

4. Back-and-forth toggling

5. Totally unpredictable in advance

6. Area dispersion

7. Point-to-point connectivity

8. Unspecified sources, fixed sinks.

2.5 COMPUTERIZED DATA BASE

2.5.1 Purpose and General Concept

The purposes of placing the hypothetical traffic model into a computerized form, that is, storing the information in a computer memory file, were to:

1. Permit straightforward modification of the data base entries as necessary to perform parametric studies without laborious manual revision of tables, charts, etc.

2. Automate what would otherwise be a series of tedious manual file searches and counts to correlate, compile, and analyze traffic requirements.

3. Expedite trend and sensitivity analyses, e.g., the generation of peak demand versus time curves.

In retrospect it has also become apparent that a useful methodology for translating system needline requirements into satellite repeater requirements or even power and weight estimates has resulted. Although such a system was not fully implemented during the course of this study, the subroutines for power budget computation and the addition of some empirical data on repeater hardware would enable one, in theory, to input requirements and receive an output in power/weight terms.

There were two clear alternatives in organizing the data base: by demand or by area. For the first approach, the list progresses from one demand to the next, listing in turn the areas for which this service is needed, i.e., a list of needlines appears under each demand (for each time block or hour). This was the approach chosen. It would also be possible to list by area, i.e., for each geographic area (or cell) one would list all requirements serving that area. Each of these approaches has advantages depending on the type of analysis to be performed.

The computerized data base is listed and described in Appendix A. A summary list of the networks only appears in Table 2-5.

Table 2-5. Networks Included in Data Base (Sheet 1 of 6)

Net	Service	Comments
Preschool, Eastern U.S.	Video	All video broadcast requirements include audio.
Preschool, Western U.S.	Video	
Grade School, New England	Video	
Grade School, Middle Atlantic	Video	
Grade School, Southeast	Video	
Grade School, Midwest	Video	
Grade School, Texas Area	Video	
Grade School, Rockies	Video	
Grade School, Northwest	Video	
Grade School, California	Video	Includes Hawaii
Adult Education, Urban Areas	Video	Major Metro Areas
Adult, All Areas	Video	Nationwide
Ailing at Home, Continental U.S.	Video	
Ailing at Home, All Areas	Video	

Table 2-5. Networks Included in Data Base (Sheet 2 of 6)

Net	Service	Comments
High School, Northeast	Video	Less regionalized than grade school
High School, Southeast	Video	
High School, Midwest	Video	
High School, Texas Area	Video	
High School, Rockies	Video	
High School, West	Video	
Criminal Rehabilitation, Selected Areas	Video	
Rural Education, Most Areas	Video	Areas of low population density
Rural, Eastern U.S.	Video	
Rural, Central U.S.	Video	
Rural, Rockies	Video	
Rural, Western U.S.	Video	
Medical Schools, Eastern U.S.	Video	Areas with medical schools
Medical Schools, Western U.S.	Video	

Table 2-5. Networks Included in Data Base (Sheet 3 of 6)

Net	Service	Comments
Medical Professionals, All Areas	Video	
Medical Professionals, East Coast	Video	Time scheduling problems
Medical Professionals, Middle U.S.	Video	
Medical Professionals, Rockies	Video	
Medical Professionals, West Coast	Video	
Medical Professionals, Eastern U.S.	Video	
Medical Professionals, Western U.S.	Video	
Medical Education for Laymen, All Areas	Video	
U.S. Legislative Teleconferencing	Video (also audio)	Regional Centers; for U.S. Congress
Political Teleconferencing	Video	Selected Areas
Civil Defense 1, National	Video	
Civil Defense 1, Northeast	Video	
Civil Defense 1 , Southeast	Video	
Civil Defense 1, Midwest	Video	

Table 2-5. Networks Included in Data Base (Sheet 4 of 6)

Net	Service	Comments
Civil Defense 1, Rockies	Video	
Civil Defense 1, Texas Area	Video	
Civil Defense 1, Northwest and Alaska	Video	
Civil Defense 1, California and Hawaii	Video	
Civil Defense 2, National	Low Rate Data	
Civial Defense 2, Northeast	Low Rate Data	
Civil Defense 2, Southeast	Low Rate Data	
Civil Defense 2, Midwest	Low Rate Data	
Civil Defense 2, Rockies	Low Rate Data	
Civil Defense 2, Texas Area	Low Rate Data	
Civil Defense 2, Northwest and Alaska	Low Rate Data	
Civil Defense 2, California and Hawaii	Low Rate Data	
Civil Defense Warning, National	Low Rate Data	
Earth Resources Satellite Data, Selected Areas	Medium Rate Data	

Table 2-5. Networks Included in Data Base (Sheet 5 of 6)

Net	Service	Comments
Weather Satellite Data, Most Areas	Video	
Weather Satellite, Selected Areas	High Rate Data	Regional Weather Centers
Weather Service, Southeast	Medium Rate Data	
Weather Service, Western U.S.	Medium Rate Data	
Weather Service, Midwest	Medium Rate Data	
Weather Service, Northeast	Medium Rate Data	
Manned Orbit Support	Video	Selected Areas (NASA and TV networks)
Manned Orbit Support	High Rate Data	Selected Areas
Astronomy	Video	Major Observatories
Astronomy	Data	Major Observatories
Satellite Control	High Rate Data	Selected Areas (NASA)
Deep Space	Video	Selected Areas
Deep Space	Low Rate Data	Selected Areas
Air Traffic Networks	Low Rate Data	Point-to-point networks linking air traffic control centers.
Medical Diagnostic and Consulting	Video	All areas

Table 2-5. Networks Included in Data Base (Sheet 6 of 6)

Net	Service	Comments
Medical Diagnostic and Consulting	Low Rate Data	All Areas
Medical Diagnostic and Consulting	Voice	All Areas
Toxicology and Epidemic Control	Low Rate Data	All Areas
Toxicology and Epidemic Control	Voice	All areas
Blood, Serum, Organ Banks	Low Rate Data	All Areas
Medical Records Transfer	Medium Rate Data	All Areas
Regional Medical Libraries Data Transfer	High Rate Data	Selected Library Center Areas
Computer Data Transfer, New York - Los Angeles	High Rate Data	
Computer Data Transfer	High Rate Data	Metropolitan Areas
Library Data	High Rate Data	Metropolitan Areas
Overnight Welfare and Employment Data Transfer	Medium Rate Data	Most Areas
FBI Net	Low Rate Data	Selected Areas
NCIC Net	Low Rate Data	Selected Areas

SECTION 3 - MODULATION AND MULTIPLE BEAM STUDIES

3.1 INTRODUCTION

The organization of the material in Sections 3 and 4 is somewhat arbitrary. There does not appear to be any fundamental best order or sequence in which to cover these topics:

1. Modulation
2. Multiplexing
3. Multiple access
4. Multiple beam coverage
5. Multiple beam interference
6. Repeater concepts
7. Bandwidth analyses.

The reason for this is that the topics are closely linked. For example, the multiple-beam interference issue is strongly dependent on the modulation/multiplexing technique and its susceptibility to interference. On the other hand, repeater structures depend on the modulation technique, its interference susceptibility, and the beam arrangement. Furthermore, the channel requirements influence choices made in all these areas. As a result, an inevitable degree of redundancy occurs, particularly with regard to modulation.

In this section, modulation (and the intimately related topics of multiplexing and multiple access) are discussed first. Certain selections are made, already looking ahead to the problems of bandwidth occupancy and power efficiency. The beam-coverage studies are covered next, and, once again looking ahead, a beam-to-geographic cell (see Paragraph 3.3.4) assignment is made. The last area treated in this section, one of the most significant factors in this study, is that of interbeam interference with multiple-beam systems. This topic is not treated from the antenna implementation standpoint; that is a function of a companion study effort (Reference 4). Rather, the system implications arising from the unavoidable beam-to-beam interference have been investigated. The degree of frequency reuse and therefore spectral efficiency are affected, with repercussions on both modulation selection and repeater design.

3.2 MODULATION AND MULTIPLEXING

3.2.1 Frequency Division Multiple Access

The primary emphasis in this study is on frequency-division techniques. In particular, the separate accesses to the satellite, from different earth terminals, are separated in frequency. This still leaves latitude to select modulation and multiplexing techniques.

For analog waveforms, modulation techniques may be classified under the general categories of phase or envelope modulation (Reference 5). Constant envelope (i.e., phase modulating only) techniques have traditionally been favored, because efficient saturated power amplifiers can be used in both the earth terminals and satellite repeaters. Although heavily preemphasized frequency modulation (FM) approaches true phase modulation, we shall use the prevalent terminology, and FM is taken as a prime candidate. The multiple channel (multiplexed) equivalent is frequency division multiplex (FDM)/FM.

The most power- and bandwidth-efficient nonconstant envelope technique is suppressed-carrier single sideband (SSB).* However, for video transmission some carrier would have to remain for demodulation purposes. Alternatively, vestigial sideband (VSB) could be used. Therefore, for video the term VSB/SSB will be used in this report. The multiplexed SSB case (FDM followed by SSB) results in a signal and spectrum identical to that of a horizontally stacked group of single SSB signals.

*Although it is, unlike AM, a hybrid which contains both envelope- and phase-modulated components.

For transmission of digital traffic, biphase or quadriphase phase-shift keying (PSK) has long been recognized as most efficient in power and bandwidth, especially when supplemented by channel coding.* Multiplexing of baseband signals is best done in the time domain (time division multiplex (TDM)), though FDM is also feasible.

Thus, three general techniques are considered: FM, VSB/SSB, and PSK. Each can be applied to a single channel or to multiplexed requirements. Therefore, Table 3-1 is a listing of all the variants considered viable. The most glaring omission is FDM/FM with video. The bandwidths demanded by this combination are typically so large (>100 MHz for several channels) that allocation and hardware problems would be created by its use.

A few remarks are in order concerning the perhaps unusual inclusion of SSB or VSB in this study. It will be shown in the interbeam interference analysis that in a multiple-beam environment the interference or clutter from other beams is the major influence and that the superior hardness of FM is more than offset by the increased bandwidth necessary. Therefore, it is reasonable to carry VSB/SSB as a candidate analog modulation technique.

3.2.2 Time Division Multiple Access

A multiple-beam repeater designed to operate in a time division mode is applicable only to digital signals (which can, in theory, be digitized video or voice in addition to data). Therefore, applicable modulation techniques are those for digital basebands. Since one of the primary advantages of time division multiple access (TDMA) over frequency division multiple access (FDMA) is that nonlinear amplifiers can be used (no intermodulation problems), only constant envelope techniques are reasonable. The various forms of PSK (i.e., varying orders of phase-level quantization, depending on where the power/bandwidth tradeoff is to be placed) are the primary contenders, with frequency shift keying (FSK) a possibility in those special cases where simplicity or low cost might predominate in importance.

*Though most codes trade power for bandwidth.

Table 3-1. Modulation and Multiplexing Techniques

Baseband Service	Multiplexing	Modulation
Video	None (single channel)	VSB/SSB
	None (single channel)	FM
	Horizontal Stack (FDM)	VSB/SSB
Analog Voice, etc. (e.g., tone-package data)	None (single channel)	FM
	None (single channel)	SSB
	Horizontal stack (FDM)	SSB
	FDM	FM
Data or Digitized Voice	None (single channel)	PSK
	TDM	PSK
	FDM	PSK/FM*

*The individual channels are modulated onto subcarriers. This frequency division multiplexed package is then frequency or phase modulated onto a carrier.

3.3 BEAM COVERAGE STUDIES

3.3.1 Introduction

The purpose of studying multiple-beam coverage within this study was not related to hardware implementation, although the best available feasibility information was applied. Instead, the general system implications of various coverage patterns, beam isolation models, and changes in the number of beams were studied; for example, it was found that the optimum number of beams is not the largest number that can be implemented, even disregarding growth in antenna weight. It was also necessary to convert the geographically oriented data base to equivalent beam-port related terms to analyze the appropriate repeater configurations; that is, it was necessary to know how many accesses and channels were present in each uplink and downlink beam.

3.3.2 Beam Coverage Models

3.3.2.1 Introduction

The work on this task was directed toward developing beam-coverage patterns over the continental United States that would provide a relatively uniform distribution. In addition, the patterns selected were to include only those which were physically realizable from a spacecraft antenna whose diameter was no greater than 30 feet and whose operating frequency is between 2 and 20 GHz. Particular emphasis was placed on 12 GHz.

3.3.2.2 Development of Patterns

The coverage patterns were developed in two categories of coverage philosophy:

1. Time Zone Coverage - four beams, each covering one time zone.

2. Multiple Beam Coverage - large numbers of beams appropriately arranged to provide coverage over the entire continental United States.

In each case, the spacecraft was assumed to be at synchronous altitude in the equatorial plane and at 100° W longitude. At this position, the United States appears as was shown in Figure 2-1. The total angle subtended by the earth is 17.38°.

Other factors that were considered in this task were the "MUSTS" and "WANTS" listed by Lockheed Missiles and Space Company (Reference 4). Those factors that are particularly applicable to this task are listed here for convenience.

1. MUSTS

   a. Coverage of the contiguous United States above the 10-dB level (referenced to the peak of the beam)

   b. 15 to 25 beams

   c. Applicable to a synchronous orbit communication satellite

   d. Hardware appropriate to the 1974-to-1976 time frame

   e. Capable of simultaneous operation of all beams

   f. Frequency bands: X and K_u.

2. WANTS

   a. Minimum spillover outside primary service area

   b. Beam aspect ratios less than 2:1

   c. Subsatellite position at 96° W to 100° W longitude

   d. Provide antenna gain better than -10 dB (relative to the peak gain) to all continental U.S. areas, and additionally minimize the area for which the gain is between -6 and -10 dB.

   e. Minimize the area within the contiguous 48 states where the beam isolation is less than 30 dB.

The two most important "WANTS" are the last two, items d and e.

If no special beam shaping is employed in the spacecraft antenna design, the shape of the main lobe can be described as Gaussian (i.e., the beam shape (in dB) is a function of the square of the angle of the beam axis). If it is assumed that no special shaping is employed, the best coverage of any general area yields minimum gain points which are 4.34 dB down from the peak of the beam. The only physically realizable arrangement to meet this condition occurs when the beams are arranged so that the centers of all the beams lie on vertices of equilateral triangles. If special shaping is employed, the 4.34-dB minima no longer apply; however, the triangular arrangement still provides the most uniform coverage. It should be noted that special shaping has the advantage of reducing the area of interference, but is done at the expense of antenna efficiency.

To relate each beam-coverage pattern to some antenna, the antenna size and gain required for each pattern have been computed, based on the ideal condition that the aperture was uniformly illuminated and no blockage or inefficiencies existed. Under these ideal conditions, the relationship between the half-power beamwidth, antenna diameter, and frequency is illustrated in Figure 3-1. Note that the beamwidth is independent of aperture shape (elliptical or circular) as long as the beamwidth is measured in the principle planes of the ellipse.

3.3.2.3 Time Zone Coverage

Three different time zone beams are illustrated in Figures 3-2 through 3-4. In each case, signal level (relative to the peak gain) for each particular beam is given in areas where it is most difficult to illuminate. Of particular interest is the coverage of the central time zone, which includes as far west as El Paso, Texas. In all cases, the central time zone beam is below the -10-dB level in the direction of El Paso and, as a result, the requirement that the area must be covered at levels greater than -10 dB below the peak cannot be satisfied. Figures 3-2 and 3-3 represent patterns which can be generated by a single antenna. In Figure 3-2, the levels relative to the peak gain are much higher, meaning that more areas must be operated further down the main beams. In Figure 3-3, the relative levels are smaller, giving more uniform coverage; however, the absolute gains in the directions of these difficult areas are lower. Thus, an interesting tradeoff is presented: Is it better to operate at higher absolute gains but lower on the beam pattern,* is the reverse true, or is there a best compromise?

Figure 3-4 represents the use of two identically sized apertures to produce the four beams. This allows beams to be positioned more closely at the expense of greater

*Steep patterns also impact on spacecraft stabilization system requirements.

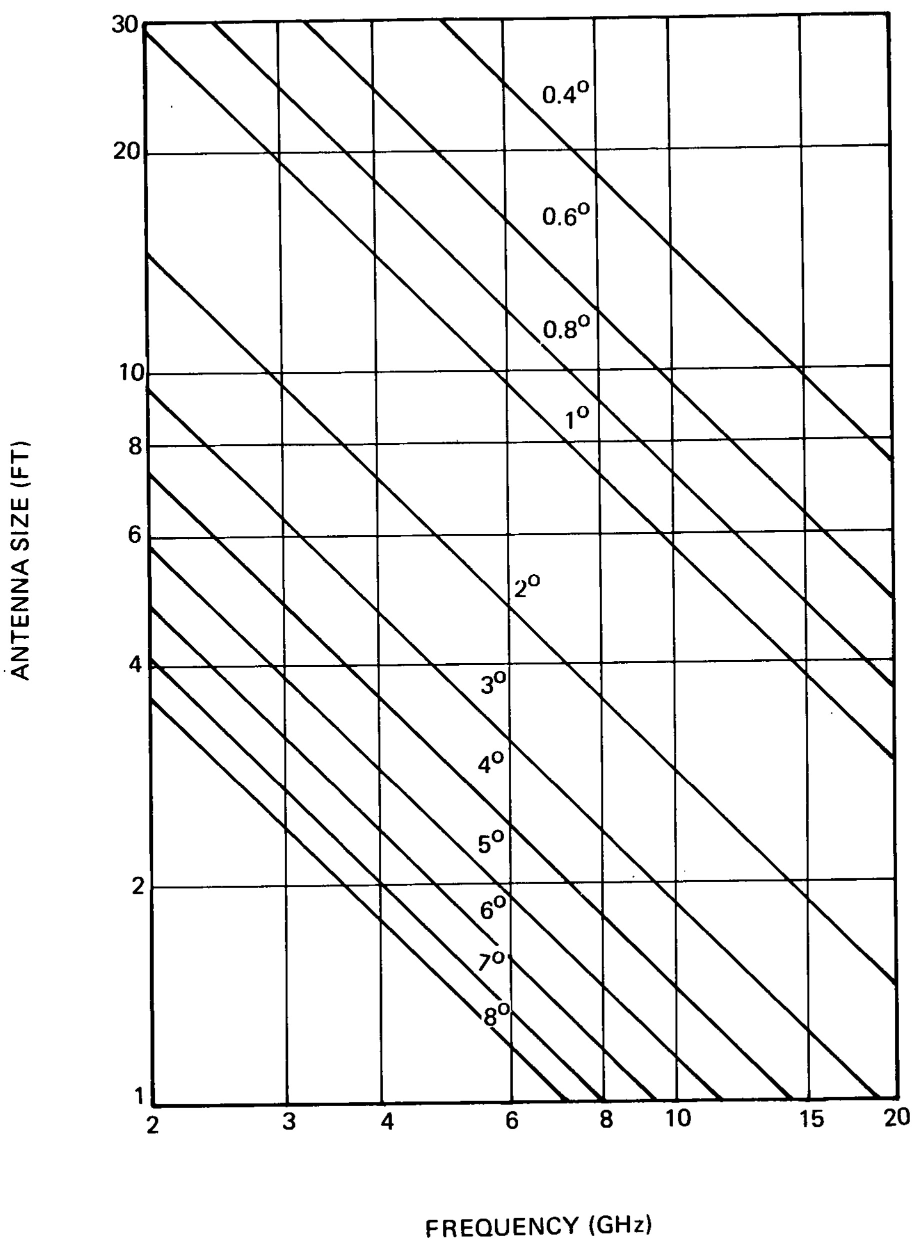


Figure 3-1. Half-Power Beamwidth Versus Frequency and Antenna Size for Elliptical and Circular Apertures

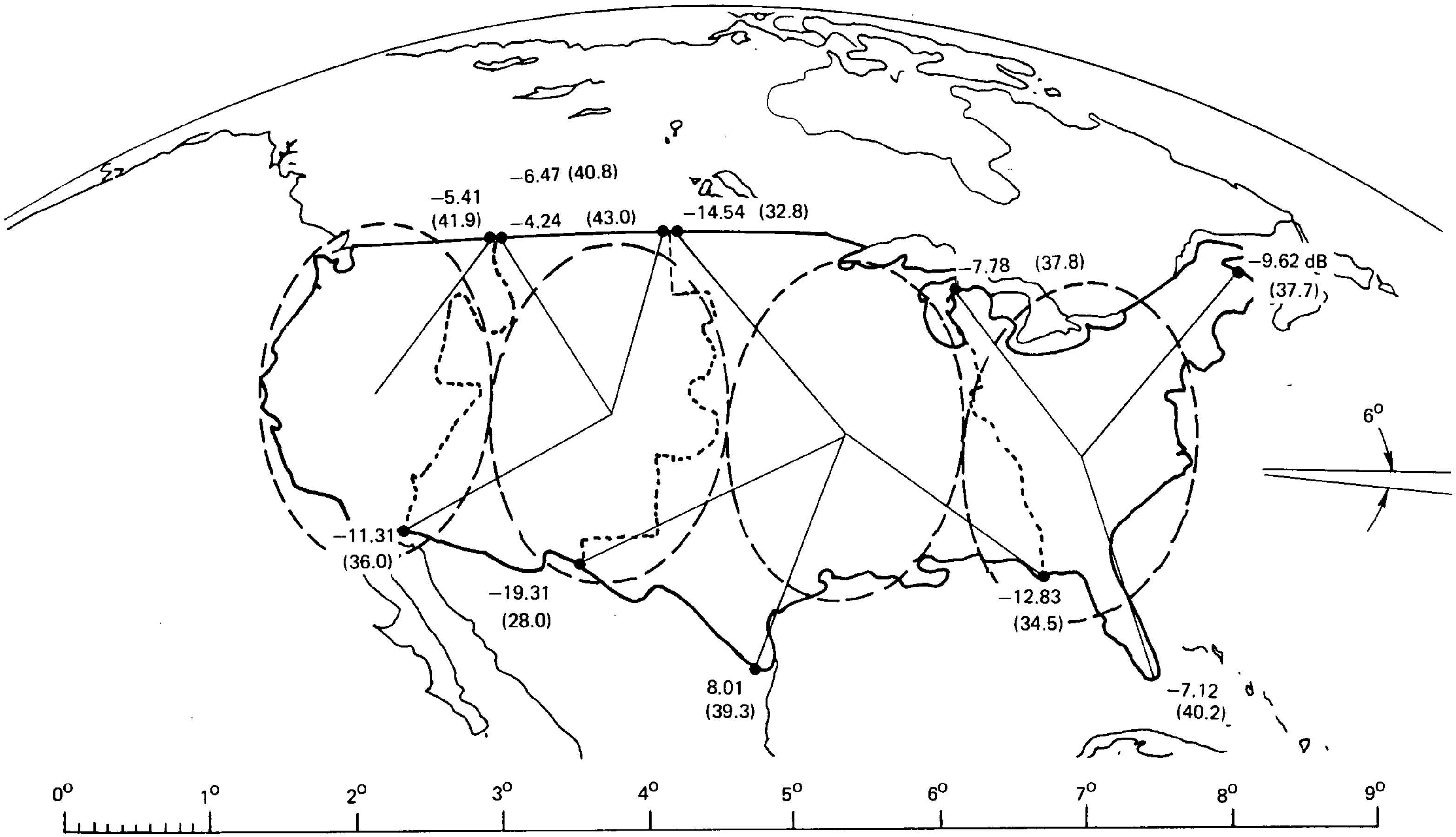


Figure 3-2. Time Zone Beams, Beamwidth = 1.15° x 0.80°, Gain = 46.05 dBi, 3.25-dB Contours

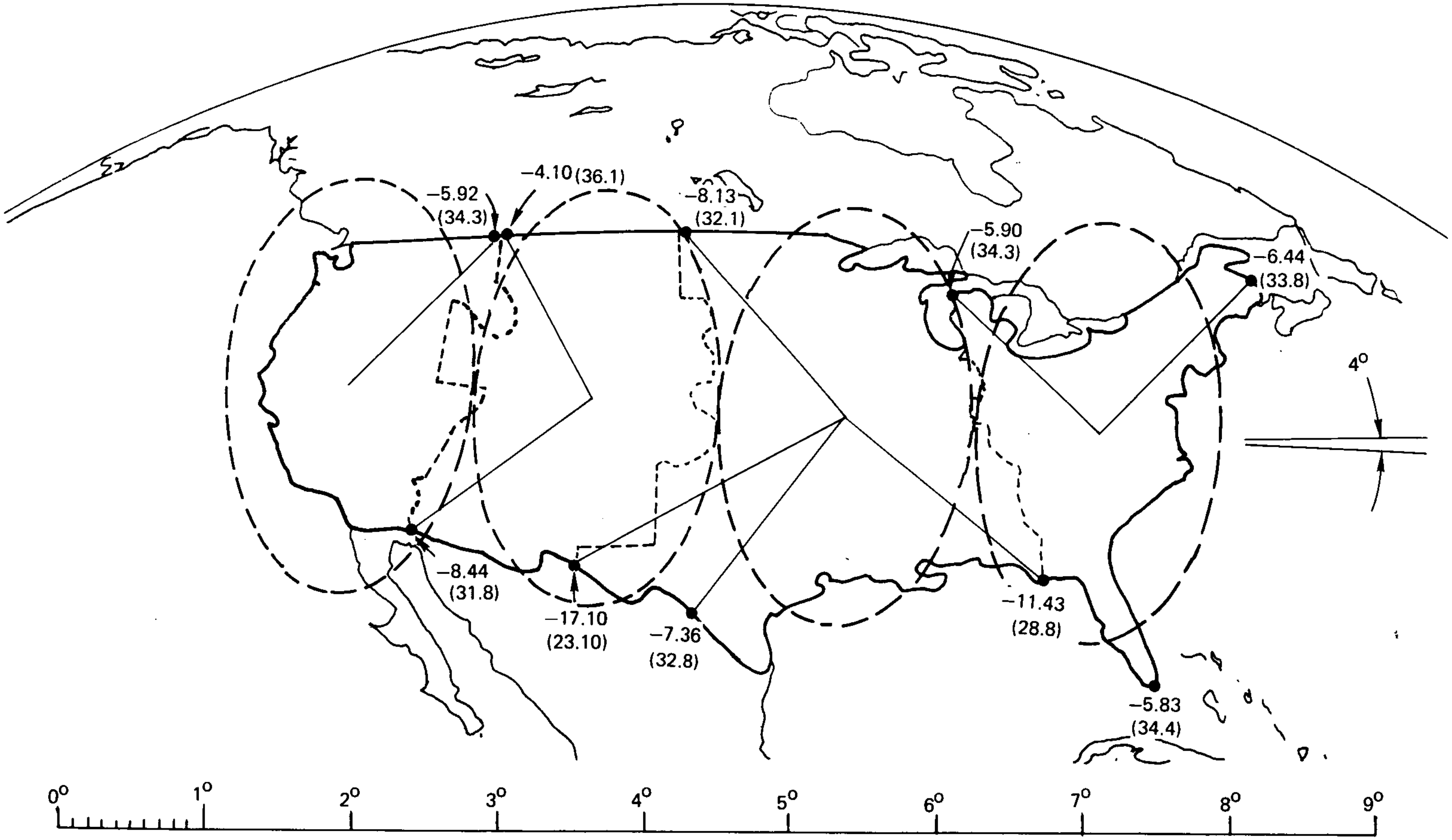


Figure 3-3. Time Zone Beams, Beamwidth = 2.8° x 1.68°, Gain = 38.97 dBi, 3.25-dB Contours

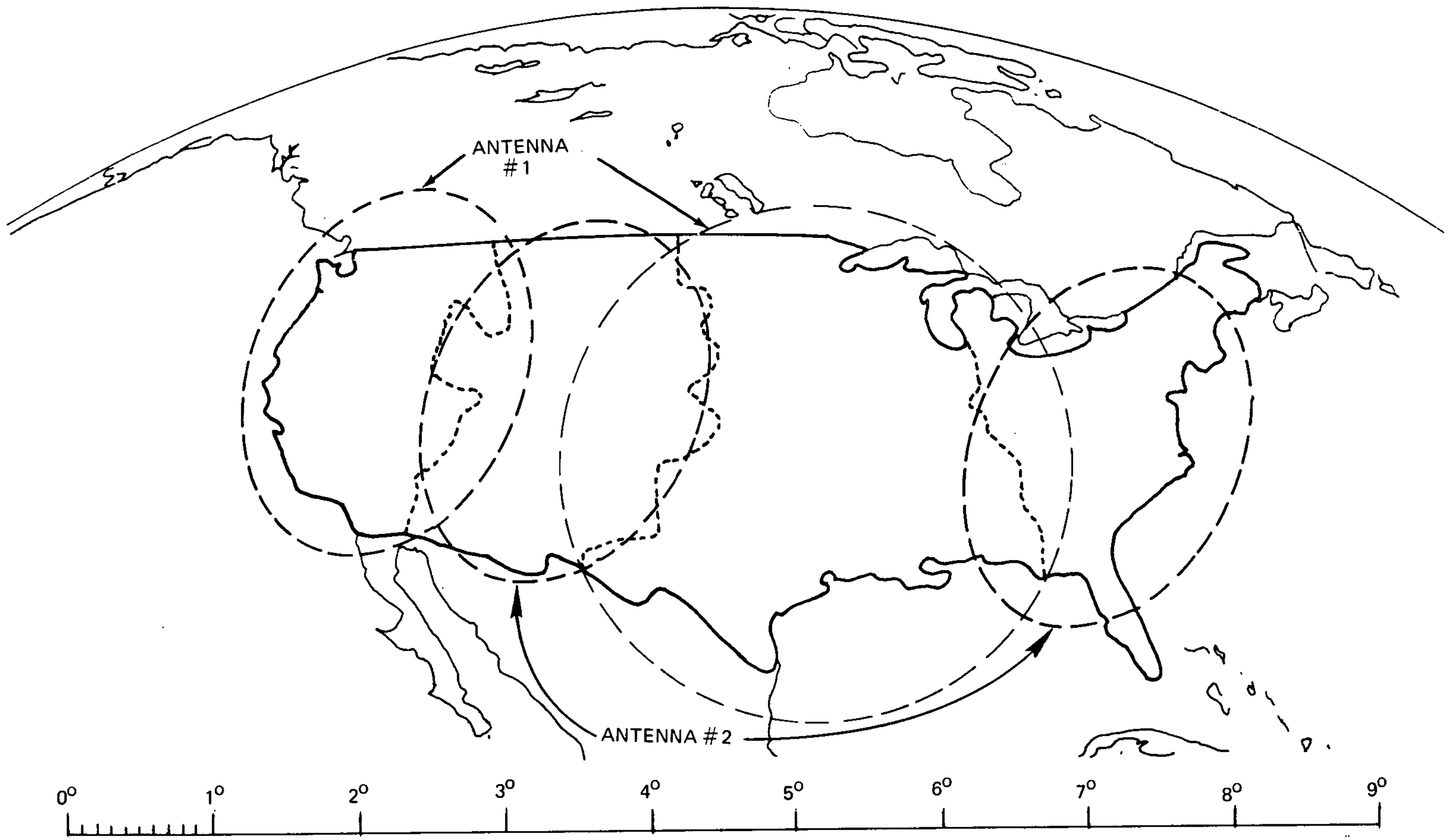


Figure 3-4. Time Zone Beams, Beamwidth = 2.57° x 188° and 3.48° x 3.48°, Gain = 38.82 and 34.84 dBi, 3.25-dB Contours

interference. The large beam is created by defocusing one feed or oversizing a feed horn so that less aperture is used. Three have peak gains of 38.8 decibels isotropic (dBi) and one has a peak gain of 34.8 dBi. The worst gain in the entire area is 31.60 dBi, compared with 23.1 dBi in Figure 3-3 and 28 dBi in Figure 3-2.

3.3.2.4 Multiple Beam Patterns

Figures 3-5 through 3-10 present coverage patterns for 9, 17, 20, 27, 29, and 30 beams. In each case, the contours drawn are the 3.25-dB contours and a triangular arrangement is used. A plot of peak gains and minimum gains in the coverage area for 17 through 30 beams is shown in Figure 3-11. Elliptical beams were used in the nine-beam case for slightly better coverage than that afforded by circular beams.

In each case, the best orientation in terms of positioning and tilt was chosen. This involved a subjective evaluation of the factors previously mentioned, plus a conscious effort to avoid poor coverage of particularly important areas such as Los Angeles, New York, and Washington. Only a second iteration, which included the requirements model, could have actually identified the best orientation of beams. However, the patterns illustrated appear to include a representative sample of possibilities.

In each case, only CONUS coverage was considered. Additional and separate feeds or apertures would be necessary for Alaska, Hawaii, and Puerto Rico.

3.3.3 <u>Selection of Representative Cases</u>

A selection from the beam-coverage models presented in Figures 3-5 through 3-10, plus several others not included here to save space, was made as follows:

1. <u>Time Zone Beam</u>

   Of the single aperture examples, the coverage shown in Figure 3-3 was chosen because, although its gain is lower than that of Figure 3-2, it is not as sensitive to slight satellite altitude changes. The poor gain in western portions of the central time zone is not really a problem, as in most cases the mountain zone beam could actually be used in these areas. With three additional extra-continental beams, then, this becomes the seven-beam model.

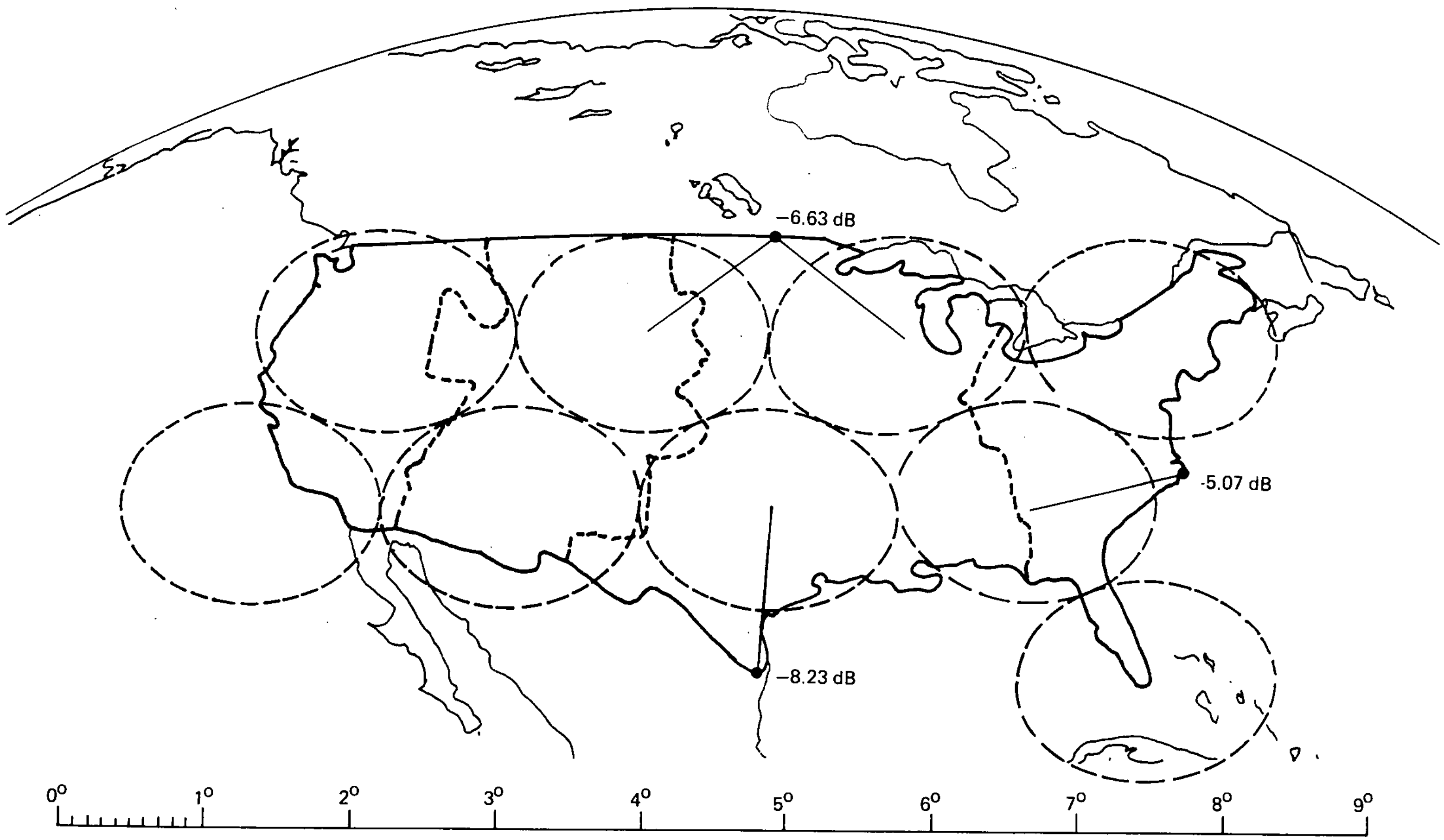


Figure 3-5. Beam Coverage With Nine Beams (Elliptical) 1.32° x 1.75°, Gain = 42.05 dBi, 3.25-dB Contours

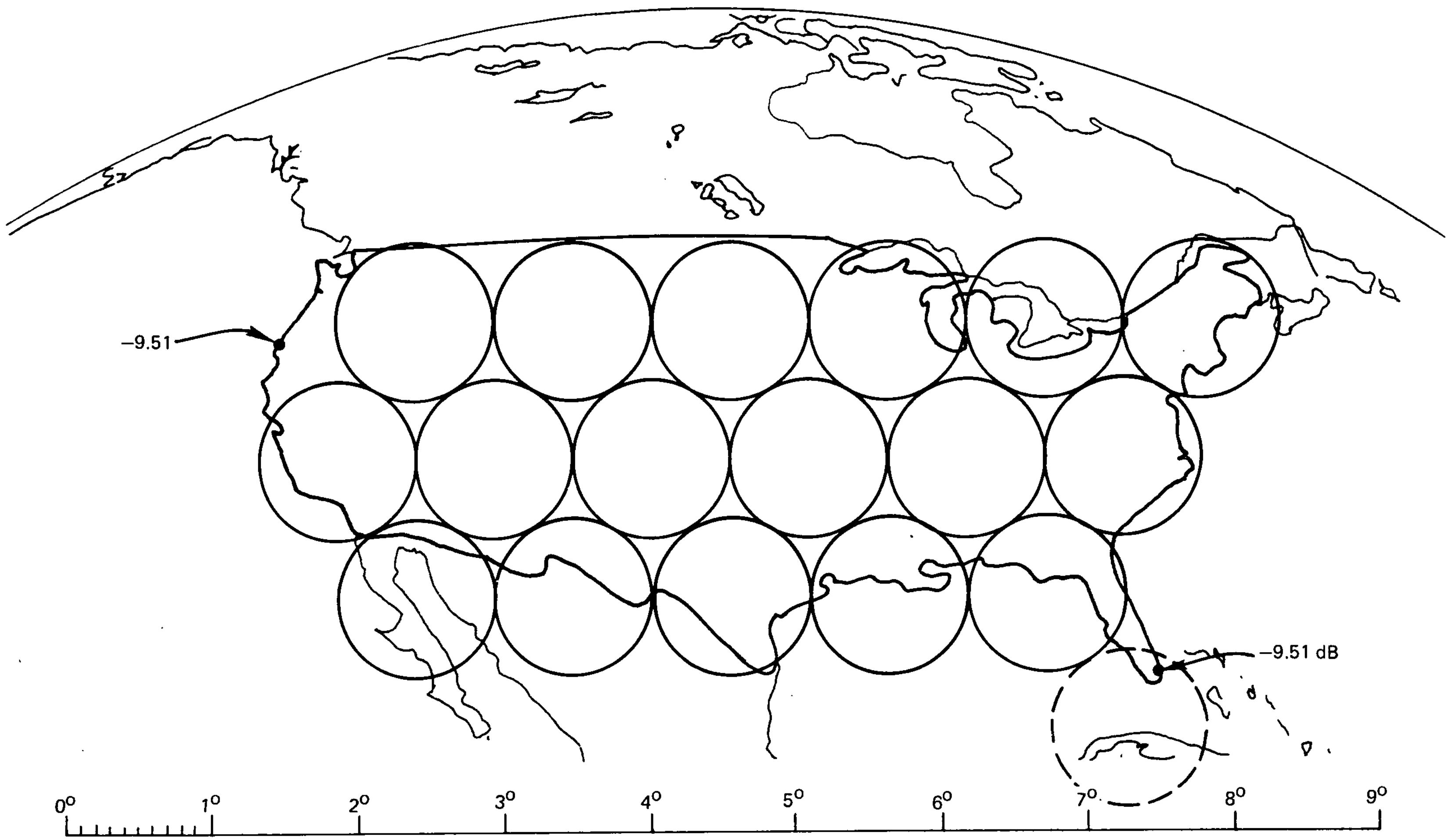


Figure 3-6. Beam Coverage With 17 Beams, Beamwidth = 1.07°, Gain = 45.08 dBi

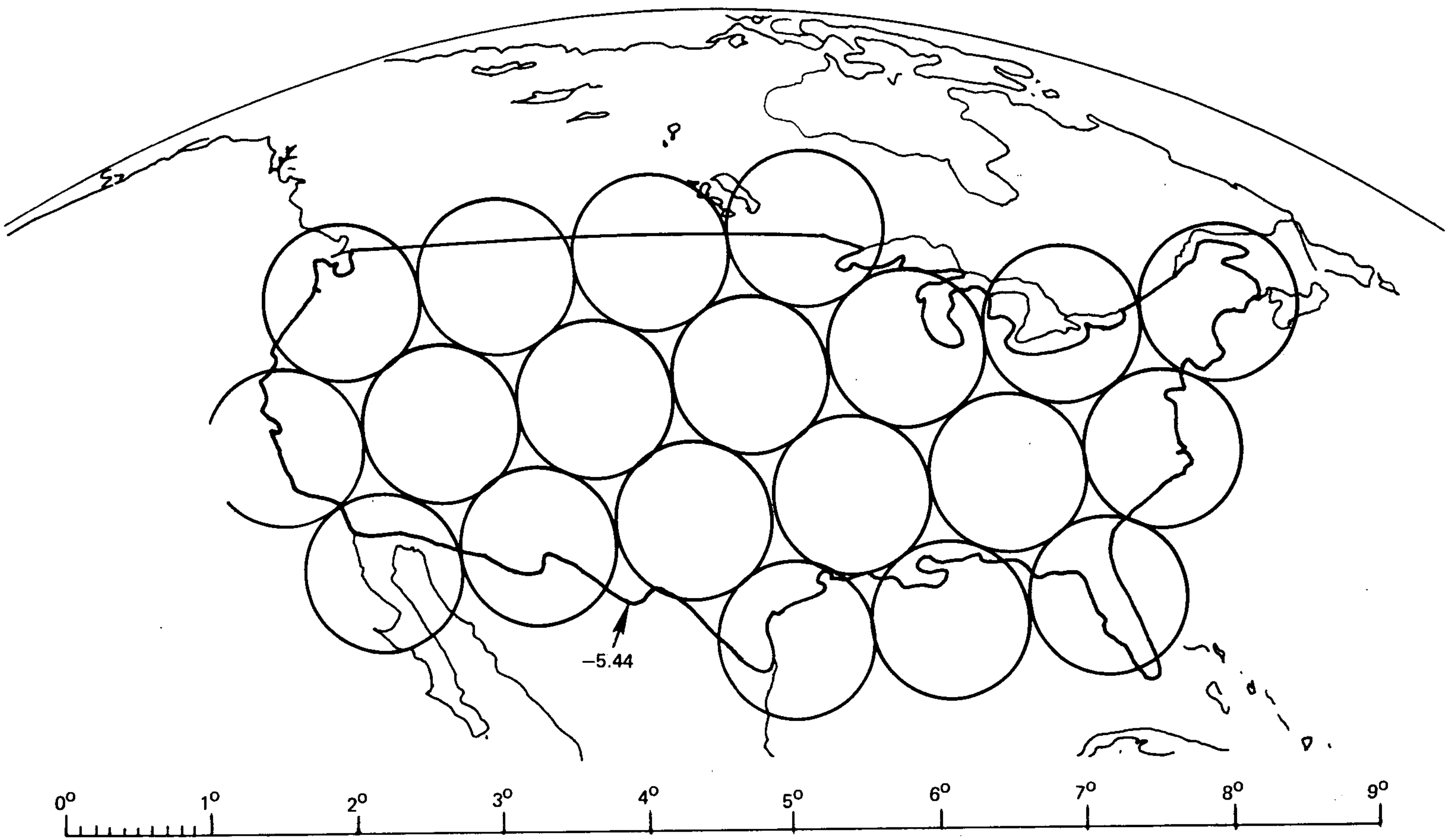


Figure 3-7. Beam Coverage With 20 Beams, Beamwidth = 1.07°, Gain = 45.08 dBi

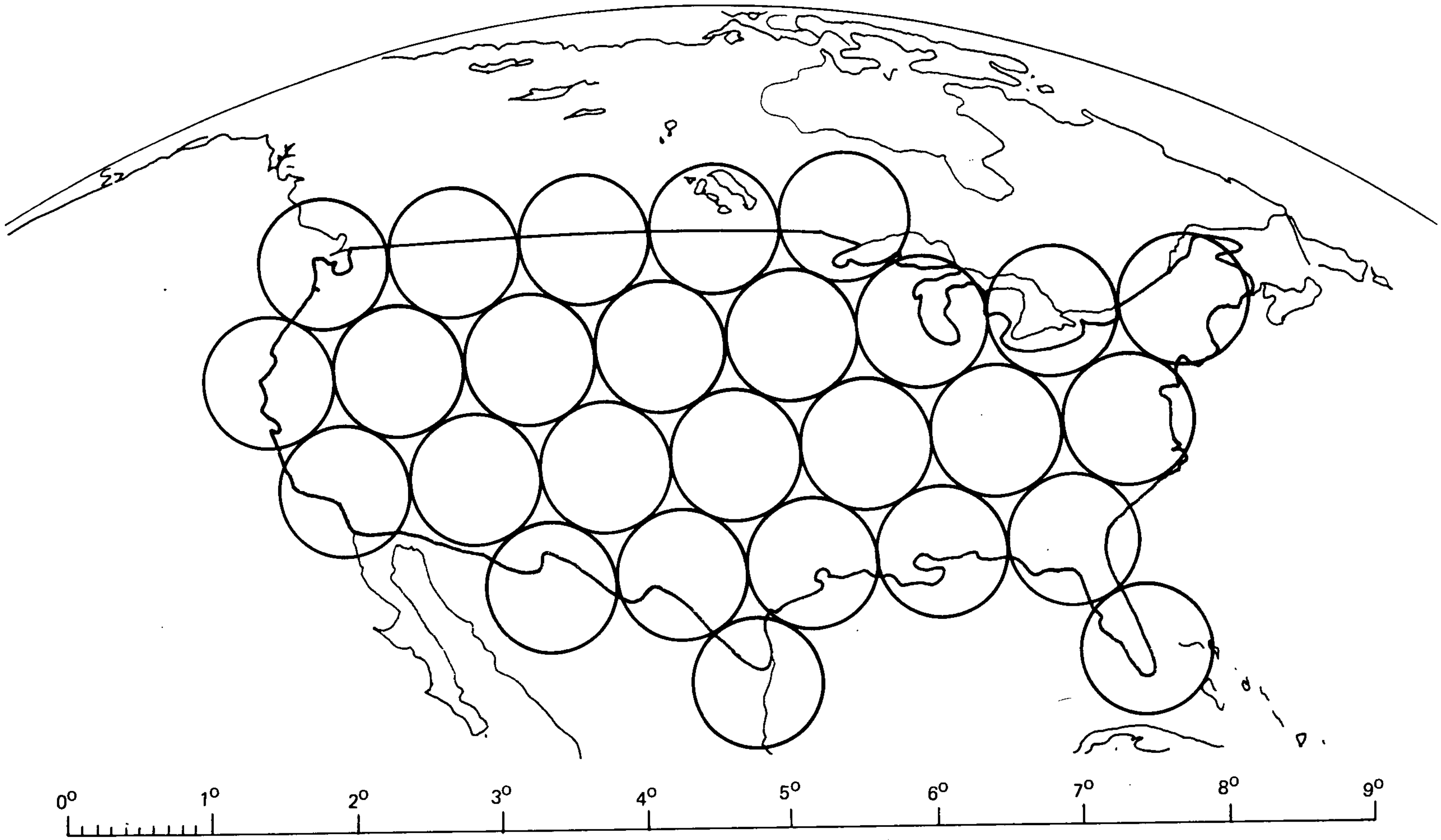


Figure 3-8. Beam Coverage With 27 Beams, Beamwidth = 0.9°, Gain = 46.60 dBi

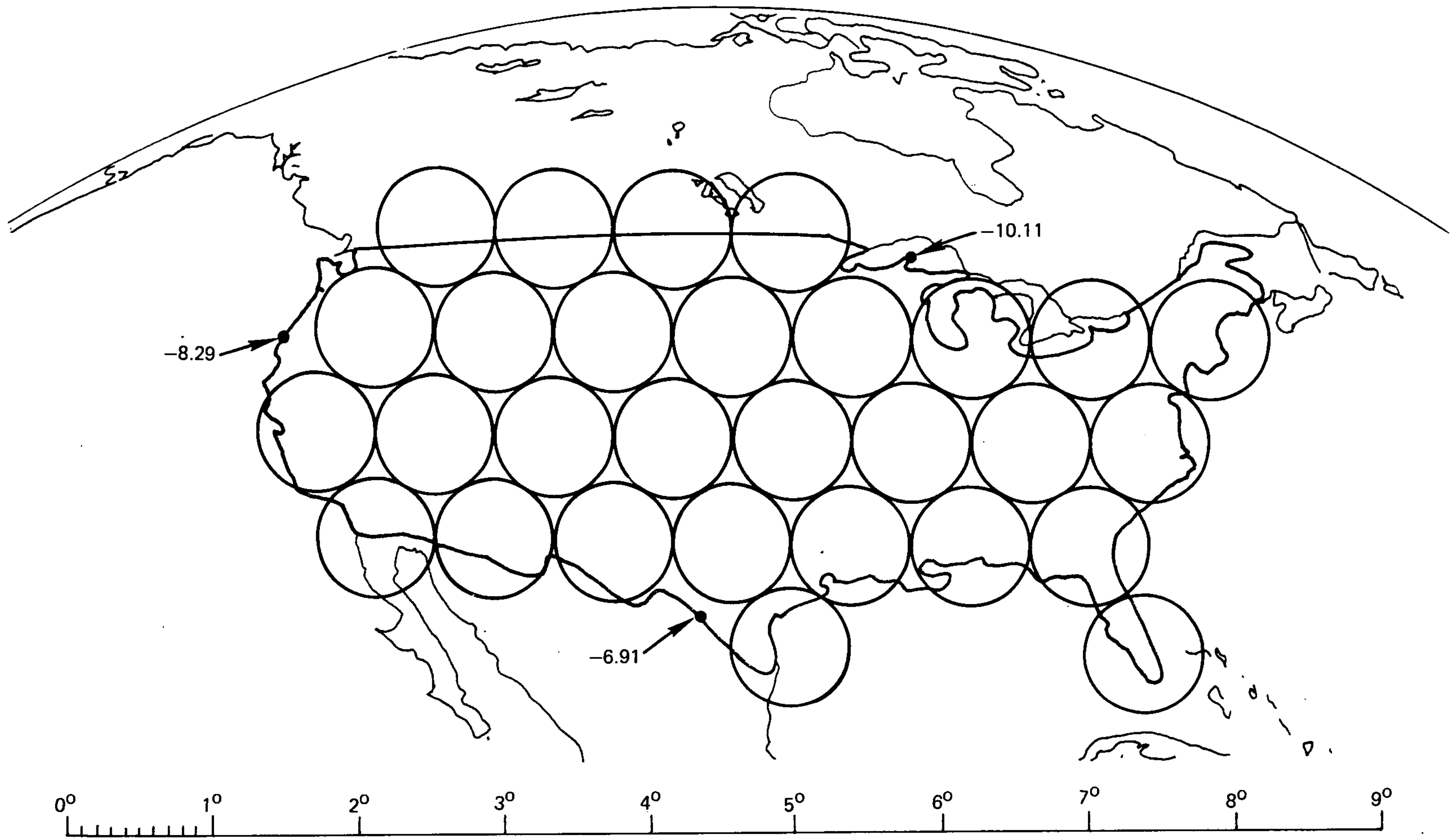


Figure 3-9. Beam Coverage With 29 Beams, Beamwidth = 0. 8°, Gain = 47. 62 dBi

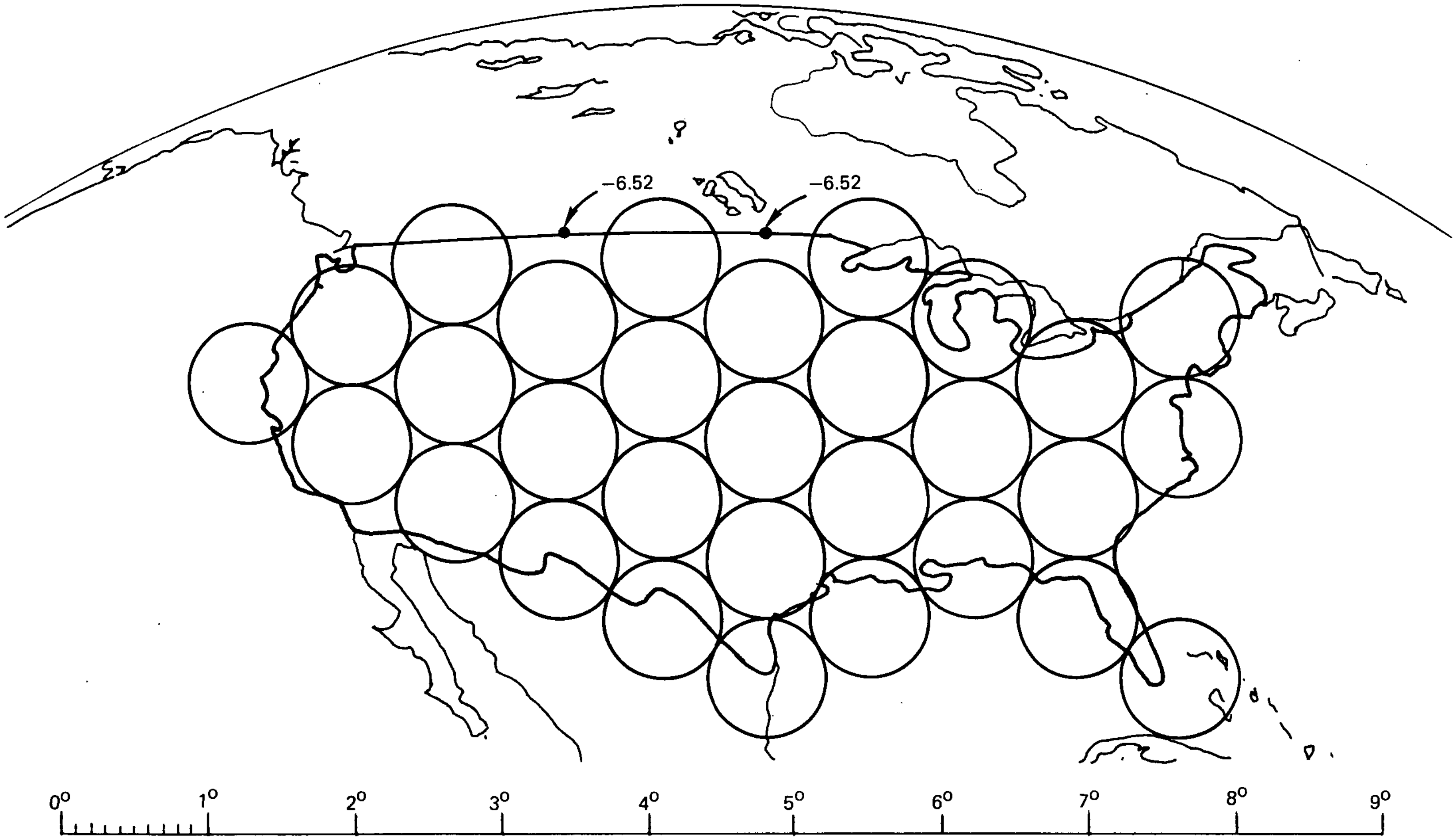


Figure 3-10. Beam Coverage With 30 Beams, Beamwidth = 0.8°, Gain = 47.62 dBi

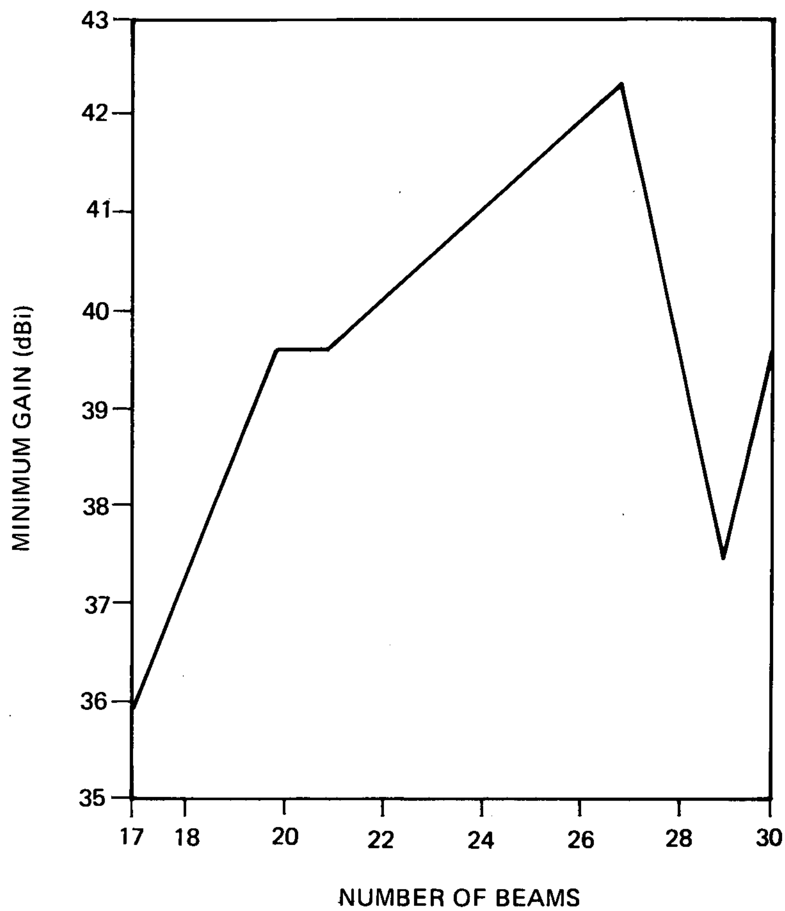


Figure 3-11. Minimum Gain in the Coverage Area Versus Number of Beams

2. Nine Beams

This appears to be a good compromise between many multiple beams and time zone coverage. With three additional zones, this is the 12-beam model.

3. Multiple Beams

The 20- and 27-beam cases (hereinafter, the "23" and "30" beam cases) are good choices according to Figure 3-11, and are representative.

These four models (7, 12, 23, and 30) appeared to be a good, well distributed selection of candidate beam-coverage models.

3.3.4 Cell-to-Beam Assignment

3.3.4.1 Introduction

Since the geographic cells (see Paragraph 2.3.2.2) and the beam-coverage contours differ in size and shape from one another, it is necessary to assign to each beam the cells to which it approximately corresponds. The procedure for doing so is necessarily somewhat arbitrary. For one particular beam model, it is far better to have started immediately by organizing the requirements according to beam number; i.e., specifying the beam number for each requirement. But here a parametric approach over a number of beam models was necessary. The arbitrariness is not detrimental, for even when working directly with the beam coverages, it would have been necessary to select beam assignments for specific earth terminal service areas, yet earth terminals are not always located near metropolitan areas. Furthermore, when the beams are large, only a few cells near the edges are in question, while when the beams are small, there must be a large number of them and so the overall system sensitivity to cell reassignments would be quite small.

3.3.4.2 Assignments

Two criteria were used to determine which cells belonged within each beam:

1. Which beam covers the greatest proportion of a cell's area?

2. Which beam best serves the major city or cities within a cell?

The assignments and the assumed antenna gain for service via each beam are shown in Tables 3-2 through 3-5. The gain was estimated according to the rule:

> "A beam's assumed gain within a given cell is the lowest gain value pertaining to any location in that cell, with reasonable exceptions for water areas, areas of very low population density if not very far from denser areas, and closely adjacent metropolitan areas."

The gain values are approximate and to the nearest dB.

3.4 INTERBEAM INTERFERENCE STUDIES

3.4.1 Introduction

One of the justifications for adopting multiple beams on communication satellites is the ability to reuse spectrum, i.e., to use the same frequency allocation in more than one beam simultaneously, the reuse contingent upon the pattern and polarization isolation between beams. One of the more surprising results of this study has been that although multiple beams do allow frequency reuse, this reuse does not always result in an increase in overall system capacity, depending on the nature of the requirements and the exact definition of system capacity used as a measure of system performance.

The frequency reuse issue in satellite systems is not very different, conceptually, from that encountered in mobile radio service (Reference 6) or in terrestrial line-of-sight (LOS) systems. In particular, it has been proposed recently (Reference 7) that in the limited bandwidth allocation environment now existing for private microwave LOS systems, it is more effective to use narrowband VSB or SSB modulation in lieu of FM, even though the latter has better interference resistance.

This recommendation, plus the results presented in a paper directly relevant to multibeam satellites (Reference 8), were motivating factors for a theoretical analysis of the system considerations of interbeam interference. In other words, the relationships between modulation and frequency reuse were studied, not the technical problems of achieving various degrees of beam-to-beam isolation.

