CR 168034

FINAL TECHNICAL REPORT

SATELLITE SWITCHED FDMA ADVANCED COMMUNICATION TECHNOLOGY SATELLITE PROGRAM

December 1982

Contract Sponsor: NASA/LERC
Contract No. NAS3-22895

MOTOROLA INC.
Government Electronics Group
8201 E. McDowell Rd., P.O. Box 1417,
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16. Abstract

This document is the final report for the SS-FDMA Program performed by Motorola Inc., Government Electronics Group (GEG), for the National Association and Space Administration (NASA) Lewis Research Center (LeRC) under NASA LeRC Contract No. NAS3-22895. The objective of the Satellite Switched Frequency Division Multiple Access system is to provide a detailed system architecture that will support a point-to-point communication system for long-haul voice, video and data traffic between small earth terminals at Ka-band frequencies at 30/20 GHz located across the continental United States. Detailed system design is presented for the space segment, small terminal/trunking segment at network control segment for domestic Traffic Model A or B, each totaling 3.8 Gb/s of small terminal traffic and 6.2 Gb/s of trunk traffic. The primary emphasis is directed to the small terminal traffic (3.8 Gb/s), for the satellite router portion of the system design, which is a composite of thousands of earth stations with digital traffic ranging from a single 32 Kb/s CVSD voice channel to thousands of channels containing voice, video and data with a data rate as high as 33 Mb/s. The system design concept presented, effectively optimizes a unique frequency and channelization plan for both Traffic Models A and B with minimum reorganization of the Satellite Payload Transponder Subsystem Hardware Design. The unique zoning concept allows multiple beam antennas while maximizing multiple carrier frequency reuse. Detailed hardware design estimates for an FDMA router (part of the satellite transponder subsystem) indicates a weight and dc power budget of 353 lbs, 195 watts for Traffic Model A and 498 lbs, 244 watts for Traffic Model B utilizing 1982 technology. A detailed hardware design implementation is presented which when developed as a proof-of-concept model for the SS-FDMA router, will simulate and provide path performance and impairment data applicable to any satellite router organization.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT
SATELLITE SWITCHED FDMA SYSTEM ANALYSIS FOR SMALL TERMINALS

This document is the final report for the SS-FDMA Program performed by Motorola Inc., Government Electronics Group (GEG), for the National Association and Space Administration (NASA) Lewis Research Center (LeRC) under NASA LeRC Contract No. NAS3-22895. The objective of the Satellite Switched Frequency Division Multiple Access system is to provide a detailed system architecture that will support a point-to-point communication system for long-haul voice, video and data traffic between small earth terminals at Ka-band frequencies at 30/20 GHz located across the continental United States. Detailed system design is presented for the space segment, small terminal/trunking segment at network control segment for domestic Traffic Model A or B, each totaling 3.8 Gb/s of small terminal traffic and 6.2 Gb/s of trunk traffic. The primary emphasis is directed to the small terminal traffic (3.8 Gb/s), for the satellite router portion of the system design, which is a composite of thousands of earth stations with digital traffic ranging from a single 32 Kb/s CVSD voice channel to thousands of channels containing voice, video and data with a data rate as high as 33 Mb/s. The system design concept presented, effectively optimizes a unique frequency and channelization plan for both Traffic Models A and B with minimum reorganization of the Satellite Payload Transponder Subsystem Hardware Design. The unique zoning concept allows multiple beam antennas while maximizing multiple carrier frequency reuse. Detailed hardware design estimates for an FDMA router (part of the satellite transponder subsystem) indicates a weight and dc power budget of 353 lbs, 195 watts for Traffic Model A and 498 lbs, 244 watts for Traffic Model B utilizing 1982 technology. A detailed hardware design implementation is presented which when developed as a proof-of-concept model for the SS-FDMA router, will simulate and provide path performance and impairment data applicable to any satellite router organization.

SECTION 1

1. INTRODUCTION

This report summarizes the important aspect, limitations and conclusion drawn from an indepth Motorola study into an SS-FDMA System Design concept for small terminal traffic as specified in NASA's Traffic Models A and B. Each of the three major segments of the system architecture are discussed in detail with supporting block diagram, interface requirements and detailed parametric analysis.

The objective of the Satellite Switched FDMA System is to provide long-haul communication voice, data, and video between individual small terminal users, primarily corporations and institutions. The system implementation will utilize a Switched Satellite operating in a Frequency-Division, Multiple-Access (SS-FDMA) mode at Ka-band with digital data communications between individual users via trunking and small earth station terminals.

A primary objective of the SS-FDMA development program is to identify and develop the critical technologies required to support detailed design and fabrication of the satellite small terminal router subsystem. To support this objective, a Proof-Of-Concept (POC) model of the satellite small terminal router will be designed, fabricated, and tested.

The technological building blocks will be designed, fabricated, assembled and tested in a limited POC, which represents the typical topology of an SS-FDMA Sector/Router portion of the Satellite Transponder Subsystem.

This presentation also describes Motorola's recommendation for the advanced technology development necessary for a POC evaluation of the technological readiness in either a sector or router configuration for an SS-FDMA concept. Critical technologies are defined with an assessment of key technologies.

1.1 Overview of Report

Section 2 presents the technical summary of the system design and proof-of-concept model hardware definition. Section 3 highlights the study goals for both the system design phase and hardware development phase. Key technologies are identified along with the rationale for the evaluation of technological building blocks.

Section 4 presents the detailed system analysis which evaluates performance criteria related to link budgets — error control — frequency plan — satellite routing — modulation schemes — antenna limitations — system control and the small terminal user interface with the terrestrial network.

Section 5 describes in detail the satellite segment, in particular, the Satellite Router Transponder Subsystem size, weight, power estimates are presented which have evolved from a detailed hardware definition of the limited proof-of-concept router model.

Section 6 addresses the Network Control Station (NCS) and evaluates the minimum requirements for user station control — user and satellite communication path orderwire scenerios and data-bit requirements for path set-up. Rain-fade detection, link margin and power boost correction is addressed extensively.

Section 7 proposes a small terminal user interface design to the terrestrial networks. Small terminals for all station sizes, as outlined in Traffic Models A and B, are addressed with specific interest dedicated to high cost drivers such as antennas and LNR's.

Section 8 projects advanced technology for a 1987 prototype design. The emphasis is on the overall reduction of size, weight, power estimates.

Section 9 summarizes the important conclusions drawn from the system analysis. Replacing the 64 Kb/s voice link with 32 Kb/s Continued Voice Slope Delta (CVSD) voice link is both efficient and effective. Section 10 makes recommendations for additional areas of study and analysis.

Section 11 contains Appendices I through J. These Appendices support the main section of this final report with the detailed analysis covering investigation into high power amplifiers, high frequency switch technology, low phase noise frequency synthesis, offset QPSK modulation/demodulation techniques and analysis, coding/decoding formats, Traffic Models A and B evaluation for pertinent temporal characteristics and change due to time and population migration, and lastly, the signaling interface requirements with the terrestrial networks.

SECTION 2

2. FINAL REPORT SUMMARY

2.1 System Summary

In overview, the ACST SS-FDMA technology comprises:

- Satellite switched communication system for small terminal (ST) traffic in 1990's.
  - 30 GHz uplinks
  - 20 GHz downlinks
  - 2.5 GHz bandwidth
- Multiple beam antennas for multiple carrier frequency reuse
- Frequency division multiple access (FDMA) for ST traffic
- Up to 10,000 small terminals (ST)
  - single channel to 100's of channels
  - fully mixed voice, data, and video channels
- Traffic - 10 Gb/s total with 3 Gb/s ST routed traffic
  - 70,000 individually routed voice channels
  - 7,000 data channels
  - 5,000 video channels
- Demand access - reservation protocol
- User availability 0.999 objective

The satellite switched frequency division multiple access system (SS-FDMA) for small terminals (ST) provides a cost effective service among thousands of small ground communication users scattered throughout the Continental United States (CONUS). The smallest user terminal is one with 14 voice equivalent channels (Traffic Model A) or even a single voice channel (Traffic Model B). The satellite provides a routing capacity of 3 Gb/s between these many ground stations.

The source satellite also supports a major TDMA trunking capacity between major terminals located within 20 or so large metropolitan areas. A frequency plan is used which includes this capacity as well. The SS-FDMA system architecture described hereafter is concerned primarily with the development of a cost effective system design for small stations using SS-FDMA.

To achieve low satellite size, weight, and power and low small terminal cost, extensive advanced technology is required.

2.1.1 COMMUNICATION TRAFFIC MODELS

An SS-FDMA system is to be developed for two possible traffic models. Model A is similar to that used to develop the Baseband Processed TDMA system architecture. Model B is a likely traffic model for an FDMA approach for ST traffic handling.

The total satellite throughput is 10 Gb/s. Unlike the TDMA approach in the FDMA system, all small terminal traffic must use the ST frequency band, regardless of origin or destination. The total traffic is the same for both models. The traffic is a mix of voice, data, and video and in this system shall use a single channel per carrier modulation, i.e., each message is routed by its carrier frequency (see Table 2.1-1).

Table 2.1-1. Communication Traffic Models

● System Capacity 10 Gb/s		
- 6.2 Gb/s Trunk - Trunk		
- 0.8 Gb/s Trunk - ST		
- 0.8 Gb/s ST - Trunk		
- 2.2 Gb/s ST - ST		
● ST Originated Traffic		
	Model A	Model B
- Number of Cities	45	277
- Number of Terminals	2,000	10,000
- Terminal Capacity		
Maximum (Mb/s* - Channels)	29-250	6.3-36
Minimum (kb/s* - Channels)	500-14	32-1
● Traffic Types (kb/s - Channels)		
- Voice	64 (32 kb/s CVSD Recommended)	
- Data	56, 1500	
- Video	56, 1500, 6300	
*With 32 kb/s Voice		

Because of its increased efficiency and flexibility 32 kbps Continuously Variable Slope Delta (CVSD) modulation was chosen for all voice links. As a result the throughput in terms of channels is the same as the 3.8 Gb/s in the SOW traffic model but the bandwidth occupancy is reduced to about 3 Gb/s.

2.1.2 SS-FDMA SYSTEM CHARACTERISTICS

The SS-FDMA ST routing system must co-exist with a TDMA trunking system. They share the same 2.5 GHz carrier bandwidth and multibeam antennas and might share LNAs and PAs. Cross-strapping of ST traffic is done in a ST traffic addition to trunking terminals.

The ST routing system uses frequency division multiple access (FDMA) exclusively. Each message channel is in a single carrier with multiple carriers in each antenna beam. Multiple beam antennas are used to enhance carrier reuse throughout the country. Channels may accommodate data rates at 32 kb/s (recommended for all voice messages), 56 kb/s medium rate data and stop video channels, 1500 kb/s high rate data and low rate video, and 6300 kb/s video links. All traffic has a digital format, however the Router will pass linear modulation of equal or lesser bandwidths.

2.1.3 SATELLITE COMMUNICATIONS PAYLOAD CHARACTERISTICS

All channels use offset QPSK. The design has a probability of error on any channel of 10^{-6} or less with a channel availability of 0.999. An alternative that requires less satellite power has an availability of 0.995 for the same BER.

Significantly rain fade occurs on both the 30 GHz uplink and 20 GHz downlink, approximately 15 dB on the former and 6 dB on the latter for an availability of 0.999. The uplink is protected by 15 dB power boost at transmitting stations. Downlink protection uses convolutional coding on the affected links.

All satellite routing control is done by a Network Control Station (NCS). An integral satellite control link is part of the SS-FDMA system. In addition an integral orderwire system is provided between the NCS and each small terminal. The number of carriers for traffic Model A is 41, and for traffic Model B is 72. The data rate for traffic Model A is 2.5 Mb/s, and 1.9 Mb/s for traffic Model B.

2.1.4 MAJOR SS-FDMA SUBSYSTEMS

The principal subsystems of the SS-FDMA systems are shown in Figure 2.1-1. These are the satellite communication payload with particular emphasis on the ST Router, the many single and multiple channel user ST terminals, and the Network Control Station (NCS).

Although this system design does not include trunking terminals, nevertheless, the ST communication system must co-exist with the trunking communication system. It must share the same satellite and all trunking - ST cross-traffic inter-connection occurs in trunking terminals. Likewise, the NCS shares a major trunk station facility.

Each of these subsystems are described in the following section. The trunking subsystem is described only as it intertwines with the ST subsystem.

2.1.5 SYSTEM BLOCK DIAGRAM

Shown in Figure 2.1-2 is a simplified block diagram for the SS-FDMA system. Included are:

- trunk terminals,
- small terminals,
- the FDMA satellite, and
- a network control station (NCS).

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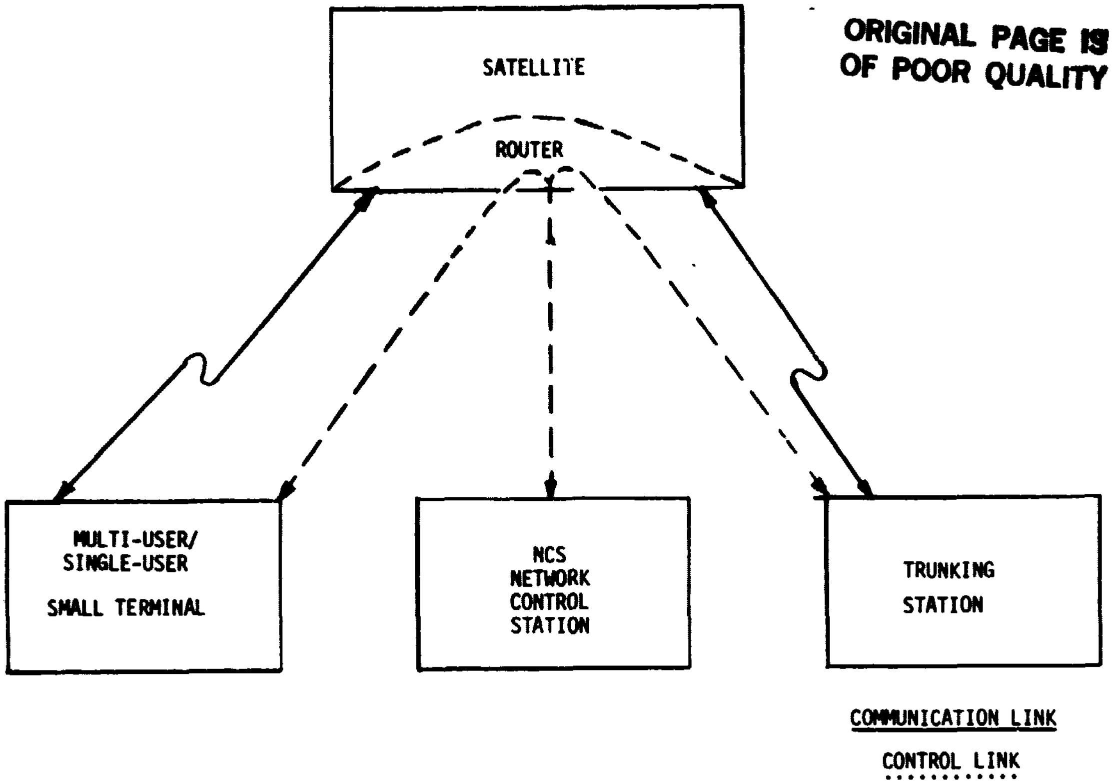

Figure 2.1-1. Major SS-FDMA Subsystems

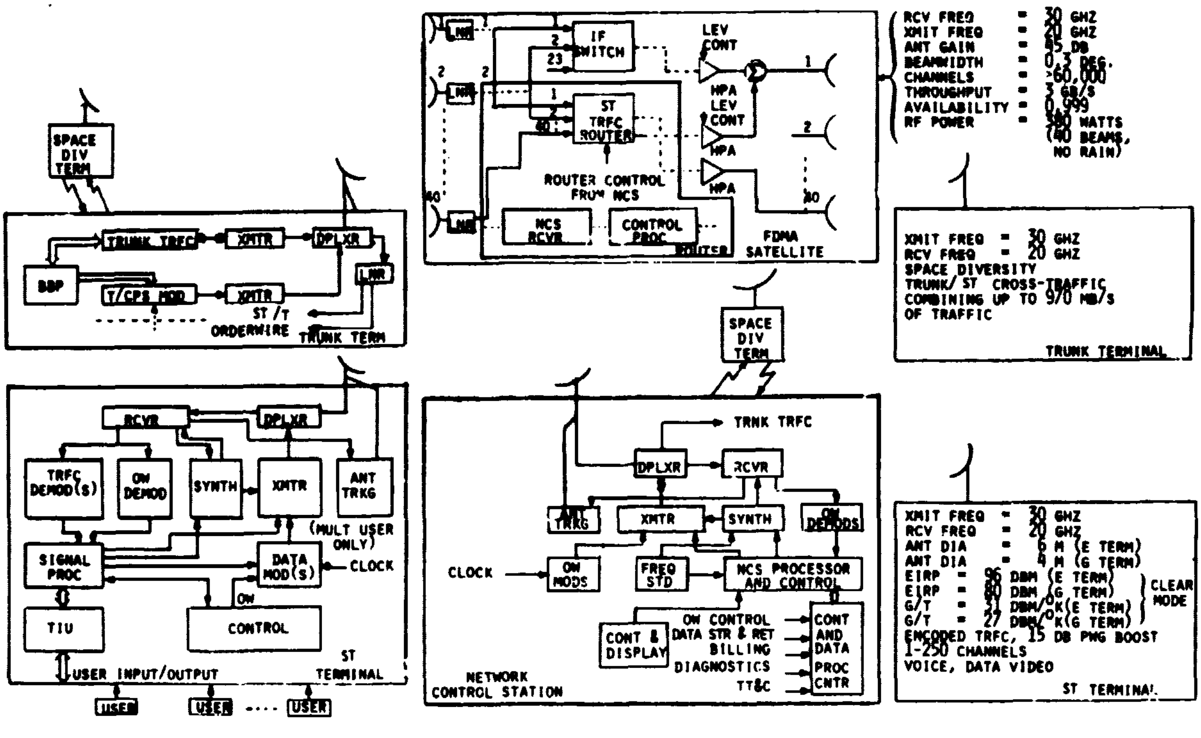

Figure 2.1-2. System Block Diagram

Entry into the system is accomplished by requests to the NCS. The NCS acts as the master terminal in:

- making channel frequency assignments,
- setting frequency and timing references,
- designating channels to be encoded for improving link margins,
- controlling satellite power output for each beam,
- commanding the satellite router switch and IF switch,
- setting system configurations, and
- system monitoring.

Small terminals very in size with composite data rates from 0.88 Mb/s (G terminal) to 33.84 Mb/s (E terminals). Traffic channels include voice, data, and video with a satellite throughput rate up to 3 Gb/s. In addition to ST traffic, the satellite must also accommodate trunk terminal traffic. The portions of this traffic designated for ST stations will be assigned to the ST band and pass through the router. That fraction of the trunking traffic designated for other trunk stations will be directly routed through an IF switch. 1.5 GHz of bandwidth is allocated for trunk traffic and 1.0 GHz for ST traffic. The ST traffic will be broken into roughly three bands handling 40 beams for Traffic Model A and 71 beams for Traffic Model B in which the satellite will handle routing of all traffic to its proper destination. In the section which follows, the basic architecture of the 30/20 GHz SS-FDMA system will be discussed.

2.1.6 SS-FDMA SATELLITE PAYLOAD

There are six basic functional parts to the satellite communication payload:

- Multibeam narrow beam receiving antennas
- Low Noise Receivers at 30 GHz
- IF Switch for TDMA trunk signal routing
- Upconverters to 20 GHz and 20 GHz Power Amplifiers
- Multibeam transmitting antennas, and the
- FDMA ST Router

Although this program is not concerned with the trunking system, nevertheless the SS-FDMA ST system is inextricably interwoven with the trunking subsystem. Figure 2.1-3 makes clear the points of contact.

2.1.7 SATELLITE BLOCK DIAGRAM

The satellite block diagram, as shown in Figure 2.1-4, contains six main subsystems relating to the FDMA communication link. These are the antenna subsystems, low noise receivers (LNR), IF switch, the ST router, and the power amplifier subsystem. With the exception of the router, these subsystems have all been studied by other contractors and the developed FDMA architecture has used the published characteristics of these studies, where applicable.

Essentially, the FDMA satellite acts as a switchboard to control source to destination traffic. The 30 GHz input is received by the antenna subsystem which contains approximately 40 beam antennas (Traffic Model A). The traffic from trunking terminals, which is destined for another trunking terminal, is allocated a 1.5 GHz bandwidth

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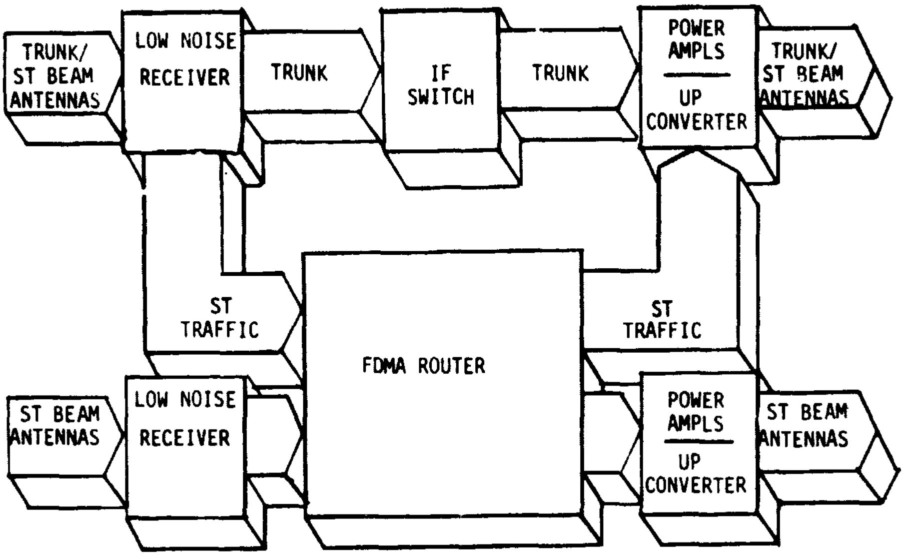


Figure 2.1-3. Satellite Payload Block Diagram

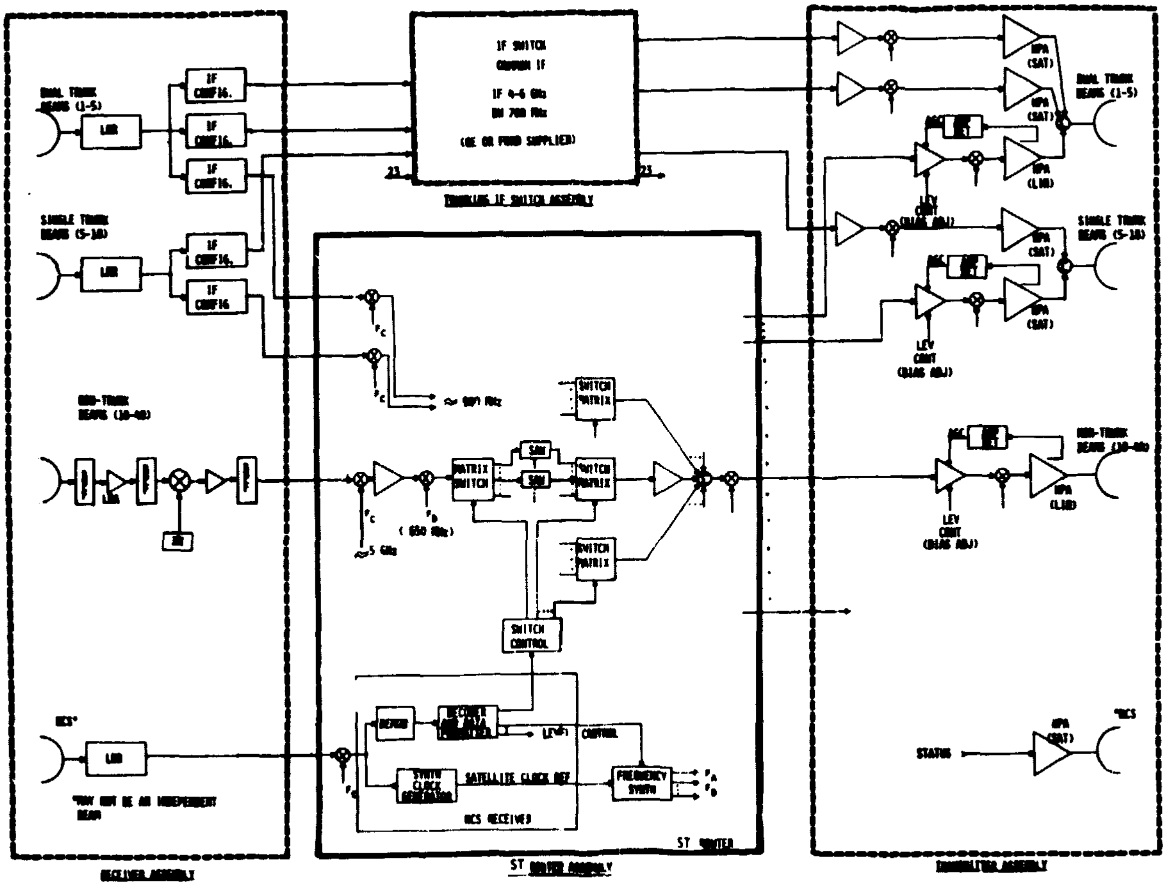


Figure 2.1-4. Satellite Block Diagram

and this TDM traffic is destination-controlled through the IF switch. All other traffic, which is ST related, is contained in a 1.0 GHz bandwidth and is destination-controlled through the router. Switch configuration, along with synthesizer settings and power output control, are derived from the NCS receiver within the router.

The router contains approximately 1600 SAW filters with 3200 switching crosspoints. The input and output IF frequencies to the router have tentatively been selected as 4.5 - 5.6 GHz and 2.65 - 3.35 GHz respectively. With a maximum 3 Gb/s throughput, the required RF output power for communicating the ST traffic is 357 watts for Traffic Model A and 465 watts for Traffic Model B. This assumes an effective satellite antenna gain of 45.4 dB.

Power amplifiers are all quasi-linear for the ST FDMA traffic and will operate saturated for the trunking TDM traffic. Details of the FDMA architecture, and in particular the router, are discussed in the following sections.

2.1.8 MODULATION, CODING, RAIN FADE COMPENSATION

Offset or staggered quadriphase shift keying (O-QPSK) has been selected for all channels in the SS-FDMA system.

All voice channels use 32 kb/s continuously variable slope delta modulation to increase power and bandwidth efficiency. Data on the voice channels shall use CVSD for rates up to 4800 bps. Higher rates to 9600 bps shall use the 56 kb/s capability of the ST.

Forward error correction coding uses convolutional $R = 1/2$, $K = 5$, $Q = 4$ with the maximum liklehood decoder being developed for the Baseband Processor. This provides 3.6 dB of error correction improvement at a BER of 10^{-6}. With adjustments in the transmitting terminals this is adequate to protect for the 6 dB downlink rain fade. Some controlled satellite reserve is desirable.

Rain fade compensation basically uses 15 dB ST power boost to combat uplink rain fading and FEC to combat the downlink fading. The rate 1/2 coding reduces the signal power density by 3 dB. This, in turn, results in a higher signal power to intermodulation power density at the output of the satellite TWT. This improvment plus the 3.6 dB coding gain exceeds the downlink 6.0 dB rain fade loss.

2.1.9 COMMUNICATION LINK SUMMARY

Table 2.1-2 summarizes the communication link assumptions. The bit error rate for the SS-FDMA system is specified at 10^{-6} for the Traffic Channel. The corresponding signal to noise ratio is 10.6 dB. The Orderwire Control Link and Satellite Control Link are both specified at an error rate of 10^{-8}. The uplink and downlink impairments are the combination of the following losses:

Adjacent channel interference: Co-channel interference
Intermodulation distortion products: Filter distortion
Phase noise: Other hardware imperfections

The 1/2 rate coding with constraint length 5 and 2 bits soft decision is assumed in the system which results in coding gain of 3.6 dB.

The 7.6 dB satellite antenna impairment assumed in the system is the combination of the following losses:

Beam to beam variation: 1 dB Area coverage: 3 dB

Pointing error (beam edge): 1.3 dB

Diplexing loss: 2.0 dB Polarization loss - 0.3 dB

Table 2.1-2. Communication Link Summary

Parameters	Unit	E-Type Termnl	F-Type Termnl	G-Type Termnl	Note
Uplink Path Loss	dB	213.5 ± 0.4	213.5 ± 0.4	213.5 ± 0.4	
Downlink Path Loss	dB	210 ± 0.4	210 ± 0.4	210 ± 0.4	
Terminal Bit Rate	MB/S	26.16	3.812	0.496	32 kbps Voice
Ideal Satellite Antenna Gain	dB	53	53	53	
Satellite Antenna System Impairment	dB	7.6	7.6	7.6	
Satellite Receiver Noise Figure	dB	5	5	5	
ST Antenna Size	METER	6	5	4	
ST Antenna Gain	dB				
30 GHz		61.8	60.3	58.3	Efficiency 43%
20 GHz		59.2	57.6	55.7	Efficiency 53%
Uplink/Downlink Impairment	dB	3.7/4.8	3.7/4.8	3.7/4.8	
ST Receiver Noise Figure	dB	7.5	6	4	
Coding Gain	dB	3.6	3.6	3.6	

2.1.10 SATELLITE RF POWER REQUIREMENTS FOR ST TRAFFIC

Table 2.1-3 contains the satellite RF power requirements for small terminal traffic. The satellite RF power can be determined from the following downlink budget equation:

$$STP = \left(\frac{E_b}{N_o}\right)_{down} - G_T + KT_R + L_d + L_{rd} + L_p + L_C - G_R + R_b$$

where

STP — Satellite RF power in dBm

$\left(\frac{E_b}{N_o}\right)_{down}$ — Downlink signal to noise ratio in dB

G_T — Satellite antenna gain in dB

KT_R — ST receiver noise power density in dBm/Hz

L_d — Path loss in dB

L_{rd} — Rain loss in dB

L_p — Pointing loss in dB

L_C — Receiver line loss in dB

G_R — ST receiver antenna gain in dB

R_b — Data rate

The RF power listed will satisfy any rain fade condition that may exist on the uplink, downlink, or both links simultaneously.

Table 2.1-3. Satellite RF Power Requirements for ST Traffic

Terminal	E-Type		F-Type		G-Type		40 Beams	
Power / Traffic Model	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
A	35.0	3.16	26.6	0.46	17.8	0.06	55.52	356.49

Terminal	E-Type		F-Type		G-Type		H-Type		I-Type		J-Type		71 Beams	
Power / Traffic Model	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
B	30.5	1.12	23.4	0.22	16.6	0.05	15.1	0.03	12.8	0.02	5.9	0.004	56.67	464.93

2.1.11 TRANSPONDER SIZE, WEIGHT, AND POWER

Table 2.1-4 is a summary of each of the five SS-FDMA satellite transponder subsystems. The antenna subsystem is the single largest subsystem within the satellite, due primarily to the large reflectors and supporting structure. The antenna estimates are based on data published by Ford Aerospace and GE.

The IF trunking switch is the smallest subsystem in terms of size, weight, and power. The estimate is taken from existing published industry data.

The transmitter subsystem is the heaviest and the largest power consumer of all the subsystems. The weight and the power are a result of the many TWT's and the high voltage power supplies needed to drive the TWT's. This high power dissipation will necessitate extensive external cooling to keep the operating temperature within reasonable limits.

Table 2.1-4. Transponder Size, Weight, and Power

Assembly	Weight (lb)		Power (Watt)		Size (Ft^3)	
	A	B	A	B	A	B
Antenna Section	250	350	—	—	300	301
Receiver Section	84	133	99	164	1.2	2
IF Switch (Trunking)	25	25	8	8	0.4	0.4
ST Router	353	498	195	244	9.2	12.6
Transmitter Section	1,944	2,966	4,902	5,528	24.7	37.7
Total	2,656	3,972	5,204	5,944	335.5	353.7

2.1.12 TRUNKING AND ST FREQUENCY PLAN REQUIREMENTS

Traffic consists of both trunk and ST traffic as shown in Table 2.1-5. Any trunk traffic which is destined for a ST terminal is assigned a frequency allocation in the ST Band. This also pertains to the ST to trunk traffic and results in a maximum total ST traffic of 3 Gb/s. All trunk-to-trunk traffic is switched in the satellite via an IF switch in which the trunk traffic is generated from approximately 18 terminals. Frequency organization for the trunk traffic is the same as in the TDMA 30/20 GHz Communication System. Since this FDM/TDMA design is presently fixed, the following discussions pertain only to the ST traffic. The frequency plans do not assume any isolation through polarization diversity. Frequency reuse is maximized while avoiding spot-to-spot interference degradation. The use of the trunking band for ST traffic is not considered at this time.

Table 2.1-5. Trunking and ST Frequency Plan Requirements

TRUNKING

Trunk Channel Bandwidth = 1.5 GHz (Three Bands)
Trunk Traffic Burst Rate = 550 Mbps
TDMA Transmission as per 30/20 GHz TDMA Communication System
Number of Beams with Trunk Traffic = 18
Peak Hour Traffic = 6053 Mbps
23 × 23 IF Switch for Routing

SMALL TERMINAL

ST Bandwidth Allocation = 1.0 GHz
Includes T/ST, ST/ST and ST/T Traffic
Traffic Model A; 45 Cities, 40 beams, 3 Gbps Throughput
Traffic Model B; 227 Cities, 71 Beams, 3 Gbps Throughput

GENERAL REQUIREMENTS

Polarization Diversity not Required
Frequency Plan to Avoid Spot-To-Spot Interference

2.1.13 ST TRAFFIC-CITY AND FREQUENCY BAND ALLOCATION FOR TRAFFIC MODEL A

Figure 2.1-5 shows a composite frequency plan for small terminal and trunk traffic. Some beams require two trunking channels. In this case bands A and C are used. In all other cases the beams use one trunk channel only. Likewise, only one small terminal band is used in any single beam, and small terminal band three is never used on the same beam as trunk channel C. Observing these rules helps to minimize co-channel and adjoint channel interference. The trunking band is nominally 1.5 GHz wide with each channel capable of 550 Mb/s serial MSK traffic as was recommended in the Baseband Processor program. The three small terminal bands are unequal in width but are each nominally 300 MHz wide. The total is about 1 GHz.

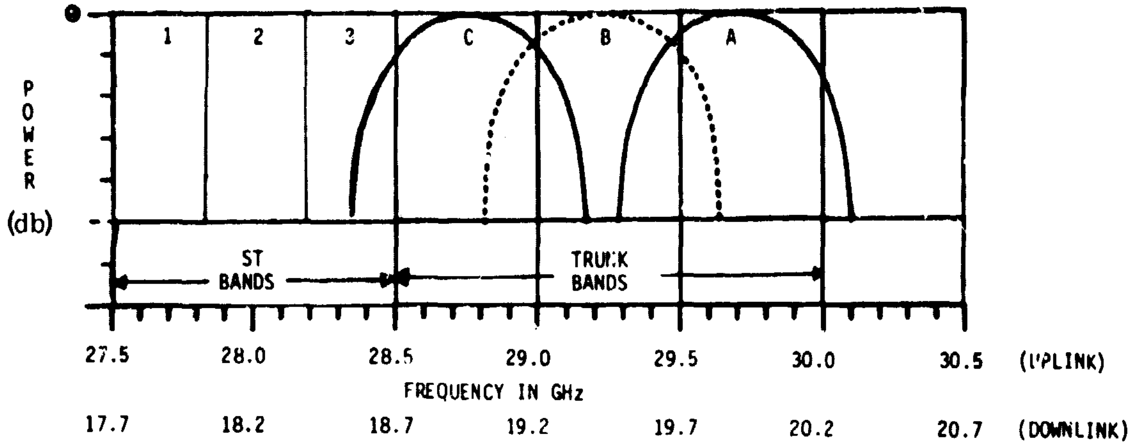


Figure 2.1-5. Traffic Frequency Plan

2.1.14 ST TRAFFIC-CITY AND FREQUENCY BAND ALLOCATION FOR TRAFFIC MODEL A UPLINK

As shown in Table 2.1-6 the ST band has been subdivided into three frequency bands in which the total bandwidth allocated for ST traffic is 833 MHz. The arrangement of cities in a given frequency band is not unique, and any number of arrangements are possible. The key consideration which led to the distribution shown is maintaining cities in close geographical proximity (250 miles separation) in separate frequency bands.

Without regard to the router design the required total bandwidth would be 496 MHz (vs the 833 MHz shown in Table 4.4-1) and each of the cities would require less bandwidth (i.e., New York would be 207 MHz instead of 310 MHz). City numbers shown are that city's position in terms of input/output traffic. For example, New York is the heaviest traffic city, and Hartford is number 33. It should be noted that even though cities are in the same zone they need not overlap in frequency allocation. For example, Kansas City and St. Louis are in the same frequency band and are less than 300 miles apart. However, with the frequency bands of these cities adjacent to one another, they still won't exceed the bandwidth of Frequency Band 2 (i.e., 137 + 147 -307).

Table 2.1-6 ST Traffic-City and Frequency Band Allocation for Traffic Model A Uplink

Frequency Band 1			Frequency Band 2			Frequency Band 3		
City No.	City	BW (MHz)	City No.	City	BW (MHz)	City No.	City	BW (MHz)
1	New York	310	7/16	Wash DC/Phila	307	19/33	Boston/Hartford	183
2	Los Angeles	295	3	Chicago	284	11	Tampa	216
15/32	Det/Cleveland	246	6	Greensboro	238	14	Salt Lake City	203
18/20	Buffalo/Roch	266	21/31	Columbus/Cinn	196	17	Dallas	170
4	Milwaukee	263	9	San Diego	255	24	Lansing	165
5	Indianapolis	255	12	Houston	177	25	Harrisburg	162
8	San Francisco	189	13	Portland	209	29	Atlanta	142
10	Phoenix	244	22	Minn/St Paul	155	42	Louisville	126
26	New Orleans	158	23	Miami	151			
30	Denver	140	27	St Louis	147			
35	Seattle	135	28	Pittsburgh	145			
36	Norfolk	134	34	Kansas City	137			
41	San Antonio	127	37	Syracuse	132			
43	Memphis	125	38	Oklahoma City	131			
44	Omaha	124	39	Nashville	129			
45	Jacksonville	122	40	Fresno	128			
16 Beams Req'd BW = 310 MHz			16 Beams Req'd BW = 307 MHz			8 Beams Req'd BW = 216 MHz		
Total Uplink Bandwidth = 833 MHz Total Downlink Bandwidth = 496 MHz								

2.1.15 BEAM AND FREQUENCY BAND ALLOCATION FOR TRAFFIC MODEL A

Figure 2.1-6 shows a graphical representation of the same data tabulated in a previous section (see ST Traffic City and Frequency Band Allocation for Traffic Model A). Even though the 3 dB bandwidths are shown as circles instead of ellipses, the presentation provides a clear picture of frequency band and city assignments.

The numbers shown accompanying the beam spots are that particular city's position in terms of input/output traffic (i.e., Fresno is number 40 in terms of traffic volume). Two numbers within a circle indicate two cities in one spot. For example, 19/33 refers to Boston/Hartford.

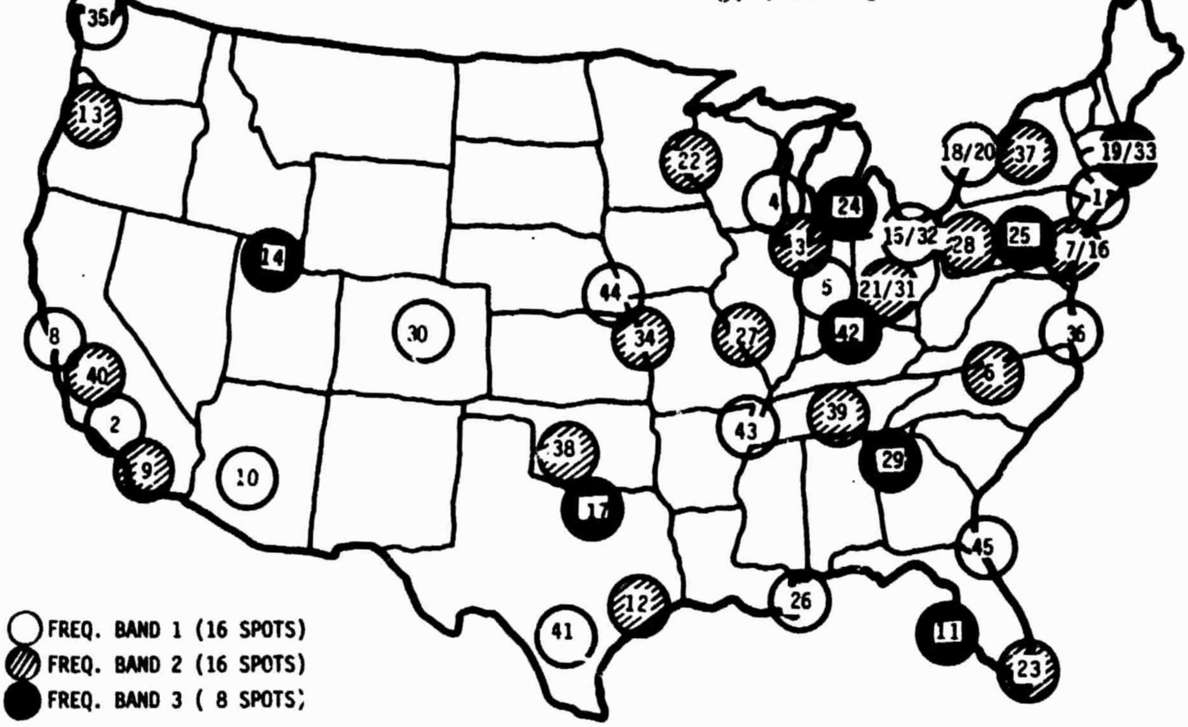


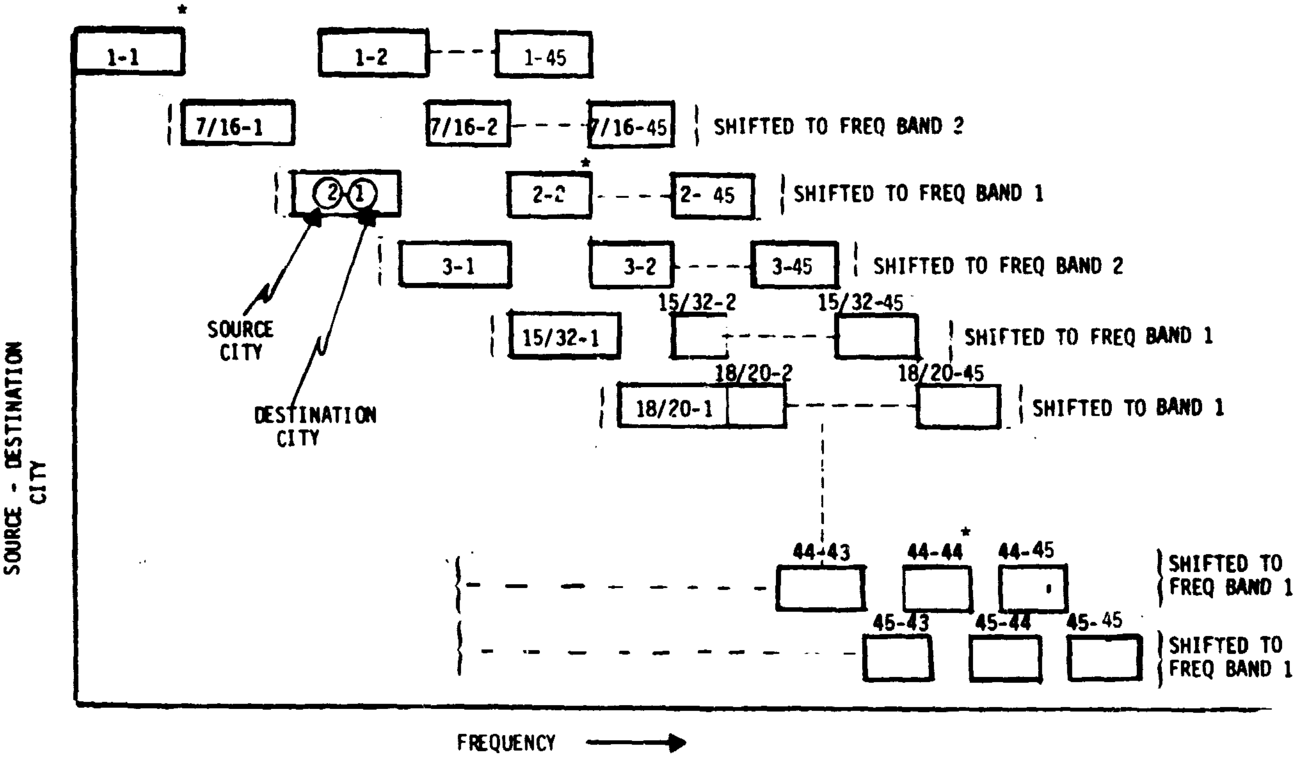
Figure 2.1-6. Map Showing Beam and Frequency and Allocation for Traffic Model A

2.1.16 CHANNEL ARRANGEMENT

The channel arrangement shown in Figure 2.1-7 is designed to simplify the satellite router while still insuring sufficient traffic flexibility. Although this will be discussed in more detail in the section titled "Satellite Routing," some comments are worth noting here.

The numbers shown in each rectangle, m-n, represents traffic frrom source city "m" to destination city "n". In all cases, the destination location, n, is made up of contiguous channel slots. That is, the end of slot 1-1 is even with the beginning of 7/16-1 and the end of 7/16-1 coincides with the beginning of 2-1 and so on. Thus, the traffic to any beam spot does not overlap in the frequency domain with any other traffic to that same destination. This has some definite router switching advantages. Source traffic is arranged in order of descending traffic. That is, the traffic from city number 1 is the heaviest while that from 7/16 is second in volume followed by that from city number 2, and so forth.

Arrangements in other than descending (or ascending) traffic volume will result in a greater required total bandwidth. The above channelization is depicted as if total frequency reuse were possible. In reality, the source transmissions must conform to the overall frequency allocations plan and offset shifts are required as shown.



* IN THE ACTUAL TRAFFIC ALLOCATION THESE SLOTS ARE NOT PRESENT SINCE COMMUNICATION FROM A BEAM SPOT TO ITSELF IS PRECLUDED.

Figure 2.1-7. Channel Arrangement

2.1.17 ST TRAFFIC BEAM SPOT FREQUENCY ALLOCATION TRAFFIC MODEL B

As shown in Table 2.1-7, the ST band has been subdivided into three frequency bands in which the total bandwidth allocated for ST traffic is 1179 HMz. The arrangement of cities in a given frequency band is not unique, and any number of arrangements are possible. The key consideration which led to the distribution shown in maintaining cities in close geographical proximity (250 miles separation) is separate frequency bands.

The beam spot numbers are those shown on the map for Traffic Model B. For the case where multiple spots are indicated these are combined before processing in the router. This will not increase the total bandwidth needed but will increase the necessary satellite transmit power (approximately 1 dB for the arrangement shown).

Without regard to the router design the required total bandwidth would be 609 MHz (vs the 1179 MHz shown in Table 4.4-2) and each of the cities would require less bandwidth. (i.e., New York area would be 280 MHz instead of 316 MHz.)

Table 2.1-7 ST Traffic Beam Spot Frequency Allocation Traffic Model B Uplink

Frequency Band 1		Frequency Band 2		Frequency Band 3	
Beam Spot No.	BW (MHz)	Beam Spot No.	BS (MHz)	Beam Spot No.	BW (MHz)
52	412	22	375	26	392
17	360	30	334	10	322
39	345	67	304	18	313
20	316	71	286	55	298
25	270	28	254	70	292
15	260	14	250	35	281
8	245	5	186	33	276
63	241	24	182	44	265
23	220	9	180	16	236
66	174	34	177	32	232
58	171	43	163	1	209
51	165	45	160	53	202
60	155				
37/46/68	216	11/31/56	198	38/29/57	288
2/36/65	212	49/50/69	195	7/27/54	224
6/21/61	192	4/41/48/64	168	13/40/59	205
		3/19/42	157	12/47/62	189
22 Beams Req'd BW = 412 MHz		25 Beams Req'd BW = 375 MHz		24 Beams Req'd BW = 392 MHz	
Total Uplink Bandwidth = 1179 MHz Total Downlink Bandwidth = 609 MHz					

2.1.18 TRAFFIC MODEL B CITIES ANTENNA BEAM SPOTS

There are 277 metropolitan areas encompassed within seventy-one 0.3° half-power beamwidth spots in Traffic Model B (see Figure 2.1-8). A large number of these spots will be combined onboard the satellite in order to reduce the size and complexity of the ST routing switch.

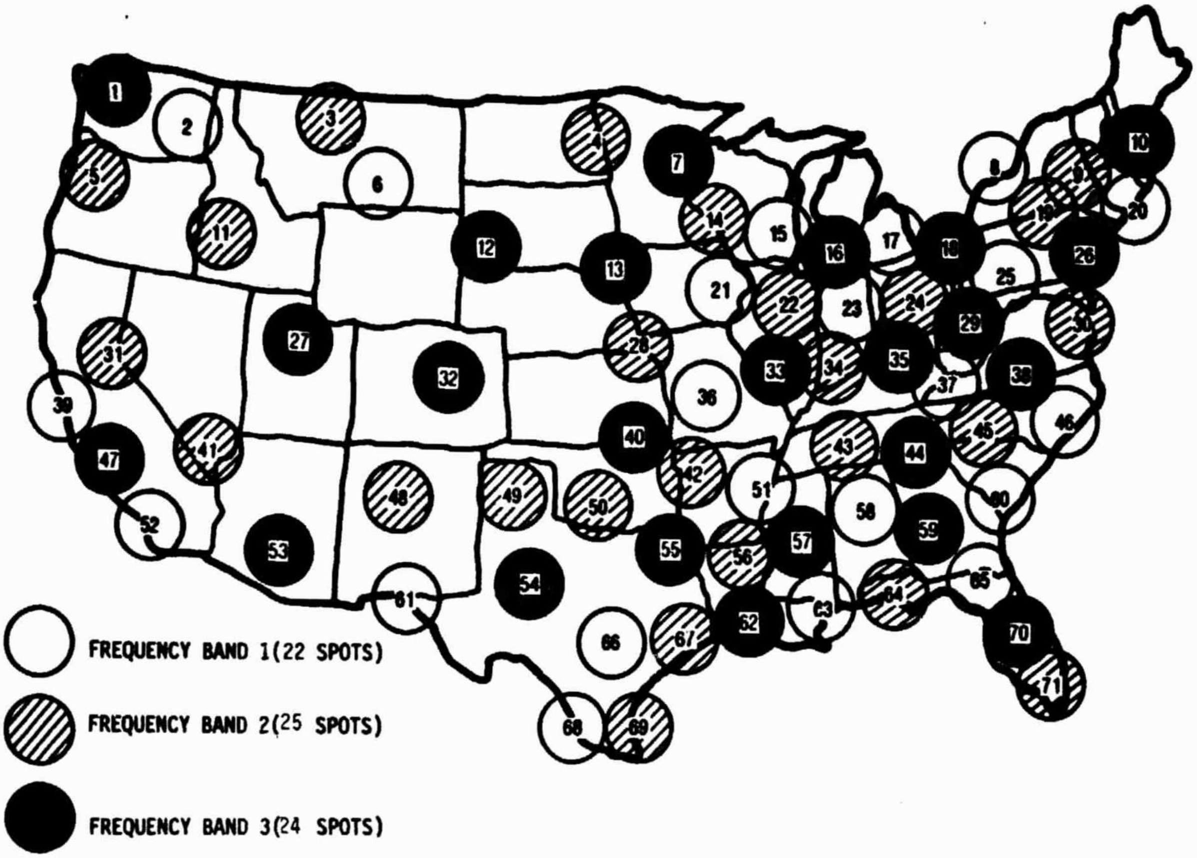


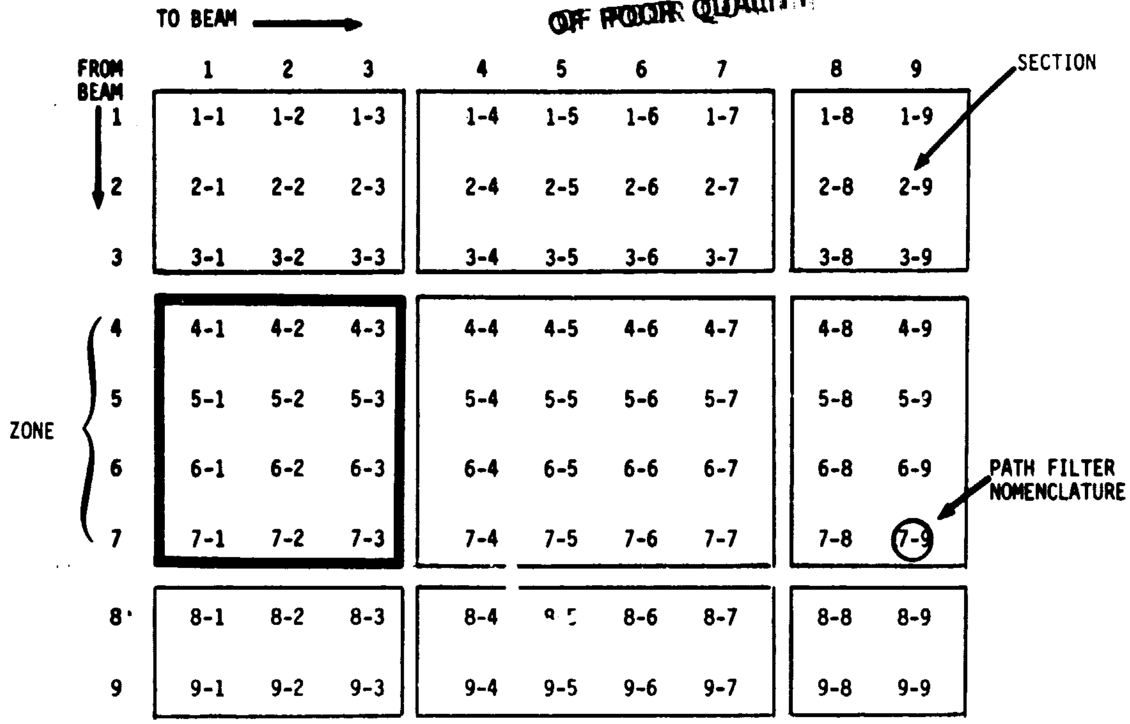
Figure 2.1-8. Traffic Model B Cities Antenna Beam Spots

2.1.19 BEAM AND PATH FILTER MATRIX FOR A NINE BEAM, THREE ZONE ARRANGEMENT

As an illustration of the concepts employed, consider a nine beam system as depicted in the matrix in Figure 2.1-9. With nine beams in which all beams can transfer traffic from any beam to any other beam (including to itself) there must be 81 (9^2) filters if path independence is to be preserved.

For the nine beam configuration, assume that there are three separate zones. Assume still further that the respective three zones contain three beams, four beams, and two beams. The number of beams assigned a zone is dependent on several factors including geographic site location, traffic volume, switching complexity and frequency allocations. With nine beams and zones of three beams, four beams, and two beams, the sections within the matrix are as shown.

The numbers within the matrix represent the nominal path filter nomenclature. That is, for the traffic originating at beam seven with an intended destination to beam nine, the path filter is designated as seven-nine. The bandwidth for this filter is designed to handle the nominal prescribed traffic. As these traffic demands change, the path filter assignments within a section are changed via the router switch. The section shown in bold outline will be used to illustrate basic router switching principles.



	1	2	3	4	5	6	7	8	9
1	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9
2	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9
3	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9
4	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9
5	5-1	5-2	5-3	5-4	5-5	5-6	5-7	5-8	5-9
6	6-1	6-2	6-3	6-4	6-5	6-6	6-7	6-8	6-9
7	7-1	7-2	7-3	7-4	7-5	7-6	7-7	7-8	7-9
8	8-1	8-2	8-3	8-4	8-5	8-6	8-7	8-8	8-9
9	9-1	9-2	9-3	9-4	9-5	9-6	9-7	9-8	9-9

Figure 2.1-9. Beam and Path Filter Matrix for a Nine Beam, Three Zone Arrangement

2.1.20 ROUTER SWITCH COMPLEXITY

A comparison of the impact of element versus row-column switching and the impact of zonal organization may be summarized as follows:

- Proportional to number of crosspoints using 9 beam example previously shown
  1. Total interchange: no zoning
     Number Crosspoints = $(81^2)(2) = 13122$
     Relative Power Required = 0 dB (Reference)
  2. Zoning: element interchange within a section
     Number Crosspoints = 1682
     Relative Power Required = −8.9 dB
  3. Zoning: row and column interchange within a section
     Number of Crosspoints = 174
     Relative Power Required = −18.8 dB
- Chosen method for operational systems
  1. Zoning with row switching within a section
  2. Column switching between sections

The relative power is based upon a unit value for no zoning and element switching. The other assumes equal power per switch point.

The selected method for both A and B systems uses five (5) or six (6) zones respectively. Row switching is used within a section. However, column switching is over all sections.

In the present frequency plan that exists internal to the router, there is a potential frequency conflict using sector column switching. The conflict does not exist with full column switching. Therefore, the latter was selected at this time. The problem is not fundamental. Also the solution does not significantly alter the router size, weight, and power.

2.1.21 ROUTER CONFIGURATION

A three dimensional pictorial view of the router is shown in Figure 2.1-10. This illustrates the traffic flow. Incoming traffic from a beam in Zone 1 is routed by frequency and distributed by a 1:5 power splitter. Each of these outputs is applied to one of five sectors (with five zones there are five squared sectors). In the lower left hand corner is shown a blowup of one such sector. The inputs from the eight beams in one zone are applied to one 8 × 8 row switch then further separated in a 1:8 power divider. Individual paths are then filtered in a bank of 64 surface acoustic wave (SAW) filters. The outputs are recombined in an 8:1 power summer. Data then rotates 90° between power division and power summation. The sector output is summed in the 5:1 beam summers with outputs of the other five sectors that contribute to that beam. Not shown is the final column switch that can interchange the column of paths that apply to any one beam.

This diagram best illustrates the horizontal-to-vertical rotation that goes on within the router structure. This rotation, coupled with the switching, is what allows the interchange of path characteristics in an economical manner.

2.1.22 SATELLITE ROUTER SIMPLIFIED BLOCK DIAGRAM

A segment of the router is shown in Figure 2.1-11 in which the primary emphasis is in presenting the switching and path filter arrangements. For any input beam, the first power splitter breaks the input signal into one output for each zone. With five zones, there are thus five outputs required. The row switch which follows the power splitter has one input for each beam in a section. That is, the inputs for any given switch is the eight common row element beams in that section.

The output of the row switch is then split into outputs for each of the beam destinations in that section. There are then 64 filters associated with each row switch (8 inputs × 8 destinations per input). The eight summers following the path filters sum all beams within that section which have a common destination. With eight such destinations there are then eight summers. These eight outputs are then followed by the beam combiner which sums all inputs destined for a particular beam from this section plus those from all other sections. This is then followed by the destination or column switch which has in its input the total traffic intended for all beams in a zone. These outputs are then converted to the proper router IF output frequency. In addition, the router contains a control processor which directs the switch configuration. Commands for this switching operation are generated in the NCS along with a system clock reference. All frequencies for the router are obtained from an internal frequency synthesizer.