Table 3-2. Time Zone Beams (For Figure 3-3)

Beam No.	Cell No.	Gain (dBi)
1	101	37
	102	37
	103	35
	201	38
	202	39
	203	36
	301	37
	302	39
	303	36
	402	38
	403	36
2	104	36
	105	37
	106	37
	204	37
	205	37
	206	37
	304	36
	305	39
	306	37
	404	36
	405	38
	406	37
	505	36
	506	35
3	107	34
	108	37
	109	37
	207	36
	208	37
	209	37
	210	35
	307	36
	308	39
	309	37
	407	36
	408	38
	409	36
3	507	35
	508	37
	509	35
	607	33
4	114	33
	211	38
	212	38
	213	36
	214	35
	310	36
	311	38
	312	38
	313	36
	410	36
	411	38
	412	37
	510	35
	511	37
	611	35
5	721	40
6	851	40
7	941	40
	961	

Table 3-3. 12-Beam Model (For Figure 3-5)

Beam No.	Cell No.	Gain (dBi)	Beam No.	Cell No.	Gain (dBi)
1	101	39	5	301	37
	102	40		402	39
	103	38			
	201	39	6	403	38
	202	42		404	40
	203	39		405	39
	302	39		505	39
	303	39			
	304	35	7	406	37
				407	39
2	104	36		408	39
	105	40		506	36
	106	41		507	39
	107	36		508	39
	204	38		607	34
	205	40			
	206	41	8	409	37
	207	39		410	39
	305	38		411	39
	306	39		412	37
	307	36		509	37
				510	40
3	108	37		511	39
	109	40			
	208	39	9	611	42
	209	41			
	210	40	10	721	42
	308	38			
	309	39	11	851	41
	310	37			
			12	941	40
4	114	40		961	
	211	38			
	212	40			
	213	42			
	214	40			
	311	37			
	312	39			
	313	40			

Table 3-4. 23-Beam Model (For Figure 3-7)

Beam No.	Cell No.	Gain (dBi)	Beam No.	Cell No.	Gain (dBi)
1	101	45	10	211	44
	102	42		212	44
	201	44		311	41
	202	42			
			11	114	43
2	103	45		213	43
	104	43		214	44
	203	41			
	204	41	12	405	40
3	105	44	13	505	42
	106	44			
	206	40	14	406	43
				407	40
4	107	42		506	43
	108	43		507	40
	109	41			
			15	408	44
5	301	45		409	41
	302	40		508	42
	402	43			
			16	410	45
6	303	44		510	40
	304	41			
	403	42	17	312	43
	404	40		313	43
				411	41
7	205	41		412	45
	305	45			
	306	41	18	607	43
8	207	42	19	509	41
	208	40			
	307	45	20	511	44
	308	40		611	42
9	209	44	21	721	43
	210	43			
	309	44	22	851	42
	310	40			
			23	941	41
				961	

Table 3-5. 30-Beam Model (For Figure 3-8)

Beam No.	Cell No.	Gain (dBi)
1	101	46
2	102	44
	103	45
3	104	43
	105	44
4	106	43
	107	43
5	108	42
6	201	42
	301	44
7	202	43
	203	41
	302	42
	303	45
8	204	43
	304	45
9	205	42
	206	45
	305	42
	306	43
10	207	44
	208	44
	307	41
	308	42
11	109	42
	209	45
	210	44
12	211	41
	212	43
13	114	45
	213	43
	214	44
14	402	46
15	403	42
	404	43
16	405	44
17	406	42
	407	45
18	309	42
	408	44
	409	42
19	310	44
	410	43
20	311	42
	312	45
	313	43
	412	43
21	505	43
22	506	44
23	507	42
	508	43
24	509	45
25	411	41
	510	41
	511	45
26	607	43
27	611	45
28	721	46
29	851	45
30	941	43
	961	

There is no technical reason for rejecting, a priori, SSB or VSB for video transmission in an MFR system, although the satellite ERP levels necessary are higher than with FM or digital techniques. On the other hand, FM and PCM have excellent interference resistance which might counteract the apparent capacity decrease arising from the wide bandwidths required. Thus, the bandwidth versus modulation hardness of potentially competing techniques such as SSB, VSB, FM, and digitized transmission needed to be compared for FDMA solutions. In a TDMA (switched beam) system there is less latitude for modulation selection, but interbeam interference as a limitation on frequency reuse is nevertheless an important issue. In the MFR system, the high proportion of video requirements implies that TDMA solutions should be considered only for voice and data transmission. Consequently, the emphasis in the analysis which follows is on FDMA and analog systems, because it is the video (analog) requirements in MFR which necessitate high frequency reuse.

The problem, then, is one of maximizing the total satellite capacity through the application of frequency reuse (reassignment) on the multiple downlink beams. It has often been assumed or implied that FM, for example, because of its hardness or resistance to interference, is superior to techniques such as SSB, which have no bandwidth expansion. The following paragraphs show that for a system with constrained bandwidth this may not be true. It will also be desirable to compare the overall performance of various modulation techniques when applied in a multibeam, frequency reassigned environment.*

It will be shown that, for the analog/FDMA case, instead of using high bandwidth-expansion modulations that can resist the high interference level which occurs because of the extensive frequency reassignment necessary to accommodate a large number of channels within limited total bandwidth, it may be better to use a narrower technique, such as SSB, with poor interference rejection capability but with little frequency reuse necessary and therefore little interference occurring.

*The problem is analogous for uplink frequency reuse, except that with many broadcast requirements predominating, the uplink occupancy is much lower than the downlink and much less reuse is necessary.

It is also shown that for readily achievable antenna sidelobe pattern models and common modulation techniques, increasing the number (therefore decreasing the beamwidth) of beams covering a given fixed area is either: (1) detrimental in terms of system capacity when requirements covering large geographical areas predominate, or (2) advantageous only in terms of satellite RF power savings (but not in the total capacity determined by allocated bandwidth), if point-to-point requirements predominate. A direct tradeoff would then be possible between the satellite weight impacts of the reduced power and the increased repeater and antenna complexity. Thus, an optimization of the number of beams is possible for a given requirements set.

The theoretical analysis in Paragraph 3.4.2 and the application in Paragraph 3.4.3 are for FDMA systems, particularly with analog video requirements. In Paragraph 3.4.4, the duality between time and frequency is used to extend the concepts to switched repeater TDMA systems.

3.4.2 Theoretical Analysis

3.4.2.1 Approximating the Total Interbeam Interference

The theoretical case of an infinite field of closely packed ("billiard ball" or triangular arrangement) circular beams, all energized at equal power, is analyzed in this paragraph, based in part upon Reference 8.

It is assumed that the antenna beam sidelobe envelope obeys the formula:

$$G(\Theta) = \frac{G(O)}{1 + (\Theta/\Theta_o)^m} \tag{3-1}$$

where Θ_o = half the 3-dB beamwidth

m = sidelobe taper parameter, typically in the range 2 to 3

$G(O)$ = peak gain, at $\Theta = O$

It will now be shown that the total interference experienced in a given coverage area can be approximated by a product of the interference from one interfering beam and a function of m.

Suppose the frequency reassignment algorithm is such that a uniform reuse spacing is achieved, i.e., no matter which beam is considered, its angular geometric relationship to its frequency-sharing partners is the same. Regardless of the absolute reuse spacing, then, reuse partners are always located at the vertices of equilateral triangles. The beam for which the interference level is being evaluated can then be considered to be at the center of a hexagon, and at the vertices of the hexagon are located the six nearest reuse partners (e.g., #1 in Figure 3-12). Six more partners are located twice as far away (#2 in Figure 3-12), and six others are $\sqrt{3}$ angle units* away (#3 in Figure 3-12). The triangles in this figure are not those whose sides are formed by the adjacent beam-to-beam centers. See Figure 3-13 for the relationship between these two sets of triangles. Next we wish to determine the possible "sizes" of these triangle sides. Let $k = \theta_i/\theta_o$, where θ_i is the angular reuse spacing. The

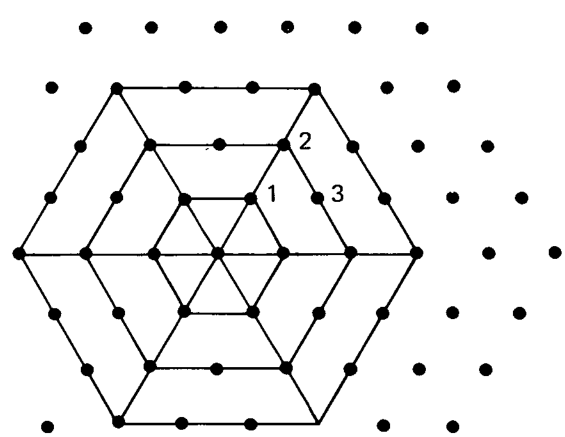


Figure 3-12. Geometrical Arrangement of Reuse Partners

*The length of a triangle side.

closest possible frequency reuse plan occurs with $k = 2\sqrt{3}$, the next with $k = 4$, and so on, according to the rule $k = 2\sqrt{N}$, N integer,* as shown in Figure 3-13. The sides of the triangles in Figure 3-12 can take on any such value of k. Using the sidelobe model of

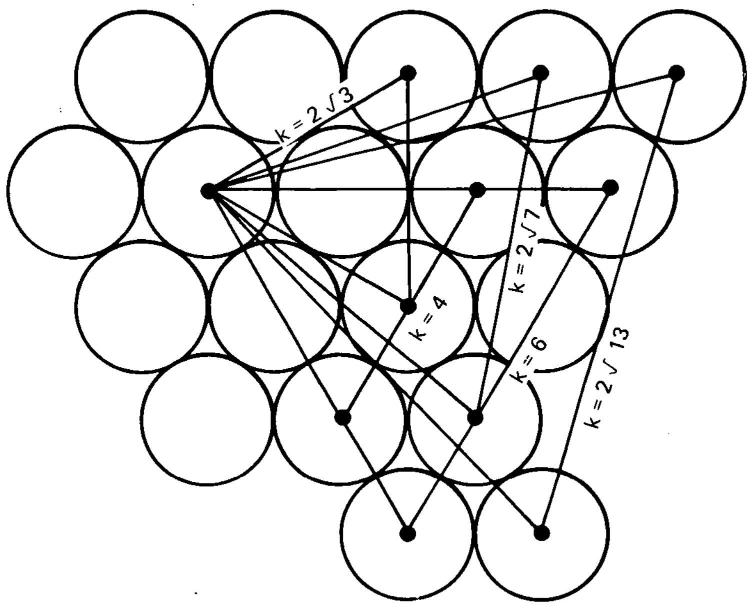


Figure 3-13. Equally Spaced Frequency Reuse Plans

**Not all values of N are permissible; for those that are, N is the number of different frequency bands provided. There is also a minor discrepancy in the assumption that the beams are "3-dB wide" instead of 3.25 dB as in Paragraph 3.3.

Equation (3-1), and assuming that most of the interference occurs from the first three* hexagonal surrounding groups, for example, the interference seen at the center of the central beam is:

$$I_T = 6I_k + 6I_{2k} + 6I_{\sqrt{3k}} + 6I_{3k} + 12I_{2.74\,k} \qquad (3\text{-}2)$$

where, for example, I_{2k} is the interference from the reuse partner spaced 2k away. These are:

$$I_k = \frac{G(O)}{1 + k^m},$$

$$I_{2k} = \frac{G(O)}{1 + (2k)^m}$$

and so on. It is asserted in Reference 8 without proof that the total interference can be approximated by a product of I_k and a function of m. This assertion can be proved empirically by determining whether $I_T/I_k \simeq F(m)$ for any reasonable value of k. The results of such a computation for m = 2 and m = 3 (with G(O) = 1) are shown in Table 3-6. Therefore the approximation:

$$I_T \simeq \left[\frac{G(O)}{1 + k^m}\right] \cdot F(m) \qquad (3\text{-}3)$$

is valid.

3.4.2.2 Measure of Performance in the Interference Limited Case

It was shown in the previous paragraph that the total reuse interference experienced by an earth terminal at the center of a beam's coverage footprint could be approximated as the product of the interference from only one nearby frequency reusing beam and a weak function of m. Under the assumption, once again, that all beams operate at the same power and are identical in gain, the carrier (desired signal) to interference ratio is then given by:

---

*Due to the exponential sidelobe taper model, the interference falls off rapidly after the second group.

Table 3-6. Computations Demonstrating Accuracy of

$$I_T \simeq [I_k] \cdot F(m)$$

m = 2:

k	I_T	I_T/I_k
$2\sqrt{3}$	0.9324	12.1
4	0.71	12.0
$2\sqrt{7}$	0.4128	11.9
6	0.3276	11.7
$2\sqrt{13}$	0.2212	11.7

m = 3:

k	I_T	I_T/I_k
$2\sqrt{3}$	0.206	8.8
4	0.1347	8.75
$2\sqrt{7}$	0.0585	8.75
6	0.0402	8.7
$2\sqrt{13}$	0.02324	8.72

$$\frac{C}{I} = \frac{G(O)}{I_T} = \left(1 + k^m\right) / F(m) \tag{3-4}$$

Now, k^m is greater than 1. Useful values of C/I are also positive and greater than 1. Consequently, in the region where Equation (3-4) is useful, $(1 + k^m)$ is larger than k^m, so that C/I is conservatively bounded by $k^m/F(m)$:

$$(C/I) \geq (k^m) \; / \; F(m) \tag{3-5}$$

where $k = \dfrac{\Theta_i}{\Theta_o}$

$$\left.\begin{array}{l} \Theta_i = \text{separation angle between beams which can be and are reassigned the same frequency band} \\ \Theta_o = 1/2 \text{ of 3-dB beamwidth} \end{array}\right\} \text{of satellite beams}$$

m = sidelobe decay index for antenna gain model given in Equation (3-1)

F(m) = a function of m, typically 8 to 14 dB.

Now suppose a total RF bandwidth, B_{RF}, is available independently to each set of beams which are separated enough to be reassigned the same frequency bands. Let the baseband bandwidth be B_{BB} and the bandwidth expansion factor for the jth modulation technique be R_j; then the number of baseband channels that can be accommodated in B_{RF} using the jth modulation technique is simply (assuming tight spectral packing):

$$n_j = \frac{B_{RF}}{R_j \, B_{BB}} \tag{3-6}$$

Each frequency band is reassigned every Θ_i degrees. Thus, we wish to normalize n_j to unit solid angle, or equivalently to k^2. This normalized number can also be thought of as the average number of channels per beam, within a multiplicative factor. The normalized number is designated $\dot{n}_j$. Inequality (3-5) can be solved for k, if the inequality sign is replaced by an equal sign:

$$k = \left(\frac{C/I}{F(m)} \right)^{1/m} \qquad (3\text{-}7)$$

so that
$$\dot{n}_j = \frac{n_j}{k^2} = \frac{A}{R_j \left(\frac{C}{I}\right)_j^{2/m}} \qquad (3\text{-}8)$$

where A = a constant within which have been absorbed geometric factors, B_{RF}, B_{BB}, and $F(m)^{2/m}$, all of which are assumed to be the same regardless of modulation technique

$(C/I)_j$ = the permissible carrier to interference ratio for modulation scheme j.

This formula is essentially identical with Equation (8) of Reference 8 except that the assumption that $C/I = \beta\ C/N$ has not been included.

In actual fact, the composite received signal-to-noise ratio contains thermal and intermodulation as well as interbeam noise components. Let it be assumed that intermodulation can be disregarded. With strong or interference-limited links, one can say $C/N \simeq C/I$. Provided this assumption applies in all the cases being compared, then one can write:

$$\dot{n}_j = \frac{A}{R_j \left(\frac{C}{N}\right)_j^{2/m}} \qquad (3\text{-}9)$$

The relevant tradeoff is, then, the change in bandwidth expansion versus necessary C/N between modulation schemes. Assume $m = 2$, for example. Then, if one modulation scheme has twice the bandwidth expansion but half the required C/N of another scheme, the two are equivalent when frequency reuse is applied.

SSB suppressed carrier modulation can be taken as a baseline or reference, since it has a bandwidth expansion of one and no modulation improvement ($S/N = C/N$). A graph is then constructed with one axis the bandwidth expansion, the other the modulation power improvement relative to SSB (i.e., the ratio of power required for SSB, and that for the modulation being considered, with the baseband quality assumed the same). For each value of m, a tradeoff line can be drawn, depicting how rapidly C/N must change as R changes for equal system capacity (equal $\dot{n}_j$). For example, m = 2 has a tradeoff line of slope 1, as shown in Figure 3-14. The bandwidth/power performance curves for various modulation techniques have been added, with assumptions as noted in the accompanying legend.

It is interesting to note the various ways of using such a graph. If power is the essential commodity, one is only interested in getting as high up on the plane as possible. On the other hand, maximization of overall capacity under a fixed bandwidth constraint requires one to operate as far to the upper-left area of the relevant tradeoff line as possible. It can be seen from Figure 3-14, for example, that not all applications of wideband modulation are desirable. Any modulation scheme which cannot trade power at least as quickly as the bandwidth expands, i.e., stay along the diagonal tradeoff line, will not be competitive with SSB! In an environment where bandwidth is not as important as power, one strives not to come close to the tradeoff line, but rather to maximize power effectiveness, i.e., choose points as high up vertically as possible.

One may draw the following conclusions from Figure 3-14:

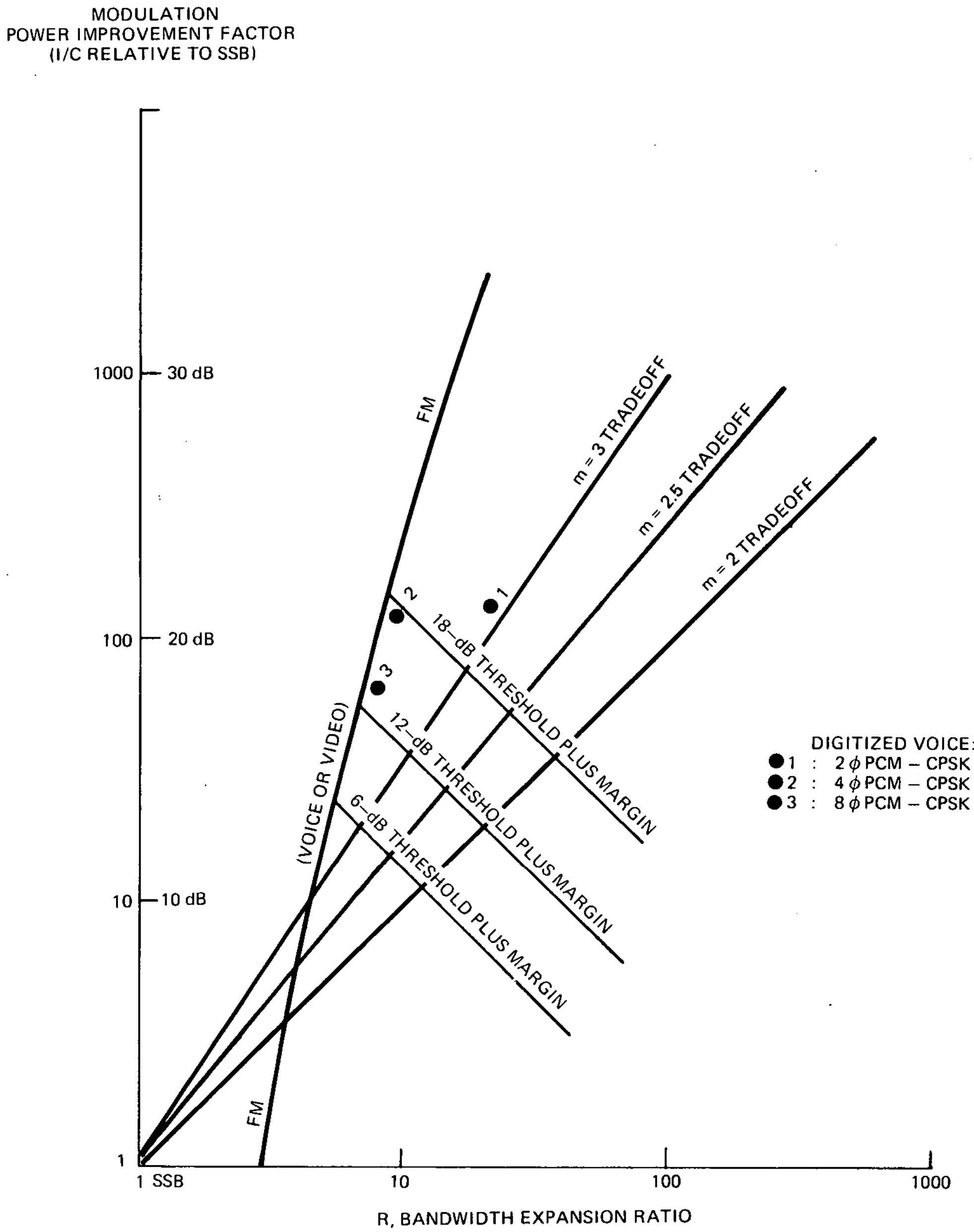
1. FM outperforms SSB only under appropriate operating conditions. These conditions may not always be practicable because of the necessity of operating above threshold.

2. For the operating parameters chosen, PCM-PSK digitized voice performance is about the same as single channel FM.

It is shown in Paragraph 3.4.4.4 that digitized transmission is not attractive for video.

3.4.2.3 Performance in Other than Interference Limited Case

The previous discussion was for $C/N \simeq C/I$. However, this is not usually the case. In the more prevalent situation where thermal noise is present, the comparison among modulation techniques is less straightforward because, as the bandwidth expansion changes, the RF bandwidth and therefore the total amount of noise changes.



NOTES:

1. PCM–PSK POINTS BASED ON 5–BIT QUANTIZATION AND $P_e = 10^{-4}$
2. FM AND FDM–FM CURVES TURN AROUND BECAUSE THRESHOLD IS REACHED, AND ABOVE THIS POINT, MORE POWER MUST BE USED IN ORDER NOT TO DROP BELOW THRESHOLD EVEN THOUGH QUALITY IMPROVES
3. FM CURVES ASSUME THAT THE DEMODULATED S/N WITHOUT PREEMPHASIS, NOISE WEIGHTING, OR PEAKING FACTOR, FOR A SUITABLY CHOSEN TEST TONE IS 30 dB FOR BOTH VIDEO AND VOICE

Figure 3-14. Power Bandwidth Tradeoff

The basic equation is given here once again:

$$\dot{n}_j = \frac{n_j}{k^2} = \frac{A}{R_j \left(\frac{C}{I}\right)_j^{2/m}} \tag{3-8}$$

The relationship between (C/I) and (C/N) for each case under scrutiny must be established. Since particular link parameters are involved, a tradeoff cannot be made in a parametric fashion. However, consider the following. Let:

N_{th_o} = thermal noise power for R = 1

γ_j = backoff factor needed to operate repeater for jth modulation.

C_j = total carrier power received from desired beam without backoff

Then $$(N)_j = R_j N_{th_o} + \gamma_j I_j \tag{3-10}$$

$$(C)_j = \gamma_j C_j \tag{3-11}$$

so that $$(C/N)_j = \frac{\gamma_j C_j}{R_j N_{th_o} + \gamma_j I_j} \tag{3-12}$$

which can be solved for C/I:

$$\left(\frac{C}{I}\right)_j = \frac{1}{\frac{1}{(C/N)_j} - \frac{R_j N_{th_o}}{\gamma_j C_j}} \tag{3-13}$$

Substituting in Equation (3-8),

$$\dot{n}_j = \frac{A}{R_j \left[\frac{1}{\frac{1}{(C/N)_j} - \frac{R_j N_{th_o}}{\gamma_j C_j}}\right]^{2/m}} \tag{3-14}$$

This unwieldy formula reduces to Equation (3-9) if N_{th_o} is negligible. Otherwise, it does not appear to provide much general insight. However, suppose m = 2. Then the formula can be reduced to

$$\dot{n}_j = \frac{A}{\left[\frac{1}{(C/N)_j R_j} - \frac{N_{th_o}}{\gamma_j C_j}\right]} - 1 \tag{3-15}$$

Equating system performance among techniques amounts to keeping $\dot{n}_j$ the same (constant). If $N_{th_o} = 0$, then $\dot{n}_j$ will be constant if $(C/N)_j R_j$ is constant, thus, the "dB-for-dB" tradeoff. If $N_{th_o} \neq 0$, then the entire term

$$\frac{1}{(C/N)_j R_j} - \frac{N_{th_o}}{\gamma_j C_j}$$

must be constant regardless of the index j (i.e., regardless of the modulation technique). This means that, for m = 2, at least, if γ_j and C_j are invariant with j, the second term $N_{th_o}/\gamma_j C_j$ is a constant, and thus holding $(C/N)_j R_j$ constant is again necessary and sufficient to keep $\dot{n}_j$ constant. In other words, the addition of thermal noise does not change the dB-for-dB tradeoff rule, and modulation/interference evaluations can be made without concern for thermal noise. When m does not equal 2, however, the specific cases in question must be evaluated.

3.4.2.4 Finite Beam Number Considerations

In the previous analysis, the following assumptions were made:

1. It was assumed that all beams are equivalent in power and bandwidth.

2. The analysis was based on an infinite field of closely packed beams.

Short of an analysis performed for the specific traffic and beam patterns in question, the first assumption is necessary. It is equivalent to the system homogeneity assumption made in multiple satellite interference analyses. The second assumption need not be made, however.

The number of beams considered in this study is far from infinite. Therefore, one would expect, in the finite beam case, an interference level (when frequency reassignment is used) lower than with an infinite field. There are several ways of demonstrating this; for example, suppose the finite field is considered to be a subset of an infinite field. If the same frequency assignment rule is followed in both cases, the interbeam interference experienced in a beam of the finite case will clearly be less, since fewer neighbor beams exist with the same frequency assignment.

From another point of view, it is clear that one might wish to minimize the degree of frequency reassignment in a finite field, particularly if the coverage area is unsymmetrical or is not equal in all dimensions. For example, with a rectangular area as k is increased (decreasing reassignment), the value of Θ_i in question (where $\Theta_i/\Theta_o = k$) eventually becomes greater than the rectangle's narrow side. When this occurs, a beam in the center is no longer completely surrounded in all directions by beams on the same frequency, and the interference falls rapidly. This highlights an important distinction with the finite field: it is possible, by using as many orthogonal bands as there are beams, to reduce interference to zero. In the infinite beam case, the interference never falls to zero (with finite bandwidth). Thus, whereas the infinite field situation leads to straightforward and smooth formulas for the bandwidth versus interference tradeoff, the finite field case possesses a zero-interference benchmark, which must always be better than any case where frequencies are reassigned. Therefore, one can compare directly only a limited number of examples, each of which has some (nonzero) degree of frequency reassignment, for their interference level versus spectrum reuse. In the practical case, however, it will be seen that the zero interference benchmark can also be included.

Such considerations suggest that in the finite field case the power (interference resistance, actually) versus bandwidth expansion tradeoff may be biased in the direction of lower bandwidth. An example is provided in the following paragraph.

A simple example of 32 closely packed (billiard ball or triangular arrangement) beams was constructed. Four frequency reuse plans were considered:

1. Plan A, with three frequency bands
2. Plan B, with four frequency bands
3. Plan C, with seven frequency bands
4. Plan D, with 16 frequency bands.

The frequency assignments for each plan are illustrated in Figure 3-15. The sidelobe model of Equation (3-1) applies. Consequently, the relative gain from an interfering beam k beamwidths away is simply $(1 + k^m)^{-1}$, and the total interference experienced in a given beam coverage area of a given model is the sum of interferences from all beams assigned the same frequency band. For example, in Plan A, beam No. 12, the fourth beam from the left in the second row, experiences interference from:

1. Five beams spaced $k = \sqrt{3}$ away
2. Two beams spaced $k = 2\sqrt{3}$ away
3. Two beams spaced $k = 3$ away.

The interference levels were computed for various values of m (2, 2.5, and 3), for the "center" No. 12 beam area and for an "edge" No. 28 beam area, for each of the four plans. The C/I for each case is summarized in Table 3-7. It can be seen that the interference drops as the amount of reassignment decreases.

If Plan D is taken as the baseline, so that with it narrowband (R = 1) modulation is used, and the total RF bandwidth, 16 B_{BB}, is kept fixed, then with the other three plans, a larger R can be allowed. For example, in Plan B there are only four bands, so that each can be 4 B_{BB} wide and the bandwidth expansion is 4. The interference increase versus bandwidth expansion can then be plotted, as in Figure 3-16. This is very similar to Figure 3-15, except that it applies to the finite beam example under the constraint that 16 B_{BB} is exactly, no more and no less, the total allowable spectrum occupancy.

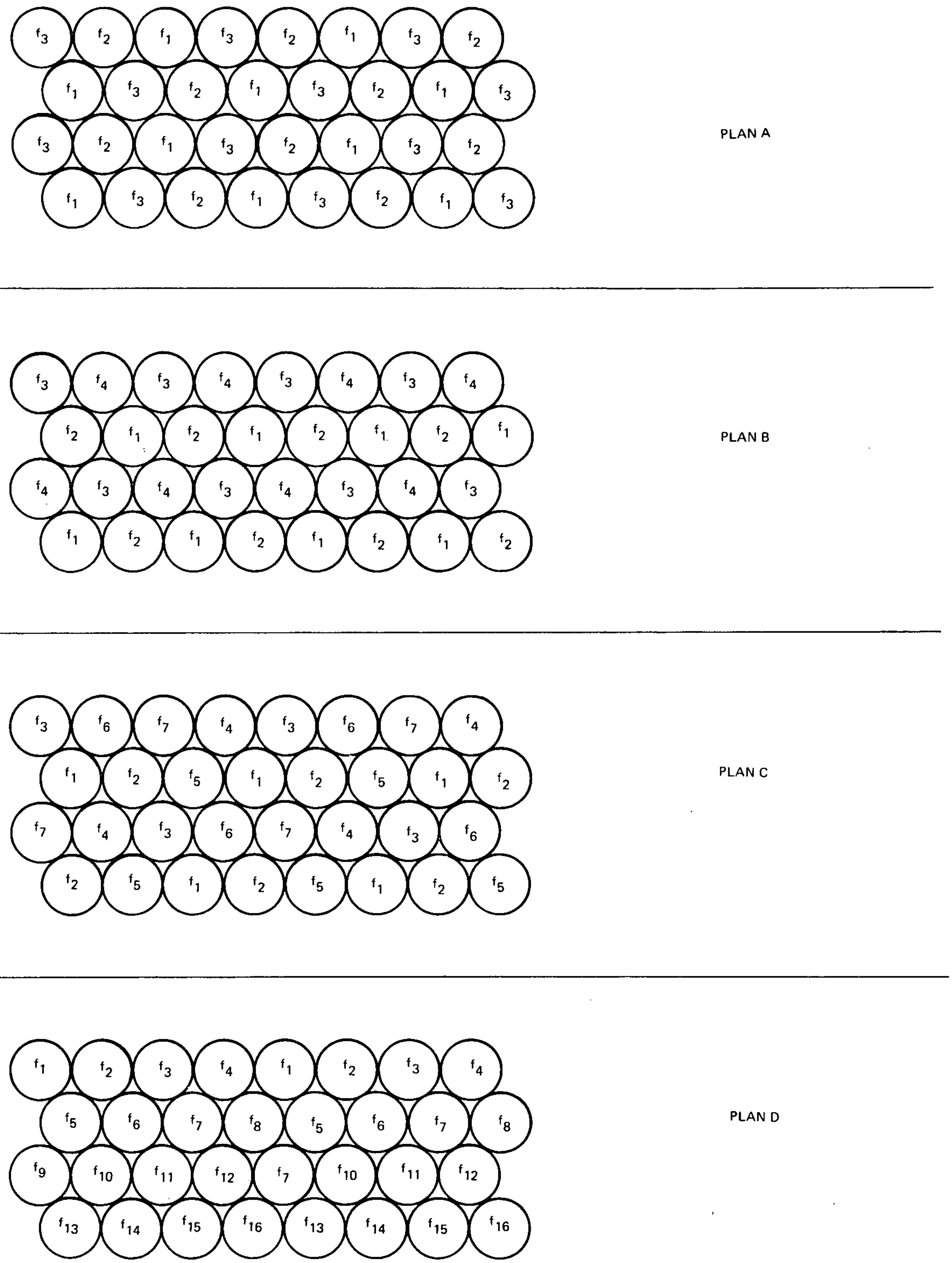


Figure 3-15. Frequency Plans

Table 3-7. Total Relative Interference Levels for 32-Beam Finite Example

Plan	Beam Area	Carrier to Interference Ratio (G(O)/I)		
		m = 2	m = 2.5	m = 3
A	Central (#12)	0.6	0.8	1.1
	Edge (#28)	0.8	1.0	1.5
B	Central or Edge	1.0	1.4	2.0
C	Central	1.7	2.1	3.5
	Edge	1.7	2.6	4.0
D	Central or Edge	17.0	33.0	87.0

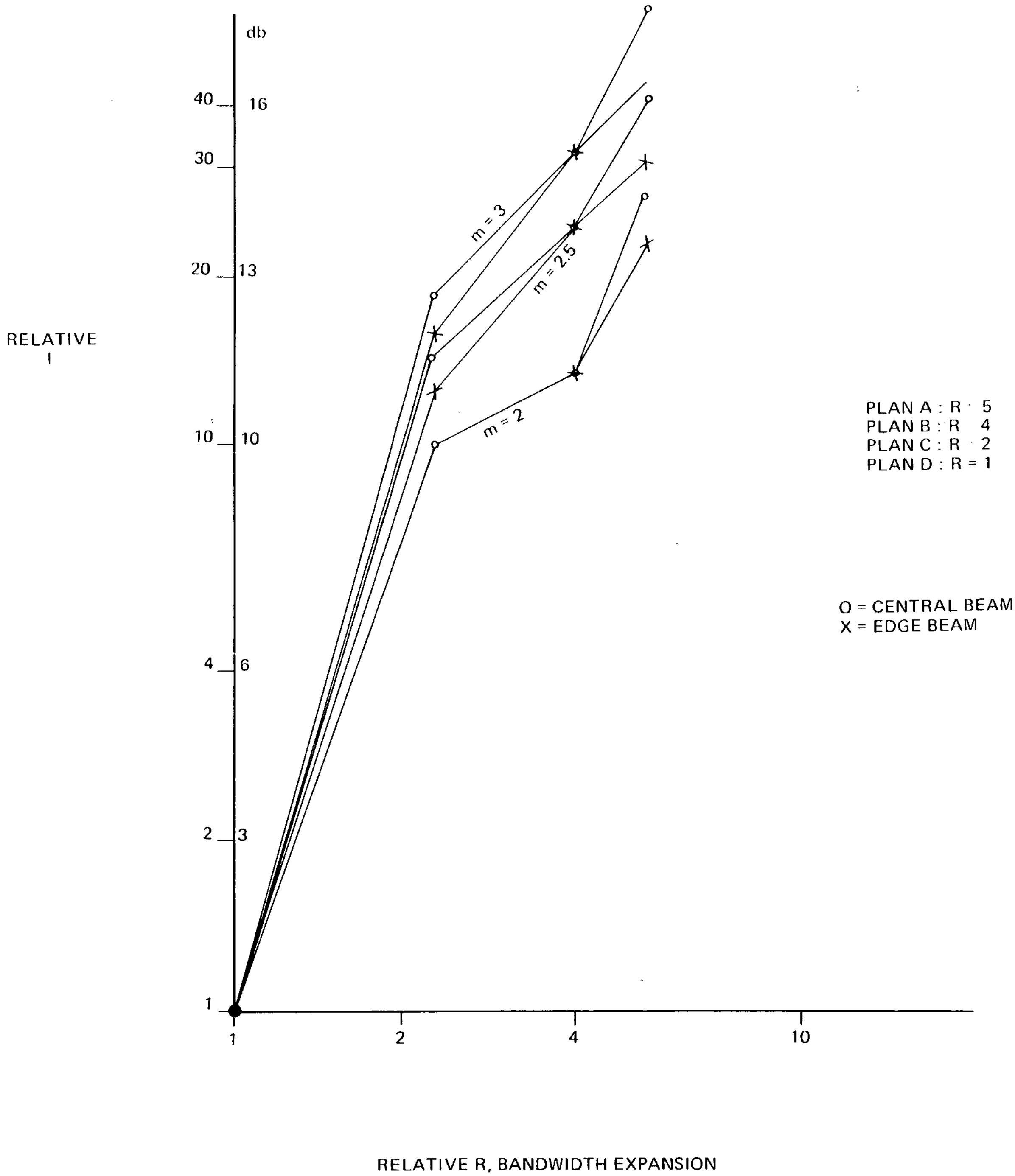


Figure 3-16. Bandwidth Expansion Versus Interference (Relative to Plan D)

It is evident that the curves are much steeper than in the infinite field case, confirming the intuitive feeling that the tradeoff will be biased towards narrowband techniques.* It may be argued that the C/I values in this example are ridiculously low for any practical system. While true, it does illustrate the trend, and also emphasizes the fact that in practice only small degrees of frequency reuse can actually be employed. Consequently, the theoretical advantages of high R modulations, such as FM or PCM-PSK cannot actually be employed in systems with finite numbers of beams. Only if the number of beams were extremely large could sufficient reuse be applied without exceeding practical C/I values. This is an extremely significant result, if applied with caution. In Reference 8, the superiority of high-R modulations was illustrated. What has been demonstrated in this example, however, as well as in the practical application to follow, is that for any reasonable number of beams a sufficient degree of isolation cannot be achieved to make use of the interference resistance of these modulations. As a result, the promised capacity improvement over SSB cannot in fact be achieved, and SSB yields greater capacities for the range of signal-to-noise ratios normally of interest.

The approach illustrated in this paragraph was then applied to specific beam patterns and requirements applicable to MFR. This is treated in Paragraph 3.4.3.

3.4.3 Application of Frequency Reuse to Actual Beam Models (FDMA)

3.4.3.1 Introduction

As has already been implied in the preceding paragraphs, frequency reuse (reassignment) is necessary in a multibeam satellite whenever the number of beam-channels is large. The alternative, a separate nonoverlapping band for every beam, results in bands which are too narrow for substantial capacity, if 500-MHz total allocation and video transmission are considered.

Therefore, the approach indicated in the previous paragraphs needed to be applied to the actual beam models which were selected as representative. In general, it would be possible to do an extensive automated search for each model, matching the particular requirements on an hourly basis with the particular beam models. However, a manual procedure was adopted which proved entirely adequate for the purposes of the repeater

*Because the desirable side of the tradeoff line is to the left.

design effort. The frequency reuse plans and concurrent analysis also lent considerable insight into some fundamental properties and constraints of multiple-beam repeaters.

The emphasis in this area was on the video (and high rate digital) applications. It is these links, which, by virtue of their high bandwidth, emphasize the importance of frequency reuse. Voice and medium/low rate digital requirements for the multifunctional repeater are not large enough to warrant as much attention to frequency reuse. Therefore, the material which follows applies to video transmission in particular. Digital transmission via the same repeater channels is also assumed, but is less demanding in both power and bandwidth than video, so the all-video solution is a good worst-case baseline.*

3.4.3.2 Assumptions and Constraints

The results to be presented are based on analyses performed under the following assumptions:

1. Two modulation techniques for analog video transmission were chosen - VSB and FM. Single channel per carrier was assumed for both. The use of two modulation techniques must not be taken to imply a direct comparison between the two.

2. The following performance parameters applied:

	VSB	FM
C/kTB_{RF}	40 dB	15 dB
B_{RF}	5 MHz	25 MHz

The performance parameters with FM are quite adequate to achieve better than TASO grade 1. On the other hand, the VSB parameters are marginal and special measures must be applied. First of all, the 5-MHz channel bandwidth requires transmission of the sound by some means other than on

*At least in the FDMA case. For TDMA a distinction between video and data may be more important.

the conventional 4.5-MHz subcarrier. The 40-dB C/N is not sufficient for TASO grade 1, not to mention CCIR standards. Some or all of the following steps would be adopted:

a) Partial suppression of the carrier, with reinsertion at the receiving terminal,

b) Reduction in the 4-dB difference between the video and the synchronization peak level.

c) As an alternative to these steps, the modulation could be inverted (i.e., positive instead of negative-going modulation).

Even with these measures, the VSB and FM performances are not comparable; as will be seen, the terminal size differences make direct comparisons invalid.

3. Total allocation - 500 MHz.

4. Sidelobe model:

$$G/G(\Theta) = 1 + (\Theta/\Theta_o)^3$$

Although m = 3 is optimistic, the formula itself applies to sidelobe envelope, and on the average, the sidelobe levels may be somewhat lower.

5. Polarization discrimination improvement = 20 dB. That is, the interference from a reuse partner beam is reduced an additional 20 dB by making its polarization opposite in sense to that of the beam under consideration.

This is an optimistic value, but it may be achievable with linear rather than circular polarizations and the use of two separate satellite antennas, as has sometimes been suggested.

6. Earth Terminal G/T - Initially, a G/T of 30 dB/°K was chosen for both FM and VSB operation. This value is consistent with relatively inexpensive (community and institution) earth terminals. However, the first repeater sizing exercise indicated repeater prime power requirements in the 20- to 60-kW area for VSB. By increasing the terminal size to 42 dB/°K, the

powers become more reasonable. The additional 12 dB can be obtained by 10 dB more antenna gain (3.1 times the diameter) and 2 dB better noise temperature. This makes the FM and VSB solutions not comparable in a direct manner, but shows two distinct approaches for two very different methods of system utilization. The FM solution has limited capacity but uses small earth terminals; the VSB has greater capacity but requires larger terminals.

In addition, the following qualitative assumptions were used. First, that the interbeam interference problem under study pertained to the downlink (i.e., satellite radiation was being considered). The amount of frequency reuse on the uplink is much less than on the downlink, due to the large degree of fanout performed (which stems from the large proportion of single source to multiple destination requirements). In most cases, little or no reassignment on the uplink would be necessary, and the interference arising from any small degree needed would be far exceeded quantitatively on the downlinks. Second, all frequency reuse plans, as opposed to solutions with no reuse, implicitly apply to equal-loading-in-each-beam traffic models; that is, in the sequel, those solutions that list "n channels per beam" apply to a satellite where every beam operates with n channels,* and beam powers are approximately the same. Some requirements patterns, e.g., with emphasis on each of the coasts of the U.S., could result in total satellite capacity greater than with all beams equally loaded, while others with heavy demands in immediately adjacent beams could result in a lower capacity. The effects of unequal beam powers would also have to be calculated for an actual system design. The all-equal assumption serves as a good baseline for determining orders of magnitude.

The third qualitative assumption is a decision which depends on repeater structures and impacts repeater design. It may be described by pointing out that operation of two adjacent beams on the same frequency and with the same signal (say by splitting the output of one amplifier and feeding two adjacent beams) is not allowed. If the same channel (program, etc.) is to be transmitted into two or more adjacent areas, it must

*Therefore, all have equal bandwidth spectrum assignments.

be fanned out in the satellite and translated to separate frequencies. While the common signal approach is attractive from a spectrum utilization point of view, it requires careful phase matching in the signal paths to prevent interference effects on the ground between the adjacent beams' signals. It also reduces the flexibility of the repeater for other connectivity patterns.

3.4.3.3 General Procedure, FDMA Systems

The frequency reuse plans shown in Figures 3-17 through 3-20 were prepared. The numbers (such as -17.10, -8.44, 5.07 dB) on these illustrations are explained in Paragraph 3.3.2, where the maps are first presented in this Report. They are not germane to the present discussion. In each case the best or most uniform arrangement apparent for the particular number of bands involved was chosen. No particular beams were favored in minimizing interference. In addition to the plans illustrated, a fully orthogonal plan (as many frequencies as beams) will be considered in some cases. Alaska, Hawaii, and Puerto Rico are included in the illustrations, but not to scale. The numbers of bands selected are not comprehensive, but are representative and exhibit relatively well behaved or symmetrically arranged distributions for purposes of analysis.

Each plan was then analyzed for:

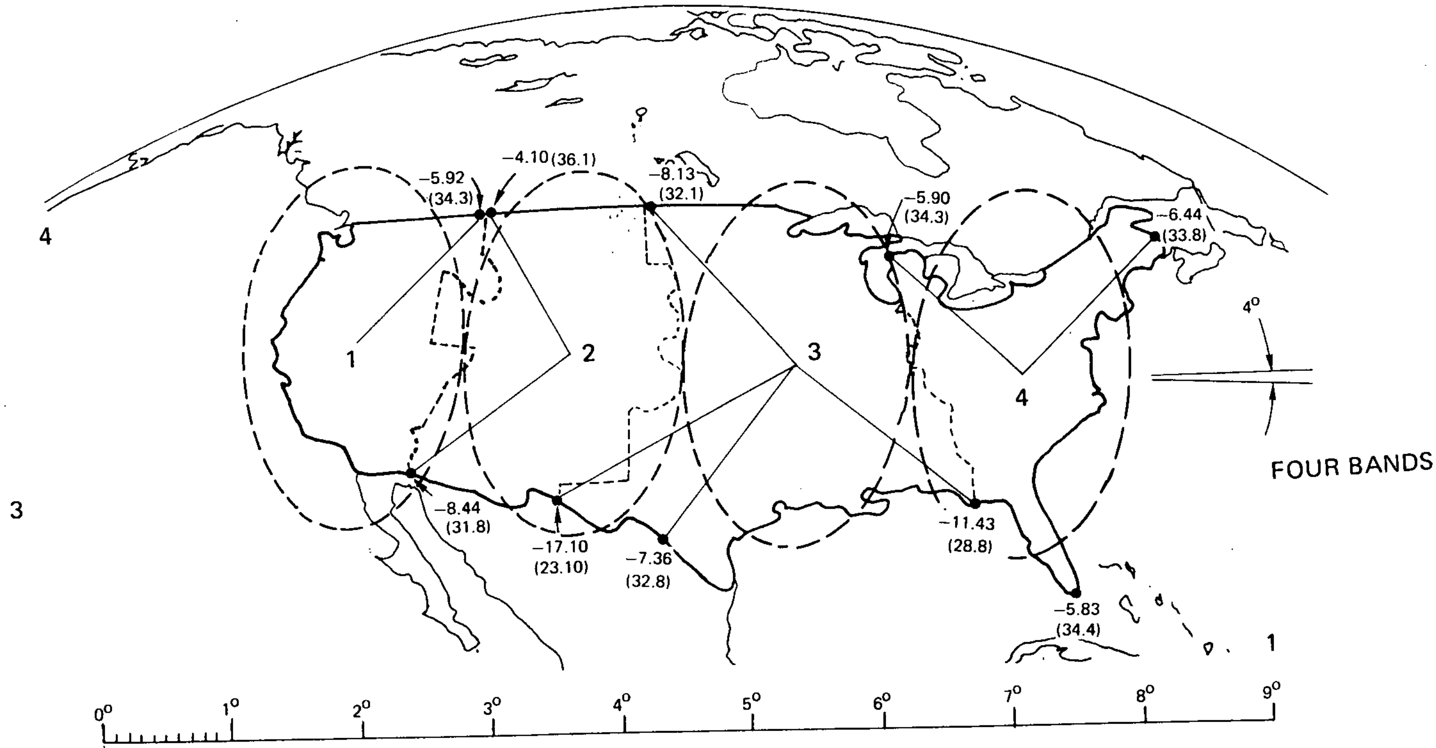
1. Bandwidth per band (theoretical, assuming all bands equal and no guard band waste).

2. Interference level in worst location of worst beam, assuming every beam operates at same power level, using sidelobe model previously discussed. When used, 20-dB polarization alternation improvement* was assumed.

3. Frequency reuse factor, defined as the number of beams divided by the number of bands. The usefulness of this will become clear when TDMA solutions are considered.

This information is shown in Table 3-8.

*From one beam to another of opposite sense. In some cases this means a full 20-dB improvement for the worst case; in others with many sharing partners, the improvement is less, as little as 3 dB.



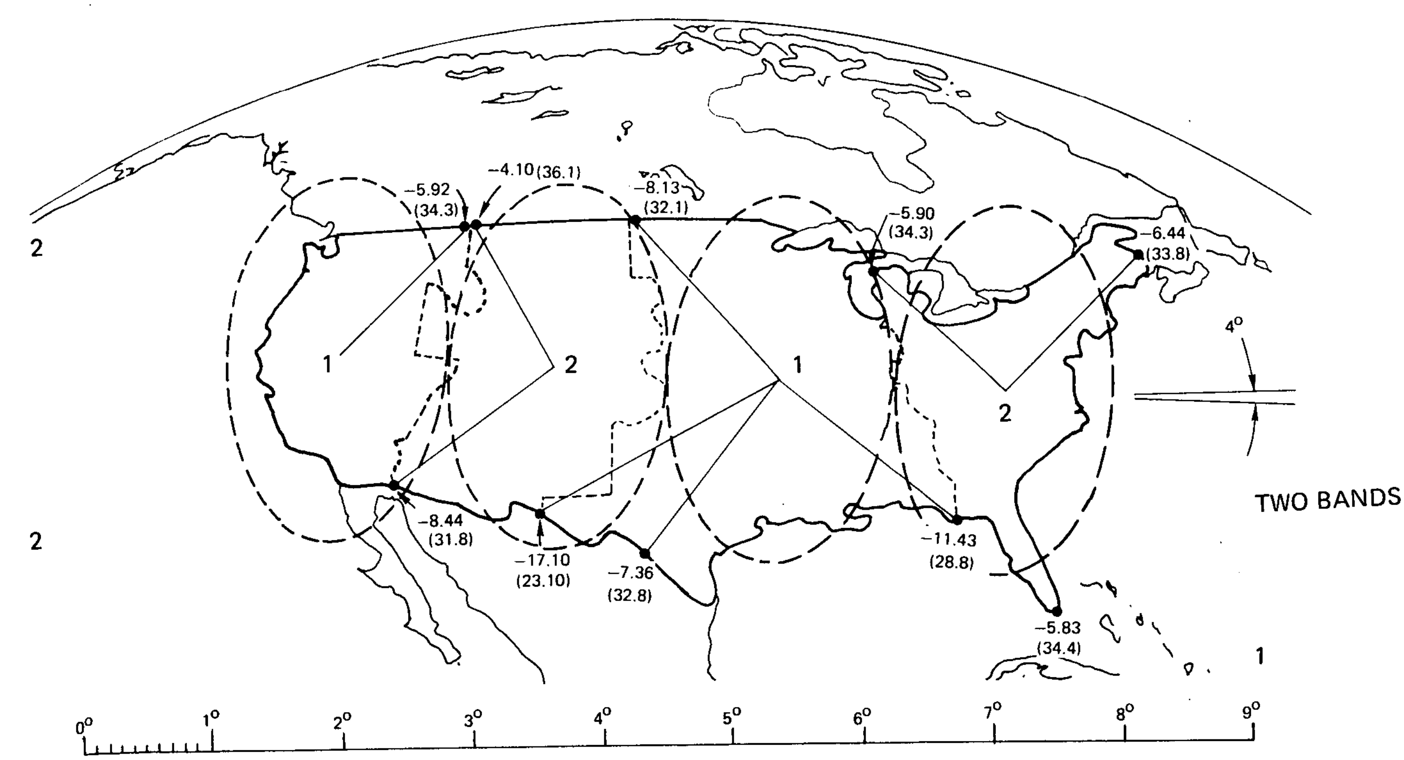


Figure 3-17. Seven-Beam Frequency Plans

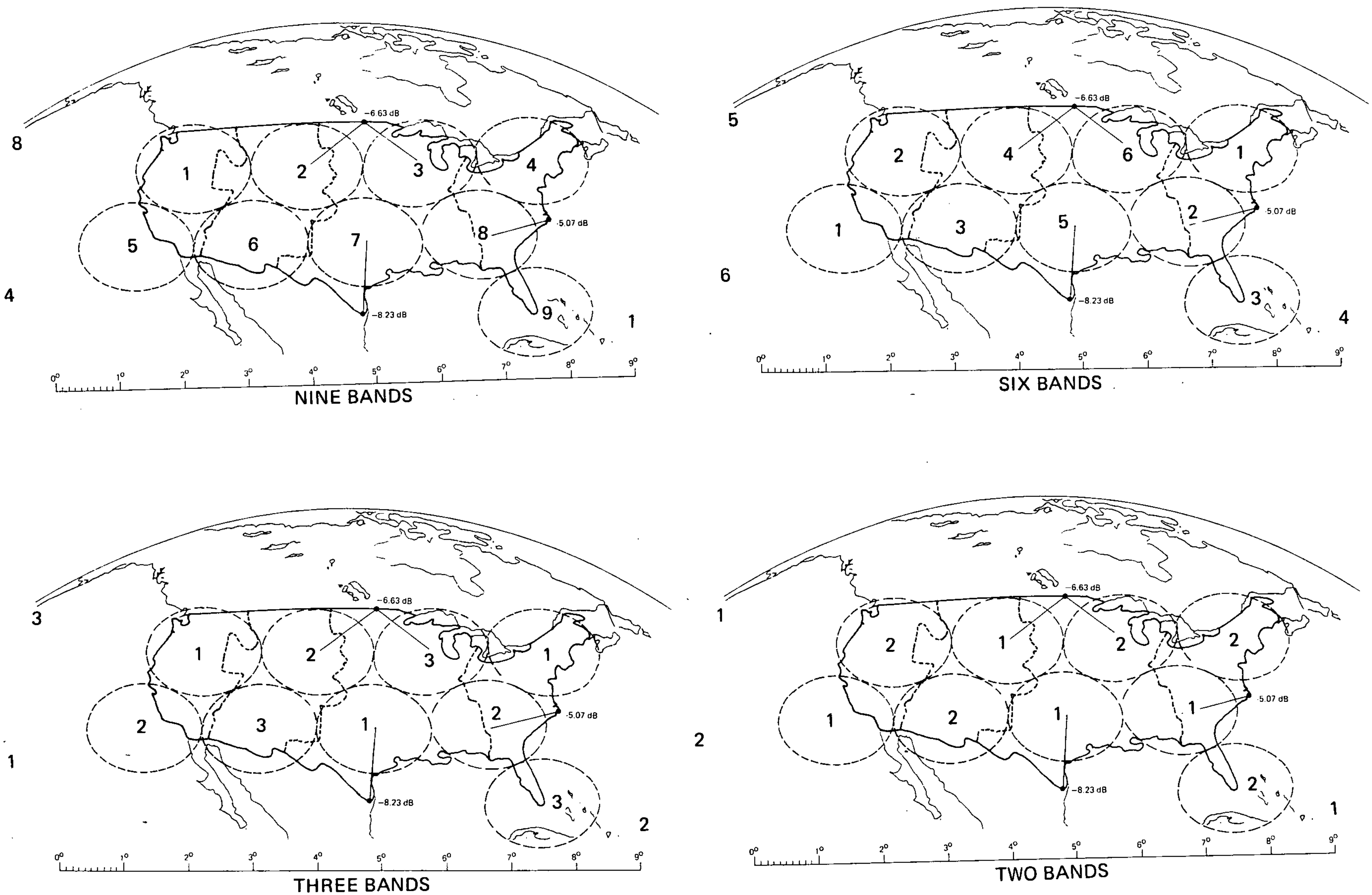


Figure 3-18. 12-Beam Frequency Plans

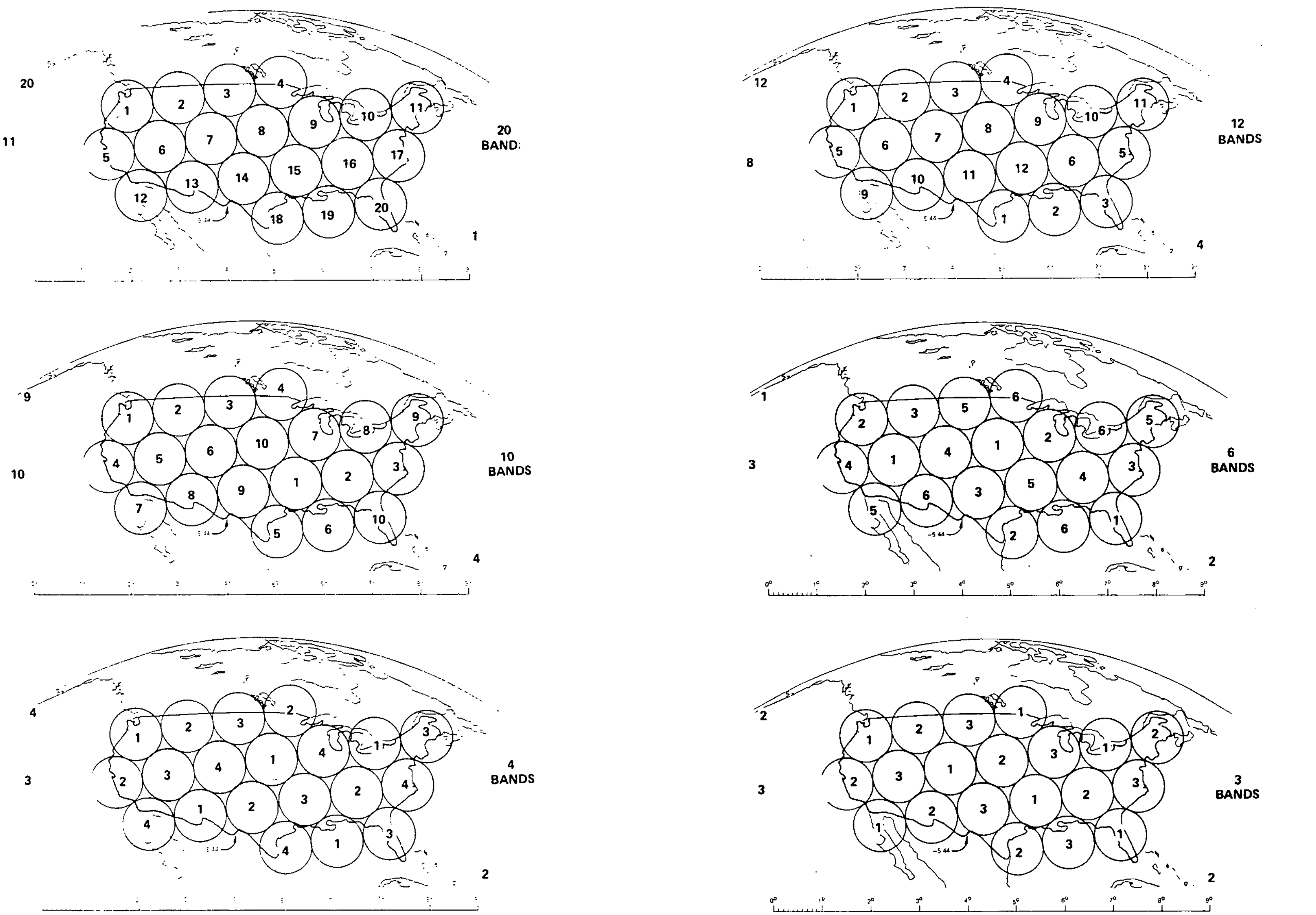


Figure 3-19. 23-Beam Frequency Plans

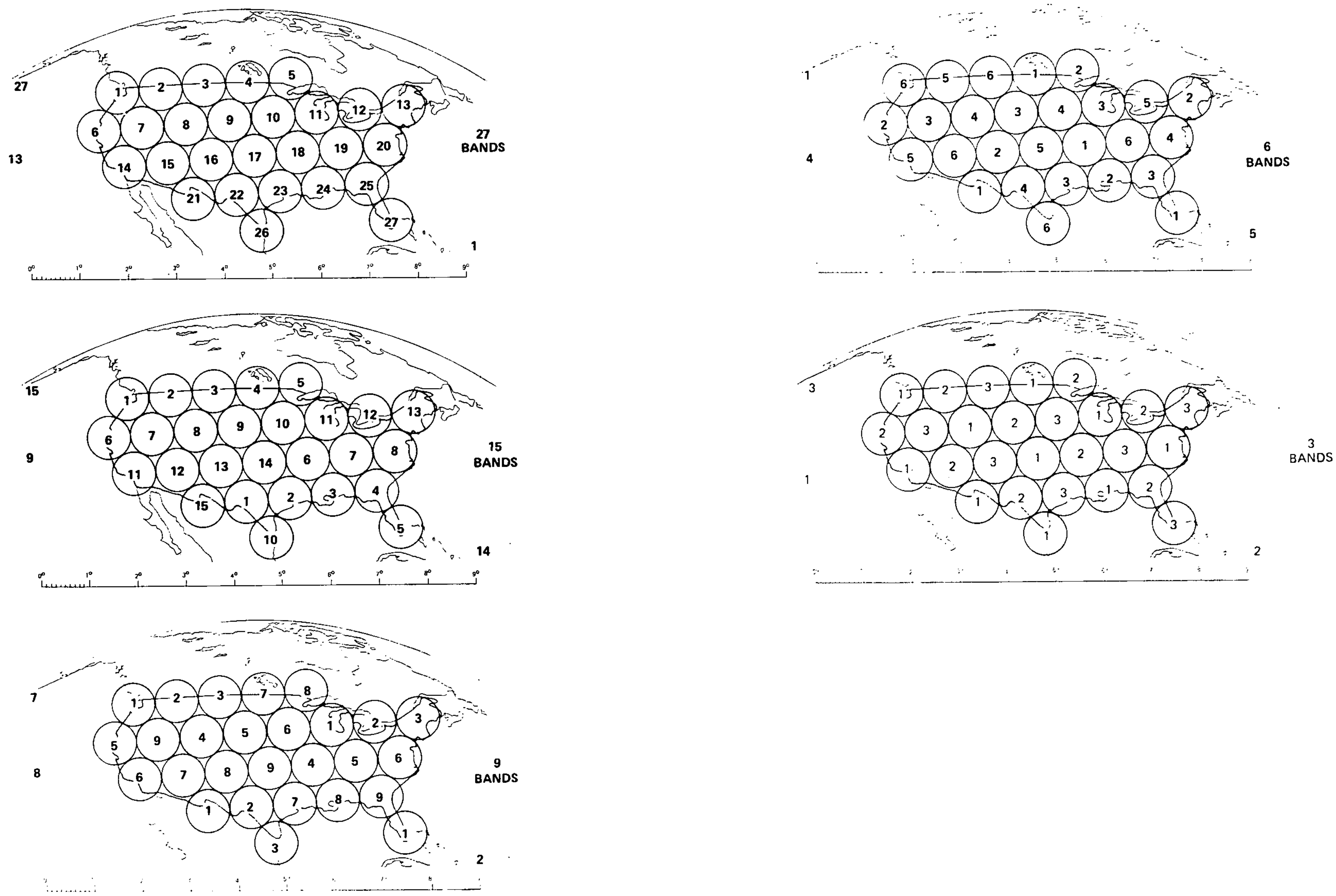


Figure 3-20. 30-Beam Frequency Plans

Table 3-8. Frequency Reuse Plans

Beam Model	Number of Bands	Frequency Reuse Factor	Approximate Bandwidth of Each Band (MHz)	Interference	
				No Polarization Alternation	With Polarization Alternation
7	7	1	70	None	None
	4	~ 2	125	Negligible	Negligible
	2	~ 3	250	- 12 dB	- 32 dB
	1	7	500	0 dB	- 12 dB
12	12	1	40	None	None
	9	~ 1	55	Negligible	Negligible
	6	2	85	- 20 dB	- 40 dB
	3	4	170	- 6 dB	- 20 dB
	2	6	250	0 dB	- 9 dB
23	23	1	22	None	None
	20	~ 1	25	Negligible	Negligible
	12	~ 2	42	- 27 dB	- 47 dB
	10	~ 2	50	- 20 dB	- 40 dB
	6	~ 4	85	- 15 dB	- 20 dB
	4	~ 6	125	- 8 dB	- 14 dB
	3	~ 7	170	- 5 dB	- 8 dB
30	30	1	16	None	None
	27	~ 1	18	Negligible	Negligible
	15	2	33	- 20 dB	- 40 dB
	9	~ 3	55	- 20 dB	- 30 dB
	6	5	85	- 11 dB	- 14 dB
	3	10	170	- 5 dB	- 8 dB

3.4.3.4 Performance of FDMA Systems and Selection for Further Analysis

The two selected modulation techniques for FDMA analog video transmission are VSB and FM. The minimum acceptable C/kTB for these was selected as 40 and 15 dB respectively. The protection ratios (C/I), when the interference consists of only a few signals similar to the desired signal, should then be close but not identical to these values. Reference 9 gives a 34- to 36-dB value for VSB, while Reference 10 implies a protection ratio of about 25 dB for FM with the parameters used here. However, FM interference performance is strongly related to the existence of discrete line components in the signal spectrum. Therefore, with the application of slight frequency offsets, as done in TV broadcasting, it should be possible to achieve satisfactory performance at a C/I of 20 dB, especially when multiple rather than single interferers are involved.

Thus, one may select from Table 3-8 those reuse plan/beam model combinations which meet the minimum C/I criteria established and which supply a reasonable number of channels per beam. The preliminary requirements analysis showed that on the order of 10 channels per beam were required regardless of beam model.

In Table 3-9, therefore, the most viable combinations are shown. The average beam channels are values derived from the requirements analysis (Paragraph 4.1) as desired for each beam model. The RF power listed pertains to the power level necessary to either achieve the bandwidth-limited maximum with beams equally loaded or to meet the actual beam-by-beam requirements given by the analysis.

The systems shown in Table 3-10 were selected for further analysis.

3.4.3.5 Observations from Results

The following observations are made, based on the data in the preceding paragraph, particularly Table 3-9.

1. There is a clear transition in the desirability of VSB over FM as the number of beams increases.

Table 3-9. Power and Bandwidth for Viable Systems

Model	Average Beam Channels	Modulation	RF Power** W	Code	Frequency Reuse Plan* (Bands)	Maximum Number of Channels Per Beam*	Comments
7	75	VSB	160	B	7	14	
			190	A	4	25	
		FM	200	B	2	10	
12	140	VSB	100	B	12	8	
			150	B	9	11	
			180	A	6	16	Marginal C/I of 40 dB
		FM	140	B	3	6	Marginal C/I of 20 dB
23	210	VSB	100	B	12	8	
			150	B	10	10	Marginal C/I of 40 dB
		FM	70	B	6	3	Marginal C/I of 20 dB
30	260	VSB	70	B	15	6	Marginal C/I of 40 dB
		FM	30	B	9	2	

*Assuming equal loading in all beams, and G/T of 30 dB/°K for FM, 42 dB/°K for VSB.

**The lower of the powers necessary either to meet the requirements approximately or achieve the bandwidth limited capacity with all beams equally loaded.

Code A = Requirements met
B = BW limited value met

Table 3-10. Systems Selected For Further Analysis

Beams	Modulation	Frequency Reuse Plan (Bands)	Power Per Beam, Watts	Channels Per Beam*	Total Channels**
7	VSB	4	6 to 50	2 to 25	103
	FM	2	10 to 50	10	70
12	VSB	6	3 to 25	2 to 16	163
	FM	3	4 to 30	7	84
23	VSB	12	3 to 5	8	184
30	VSB	15	1 to 3	6	180

*If equally loaded

**As per requirements or bandwidth limited number, whichever is smaller.

2. For broadcast-related applications, large beam numbers are not desirable. The improvement in RF power is not great, while channel capacity suffers.

3. The number of beam channels is bounded by about 200 for VSB and 100 for FM, regardless of the number of beams. Therefore, the optimum number of beams is requirements related. If requirements which serve fairly extensive areas predominate, it becomes counterproductive to implement beams which cover areas smaller than those to be served. Point-to-point requirements would benefit from very small beams, of course. This conclusion would be somewhat modified if adjacent beam use of the same frequency were permitted.

4. It was necessary to postulate much larger earth terminals with VSB than with FM. Therefore, FM and VSB values must not be directly compared. Also, VSB required a more linear power amplifier in the satellite.

It is interesting to note that the total RF power is constant for a given channels-per-beam capability, regardless of beam model. For example, with VSB each channel-per-beam requires about 10 to 12 watts. Or, if eight-channel-per-beam capability is desired, it requires 100 total RF watts regardless of whether 7, 12, or 23 beams are used. These are not identical in capability, however. With smaller beams, a greater flexibility is achieved, since all the beam channels can be made distinct. A fundamental concept is illustrated: the beams should be made only small enough to achieve the desired flexibility or separability of requirements. Beyond this point, smaller beams neither save power nor increase capability through spectrum reuse. With broadcast-like requirements, therefore, the parameter of interest is "channels-per-beam," and one should stop increasing the number of beams when no improvement in total RF power requirement is noted.

It is therefore clear that if channels per beam is a design criterion, the smaller-number-of-beams models will always be chosen. This is illustrated in Table 3-11. On the other hand, the total number of channels, a criterion applicable to point-to-point

Table 3-11. Systems Arranged on Channels-Per-Beam Basis

Channels-Per-Beam	Beams	Modulation	Total RF Power (approx.), W.
6	30	VSB	70
	23	VSB	80
	12	VSB	75
	7	VSB	70
	12	FM	140
	7	FM	120
8	23	VSB	100
	12	VSB	100
	7	VSB	92
	7	FM	160
10	23	VSB	150
	12	VSB	135
	7	VSB	115
	7	FM	200
12	12	VSB	160
	7	VSB	150
16	12	VSB	220
	7	VSB	180
25	7	VSB	280

systems, is more or less constant, yet the RF power does decrease as the number of beams increases, as shown in Table 3-12.

Table 3-12. Decrease of RF Power in Relation to Increase in Number of Beams

Beams	Total Channels	RF Power (Watts)
7	175	300
12	192	200
23	183	100
30	180	70

The conclusion is that the "optimum" number of beams depends on the structure of the requirements needlines.

3.4.4 Frequency Reuse with Switched Repeaters (TDMA)

3.4.4.1 Introduction

The duality of time and frequency allows ready extension of the previous analysis to time-switched repeater concepts. In the FDMA system, interfering beams are those which operate on the same frequency band. Separate or orthogonal frequency bands are assigned to beams which are too close to one another to operate on the same band. In a purely time-division system, orthogonality between beams is achieved in the time domain, by not connecting repeater channels (transmitters) simultaneously to two beams which are too close together. Hybrid techniques are also possible, for example obtaining interbeam orthogonality via frequency channelization (bands), but performing intrabeam channel separation (therefore, multiplexing and multiple access) in the time domain.

3.4.4.2 Time-Frequency Duality

In applying frequency reuse to beam models with FDMA, the total frequency allocation band was divided into a number, say N, of equally wide frequency bands. This set of bands was reapplied to each set of N beams as many times as possible, in a geometrically uniform fashion where feasible. The frequency reuse factor was just the number of times the set of bands could be reassigned. Taking a three-band plan as an example, then, a frequency, time, and space assignment diagram may be constructed as in Figure 3-21. Beam 1 is assigned Band 1 all the time, Beam 2 Band 2, etc.* Now suppose Beam 1 could occupy the entire bandwidth (formerly divided into the three bands) for 1/3 of the time, Beam 2 for 1/3, and Beam 3 for 1/3, as in Figure 3-22. Once again, the beam transmissions are orthogonal. Also note that Figure 3-22 is just Figure 3-21 turned by 90° about the x axis. Thus, "time-band" (or slot) reuse is exactly analogous to frequency band reuse. Reassignment of a frequency band has its dual in allowing the same two beams to transmit at the same time. The reuse factor is then just the number of such synchronously switched transmitters, as illustrated in Figure 3-23 for six beams and two repeaters.

As with the FDMA discussion, the above was couched in terms of frequency band or time slot assignment on the output (downlink, transmit) side. Similar reassignment and reuse apply for the uplink receivers. In either case, the band assignments and the reuse achieved pertain to the entire composite transmission (or signal received) within a given repeater channel (beam), and are therefore applicable regardless of whether single or multiple baseband channels are handled within the repeater channels. One should not confuse the options available within each beam with the interbeam situation. However, if time slots rather than frequency bands are used for the interbeam isolation, time division methods (TDM and TDMA) are also the most appropriate for separating and organizing signals within each beam.

3.4.4.3 Bandwidth and Power Utilization

A single repeater, with its input and output switched among uplink and downlink beam ports, respectively, is the simplest and most fundamental form of time division repeater. It has no spectrum reuse, but is always power-efficient in the sense that, assuming the switches are programmable as necessary, all the repeater output power is utilized for communication signal transmission. That is, there are no time shots

*Beam 4 is (re)assigned Band 1, etc.

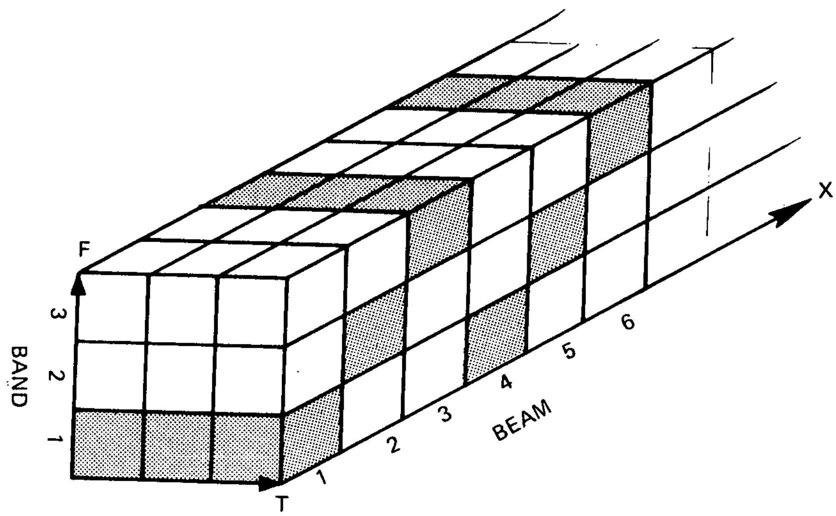


Figure 3-21. Frequency Reuse

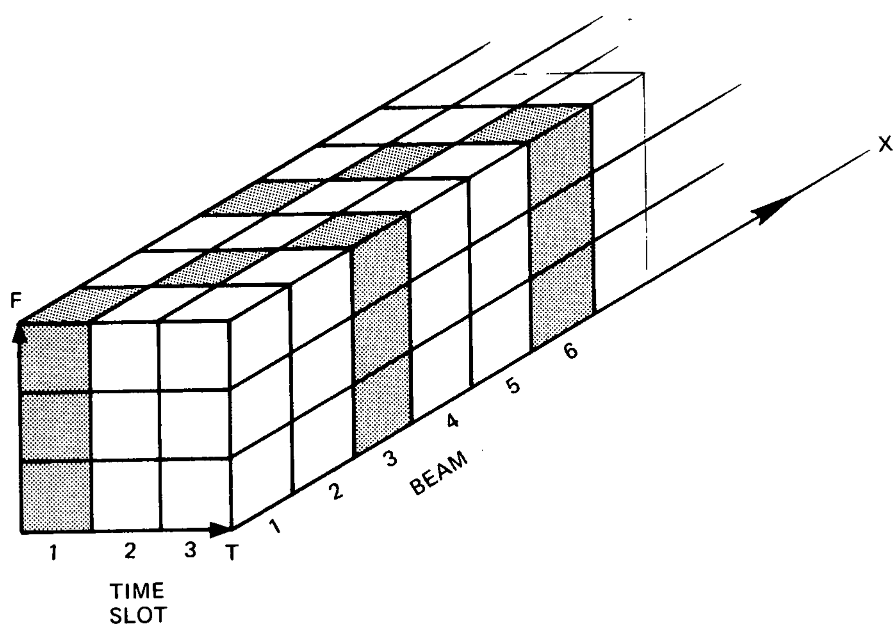


Figure 3-22. Time Slot Reuse

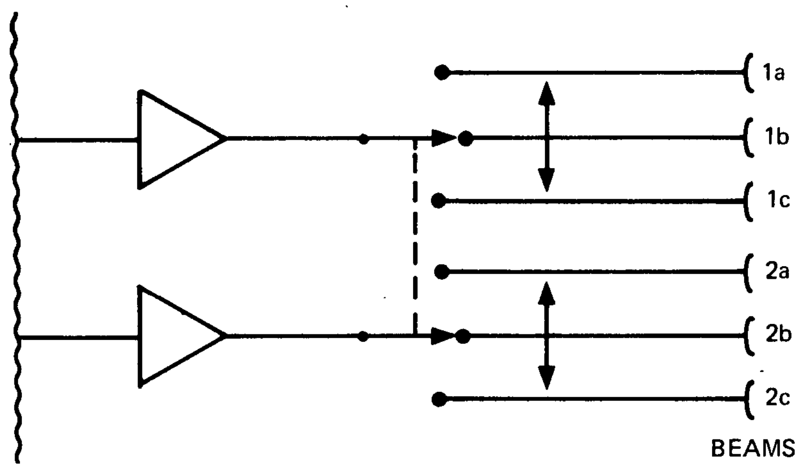


Figure 3-23. Time Band Reuse With Ganged Output Switches

or intervals when the output must be suppressed due to connectivity or interference constraints. A more advanced repeater system uses n* receivers, n transmitters, and n single-pole n throw switches (Reference 11), or equivalently n repeater channels with an appropriate routing switch. This configuration can be designed such that every transmitter operates on a different frequency band, and likewise for the receivers, or frequency bands can be reassigned. It is shown in the cited reference that bandwidth utilization suffers in this type of system whenever the traffic matrix is not of a certain form (the rows and columns all have identical sums). However, the power utilization also suffers because at certain times slots must be left empty. Furthermore, if memory is not allowed in the satellite, all earth station transmitters must arrange their transmissions in the proper sequence. Instead of frequency band reassignment, time slots can be reassigned, requiring ganged input and ganged output switches. Either frequency or time slot reassignment achieves the same improvement in spectrum utilization, but places restrictions on the allowable connectivity structures. In traffic models such as broadcast, where the uplink is not densely occupied compared with the downlink, these restrictions are not a problem. However, in systems with little fanout (single source, multiple sinks) the difficulties of coordinating both the uplink and downlink orthogonalities could get very severe. With frequency band reassignment, ample flexibility is achievable through frequency translation agility, whereas in time-slot reassigned systems an onboard memory would have to be provided to accomplish the equivalent.

3.4.4.4 Application of TDMA Band-Reuse to MFR Beam Models with Video

In computing Table 3-13 it was assumed that synchronous output switching as illustrated in Figure 3-23 would be used, and the degree of spectrum reuse therefore equaled the number of such ganged repeaters. The following assumptions also apply:

1. The "channels" are digitized video channels of 50 MHz RF bandwidth
2. The acceptable protection ratio is 10 dB.

*n = the number of beams.

Table 3-13. TDMA System Alternatives

Beams	Repeaters	Interference Level	Channels Per Beam	Acceptable?*
7	1	None	1	Yes
	2	Negligible	~ 3	Yes
	3	- 40 dB	~ 4	Yes
	4	- 40 dB	5	Yes
12	1	None	~ 1	Yes
	2	- 45 dB	~ 2	Yes
	3	- 40 dB	2-3	Yes
	4	- 20 dB	3	Yes
	6	- 9 dB	5	No
23	1	None	< 1	No
	2	Negligible	~ 1	Yes
	3	- 45 dB	~ 1	Yes
	4	- 20 dB	1-2	Yes
	6	- 10 dB	~ 3	Marginal
30	1	None	< 1	No
	2	Negligible	~ 1	Yes
	3	Negligible	1	Yes
	4	- 30 dB	~ 1	Yes
	5	- 14 dB	~ 2	Yes
	8	~ - 10 dB	~ 3	Marginal

Basically, the 50-MHz bandwidth results in total system capacities about half those of FDMA/FM, even though the assumed protection ratio is lower. On the other hand, if sufficient redundancy reduction could be applied to bring channel bandwidths down to 25 MHz, there would be some cases (e.g., 23 beams with 6 channels per beam) where the TDMA solution would be superior. However, such digitized video could equally well apply to an FDMA repeater. Furthermore, the reduced C/kT requirement of the digital signal, translatable to reduced satellite ERP or earth terminal G/T requirements, would probably be offset by the complexity of equipment necessary for 25-MHz-wide digital video signal generation.

3.4.4.5 Application to Other Types of Requirements

Voice signals can be digitized at rates ranging from 2.4 to 64 kbps, with 20 to 64 kbps the most probable range for MFR applications. Therefore, the bandwidths required with voice (and data at medium or low rates) are small compared with video. This means that:

1. Spectrum reuse is not as critical an issue
2. Onboard digital memories of reasonable capacity may be used, if time slot reassignment is implemented, to improve the connectivity capabilities of the repeater. Memories with digital video repeaters would require immense storage capacity.

Basically, it is concluded that TDMA/switched repeater systems are not attractive for video transmission, but may be applicable for voice and medium- or low-rate data requirements. Time-frequency duality allows analysis of multiple-beam systems in the more familiar frequency band domain, with the assurance that the results can be directly applied to an equivalent-capability, time-switched system.

SECTION 4 - REQUIREMENTS PROCESSING AND REPEATER CATEGORIZATION

4.1 PROCESSING OF DATA BASE

4.1.1 Introduction

The computerized data base described in Section 2 and Appendix A contains such a great volume of information that it is too complex and extensive to be of direct use to a repeater designer or even of interest in estimating gross system performance. There were two fundamental reasons for processing the data base: (1) to compile in concise form the specific parameters necessary to perform the repeater design and tradeoff studies and (2) to derive simplified data, ultimately presented in tables and graphs, which would by itself be of interest in comprehending the order of magnitudes and operating characteristics of the system. In the first category, for example, the number of internal satellite repeater channels necessary to accommodate peak loading would be of interest. In the second category, a plot of total beam channels versus time of day not only presents the approximate total system capacity but also shows the variation between time periods.

Therefore, the following paragraphs present the procedure and results of all the processing that was performed. Not all of the results were directly applied toward the repeater design and tradeoffs work, but they lend insight into system structure and operation and are indicative of the variety of processing that would need to be performed in a system design effort.

Appendix B presents a brief description and listing of the program which converted the cell-oriented data base (needlines given in terms of geographic cell numbers) to a series of beam-oriented bases. One such data base file was thus established for each of the four representative beam models selected, containing the requirements on a beam-to-beam basis. These four files were then ready for further processing, which will be described.

4.1.2 Video and High-Rate Data Channel Analysis

4.1.2.1 Introduction - Channel Counting Rules

As previously mentioned, the data base itself does not contain explicitly the information necessary to "size-out" the repeater models. Such information is readily obtained, however, by straightforward processing of the data base.* This is not quite the simple counting exercise that it may at first appear to be. The variety of network types and structures, and their functional diversity, in a multi-functional communications system impact greatly on the relative significance of each given needline. For example, a point-to-point network involves only one active uplink and one downlink beam, whereas a broadcast network has one uplink yet several downlinks. Therefore, a set of rules had to be developed by which channels could be counted.

It was found upon examination of the data base that the descriptive parameters (Paragraph 2.4.3) of each network could be used to formulate the channel counting rules. The counting rules also specified the average demands to be attributed to each case. Both temporal and geographic factors influenced these averages. The processed data fall into two general categories: overall satellite totals and beam-by-beam channel counts, both up and downlinks.

The particular factors which were found useful in specifying the counting rules were toggling (T), connectivity (C), and specificity (S). Since only 18 combinations of these factors were present in the entire data base, it was sufficient to examine the assumed mode of operation of networks fitting each of the 18 combinations, and ascribe a counting rule to each. These rules are listed in Table 4-1. Note that the internal channel count is performed only once (for each beam model), but the uplink and downlink counts must be performed separately for each beam. The rule designations (A, B, or C) are described in Table 4-2. For example, if T, C, and S are 1, 2, and 5, then the procedure is B for all uplink and downlink beams, and A for internal satellite channels.

*Actually, the processing is applied to each of the four restructured beam-oriented models (see Appendix B).

Table 4-1. Counting Rule Assignment

Toggling, Connectivity, and Specificity (TCS)	Counting Rules*		
	Uplink	Downlink	Internal Satellite Channels
011	A	A	A
016	B	A	A
022	B	B	A
041	C	C	B
045	B	A	A
046	B	A	A
052	B	B	A
056	B	B	A
121	B	B	A
123	B	B	A
125	B	B	A
126	B	B	A
232	B	A	A
235	B	A	A
242	B	A	A
325	B	B	A
355	B	A	A
356	B	A	A

*See Table 4-2 for definitions of the letters.

Table 4-2. Counting Rules

Designation	Peak (Maximum) Value	Average Value*	Minimum
	Uplink Rules		
A	One, if the beam being tabulated is listed in the data as a beam with a source cell.	One, if the beam being tabulated is listed in the data as a beam with a source cell.	One, if the beam being tabulated is listed in the data as a beam with a source cell.
B	One, if the beam being tabulated is shown in the data as one of the source containing beams.	X/N, where N is the total number of times all beam designations appear as source beams, and X is the number of times that the particular beam being tabulated is so listed.	Zero
C	Add 1.0 for each active source cell within the beam being tabulated only.	Add 1.0 for each active source cell within the beam being tabulated only.	Add 1.0 for each active source cell within the beam being tabulated only.
	Downlink Rules		
A	Same as uplink A, replace the term "source" with "sink" wherever it appears.		
B	Same as uplink B, replace the term "source" with "sink", "N" with "M" and "X" with "Y".		
C	If the beam being tabulated is listed as a sink beam, the count is equal to the number of active source cells (total).		
	Internal Rules		
A	Count one internal channel for this demand.		
B	Count the number of internal channels as equal to the total number of source cells appearing under this demand.		

*The average channel values thus derived are then to be multiplied by the network duty ratio to get the overall average.

4.1.2.2 Trunking

It was considered probable that several needlines would have identical structures or connectivities, especially in the models with lower beam numbers (seven and 12). For example, several educational television channels, all intended for the same reception areas, as for a regional network, might originate (in an RF emission point of view) from the same source. Depending on the modulation/multiplexing techniques and repeater structures involved, there could be implementation advantages in transmitting and relaying the several channels as a group or trunk, instead of handling them individually as if there were no similarity among them. Anticipating the requirement for such data, we performed a trunking analysis to identify such parallel needlines with the following restrictions: First, only video/high rate data needlines were candidates for trunking. Although it might appear that voice channels offer an obvious opportunity for trunking, the assumption that real-time reconfiguration of the repeater would not be permitted and the sporadic, on-demand nature of voice requirements in this system meant that no voice trunking candidates were found. A narrow, precise definition of what constituted a trunk was applied: Several channels constituted a trunk if and only if they originated in the same source beam, could be handled in the satellite repeater without channel separation, and were all, as a group, required to be transmitted in one or more downlink beams. A trunk could not include a channel which also needed to be separately (individually) routed to some other beam. For example, if the following applied:

Channel	Source Beam	Sink Beams
TV 1	3	5, 8, 11
TV 2	3	5, 8, 11
High-Data 3	3	5, 8, 11

then the three channels could be combined as a trunk. But if:

TV 1	3	5, 8, 11
TV 2	3	5, 8, 11
High-Data 3	3	5, 12

or:

Channel	Source Beam	Sink Beams
TV 1	3	5, 8, 11
TV 2	3	5, 8, 11
High-Data 3	3	5, 8, 11, 12

applied, then only TV 1 and TV 2 could be trunked, while High-Data 3 would have to be handled as a single channel. If the first counterexample applied, separation (drop and reinsert) would be required in the satellite, while in the second, the source station would have to transmit not only the (TV 1 + TV 2 + High-Data 3) trunk but an additional High-Data 3 signal. Neither of these was allowed under the trunking definition; the ground station situation is expressed as a "No fan-out on the ground" rule, considered necessary for reasons of spectrum efficiency.

Despite the restrictive nature of the trunking definition, a surprisingly large degree of trunking potential was found in the seven- and 12-beam models. For lack of space, the complete beam-by-beam and hour-by-hour results will not be reproduced herein. Instead, it is noted that during the analysis a trunk thickness of one, i.e., a single channel needline, was allowable. Therefore, the summation over all beams of the single and multiple channel trunk numbers, as a function of time, is identical to the uplink channel total for each beam model. These data are presented graphically in Paragraph 4.1.2.3. A sample only of the results is reproduced in Table 4-3.

4.1.2.3 Quantitative Analysis Results

The results presented in this report are only a small portion of the total processed data available. The more meaningful and general totals have been selected, whereas the detailed beam-by-beam and hour-by-hour data, useful only for specific repeater design, are not included here, but were available during the repeater tradeoffs task whenever it was necessary to ascertain the desirability of a certain approach or to size certain functions such as filtering and routing (switching).

Table 4-3. Sample of Trunking Analysis Output

12-Beam Model, Video Plus High-Rate Data, Hour 01

Uplink Beam \ Trunk Thickness	1	2	3	4
1	0	1	0	0
2	2	0	1	0
3	1	1	0	0
4	5	0	1	0
5	3	0	1	0
6	0	1	0	0
7	2	1	0	0
8	3	1	0	0
9	1	1	0	0
10	2	1	0	0
11	0	1	0	0
12	0	1	0	0

Two downlink-oriented sizing parameters of interest are: (1) the range in number of channels for each beam,* and (2) the total beam-channel** demand as a function of time for each beam model. The first parameter is of interest in sizing the number of uplink filters, etc., necessary in each beam. The second can be directly used as a rough measure of satellite effective radiated power (ERP) required, and the variation with time would be of interest in the general case to assist in scheduling, control planning, and the like. The first parameter is shown in Tables 4-4 through 4-7. The second is presented graphically in Figures 4-1 through 4-4.

The uplink and internal parameters of greatest interest were obtained directly from the trunking analysis and from the uplink channel counting analysis. The overall satellite total channel and trunk loading as a function of time are presented in Figures 4-5 through 4-8. Since the total obscures the variation in beam-by-beam distribution, it was also desirable to ascertain, for each beam, the largest value (over the 24-hour period) of channels and trunks handled. These values appear in Tables 4-8 through 4-11.

The following observations are made based on the beam-channel plots:

1. It was not possible to smooth out the demand even though early morning hours were ideal for bulk data transfer and the like. Clearly, however, the potential exists for a large amount of electronic mail, for example, in the 1 a.m. to 7 a.m. slack period.

2. As the number of beams is increased, the variation in demand as a function of time increases (the plot becomes more jagged or erratic). Large-area beams are therefore superior from the standpoint of demand smoothing.

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*The ranges of variation of the maximum (peak), average, and minimum values have been separately determined and presented.

**A channel in one downlink beam is one beam-channel. A channel simultaneously transmitted in N beams is N beam-channels.

Table 4-4. Ranges in Number of Channels for Each Downlink Beam, Video Plus High Data

Beam	Maximum	Average	Minimum
1	17 - 25	8 - 13.4	7 - 12
2	13 - 22	7.4 - 14.5	7 - 14
3	18 - 25	8.2 - 13	7 - 12
4	19 - 28	8.8 - 15.4	7 - 14
5	13 - 17	6.3 - 9.6	6 - 9
6	11 - 14	6.2 - 8.4	6 - 8
7	11 - 15	6.2 - 9.4	6 - 9

Table 4-5. Ranges in Number of Channels for Each Downlink Beam, Video Plus High Data

Beam #	Maximum	Average	Minimum
1	13 - 19	6.5 - 12	6 - 11
2	13 - 21	7.4 - 13.4	7 - 13
3	13 - 18	7.4 - 10.6	7 - 10
4	18 - 26	7.8 - 13.8	7 - 13
5	15 - 22	7.8 - 12.2	7 - 11
6	11 - 16	4.4 - 8.6	4 - 8
7	16 - 21	6.8 - 10	6 - 9
8	17 - 23	7.7 - 11.7	7 - 11
9	14 - 19	7.4 - 11.5	7 - 11
10	13 - 17	6.3 - 9.6	6 - 9
11	11 - 14	6.2 - 8.4	6 - 8
12	11 - 15	6.2 - 9.4	6 - 9

Table 4-6. Ranges in Number of Channels for Each Downlink Beam, Video Plus High Data

Beam #	Maximum	Average	Minimum
1	12 - 19	6.3 - 10.6	6 - 10
2	9 - 13	3.3 - 6.5	3 - 6
3	10 - 16	5.2 - 10.3	5 - 10
4	9 - 13	3.3 - 6.5	3 - 6
5	15 - 22	7.8 - 12.2	7 - 11
6	10 - 15	4.3 - 8.5	4 - 8
7	12 - 20	7.2 - 13.4	7 - 13
8	11 - 15	4.4 - 7.5	4 - 7
9	13 - 18	7.4 - 10.6	7 - 10
10	10 - 17	4.3 - 10.4	4 - 10
11	12 - 19	7.2 - 12.4	7 - 12
12	9 - 14	4.2 - 8.4	4 - 8
13	6 - 9	3.2 - 6.2	3 - 6
14	12 - 17	6.3 - 9.5	6 - 9
15	13 - 18	4.7 - 8.7	4 - 8
16	12 - 18	5.4 - 9.5	5 - 9
17	18 - 26	8.2 - 14	7 - 13
18	7 - 10	4.2 - 7.2	4 - 7
19	12 - 16	7.2 - 10.4	7 - 10
20	14 - 19	7.4 - 11.5	7 - 11
21	13 - 17	6.3 - 9.6	6 - 9
22	11 - 14	6.2 - 8.4	6 - 8
23	11 - 15	4.2 - 9.4	6 - 9

Table 4-7. Ranges in Number of Channels for Each Downlink Beam, Video Plus High Data (Sheet 1 of 2)

Beam #	Maximum	Average	Minimum
1	11 - 17	6.2 - 10.5	6 - 10
2	9 - 14	3.3 - 7.5	3 - 7
3	6 - 9	3.2 - 6.2	3 - 6
4	6 - 10	3.2 - 6.4	3 - 6
5	8 - 12	3.2 - 6.4	3 - 6
6	15 - 20	7.4 - 11.7	7 - 11
7	7 - 12	3.3 - 7.5	3 - 7
8	8 - 12	3.2 - 7.2	3 - 7
9	12 - 20	7.2 - 13.4	7 - 13
10	11 - 15	4.4 - 7.5	4 - 7
11	12 - 17	7.2 - 10.5	7 - 10
12	10 - 17	4.3 - 10.4	4 - 10
13	12 - 19	7.2 - 12.4	7 - 12
14	14 - 19	6.5 - 8.9	6 - 8
15	8 - 13	4.3 - 8.5	4 - 8
16	9 - 14	4.2 - 8.4	4 - 8
17	8 - 12	3.2 - 6.4	3 - 6
18	10 - 16	4.3 - 9.4	4 - 9
19	12 - 18	6.3 - 10.4	6 - 10
20	19 - 28	8.1 - 15.1	7 - 14
21	6 - 9	3.2 - 6.2	3 - 6
22	7 - 10	4.2 - 7.2	4 - 7
23	14 - 19	5.6 - 8.9	5 - 8
24	12 - 16	7.2 - 10.4	7 - 10

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Table 4-7. Ranges in Number of Channels for Each Downlink Beam, Video Plus High Data (Sheet 2 of 2)

Beam #	Maximum	Average	Minimum
25	10 - 15	4.3 - 8.3	4 - 8
26	7 - 10	4.2 - 7.2	4 - 7
27	14 - 19	7.4 - 11.5	7 - 11
28	13 - 17	6.3 - 9.6	6 - 9
29	11 - 14	6.2 - 8.4	6 - 8
30	11 - 15	6.2 - 9.4	6 - 9

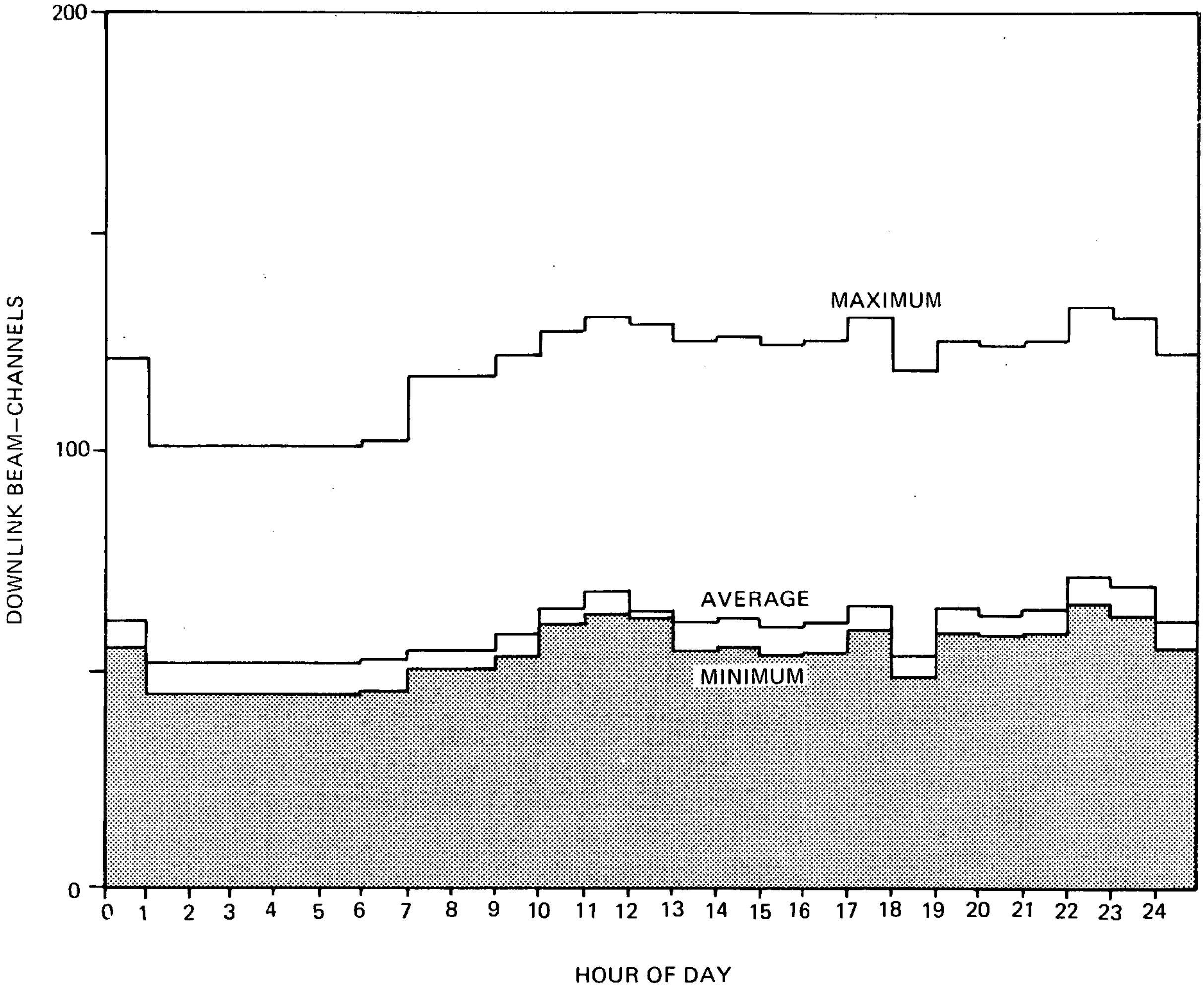

Figure 4-1. Total Beam-Channel Demand, Seven-Beam Model, Video and High Data

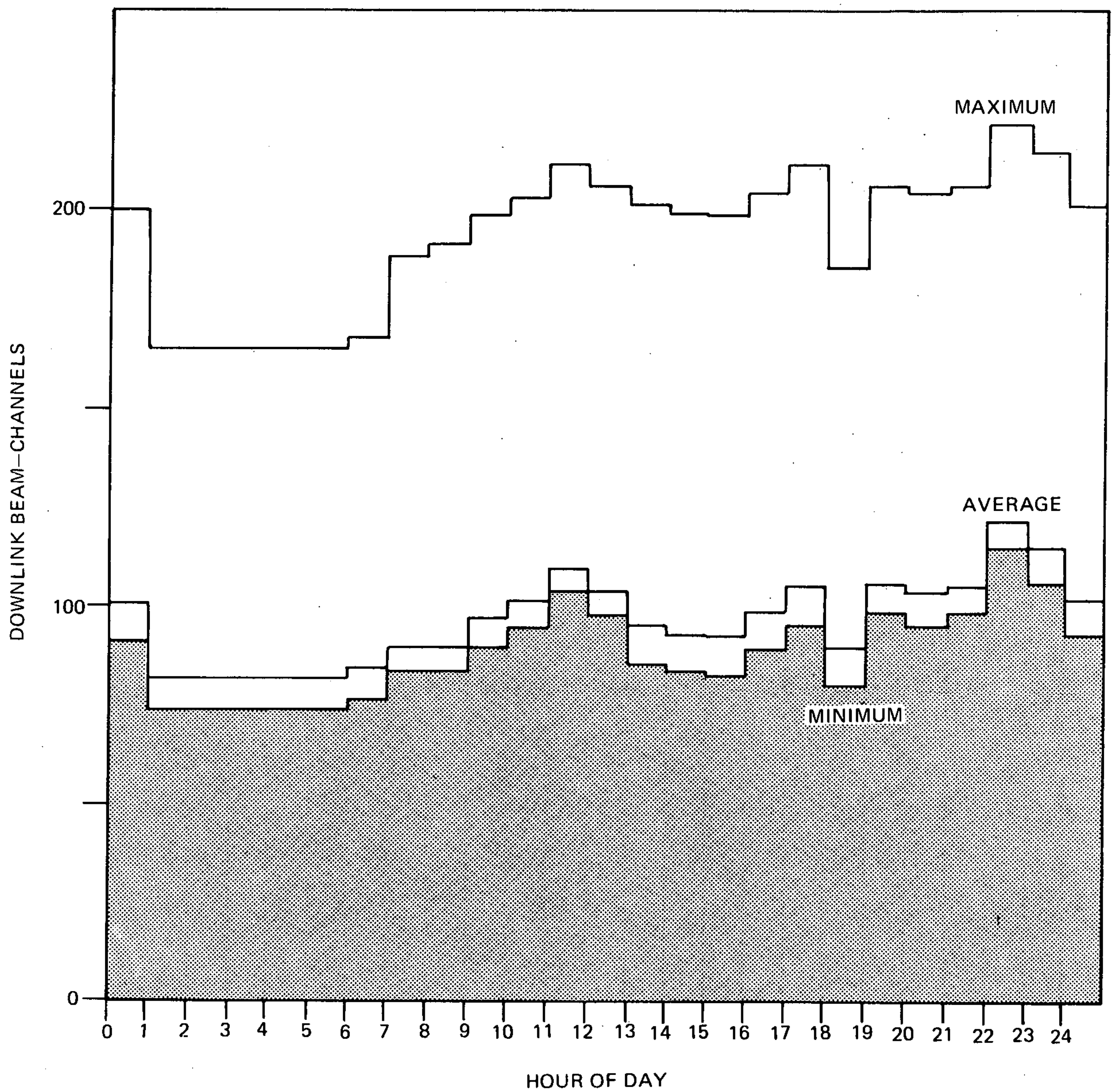

Figure 4-2. Total Beam-Channel Demand, 12-Beam Model, Video and High Data

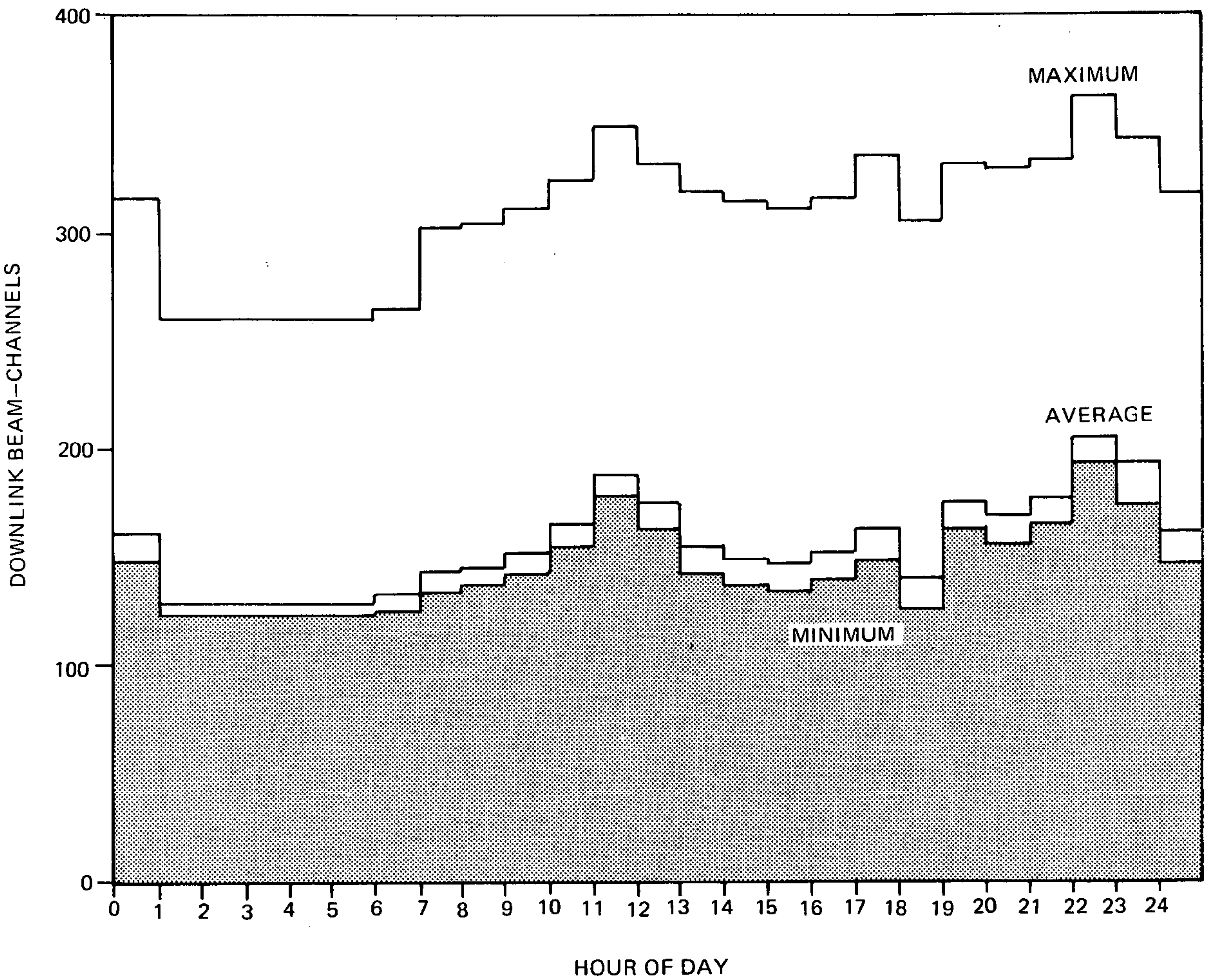

Figure 4-3. Total Beam-Channel Demand, 23-Beam Model, Video and High Data

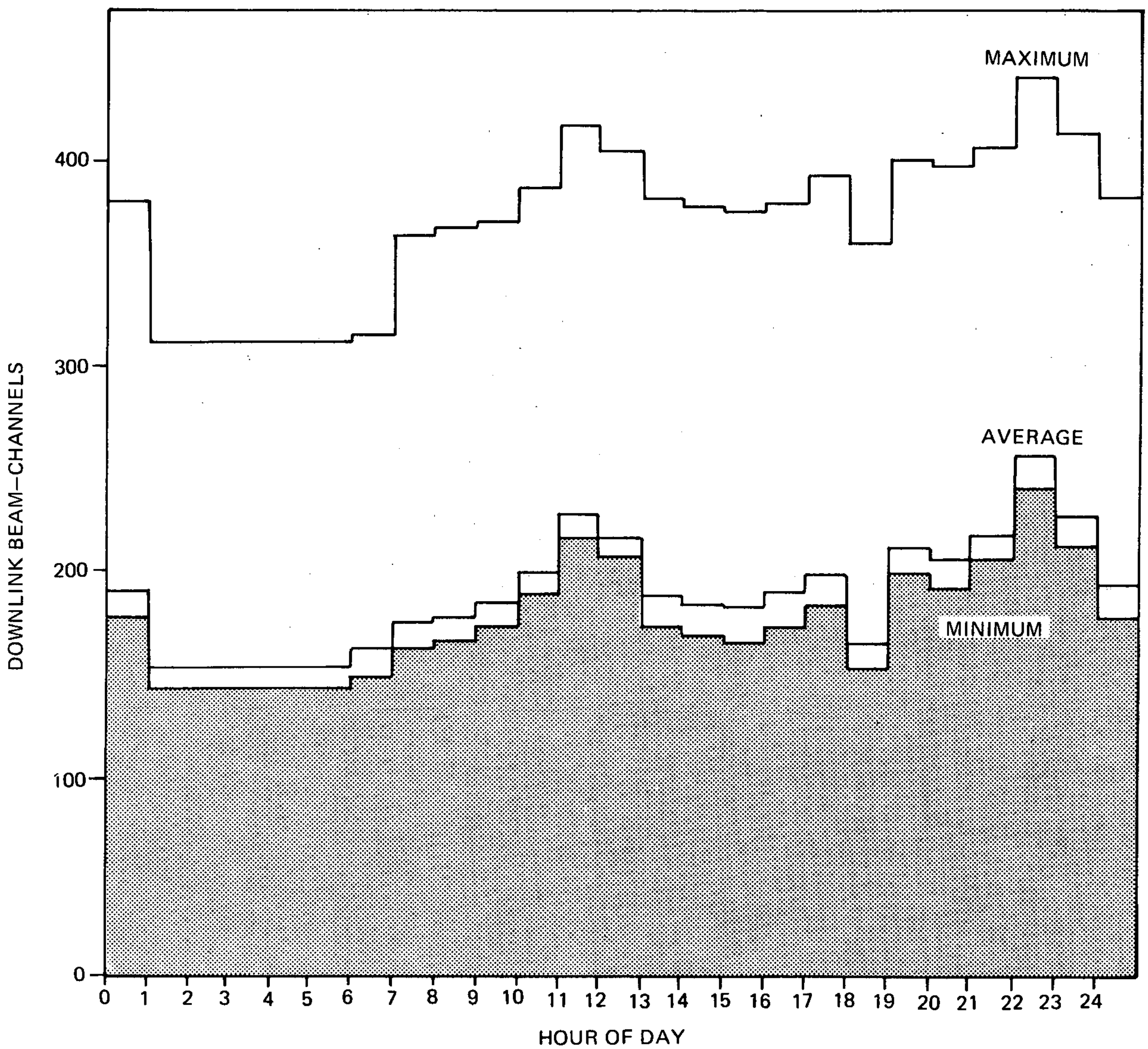

Figure 4-4. Total Beam-Channel Demand, 30-Beam Model, Video and High Data

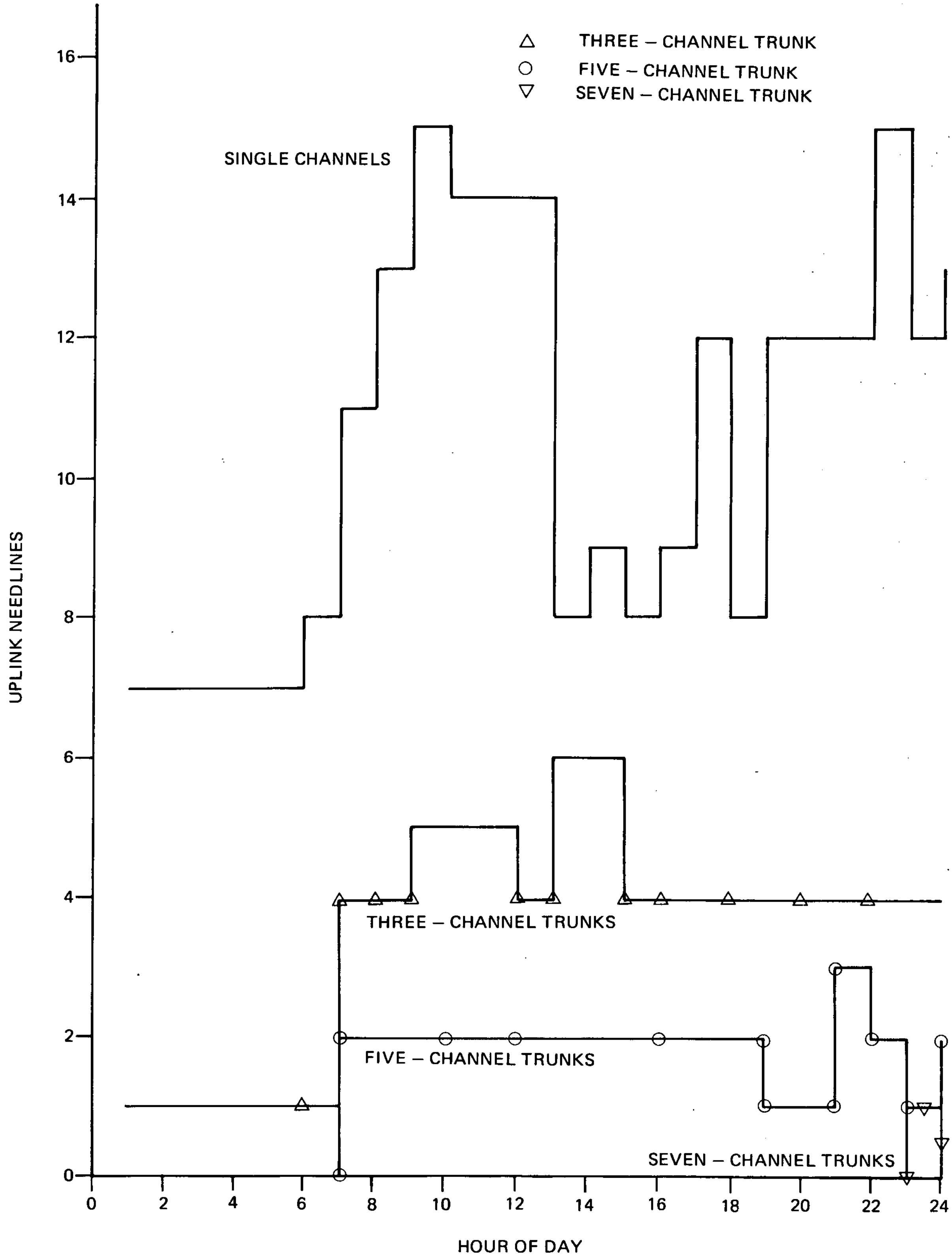

Figure 4-5. Satellite Uplink Needlines, Seven-Beam Model, Video and High Data (Sheet 1 of 2)

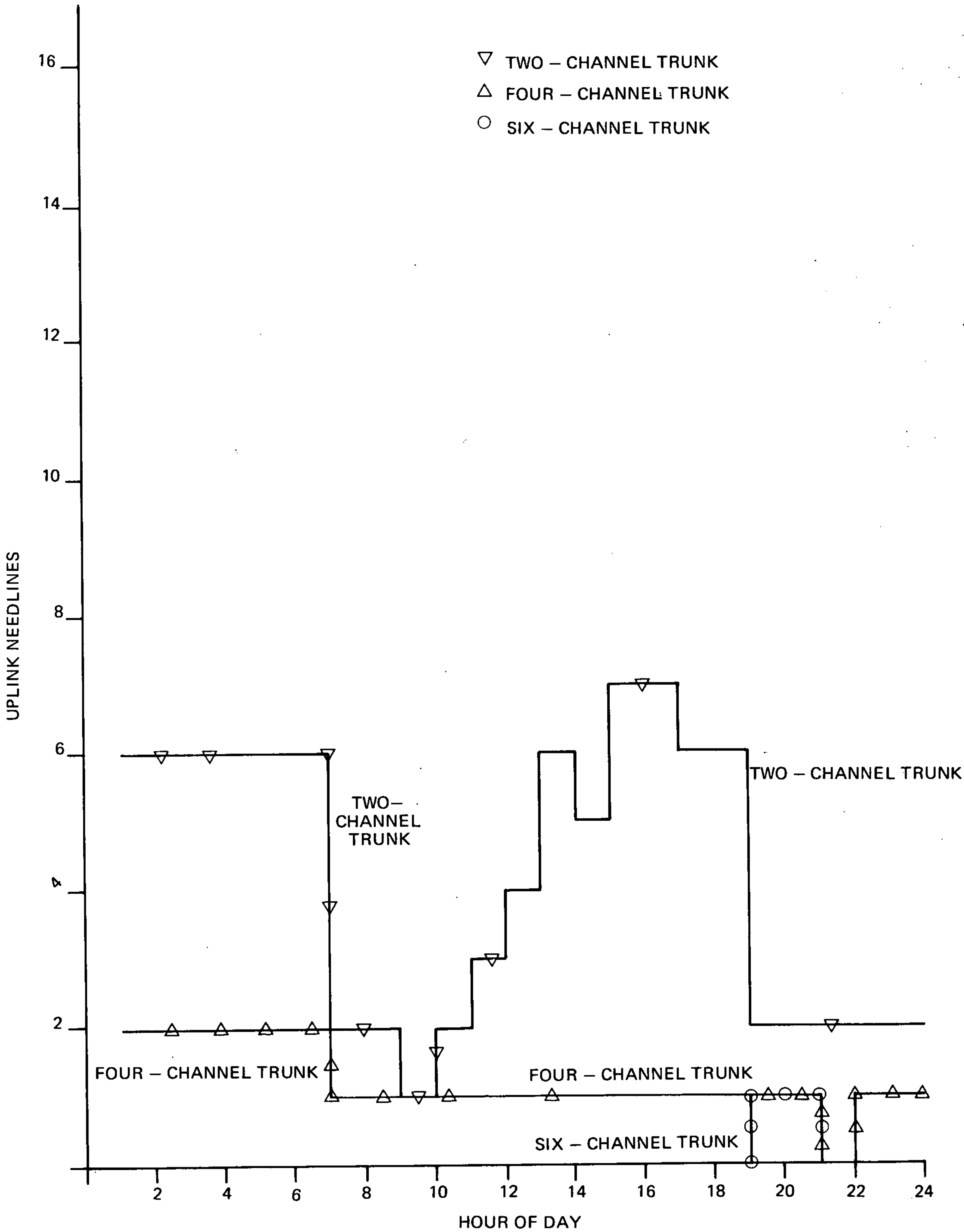

Figure 4-5. Satellite Uplink Needlines, Seven-Beam Model, Video and High Data (Sheet 2 of 2)

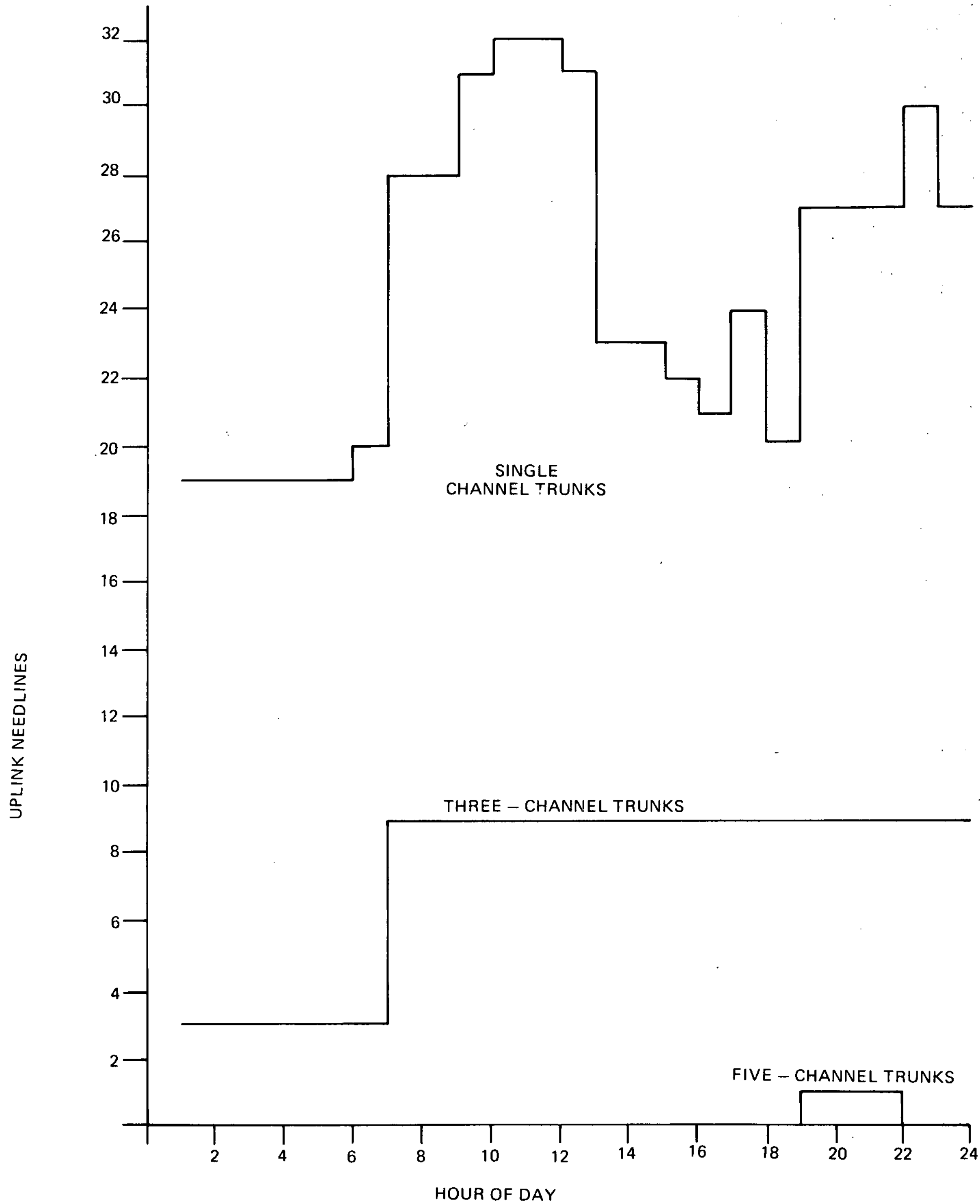

Figure 4-6. Satellite Total Uplink Needlines, 12-Beam Model, Video and High Data (Sheet 1 of 2)