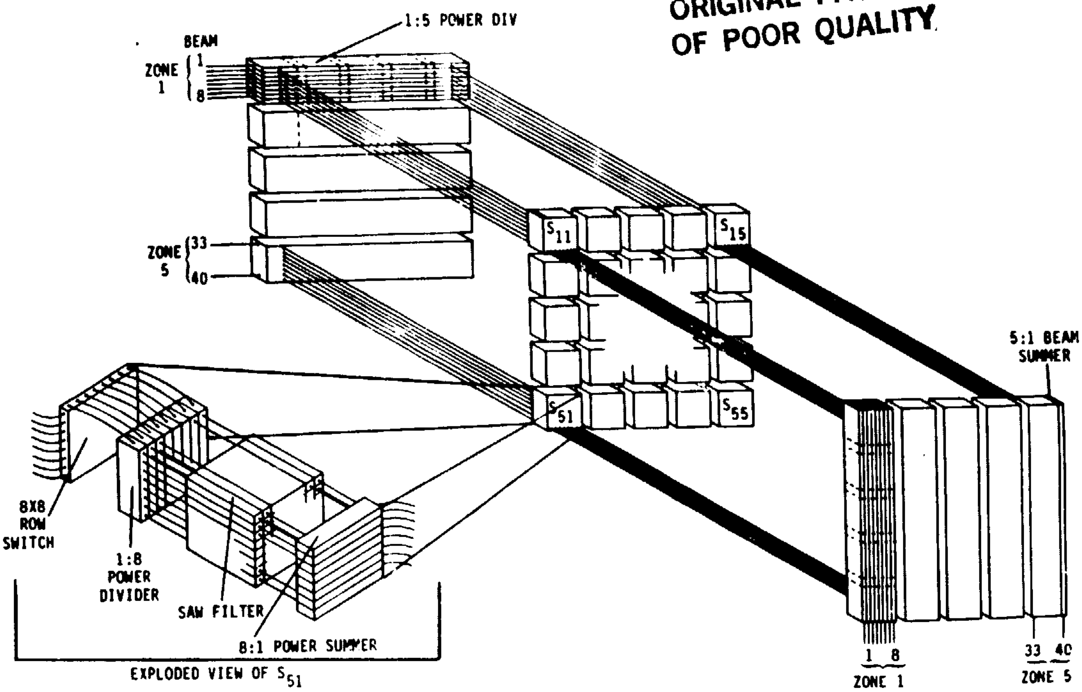
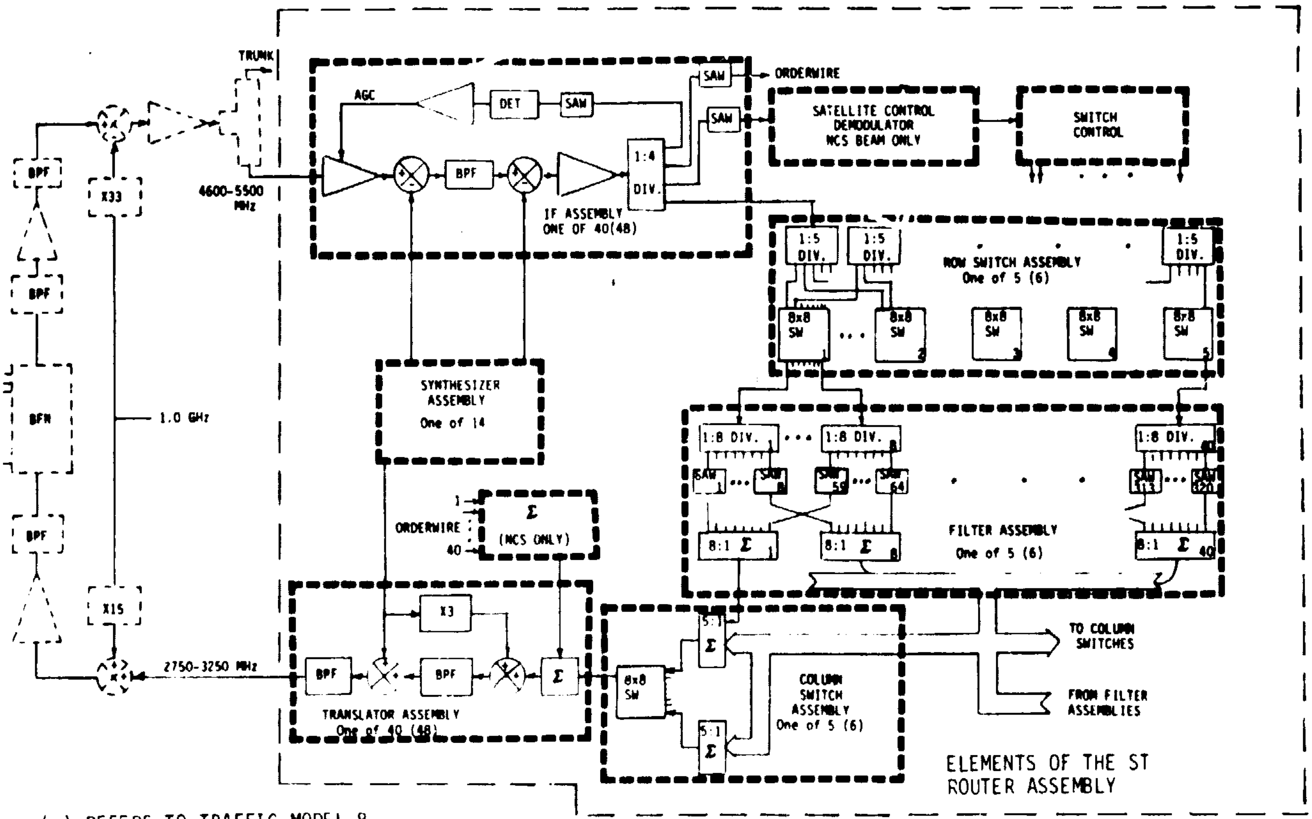


Figure 2.1-10. Router Configuration



( ) REFERS TO TRAFFIC MODEL B

Figure 2.1-11. Satellite Router Simplified Block Diagram

2.1.23 ROUTER FUNCTIONAL REQUIREMENTS

Functional requirements of the router are listed below for Traffic Model A and B:

- Traffic input: Multiple beam FDMA
- Total ST channel quantities available for Traffic Model A and B

Channel →	6.3Mb/s	1.5Mb/s	56 kb/s	32 kb/s	Total Channels
Traffic Model A	80	860	8148	59,088	68,176
Traffic Model B	200	800	7400	48,600	57,000

- Throughput

  up to 50% of available channels
- Beam to beam routing thorugh flexible switching
- Traffic variations

  high volume beams (approximately 18 beams) = ±30%

  other beams = ±50%

- Blocking probability <0.1%
- Linear input to output transfer (no limiting)
- Maximum input bandwidth = 1.5 GHz
- Input/output impedance: 50 ohms, VSWR <1.2:1
- Minimum weight and power

In both cases the router throughout is based on a 32 Kb/s voice traffic rate. Traffic from any input beam will be capable of routing to all other beam locations. In the case of Traffic Model A there are 45 cities in which 5 of the beams are combined to give a resulting 40 inputs to the router. Traffic Model B has 277 cities and approximately 71 beams. Traffic from these beams are combined. The router requirements do not change materially for Traffic Model B as compared to Traffic Model A. In addition to the requirements regarding traffic control, the router must also be responsive to the NCS control signals inputs and must address the selected frequency plan.

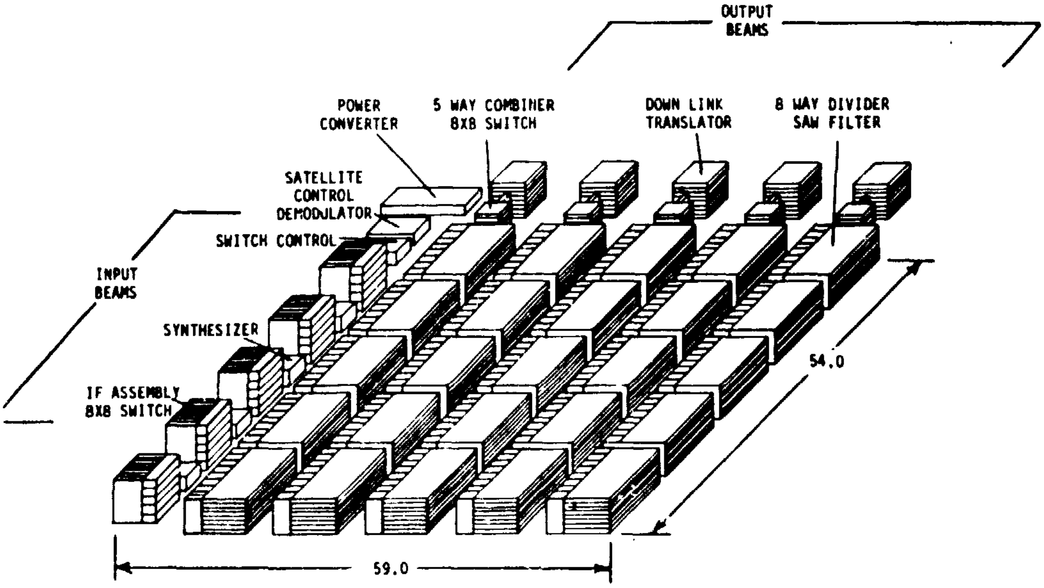
The total small terminal channels available is the sum of all the ST station capacities. Using 65 Kb/s voice the corresponding total available traffic would be about 6 Gb/s for both models. At 50% of available channel use at peak loading this is 3 Gb/s to which must be added the 800 Mb/s trunk to ST traffic.

2.1.24 ROUTER LAYOUT

The layout of the router is essentially an array of individual module stacks mounted on a common baseplate (see Figure 2.1-12). The module stacks have been arranged to minimize the lengths of the interconnecting cables. Referring to Figure 2.1-12, and assuming that rows are from left to right and columns from bottom to top, the input signals to the router from the receiver subsystem are located in each of the IF assembly module stacks on the far left. The outputs from the stacks are distributed to each of the five 8 way divider module stacks located directly to the right in the same row. The output from this stack and each of the other four module stacks in the same column must be routed up to the five way combiner stack located at the top of the drawing. The output from this stack is then routed to the Downlink Translator stack in the same column and the output from this stack, located at the top of the stack, then becomes the input to the transmitter subsystem.

2.1.25 A SLICE THROUGH THE ROUTER

Shown in Figure 2.1-13 is one slice through the Router. A modular approach is used in packaging the router as this has proven to be the most rugged and reliable method of packaging large spaceborne electronic equipment. This packaging scheme will minimize both the size of the router and the number of interconnecting cables needed within the router. Semi-rigid cables must be used on the input to the IF assembly and on the outputs of the Downlink Translator/Amplifier modules. Flexible coaxial cables may be used for all other RF interconnections between the assemblies shown.



ALL DIMENSIONS IN INCHES

Figure 2.1-12. Router Layout

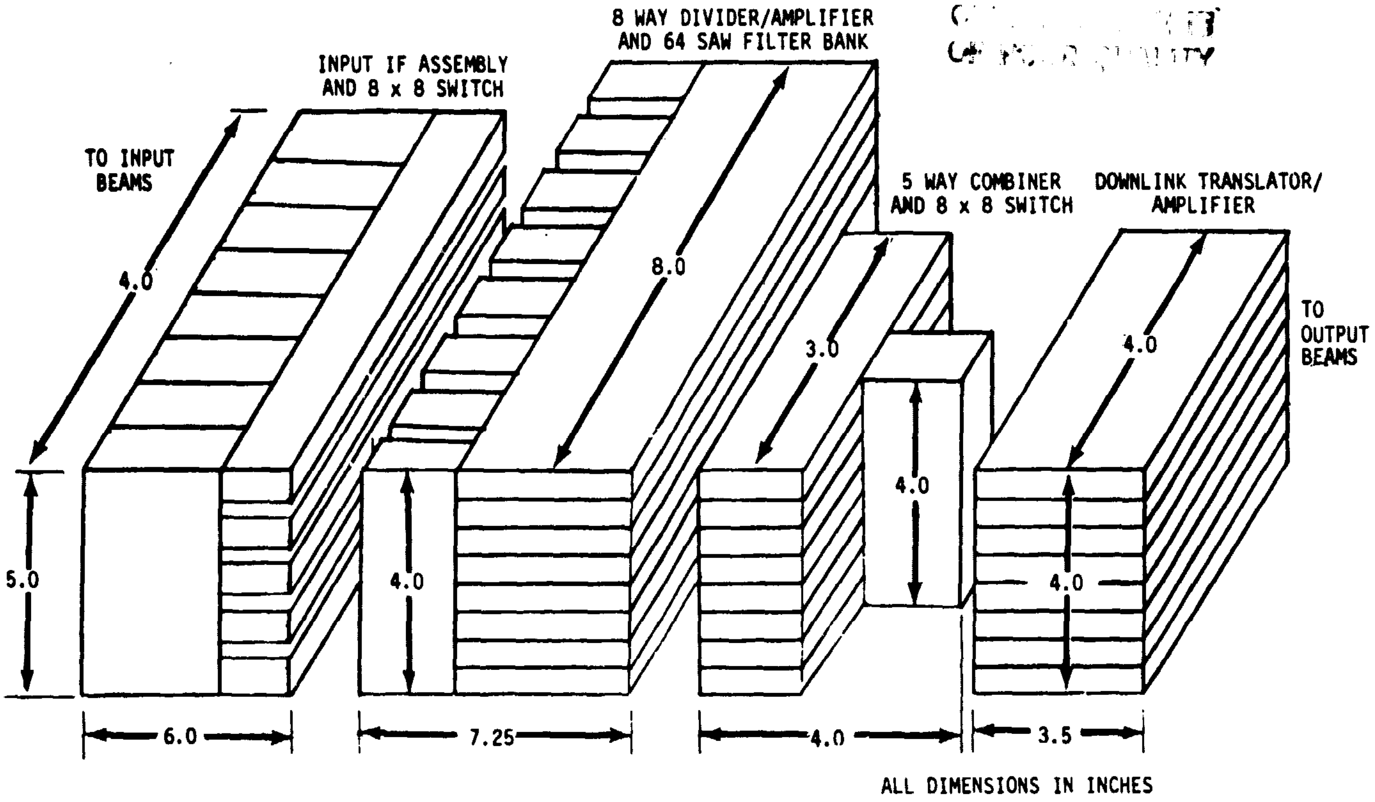


Figure 2.1-13. A Slice Through the Router

2.1.26 ST ROUTER SIZE, WEIGHT, AND POWER SUMMARY

Table 2.1-8 is a summary of the overall size, weight, and power of the ST Router for both Traffic Model A and Traffic Model B. The router for Traffic Model B is the larger of the two because there are more beams associated with Traffic Model B.

Table 2.1-8. Router S_Z, W_T, and Power

	Weight (lb)	Power (watt)	Size (ft^3)
ST Router—Traffic Model A	353	195	9.2
ST Router—Traffic Model B	498	244	12.6
Traffic Model A—40 Beams—25 Sectors Traffic Model B—71 Beams—36 Sectors			

2.1.27 ROUTER RELIABILITY SUMMARY

The initial reliability study performed on the FDM was limited to the Router Switching Network.

The probability of success for 67.6% throughput of the Router Switching has been calculated to be 0.9667 for a 10 year mission.

Studies indicate that in addition to the redundant 8 × 8 switch, additional redundancies will be required for those elements which are common to each of the beam switching paths. These elements include oscillators, synthesizers, power supplies, and switch controls.

The 8 × 8 switches intended for use in the FDM Router Switching will be a modification to switches developed on the Baseband Processor program.

2.1.28 SYSTEM CONTROL CONCEPT

As shown in Figure 2.1-14, the system control consists of the following four control links:

- Access Control Link

  The user initiates his call request through the access control link by using the ordinary telephone signalling information.

- Orderwire Control Link

  It conveys request and status messages between ground stations and the network control station through the satellite and provides the following functions:

  - Communication frequencies assignment
  - Terminal coding and/or power adaptation control
  - Time and frequency standards for ST stations
  - Diagnosis and monitoring of ST stations

- Satellite Control Link

  It conveys command, control, and supervision messages between the satellite and the network control station and provides the following functions:

  - Satellite path rearrangement
  - Satellite radiated power control
  - TT&C
  - Time and frequency standard for the satellite

- Traffic Link

  Once a traffic link is established, all user's messages are transmitted through the traffic link.

2.1.29 NCS FUNCTIONAL REQUIREMENTS

As shown in Figure 2.1-15, the NCS functional requirements are divided into four functional areas:

- System Management
- Satellite Control
- Orderwire
- NCS Computer

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The NCS computer is the focal point for the three remaining functions. The NCS computer coordinates the interchange of data. As examples:

- System operation (a System Management function) is the function that establishes the traffic paths between the small terminals. System operation function relies on the signalling and supervision information provided by the Orderwire function.
- Maintenance function provides beam status and network fault diagnosis. The NCS computer must input data from:
  - Satellite control function (TT&C), and
  - The orderwire (small terminal status)

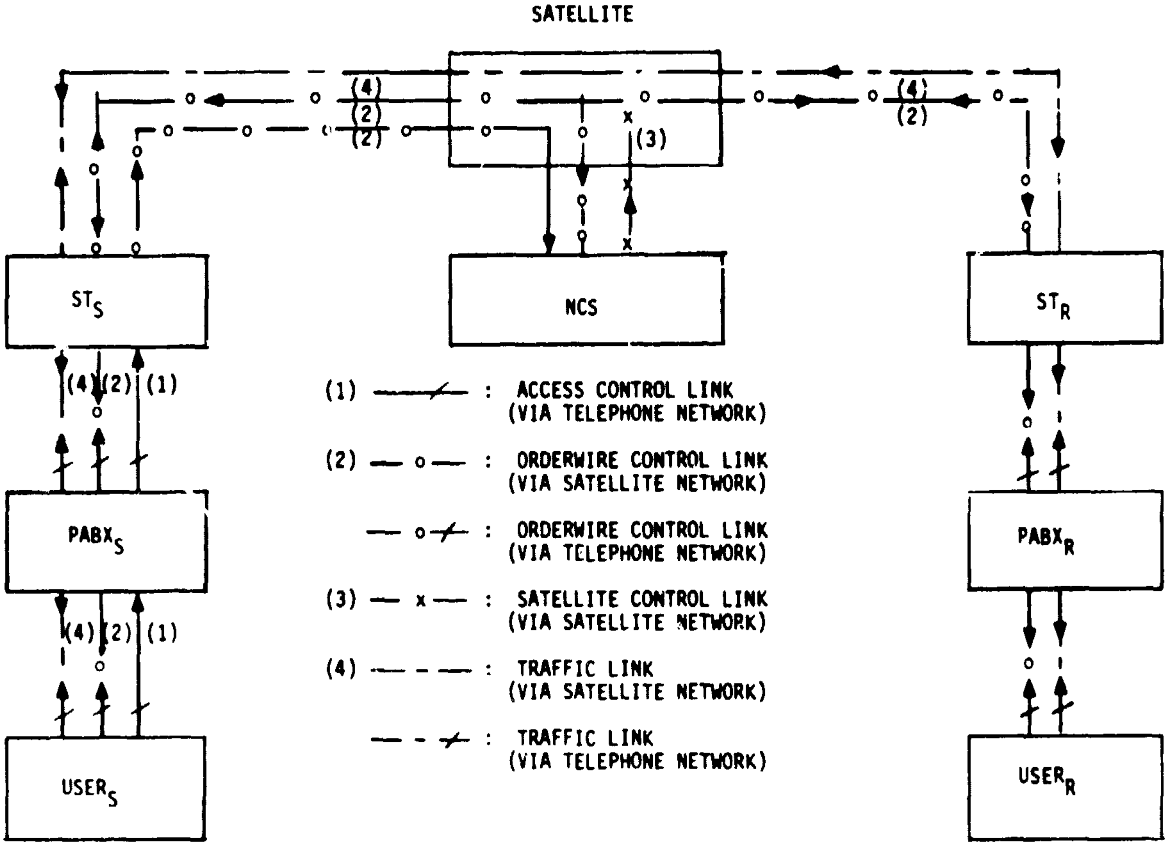

Figure 2.1-14. System Control Concept

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2.1.30 NCS BLOCK DIAGRAM

A simplified block diagram of the Network Control Station is shown in Figure 2.1-16. The baseline orderwire architecture incorporates 40 unique frequencies (one frequency per beam) for transmission and reception. Satellite control will be effected over a dedicated channel to the satellite.

The channels (transmitters and receivers) will include convolutional encoding/decoding to maintain BER $\leq 1 \times 10^{6}$.

A time/frequency reference will be used as the station clock. The time/frequency reference shall be transmitted over the orderwire channels to ensure that all stations operating within the system are time referenced to the NCS.

The NCS will provide processors for system operation and maintenance functions; telemetry, tracking, control of the satellite; billing and system reconfigurations; and ST adaptive control. The four processors will be slaved to a station computer. The station computer coordinates and controls all NCS functions. A space diversity switch is included to route communication to/from a remote trunking station RF subsystem (HPA, LNA, ANTENNA, and UP/DOWN CONVERTERS). Space diversity is used in combatting severe weather conditions at the primary trunking station site.

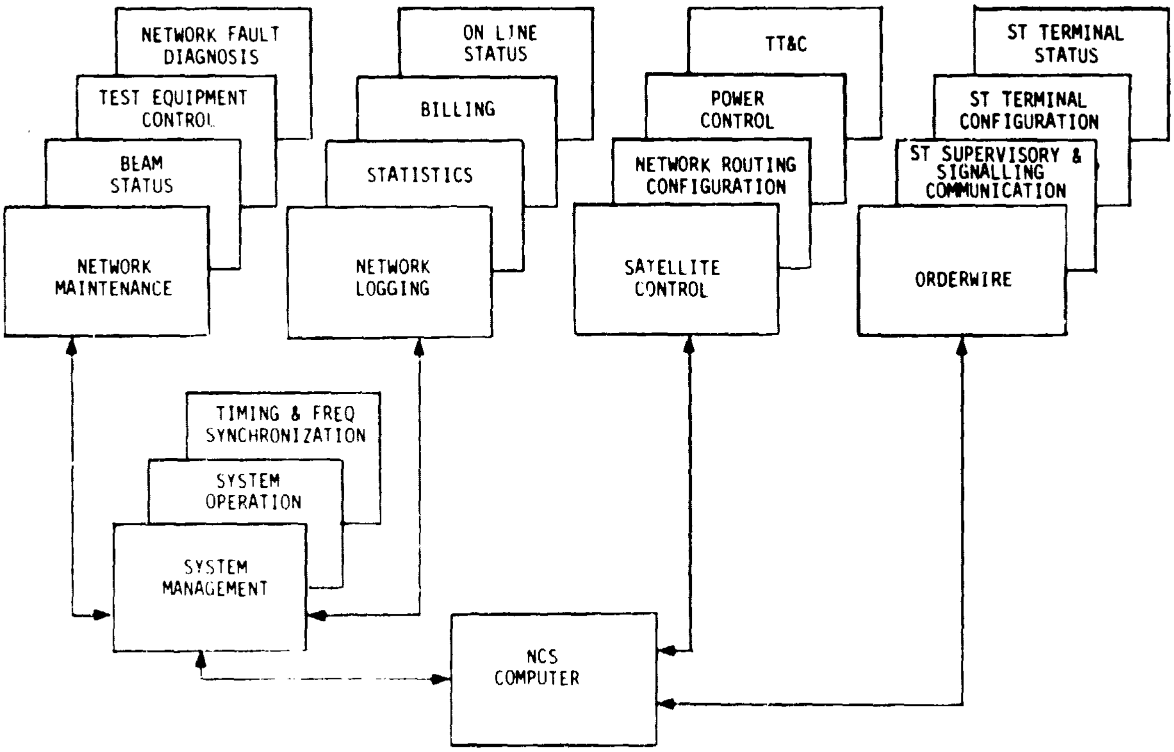

Figure 2.1-15. NCS Functional Requirements

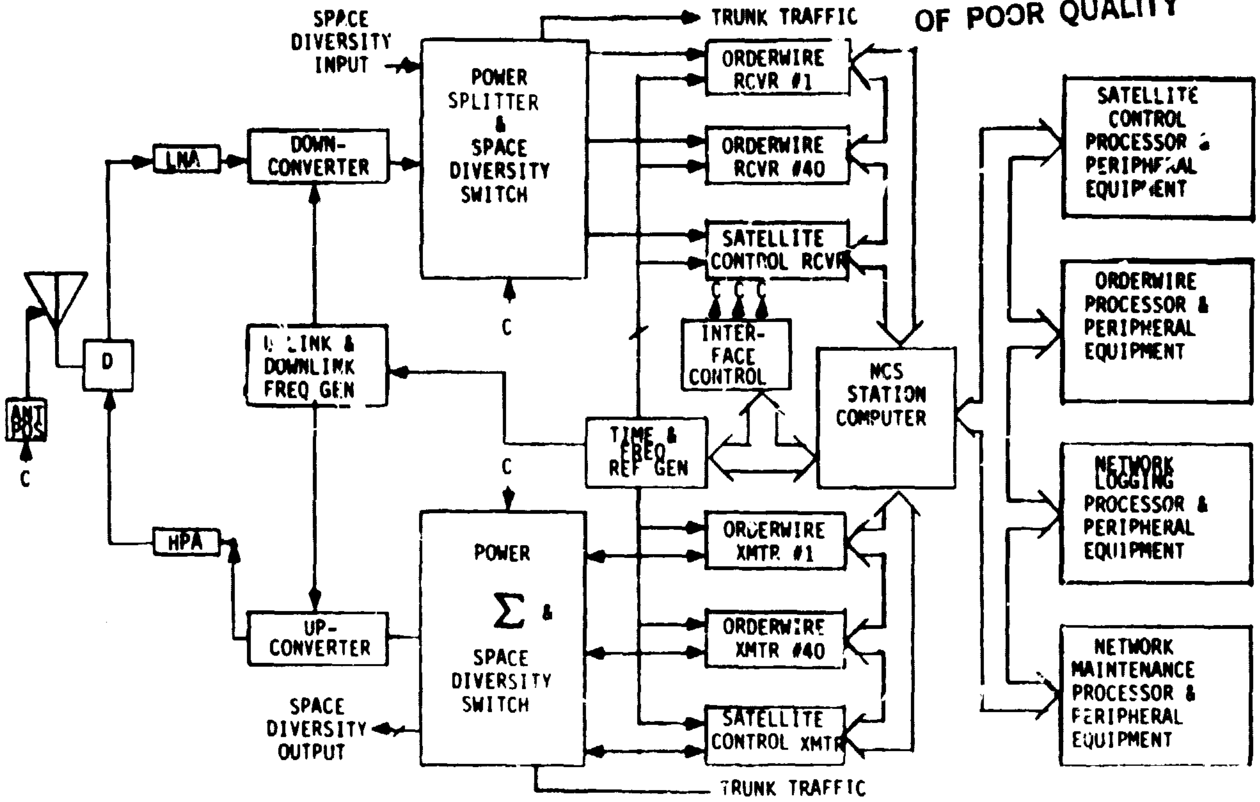

Figure 2.1-16. NCS Block Diagram

2.1.31 *NCS PERFORMANCE SUMMARY*

The NCS is part of a trunking station. Common circuitry of the NCS and trunking station includes the LNA, HPA, and Antenna. Since the trunking station is presently undefined, the transmit characteristics and receive characteristics of the NCS are presented in Table 2.1-9 are in terms of EIRP and G/T. The transmit and receive characteristics are the combined requirements of the Orderwire and Satellite Control links. Traffic Model A requires 40 channels of orderwire and Traffic Model B requires 71 channels of orderwire. At least one additional channel will be used for Satellite Control.

The bandwidths assume FEC and includes the orderwire bandwidth and the 0.5 MHz dedicated to Satellite Control. The EIRP requirements are based on the satellite's receiver performance and the link margin previously defined for the traffic uplink at 30 GHz. The specified no rain EIRP will provide a BER $\leq 1 \times 10^{-8}$ for the NCS transmit link.

The specified G/T requirements will provide a BER $\leq 1 \times 10^{-8}$ for the NCS receive link.

The specified frequency stability is a baseline performance specification based on practical cost and technology.

Table 2.1-9. NCS Performance Summary

TRANSMIT CHARACTERISTICS	
Traffic Model A	Traffic Model B
BW - 5 MHz (Composite) Bit Rate - 2.5 Mbps (Composite) Channels Required - 41 No Rain, EIRP - 86.5 dBm	4.3 MHz (Composite) 2.15 Mbks (Composite) 72 85.8 dBm
RECEIVE CHARACTERISTICS	
Traffic Model A	Traffic Model B
BW - 5.0 MHz (Composite) Bit Rate - 2.5 Mbps (Composite) Channels Required - 41	4.3 MHz (Composite) 2.15 Mbps (Composite) 72
G/T - 28.5 dB/°K (Based on satellite EIRP density of 6.2 dBm/bit)	
Frequency Stability Better Than - 1×10^{-8} BER < 1×10^{-8} Forward Error Correction Encoding Constraint Length - 5 Rate - 1/2 Bit Decision - 2 Bit Soft Decision	

2.1.32 MULTICHANNEL ST BLOCK DIAGRAM

The multi-channel ST as shown in Figure 2.1-17 is characteristic of the E, F, and G class terminals in Traffic Model A and the E, F, G, H, and I terminals of Traffic Model B.

The multi-channel small terminal is comprised of the same subsystems as the single channel small terminal. The TIU, traffic transmitters and traffic receivers will increase on a one for one basis as the channel capacity increases.

The TIU capacity may be increased by adding a module to the TIU subsystem main frame for each channel added. Complete subsystems (traffic receivers and traffic transmitters) must be added for each additional channel added. The orderwire subsystem will not change since all channels are controlled from a single bus structure.

Additional HPA's, different antenna sizes and antenna positioning control must be added as channel capacity increases (increased EIRP requirements). If necessary, the Ka-band outputs may be summed spatially in a Cassegrain feed structure at the antenna.

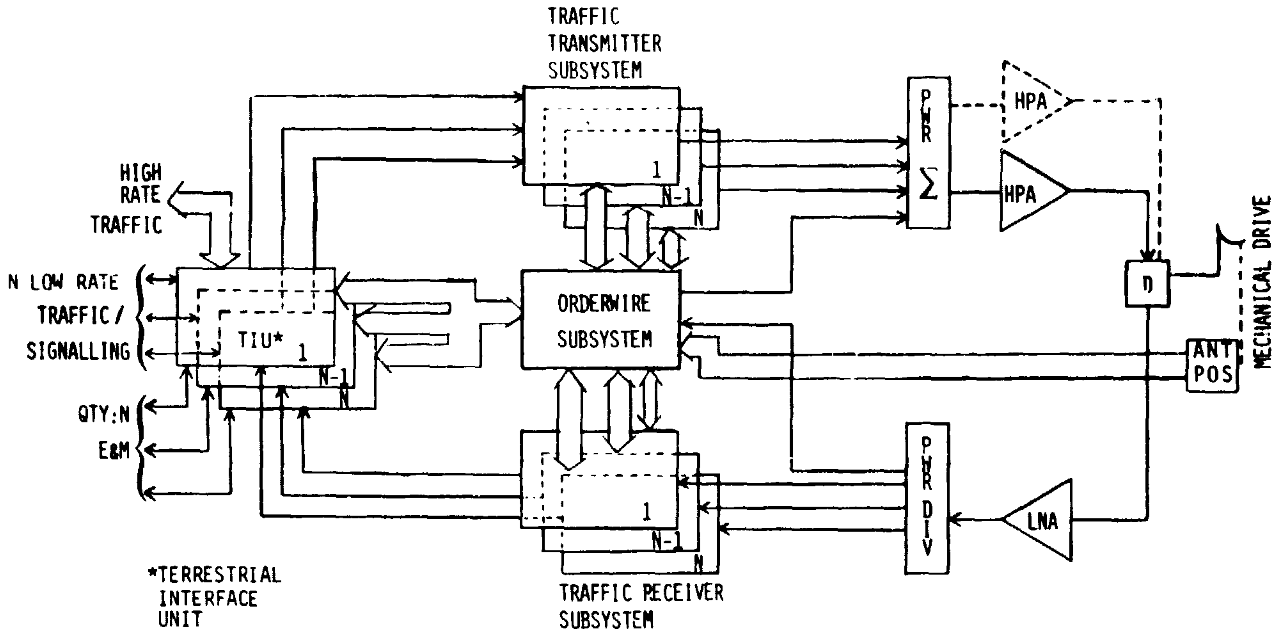

Figure 2.1-17. Channel Arrangement

The high rate user interface is a direct hardwired interface over dedicated lines. The high rate data is inputted/outputted by the TIU. The TIU contains I/O bus circuitry and reclocking circuitry. The signalling and supervision signals are provided by a companion low rate traffic circuit.

2.1.33 SMALL TERMINAL RF CHARACTERISTICS SUMMARY (BER 1×10^{-6})

The antenna size, HPA power, and LNA noise temperature for the Traffic Model A stations, shown in Table 2.1-10, were determined through parametric analysis. The parametric analysis is presented in sections 7.12, 7.13, 7.14, and 7.15. Parametric analysis was not performed on Traffic Model B stations. The equipment characteristics for Traffic Model B stations are based on Traffic Model A stations of comparable capacities.

The HPA saturated power sizes the maximum power capability required. Normal operation (rain fade and clear conditions) will be backed off from the saturated power. The powers listed are intended only to show the range of power required for each class of station.

The LNA noise temperature listed includes the noise temperature of the antenna due to rain (290°K). Delta PSK modulation will be used on the traffic channels. The FEC characteristics as listed will provide the required signal to noise ratio (downlink rain fade) to achieve the required BER when the downlink is experiencing rain fade.

The LNA low noise temperature characteristics for the smaller classes of stations is a paradox: The better LNA's when operated with a smaller antenna results in minimum station costs.

Table 2.1-10. Small Terminal RF Characteristics Summary (BER 1 × 10^{-6})

	Traffic Model A			Traffic Model B					
Equipment	E	F	G	E	F	G	H	I	J
Antenna Diameter (M)	6	5	4	6	5	4	4	4	4
HPA (Saturated Power)	200 W	50 W	10 W	100 W	25 W	10 W	5 W	5 W	1 W
Rain Fade	≈75 W	≈15 W	≈3 W	≈25 W	≈7 W	≈2 W	≈1.5 W	≈1 W	≈200 mW
Clear (No Rain)	≈ 3 W	≈0.5 W	≈0.1 W	≈0.7 W	≈0.2 W	≈75 mW	≈56 mW	≈30 mW	≈5 mW
LNA (Max. Noise Temperature in °K)	1621	1148	724	1621	1148	724	724	724	724

Modem: - O-QPSK

FEC CODEC - Rate 1/2, Constraint Length 5, 2 Bit Soft Decision

2.1.34 ST RECEIVE, TRANSMIT AND INTERFACE CHARACTERISTICS

EIRP and G/T requirements shown in Table 2.1-11 were determined by link budgets giving a total system EB/NO >10.6 dB (BER $\leq 10^{-6}$) when maximum rain fade occurs on the uplink and downlink.

The user interface functional requirements are based on the most common type of signalling anticipated in the 1987 time frame. As a baseline assumption, potential subscribers with unique interface requirements will provide the necessary interfacing equipment which will make their user interface compatible with the ST TIU. Commercial equipment is readily available to satisfy many unique interface requirements.

Table 2.1-11. ST Receive, Transmit and Interface Characteristics

	Traffic Model A Class			Traffic Model B Class					
	E	F	G	E	F	G	H	I	J
EIRP (With Rain Fade) dBm	109.8	101.3	92.6	105.1	98.5	91.4	90	87.7	80.7
Ant Gain (dB)	61.8	60.3	58.3	61.8	60.3	58.3	58.3	58.3	58.3
HPA (dBm)	48.0	41.0	34.3	43.3	38.3	33.1	31.7	29.4	22.4
G/T (dB/°K)	27	27	27	27	27	27	27	27	27
Ant Gain (dB Min)	59.1	57.6	55.6	59.1	57.6	55.6	55.6	55.6	55.6
Sys Noise Temp (Max. °K)	1621	1148	724	1621	1148	724	724	724	724
USER INTERFACE Low Rate and Voice — Standard two wire inband signalling interface. Baseline signaling is assumed to be dual tone (touch tone). Supervisory information provided by two wire E&M.									

2.1.35 ST ORDERWIRE CHARACTERISTICS

Table 2.1-12 is a summary of the small terminal orderwire characteristics. The orderwire communication link between the NCS and ST should perform at better than the specified traffic BER (1×10^{-6}). As a baseline, the OW BER is established at 1×10^{-8}. The orderwire communication link shares the ST traffic link's HPA and LNA. To achieve the required OW BER, FEC will be implemented on a permanent basis.

Capacity for call initiation/termination is based on the worst case beam capacity (New York). Per protocol, each call will require 3 separate sets ST↔NCS data transfers. Each ST transmit requires 300 bits. Each ST receive requires 600 bits. As a minimum, 108 slots per second must be available (5 msec slot duration). The ST transmitted data in each slot must contain 300 bits.

The transmit data rate is:

$$\frac{300 \text{ BITS}}{5 \text{ msec}} = 60 \text{ kb/s}$$

The receive data rate is:

$$\frac{600 \text{ BITS}}{5 \text{ msec}} = 120 \text{ db/s}$$

The bandwidth requirements include rate 1/2 encoding for FEC.

The capacity for the (Traffic Model B) I and J stations was increased by dedicating more time slots to those stations. Increasing the available time slots reduces the access time to effect a call.

Table 2.1-12. ST Orderwire Characteristics

	Traffic Model A Station			Traffic Model B Station					
	E	F	G	E	F	G	H	I	J
Capacity Required (Calls/second)	5	1.2	0.25	0.6	0.183	0.117	0.117	0.083	0.167
Capability (Calls/second)	5	1.2	0.25	0.6	0.183	0.117	0.117	0.25	0.2

BER $\leq 10^{-8}$

FEC

RATE — 1/2

CONSTRAINT LENGTH — 5

QUANTIZATION — 2 BIT SOFT DECISION

Table 2.1-12. ST Orderwire Characteristics (Cont)

Data Rate

Transmit — 300 bits per 5.0 msec slot (60 kbps burst rate)

Receive — 600 bits per 5.0 msec slot (120 kbps continuous)

RF Bandwidth

Transmit — 120 kHz (includes rate 1/2 encoding)

Receive — 240 kHz (includes rate 1/2 encoding)

2.1.36 SYSTEM ARCHITECTURE SUMMARY (TRAFFIC MODEL A)

Characteristics summarized in Table 2.1-23 are based on either Statement of Work (S.O.W) requirements or response thereto as discussed in the previous sections. The letters shown, in conjunction with the antenna size, transmit power, and traffic rate, are the particular stations defined in the S.O.W. The data modulation selected is O-QPSK although there is not a great deal to choose between it and MSK.

Link improvement will be realized through convolutional encoding and power boost. Uplink rain fades are handled through power boost and downlink through coding and power boost. This, along with frequency and time reference, will be controlled by the NCS as will assignment of path filters in the satellite router. The basic frequency plan has been organized to effect a simpler router design at the expense of bandwidth efficiency.

The frequency plan for the ST traffic will contain three bands which are divided into five zones with eight sections per zone. This will result in all switches in the satellite router being 8 × 8. Required satellite RF transmit power for the ST traffic will be less than 400 watts.

Table 2.1-13. System Architecture Summary (Traffic Model A)

ST STATION TYPE	E	F	G
Antenna Diameter	6	5	4
Transmitter Power (Clear Air)	2	0.4	0.08
Transmitter Saturated Power Req'd	200	50	10
Signal			
Modulation	O-QPSK		
BER, Availability	10^{-6}, 0.999		
Uplink Rain Fade Power Boost	15 dB		
Downlink FEC Fain Protection	3.6 dB ($R = ½, K = 5, Q = 4$ convolutional code)		
Frequency	30 GHz uplink; 20 GHz downlink		
ST Allocated RF Bandwidth	1.0 GHz		
System Control and Monitor	NCS based		
Orderwire Data Rate	2.28 Mbps		
Number of Channels	41		
Access Time	<4 Sec		
Orderwire BER	10^{-8}		
Satellite Transponder			
Trunking Capacity	6.2 Gbps		
ST-ST and ST-Trunk Capacity	3 Gbps		
Number of Antenna Beams	40		
Number of LNR's	40		
Number of HPA's	61		
Size, Weight, Power	336 cu ft, 2656 lbs, 5204 watts		
Satellite RF Power Out	357 watts		
FDMA Router			
Capacity	70,000 channels		
Number of Filter Paths	1600		
Switch Cross Points	1920		
Switch size	8 × 8		
Size, Weight, Power	9.2 cu ft, 353 lbs, 195 watts		

2.1.37 SYSTEM ARCHITECTURE SUMMARY (TRAFFIC MODEL B)

Table 2.1-14 provides the architectural summary for Traffic Model B. The significant differences are the station capacities which range from a single voice channel up to a 36 channel voice, data, and video station. The total throughput is as before. The number of antenna beams has been increased to 71 although the number of router paths has increased only to 48.

Table 2.1-14. System Architecture Summary (Traffic Model B)

ST STATION TYPE	E	F	G	H	I	J
Antenna Diameter	6	5	4	4	4	4
Transmitter Power (Clear Air)	0.7	0.2	0.075	0.056	0.03	0.005
Transmitter Saturated Power Req'd	100	25	10	5	5	1
Signal						
Modulation	O-QPSK					
BER, Availability	10^{-6}, 0.999					
Uplink Rain Fade Power Boost	15 dB					
Downlink FEC Rain Protection	3.6 dB ($R = ½$, $K = 5$, $Q = 4$ convolutional code)					
Frequency	30 GHz uplink; 20 GHz downlink					
ST Allocated RF Bandwidth	1.0 GHz					
System Control and Monitor	NCS based					
Orderwire Data Rate	1.9 Mbps					
Number of Channels	71					
Access Time	<5 sec					
Orderwire BER	10^{-8}					
Satellite Transponder						
Trunking Capacity	6.2 Gbps					
ST-ST and ST-Trunk Capacity	3 Gbps					
Number of Antenna Beams	71					
Number of LNR's	71					
Number of HPA's	93					
Size, Weight, Power	354 cu ft, 3972 lbs, 5944 watts					
Satellite RF Power Out	465 watts					
FDMA Router						
Capacity	57,000 channels					
Number of Filter Paths	2304					
Switch Cross Points	2688					
Switch size	8 × 8					
Size, Weight, Power	12.6 cu ft, 498 lbs, 244 watts					

2.2 Proof of Concept Summary

In overview, the ACST SS-FDMA Proof of Concept (POC) design comprises:

- POC
  - Sector
    - LSI 8 × 8 switch
    - Multiple unidirectional SAW filters
  - Router—Sector Development Plus
    - C-band synthesizer
    - Packaging
- POC CAPABILITY

	Sector	Router
Uplink Frequency	78.9–400.0 MHz	4.6–4.5 GHz
Downlink Frequency	78.9–400.0 MHz	2.3–3.5 GHz
Bandwidth	140.0 MHz	140.0 MHz
Number of Simulated Beams Uplink/Downlink	8	8

- POC BRASSBOARD PHYSICAL

	Sector	Router
Baseplate area	31 × 47 inches	37 × 47 inches

The POC Development recommendation proposed consists of two types of programs: POC Sector or POC Router. The POC Sector essentially develops critical technology of linear LSI 8 × 8 switches and unidirectional SAW filters which are necessary building blocks for any router organization. The POC Router program develops (in addition to the sector technology) secondary technologies of synthesizer and mechanical packaging. In addition, the Router program allows path evaluation at C-band uplink/downlink frequencies where the Sector program operates at much lower frequencies.

2.2.1 POC DEVELOPMENT GOALS

The proof of concept development goals are:

- Develop key technological building blocks necessary for a router organization
- Fabricate a limited proof-of-concept model, utilizing the technology building blocks, to assess and evaluate the technology readiness.
- Develop the necessary deliverable special test equipment to support testing
- Evaluate performance impairment mechanisms, applicable to any typical router, by path evaluation.

The POC goals for this recommendation are primarily directed towards advancing key technology necessary for a Router organization. This was the conclusion drawn from the Task I Final Report on the System Architecture Baseline.

To facilitate the test and evaluation of key technologies, a limited brassboard will be fabricated (along with any deliverable special test equipment), and evaluated for the technological readiness of the critical building blocks for a Full Flight Router Payload.

2.2.2 KEY TECHNOLOGY IDENTIFICATION

The following areas of key technology are identified:

LSI 8 × 8 ANALOG SWITCH

- Key Component in Any Router Organization
- Principal Problems
  - Frequency Response
  - Path Isolation
  - Input Power

HIGH FREQUENCY SYNTHESIZER

- Key Router and Payload Assembly
- Principal Problems
  - Low Power
  - Low EMI susceptibility
  - Low phase noise
  - Flexibility of tuning range

MULTIPLE SAW FILTER IMPLEMENTATION

- Essential for Any Path Definition
- Principal Problems
  - 20:1 frequency response range
  - Efficient packaging requirement

THREE DIMENSIONAL SECTOR FORM FIT CONSTRUCTION

- Key to Practical Router Implementation to Reduce High Number of Interconnects
- Principal Problems
  - Accessibility
  - Heat transfer
  - Structural integrity
  - Stress relief
  - Fabrication tolerance allowance

Task I, System Design, identified four major areas of critical technology that require advanced development for inclusion into a flight type router assembly. Each of the four are listed above with their respective rationale for technology advancement and the key problem areas to be addressed.

2.2.3 TECHNOLOGY DEVELOPMENT

The technology to be developed involves both design and processes:

- LSI 8 × 8 Analog Switch
  LSI development using existing GB6 cell array
- Multiple SAW Filters
  Single substrate development
- High Frequency Synthesizer
  Breadboard development for later LSI implementation
- Three Dimensional Construction
  Dynamic test model subjected to environmental test

The existing GB6 cell array used on the baseband processor (SS-TDMA) will be redesigned for linear operation with a form, fit, and functional LSI chip.

The SAW filters involve multifilter design and fabrication on a single substrate. Major problems associated with this technology are the use of either Quartz or Lithium Niobate for the wide 20:1 frequency response, insertion loss, and RF isolation.

The synthesizer will be designed and breadboarded to demonstrate the feasibility of a highly stable, low phase noise, and flexible synthesizer at C-band.

The reduction of thousands of interconnects requires a separate study to evaluate the three dimensional approach to facilitate form and fit.

2.2.4 TECHNOLOGY EVALUATION

The test and evaluation of this technology will be conducted on a limited proof-of-concept model as follows:

- 8 × 8 Switch — by functional test and POC sector test
- SAW Filters — by functional test and POC sector test
- Synthesizer — by functional test and POC router test
- Three Dimensional Concept — DTM environmental test
- Brassboard Sector POC
  - Includes first two items technology building blocks
  - Path evaluation of transfer function, isolation, and gain stability
  - Input/output frequencies at 8 × 8 switch IF frequency (approximately 100–400 MHz)
- Brassboard Router POC
  - Includes first three items technology building blocks
  - Part evaluation from beam input-to-beam output at the LNA and transmit IF frequencies of approximately 3–5 GHz.

No brassboard sector POC represents a very limited program, where the brassboard Router POC represents an enlarged program to fully demonstrate the path performance characteristics and additional technology that would be applicable for a flight type router.

2.2.5 ROUTER CONFIGURATION

A three dimensional pictorial view of the Router is shown in Figure 2.2-1. This illustrates the traffic flow. Incoming traffic from a beam in Zone 1 is routed by frequency and distributed by a 1:5 power splitter. Each of these outputs is applied to one of five sectors (with five zones there are five squared sectors). In the lower left hand corner is shown a blowup of one such sector. The inputs from the eight beams in one zone are applied to one 8 × 8 row switch then further separated in a 1:8 power divider. Individual paths are then filtered in a bank of 64 surface acoustic wave (SAW) filters. The outputs are recombined in an 8:1 power summer. Data then rotates 90° between power division and power summation. The sector output is summed in the 5:1 beam summers with outputs of the other five sectors that contribute to that beam. Not shown is the final column switch that can interchange the column of paths that apply to any one beam.

This diagram best illustrates the horizontal-to-vertical to horizontal-to-vertical rotation that goes on within the Router structure. This rotation, coupled with the switching, is what allows the interchange of path characteristics in an economical manner.

2.2.6 POC SECTOR DESCRIPTIONS

The POC Sector Brassboard includes four major assemblies which include 18 subassemblies:

- Row Switch Assembly
- SAW Filter Assembly
- Column Combiner Assembly
- Column Switch Assembly

The LSI 8 × 8 switch and unidirectional SAW filters are the main technology building blocks at the Sector level.

The testing philosophy essentially allows evaluation of a path through the Sector with respect to sigal-to-noise degradation, gain variation, and AM-PM conversation.

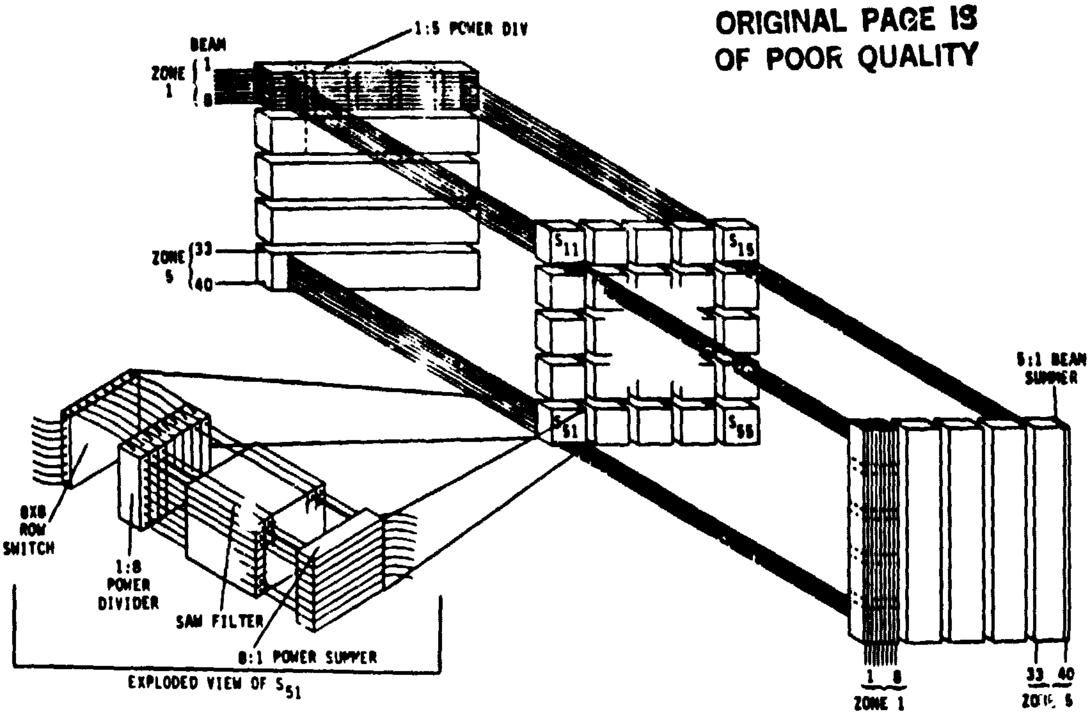

Figure 2.2-1. Router Configuration

2.2.7 POC SECTOR BRASSBOARD PERFORMANCE REQUIREMENTS

The POC sector brassboard performance requirements are:

- POC Capability — 140 MHz
- Switching Arrangement — Limited element pairs within a section
- Switch Control — HPIB BUS via STE
- Input Frequency — UHF: (100–400) MHz
- Output Frequency — UHF: (100–400) MHz
- Number of Simulated uplink beams — eight
- Number of Simulated downlink beams — eight
- Electrical Performance (gain, additive noise, IM generation) — virtual electrical duplication of end item section to be used in flight equipment.

The POC Sector Brassboard is intended to duplicate (in a brassboard configuration) the electrical performance of one section of the FDMA router as defined in paragraph 4.1.2.

The sector capacity of 140 MHz represents a portion (approximately 50 percent) of the larger traffic beams existing in Traffic Models A and B.

The 140 MHz capacity will be achieved with one-half of a normal sector's filter complement (32 versus 64).

Since the filter complement is reduced, switching arrangements will be limited at the sector level. The electrical performance of the POC will be modeled as nearly to the end-item flight sector as practical. The number of inputs, outputs, and associated frequency ranges will be compatible with the switch capabilities.

2.2.8 POC SECTOR BLOCK DIAGRAM

The POC Sector (see Figure 2.2-2) will be suubdivided into 18 modules:

Nomenclature	Qty.
Row Switch Module	1
Filter Module	8
Column Combiner Module	8
Column Switch Module	1

The attenuators at the input to the filter modules are used to stimulate the difference in power reduction between a 1 : 4 divider and 1 : 8 divider. The attenuators at the output of the column combiner modules are used to simulate the difference in power reduction between a 4 : 1 combiner and a 8 : 1 combiner. The attenuator imbedded in the column switch module simulates the 5 : 1 combiner required in the router.

2.2.9 POC SECTOR GAIN DISTRIBUTION

The gain distribution diagram as presented in Figure 2.2-3 is a single path and is representative of any possible gain path through the sector. Since the insertion loss of SAW filters vary with bandwidth, the maximum anticipated SAW filter insertion loss was used. Less lossy SAW filters will require an attenuator to keep the nominal path gain constant.

The input signal noise ratio of 18 dB is degraded to 17.8 dB by the sector's internal thermal noise. Worst case intermodulation products are produced by the row switch. The output intermodulation products are 15.5 dB below the output noise and as a result are inconsequential. The sector's additive noise is insignificant.

2.2.10 LSI 8 × 8 SWITCH REQUIREMENTS

The LSI 8 × 8 switch requirements are (Redesign existing GB6 (BBP) digital 8 × 8 switch):

- Linear Operation
- Decode and Address — external
- Latching — on switch chip
- Isolation — 40 dB
- Crosstalk — 50 dB
- Bandwidth — 300 MHz
- Power Management — internal by latch closure
- Intermodulation — 42 dBc (three tone)
- Interconnection — two layer metal
- Thermal control — heat sink equipped ceramic package

Consideration of the above items is essential in the design of the crossbar switch, and trade-offs must be made among them as several are in direct conflict with others.

The present plan is to perform the decoding and addressing external to the switch but to latch the information at the switch site. This permits the latch to also perform the power management function, greatly reducing the thermal load.

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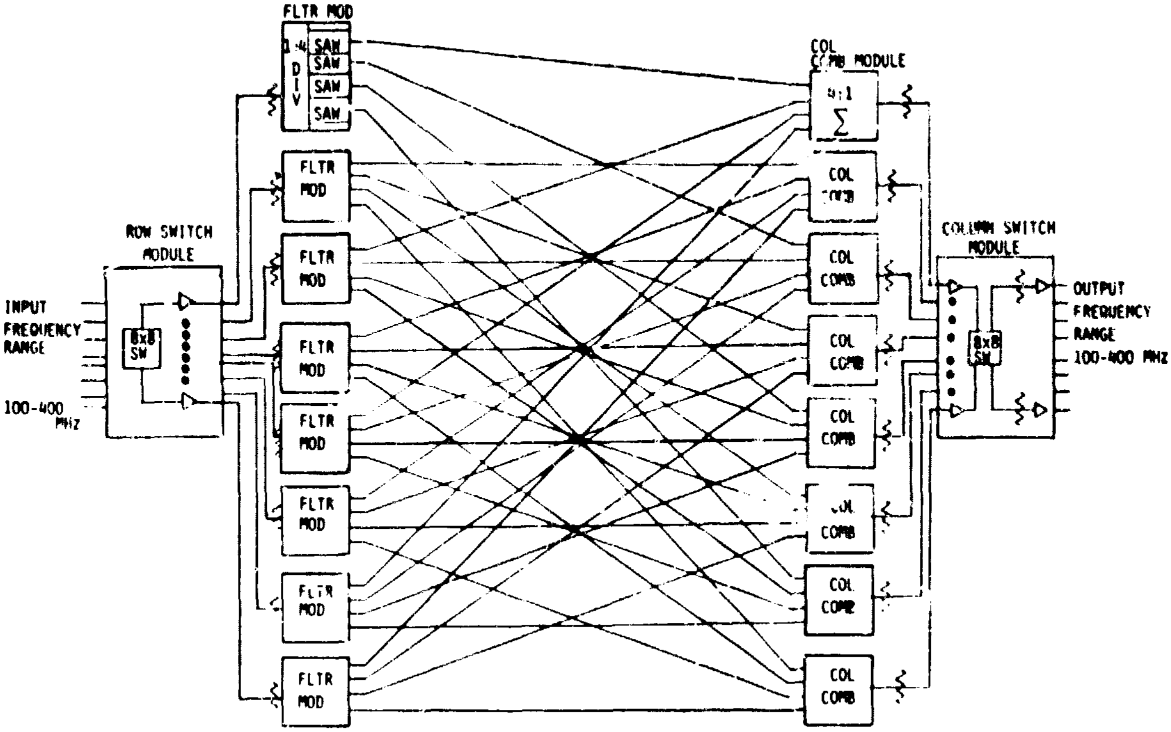


Figure 2.2-2. POC Sector Block Diagram

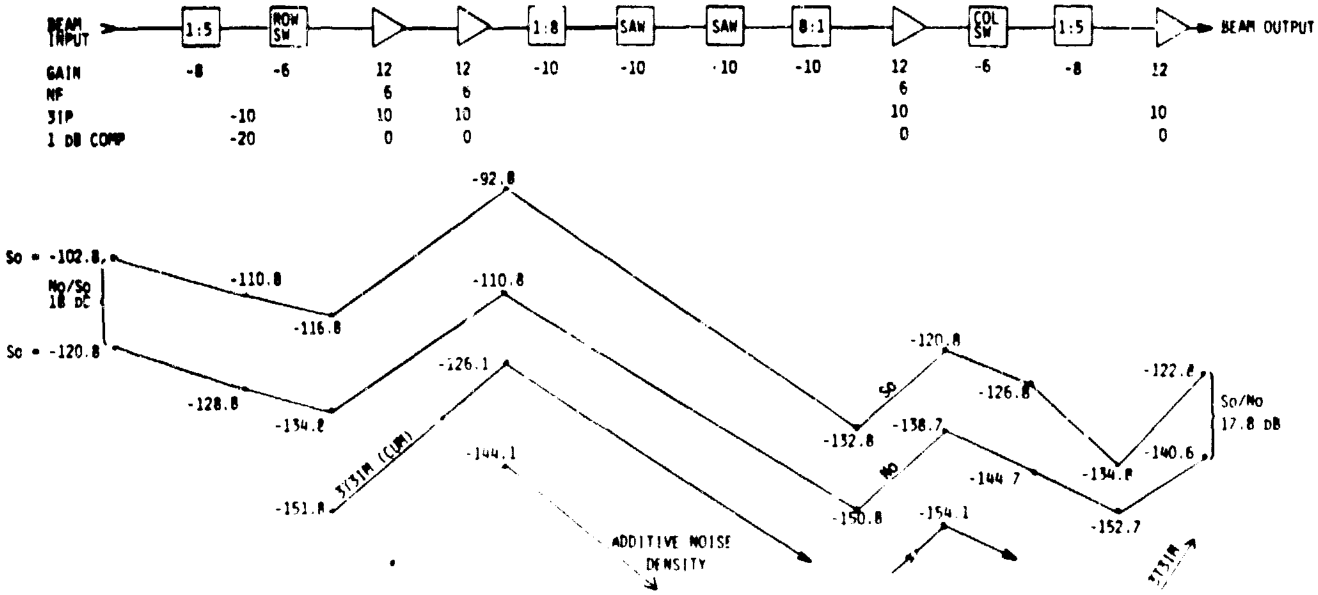


Figure 2.2-3 POC Sector Gain Distribution

The off switch isolation and the cross talk levels of −42 and −50 dB are goals at this time, but the three-tone intermodulation level of −42 dB is a computed value.

2.2.11 SAW FILTER DESIGN

The surface acoustic wave filters have a major impact upon the size and weight of the router. They also indirectly impact the power consumption as the filter insertion loss must be recovered with additional signal gain.

The surface acoustic wave filters for the POC are to demonstrate that the required electrical requirements (see Table 2.2-1) can be reproducibly achieved with tolerable insertion loss over the required frequency range. POC filters are to demonstrate both minimum and maximum bandwidths at the frequency extremes.

Table 2.2-1 SAW Filter Design Requirements

Frequency	Bandwidth
78.9 MHz	1 MHz (1%)
78.9 MHz	2 MHz (2%)
400.0 MHz	2 MHz (0.5%)
400.0 MHz	16 MHz (4%)
Remaining frequencies/bandwidths — TBD	
Technology — Unidirectional versus Bidirectional	
Materials — Quartz and Lithium Niobate Flatness — < 1.0 dB Ripple — < 1.0 dB Phase Linearity — < 6 deg Insertion Loss — < 15 dB Packaging — Sealed Metal Case	

2.2.12 POC SECTOR BRASSBOARD MECHANICAL DEFINITION

The POC Sector Brassboard is comprised of 18 individual modules mounted on a single structural baseplate. The modules will be laid flat to provide easy access for adjustments, testing, or rework. The overall baseplate area will be 31 inches by 37 inches.

Each module will be fabricated from aluminum, and module covers will be provided to eliminate RF leakage. SMA connectors will be used for all RF connections, and multipin connectors will be used for the DC connections. Additional connectors will be provided for test points. Flexible coaxial cables will be used for all RF interconnections between modules.

No environmental testing is planned for the POC model.

2.2.13 SECTOR POC/STE BLOCK DIAGRAM

The basic test mode is semiautomated. The HP 9825 calculator, shown in figure 2.2-4, controls the commercial test equipment used as stimulus and measurement devices. Motorola designed special test equipment includes:

- Input Network Monitor and Control
- Output Network Monitor and Control
- Row Switch Interface
- Column Switch Interface

All the STE is commanded by the HP 9825 calculator via an HP 6940B multiprogrammer. The multiprogrammer provides switch closures to control:

- Coaxial Relays
- Switch Arrangement

Software measurement tests include (but are not limited to)

- Additive Phase Noise Measurements
- Gain Measurements
- Signal Noise Ratio Measurements
- Intermodulation Distortion Measurements

2.2.14 POC ROUTER DESCRIPTION

The POC Router Brassboard includes the POC Sector Brassboard, C-band Upconverters, C-band Downconverters, and C-band Synthesizers. The POC Router Brassboard is an extension of the POC Sector Brassboard to the C-band input and output frequency range.

This section identifies and describes the POC Router Brassboard building blocks with a description of the necessary special test equipment (STE) for evaluation of the POC.

2.2.15 POC ROUTER BRASSBOARD PERFORMANCE REQUIREMENTS

The POC router brassboard performance requests are:

- POC capability — 40 MHz
- Switching arrangement — limited element pairs within a section
- Synthesizer control — HPIB BUS via STE
- Switch Control — HPIB BUS via STE
- Input frequency — C-Band (4.6–5.5) GHz
- Output frequency — C-Band (2.5–3.5) GHz
- Number of simulated uplink beams — one
- Number of simulated downlink beams — eight
- Electrical performance (gain, additive noise, IM generation) virtual duplication of end item section to be used in flight experiment.