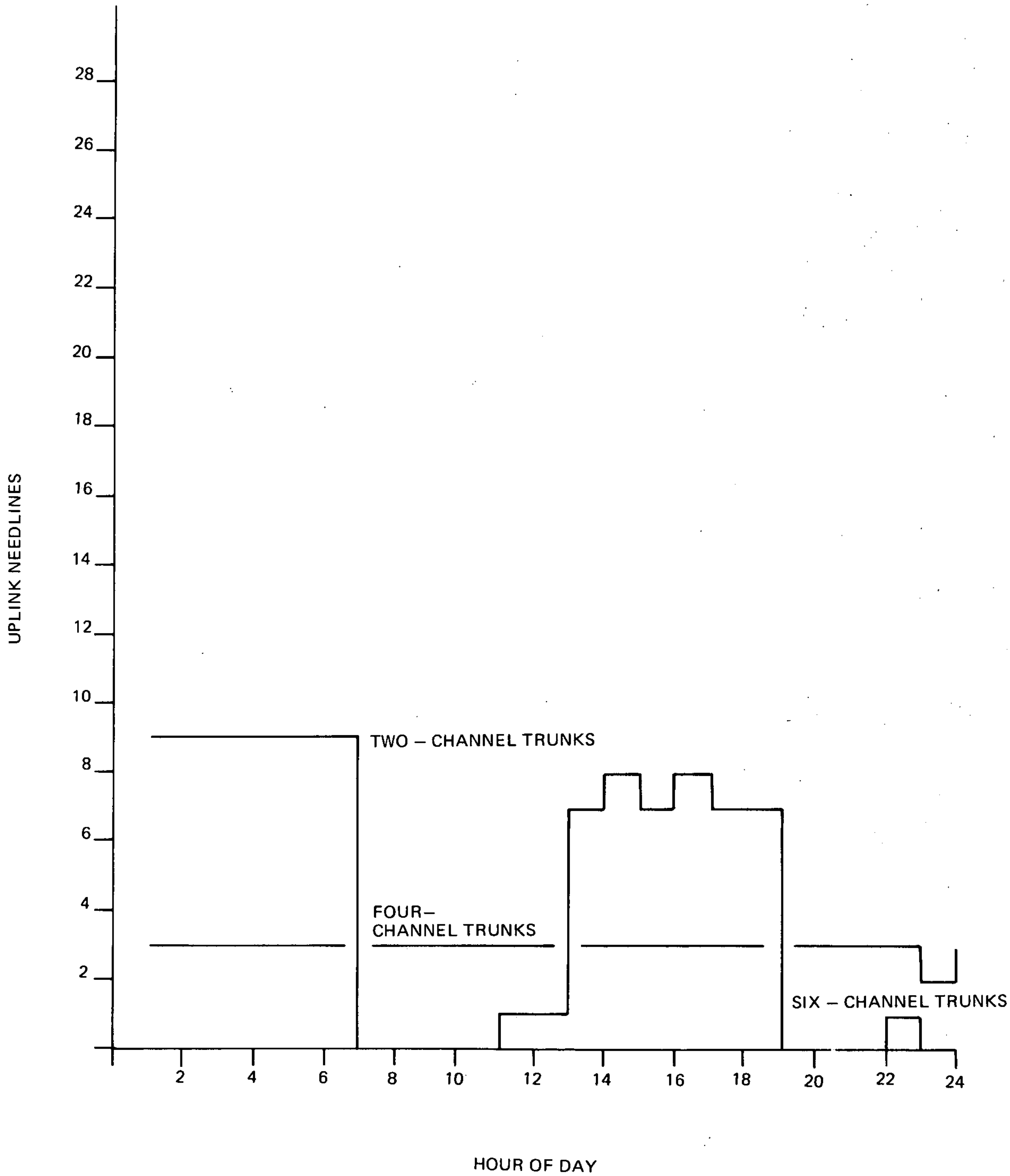

Figure 4-6. Satellite Total Uplink Needlines, 12-Beam Model, Video and High Data (Sheet 2 of 2)

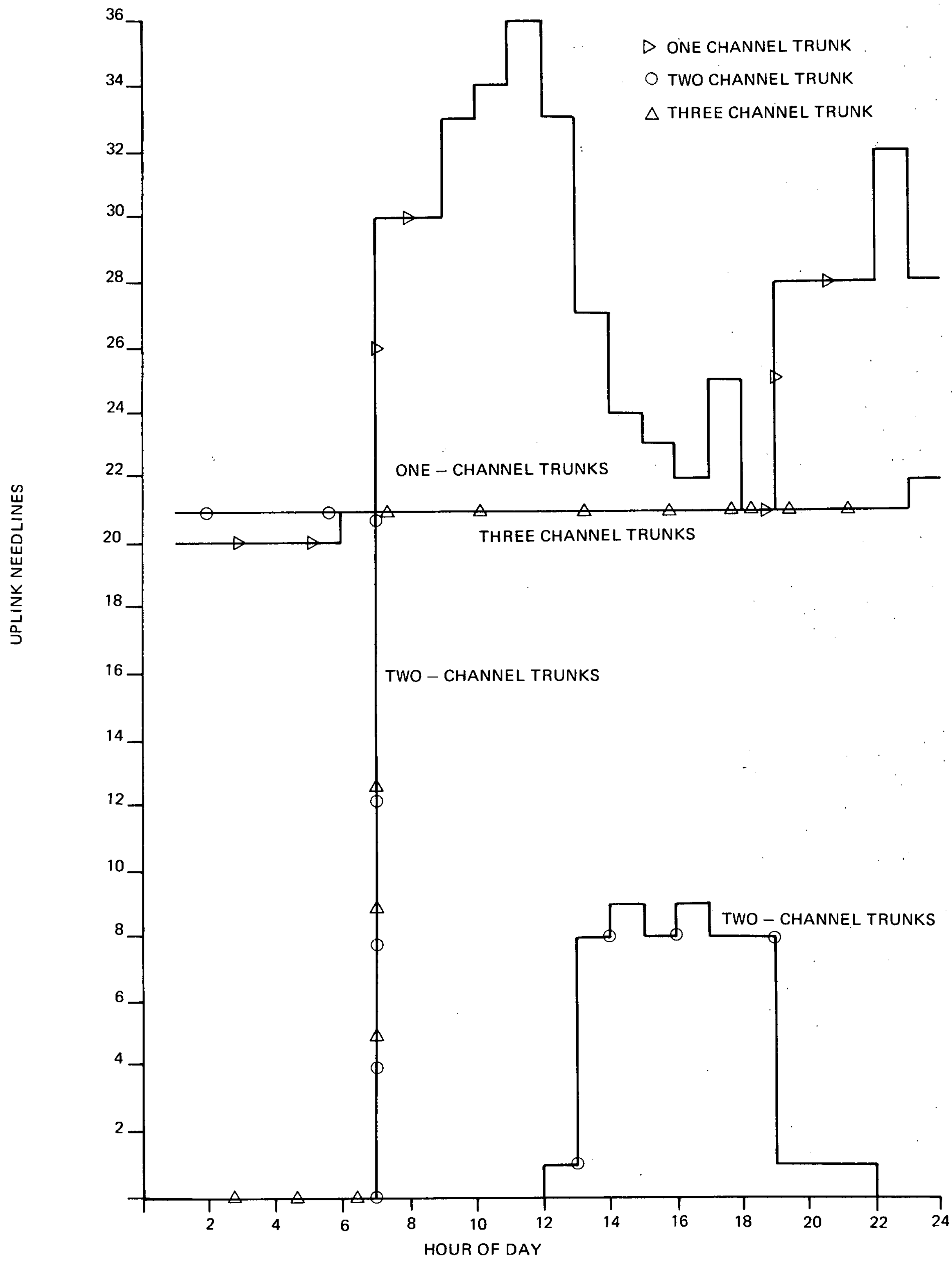

Figure 4-7. Satellite Total Uplink Needlines, 23-Beam Model, Video and High Data

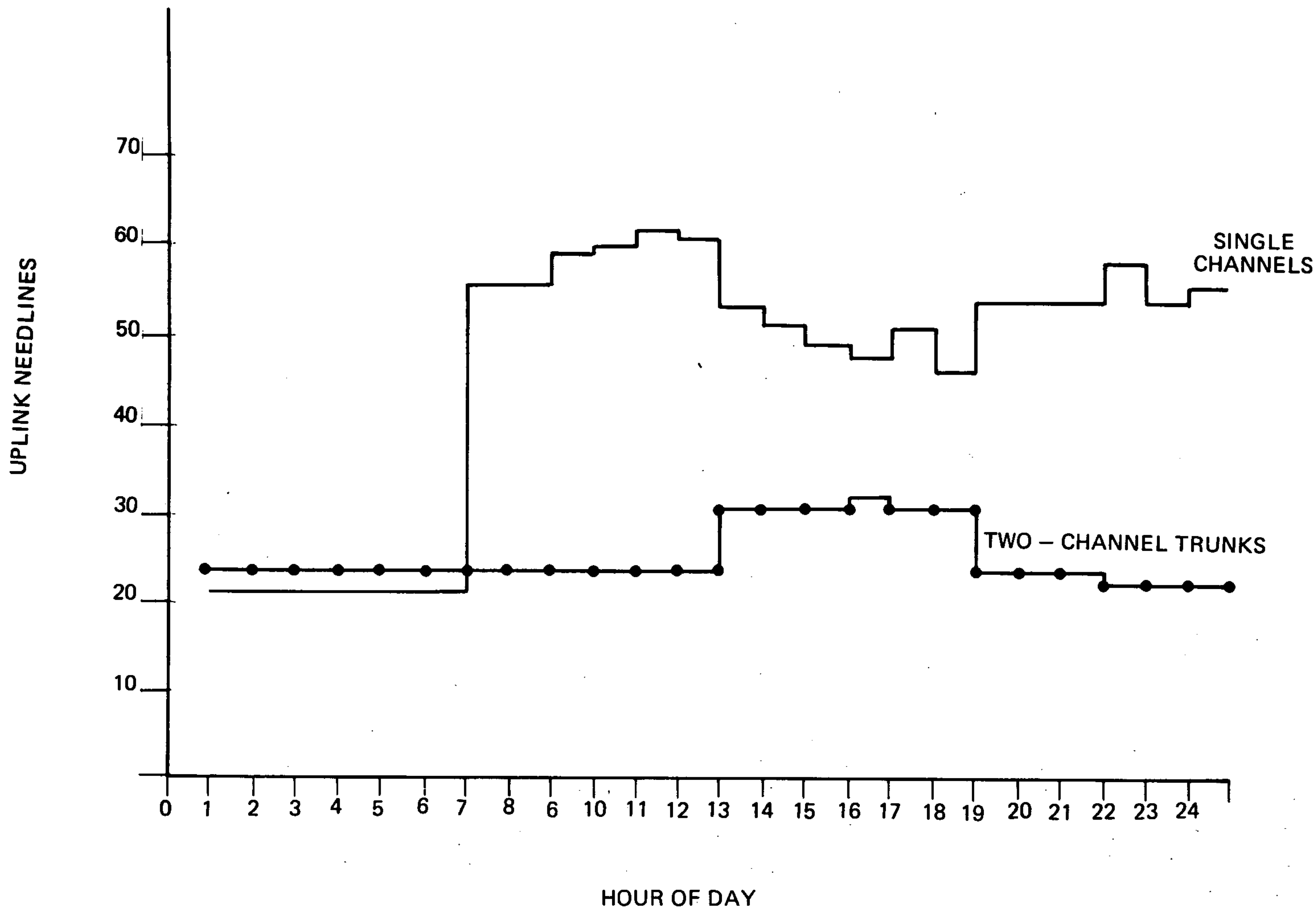

Figure 4-8. Satellite Uplink Needlines, 30-Beam Model, Video and High Data

Table 4-8. Largest Uplink Requirements for Each Beam, Seven Beam Case, Video Plus High Data

Beam Number	Trunk Size						
	1	2	3	4	5	6	7
1	8	2	1	1	1	0	0
2	2	2	0	1	1	0	0
3	3	3	1	0	0	0	0
4	5	2	2	1	1	1	1
5	2	1	1	0	0	0	0
6	0	1	1	0	0	0	0
7	0	1	1	0	0	0	0

Table 4-9. Largest Uplink Requirements for Each Beam, 12-Beam Model, Video Plus High Data

Beam Number	Trunk Size					
	1	2	3	4	5	6
1	2	1	1	0	0	0
2	4	2	1	1	0	0
3	4	1	1	0	0	0
4	9	1	1	1	1	1
5	7	1	1	1	1	0
6	0	1	1	0	0	0
7	4	2	1	0	0	0
8	6	1	1	0	0	0
9	2	1	1	0	0	0
10	2	1	1	0	0	0
11	0	1	1	0	0	0
12	0	1	1	0	0	0

Table 4-10. Largest Uplink Requirements for Each Beam, 23-Beam Model, Video Plus High Data

Beam Number	Trunk Size		
	1	2	3
1	2	1	1
2	0	1	1
3	0	1	1
4	0	1	1
5	8	1	1
6	0	1	1
7	4	2	1
8	3	1	1
9	4	1	1
10	1	1	1
11	2	1	1
12	0	1	1
13	0	0	0
14	3	2	1
15	2	1	1
16	4	1	1
17	10	1	1
18	0	0	0
19	1	1	1
20	2	1	1
21	2	1	1
22	0	1	1
23	0	1	1

Table 4-11. Largest Uplink Requirements for Each Beam, 30-Beam Model, Video Plus High Data

Beam Number	Single Channels	Two-Channel Trunks
1	3	2
2	1	1
3	0	0
4	1	0
5	1	1
6	5	2
7	1	0
8	0	1
9	5	3
10	4	1
11	4	1
12	2	1
13	3	2
14	7	2
15	1	0
16	1	1
17	2	1
18	1	1
19	5	2
20	11	2
21	0	0
22	0	0
23	5	2
24	2	1
25	2	1
26	0	0
27	3	1
28	3	1
29	1	1
30	1	1

3. The minimum gain versus beam-channels for each beam model are shown in Table 4-12. The magnitude of each increase is of note. For example, the 23-beam model provides a 4-dB antenna gain increase (in the worst cases) over the 12-beam model. However, the beam-channel quantity only increases by 2.1 dB. Thus, there is a theoretical radio frequency (RF) power saving of 1.9 dB; that is, increasing the number of beams improves the effective isotropically radiated power (EIRP) arising from antenna gain increases faster than the number of beam-channels increases. On the other hand, the satellite repeater will become more complex and frequency utilization problems will become more severe. The tradeoff of these factors is the essential aspect of Task 5.

4. The sheer magnitude of these requirements tends to favor narrowband modulation (VSB video, PSK digital), as previously concluded for other reasons.

5. The fact that the average is only slightly larger than the minimum is a direct result of the fact that averaging occurs both over the time and spatial domains. Precise determination of the requirement for such demand-assigned channels is difficult without statistical usage data, but one expects that a small number of such on-demand channels would suffice, providing they had adequate switching flexibility. However, only a repeater design which switched in real-time would enable a system to operate efficiently at or near the theoretical average beam-channel values shown in the plots.

4.1.2.4 Inputs to Repeater Tradeoffs Task

In addition to the detailed processing outputs and the four sizing parameters treated in the previous paragraph, it was felt necessary to select specific values of satellite capacity to perform the repeater design and tradeoff tasks. In further

Table 4-12. Change in Beam-Channel Demand Versus Change In Beam Gain

Beam Model	Minimum Gain (dB)	Absolute Peak Beam-Channel Demand	Early Morning Beam-Channel Demand	dB Increase in Beam-Channels Over Previous Beam Model	dB Increase in Gain Over Previous Beam Model
7	33	133	102	-----	-----
12	36	221	165	2.0/2.1	3
12	40	361	261	2.1/2.0	4
30	41	439	312	0.85/0.77	1

extension of this line of effort, baseline and alternative system models were chosen, which is discussed in Paragraph 4.2. Table 4-13 presents the channel and trunk numbers which, it was felt, would approximately meet the requirements. A degree of subjective interpretation was necessary in arriving at these values. On the one hand, the expense in weight and power terms of providing ample uplink (access) channel capacity is negligible compared with downlink beam channels. Therefore, it should be possible to equip each baseline with sufficient filters and switches that system capacity is limited by downlink bandwidth, weight, or power. On the other hand, it is not reasonable to postulate channel quantities grossly in excess of what the downlink constraints allow. Furthermore, the necessary statistical data are not available at this early stage to determine a number of channels versus grade-of-service tradeoff, to resolve where in the minimum, average, or maximum channel requirements areas one should place the baselines. It was felt that, by working from the satellite uplink needlines graphs, a good estimate of uplink/internal channel requirements could be made. The beam-channel graphs, combined with the bandwidth restrictions as treated in Paragraph 3.4, would place definite bounds on downlink capacity in the baseline specification. The trunk versus single channel determination necessary for each case shown in Table 4-13 was made according to the following rule:

> "Trunk values were specified, in lieu of equivalent individual channel capability, only up to the level where such capability would be used most of the time. For example, if part of the time 10 three-channel trunks are necessary, and part only five, then only five trunks would be provided, but 15 additional single-channel needlines would be provided to handle the peak."

It should not be inferred from the trunk values that the baseline or alternate solutions must provide trunking capability. The equivalent service with all single channels would be acceptable. Repeater configuration and design tradeoffs must be applied to determine the approach.

Table 4-13. Channel and Trunk Quantities

(Uplink or Internal Routing Capability)

30 Beams	
Single channels	66
Two-channel trunks	24
23 Beams	
Single channels	57
Two-channel trunks	21
12 Beams	
Single channels	51
Three-channel trunks	9
Four-channel trunks	3
Seven Beams	
Single channels	28
Two-channel trunks	8
Four-channel trunks	2

4.1.3 Voice and Medium- or Low-Rate Data

The data processing for the more moderate-rate requirements was similar in concept and execution to the video/high-rate data. However, the following considerations apply:

1. If the same system assumptions (parameters) apply as for video transmission, then the satellite ERP required is almost trivially low. Here, it has been assumed that a single, integrated multifunctional system would be used, with the result that antenna (terminal and satellite) compatibility considerations constrain the operating band to upper X-Band.

2. Due to the minimal power required, it is permissible to be less precise in quantifying the requirements or, in a more positive vein, the system design can be for peak demands instead of average.

3. Voice demands are too dynamic to lend themselves to trunking unless grouped on the ground in a demand access type of system (Reference 12).

4. While low-rate data demands do contain opportunity for trunking, it does not appear reasonable to perform trunking in the same manner as for video. Most low-rate data links are point-to-point, and their rates are so low that substantial data concentration and multiplexing can be performed at ground stations in a conventional manner.

As covered in more detail in Paragraph 4.3, the voice demands (other than the audio lines which parallel each video broadcast link) will be assumed to be satisfied by a separate repeater subsystem in the MFR satellite, but nevertheless operating via the same multiple-beam antenna system.

The range in number of channels for each beam (downlink) is shown in Tables 4-14 through 4-17 for the combined channel category of voice and medium-rate data. The peak total beam-channel demand, for both uplinks and downlinks, is shown in Table 4-18. Finally, for voice and medium data, the range in channels for each uplink beam is shown in Tables 4-19 through 4-22.

4.1.4 Significance

In addition to the general observations pointed out in Paragraph 4.1.2.3, the significance of the detailed channel counting and similar analyses described and presented in the previous paragraphs lies not so much in the absolute values, which of course are directly dependent on the hypothetical traffic model, as in the demonstrated effectiveness and availability of the processing algorithms and procedures. In the future, when other, perhaps more realistically based requirements data become available, the reduction to system-oriented parameters should be quite efficient and rapid. This direct transition from user-based requirements to a system-oriented repeater model should be of great utility in system tradeoff and design efforts on future multiple-beam satellites envisioned by NASA.

4.2 REPEATER STRUCTURE CATEGORIZATION

4.2.1 Introduction

The general problem under consideration is the categorization and evaluation of alternative repeater configurations applicable to the MFR satellite. This type of satellite possesses multiple input and output antenna beams, with the requirement to simultaneously interconnect various sets of these beams. Communication relay requirements are thereby fulfilled among and between earth terminals located in

Table 4-14. Range in Number of Channels for Each Downlink Beam, Seven-Beam Model, Voice and Medium Data

Beam Number	Channels
1	1 - 6
2	3 - 8
3	2 - 7
4	3 - 8
5	0 - 4
6	1 - 5
7	1 - 5

Table 4-15. Range in Number of Channels for Each Downlink Beam, 12-Beam Model, Voice and Medium Data

Beam Number	Channels
1	1 - 6
2	2 - 7
3	2 - 7
4	1 - 6
5	1 - 6
6	2 - 6
7	1 - 5
8	2 - 7
9	1 - 6
10	0 - 4
11	1 - 5
12	1 - 5

Table 4-16. Range in Number of Channels for Each Downlink Beam, 23-Beam Model, Voice and Medium Data

Beam Number	Channels
1	1 - 6
2	2 - 6
3	2 - 6
4	1 - 5
5	1 - 6
6	1 - 5
7	1 - 6
8	1 - 5
9	2 - 7
10	1 - 5
11	1 - 6
12	1 - 5
13	1 - 5
14	1 - 5
15	1 - 5
16	1 - 5
17	1 - 6
18	1 - 5
19	1 - 6
20	1 - 6
21	0 - 4
22	1 - 5
23	1 - 5

Table 4-17. Range in Number of Channels for Each Downlink Beam, 30-Beam Model, Voice and Medium Data

Beam Number	Channels
1	1 - 6
2	1 - 5
3	1 - 5
4	1 - 5
5	1 - 5
6	1 - 6
7	1 - 5
8	2 - 6
9	1 - 6
10	1 - 5
11	1 - 6
12	1 - 5
13	1 - 6
14	1 - 5
15	1 - 5
16	1 - 5
17	1 - 5
18	2 - 6
19	3 - 7
20	1 - 6
21	1 - 5
22	1 - 5
23	1 - 5
24	1 - 6
25	2 - 6
26	1 - 5
27	1 - 6
28	0 - 4
29	1 - 5
30	1 - 5

Table 4-18. Peak Total Beam-Channel Demands, Voice and Medium Data

Beam Model	Uplink	Downlink
7	41	43
12	65	70
23	119	125
30	150	162

Table 4-19. Range in Number of Channels for Each Uplink Beam, Seven-Beam Model, Voice and Medium Data

Beam Number	Channels
1	0 - 5
2	0 - 8
3	0 - 6
4	0 - 8
5	0 - 4
6	0 - 5
7	0 - 5

Table 4-20. Range in Number of Channels for Each Uplink Beam, 12-Beam Model, Voice and Medium Data

Beam Number	Channels
1	0 - 5
2	0 - 7
3	0 - 6
4	0 - 6
5	0 - 5
6	0 - 6
7	0 - 5
8	0 - 6
9	0 - 5
10	0 - 4
11	0 - 5
12	0 - 5

Table 4-21. Range in Number of Channels for Each Uplink Beam, 23-Beam Model, Voice and Medium Data

Beam Number	Channels
1	0 - 5
2	0 - 6
3	0 - 6
4	0 - 5
5	0 - 5
6	0 - 5
7	0 - 6
8	0 - 5
9	0 - 6
10	0 - 5
11	0 - 5
12	0 - 5
13	0 - 5
14	0 - 5
15	0 - 5
16	0 - 5
17	0 - 6
18	0 - 5
19	0 - 5
20	0 - 5
21	0 - 4
22	0 - 5
23	0 - 5

Table 4-22. Range in Number of Channels for Each Uplink Beam, 30-Beam Model, Voice and Medium Data

Beam Number	Channels
1	0 - 5
2	0 - 5
3	0 - 5
4	0 - 5
5	0 - 5
6	0 - 5
7	0 - 5
8	0 - 6
9	0 - 6
10	0 - 5
11	0 - 5
12	0 - 5
13	0 - 5
14	0 - 5
15	0 - 5
16	0 - 5
17	0 - 5
18	0 - 6
19	0 - 7
20	0 - 6
21	0 - 5
22	0 - 5
23	0 - 5
24	0 - 5
25	0 - 6
26	0 - 5
27	0 - 5
28	0 - 4
29	0 - 5
30	0 - 5

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various portions of the United States. The configuration of the network thus established changes with time. The existence of multiple beams means that switching of repeater signal paths must, in general, occur, while the simultaneity of requirements means that the repeater must be channelized, with multiple connection paths, or channels, simultaneously available.

The repeater should satisfy, at least partially, certain connectivity and service requirements. These place certain performance constraints on the design. But the configuration must also be considered in association with the signaling, modulation, multiple access, and multiplexing design. Therefore, these areas must be addressed in concert with repeater configuration design and evaluation. Modulation and multiple access were treated in Paragraph 3.2. It will be necessary nevertheless in studying repeater configurations to ensure compatibility of each approach with the signal structure assumed applicable.

A general categorization is necessary to facilitate distinguishing between variants in approach which differ only in implementation details from those which are fundamentally different in their switching and routing design. If general enough, the basic description of a given structure, in block-diagrammatic or verbal form should be insensitive to such mechanical details as internal frequency translations.

The approach described here represents an attempt to coordinate the various system relationships and then identify the several most promising system concepts, wherein the system is composed of not only the repeater but also the multiple access, modulation, and multiplexing technique as well as the significant space segment hardware-related factors. In other words, the repeater configuration descriptions contain, as inherent and inseparable components, descriptions of the signal and the hardware factors mentioned. The approach to be followed is summarized in the next paragraph.

The emphasis in this report is on frequency-divided schemes. This means FDMA, separation of signals by frequency, and primarily frequency division multiplexing. First, the topic of signal structure is treated. The signal in question is the composite present in each uplink and each downlink antenna beam. Therefore, multiple access is involved, as well as multiplexing in some cases. The modulation, also related, is then considered. Next, the general functions which must be performed, at least conceptually, in a space repeater system of the desired type will be described. Thus, having considered the general repeater functions and the signal structure, it is necessary to examine some subsystem implementation alternatives and tradeoffs. It is then possible to postulate specific alternative repeater/signal schemes. Some of these, upon evaluation of performance or implementation advantages and disadvantages, are then rejected, while some are retained as primary candidates for more detailed tradeoff analysis. Systems are separately evaluated for video/high rate data and for voice/low rate data. In other words, mixing traffic categories within one repeater system will not be permitted.

4.2.2 Frequency Division Concepts

4.2.2.1 Signal-Structure Categorization

Within the coverage area of each uplink beam there may be multiple earth stations which transmit to the MFR satellite. Each terminal's transmission may carry multiple user or baseband (video, audio, or data) channels. Within the coverage footprint of each downlink beam lie multiple earth stations, each of which is a sink or recipient of satellite-relayed signals. There may be more than one user channel intended for each such terminal.

The organization, structure, and format of these uplink and downlink signals is the objective of signal-structure categorization. The downlink signal of a beam is taken as the entire composite radiated by that beam. The uplink signal in a given beam is the composite signal present at the output port of that beam. Clearly then, multiple access and multiplexing are inherent factors in the signal structure; by definition, FDMA applies. Frequency division multiplexing is also favored when applicable, though it is conceivable that digital channels might be time division multiplexed even in an FDMA system. Modulation is not as closely related, however, and has been covered as a separate topic in Paragraph 3.2.

Consider an earth station which must transmit for satellite relay a number of user channels. One signal structure which could be adopted would be to modulate separately as many carriers as channels. This single-channel-per-carrier technique is designated "A." Another scheme would be to modulate one carrier with a multiplexed composite baseband of all the user channels being handled by that one terminal. This single carrier per source technique is designated "B." The station might also transmit several (modulated) carriers, each of which carries, in general, several multiplexed user channels; this is designated "C." In general, the existence of multiple terminals and therefore accesses within a beam means that a B uplink always generalizes to C.

The downlink categorization is analogous. If the composite downlink contains single-channel-per-carrier signals, it is A. If the entire downlink signal in a beam is a single carrier modulated by all the user channels for that beam or, single carrier per beam, it is B. A C downlink is one which carries multiple multiplexed signals; for example, single carrier per sink, meaning that the multiplexing has been so organized that there is a one-to-one correspondence between the carriers in a beam and the receiving terminals served in that beam. The following important clarification is made for reasons which will become evident shortly. If a terminal transmits certain multiple single channels per carrier in such a way that these carriers are contiguous in frequency and are to be routed to the same downlink beam, and consequently satellite filtering and translation can operate on this horizontally stacked composite as if it were one broadband signal, the signal will be considered a B (multiplexed) signal rather than multiple As. Likewise, a B or one portion of a C downlink can resemble horizontally stacked As, and will be considered a B or C if, and only if, the entire signal package has been passed through the repeater unaltered except in center frequency; that is, the distinction between multiple As and a single B (or C segment) depends on how the composite is handled.

With the A, B, C designation for both up- and downlinks, a two-letter code can then be used to describe a repeater system in signal-structure terms so that AB stands for a single channel per carrier uplink, single channel per downlink beam concept, for example. Thus, there would appear to be nine general structures (AA, AB, AC, BA, BB, BC, CA, CB, and CC). However, with the deletion of B uplinks, there are six possibilities. These six significant techniques are listed and described in Table 4-23.

Table 4-23. Uplink/Downlink Signal Structure Categorization

Code	Description
AA	Single channel per carrier on both up- and downlinks.
AB	Single-channel-per-carrier uplinks. Single- (multiplexed) carrier-per-beam downlinks.
AC	Single-channel-per-carrier uplinks. Multiple multiplexed carriers on downlinks.
CA	Multiplexed carriers on uplinks (may be one or more per source). Single-channel-per-carrier downlinks.
CB	Multiplexed carriers on uplinks (may be one or more per source). Single- (multiplexed) carrier-per-beam downlinks.
CC	Multiplexed carriers on uplinks and on downlinks.

4.2.2.2 Modulation and Multiplexing

Modulation and related topics were covered in Paragraph 3.2. The reader is referred to Table 3-1 for a listing of modulation and multiplexing techniques considered applicable for the MFR system.

4.2.2.3 Functional Categorization

The functional categorization is perhaps the most fundamental aspect of the repeater techniques categorization, even though in practice the functions are often combined in a way that make it difficult to determine where each is actually being performed.

The functional categorization has to do with identifying the various signal routing functions performed in a multibeam multichannel satellite. The general or overall function to be performed by the satellite is to provide a relay or repeater between various earth transmitters and corresponding receivers. There are several ways of doing this, but, in general, signal paths must be established between uplink and downlink beams. The categorization approach to be described may not be the most general but clearly delineates the various functions performed in fulfilling the overall beam signal path connectivity requirement.

There is a multiplicity, say "k," of uplink beams and a number, say "1," of downlink beams. It is useful to think of the entire repeater system in baseband channel terms (e.g., one video channel, one audio needline, etc.). (Later this can be generalized by combining baseband channel routes which are parallel into trunks.) Thus, when we say that an uplink beam needs to be connected to a downlink beam, we mean that there is a service demand between the two coverage areas in question. The entire repeater categorization is thus a baseband channel routing exercise.

The functional categorization can be derived by considering in order the functions that must be performed, from input (uplink beam) all the way to output (downlink) beam. Please refer to Figures 4-9 and 4-10 (the difference will be explained later). In general, any channel transmitted to the satellite may need to be routed to any subset of downlink beams. But the composite signal received by each beam contains multiple baseband channels. Therefore, the function of separation must be performed. Next, since some of these channels need to be connected to several downlink beams, and therefore routed along several different paths, it is necessary to generate multiple versions of such channels. This has sometimes been termed "splitting," but it is less ambiguous to call it fanout branching or simply fanout. Switching or routing follow the fanout. To continue the input/output symmetry, to make the routing switch a one-to-one crossbar, and to accommodate certain multiple input-to-one-output requirements (data collection, conferencing), a function termed fanin routing or simply fanin may be postulated to follow the switch.

In many cases the switching matrix can perform fanout and fanin. This routing switch might be an impedance insensitive crossbar arrangement or a three-dimensional crossbar. The last function to be performed is combining, to bring together all the channels (signals) destined for each beam. Thus, five functions have been identified: separation, fanout, switching, fanin, and combining. It is possible to change the order of some functions, as, for example, some routing can be done prior to separation. Also, frequency translation and ordering functions have been ignored in this baseband routing oriented approach, though it is exactly in such functions that various implementation techniques differ. In like manner, demodulation, demultiplexing, and modulation have not been separately identified; functionally, these are just specific ways of accomplishing separation, combining, etc.

There are at least two fundamentally different ways of organizing the general functional repeater. In the first, subsystems such as the separator and combiner, in particular, are common to and shared by all beams. This pooled approach is illustrated in Figure 4-9. It is also possible to construct a separate, dedicated subsystem for each beam. This is the per-beam approach illustrated in Figure 4-10. Hybrid approaches are also possible, e.g., pooled separation but separate combiners for each beam.

The analogy can be made between the switching, multiple beam repeater and a telephone exchange. Replace the antenna beams with multichannel trunks, the separators with demultiplexers, and the combiners with multiplexers. The switch is still a crossbar, at audio. The fanout and fanin take some thought to properly handle the analogy, and the simplest illustration would be a manual switchboard or jack panel. Fanout occurs in a row of jacks which are paralleled to allow conferencing. Fanin is the similar and concurrent paralleling of "listen" lines to allow each conference party to hear all other parties.

4.2.2.4 Repeater Subsystem Considerations

To further define and identify repeater configuration alternatives, it is necessary to look at general hardware design considerations which may be affected by the modulation choice and signal structure and at the specific alternatives possible when implementing each repeater subsystem.

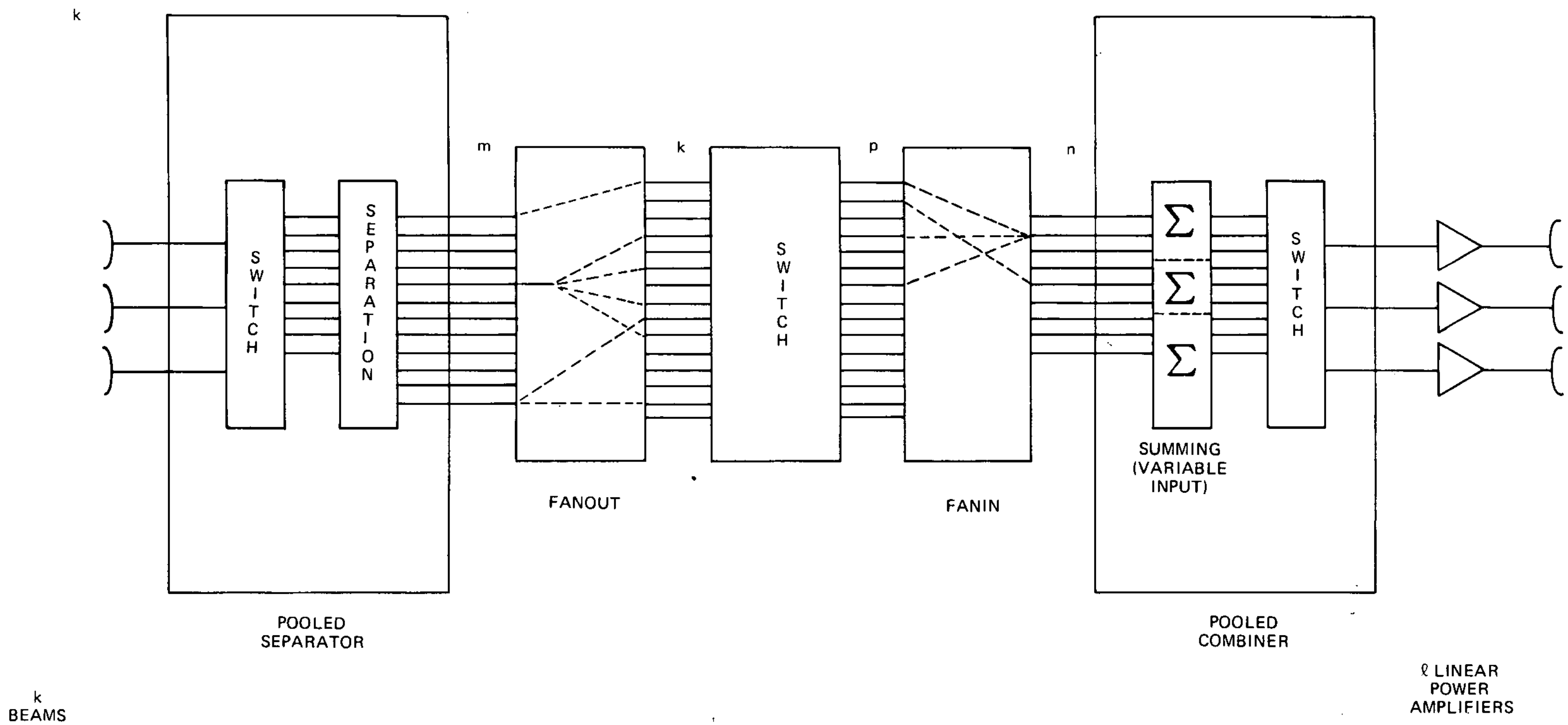

Figure 4-9. Pooled Repeater

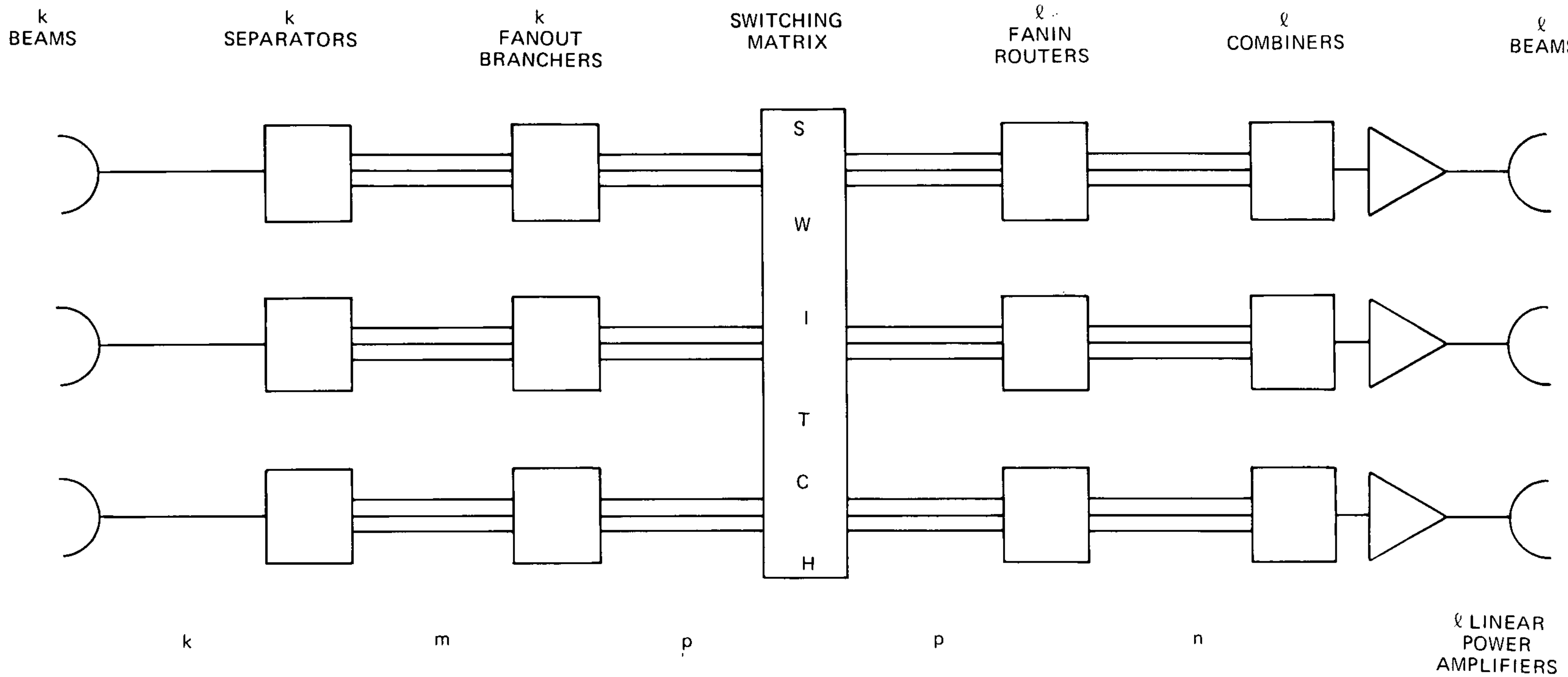

Figure 4-10. Unpooled Repeater

The most important general considerations are bandwidth requirements as a function of the modulation, and linearity requirements imposed upon the repeater power amplifiers. In the case of the latter, one may characterize a given repeater/ signal concept as either requiring or not requiring a linear amplifier, although, in general, linearity is always a matter of degree. The significance of this is that, in general, linear amplifiers have poorer DC-to-RF conversion efficiency than nonlinear (saturated) amplifiers.

One may ask whether a given design makes use of the following procedures: demodulation, demultiplexing, modulation (other than pure RF translation), and multiplexing. Also, one asks whether the fundamental routing switch operates at an intermediate frequency or at baseband.

The answers to such questions, which amount to defining the repeater implementation more precisely, serve to distinguish and categorize various alternative concepts. It would appear that there are many different alternatives. However, some combinations are strictly incompatible (e.g., if the repeater demodulates, it must subsequently modulate), while others will be rejected immediately as too complex to implement (e.g., schemes which demodulate and/or modulate on a channel-by-channel basis).

4.2.2.5 Complete System Categorization

The previous repeater categorization has been concerned only with the input and output signal structure (e.g., Table 4-24), though certain assumptions about the most reasonable design choices were made, for example, that in AA there is no advantage to demodulation/remodulation. It is more general to allow for all possible variations and then to cite the ground rules and assumptions which rule out certain combinations or make certain other combinations the most natural within a given general category.

A complete system description will then consist of more than the signal structure two-letter code. It will also cover modulation and multiplexing and repeater implementation conditions. Table 4-24 lists the questions that should be answered to characterize a system. Unless otherwise apparent, the answer to each is a binary, yes or no decision.

Table 4-24. Categorization Questions

Item No.	Question or Factor	Answer	Code
1	Uplink Structure	See Paragraph 4.2.2.1	A or C
2	Modulation, Multiplexing, and Multiple Access on Uplink	See Table 3-1	FM, FDM/FM, Stacked VSB, etc.
3	Pooled Separator?	Yes or No	
4	Demodulation Performed?	Yes or No	
5	Demultiplexing (to baseband) performed?	Yes or No	
6	Switching at IF or baseband?	IF or Baseband	
7	Multiplexing Performed?	Yes or No	
8	(Re) modulation Performed?	Yes or No	
9	Pooled Combiner?	Yes or No	
10	Modulation and Multiplexing on Downlink	See Table 3-1	FM, FDM/FM, etc.
11	Linearity Required in Power Amplifier?	Yes or No	
12	Downlink Signal Structure	See Paragraph 4.2.2.1	A, B, or C

Clearly, there are hundreds of possibilities. However, the scope is drastically curtailed by some obvious restrictions such as the following:

1. Item 2. If a C uplink is being considered, then a multiplexed choice must be made here. If an A uplink is being considered, a single channel choice (FM, VSB/SSB, or PSK) applies.

2. Item 5. Demultiplexing applies only to C uplinks.

3. Item 6. If there has been no demultiplexing or demodulation to baseband, switching is at IF. If there has, switching is at baseband.

4. Items 10, 11, 12. These factors are related to one another, so the choices are not independent.

Further screening criteria to be described in the next paragraph will result in a reduction of system categories to a reasonable number.

4.2.2.6 Initial Screening and Tradeoffs Between Techniques

Several screening criteria can be applied to the large variety of possible techniques. Some of these are in the category of reasonable assumptions; others are more or less essential for viability; for example:

1. Demodulation/remodulation is avoided whenever possible, i.e., whenever a given signal structure scheme can be postulated to operate without it.

2. Techniques which, when compared with other schemes, differ only in that they are of benefit in simplifying earth terminals while complicating the satellite are rejected. Thus, CA differs from AA only in that the satellite requires demodulators not needed for AA; the multiplexed C uplink removes linearity requirements for earth terminals but complicates the repeater. Since AA is a viable technique, then CA can be rejected.

Alternatives after initial screening and intertechnique comparison are shown in Table 4-25. In CC the separator would more likely be pooled because the multichannel uplinks are of varying bandwidths, depending on the requirement at a given time, so it is more efficient to share a pool of filters of various bandwidths.

Table 4-25. Screened List of Techniques (Sheet 1 of 2)

Signaling	Service	Other Parameters	
AA	Video, Voice; Data	Uplink Mod:	FM or SSB/VSB; PSK
		Separator:	Pooled or unpooled
		Demodulation:	No
		Demultiplex:	None
		Switching:	IF
		Multiplex:	None
		Modulation:	None
		Combiner:	Same as separator
		Downlink Mod:	Same as uplink
		Linearity Needed:	Yes
AB	Analog Voice; Data	Uplink Mod:	SSB; PSK
		Separator:	Pooled or unpooled
		Demodulation:	No
		Demultiplex:	None
		Switching:	IF (subcarrier)
		Multiplex:	Frequency stacking only
		Modulation:	Yes
		Combiner:	Pooled or unpooled
		Downlink Mod:	FDM/FM; PSK/FDM/FM
		Linearity Needed:	No
AC	Shows no satellite advantage over CC		
CA	Shows no satellite advantage over AA		
CB	Shows no satellite advantage over AB		

Table 4-25. Screened List of Techniques (Sheet 2 of 2)

Signaling	Service	Other Parameters	
CC	Video, Voice; Data	Uplink Mod:	Stacked SSB/VSB; TDM/PSK
		Separator:	Pooled or unpooled
		Demodulation:	No
		Demultiplex:	None
		Switching:	IF
		Multiplex:	None
		Modulation:	No
		Combiner:	Pooled or unpooled
		Downlink Mod:	Same as uplink
		Linearity Needed:	Yes

4.2.2.7 Subsystem Similarities

Three general categories (AA, AB, and CC), each with design alternatives, have been identified as primary candidates. It would appear, then, that there still remains a large number of subsystems which must be examined in terms of hardware implementation. However, there is a great degree of functional similarity between portions of each scheme. For example, most of the AB repeater is identical to an AA design of like operation; the only differences are: in AB, a modulator is inserted between the combiner function* and the power amplifier, and the power amplifier does not require linearity. In block diagram form, the pooled CC repeater is functionally identical to a pooled AA, except that the filters are wide enough to pass several instead of one modulated carrier. Therefore, the subsystems to be studied in detail are: all the components of various possible AA approaches, the modulators which change an AA into an AB, and whatever differences exist between CC's filters and AA's single-channel filters. These will be more accurately identified and specified in Paragraph 4.2.2.8.

4.2.2.8 Identification of Prime Candidates

Figures 4-11 and 4-12 show two possible ways of implementing an unpooled AA repeater. (In these and following figures, the fanout switching and fanin functions have been combined within the ROUTING box.) The differences are in the use of fixed versus tunable filters and relative placement of channel translation mixers, which can be summed up as a difference in the location of frequency agility. There may also be parts count differences, depending on the relative numbers of received (and fanned out) versus transmitted (and fanned in) baseband channel paths needed. Figure 4-13 is the pooled AA system. Any one of these can be applied to AB by the simple addition of an FM modulator (and the change from linear to nonlinear amplifier). The three results might be designated AB1, AB2, and AB3. For CC, we have stated that the separator would probably be pooled, but the combiner can be either pooled or unpooled. Thus, two possible CC diagrams, Figures 4-14 and 4-15, have been generated by borrowing from Figures 4-12 and 4-13 as necessary. Even among these various implementations, there is much subsystem commonality, which eases the hardware study chore.

*In this form of an AB repeater, the frequency stacking of the AA performs the multiplexing role, and the modulator becomes part of the combiner.

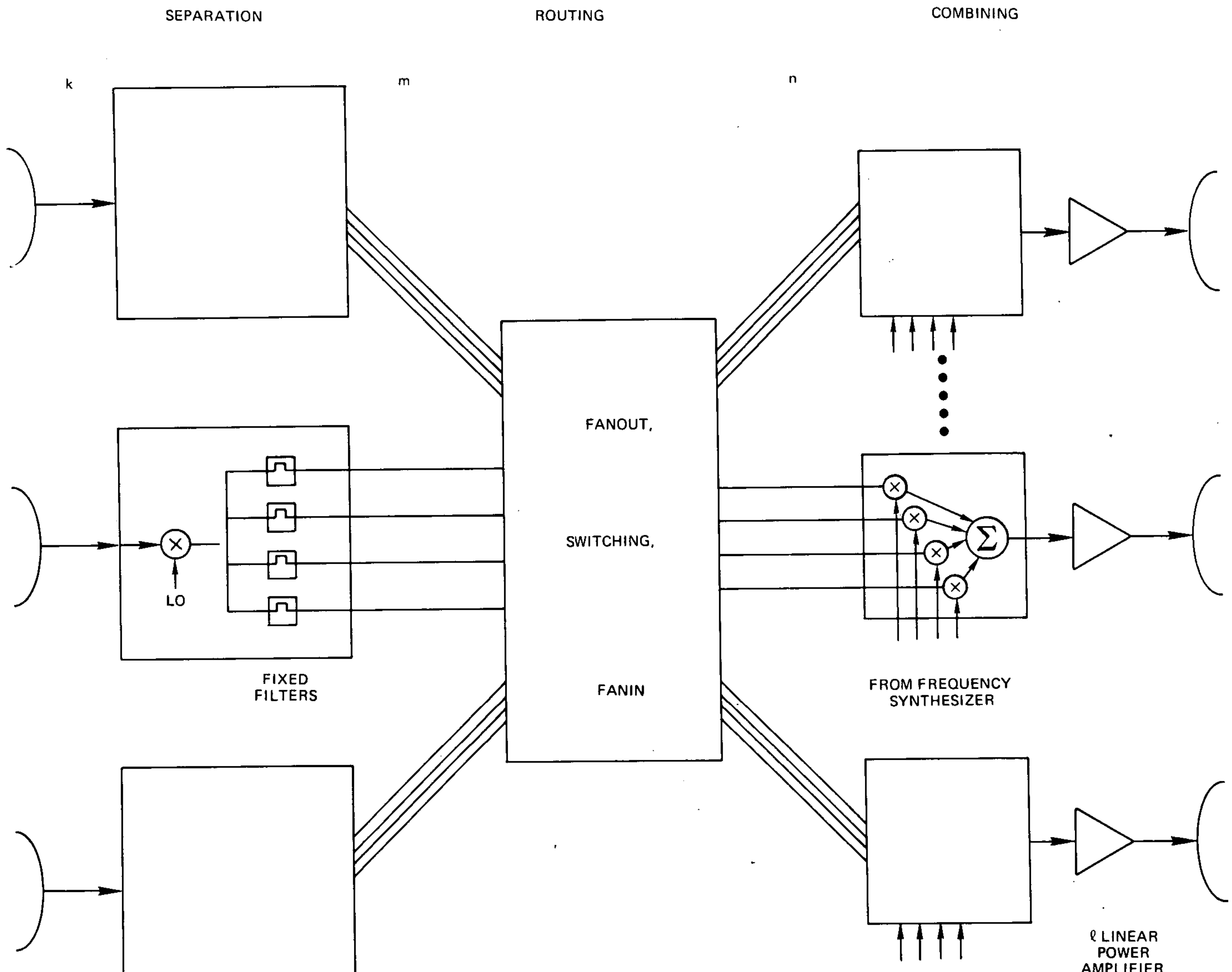

Figure 4-11. AA1 Concept

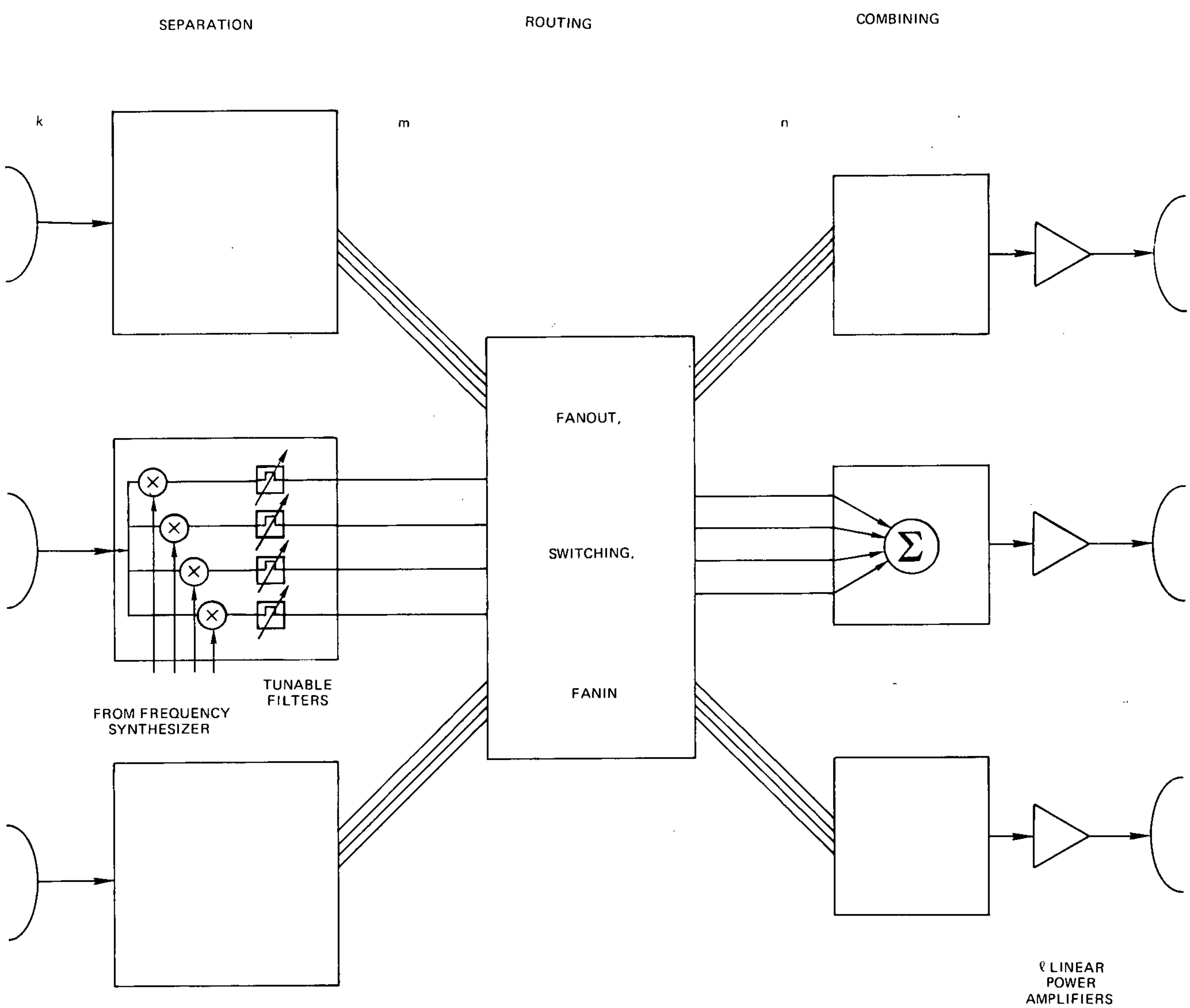

Figure 4-12. AA2 Concept

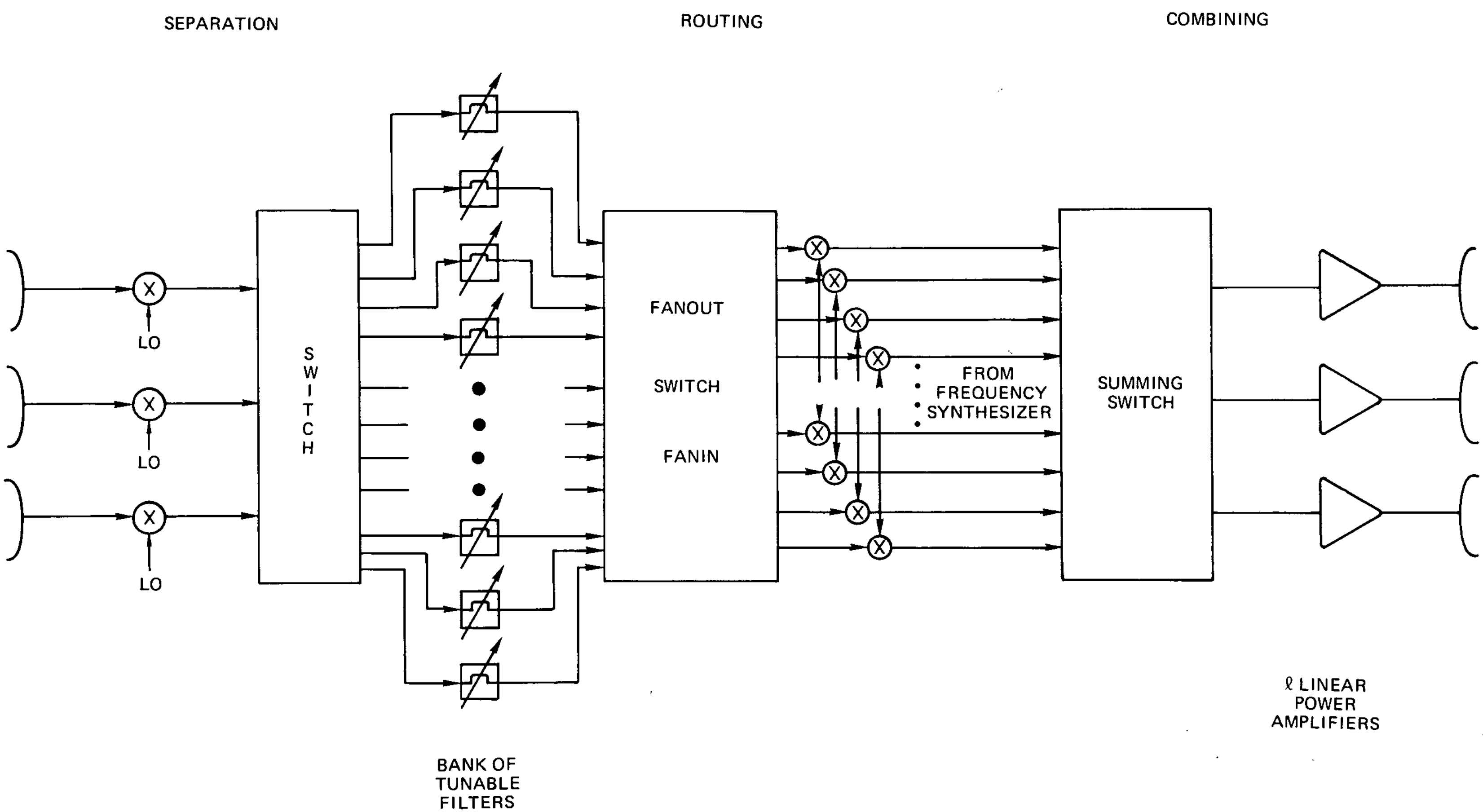

Figure 4-13. AA3 Concept

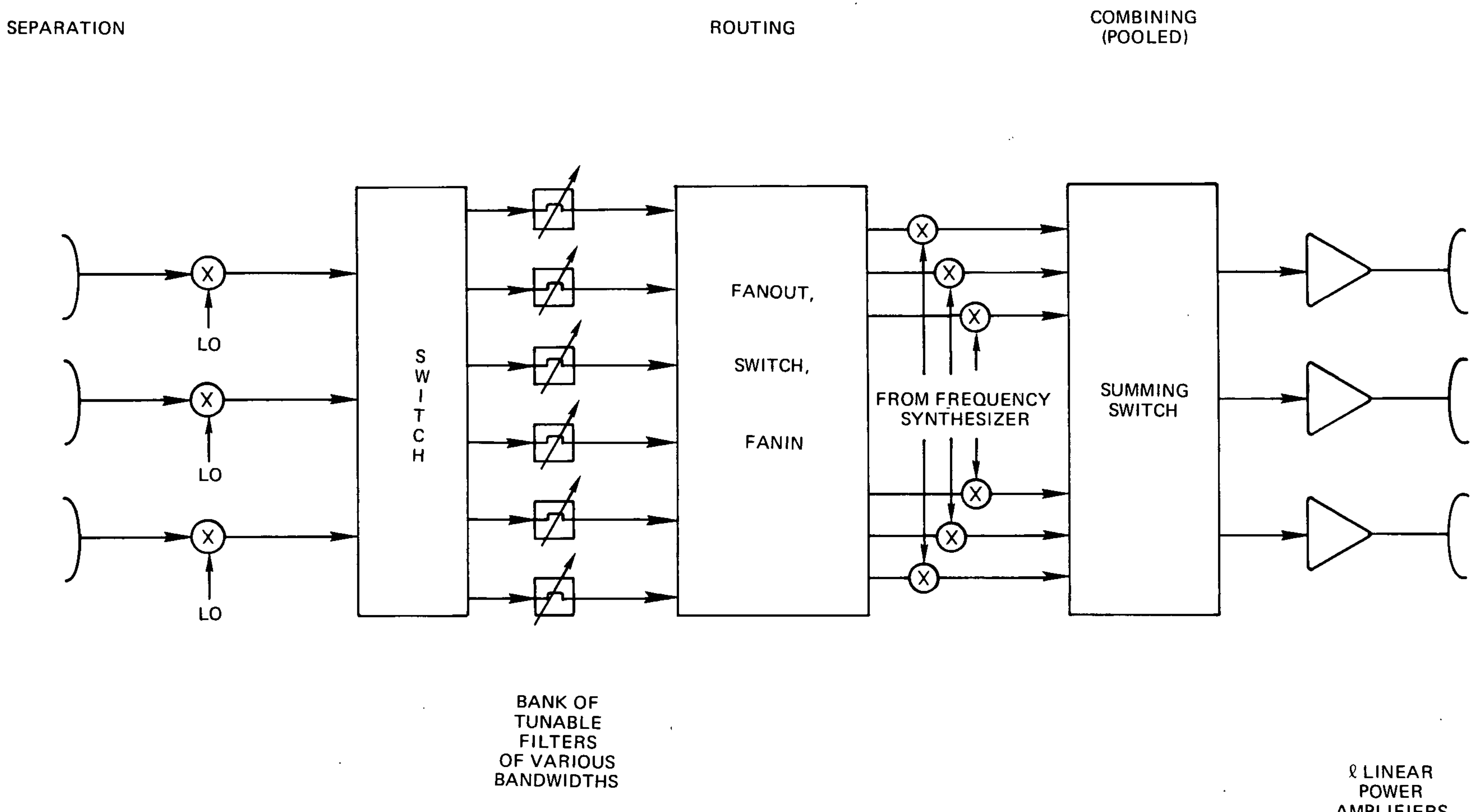

Figure 4-14. CC1 Concept

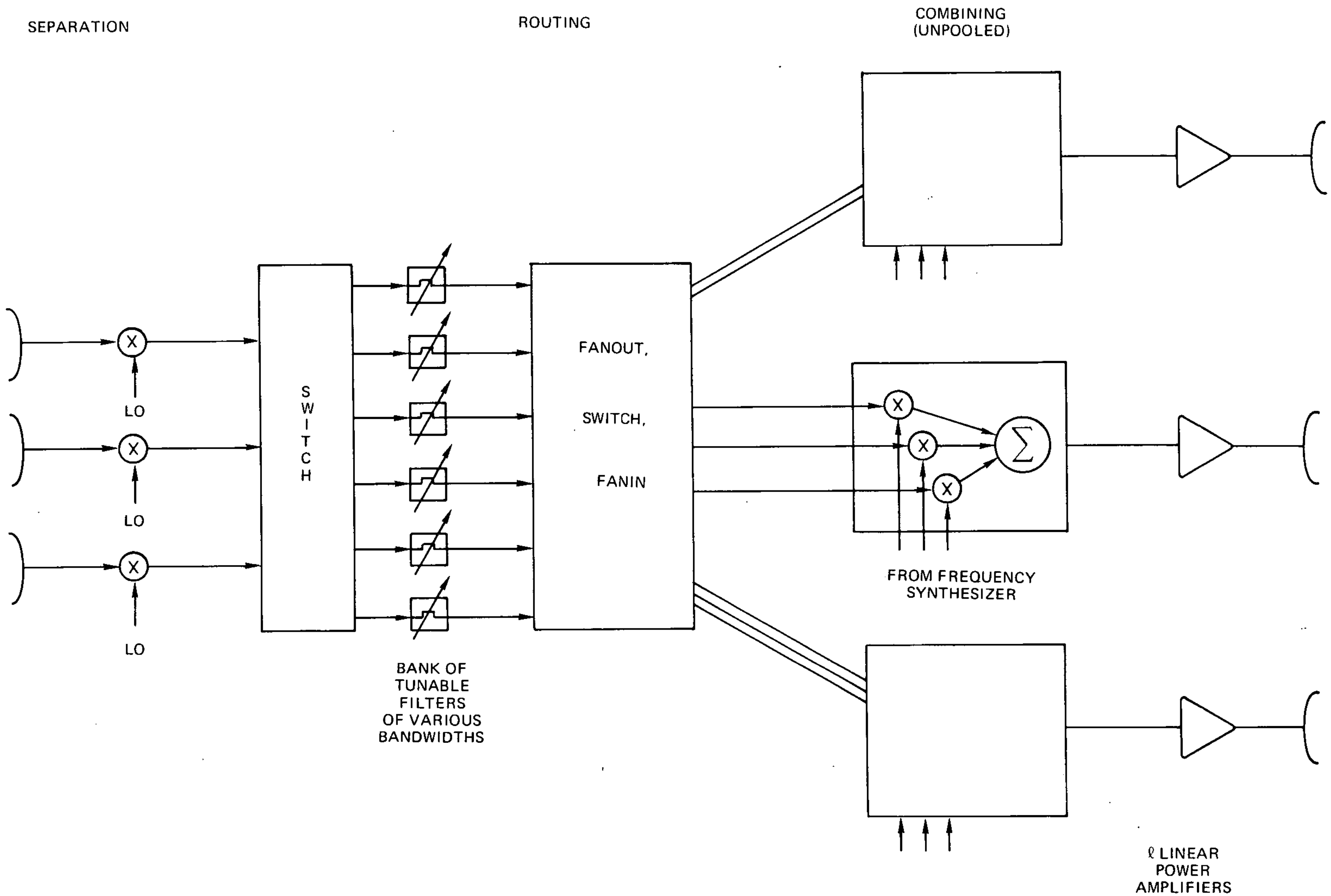

Figure 4-15. CC2 Concept

The alternatives could also be compared in terms of system performance; however, this is a multidimensional, parametric problem. For example, AA3 can always be set up with sufficient filters, etc., to match AA1/AA2 performance under all conditions. However, its advantage is that the pooling of filters may often allow a small total number of filters to perform just as well on the average for a given typical requirements pattern as an AA1/AA2 with a larger number. On the other hand, AA3 needs more switching hardware.

AA3 appears to be the most flexible and general concept, against which other schemes could be compared. However, it is not certain that less flexible "AA" concepts might not, in practice, perform just as well. Only a full simulation would be able to answer this question. It will be seen that, if the number of beams and channels is relatively low, full flexibility is not necessary for typical requirements structures, because the large amount of fanout encountered in broadcast and conference modes means that uplink efficiency and flexibility are not very important; satellite capacity is limited by downlink bandwidth limitations long before the uplink. It will also be shown that, with active filter technology, the savings in total repeater weight obtained by trunking (CC instead of AA) are not very great. Therefore, the fully channelized AA concept appears to be the prime candidate as the baseline repeater structure.

4.2.3 Time Division Concepts

4.2.3.1 Introduction

It has been shown in Paragraph 3.4.4.4 that TDMA and digital techniques must be ruled out for video application unless significant reductions in bandwidth* are possible. However, for digitized voice and for data at medium or low rates, TDMA techniques should be applicable. The following paragraphs present a repeater categorization for time division, one that is analogous to the FDM categorization. The

*Recently published information (Reference 13) suggests that with sufficient coding equipment, digital video can be brought down in bandwidth to that of FM (about 20 MHz). Whether such complexity is applicable for MFR applications is questionable.

functional analogies between time and frequency (see Paragraph 3.4.4.2) are advantageous in this categorization.

4.2.3.2 Categorization of Time-Organized Repeater Structures

It is desired to establish a categorization of strictly time division-oriented multibeam, multiple-channel repeater concepts, similar to what was done for frequency division concepts (see Paragraph 4.2.2). "Strictly time division" means that separation of signals both between and within beams is accomplished in the time domain only. The time domain equivalent of the frequency division domain's "carrier" is the burst. Thus, one is motivated to establish the following equivalencies:

Frequency Domain Concept	Time Domain Equivalent
Single channel per carrier	One burst per channel (A)
One carrier per source with multiplexed channels	One burst per source with multiplexed channels (B)
Multiple carriers per source	Multiple bursts per source with some of them containing multiplexed channels (C)

However, it is apparent that the time domain categorization may not be as useful. There is not very much difference between multiple (but contiguous) bursts and one long burst.

Nevertheless, one may continue the analogy by applying the A, B, and C categorization on both up- and downlinks,* as in the FDM case. Before this can be done, however, another issue must be examined. In the FDM situation, it was clear that frequency translation was not an essential function in the sense that basic modes of operation would not be affected by changing the various signal frequencies. The equivalent in time is temporal rearrangement, or in its most significant variation, storage in time. In time division-oriented applications, whether or not the signals (data) are stored and forwarded

*As with FDM, the B uplink generalizes in the case of multiple accesses per beam to a C uplink. Therefore, only A or C will be carried on the uplink.

is essential. Thus, it is necessary to distinguish between retransmit immediately (R) and store and forward (S).

In those concepts which do perform a store-and-forward operation, it is straightforward to time coherently and arrange contiguously the output data (for the downlink signal). Thus, although the A or C categorization might apply to up- or downlink, the cases where store and forward is used should all have a B downlink. On the other hand, one might initially expect that in an R system, the output must resemble the input; however, such would not always be the case (e.g., several B inputs can result in a C output). An A output can also result from the extraction of one channel from a B or C uplink composite.

The classification rules and restrictions discussed previously lead to the categorization shown in Table 4-26. The end result of these considerations has thus led to two approaches differing in data organization on the downlink transmissions. The store-and-forward scheme (CSB) uses the storage and reorganization feature to allow a single contiguous data burst on each downlink, while the retransmit immediately scheme (CRC) must allow a multiple-burst capability. The major tradeoff is thus seen to be earth terminal versus satellite complexity. Furthermore, the major factor influencing the categorization is the presence or absence of storage in the repeater. It should also be noted that store-and-forward concepts require demodulation in the satellite repeater.

4.2.3.3 Data Formatting, Onboard Storage (Memory), and Spectrum Reuse Considerations

4.2.3.3.1 Introduction

In a time division organized, multiple-beam repeater system, there are close relationships among:

- Data formatting of the earth terminal transmissions (uplink signals)
- Onboard storage or memory that enables rearrangement and reformatting of the data being relayed, thereby performing downlink signal organization
- Spectrum reuse, which depends on the up- and downlink signal organization.

Table 4-26. Time Division Approaches

Technique	Separator Functions	Switch At	Comments	Prime Candidates
ASB	Detect and demodulate on channel-by-channel basis	Baseband	More complex than CSB with no obvious advantages	No
CSB	Detect and demodulate	Baseband	The general store-and-forward scheme	Yes
ARA	None	IF/RF	Most general and flexible retransmit approach. A special case of CRC.	No. Use CRC instead
ARB ARC	A on uplink with R not compatible with B or C on downlink			No No
CRA	Combination not compatible			No
CRB	C uplink, R repeater, and B downlink restrict flexibility			No
CRC	Switching (at most)	IF/RF	Feasible. A most general R approach	Yes

The previous paragraph considered the categorization and operation of essentially single-path TDM/TDMA repeaters. It is necessary, however, to be somewhat more comprehensive and consider the operation of sets of repeaters (or the equivalent, subsystems with multiple paths), especially in conjunction with multiple antenna beams which are not perfectly isolated from one another.

4.2.3.3.2 Single Repeater Path Concepts

The single-path system is the most elementary time division multiple-beam concept. It consists of a single-input, single-output repeater with the input and output connected to the uplink and downlink beam ports by single-pole n throw switches, where n is the number of beams. The signals in the different uplink beams, and likewise those in the n downlink beams, are separated purely in the time domain, while their spectra overlap completely. Only one beam can receive and one transmit at any given time. The repeater can be either the simple "R" type or an "S" type with storage. The latter offers formatting convenience in that multiple noncontiguous bursts can be eliminated. That is, each source (uplink transmitting station) can send all its outgoing data in one block; similarly, each beam's set of downlink signals can be a multiplexed "B" type burst. There is, however, no capacity or spectrum occupancy advantage in the use of an "S" over an "R" repeater with only one path. If a memory is used, however, it can be very simple since all it has to do is delay certain message bursts by certain quantized increments of time. Therefore, true random access memory is not necessary (i.e., rather only a collection of shift registers). A memory with nondestructive readout would also offer a convenient way of solving the fanout or broadcast requirements, wherein the same message must be transmitted in more than one downlink beam.

The single-path repeater has excellent power efficiency since the repeater power can be used at all times. However, the bandwidth utilization is low, as evidenced by the high peak-to-average bandwidth ratio.* There is no spectrum reuse with only one repeater path.

*It is useful with TDMA systems to postulate the concept of average bandwidth, which is the channel bandwidth multiplied by the duty factor of the beam or signal in question. This concept is in direct analogy to the concepts of average and peak power.

4.2.3.3.3 Multiple Repeater-Path Concepts

Suppose a multiplicity of repeaters (or an equivalent system with multiple inputs and outputs) is to be used to interconnect the input and output beam ports. How should these repeaters be organized? The fundamental principle is that orthogonality (isolation) must exist between signals in at least those beams which are close to each other.

One way to achieve this isolation is to use frequency separation (i.e., place every beam on a different frequency band). Thus, up to n repeaters, where n is the number of beams, can be connected. This popular solution (Reference 11) has no spectrum reuse, however, so that its only direct theoretical advantage over the single-path repeater of equal power and bandwidth is that the frequency channelization results in lower peak-to-average ratios in both power and bandwidth. In a densely loaded system, in fact, the duty cycles may approach one. This is a substantial advantage in terms of system operability. In practice a further advantage would accrue from the reduced percentage of time wasted on guard times, synchronization, etc.

The single-path repeater uses time separation between beams. The multiple-path, multiple-band concept uses frequency separation. A third degree of freedom is available (i.e., spatial* isolation). In some systems (e.g., Intelsat), the separation between many service areas is great enough so that most of the satellite's spot beams are very well isolated from one another. In a system such as MFR, however, where the beams are closely packed, all the beams cannot be isolated from all the others purely through the use of spatial isolation. Therefore, it must be used in conjunction with either time or frequency separation. The spatial separation axis is used to separate groups of beams, while the beam signals within each such group may be separated either in time or frequency. If time is selected, the concept reduces to the ganged switch repeater discussed in Paragraph 3.4.4.2. However, both the up- and downlink must be organized according to a separation plan. Consequently, the repeater ganging would have to be used on both the up- and downlink. This places great restrictions on

*Polarization discrimination, due to its limited degree of effectiveness (only two polarizations are available), is treated as part of spatial separation.

the allowable connectivity patterns. This problem can be solved by using a storage (S) repeater instead of an R type. Now suppose that frequency is chosen as the auxiliary separating axis. Then up to n repeaters or paths can be adopted. If so, the result is functionally the same as the purely frequency channelized concept. Instead of n separate bands, n/m are used, m being the degree of reuse. For example, with six beams one might postulate three bands which are used twice instead of six separate bands. Thus spatial isolation has been applied to achieve spectrum reuse.

Table 4-27 shows the various alternatives identified. Once again it should be noted that intrabeam separation of individual user channels is a matter distinct from interbeam separation. The second and fourth alternatives in the table have virtually continuous signals in every beam when the system is fully "loaded," yet time division concepts (TDM and TDMA) can still be applied in the routing and processing of each such "continuous" signal. This point is made because there is a problem of terminology in the fact that although these concepts are being treated under the heading of "time division" concepts, some of them are really hybrids in the sense that frequency division is also necessary. Only the single switched repeater is a "pure" time division concept.

4.2.3.3.4 Merits of Onboard Data Storage

The advantages and relative merits of store and forward versus retransmit immediately TDM/TDMA repeater operation need to be examined. It is clear that the use of storage in a repeater system adds complexity to the satellite, while offering greater flexibility and ease of formatting to the earth terminals. Thus, a typical space-segment versus ground-segment tradeoff is identified. However, the advantages to be gained by inclusion of memory depend on the overall system structure. As indicated previously, the single-path repeater does not gain in efficiency or effectiveness, as measured by criteria such as spectrum occupancy or power utilization, by the addition of storage. On the other hand, the ganged switch, multiple-path concept suffers if storage is not included. Although S or R repeaters of equivalent capability must, by definition, operate with the same average link powers, data rates and bandwidths, the difference, if any, in what we term efficiency is not purely a function of the averages. In fact, the peak-to-average ratios are a better criterion, and potential advantages from storage occur

Table 4-27. "Time Division" Alternatives

	Type	Number of Simultaneous Repeater Paths	Primary Axis of Intrabeam Separation	Secondary Axis of Interbeam Separation	Restrictions on Connectivity Pattern	Spectrum Reuse	Type of Repeater Channels
1	Single Path	1	Time	---	Few	None	R or S
2	Multiple (Ref. 14)	up to n*	Frequency	---	Few	None	R or S
3	Multiple Ganged	m*	Spatial**	Time	Substantial	m	S advisable
4	Multiple	n	Spatial**	Frequency	Few	m	R or S

* n = number of beams
m = degree of frequency reuse

**Polarization isolation included as part of spatial isolation.

because the reformatting, which is an inherent aspect of such repeaters, can be programmed to keep the frames full, thereby reducing peak-to-average power ratios and therefore bandwidths to an absolute minimum. Also, there must always be some additional advantage to the use of storage in addition to the fact that less overhead can be used. For example, the satellite downlink output consists of one coherently timed contiguous burst, whereas without storage the output consists of separate bursts originating from different earth terminals; thus, each burst must carry overhead bits for receiver and demodulator acquisition.

Preliminary hardware information has suggested that the weights and powers necessary for digital storage in repeaters handling modest numbers of voice channels are not so great as to exclude storage from consideration. It will be seen that in the case of the MFR system and the particular "add-on" philosophy adopted for the voice requirements, memory offers no system advantage relative to the multiple-path frequency channelized concept.

4.2.3.3.5 Advantages of TDMA for Voice and Other Requirements with "Thin" Connectivity

At this point it should be stated that the time division repeater techniques were considered to be most applicable to the "on-demand" voice and data channel requirements (e.g., teleconsultation, emergency communication, data inquiries, etc.). The audio transmission requirements accompanying virtually all video needlines were not part of the category because it was assumed that an FDMA-oriented repeater system would be established for the video transmissions. It is then relatively straightforward to transmit the parallel audio needlines by some parallel transmission mode (e.g., on a subcarrier or by modulating a portion of the video waveform itself as in the "back-porch" technique).

Turning now to the separate, "on-demand" voice requirements, it is apparent that time division techniques are highly desirable for the following reasons:

1. Variable routing is more complex to establish with FDMA (filters) than with TDMA (switches) since the filters must be accompanied by switches anyway.

C3

2. The relative bandwidth of voice and medium-rate data is low compared with video. Therefore, spectrum reuse in an optimum fashion is not as critical, so the price paid in extra bandwidth for digital transmission is not severe.

3. This nonnecessity of a high degree of bandwidth use efficiency allows consideration of less than optimum, but potentially much simpler, forms of time switched repeaters.

4. The relatively low data rates mean that memory requirements (if storage is adopted) are modest.

Thus time division-oriented configurations are prime candidates for the on-demand voice and data requirements in the MFR system.

4.2.3.3.6 Initial Selection of Candidates

The general philosophy of "design" or selection of possible repeater configurations to be used for voice and data is that the provision of these services would be "added on" to a repeater/antenna system already designed for the video high-rate data requirements. This philosophy is discussed in more detail in Paragraph 4.3.1. This concept tends to favor certain techniques and make others undesirable. Fundamentally, advantage can be taken of the frequency channelization (band organization) adopted by necessity for FDMA.

A single-path "R" repeater is chosen as one candidate due to its inherent simplicity. The duty cycle of each beam in such a repeater is just 1/n, (n the number of beams), so that the RF bandwidth necessary in each beam is n times the RF bandwidth which would be necessary to transmit the total bit rate in that beam. Thus with 12 beams and 10 channels at 50 kbps in each beam, an RF bandwidth of 6 MHz is necessary (if the modulation technique permits transmission of 6 Mbps in 6 MHz, and without accounting for overhead time). This single-path repeater concept does not require and does not take advantage of the frequency channelization (i. e., the fact that the beams operate at different frequencies).

The second concept selected (see the fourth concept in Table 4-27), is designed to take advantage of both the spatial and frequency separation with no onboard memory, since none is really necessary. It also corresponds analytically with that of Reference 11.

The third concept selected does use memory storage. As a result, it is not necessary to have n repeater paths, but rather only m, which is the degree of frequency reuse or the number of beam "groups." These three concepts will be analyzed and specified in more detail in Paragraph 4.3.3, after presentation of the FDMA baseline concepts to which the time division repeater systems would be added.

4.2.3.3.7 Control Issues

Control of the satellite functions, primarily the routing (switching), is not felt to present much of a problem for the video and other requirements which do not need to be reconfigured rapidly and which, by and large, are scheduled in advance. Conventional and well established satellite command techniques could be used.

The problem is much more complex and less amenable to conventional solution in the case of the "on-demand" voice and data transmission requirements. These are not, in general, predictable and often require rapid response, as for emergency communications. In a satellite system with one or only a few beams, system control is purely a function of access control and the solutions are straightforward, being modelled on conventional radio communication nets (e.g., net control stations, calling channels, etc.) and/or terrestrial common user manual or automated switching. With multiple beams, access control and satellite configuration control are closely coupled. A user accessing the satellite via uplink Beam A may need to communicate with a user served by a terminal within the coverage of Beam C, on one occasion, Beam D on another, etc. Assuming for the moment that somehow the user's need to establish the necessary repeater interconnection is translated into a reconfiguring action (switching pattern change) within the repeater, there are further difficulties if other users already in communication through the satellite repeater have their signal patterns disrupted or changed in the reconfiguration process. The matter is particularly complex in the cases where memory is used on the satellite. The repeater is then a communication processor, concentrator, and switching center.

Due to the complexities, it is believed that the control decision functions should be performed on the ground for satellites designed for the 1975 to 1985 time frame. This decision eliminates one operationally attractive approach whereby each accessing station could "command" or switch the repeater to accomplish the necessary connectivity.

With the decision functions on the ground,* the implementation of the programmable switches is once again relatively conventional. A satellite command system memory (not to be confused with the repeater data memory, if any) would be loaded from the ground with switch positions and sequences, and a simple decoder would use the loaded memory to control the switch drivers as necessary.

This does not answer the question of how reconfiguration demands would pass from a user to the ground control point. It appears most reasonable to accomplish this via a calling or orderwire channel (time slot). This channel would be a "connection" in the repeater from every satellite beam to the beam serving the area within which the control center were located. For example, if a medical center in Alaska wished to be connected with the epidemic control center in Atlanta, first the Alaskan earth terminal would use the calling channel or slot to request such a connection from the control center. The control center would establish, if necessary, a channel between its beam and the Alaskan beam, by means of which the necessary channel allocation or other administrative data could be sent to the Alaskan terminal, and then would reconfigure the repeater to have a connection between the Alaskan and Georgian beams. In practice, during periods of moderate loading, certain slots or channels could be pre-established and remain continuously connected between regions of high demand; however, the orderwire would still have to be used because, in general, more than one earth terminal would have access to each such channel, and access control would have to be exercised.

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*Some form of control center is necessary in any case for the hourly reconfiguration of the video repeater.

4.3 SELECTION OF BASELINE AND ALTERNATE SYSTEMS

4.3.1 Introduction and Approach

The selection of a baseline system represents a starting point for the repeater weight and power tradeoff study. The alternates and a description of the order in which they should be addressed can then be thought of as a flowchart or road map by which to proceed in performing meaningful comparisons among system alternatives.

Fundamentally, there were two major separate system selections to be made: one for video/high-rate data, another for voice/medium- and low-rate data. The video solution is really the pacing or defining item because of the large power and bandwidth required. The voice repeater system can then be thought of as added-on to the selected video system. If this approach were not to be followed, but instead a system were designed expressly for voice requirements in particular, a very different satellite would probably be the result. Most significantly, the 12-GHz band would probably not be used, but rather 2.5 GHz. Regardless of the frequency band of operation, for any given satellite ERP the earth terminal size for voice only is much smaller than for video and voice. The separate system approach has not been adopted here. Now, the total voice requirements are dominated by the audio channel requirements of television needlines. However, these are logically handled in parallel with the video signal (i.e., via the same satellite repeater path). Once a connectivity has been established for a video transmission, it is natural to use the same routing for the audio which requires the exact same connectivity. Thus only the "on-demand" voice and data needlines remain, and an approach can be selected or designed around these. Thus the sequence is as follows. Choose the video/high-rate baseline (or alternate) repeater approach, assuming this will also serve for the parallel audio channels. Then, select a system approach which can provide service for the on-demand voice and data needlines, an approach which takes advantage of and adds on to the postulated video repeater system. As stated previously, an FDMA solution is virtually imperative for video, while a hydrid* time division-oriented approach is attractive for voice and data.

There are two basic inputs or sources of information to the selection of a baseline: the processed requirements (Paragraph 4.1) and the interbeam interference and power budget information (Paragraph 3.4, especially Table 3-8). Other considerations which warranted attention are possible repeater complexity, antenna implementation constraints, and optimum coverage and connectivity; however, these are secondary.

4.3.2 Video System Selections

4.3.2.1 Baselines

The baseline description should specify the number of beams, the signaling (modulation, multiplexing, multiple access), and the specific repeater structure to whatever degree of detail would seem prudent without making unjustified implementation assumptions.

The following factors had to be considered in choosing one of the systems shown in Table 3-10 as a baseline:**

1. Number of beam channels needed (per requirement)
2. Number of beam channels possible (bandwidth limitation)
3. Satellite ERP and approximate prime power needed
4. Relationship of earth terminal size.

The first fact to be noted is that FM solutions cannot provide sufficient beam channels to meet the hypothetical requirements. On the other hand, VSB solutions require exorbitant power with a 30-dB/°K G/T earth terminal. Thus, a 42-dB/°K terminal was

*The concepts are termed hybrids because although time division is used, advantage is also taken of the frequency channelization already established in the video repeater system.

**As will be shown, two baselines were chosen (i. e., one with FM, the other with VSB modulation).

specified for VSB. A definite dichotomy then exists: there are two very different approaches presented for analysis. The FM systems provide relatively few channels, but do so with modest satellites and terminals. The VSB systems provide much greater capacity, but only if larger terminals and satellites are adopted. The changes are not linear, however; the VSB solution requires much greater power and G/T even for system capacity equivalent to an FM system. (However, it should be emphasized that these conclusions apply only to single-satellite approaches. The additional isolation obtainable by using multiple, smaller satellites may make FM more viable for large overall capacity). Simply stated, if moderate capacity is needed, FM is a superior solution. If greater capacity is desired, VSB must be adopted and the price paid in satellite and terminal size. Thus, a parallel baselines approach was selected. Next, it should be noted that the smaller number of beams solutions either meet or come closer to meeting the requirements than do the 23- or 30-beam models; therefore, it would be desirable to select baselines with seven or 12 beams. In order not to place the baseline at one end of the range, 12-beam models were chosen. The FM baseline is a three-band solution, providing a six-channel* per beam capability under equal loading conditions, and an average (or nominal design value) RF power to the antenna of 2 watts per channel (carrier). Initially, a fully channelized AA technique should be investigated. The VSB baseline, also with 12 beams, operates with the six-band frequency plan and a nominal 16 channels per beam, also at about 2 watts per carrier.

4.3.2.2 Approach to Alternate System Evaluation

The approach taken was as follows. The two baselines were fully designed. In the process, configuration design tradeoffs were performed, for example:

1. Single PA per beam or single PA per channel?
2. Pooled or unpooled filters?
3. Trunks or all single channel?

While it cannot be assured that a configuration decision valid for 12 beams continues to apply for 30 beams, neither should it be the worst possible choice. Satellite repeater

*Instead of seven, to allow for guard space.

models for other beam configurations can then be parametrically sized, at least in weight and power terms, from the data compiled for the baseline design. To ascertain the variation in weight and power as a function of the two most important driving parameters (number of channels and number of beams), the alternatives shown in Table 4-28 will be considered.* The channel numbers are those values which occur in the bandwidth-limited cases. They correspond to the requirements values as follows. For seven beams, the beam-channel total is 103. This value is met by the 7-16 (seven beam, 16 channels per beam) VSB solution, and is within striking distance of the 7-10 (seven beam, 10 channels per beam) FM solution. For 12 beams, the beam channel total is 163. This is met by the VSB baseline only. Paragraph 4.1 discusses the relative proportion of single and trunked channels and requirements with other beam numbers.

4.3.3 Provision for Voice and Medium Data

Having selected a video baseline, it is now necessary to determine what provisions for voice and data can be made. Note once again that only the "on-demand" or separate voice and data needlines are involved, not those which accompany television links.

Several facts are in order. First, one should consider the magnitude of the requirements and the degree of accuracy in their specification. Summarizing the data in Paragraph 4.1.3, the per beam requirements (both up- and downlink due to symmetrical nature of most voice and data) are:

Beam Model	Channels/Beam
7	≦8
12	≦7
23	≦6
30	≦6

*It will be seen that several additional possibilities were also considered in the weight and power estimating task.

Table 4-28. System Alternatives

Beams	Channel/Beam	Total Beam-Channels	System
FM Systems			
7	3	21	7 - 3
	6	42	7 - 6
	10	70	7 - 10
12	3	36	12 - 3
	6	72	FM - Base
23	3	69	23 - 3
VSB Systems			
7	6	42	7 - 6
	16	112	7 - 16
12	6	72	12 - 6
	16	192	VSB - Base
23	6	138	23 - 6
	8	184	23 - 8
30	6	180	30 - 6

Allowing for growth and uncertainty, then, an allowance for 10 channels per beam would probably be appropriate. The peak downlink beam channel totals (entire satellite) are:

Beam Model	Beam Channels
7	43
12	70
23	125
30	162

These peak totals are thus slightly but not significantly lower than the number of beams times the peak number per beam. An allowance of 10 channels per beam in every beam would thus meet these requirements as well. Now, assuming PCM digitization at 50 kbps, also a convenient rate for much medium-rate data transmission, the C/kT requirement for 10 such channels is on the order of 25 dB lower than one video channel. This suggests that the voice repeater approach be one which is combined at a low level with the video signals; in other words, full advantage should be taken of the video repeater structure. Furthermore, the liberal upward revision of the design goal to 10 or even to 20 channels per beam would not have great impact. In terms of bandwidth, the several MHz required are not of consequence relative to the FM repeaters, although with a VSB repeater the dense multiplexing of video channels leaves no free space, so it is necessary to assume the preempting of one video channel slot in each beam to accommodate the voice/data band.

Three potential time division approaches were identified in Paragraph 4.2.3.3.6. In theory any one of them can be applied as an addition to any one of the video baseline or alternate repeaters. However, the poor bandwidth efficiency of the single-path repeater, an efficiency which decreases as the number of beams increases, rules out this approach when the number of beams exceeds 12. The other two concepts are applicable to any baseline or alternate because of their better bandwidth utilization. System parameters are summarized in Table 4-29. The following observations are made:

1. The ganged-switches approach with memory offers no advantage over the multiple n-path approach. This is due to the fact that the VSB systems do not reuse spectrum very much, and also that the systems are added-on to already channelized repeaters so that the bandwidth conserving properties of a memory cannot be taken advantage of.

2. Combined with the hardware penalties of the demodulators, demultiplexers, etc., required (relative to the small savings in RF hardware* of the ganged/memory scheme), these observations lead to the conclusion that for this type of application a memory carrying system is not warranted. This would not be true with different system assumptions.

Therefore, the single switched path and the multiple n-path concepts will be investigated in more detail. The single path will apply only to 7- or 12-beam models.

*Fewer paths.

Table 4-29. Voice/Medium Rate Data Approaches

Type	Applicable for Addition to These Video Repeaters		Bandwidth Required, MHz* Per Beam	Total
Single Path Switched	FM	7-x	3.5	7
		12-x	6	18
	VSB	7-x	3.5	14
		12-x	6	36
Multiple n-Path (Hybrid)	FM	7-x	1.0**	2
		12-x	1	3
		23-3	1	6
	VSB	7-x	1	4
		12-x	1	6
		23-x	1	12
		30-x	1	15
Ganged m-Path with Memory (Hybrid)	FM	7-x	2	4
		12-x	2	6
		23-3	2	12
	VSB	7-x	1	4
		12-x	1	6
		23-x	1	12
		30-x	1	15

*for 10 channels/beam
n = number of beams
assumes 50 kbps = 50 kHz per channel
theoretical; no allowance for overhead

**Due to the inherent inefficiency of frame utilization, a 50 percent duty cycle has been assumed with 10 channels operating.

SECTION 5 - REPEATER DESIGNS AND TRADEOFFS

5.1 INTRODUCTION - APPROACH AND SCOPE

The material in this section actually encompasses several tasks of the study. This is a natural outcome of the inextricable relationship between repeater design and power and weight tradeoffs, as well as of the fact that, by definition, the multi-functional system should serve a diversity of requirements with a large spread in data rates. Therefore, the repeater design and the tradeoffs were performed in somewhat of an iterative fashion, and the provision for voice/medium rate data service is presumed to be part of a multifunctional satellite rather than a separate one. It should be noted that there is no single "best" system approach or, therefore, selected best design, because the selection depends on the criterion or measure of desirability and on the requirements structure. Thus, the baseline designs are not to be taken as the optimum designs. They were chosen purely as convenient starting point references.

In the case of the video/high rate data repeater approaches, the baseline systems were pursued in some detail, that is, actual designs down to subsystem and component level were performed. Therefore, a good deal of hardware (component and techniques) investigation was performed at this point. Given the detailed designs, weights, and power requirements of these baseline systems, it was then straightforward to size parametrically systems with different numbers of channels or beams. The fundamental system tradeoffs are driven primarily by these two parameters, i.e., beam number and channel requirement. Thus, the repeater weight and power values for the various beam and channel quantities are the basic data from which conclusions can be drawn. A complete satellite tradeoff would have to include the satellite antenna data, and take account of the additional hardware necessary for the channels with lower data rates. A complete system tradeoff would also encompass ground system parameters. These more comprehensive tradeoffs are actually now possible, given the results of this study, the companion multibeam antenna study (Reference 4), and previously available cost-oriented system evaluation routines.

5.2 BASELINE AND ALTERNATIVE DESIGNS FOR VIDEO/HIGH RATE DATA

5.2.1 Introduction: The Need for Two Baselines

The results of the interbeam interference analysis, Paragraph 3.4, indicated that it would not be reasonable to select one baseline representative of the optimum repeater techniques and modulation. Fundamentally, it was shown that on the one hand, a fully channelized repeater intended for FM could result in an attractive system approach with modest satellite power and earth terminal requirements. However, bandwidth limitations restricted the system capacity to substantially below that given by the system requirements analysis. Only narrowband (VSB or SSB) modulation could result in a high-capacity system for video transmission. However, the power efficiency and the repeater backoff requirement led to immense satellite prime power requirements, in the tens of kilowatts, even for channel capacity equivalent to that provided by an FM system. Therefore, the results were then recalculated based on an earth terminal G/T 12 dB greater than previously used. Because the system parameters were so disparate in the two cases, it was not possible to select one of the two modulation techniques as the "best," and consequently two baselines were adopted. Both had 12 beams. However, the FM baseline was limited to six channels per beam, whereas the VSB baseline could provide 16 channels per beam, meeting the requirement for a total of 163 beam-channels. From these baselines, system alternates were then sized parametrically (i.e., scaled according to approximate parts count). Therefore, one may use the results in sizing and evaluating two very different classes of system: modest or low capability systems, capable of service to compact earth terminals small enough to be located at the user's site in many cases; and the high capacity approaches, with terminals large enough to be reasonable only on the basis that they would serve many users via end distribution.

The material in this paragraph consists of a detailed design and weight/power estimate for the FM baseline, a somewhat less detailed design and estimate for the VSB baseline, scaled weight and power estimates for beam or channel alternatives differing from the baselines, tradeoff analyses based on these data, and implementation information on repeater approaches for the voice/medium rate data requirements in the system.

5.2.2 FM Baseline Design

5.2.2.1 Introduction - Summary of Constraints

The preliminary design of a repeater suitable for use in a multifunctional satellite is based upon several systems considerations. The area to be served is the United States, including the continental states, Alaska, Hawaii, and Puerto Rico. The coverage area can be covered with different numbers of antenna beams. The fewest under consideration here are seven beams (Alaska, Hawaii, Puerto Rico, and the four time-zone beams). The maximum number of beams considered is 30; intermediate values of 12 beams and 23 beams were also considered. The 12-beam case is taken as a baseline. The spectrum allocation for the multifunctional satellite is taken to be the 11.7- to 12.2-GHz downlink band and the 14.0- to 14.5 GHz uplink band in accord with WARC-71 recommendations. The multiple-beam coverage enables reuse of the basic 500-MHz wideband. This band can be reused several times in accordance with various beam frequency plans without incurring excessive interbeam interference.

Although the multifunctional nature of the satellite implies a mixture of television, voice, and digital data signals, the major impact on the repeater design stems from the television signals because their requirements on spectrum and satellite power are predominant. For FM modulation, the RF band for a television channel is taken as 25 MHz. For vestigial sideband modulation (VSB), the RF band is about 5 MHz. With assumed earth terminals of G/T = 30 dB/°K, the satellite transmitter power per FM television channel is taken as 2 watts for the 12-beam baseline; the RF power per channel for the other beam-coverage models is chosen to maintain the same EIRP as in the 12-beam model. Initially, the EIRP per VSB television channel was determined on the basis of the same earth terminal G/T as for the FM case. However, this led to very large RF power requirements on the satellite, so that it was decided to consider larger earth terminals for VSB television. The design study is thus made with approximately the same satellite RF power requirements per channel for both FM and VSB modulation with the understanding that this implies larger earth terminals for the VSB case.

The repeater design should stem from the traffic requirements of the satellite system. In a simplified form the traffic requirements can be viewed as being three to 12 television channels per beam uplink and six to 24 channels per beam on downlink.

The FM approach, however, though economical of power, is bandwidth limited to less than 50 percent of the capacity predicted by the traffic model. For this reason both FM and VSB repeaters are considered.

5.2.2.2 Preliminary Design Alternatives

At the outset of the repeater study, there were certain choices regarding the configuration of the receiver, the IF section, and the transmitter.

The main alternative with regard to the receiver was whether to employ a separate receiver for each beam or to use a single receiver for several beams with non-overlapping frequency bands. In the case of the 12-beam baseline, the choice is between 12 receivers of ~170 MHz bandwidth or four receivers of ~500 MHz bandwidth. The four-receiver configuration would require additional combining and separating. Because the receiver is relatively simple and lightweight, it was decided to use one receiver per beam in the baseline configuration.

The intermediate frequency portion of the repeater involves quite a few design alternatives: Should there be an IF? Should there be more than one intermediate frequency? What should the intermediate frequency be? How will the channel separation filters, the branching and crosstrap circuits, and the switching circuits be implemented? A guiding philosophy in approaching these questions has been to attempt to use lumped rather than distributed circuit elements to minimize the size and weight of the switching and routing networks. The desire to use lumped elements naturally leads to an intermediate frequency band below 1 GHz.

High Q filtering for channel separation can be achieved in minimum size and weight by using active filters. The classical active filter uses transistor stages having a constant zero or 180° phase shift and an appropriate external feedback circuit. This approach is feasible up to about 20 MHz; above this frequency transit time effects degrade the usual synthesis procedure. The synthesis of active filters at higher frequencies takes the transit time effects into account. Adams and Ho (Reference 14) show that in an inverted common collector transistor configuration the output impedance is the sum of the emitter-base junction impedance plus a transformed version of the base impedance. Because of transit time effects, the transformed version of the base impedance has a negative real part and a positive imaginary part; i.e., a negative resistance in series with an impedance. A resonator formed by an external or parasitic capacitance and the transformed base impedance will have a very large Q when the negative resistance is about equal to the emitter resistance. Several such resonators can be cascaded to obtain multipole filters. Active filters synthesized in the above manner can operate up to about 2 GHz. Percentage bandwidths of 0.05 to 10 percent can be obtained with ~5 percent being the easiest. The limitations on dynamic range are not important in the present application since signals of level -70 to -20 dBm are well within the filter dynamic range.

The active filter is amenable to temperature compensation techniques so that over a temperature range of 50°C, the variations in filter center frequency and insertion loss can be held to ±one part in 10^4 and ±0.2 dB.

For an active filter bandwidth of 5 percent, an IF frequency of about 500 MHz is indicated for FM modulated TV signals (~25 MHz RF band); an IF frequency of about 100 MHz is indicated for VSB modulated TV signals (~5 MHz RF band).

The branching and crossover network (see Paragraph 5.2.2.3) is visualized as consisting of an array of hybrid junctions to achieve isolation between branches, and the branches themselves as being made of small diameter rigid coaxial transmission line. Coaxial line is tentatively chosen over a printed circuit to guarantee minimum crosstalk in a configuration likely to be nonplanar.

The PIN diode switch is selected over other possibilities such as a ferrite switch, a mercury film switch, or a reed switch because it offers advantages in size, weight, and long life. The latching property of the ferrite switch was attractive, but its size and weight were prohibitive for the quantities of units in the switching and routing network. The basic PIN switch is SPST; it may be necessary to have two or three diodes per switch to obtain over 40 dB isolation in the "off" position. The insertion loss in the 'bn" position is about 1 dB.

A very important design choice remains for the IF portion of the repeater:

1. Use a single local oscillator (LO) frequency so that the entire band is translated to IF.

2. Use different local oscillator frequencies for each different carrier frequency so that all channels are translated to the same 25 MHz wide IF band (FM) or to the same 5-MHz band (VSB).

3. Use an intermediate approach such as having three local oscillator frequencies, corresponding to each of the RF bands in a three-band frequency reuse plan.

An advantage of approach (1) is its relative simplicity; few mixers and LO frequencies are required. A disadvantage of this approach is its lack of flexibility. Approach (1) does allow any single uplink signal to be routed to any downlink beam. However, it does not allow any combination of uplink signals to be routed to any downlink beam because of the fixed channel-frequency structure. To attain total flexibility in the repeater, it is necessary to use approach (2), which removes the uplink channel-frequency structure. Approach (2), however, is quite involved in that a separate mixer is required for each uplink and downlink beam-channel. A number of local oscillator signals of distinct frequencies is also required. A definitive choice between the above alternatives is not made at this time. Approach (1) is used in the FM repeater design. (Approach (2) is presented in the VSB repeater design.)

The transmitter is the most significant portion of the repeater in terms of its function and its contribution to weight and power consumption. Preliminary tradeoffs were concerned with how many power amplifiers per beam seem best. An initial desire was to use one power amplifier per carrier to allow full saturated operation. However, if TWT amplifiers are used, the total weight tends to be very large. Solid-state was also considered. At 12 GHz a conservative estimate for bulk-effect amplifier efficiency is about 10 percent (as compared with 30 to 50 percent for tubes) so that the power consumption becomes large with solid-state amplifiers. Another disadvantage of providing an amplifier for each carrier is the multiplexing problem which is severe for 25-MHz channels at 12 GHz and prohibitively difficult for 5-MHz channels. In view of these difficulties, a single carrier per amplifier approach was not adopted.

The advisability of using a single power amplifier to drive several beam feeds was next examined. An initial feeling towards such an approach was that it was awkward to combine and then to separate signal flow lines. A more concrete objection arises from the desire to have adaptable interbeam capacity sharing. In a bandwidth-limited situation, adaptable capacity can be obtained only by bandwidth transfer between beams; this appears to be difficult to implement when a single power amplifier drives several beams.

It was decided to use one or two power amplifiers per feed as the preferred transmitter configuration. Connection to the feed would be either direct or through a combining diplexer. The same approach is maintained for the VSB repeater even though its capacity is not bandwidth limited as is the FM repeater.

It was decided to configure the baselines in fully channelized ("AA") format, though some component savings might be realizable by including trunking channels. The overall impact would not be very great, however, as the proportion of trunked channels is small, and the majority of repeater weight and power lies in the transmitter.

5.2.2.3 Baseline Design

The FM baseline is a 12-beam FM television repeater having a capacity of 72 beam-channels with a three-band frequency plan.

A diagram of the FM repeater is shown in Figure 5-1. Each antenna feed is connected to a transmit-receive diplexer which enables the same feed to be used for both uplink and downlink signals. This diplexer routes uplink signals to a receiver which performs the functions of amplification and down conversion to a much lower intermediate frequency. The receiver itself is diagramed in Figure 5-2. The pre-amplifier is a three-stage TDA having some 40 dB of gain; the down converter with a local oscillator at 13.7 GHz gives an IF in the 300- to 800-MHz range. The receiver output is fed to an IF channel separation and limiting network, which is shown in Figure 5-3. After initial amplification, the signals are separated into six branches using hybrids or other methods able to give isolation between the branches. An active filter in each branch establishes the channel; the signal is then amplified further and limited so as to prevent unequal signal suppression effects in the subsequent power amplifier.

Each channel separation network feeds up to six signals into a crosstrap network. Thus, there can be up to 72 signals at the input to the crosstrap network. This network, Figure 5-4, consists of 72 three-way hybrid splitters arranged so as to triplicate all incoming signals to make them available to each of three switching networks.

The switching network is shown in Figure 5-5. Here, each of the 72 inputs is replicated four times to route each input to the four transmitters being fed by each switching network. A PIN diode switch is in each of the 288 branches to select which of the uplink signals are routed to which transmitter. Considering a typical transmitter, we note that only six of 24 A band channels can be handled by the transmitter due to the spectrum limitation. Moreover, these six must not include two or more channels on the same frequency, so that the switching scheme in effect selects one of four uplink signals for each downlink channel. To extend the capability of the A band transmitter beyond six channels, the switching network also routes the A channels to B and C channel inputs.

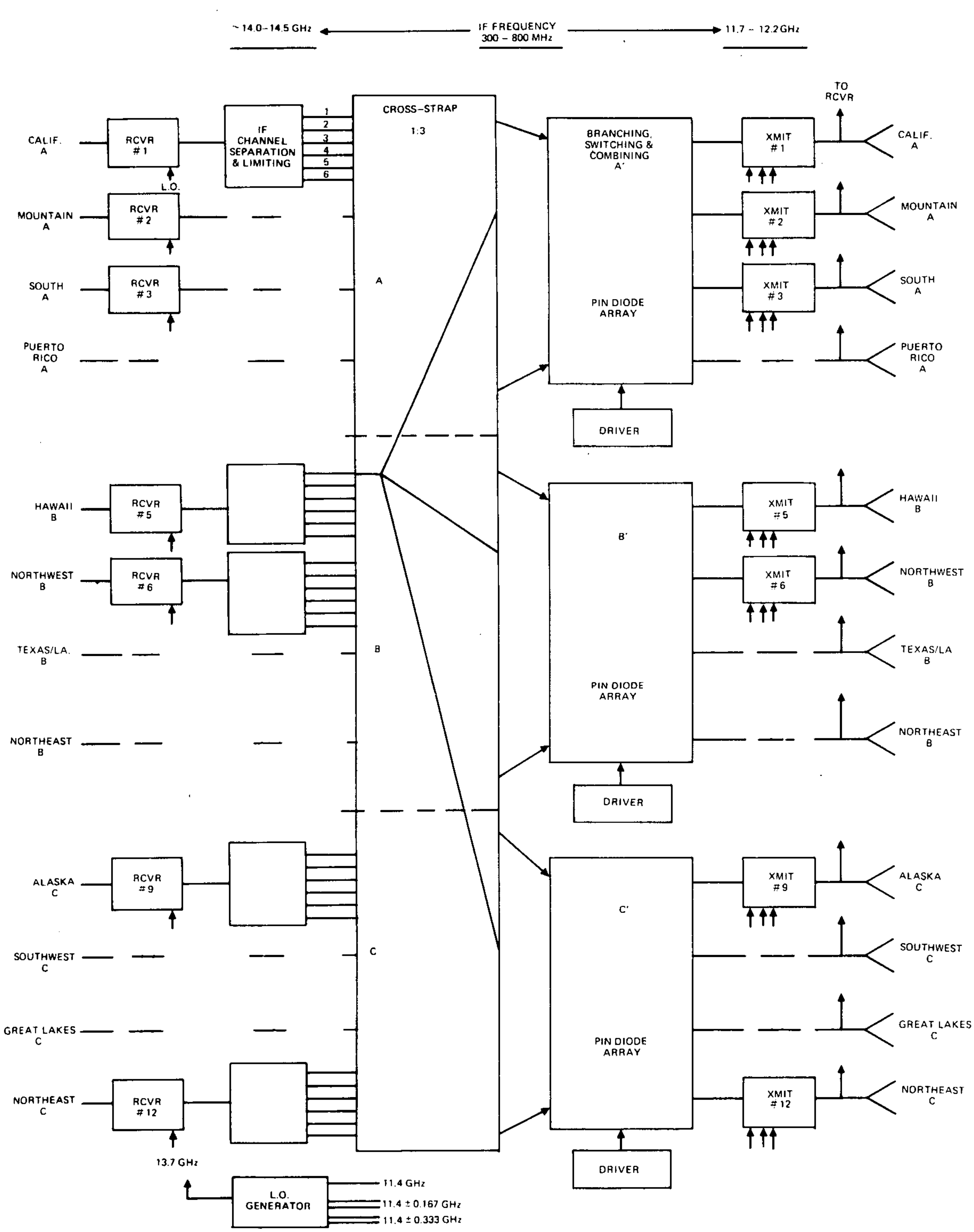
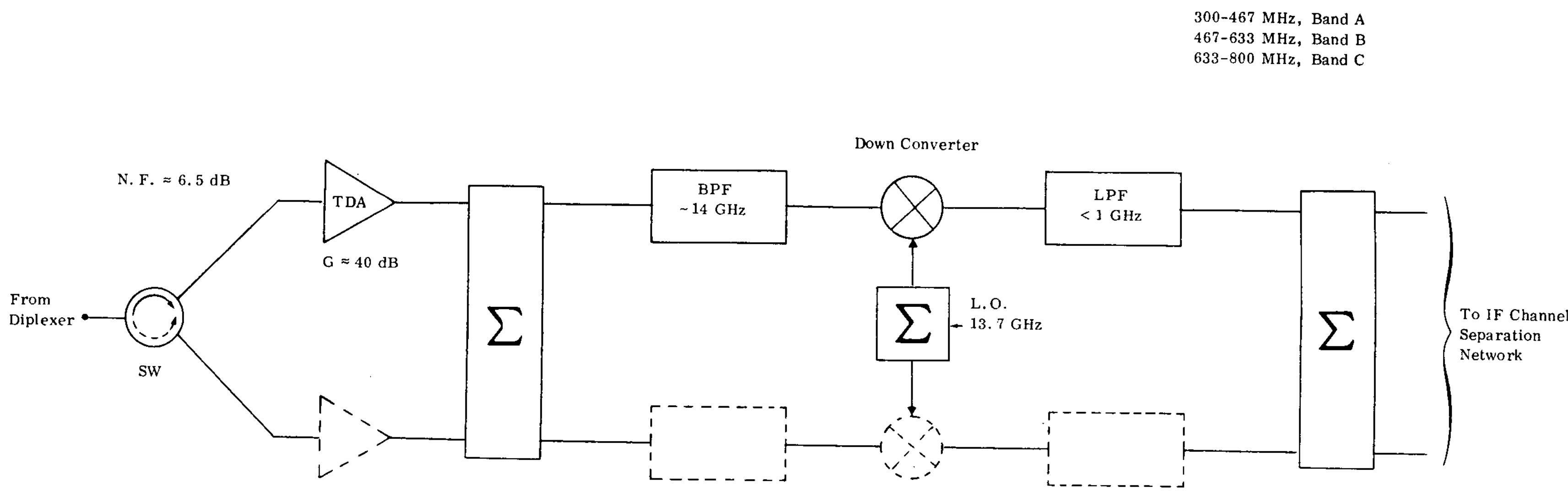


Figure 5-1. Switching and Routing Repeater (12 Beams, Three Frequency Bands)



<u>Estimated Weight (redundancy included)</u>: 5 Pounds

<u>Estimated Power Consumption</u>: 1 watt

Figure 5-2. Receiver Diagram

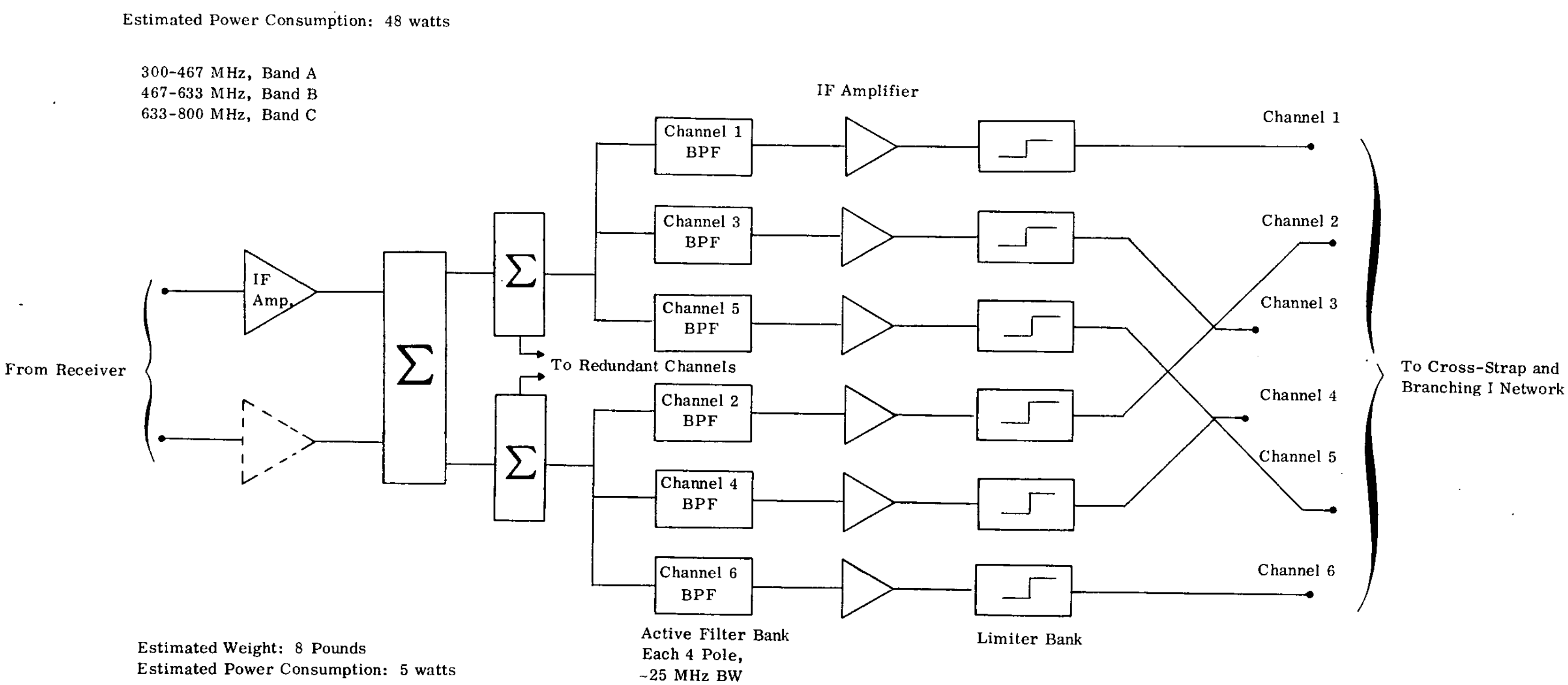
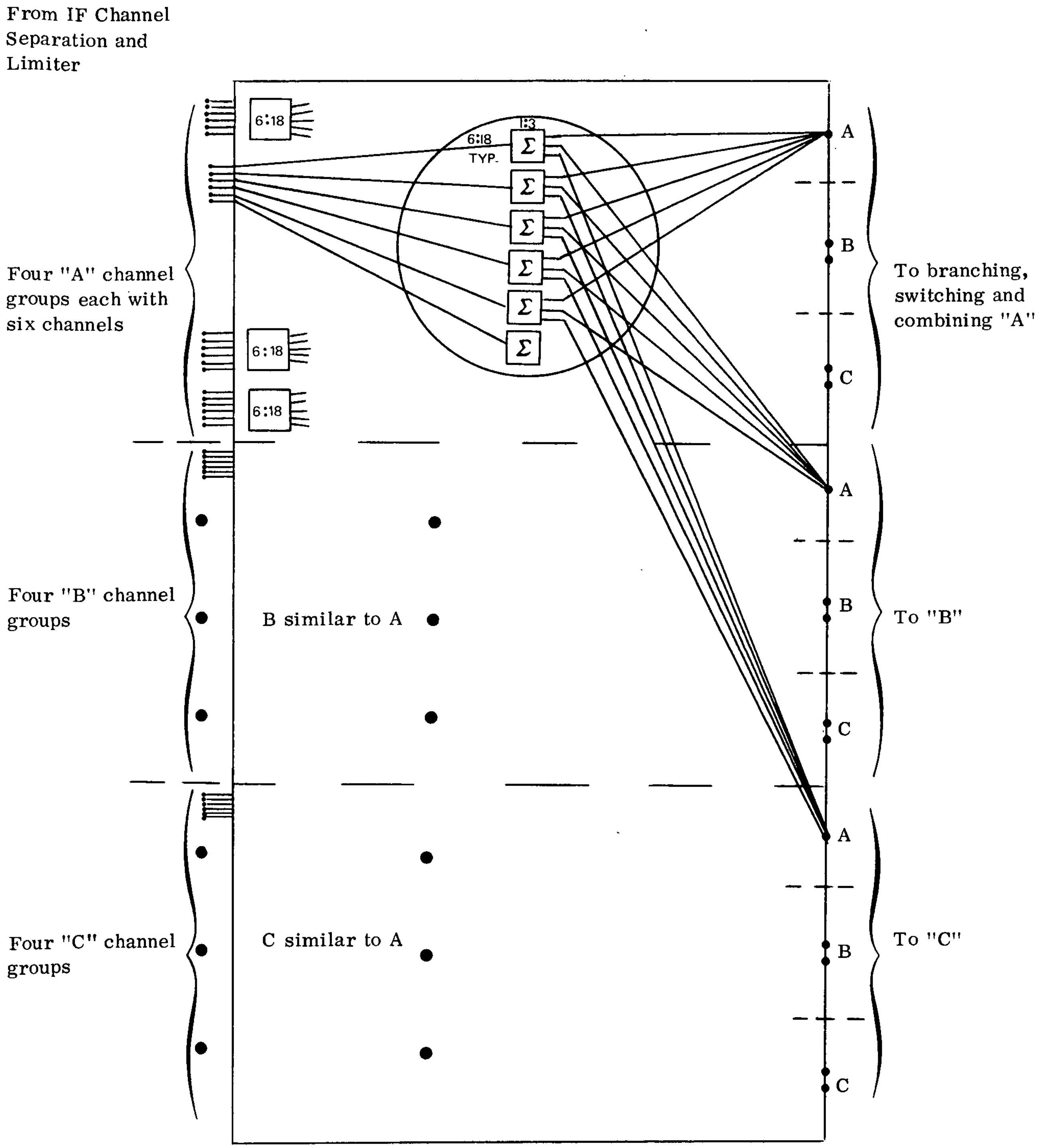


Figure 5-3. IF Channel Separation and Limiting Diagram



Estimated Weight: 20 Pounds
Estimated Power Consumption: None

Figure 5-4. Cross-Strap Network

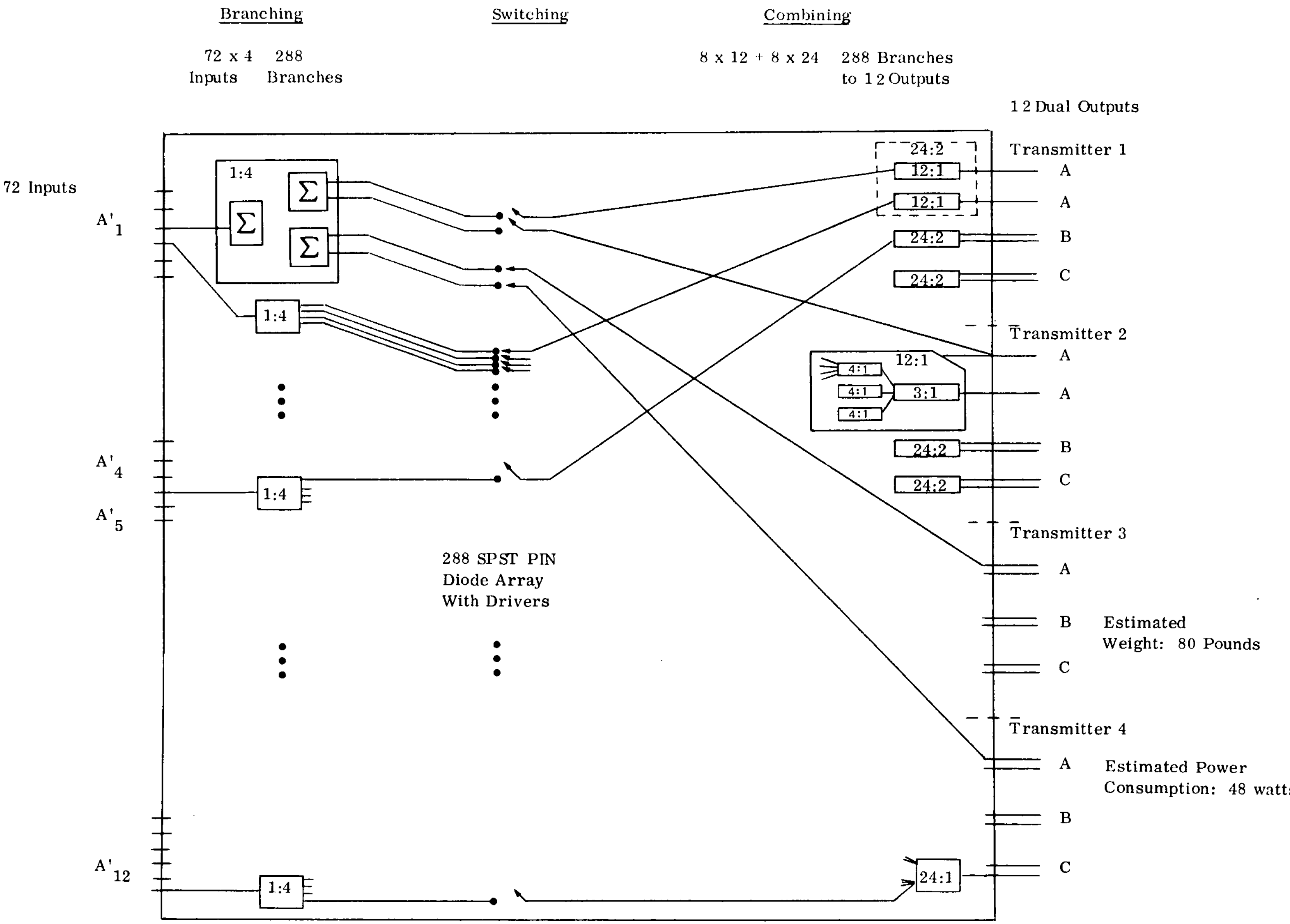


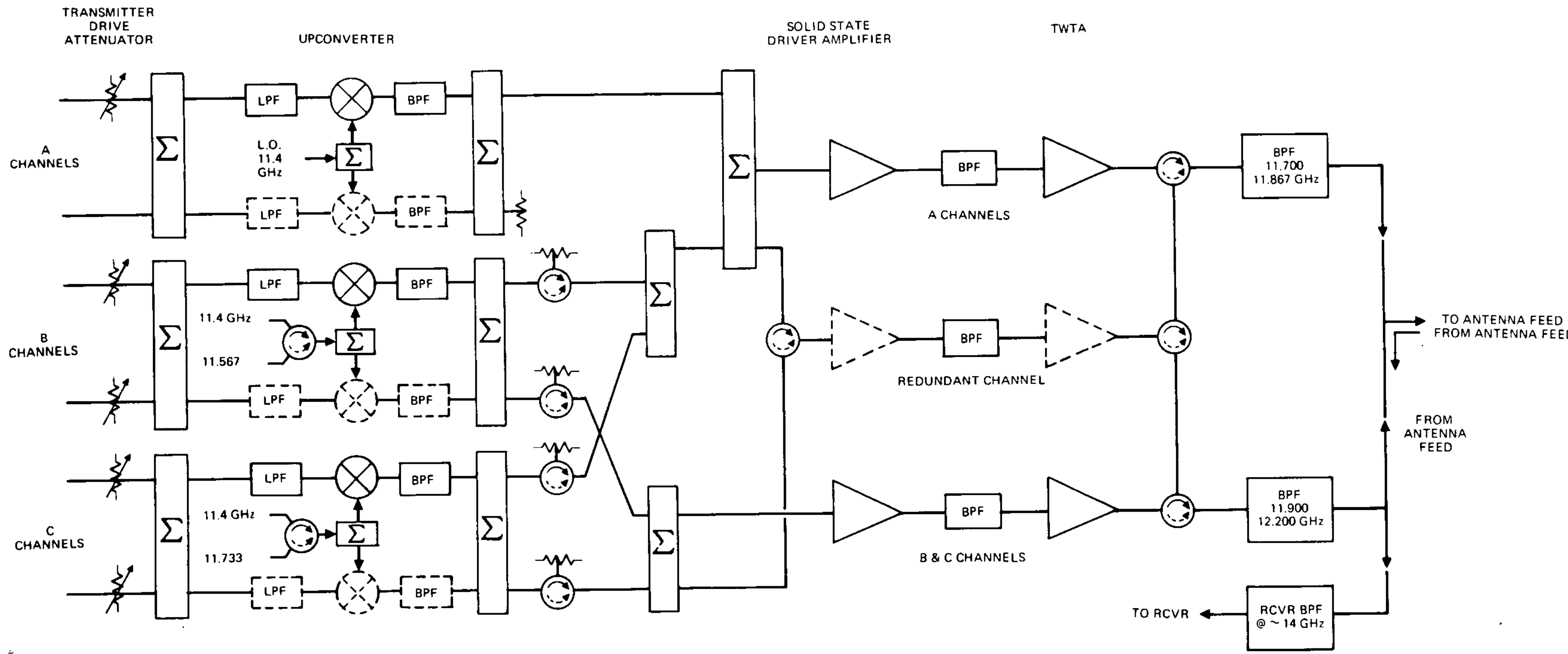
Figure 5-5. Branching, Switching, and Combining Network

Each of the input-output branches of the network is indicated as being switchable. It is anticipated that many of the uplink-downlink paths would be dedicated in a real system (i.e., as in regional broadcasting) so that many of the network paths could be hard wired.