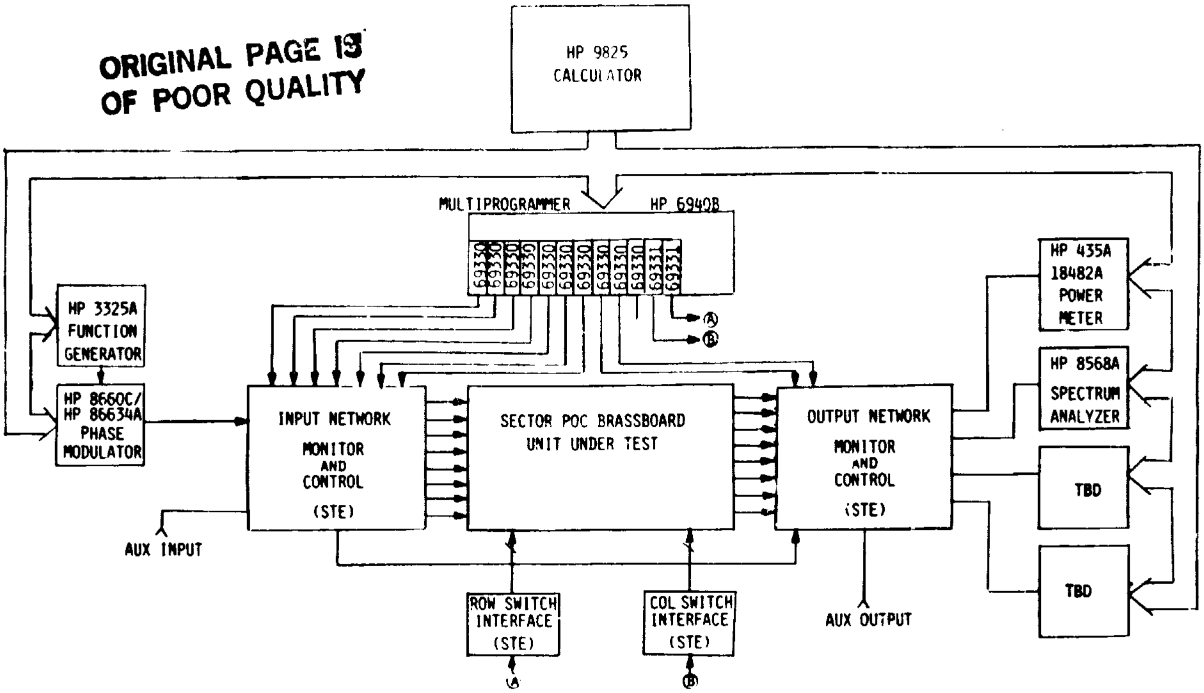


Figure 2.2-4. Sector POC/STE Block Diagram

The POC Sector Brassboard is intended to duplicate (within economic reason) the electrical performance of an FDMA router as defined in Section 5, Task I, Communication System Design Final Report, June 25, 1982.

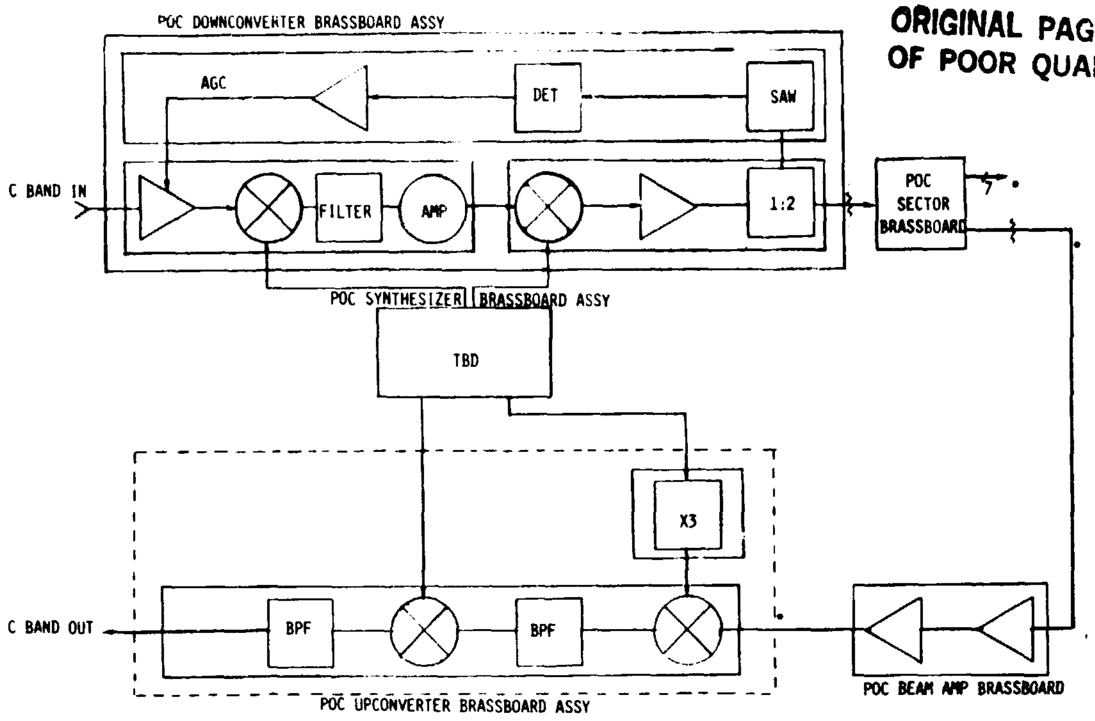
The sector capacity of 140 MHz represents a portion (approximately 50 percent) of the larger traffic beams existing in Traffic Models A and B. The 140 MHz capacity will be achieved with one-half of a normal sector's filter complement (32 vs 64).

Since the filter complement is reduced, switching arrangements will be limited at the sector level. The electrical performance of the POC will be modeled as nearly to the end-item flight router as practical. The number of inputs, outputs and associated frequency ranges will be compatible with the switch capabilities.

2.2.16 POC ROUTER BLOCK DIAGRAM

The POC router will be subdivided into five subassemblies (see Figure 2.2-5). Each assembly will be divided into modules. Present requirements for modules are:

Assembly Name	Modules
Downconverter	3
Sector Assembly	18
Beam Amplifier	1
Upconverter	2
Synthesizer	2
Total	26



* POINTS DENOTED BY ASTERISK MUST BE INTERFACED WITH STE FOR TESTING.

Figure 2.2-5. POC Router Block Diagram

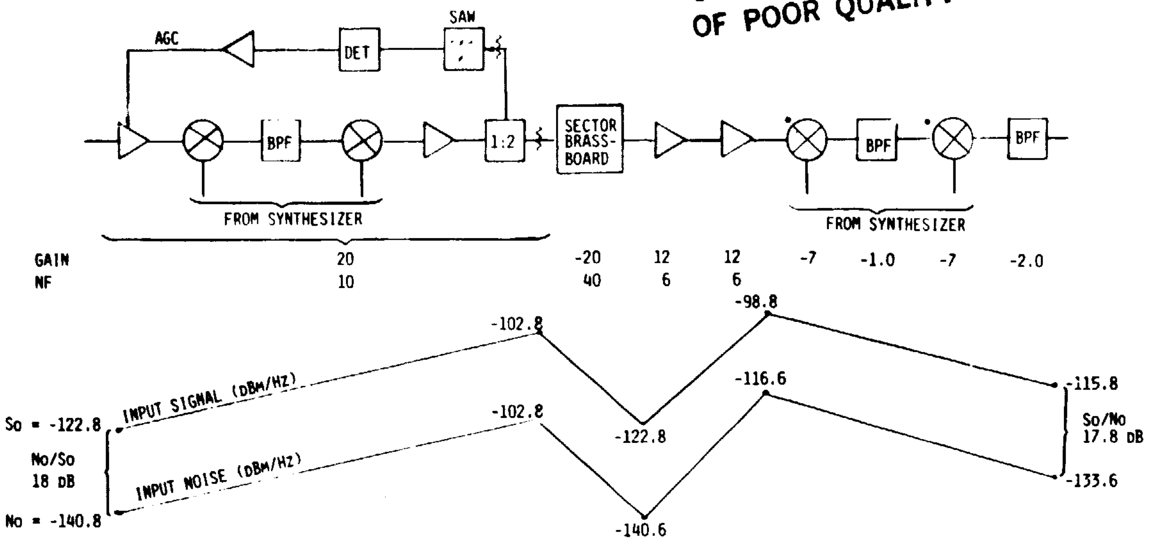
The attenuators located at assembly interfaces are required to simulate the actual gain distribution. The asterisks indicate interconnection points where special test equipments are placed to facilitate monitoring and testing.

2.2.17 POC ROUTER GAIN DISTRIBUTION

The gain distribution (see Figure 2.2-6) is based on an input signal power density (−150 dBm/Hz) that is compatible with the link budget calculations reported in the Task I Final Report. The LNA and associated circuitry preceding the router input are assumed to provide a net gain of 27.2 dB with a noise figure of 6 dB. As a result, the router's input signal power density is −122.8 dBm/Hz and the router's input noise density is −140.8 dBm/Hz.

The router exhibits a net gain of 7 dB and a noise figure of 20.6 dB.

Intermodulation performance is dominated by the sector brassboard capacity. The input frequency translation circuitry (the first two mixers) will not contribute to the intermodulation circuitry. The output frequency translation circuitry (last two mixers) must exhibit a high third order intercept point to prevent BER degradation due to intermodulation products.



* THIRD ORDER INTERCEPT POINT MUST BE GREATER THAN 3 DBM.

Figure 2.2-6. POC Router Gain Distribution

2.2.18 FREQUENCY SYNTHESIZERS

The frequency synthesizers requirements which must be addressed are:

- Added Phase Noise
- Translator Frequency Response
- Conversion Loss
- Step Size
- Intermodulation
- LSi Compatible Design

The frequency plan to be incorporated in the Router design conserves bandwidth on the downlink requiring the outputs of the switching and filtering elements be translated in frequency by a precisely predetermined offset to a different frequency band. Similarly, the uplink IF signals need translation to the frequencies at which the required switching and filtering can be accomplished. The translating frequencies are to be coherently related to the uplink network control carrier frequency.

The wide bandwidth of the composite signal spectrum and the relatively low frequency of realizable filters and switches requires multiple translating to avoid high intermodulation product levels. Both the receiver downconverters and the transmitter upconverters have been modeled as double conversion designs.

2.2.19 POC ROUTER BRASSBOARD MECHANICAL DEFINITION

The router POC model is comprised of five complete assemblies mounted to a single structural plate which contain 23 individual modules. The modules will be laid flat to provide easy access for adjustments, testing, or rework. Each module will be fabricated from aluminum and module covers will be provided to eliminate RF leakage. The overall baseplate area is 47 inches by 37 inches.

SMA connectors will be used for all RF connections and multipin connectors will be used for the DC connections. Additional connectors will be provided for test points. Flexible coaxial cables will be used for all RF interconnections between modules.

No environmental testing is planned for the POC model.

2.2.20 POC ROUTER THREE DIMENSIONAL MECHANICAL DESIGN

The mechanical design is of prime importance in the overall development of the SS-FDMA ST router. The overriding concern is the staggering number of RF coaxial cables needed — nearly 2600 for Traffic Model A design and over 3600 for the Traffic B design. Considering there are four connectors associated with each cable (two on the cable and two that attach to the cable), Traffic Model B design would require more than 14,000 threaded connectors for the RF interconnect system. The result is a system which requires considerable space for cable bends and routing and for connector protrusions. Assembly and rework would be a very difficult and time consuming process.

The most promising method for reducing the number of interconnecting cables is the development of the "three dimensional" packaging concept. The three-dimensional concept is one where modules are physically attached to each other to form one integral unit as opposed to the more traditional method of individually mounting each module to a common baseplate. If the three-dimensional concept were implemented for each sector of the router, where a sector consists of an 8 × 8 input switch, eight 1:8 power dividers, sixty-four SAW filters, eight 8:1 power combiners, and an 8 × 8 output switch, over 2600 cables would be eliminated. This would result in a substantial reduction in the overall size of the router as space required for the cable bends, the cable itself, and connectors is reduced.

2.2.21 ADVANTAGES OF THREE DIMENSIONAL DESIGN

The greatest advantage of the development of the three-dimensional packaging concept is in the reduction of the required number of coaxial cables. This packaging scheme will eliminate over 2000 coaxial cables and 4000 threaded RF connectors from the Traffic Model A router design and nearly 200 coaxial cables and 5800 threaded RF connectors from the Traffic Model B router design. Instead, an RF interconnect will be developed which will allow each module to plug directly into another module. This will result in a design which is much simpler to assemble or disassemble. Also, because the connector and cable are eliminated, a more compact sector design is achieved which, when multiplied times the number of sectors in the router design, results in a substantial reduction in the overall size.

2.2.22 THREE DIMENSIONAL POC MECHANICAL MODEL

The three dimensional mechanical POC model effort consists of:

- Design, analyze, and build one dynamic test model (DTM) of one sector
- Perform finite element structural analysis to optimize initial design
- Fabricate one sector to determine maximum allowable tolerances for plug-in type modules
- Perform environmental tests (random vibration and thermal cycle) to verify structural integrity of sector

The most challenging part of the three-dimensional package design will be to obtain proper alignment of the RF interconnect pins from one module into the others during assembly. This is critical to both the electrical performance and the structural integrity of the RF interconnect.

The three-dimensional concept requires very tight tolerances be held during fabrication of all modules of the sector. One way to lessen the tolerance requirement is to use a floating interconnect design which will allow the interconnect both lateral and axial displacement.

Another important consideration in the sector design is to keep the resonant frequency of the overall unit high to keep relative motions within the sector very low during dynamic testing.

Finite element computer analysis will be done during the design phase to ensure these requirements are met. Using finite element analysis allows a sector model to be built on the computer and study the effects of changing different parameters, i.e., wall thickness, floor thickness, ribs, etc.

Once a satisfactory design has been completed, a dynamic test model (DTM) of one sector will be built. A dynamic test model is a mockup which is an exact mechanical replica in terms of form, size, and weight of the end product but is electrically nonfunctioning.

The DTM will be used to determine the practical problems encountered during fabrication and assembly of the sector. Once assembled, the DTM will be subjected to typical qualification level environmental tests to verify the structural integrity of the unit. In addition, some of the RF interconnections will be "wired" so that input to output insertion loss and VSWR can be measured before and after the environmental tests to verify the RF interfacing integrity.

2.2.23 ROUTER POC/STE TOP LEVEL BLOCK DIAGRAM (PART 1)

Part of the Router POC/STE configuration is comprised of Sector POC/STE configuration modified to include uplink and downlink noise source control. The modification includes adding several relay output cards (HP 69330) to the HP 6940B Multiprogrammer (see Figure 2.2-7).

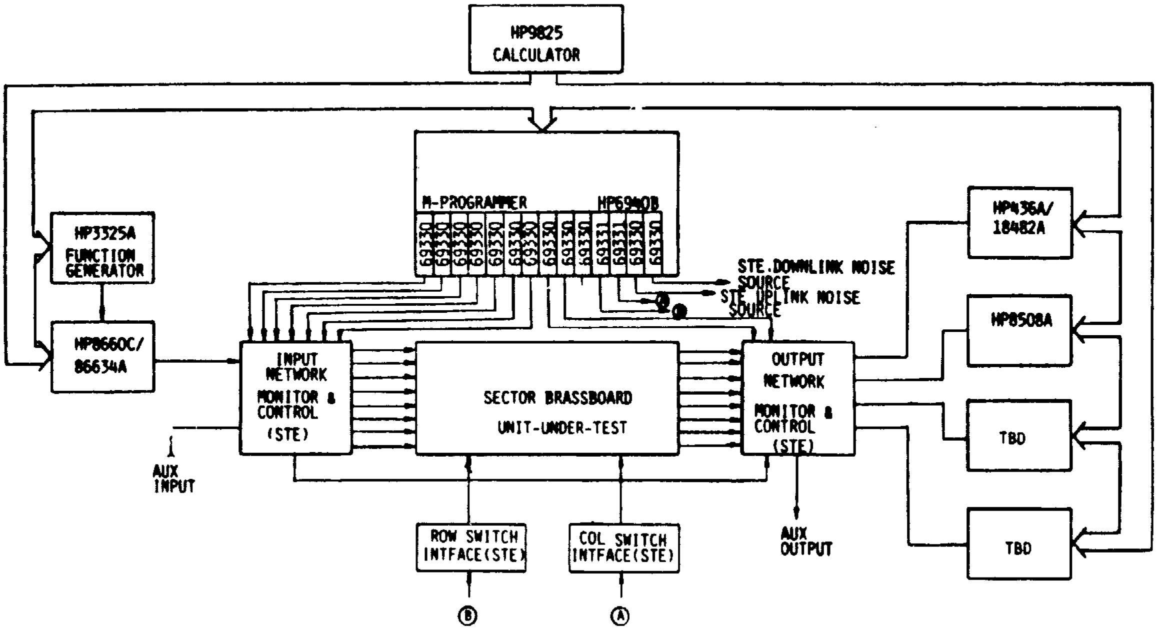


Figure 2.2-7. Router POC/STE Top Level Block Diagram (Part 1)

2.2.24 ROUTER POC/STE TOP LEVEL BLOCK DIAGRAM (PART 2)

The remaining portion of the Router POC/STE configuration (see Figure 2.2-8) includes equipment necessary to simulate uplink and downlink C-band signals. The basic mode is semiautomated. The HP 9825 Calculator controls the commercial test equipment used as stimulus and measurement devices. A summary of Motorola special test equipment follows:

- Input Network Monitor and Control Uplink Simulator
- Output Network Monitor and Control Downlink Simulator
- Row Switch Interface
- Column Switch Interface
- Uplink Noise Source
- Downlink Noise Source

All the STE is commanded by the HP 9825 Calculator via a HP 6940B Multiprogrammer. The multiprogrammer provides switch closures to control:

- Coaxial Relays
- Switch Arrangement

Software measurement tests include (but are not limited to):

- Additive Phase Noise Measurements
- Gain Measurements
- Signal Noise Ratio Measurements
- Intermodulation Distortion Measurements

2.2.25 TEST DEFINITION

The list of major tests to be performed is as follows:

- Interface Compatibilities
- Voltage Stability
- Router Control
- Frequency Response
- Gain Variation
- Intermodulation Effects
- Adjacent Path Interference
- Connectivity and Blocking
- AM-PM Conversion
- Thermal Noise
- End-to-End BER Performance*

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*The BER test is only applicable to the POC Router End-to-End test.

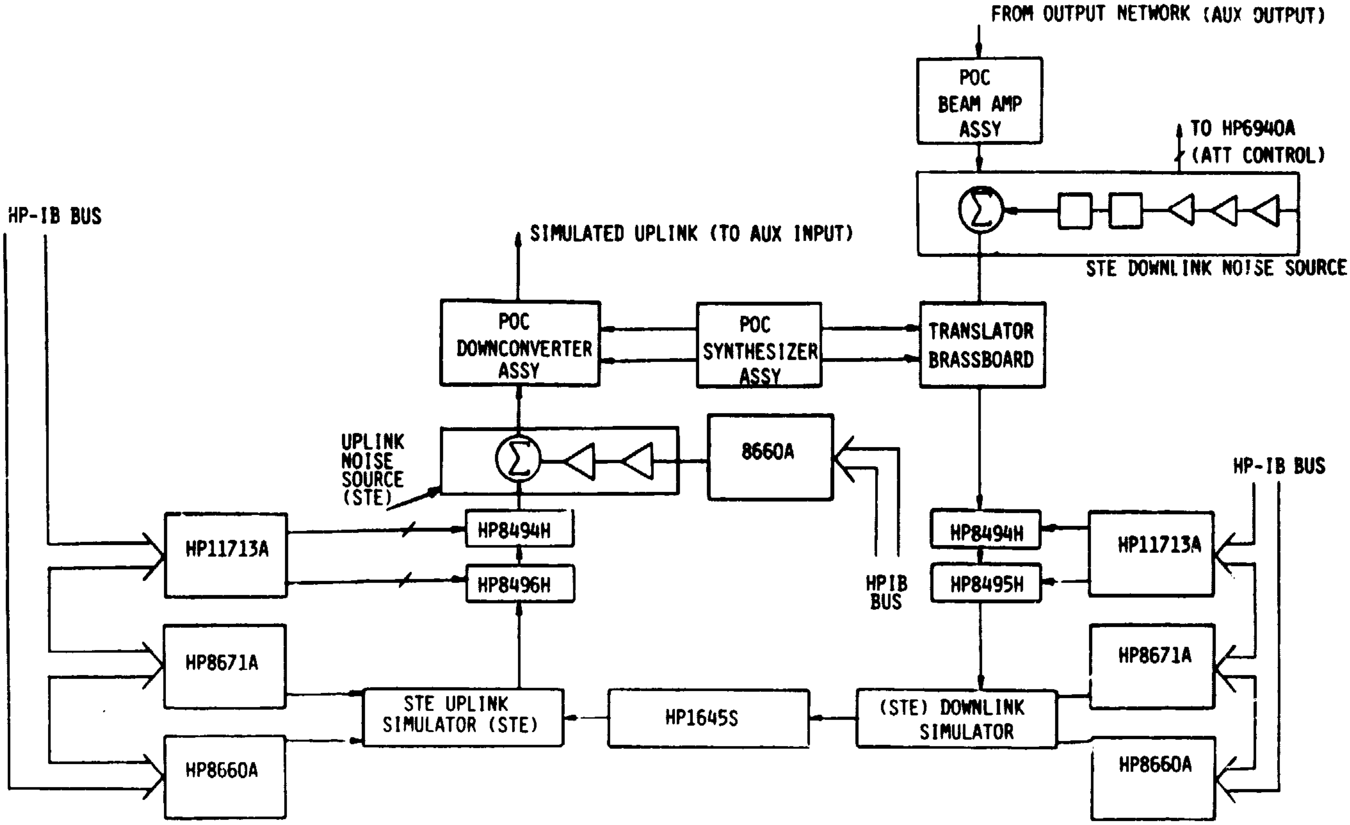

Figure 2.2-8. Router POC/STE Top Level Block Diagram (Part 2)

SECTION 3

3. PROGRAM GOALS

3.1 System Design Goals

In brief, the system design goals are to:

- Route up to 3.8 GBPS — ST to ST to trunk to ST traffic
- Use SCPC FDMA
- Mix voice, video, and data
- Maximize system flexibility and capacity
  - Provide extensive carrier frequency reuse
  - Use narrow beam fixed satellite antennas
  - Provide switchable satellite beam-to-beam filtering
  - Adapt to changing traffic loads
- Protect against rain losses
  - 15 dB on 30 GHz uplinks
  - 6 dB on 20 GHz downlinks
- Provide an availability of 0.999
- Maximize RF spectrum utilization

The 30/20 GHz SS-FDMA program design goal is to provide a flexible operational point-to-point communication system that can service a large number of users, each equipped with a ground station on or near the user premises. The satellite router is required to handle 3.8 Gb/s of ST traffic which is a mixture of voice — data and video to support both Traffic Models A and B. Design goals of maximizing flexibility and capacity necessarily drives the system architectural frequency plan to consider extensive carrier frequency reuse for nonadjacent beams, require narrow-beam satellite antennas for beam — beam RF isolation and suitable switching through beam-to-beam filtering techniques. RF link margin of 15 dB/6 dB, on the uplink/downlink, will be designed to maintain an availability of 0.999 due to rain loss.

3.1.1 SS-FDMA 1982 SYSTEM TECHNOLOGIES

The entire SS-FDMA system architecture design in Task I is predicated upon using technology that is available off the shelf in 1982. However, in addition the various portions of the system can use technology now in development. In the ground ST and NCS subsystems any applicable NASA ACST program space technology may be used such as the demodulator chip currently being developed in the Baseband Processor program.

The satellite subsystem other than the router may use any 1982 technology that can be expected to have the SS-FDMA requirement capability by 1987. For example one or the other multiple beam antennas modified for more fixed beams and no scanning beams.

The router may use any 1982 NASA 30/20 GHz program advanced space technology. It may also use any technology developed on the Baseband Processor program. Finally it may use any advanced technology to be developed on this the SS-FDMA program such as IF array switches or programmable synthesizers.

3.1.2 SATELLITE—ST—NCS ROUTING ROLES

The satellite provides stable paths between beams and adjusts for expected traffic load changes on an hourly, daily, and yearly basis.

The ST does message switching by frequency selection as directed by the NCS, translates user communication traffic to FDMA format and back, transfers station (area) signalling to NCS, and forwards user signalling to the user.

The NCS monitors message requests and directs all channel selection, receives and forwards all station signalling, directs use of FEC coding, commands satellite path structure changes, and monitors and regulates station power. Each of the SS-FDMA subsystem plays a destinct role in the overall architectural design. This design is based upon the following broad conceptual rules: The satellite provides stable paths or routes between uplink beams and downlink beams of the satellite. The path characteristics can be modified on command from the NCS to reflect traffic needs on an hourly, daily or yearly basis. Each ST terminal performs user message switching by frequency selection as directed by the NCS. Each message uses a new set of frequencies dependent upon the source and the destination. The ST translates the user communication traffic to the appropriate FDMA format and back. The ST transfers (area) signalling to the NCS. The ST forwards user signalling to the destination user via the communication link. The NCS monitors message requests and directs all channel frequency selection. It receives and forwards all station signalling. The NCS directs the use of FEC coding and monitors and regulates ST transmitted powers. The NCS commands satellite path structure changes and monitors and regulates satellite power.

3.1.3 USER AND USER SIGNALLING/SUPERVISION

"Local" user use preformatted data via dedicated data lines, preformatted video via dedicated video lines, and analog voice or low rate data via local PABX or similar voice interconnection. "Local" users are defined as: 1. Any user having dedicated hardwired interfaces with the ST. 2. Any user capable of accessing the ST through private branch exchange (PABX)—ST interface.

Telephone signalling/supervision will be used to establish/terminate all the types of traffic links the ST is capable of supporting. Local users having "dedicated hardwired data" and video interfaces will require a companion telephone line to provide the signalling/supervision. Signalling/supervision for the remaining local users (via PABX) will be inherent in the traffic interface. User—User signalling/supervision will be performed by the NCS via the orderwire.

3 1.4 USER INTERFACE

The success of the ACST SS-FDMA system will depend on the willingness of potential users to buy the available service (see Table 3.1-1). The major consideration should be compatibility with existing local telephone switch centers and local private branch exchanges. The system should also be simple to use. Long or complicated "dialling" sequences would make the system prone to human error, and unattractive to use.

Table 3.1-1. User Interface Assumptions

User Interface Traffic Type	Traffic Paths	Signalling
Voice	Existing telephone lines.	Existing methods.
Low Rate Data	Existing telephone lines.	Existing methods.
High Rate Data	Commercially leased lines or privately owned lines.	Via companion voice channel.
Video	Commercially leased lines or privately owned lines.	Via companion voice channel.

Voice and low rate traffic and their companion signalling and supervision will be compatible with the existing telephone systems.

High rate data and video to/from the ST will be over dedicated lines capable of supporting the required bandwidth. Present architecture requires a separate voice traffic path for signalling and supervision.

The high rate data and video users are restricted to local users who have access to the hardwired dedicated interfaces. In contrast, the voice and low rate traffic users may be anyone who can access the switch center or private branch exchange used to interface the ST station.

3.2 Proof-of-Concept Technology Development Goals

The POC development goal may be summarized as:

- Develop key technological building blocks necessary for a router organization
- Fabricate a limited proof-of-concept model, utilizing the technology building blocks, to assess and evaluate the technology readiness
- Develop the necessary deliverable STE to support testing
- Evaluate performance impairment mechanisms, applicable to any typical router, by path evaluation.

The POC goals for this recommendation are primarily directed towards advancing key technology necessary for a Router organization. This was the conclusion drawn from the Task I Final Report on the System Architecture Baseline.

To facilitate the test and evaluation of key technologies, a limited brassboard will be fabricated (along with any deliverable special test equipment), and evaluated for the technological readiness of the critical building blocks for a Full Flight Router Payload.

3.2.1 KEY TECHNOLOGY IDENTIFICATION

The key technologies involved are the:

- LSI 8 × 8 analog switch
  - key component in any router organization
  - principal problems
    - frequency response
    - path isolation
    - input power
- High frequency synthesizer
  - key router and payload assembly
  - principal problems
    - low power
    - low EMI susceptibility
    - low phase noise
    - flexibility of tuning range
- Multiple SAW filter implementation
  - essential for any path definition
  - principal problems
    - 20:1 frequency response range
    - efficient packaging requirement
- Three dimensional sector form fit construction
  - key to practical router implementation to reduce high number of interconnects.
  - principal problems
    - accessibility
    - heat transfer
    - structural integrity
    - stress relief
    - fabrication tolerance allowance

Task I, System Design, identified four major areas of critical technology that require advanced development for inclusion into a flight type router assembly. Each of the four are listed above with their respective rationale for technology advancement and the key problem areas to be addressed.

3.2.2 TECHNOLOGY DEVELOPMENT

The technology to be developed is:

- LSI 8 × 8 analog switch
  - LSI development using existing GB6 cell array
- Multiple SAW filters
  - single substrate development
- High frequency synthesizer
  - breadboard development for later LSI implementation
- Three dimensional construction
  - dynamic test model subjected to environmental test

The technology to be developed involves both design and processes. The existing GB6 cell array used on the baseband processor (SS-TDMA) will be redesigned for linear operation with a form, fit, and functional LSI chip.

The SAW filters involve multifilter design and fabrication on a single substrate. Major problems associated with this technology are the use of either Quartz or Lithium Niobate for the wide 20:1 frequency response, insertion loss, and RF isolation.

The synthesizer will be designed and breadboarded to demonstrate the feasibility of a highly stable, low phase noise, and flexible synthesizer at C-band.

The reduction of thousands of interconnects requires a separate study to evaluate the three dimensional approach to facilitate form and fit.

3.2.3 TECHNOLOGY EVALUATION

The methods of technology evaluated are:

- 8 × 8 switch—by functional test and POC sector test
- SAW filters—by functional test and POC sector test
- Synthesizer—by functional test and POC router test
- Three dimensional concept—DTM environmental test
- Brassboard sector POC
  - includes 1) and 2) technology building blocks
  - path evaluation of transfer function, isolation, and gain stability
  - input/output frequencies at 8 × 8 switch IF frequency (approximately 100–400 MHz)
- Brassboard router POC
  - includes 1), 2), and 3) technology building blocks
  - part evaluation from beam input-to-beam output at the LNA and transmit IF frequencies of approximately 3–5 GHz.

The test and evaluation of this technology will be conducted on a limited proof-of-concept model. The brassboard sector POC represents a very limited program, where the brassboard router POC represents an enlarged program to fully demonstrate the path performance characteristics and additional technology that would be applicable for a flight type router.

SECTION 4

4. SYSTEM ANALYSIS

The primary emphasis of Task I to date has been the development of a system architecture for the SS-FDMA approach for small terminal traffic routing. This section provides a summary of that system architecture.

4.1 System Definition and Requirements

Figure 4.1-1 is a simplified block diagram for the SS-FDMA system. Included are:

- Trunk terminals,
- Small terminals,
- The FDMA satellite, and
- A network control station (NCS).

Entry into the system is accomplished by requests to the NCS. The NCS acts as the master terminal in:

- Making channel frequency assignments,
- Setting frequency and timing references,
- Designating channels to be encoded for improving link margins,
- Controlling satellite power output for each beam,
- Commanding the satellite router switch and IF switch,
- Setting system configurations, and
- System monitoring.

Small terminals vary in size with composite data rates from 0.88 Mb/s (G terminal) to 33.84 Mb/s (E terminals). Traffic channels include voice, data, and video with a satellite throughput rate up to 3.8 Gb/s. In addition to ST traffic, the satellite must also accommodate trunk terminal traffic. The portions of this traffic designated for ST stations will be assigned to the ST band and pass through the router. That fraction of the trunking traffic designated for other trunk stations will be directly routed through an IF switch. 1.5 GHz of bandwidth is allocated for trunk traffic and 1.0 GHz for ST traffic. The ST traffic will be broken into roughly three bands handling 40 beams for Traffic Model A and 71 beams for Traffic Model B in which the satellite will handle routing of all traffic to its proper destination. In the following subparagraphs the basic architecture of the ACST SS-FDMA system will be discussed.

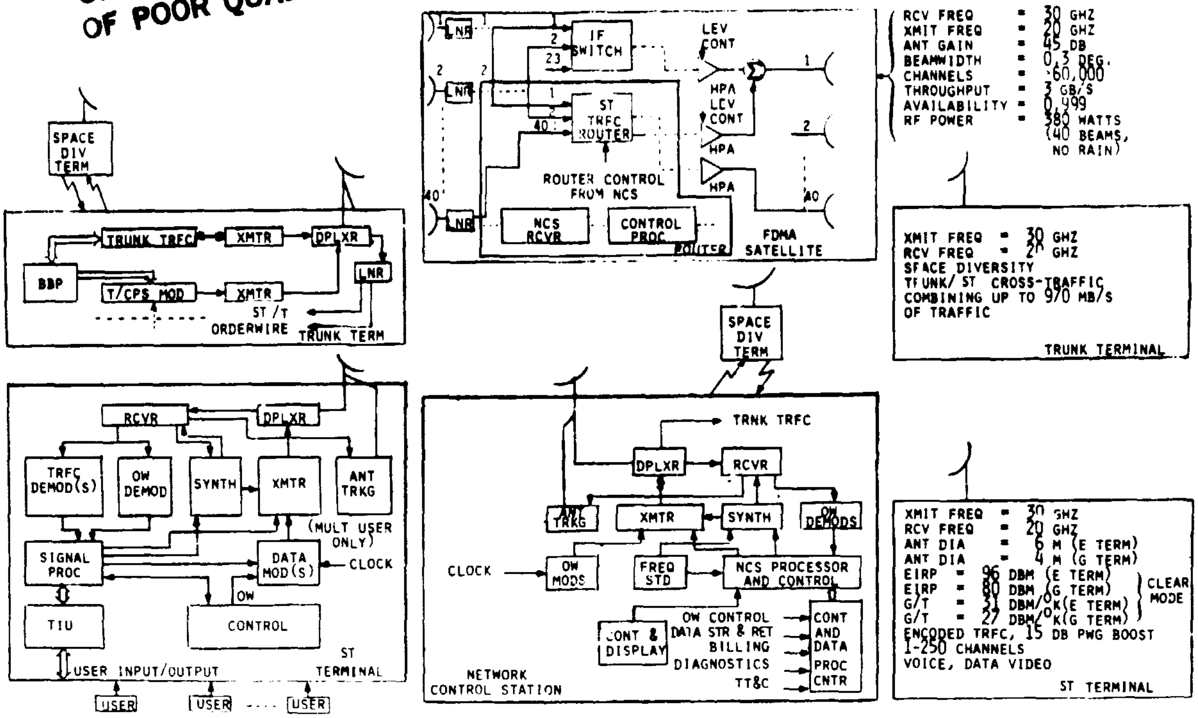

Figure 4.1-1. SS-FDMA System Block Diagram

4.1.1 SS-FDMA SYSTEM CHARACTERISTICS

The SS-FDMA system characteristics comprise:

- System capacity 10 Gb/s
  - 2.2 Gb/s ST - ST
  - 0.8 Gb/s Trunk - ST
  - 0.8 Gb/s ST - Trunk
  - 6.2 Gb/s Trunk - Trunk
- Traffic - individually routed voice, data, and video (all digital - but does not preclude analog)
- Two traffic models

	Model A	Model B
Number of cities	45	277
Number of stations	2,000	10,000
STA CAP (chan)	14 - 25	1 - 36

- Performance - BER 10^{-6} at 0.999 availability (0.995 alternative)
- Rain fade
  - 6 dB on 20 GHz downlink
  - 15 dB on 30 GHz uplink

- Multiple beam antennas - carrier frequency reuse
- TDMA trunking traffic
- Crosslink traffic performed at trunking terminals
- Network control at a trunking terminal.

The total satellite communication system has a capacity of 10 Gb/s with 3.8 Gb/s involving ST traffic. Of the latter, 800 Mb/s is from trunking terminals to small terminals and 800 Mb/s from ST to trunking terminals. The rest, or 2.2 Gb/s, is ST to ST traffic. All ST traffic, whether originating or terminating at ST station is handled in the 1 GHz ST band.

Traffic is entirely single channel per carrier FDMA and is to coexist with the trunking system. It is a mix of voice, data, and video according to one of two traffic models. A user availability of 0.999 at 10^{-6} BER is the design objective. All ST traffic must be protected to 15 dB rain fade on the 30 GHz uplink and 6 dB on the 20 GHz downlink.

Critical to the system is the use of high gain multi-beam antennas which permit extensive carrier frequency reuse without co-channel interference.

4.1.2 SATELLITE BLOCK DIAGRAM

The satellite block diagram, Figure 4.1-2, contains five main subsystems relating to the FDMA communication link. These are the antenna subsystem, low noise receivers (LNR), IF switch, the ST router, and the power amplifier subsystem. With the exception of the router, these subsystems have all been studied by other contractors and the developed FDMA architecture has used the published characteristics of these studies, where applicable.

Essentially, the FDMA satellite acts as a switchboard to control source to destination traffic. The 30 GHz input is received by the antenna subsystem which contains approximately 40 beam antennas (Traffic Model A). The traffic from trunking terminals, which is destined for another trunking terminal, is allocated a 1.5 GHz bandwidth and this TDM traffic is destination-controlled through the IF switch. All other traffic, which is ST related, is contained in a 1.0 GHz bandwidth and is destination-controlled through the router. Switch configuration, along with synthesizer settings and power output control, are derived from the NCS receiver within the router.

The router contains approximately 1600 SAW filters with 3200 switching crosspoints. The input and output IF frequencies to the router have tentatively been selected as 4.5 - 5.6 GHz and 2.65 - 3.35 GHz respectively. With a maximum 3.8 Gbps throughput, the required RF output power for communicating the ST traffic is 460 watts with all terminals in the clear and up to 492 watts with worst case rain conditions. This assumes an effective satellite antenna gain of 45.4 dB.

Power amplifiers are all quasi-linear for the ST FDMA traffic and will operate saturated for the trunking TDM traffic. Details of the FDMA architecture, and in particular the router, are discussed in later sections.

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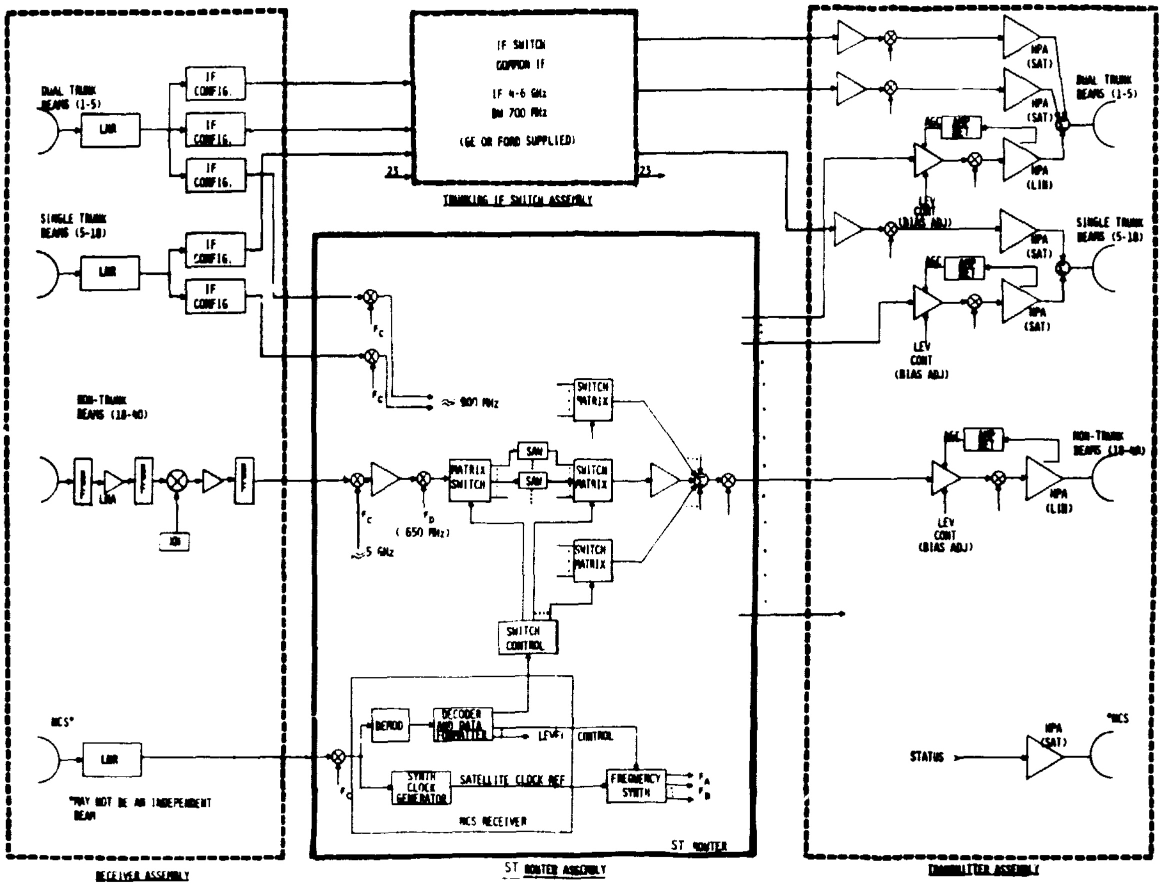

Figure 4.1-2. Satellite Block Diagram

4.1.3 SATELLITE COMMUNICATION PAYLOAD CHARACTERISTICS

The satellite communication system has a capacity of 10 Gb/s with 6.2 Gb/s on the TDMA trunking system. The rest, or 3.8 Gb/s, is ST traffic among ST's or between ST's and trunking terminals. The trunking system will share the multibeam satellite transmitting and receiving antennas and the 2.5 GHz allocated RF spectrum. Inasmuch as the trunking system is TDMA, it precludes placing any FDMA channels in the trunking band or any beam having a trunk station. To allow trunking capacity to increase, no use of the 1.5 GHz trunking band is used for any ST traffic anywhere. A separate control system is considered for the trunking subsystem although it could be integrated with the ST satellite control link.

The satellite probably will be from 100° to 105° West latitude to yield the best coverage of CONUS. Close arc Ka-band satellite spacing is expected. As a result, significant care must be used to ensure that small terminal antennas do not transmit to or receive from other Ka-band satellites. This is particularly true since this system uses and reuses the entire available 2.5 GHz spectrum on both the up and down links.

The ST SS-FDMA satellite communication payload receivers and transmitter FDMA single channel per carrier signals on 40 or more fixed beams. The system uses digital 0-QPSK modulation for a mix of voice, data, and video channels. The satellite payload is configured, however, to allow linear modulation signals of equal or less bandwidth.

Since 32 kb/s CVSD is used for the voice channels, these require 3 dB less power at a BER of 10^{-6} than 64 kb/s PCM. Toll quality is preserved for BER as high as 10^{-3} when using CVSD. In this case, there is yet another 3 dB power saving for a total of 6 dB. Hence, these channels could have a spectral density of 3 dB less than data and video channels which require a BER of 10^{-6}.

In summary, the satellite communication payload characteristics are:

- Throughput 10 GBPS
  - 6.2 Gb/s: Trunk - trunk
  - 0.8 Gb/s: trunk - ST
  - 0.8 Gb/s: ST - trunk
  - 2.2 Gb/s: ST - ST
- Trunking a separate system
  - Shares antennas
  - Shares 2.5 GHz allocated bandwidth
  - May share LNR's and PA's
  - Separate control system
  - Cross traffic tie at trunk ground stations
  - 3- 550 Mb/s bands (BBP - TDMA configuration)
- Satellite characteristics
  - Shuttle lauched
  - 105° west latitude synchronous orbit
  - ± 22 Km range ± 0.05° lat - long
  - 1.6 m/s max radial vel, ± 0.005° max lat-long vel
  - Arc separation > 1.5°
  - Antenna isolation required >25 dB
- FDMA
  - Multiple carriers/beam
  - Single digital channel/carrier
  - Data rates 32, 56, 1500, 6300 kb/s uncoded
    64, 112, 3000, 12600 ks/s coded
  - 32 kb/s CVSD recommended
  - Linear signals of equal or less bandwidth

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- Dynamic range
  - Ideal: Equal power density for all data and video channels
    Voice channels 3 dB less power density for BER of 10^{-3}
  - Practice: TBD
  - Output S/N per channel > 14 or 15 dB for high input S/N
- Satellite routing under NCS control
- Integral orderwire system: NCS - ST (separate carriers)
- Integral satellite control link: NCS - router (separate carriers)

4.1.4 MULTICHANNEL ST BLOCK DIAGRAM

The multi-channel ST (see Figure 4.1-3) is characteristic of the E, F, and G class terminals in Traffic Model A and the E, F, G, H, and I terminals of Traffic Model B.

The multi-channel small terminal comprises the same subsystems as the single channel ST terminal. The TIU, traffic transmitters and traffic receivers will increase on a one for one basis as the channel capacity increases.

The TIU capacity may be increased by adding a module to the TIU subsystem main frame for each channel added. Complete subsystems (traffic receivers and traffic transmitters) must be added for each additional channel added. The orderwire subsystem will not change since all channels are controlled from a single bus structure.

Additional HPA's, different antenna sizes and antenna positioning control must be added as channel capacity increases (increased EIRP requirements). If necessary, the Ka-band outputs maybe summed spatially in a Cassegrain feed structure at the antenna.

The high rate user interface is a direct hardwired interface over dedicated lines. The high rate data is both input and output by the TIU. The TIU contains I/O buss circuitry and reclocking circuitry. The signailing and supervision signals are provided by a companion low rate traffic circuit.

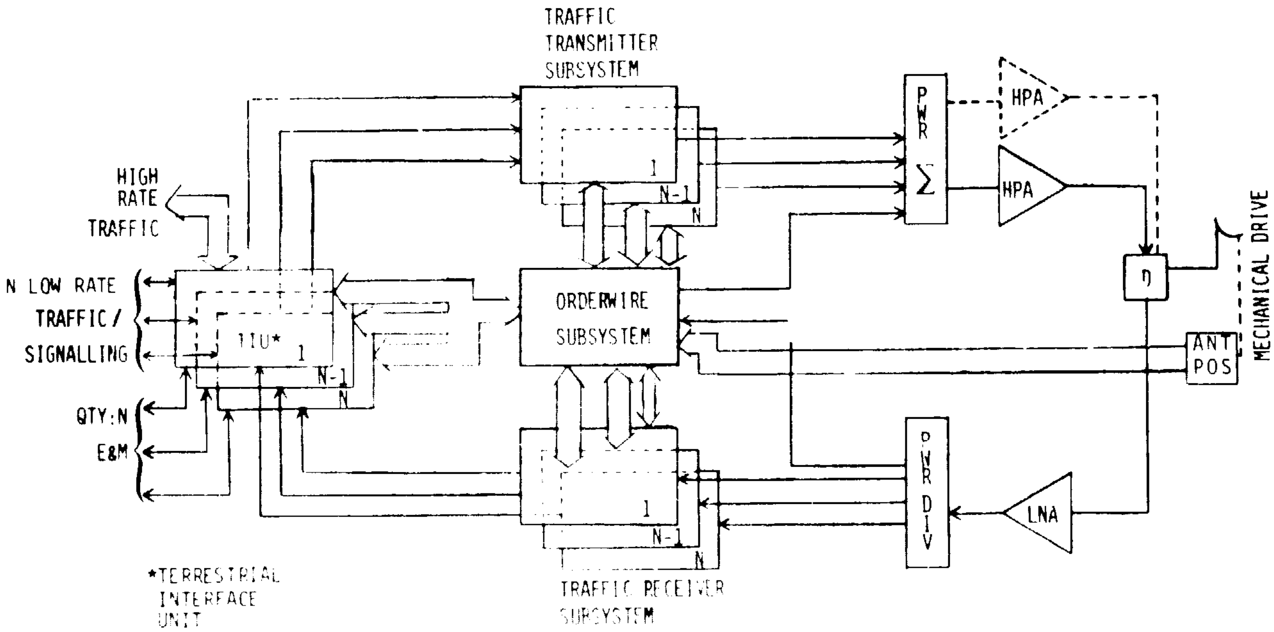

Figure 4.1-3 Multichannel ST Block Diagram

4.1.5 ST TRANSMIT, RECEIVE, AND INTERFACE CHARACTERISTICS

Table 4.1-1 shows the EIRP and G/T requirements determined by link budgets yielding a total system E_N/N_O >10.6 dB (BER $\leq 10^{6}$) when maximum rain fade occurs on the uplink and downlink.

Table 4.1-1. Transmit and Receive Characteristics

	Traffic Model A Class			Traffic Model B Class					
	E	F	G	E	F	G	H	I	J
EIRP (With Raid Fade) dBm	109.8	101.3	92.6	105.1	98.5	91.4	90	87.7	80.7
Ant. Gain (dB)	61.8	60.3	58.3	61.8	60.3	58.3	58.3	58.3	58.3
HPA (dBm)	48.0	41.0	34.3	43.4	38.3	33.1	31.7	29.4	22.4
GT (d/B°K)	27	27	27	27	27	27	27	27	27
Ant. Gain (dB Min)	59.1	57.6	55.6	59.1	57.6	55.6	55.6	55.6	55.6
Sys Noise Temp (Max, °K)	1621	1148	724	1621	1148	724	724	724	724

The user interface functional requirements are based on the most common type of signalling anticipated in the 1987 time frame:

- Low Rate and Voice

  Standard two wire inband signaling interface. Baseline signalling is assumed to be dual tone (touch tone). Supervisory information provided by two wire E&M.
- High Rate

  Bus compatible, bus standard and levels TBD. High rate user traffic, signalling, and supervision are assumed to be via dedicated leased lines.

As a baseline assumption, potential subscribers with unique interface requirements will provide the necessary interfacing equipment which will make their user interface compatible with the ST TIU. Commercial equipment is readily available to satisfy many unique interface requirements.

4.1.6 NCS BLOCK DIAGRAM

The baseline orderwire architecture incorporates 40 unique frequencies (one frequency per beam) for transmission and reception (Figure 4.1-4 shows orderwire transmitters and receivers numbers 1 and 40 only, the other 38 share the bus and control lines in the same manner.). Satellite control will be effected over a dedicated channel to the satellite.

The channels (transmitters and receivers) will include convolutional encoding/decoding to maintain BER $\leq 1 \times 10^{8}$. A time/frequency reference will be used as the station clock. The time/frequency reference shall be transmitted over the orderwire channels to ensure that all stations operating within the system are time referenced to the NCS.

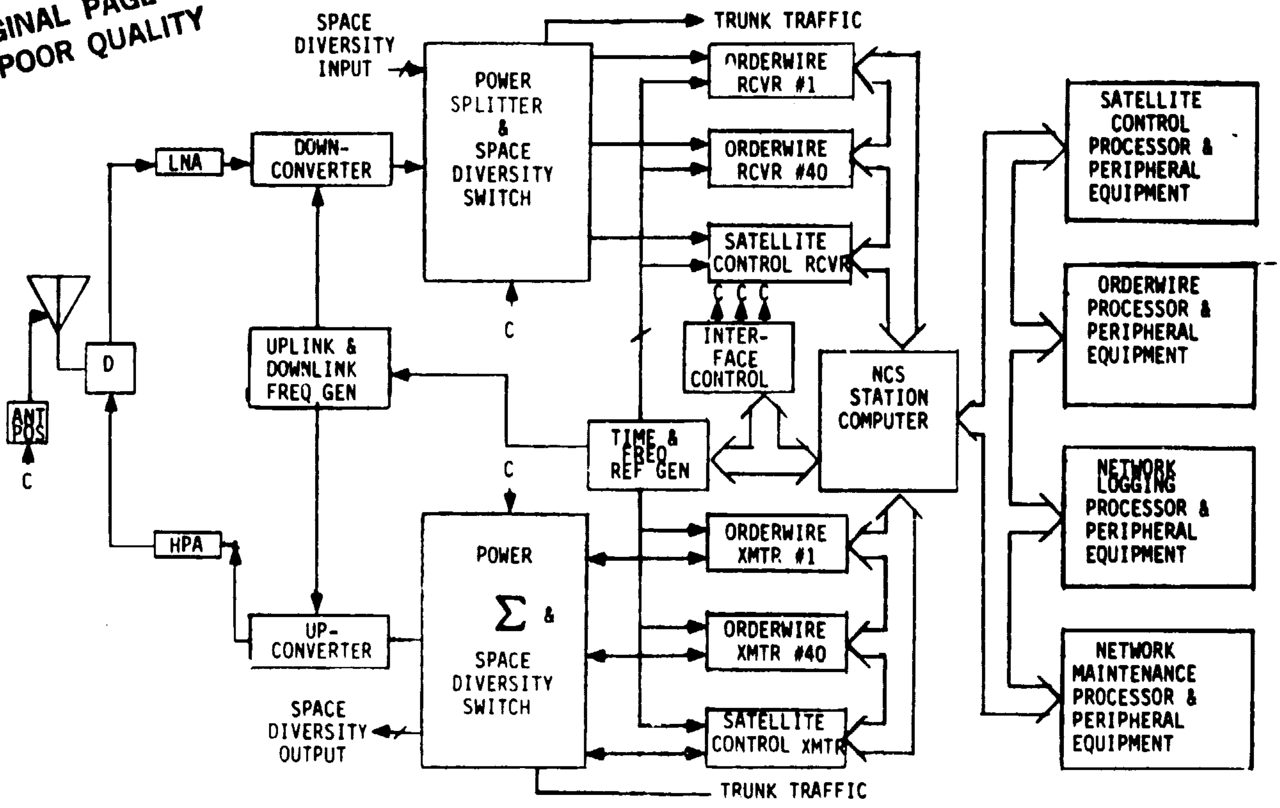

Figure 4.1-4. NCS Block Diagram

The NCS will provide processors for system operation and maintenance functions; telemetry, tracking, control of the satellite; billing and system reconfigurations; and ST adaptive control. The four processors will be slaved to a station computer. The station computer coordinates and controls all NCS functions. A space diversity switch is included to route communication to/from a remote trunking station RF subsystem (HPA, LNA, ANTENNA, and UP/DOWN CONVERTERS). Space diversity is used in combatting severe weather conditions at the primary trunking station site.

4.1.7 NCS PERFORMANCE SUMMARY

The network control station's performance may be summarized as:

- NCS shares LNA, HPA, and antenna with trunking station
  - XMIT characteristics
    - BW: ≈5.0 MHz (composite)
    - Bite rate: ≈ 2.5 Mb/s (composite)
    - Channels required: ≈41
    - No rain-EIRP: 86.5 dBm
  - REC characteristics
    - BW: ≈5.0 MHz (composite)
    - Bit rate: ≈ 2.5 Mb/s (composite)
    - Channels required: ≈41
    - G/T: ≈28.5 dB/°K (based on satellite EIRP density of 9.7 dBm/Bit)
- Frequency stability better than: 1×10^{-8}
- BER: $\leqslant 1 \times 10^{-8}$
- Forward error correction encoding:

  constraint Length: 5

  Rate: 1/2

  Bit decision: 2 bit soft decision

The NCS is part of a trucking station. Common circuitry of the NCS and trucking station includes the LNA, HPA, and Antenna. Since the trunking station is presently undefined, the transmit characteristics and receive characteristics of the NCS are presented in terms of EIRP and G/T. The transmit and receive characteristics are the combined requirements of the orderwire and Satellite Control links. Forty channels (one per beam) are required for the Orderwire and at least one channel will be used for Satellite Control.

The 5 MHz bandwidth assumes FEC and includes the 4.5 MHz dedicated to the Orderwire channels and the 0.5 MHz dedicated to Satellite Control. The EIRP requirements are based on the satellite's receiver performance and the link margin prevously defined for the traffic uplink at 30 GHz. The specified no rain EIRP will provide a BER $\leqslant 1 \times 10^{-8}$ for the NCS transmit link.

The specified G/T requirements will provide a BER $\leqslant 1 \times 10^{-8}$ for the NCS receive link.

The specified frequency stability is a baseline performance specification based on practical cost and technology.

4.1.8 KEY TECHNOLOGIES

The key technologies involved in the ACST SS-FDMA Communication System are:

- Satellite

  Current development studies

  - Antennas - TRW and Ford
  - Low noise receivers - LNR and ITT
  - IF switch - GE and Ford
  - Power amplifiers - TRW, LNR, TI and Hughes

  FDMA required

  - Router switches
  - Frequency synthesizer
  - Saw filters
  - Packaging

- Small Terminals

  - Power Amplifiers
  - Antennas
  - Low noise receivers

There are four principal technology areas under investigation for use in the satellite. In developing the FDMA architecture, the published characteristics of these items were used as applicable. For the ACST FDMA system router switching, frequency synthesis, SAW filters, and packaging are satellite technologies which require further development.

Router switching characteristics which required particular attention are bandwidth, crosstalk, control, power, and redundancy. The status of these characteristics is discussed in the respective sections within the "Support Studies". For the SAW filters, the bandwidth, center frequency range, selectivity and stability are key factors. In addition, since there are about 1600 such filters, packaging becomes an important consideration. In fact, packaging itself is critical and must be addressed.

Technology breakthroughs may not be required, but organizing and designing a compatible packaging concept is critically important. Synthesizer development must address phase noise, power requirements, and tunability when placed in a satellite environment. For the small terminals, the three areas requiring technology improvement are low noise amplifier, transmitters, and antennas. Technology to meet the ground terminal requirements of the FDMA system are available, but the costs are prohibitive, and some advancement in technology is necessary to make the stations cost competitive.

4.2 Link Budgets

Table 4.2-1 lists the requirements and assumptions used in developing the link budgets.

Table 4.2-1. Link Budget Requirements and Assumptions

REQUIREMENTS

Channel Link	Bit Error Rate
Traffic Channel	10^{-6}
Orderwire Control Link	10^{-8}
Satellite Control Link	8^{-8}

ASSUMPTIONS

Parameters	Unit	E-Type TERMNL	F-Type TERMNL	G-Type TERMNL	Note
Uplink Path Loss	dB	213.5 ± 0.4	213.5 ± 0.4	213.5 ± 0.4	
Downlink Path Loss	dB	210 ± 0.4	210 ± 0.4	210 ± 0.4	
Terminal Bit Rate	Mb/s	26.16	3.812	0.496	32 Kb/s Voice
Ideal Satellite Antenna Gain	dB	53	53	53	
Satellite Antenna System Impairment	dB	7.6	7.6	7.6	
Satellite Receiver Noise Figure	dB	5	5	5	
ST Antenna Size	Meter	6	5	4	
ST Antenna Gain	dB				
30 GHz		61.8	60.3	58.3	Efficiency 43%
20 GHz		59.2	57.6	55.7	Efficiency 53%
Modem/Channel Impairment	dB	5.4	5.4	5.4	
ST Receiver Noise Figure	dB	7.5	6	4	
Coding Gain	dB	3.6	3.6	3.6	

From table 4.2-1 we see that the bit error rate for the SS-FDMA system is specified at 10^{-6}. The corresponding signal to noise ratio is 10.6 dB.

The 5.4 dB modem and channel impairment assumed in the system is the combination of the following losses:

Adjacent channel interference: 1 dB, Co-channel interference: 0.7 dB

Intermodulation distortion products: 1.5 dB, Filter distortion: 0.5 dB

Phase noise: 0.7 dB, Other hardware imperfections: 1.0 dB

The ½ rate coding with constraint length 5 and 2 bits soft decision is assumed in the system which results in coding gain of 3.6 dB.

The 7.6 dB satellite antenna impairment assumed in the system is the combination of the following losses:

Beam to beam variation: 1 dB   Area coverage: 3 dB

Pointing error (beam edge): 1.3 dB

Diplexing loss: 2.0 dB   Polarization loss: 0.3 dB

4.2.1 SMALL TERMINAL RF POWER REQUIREMENTS

The required small terminal RF powers in clear air and in rain with method 2 compension scheme are shown in tables 4.2-2 and 4.2-3.

Table 4.2-2. Small Terminal RF Power Requirements

	E-Type Terminal		F-Type Terminal		G-Type Terminal	
Power	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
Environment Clear Air	32.9	1.97	26.2	0.41	19.2	0.034

Table 4.2-3. Rain With Method 2 Compensation Scheme

	E-Type Terminal		F-Type Terminal		G-Type Terminal	
Power	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
Environment Rain	47.9	61.66	41.2	13.18	34.2	2.63

The required small terminal RF power can be determined from the following uplink budget equation:

$$\mathrm{EIRP} \quad \left(\frac{E_b}{N_o}\right)_{up} \quad G_s + KT_s + L_u + L_{ru} + L_p + R_b$$

where

EIRP = required small terminal EIRP in dBm

$\left(\frac{E_b}{N_o}\right)_{up}$ = the uplink signal-to-noise ratio in dB

G_s = satellite antenna gain in dB

kT_s = satellite noise power density in $\frac{dBm}{Hz}$

L_u = path loss in dB

L_{ru} = rain loss in dB

L_p = pointing loss in dB

R_b = terminal bit rate in dB

Seven possible rain fade compensation schemes will be discussed in paragraph 4.2.7. The required small terminal RF power for method 2, that is increasing the terminal power by 15 dB, is tabulated for comparison with a clear air link.

4.2.2 SATELLITE RF POWER REQUIREMENTS

The required satellite RF powers in clear air and in rain with method 2 compensation scheme are as shown in tables 4.2-4 and 4.2-5.

Table 4.2-4. Clean Air Satellite RF Power Requirements

	E-Type Terminal		F-Type Terminal		G-Type Terminal		Total 40 beams	
Power	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
Environment Clear Air	36.7	4.68	28.3	0.68	19.0	0.08	56.62	459.59

Table 4.2-5. Rain With Method 2 Compensation Scheme

	E-Type Terminal		F-Type Terminal		G-Type Terminal		Total 40 Beams in Worst Case*	
Power	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
Environment Rain	39.4	8.70	31.2	1.32	22.2	0.17	56.92	491.73

*It is the case when New York beam is in rain.

The satellite RF power can be determined from the following downlink budget equation:

$$STP = \left(\frac{E_b}{N_o}\right)_{down} - G_T + KT_R + L_d + L_{rd} + L_P + L_C + G_R + R_b$$

STP = Satellite RF power in dBm

$\left(\frac{E_b}{N_o}\right)_{down}$ = Downlink signal to noise ratio in dB

G_T = Satellite antenna gain in dB

KT_R = ST receiver noise power density in dBm/Hz

L_d = Path loss in dB

L_{rd} = Rain loss in dB

L_P = Pointing loss in dB

L_C = Receiver line loss in dB

G_R = CPS receiver antenna gain in dB

R_b = Data rate

Seven possible rain fade compensation schemes will be discussed in paragraph 4.2.7. The required satellite RF power for Method 2, by using rate ½, constraint length 5 and 2 bits soft decision coding at the small terminal and boosting satellite power by 2.4 dB, is tabulated for comparison with a clean air link.

4.2.3 RAIN FADE MARGIN VS AVAILABILITY

Figure 4.2-1 plots cumulative distributions of rain attenuation for 19 and 28 GHz earth-space signals as derived from measurements using the COMSTAR beacon at Crawford Hill. The left ordinate scale is the time that the

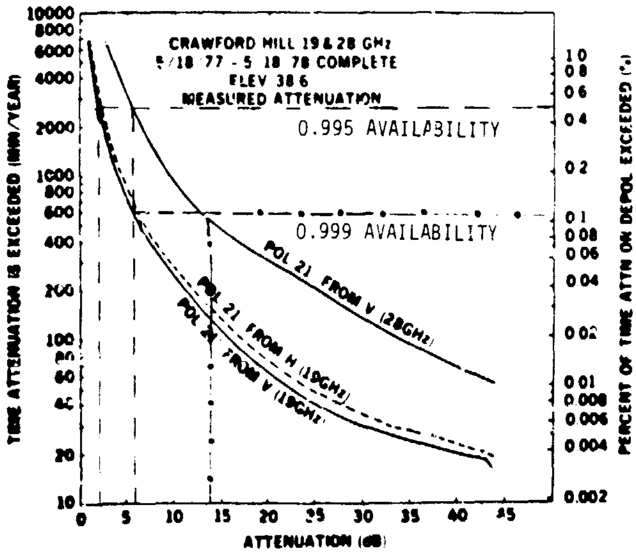

Figure 4.2-1 Small Terminal RF Power Requirements

attenuation on the abscissa was exceeded during the year May 1977 to May 1978. The right ordinate scale is the percent of the year that the attenuation was exceeded. Signal-to-noise ratio of the measurement in the narrow receiver IF bandwidths is ~ 15 dB at the 45 dB attenuation level. (Courtesy of H.W. Arnold et al "Rain Attenuation from a 19 and 28 GHz COMSTAR Beacon Propagation Experiment: One Year Cumulative Distributions and Relationships between the Two Frequencies".)

From curves, such as these, the up-and down-link rain fade margins can be determined from the specified availability requirements. Conservative estimates are shown in table 4.2-6.

Table 4.2-6. Rain Fade Margins

Availability (%)	Uplink Rain Fade Margin (dB)	Downlink Rain Fade Margin (dB)
99.95	22	9
99.9	14	6
99.5	6	2.5
99.0	4	1.5

For 99.9% availability the uplink and downlink rain fade margins obtained from above are 14 dB and 6 dB respectively which are compatible with the values 15 dB and 6 dB respectively as specified in the link budget.

4.2.4 RAIN FADE CHARACTERISTICS

The geographical location of the ST terminal affects rain fade attenuation in two ways:

1. The elevation angle of the ST terminal to the satellite changes as a function of the geographical location of the ST terminal. The path attenuation in dB in rain is proportional to the cosecant of the path elevation angle measured from the horizon. For a satellite at 95 degree west longitude and the CONUS ST elevation angles to the satellite varying from approximately 30° to 55°, it then has the ratio of attenuations (dB) of 1.64.
2. The rain statistic at the location of the ST terminal contributes the second factor for the rain attenuation statistic. A piecewise linear model has been proposed to relate the rain attenuation statistic as a function of the instantaneous rain rate.

At the same geographical location, the ratio of rain fade attenuations (in dB) at two different frequencies is proportional to the square of the ratio of these two frequencies. Therefore if the rain fade attenuation in the downlink is available, then the rain fade attenuation in the uplink can be easily estimated by the equation:

$$R_u(dB) = R_d(dB) \cdot \left(\frac{f_u}{f_d}\right)^2$$

where f_u, f_d are the carrier frequencies used in the uplink and downlink respectively, and $R_u(dB)$, $R_d(dB)$ are the rain fade attenuations of the uplink and downlink respectively.

4.2.5 RAIN FADE WITHOUT COMPENSATION SCENARIO

Referring to figure 4.2-2, suppose terminal A is in rain and it is communicating with terminal B which is in clear air. If both terminals are transmitting the same power as they are in the clean air without implementing any rain fade compensation scheme, then due to the A-B link suffering uplink rain fade attenuation terminal B will receive less power than the power it receives when terminal A is in clear air by the amount of the uplink rain fade margin. Similarly, due to the B-A link suffering downlink rain fade attenuation, terminal A will receive less power than the power it receives when it is clear air by the amount of the downlink rain fade margin.

4.2.6 RAIN FADE COMPENSATION SCENARIO

Referring to figure 4.2-3, the rain fade compensation scheme is the way the communicating terminals and/or satellite will act to compensate the up- and down-link rain fade margins when the communication link suffers rain fade attenuation.

Suppose in the communication link A-B, terminal A is in rain fade while terminal B is in clear air then one possible rain fade compensation will occur as follows: Terminal A increases its transmitting power by 15 dB to compensate the uplink rain fade margin in the communication link A-B, while terminal B has its power boosted by 6 dB to compensate the down link rain fade margin in the communication link A-B.

Since satellite transmitting power is high even before including rain fade margin in the above scheme, increasing it further (by increasing the terminals' transmitting powers) will place a heavy burden on the satellite.

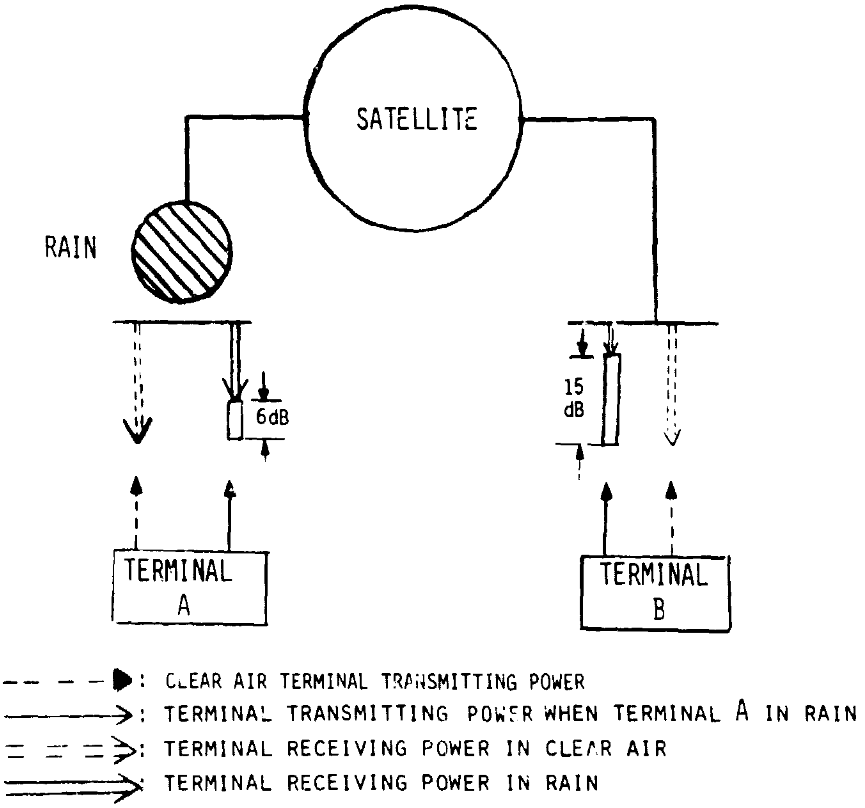

Figure 4.2-2. Satellite RF Power Requirements

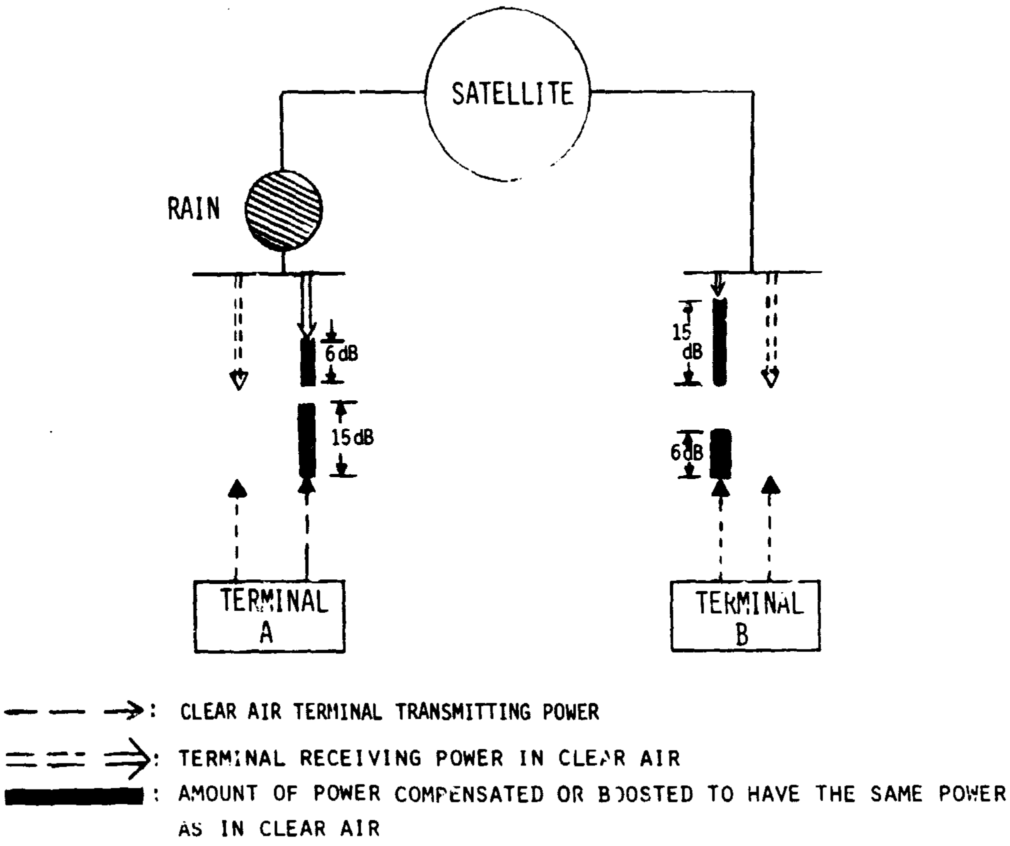

Figure 4.2-3. Rain Fade Compensation Scenario

4.2.7 RAIN FADE COMPENSATION METHODS

Some other possible rain fade compensation schemes are summarized in table 4.2.7.

Table 4.2-7. Rain Fade Compensation Methods

Mechanism Operation Method	Uplink Rain Fade Compensation	Downlink Rain Fade Compensation	
	Small Terminal in Rain	Satellite Transmitting to Rain-Affected Small Terminal	Clear air Small Terminal
Method 1	15 dB power boost	No change	2.4 dB power boost and coding
Method 2	15 dB power boost	2.4 dB power boost	Coding
Method 3	11.4 dB power boost and coding	No change	2.4 dB power boost and coding
Method 4	11.4 dB power boost and coding	2.4 dB power boost	Coding
Method 5	15 dB power boost	No change	6 dB power boost
Method 6	11.4 dB power boost and coding	No change	6 dB power boost
Method 7	15 dB power boost	6 dB power boost	No change

From Table 4.2-7 we note that:

- When two beams are in communication, only one of them is in rain.
- Terminals in rain-affected beam will have the same bit-error-rate as in clear air.
- Uplink rain fade margin: 15 dB
- Downlink rain fade margin: 6 dB
- For coding, the ½ rate coding with constraint length 5 and 2 bits soft decision is assumed to be implemented in the system. The associated coding gain is 3.6 dB.

4.2.8 SMALL TERMINAL RF POWER VS. RAIN FADE COMPENSATION METHODS

By implementing each of the seven possible rain fade compensation schemes in the derived uplink budget equation, as in paragraph 4.2.1, the transmitting power required for each type of small terminal to meet the specified bit error rate can be determined. Table 4.2-8 shows the required small terminal RF powers in clear air and rain for the different rain fade compensation schemes (no margin):

Table 4.2-8. Small Terminal RF Power Vs. Rain Fade Compensation Method

Power / Method	E-Type Terminal		F-Type Terminal		G-Type Terminal	
	(dBm)	(WATT)	(dBm)	(Watt)	(dBm)	(Watt)
No-Rain	32.9	1.97	26.2	0.41	19.20	0.084
1	47.9	61.66	41.2	13.18	34.2	2.63
2	47.9	61.66	41.2	13.18	34.2	2.63
3	44.3	26.91	37.6	5.75	30.6	1.15
4	44.3	26.91	37.6	5.75	30.6	1.15
5	47.9	61.66	41.2	13.18	34.2	2.63
6	44.3	26.91	37.6	5.75	30.6	1.15
7	47.9	61.66	41.2	13.18	34.2	2.63

4.2.9 SATELLITE RF POWER BY TERMINAL TYPE VS RAIN FADE COMPENSATION METHODS

By implementing each of the seven possible rain fade compensation schemes in the derived downlink budget equation, as in paragraph 4.2.2, the required satellite RF transmitting power to each type of small terminal can be determined.

Table 4.2-9 shows the required satellite RF powers in clear air and rain for the different rain fade compensation schemes (no margin):

Table 4.2-9. Satellite RF Power by Terminal Type Vs Rain Fade Compensation Method

Power / Method	E-Type Terminal		F-Type Terminal		G-Type Terminal	
	(dBm)	(Watt)	(dBm)	(Watt)	(dBm)	(Watt)
No-Rain	36.7	4.68	28.3	0.68	19.0	0.08
1	38.4	6.92	30.2	1.05	21.2	0.13
2	38.4	6.92	30.2	1.05	21.2	0.13
3	38.4	6.92	30.2	1.05	21.2	0.13
4	38.4	6.92	30.2	1.05	21.2	0.13
5	43.0	19.95	34.8	3.02	25.8	0.38
6	43.0	19.95	34.8	3.02	25.8	0.38
7	43.0	19.95	34.8	3.02	25.8	0.38

4.2.10 SATELLITE RF BEAM POWER VS RAIN FADE COMPENSATION METHODS

The required satellite RF power to each beam can be determined from the number of E-, F- and G- type terminals in each beam and the satellite RF power transmitting to each terminal. It has the following results:

- In clear air, the satellite RF power required to New York beam is 32.37 watt. It is 459.59 watt for all 40 beams
- In worst case when New York beam is in rain, the required satellite RF power to New York beam with Method 2 rain fade compensation 63.78 watt, while it is 146.13 watt with Method 5 rain fade compensation scheme.
- In worst case when New York beam is in rain, the required total satellite RF power to all 40 beams is 491.73 watt with Method 2 rain fade compensation scheme, while it is 574.06 watt with Method 5 rain fade compensation scheme.
- In calculating the required satellite RF power to the NCS, the following information is used as the baseline:
  - Coded bit error rate: 10^{-8}
  - Bit rate: 2.5 Mb/s
  - Coding gain: 3 dB
  - Antenna characteristic
    - Antenna size 6 meter (as E-Type terminal antenna)
    - Antenna gain 59.2 dB (as E-Type terminal antenna)
    - Receiver noise figure 5 dB

Then the satellite RF power required is around 0.8 watt.

For rain of the downlink, the transmitting small terminal will have some coding scheme implemented and the satellite beam power will be increased. The convolutional code with rate 1/2, constraint length 5, and 2 bits soft decision is assumed to be implemented in the system. This coding circuit is available from 30/20 GHz TDMA Baseband Processor Development Program. The amount of satellite power increase is to be determined, but is around 2.4 dB.

For rain on the uplink, the affected terminal will have its transmitting power increased. The amount of power increase is to be determined, but is around 15 dB.

In clear air, in order to insure the proper system performance, some fixed power margins can be added in the small terminal and the satellite. The amount to be added is to be determined.

4.2.11 LINK BUDGET REFINEMENT (DISTRIBUTED MODEL)

The previous mathematical model used for calculating system $\frac{E_b}{N_o}$ assumed equal uplink and downlink $\frac{E_b}{N_o}$ contributors, did not include effects of small terminal TWT compensation, and assumed impairments were as presented in the proposal:

$$\left(\frac{E_b}{N_o}\right) (\mathrm{dB}) = 10 \,\mathrm{Log}\left[\frac{1}{\left(\frac{N_o}{E_b}\right)_{up} + \left(\frac{N_o}{E_b}\right)_{Dn}}\right] - \sum \mathrm{IMPAIRMENTS}\,(\mathrm{dB})$$

The refined mathematical model used for calculating the system E_o/N_o is more realistic. It does not assume weighting of uplink and downlink $\frac{E_b}{N_o}$ contributors, it updates the impairments, and it includes the effects of small terminal TWT compensation. It also includes the anticipated intermodulation products which will yield yet more accurate results:

$$\left(\frac{E_b}{N_o}\right)_{sys}(\text{dB}) = 10\,\text{Log}\left[\left(\frac{N_o}{E_b}\right)_{UL} + \sum U_i\left(\frac{N_o}{E_b}\right)_{UL} + \left(\frac{N_o}{E_b}\right)_{DL} + \sum_{j} D_j\left(\frac{N_o}{E_b}\right)_{DL}\right]^{-1}$$

where the uplink impairments $\left[\sum_{j=1}^{4} U_i\left(\frac{N_o}{E_b}\right)_{DL}\right]$ are defined as:

U_1	Source
U_1	Ground Station Intermodulation & Modulator
U_2	Phase Noise
U_3	Co-channel Interference
U_4	Other

and the downlink impairments $\left[\sum_{j=1}^{6} D_j\left(\frac{N_o}{E_b}\right)_{DL}\right]$ are defined as:

D_j	Source
D_1	Satellite Intermodulation
D_2	Phase Noise
D_3	Co-channel Interference
D_4	Adjacent Channel Interference
D_5	Filter Distortion
D_6	Other

From Table 4.2-10 we see that TWT impairments U1 and D2 (ground and satellite respectively) change as the weather conditions vary:

- Condition: Uplink rain. downlink clear

  Impairment U_1 degrades from 0 dB to 3 dB because the ground station TWT must be driven close to saturation to increase power out and compensate uplink fade due to rain. Without compensation U_1 degrades to 4.8 dB.

- Condition: Uplink and downlink rain

  Impairment U_1 improves from 3 dB to 1.8 dB because coding will spread the intermodulation products over twice the bandwidth: C/IM ratio improves 3 dB.

- Condition: Downlink rain

  Impairment D1 improves from 3.4 dB to 0.5 dB because:

  1. Drastic degradation of the signal strength due to increased path losses and,
  2. Spreading of the intermodulation products due to coding.

Table 4.2-10. E_b/N_o Impairments

Impairment Source	Magnitude			
	Uplink & Downlink Clear	Uplink Rain Downlink Clear	Uplink Clear Downlink Rain	Uplink & Downlink Rain
*3 U_1	0.0 dB	*1 3.0 dB	0.0 dB	*2 1.8 dB
U_2	0.7 dB	0.7 dB	0.7 dB	0.7 dB
U_3	0.7 dB	0.7 dB	0.7 dB	0.7 dB
u_4	1.0 dB	1.0 dB	1.0 dB	1.0 dB
*4 D_1	3.4 dB	3.4 dB	0.5 dB	0.5 dB
D_2	0.7 dB	0.7 dB	0.7 dB	0.7 dB
D_3	0.7 dB	0.7 dB	0.7 dB	0.7 dB
D_4	1.0 dB	1.0 dB	1.0 dB	1.0 dB
D_5	0.5 dB	0.5 dB	0.5 dB	0.5 dB
D_6	1.0 dB	1.0 dB	1.0 dB	1.0 dB

*1 ST TWT compensated: uncompensated impairment = 4.8 dB.

*2 ST TWT compensated: uncompensated impairment = 3 dB

*3 Uplink E_b/N_o is assumed to be 19 dB:

*4 Downlink E_b/N_o is assumed to be 17.8 dB.

Table 4.2-11 shows the RF power requirements of ST and satellite for each link weather condition.

Table 4.2-11. RF Power Requirements

Link Conditions		Power Source	Traffic Model A (Power In dBm)			Traffic Model B (Power In dBm)					
Uplink	Downlink		E	F	G	E	F	G	H	I	J
Clear	Clear	ST	32.9	26.2	19.2	28.3	22.9	18.1	16.6	14.3	7.4
		Satellite	34.1	25.7	16.9	29.4	22.5	15.7	14.2	11.9	5.0
Rain	Clear	ST	47.9	41.2	34.2	43.3	37.9	33.1	31.6	29.3	22.4
		Satellite	34.5	26.1	17.3	29.8	22.9	16.1	14.6	12.3	5.4
Clear	Rain	ST	32.9	26.2	19.2	28.3	22.9	18.1	16.6	14.3	7.4
		Satellite	34.7	26.3	17.5	30.0	23.1	16.3	14.8	12.5	5.6
Rain	Rain	ST	47.9	41.2	34.2	43.3	37.9	33.1	31.6	29.3	22.4
		Satellite	35.0	26.6	17.8	30.5	23.4	16.6	15.1	12.8	5.9

Several important features may be deduced by comparing the distributed model results with the lumped model results:

Condition	Nominal Δ Power Improvement	
	Small Terminal	Satellite
Clear Air	No Change	2.4 dB
Downlink Rain	No Change	3.7 dB

An important consequence of using the distributed model leads to the conclusion that power boost is not necessary in the satellite when the downlink experiences rain. If the satellite power is nominally set for the worst case condition (rain on both links), the distributed model requires 3.4 dB less satellite power than the lumped model under the same conditions. If rain exists in only one of the two beams, the distributed model requires 3.7 dB less satellite power. (See Table 4.2-12 below).

Table 4.2-12. Satellite New York Beam RF Power Requirements

Condition	Traffic Model A	Traffic Model B
DL Rain		
Distributed Model (Gnd Station TWT Not Compensasted)	21.6 Watts	29.2 Watts
Distributed Model (Gnd Station TWT Compensated)	21.6 Watts	29.2 Watts
Lumped Model	63.8 Watts	86.2 Watts
2 Beam Rain		
Distributed Model (Gnd Station TWT Not Compensated)	23.2 Watts	31.4 Watts
Distributed Model (Gnd Station TWT Compensated)	23.2 Watts	31.4 Watts
UL Rain		41.2 Watts
Distributed Model (Gnd Station TWT Not Compensated)	30.5 Watts	
Distributed Model (Gnd Station TWT Compensated)	20.6 Watts	27.8 Watts
Lumped Model	34.3 Watts	46.4 Watts

The values of power were computed by extrapolating the relative powers to the appropriate bandwidth for the New York beam. The RF power shown is required to produce a BER of 1×10^{-6}.

The effects of ST TWT compensation may be calculated from the two values for the distributed link budget model:

$$\%\ \text{reduction} = \left(\frac{30.5 - 20.6}{30.5}\right) 100 = 32\%$$

If the model assumes worst case power on the downlink for the simultaneous uplink and downlink rain case, the effects of ST TWT compensation may be calculated:

$$\%\ \text{reduction} = \left(\frac{30.5 - 23.2}{30.5}\right) 100 = 24\%$$

The RF powers shown are those required to support a bit rate of 207 Mb/s for Traffic Model A and 279.8 Mb/s for Traffic Model B.

4.3 Forward Error Control

The following subparagraphs discuss the methods used to achieve forward error control.

4.3.1 MONITOR, SENSING AND CONTROL

Each ST station monitors its downlink orderwire AGC level. If the level is below its nominal value, the link between the small terminal and the satellite is assumed enduring fade. The station will increase its total transmitting power 2.5 dB per dB fade in the received signal strength. The baseline for this power boosting is that the system uplink rain fade margin is assumed to be 15 dB while it is only 6 dB in the downlink. Therefore, proportionally it has 2.5 dB fade in the uplink when it has 1 dB fade in the downlink.

Each ST station monitors downlink traffic channel power level. If the level is below its nominal value, it reports this situation to the NCS and asks for the NCS decision. The NCS monitors the orderwire of each small terminal uplink signal level. If some link fades, the NCS directs the affected transmitting small terminal to use coding and commands the satellite to boost its power.

4.3.2 ENCODING

The recommended encoding scheme is the rate one-half, constraint length five, and two bits soft decision convolution code. This provides a coding gain of 3.6 dB at a 10^{-6} bit error rate. The chip circuit (μ − CMOS) is in processing for the 30/20 GHz TDMA Baseband Processor Program and is scheduled for chip tests in the test module in July 1982.

4.4 Frequency Plan

The trunking and ST frequency plan requirements are:

- Trunking
  - Trunk channel bandwidth = 1.5 GHz (three bands)
  - Trunk traffic burst rate = 550 Mb/s
  - TDMA transmission as per 30/20 GHz TDMA communication system
  - Number of beams with trunk traffic = 18
  - Peak hour traffic = 6053 Mb/s
  - 23 × 223 IF switch for routing
- ST
  - ST bandwidth = 1.0 GHz
  - Includes T/ST, ST/ST and ST/T traffic
  - Traffic model A; 45 cities, 40 beams, 3.0 Gb/s throughput
  - Traffic model B; 277 cities, 71 beams, 3.0 G/bs throughput
- General requirements
  - Polarization diversity not required
  - Frequency plan to avoid spot-to-spot interference

Traffic consists of both trunk and ST traffic. Any trunk traffic which is destined for a ST terminal is assigned a frequency allocation in the ST band. This also pertains to the ST to trunk traffic and results in a maximum total ST traffic of 3.0 Gb/s. All trunk-to-trunk traffic is switched in the satellite via an IF switch in which the trunk traffic is generated from approximately 18 terminals. Frequency organization for the trunk traffic is the same as in the TDMA 30/20 GHz Communication System. Since this FDM/TDMA design is presently fixed, the following discussions pertain to just the ST traffic. Frequency plans for Traffic Model A and Traffic Model B are included in which the traffic models described in the NASA Statement of Work and Western Union refinement of these traffic models are the baseline from which frequency allocations have been derived. The frequency plans do not assume any isolation through polarization diversity. Frequency allocations are tempered by router complexity but essentially reuse is maximized while avoiding spot-to-spot interference degradation. The use of the trunking band for ST traffic is not considered at this time.

4.4.1 TRAFFIC FREQUENCY PLAN

Shown in Figure 4.4-1 is a composite frequency plan for small terminal (ST) and trunk traffic. For beams requiring two trunking channels A and C are used. For ST traffic only one of the three ST bands are required and in most cases these bands are only partially filled by any single beam. For the special case where two trunk bands are required, the ST traffic will avoid placement in band three, thus minimizing co-channel and adjacent channel interference.

The trunking band is nominally 1.5 GHz wide with each channel capable of 550 Mb/s serial MSK traffic as was recommended in the Baseband Processor program. The three small terminal bands are unequal in width but are each nominally 300 MHz wide. The total is about 1 GHz.

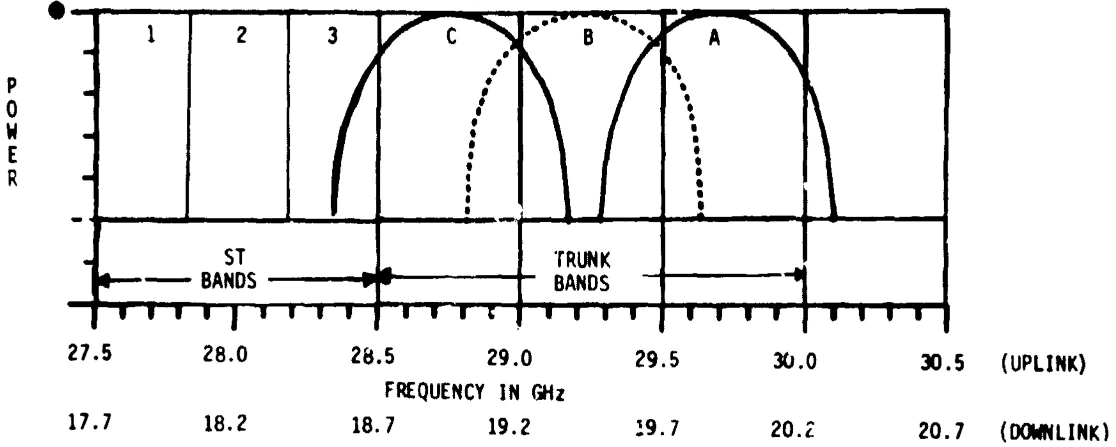

Figure 4.4-1. Composite Frequency Plan

4.4.2 FREQUENCY PLAN DESIGN ASSUMPTIONS

In capsule form, the frequency plan design assumptions are:

- beam spot coverage equal approximately a 150 mile diameter on the earth's surface
- beam spot centers separated by 250 miles or less must operate in different frequency bands
- bandwidth allocation — 1 Hz/bit (i.e., bandwidth required equal data bit rate)
- voice traffic is 32 kb/s
- every beam spot communicates to all other beam spots except to itself
- spot traffic follows relationship

  $T_{IJ} = T_I T_J/(T - T_I)$ (traffic from beam I to beam J equals traffic from beam I times traffic from beam J divided by if I = J, the total traffic from all beams less that from beam I, $T - T_I$)

  $T_{I,I} = 0$
- router complexity to be considered in the frequency plan design

Beamwidth of the satellite antenna is approximately 0.3 degrees. Although the actual antenna pattern will vary over the CONUS, a spot diameter of 150 miles is estimated for frequency planning purposes. As the spot diameter increases, the number of frequency bands will increase accordingly. In the limit, with a data rate of 3.0 Gb/s and a bandwidth of 1 Hz/b/s then without frequency reuse the required bandwidth would be a minimum of 3.0 GHz. Studies to date indicate that the required Hz/b/s is approximately 1.25 if worst case channel degradation is to be less than 2 db. Also coding and channel availability requirements will add another 15–20% to the uplink bandwidths shown. If conversation of uplink bandwidth becomes crucial there are other routing and frequency organizations which can be employed. However, for the architecture described herein, the downlink bandwidth is near minimum and the router design is kept reasonable at the expense of uplink bandwidth. Many factors must be considered before final allocations are assigned and consequently bandwidths shown are baseline and can be adapted as operating conditions change.

4.4.3 ST TRAFFIC-CITY AND FREQUENCY BAND ALLOCATION FOR TRAFFIC MODEL A UPLINK

As shown in Table 4.4-1, the ST band has been subdivided into three frequency bands in which the total bandwidth allocated for ST traffic is 833 MHz. The arrangement of cities in a given frequency band is not unique, and any number of arrangements are possible. The key consideration which led to the distribution shown is maintaining cities in close geographical proximity (250 miles separation) in separate frequency bands.

Table 4.4-1. Traffic-City and Frequency Band Allocation for Traffic Model A Uplink

Frequency Band 1			Frequency Band 2			Frequency Band 3		
1	New York	310	7/16	Wash DC/Phila	307	19/33	Boston/Hartford	183
2	Los Angeles	295	3	Chicago	284	11	Tampa	216
15/32	Det/Cleveland	246	6	Greensboro	238	14	Salt Lake City	203
18/20	Buffalo/Roch	266	21/31	Columbus/Cinn	196	17	Dallas	170
4	Milwaukee	263	9	San Diego	255	24	Lansing	165
5	Indianapolis	255	12	Houston	177	25	Harrisburg	162
8	San Francisco	189	13	Portland	209	29	Atlanta	142
10	Phoenix	224	22	Minn/St Paul	155	42	Louisville	126
26	New Orelans	158	23	Miami	151			
30	Denver	140	27	St Louis	147			
35	Seattle	135	28	Pittsburgh	145			
36	Norfolk	134	34	Kansas City	137			
41	San Antonio	127	37	Syracuse	132			
43	Memphis	125	38	Oklahoma City	131			
44	Omaha	124	39	Nashville	129			
45	Jacksonville	122	40	Fresno	128			
16 Beams Req'd BW 310 MHz			16 Beams Req'd BW 307 MHz			8 Beams Req'd BW 216 MHz		
Total Uplink Bandwidth 833 MHz						Total Downlink Bandwidth - 496 MHz		

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Without regard to the router design the required total bandwidth would be 496 MHz (vs the 833 MHz shown in Figure 4.4-2) and each of the cities would require less bandwidth (i.e., New York would be 207 MHz instead of 310 MHz). City numbers shown are that city's position in terms of input/output traffic. For example, New York is the heaviest traffic city, and Hartford is number 33. It should be noted that even though cities are in the same zone they need not overlap in frequency allocation. For example, Kansas City and St. Louis are in the same frequency band and are less than 300 miles apart. However, with the frequency bands of these cities adjacent to one another, they still won't exceed the bandwidth of Frequency Band 2 (i.e., 137 + 147 < 307).

Figure 4.4-2 shows a graphical representation of the same data tabulated in a previous section (see ST Traffic City and Frequency Band Allocation for Traffic Model A). Even though the 3 dB bandwidths are shown as circles instead of ellipses, the presentation provides a clear picture of frequency band and city assignments.

The numbers shown accompanying the beam spots are that particular city's position in terms of input/output traffic (i.e., Fresno is number 40 in terms of traffic volume).

4.4.4 ST TRAFFIC BEAM SPOT FREQUENCY ALLOCATION TRAFFIC MODEL B UPLINK

As shown in Table 4.4-2, the ST band has been subdivided into three frequency bands in which the total bandwidth allocated for ST traffic is 1179 MHz. The arrangement of cities in a given frequency band is not unique, and any number of arrangements are possible. The key consideration which led to the distribution shown is maintaining cities in close geographical proximity (250 miles separation) in separate frequency bands.

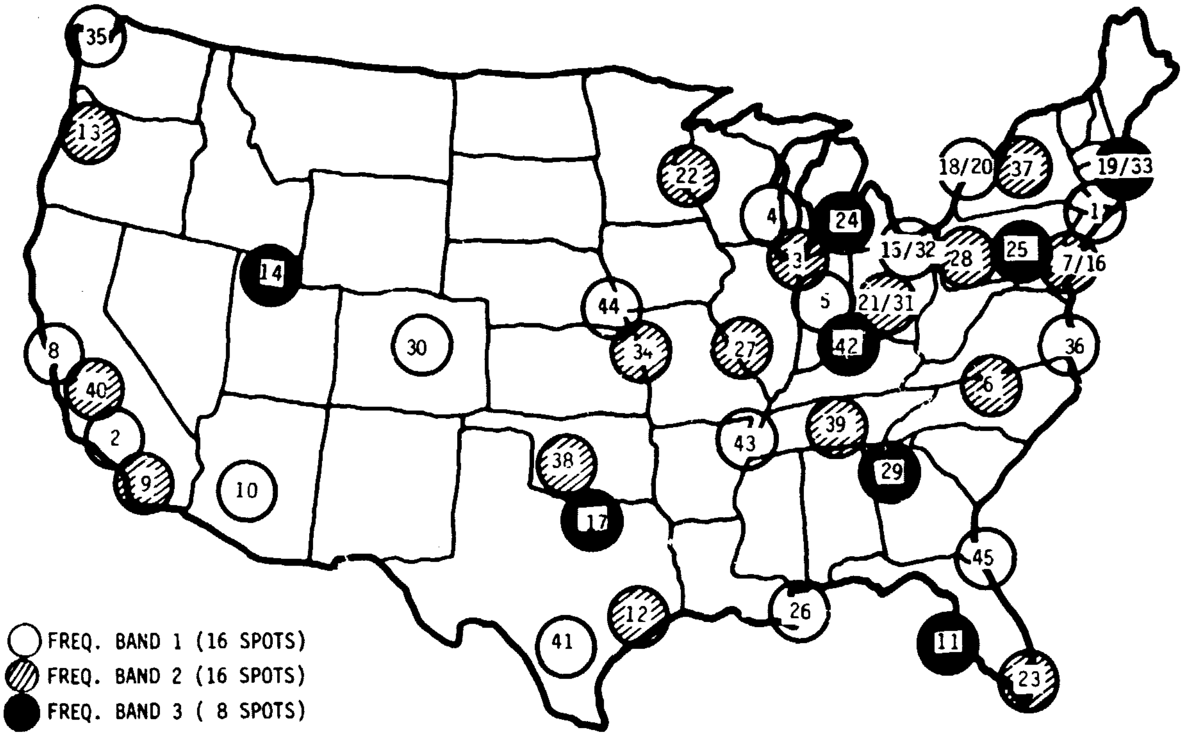

Figure 4.4-2. Beam and Frequency Allocation for Traffic Model A

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Table 4.4-2. ST Traffic Beam Spot Frequency Alloction Traffic Model B Uplink

Frequency Band 1		Frequency Band 2		Frequency Band 3	
Beam Spot #	BW (MHz)	Beam Spot #	BW (MHz)	Beam Spot #	BW (MHz)
52	412	22	375	26	392
17	360	30	334	10	322
39	345	67	304	18	313
20	316	71	286	55	298
25	270	28	254	70	292
15	260	14	250	35	281
8	245	5	186	33	276
63	241	24	182	44	265
23	220	9	180	16	236
66	174	34	177	32	232
58	171	43	163	1	209
51	165	45	160	53	202
60	155				
37/46/68	216	11/31/56	198	38/29/57	228
2/36/65	212	49/50/69	195	7/27/54	224
6/21/61	192	4/41/48/64	168	13/40/59	205
		3/19/42	157	12/47/62	189
22 Beams Req'd BW = 412 MHz		25 Beams Req'd BW = 375 MHz		24 Beams Req'd BW = 392 MHz	
Total Uplink Bandwidth = 1179 MHz				Total Downlink Bandwidth = 609 MHz	

The beam spot numbers are those shown on the map for Traffic Model B. For the case where multiple spots are indicated these are combined before processing in the router. This will not increase the total bandwidth needed but will increase the necessary satellite transmit power (approximately 1 dB for the arrangement shown).

Without regard to the router design the required total bandwidth would be 609 MHz (vs the 1179 MHz) and each of the cities would require less bandwidth. (i.e., New York area would be 280 MHz instead of 316 MHz.)

Figure 4.4-3 shows a graphical representation of the same data tabulated in a previous section (see ST Traffic City and Frequency Band Allocation for Traffic Model B). Even though the 3 dB bandwidths are shown as circles instead of ellipses, the presentation provides a clear picture of frequency band and beam spot assignments. Beam spot numbers have no particular significance except as reference to the preceding table showing frequency allocation.

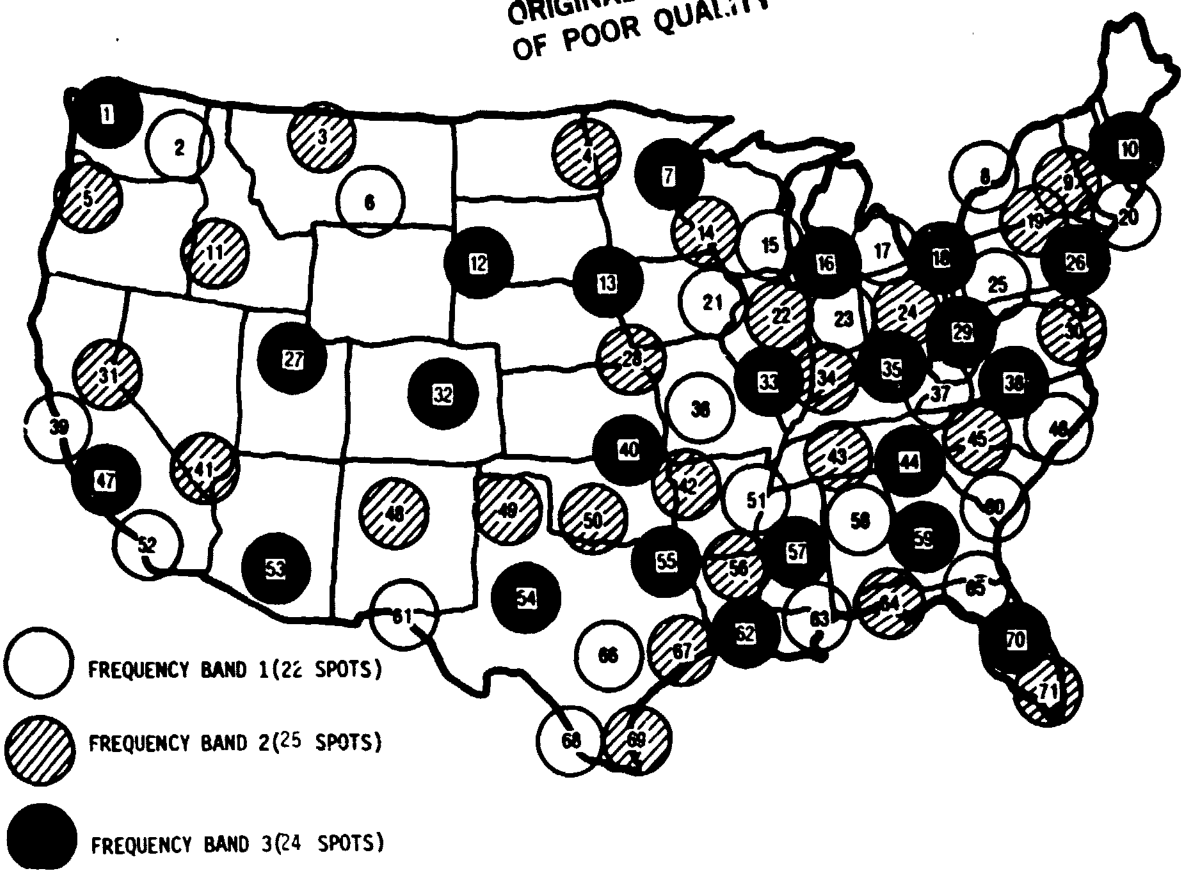

Figure 4.4-3. Beam and Frequency Allocation for Traffic Model B

4.4.5 CHANNEL ARRANGEMENT

The channel arrangement shown in Figure 4.4-4 is designed to simplify the satellite router while still insuring sufficient traffic flexibility. Although this will be discussed in more detail in the section titled "Satellite Routing", some comments are worth noting here.

The numbers shown in each rectangle, m-n, represents traffic from source city "m" to destination city "n". Although not deleted above, there is no frequency allocation for the case when m=n since instraspot traffic is precluded. Neglecting this detail here then in all cases, the destination location, n, is made up of contiguous channel slots. That is, the end of slot 1-1 is even with the beginning of 7/16-1 and the end of 7/16-1 coincides with the beginning of 2-1 and so on. Thus, the traffic to any beam spot does not overlap in the frequency domain with any other traffic to that same destination. This has some definite router switching advantages. Source traffic is arranged in order of descending traffic. That is, the traffic from city number 1 is the heaviest while that from 7/16 is second in volume followed by that from city number 2, and so forth.

Arrangements in other than descending (or ascending) traffic volume will result in a required total bandwidth greater than that described in the paragraph titled "ST Traffic-City and Frequency Band Allocation for Traffic Model A". The above channelization is depicted as if total frequency reuse were possible. In reality, the source transmissions must conform to the overall frequency allocations plan and offset shifts are required as shown.

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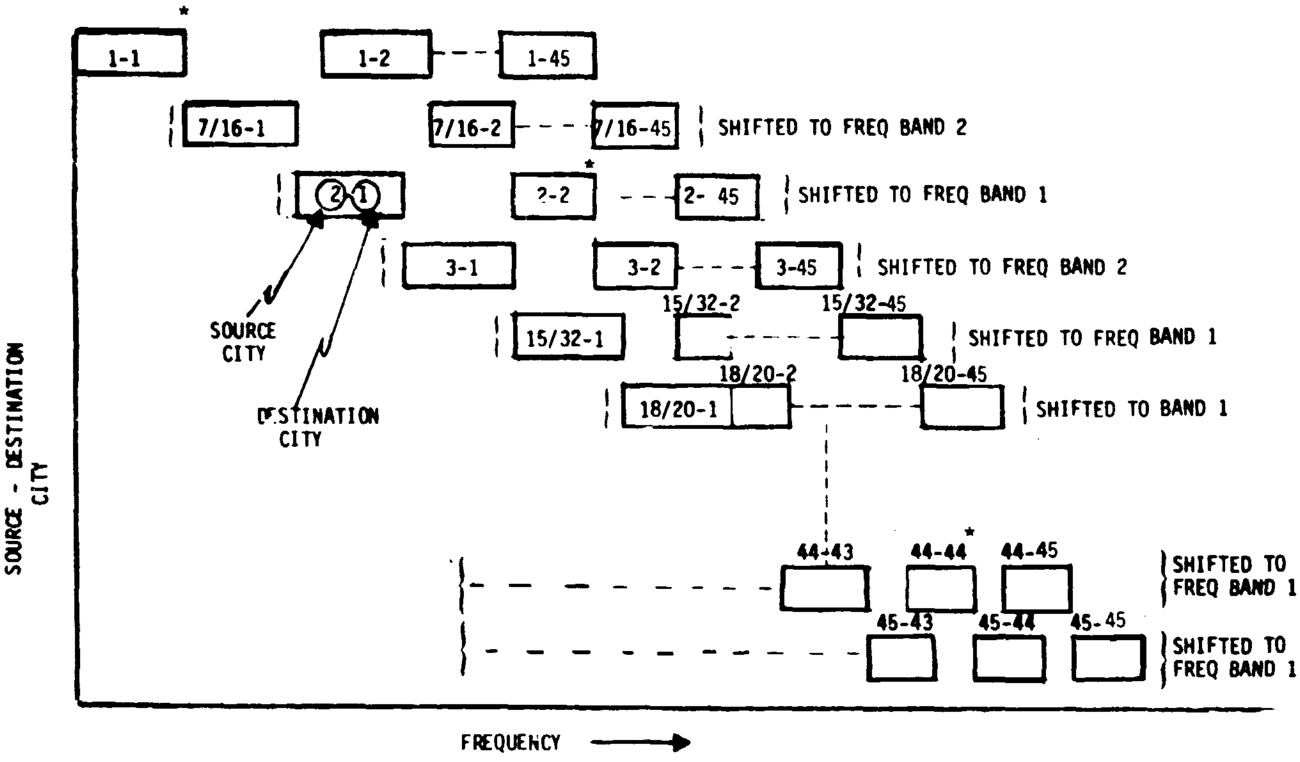

* IN THE ACTUAL TRAFFIC ALLOCATION THESE SLOTS ARE NOT PRESENT SINCE COMMUNICATION FROM A BEAM SPOT TO ITSELF IS PRECLUDED.

Figure 4.4-4. Channel Arrangement

4.4.6 ALTERNATE FREQUENCY PLAN FOR TRAFFIC MODEL A

The channel arrangement shown in Figure 4.4-5 will result in the minimum uplink bandwidth required for ST traffic transmission. This 496 MHz bandwidth contains the same cities in each band as that shown in the recommended frequency plan. The difference here is contiguous arrangement of transmit frequency slots. This in turn requires considerably more processing in the satellite for destination frequency channelization.

A number of other frequency plans were investigated, including a six band allocation and a channelization plan where all destination locations were "vertically" aligned. That is, referring to Figure 4.4-5, channel 45-1 would be centered in the 1-1 frequency band, 45-45 would be centered in the 1-45 frequency slot, and so forth.

This arrangement can also be established at the section level where a section is defined as a subdivided portion of the total traffic matrix. A "vertically" aligned design at the section level appears to have definite advantages in both router simplicity and in conserving bandwidth. However, studies were not completed in this area.

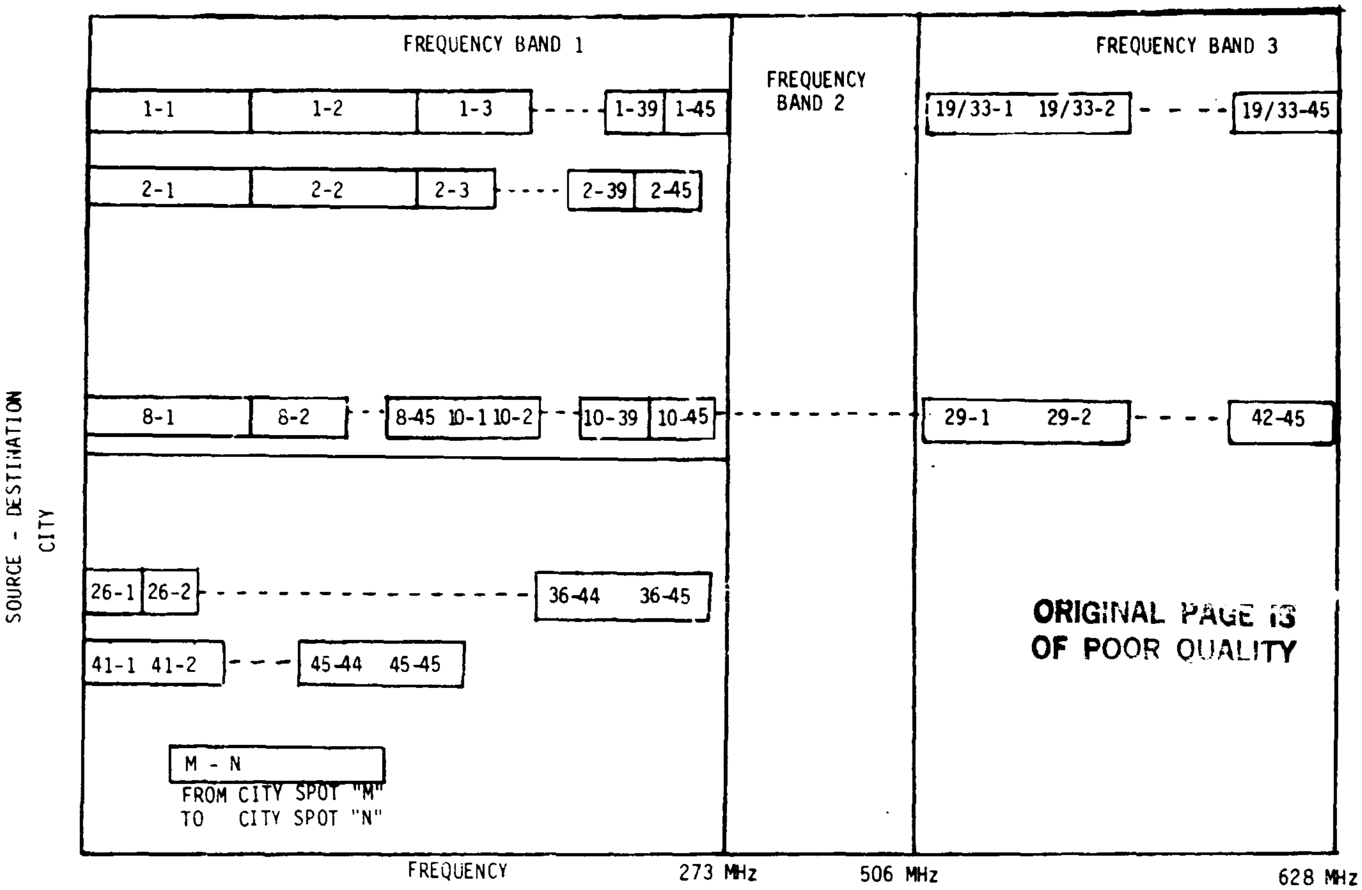

Figure 4.4-5. Alternate Frequency Plan for Traffic Model A

4.5 Satellite Routing

The following subparagraphs discuss satellite router requirements, router architecture, and router switching design.

4.5.1 SATELLITE ROUTER REQUIREMENTS

In summary form, the satellite router requirements are:

- Route multiple beam input traffic to proper output beam destinations.
- Input from single beam segmented into traffic for all other beams.
- Beam traffic controlled by path filter sizing and arrangement.
- Switching to provide for rearrangement of traffic to output beams.
- Frequency conversions to minimize interference and meet traffic flexibility requirements. ± 30% on major traffic beams (approximately 18 beams) and ± 50% on all other beams.
- Design to address frequency plan impact.

Listed above are the general architecture requirements for the satellite router. The primary concern in designing the router is satisfying the flexibility requirements and minimizing router complexity. To this end, reasonable compromises should be considered and evaluated using the total requirements as guidelines.

Essentially, the router must handle up to 3.0 Gbps of digital traffic or equivalent analog information (i.e., it must be a linear transfer) from approximately 40 inputs in Traffic Model A and 71 inputs for Traffic Model B. Each input is segmented into traffic for the outputs. The amount of traffic from a given beam to an output beam is sized according to the traffic requirements and is set by the path filter bandwidth.

Changes in traffic demand are accommodated by changing the path filter. Since filters and switches have a finite bandwidth capability, the required frequency conversions must be carefully selected to avoid any interference problems. This is particularly important when it is realized that within the router there are 1600 path filters in Traffic Model A and 2304 in Traffic Model B. Thus, the router design must consider hardware restrictions in conjunction with architectural constraints. In the paragraphs which follow, the router will be discussed primarily from an architectural standpoint.

4.5.2 ROUTER ARCHITECTURE SUMMARY

The basic router architecture will affect a compromise between flexibility and complexity. To this end, an approach has been developed which will significantly reduce switching and synthesizer requirements relative to a total interchange capability.

Studies indicate that using the frequency plan previously discussed with switching arranged to handle sets of path filters instead of individual path filters, a significant hardware savings can be realized with only minor impact on flexibility.

In the following section, a description of the basic architecture will be presented. In brief, the router architectue is:

- Router architecture is related to the frequency plan. Frequency plan of previous section assumed.
- Switching interchanges sets of path filters and not individual path filters.
- Switching will be restrictive in that any path filter cannot be assigned any path.
- Switching will be among beams of comparable traffic volume.
- Flexibility requirements met with a minimum of switch crosspoints.
- Switch requirements are moderate.
- Synthesizer requirements are moderate.

4.5.3 ROUTER SWITCHING DESIGN GENERAL

In developing a router architecture, an ordered and logical process must be followed. In the discussion which follows, fundamental rules, characteristics and terminology observed throughout the router switching design are established.

The approach taken here follows only the rules of common sense. Terminology employed is not necessarily that of any other switching theory definitions. At the outset, the traffic model is broken into a matrix which defines all the source and destination path filters. The complete matrix is broken into smaller switching blocks of traffic defined as zones and sections. Within sections, are independent switching blocks. That is, within each section, switching can be accomplished to rearrange the bandwidth (path filter assignment) from the various beam sources to the beam sources to the beam destinations within that section. Thus switching does not influence other sections. Switching may occur at the element level (one path filter for another) or at the row/column level where a number of path filters are rearranged for any one switch change.

These concepts will be illustrated in the following sections. Switching traffic from one section to another may be accomplished by means of overlap switching and will be described herein.

4.5.4 BEAM AND PATH FILTER MATRIX FOR A NINE BEAM, THREE ZONE ARRANGEMENT

As an illustration of the concepts employed, consider a nine beam system as depicted in Figure 4.5-1. With nine beams in which all beams can transfer traffic from any beam to any other beam (including to itself) there must be 81 (g^2) filters if path independence is to be preserved.

For the nine beam configuration, assume that there are three separate zones. Assume still further that the respective three zones contain three beams, four beams, and two beams. The number of beams assigned a zone is dependent primarily on traffic volume. With nine beams and zones of three beams, four beams, and two beams, the sections within the matrix are as shown.

It should be noted that a traffic zone and section arrangement is not normally related to the frequency plan organization. Obviously it would be desirable to have such correspondence in order to simplify the frequency synthesis in the router. However this is generally not realizable since beams of comparable traffic volume often overlap geographically and thus must be frequency separated.

The numbers within the matrix represent the nominal path filter nomenclature. That is, for the traffic originating at beam seven with an intended destination to beam nine, the path filter is designated at 7-9. The bandwidth f[illegible] this filter is designed to handle the nominal prescribed traffic. As these traffic demands change, the path filter assignments within a section are changed via the router switch. The section in bold outline will be used to illustrate basic router switching principles.

4.5.5 GENERAL SWITCH CONFIGURATION FOR A 4 × 3 BEAM DATA TRANSFER

Consider a 4 × 3 section which might follow from the matrix described in Figure 4.5-2. For inputs from beams 4 - 7, which have traffic destined for beam 1 - 3, the possible switch arrangements are shown. The first switch is designated as a row switch since a change in this switch will transfer path filters between two rows in a section.

From the example shown, let the original state of the switches be straight through as shown in the dotted line for the row switch. This will then satisfy the matrix designations shown previously. Now, let the row switch from beams four and five have their destinations reversed. Then the path filters previously allocated to paths 41, 42, and 43 will be the path filters for paths 51, 52, and 53. This corresponds to a row interchange as shown. The column switch performs an interchange between column elements within a section and can be verified rather easily by performing the switch interchange and noting the effect. The inner switches allow switching between individual elements and if these were implemented, there would be little need for the outer column and row switches. More important, however, is the possibility of eliminating the element switches and employing only the row and column switches.

This certainly reduces the switch crosspoints and with a well chosen frequency plan will greatly reduce synthesizer requirements. This will be demonstrated in the succeeding paragraph.

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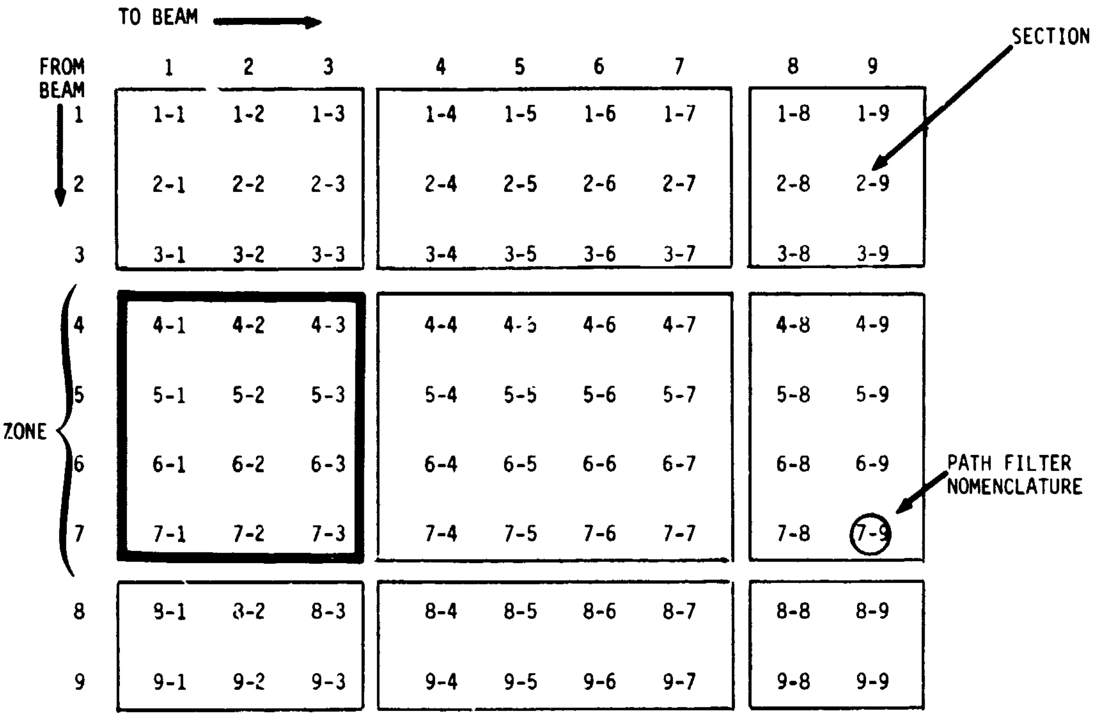
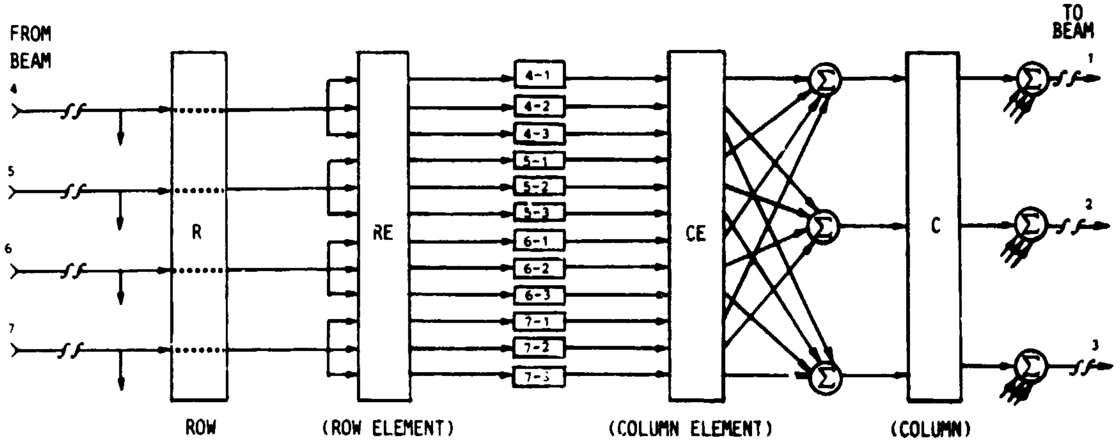


FROM BEAM \ TO BEAM	1	2	3	4	5	6	7	8	9
1	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9
2	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9
3	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9
4	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9
5	5-1	5-2	5-3	5-4	5-5	5-6	5-7	5-8	5-9
6	6-1	6-2	6-3	6-4	6-5	6-6	6-7	6-8	6-9
7	7-1	7-2	7-3	7-4	7-5	7-6	7-7	7-8	7-9
8	8-1	8-2	8-3	8-4	8-5	8-6	8-7	8-8	8-9
9	9-1	9-2	9-3	9-4	9-5	9-6	9-7	9-8	9-9

Figure 4.5-1. Beam and Path Filter Matrix for a Nine Beam, Three Zone Arrangement



EXAMPLE

SWITCH	INTERCHANGE ELEMENT(S)	WITH ELEMENT(S)
ROW	4-1, 4-2, 4-3	5-1, 5-2, 5-3
ROW ELEMENT	4-1	5-1
COLUMN ELEMENT	4-1	4-2
COLUMN	4-1, 5-1, 6-1, 7-1	4-2, 5-2, 6-2, 7-2

Figure 4.5-2. General Switch Configuration for a 4 × 3 Beam Data Transfer

4.5.6 EXAMPLE SHOWING CONFLICT AND NEED FOR SYNTHESIZER WITH SINGLE ELEMENT SWITCHES

The example shown in Figure 4.5-3 considers element switching, and in particular a column element switch operation. The same comments would apply to a row element switch. The frequency channelization plan is that as described in the section titled "Frequency Plan and Channelization" and its basis will become apparent as the discussion proceeds.