A diagram of the transmitter is shown in Figure 5-6. The input is still at IF with separate ports for the A, B, and C band channels. Ground commandable transmit drive attenuators are used to optimize the drive to the power amplifier as changes occur in the number of channels being transmitted. The A band IF channels are upconverted into the A band RF channels via an 11.4-GHz local oscillator signal. The upconversion of the B and C band IF signals is more involved. If there are open channels in the A band downlink, the B or C channels can be translated into these open bands via offset local oscillators at 11.567 GHz or 11.733 GHz, respectively. If, on the other hand, the A band downlink is filled, it may be necessary to enlarge the RF band by switching in a portion of RF bands B or C. In this case the B or C IF channels are directly translated into the B or C RF band via an 11.4-GHz local oscillator. Circulator switches in the L.O. ports of the B and C upconverters select the desired L.O. frequency on ground command. Circulator switches following the upconverter respond to the same ground commands and route the upconverted signals to the proper transmitter amplifier.

The upconverter is followed by a driver amplifier to raise the signal level to about -38 dBW per channel, or about -30 dBW total. This is well below the driver saturated output level of about 0 dBW so that intermodulation noise is sufficiently low. The 0 dBW output power required of the driver amplifier is within the capability of a solid-state bulk effect amplifier.

The power amplifier is a TWTA sized to handle six channels with an output power of 2 watts per channel. A TWTA with a saturated power output of 30 watts can thus be operated with 4 dB of output backoff to give a carrier-to-intermodulation ratio of about 23 dB. Separate TWT amplifiers are provided for the A band and for the B and C bands. These are brought together in a diplexer at the antenna feed. A single standby redundant driver and power amplifier is provided to support both amplifier trains.



ESTIMATED WEIGHT INCLUDING REDUNDANCY = 38 LBS

ESTIMATED POWER CONSUMPTION =	A CHANNELS ONLY	90 WATTS
	A & B, C CHANNELS	180 WATTS
	ASSUMED AVERAGE	120 WATTS

Figure 5-6. Transmitter Diagram (One Beam)

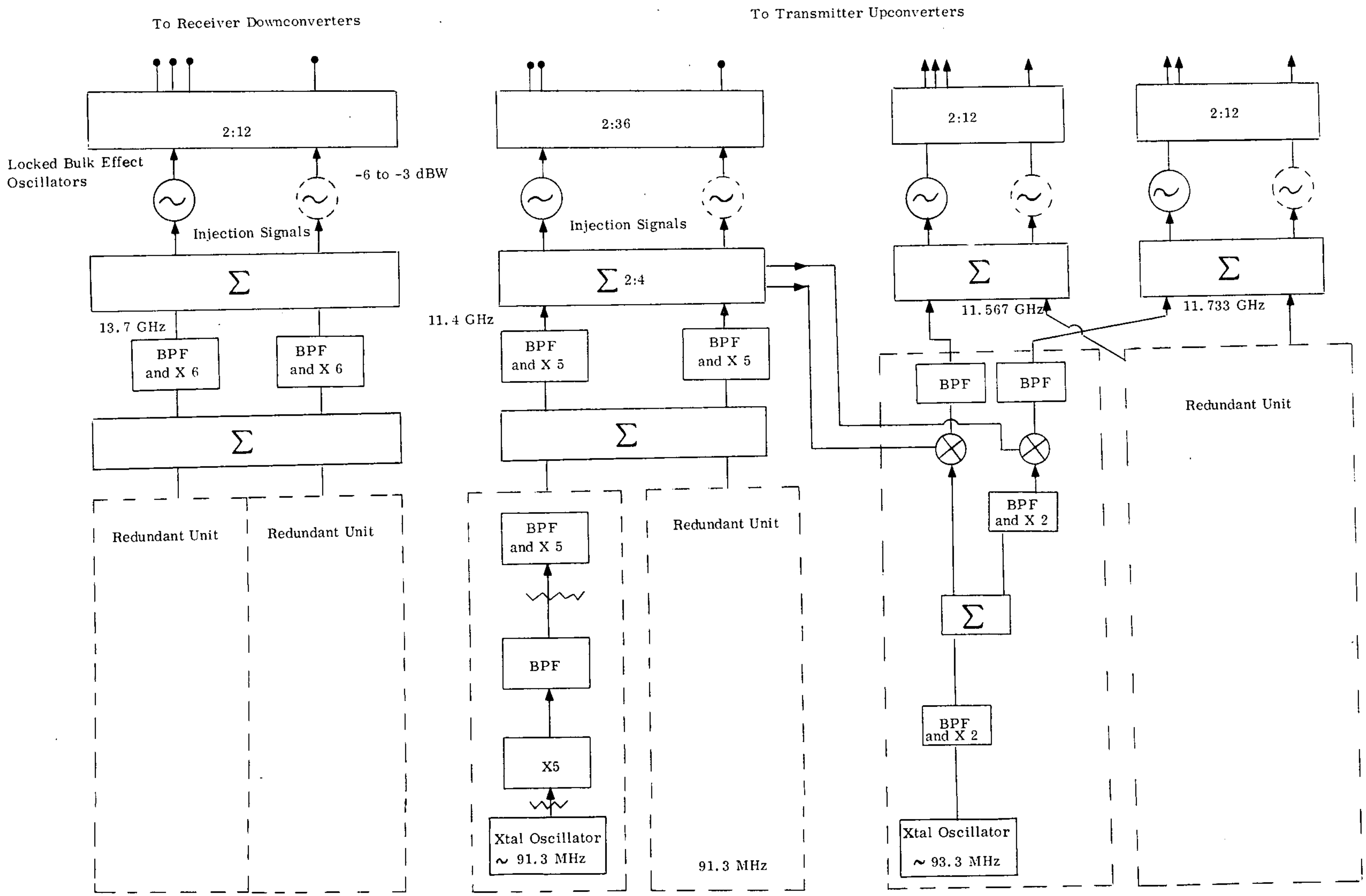
A diagram of the local oscillator generator is shown in Figure 5-7. The L. O. signal begins in a 91.3-MHz crystal oscillator whose output is multiplied to S-band in two x5 stages. The S-band signal is further multiplied by x6 to derive the 13.7 GHz receiver downconverter L. O.; the S-band signal is also multiplied by x5 to derive the 11.4 GHz transmitter upconverter L. O. The offset local oscillator signals of ~166.6 MHz and 333 MHz are generated from an 83.3-MHz crystal oscillator. These offset signals are mixed with the 11.4 GHz L. O. signal to derive the 11.567 and 11.733 GHz offset L. O. signals in the transmitter upconverter. All of the signal generation described above is done at low level; to obtain the moderate levels needed to drive the various signal converters, bulk-effect oscillators, which are injection locked to the low level signals, are used. The output of the injection-locked oscillator is about -3 dBW; it is split and routed to the various converters via hybrid branching networks.

5.2.2.4 Baseline Weight and Power Consumption

The weight and power consumption estimates, which begin at the component or module level, are based on (1) comparisons with similar units (such as TDAs, mixers, or circular switches) on Intelsat IV, DSCS II, and other satellite repeaters, and (2) conversations with component manufacturers, such as Wavecom Corporation for active filters and diode switches and Anzac Division for IF hybrid branching circuits and IF mixers.

There remains a degree of uncertainty in these estimates due to recent advances tending to reduce weight or power consumption on the one hand, or due to reliability considerations which may force an increase in weight or power consumption on the other hand. The component and module estimates that are used herein in arriving at repeater estimates are given in Table 5-1. TWTA weight estimates were based on information given in Reference 15. Typical values are 5 lbs for 10 watts, 12.3 lbs at 100 watts, and 24 lbs at 500 watts. The TWTA power consumption is estimated from its saturated output DC to RF efficiency* which is assumed to be:

*See discussion in Paragraph 5.2.3.2.



Estimated Weight: 25 Pounds
(incl. Redundancy)

Figure 5-7. Local Oscillator Generator Diagram

Table 5-1. Unit Weights and Power Consumptions

	Weight (Lbs)	Power Consumption (watts)
RF Hybrid	0.25	-
RF Mixer	0.5	-
Tunnel Diode Amplifier	1.5	1
Ferrite Switch	0.25	latching
IF Amplifier	0.5	0.5
Active Filter	0.25	0.25
IF Limiter	0.1	0.1
IF Hybrid 1:4	0.15	-
0.141 OD Rigid Coax	0.03/ft	-
IF 12 Unit PIN Switch and Drivers	1	2
IF 12 Unit Mixer Assembly	2	-
IF 12:1 Hybrid Combiner	0.5	-
IF Variable Attenuator	0.5	-
RF Solid State Driver Amplifier	1	20
12 GHz Low Loss BPF	1	-
S-Band Oscillator Assembly	1	2
X5 or X6 and BPF to 12 or 14 GHz	0.5	-

Output Power	80 watts	80 to 160 watts	160 watts
Efficiency (Percentage)	33-1/3	40	50

These weight and power estimates indicate better performance for the higher output powers; this is probably not an inherent physical property, but more likely a reflection of the intensive work to improve the weight and efficiency of the higher power tubes.

The weight and power consumption of the major portions of the repeater were estimated using the above component values. These equipment estimates are noted on the block diagrams of Figures 5-2 through 5-7; the complete breakdown for the 12-beam FM television baseline repeater is given in Table 5-2. The total repeater weight is about 900 pounds and the total dc power is about 1700 watts. The breakdown has several interesting features:

- The transmitter accounts for about 85 percent of the dc power requirement.
- The transmitter accounts for about 50 percent of the repeater total weight.
- The various channelizing, switching, and routing equipment accounts for about 40 percent of the repeater total weight.

The baseline repeater weight of 900 pounds and power requirement of 1700 watts are large when compared with large existing satellites, such as the Intelsat IV whose repeater weighs about 300 pounds and consumes about 400 watts. However, a satellite carrying the baseline repeater would probably be well within the capability of a Titan III-C launch vehicle, and can be readily compared with the ATS-F-based proposed domestic satellite of Fairchild, which had 120 transponder channels and 24 spot beams.

5.2.3 VSB Baseline Design

5.2.3.1 Introduction

The VSB baseline design was performed after the FM baseline design was completed. Consequently, it was not necessary to go into as much detail in the many areas of commonality. The primary differences between FM and VSB approaches are:

Table 5-2. 12 Beam FM Baseline Repeater

12 Beams, three frequency plan

~23 MHz RF Bandwidth Per TV Channel

~2 watts RF Power Per TV Channel

0 to six Channels Per Uplink Beam

0 to 12 Channels Maximum Per Downlink Beam

Eight Channels Per Downlink Beam For Power Requirements

~72 Beam-Channels Total Capacity, Bandwidth Limited

Equipment	No.	Estimated Weight (Including Redundancy), Lbs. Each	Total	Estimated Power Consumption, watts Each	Total
Receivers	12	5	60	1	12
IF Channelizing & Limiting Networks	12	8	96	6	72
Cross-Strap Network	1	20	20	----------	
Branchings, Switching & Combining Networks	3	80	240	48	144
Transmitters	12	38	456	120	1440
Local Oscillator, Generator	1	25	25	48	48
		Total:	897 Lbs		1716 watts

1. The considerably larger number of channels which a VSB approach can accommodate virtually necessitates the use of an L.O. and mixing scheme where all channels are brought down to the same IF channel frequency. This allows the full routing flexibility to be used.

2. The greater channel capacities and the more stringent intermodulation level requirements lead to much higher prime power requirements. This in turn reflects back on the topics of amplifier efficiency, backoff, and possible special techniques for improving the net RF output versus DC input ratio.

5.2.3.2 VSB Design

The 12-beam VSB baseline provides 192 downlink beam-channels. A diagram of a VSB repeater for a six-band frequency reuse plan is shown in Figure 5-8. In contrast to the FM repeater which allowed a maximum of six channels per uplink beam, this repeater allows for a variety of uplink capacities. Specifically, receivers 1 and 2 can handle 24 and 36 channels, respectively; receivers 3 through 6 can handle 12 channels each; while receivers 7 through 12 are sized for six channels each. A frequency plan for both the uplink and downlink transmissions with the VSB repeater is shown in Figure 5-9. The uplink allocations are unequal in accordance with the unequal capacities; the downlink frequency allocations are equal in accordance with the assumed 16 channels per beam. These plans and their organization are shown by way of example only and are not critical to the baseline design.

Receivers 1 and 2 employ multiple local oscillator frequencies to form 12 channel groups. The rest of the local oscillator frequencies are appropriately stepped from receiver to receiver so as to convert each of the RF bands A through F to the same 800- to 860-MHz band (for 12 channel groups) or 800- to 830-MHz band (for six channel groups).

A typical channel separation network begins with a hybrid branching circuit which feeds six mixers. Each mixer is also driven by a local oscillator signal appropriately stepped (in 5-MHz steps) to convert the six input signals to the same 5-MHz band at

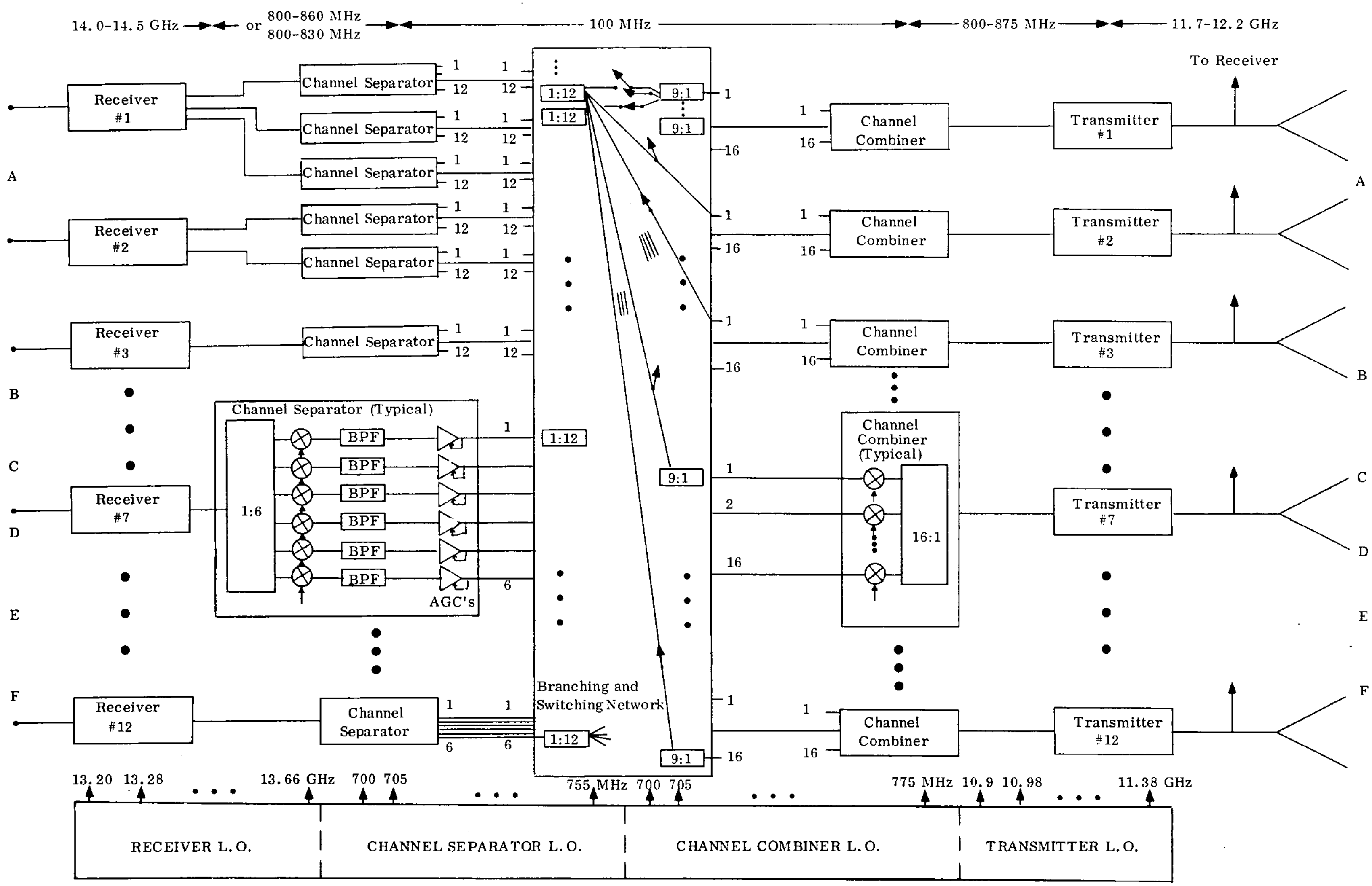


Figure 5-8. Diagram of SSB AM Multifunctional Repeater

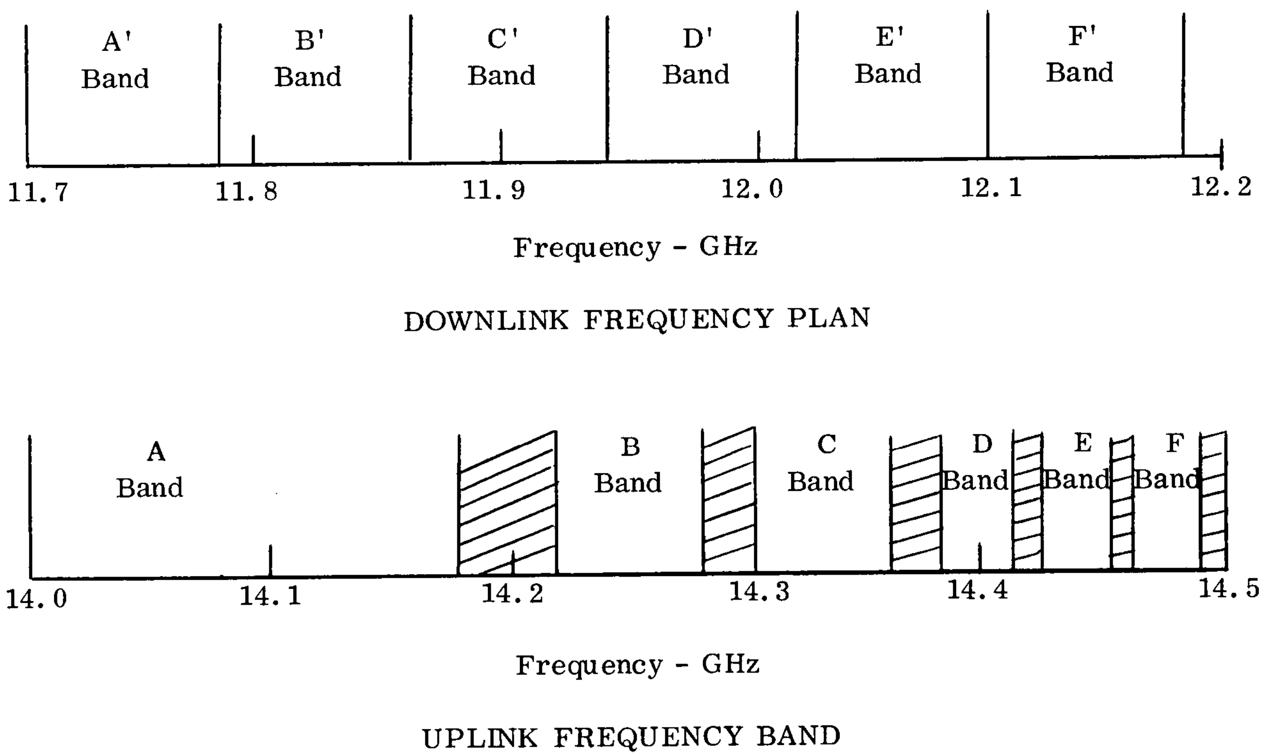


Figure 5-9. Frequency Plan for 12-Beam VSB Television Repeater

~100 MHz. Thus, fixed tuned active filters covering the identical 100- to 105-MHz band are used to select each desired channel. Each channel then undergoes further IF amplification with automatic gain control to establish a constant channel-to-channel signal level.

All the channels (still at 100 MHz) are then collected into a branching and switching network which has 144 input channels. To make each channel available to any of 12 transmitters, each channel is replicated 12 times by a hybrid branching circuit. An array of 1728 PIN diode switches then routes the channels to the proper beam selected by ground command. With a maximum of 16 channels per downlink beam, a hybrid circuit which combines 144/16 = 9 branches into one is needed.

Following the branching and switching network are 12 channel combining networks. one for each beam. This channel combining network is like an inverted version of the previously described channel separation network. Each of the 16 channels feeds a mixer; the mixer local oscillators are appropriately stepped (in 5-MHz steps) to structure the 16 channels into the 800- to 875-MHz band. The outputs are combined via a 16:1 hybrid combining network. In contrast to the channel separation network, no narrow-band filters are needed here.

The transmitter for the VSB repeater is simpler than for the FM baseline repeater in that there is no band switching in the upconverter. Its configuration is that of an online upconverter/driver/power amplifier chain together with a similar redundant standby chain. VSB TV signals require a greater EIRP than FM TV signals for a given earth terminal; also, it was decided to ease the VSB RF power requirements on the satellite by using a larger earth terminal for VSB. With the RF power per channel set at 2 watts for both VSB and FM for the 12-beam repeater, the DC power requirements for VSB are nevertheless greater for two reasons:

1. There are more channels in the VSB transmitter.

2. The carrier-to-intermodulation ratio for VSB is much more stringent.

C/IM for FM TV is taken at ~23 dB; while for VSB TV the ratio is taken as ~40 dB.

With conventional TWT amplifiers, achieving a C/IM of 40 dB would require a "backoff" relative to the saturated single carrier output of about 10 dB. It is perhaps more direct to specify the ratio of (total) RF power output to prime power input, with a specified intermodulation level. Thus, instead of speaking of "40 percent" efficiency and 10-dB backoff, one could specify a net efficiency of 4 percent. This point is made here because at the present time there is a great deal of research on techniques which improve linear amplifier performance, such as predistortion, special circuits, and feed-forward (Reference 16). On the other hand, TWT efficiencies have been steadily rising over the years. The repeater power estimates in this report are based on an overall RF to prime power efficiency of 5 percent (such as with a 50-percent tube and 10-dB backoff). This is felt to be conservative, but any improvements may perhaps be better applied to achieving C/IM ratios greater than the marginal 40 dB.

The local oscillator generator must provide the following frequencies:

1. Eight frequencies at ~13 GHz for the receiver downconverter; these occur in 40-MHz and 80-MHz steps.

2. Sixteen frequencies at ~700 MHz for the channel separation and the channel combining networks; these occur in 5-MHz steps.

3. Six frequencies at ~11 GHz for the transmitter upconverter; these occur in 80-MHz steps.

One method of implementing these signals is to make use of comb generators using a step recovery diode. The signals in the 700-MHz range begin in a 5-MHz oscillator whose output drives a step recovery diode. Following the diode comb generator, a bank of crystal filters separates the 5-MHz, 10-MHz ... and 80-MHz signals. Each separated signal is amplified and upconverted in a high level mixer also driven by 695 MHz. The signals at ~13 or ~11 GHz begin in a 40-MHz oscillator which drives a comb generator. A bank of active filters separates the 40-MHz, 80-MHz .... and 480-MHz signals.

5.2.3.2 VSB Baseline Weight and Power Consumption Estimate

An estimated weight and power breakdown for the 12-beam VSB television baseline repeater is given in Table 5-3. The total weight and power are about 1600 pounds and 8500 watts, significantly larger than for the FM baseline repeater even though the VSB repeater was aided by assuming larger earth terminals. Of course, the capability of the VSB repeater in terms of beam-channels is some 2-1/2 times that of the FM repeater. The main features of the breakdown among the various equipments of the VSB repeater are:

- The transmitter consumes 90 percent of the total DC requirement.
- The transmitter accounts for about 40 percent of the repeater total weight.
- The various channelizing, switching, and routing equipment accounts for about 55 percent of the repeater total weight.

5.2.4 Weight and Power Estimates for Alternatives

5.2.4.1 FM Repeater Alternatives

The beam and channel alternatives shown in Table 5-4 were estimated in weight and power consumption. These estimates were readily performed by scaling weights and powers of the various subsystems and components. For example, the 12-beam baseline used 12 receivers, each requiring a watt and weighing 5 pounds. Therefore, the receivers portion of a seven-beam alternative would weigh 35 pounds and consume seven watts. An example of the weight and power estimation procedure was shown in Table 5-2. There are alternatives in Table 5-4 which were not specified in Table 4-28. These have to do with differences in capability and flexibility not identified by giving only the number of beams and number of channels per beam. For example, the FM baseline calls for six channels per beam. It is possible, however, to design a repeater which has sufficient power to provide, in any one beam, either six or eight channels, even though spectrum limitations would constrain operation to a total of 72 beam channels or six per beam if all beams were equally loaded. The additional weight and power data points are useful for the tradeoffs described in Paragraph 5.3.

Table 5-3. 12-Beam SSB Baseline Repeater

12 Beams, Six Frequency Plan

~5 MHz RF Bandwidth Per TV Channel

~2 watts RF Power Per TV Channel (earth station G/T 40 dB/°K)

6, 12, 24 and 36 Channel Capacities on Various Uplink Beams

0 to 16 Channels Maximum Per Downlink Beam

16 Channels Per Downlink Beam For Power Requirements

~192 Beam Channels Total Capacity

Equipment	No.	Estimated Weight (Including Redundancy), Lbs Each	Total	Estimated Power Consumption, watts Each	Total
Receivers	12	6	72	1	12
IF Channelizing & Limiting Networks	15	15	225	12	180
Branching & Switching Network	1	400	400	288	288
Channel Combining Networks	12	20	240	16	192
Transmitters	12	50	600	640	7680
Local Oscillator, Generators	1	50	50	100	100
		Total:	1587 Lbs		8452 watts

Table 5-4. FM Repeater Alternatives

System		Uplink Capability, Channels/Beam	Downlink Capability, Channels Per Beam (with equal loading)	Power in Beam Sufficient for, Channels	Total Beam-Channels	Weight, lbs.	Power Consumption, watts
Beams	Designation						
7	7 - 10	≤ 10	10	13	70	666	2,478
	7 - 8	≤ 6	8	8	56	534	1,800
	7 - 6	≤ 6	6	6	42	489	1,371
	7 - 4	≤ 3	4	4	28	387	907
	7 - 3	≤ 3	3	3	21	354	691
12	12 - 6a	≤ 6	6	8	72	897	1,716
	FM Baseline	≤ 6	6	6	72	845	1,348
	12 - 3	≤ 3	3	3	36	667	718
23	23 - 3	≤ 3	3	4	69	1,431	990

5.2.4.2 VSB Repeater Alternatives

The VSB repeater alternative weights and powers appear in Table 5-5. The reader is reminded that the earth terminals assumed for VSB systems have a 12 dB better G/T than for FM systems, so weight and power figures must not be compared between the two classes of system.

5.3 PARAMETRIC TRADEOFFS, VIDEO/HIGH RATE DATA REPEATERS

5.3.1 Introduction - Driving Parameters

The multifunctional satellite repeaters are characterized primarily by the multiple-beam satellite antenna and the large multiple channel requirements. The fundamental driving parameters (or independent variables), therefore, are the number of beams and the number of channels. In the case of the latter variable, it is more accurate to distinguish between a number of channels per beam variable and a total beam channels variable because, as was emphasized in Paragraph 3.4.3.4, these measures are fundamentally different, depending on the structure of the requirements. It is therefore worthwhile to examine the impact on the repeater weight and power (the dependent parameters) of varying the driving parameters. These tradeoffs yield considerable insight not only into the MFR application but into the general parametric behavior of multiple beam, multiple channel repeater systems.

5.3.2 Variation in Number of Channels per Beam

The number of channels per beam* is a good measure of system capability for systems in which the requirements are to broadcast channels over fairly extensive areas. That is because once the beam footprint is on the same order of magnitude in area as the geographic region of service for each channel needline, making the beams smaller does not change the channels/beam requirements. For example, if solely time-zone oriented broadcast requirements were to be served, and six such channels were needed in each area, a 30-beam satellite would still require six channels per beam to meet the same requirements.

*Assuming all beams are equally loaded.

Table 5-5. VSB Repeater Alternatives

System: Beams	System: Designation	Uplink Capability, Channels/Beam	Downlink Capability, Channels Per Beam (with equal loading)	Power in Beam Sufficient for, Channels	Total Beam-Channels	Weight, lbs.	Power Consumption, watts
7	7 - 25	≤ 25	25	25	175	1,420	14,740
	7 - 16	≤ 25	16	16	112	1,100	9,600
	7 - 6	≤ 6	6	6	42	700	3,700
12	VSB Baseline	≤ 16	16	16	192	1,590	8,452
	12 - 6	≤ 6	6	8	72	864	3,196
23	23 - 8	≤ 18	8	8	184	1,779	4,455
	23 - 6	≤ 18	6	6	138	1,587	3,417
30	30 - 6	≤ 12	6	6	180	1,890	3,448

The requirements model in the present study indeed is predominantly composed of such wide area broadcast needlines, in the video case, and it is also interesting that time zone beams are likely for future NASA Applications Technology Satellites, even though much smaller beams might be used to synthesize the time zone beams (Reference 17). In Figure 5-10, therefore, the weight and power trends for the time zone (seven) beam FM repeaters have been plotted as a function of number of channels per beam. As one might expect, the power increases linearly with the number of beams and in addition appears to come very near the zero channel, zero watts intersection if extrapolated. This is a reflection of the simple fact that transmitter power is by far the major portion of the total repeater power consumption, and DC to RF conversion efficiency is essentially constant over the range of interest. The trend in weight is not as obvious, except that it is clear that the more gradual slope at lower channel values is due to the increased proportion of component weight which is independent of the number of channels, such as the receivers. Very similar trends can be seen in the weight and power estimates for VSB repeaters and seven beams:

Channels/Beams	Weight, lbs	Power, W
6	700	3,700
16	1,100	9,600
25	1,420	14,740

5.3.3 Variation in Number of Beams

5.3.3.1 Introduction

The number of beams is a fundamental parameter in defining and designing a multichannel system. In using it as the driving parameter or independent variable in a tradeoff with repeater weight and power the dependent variables of interest, it is necessary to hold "other variables" constant. In particular, one is interested in the changes in weight and power as a function of changing the beam model (number of beams, usually) under the assumption that the service or system capability remains the same. It has been shown, however, that there are two different measures of

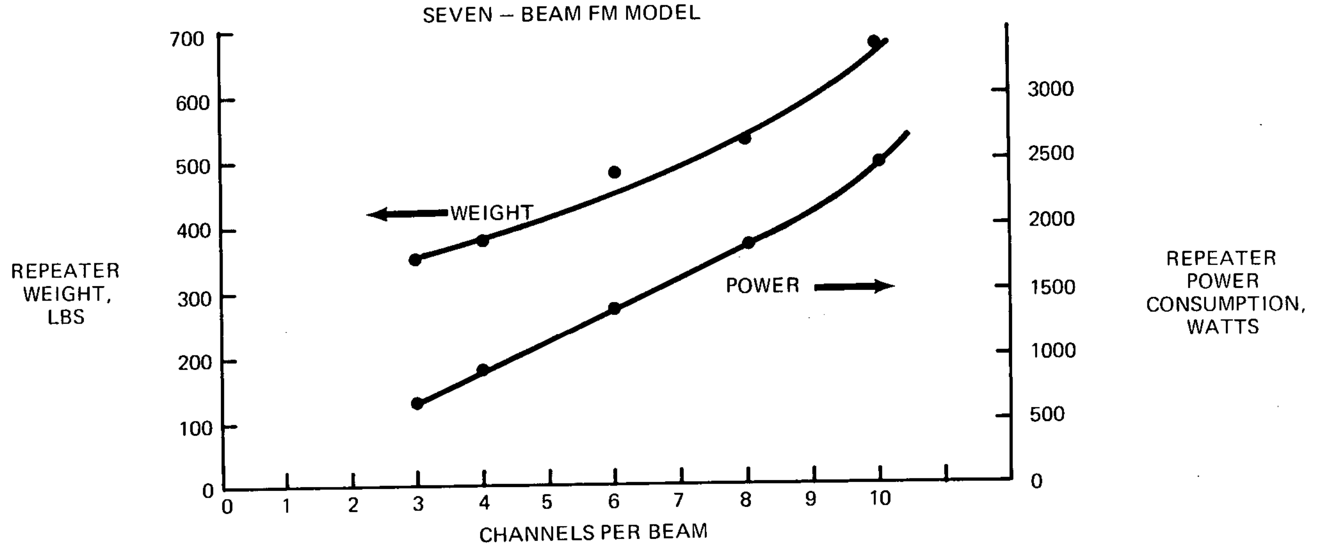


Figure 5-10. Repeater Weight and Power as a Function of Channels/Beam

system capability: the number of channels per beam, and the total number of beam-channels. Therefore, tradeoffs were performed separately with each of these held constant.

5.3.3.2 With Number of Channels per Beam Constant

As noted previously, the number of channels per beam is a useful variable for defining and measuring system capability for systems with extensive fanout (broadcast) connectivity such that a given channel is transmitted simultaneously in more than one satellite downlink. Thus, if the number of channels per beam is held constant and the number of beams changed, the dependence of repeater power and weight on beam number can be obtained. These dependencies are shown in Figures 5-11 and 5-12. The following observations can be made:

1. The essentially monotonic relationships are not really surprising. An optimum or minimum cannot occur in these graphs, because the defining variable used, channels per beam, is exactly indicative of the satellite's broadcast capability, so that if the coverage area is fixed, dividing it up into more pieces by increasing the number of beams cannot result in a power or weight saving.

2. By the same token, while the weight increases linearly with the number of beams, and the graph has a large slope, the power changes very little. This is a direct consequence of the fact that a fixed channel per beam capability, with coverage area constant, is directly translatable to a fixed total satellite ERP value. In other words, for fixed channels per beam and fixed total area, the number of beams and the beam gain are inversely related, so that the total RF (therefore DC) power remains constant.* The net result of these factors is the conclusion that for wide-area broadcast related applications a large number of beams is clearly not desirable.

*It may actually rise slightly due to the additional power required for subsystems other than the transmitters.

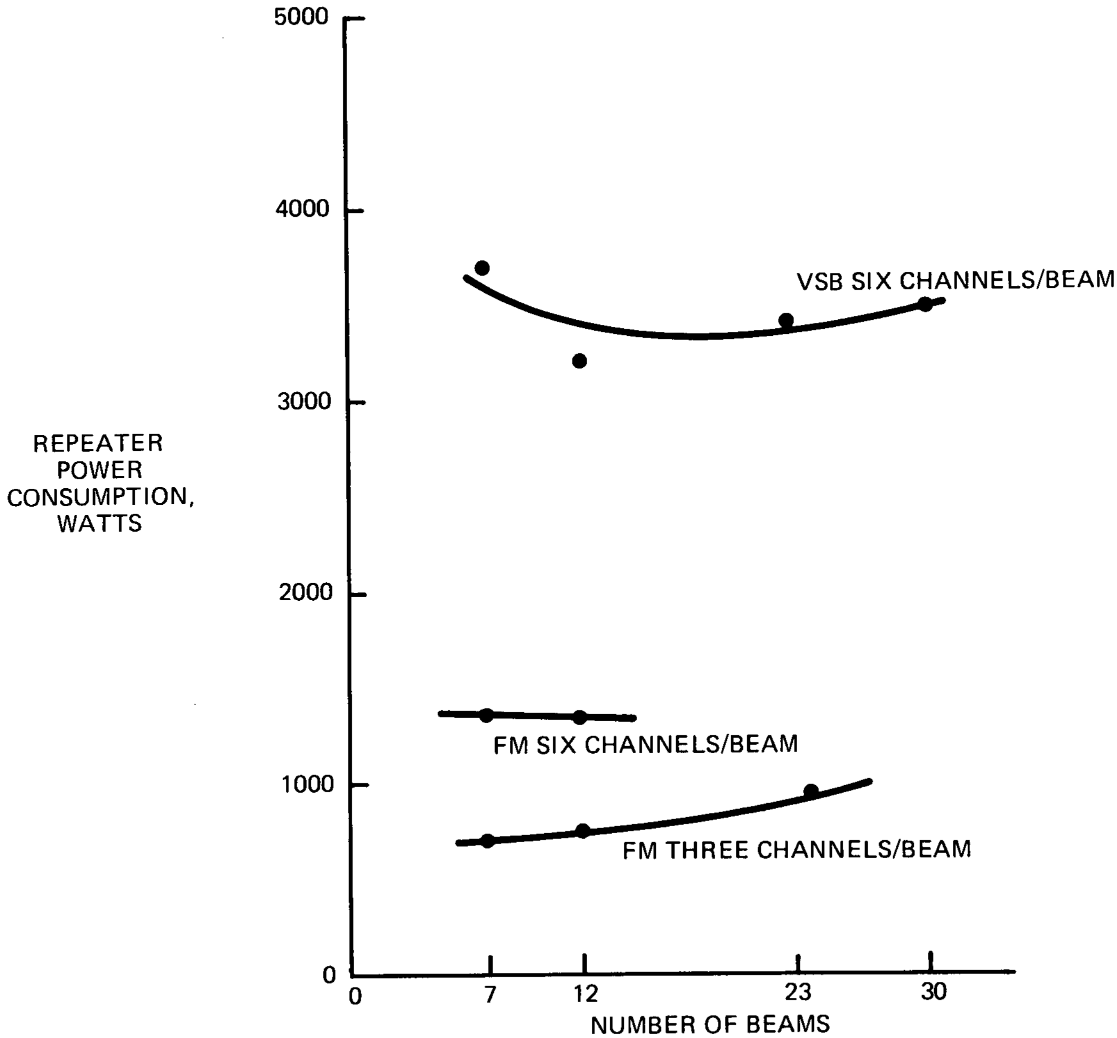


Figure 5-11. Repeater Power Consumption Versus Number of Beams With Fixed Channels Per Beam

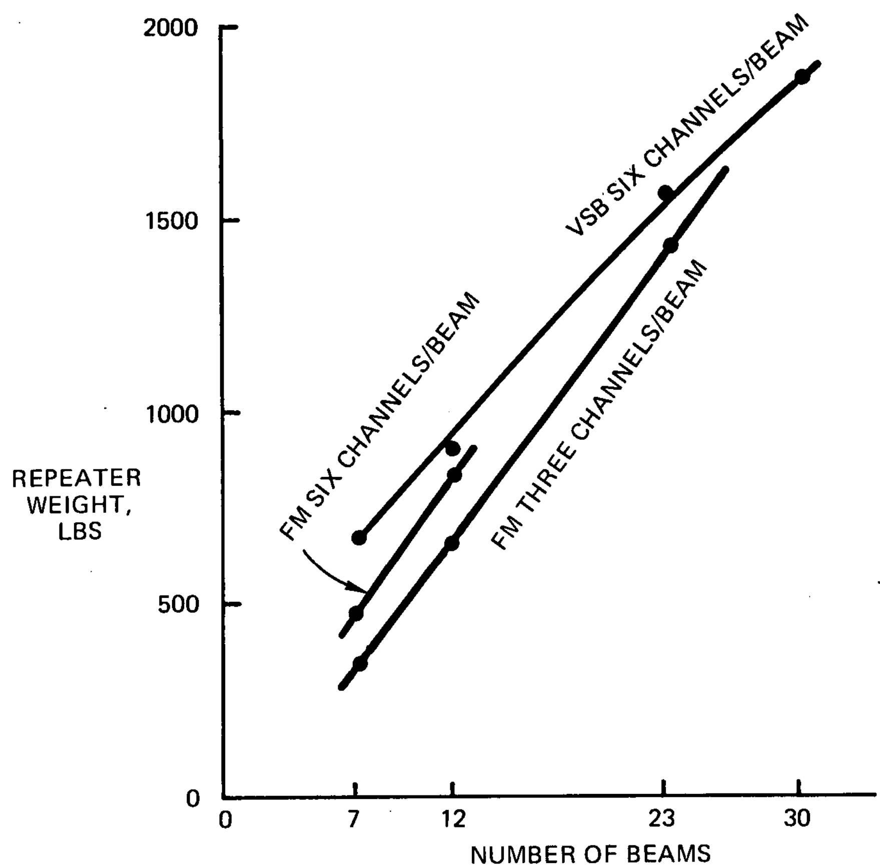


Figure 5-12. Repeater Weight Versus Number of Beams With Fixed Channels Per Beam

3. Emphasis must be placed on the phrase "for wide-area broadcast related applications" in item 2. It is not exactly true that a seven-beam satellite and a 23-beam satellite, each with n channels per beam, have the same capability. For wide-area broadcast they do, but if even a small portion of the requirements is for small area coverage (or point-to-point), the 23-beam model is more capable and flexible. Take a specific example: assume three channel per beam systems. Now suppose there is one requirement for a Pacific Northwest video broadcast, plus a point-to-point high rate data needline with the sink in Los Angeles. The seven-beam model would place both of these in the Pacific Time Zone beam, leaving only one channel for the entire beam 1 area. A 23-beam model (see Figure 3-19) would, on the other hand, have remaining two channels in beam 1, three in beam 2, two in beam 5, three in beam 6, and three in beam 12.

4. The example given suggests a very appropriate area for further research using specific requirements and beam models: how much better is one given beam model than another in satisfying the requirements? This was not done in the present study and cannot be done until: (1) measures of the degree of satisfaction of requirements are established, and (2) priorities on the requirements are established. Without such rules, one could always assume the wide-area broadcast requirements would be satisfied first, with the result that the large beam model would do just as well as any other.

5.3.3.3 With Total Beam-Channels Constant

In a system where all the needlines are point-to-point, the total number of downlink beam-channels is equivalent to the total number of channels (links) provided by the system. Therefore, this is another good parameter for characterizing system capacity or capability, though it must be used with care when wider-area broadcast or distribution needlines exist. In complete distinction to the point-to-point case, when broadcast needlines predominate equivalent capability exists only if the total number of beam channels rises exactly as the number of beams increases.

Repeater weight and power as a function of the number of beams were compared. For each comparison the total number of beam channels was held approximately* constant. These data are plotted in Figures 5-13 and 5-14. For this set of graphs, it is the power consumption tradeoff which is the more interesting. With fixed total beam channels, increasing the number of beams (and therefore the beam gain) clearly must lead to reduced power requirements. ** However:

1. As the beams get smaller and smaller, the transmitter's proportion of the total repeater power requirement becomes smaller and smaller, and diminishing returns set in. At some large number of beams, in fact, the transmitters would need only milliwatts and no power saving could be achieved by making the beams any smaller. In fact, Figure 5-13 shows that this point is essentially reached with FM at somewhere around 20 to 30 beams.

2. The diminishing returns nature of the power curves, and the ascending nature of the weight curves means that, unlike the constant channels-per-beam cases, an "optimum" number of beams can be found, by combining repeater data with satellite antenna and structural weight data and estimates of the pounds per watt power generation conversion factor. This is done in a preliminary manner in Paragraph 5.3.3.4.

5.3.3.4 Overall Satellite System Tradeoffs

The scope of this study does not include general satellite tradeoff considerations, but it is interesting to consider generally the approximate trends involved. For example, Figures 5-13 and 5-14 are based on repeater power consumption and weight estimates. Power consumption can be readily related to spacecraft power subsystem weight. For example, assume 15 watts per pound for advanced oriented solar array

*Within the availability of data. For example, the exact number of beam channels was 70, 72, or 69 with seven, 12, and 23 beams in one comparison.

**This has sometimes been expressed as the "puts the power where it is needed" aspect of point-to-point multiple beam satellite systems.

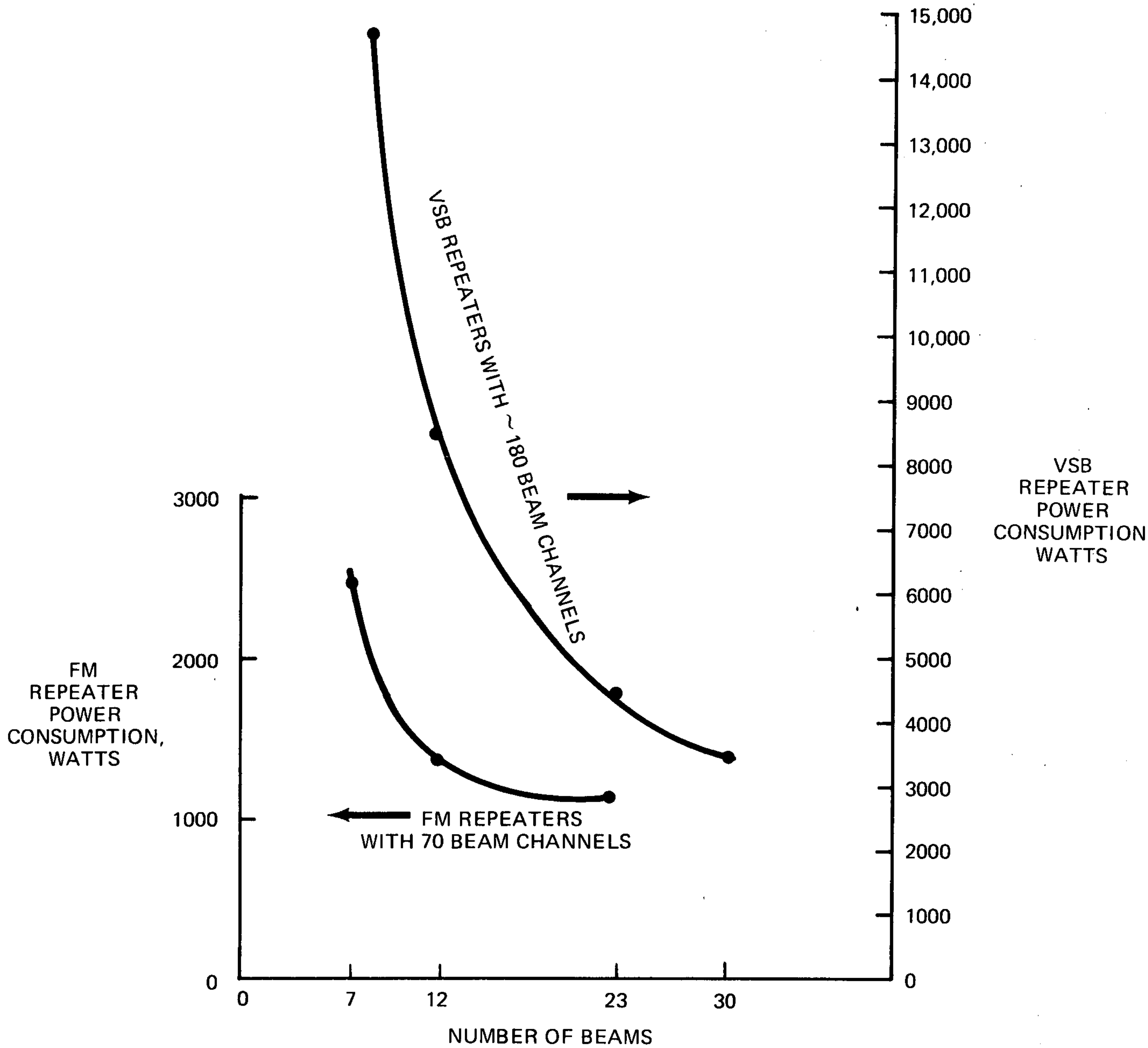


Figure 5-13. Power Consumption Versus Beam Model With Total Beam-Channels Held Constant

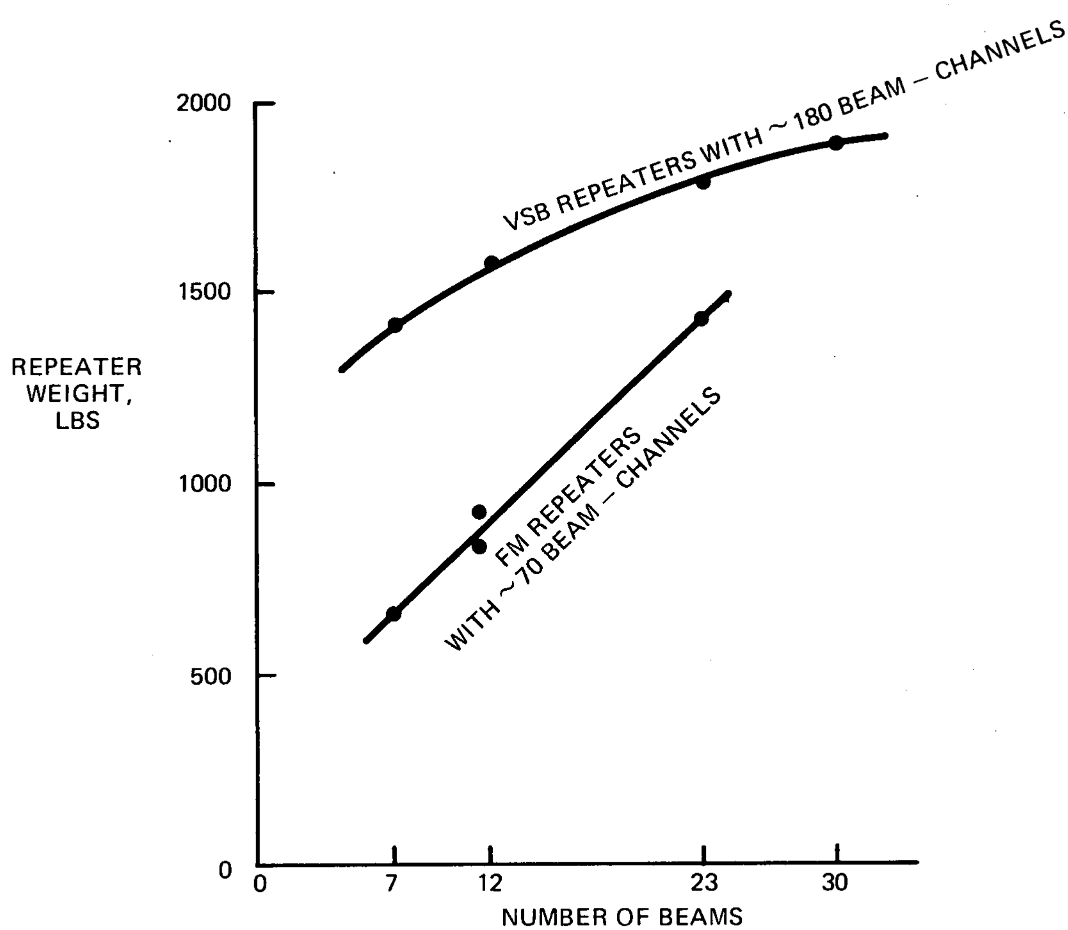


Figure 5-14. Repeater Weight Versus Beam Model With Total Beam-Channels Held Constant

power subsystems, * and 5 watt-hours per pound for eclipse battery capability. ** Then the total repeater plus power systems weights versus number of beams can be plotted as shown in Figures 5-15 and 5-16. The VSB does not show an optimum within the range considered, but the FM appears to, though no significance should be attached to the particular location of the minimum as it is very sensitive to structural details and assumed conversion factors. A full satellite tradeoff would require the addition of antenna and structure data parametric in the number of beams. A similar tradeoff could be performed using the channels-per-beam parameter instead of total beam channels, but, owing to the flat nature of the power curve (Figure 5-11) the "optimum" would be for the smallest possible number of beams.

*Including conditioning, regulation, switching, etc.

**Note that full eclipse capability for the MFR satellite is not necessary, however, since requirements do not peak at local midnight.

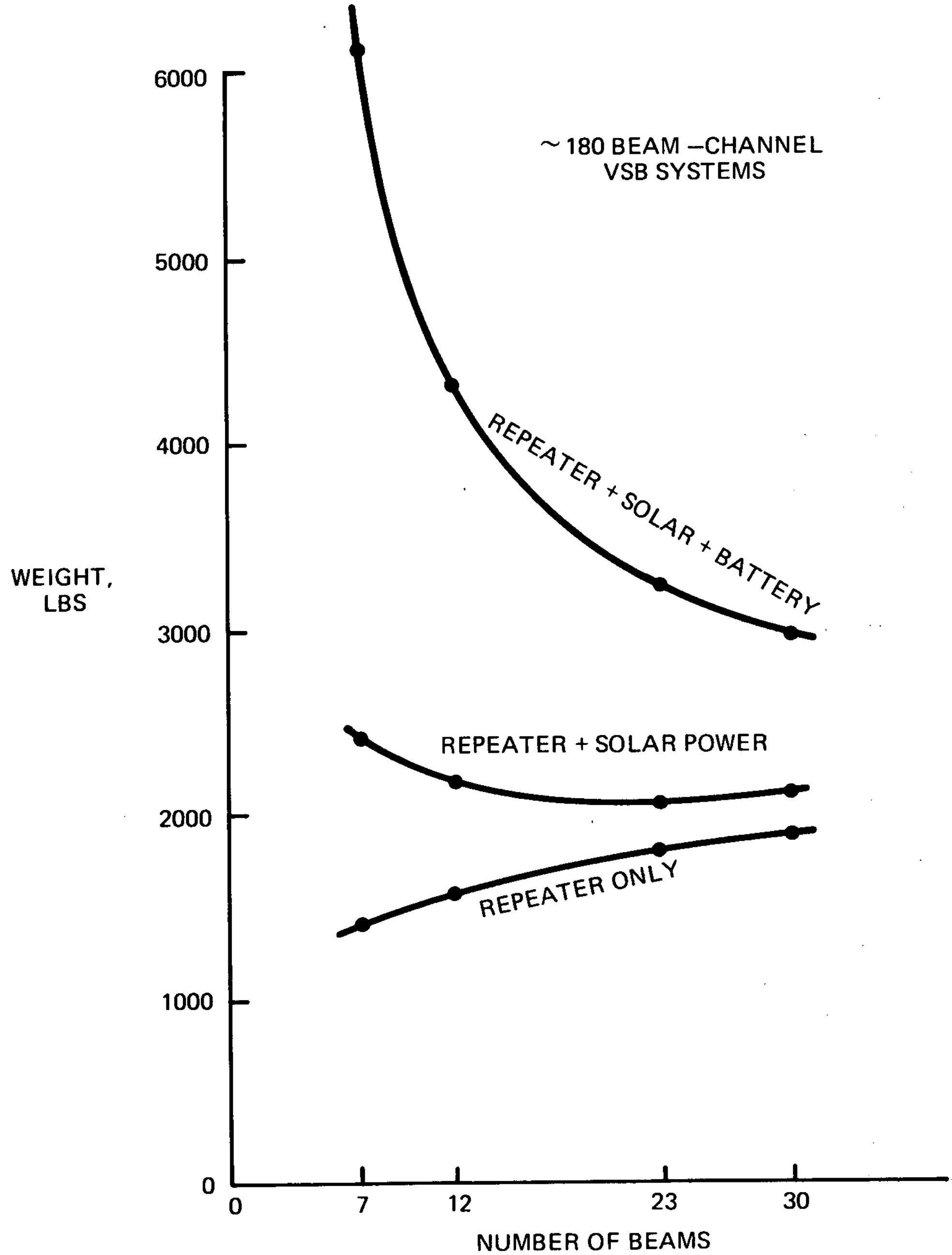


Figure 5-15. Repeater and Power Subsystem Weight Versus Number of Beams

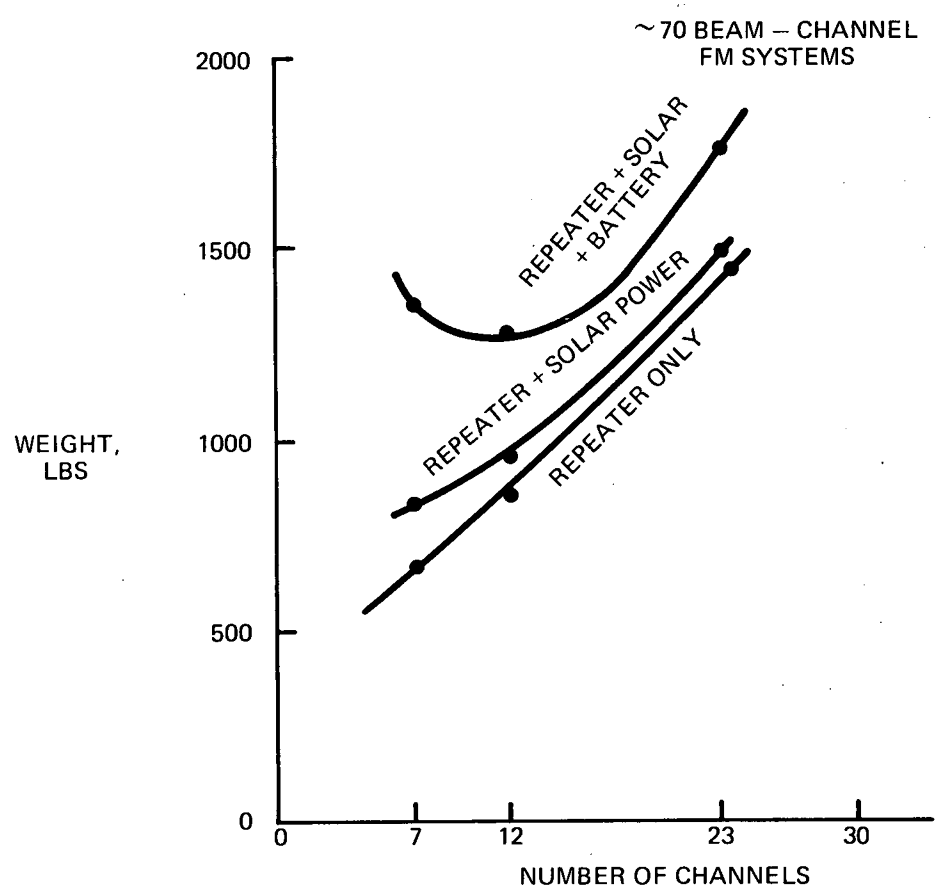


Figure 5-16. Repeater and Power Subsystem Weight Versus Number of Beams

5.4 PROVISION FOR OTHER SERVICES

5.4.1 Introduction

The emphasis in analysis and design in this study and its report has been on the high bandwidth, high ERP services, particularly video. The high power requirements of these needlines mean that any integrated* or unified multifunctional satellite will be overwhelmingly dominated by the hardware necessary for serving these needlines. Even large numbers of requirements of lower bandwidth or bit rate can be accommodated with relatively minor augmentation of the system concept selected for the video. The integrated satellite approach has been assumed in this effort. Therefore, the video/high rate data solutions were studied and designed in some detail, with the understanding that augmentation for voice, medium- and low rate data would be studied afterwards. In the course of the frequency reuse and the modulation studies, it became evident that while frequency division oriented techniques were strongly favored for video relay, time division techniques (possibly hybrids which used some frequency separation) were very attractive for voice transmission, not to mention data at up to and including the voice digitization rate (nominally chosen at 50 kbps for analytic purposes only).