The diagram on the left shows a path, a path filter, and an assigned path filter channelization bandwidth (bears no relation to actual assignments). The graph to the right shows the result if a column element switch change is made to reverse the paths of beam segments 61 and 62. When this occurs, then the traffic from beam six to beam two will occupy a frequency band which overlaps that from beam five to beam two. A similar overlap occurs for traffic to beam one from beams six and seven.

Obviously, this kind of downlink interference cannot be allowed and a frequency offset (or some equivalent method) must be provided. Thus, a synthesizer is required to avoid downlink frequency band overlap. This condition can always exist with element switching unless the transmit bandwidths are extremely wide. For this system, the required bandwidth would be prohibitive.

4.5.7 EXAMPLE SHOWING RESULT OF COLUMN INTERCHANGE

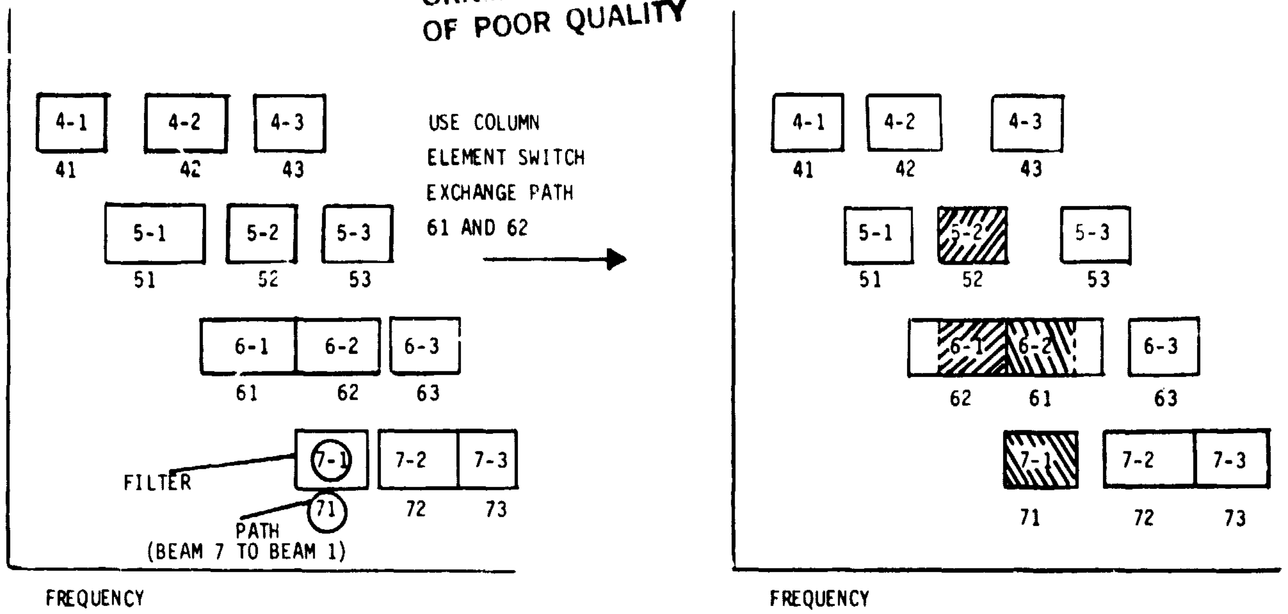
Figure 4.5-4 demonstrates row and column switching. Note that for the frequency plan as previously described, row and column switching will never result in the frequency band overlap as demonstrated in the preceding cell.

The right half of the figure shows the result of changing the column row switch between beam destinations one and two. In this case, the band of frequency slots originally routed to beam one has been allocated to beam two and visa versa. Obviously, the drawback to this arrangement is the increased transmit bandwidth and multiple path filter switching as opposed to single element interchange. The advantages are a significant reduction in switch complexity and less severe synthesizer requirements.

These savings, plus increased reliability, reduced power, size, and weight savings, lead to its recommendation as the baseline architecture. Its acceptance as a final architecture requires further evaluation in terms of hardware implementation and flexibility analysis. This is in process.

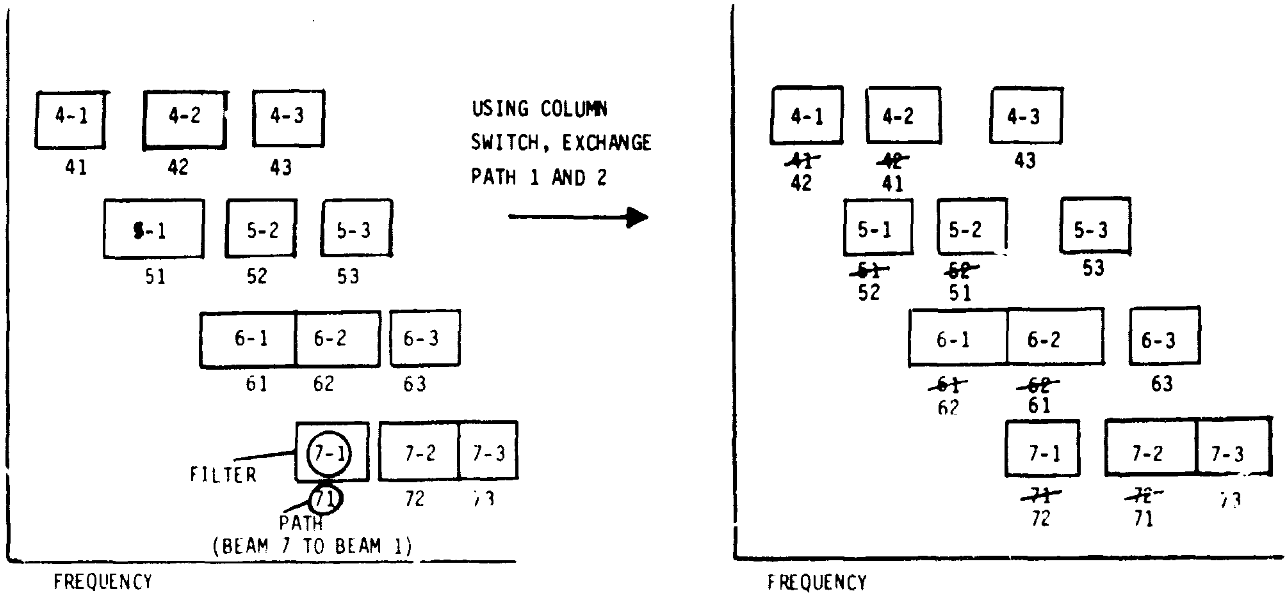
4.5.8 OVERLAP SWITCHING

Figure 4.5-5 illustrates a method whereby traffic from one section can be routed to another section. This capability is not currently employed, but may become a consideration if flexibility studies indicate such is necessary. Overlap switch advantages and disadvantages are as shown in which the primary tradeoff is between flexibility and complexity.


USE COLUMN ELEMENT SWITCH EXCHANGE PATH 61 AND 62

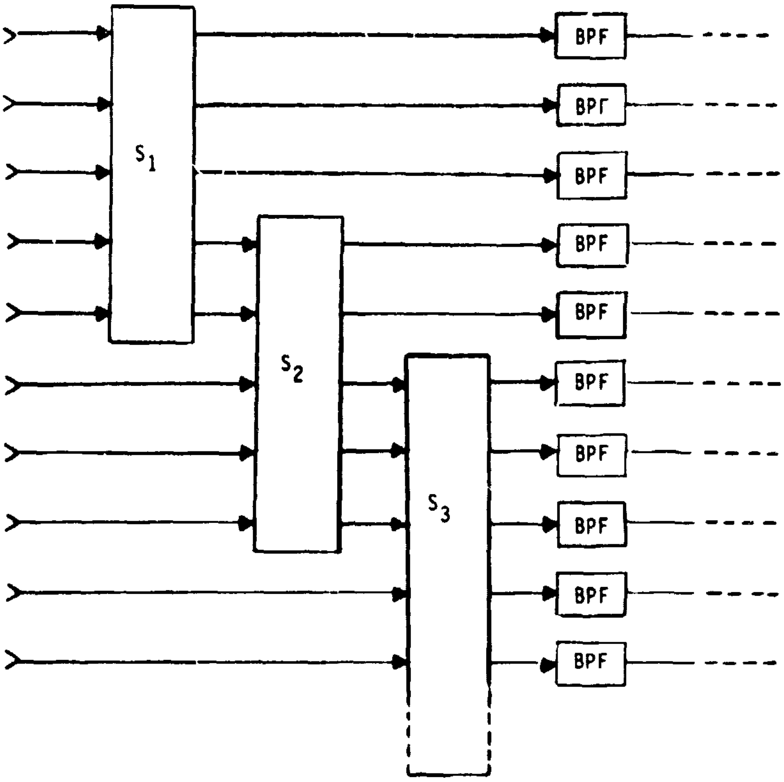
NOTE: FREQUENCY INTERFERENCE IN DOWNLINK BEAM 1 AND BEAM 2
UNLESS FREQUENCY MANAGEMENT IS PROVIDED BEFORE COMBINING.

Figure 4.5-3. Need For Synthesizer With Single Elements Switches


USING COLUMN SWITCH, EXCHANGE PATH 1 AND 2

NOTE THAT FREQUENCY INTERFERENCE IN DOWNLINK CANNOT OCCUR FOR ANY
COLUMN OR ROW INTERCHANGE.

Figure 4.5-4. Results of Column Interchange



ADVANTAGES

1. IMPROVES TRAFFIC CONTROL FLEXIBILITY.
2. TRAFFIC NOT ISOLATED AND INDEPENDENT IN A SECTION.
3. ADDED REDUNDANCY.

DISADVANTAGES

1. MORE CROSSPOINTS AND THEREFORE MORE POWER FOR SWITCHES.
2. SWITCH CROSSTALK INCREASED.
3. SWITCH LOADING MORE SEVERE.

Figure 4.5-5. Overlap Switching

4.6 Modulation Selection

4.6.1 REQUIREMENTS AND CONDITIONS AND CANDIDATE MODULATION FORMS

In summary, the modulation requirements and conditions are:

Requirements

- For a given communication link, select a modulation technique which will minimize the required transmit power to give a bit error rate (BER) of 10^{-6}.
- For a given communication link minimize the required channel separation for a given adjacent channel signal level relative to that in the desired channel.

Conditions

- Degradation due to individual channel filtering shall be less than 1.0 dB.
- Adjacent channel interference will not exceed 20 dB and shall result in a signal channel degradation less than 1.0 dB.

Candidate Modulation Forms

- Offset quadraphase shift keying (O-QPSK).
- Minimum shift keying (MSK).

The modulation requirements as stated above allow considerable latitude unless some boundary conditions are established. For example, closer packing of the traffic channels may be accomplished by decreasing channel bandwidths which will aid in filtering adjacent channel interference. However, as the channel filter bandwidth decreases the basic individual channel loss will increase. Since adjacent channel interference is not the normal mode it is considered more realistic to first decrease the channel bandwidth until some small individual channel degradation is established. Then for this condition begin adding adjacent channels with a fixed relative signal level and slide these in frequency toward the signal channel until some additional allowed degradation is observed. This then is the procedure followed here. It is fully realized that this must be approached with caution since many other factors can influence the final modulation selection. These include channel filter response characteristics, sensitivity to phase distortion, response to operation in a quasi-linear mode, modem complexity and efficiency, and equalizer requirements. Although significant, these items are not the selection drivers in this case, but will remain as topics for consideration in the final selection.

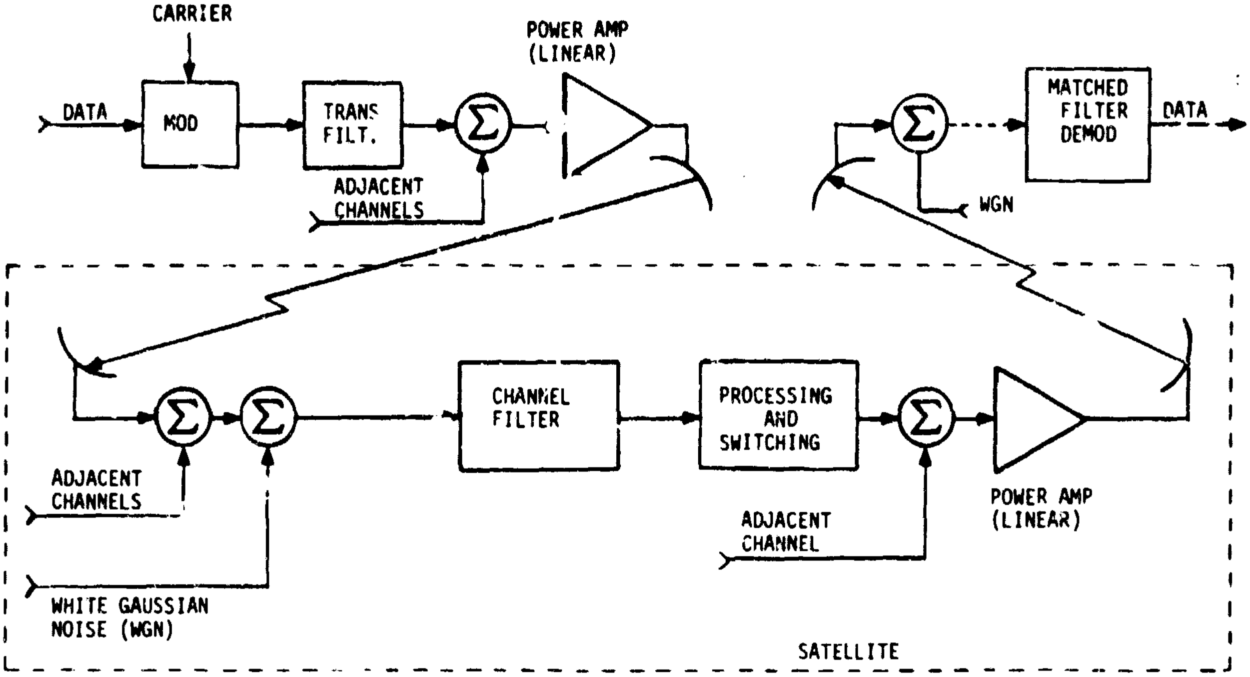
From the first requirement to minimize transmit power to provide the most efficient data link the obvious modulation class to be selected is one which has phase coherency. Thus the primary forms considered here are bi-phase (BPSK), quadraphase (QPSK), offset quadraphase (O-QPSK) and minimum shift keying (MSK). BPSK may be eliminated due to spectrum inefficiency and QPSK is not considered a strong candidate due to spectrum inefficiency when operated in a limited or saturated environment. Since this is a distinct possibility (i.e. video channels) the forms of modulation considered here are O-QPSK and MSK.

4.6.2 FUNCTIONAL BLOCK DIAGRAM

The functional block diagram in Figure 4.6-1 shows linear operation for the traffic channel subject to white gaussian noise (WGN) only. Linear operation permits a model with a single transmission filter for channel shaping and application of theoretical BER curves. The satellite channel filter includes traffic from other terminals in the same beam. All SAW filters are assumed to have bandwidths greater than an individual traffic channel bandwidth, and are therefore assumed to be transparent for analysis purposes. The modulator/detector transfer function in the receiver is assumed to be an ideal matched filter, matched to the transmitted waveform.

4.6.3 BANDWIDTH PERFORMANCE COMPARISON

From Table 4.6-1 we can see that for what are considered unbiased conditions, there is not a significant difference to be observed between O-QPSK and MSK in terms of allowable channel density in a given bandwidth. For a 20 dB relative adjacent channel signal level and allowing 2 dB total degradation the MSK will allow about 10% greater channel density (1.13 R separation vs 1.25 R) whereas for the same total 2 dB degradation and equal power in the adjacent and signal channels O-QPSK has a 6% advantage. If the filter for O-QPSK were to have one more pole than that for MSK the scales would tip in favor of O-QPSK for all above conditions. However, in this comparison a four pole Butterworth filter was used for the transmission filter and only the bandwidth was allowed to vary. Derivation of the data shown in the above has been extracted from the analysis described in Section 11, Support Studies.



ASSUMPTIONS: LINEAR OPERATION THROUGHOUT

CHANNEL FILTER BW >> TRANSMIT FILTER BW

Figure 4.6-1. Functional Block Diagram

Table 4.6-1. Bandlimited Performance Comparison

Modulation Format	Filter BW	Adjacent Channel Int Level (dB)	Channel Separation	Channel Separation Degradation (dB) "A"	Degradation Due to Signal Loss in Filt (dB) "B"	Total Degradation (dB) A + B
O - QPSK	1.35R	0	0.97R	1	0.5	1.5
	1.05R	0	0.79R	1	1.0	2.0
	1.35R	20	1.55R	1	0.5	1.5
	1.05R	20	1.25R	1	1.0	2.0
MSK	1.35R	0	0.89R	1	0.5	1.5
	1.17R	0	0.84R	1	1.0	2.0
	1.35R	20	1.25R	1	0.5	1.5
	1.17	20	1.13R	1	1.0	2.0

From Table 4.6-1 we can see that for what are considered unbiased conditions, there is not a significant difference to be observed between O-QPSK and MSK in terms of allowable channel density in a given bandwidth. For a 20 dB relative adjacent channel signal level and allowing 2 dB total degradation the MSK will allow about 10% greater channel density (1.13 R separation vs 1.25 R) whereas for the same total 2 dB degradation and equal power in the adjacent and signal channels O-QPSK has a 6% advantage. If the filter for Q-QPSK were to have one more pole than that for MSK the scales would tip in favor of O-QPSK for all above conditions. However, in this comparison a four pole Butterworth filter was used for the transmission filter and only the bandwidth was allowed to vary. Derivation of the data shown in the above has been extracted from the analysis described in Section 11, Support Studies.

O-QPSK has been chosen for the SS-FDMA system. This choice is based on the following considerations.

1. An equivalence has been shown, under the condition stated, between O-QPSK and MSK modulation schemes.
2. The choice allows a comparison between O-QPSK chosen here for the SS-FDMA system and SMSK (a theoretical equivalence between MSK and SMSK is assumed) chosen for the Baseband Processor System given O-QPSK demodulation being accomplished with the Baseband Processor SMSK demodulation chip as has been proposed.

4.6.4 CODING FOR VOICE LINK TRAFFIC

A continuous slope delta modulator (Motorola MC3518 CVSD) digitally sampled at 32 kb/s is defined for all voice link traffic.

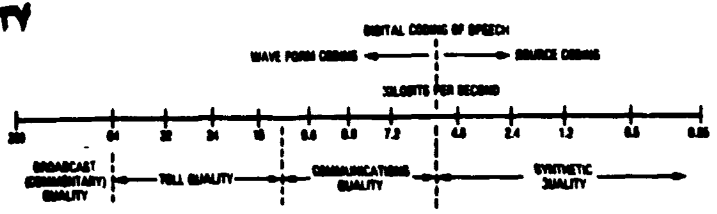
The digitize voice signal (speech encoded signal) quality as a function of sample rate is summarized as follows.

Current state-of-the-art in speech coding is shown in Figure 4.6-2(a) where it is assumed that "toll quality" or better voice transmission is required. The encoder selected for application to the SS-FDMA system is the Motorola MC3518 CVSD coder. The block diagram for the CVSD encoder is shown in Figure 4.6-2(b). The CVSD contains the basic delta modulator (comparator, sampler and integrator) in which the gain of the integrator is changed by utilizing previous signal history and thereby increases the basic delta modulator dynamic range. External to the basic delta modulator is an algorithm which monitors the past few outputs of the delta modulator in a simple shift register. The register is 3 or 4 bits long, depending on the application. The accepted CVSD algorithm simply monitors the contents of the shift register and indicates if it contains all 1's or 0's. This condition is called coincidence. When it occurs, it indicates that the gain of the integrator is too small. The coincidence output charges a single-pole low-pass filter. The voltage output of this syllabic filter controls the integrator gain through a pulse amplitude modulator whose other input is the sign bit or up/down control.

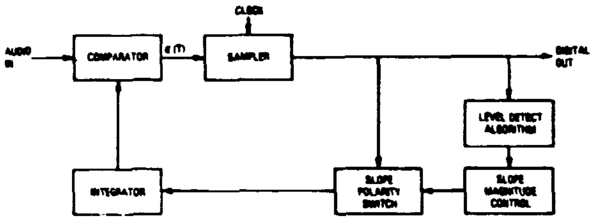
The algorithm is repeated in the receiver and, thus, the level data is recovered in the receiver. Because the algorithm only operates on the past serial data, it changes the nature of the bit stream without changing the channel bit rate.

The effect of the algorithm is to compact the input signal. If a CVSD encoder is played into a basic delta modulator, the output of the delta modulator will reflect the shape of the input signal but all of the output will be at an equal level. Thus, the algorithm at the output is needed to restore the level variations. The bit stream in the channel is as if it were from a standard delta modulator with a constant level input.

The delta modulator encoder with the CVSD algorithm provides an efficient method for digitizing a voice input in a manner which is especially convenient for digital communications requirements. A key factor in the



(a) SPEECH CODING TRANSMISSION RATES AND ASSOCIATED QUALITY (FROM FLANAGAN "SPEECH CODING" IEEE TRANS. ON COMM. TECH. APRIL 1979)



(b) Motorola CVSD Encoder

Figure 4.6-2. Coding For Voice Link Traffic

selection of the Motorola MC3518 is that it can be configured to be identical to the delta modulator used by the Bell System in subscriber loop telephone systems. This factor will facilitate interface with the Bell System and is an indicator of the voice quality which can be achieved with this algorithm.

Motorola has tested the identified CVSD's ability to handle general modem traffic. The results are tabulated in Table 4.6-2. Tests were conducted as follows:

Table 4.6-2. CVSD Model Results

Modem BER	$\frac{f_{CVSD}}{f_{MDR}}$
10^{-2}	3.0
10^{-3}	3.4
10^{-4}	3.8
10^{-5}	4.3
10^{-6}	5.0

An analog signal was passed through a Codex modem. The Codex's output is an eight phase modulated signal that is clocked into the CVSD encoder. This encoder's output is clocked into a CVSD decoder and then into the receiver section of the modulator/detector. Bit error rate were measured as a function of the codex modem's bits per second rate and the CVSD clock rate. Conclusions regarding high modem rates are shown above. Further, it was shown that 4800 bps modem rate is supported by a 32 kb/s CVSD clock rate for BER's $\leq 10^{-6}$.

4.7 Terminal and Satellite Antenna Design

4.7.1 CANDIDATE FEED AND REFLECTOR CONFIGURATIONS-GROUND TERMINALS

In order to provide the necessary antenna gain the ground terminal antenna size will be in the 3-6 meter class. Consequently, one of the prime considerations is selection of the basic radiation technique. The most simple and probable designs are prime focus, cassegrain or offset cassesgrain as shown in Figure 4.7-1. Selection of a particular design involves both mechanical and electrical considerations in which the cassegrain antenna configuration will, in general, offer some advantages when the gain exceeds 40 dB. Blockage due to the subreflector is no longer serious and the increased efficiency obtained by shaping both the reflector and subreflector make this configuration the selected choice for the baseline design.

4.7.2 ANTENNA CHARACTERISTICS FOR THE BASELINE SMALL TERMINALS

Shown in table 4.7-1 are estimated baseline antenna characteristics for the E, F, and G small terminals. Physical size of the antenna is based on link budget requirements and primarily involves system tradeoffs between antenna size, transmit power, receiver noise figure and cost. Cost is a key factor in these tradeoffs since the antenna and transmitter are the most significant hardware cost items in the ground terminals. Maintaining good surface accuracy on the antenna reflector and subreflector is an important consideration and has been initially established as 0.5 mm RMS. As the antenna size becomes larger, surface errors will tend to increase. However, with care, this error can be kept less than the estimated 0.5 mm RMS. Overall antenna efficiency is budgeted as 53% at 20 GHz and 43% at 30 GHz. Both the 5 and 6 meter antenna are estimated to require continuous tracking. Requirements for tracking are dependent on relative satellite motion. Since with reasonable foundation support, fixed antenna pointing can be maintained within ±0.01° for long periods of time. However, with beamwidths approaching satellite drift, some form of tracking is required. In some cases a manual track may be acceptable, although it is not assumed here. Polarization diversity is assumed with 30 dB sidelobes on both transmit and receive links. In summary these antenna characteristics are based on reasonable antenna capabilities which are compatible with the remaining system architecture.

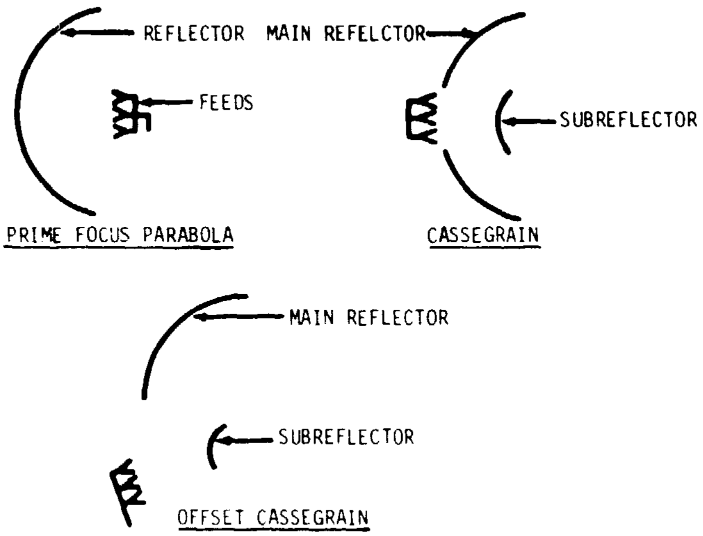


Figure 4.7-1. Antenna Feed Design

Table 4.7-1. Antenna Characteristics for Baseline Small Terminals

Item Description	Characteristics						Comments
Terminal Type	E		F		G		
Ant. Dia (Meters)	6		5		4		
Frequency (GHz)	20	30	20	30	20	30	
Directive Gain (dBI)	61.9	65.5	60.3	64.0	58.4	62.0	$4\pi A/\lambda^2$
Surface Tol. Error (dB)	−0.7	−1.4	−0.7	−1.4	−0.7	−1.4	0.5 mm RMS error
Efficiency Loss (dB)	−2.0	−2.3	−2.0	−2.3	−2.0	−2.3	Other antenna losses
Effective Gain (dB)	59.2	61.8	57.6	60.3	55.7	58.3	
Beamwidth (Deg)	0.17	0.12	0.21	0.14	0.26	0.17	3 dB beamwidth
Sidelobes (dB)	30		30		30		Below peak gain
Polarization	horiz or vert		horiz or vert		horiz or vert		either linear available
Bandwidth (GHz)	2.5		2.5		2.5		
Peak Power (KW)	1		1		1		Handling capability
Feed Type	cassegain		cassegrain		cassegrain		
Tracking Req'd	continuous ±0..01°		continuous ±0.01°		step within ±0.02°		Requirements depend on satellite stability
Foundation Req'd	yes		yes		possibly		

4.7.3 SATELLITE ANTENNA REQUIREMENTS AND CHARACTERISTICS

The following is a list of the basic satellite antenna requirements being addressed by TRW and Ford:

- Requirements

– Uplink frequency	27.5 - 30.0 GHz
– Downlink frequency	17.7 - 20.2 GHz
– On axis gain	56 dB @ 20 GHz
(excluding losses)	56 dB @ 30 GHz
– Bandwidth	500 MHz
– C/I performance	>30 dB (relative to all other beams)
– Polarization	horizontal or vertical
– Pointing accuracy	
Pitch and roll	<0.02°
Yaw	<0.40°

- Other characteristics

– 3 dB beamwidth	0.30°
– Station keeping accuracy	±0.04°

- Assumptions
  - Antenna can provide 25 dB of adjacent spot isolation through frequency diversity

This very complex development will include many other stringent requirements and those listed pertain only to items which impact the overall traffic communication link. Motorola intends to employ the configuration selected by NASA and therefore has not pursued any design effort on its own. The most disturbing area at this time is the antenna bandwidth. For both the uplink and downlink this is specified as 500 MHz. If this is the actual design bandwidth then trunk traffic covering 2.5 GHz cannot be handled by the satellite antenna. For the recommended frequency plan the ST traffic requires less than 500 MHz for any beam and is therefore compatible with the antenna design. However the total coverage is on the order of 1 GHz, thus requiring "tuned" antennas to cover the complete band.

Antenna gains listed do not include such losses as beam to beam variation, pointing errors area coverage, polarization, diplexer and line losses. Taking these into account the actual antenna gain used in the link budgets is 45.4 dB. The beamwidth of the antenna is approximately 0.3° thus providing a 3 dB earth coverage of about 150 miles. In addition to narrowbeam isolation and 30 dB beam isolation, polarization diversity is available. Such has not been assumed in any link calculations.

Station keeping and pointing accuracy of the antennas will determine, to some extent, the requirements of the ground terminal antenna. It is certainty desirable to avoid any autotracking at the ground terminal station. However, it appears that for the higher gain terminals such will be necessary in order to avoid signal fades.

4.7.4 EXAMPLE OF BEAM ISOLATION CONTOURS

Figure 4.7-2, reproduced from a TRW report, shows the −3 dB and −30 dB antenna gain contours for the spot beams centered upon the cities of Minneapolis, St. Louis, New Orleans, Miami, Washington, and Boston. From the extent of overlap of the −30 dB contours, Motorola's concern with adjacent spot interference is apparent.

4.7.5 TRAFFIC MODEL A CITIES ANTENNA BEAM SPOTS

There are forty-five metropolitan areas encompassed within forty 0.3° half-power beamwidth spots in Traffic Model A (see figure 4.7-3). Ten of these forty-five cities are covered by five spot beams – two cities per beam. Consequently, the total number of beams is 40 in which the circled numbers are the SOW cities listed in order of decreasing traffic.

4.7.6 TRAFFIC MODEL B CITIES ANTENNA BEAM SPOT

There are 277 metropolitan areas encompassed within seventy-one 0.3° half-power beam width spots in Traffic Model B (see figure 4.7-4). A large number of these spots will be combined onboard the satellite in order to reduce the size and complexity of the ST routing switch.

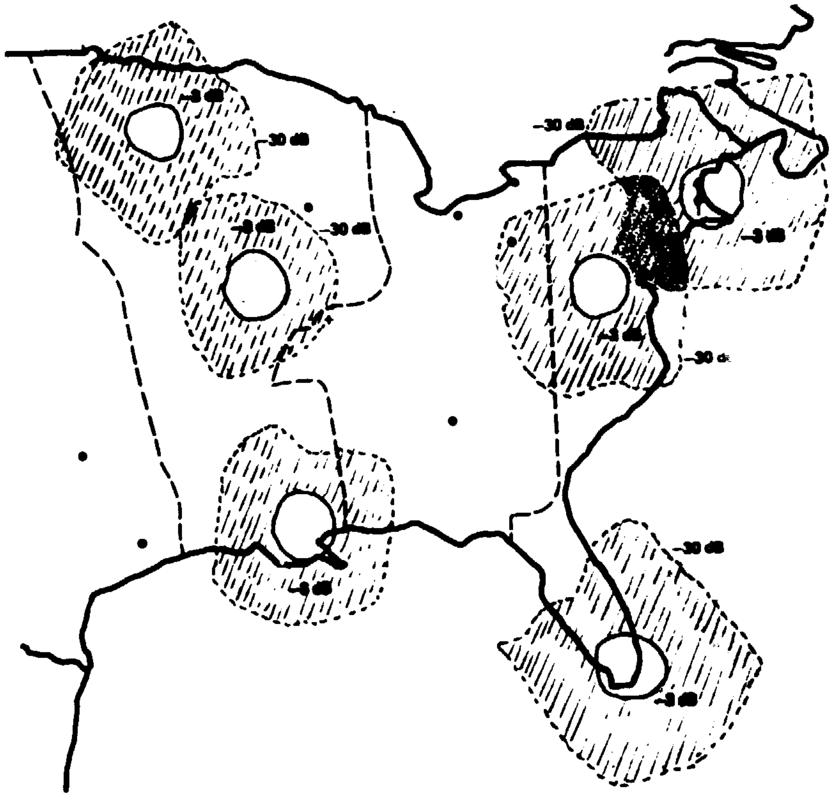


Figure 4.7-2. Beam Isolation Contours

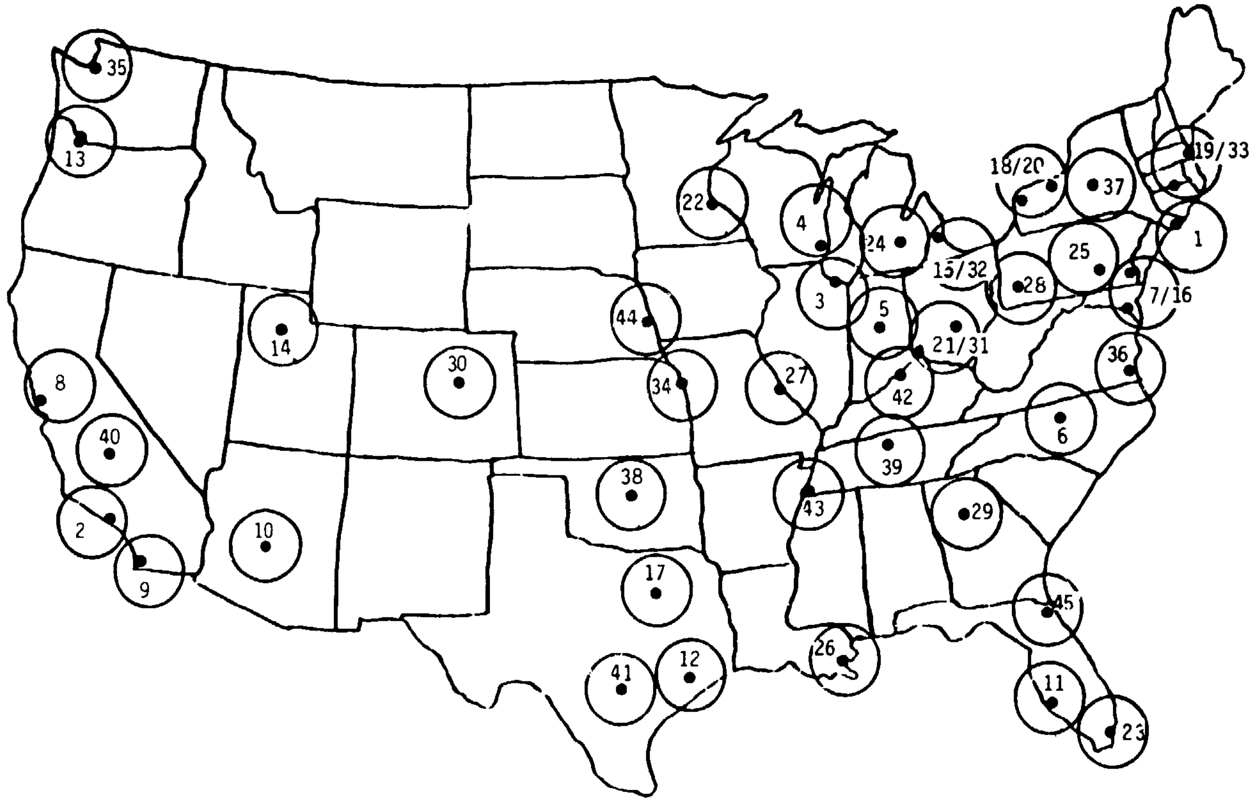


Figure 4.7-3. Traffic Model A Cities Antenna Beam Spots

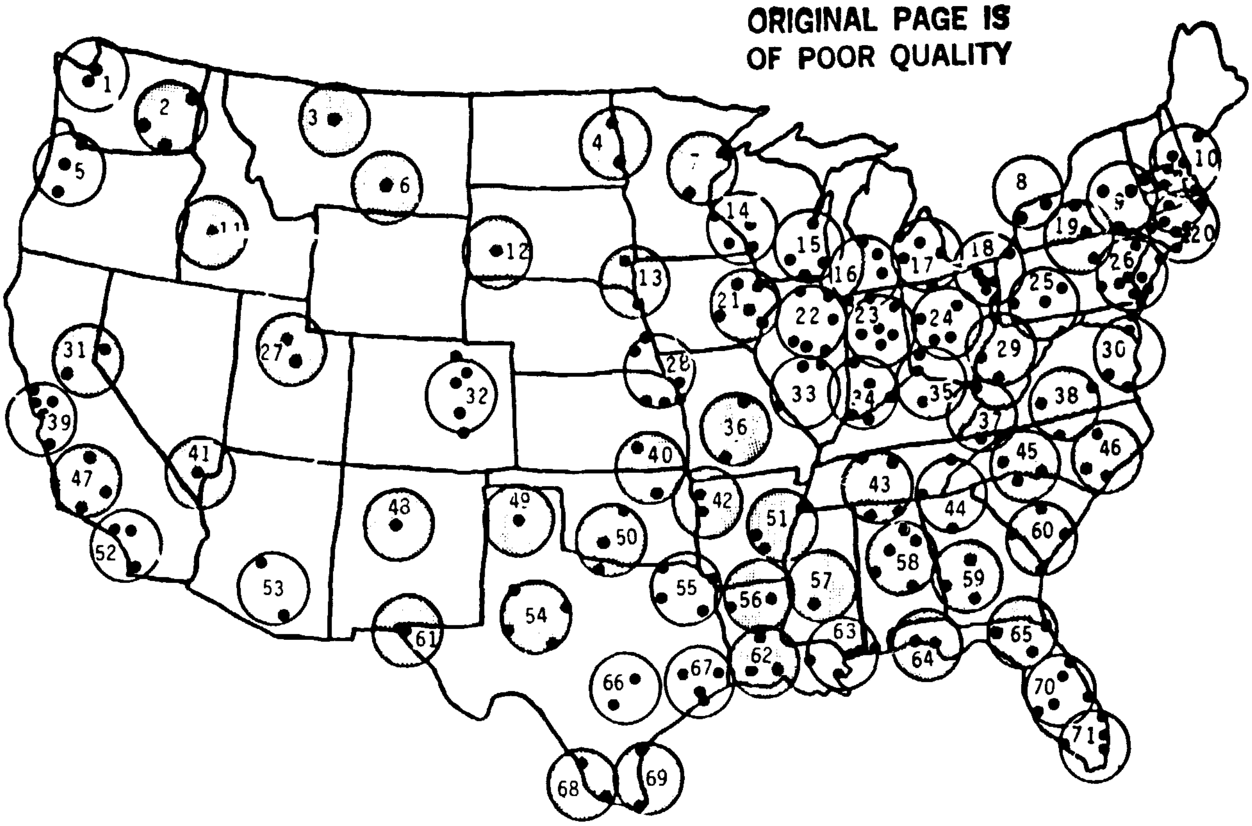


Figure 4.7-4. Traffic Model B Cities Antenna Beam Spots

4.8 System Control

4.8.1 SYSTEM CONTROL REQUIREMENT

The system control requirements are as follows:

Availability –	The system control provides the service between any two traffic users of compatible capabilities in the system whenever they have messages to transfer.
Connectivity –	The system control provides a suitable communication path between users. Users must be insensitive to any path differences when different messages pass through different communication paths.
Monitor –	The system control monitors the status of the satellite and the ST stations and signals diagnostic and corrective comands.
Low Cost –	The system is to provide low cost communication medium to users. The system control implementation is based on the priority that the users' cost burden be as low as possible.
Simplicity –	The procedure for the user to enter into the system should be simple.
Resource Sharing –	The operation of the system control should consider the shared use of the resources; e.g., the usage of the orderwire control link and the traffic link.

4.8.2 SYSTEM CONTROL CONCEPT

As can be seen from Figure 4.8-1, the system control consists functionally of the following four control links:

- Access Control Link:

  The user initiates his call request through the access control link by using the ordinary telephone signalling information.

- Orderwire Control Link:

  It conveys request and status message between ground stations and the network control station through the satellite and provides the following functions:

  - Communication frequencies assignment
  - Terminal coding and/or power adaptation control
  - Time and frequency standards for ST stations
  - Diagnosis and monitoring of ST stations

- Satellite Control Link:

  It conveys command, control, and supervision messages between the satellite and the network control station and provides the following functions:

  - Satellite path rearrangement
  - Satellite radiated power control
  - TT&C
  - Time and frequency standard for the satellite

- Traffic Link:

  Once a traffic link is established, all users' messages are transmitted through the traffic link.

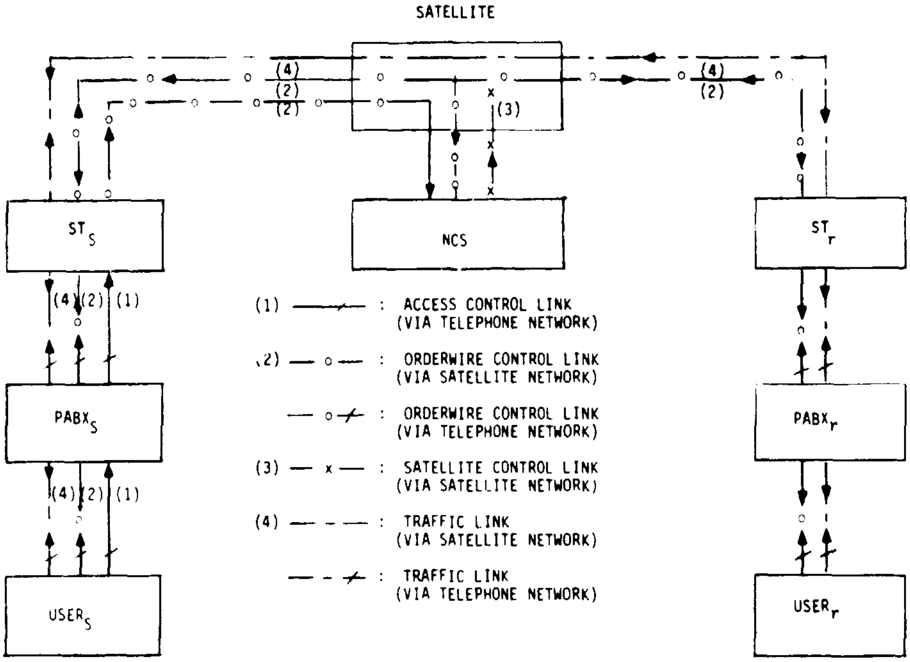


Figure 4.8-1. System Control Concept

4.8.3 MULTIPLE ACCESSING

In satellite communication, there are three possible multiple accessing candidates: (1) contention; (2) reservation; and (3) polling.

In contention multiple accessing, there is no identification nor scheduling procedures. Users are allowed to transmit their messages as soon as they have messages to transmit. Since there are no scheduling steps, the users endure access collisions. If a localized scheduling among users can be implemented, the possibility of access collisions can be reduced. If no access collision occurs, the user access time is very low.

In reservation multiple accessing, users schedule the system usage before transmitting their messages. There are no access collisions among users entering the system. The system availability decreases as the number of users increases.

In polling multiple accessing, a central controller polls individual users. When polled, a user has the right to access the system, either for reception or transmission of messages. As more and more users have access to the system, the time between polling requests to nonactive users increases.

RECOMMENDATION

The contention access method will be used for users to access into the system. As soon as the user gets into the system, a reserved traffic link is established for the user to transmit his messages. Specifically, the system will have the following access characteristics:

- Access Contention: When a user has message to transmit, he contends with other users to access into the system. Access denial probability is assumed low enough to allow this procedure.
- Communication Reservation: After the user gets into the system, a traffic channel with dedicated communication frequencies assigned by the NCS will be established. The user will transmit his messages through this reserved traffic channel.

4.8.4 USER ACCESS PROTOCOL

Two possible access protocols, shown in Figure 4.8-2, can be implemented in the system: (1) NCS-based and (2) Terminal-based. In NCS-based access protocol, the sending user ($USER_s$) dials the called party number to the NCS. The NCS interface provides the dialing register, number interpretation, and translation. Also, the NCS possesses the routing arrangement information so that it can transfer the call request from the NCS to the receiving user. The NCS has complex structure, but the average channel cost is not expensive since the system will support several thousand channels.

In terminal-based access protocol, the sending user dials the called party number to the sending ST terminal (ST_s). The ST_s interface provides the dialing register, number interpretation, and translation. When the ST_s is connected with the receiving small terminal (ST_r), the routing arrangement information in the ST_r will transfer the call request to the receiving user ($USER_r$) through suitable terrestrial telephone networks. The terminal structure is complex, and the average channel cost is expensive especially for those low traffic terminals.

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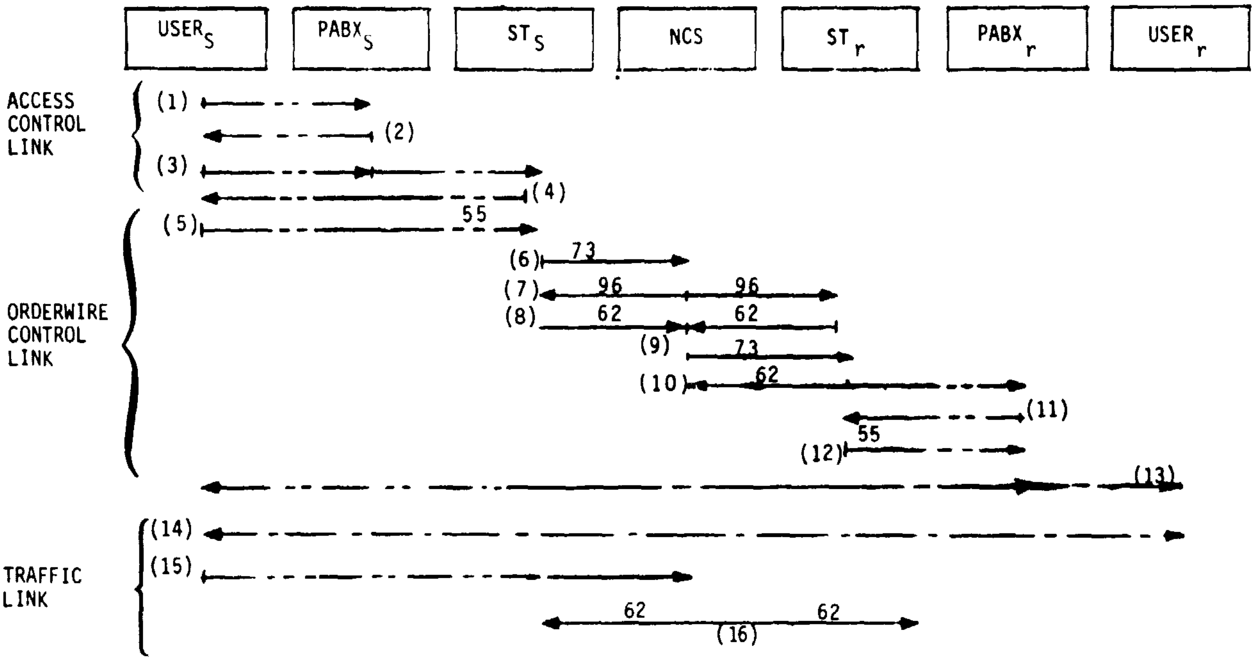


1. ——— - - ———: TELEPHONE CIRCUIT

2. ——————: ORDERWIRE CIRCUIT

3. ——— - ———: TRAFFIC CIRCUIT

4. THE NUMBER ABOVE A LINE REPRESENTS THE NUMBER OF BITS REQUIRED TO COMPLETE THE OPERATION.

Figure 4.8-2. Access Protocol NCS-Based

The NCS-based access protocol is recommended for the system. Simple and less expensive small terminal is the main concern for the selection of this access protocol. This NCS-based access protocol has the following characteristics:

- The NCS provides the dialing register, number interpretation, and translation.
- The NCS possesses the information for routing arrangement and access codes interpretation.
- The small terminal structure is not complex, and the average channel cost is low.

User-to-User Call Sequence:

1. USER$_s$ off-hook
2. PABX$_s$ sends dial tone
3. USER$_s$ dials access code, and PABX$_s$ routes the access code to ST$_s$
4. ST$_s$ dial tone to users
5. Users dials destination address
6. ST$_s$ sends off hook and destination address to NCS
7. NCS sends frequency assignments to ST$_s$ and ST$_r$
8. ST$_s$ and ST$_r$ send acknowledgement
9. NCS sends destination address to ST$_r$

10. ST_r sends acknowledgement to NCS and off-hook to $PABX_r$
11. $PABX_r$ sends dial tone to ST_r
12. ST_r dials called party number
13. $PABX_r$ rings call request to $USER_r$ and rings back to $USER_s$
14. $USER_r$ off-hook and the communication link is established
15. $USER_s$ on-hook to the NCS
16. NCS cuts off the communication link between ST_s and ST_r

4.8.5 SYSTEM CONTROL PERFORMANCE CHARACTERISTICS DESCRIPTION

The Traffic Model A peak hour system capacity is 1200 calls per second. Traffic Model B peak hour system capacity is 1000 calls per second. The time slot per second per beam is 200, and the time duration for each time slot is 5 millisecond.

The NCS will possess the system time and frequency standard which will be broadcasted to all ST stations and the satellite for time and frequency reference for modulators and frequency converters. The frequency stability will be better than 10^{8}.

The frequency allocation for the orderwire control link will be placed within the frequency band reserved for each beam. The orderwire message from the NCS to the ST is combined with the beam traffic in the combiner of the ST routing assembly and then the composite messages are transferred to the ST station. The orderwire messages from all ST stations are FDM in the satellite before routing to the NCS.

The frequency allocation for the satellite control link should be a dedicated frequency. The satellite control link message is filtered out from the NCS beam to provide the information for satellite path rearrangement, satellite power adaptation, TT&C, etc. The satellite information is combined with the orderwire messages from all small terminals to transmit from the satellite to the NCS.

4.8.6 SATELLITE CONTROL LINK PERFORMANCE CHARACTERISTICS

The contention protocol will be used for the user to access into the system. Dedicated channels, one for each beam, are provided for the orderwire operation between the NCS and the ST stations. From the user access protocol proposed in paragraph 4.8.4, it totally requires 1900 bits for the NCS to complete a call request (includes 200 bit overhead for each message transmitted).

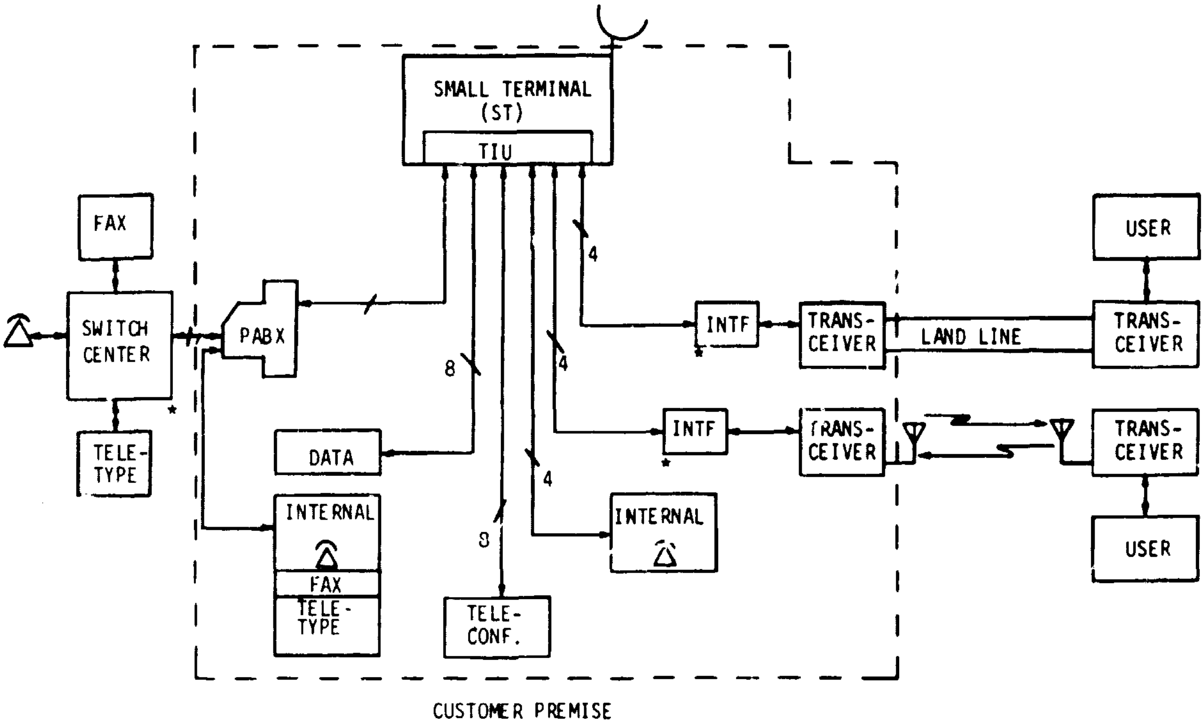
Traffic Model A system capacity is 1200 calls/second. The NCS requires the bit rate of 2.28 Mbits/second to meet the calls request. Proportionally, the NCS has the bit rate of 121.6 Kbits/sec to New York (Traffic Model A) beam to handle its 64 calls/second calls request. On the other hand, it totally needs 950 bits to complete a call request from the ST station to the NCS (includes 200 bit overhead for each message transmitted). It then has the bit rate of 2.28 Mbits/second (Traffic Model A) from all ST stations to the NCS. Delta PSK modulation will be implemented in the orderwire control link, and the link has the coded bit error rate better than 10^{8}.

One dedicated channel is provided for the satellite control link. The link bit rate is 0.25 Mbits/second to provide the information for satellite path rearrangement, satellite power adaptation control, and TT&C. Delta PSK modulation will be implemented in the satellite control link, and the link has the coded bit error rate better than 10^{8}.

User's traffic is transmitted along the reserved traffic channel with communication frequencies assigned by the NCS. The traffic bit error rate is 10^{6}.

4.9 Small Terminal User Interface

High rate data or video users may only interface with the ST (as shown in Figure 4.9-1) over a set of dedicated lines which do not pass through a PABX or SC. The set of dedicated lines include; 4 lines for traffic (full duplex: 2 transmit, 2 receive), 2 lines for signalling, and 2 lines for supervision. Signalling and supervision may be provided through a telephone extension originating at the users location and terminating in the local ST station.



* OPTIONAL CUSTOMER INTERFACE: NOT CONSIDERED AS BASELINE

Figure 4.9-1. Potential Customer Interfaces

Voice and low rate data, shown in Table 4.9-1, (4800 b/s maximum) users interface with the ST through private branch exchanges (PABX) or switch centers (SC). The PABX and SC are part of the existing telephone system. Signalling will be done by dual tone multiple frequency (DTMF). DTMF is inband signalling (on traffic path). DTMF is used on the pushbutton telephones commonly used today. Supervision (on-hook/off-hook status) is provided by separate E and M lines. Each voice or low rate data interface at the ST is comprised of 4 lines: 2 wire traffic and 2 wire supervision (E&M).

Table 4.9-1. SS-FDMA Interface

Traffic			Signalling			Supervision		
Type	User/ST Interconnect	No. of Interconnects	Type	User/ST Interconnect	No. of Interconnects	Type	User/ST Interconnect	No. of Interconnects
Voice or Low Rate Data	PABX or Switch cntr	2	Inband DTMF	Via Traffic interconnect	0 (Inband)	E&M	PABX or switch center	2
High Rate Data or Video	Dedicated lines	4 (min)	DTMF	Dedicated lines	2	E&M	Dedicated lines	2

4.10 Signal Level Variations

An important part of a satellite switched FDMA system is the signal level variations that may be encountered and the means whereby to minimize the variation. Since this system does not employ demodulation and remodulation in the satellite, the role of the router is to provide a "bent pipe" relay for each signal. Signal variations throughout the system can be seen at the receiving terminal if proper level control is not exercised.

Figure 4.10-1 broadly illustrates the general sources of amplitude variation. It also illustrates graphically how small channels are combined to form larger groupings on the uplink. These are then combined with other station inputs within the same beam by the satellite antenna to form a still larger set into the router. Here through filtering a separation occurs and a recombination before retransmission. The key here is that the router does not reduce the channelization to a single message signal. It can only treat groups of message signals at one time. And even here a choice must be made as to the place to control signal levels in order to assure each message adequate output power and at the same time to minimize the power required of the satellite power amplifiers.

Small groupings at the router switch output at the input to the summer are a logical choice, but there are 1600 or more of these. Larger groups provide less control but require a fewer number of stages of AGC or equivalent circuits.

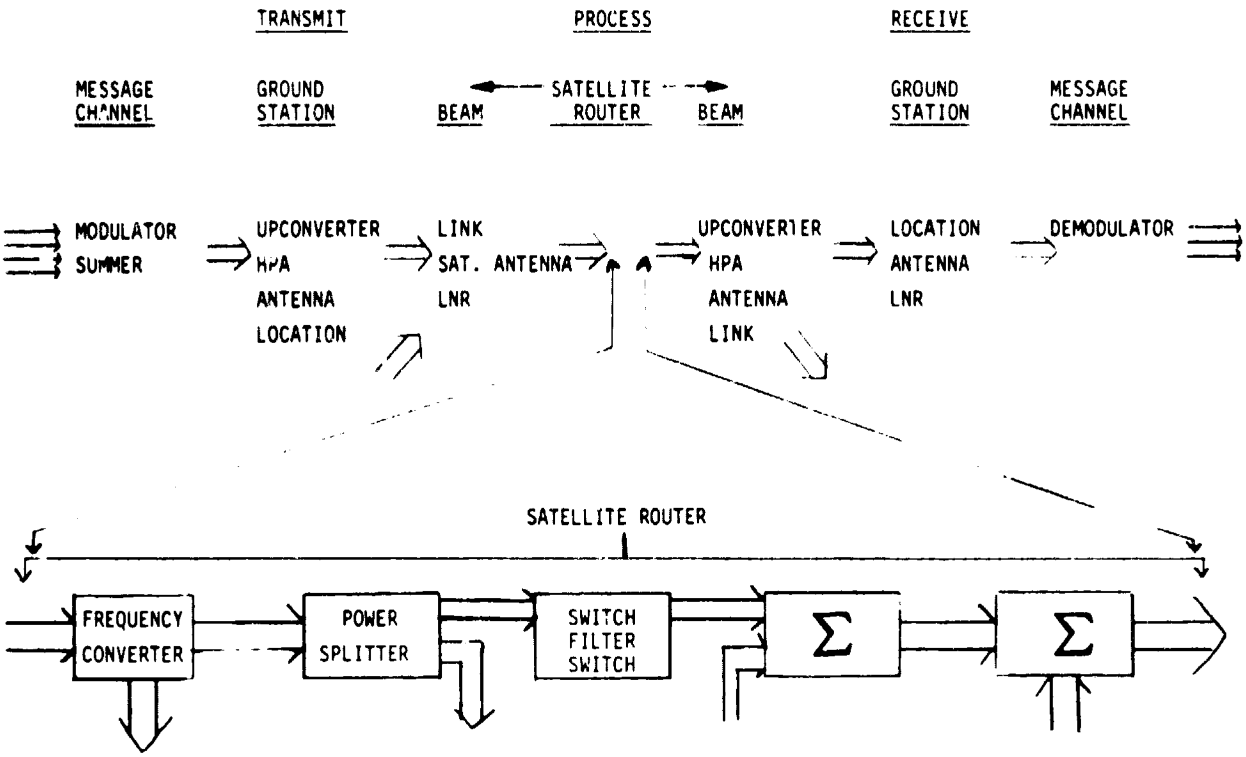


Figure 4.10-1. Signal Label Variations

4.10.1 SYSTEM GAIN LEVEL VARIATION SUMMARY

There are some 43 principle sources of gain variation in any given message path. The standard deviation of any path could be 3.34 dB without some monitor and control. Monitoring the uplink orderwire signal level from each station at the NCS and directing station power adjustments accordingly can reduce this to 1.9 dB. Further monitoring, outlined hereafter, can reduce the variation to the order of 1.3 dB residual.

To preserve an availability of at least 0.999, defined here to mean that less than one message path in a 1000 will fail to yield a maximum error rate in clear air of 10^{-6}, requires that the power be boosted by 3.1 times to standard deviation or about 4 dB total. This boost is distributed between the ground and the satellite.

For an availability of 0.995, the corresponding power boost is about 3.3 db.

4.10.2 MESSAGE ROUTE GAIN VARIABILITY (UPLINK)

Table 4.10-1 indicates the main gain variation factors that apply to an uplink. These variations can be categorized as random (RAND), compensatable by automatic gain control (AGC), reduced by orderwire monitor (OW MON), or preadjustable (PREADJ). Given above are the ranges, the standard deviations assuming the variable is uniformly distributed, and the composite standard deviation (S_{st}) for that portion of a path.

Table 4.10-1. Message Route Gain Variability (Uplink)

Transmit						
Channel	Plus	Minus	Range	S_x	S_{st}	Note
Modulator	0.2	0.2	0.4	0.12	0.12	Rand
Station						
Summer	0.2	0.2	0.4	0.12		Rand
PA	2.0	2.0	4.0	1.2		AGC
Ant. Pointing	0.5	0.5	1.0	0.3		OW MON
Range	0.4	0.4	0.8	0.24		OW MON
Location	0.0	3.0	3.0	0.3		OW MON
Rain Comp	2.0	2.0	4.0	1.2		(Residual)
Carr Freq (1 dB/200 MHz)	0.5	0.5	1.0	0.3		Rand
Total	5.6	8.6	14.2	0.69		1.7
Beam						
SAT Ant. Axis	0.0	3.0	3.0	0.9		OW MON
Ant. Gain	1.0	1.0	2.0	0.6		OW MON
Beam Pointing	0.0	0.5	0.5	0.15		OW MON
Carr Freq	0.1	0.1	0.2	0.06		Rand
Polar Loss	0.05	0.05	0.1	0.03		Rand
Rec Gain	0.5	0.5	1.0	0.3		Rand
Rec Freq.	1.0	1.0	2.0	0.6		Rand
Feed Loss	0.5	0.5	1.0	0.3		Rand
1st Mix	0.4	0.4	0.8	0.24		Rand
IF Filt	0.2	0.2	0.4	0.12		Rand
Total	3.75	7.25	11.0	.425		1.34

4.10.3 MESSAGE ROUTE GAIN VARIABILITY (ROUTER PROCESSING)

Table 4.10-2 illustrates the variations within the router. The same definitions apply as in Table 4.10-1.

Table 4.10-2. Message Route Gain Variability (Router Processing)

Router	Plus	Minus	Range	S_x	S_{st}	Note
Mixer	0.2	0.2	0.4	0.12		Random
Filter	0.2	0.2	0.4	0.12		Random
Row Switch	2.0	2.0	4.0	1.2		Random
SAW Filt	0.5	0.5	1.0	0.3		Random
Colm Switch	0.5	0.5	1.0	0.3		Random
Summer	0.2	0.2	0.4	0.12		Random
Mixer	0.2	0.2	0.4	0.12		Random
Total	3.8	3.8	7.2	0.57		1.28

4.10.4 MESSAGE ROUTE GAIN VARIABILITY (DOWNLINK)

Table 4.10-3 continues the summary of gain variations for the downlink. The same definitions apply as for the uplink.

Table 4.10-3. Message Route Gain Variability (Downlink)

Receiving						
	Plus	Minus	Range	S_x	S_{st}	Note
Beam						
Rout Mix	0.4	0.4	0.8	0.24		AGC
Rout Filt	0.2	0.2	0.4	0.12		Rand
Summer	0.2	0.2	0.4	0.12		Rand
Upconv	0.5	0.5	1.0	0.3		AGC
PA*	2.0	2.0	4.0	1.2		AGC
Feed Loss	0.5	0.5	1.0	0.3		Rand
Freq (1 dB/200 MHz)	0.5	0.5	1.0	0.3		Rand
SAT Ant. Axis	0.0	3.0	3.0	0.9		Preadj
SAT Ant. Gain	1.0	1.0	1.0	0.3		Rand

Table 4.10-3. Message Route Gain Variability (Downlink) (Cont)

Receiving						
	Plus	Minus	Range	S_x	S_{st}	Note
SAT Ant. Pointing	0.0	0.5	0.5	0.15		Rand
Rain	0.6	0.6	1.2	0.36		Rand
Total	5.9	9.4	15.3	0.55		1.84
Station						
Location	0.0	3.0	3.0	0.9		Rand
Range	0.4	0.4	0.8	0.24		Preadj
Ant. Pointing	0.5	0.5	1.0	0.3		Rand
Polarization	0.05	0.05	0.1	0.03		Rand
Freq	0.5	0.5	1.0	0.3		Rand
Noise Figure	0.0	1.0	1.0	0.3		Rand
Total	1.45	5.45	6.9	0.435	0.66	
User Channel						
Demod Sensitivity	0.0	1.0	1.0	0.3	0.3	Rand

4.10.5 SYSTEM GAIN LEVEL MONITOR AND CONTROL

By monitoring portions of the system signals throughout, the variability per path can be reduced. The simplest is to monitor the uplink performance from each station by monitoring each uplink orderwire signal level at the NCS. This provides a reasonable measure of general uplink performance. This provides the means to lower the path variation to 1.9 dB.

Further monitor requires downlink monitor by each receiving station. This is then reported to the NCS on a message basis. The NCS catalogues this data and builds a long-term history from which some adjustment can be made on downlink power to reduce the standard deviation to perhaps 1.3 dB.

Detailed path history is probably not possible due to the sheer magnitude of the numbers involved. This can be seen in the Table 4.10-4.

4.10.6 SS-FDMA INTERCONNECTIONS

As can be seen from table 4.10-4 the number of possible paths is some 5 billion. This presents an unattractive number of paths on which to attempt to maintain a history. Even the number of station interconnects is imposing. Some means must be found to collect information on uplinks by station and downlinks by beam.

Table 4.10-4. SS-FDMA Interconnections

	Traffic Model A	Traffic Model B
No. of Message Channels	70,000	70,000
No. of Stations	2,100	10,000
No. of Beams	40	71
No. of Beam to Beam	1,600	5,041
No. of Possible Sta. Interconnects	4.41×10^6	10^8
No. of Possible Message Paths	4.9×10^9	4.9×10^9

4.11 System Architecture Summary

4.11.1 SYSTEM ARCHITECTURE SUMMARY (TRAFFIC MODEL A)

Characteristics summarized in table 4.11-1 are based on either Statement of Work (SOW) requirements or response thereto as discussed in the previous sections. The letters shown, in conjunction with the antenna size, transmit power, and traffic rate, are the particular stations defined in the SOW. The data modulation selected is 0-QPSK although there is not a great deal to choose between it and MSK.

Table 4.11-1. System Architecture Summary (Traffic Model A)

ST Station Type	E	F	G
Antenna Diameter	6	5	4
Transmitter Power (clear air)	2	0.4	0.08
Transmitter Saturated Power Req'd	200	50	10
Signal			
Modulation	0-QPSK		
BER, Availability	10^{-6}, 0.999		
Uplink Rain Fade Power Boost	15 dB		
Downlink FED Rain Protection	3.6 dB (R = 1/2, K = 5, Q = 4 convolutional code)		
Frequency	30 GHz uplink, 20 GHz downlink		
ST Allocated RF Bandwidth	1.0 GHz		
System Control and Monitor	NCS based		
Orderwire Data Rate	2.28 Mb/s		
Number of Channels	41		
Access Time	< 4 sec		
Orderwire BER	10^{-8}		

Table 4.11-1. System Architecture Summary (Traffic Model A) (Cont)

ST Station Type	E	F	G
Satellite Transponder			
Trunking Capacity	6.2 Gb/s		
ST - ST and ST - Trunk Capacity	3 Gb/s		
Number of Antenna Beams	40		
Number of LNR's	40		
Number of HPA's	61		
Size, Weight, Power	336 cu ft, 2,660 lbs, 5130 watts		
Satellite RF Power Out	357 W		
FDMA Router			
Capacity	70,000 channels		
Number of Filter Paths	1600		
Switch Cross Points	1920		
Switch Size	8 × 8		
Size, Weight, Power	15,900 cu in, 360 lbs, 200 watts		

Link improvement will be realized through convolutional encoding and power boost. Uplink rain fades are handled through power boost and downlink through coding and power boost This, along with frequency and time reference, will be controlled by the NCS as will assignment of path filters in the satellite router. The basic frequency plan has been organized to effect a simpler router design at the expense of bandwidth efficiency.

The frequency plan for the ST traffic will contain three bands which are divided into five zones with eight sections per zone. This will result in all switches in the satellite router being 8 × 8. Required satellite RF transmit power for the ST traffic will be less than 400 watts.

4.11.2 SYSTEM ARCHITECTURE SUMMARY (TRAFFIC MODEL B)

Table 4.11-2 provides the architectural summary for Traffic Model B. The significant differences are the station capacities which range from a single voice channel up to a 36 channel voice, data, and video station. The total throughput is as before. The number of antenna beams has been increased to 71 although the number of router paths has increased only to 48.

Table 4.11-2. System Architecture Summary (Traffic Model B)

ST Station Type	E	F	G	H	I	J
Antenna Diameter	6	5	4	4	4	4
Transmitter Power (clear air)	0.7	0.2	0.075	0.056	0.03	0.005
Transmitter Saturated Power Req'd	100	25	10	5	5	1
Signal						
Modulation	0-QPSK					
BER, Availability	10^{-6}, 0.999					
Uplink Rain Fade Power Boost	15 dB					
Downlink FEC Rain Protection	3.6 dB (R = 1/2, K = 5, Q = 4 convolutional code)					
Frequency	30 GHz uplink, 20 GHz downlink					
ST Allocated RF Bandwidth	1.0 GHz					
System Control and Monitor	NCS based					
Orderwire Data Rate	1.9 Mb/s					
Number of Channels	71					
Access Time	<5 sec					
Orderwire Bare	10^{-8}					
Satellite Transponder						
Trunking Capacity	6.2 Gb/s					
ST - ST and ST - Trunk Capacity	3 Gb/s					
Number of Antenna Beams	71					
Number of LNR's	71					
Number of HPA's	93					
Size, Weight, Power	354 cu ft, 3,970 lbs, 5850 watts					
Satellite RF Power Out	465 W					
FDMA Router						
Capacity	57,000 channels					
Number of Filter Paths	2304					
Switch Cross Points	2688					
Switch Size	8 × 8					
Size, Weight, Power	21,700 cu in, 500 lbs, 250 watts					

SECTION 5

5. SATELLITE DEFINITION

The transponder subsystem of the spacecraft consists of the following five assemblies:

1. Two antenna feed assemblies
2. Receiver assembly
3. Trunking IF switch
4. ST router
5. Transmitter assembly

- The antenna assembly consists of two 3 meter reflections.
- The receiver assembly includes all low noise receivers/down converters, power splitters, diplexers, down converters, etc., for all beams.
- The trunking IF switch
- The ST IF switch router consists of down converters – analogue processing – up converters
- The transmitter assembly includes all TWT's, high voltage power supplies, diplexers, combiners, etc., for all beams.

The major components of the spacecraft transponder subsystem are those listed above. With the exception of the ST router, the size, weight, and power estimates were derived from industry briefings or proposals submitted to NASA. Specifically, the antenna feed assembly estimates were derived from the GE study, "Customer Premise Service Study for 30/20 Satellite Systems", January 13, 1982, and the March 5, 1982, Task I and II report "Spacecraft Multibeam Antenna System for 30/20 GHz" by Ford Aerospace and Communications Corp.

The low noise receiver estimates were based on reports published by ITT Defense Communications Division, "30/20 GHz Communications Satellite Low Noise Receiver", October 1980 and by LNR Communications, Inc., "30/20 GHz Communications Low Noise Receiver". The IF trunking switch estimate was derived from the GE report "30/20 GHz Satellite Switching Matrix Development", May 7, 1981.

The estimate was based on a 20 × 20 matrix switch and was appropriately scaled to reflect the 23 × 23 matrix need for the SS-FDMA satellite. The 20 GHz TWT estimates were derived from data supplied by Hughes and Watkins-Johnson for the Hughes 918 TWT and the Watkins-Johnson 3712 TWT. The remainder of the estimates were derived from readily available existing hardware.

There are six basic functional parts to the satellite communication payload:

1. Multibeam narrow beam receiving antennas
2. Low noise receivers at 30 GHz
3. IF switch for TDMA trunk signal routing
4. Upconverters to 20 GHz and power amplifiers

5. Multibeam transmitting antennas
6. FDMA ST router

Although this program is not concerned with the trunking system, nevertheless the SS-FDMA ST system is inextricably interwoven with the trunking subsystem. Figure 5.0-1 makes clear the points of contact.

The satellite block diagram, Figure 5.0-2, contains six main subsystems relating to the FDMA communication link. These are two antenna subsystems, low noise receivers (LNR), IF switch, the ST router, and the power amplifier subsystem. With the exception of the router, these subsystems have all been studied by other contractors and the developed FDMA architecture has used the published characteristics of these studies, where applicable.

Essentially, the FDMA satellite acts as a switchboard to control source to destination traffic. The 30 GHz input is received by the antenna subsystem which contains approximately 40 beam antennas (Traffic Model A). The traffic from trunking terminals, which is destined for another trunking terminal, is allocated a 1.5 GHz bandwidth and this TDM traffic is destination-controlled through the IF switch. All other traffic, which is ST related, is contained in a 1.0 GHz bandwidth and is destination-controlled through the router. Switch configuration, along with synthesizer settings and power output control, are derived from the NCS receiver within the router.

The router contains approximately 1600 SAW filters with 1920 switching crosspoints. The input and output IF frequencies to the router have tentatively been selected as 4.5-5.6 GHz and 2.65-3.35 GHz, respectively. With a maximum 3.8 Gbps throughput, the required RF output power for communicating the ST traffic is 357 watts for Traffic Model A and 465 watts for the Traffic Model B. This assumes an effective satellite antenna gain of 45.4 dB.

Power amplifiers are all quasi-linear for the ST FDMA traffic and will operate saturated for the trunking TDM traffic. Details of the FDMA architecture, and in particular the router, are discussed in the following subparagraphs.

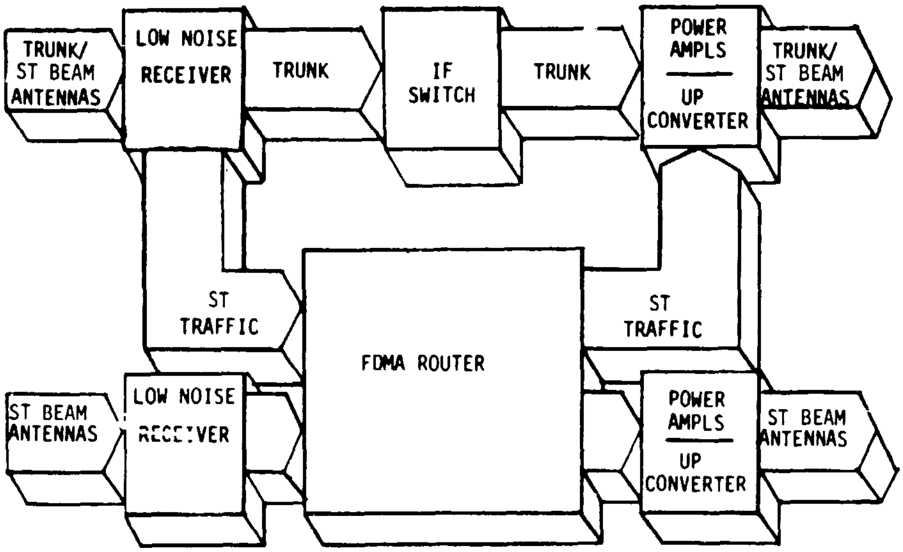


Figure 5.0-1. Satellite Payload Block Diagram

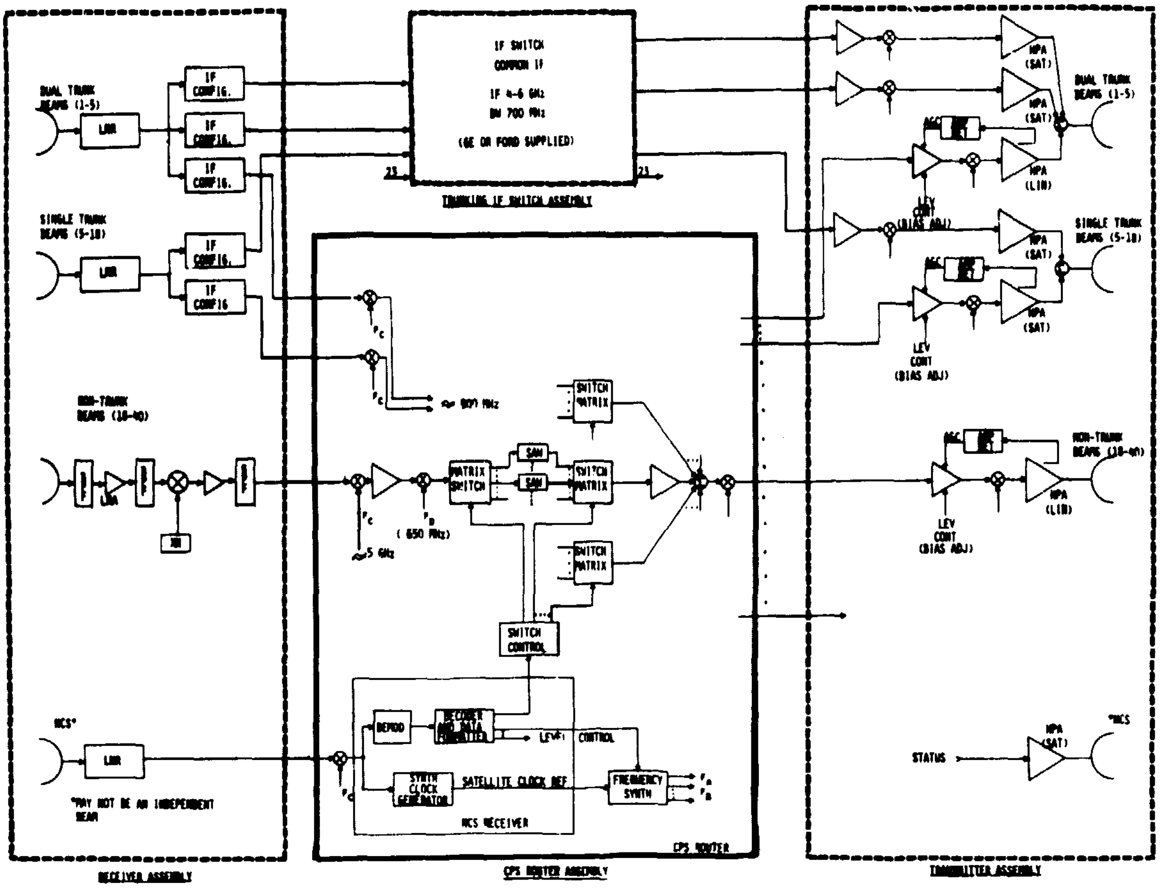


Figure 5.0-2. Satellite Block Diagram

5.1 Small Terminal Router

5.1.1 FUNCTIONAL REQUIREMENTS

Functional requirements of the router are listed below for Traffic Model A and B:

- Traffic input: multiple beam FDMA
- Total ST channel quantities available for traffic model A and B

Channel	6.3Mb/s	1.5Mb/s	56 kb/s	32 kb/s	Total Channels
Traffic Model A	80	860	8148	59,088	68,176
Traffic Model B	200	800	7400	48,600	57,000

- Throughput

  Up to 50% of available channels
- Beam to beam routing through flexible switching
- Traffic variations

  High volume beams (approximately 18 beams) = ±30%

  Other beams = ±50%

- Blocking probability $< 0.1\%$
- Linear input to output transfer (No limiting)
- Maximum input bandwidth = 1.5 GHz
- Input/output impedance: 50 ohms, VSWR $\leq 1.2:1$
- Minimum weight and power

In both cases, the router throughput is based on a 32 kb/s voice traffic rate. Traffic from any input beam will be capable of routing to all other beam locations. In the case of Traffic Model A, there are 45 cities in which five of the beams are combined to give a resulting 40 inputs to the router. Traffic Model B has 277 cities and approximately 71 beams. Traffic from these beams are combined. The router requirements do not change materially for Traffic Model B as compared to Traffic Model A. In addition to the requirements regarding traffic control, the router must also be responsive to the NCS control signals inputs and must address the selected frequency plan.

The total small terminal channels available is the sum of all the ST station capacities. Using 65 Kb/s voice the corresponding total available traffic would be about 6 Gb/s for both models. At 50% of available channel use at peak loading this is 3 Gb/s to which must be added the 800 Mb/s trunk to ST traffic.

5.1.2 BEAM AND PATH FILTER MATRIX

Referring to figure 5.1-1, the general traffic matrix and recalling that Traffic Model A contain 40 beams, then the source-destination filtering can be described by a 40 × 40 matrix. This matrix is identical for Traffic Model B except the size will increase from 40 × 40 to 48 × 48. For Traffic Model B there are actually 71 beams, which through combining, result in an equivalent 48 beams so far as the router design is concerned. This combining will simplify the router at the expense of approximately 1 dB in satellite transmit power. In both traffic models, subdividing occurs in 8 × 8 sections as illustrated above. For Traffic Model A there are 25 sections and a required 1600 filters while Traffic Model B contains 36 sections and 2304 filters (48^2). Each of these 8 × 8 sections acts more or less independently from other sections and with this breakdown a segmented router block diagram can be easily represented and is shown in paragraph 5.3.

5.1.3 ROUTER CONFIGURATION

A three dimensional pictorial view of the router is shown in figure 5.1-2. This illustrates the traffic flow. Incoming traffic from a beam in Zone 1 is routed by frequency and distributed by a 1:5 power splitter. Each of these outputs is applied to one of five sectors (with five zones there are five squared sectors). In the lower left hand corner is shown a blowup of one such sector. The inputs from the eight beams in one zone are applied to one 8 × 8 row switch then further separated in a 1:8 power divider. Individual paths are then filtered in a bank of 64 surface acoustic wave (SAW) filters. The outputs are recombined in an 8:1 power summer. Data then rotates 90° between power division and power summation. The sector output is summed in the 5:1 beam summers with outputs of the other five sectors that contribute to that beam. Not shown is the final column switch that can interchange the column of paths that apply to any one beam.

This diagram best illustrates the horizontal-to-vertical to horizontal-to-vertical rotation that goes on within the Router structure. This rotation, coupled with the switching, is what allows the interchange of path characteris- in an economical manner.

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TO BEAM →

FROM BEAM ↓

	1	2	3	4	5	6	7	8	9	37	38	39	40
1	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-37	1-38	1-39	1-40
2	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9				2-40
3	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9				3-40
4	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9				4-40
5	5-1	5-2	5-3	5-4	5-5	5-6	5-7	5-8	5-9				5-40
6	6-1	6-1	6-3	6-4	6-5	6-6	6-7	6-8	6-9				6-40
7	7-1	7-2	7-3	7-4	7-5	7-6	7-7	7-8	7-9				7-40
8	8-1	8-1	8-3	8-4	8-5	8-6	8-7	8-8	8-9				8-40
9	9-1	9-2	9-3	9-4	9-5	9-6	9-7	9-8	9-9				9-40
10	10-1	10-2	10-3	10-4	10-5	10-6	10-7	10-8	10-9				10-40
31	31-1	31-2	31-3	31-4	31-5	31-6	31-7	31-8	31-9				31-40
32	32-1	32-2	32-3	32-4	32-5	32-6	32-7	32-8	32-9				32-40
33	33-1	33-2	33-3	33-4					33-9				33-40
34	34-1	34-2	34-3	34-4					34-9				34-40
35	35-1	35-2	35-3	35-4					35-9				35-40
36	36-1	36-2	36-3	36-4					36-9				36-40
37	37-1	37-2	37-3	37-4					37-9				37-40
38	38-1	38-2	38-3	38-4					38-9		38-38	38-39	38-40
39	39-1	39-2	39-3	39-4			39-7	39-8	39-9		39-38	39-39	39-40
40	40-1	40-2	40-3	40-4			40-7	40-8	40-9		40-38	40-39	40-40

PATH FILTER NOMENCLATURE

Figure 5.1-1. General Traffic Matrix

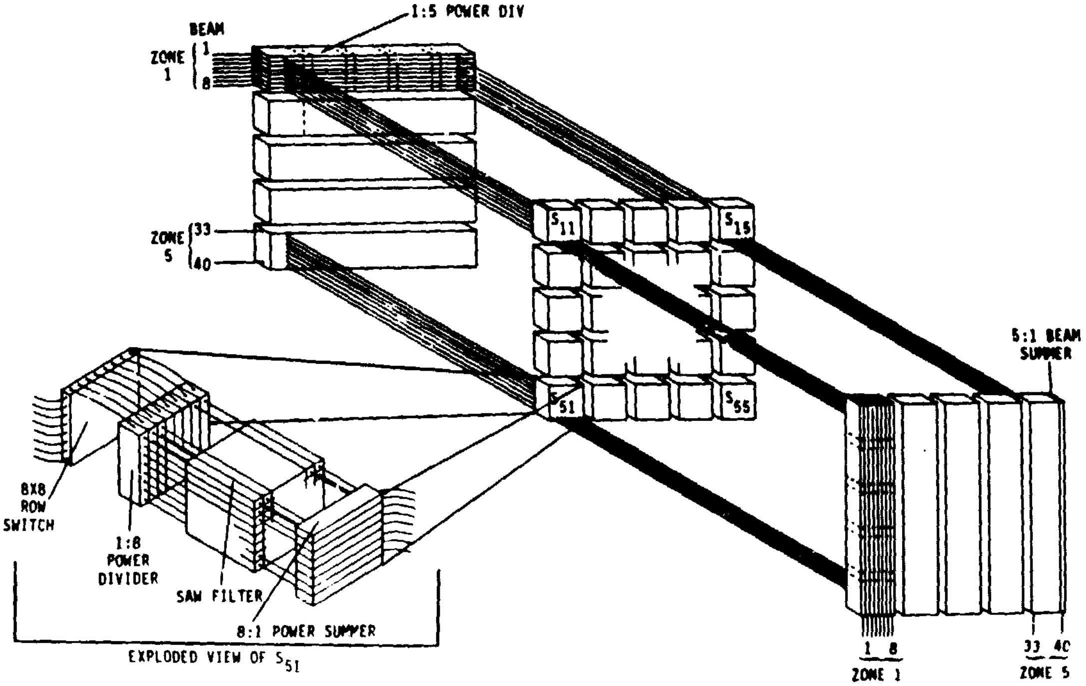


Figure 5.1-2. Router Configuration

5.1.4 ROUTER OUTPUT SEGMENT

The output segment of the router is illustrated in figure 5.1-3. This shows the detail of the 5:1 beam summer. Each beam has its own LO frequency synthesis for up conversion in the mixer before filtering and summation. The beam is further up converted before being sent to the output.

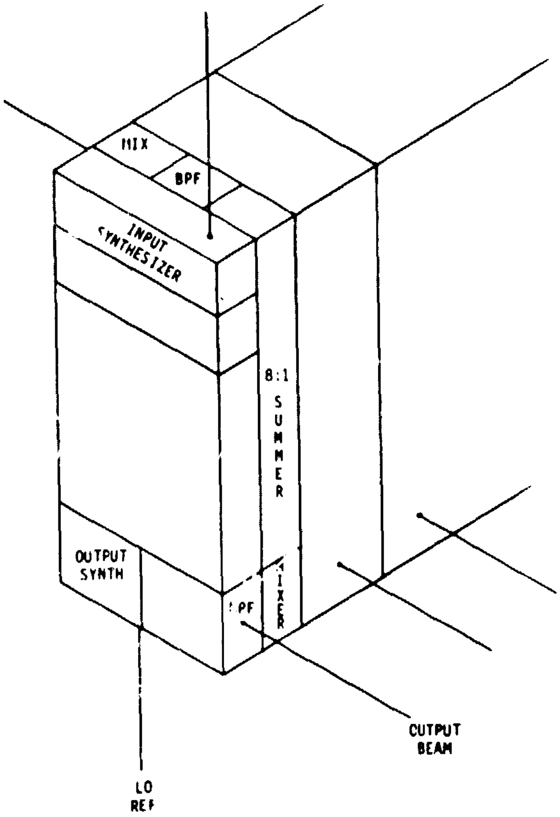


Figure 5.1-3. Router Output Segment

5.1.5 ROUTER INPUT SEGMENT

Figure 5.1-4 illustrates the detail of the input segment of the router called the 1:5 power divider in the previous diagram. The input signal is mixed down in frequency in the mixer by a local frequency generated by the frequency multiplier before being split by the power splitter. Each output is filtered in a sector filter before being applied to the sector circuitry.

5.1.6 ROUTER BLOCK DIAGRAM

A segment of the router is shown in Figure 5.1-5 in which the primary emphasis is in presenting the switching and path filter arrangements. Although applicable to both traffic models, the following discussion is directed to Traffic Model A. Functions for both are identical and only the assembly quantities will differ. These differences can be seen in paragraph 5.1.7. For any input beam, after down conversion, the power divider breaks the input signal into one output for each zone. With five zones, there are then 25 processing sections. The row switch in each section has one input from each beam in that input zone, that is, the inputs to any given switch are the eight common row element beams in that section.

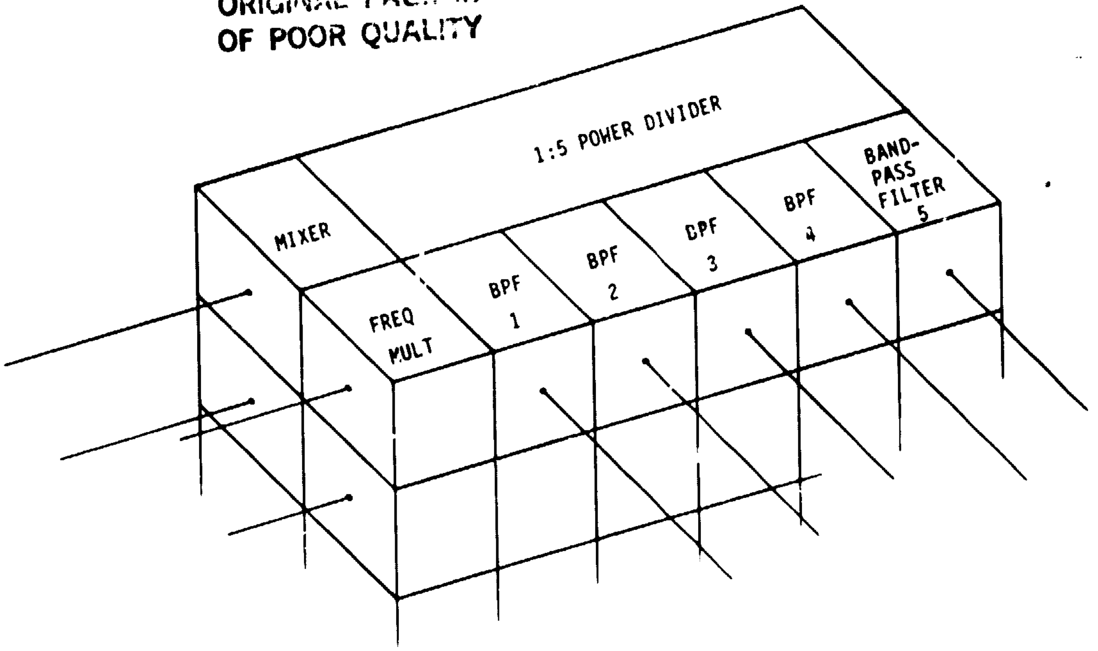
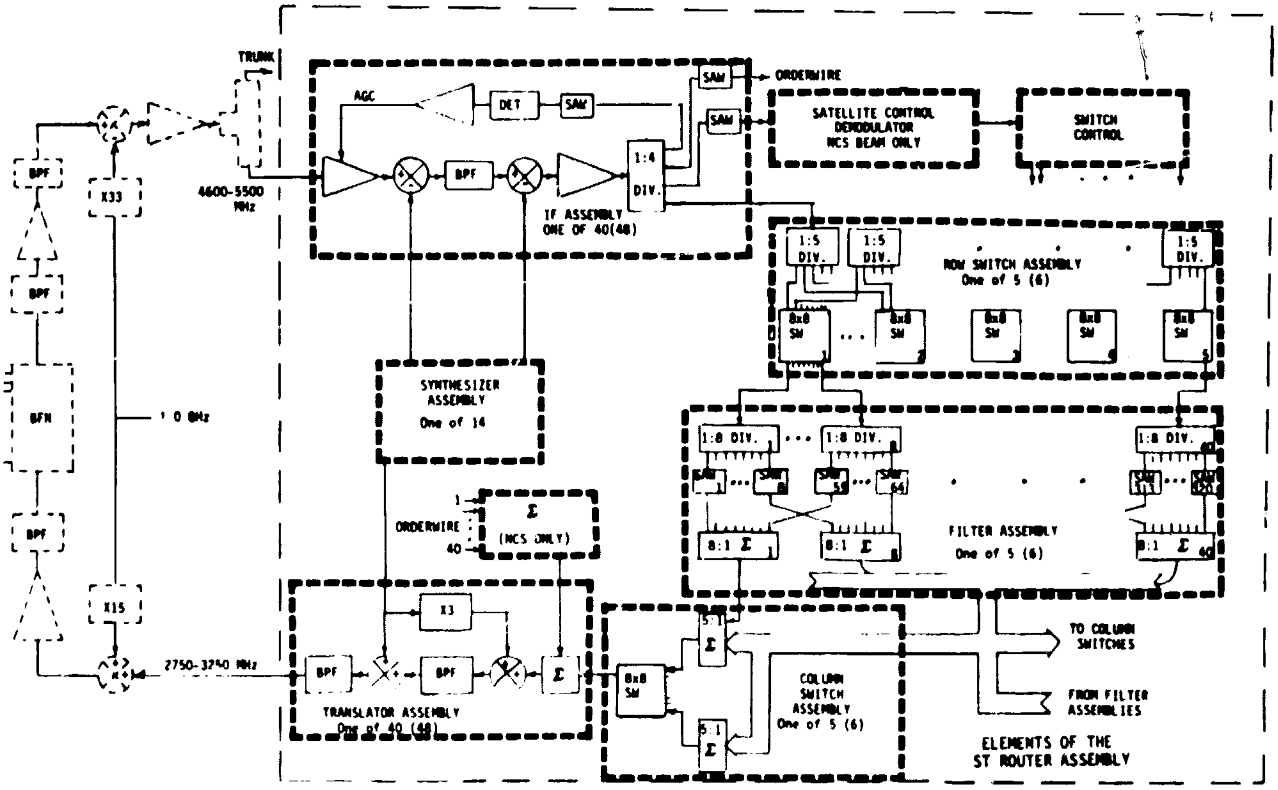


Figure 5.1-4. Router Input Segment



( ) REFERS TO TRAFFIC MODEL B

Figure 5.1-5. Router Block Diagram

The outputs of the row switches are then separated by frequency division into outputs to each of the destination zones with surface acoustic wave filters. There are 64 such filters in each of the 25 processing sections. Filter outputs destined for the same output zone are then summed first with other outputs in the same section and then with common destination signals from the other four input zones. They are then directed to the column switches. Analogous to the row switches, the column switches have as inputs the forty common column filter outputs, eight on each switch. The outputs of the common switches are then translated to the proper router IF output frequency.

In addition, the router contains a control processor which directs the switching configuration. This direction is generated in the Network Control Station together with system clock and frequency references. All translating frequencies for the router are derived by frequency synthesis from these references.

5.1.7 ROUTER CHARACTERISTICS

The router for Traffic Model A has 40 intermediate frequency inputs which are segmented into traffic for all other beam spots. Thus, there are 1600 (40 × 40) paths through the router which are controlled by the row and column switches. Traffic Model B differs only in that there are 48 intermediate frequencies and 2304 (48 × 48) paths which are available. In both cases, a path can carry many transmissions being dedicated only to having common source and destination spot beams (see Table 5.1-1).

Table 5.1-1. Router Characteristics

Item Description	Traffic Model A	Traffic Model B
IF Input Frequency	4.5 - 5.5 GHz	Same
IF Output Frequency	2.7 - 3.2 GHz	Same
Input Signal Power Density	$-120 < \psi < -100$ dBm/Hz	Same
Number of Beams	40	48
Number of SAW Filters	1600	2304
Total Available Bandwidth	2964 MHz	2828 MHz
SAW Filter Bandwidths	1 MHz $<$ B $<$ 20 MHz	1 MHz $<$ B $<$ 20 MHz
Power Divider: quantity (size)	40 (1 : 4)	48 (1 : 4)
	40 (1 : 5)	48 (1 : 6)
	200 (1 : 8)	288 (1 : 8)
Power Combiner: quantity (size)	200 (8 : 1)	288 (8 : 1)
	40 (5 : 1)	48 (6 : 1)
Interconnect Switch: quantity (size)	30 (8 × 8)	42 (8 × 8)
Cross Points - Total	1920	2688
Reconfiguration Time	$<$ 100 μsec	$<$ 100 μsec
Frequency Synthesizers	14 - fixed program	14 - fixed program

Table 5.1-1. Router Characteristics (Cont)

Item Description	Traffic Model A	Traffic Model B
NCS Receiver	one	one
Prime Power	195 Watts	244 Watts
Size	9 ft^3	13 ft^2
Weight	350 pounds	500 pounds

All switches are identical 8 × 8 crossbar types, the design being based upon Motorola's GB6 cell array, and the SAW filters are ripple-cancellation designs with bandwidths in the 1-20 MHz range. The range of center frequencies for both the switches and filters is from about 80 MHz to 400 MHz.

All reference frequencies are derived through frequency synthesis from references supplied by the Network Control Receiver which in turn are locked to the System Reference in the Network Control Station. The Network Control Receiver also is the source for the switch control function.

5.1.8 FDM RELIABILITY MODEL ROUTER SWITCHING SINGLE PATH

This reliability model of Figure 5.1-6, shows the functional dependency for the throughput of a single input beam to a preselected single output beam The probability of successful operation for ten years has been calculated at 0.8247. The primary contributors to the high failure rate (2.2 × 10^{-6} failures/hour) are the mixers, which contribute 58% of the total failure rate. The 8 × 8 switches are assumed to be current 8 × 8 switches with some modifications incorporated to switch analog signals. The equipment that is common to more than one beam has been considered to have redundant elements (possible multiple redundancies) such that the resulting high probability of success does not affect the reliability of the remainder of the system. It is possible that portions of this circuit can be bypassed through switching techniques. That portion would be from the input of the first 8 × 8 switch to the input of the second 8 × 8 switch. This allows a slight improvement in the reliability to 0.8333.

5.1.9 FDM RELIABILITY MODEL ROUTER SWITCHING

A slicing technique has been used to model and calculate the reliability of the FDM router switch network. As shown by the model in Figure 5.1-7, the router switch has been sliced into six distinct functional elements: 1) 40 identical beam input circuits; 2) 40 power splitters to provide a fanout to 200 lines; 3) 3 × 8 switches to route signals to power splitter which provide 1600 outputs; 4) 1600 SAW filters for filtering; 5) summing networks to combine SAW filter outputs to 40 outputs; and 6) final switching, mixing and filtering to provide the 40 output beams.

An additional block on this diagram provides for those elements that are common throughout the router. These elements are power supplies, master oscillator, switch controls, synthesizers, etc. It is recognized that these common elements are critical to the proper operation of the entire system. Because of this critical nature, redundant techniques will be utilized to assure that the reliability of the common elements will have only a minor impact on the total systems probability of success.

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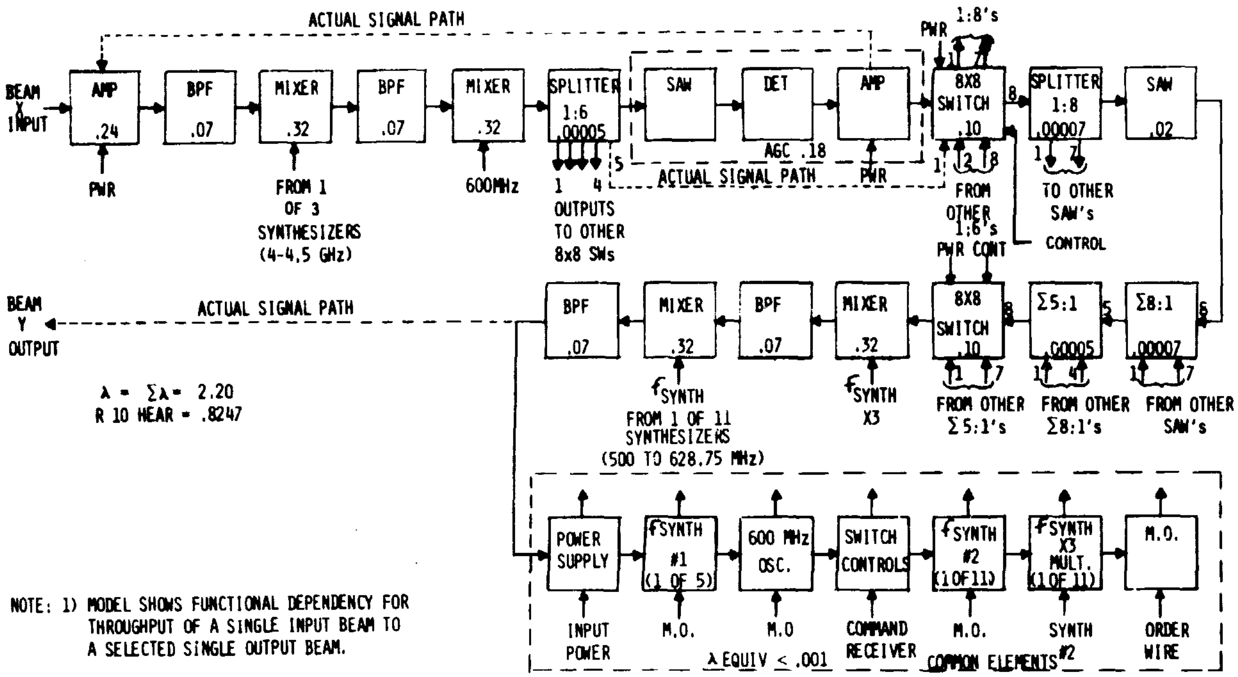
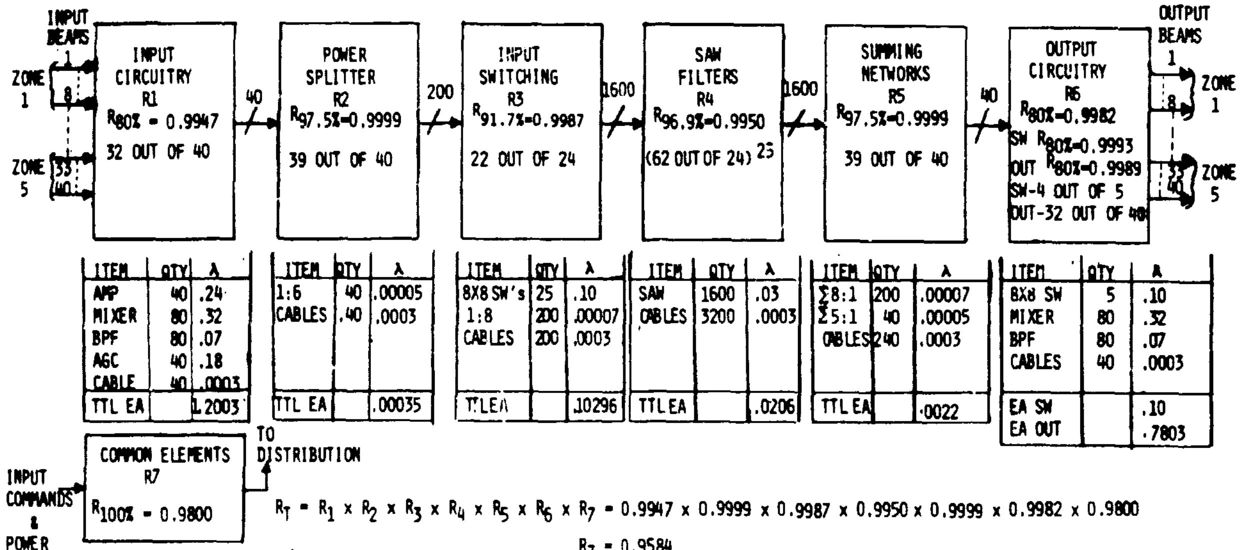


NOTE: 1) MODEL SHOWS FUNCTIONAL DEPENDENCY FOR THROUGHPUT OF A SINGLE INPUT BEAM TO A SELECTED SINGLE OUTPUT BEAM.

2) ALL λ's ARE X 10^{-6} FAILURES/HOUR

Figure 5.1-6. Router Switching Reliability Model



ITEM	QTY	λ
AMP	40	.24
MIXER	80	.32
BPF	80	.07
AGC	40	.18
CABLE	40	.0003
TTL EA		1.2003

ITEM	QTY	λ
1:6	40	.00005
CABLES	40	.0003
TTL EA		.00035

ITEM	QTY	λ
8X8 SW's	25	.10
1:8	200	.00007
CABLES	200	.0003
TTL EA		.10296

ITEM	QTY	λ
SAW	1600	.03
CABLES	3200	.0003
TTL EA		.0206

ITEM	QTY	λ
Σ8:1	200	.00007
Σ5:1	40	.00005
CABLES	240	.0003
TTL EA		.0022

ITEM	QTY	λ
8X8 SW	5	.10
MIXER	80	.32
BPF	80	.07
CABLES	40	.0003
EA SW		.10
EA OUT		.7803

$$R_T = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \times R_6 \times R_7 = 0.9947 \times 0.9999 \times 0.9987 \times 0.9950 \times 0.9999 \times 0.9982 \times 0.9800$$

$$R_7 = 0.9584$$

ITEM	QTY	λ
PWR CONV	TBD	TBD
fSYNTH	TBD	TBD
OSC	TBD	TBD
MULT's	TBD	TBD
CONTROLS	TBD	TBD
M.O.	TB.	TBD

THROUGHPUT = 80% (INPUT AND OUTPUT CKTS) x 97.5% x 91.7% x 96.9% x 97.5%
= 67.6%

NOTE: COMMON ELEMENTS WILL HAVE REDUNDANCIES AS REQUIRED TO PROVIDE R = .98 @ 100% OUTPUT

NOTES: 1) ALL λ's ARE X 10^{-6} FAILURE/HOUR

2) RELIABILITY FIGURES ARE FOR 10 YEAR MISSION - SPACE FLIGHT

Figure 5.1-7. Router Switching Model

The objective of this reliability analysis was to determine the reliability for a ten year mission with a 67% data throughput. The reliability for each slice has been calculated on the basis of the throughput. For example, the Input Circuitry Block has a reliability figure of 0.9947 for 80% throughput, or 32 out of 40 of the input circuits are operating properly. Because of the switching capabilities of the Router, it is posssible to switch the 80% good inputs to the 80% good outputs. If all remaining failures occur on the remaining "good" lines within the block power splitter, input switching, SAW filters, and summing network, the total throughput would be 67.6%. This calculation is shown on the diagram. The calculations predict that there is a probability of 0.9584 for a 67.6% data throughput of the Router Switching, for a ten year mission.

5.1.10 ST IF FREQUENCY SELECTION REQUIREMENTS

As it is not now feasible to perform the required router functions of filtering and switching directly at the uplink frequencies, it is necessary to reduce both the center frequencies and the bandwidths in which the operations are accomplished. Thus, the choice of the router input frequency range is heavily influenced, not only by the interface with the receiving subsystem and the impact upon the complexity of that subsystem, but also by the constraints that the router itself imposes upon the choice.

Similarly, the router output intermediate frequency selection is influenced both by the router configuration and its internal operating frequencies as well as the impact upon the final upconverters, filters, power amplifiers, and combiner.

Candidate frequency ranges for the first intermediate frequency at the router input were examined from 2 GHz to 8 GHz for suitability with a 1 GHz signal bandwidth in accordance with the frequency plan. Frequencies above 6 GHz were found to have a dominant fifth order intermodulation product and those below 3 GHz would make it difficult to reject images for the receiver. The selected range of 4.5 to 5.6 GHz has, as worst case, a ninth order intermodulation product appearing in band.

The router output intermediate frequency has also been selected by examining the potential intermodulation products generated in the translations from the signal filtering and switching frequencies to the desired transmit frequency band and the rejection of undesired mixing side bands.

The selected output IF range of 2.56 to 3.34 GHz results in intermodulation products which can be easily controlled in level. This frequency range selection was dominated by the processing frequencies internal to the router.

5.1.11 ROUTING INTERFACE

The routing assembly, Figure 5.1-8, will interface with the receiving assembly and the transmitting assembly using coaxial cables. As the planned intermediate frequencies are high and the distances between these assemblies considerable, a low loss interconnect using solid wall coaxial cable is planned. The lower frequency signals connecting the network control receiver to the routing assembly should also be coaxial, but can be miniature flexible cables.

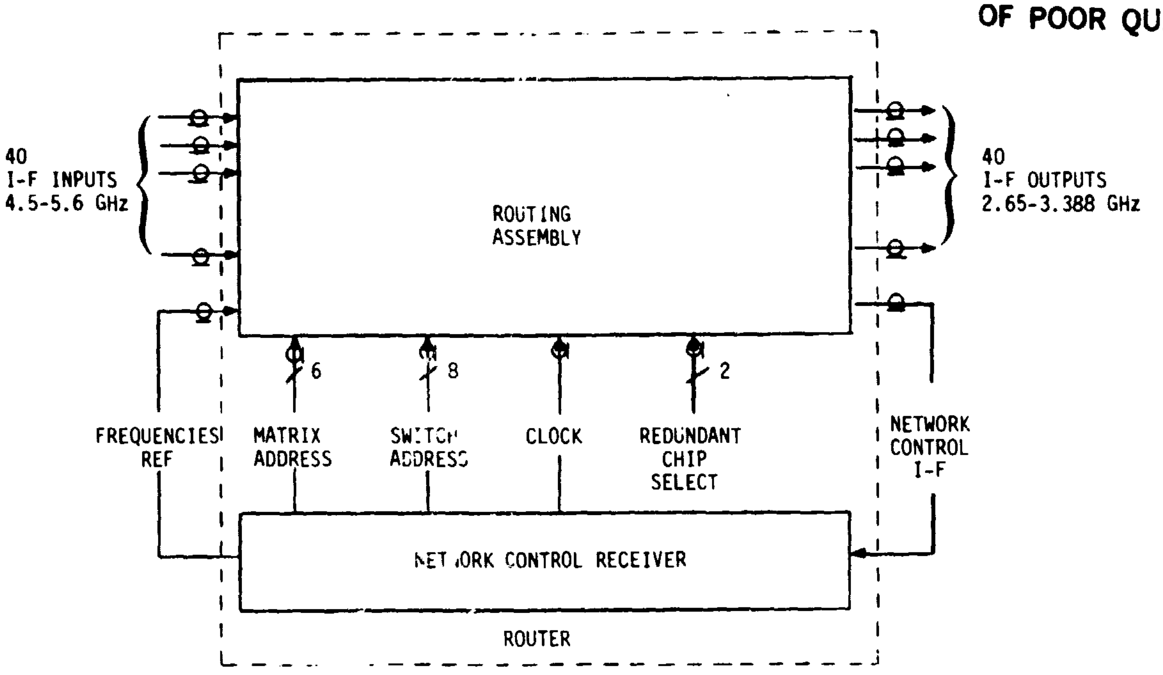


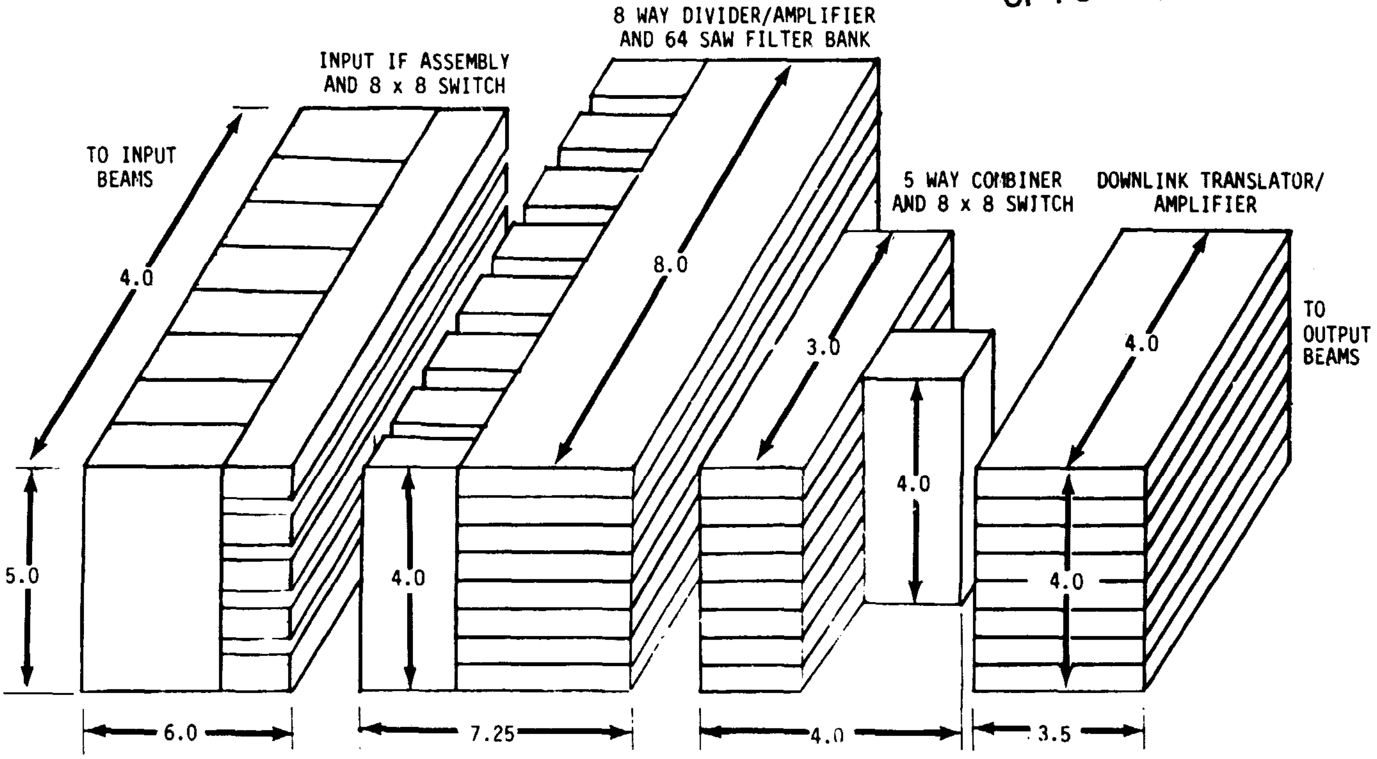
Figure 5.1-8. Routing Interface

5.1.12 A SLICE THROUGH THE ROUTER

Shown in Figure 5.1-9 is one slice through the router. A slice is intended to shown the signal flow through the router and to give the overall dimensions, in inches, of each of the four major subassemblies within the router. A modular approach is used in packaging the router as this has proven to be the most rugged and reliable method of packaging large spaceborne electronic equipment. This packaging scheme will minimize both the size of the router and the number of interconnecting cables needed within the router. Semi-rigid cables must be used on the input to the IF assembly and on the outputs of the downlink translator/amplifier modules. Flexible coaxial cables may be used for all other RF interconnections between the assemblies shown.

5.1.13 ROUTER LAYOUT

The layout of the router is essentially an array of individual module stacks mounted on a common baseplate. The module stacks have been arranged to minimize the lengths of the interconnecting cables. Referring to Figure 5.1-10, and assuming that rows are from left to right and columns from bottom to top, the input signals to the router from the receiver subsystem are located in each of the IF assemble module stacks on the far left. The outputs from the stacks are distributed to each of the five 8 way divider module stacks located directly to the right in the same row. The output from this stack and each of the other four module stacks in the same column must be routed up to the five way combiner stack located at the top of the drawing. The output from this stack is then routed to the downlink translator stack in the same column and the output from this stack, located at the top of the page, then becomes the input to the transmitter subsystem.



ALL DIMENSIONS IN INCHES

Figure 5.1-9. A Slice Through The Router

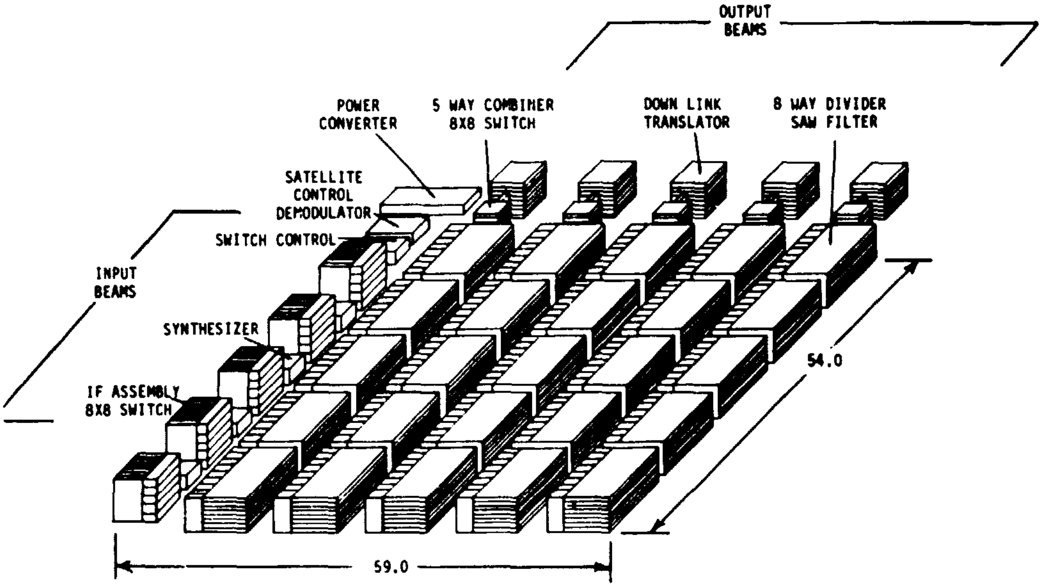


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Figure 5.1-10. Router Layout

5.1.14 SATELLITE ST ROUTER ASSEMBLIES TRAFFIC MODEL A

The corresponding table, Table 5.1-2, is a detailed breakdown of the major subassemblies within the router. Estimates for the size, weight, and power of each module were derived from similar existing hardware.

The modules are machined from 6061 aluminum to minimize the weight of the router. The modules are then arranged to form several individual module stack assemblies. The first assembly, of which there are five, consists of eight IF assembly modules and five 8 × 8 input switch/decoder modules. The eight IF assembly modules are mounted vertically in a breadslice fashion and mounted to these are the five 8 × 8 input switch/decoder modules. Shear panels are attached to the top and sides to provide additional strength and rigidity and to improve the heat transfer characteristics.

The next assembly, of which there are 25, consists of eight amplifier/eight-way divider modules and eight SAW filter/eight-way combiner modules. The SAW filter/eight-way combiner modules are stacked horizontally and mounted to these are the amplifier/eight-way divider modules. The SAW filter/eight-way combiner module is the largest and heaviest module within the router and these 25 assebmlies account for over one-half of the total size and weight of the router. The size and weight of each assembly could be reduced approximatley 25% if four SAW filters were mounted onto a single substrate.

The next assembly, of which there are five, consists of eight five-way combiners and one 8 × 8 output switch/decoder. The eight five-way combiner modules are stacked horizontally and mounted to these is the 8 × 8 output switch. This output switch module is identical to the input switch module.

The last assembly, of which there are five, consists of eight downlink translator/amplifier modules stacked horizontally.

The previously described assemblies comprise the major portion of the ST router. Two additional units, the satellite control demodulator and the switch control are of similar design and consist of six modules each.

5.1.15 SATELLITE ST ROUTER ASSEMBLIES TRAFFIC MODEL B

The corresponding table, Table 5.1-3, is a detailed breakdown of the major subassemblies within the router. Estimates for size, weight, and power of each module were derived from similar hardware.

The modules are machined from 6061 aluminum to minimize the weight of the router. The modules are then arranged to from several individual module stack assemblies. The first assembly, of which there are six, consists of eight IF assembly modules and six 8 × 8 input switch/decoder modules. The eight IF assembly modules are mounted vertically in a breadslice fashion and mounted to these are the six 8 × 8 input switch/decoder modules. Shear panels are attached to the top and sides to provide additional strength and rigidity and to improve the heat transfer characteristics.

The next assembly, of which there are 36, consists of eight amplifier/eight-way divider modules and eight SAW filter/eight-way combiner modules. The SAW filter/eight-way combiner modules are stacked horizontally and mounted to these are the amplifier/eight-way modules. The SAW filter/eight-way combiner module is the largest and heaviest module within the router and these 36 assemblies account for over one-half of the total size and weight of the router. The size and weight of each assembly could be reduced approximately 25% if four SAW filters were mounted onto a single substrate.