The reduction (processing) of requirements, and the development and selection of repeater concepts have been extensively treated in other sections of this report. In summary, it was found that, regardless of the beam model, approximately 10 channels per beam (both up and downlink) would meet the requirements. The majority of these are clearly point-to-point, but some capability for point-to-multipoint (in the repeater, beam-to-several-beam) is also desirable. A single switched path memoryless repeater concept should be investigated, although it is applicable only to seven or 12 beam models.** This is not a very flexible or capable repeater concept, but is simple and may serve as

*That is, the diverse communication needs would be accommodated by one communication satellite. Furthermore, this satellite would be more unified in its technical execution than just a collection of separate repeaters which could have flown on separately launched structures.

**Multipoint downlink connectivity can be accomplished with this type of repeater only by repeating the uplink transmission as many times as necessary, i.e., fanout on the ground.

a basis for comparison. The second time switched repeater concept to be investigated is the n-path switched repeater (Reference 11), with n equal to the number of beams. This is a hybrid concept because the simultaneity of repeater path operation requires separation in frequency and/or space between antenna beams. With n paths, in fact, time separation is used only to separate channels within each beam. These channels may emanate from one station, in which case time division multiplexing is involved, or from separate stations, in which case time division multiple access occurs. At some cost in frame efficiency, it is straightforward to accomplish multiple downlink beam connectivity providing the repeater path amplifiers and switches can in fact tolerate the connection of several output paths to one input. Because this approach is relatively efficient of bandwidth, and because it uses RF power from the video beam amplifiers (i.e., is an "add-on" approach), the sensitivity to number of channels is not accute, so the 10 channels per beam value should be taken only as a baseline. The n-path concept, as well as the single path, will be investigated in detail only for application to the 12 beam baseline repeaters, but the n-path (with n changed) is applicable to any beam model. The sensitivity to beam number will be determined.

The C/kT for a single 50 kbps channel is taken as 62 dB-Hz. For the single path repeater, there are 120 such channel connections per frame, so the C/kT during a single burst must be 83 dB-Hz. This is 10 dB below a single FM video channel, or 20 dB below one for VSB. Therefore the single-path voice repeater add-on, when switched into a beam, takes 10 percent of the beam's power in the FM case, and less than 1 percent in VSB.* The n-path repeater carries continuously 10 channels, and thus needs only 1 percent with FM, 0.1 percent with VSB, **in each beam continuously. In both cases it is assumed that the operating frequency band for these signals is offset to one side of each beam's band. The necessary bandwidth is negligible and can readily be accommodated in each case.

*This difference merely reflects the 12 dB difference in earth terminal G/T in the two types of systems.

**These should be 2 percent and 0.2 percent if the burst times are shortened by 50 percent to allow for more flexible frame utilization.

5.4.2 Addition of TDMA - Voice Capability to FM Baseline

To add a TDMA capability of either kind to the FM Baseline repeater, it is necessary to establish a separate TDMA band in each of the three 167-MHz general bands (A, B, and C). This TDMA band or channel is then separated out by an additional filter, IF amplifier, and limiter added to the filter bank illustrated in Figure 5-3. This channel would have a bandwidth of 6 MHz. The output of this TDMA channel unit is fed to a separate switch matrix. The nature of this matrix depends on the type of repeater being implemented.

In the single path TDMA mode this switch matrix can be quite simple. This is shown in Figure 5-17. This matrix consists of two groups of SPST PIN diode switches. The first group of switches connects any of the TDMA outputs from each of the 12 receivers to the receiver bus. These switches are interlocked such that only one of the 12 switches is on at a time. The second group of switches connects the transmitter bus to any transmitter input. Note that there are three inputs for each transmitter so that the appropriate up-converter is used depending upon the received frequency band. Here again, these switches are interlocked such that only one of the 36 switches is on at a time. An attenuator is provided to connect the transmitter and receiver buses.

The outputs of the TDMA switch matrix are connected to the transmitters via hybrids or directional couplers.

In the "n"-path TDMA mode the TDMA switching matrix is more complicated. This matrix is shown in Figure 5-18. In this matrix each of the 12 received TDMA channels is triplicated to make it available to the three transmitter bands. Then each output of this 1:3 divider is fed to a 1:4 divider to further feed each of the four transmitters in each band. In this manner the 12 required independent paths can exist simultaneously through this TDMA switch matrix. Actually, because of the 1:3 and 1:4 dividers, 36 paths can be achieved through this matrix, with some receivers feeding more than one transmitter. The switch matrix of Figure 5-18 requires 144 SPST PIN diode switches, 12 - 1:3 dividers and 36 - 1:4 dividers.

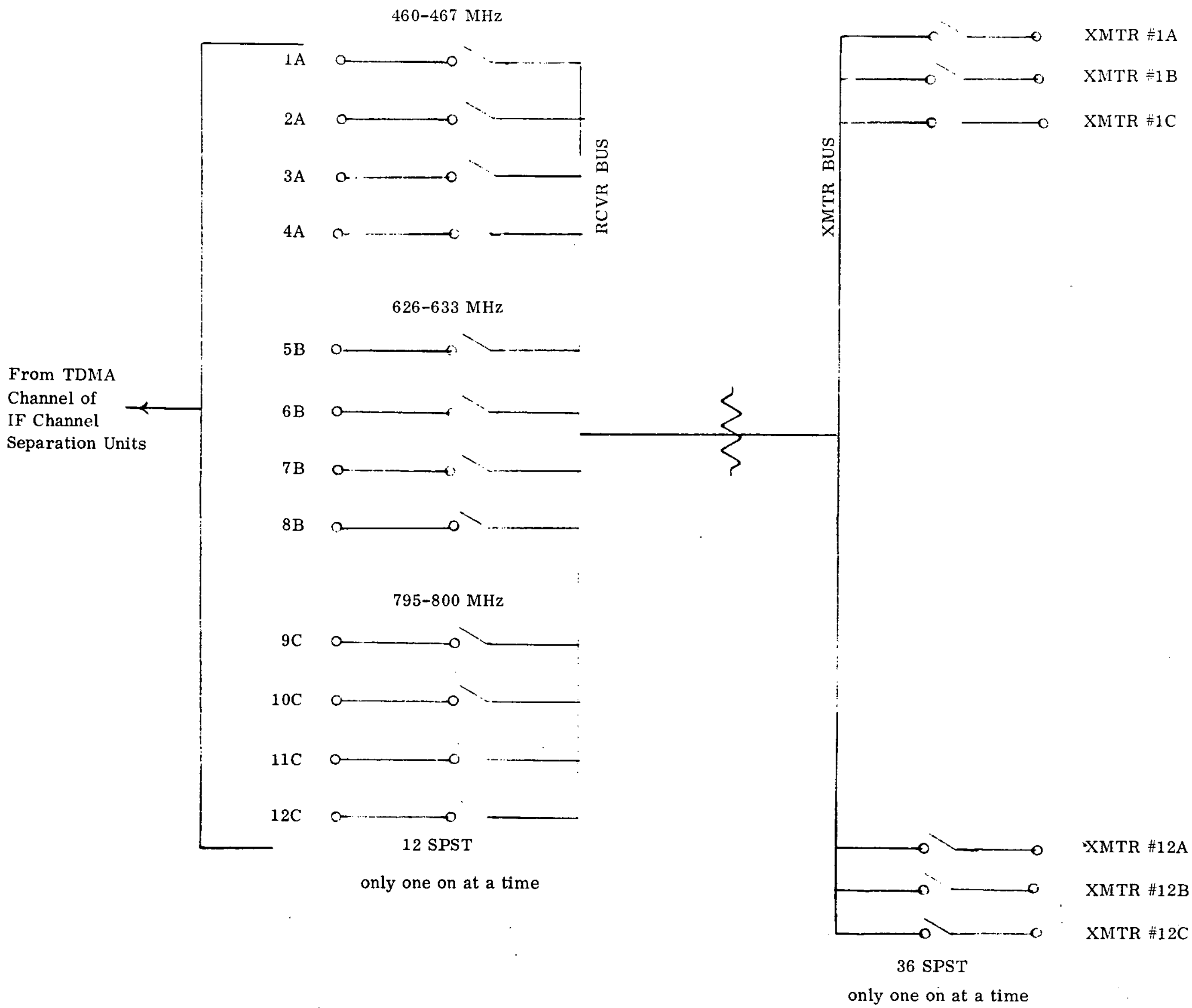


Figure 5-17. TDMA Switch Matrix, One Channel Mode

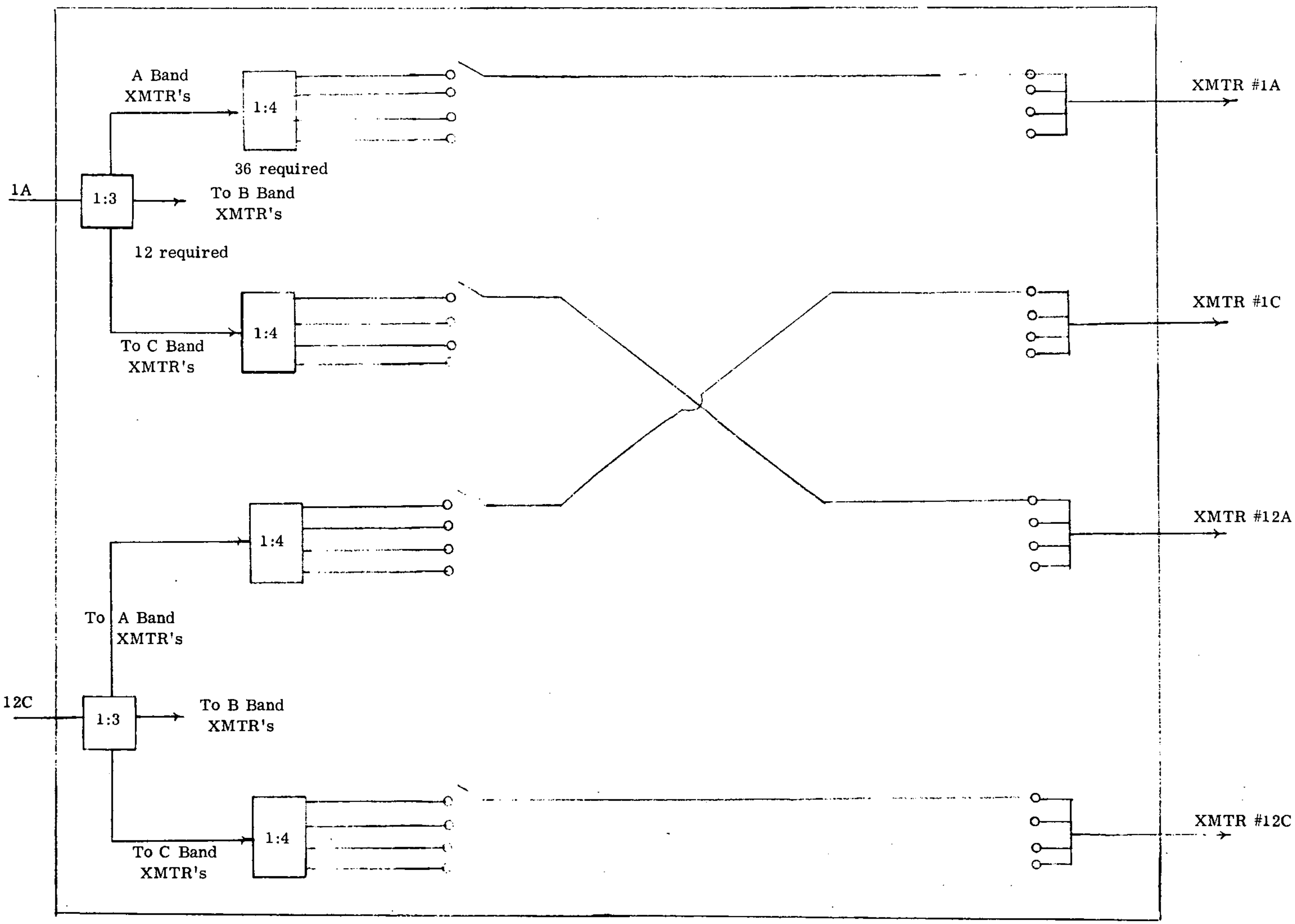


Figure 5-18. TDMA Switch Matrix, "n" Channel Mode

Table 5-6 summarizes the extra weight and power required to add either of these TDMA capabilities to the FM baseline design.

5.4.3 Addition of TDMA - Voice Capability to VSB Baseline

To add a TDMA capability to the VSB baseline repeater is fairly simple compared to the FM repeater. This is because all received channels are down-converted to a common IF of 100 MHz. This also means that there is no need for band switching in the repeater up-converters.

To add the TDMA capability, one existing 5-MHz wide channel from each receiver will be dedicated to TDMA users. This channel at the intermediate frequency of 100 MHz will be routed to an additional TDMA switching matrix.

For the one channel mode the TDMA switching matrix resembles that of Figure 5-17 with the exception that there are only 12 connections (instead of 36) from the transmitter bus. In the "n" channel TDMA mode, the switching matrix is for all practical purposes identical to Figure 5-18.

Since existing separating and combining components are used, the additional power and weight to "add" the TDMA is only that of the switching networks, 2 pounds and 0.4W for the single path, 28.6 pounds and 7.2W for n-path.

5.4.4 Extensions of Capability

The data in Table 5-6 and Paragraph 5.4.3 can readily be applied to determine the weight and power impact of: (1) different beam models or (2) different numbers of repeater paths.

Changing the beam models directly affects the number of channel separators and transmitter hybrids, in a one-to-one fashion. It also has an essentially direct impact on the switching matrix, due to the receiver bus/transmitter bus method of implementation selected. On the other hand, it is important to note that the structure and weights do not change substantially with changes in the total number of voice/data channels accommodated. Only switch speed and channel bandwidths are affected, and these parameters do not influence parts count or weight over reasonable ranges. On

Table 5-6. Additional Weight and Power Required to Add TDMA Subsystems to FM Baseline

	Single Path		"n" Path	
	Weight (lbs)	Power (W)	Weight (lbs)	Power (W)
Channel Separation (12 required)	20.4*	9.6 *	20.4*	9.6 *
Switch Matrix (1)	3.4	0.4	28.6	7.2
Hybrids for Transmitters (36 required)	4.8 *	0	4.8*	0
Total	28.2	10.0	53.8	16.8

*Total for the number of subsystems specified.

the other hand, the power budget will not allow the single path/FM combination to operate with many more than 10 channels per beam. The n-path concept is more power efficient and would allow up to 50 or 100 channels per beam without exceeding power or bandwidth constraints. In Table 5-7 are shown the total power and weight values for a number of such beam/capacity variants.

Table 5-7. Weight and Power for Variants

Beams	Channels Per Beam:	1	10	100
	Type			
7	Single Path, FM	14 lbs, 5W	18 lbs, 6W	Notes A and B
	n-path, FM	27 lbs, 10W	31 lbs, 11W	Note B
	Single Path, VSB	2 lbs, .3W	2 lbs, .3W	Note A
	n-path, VSB	16 lbs, 3W	18 lbs, 4W	20 lbs, 6W
12	Single Path, FM	23 lbs, 8W	28 lbs, 10W	Notes A and B
	n-path, FM	49 lbs, 12W	54 lbs, 17W	50 lbs, 20W
	Single Path, VSB	2 lbs, .3W	2 lbs, 0.4W	Note A
	n-path, VSB	25 lbs, 6W	28.6 lbs, 7W	30 lbs, 15W
23	Single Path, FM	50 lbs, 15W	55 lbs, 19W	Notes A and B
	n-path, FM	80 lbs, 25W	95 lbs, 30W	100 lbs, 40W
	Single Path, VSB	2 lbs, .3W	Note A	Note A
	n-path, VSB	50 lbs, 12W	55 lbs, 13W	60 lbs, 25W
30	Single Path, FM	55 lbs, 25W	Note C	Notes A and B
	n-path, FM	90 lbs, 30W	Note C	120 lbs, 50W
	Single Path, VSB	2 lbs, .3W	Note A	Note A
	n-path, VSB	60 lbs, 15W	68 lbs, 16W	75 lbs, 35W

Note A - Not feasible, excessive RF bandwidth

Note B - Not feasible, requires excessive RF power

Note C - 30 beam FM repeater not practical

SECTION 6 - ACCOMPLISHMENTS, OBSERVATIONS, CONCLUSIONS AND AREAS FOR POSSIBLE FUTURE WORK

6.1 SIGNIFICANT ACCOMPLISHMENTS OF THIS EFFORT

The various identifiable areas of study emphasis in many cases have yielded tangible accomplishments or products which should be of value in future study and analysis of satellite systems for MFR and many other applications. In most of these cases, it was the structure or methodology evolved that was useful, not the particulars. Thus, for example, it was found in the course of requirements analysis that the geographic cell locating approach could readily be applied, in principle, to any geographic or spatial coordinate system, even to a listing of Alaskan telecommunication requirements specified in terms of the villages being served. Likewise, the magnitude of channel requirements and the like are not as important as the data reduction techniques developed for quickly deriving these numbers.

Some significant accomplishments of both a general and a specific nature were:

1. A geographic cell overlay or grid was developed for the continental U.S. and found useful in describing service needlines.

2. A set of temporal and geographic parameters was formulated which described communication needlines. These parameters were those which are most useful in determining repeater system impact. These and similar parameters should be useful in future requirements surveys and system studies.

3. A computerized data base was formulated from the requirements data. The approach to and organization of this should be useful in future studies.

4. The analysis of the system effects of interbeam interference was extended beyond that previously published. In particular, the approximations used in the published work were identified and their ranges of validity established, so that the exact expressions can be used whenever the approximating

assumptions (such as that the interbeam interference dominates the total received noise) are not valid.

5. A computer program was developed to translate the geographic cell-oriented requirements data base to a new reorganized data base oriented around each particular multiple-beam model. This procedure allows the same requirements data base to be used for any number of different beam-coverage models, which is a necessary tool for comparing the different beam models.

6. The descriptive temporal and geographic parameters were found to be both necessary and sufficient to perform channel counting for the repeater models, i.e., converting requirements needlines to repeater channel requirements.

7. Frequency division and time-separation oriented repeater concepts were classified and categorized along the following lines:

   a. Signal structure

   b. Functional

   c. Implementation choices

8. Three prime candidates of FDMA-oriented repeaters were identified, two of which were applicable to video transmission. A great deal of commonality among the three types was noted.

9. Three TDMA-oriented prime candidates were identified, of which two seemed useful in the MFR voice relay application.

10. 12-beam baseline repeater models were selected.

11. The baselines and alternate systems were sized in weight and power consumption.

6.2 OBSERVATIONS AND CONCLUSIONS

Listed below are items which might be characterized as observations based on the data and the analysis results, as well as general conclusions stemming from these observations and from work performed in this study.

1. Most of the "usual" modulation techniques were found to be applicable, but FDM/FM for video relay was definitely excluded. FDM/FM and TDM/PCM-PSK multichannel voice are efficient from a system capacity point of view only with a degree of frequency reuse not achievable with closely packed multiple beams of reasonable quantity.

2. The triangular "billiard ball" arrangement of multiple antenna beams is most effective.

3. The minimum gain (towards any place within the continental U. S. coverage area) of a multiple-beam antenna is very sensitive to the actual beam model and its exact orientation. Therefore, considerable effort is warranted in optimally sizing, aiming, and orienting proposed beam model arrangements.

4. The bandwidth expansion versus power saving (C/kT reduction) plot is the fundamental output of an interbeam interference analysis. It can be used to optimize a system for bandwidth, power, or system capacity (the latter depends on a combination of power and bandwidth, and is gauged by the "tradeoff line" which is parametric in m, the sidelobe taper exponent).

5. The case of a finite number of beams is more disposed toward small bandwidth-expansion techniques than the infinite beam case.

6. It is concluded, likewise, for the actual beam models investigated, that to achieve the largest possible system capacity, narrowband techniques (VSB for video) are mandatory.

7. Digital video transmission is not competitive even with FM by about a factor of two in system capacity. Redundancy reduction by a factor of two would be necessary to make it competitive.

8. FM is better than SSB transmission, for the theoretical infinite beam case, only in those cases where system requirement and constraints both require and allow a bandwidth expansion greater than about 5.

9. The duality of time and frequency is a convenient tool for analyzing TDMA systems, and can also be used to demonstrate that there can be nothing

magical about TDMA which might enable a system to outperform the FDMA case.

10. Of the TDMA concepts investigated, the hybrid* n-path (n = number of beams) was considered the most effective.

11. The general order of magnitude of video and high rate data service required, based on the postulated hypothetical data base, was 10 channels per beam.

12. Two measures of system capability or capacity were used:

    a. Channels per beam

    b. Total beam-channels

13. Despite the regionalized nature of most of the networks involved, the channels per beam criterion was found to be a better indicator of capacity than total beam-channels.

14. Separate FM and VSB baselines had to be created for analysis. The VSB approach provides much greater capability but the price must be paid both in satellite power and earth station G/T. In other words, the marginal or incremental cost of achieving capacity greater than FM can provide is very large.

15. Implementation choices in the repeaters included:

    a. Active filters for channel separation

    b. PIN diode switches

    c. TWTs instead of solid-state amplifiers for transmitters

    d. Single amplifier per beam was chosen over feeding multiple beams from one amplifier

16. With systems which relay signals to wide areas, channels per beam is the fundamental performance criterion. In these cases, increasing the number of beams beyond a small value (in MFR, time zone beams) is not advantageous

*Requires frequency and/or spatial isolation between beam signals.

in terms of system capacity. However, if there is even a small proportion of point-to-point or small area needlines within the requirements, the increased number-of-beams-models have much greater flexibility in routing and resource allocation.

17. If all point-to-point needlines exist, the total number of beam channels equals the total number of channels, and is the best criterion of system performance. As the number of beams is increased then, the total repeater power consumption curve flattens out towards a point of diminishing returns. Thus an optimum number of beams can be found in this case by combining repeater weight, antenna weight, and power supply (as a function of power required) weight data. This optimum favors the smallest number of beams in the case of FM, and the largest number of beams for VSB (if eclipse batteries are included).

18. The fact that the total beam-channel measure does have this ability to permit an optimization of number of beams* may, in future analyses, cause it to be applied in cases where it is not a good performance measure. For example, for a nationwide broadcast needline, the number of beam channels involved goes up linearly with the number of beams even though the actual service is the same. Caution is necessary.

19. In summary, then, the two capacity measures apply to systems with the opposite extremes of requirements structure. In a typical system with a mix of requirements, it is necessary to assign "costs" and benefits to flexibility of routing, degree of satisfaction of requirements, and similar factors, if system effectiveness is to be evaluated.

6.3 FUTURE WORK

6.3.1 Requirements

A continuing and iterative process of user information/edification and requirements definition is necessary. But the very slow progress in this area suggests that a full

*A true satellite optimization would require the use of structural and overhead systems data in addition to repeater, antenna, and power data cited.

scale requirements study will not be productive before potential users have had at least one round of hands on experience with the benefits of satellite communications.

6.3.2 Linear Satellite Power Amplifiers

A great premium exists on improvements in overall DC to RF conversion efficiency of power amplifiers operating under multiple carrier, low I. M. specification conditions. A 1 dB reduction in "backoff" requirement leads to a 25 percent reduction in prime power requirements for a VSB video service system, for example. Improvements can occur in the basic transfer characteristic, the basic saturated efficiency, or the effective linearity at a given drive level. The latter could be achieved by predistortion or by feedforward techniques presently under investigation. These show great promise.

6.3.3 System Analysis

If (1) an accurate requirements model were established and (2) relative costs or priorities could be established for satisfying the different needlines, then various beam/repeater models could be evaluated on a more meaningful basis than total beam channels or channels per beam. In addition, the total satellite tradeoff can be performed by combining the data from this study and the companion antenna study with satellite structural and launch vehicle cost data. Lastly, a system tradeoff analysis could be performed, varying parameters such as the earth terminal size, by combining such satellite tradeoff data with the overall system optimization routines available.

APPENDIX A - COMPUTERIZED DATA FILE CODING DESCRIPTION AND LISTING

A.1 INTRODUCTION AND ARRANGEMENT

The computerized data file, which was established in the form of a deck of punched cards, contains a record of the hypothetical traffic model described in Paragraph 2.4.

There were over 50 demands and 61 geographic cells. The data base was organized according to a "by demand" arrangement, i.e., following each demand the needlines applicable were listed, and they gave the cells to be interconnected. Broadcast and other scheduled (including continuous) demands were described on an hourly basis, whereas "on demand" and similar unpredictable requirements were specified only in terms of their relative usage rates for each 6-hour time block.

Once again, the data base is organized by the demands, i.e., the connectivity needlines are listed for each separate demand (at each separate time unit). The deck is organized as follows:

1. Demand Card for demand xxx at time yyy

    Needline card

    Needline card

    ⋮

    Needline card

2. Demand Card for demand xxx at time zzz

    Needline card

    Needline card

    ⋮

    Needline card

F

3. Demand Card for demand ddd at time yyy

   Needline card

   Needline card

4. Demand Card for demand ddd at time zzz

   Needline card

   etc.

The demands were numbered consecutively, as will be described.

A.2 CODING DESCRIPTION

The demand cards have entries arranged, as shown in Figure A-1. The specific meanings of the designations are as follows.

1. <u>Demand number</u>

   The first two digits identify basic demand; the second two, a subcategorization.

2. <u>Time Code</u>

   101 through 124 - hour 1 (0000 to 0001 EST) to hour 24, or 601 through 604 - time block 01 (0000 to 0600 EST) through block 04 (1800 to 2400 EST)

3. <u>Service Code</u>

   a. 1000 = Video
   b. 2000 = Voice
   c. 3000 = Data, low (2400 bps) rate
   d. 4000 = Data, medium rate
   e. 5000 = Data, high rate

0.5	XXXX	XXX	XXXX	XXXX	XXX
A flag which designates the card as a demand card.	Demand Number	Time Code	Service Code	Time Pattern	Geographic Pattern

Figure A-1. Demand Card Arrangement

4. Time Pattern

a. First digit: duty cycle (during relevant time period only)

1 ⇒10 percent

2 ⇒25 percent

3 ⇒50 percent

4 ⇒100 percent

b. Second digit: duration of message or connection

1 ⇒1 minute

2 ⇒5 minutes

3 ⇒10 minutes

4 ⇒Continuous (during relevant time period)

c. Third digit: toggling. This refers to how the network reconfigures on a short-term basis.

0 ⇒Fixed (unidirectional from source to sink)

1 ⇒Back and forth (duplex)

2 ⇒Roundtable (conference)

3 ⇒Multipoint/single point. This is a network where many points are all communicating with one central or focal point, as occurs in disaster or emergency communication.

d. Fourth digit: predictability

1 ⇒Totally predictable

2 ⇒Partial (24-hour notice)

3 ⇒Generally (roughly occurs within time block)

4 ⇒Totally unpredictable

5. Geographic Pattern

a. First digit: geographic dispersion of net members

1 ⇒Area

2 ⇒Regional

3 ⇒Continental

4 ⇒Mixed

b. Second digit: connectivity

1 ⇒ Broadcast (one way, point to multipoint)

2 ⇒ Point to point

3 ⇒ Conference

4 ⇒ Multipoint to multipoint (data dissemination, etc.)

5 ⇒ Point to multipoint, half duplex

c. Third digit: geographic specificity (how well known in advance are the locations?)

1 ⇒ Fixed unchanging configuration

2 ⇒ Temporarily fixed, specified 24 hours in advance

3 ⇒ Random* selection of source(s) and sink(s)

4 ⇒ Fixed source(s), random sink(s)

5 ⇒ Random source(s), fixed sink(s)

6 ⇒ Unspecified* source(s), fixed sink(s)

The needline cards have entries arranged as shown in Figure A-2. The entries mean the following:

1. Source Structure

1 ⇒ One source

2 ⇒ Two sources, half duplex

3 ⇒ Multiple simultaneous sources

4 ⇒ Multiple sources, operating one at a time

---

*The difference between random and unspecified is as follows: unspecified means that one cannot predict in advance which of the candidate source locations will be involved. In a random situation, the location may also shift around during a network's operation.

2. Number of Sources

The number of cell entries contained in the next card entry category. Primarily a programming convenience.

3. Source Cells*

Identification numbers of all cells which contain a source for this needline.

4. Code

a. "Inclusive" - The cell numbers in the last card entry category are those of all cells which contain a sink for this needline.

b. "Exclusive" - The cell numbers listed in the last card entry category are only for those cells not including sinks for the needline in question.

5. Structure

1 ⇒ One sink

2 ⇒ Multiple simultaneous sinks

3 ⇒ Multiple sinks, one at a time active

4 ⇒ Toggles between multiple sinks and one sink

6. Number of Sinks

Number of cell designation entries in the card entry category immediately following this one.

7. Sink Cells

Identification numbers of all cells which contain a sink for this needline.

*If there is no entry here, the source cells are the same as the sink cells.

X	XX	xxx, xxx, xxx, ... xxx	X	X	XX	xxx, xxx, xxx. xxx
Source Structure	Number of Sources	Source cell designations	Code	Sink Structure	Number of Sinks	Sink cell designations

Note: Data may be continued onto a second card if space on one is insufficient.

Figure A-2. Needline Card Arrangement

A.3 EXAMPLES

The following are given as examples:

1. Demand Card

0.5	313	604	1000	1334	256
Demand Card Flag	Demand Number 313	Time Block 04 (1800-2400 EST)	Video	10 percent 10 minutes Multi/single Unpredictable	Regional, Point to Multipoint, Unspecified Source, Fixed Sinks

2. Needline Card(s)

4	08		1	4	08
Multiple, Sources One at a time	Eight Sources	No entries; therefore, sources same as sinks	Inclusive	Multiple Sinks or One Sink	Eight Sinks

(Continuation of needline card)

411	412	508	509	510	511	611	851

-----------------------sink cell numbers---------------------

A.4 DATA BASE LISTING

The complete data base is listed here, with descriptive labels attached on the right side. To save space, however, the complete air traffic control net listing has not been included here. The complete ATC network listing consists of 43 ATC center to ATC center, low-rate data, point-to-point descriptions (i.e., demand and needline cards) identified to the several that have been included in the listing reproduced here.

DATA BASE

```
C
C
C
            CELL BLOCK NUMBERS
C
      101,102,103,104,105,106,107,108,109,114,201,202,203,204,205,206,207,
      208,209,210,211,212,213,214,301,302,303,304,305,306,307,308,309,310,
      311,312,313,402,403,404,405,406,407,408,409,410,411,412,505,506,507,
      508,509,510,511,607,611,721,851,941,961
C
C
            EDUCATION                                                                EDUCATION
C
C
         PRESCHOOL
C
 .5, 011,     110,     1000,        4401,     211                        Preschool, Eastern U.S., 10 AM
         1,01,     214,                              1,2,26,
      108,109,114,208,209,210,211,212,213,308,309,310,311,312,313,
      408,409,410,411,412,508,509,510,511,611,851
 .5, 011,     111,     1000,        4401,     211                        Preschool, Eastern U.S., 11 AM
         1,01,     214,                              1,2,26,
      108,109,114,208,209,210,211,212,213,308,309,310,311,312,313,
      408,409,410,411,412,508,509,510,511,611,851
 .5, 012,     112,     1000,        4401,     211                        Preschool, Western U.S.,  9 AM
         1,01,     301,                              1,2,30
      101,102,103,104,105,106,107,201,202,203,204,205,206,207,302
      303,304,305,306,307,402,403,404,405,406,407,505,506,507,607
 .5, 012,     117,     1000,        4401,     211                        Preschool, Western U.S.,  2 PM
         1,01,     301,                              1,2,33,
      101,102,103,104,105,106,107,201,202,203,204,205,206,207,302
      303,304,305,306,307,402,403,404,405,406,407,505,506,507,607
      721,941,961
C
         GRADE SCHOOL
C
 .5, 021,     109,     1000,        4401,     211                        Grade School, New England,  9AM
         1,01,     214,                              1,2,02,
      114,213
 .5, 021,     113,     1000,        4401,     211                        Grade School, New England,  1 PM
         1,01,     213,                              1,2,02,
      114,214
 .5, 022,     111,     1000,        4401,     211                        Grade School, Middle Atlantic, 11 AM
         1,01,     313,                              1,2,03,
      212,213,312
 .5, 022,     113,     1000,        4401,     211                        Grade School, Middle Atlantic,  1 PM
         1,01,     312,                              1,2,03,
      212,213,313
 .5, 022,     114,     1000,        4401,     211                        Grade School, Middle Atlantic,  2 PM
         1,01,     212,                              1,2,03,
      213,312,313
 .5, 023,     109,     1000,        4401,     211                        Grade School, Southeast,  9 AM
         1,01,     410,                              1,2,07,
      409,411,412,504,510,511,611
 .5, 023,     110,     1000,        4401,     211                        Grade School, Southeast, 10 AM
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A-9

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        1,C1,     41C,                                             1,2,07,
    4C9,411,412,5C9,51C,511,611
.5, C23,         113,      1C00,          4401,      211                          Grade School, Southeast,  1 PM
        1,C1,     611,                                             1,2,07,
    409,41C,411,412,509,51C,511
.5, C23,         114,      1CCC,          44C1,      211                          Grade School, Southeast,  2 PM
        1,C1,     5C9,                                             1,2,07,
    409,41C,411,412,510,511,512
.5, C24,         111,      1CCC,          44C1,      211                          Grade School, Midwest,  10 AM
        1,C1,     210,                                             1,2,15,
    106,1C7,108,1C9,2C6,207,2C8,2C9,211,3C6,307,308,3C9,31C,311
.5, C24,         112,      1CCC,          44C1,      211                          Grade School, Midwest,  11 AM
        1,C1,     21C,                                             1,2,15,
    1C6,1C7,108,1C9,2C6,2C7,2C8,2C9,211,3C6,307,308,309,31C,311
.5, C24,         115,      1CCC,          4401,      211                          Grade School, Midwest,  2 PM
        1,C1,     208,                                             1,2,15,
    1C6,1C7,108,1C9,2C6,207,2C9,210,211,3C6,307,308,309,31C,311
.5, C25,         111,      1CCC,          4401,      211                          Grade School, Texas (etc.), 10 AM
        1,C1,     507,                                             1,2,06,
    406,4C7,408,5C6,5C8,6C7
.5, C25,         114,      1CCC,          4401,      211                          Grade School, Texas (etc.),  1 PM
        1,C1,     4C7,                                             1,2,06,
    4C6,4C8,5C6,5C7,5C8,607
.5, C26,         112,      1C00,          4401,      211                          Grade School, Rockies, 10 AM
        1,C1,     3C5,                                             1,2,12,
    1C3,1C4,105,2C3,2C4,205,3C3,3C4,403,4C4,405,505
.5, C26,         116,      1CCC,          4401,      211                          Grade School, Rockies,  2 PM
        1,C1,     3C5,                                             1,2,12,
    1C3,1C4,105,2C3,2C4,2C5,3C3,3C4,403,4C4,4C5,505
.5, C27,         113,      1C00,          4401,      211                          Grade School, Northwest, 10 AM
        1,C1,     1C1,                                             1,2,03,
    102,2C1,202
.5, C27,         117,      1CCC,          44C1,      211                          Grade School, Northwest,  2 PM
        1,C1,     1C1,                                             1,2,05,
    1C2,2C1,202,941,961
.5, C28,         114,      1CCC,          4401,      211                          Grade School, California, 11 AM
        1,C1,     301,                                             1,2,02,
    302,4C2
.5, C28,         116,      1C00,          44C1,      211                          Grade School, California,  1 PM
        1,C1,     4C2,                                             1,2,03,
    301,3C2,721
.5, C28,         117,      1C00,          4401,      211                          Grade School, California,  2 PM
        1,C1,     4C2,                                             1,2,03,
    301,3C2,721
C
      ACULT
C
.5, C31,         119,      1C00,          44C1,      411                          Adult, Urban Areas,  6 PM Central
        1,C1,     312,                                             2,2,19,
    102,1C3,104,1C5,1C6,114,2C1,2C2,203,2C4,205,206,302,303,312,
    5C5,721,941,961,
.5, C31,         122,      1C00,          4401,      411                          Adult, All Areas,  9 PM Central
        1,C1,     402,                                             2,2,04,
    1C9,114,402,721
.5, C31,         124,      1CCC,          44C1,      411                          Adult, Urban Areas, 11 PM Central
        1,C1,     3C1,                                             2,2,14,
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      106,107,114,207,301,307,310,311,406,408,411,505,607,851
C
    AILING AT HOME
C
 .5, 041,      111,      1000,           4401,     311                        Ailing at Home, CONUS, 10 AM CST
       1,01,     313,                                      2,2,05,
     313,721,851,941,961
 .5, 041,      121,      1000,           4401,     311                        Ailing at Home, All Areas,  7 PM MST
       1,01,     301,                                      2,2,01,
     301
C
C
        IGH SCHOOL
 .5, 051,      110,      1000,           4401,     211                        High School, Northeast, 10 AM
       1,01,     313,                                      1,2,07,
     114,211,212,213,214,311,312
 .5, 051,      111,      1000,           4401,     211                        High School, Northeast, 11 AM
       1,01,     211,                                      1,2,07,
     114,212,213,214,311,312,313
 .5, 051,      113,      1000,           4401,     211                        High School, Northeast,  1 PM
       1,01,     214,                                      1,2,07,
     114,211,212,213,311,312,313
 .5, 052,      110,      1000,           4401,     211                        High School, Southeast, 10 AM
       1,01,     410,                                      1,2,08,
     409,411,412,509,510,511,611,851
 .5, 052,      111,      1000,           4401,     211                        High School, Southeast, 11 AM
       1,01,     410,                                      1,2,07,
     409,411,412,509,510,511,611
 .5, 052,      114,      1000,           4401,     211                        High School, Southeast,  2 PM
       1,01,     611,                                      1,2,07,
     409,410,411,412,509,510,511
 .5, 053,      110,      1000,           4401,     211                        High School, Midwest,  9 AM
       1,01,     210,                                      1,2,13,
     106,107,108,109,206,207,208,209,306,307,308,309,310
 .5, 053,      112,      1000,           4401,     211                        High School, Midwest, 11 AM
       1,01,     210,                                      1,2,13,
     106,107,108,109,206,207,208,209,306,307,308,309,310
 .5, 053,      115,      1000,           4401,     211                        High School, Midwest,  2 PM
       1,01,     208,                                      1,2,13,
     106,107,108,109,206,207,209,210,306,307,308,309,310
 .5, 054,      112,      1000,           4401,     211                        High School, Texas (etc.), 11 AM
       1,01,     508,                                      1,2,06,
     406,407,408,506,507,607
 .5, 054,      114,      1000,           4401,     211                        High School, Texas (etc.),  1 PM
       1,01,     507,                                      1,2,06,
     406,407,408,506,508,607
 .5, 054,      115,      1000,           4401,     211                        High School, Texas (etc.),  2 PM
       1,01,     407,                                      1,2,06,
     406,408,506,507,508,607
 .5, 055,      112,      1000,           4401,     211                        High School, Rockies, 10 AM
       1,01,     305,                                      1,2,12,
     103,104,105,203,204,205,303,304,403,404,405,505
 .5, 055,      113,      1000,           4401,     211                        High School, Rockies, 11 AM
       1,01,     305,                                      1,2,12,
     103,104,105,203,204,205,303,304,403,404,405,505
 .5, 055,      116,      1000,           4401,     211                        High School, Rockies,  2 PM
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      1,01,      305,                                        1,2,12,
    103,104,105,203,204,205,303,304,403,404,405,505
.5, 056,      113,      1000,       4401,      211                        High School, West, 10 AM
      1,01,      101,                                        1,2,06,
    102,201,202,301,302,402
.5, 056,      116,      1000,       4401,      211                        High School, West,  1 PM
      1,01,      301,                                       *1,2,09,
    101,102,201,202,302,402,721,941,961
.5, 056,      117,      1000,       4401,      211                        High School, West,  2 PM
      1,01,      402,                                        1,2,09
    101,102,201,202,301,302,721,941,961
C
       CRIMINAL REHAB
C
.5, 061,      122,      1000,       4401,      411                        Criminal Rehabilitation,
      1,01,      312,                                        2,2,17,         Selected Areas, 10 PM EST
    103,104,105,106,107,114,203,204,205,206,207,303,312,505,851,
    941,961
C
   RURAL
C
.5, 071,      121,      1000,       4401,      411                        Rural, Most Areas,  8 PM CST
      1,01,      308,                                        2,2,05,
    201,210,308,721,851
.5, 071,      122,      1000,       4401,      411                        Rural, Most Areas,  9 PM CST
      1,01,      308,                                        2,2,05,
    201,210,309,721,851
.5, 072,      106,      1000,       4401,      211                        Rural, Eastern U.S.,  6 AM EST
      1,01,      312,                                        1,2,11,
    114,211,212,213,214,311,313,411,412,511,611
.5, 073,      107,      1000,       4401,      211                        Rural, Central U.S.,  6 AM CST
      1,01,      308,                                        1,2,21,
    107,108,109,207,208,209,210,307,309,310,406,407,408,409,410,
    506,507,508,509,510,607
.5, 074,      108,      1000,       4401,      211                        Rural, Rockies (etc.),  6 AM MST
      1,01,      305,                                        1,2,15,
    103,104,105,106,203,204,205,206,303,304,306,403,404,405,505
.5, 075,      109,      1000,       4401,      211                        Rural, Western U.S.,  6 AM PST
      1,01,      301,                                        1,2,08,
    101,102,201,202,302,402,403,941
C
       MEDICAL SCHOOLS
C
.5, 081,      109,      1000,       4401,      211                        Medical Schools, Eastern U.S.,  9 AM
      1,01,      313,                                        1,2,12,
    211,212,213,214,311,312,410,411,412,511,611,851
.5, 081,      111,      1000,       4401,      211                        Medical Schools, Eastern U.S., 11 AM
      1,01,      313,                                        1,2,12
    211,212,213,214,311,312,410,411,412,511,611,851
.5, 083,      112,      1000,       4401,      211                        Medical Schools, Western U.S.,  9 AM
      1,01,      301,                                        1,2,06,
    101,304,305,402,404,405
.5, 083,      117,      1000,       4401,      211                        Medical Schools, Western U.S.,  2 PM
      1,01,      301,                                        1,2,06,
    101,304,305,402,404,405
.5, 083,      118,      1000,       4401,      211                        Medical Schools, Western U.S.,  3 PM
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        1,01,     402,                                         1,2,06,
     101,301,304,305,404,405
 .5, 083,      123,      1000,          4401,     211                         Medical Schools, Western U.S.,  8 PM
        1,01,     402,                                         1,2,07,
     101,301,304,305,404,405,721
 .5, 083,      124,      1000,          4401,     211                         Medical Schools, Western U.S.,  9 PM
        1,01,     402,                                         1,2,07,
     101,301,304,305,404,405,721
C
         MEDICAL PROFESSIONALS
C
 .5, 091,      119,      1000,          4401,     311                         Medical Professionals, All Areas,  6 PM CST
        1,01,     312,                                         2,2,01,
     312
 .5, 091,      123,      1000,          4401,     311                         Medical Professionals, All Areas, 10 PM CST
        1,01,     312,                                         2,2,01,
     312
 .5, 092,      107,      1000,          4401,     211                         Medical Professionals, East,  7 AM
        1,01,     214,                                         1,2,12,
     114,211,212,213,311,312,313,411,412,511,611,851
 .5, 093,      108,      1000,          4401,     211                         Medical Professionals, Middle U.S.,  7 AM
        1,01,     210,                                         1,2,21,
     107,108,109,207,208,209,307,308,309,310,406,407,408,409,410,
     506,507,508,509,510,607,
 .5, 094,      109,      1000,          4401,     211                         Medical Professionals, Rockies,  7 AM
        1,01,     305,                                         1,2,14,
     103,104,105,106,203,204,205,206,303,304,306,403,405,505
 .5, 095,      110,      1000,          4401,     211                         Medical Professionals, West,  7 AM
        1,01,     301,                                         1,2,10,
     101,102,201,202,302,402,403,721,941,961
 .5, 096,      120,      1000,          4401,     211                         Medical Professionals, Eastern U.S.,  8 PM
        1,01,     210,                                         1,2,34,
     107,108,109,114,207,208,209,211,212,213,214,307,308,309,310,
     311,312,313,406,407,408,409,410,411,412,506,507,508,509,510,
     511,607,611,851
 .5, 097,      122,      1000,          4401,     211                         Medical Professionals, Western U.S.,  7 PM
        1,01,     402,                                         1,2,25,
     101,102,103,104,105,106,201,202,203,204,205,206,301,302,303,
     304,305,306,403,404,405,505,721,941,961
C
         MEDICAL FOR THE LAYMEN
C
 .5, 101,      120,      1000,          4401,     311                         Medical for Laymen, All Areas,  7 PM CST
        1,01,     312,                                         2,2,01,
     312
 .5, 101,      123,      1000,          4401,     311                         Medical for Laymen, All Areas, 10 PM CST
        1,01,     312,                                         2,2,01,
     312
C
C
              POLITICS                                                                   POLITICS
C
         LEGISLATIVE MEETINGS
C
 .5, 211,      602,      1000,          1322,     432                         U.S. Legislative Teleconference
        4,08,                                                  1,2,08,           Regional Centers, Morning
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      101,209,214,305,312,402,410,507
 .5, 211,     603,     1000,        2322,     432                     U.S. Legislative Teleconferencing,
         4,08,                                        1,2,08,            Regional Centers, Afternoon
      101,209,214,305,312,402,410,507
 .5, 211,     604,     1000,        1322,     432                     U.S. Legislative Teleconferencing,
         4,08,                                        1,2,08,            Regional Centers, Evening
      101,209,214,305,312,402,410,507
 .5, 212,     603,     1000,        2322,     432                     U.S. Legislative Teleconferencing Second Channel,
         4,08,                                        1,2,08,            Regional Centers, Afternoon
      101,209,214,305,312,402,410,507
C
        POLITICAL MEETINGS
C
 .5, 221,     602,     1000,        1322,     332                     Political Teleconferencing, Selected Areas,
         4,39,                                        2,2,22,            Morning
      102,104,105,107,109,114,201,202,204,206,207,212,303,304,306,
      404,406,505,506,508,511,607
 .5, 221,     603,     1000,        1322,     332                     Political Teleconferencing, Selected Areas,
         4,39,                                        2,2,22,            Afternoon
      102,104,105,107,109,114,201,202,204,206,207,212,303,304,306,
      404,406,505,506,508,511,607
 .5, 221,     604,     1000,        2322,     332                     Political Teleconferencing, Selected Areas,
         4,39,                                        2,2,22,            Evening
      102,104,105,107,109,114,201,202,204,206,207,212,303,304,306,
      404,406,505,506,508,511,607
C
C
            CIVIL DEFENSE                                                          CIVIL DEFENSE
C
        CIVIL DEFENSE COMMUNICATIONS NET. 1
C
 .5, 311,     601,     1000,        1334,     356                     CD Net 1, Video, National
         4,61,                                        2,2,00
 .5, 311,     602,     1000,        1334,     356                     CD Net 1, Video, National
         4,61,                                        2,2,00
 .5, 311,     603,     1000,        1334,     356                     CD Net 1, Video, National
         4,61,                                        2,2,00
 .5, 311,     604,     1000,        1334,     356                     CD Net 1, Video, National
         4,61,                                        2,2,00
 .5, 312,     601,     1000,        1334,     256                     CD Net, Northeast, Video
         4,07,                                        1,4,07,
      114,212,213,214,312,313,412
 .5, 312,     602,     1000,        1334,     256                     CD Net, Northeast, Video
         4,07,                                        1,4,07,
      114,212,213,214,312,313,412
 .5, 312,     603,     1000,        1334,     256                     CD Net, Northeast, Video
         4,07,                                        1,4,07,
      114,212,213,214,312,313,412
 .5, 312,     604,     1000,        1334,     256                     CD Net, Northeast, Video
         4,07,                                        1,4,07,
      114,212,213,214,312,313,412
 .5, 313,     601,     1000,        1334,     256                     CD Net, Southeast, Video
         4,08,                                        1,4,08,
      411,412,508,509,510,511,611,851
 .5, 313,     602,     1000,        1334,     256                     CD Net, Southeast, Video
         4,08,                                        1,4,08,
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      411,412,508,509,510,511,611,851
.5, 313,      603,       1000,          1334,      256                        CD Net, Southeast, Video
         4,08,                                                 1,4,08,
      411,412,508,509,510,511,611,851
.5, 313,      604,       1000,          1334,      256                        CD Net, Southeast, Video
         4,08,                                                 1,4,08,
      411,412,508,509,510,511,611,851
.5, 314,      601,       1000,          1334,      256                        CD Net, Midwest, Video
         4,13,                                                 1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
.5, 314,      602,       1000,          1334,      256                        CD Net, Midwest, Video
         4,13,                                                 1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
.5, 314,      603,       1000,          1334,      256                        CD Net, Midwest, Video
         4,13,                                                 1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
.5, 314,      604,       1000,          1334,      256                        CD Net, Midwest, Video
         4,13,                                                 1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
.5, 315,      601,       1000,          1334,      256                        CD Net, Rockies, Video
         4,14,                                                 1,4,14
      103,104,105,106,107,204,205,206,207,304,305,306,307,404
.5, 315,      602,       1000,          1334,      256                        CD Net, Rockies, Video
         4,14,                                                 1,4,14
      103,104,105,106,107,204,205,206,207,304,305,306,307,404
.5, 315,      603,       1000,          1334,      256                        CD Net, Rockies, Video
         4,14,                                                 1,4,14
      103,104,105,106,107,204,205,206,207,304,305,306,307,404
.5, 315,      604,       1000,          1334,      256                        CD Net, Rockies, Video
         4,14,                                                 1,4,14
      103,104,105,106,107,204,205,206,207,304,305,306,307,404
.5, 316,      601,       1000,          1334,      256                        CD Net, Texas (etc.), Video
         4,09,                                                 1,4,09
      405,406,407,408,505,506,507,508,607
.5, 316,      602,       1000,          1334,      256                        CD Net, Texas (etc.), Video
         4,09,                                                 1,4,09
      405,406,407,408,505,506,507,508,607
.5, 316,      603,       1000,          1334,      256                        CD Net, Texas (etc.), Video
         4,09,                                                 1,4,09
      405,406,407,408,505,506,507,508,607
.5, 316,      604,       1000,          1334,      256                        CD Net, Texas (etc.), Video
         4,09,                                                 1,4,09
      405,406,407,408,505,506,507,508,607
.5, 317,      601,       1000,          1334,      256                        CD Net, Northwest & Alaska
         4,08                                                  1,4,08
      101,102,103,201,202,203,941,961
.5, 317,      602,       1000,          1334,      256                        CD Net, Northwest & Alaska
         4,08                                                  1,4,08
      101,102,103,201,202,203,941,961
.5, 317,      603,       1000,          1334,      256                        CD Net, Northwest & Alaska
         4,08                                                  1,4,08
      101,102,103,201,202,203,941,961
.5, 317,      604,       1000,          1334,      256                        CD Net, Northwest & Alaska
         4,08                                                  1,4,08
      101,102,103,201,202,203,941,961
.5, 318,      601,       1000,          1334,      256                        CD Net, Calif. & Hawaii, Video
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          4,07,                                                   1,4,07
      201,301,302,303,402,403,721
 .5, 318,       602,        1000,           1334,      256                 CD Net, Calif. & Hawaii, Video
          4,07,                                                   1,4,07
      201,301,302,303,402,403,721
 .5, 318,       603,        1000,           1334,      256                 CD Net, Calif. & Hawaii, Video
          4,07,                                                   1,4,07
      201,301,302,303,402,403,721
 .5, 318,       604,        1000,           1334,      256                 CD Net, Calif. & Hawaii, Video
          4,07,                                                   1,4,07
      201,301,302,303,402,403,721
C
        CIVIL DEFENSE COMMUNICATIONS NET. 2
C                                                                          Civil Defense Net 2
 .5, 321,       601,        3000,           1334,      356                 (similar to Net 1, etc. above,
          4,61,                                                   2,2,00   except low rate data instead
 .5, 321,       602,        3000,           1334,      356                 of video)
          4,61,                                                   2,2,00
 .5, 321,       603,        3000,           1334,      356
          4,61,                                                   2,2,00
 .5, 321,       604,        3000,           1334,      356
          4,61,                                                   2,2,00
 .5, 322,       601,        3000,           1334,      256
          4,07,                                                   1,4,07,
      114,212,213,214,312,313,412
 .5, 322,       602,        3000,           1334,      256
          4,07,                                                   1,4,07,
      114,212,213,214,312,313,412
 .5, 322,       603,        3000,           1334,      256
          4,07,                                                   1,4,07,
      114,212,213,214,312,313,412
 .5, 322,       604,        3000,           1334,      256
          4,07,                                                   1,4,07,
      114,212,213,214,312,313,412
 .5, 323,       601,        3000,           1334,      256
          4,08,                                                   1,4,08,
      411,412,508,509,510,511,611,851
 .5, 323,       602,        3000,           1334,      256
          4,08,                                                   1,4,08,
      411,412,508,509,510,511,611,851
 .5, 323,       603,        3000,           1334,      256
          4,08,                                                   1,4,08,
      411,412,508,509,510,511,611,851
 .5, 323,       604,        3000,           1334,      256
          4,08,                                                   1,4,08,
      411,412,508,509,510,511,611,851
 .5, 324,       601,        3000,           1334,      256
          4,13,                                                   1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
 .5, 324,       602,        3000,           1334,      256
          4,13,                                                   1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
 .5, 324,       603,        3000,           1334,      256
          4,13,                                                   1,4,13
      108,109,208,209,210,211,308,309,310,311,408,409,410
 .5, 324,       604,        3000,           1334,      256
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            4,13,                                                          1,4,13
          108,109,208,209,210,211,308,309,310,311,408,409,410
 .5, 325,       601,        3000,           1334,      256
            4,14,                                                          1,4,14
          103,104,105,106,107,204,205,206,207,304,305,306,307,404
 .5, 325,       602,        3000,           1334,      256
            4,14,                                                          1,4,14
          103,104,105,106,107,204,205,206,207,304,305,306,307,404
 .5, 325,       603,        3000,           1334,      256
            4,14,                                                          1,4,14
          103,104,105,106,107,204,205,206,207,304,305,306,307,404
 .5, 325,       604,        3000,           1334,      256
            4,14,                                                          1,4,14
          103,104,105,106,107,204,205,206,207,304,305,306,307,404
 .5, 326,       601,        3000,           1334,      256
            4,09,                                                          1,4,09
          405,406,407,408,505,506,507,508,607
 .5, 326,       602,        3000,           1334,      256
            4,09,                                                          1,4,09
          405,406,407,408,505,506,507,508,607
 .5, 326,       603,        3000,           1334,      256
            4,09,                                                          1,4,09
          405,406,407,408,505,506,507,508,607
 .5, 326,       604,        3000,           1334,      256
            4,09,                                                          1,4,09
          405,406,407,408,505,506,507,508,607
 .5, 327,       601,        3000,           1334,      256
            4,08                                                           1,4,08
          101,102,103,201,202,203,941,961
 .5, 327,       602,        3000,           1334,      256
            4,08                                                           1,4,08
          101,102,103,201,202,203,941,961
 .5, 327,       603,        3000,           1334,      256
            4,08                                                           1,4,08
          101,102,103,201,202,203,941,961
 .5, 327,       604,        3000,           1334,      256
            4,08                                                           1,4,08
          101,102,103,201,202,203,941,961
 .5, 328,       601,        3000,           1334,      256
            4,07,                                                          1,4,07
          201,301,302,303,402,403,721
 .5, 328,       602,        3000,           1334,      256
            4,07,                                                          1,4,07
          201,301,302,303,402,403,721
 .5, 328,       603,        3000,           1334,      256
            4,07,                                                          1,4,07
          201,301,302,303,402,403,721
 .5, 328,       604,        3000,           1334,      256
            4,07,                                                          1,4,07
          201,301,302,303,402,403,721
C
               CIVIL DEFENSE WARNING NET. 1
 .5, 341,       601,        3000,           1204,      316
            4,04,       301,305,312,611,                                   2,2,00,
 .5, 341,       602,        3000,           1204,      316
            4,04,       301,305,312,611,                                   2,2,00,
```

Civil Defense Net 2
(similar to Net 1, etc. ablve, except low rate data instead of video)

(Continued)

CD Warning, National, Night

CD Warning, National, Morning

A-17

```
.5, 341,        6C3,       3CCC,            12C4,      316
          4,C4,       3C1,3C5,312,611,                          2,2,CC,
.5, 341,        6C4,       3CCC,            12C4,      316
          4,C4,       3C1,3C5,312,611,                          2,2,00,
```

CD Warning, National, Evening

CD Warning, National, Afternoon

```
C
C
            CATA COLLECTION
C
          EARTH RESCURCES SAT 1
C
.5, 411,        6C1,       4CCC,            3303,      445
          3,C2,       312,3C5,                                  1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 411,        602,       4CCC,            3303,      445
          3,C2,       312,3C5,                                  1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 411,        6C3,       4CCC,            3303,      445
          3,C2,       312,3C5,                                  1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 411,        6C4,       4CCC,            3303,      445
          3,C2,       312,3C5,                                  1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
```

DATA COLLECTION

Earth Resources Satellite, Data, Selected Areas

```
C
          EARTH RESCURCES SAT 2
C
.5, 421,        6C1,       1CCC,            44C3,      445
          3,C3,       3C1,3C5,312                               1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 421,        6C2,       1CCC,            44C3,      445
          3,C3,       3C1,3C5,312                               1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 421,        6C3,       1CCC,            44C3,      445
          3,C3,       3C1,3C5,312                               1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
.5, 421,        6C4,       1CCC,            44C3,      445
          3,C3,       3C1,3C5,312                               1,2,09,
      1C1,21C,214,3C1,3C5,312,313,5C9,611
```

Earth Resources Satellite, Video, Selected Areas

```
C
          WEATHER SAT CATA 1
C
.5, 451,        6C1,       1CCC,            4402,      341
          3,C3,       3C1,3C5,312,                              2,2,01,
      114
.5, 451,        6C2,       1CCC,            4402,      341
          3,C3,       3C1,3C5,312,                              2,2,01,
      114
.5, 451,        6C3,       1CCC,            4402,      341
          3,C3,       3C1,3C5,312,                              2,2,01,
      114
.5, 451,        6C4,       1CCC,            4402,      341
          3,C3,       3C1,3C5,312,                              2,2,01,
      114
```

Weather Satellite, Video, Most Areas

```
C
          WEATHER SAT CATA 2
C
.5, 461,        6C1,       5CCC,            4402,      441
```

Weather Satellite, Data, Selected Areas

```
        3,02,      305,312,                                     1,2,16,
      101,206,210,214,301,305,312,313,402,410,507,509,611,721,851,
      941,
.5, 461,      602,       5000,           4402,      441
        3,02,      305,312,                                     1,2,16,
      101,206,210,214,301,305,312,313,402,410,507,509,611,721,851,
      941,
.5, 461,      603,       5000,           4402,      441
        3,02,      305,312,                                     1,2,16,
      101,206,210,214,301,305,312,313,402,410,507,509,611,721,851,
      941,
.5, 461,      604,       5000,           4402,      441
        3,02,      305,312,                                     1,2,16,
      101,206,210,214,301,305,312,313,402,410,507,509,611,721,851,
      941,
```

Weather Satellite, Data, Selected Areas (Continued)

```
C
       REGIONAL WEATHER SERVICE STATIONS
C
.5, 551,      601,      4000,           4421,      235
        4,16,                                                   1,2,16,
      405,406,407,408,409,410,505,506,507,508,509,510,511,607,611,
      851,
.5, 551,      602,      4000,           4421,      235
        4,16,                                                   1,2,16,
      405,406,407,408,409,410,505,506,507,508,509,510,511,607,611,
      851,
.5, 551,      603,      4000,           4421,      235
        4,16,                                                   1,2,16,
      405,406,407,408,409,410,505,506,507,508,509,510,511,607,611,
      851,
.5, 551,      604,      4000,           4421,      235
        4,16,                                                   1,2,16,
      405,406,407,408,409,410,505,506,507,508,509,510,511,607,611,
      851,
```

Regional Weather, Southeast, Data

```
.5, 552,      601,      4000,           4421,      235
        4,17,                                                   1,2,17
      101,102,103,104,105,201,202,203,301,302,303,304,402,403,404
      941,961
.5, 552,      602,      4000,           4421,      235
        4,17,                                                   1,2,17
      101,102,103,104,105,201,202,203,301,302,303,304,402,403,404
      941,961
.5, 552,      603,      4000,           4421,      235
        4,17,                                                   1,2,17
      101,102,103,104,105,201,202,203,301,302,303,304,402,403,404
      941,961
.5, 552,      604,      4000,           4421,      235
        4,17,                                                   1,2,17
      101,102,103,104,105,201,202,203,301,302,303,304,402,403,404
      941,961
```

Regional Weather, Western U.S., Data

```
.5, 553,      601,      4000,           4421,      235
        4,17,                                                   1,2,17,
      106,107,108,109,204,205,206,207,208,209,210,305,306,307,308
      309,310
.5, 553,      602,      4000,           4421,      235
        4,17,                                                   1,2,17,
```