Table 5.1-2. Satellite ST Router Assemblies — Traffic Model A

Assembly	Technology	Unit Size L × W × H (IN)	Unit Wt (LB)	Unit PW (WT)	Qty Req'd	Total Weight	Total Power
IF Input Assembly	Stripline	4.0 × 5.0 × 0.5	0.67	0.9	40	26.8	36
8 × 8 Input Switch/Decoder	Bipolar-Mosaic	4.0 × 2.0 × 0.8	0.23	0.85	25	5.75	21.25
8 Way Divider/Amplifier	Bipolar	4.0 × 2.0 × 0.5	0.155	0.035	200	31.0	7.0
SAW Filter/8 Way Combiner	SAW/Discrete	8.0 × 5.25 × 0.5	0.763	0.035	200	143.2	7.0
5 Way Combiner	Stripline	3.0 × 2.0 × 0.5	0.10	Passive	40	4.0	—
8 × 8 Output Switch/Decoder	Bipolar-Mosiac	4.0 × 2.0 × 0.8	0.23	0.85	5	1.15	4.25
Downlink Translator	Bipolar	4.0 × 3.5 × 0.5	0.54	0.97	40	21.6	38.8
Synthesizers/LO Distribution	Bipolar	5.0 × 2.5 × 0.5	0.198	0.27	14	5.6	22.4
Satellite Control Demodulator	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.39	2.0
Switch Control	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.89	2.0
Power Converter	Bipolar	10.0 × 6.0 × 2.0	6.5	54.7	1	6.5	54.7
Cables	Coaxial				1250 ft	10.5	—
Structure	Aluminum					91.8	—
Total		59 × 54 × 5.0				353.1	195.4

Table 5.1-3. Satellite ST Router Assemblies Traffic Model B

Assembly	Technology	Unit Size L × W × H (IN)	Unit WT (LB)	Unit PW (WT)	Qty Req'd	Total Weight	Total Power
IF Input Assembly	Stripline	4.0 × 5.0 × 0.5	0.67	0.9	48	32.2	43.2
8 × 8 Input Switch/Decoder	Bipolar-Mosiac	4.0 × 2.0 × 0.8	0.23	0.85	36	8.3	30.6
8 Way Divider Amplifier	Bipolar	4.0 × 2.0 × 0.5	0.55	0.35	288	44.6	10.1
SAW Filter/8 Way Combiner	SAW/Discrete	8.0 × 5.25 × 0.5	0.763	0.35	288	219.7	10.1
6 Way Combiner	Stripline	3.0 × 2.0 × 0.5	0.10	Passive	48	4.8	—
8 × 8 Output Switch/ Decoder	Bipolar-Mosaic	4.0 × 2.0 × 0.8	0.23	0.85	6	1.38	5.1
Downlink Translator	Bipolar	4.0 × 3.5 × 0.5	0.54	0.97	48	25.9	46.6
Synthesizers/LO Distribution	Bipolar	5.0 × 2.5 × 0.5	0.40	1.87	14	5.6	26.18
Satellite Control Demodulator	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.89	2.0
Switch Control	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.89	2.0
Power Converter	Bipolar	12.0 × 6.0 × 2.0	8.0	68.4	1	8.0	68.4
Cables	Coaxial				1920 ft	14.1	—
Total		65 × 62.5 × 5.0				497.7	244.3

The next assembly, of which there are six, consists of eight six-way combiners and one 8 × 8 output switch/decoder. The eight six-way combiner modules are stacked horizontally and mounted to these is the 8 × 8 output switch. This output switch module is identical to the input switch module.

The last assembly, of which there are six, consists of eight downlink translator/amplifier modules stacked horizontally.

The previously described assemblies comprise the major portion of the ST router. Two additional units, the satellite control demodulator and the switch control are of similar design and consists of six modules each.

5.1.16 ROUTER TECHNOLOGIES

Below are listed the key technologies with the router:

- Switching:
  bandwidth
  crosstalk
  control
  power requirements
  crosspoint limitation
  redundancy
  packaging
- Synthesizer(s):
  power
  tunability
  phase noise
- SAW filters:
  center frequency range
  bandwidth
  stability
  selectivity
  packaging
- Packaging:
  crosstalk
  ground loops
  reliability

For each of the four primary items, the most critical decision characteristics are listed. Requirements for each has not been detailed at this time; however, design of the router has proceeded in conjunction with support studies involving the switch, synthesizers and SAW filters. Although packaging is not normally included as a technology development, its importance cannot be neglected in view of the complexity of the router.

Crosstalk, ground loops, interconnects, EMI, heat transfer, relibility, size and weight are a few of the items which must be addressed in the packaging design of the router. From a review of the architecture to present technology status, there are no design requirements in the router which are imcompatible with current design capabilities. Certainly some refinements are required, but there are no apparent technology breakthrough necessary to satisfy the architecture described herein.

5.2 Transponder Subsystem Size, Weight, and Power

5.2.1 UPLINK SATELLITE RECEIVER CONFIGURATION DUAL TRUNK/ST BEAM (TRAFFIC MODELS A AND B)

The LNR, common to all satellite receiver configuration required to decompose dual trunk, single trunk and ST only beams, is comprised of; two filters used to strongly reject transmitter leakage before downconverting (i.e. $>$ 140 dBm of rejection required), an RF LNA delivering 20 dB gain and having a 4 dB noise figure (NF), a highside LO for downconverting to ensure that no images fall within the receiver passband, and an initial IF low noise GaAs amplifier (10 dB gain, 5 dB NF) used to set E_b/N_o at the LNR's output.

Figure 5.2-1 identifies the dual trunk configuration. This figure is applicable to both Traffic Models A and B. The dual trunk beam is comprised of trunk bands A and C and ST band 1 and 2 and spans a bandwidth of 2.5 GHz or 2.0 GHz respectively. The first IF BPF, used to reject spurious signals produced by the RF/IF mixer, has a relatively broad bandwidth.

Two diplexing operations are used to fully decompose the dual trunk beams. Filters shown as part of diplexing operations possess bandwidths, as depicted in the figure, and strongly tapered skirts that fully separate the signals in both arms of the diplexers. The first diplexing operation separates the uplink beam's full trunk bandwidth (1.5 GHz) from the ST band while the second diplexing operation separates the full trunk band into its constituent bands, A and C. The second IF amplifiers shown prior to the second diplexing operation is also a low noise GaAs amplifier with 5 dB noise figures and 10 dB gain, and is used to counter line losses due to filtering and signal splitting. While each separated ST channel enters the ST Routers with the same relative IF frequency it had upon RF/IF downconverting* the trunk bands are required to have a common center frequency upon entering the trunk IF switch. The center of trunk band A is taken as this common center and the translation of band C to band A is accomplished by downconverting as shown. The BPF at the mixer output passes trunk band A to the IF switch and reject spurious signals produced by the mixer.

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*Further frequency translations are accomplished with the ST Router to accommodate the restricted switching bandwidth.

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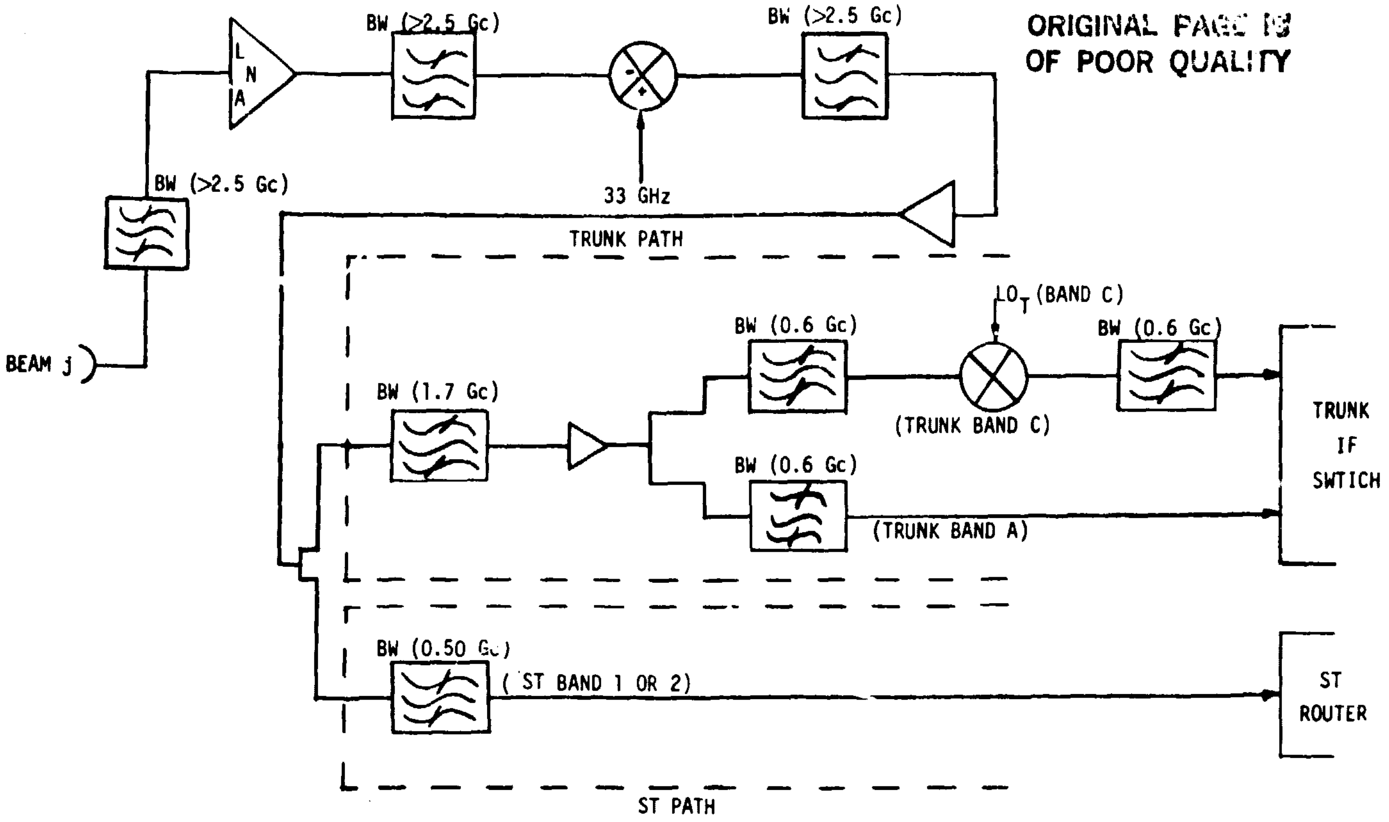

Figure 5.2-1. Uplink Satellite Receiver Configuration Dual Trunk/ST Beam (Traffic Models A and B)

5.2.2 UPLINK SATELLITE RECEIVER CONFIGURATION SINGLE TRUNK/ST BEAM (TRAFFIC MODELS A AND B)

The "single trunk" (single trunk band/single ST band) receiver configuration is identified in Figure 5.2-2. The diagram is applicable to Traffic Models A and B. The presence of one of eight possible combinations of trunk band and ST band in a "single trunk" beam* necessitates two single trunk IF receiver forms. When trunk band A is a beam component the structure of the first form is:

- A BPF used to reject spurious signal from the RF/IF downconverter.
- A single diplexing operation with the associated BPF's (are centered for one of three possible ST bands and one centered for trunk band (A) being shaped in bandwidth and band edge rolloff to yield good signal separation in the diplexer arms.

Since the IF frequency position of trunk band A is taken, in this report, as the common IF band into the trunk IF switch no further operations are required in the trunk path to the IF's switch. In addition, no further operations are required in the ST path to the ST router because all addition frequency translation are accomplished within the router itself.

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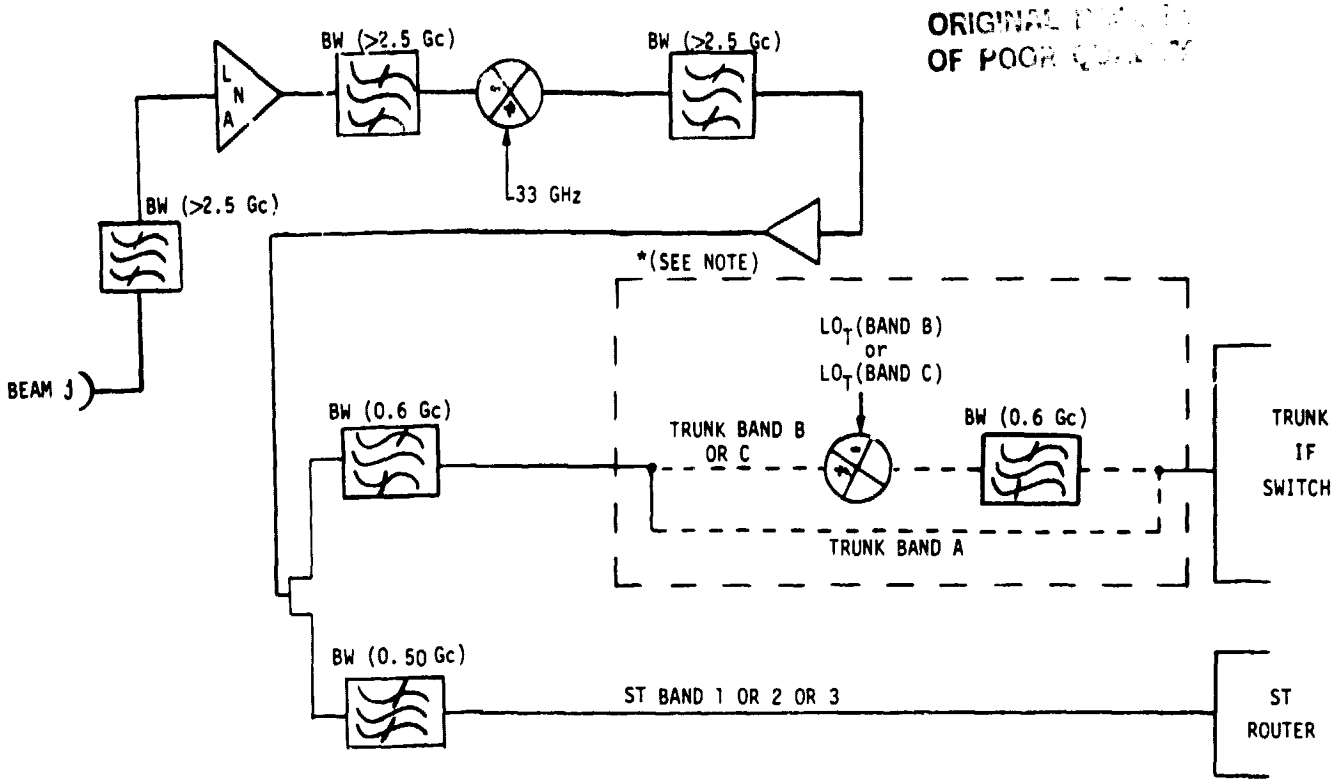
*The combinations are: Trunk A with ST 1 or 2 or 3; Trunk B with ST 1 or 2 or 3; Trunk C with ST 1 or 2.



* TRUNK BANDS B AND C REQUIRE TRANSLATION TO PROPER IF FREQUENCY.

Figure 5.2-2. Uplink Satellite Receiver Configuration Single Trunk/ST Beam (Traffic Models A and B)

When trunk band B or C is a beam component the IF receiver form for the "single trunk" case is:

- Identical first BPF used in the first form
- A single diplexing operation with the two BPF's (one centered for one of one three ST bands and one centered for trunk band B or C) being shaped in bandwidth and band edge rolloff to yield good signal separation in the diplexer arms.

To achieve the common IF band required for at the trunk IF switch frequency translations taking trunk band B to trunk band A or trunk band C to trunk band A are implemented. The mixer with appropriate LO is shown in the trunk arm of the diplexer. The filter following mixing passes trunk band A and rejects spurious signals produced by the mixer. Again no further operations are required in the ST arm of the diplexer.

5.2.3 UPLINK SATELLITE RECEIVER CONFIGURATION TYPICAL ST BEAM (TRAFFIC MODELS A AND B)

Figure 5.2-3 identifies the "ST only" receiver configuration. The configuration is applicable to Traffic Models A and B. The IF component at the LNR's output identified is a single BPF. This filter is not used to tightly confine the channel bandwidth around the ST band present in the beam. The filter is used to reject spurious signals produced by the RF/IF downconverter. Further bandwidth restriction is accomplished in the ST router.

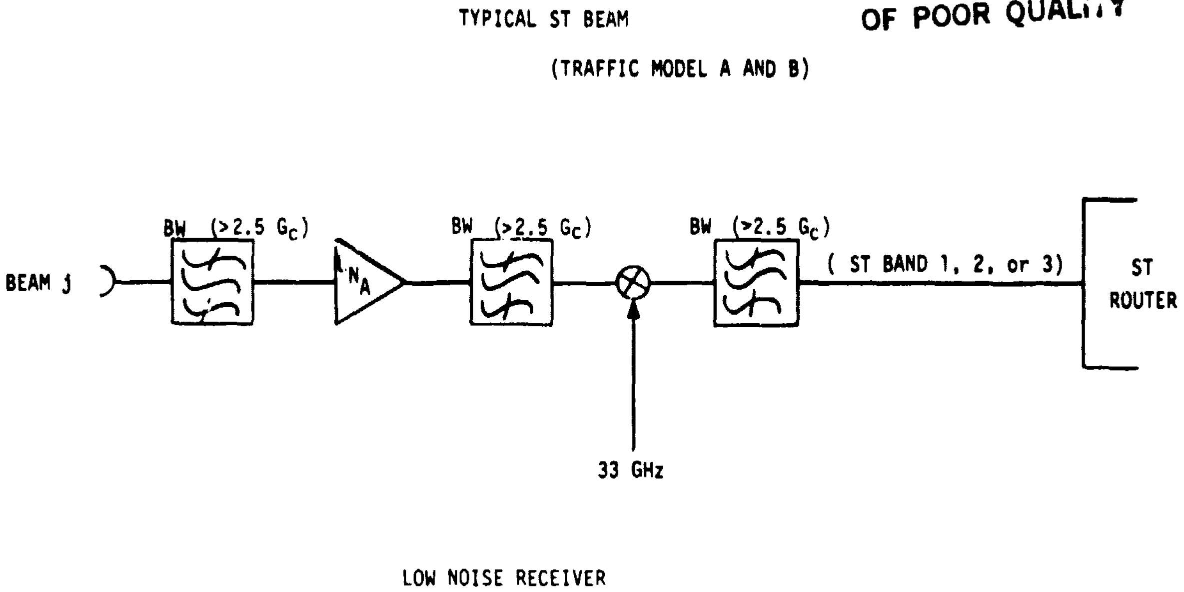


Figure 5.2-3. Uplink Satellite Receiver Configuration Typical ST Beam (Traffic Models A and B)

5.2.4 DOWNLINK SATELLITE TRANSMITTER CONFIGURATION TYPICAL DUAL TRUNK/ST BEAM (TRAFFIC MODELS A AND B)*

All data output, in the form of data bands, from the trunk IF switch are essentially handled in the same manner. As can be seen from the figures defining downlink transmitter configurations a trunk data band is:

- Initially amplified to an appropriate signal level into the mixer,
- IF/RF upconverted to produce bands center at trunk band A, B, or C, with one of three LO's [LO(A_T), LO(B_T), LO(C_T)] since all data output from the IF switch are at a common center frequency,
- Filtered with a relatively wide BPF to reject any spurious signals produced by the mixer while minimizing insertion loses at approximately 20 GHz center frequency.
- Amplified with a TWT operating in a saturated mode supporting 550 Mbps of data through the channel,
- Filtered to remove spurious signals generated by the TWT and to eliminate band overlay when channels are combined as in the dual and single trunk beam cases.

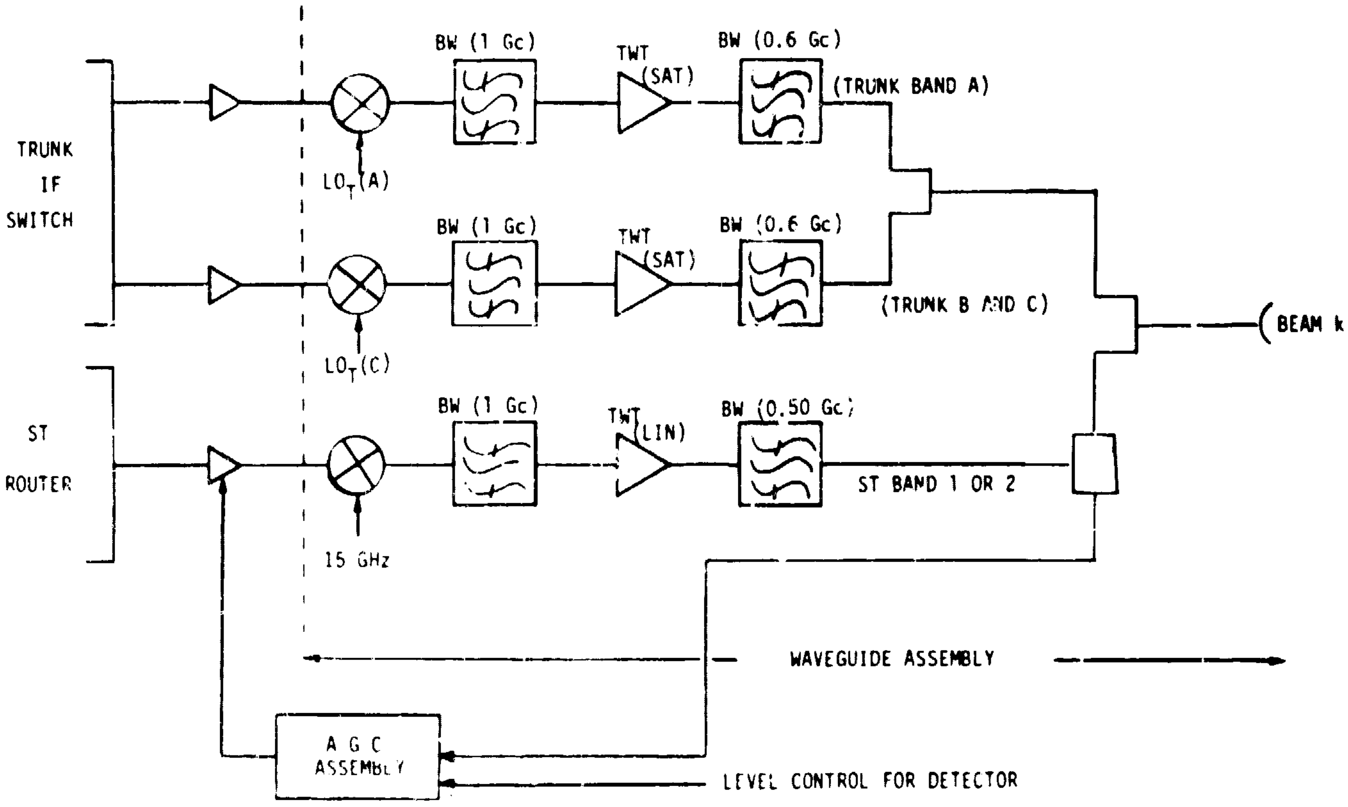
---

*ST band 3 and trunk band C are not permitted simultaneously, all other combinations of A trunk band and ST band are permitted.

All data output from the ST router in the form of ST bands is essentially handled in the same manner. As can be seen from Figure 5.2-4 the essential differences between the handling in trunk and ST channels are:

- The initial amplification is part of an AGC function to ensure an adequate power density at the output of the linear mode TWT minimizing of overall satellite power requirements,
- The TWT is operated in a linear mode,
- A directional coupler is used for a feedback path into the AGC assembly which runs off an NCS level control used appropriately set the threshold detector level based on the traffic load anticipated for beam k,
- One LO value is required for upconvertion since the data bands output from the ST router are already centered at the IF for ST band 1 or 2 or 3.

The dual trunk beam case shown in Figure 5.2-4 is appropriate for Traffic Model A and Traffic Model B loading considerations with the exception of Traffic Model B's New York beam which is discussed on the following pages. RF trunk bands A and C are produced through upconversion for all dual trunk beams, while ST band 1 or 2 can appear in a dual beam depending on router zoning considerations. Diplexers are used to; sum trunk bands A and C which have been well separated through final bandwidths restriction in the final BPFing after TWT amplification, and then sum the full trunk bandwidth with the ST band.



*TYPICAL IN THAT THE CONFIGURATION SHOWN REPRESENTS ALL DUAL TRUNK/SINGLE ST BEAMS EXCEPT THE TRAFFIC MODEL B NEW YORK BEAM.

Figure 5.2-4 Downlink Satellite Transmitter Configuration Typical Dual Trunk/ST Beam (Traffic Models A and B)

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5.2.5 DOWNLINK SATELLITE TRANSMITTER CONFIGURATION UNIQUE DUAL TRUNK/ST BEAM (TRAFFIC MODEL B - NEW YORK BEAM)

The dual trunk beam associated with the Traffic Model B's New York beam is shown in Figure 5.2-5. Here the trunk channels are operated upon in the same manner as defined for the other dual trunk beams. The ST band, however, requires two TWT's to output an adequate power density for the peak traffic load defined. To handle this case with minimum E_B/N_O loses due to signal splitting and recombining, contiguous diplexers are used to split the single ST band into two half, (i.e., slightly overlapping bands). After amplification in two arms of the diplexer with TWT's acting in a linear mode another contiguous diplexer is used to recombine the two band halves. Filters in the final diplex summing operation have a restricted bandwidth capable of handling further summing with the combined trunk bands.

The directional coupler used for an AGC feedback path as shown is placed at the output port of the ST band summer.

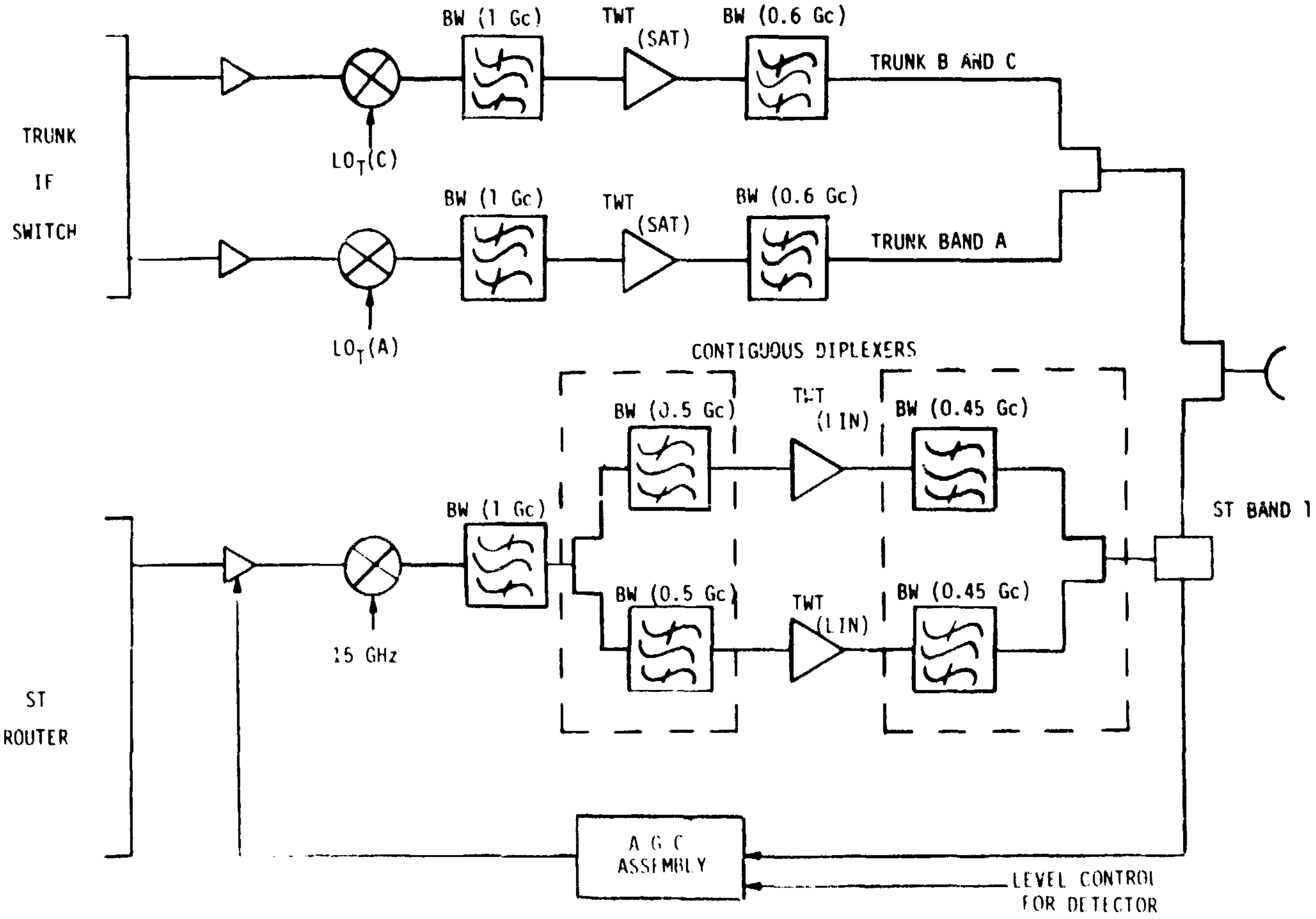

Figure 5.2-5. Downlink Satellite Transmitter Configuration Unique Dual Trunk/ST Beam (Traffic Model B-New York Beam)

5.2.6 DOWNLINK SATELLITE TRANSMITTER CONFIGURATION TYPICAL SINGLE TRUNK/ST BEAM (TRAFFIC MODELS A AND B)*

The single trunk beams transmitter configuration shown in Figure 5.2-6 is appropriate for both Traffic Model A and Traffic Model B cases with no exceptions. Eight possible combinations between trunk band and ST band can occur*. This necessitates that one of three trunk LO's be used to produce trunk band A, B, or C depending on specific beams assignments. The trunk band output from the trunk IF switch and ST band output from the ST router are acted upon in the same manner discussed at the beginning of this subsection. The summing between trunk and ST channels is accomplished with a diplexer as shown and the AGC circuitry is the same as described for the dual trunk case.

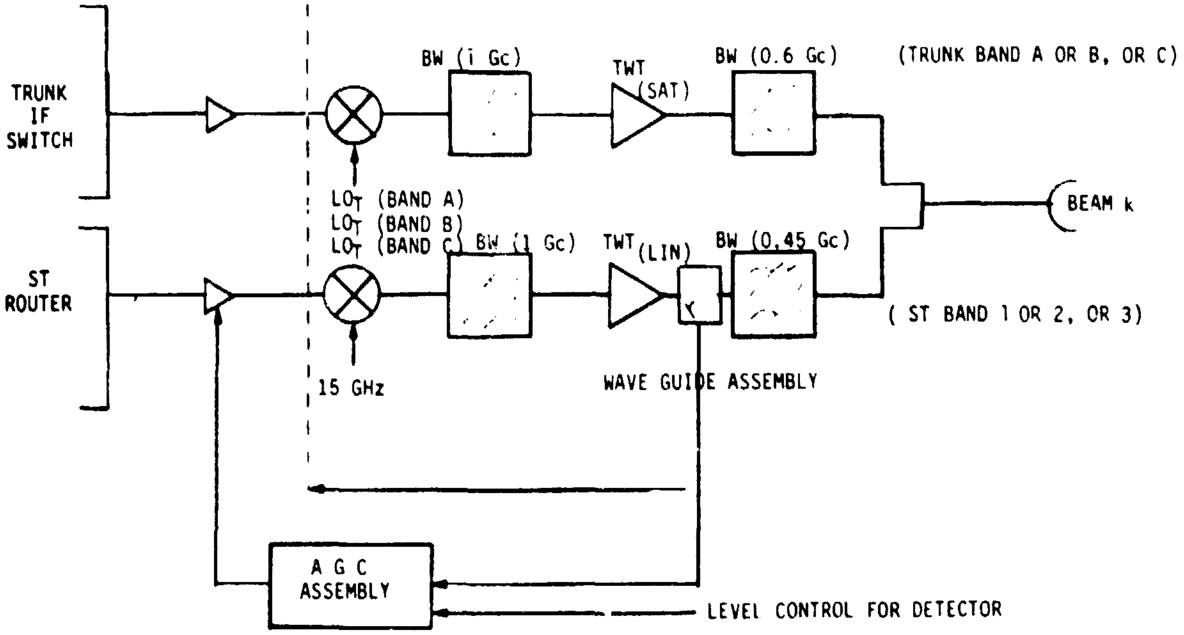

Figure 5.2-6. Downlink Satellite Transmitter Configuration Typical Single Trunk/ST Beam (Traffic Models A and B)

5.2.7 DOWNLINK SATELLITE TRANSMITTER CONFIGURATION TYPICAL ST BEAM (TRAFFIC MODELS A AND B)

The ST band only transmitter configuration is shown in Figure 5.2-7. The only difference between the ST channel in this figure compared to those in the dual and single trunk cases is the bandwidth of the final BPF. The exclusion of summing between ST and trunk bands negates the need for a narrow bandwidth in a given channel. The wider bandwidth minimizes any insertion loss at 20 GHz.

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*ST band 3 and trunk band C are not permitted simultaneously, all other combinations of A trunk band and ST band are permitted.

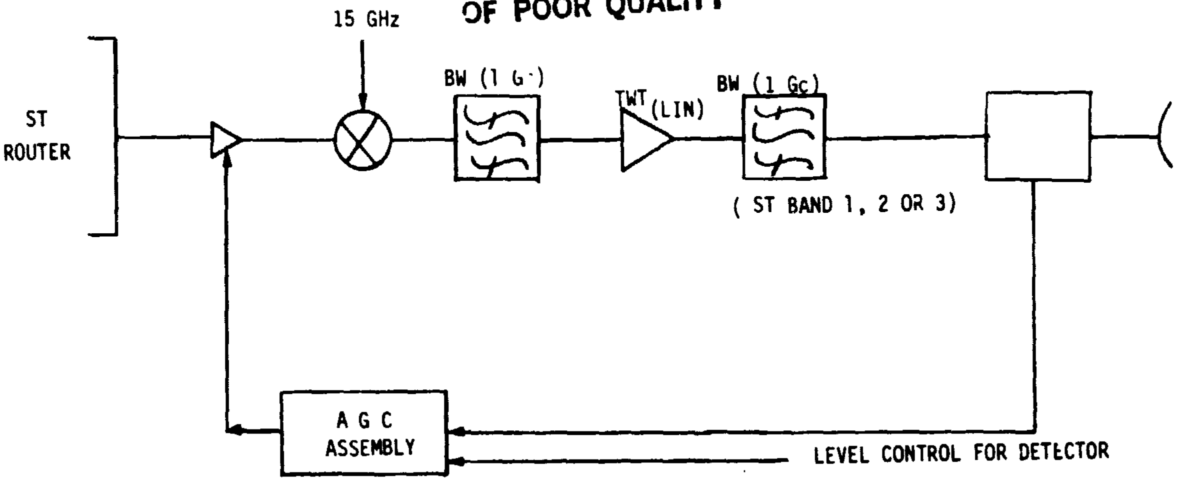


Figure 5.2-7. Downlink Satellite Transmitter Configuration Typical ST Beam (Traffic Models A and B)

For relatively large downlink ST traffic beams, drive levels to the TWT were not sufficient to produce the required output power levels required to support the downlink E8/N0. For such cases (19 in Traffic Model A, and 10 in Traffic Model B), a GaAs FET driver will be placed between the mixer and TWT to increase the drive level out of the mixer.

5.2.8 TRAFFIC MODEL A TRANSPONDER BLOCK DIAGRAM

The satellite transponder block diagram associated with Traffic Model A is depicted in Figure 5.2-8. The diagram identifies the receiver and transmitter configurations necessary to handle the decomposition and structuring of dual trunk/single ST (dual trunk), single trunk/single ST and ST only beams.

The dual trunk receiver configuration decomposes each of three dual trunk beams and yields six trunk channels for entrance into the trunk IF switch at a common IF frequency, and three ST channels for entrance into the ST router. Each channel supports a band of data (i.e., band A, B, or C for trunk channels with each band supporting 0.55 Gbps of data and band 1, 2, or 3 for the ST channels with each band supporting up to 0.40 Gbps of data).

The single trunk receiver configuration takes on two forms, as shown, to support the eight possible combinations of trunk bands and ST comprising the beam. The decomposition of fifteen single trunk beams yields fifteen trunk channels and 15 ST channels for entrance into the trunk IF switch and ST router, respectively. The two configuration forms are required to translate all trunk channels to the proper IF for entrance into the trunk IF switch.

The ST only receiver configuration of an LNR and BPF passing ST band 1 or 2 or 3 as is appropriate to beam make up is defined for 22 beams. There are then, no decomposing simple 22 ST channels constructed for passage to the ST router. The ST router then for Traffic Model A supports 40 input channels, while the trunk IF switch supports 21 channels.

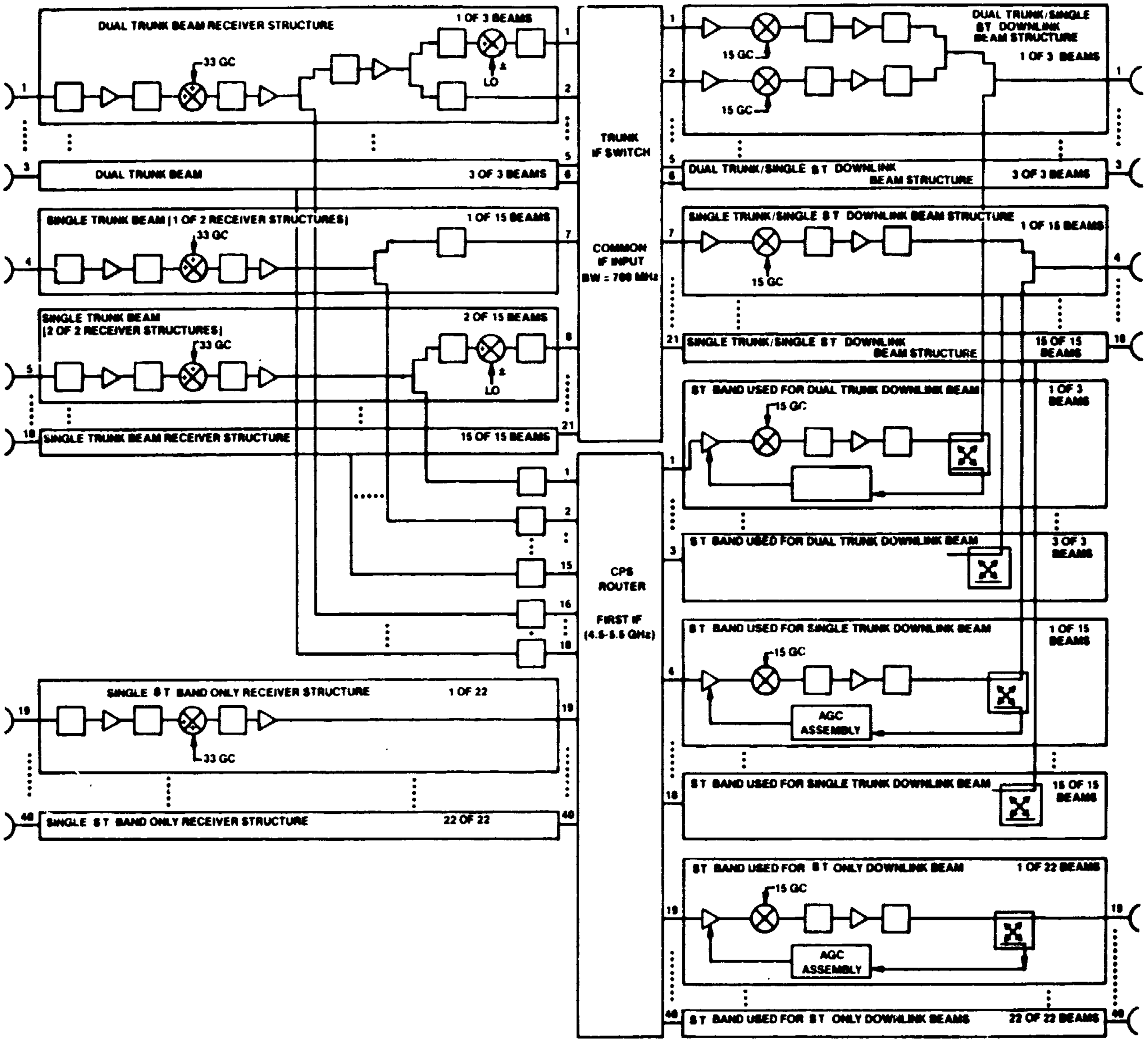


Figure 5.2-8. Traffic Model A Transponder Block Diagram

The satellite system outputs the same number of dual trunk (3), single trunk (15) and ST only (22) beams as was input to it. On the transmitter side of the trunk switch and ST router all 21 trunk channels are upconverted from IF to RF and amplified for transmission by a TWT operating in a saturated mode, while all forty ST channels after upconversion from IF to RF are amplified by a linear mode TWT. Further, the output power density from the ST channels are regulated with the AGC circuitry as shown.

5.2.9 UPLINK SATELLITE RECEIVER COMPONENT COUNT FOR TRAFFIC MODEL A

The component numbers were derived from:

- The uplink satellite receiver configuration. Table 5.2-1.
- The traffic model A transponder block diagram, Figure 5.2-8.
- Assumptions made concerning the use of trunk bands A, B and C in specific beams.
- The ST zone designations in paragraph 4.4 identifying the use of ST bands 1, 1 and 2 for specific beams.

Table 5.2-1 lists the uplink satellite receiver component count for Traffic Model A.

Table 5.2-1. Uplink Satellite Receiver Component Count for Traffic Model A

Uplink Satellite Receiver Component Count									
	Dual Trunk		Single Trunk		ST Only		Final Uplink Component Count		
Items	Per Beam	Total	Per Beam	Total	Per Beam	Total		ST	Trunk
RF BPFS'	2	6	2	30	2	44	RF BFS'	80	0
IF BPFS'	6	18	3 or 4[1]	55	1	22	IF BPFS'	58	37
RF/IF Mixers	1	3	1	15	1	22	RF/IF Mixers	40	0
IF/IF Mixers	1	3	0 or 1[1]	10	0	0	IF/IF Mixers	0	13
LNA's	1	3	1	15	1	22	LNA'S	40	0
Amplifiers	2	6	1	15	0	0	Amplifiers	0	21
Diplexers	2	6	1	15	0	0	Diplexers	0	21

[1] Common IF inputs to the trunk IF switch are achieved by frequency translation of trunk bands B and C down to trunk band A. Required hardware is noted.

5.2.10 DOWNLINK SATELLITE TRANSMITTER COMPONENT COUNT FOR A TRAFFIC MODEL A

The component numbers were derived from:

- The downlink satellite transmitter configuration, Table 5.2-2.
- The traffic model A transponder block diagram, Figure 5.2-8.
- Assumptions made concerning the use of trunk bands A, B, and C in specific beams.
- The ST zone designations in paragraph 4.4 identifying the use of ST bands.

Table 5.2-2 lists the downlink satellite transmitter component count for a Traffic Model A.

Table 5.2-2. Downlink Satellite Receiver Component Count for Traffic Model A

Downlink Satellite Receiver Component Count									
	Dual Trunk		Single Trunk		ST Only		Final Downlink Component Count		
Items	Per Beam	Total	Per Beam	Total	Per Beam	Total		ST	Trunk
RF BPS'S	6	18	4	60	2	44	RF BPF'S	80	42
IF/RF Mixers	3	9	2	30	1	22	IF/RF Mixers	40	21
TWT'S	3	9	2	30	1	22	TWT'S	40	21
Amplifiers	3	9	2	30	1	22	Amplifiers	40	21
Diplexers	2	6	1	15	0	0	Diplexers	0	21
Directional Couples	1	3	1	15	0	22	Directional Couples	40	0
GaAs Drivers	1	3	1	7	1	9	GaAs Drivers	19	0

5.2.11 NUMERICAL TABLES TRAFFIC MODEL A COMPONENT COUNT DOWNLINK ST CHANNEL AGC ASSEMBLY

The component numbers were derived from:

- The downlink satellite transmitter configuration, Table 5.2-2.
- The traffic model A transponder block diagram, Figure 5.2-8.

Table 5.2-3 lists the numerical tables Traffic Model A component count for downlink ST channel AGC assembly.

Table 5.2-3. Numerical Tables Traffic Model A Component Count Downlink ST Channel AGC Assembly

Items	ST Channels Only	
	Per Beam	Total
IF BPS'S	2	80
RF/IF Mixers	1	40
IF/IF Mixers	1	40

Common IF inputs to trunks IF switch are achieved by frequency translating trunk bands B and C down to A. Required hardware is noted.

5.2.12 TRAFFIC MODEL A SUMMARY

Table 5.2-4 is a summary of each of the five SS-FDMA satellite transponder subsystems. The antenna subsystem is the single largest subsystem within the satellite, due primarily to the large reflectors and supporting structure. The antenna estimates are based on data published by Ford Aerospace and General Electric.

The IF trunking switch is the smallest subsystem in terms of size, weight, and power. The estimate is taken from existing published industry data.

The transmitter subsystem is the heaviest and the largest power consumer of all the subsystems. The weight and the power are a result of the many TWT's and the high voltage power supplies needed to drive the TWT's. This high power dissipation will necessitate extensive external cooling to keep the operating temperature within reasonable limits. Information obtained verbally from Watkins-Johnson indicates it may be possible to reduce the transmitter section weight to 1500 lbs. This is primarily due to power supply improvements.

Table 5.2-4. Transponder Subsystem Size-Weight Power-Traffic Model A

Assembly	Weight (lb)	Power (Watt)	Size (ft^3)
Antenna w/ Reflectors	250	—	300.0
Receiver Section	84	99	1.2
IF Switch (Trunking)	25	8	0.4
ST Router	353	195	9.2
Transmitter Section	1944	4902	24.7
Total	2656	5204	335.5

5.2.13 TRANSMITTER ASSEMBLY TRAFFIC MODEL A

Table 5.2-5 is a detailed breakdown of the transmitter section of the SS-FDMA satellite for Traffic Model A. The quantities required were derived from the transponder block diagrams. The TWT estimate are based on the Hughes 918 and the Watkins-Johnson 3712 TWT's. The high voltage power supply estimate was derived from existing power supplies presently available and a power supply efficiency of 82% was used. The amplifier and local oscillator estimates were obtained from existing published industry data. The remainder of the estimates are from actual hardware presently available. The contingency is included to account for cables, wiring, and mounting hardware, and to account for any uncertainties in the estimates.

Table 5.2-5. Transmitting Assembly—Traffic Model A

	Unit Size (in)^3	Unit Weight (lb)	Unit power (W)	Qty. Req'd.		Total Size (in)^3		Total Weight (lb)		Total Power (W)	
				ST	Trunk	ST	Trunk	ST	Trunk	ST	Trunk
RF Filter	0.4	0.04	—	80	42	32	16.8	3.2	1.7	—	—
IF to RF Mixer	0.5	0.05	—	40	21	20	10.5	2.0	1.1	—	—
TWT*				40	21	5760	3024	240	126	1633	1862
Power Supply*				40	21	16000	8400	880	462	365	425
LO	9.8	0.4	1.2	40	21	392	205.8	16.0	8.4	48	25.2
Amplifier	1.2	0.1	0.5	40	21	48	25.2	4.0	2.1	20	10.5
Diplexer	1.0	0.1	—	0	21	0	21.0	0	2.1	—	—
Directional Coupler	1.0	0.1	—	40	0	40	0	4.0	0	—	—
AGC Assembly	3.5	0.3	—	40	0	140	0	12.0	0	—	—
GaAs FET Driver	1.7	0.2	3.6	19	0	32.3	0	3.8	0	68.4	0
Subtotals						22464	11703	1165	603	2134.4	2322.7
Contingency						5616	2925	117	60	213	232
Total						28080	14628	1281	663	2347.4	2554.7
Overall Total						42708		1944		4902	

*Differences in size, weight, and power between the different TWT's and the different power supplies make unit values meaningless.

5.2.14 RECEIVER ASSEMBLY TRAFFIC MODEL A

Table 5.2-6 is a detailed breakdown of the receiver assembly of the SS-FDMA satellite for Traffic Model A. The quantities required were derived directly from the block diagrams of the satellite transponder preceding this section. The low noise amplifier/power converter and the local oscillator estimates were derived from existing published industry data. The remainder of the estimates were derived from actual hardware presently available. The power converters were assumed to have a 72% efficiency which is typical for equipment of this type. The contingency is included to account for cables and wiring, mounting hardware, and to account for uncertainities in all estimates.

Table 5.2-6. Receiving Assembly—Traffic Model A

	Unit Size (in)^3	Unit Weight (lb)	Unit Power (W)	Qty. Req'd.		Total Size (in)^3		Total Weight (lb)		Total Power (W)	
				ST	Trunk	ST	Trunk	ST	Trunk	ST	Trunk
RF Filter	0.4	0.04	—	80	0	32	0	3.2	0	—	—
IF Filter	2.8	0.14	—	58	37	162	104	8.0	5.3	—	—
RF to IF Mixer	0.5	0.04	—	40	0	20	0	1.6	0	—	—
IF to IF Mixer	1.2	0.07	—	0	13	0	15.6	0	0.91	—	—
First LO	9.8	0.4	1.2	40	0	392	0	16	0	48	0
Second LO	9.0	0.38	0.25	0	13	0	117	0	4.9	0	3.25
LNA	3.4	0.2	0.1	40	0	136	0	8.0	0	4.0	0
Amplifier	1.2	0.1	0.5	0	21	0	25.2	0	2.1	0	10.5
Diplexer	1.0	0.1	—	0	21	0	21	0	2.1	—	—
Power Converter	15.0	0.6	0.6	40	0	600	0	24	0	24	0
Subtotals						1342	283	60.8	15.3	76	13.75
Contingency						335	71	7.1	1.5	7.6	1.3
Total						1677	354	66.9	16.8	83.6	15.05
Overall Total						2031		83.7		98.7	

*Differences in size, weight, and power between the different TWT's and the different power supplies make unit values meaningless.

5.2.15 SATELLITE ST ROUTER ASSEMBLIES TRAFFIC MODEL A

Table 5.2-7 is a detailed breakdown of the major subassemblies within the router. Estimates for the size, weight, and power of each module were derived from similar existing hardware. The modules are machined from 6061 aluminum to minimize the weight of the router. The modules are then arranged to form several individual module stack assemblies. The first assembly, of which there are five, consists of eight IF assembly modules and five 8 × 8 input switch/decoder modules. The eight IF assembly modules are mounted vertically in a breadslice fashion and mounted to these are the five 8 × 8 input switch/decoder modules. Shear panels are attached to the top and sides to provide additional strength and rigidity and to improve the heat transfer characteristics.

The next assembly, of which there are 25, consists of eight amplifier/eight-way divider modules and eight SAW filter/eight-way combiner modules. The SAW filter/eight-way combiner module is the largest and heaviest module within the router and these 25 assemblies account for over one-half of the total size and weight of the router. The size and weight of each assembly coulde be reduced approximately 25% if four SAW filters were mounted onto a single substrate.

The next assembly, of which there are five, consists of eight five-way combiners and one 8 × 8 output switch/decoder. The eight five-way combiner modules are stacked horizontally and mounted to these is the 8 × 8 output switch. This output switch module is identical to the input switch module.

The last assembly, of which there are five, consists of eight downlink translator/amplifier modules stacked horizontally.

The previously described assemblies comprise the major portion of the ST router. Two additional units, the satellite control demodulator and the switch control are of similar design and consist of six modules each.

Table 5.2-7 Satellite ST Router Assemblies—Traffic Model A

Assembly	Technology	Unit Size LXWXH (in)	Unit WT (lb)	Unit PW (wt)	Qty Req'd	Total Weight (lb)	Total Power (W)
IF Input Assembly	Stripline	4.0 × 5.0 × 0.5	0.67	0.9	40	26.8	36
8 × 8 Input Switch/Decoder	Bipolar-mosaic	4.0 × 2.0 × 0.8	0.23	0.85	25	5.75	21.25
8 Way Divider/Amplifier	Bipolar	4.0 × 2.0 × 0.5	0.155	0.035	200	31.0	7.0
SAW Filter/8 Way Combiner	SAW/discrete	8.0 × 5.25 × 0.5	0.763	0.035	200	143.2	7.0
5 Way Combiner	Stripline	3.0 × 2.0 × 0.5	0.10	Passive	40	4.0	—
8 × 8 Output Switch/Decoder	Bipolar-Mosaic	4.0 × 2.0 × 0.8	0.23	0.85	5	1.5	4.25
Downlink Translator	Bipolar	4.0 × 3.5 × 0.5	0.54	0.97	40	21.6	38.8
Synthesizers/LO Distribution	Bipolar	5.0 × 2.5 × 0.5	0.198	0.27	14	5.6	22.4
Satellite Control Demodulator	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.89	2.0

Table 5.2-7 Satellite ST Router Assemblies—Traffic Model A (Cont)

Assembly	Technology	Unit Size LXWXH (in)	Unit WT (lb)	Unit PW (wt)	Qty Req'd	Total Weight (lb)	Total Power (W)
Switch Control	Bipolar	5.5 × 6.0 × 2.5	2.89	2.0	1	2.89	2.0
Power Converter	Bipolar	10.0 × 6.0 × 2.0	6.5	54.7	1	6.5	54.7
Cables	Coaxial				1250 ft	10.5	—
Structure	Aluminum					81.8	—
Total		59 × 54 × 5.0				353.1	195.4

5.2.16 TRAFFIC MODEL B TRANSPONDER BLOCK DIAGRAM

The satellite transponder block diagram associated with traffic Model B is depicted in Figure 5.2-9. The diagram identifies the same receiver configurations for dual trunk, single trunk and ST only beam decomposition as shown in the Traffic Model A diagram, paragraph 8.2. The diagram indicates that: each of three dual trunk beams is decomposed into two trunk channels and one ST channel; each of 15 single trunk beams is decomposed into one trunk channel and one ST channel; 53 three ST only beams are received downconverted and BPF to produce 53 channels into the ST Router. The total number of channels supported by the trunk IF switch is 21 while the number of channels supported by the ST Router is 71.

The transmitter configurations that structure the dual trunk, single trunk and ST beams for down link transmission are the same as for Traffic Model A except in the case of the configuration for the New York dual trunk beam.

To maintain the appropriate power density for the New York ST traffic at peak load periods two linear mode TWT's must be used. Contiguous diplexers are used to split the signal and recombine it as shown. Three dual trunk, 15 single trunk and 71 ST only beams are structured and transmitted.

5.2.17 NUMERICAL TABLES TRAFFIC MODEL B COMPONENT COUNT UPLINK SATELLITE RECEIVER

The component numbers were derived from:

- The uplink satellite receiver configuration, Table 5.2-8.
- The traffic model B transponder block diagram, Figure 5.2-9.
- Assumptions made concerning the use of trunk bands A, B and C in specific beams.
- The ST zone designations in paragraph 4.4 identifying the use of ST bands 1, 2 and 3 for specific beams.

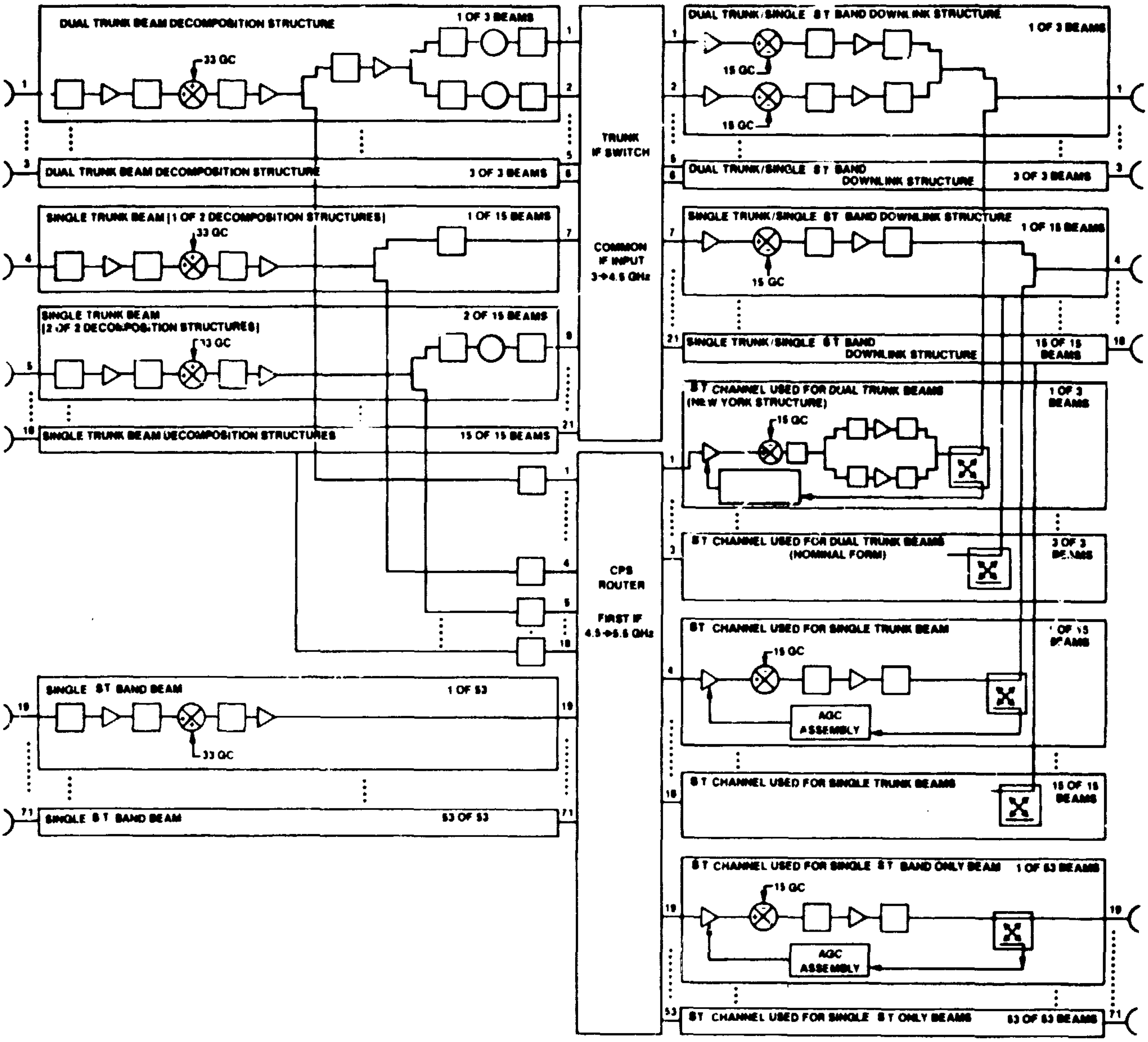


Figure 5.2-9. Traffic Model B Transponder Block Diagram

Table 5.2-8. Numerical Tables Traffic Model B Component Count Uplink Satellite Receiver

Items	Dual Trunk		Single Trunk		ST Only		Final Uplink Component Count		
	Per Beam	Total	Per Beam	Total	Per Beam	Total		ST	Trunk
RF BPF's	2	6	2	30	2	106	RF BPS's	142	0
IF BPF's	6	18	3 or 4(1)	55	1	53	IF BPF's	99	37
RF/IF Mixers	1	3	1	15	1	53	RF/IF Mixers	71	0
IF/IF Mixers	1	3	0 or 1(1)	15	0	0	IF/IF Mixers	0	13
LNAS'	1	3	1	10	0	53	LNAS'	71	0
Amplifiers	2	6	1	15	0	0	Amplifiers	0	21
Diplexers	2	6	1	15	0	0	Diplexers	0	21

(1)Common IF inputs to the trunk IF switch are achieved by frequency translation of trunk bands B and C down to trunk band A. Required hardware is noted.

5.2.18 NUMERICAL TABLES TRAFFIC MODEL B COMPONENT COUNT DOWNLINK SATELLITE TRANSMITTER

The component numbers were derived from:

- The downlink satellite transmitter configuration, Table 5.2-9.
- The traffic model B transponder block diagram, Figure 5.2-9
- Assumptions made concerning the use of trunk bands A, B and C in specific beams.
- The ST zone designations in paragraph 4.4 identifying the use of ST bands 1, 2 and 3 for specific beams

Table 5.2-9. Numerical Tables Traffic Model B Component Count Downlink Satellite Transmitter

Items	Dual Trunk		Single Trunk		ST Only		Final Downlink Component Count		
	Per Beam	Total	Per Beam	Total	Per Beam	Total		ST	Trunk
RF BPF's	6 or 9(2)	21	4	60	22	106	RF BPF's	145	42
IF/RF Mixers	3	9	2	30	11	53	IF/RF Mixers	71	21
TWTS'	3 or 4(2)	10	2	30	1	53	TWTS'	72	21
Amplifiers	2	9	2	30	1	53	Amplifiers	71	21
Diplexers	2 or 4(2)	8	1	15	0	0	Diplexers	2	21
Directional Coupler	1	3	1	15	1	53	Directional Coupler	71	0
GaAs Drivers	1	3	1	3	1	4	GaAs Drivers	10	0

(2)Two TWTS' are required for the New York downlink. The increased hardware for this dual trunk case is noted.

5.2.19 NUMERICAL TABLES TRAFFIC MODEL B COMPONENT COUNT AGC ASSEMBLY

The component numbers were derived from:

- The downlink transmitter configuration diagram, Table 5.2-9.
- The traffic model B transponder block diagram, Figure 5.2-9.

Table 5.2-10 is a numerical table for Traffic Model B Component count on AGC assembly.

Table 5.2-10. Numerical Table Traffic Model B Component Count AGC Assembly

Items	ST Channels Only	
	Per Beam	Total
IF BPS'S	2	142
RF/IF Mixers	1	71
IF/IF Mixers	1	71

5.2.20 TRAFFIC MODEL B SUMMARY

Table 5.2-11 is a summary of each of the five SS-FDMA satellite transponder subsystems. The antenna subsystem is the single largest subsystem within the satellite, due primarily to the large reflectors and supporting structure. The antenna estimates are based on data published by Ford Aerospace and General Electric.

The IF trunking switch is the smallest subsystem in terms of size, weight, and power. The estimate is taken from existing published industry data.