Regional Weather, Midwest, Data

```
      1C6,1C7,108,1C9,204,2C5,2C6,2C7,208,2C9,210,305,306,307,308
      3C9,31C
 .5, 553,     6C3,     4CCC,          4421,    235
          4,17,                                           1,2,17,
      1C6,1C7,1C8,1C9,2C4,2C5,2C6,2C7,208,2C9,210,305,306,307,308
      3C9,31C
 .5, 553,     6C4,     4CCC,          4421,    235
          4,17,                                           1,2,17,
      1C6,1C7,108,1C9,2C4,2C5,2C6,2C7,2C8,2C9,210,305,306,307,3C8
      3C9,31C
```

Regional,Weather, Midwest, Data
(Continued)

```
 .5, 554,     6C1,     4CCC,          4421,    235
          4,11,                                           1,2,11
      114,211,212,213,214,31C,311,312,313,411,412
 .5, 554,     6C2,     4CCC,          4421,    235
          4,11,                                           1,2,11
      114,211,212,213,214,31C,311,312,313,411,412
 .5, 554,     6C3,     4CCC,          4421,    235
          4,11,                                           1,2,11
      114,211,212,213,214,31C,311,312,313,411,412
 .5, 554,     6C4,     4CCC,          4421,    235
          4,11,                                           1,2,11
      114,211,212,213,214,31C,311,312,313,411,412
```

Regional Weather, Northeast, Data

```
C
        MANNED CRBIT SUPPORT 1
C
 .5, 611,     6C1,     1CCC,          3322,    242
          4,10,    101,214,3C1,312,4C2,412,508,611,721,851, 1,2,C5,
      312,313,402,5C8,611
 .5, 611,     6C2,     1CCC,          3322,    242
          4,1C,    101,214,3C1,312,4C2,412,508,611,721,851, 1,2,C5,
      312,313,402,5C8,611
 .5, 611,     6C3,     1CCC,          3322,    242
          4,1C,    1C1,214,3C1,312,4C2,412,5C8,611,721,851, 1,2,05,
      312,313,402,5C8,611
 .5, 611,     6C4,     1CCC,          3322,    242
          4,1C,    101,214,3C1,312,4C2,412,5C8,611,721,851, 1,2,C5,
      312,313,402,5C8,611
```

Manned Orbit Support, Video,
Selected Areas

```
C
        MANNED CRBIT SUPPORT 2
C
 .5, 631,     6C1,     5CCC,          2202,    122
          4,C6,    312,402,412,5C8,611,721,               1,2,C3,
      312,5C8,611
 .5, 631,     6C2,     5CCC,          2202,    122
          4,C6,    312,4C2,412,5C8,611,721,               1,2,03,
      312,5C8,611
 .5, 631,     6C3,     5CCC,          2202,    122
          4,C6,    312,4C2,412,5C8,611,721,               1,2,03,
      312,5C8,611
 .5, 631,     6C4,     5CCC,          2202,    122
          4,C6,    312,402,412,5C8,611,721,               1,2,03,
      312,5C8,611
```

Manned Orbit Support, High Rate Data,
Selected Areas

```
C
        ASTRCNOMY CATA RELAY 1
C
 .5, 641,     6C1,     1CCC,          4403,    146
```

Astronomy, Video, Major Observatories

```
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 641,      602,      1000,          4403,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 641,      603,      1000,          4403,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 641,      604,      1000,          4403,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
```

Astronomy, Video, Major Observatories (Continued)

```
C
         ASTRONOMY DATA RELAY 2
C
 .5, 651,      601,      3000,          3303,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 651,      602,      3000,          3303,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 651,      603,      3000,          3303,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
 .5, 651,      604,      3000,          3303,      146
         4,26,                                                    1,2,26
      208,209,211,212,213,214,301,305,309,310,311,312,313,402,404,
      405,409,411,506,509,519,607,611,721,851,961
```

Astronomy, Data, Major Observatories

```
C
         SATELLITE CONTROL DATA
C
 .5, 661,      601,      5000,          4402,      152
         4,05,     301,312,402,412,721                            1,2,07,
      301,312,402,412,508,611,721
 .5, 661,      602,      5000,          4402,      152
         4,05,     301,312,402,412,721                            1,2,07,
      301,312,402,412,508,611,721
 .5, 661,      603,      5000,          4402,      152
         4,05,     301,312,402,412,721                            1,2,07,
      301,312,402,412,508,611,721
 .5, 661,      604,      5000,          4402,      152
         4,05,     301,312,402,412,721                            1,2,07,
      301,312,402,412,508,611,721
```

Satellite Control Data, High Rate Data, Selected Areas

```
C
         DEEP SPACE DATA NET. 1
C
 .5, 671,      601,      1000,          2303,      156
         4,06,     214,312,402,412,721,851,                       1,2,05,
      301,312,402,412,721
 .5, 671,      602,      1000,          2303,      156
```

Deep Space, Video, Selected Areas

```
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
.5, 671,       603,       1000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
.5, 671,       604,       1000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
```

Deep Space, Video, Selected Areas (Continued)

```
C
       DEEP SPACE DATA NET. 2
C
.5, 681,       601,       3000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
.5, 681,       602,       3000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
.5, 681,       603,       3000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
.5, 681,       604,       3000,           2303,      156
      4,06,      214,312,402,412,721,851,                   1,2,05,
   301,312,402,412,721
C
C
```

Deep Space, Data, Selected Areas

```
           AIRCRAFT TRAFFIC CONTROL
```

AIR TRAFFIC CONTROL

```
C
       AIR TRAFFIC CONTROL NET.
C
.5, 711,       601,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   313
.5, 711,       602,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   313
.5, 711,       603,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   313
.5, 711,       604,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   313
```

ATC, Boston - New York

```
.5, 712,       601,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   211
.5, 712,       602,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   211
.5, 712,       603,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   211
.5, 712,       604,       3000,           4411,      121
      1,01,      214,                                       1,1,01,
   211
```

ATC, Boston - Cleveland

```
.5, 713,       601,       3000,           4411,      121
      1,01,      313,                                       1,1,01,
   312
```

ATC, New York - Washington

ATC, Seattle - Utah
(Continued)

```
        1,C1,     1C1,                                      1,1,01,
     3C4
 .5, 75C,     6C4,     3CCC,        4411,     121
        1,C1,     1C1,                                      1,1,01,
     3C4
 .5, 751,     6C1,     3CCC,        4411,     121
        1,C1,     1C1,                                      1,1,01,
     941
```

ATC, Seattle - Alaska

```
 .5, 751,     6C2,     3CCC,        4411,     121
        1,C1,     101,                                      1,1,01,
     941
 .5, 751,     6C3,     3CCC,        4411,     121
        1,C1,     1C1,                                      1,1,01,
     941
 .5, 751,     6C4,     3C0C,        4411,     121
        1,C1,     1C1,                                      1,1,01,
     941
 .5, 752,     6C3,     300C,        4411,     121
        1,C1,     508,                                      1,1,01,
     507
```

ATC, Dallas - Houston

```
 .5, 752,     6C4,     3C00,        4411,     121
        1,C1,     5C8,                                      1,1,01,
     5C7
 .5, 752,     6C1,     3CC0,        4411,     121
        1,C1,     5C8,                                      1,1,01,
     507
 .5, 752,     6C2,     3CCC,        4411,     121
        1,C1,     5C8,                                      1,1,01,
     5C7
 .5, 753,     6C1,     3C0C,        4411,     121
        1,C1,     611,                                      1,1,01,
     851
```

ATC, Miami - Puerto Rico

```
 .5, 753,     6C2,     3CCC,        4411,     121
        1,C1,     611,                                      1,1,01,
     851
 .5, 753,     6C3,     3CCC,        4411,     121
        1,C1,     611,                                      1,1,01,
     851
 .5, 753,     6C4,     3CCC,        4411,     121
        1,C1,     611,                                      1,1,01,
     851
C
C
                MECICAL
C
```

BIOMEDICAL

Medical Diagnostic & Consultation,
Video, All Areas

```
          MECICAL CIAGNCSTIC 1
 .5, 821,     6C1,     1CCC,        1314,     126
        4,61,                                               2,3,00
 .5, 821,     6C2,     1CCC,        2314,     126
        4,61,                                               2,3,0C
 .5, 821,     6C3,     1CCC,        2314,     126
        4,61,                                               2,3,00
 .5, 821,     6C4,     1CCC,        2314,     126
        4,61,                                               2,3,00
C
          MECICAL CIAGNCSTIC 2
```

```
C
 .5, 831,      601,      3000,        1334,     125
          4,61,                                              2,3,00
 .5, 831,      602,      3000,        2334,     125
          4,61,                                              2,3,00
 .5, 831,      603,      3000,        2334,     125
          4,61,                                              2,3,00
 .5, 831,      604,      3000,        2334,     125
          4,61,                                              2,3,00
C
          MEDICAL DIAGNOSTIC 3
C
 .5, 841,      601,      2000,        3314,     126
          4,61,                                              2,3,00
 .5, 841,      602,      2000,        3314,     126
          4,61,                                              2,3,00
 .5, 841,      603,      2000,        3314,     126
          4,61,                                              2,3,00
 .5, 841,      604,      2000,        3314,     126
          4,61,                                              2,3,00
C
          TOXICOLOGY CONTROL NET. 1
C
 .5, 851,      601,      3000,        1334,     125
          4,61,                                              2,3,00
 .5, 851,      602,      3000,        2334,     125
          4,61,                                              2,3,00
 .5, 851,      603,      3000,        2334,     125
          4,61,                                              2,3,00
 .5, 851,      604,      3000,        2334,     125
          4,61,                                              2,3,00
C
          TOXICOLOGY CONTROL NET. 2
C
 .5, 861,      601,      2000,        2314,     126
          4,61,                                              2,3,00
 .5, 861,      602,      2000,        2314,     126
          4,61,                                              2,3,00
 .5, 861,      603,      2000,        2314,     126
          4,61,                                              2,3,00
 .5, 861,      604,      2000,        2314,     126
          4,61,                                              2,3,00
C
          BLOOD, SERUM, AND ORGAN BANK DATA
C
 .5, 871,      601,      3000,        1314,     125
          4,61,                                              2,3,00
 .5, 871,      602,      3000,        1314,     125
          4,61,                                              2,3,00
 .5, 871,      603,      3000,        1314,     125
          4,61,                                              2,3,00
 .5, 871,      604,      3000,        1314,     125
          4,61,                                              2,3,00
C
          MEDICAL RECORDS DATA TRANSFER
C
```

Medical Diagnostic & Consulting, Data, All Areas

Medical Diagnostic & Consulting, Voice, All Areas

Toxicology and Epidemic Control, Data, All Areas

Toxicology and Epidemic Control, Voice, All Areas

Blood, Serum, Organ Banks, Data, All Areas

```
       881,      601,       4000,          3314,      126
          3,61,                                                 2,4,00
       881,      602,       4000,          2314,      126
          3,61,                                                 2,4,00
       881,      603,       4000,          2314,      126
          3,61,                                                 2,4,00
       881,      604,       4000,         32314,      126
          3,61,                                                 2,4,00
```

Medical Records Transfer, Data, All Areas

```
C
          REGIONAL MEDICAL LIBRARY DATA
C
  .5, 941,       601,       5000,          3312,      126
          4,05,                                                 1,3,05,
       207,310,312,507,510
  .5, 941,       602,       5000,          1312,      126
          4,05,                                                 1,3,05,
       207,310,312,507,510
  .5, 941,       603,       5000,          1312,      126
          4,05,                                                 1,3,05,
       207,310,312,507,510
  .5, 941,       604,       5000,          2312,      126
          4,05,                                                 1,3,05,
       207,310,312,507,510
```

Regional Medical Libraries, High Rate Data
Transfer, Selected Library Center Areas

```
C
C
              COMPUTER AND LIBRARY DATA
C
          COMPUTER DATA TRANSFER
  .5, 911,       601,       5000,          3312,      121
          1,02,      313,402,                                   1,1,02
       313,402
  .5, 911,       602,       5000,          1312,      121
          1,02,      313,402,                                   1,1,02
       313,402
  .5, 911,       603,       5000,          1312,      121
          1,02,      313,402,                                   1,1,02
       313,402
  .5, 911,       604,       5000,          2312,      121
          1,02,      313,402,                                   1,1,02
       313,402
```

COMPUTER AND LIBRARY

Computer Data, New York - Los Angeles,
High Rate Data

```
  .5, 912,       601,       5000,          3312,      123
          4,40,                                                 2,4,21
       103,104,105,106,107,109,114,202,203,205,302,303,306,307,403,
       404,505,506,510,607,961
  .5, 912,       602,       5000,          1312,      123
          4,40,                                                 2,4,21
       103,104,105,106,107,109,114,202,203,205,302,303,306,307,403,
       404,505,506,510,607,961
  .5, 912,       603,       5000,          1312,      123
          4,40,                                                 2,4,21
       103,104,105,106,107,109,114,202,203,205,302,303,306,307,403,
       404,505,506,510,607,961
  .5, 912,       604,       5000,          2312,      123
          4,40,                                                 2,4,21
       103,104,105,106,107,109,114,202,203,205,302,303,306,307,403,
       404,505,506,510,607,961
```

Computer Data, Metropolitan Areas, High Rate Data

```
C
        LIBRARY CATA TRANSFER
C
 .5, 922,      6C1,      5CCC,        3312,     123
          4,4C,                                        2,4,21
       1C3,1C4,1C5,1C6,1C7,1C9,114,2C2,203,2C5,302,303,306,307,4C3,
       404,5C5,5C6,51C,6C7,961
 .5, 922,      602,      5CCC,        1312,     123
          4,4C,                                        2,4,21
       1C3,1C4,105,1C6,1C7,109,114,2C2,203,2C5,302,303,3C6,307,4C3,
       404,5C5,506,51C,6C7,961
 .5, 922,      603,      5CCC,        1312,     123
          4,4C,                                        2,4,21
       1C3,1C4,105,1C6,1C7,109,114,2C2,203,2C5,302,303,306,307,403,
       404,5C5,506,51C,6C7,961
 .5, 922,      6C4,      5CCC,        2312,     123
          4,4C,                                        2,4,21
       1C3,1C4,105,1C6,1C7,109,114,2C2,203,2C5,302,303,306,307,403,
       4C4,5C5,5C6,51C,6C7,961
```

Library Data, Metropolitan Areas, High Rate Data

```
C
        WELFARE ANC EMPLCYMENT CATA
C
 .5, 811,      604,      4CCC,        3312,     123
          4,6C,     114,                               2,3,01
       114
```

Overnight Welfare and Employment Data Transfer, Most Areas

```
C
C
            LAW ENFCRCEMENT
C
        FBI CATA NETWCRK
C
 .5, 951,      6C1,      3CCO,        2234,     455
          4,32,                                        1,3,32
       101,2C7,208,2C9,210,211,212,213,214,3C1,304,305,308,309,310,
       311,312,313,4C2,4C3,4C4,4C7,4C8,409,410,411,507,508,509,51C,
       511,611
 .5, 951,      602,      3CCC,        3234,     455
          4,32,                                        1,3,32
       101,2C7,208,2C9,210,211,212,213,214,3C1,304,305,308,309,31C,
       311,312,313,4C2,4C3,404,4C7,408,409,410,411,507,508,509,51C,
       511,611
 .5, 951,      603,      3CCO,        3234,     455
          4,32,                                        1,3,32
       101,207,208,2C9,210,211,212,213,214,3C1,304,305,308,309,31C,
       311,312,313,4C2,4C3,404,4C7,4C8,409,410,411,507,508,509,51C,
       511,611
 .5, 951,      604,      3000,        2234,     455
          4,32,                                        1,3,32
       101,2C7,208,2C9,210,211,212,213,214,301,304,305,308,309,31C,
       311,312,313,402,403,404,407,408,409,410,411,507,508,509,51C,
       511,611
```

LAW ENFORCEMENT

FBI Net, Data, Selected Areas

```
C
        NCIC CATA NETWCRK
C
 .5, 961,      6C1,      3000,        2234,     455
          4,26,                                        1,3,26
```

NCIC Net, Data, Selected Areas

```
      101,103,202,205,207,208,209,210,213,214,302,308,309,310,311,
      312,313,405,410,412,507,509,510,511,721
.5, 961,      602,      3000,          2234,      455
         4,26,                                               1,3,26
      101,103,202,205,207,208,209,210,213,214,302,308,309,310,311,
      312,313,405,410,412,507,509,510,511,721
.5, 961,      603,      3000,          2234,      455
         4,26,                                               1,3,26
      101,103,202,205,207,208,209,210,213,214,302,308,309,310,311,
      312,313,405,410,412,507,509,510,511,721
.5, 961,      604,      3000,          2234,      455
         4,26,                                               1,3,26
      101,103,202,205,207,208,209,210,213,214,302,308,309,310,311,
      312,313,405,410,412,507,509,510,511,721
```

NCIC Net, Data, Selected Areas

(Continued)

APPENDIX B - DATA BASE PROCESSING PROGRAM

B.1 GENERAL

The uplink/downlink data for each demand in the MFR data base are structured in terms of an arbitrary cell grid superimposed over the continental U. S., Alaska, Hawaii, and Puerto Rico. To compile beam activity data for each beam configuration, it is necessary to restructure the uplink/downlink data in terms of the beam coverage for that configuration.

A computer program was written to accomplish this processing. This program operates on an IBM 1130 system and uses less than 16K of core; a minimum of two 2314 disk units is required to facilitate files handling.

B.2 PROCESSING

In general, the beam configuration for the satellite is input in terms of the grid cells covered by each beam. The program then accesses, in turn, the data file for each type of service and scans each demand/needline record therein. As each record is scanned, the uplink/downlink data, in terms of the active cells, are transformed into a record of the number of active uplinks/downlinks in each beam. The transformed data are then written into a new service file to be used by other processing programs. It is also necessary to perform some revisions on the source and sink data itself, for example, convert exclusive descriptions of sink locations into inclusive descriptions. The program listed here takes care of such conversions.

B.3 INPUTS, OUTPUTS, AND SUBROUTINES

B.3.1 Inputs

Inputs to the program are of two types: (1) card inputs describing the number of beams in a configuration and defining the coverage of each beam in terms of grid cells; (2) disk inputs - a file for each service type to be processed (a reorganized version of the data base).

B. 3. 2 Outputs

A new disk file for each service processed, containing the required beam activity data for each demand, in that service.

B. 3. 3 Subroutine

The program uses one subroutine, PATRN, which accepts the number of beams to be defined and reads the data cards defining each beam's pattern. This subroutine returns two arrays, one containing the beam pattern information and the other, the number of grids covered by each beam.

B. 4 KEY VARIABLES

The following list is not intended to be exhaustive, but covers all key variables encountered in the program.

CARD PRINT	IO unit numbers for card reader and printer.
FLIN FLOUT	Input and output file numbers.
BFIN	This array holds one complete input file record.
BFOUT	This array holds one complete output file record.
HEDR	This array holds a file record header.
ASRCE	This array holds the number of grid cells assigned to each uplink beam after processing.
ASINK	This array holds the number of grid cells assigned to each downlink beam after processing.
GRDCL	This array holds the 61 grid cell numbers.
ANTGR	This array holds the coverage pattern defined for each of up to 30 uplink/downlink beams.

C 4

AGRDN	This array holds the number of grid cells assigned to each beam by the coverage pattern definition.
NBEAM	Number of beams in configuration.
NSRSC	Number of source cells in a demand.
NSNKS	Number of sink cells in a demand.

The program listing follows.

```
// JOB     002F 0001 0007                    0001
// FOR
*ONE WORD INTEGERS
      SUBROUTINE PATRN(ANTGR,AGRDN,NBEAM)
C
C     THIS SUBROUTINE SETS UP ANTENNA COVERAGE IN TERMS OF GRID SQUARES.
C     EACH BEAM IS REPRESENTED BY A NUMBER BETWEEN 1-30 INCLUSIVE. THE
C     ROW OF ARRAY ANTGR (I,J) CORRESPONDING TO A BEAM NO. 'I' CONTAINS
C     THE GRID SQUARES COVERED BY THAT BEAM. THE NUMBER OF GRID SQUARES
C     COVERED BY A PARTICULAR ANTENNA 'I' IS STORED IN THE 'I'TH ELEMENT
C     OF ARRAY AGRDN (I). NBEAMS IS A REQUIRED INPUT, BEING EQUAL IN
C     VALUE TO THE NO. OF ANTENNAS TO BE DEFINED. VARIABLES 'ANTGR ' AND
C     'AGRDN ' MUST BE DECLARED 'INTEGER' BY THE CALLING PROGRAM.
C
      INTEGER ANTGR (30,1),AGRDN (1)
      IN=2
      DO 20 I=1,NBEAM
      READ(IN,5) INDEX,(ANTGR (INDEX,J),J=1,18)
    5 FORMAT(I2,1X,25I3)
      DO 10 J=1,18
      IF(ANTGR(INDEX,J)) 10,15,10
   10 CONTINUE
   15 AGRDN (INDEX)=J-1
   20 CONTINUE
      RETURN
      END
// DUP
*DELETE                PATRN
*STORE        WS   UA  PATRN                 1
// FOR
*ONE WORD INTEGERS
*IOCS(CARD,1403 PRINTER,DISK)
C
C     THIS PROGRAM READS THE ORDERED SERVICE FILES AND TRANSFORMS THE
C     SOURCE AND SINK CELL DATA INTO ANTENNA DATA WHICH IS THEN OUTPUT
C     TO NEW FILES
C
      INTEGER CARD,PRINT
      INTEGER FLIN,FLOUT
      INTEGER BFIN(59),BFOUT(70)
      INTEGER HEDR(8),ASRCE(30),SKDAT(2),ASINK(30)
      INTEGER ZERO(11)
      INTEGER GRDCL(61),TCELL(61)
      INTEGER ANTGR(30,18),AGRDN(30)
      INTEGER OUT1,OUT2,OUT3,OUT4,OUT5
C
C
      EQUIVALENCE (BFOUT(1),HEDR(1)),(BFOUT(9),ASRCE(1))
      EQUIVALENCE (BFOUT(39),SKDAT(1)),(BFOUT(41),ASINK(1))
C
C     DEFINE INPUT FILES
C
      DEFINE FILE 1(250,59,U,IN1),2(15,59,U,IN2),3(250,59,U,IN3)
      DEFINE FILE 4(40,59,U,IN4),5(40,59,U,IN5)
C
C     DEFINE WORKING STORAGE FILE
```

```
C
      DEFINE FILE 9(250,71,U,ITEMP)
C
C     DEFINE OUTPUT FILES
C
      DEFINE FILE 10(250,70,U,OUT1),20(15,70,U,OUT2),30(250,70,U,OUT3)
      DEFINE FILE 40(40,70,U,OUT4),50(40,70,U,OUT5)
C
C     INITIALIZATION
C
      DATA CARD,PRINT/2,5/
      DATA ZERO/11*0/
      DATA ASRCE,ASINK/30*0,30*0/
      DATA GRDCL/101,102,103,104,105,106,107,108,109,114,201,202,203,204
     *,205,206,207,208,209,210,211,212,213,214,301,302,303,304,305,306,
     *307,308,309,310,311,312,313,402,403,404,405,406,407,408,409,410,
     *411,412,505,506,507,508,509,510,511,607,611,721,851,941,961/
C
      IN1=1
      IN2=1
      IN3=1
      IN4=1
      IN5=1
      OUT1=1
      OUT2=1
      OUT3=1
      OUT4=1
      OUT5=1
C
      ITEMP=1
C
C     LOCATE FIRST RECORD OF WORK FILE. THEN READ FROM A CARD THE NUMBER
C     OF BEAMS TO BE USED, AND SET UP BEAM PATTERN DEFINITION ARRAY.
C
      FIND(9'ITEMP)
C
      READ(CARD,5) NBEAM
    5 FORMAT(I2)
      CALL PATRN(ANTGR,AGRDN,NBEAM)
C
C     THIS LOOP PROCESSES EACH INPUT FILE IN TURN.
C
      DO 1000 FLIN=1,5                                                  Z Z Z Z
C
C     READ FIRST RECORD OF INPUT FILE (FILE HEADER) AND WRITE TO WORK
C     FILE.
C
      IN=1
      FIND(FLIN'IN)
      ITEMP=1
      FLOUT=FLIN*10
      READ(FLIN'IN) BFIN
      IN=IN+1
      FIND(FLIN'IN)
      WRITE(9'ITEMP)BFIN,ZERO
      FIND(9'ITEMP)
```

```
C
C     NOW READ SECTION HEADER- WD 1.=SECTION ID, WD 2.=NO. RECS. IN THIS
C     SECTION, WD 3.=LOCATION OF NEXT SECTION HEADER. NOTE WD 1.=0=EOF.
C
   10 READ(FLIN'IN) BFIN
      IF(BFIN(1)) 9999,500,20
   20 IF(BFIN(2)) 9999,30,40
C
C     THIS SECTION CONTAINS NO RECORDS, WRITE THIS HEADER TO WORK FILE
C     AND LOCATE NEXT HEADER.
C
   30 IN=BFIN(3)
      FIND(FLIN'IN)
      WRITE(9'ITEMP) BFIN,ZERO
      FIND(9'IN)
      GO TO 10
C
C     WRITE HEADER TO WORK FILE, SET NO. OF DATA RECORDS IN SECTION, AND
C     PROCESS SECTION.
C
   40 WRITE(9'ITEMP) BFIN,ZERO
      FIND(9'ITEMP)
      NREC=BFIN(2)
C
      DO 41 I=1,30
      ASRCE(I)=0
   41 ASINK(I)=0
C
C     THIS LOOP READS AND PROCESSES DATA RECORDS IN A SECTION
C
      DO 250 IREC=1,NREC                                                 X X X X
C
C     INCREMENT RECORD POINTER, READ AND PROCESS.
C
      IN=IN+1
      READ(FLIN'IN) BFIN
C
C     SET UP FIRST 8 WORDS OF NEW RECORD.
C
      DO 45 I=1,5                                                        Λ Λ Λ Λ
   45 HEDR(I)=BFIN(I)                                                    Λ Λ Λ Λ
      ITOG=((BFIN(4)-(BFIN(4)/100)*100)/10)*100
      ICONS=BFIN(5)-(BFIN(5)/100)*100
      HEDR(6)=ITOG+ICONS
      HEDR(7)=BFIN(6)
      HEDR(8)=BFIN(7)
C
C     STORE SINK CODES
C
      SKDAT(1)=BFIN(18)
      SKDAT(2)=BFIN(19)
C
C**** PROCESS SOURCES
C
C     CASE 1. - NO. SOURCES IS .GT. 0 AND .LT. 61 AND SOURCES LISTED
C                 SEPARATELY.
```

```
C
      IF(BFIN(7)) 9999,150,50
   50 IF(BFIN(8)) 9999,70,55
C
   55 NSRSC=BFIN(7)
      DO 66 I=1,NSRSC                                               C C C C
      ICELL=BFIN(I+7)
      DO 65 J=1,NBEAM                                               B1 B1 B1
      IGRDL=AGRDN(J)
      DO 65 K=1,IGRDL                                               B2 B2 B2
      IF(ICELL-ANTGR(J,K)) 65,60,65
   60 ASRCE(J)=ASRCE(J)+1
      GO TO 66
   65 CONTINUE                                                      B12B12
   66 CONTINUE                                                      C C C C
      GO TO 150
C
C     CASE 2. NO. SOURCES=61
C
   70 IF(BFIN(7)-61) 90,75,9999
   75 DO 80 I=1,NBEAM                                               D D D D
      ASRCE(I)=AGRDN(I)
   80 CONTINUE                                                      D D D D
      GO TO 150
C
C     CASE 3. - NO. SOURCES .GT. 0 AND .LT. 61 AND SOURCE LIST IS
C                   CONTAINED IN SINK LIST.
C
   90 IF(BFIN(17)-1) 9999,95,110
C
C     CASE 3A. - SINK LIST IS INCLUSIVE.
C
   95 NSNKS=BFIN(19)
      DO 106 I=1,NSNKS                                              F F F F
      ICELL=BFIN(I+19)
      DO 105 J=1,NBEAM                                              E1 E1 E1
      IGRDL=AGRDN(J)
      DO 105 K=1,IGRDL                                              E2 E2 E2
      IF(ICELL-ANTGR(J,K)) 105,100,105
  100 ASRCE(J)=ASRCE(J)+1
      GO TO 106
  105 CONTINUE                                                      E12E12
  106 CONTINUE                                                      F F F F
      GO TO 150
C
C     CASE 3B. - SINK LIST IS EXCLUSIVE
C
  110 IF(BFIN(19)) 9999,150,120
C
C     IF NO. SINKS=61 THEN SOURCES HAVE BEEN PROCESSED IN CASE 2. ABOVE
C
C     OTHERWISE SINKS ARE LISTED EXCLUSIVELY
C
  120 IF(BFIN(20)) 9999,150,121
  121 DO 125 I=1,61                                                 G G G G
  125 TCELL(I)=GRDCL(I)                                             G G G G
```

```
      NSNKS=BFIN(19)
      DO 135 I=1,NSNKS                                          I I I I
      ICELL=BFIN(I+19)
      DO 130 J=1,61                                             H H H H
      IF(ICELL-TCELL(J)) 130,127,130
  127 TCELL(J)=0
      GO TO 135
  130 CONTINUE                                                  H H H H
  135 CONTINUE                                                  I I I I
C
      DO 146 I=1,61                                             K K K K
      DO 145 J=1,NBEAM                                          J1 J1 J1
      IGRDL=AGRDN(J)
      DO 145 K=1,IGRDL                                          J2 J2 J2
      IF(TCELL(I)-ANTGR(J,K)) 145,140,145
  140 ASRCE(J)=ASRCE(J)+1
      GO TO 146
  145 CONTINUE                                                  J12 J12
  146 CONTINUE                                                  K K K K
C
C**** END SOURCE PROCESSING.
C
C**** NOW PROCESS SINKS.
C
  150 IF(BFIN(17)-1) 9999,155,170
C
C     SINKS ARE LISTED INCLUSIVELY
C
  155 NSNKS=BFIN(19)
      DO 166 I=1,NSNKS                                          M M M M
      ICELL=BFIN(I+19)
      DO 165 J=1,NBEAM                                          L1 L1 L1
      IGRDL=AGRDN(J)
      DO 165 K=1,IGRDL                                          L2 L2 L2
      IF(ICELL-ANTGR(J,K)) 165,160,165
  160 ASINK(J)=ASINK(J)+1
      GO TO 166
  165 CONTINUE                                                  L12 L12
  166 CONTINUE                                                  M M M M
      GO TO 200
C
C     SINKS ARE LISTED EXCLUSIVELY.
C
  170 IF(BFIN(19)) 9999,180,175
  175 IF(BFIN(20)) 9999,180,190
C
  180 DO 185 I=1,NBEAM                                          N N N N
      ASINK(I)=AGRDN(I)
  185 CONTINUE                                                  N N N N
      GO TO 200
C
  190 NSNKS=BFIN(19)
      DO 191 I=1,61                                             O O O O
  191 TCELL(I)=GRDCL(I)                                         O O O O
      DO 194 I=1,NSNKS                                          Q Q Q Q
      ICELL=BFIN(I+19)
```

```
      DO 193 J=1,61                                                         P P P P
      IF(ICELL-TCELL(J)) 193,192,193
  192 TCELL(J)=0
      GO TO 194
  193 CONTINUE                                                              P P P P
  194 CONTINUE                                                              Q Q Q Q
C
      DO 197 I=1,61                                                         S S S S
      DO 196 J=1,NBEAM                                                      R1 R1 R1
      IGRDL=AGRDN(J)
      DO 196 K=1,IGRDL                                                      R2 R2 R2
      IF(TCELL(I)-ANTCR(J,K)) 196,195,196
  195 ASINK(J)=ASINK(J)+1
      GO TO 197
  196 CONTINUE                                                              R12 R12
  197 CONTINUE                                                              S S S S
      SKDAT(2)=61-BFIN(19)
C
C**** END SINK PROCESSING.
C
C     WRITE PROCESSED RECORD TO WORK FILE, THEN BRANCH TO READ NEXT.
C
  200 WRITE(9'ITEMP) HEDR,ASRCE,SKDAT,ASINK
      FIND (9'ITEMP)
      DO 210 I=1,30                                                         T T T T
      ASRCE(I)=0
      ASINK(I)=0
  210 CONTINUE                                                              T T T T
C
  250 CONTINUE                                                              X X X X
C
      IN=IN+1
      GO TO 10
C
C     A COMPLETE FILE HAS BEEN PROCESSED, WRITE RESULT FROM WORK FILE TO
C     PERMANENT FILE - THEN LOOP BACK TO PROCESS ANOTHER
C
  500 WRITE(9'ITEMP) BFIN,ZERO
      IFIN=ITEMP-1
      ITEMP=1
      IOUT=1
      FIND(9'ITEMP)
      FIND(FLOUT'IOUT)
      DO 520, I=1,IFIN
      READ(9'ITEMP) BFOUT
      FIND(9'ITEMP)
      WRITE(FLOUT'I)BFOUT
      K=I+1
      FIND(FLOUT'K)
  520 CONTINUE
C
      WRITE(PRINT,525) FLIN,IFIN
  525 FORMAT(1H0,'FILE NO.',I3,' PROCESSED, CONTAINS',I4,' RECORDS.')
C
 1000 CONTINUE                                                              Z Z Z Z
C
```

```
 9999 CALL EXIT
      END
// XEQ         L   4
*FILES(1,ORDVO,0007),(2,ORDVE,0007),(3,ORDDL,0007),(4,ORDDM,0007)
*FILES(5,ORDDH,0007)
*FILES(10,VID1,0007),(20,VOC1,0007),(30,DATL1,0007),(40,DATM1,0007)
*FILES(50,DATH1,0007)
 7
 1 101102103201202203301302303402403
 2 104105106204205206304305306404405406505506
 3 107108109207208209210307308309407408409507508509607
 4 114211212221321431031113123134104114125105116 11
 5 721
 6 851
 7 941961
```

APPENDIX C - HARDWARE REQUIREMENTS FOR SIGNAL ROUTING

C.1 INTRODUCTION

The various components which might be used for routing and switching in multibeam, multichannel repeaters have been investigated. The actual control of the routing networks and the problem of establishing reciprocal linkages (as for two-way communications) would be provided by a logic network. This logic can be provided by standard integrated circuit functions, and is distinct from the elements contained in the signal path. Logic aspects are not covered in this appendix.

From a practical standpoint, it appears that all required signal routing functions (without regard to modulation type and signal format) can be performed by various combinations of four categories of components:

1. Switches
2. Filters
3. Couplers
4. Digital Logic

These four categories are further classified in Table C-1. For each classification in the table, the individual device parameters necessary to establish an actual design tradeoff are given in Table C-2.

C.2 COMMENTS ON TDMA AND FDMA

In the case of TDMA satellite repeaters, the major factor in determining the hardware configuration is the requirement for "on-board" storage. In the simple case of the direct repeater (i.e., retransmit immediately), the routing is accomplished by simple synchronous switching on the satellite. This is achieved by proper "time ordering" of the accessing signals such that one, and only one, message for a given destination is received in a particular time slot. The switch driving/synchronizing logic must be of the "exclusive-OR" variety. The efficiency and problems of this type of repeater are to be studied in Phase II of this project.

Table C-1. Classification of Signal Switching/Routing Hardware

Switches

SPNT

1. Mechanical
2. Semiconductor
   - Integrated
   - Chopper
   - FET (passive)
   - PIN diode
   - MOS array (mux)
3. Gated amplifier/ with combiner
4. Balanced mixer/ modulator

kxSPNT

Same as single point but arranged in a kxm matrix

Filters (2 port)

Fixed

1. LC
2. Crystal
3. Mechanical
4. Delay line

Agile (tunable)

1. Commutating (n path) with variable f_c
2. Mixer/filter with variable f_c
3. Varactor tuned
4. Variable delay line
5. Active (feedback)
6. Digital
   - Quantizing
   - Computing

Couplers

1. Resistive Σ network
   - Active
   - Passive
2. n-way power divider/combiner
3. RF multiport filter (multicoupler)

Logic/Storage

1. Combinatorial/arithmetic
2. S/R (serial store)
3. RAM
4. Logic-bus organized, combinatorial

Table C-2. Characterization Requirements

1. Switches

   Parameters to be identified: (for each type)

   a. Switching time
   b. Operating frequency range (switched path)
   c. Bandwidth (switched path)
   d. Input/output matching
   e. "on" to "off" resistance ratio or isolation (matched case)
   f. Combining method
   g. Operating bias
   h. Switching bias
   i. Control method
   j. Volume
   k. Weight
   l. Max switched path voltage/power

2. Filters

   Parameters to be identified: (for each type)

   a. Fixed Filters

      (1) Center frequency (range)
      (2) Bandwidth/skirt selectivity
      (3) Phase linearity (deviation from linearity over specific bandwidth)
      (4) Insertion loss
      (5) Matching requirements (source and load)
      (6) Frequency stability
      (7) Maximum voltage/power
      (8) Additional active filter parameter operating bias
      (9) Volume
      (10) Weight

   b. Agile Filters (in addition to above)

      (1) Tuning range
      (2) Tuning time
      (3) Method of control
      (4) Control bias

Table C-2. Characterization Requirements (Continued)

3. Couplers

   a. Resistive Summing Networks

      (1) Frequency/bandwidth
      (2) Combining loss/gain
      (3) Port to port isolation
      (4) Matching requirements (source and load)
      (5) Maximum voltage/power
      (6) Additional parameter for active combiner: operating bias
      (7) Volume
      (8) Weight
      (9) Number of parts

   b. N-way power divider/combiner

      (1) Same as resistive summing networks excluding (6).

   c. RF-Multiport Filter (multicoupler)

      Note: The RF multiport filter is a special case of conventional LC fixed tuned filters. It is identified separately because the techniques involved are limited.

      (1) Center frequency/bandwidth
      (2) Number of ports
      (3) f_o spread
      (4) Isolation - port to port
      (5) Forward insertion loss
      (6) Phase linearity
      (7) Matching requirements
      (8) Frequency stability
      (9) Maximum voltage/power
      (10) Volume
      (11) Weight

4. Logic/Storage

The large number of different logic families (e.g.: TTL, ECL, HTL, TRI-STATE, etc.) and the variety of gate arrangements/functions make it difficult to classify logic/storage functions in simple tabular form. Therefore, it is assumed that where digital functions are applied, either for control purposes, or for storage:

Table C-2. Characterization Requirements (Continued)

a. Input/outputs are always in two-level form, with the levels determined by the particular logic family used.

b. Level transition (i.e.: conditioning to accommodate particular logic families) is not a significant problem and does not impact on switching/routing functions.

c. Any suitable logic family may be chosen based on selection of suitable parameters.

d. An adequate variety of gate arrangements/functions is available to implement any required logic function.

e. For density and power calculations, figures will be derived directly from appropriate logic family data. Unless otherwise specified, 5400 Series TTL will be considered having the following parameters:

   (1) Power consumption (bias - 22 mW/gate at 5.0V)
   (2) Packing density 4.0 gates/14 lead DIP
   (3) Each DIP package occupies 0.75 in^2 of P.C. card.

B

For the more complex case, where time ordering is not possible (or for the purpose of changing uplink/downlink data rate, reformatting, etc.), storage is required. Therefore, demodulation is necessary. The data storage would be accomplished using standard digital techniques. Remodulation is also necessary prior to retransmission in the proper time interval. Thus:

1. If the uplink is TDMA, and storage is provided, the downlink signals can be modified in any convenient manner. In fact, the downlink need not be constrained to TDM, but may be converted to FDM, since the choice of remodulation is independent of the uplink signal form.

2. The actual routing of the signal is performed using standard logic (digital) circuit functions and thus is not constrained by the physical limitations imposed on analog switching networks.

The switching and routing techniques for this type are not further expanded in this appendix, since they are resolved by straightforward logic design.

In all practical FDM arrangements, the routing function will be performed by a combination of switching, filtering, mixing and combining. One arrangement permits flexible use of frequency separation filters by permitting any filter(s) to be assigned to any receiver output (pooled filters), while the second approach uses iterative filter banks for each receiver (dedicated) with the use of any particular filter on a specific receiver determined by an "on-off" condition at the combining switch network.

C.3 SWITCHING CONCEPTS

The principal problem foreseen in the design of the signal routing networks is in the actual switch path characteristics. While mechanical switching can provide virtually any contact/pole arrangement, the use of solid state switching devices is usually limited to SPST equivalents. Thus, any desired switch contact arrangement must be configured as a collection of SPST switches, with the control logic arranged to provide the desired function. A 4 x 4 crossbar arrangement is shown in Figure C-1. Extracting one column (or row) from the crossbar as shown in the figure yields a simple arrangement of four SPST swtiches with all inputs (or outputs) on a common bus. By use of the proper control logic any combination of switch closures may be effected. If the logic is "exclusive-OR", the arrangement will yield a SP4T function like the familiar rotary switch.

There are some fundamental circuit limitations with bus organized switching. For the case of multiple sources connected to a single load, it is desirable that $R_S >> R_L$, i.e., current source drive. However, in the case of a single source driving multiple loads, the reverse is true, i.e. $R_S << R_L$ is the desired condition. Thus, a general case of multiple source to multiple load is, at best, a compromise if only passive bus organized switching networks are used.

Some of the fundamental limitations imposed on bus organized switching can be overcome or significantly reduced through the use of matched switching as shown in Figure C-2. Each source sees an iteratively matched load, both in the "on" and "off" condition. Similarly, each load looks back to a matched source.

Each SPST matched switch is composed of two SPDT or four SPST switch elements plus two terminating resistors. A typical 2 x 2 switch matrix is shown with the SPST arrangement. Isolation in each switch is enhanced since in the "off" condition, the parasitic capacitance and leakage resistance are in series and, in general, are always very much larger than R_O. Because of the matched conditions, signal levels at all sources and loads are constant.

C.4 SWITCHING DEVICES

Some of the typical solid state switching devices include the integrated chopper (dual emitter transistor) and field effect transistor (FET) devices. The FET, when used in the passive mode, appears as a voltage controlled resistor. Choice of "on to off" ratio is dependent on the device fabrication technology and geometry. In general, FET switches can be designed for operation from dc to about 120 MHz,

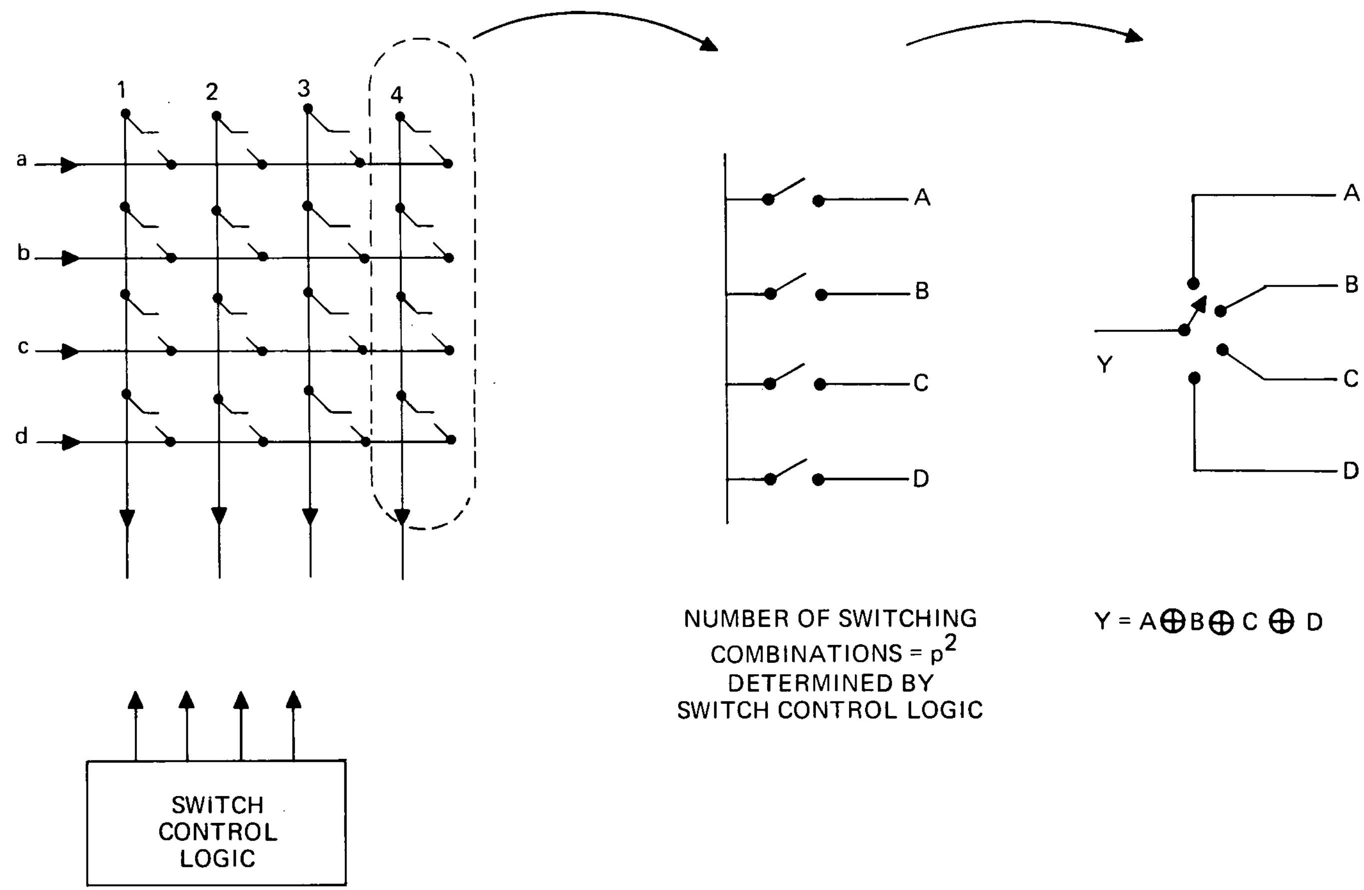
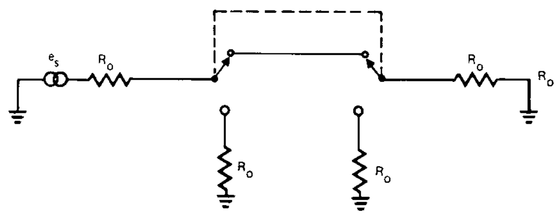
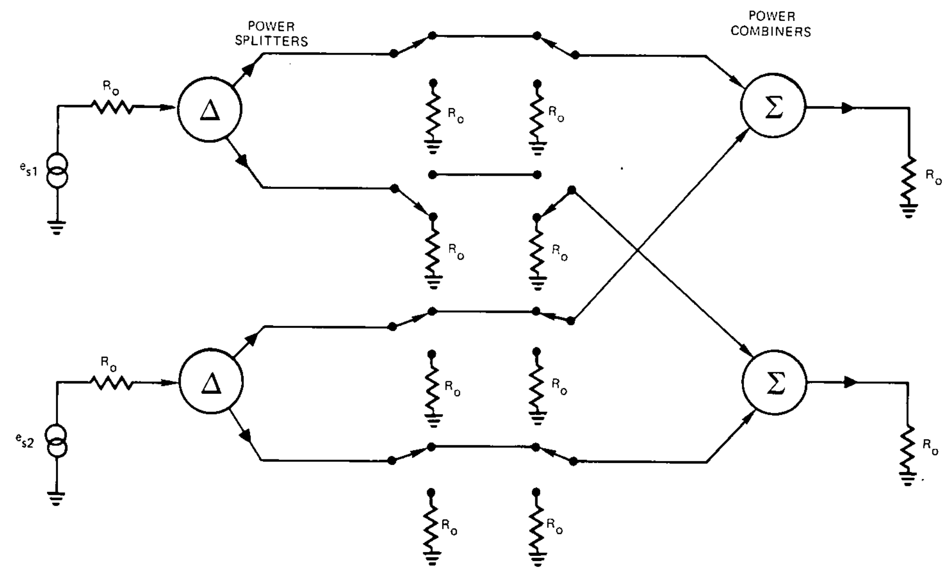


Figure C-1. Wired and-OR/Exclusive OR



SPST SWITCHED
SOURCE AND LOAD ALWAYS TERMINATED
IN R_o



MATCHED 2 X 2 MATRIX

Figure C-2. Matched Switching

depending on the selection of the specific device parameters. The principal advantage to the integrated chopper and FET lies in the fact that they are three terminal devices and do not require the application of the control bias to the signal path. (This is true also of mechanical switches).

In the case of diode switching arrangements, current technology permits higher on-off ratios (hence greater isolation) than integrated choppers or FETs. Further, the simple diode structure makes possible operation at higher frequencies. However, above approximately 120 MHz the physical arrangement and circuit techniques begin to appear more in distributed circuit form rather than as lumped elements. The principal disadvantage to diode switching arrangements is the requirement for control bias to appear on the signal path. This causes the signal to be superimposed on a dc (or control voltage) pedestal. Even with ac signal coupling, the transients associated with the leading and trailing edge of the pedestal can be difficult to eliminate from the signal path. This pedestal and its associated transient are frequently eliminated by using balance switching arrangements (such as a balanced modulator), but this results in considerably bulkier hardware than if a simple diode switch were used.

In Table C-3 are shown parameter values for various switching devices.

C.5 FILTERS

A tabulation of filters, by operating frequency range and performance parameters, is given in Figure C-3. Unlike switching devices, filters do not lend themselves to simple characterization, and, because of the wide range of technology used in the physical implementation, sizing is difficult to classify on a generalized base. Physical size information on representative filters is given in Table C-4.

Included in the filter classification are the conventional digital filters and the commutating (or n-path) filter (Reference 18). Both of these techniques permit a high degree of flexibility in center frequency and bandwidth. N-path filters are inductorless units that function on a time-division multiplex principle. This means

Table C-3. Switch Parameters

Type	Contact Form.	Switch Path Operating Frequency	Switching Time	I/O Match	On-Off Ratio or Isolation	Combining Method	Maximum Switching Path Power/ Voltage	Operating Bias	Switching Bias	Control Method	Volume	Weight	Density Factor	Source(s)	Production Type	Remarks
Mechanical Reed and Armature	SPST SPDT	dc - 20 MHz	1.5 ms	None	$0.5\Omega/10^6$	Wired	150V/1/2A	TTL Logic	TTL Logic	Control Logic	$0.125\ in^3$ (Reed) $0.100\ in^3$ (Armature)	0.01 lb	(8) SPST/in^3 (Reed) (10) DPDT/in^3 (Armature)	Many	Production	Life > 10^8 Cycles Bidirectional
Coaxial	SPNT (OSM)	dc - 12 GHz	25-50 ms	50Ω	$\approx 10^5$	Matched Combiner	To 1 kW	None	$\approx$300 mW	Control Logic	$0.78\ in^3$ (Excluding Connectors)	0.0625 lb	1.3 SPST/ in^3	Many	Production	Bidirectional Match only in closed circuit
Semiconductor Integrated Chopper	SPST	dc $\approx$ 2.0 MHz	$\approx 0.1\ \mu s$	None	$8\Omega/\approx 10^8$	Wired	50V/30 mA	Vcb $\approx$ 20 V	Requires Driver	Driver w/ Control Logic	w/Driver $0.4\ m^3$	0.035 lb	(2.5) SPST/in^3	Crystalonics	Custom	Driver must be custom design Bidirectional
FET	SPST	dc - 120 MHz	$\approx 0.1\ \mu s$	None	$6\Omega/\approx 10^7$ to $20\Omega/\approx 10^6$	Wired	$\approx$10V/30 mA	~15 V	TTL Logic	Logic	$0.100\ in^3$	0.01 lb	10 SPST/in^3	Crystalonics TI, MOT, FSC	Production Custom	Performance highly dependent on device. Bidirectional
MOS Array	NX SPST	dc $\approx$ 2.0 MHz	$\approx 0.2\ \mu s$	None	$200\Omega/10^7$	Wired	$\approx$10V/30 mA	$\approx$15 V	TTL or P-MOS Logic	Self Contained Logic	$0.035\ in^3$	0.003 lb	470 SPST/in^3	GI, Hughes	Production	Some types require external logic. Bidirectional
Diode (Unmatched)	SPST	dc $\approx$120 MHz	$\approx$10 ns	None	$<0.5\Omega/>10^7$	Wired	$\approx$1 W Av.	0.7 V, I Depends on Peak Power	Depends on Peak Power	External Bias Drive	$0.005\ in^3$	-	$\approx$ (100) SPST/ in^3	Microwave Assoc. TI, FSC, MOT	Custom	Custom arrangements only. Bidirectional
Diode (Matched)	SPNT	dc - 12 GHz	$\approx$10 ns	50Ω	35 dB	Matched Combiner	$\approx$1 W Av.	0.7 V, I Depends on Peak Power	Depends on Peak Power	External Bias Drive	Depends on Frequency	Depends on Frequency	Depends on Frequency	HP, ARRA, FSC	Production	Directivity depends on design
Gated Ampl. (Op. Ampl.)	SPST	dc - 2 MHz	$\approx 5\ \mu s$	None	$\approx$30 dB	Wired	5 V PP	250 mW	None	Logic to Operating Bias	$0.4\ in^3$	0.35 lb	(2.5) SPST/ in^3	Custom Use of Std. IC Devices	Custom	Unidirectional
Gated Ampl. (Video/IF Ampl.)	SPST	2 MHz - 1.5 GHz	$\approx 0.1\ \mu s$	-	30 - 50 dB	Matched Combiner	- 12 dBm	500 mW	None	Logic to Operating Bias	$0.200\ in^3$	0.02 lb	(5) SPST/in^3	AVANTEC, AERTEL, FSC	Production	Unidirectional
Balanced Modulator (1)	SPST	dc - 5 MHz	50 ns	None	30 dB	Wired	$\approx$2 V PP	250 mW	None	Logic	$0.4\ in^3$	0.35 lb	(2.5) SPST/ in^3	Custom Use of Std. IC Devices	Custom	Unidirectional
(2)		0.2 MHz - 1.0 GHz	10 ns	50Ω	35 dB	Matched Combiner	$\approx$0 dBm	None	0 dBm	Logic	$0.25\ in^3$	0.02 lb	(4) SPST/in^3	RELCOM, HP	Production	

A

B

FOLDOUT FRAME - 1

FOLDOUT FRAME - 2

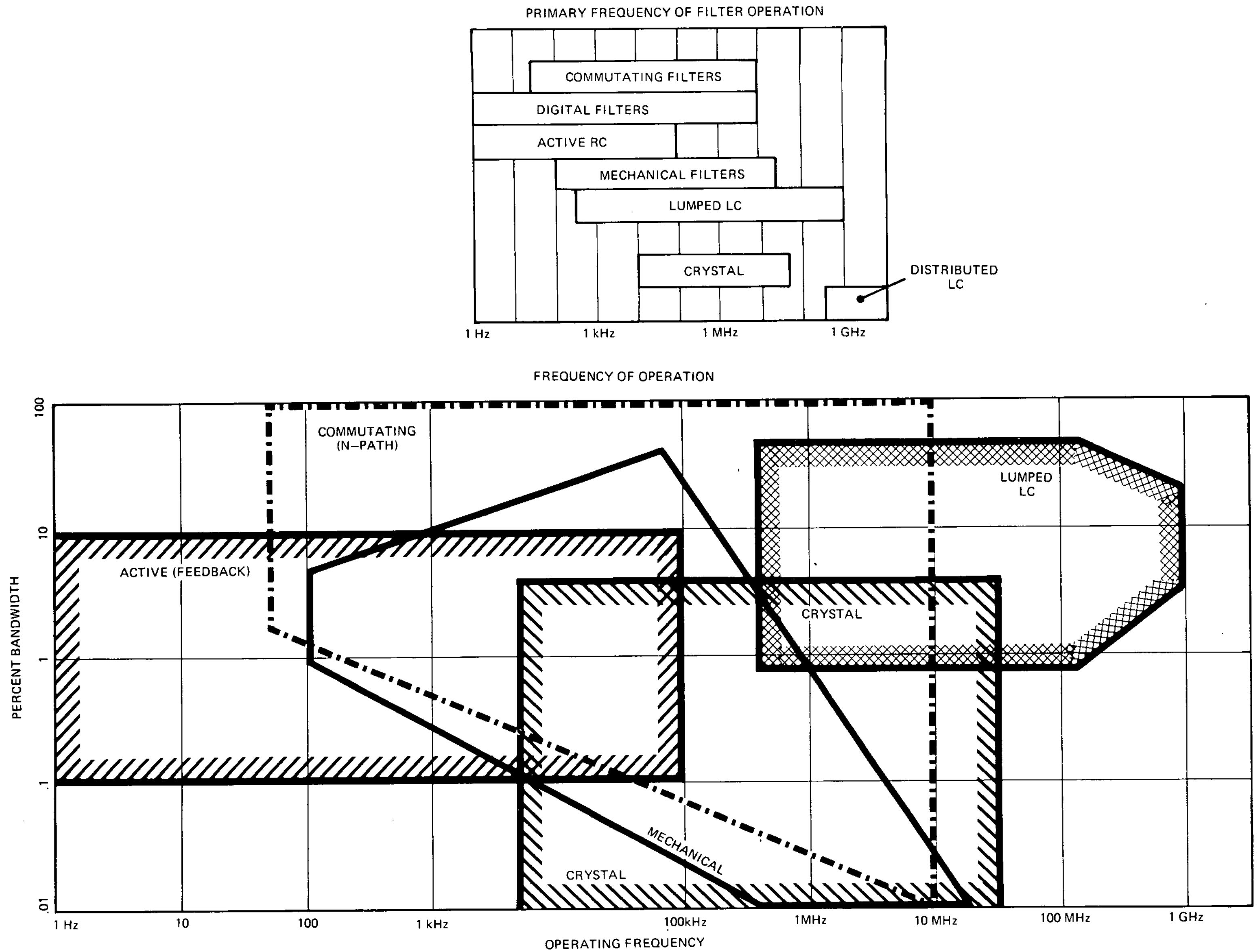


Figure C-3. Operating Range For Various Filter Types

Table C-4. Physical Size of Representative Filters

Bandpass LC

1. Torroidal or cup core magnetics: $f_o < 10$ MHz
   Volume: 0.25 in^3/pole
   Dimensions: (typical) 3.6" x 0.6" x 0.4" (5 pole)

2. Slug tuned on miniature torroidal magnetics: $10 < f_o < 30$ MHz
   Volume: 0.2 in^3/pole
   Dimensions: (typical) 3.0" x 0.8" x 0.4" (5 pole)

3. Air wound solenoidal inductors: 30 MHz $< f_o <$ 120 MHz
   Volume: 0.2 in^3/pole
   Dimensions: (typical) 2.5" x 1.0" x 0.4"

Crystal Filters

1. Separate prepackaged resonators:
   Volume: 0.15 in^3/pole
   Dimensions: (typical) 0.8" x 0.7" x 0.8"

2. Integrated packaging (monolithic construction)
   Total volume: 0.27 in^3
   Typical dimensions: 0.3" x 0.6" x 1.5"

Mechanical Filters

1. Single resonator (disc) - single element
   Volume: 0.06 in^3 (total)
   Dimensions: (typical) 0.3" x 0.4" x 0.2"

2. Multiple disc - (typical 11 resonator structure)
   Volume: 0.26 in^3
   Dimensions: 0.4" x 0.4" x 1.6"

Table C-4. Physical Size of Representative Filters (Continued)

Active Filters: (Feedback)

1. Fabricated from discrete IC and other passive components

   P. C. board area 2.4 in^2

2. Hybrid IC version

   P. C. board area 0.5 in^2 (TO-8 package)

Commutating (n-path) Filters

1. Fabricated from discrete IC and other passive components

   P. C. board area 3.25 in^2

that N successive identical channels or paths are cyclically cut into the signal path. Such networks are said to have a variable-time character. If a lowpass element with transfer function $H(j\omega)$ is present in each of these paths, the cyclical switching process causes a lowpass to bandpass transformation. The resulting transfer characteristic is symmetrical with respect to the switching frequency, ω_o.

C.6 COUPLERS

See Table C.5.

C.7 FUTURE TECHNOLOGY

Because the detailed technology used in the physical fabrication of switching devices, filters, etc., is dynamic, it is expected that performance limits will expand concurrently with developments in various technology areas. These are expected to be:

1. Improvements in MOS-FET device fabrication (metal or silicon gate, ion-implant) resulting in higher on-off ratios, lower R_{on} for FET switches.
2. Improvements in diode device fabrication (nitriding, glassivation) resulting in lower leakage resistance in diode switches.
3. Smaller geometry A/D converters resulting in higher frequency performance of A/D converters, coupled with higher speed (bipolar logic, e.g., ECL or C-MOS) logic permitting higher frequency limits in digital and n-path (commutating) filters.
4. Application of photolithographic/chemical etching techniques to crystal filter fabrication permitting broader operating limits.
5. Developments in praetersonics (microwave surface wave devices) including the development of high Q microwave ultrasonic filters.
6. Improvements in thin/thick film technology and extending the lower bounds of microwave integrated circuit techniques to permit fabrication of low frequency distributed (transmission line) circuits.

Table C-5. Coupler Information

1. Resistive Power Dividers/Combiner

   a. Discrete Component

      (n + 1) RN-55 resistors

      volume (2 way divider): 0.035 in^3 or 0.012 in^3/terminal

   b. Film Hybrid

      (TO-116 DIP Package)

      volume (up to 14 terminals): 0.30 in^3 or approximately 0.23 in^3/terminal.

2. Active Power Combiner

   IC operational amplifier in summing amplifier configuration

   P.C. board area 1.5 in^2 for five-way combiner

3. Active Power Divider

   IC operational amplifier array

   P.C. board area 0.75 in^2 per output.

4. Reactive Power Divider/Combiner

   a. Sage - Wireline - two way coupler

      dimensions 12.0" x 0.25 at 100 MHz

   b. Lumped element reactive divider

      dimensions: TO-5 transistor - 0.10 in^3

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