The transmitter subsystem is the heaviest and the largest power consumer of all the subsystems. The weight and the power are a result of the many TWT's and the high voltage power supplies needed to drive the TWT's. This high power dissipation will necessitate extensive external cooling to keep the operating temperature within reasonable limits. Information obtained verbally from Watkins-Johnson indicates it may be possible to reduce the weight of the transmitter section to 2000 lbs. This is primarily due to power supply improvements.

Table 5.2-11. Transponder Subsystem Size-Weight Power—
Traffic Model B

Assembly	Weight (lb)	Power (Watt)	Size (ft³)
Antenna w/ Reflectors	350	—	301
Receiver Section	133	164	2
IF Switch (Trunking)	25	8.0	0.4
ST Router	498	244	12.6
Transmitter Section	2966	5528	37.7
Total	3972	5944	353.7

5.2.21 TRANSMITTING ASSEMBLY TRAFFIC MODEL B

Table 5.2-12 is a detailed breakdown of the transmitter section of the SS-FDMA satellite for Traffic Model B. The components listed here are identical to those listed for Traffic Model A. The only difference between the two transmitter subsystems is in the number of required components, Traffic Model B being the larger of the two.

Table 5.2-12. Transmitting Assembly—Traffic Model B

	Unit Size (in^3)	Unit Weight (lb)	Unit Power (W)	Qty. Req'd.		Total Size (in^3)		Total Weight (lb)		Total Power (W)	
				ST	Trunk	ST	Trunk	ST	Trunk	ST	Trunk
RF Filter	0.4	0.04	—	145	42	58	16.8	5.8	1.7	—	—
IF to RF Mixer	0.5	0.05	—	71	21	35.5	10.5	3.6	1.0	—	—
LO	9.8	0.4	1.2	71	21	696	206	28.4	8.4	85.2	25.2
TWT*				72	21	10368	3024	432	126	2070	1864
Power Supply*				72	21	28800	8400	1584	462	473	425
Amplifier	1.2	0.1	0.5	71	21	85.2	25.2	7.1	2.1	35.5	10.5
Diplexer	1.0	0.1	—	2	36	2	36	0.2	3.6	—	—
Directional Coupler	1.0	0.1	—	71	0	71	0	7.1	0	—	—
AGC Assembly	3.5	0.3	—	71	0	248.5	0	21.3	0	—	—
GaAs FET Driver	1.7	0.2	3.6	10	0	17	0	2.0	0	36	0
Subtotals						40381	11719	2092	605	2700	2325
Contingency						10095	2930	209	60	270	233
Total						50	14649	2301	665	2970	1558
Overall Total						65125		2966		5528	

*Differences in size, weight, and power between the different TWT's and the different power supplies make unit values meaningless.

5.2.22 RECEIVER ASSEMBLY TRAFFIC MODEL B

Table 5.2-13 is a detailed breakdown of the receiver section of the SS-FDMA satellite for Traffic Model B. The components listed here are identical to those listed for Traffic Model A. The only difference between the two receiving subsystems is in the number of required components, Traffic Model B being the larger of the two.

Table 5.2-13. Transmitting Assembly—Traffic Model B

	Unit Size (in^3)	Unit Weight (lb)	Unit Power (W)	Qty. Req'd.		Total Size (in^3)		Total Weight (lb)		Total Power (W)	
				ST	Trunk	ST	Trunk	ST	Trunk	ST	Trunk
RF Filter	0.4	0.04	—	142	0	56.8	0	5.7	0	—	—
IF Filter	2.8	0.14	—	99	27	277.2	75.6	13.9	3.8	—	—
RF to IF Mixer	0.5	0.04	—	71	0	35.5	0	2.8	0	—	—
IF to IF Mixer	1.2	0.07	—	0	13	0	15.6	0	0.91	—	—
First LO	9.8	0.40	1.2	71	0	696	0	28.4	0	85.2	0
Second LO	9.0	0.38	0.25	0	13	0	117	0	4.9	0	3.25
LNA	3.4	0.2	0.1	71	0	241.2	0	14.2	0	7.1	0
Amplifier	1.2	0.1	0.5	0	21	0	25.2	0	2.1	0	10.5
Diplexer	1.0	0.1	—	0	21	0	21	0	2.1	—	—
Power Converter	15	0.6	0.6	71	0	1065	0	42.6	0	42.6	0
Subtotals						2372	254	107.6	13.8	134.9	13.75
Contingency						593	64	10.7	1.4	13.5	1.4
Total						2965	318	118.3	15.2	148.4	15.15
Overall Total						3283		133.5		163.6	
*Differences in size, weight, and power between the different TWT's and the different power supplies make unit values meaningless.											

5.2.23 SATELLITE ST ROUTER ASSEMBLIES TRAFFIC MODEL B

Table 5.2-14 is a detailed breakdown of the major subassemblies within the router. Estimates for size, weight, and power of each module were derived from similar hardware. The modules are machined from 6061 aluminum to minimize the weight of the router. The modules are then arranged to form several individual module stack assemblies. The first assembly, of which there are six, consists of eight IF assembly modules and six 8 × 8 input switch/decoder modules. The eight IF assembly modules are mounted vertically in a breadslice fashion and mounted to these are the six 8 × 8 input switch/decoder modules. Shear panels are attached to the top and sides to provide additional strength and rigidity and to improve the heat transfer characteristics.

The next assembly, of which there are 36, consists of eight amplifier/eight-way divider modules and eight SAW filter/eight-way combiner modules. The SAW filter/eight-way combiner modules are stacked horizontally and mounted to these are the amplifier/eight-way modules. The SAW filter/eight-way combiner module is the largest and heaviest module within the router and these 36 assemblies account for over one-half of the total size and weight of the router. The size and weight of each assembly could be reduced approximately 25% if four SAW filters were mounted onto a single substrate.

The next assembly, of which there are six, consists of eight six-way combiners and one 8 × 8 output switch/decoder. The eight six-way combiner modules are stacked horizontally and mounted to these is the 8 × 8 output switch. This output switch module is identical to the input switch module. The last assembly, of which there are six, consists of eight downlink translator/amplifier modules stacked horizontally.

The previously described assemblies comprise the major portion of the ST router. Two additional units, the satellite control demodulator and the switch control, are of similar design and consist of six modules each.

Table 5.2-14. Satellite ST Router Assemblies—Traffic Model B

Assembly	Technology	Unit Size L×W×H (IN)	Unit WT (LB)	Unit PW (WT)	Qty Req'd	Total Weight	Total Power
IF Input Assembly	Stripline	4.0×5.0×0.5	0.67	0.9	48	32.2	43.2
8 × 8 Input Switch/Decoder	Bipolar-mosaic	4.0×2.0×0.8	0.23	0.85	36	8.3	30.6
8 Way Divider/Amplifier	Bipolar	4.0×2.0×0.5	0.55	0.35	288	44.6	10.1
SAW Filter/8 Way Combiner	SAW/discrete	8.0×5.25×0.5	0.763	0.35	288	219.7	10.1
6 Way Combiner	Stripline	3.0×2.0×0.5	0.10	Passive	48	4.8	—
8 × 8 Output Switch/Decoder	Bipolar-mosaic	4.0×2.0×0.8	0.23	0.85	6	1.38	5.1
Downlink Translator	Bipolar	4.0×3.5×0.5	0.54	0.97	48	25.9	46.6
Synthesizers/LO Distribution	Bipolar	5.0×2.5×0.5	0.40	1.87	14	5.6	26.18
Satellite Control Demodulator	Bipolar	5.5×6.0×2.5	2.89	2.0	1	2.89	2.0
Switch Control	Bipolar	5.5×6.0×2.5	2.89	2.0	1	2.89	2.0
Power Converter	Bipolar	12.0×6.0×2.0	8.0	68.4	1	8.0	68.4
Cables	Coaxial				1920 ft	14.1	—
Structure	Aluminum					127.4	—
Total		65×62.5×5.0				497.7	244.3

5.2.24 TRANSPONDER SUBSYSTEM SIZE, WEIGHT, AND POWER SENSITIVITIES

The transmitter assembly dominates the weight and power requirements of the transponder subsystem for both Traffic Models A and B. The antenna assembly dominates the size of both the transponder subsystems.

Reliability and availability requirements will also impact the transponder system size and weight as each will require redundancy which will increase the size, weight, and power requirements. All estimates presented do not include redundancy and are considered baseline values.

Ground station (G/T) will have a significant effect on the transmitter assembly power requirements which will be reflected in the entire satellite power requirements.

5.3 Proof of Concept Router Definition

The POC router brassboard includes the POC sector brassboard, C-band upconverters, C-band downconverters, and C-band synthesizers. The POC router brassboard is an extension of the POC sector brassboard to the C-band input and output frequency range.

The following subparagraphs identify and describe the POC router brassboard building blocks with a description of the necessary special test equipment (STE) for evaluation of the POC.

5.3.1 POC ROUTER BRASSBOARD FUNCTIONAL REQUIREMENTS

The development of an LSI 8 × 8 analog switch is essential to the success of an FDMA system.

New technologies of SAW filter construction must be addressed. New SAW filter technologies include:

Multiple SAW filters per substrate

Unidirectional SAW filter construction

The discrete development of a synthesizer is essential to provide the necessary frequency translations to implement the frequency plan.

The POC router brassboard includes the POC sector brassboard and will provide demonstration of the frequency plan at C-band.

Testing and evaluation of the POC brassboard will provide accurate impairments to be used in BER calculations.

5.3.2 POC ROUTER BRASSBOARD PERFORMANCE REQUIREMENTS

The POC sector brassboard is intended to duplicate (within economic reason) the electrical performance of an FDMA router as defined in Section 5, Task I, Communication System Design Final Report, June 25, 1982.

The sector capacity of 140 MHz represents a portion (approximately 50 percent) of the larger traffic beams existing in Traffic Models A and B. The 140 MHz capacity will be achieved with one-half of a normal sector's filter complement (32 vs 64).

Since the filter complement is reduced, switching arrangements will be limited at the sector level. The electrical performance of the POC will be modeled as nearly to the end-item flight router as practical. The number of inputs, outputs, and associated frequency ranges will be compatible with the switch capabilities.

5.3.3 POC ROUTER BLOCK DIAGRAM

The POC router will be subdivided into five assemblies (see Figure 5.3-1). Each assembly will be divided into modules. Present requirements for modules are:

Assembly Name	Modules
Downconverter	3
Sector Assembly	18
Beam Amplifier	1
Upconverter	2
Synthesizer	2
Total	26

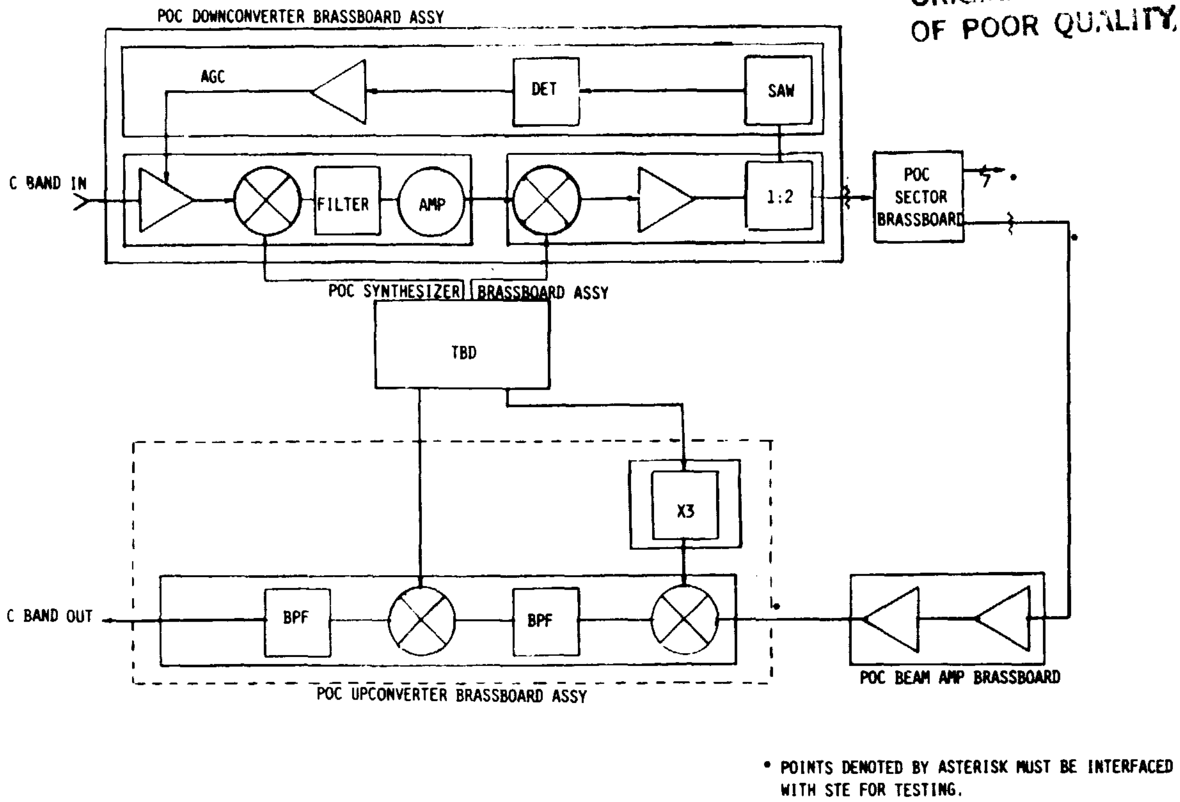


Figure 5.3-1. POC Router Block Diagram

The attenuators located at assembly interfaces are required to simulate the actual gain distribution. The asterisks indicate interconnection points where special test equipments are placed to facilitate monitoring and testing.

5.3.4 POC ROUTER GAIN DISTRIBUTION

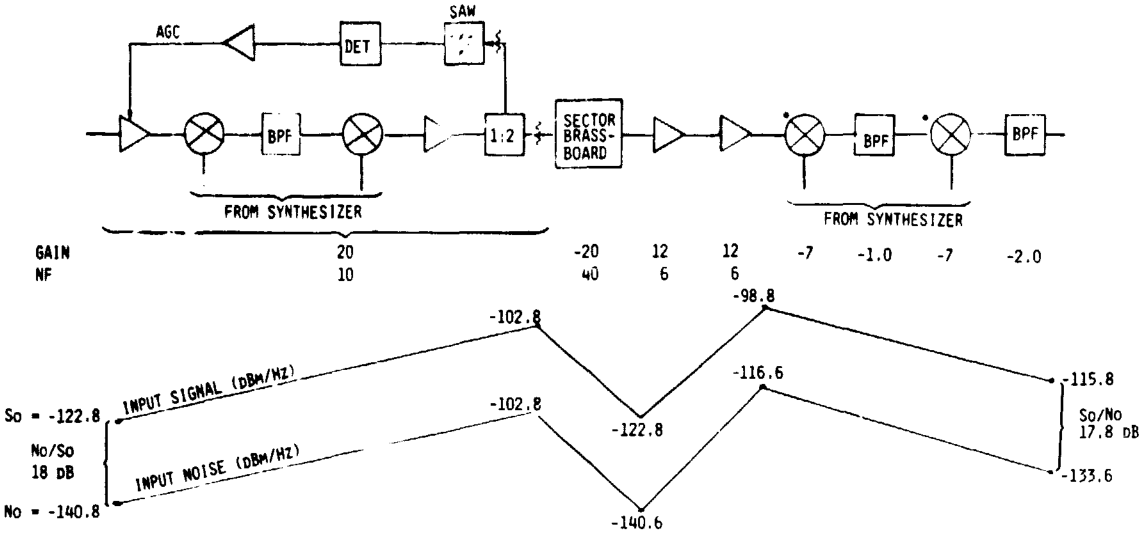
The gain distribution, Figure 5.3-2, is based on an input signal power density (−150 dBm/Hz) that is compatible with the link budget calcultions reported in the Task I Final Report. The LNA and associated circuitry preceding the router input are assumed to provide a net gain of 27.2 dB with a noise figure of 6 dB. As a result, the router's input signal power density is −122.8 dBm/Hz and the router's input noise density is −140.8 dBm/Hz.

The router exhibits a net gain of 7 dB and a noise figure of 20.6 dB.

Intermodulation performance is dominated by the sector brassboard capacity. The input frequency translation circuitry (the first two mixers) will not contribute to the intermodulation circuitry. The output frequency translation circuitry (last two mixers) must exhibit a high third order intercept point to prevent BER degradation due to intermodulation products.

5.3.5 ROUTER SWITCH AND SAW FILTER TECHNOLOGY

The switch and SAW filter technology for the router is identical to the technology requirements of the sector.



* THIRD ORDER INTERCEPT POINT MUST BE GREATER THAN 3 DBM.

Figure 5.3-2. POC Router Gain Distribution

5.3.6 FREQUENCY SYNTHESIZERS

The frequency plan to be incorporated in the router design conserves bandwidth on the downlink requiring the outputs of the switching and filtering elements be translated in frequency by a precisely predetermined offset to a different frequency band. Similarly, the uplink IF signals need translation to the frequencies at which the required switching and filtering can be accomplished. The translating frequencies are to be coherently related to the uplink network control carrier frequency.

The wide bandwidth of the composite signal spectrum and the relatively low frequency of realizable filters and switches requires multiple translating to avoid high intermodulation product levels. Both the receiver downconverters and the transmitter upconverters have been modeled as double conversion designs.

5.3.7 ELECTRICAL CONFIGURATION RATIONALE

In Table 5.3-1 the router will inherently include the new technologies associated with the sector assembly. In addition, synthesizer technology will be addressed.

The frequency plan will be extended to include the C-band range.

Both sector and router impairments on system BER will be demonstrated.

Table 5.3-1. Electrical Configuration Rationale

Flight Router		POC Router	
Configuration	Rationale	Configuration	Rationale
Downconverter Assembly/Beam (40 required)	Required to provide frequency translation from C-band input to sector's UHF input.	One downconverter assembly	POC router accepts only one beam input.
Sector Assembly (25 required)	Provide switchable frequency paths.	One partial sector assembly	POC router will demonstrate LSI switch and SAW technology.
Upconverter Assembly (40 required)	Provide frequency translation from UHF to C-band output.	One upconverter assembly	POC router provides only one beam output.
Synthesizer Assembly (4 required)	Provide fixed frequencies for uplink and downlink translations.	One synthesizer assembly	POC router accepts and outputs only one beam.

5.3.8 BREADBOARD ACTIVITY

The switch design (essentially a redesign) will have a limited breadboarding activity to determine design/analysis integrity on a functional basis.

The SAW filter will be designed and breadboarded by the Integrated Circuits Facility (actually, the breadboard activity is synonomous with a prototype prior to production quantity build).

The synthesizer will be breadboarded in its entirety (100%) for design confidence testing.

The UHF amplifier will be breadboarded as a single stage to determine wideband-frequency response.

The frequency converters require precise layouts to determine the effects of parasitic capacitance on gain versus frequency response.

5.3.9 POC ROUTER THREE DIMENSIONAL MECHANICAL DESIGN

The mechanical design is of prime importance in the overall development of the SS-FDMA ST router. The overriding concern is the staggering number of RF coaxial cables needed—nearly 2600 for Traffic Model A design and over 3600 for the Traffic Model B design. Considering there are four connectors associated with each cable (two on the cable and two that attach to the cable), Traffic Model B design would require more than 14,000 threaded connectors for the RF interconnect system. The result is a system which requires considerable space for cable bends and routing and for connector protrusions. Assembly and rework would be a very difficult and time consuming process.

The most promising method for reducing the number of interconnecting cables is the development of the "three dimensional" packaging concept. The three-dimensional concept is one where modules are physically attached to each other to form one integral unit as opposed to the more traditional method of individually mounting each module to a common baseplate. If the three-dimensional concept were implemented for each sector of the router, where a sector consists of an 8 × 8 input switch, eight 1:8 power dividers, sixty-four SAW filters, eight 8:1 power combiners, and an 8 × 8 output switch, over 2600 cables would be eliminated. This would also result in a substantial reduction in the overall size of the router as space required for the cable bends, the cable itself, and connectors is reduced.

5.3.10 ADVANTAGES OF THREE DIMENSIONAL DESIGN

The greatest advantage of the development of the three-dimensional packaging concept is in the reduction of the required number of coaxial cables. This packaging scheme will eliminate over 2000 coaxial cables and 4000 threaded RF connectors from the Traffic Model A router design and nearly 200 coaxial cables and 5800 threaded RF connectors from the Traffic Model B router design. Instead, an RF interconnect will be developed which will allow each module to plug directly into another module. This will result in a design which is much simpler to assemble or disassemble. Also, because the connector and cable are eliminated, a more compact sector design is achieved which, when multiplied times the number of sectors in the router design, results in a substantial reduction in the overall size.

5.3.11 THREE DIMENSIONAL POC MECHANICAL MODEL

The most challenging part of the three-dimensional package design will be to obtain proper alignment of the RF interconnect pins from one module into the others during assembly. This is critical to both the electrical performance and the structural integrity of the RF interconnect.

The three-dimensional concept requires very tight tolerances be held during fabrication of all modules of the sector. One way to lessen the tolerance requirement is to use a floating interconnect design which will allow the interconnect both lateral and axial displacement.

Another important consideration in the sector design is to keep the resonant frequency of the overall unit high to keep relative motions within the sector very low during dynamic testing.

Finite element computer analysis will be done during the design phase to ensure these requirements are met. Using finite element analysis allows a sector model to be built on the computer and study the effects of changing different parameters, i.e., wall thickness, floor thickness, ribs, etc.

Once a satisfactory design has been completed, a dynamic test model (DTM) of one sector will be built. A dynamic test model is a mockup which is an exact mechanical replica in terms of form, size, and weight of the end product but is electrically nonfunctioning.

The DTM will be used to determine the practical problems encountered during fabrication and assembly of the sector. Once assembled, the DTM will be subjected to typical qualification level environmental tests to verify the structural integrity of the unit. In addition, some of the RF interconnections will be "wired" so that input to output insertion loss and VSWR can be measured before and after the environmental tests to verify the RF interfacing integrity.

5.3.12 POC ROUTER BRASSBOARD MECHANICAL DEFINITION

The router POC model is comprised of five complete assemblies which contain 23 individual modules. The modules will be laid flat to provide easy access for adjustments, testing, or rework. Each module will be fabricated from aluminum and module covers will be provided to eliminate RF leakage. SMA connectors will be used for all RF connections and multipin connectors will be used for the DC connections. Additional connectors will be provided for test points. Flexible coaxial cables will be used for all RF interconnections between modules. No environmental testing is planned for the POC model.

5.3.13 POC ROUTER LAYOUT

Shown in Figure 5.3-3 is the preliminary layout of the router POC model brassboard. The router is laid out on a single aluminum baseplate. One cable runs from the downconverter module into the 8 × 8 input switch. Eight cables run from the switch to the 1:4 divider/SAW filter bank. Thirty-two cables run from there into the 4:1 combiners. Eight cables run from the combiner to the 8 × 8 output switch. One cable runs from the output switch to the beam amplifier and one from the beam amplifier to the upconverter. Semirigid cables will run from the synthesizer to the downconverter and to the upconverter.

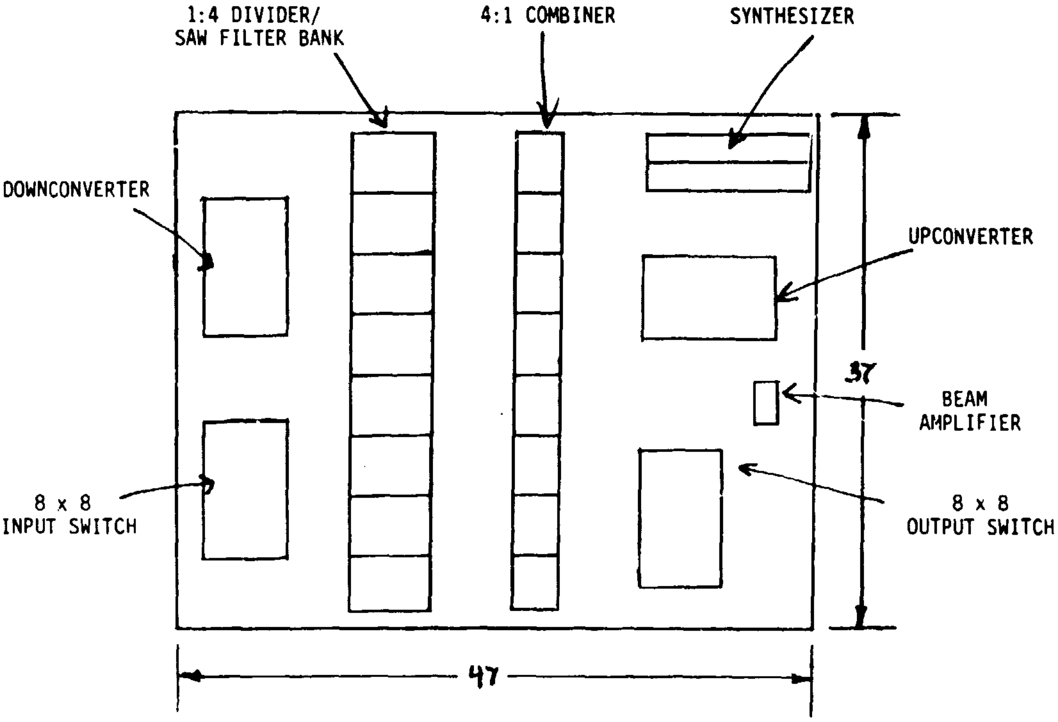


Figure 5.3-3. POC Router Layout

5.3.14 PART OF THE ROUTER POC/STE TOP LEVEL BLOCK DIAGRAM

In Figures 5.3-4 and 5.3-5 the router POC/STE configuration is comprised of sector POC/STE configuration modified to include uplink and downlink noise source control. The modification includes adding several relay output cards (HP 69330) to the HP6940B Multiprogrammer.

In Figure 5.3-5 the remaining portion of the router POC/STE configuration includes equipment necessary to simulate uplink and downlink C-band signals. The basic mode is semiautomated. The HP 9825 Calculator controls the commercial test equipment used as stimulus and measurement devices. A summary of Motorola special test equipment is as follows.

- Input network monitor and control uplink simulator
- Output network monitor and control downlink simulator
- Row switch interface
- Column switch interface
- Uplink noise source
- Downlink noise source

All the STE is commanded by the HP 9825 Calculator via a HP 6940B Multiprogrammer. The multiprogrammer provides switch closures to control:

- Coaxial relays
- Switch arrangement

Software measurement tests include (but are not limited to):

- Additive phase noise measurements
- Gain measurements
- Signal noise ratio measurements
- Intermodulation distortion measurements

5.3.15 COMMERCIAL TEST EQUIPMENT

As configured in Table 5-3.2, four methods of testing the router POC are possible:

Input		Output	
Router (C-band)	Sector (UHF)	Router (C-Band)	Sector (UHF)
X		X	
	X	X	
X			X
	X		X

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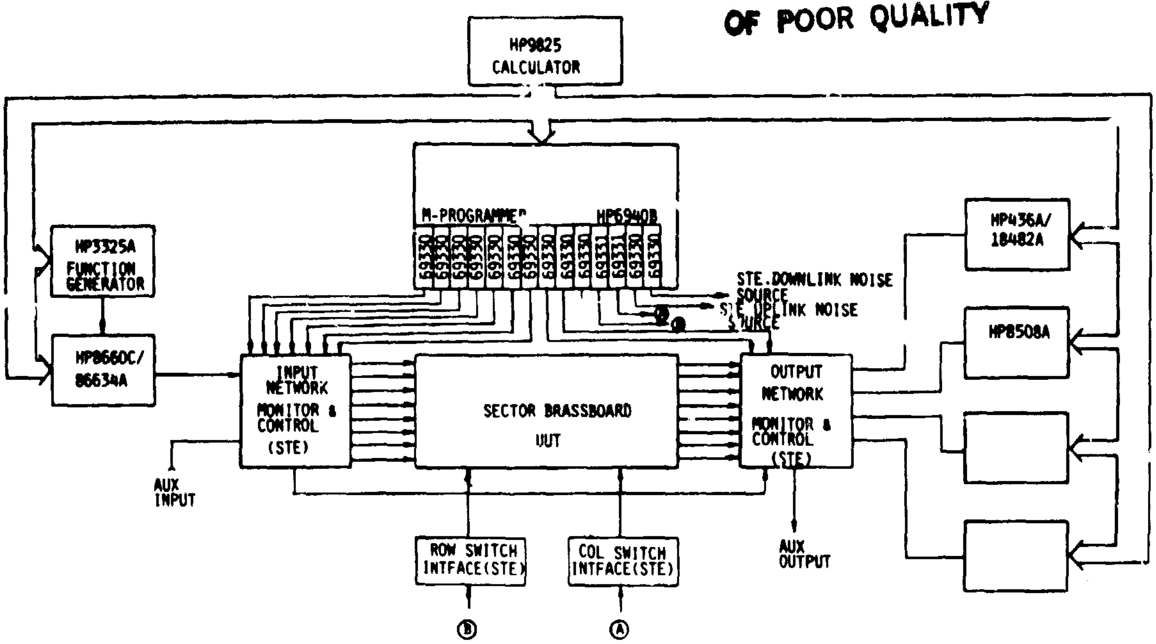

Figure 5.3-4. Part of the Router POC/STE Top Level Block Diagram

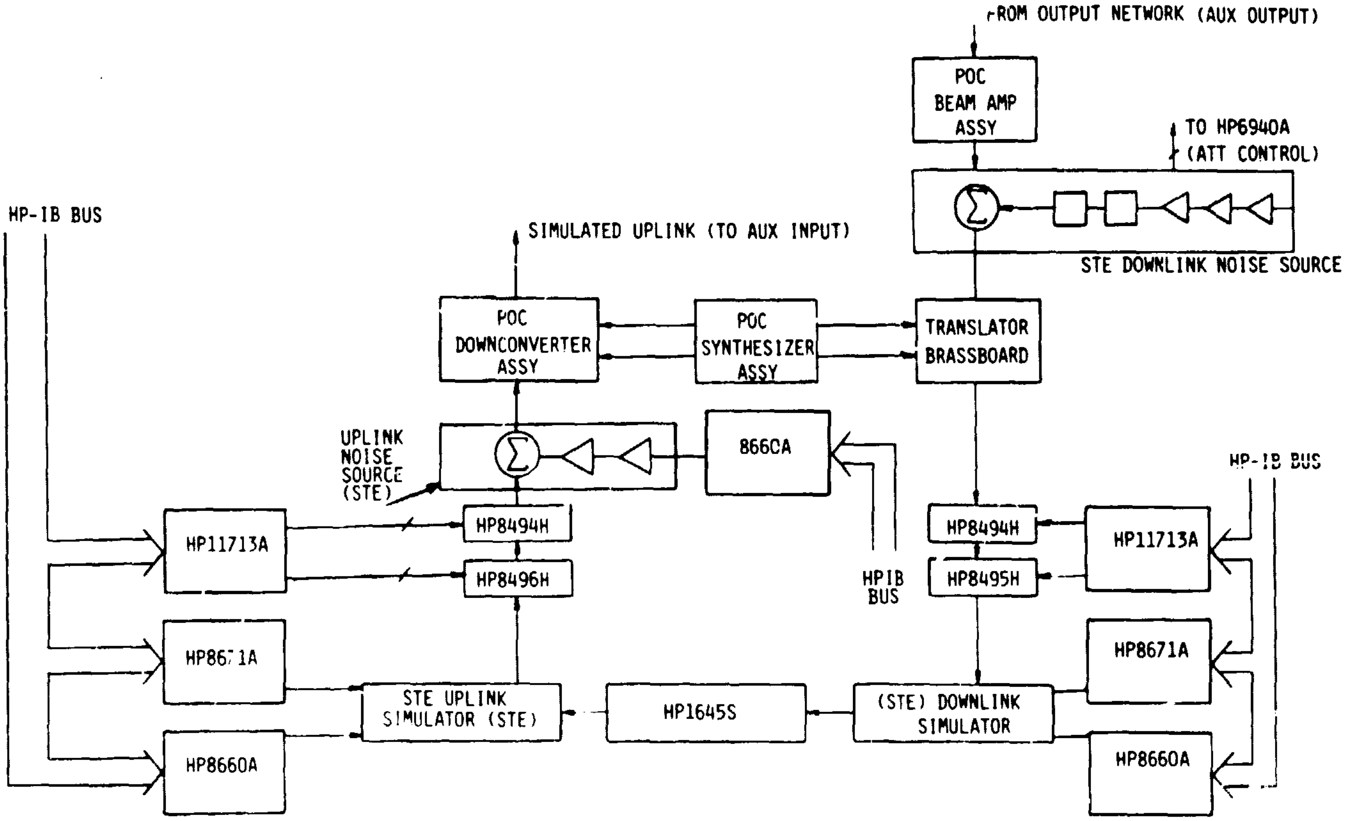

Figure 5.3-5. Part of the Router POC/STE Top Level Block Diagram

5.3.15.1 System Demonstration (BER Testing)

Stimulus at the router's input is provided by an HP 1645S Data Error Analyzer. STE uplink simulator provides QPSK modulation. The modulated signal is upconverted twice by stable synthesizer signals supplied by an HP 8660A and an HP 9617A. The modulated C-band signal's power level may be varied by the variable attenuators, HP 949H and HP 8495H, operating from bus commands via HP 11713A Switch Driver. Downconversion and demodulation is performed on the downlink side of the router. Bit error analysis is performed by the HP 1645S Data Error Analyzer.

5.3.15.2 Path Performance Testing

Uplink C-band stimulus is generated by the HP 8671A. Path performance measurements are made using the HP 8566A Spectrum Analyzer.

Table 5.3-2. Commercial Test Equipment

Qty.	Equipment	Description
1	HP 9825	Calculator
1	HP 6940B	Multiprogrammer
1	HP 14550C	Interface Kit
1	HP3325A; OPT 1001	Function Generator
1	HP 8660C; OPT 001, 004, 005, 100	Synthesizer
1	HP 86634A	Phase Modulator
1	HP 86602B; OPT 002	RF Section
1	HP 436A; OPT 022	Power Meter
1	HP 8484A	Sensor
1	HP 8568A	Spectrum Analyzer
2	HP 69331A	Digital Output Card
12	HP 69330A	Relay Output Card
2	HP 11713A	Switch Driver
2	HP 8494H; OPT 022	Attenuator
2	HP 8495H; OPT 002	Attenuator
2	HP 8671A	Synthesizer
3	HP 8660A; OPT 001, 004, 005, 100	Synthesizer
1	HP 1645S	Data Error Analyzer
3	HP 86603; OPT 003	RF Section
1	HP 8566A	Spectrum Analyzer

5.3.16 MOTOROLA SPECIAL TEST EQUIPMENT INPUT NETWORK MONITOR AND CONTROL

In Figure 5.3-6 low level digital test commands from the calculator (via the multiprogrammer) are interfaced through the digital interface where they are buffered to 28-Volt relay excitation voltages.

The input switch configuration provides for one of two input signals to be distributed to one of eight possible POC inputs. The remaining seven inputs may be independently set to various noise levels. Eight noise sources are provided to accomplish this. The eight outputs are sampled through directional couplers. Each sampled output may be monitored to determine POC input level.

5.3.17 MOTOROLA SPECIAL TEST EQUIPMENT OUTPUT NETWORK MONITOR AND CONTROL

In Figure 5.3-7 low level test commands from the calculator (via the multiprogrammer) are interfaced through the digital interface where they are buffered to 28-Volt relay excitation voltages.

The input switch configuration provides for selecting one of eight possible inputs. The selected input may be routed to two possible output paths (aux output or commercial test equipment). As configured, the commercial test equipment may be used to measure the sector's output signals or the sector's input signals.

5.3.18 MOTOROLA SPECIAL TEST EQUIPMENT ROW/COLUMN SWITCH INTERFACE

The switch bus structure is not explicity detailed. The complexity of the STE switch interface may range from simple to moderate. As presently envisioned, 12 data lines will be required for proper switch operation. The switch bus structure will be determined primarily by the LSI design of the switch and its complexity.

5.3.19 MOTOROLA SPECIAL TEST EQUIPMENT NOISE SOURCES

5.3.19.1 Uplink Noise Source

In Figure 5.3-8 the uplink noise source is used to simulate the noise figure of the 30 GHz satellite low noise amplifier that precedes the router's downconverter assembly. It is capable of generating −140 dBm/Hz thermal noise. This value of noise is compatible with the input noise demonstrated in the gain distribution diagram.

5.3.19.2 Downlink Noise Source

The downlink noise source is used to simulate the noise figure of the 20 GHz satellite low noise amplifier. It is capable of generating −115 dBm/Hz thermal noise. A variable attenuator is included to set the noise level. A 3P bandpass filter shapes the frequency response of the wideband amplifiers used to generate the noise.

5.3.20 MOTOROLA SPECIAL TEST EQUIPMENT UPLINK AND DOWNLINK SIMULATOR

5.3.20.1 STE Uplink Simulator (Refer to Figure 5.3-9)

A commercial QPSK Mod, e.g., Comtech QTV, is used to develop a QPSK signal at a nominal IF carrier frequency. Dual upconversion translation using calculator controlled commercial test equipment provides the C-band signal. The data is provided by the HP 1645S Error Analyzer. The maximum data rate is limited to 5 MHz.

5.3.20.2 STE Downlink Simulator (Refer to Figure 5.3-9)

The STE downlink simulator performs a reciprocating function of the STE uplink simulator. The received C-band downlink signal is translated twice to a nominal IF frequency where the commercial QPSK demod, e.g., Comtech QRV, is used to recover baseband data. The data is then forwarded to the HP 1645S Error Analyzer for bit error rate calculations.

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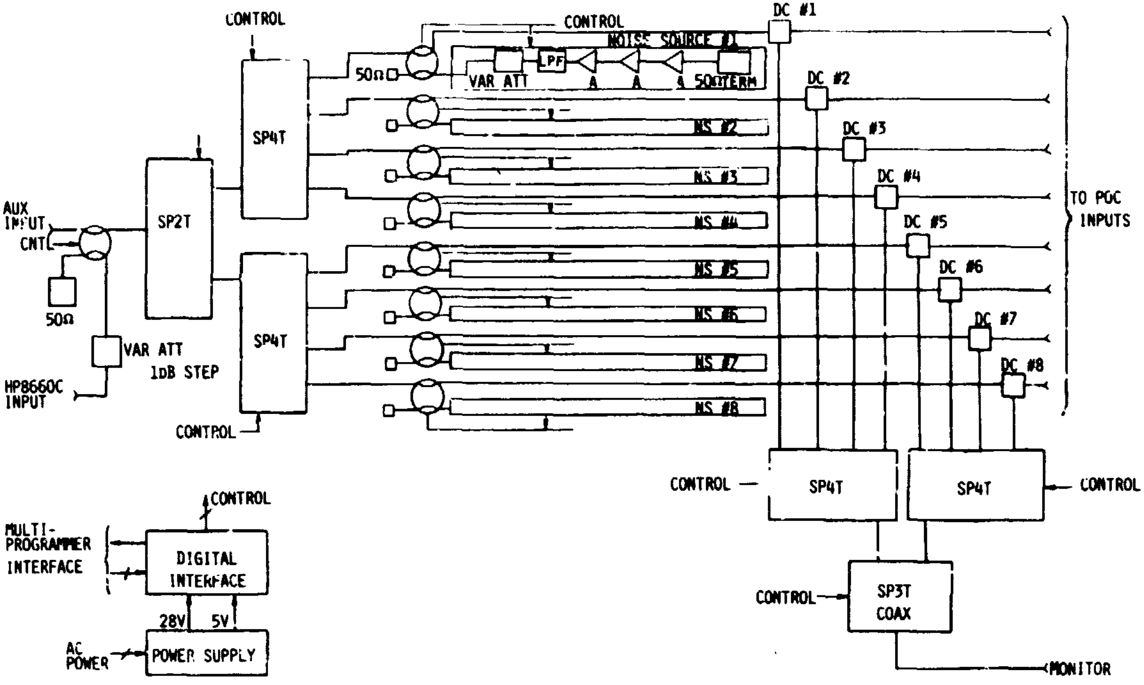

Figure 5.3-6. Motorola STE Input Network Monitor and Control

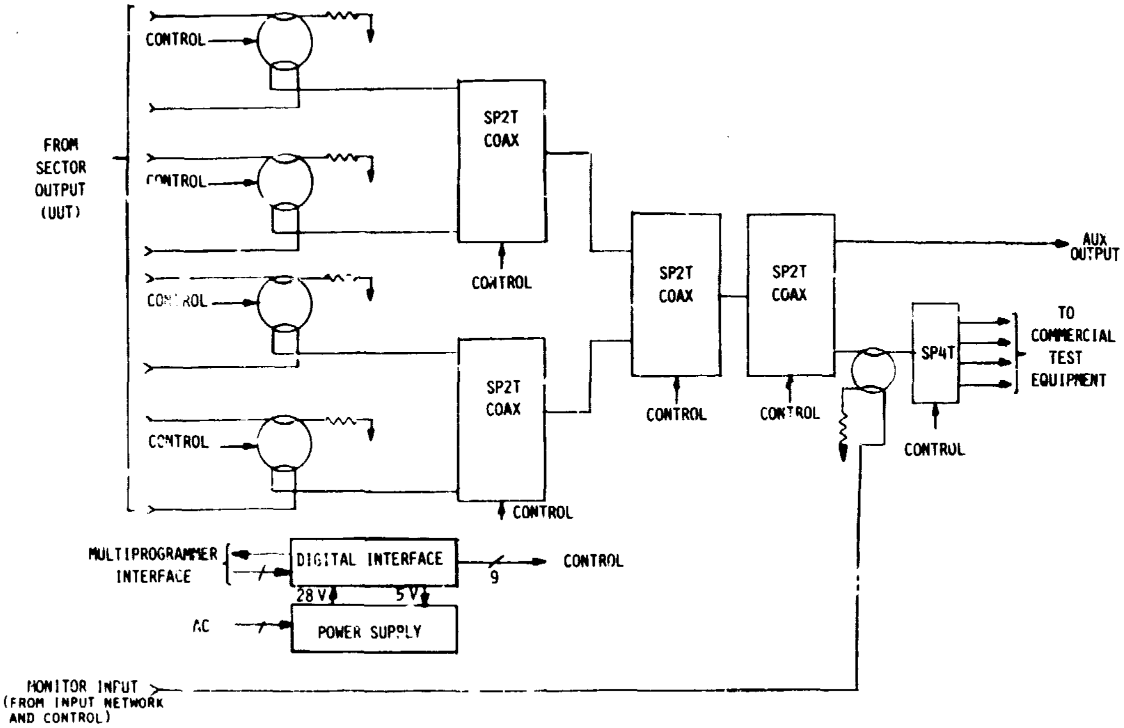

Figure 5.3-7. Motorola STE Output Network Monitor and Control

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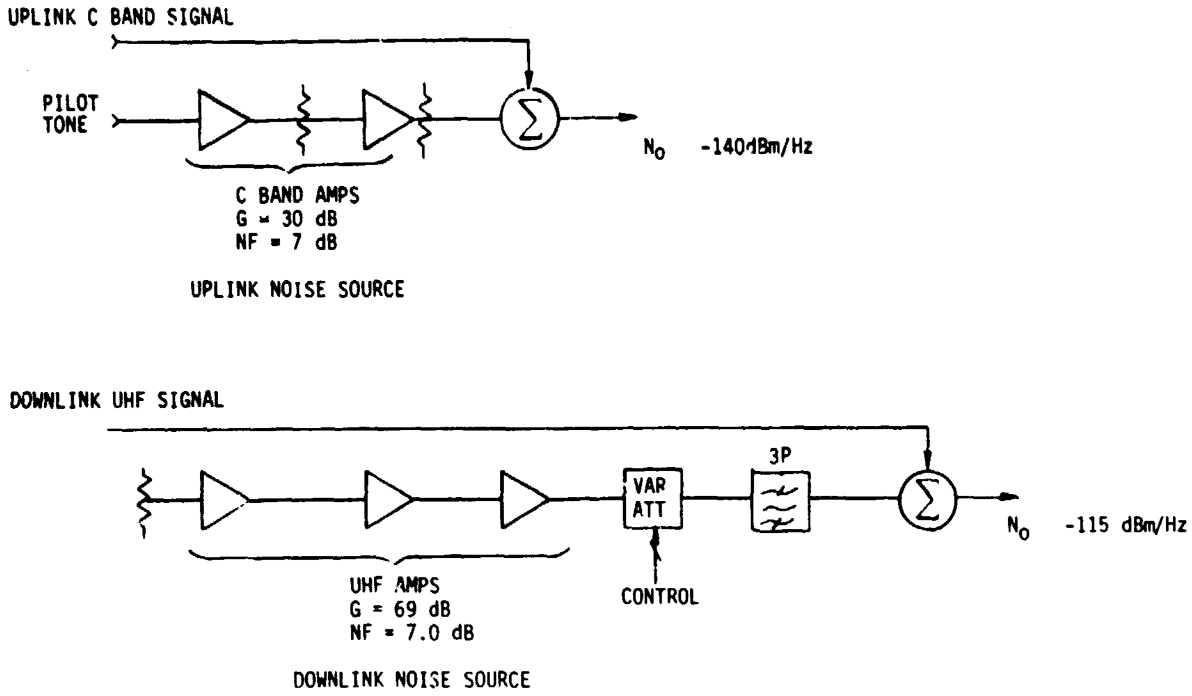

Figure 5.3-8. Motorola STE Noise Sources

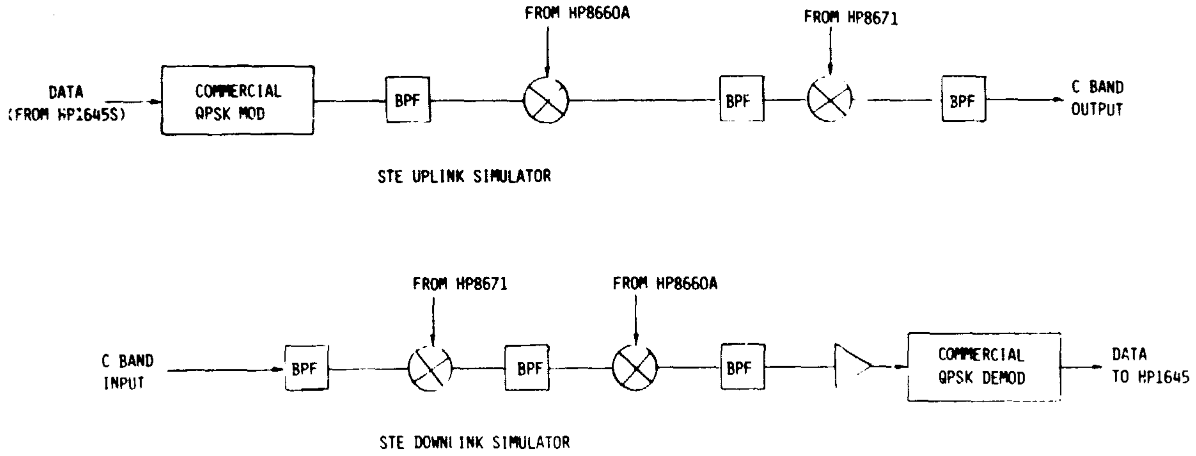

Figure 5.3-9. Motorola STE Uplink and Downlink Simulator

5.3.21 TESTING DEFINITION MATRIX SECTOR TESTING

In Table 5.3-3 sector output test measurements are made with the HP8566A Spectrum Analyzer operating under calculator control. The primary advantage of computer control is the execution of complicated and time consuming measurement routines with a minimum involvement of a human operator. The test data is not biased by human error. Accuracy of measurements performed by the 8568A are:

- Spurious response — ±0.6 dB
- Phase noise — ±2.3 dB
- RF power — ±0.4 dB

Table 5.3-3. Test Definition Matrix Sector Testing

	Remaining Paths		Output Tests						
Input Path Under Test	Noise Loaded	Terminated	Intermodulation	Frequency Response	Gain Variations	VSWR	Adjacent Path Interface	Internally Generated Thermal Noise	AM-PM Conversion
Phase Modulated Carrier	0	7		X	X				
Phase Modulated Carrier	7	0	X						
Carrier Only	7-N	N	X				X		X
Carrier Only	0	7		X		X			
Terminated	8	0	X						X
Terminated	0	7						X	
(Where $1 \leq N \leq 6$)									

5.3.22 TESTING DEFINITION MATRIX ROUTER TESTING

In Table 5.3-4 the seven router output tests are measured with the HP 8566A Spectrum Analyzer operating under calculator control. The eighth test (BER testing) will be a "loop back test" and will be a system demonstration test only.

1. Intermodulation
2. Frequency response
3. Gain variations
4. Adjacent path interference
5. Internally generated noise

6. AM-PM conversion
7. Phase noise

The test matrix includes a carrier only test where the remaining paths are noise loaded in different combinations (N ways) to determine interdependence of various paths through the sector.

Table 5.3-4. Testing Definition Matrix Router Testing

	Remaining Sector Paths		Output Tests								
Router Input	Noise Load	Terminated	Intermodulation	Frequency Response	Gain Variations	VSWR	Internally Generated Thermal Noise	Adjacent Path Intf	AM-PM Conversion	Phase Noise	BER Testing
FM Modulated Carrier	0	7		X	X						
QPSK Modulated Carrier	7	0									X
Carrier Only	7-N	N	X			X	X		X	X	
Terminated	8	0	X						X		
Terminated	0	7						X			
1 ≤ N ≤ 6											

5.3.23 MOTOROLA SPECIAL TEST EQUIPMENT MECHANICAL CONFIGURATION

The Motorola special test equipment (STE) will be housed in four drawers, two large and two small. The drawers will be mounted in a rack which is located directly under the router POC model baseplate. The drawers will be mounted side by side so that their location will be very close to the points being monitored within the Router POC model in order to minimize the interconnecting cable lengths from the STE to the router. All connectors will be located on the drawer rear panels, and cable retractors will be used so the drawers can be pulled out without having to disconnect any cables. All controls will be located on the front panels with labels engraved for ease of reference.

SECTION 6

6. NETWORK CONTROL STATION

This section discusses the Network Control Station (NCS) of the ACST SS-FDMA system.

6.1 NCS Functional Requirements and Performance Summary

The NCS functional requirements are divided into four functional areas (see Figure 6.1-1). The NCS computer is the focal point for the three remaining functions.

1. System management
2. Satellite control
3. Orderwire
4. NCS computer

The NCS computer coordinates the interchange of data. As examples:

1. System operation (a system management function) is the function that establishes the traffic paths between the small terminals. System operation function relies on the signalling and supervision information provided by the orderwire function.
2. Maintenance function provides beam status and network fault diagnosis. The NCS computer must input data from:
   a. Satellite control function (TT&C), and
   b. The orderwire (small terminal status).

The NCS performance characteristics are:

- NCS LNA, HPA and antenna with trunking station
- XMT characteristics

Traffic Model A	Traffic Model B
– BW: 5 MHz (composite)	4.3 MHz (composite)
– Bit rate: 2.5 Mb/s (composite)	2.15 Mb/s (composite)
– Channels required: 41	72
– No rain – EIRP: 86.5 dBm	85.8 dBm

- REC characteristics

Traffic Model A	Traffic Model B
– BW: 5.0 MHz (composite)	4.3 MHz (composite)
– Bit rate: 2.5 Mb/s (composite)	2.15 Mb/s (composite)
– Channels required: 41	72
– G/T: ≈28.5 dB/°K (based on satellite EIRP density of 6.2 dBm/bit)	

- Frequency stability better than: 1×10^{-8}
- BER: $\leq 1 \times 10^{-8}$
- Forward error correction encoding:

  Constraint length: 5

  Rate: 1/2

  Bit decision: 2 bit soft decision

The NCS is part of a trunking station. Common circuitry of the NCS and trunking station includes the LNA, HPA, and antenna. Since the trunking station is presently undefined, the transmit characteristics and receive characteristics of the NCS are presented in terms of EIRP and G/T. The transmit and receive characteristics are the combined requirements of the orderwire and satellite control links. Traffic Model A requires 40 channels of orderwire and Traffic Model B requires 71 channel of orderwire. At least one additional channel will be used for satellite control.
The bandwidths assume FEC and includes the orderwire bandwidth and the 0.5 MHz dedicated to satellite control. The EIRP requirements are based on the satellite's receiver performance and the link margin previously defined for the traffic uplink at 30 GHz. The specified no rain EIRP will provide a BER $\leq 1 \times 10^{-8}$ for the NCS transmit link.

The specified frequency stability is a baseline performance specification based on practical cost and technology.

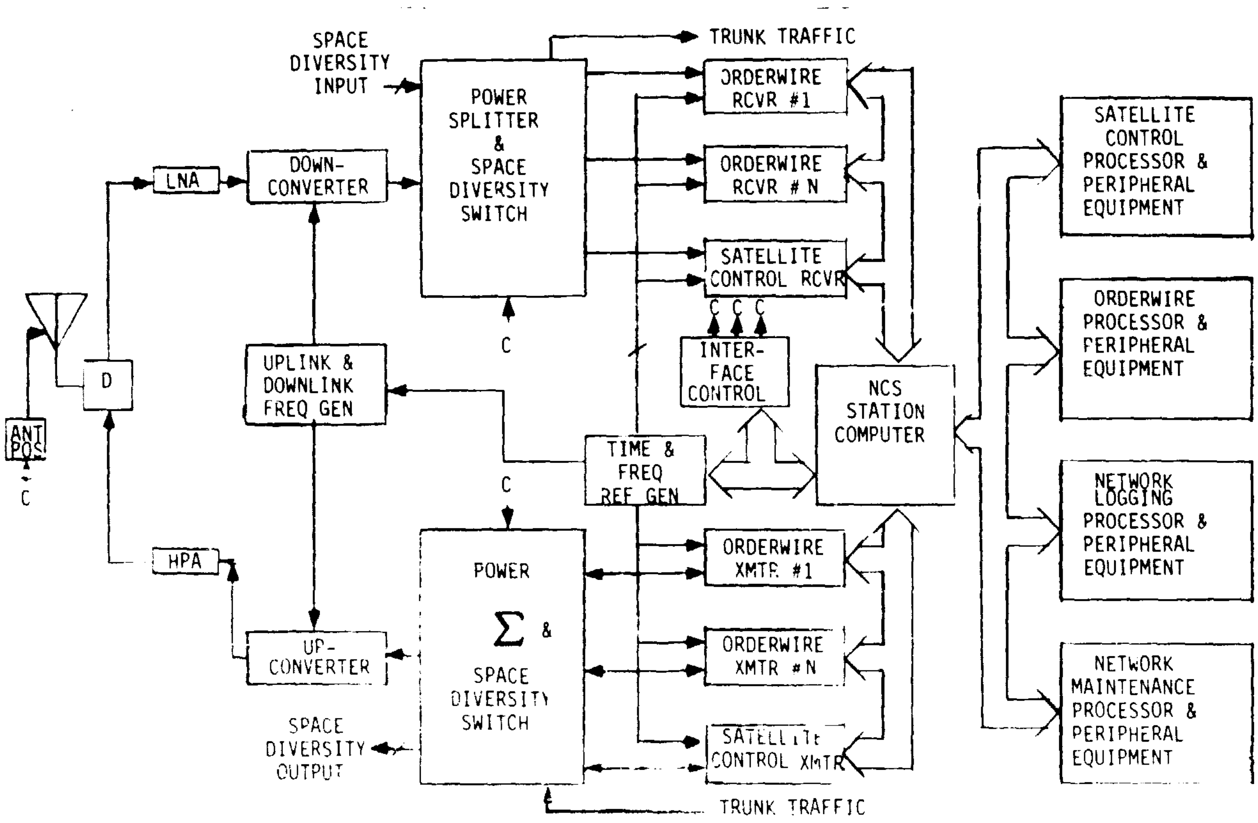

Figure 6.1-1. NCS Functional Requirements

6.2 NCS Block Diagram

Figure 6.2-1 is a block diagram of the NCS.

The baseline orderwire architecture incorporates a unique frequency per beam (Traffic Model A: 40 total, Traffic Model B: 71 total) for transmission and reception. Satellite control will be effected over a dedicated channel to the satellite. The channels (transmitters and receivers) will include convolutional encoding/decoding to maintain BER $\leq 1 \times 10^{-8}$. A time/frequency reference will be used as the station clock. The time/frequency reference shall be transmitted over the orderwire channel to ensure that all stations operating within the system are time referenced to the NCS. The NCS will provide processors for system operation and maintenance functions; telemetry, tracking, and control of the satellite; billing and system reconfigurations; and GT adaptive control. The four processors will be slaved to a station computer. The station computer coordinates and controls all NCS functions. A space diversity switch is included to route communication to/from a remote trunking station RF subsystem (HPA, LNA, ANTENNA, and UP/DOWN CONVERTERS). Space diversity is used in combatting severe weather conditions at the primary trunking station site.

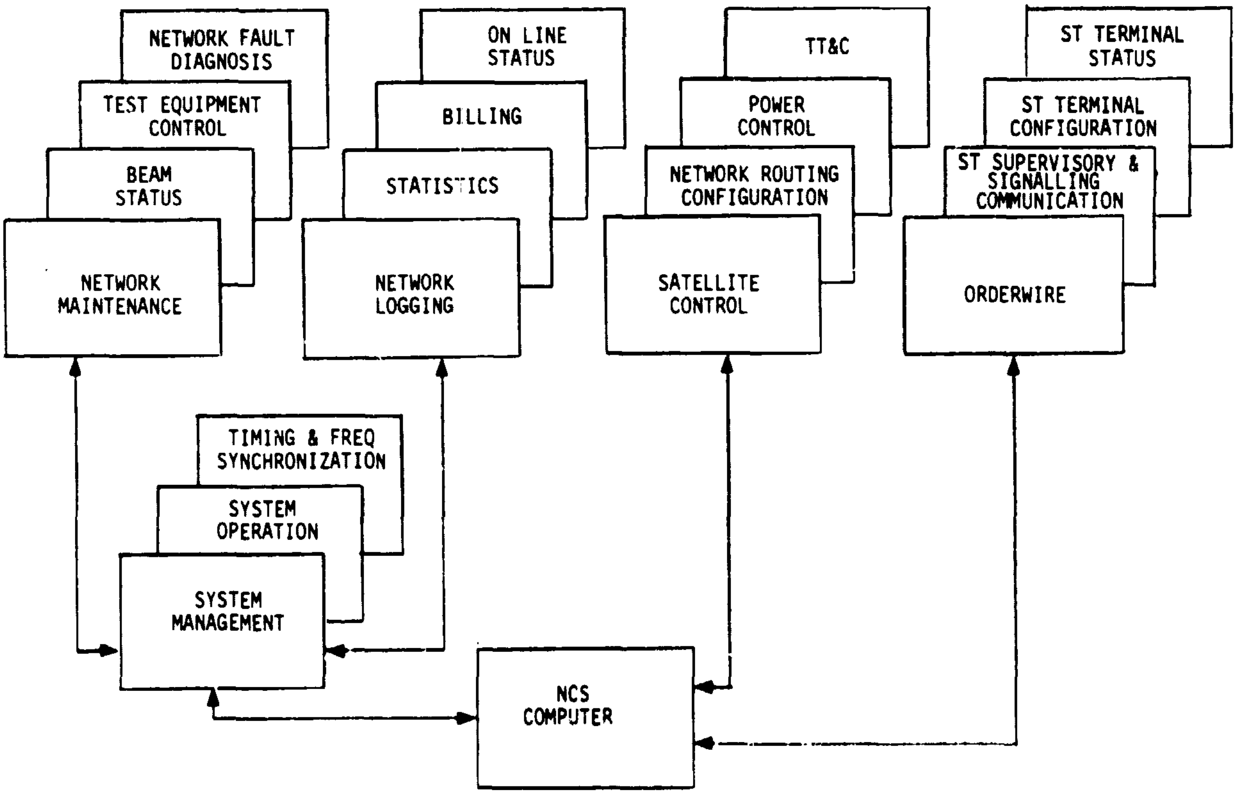

Figure 6.2-1. NCS Block Diagram

6.3 System Managements Concepts Summary

To ensure the interchange of order traffic flow between small terminals, the NCS must manage the attempts of potential users to access the system and once access has been gained, the NCS must manage the frequency use.

System timing and frequency synchronization is incorporated into the orderwire to ensure every user may access and use the system without interfering with other users.

Operation includes managing the satellite's bandwidth resources as traffic patterns change (long term). Operation also includes managing the ST (real time) use of available bandwidth for the existing traffic pattern.

Maintenance is limited to unscheduled (improper operation) activity. The intent is to provide fault isolation within the system so that one problem source does not effect the entire system.

Billing is a computational feature (using existing data within the system) providing traceability and charges for the use of satellite resources.

6.3.1 SYSTEM TIMING SYNCHRONIZATION

Propagation delays from the NCS to ST stations results in time ambiguity and causes a significant problem when a TDM orderwire system is used. Each small terminal will resolve the time ambiguity by continuously monitoring the NCS transmit orderwire frequency within its spot beam.

Coding will be incorporated into the NCS transmit data stream to indicate a time reference start. The ST station achieves time synchronization by correlating the received time reference and the ST geographic location (propagation delay) in the ST processor. The ST processor will use the time synchronization to transmit data only within its reserved time slot on the orderwire return link thus avoiding collisions with other stations and ensuring more reliable orderwire communication.

6.3.2 SYSTEM FREQUENCY SYNCHRONIZATION

Transmission of narrowband signals at EHF requires some method of providing system frequency synchronization to the ST stations and to the satellite. Since the orderwire link and satellite control link are necessary, the frequency synchronization should be incorporated into these links. The carrier frequency for the links will be used as the frequency reference and will be recovered by employing suppressed carrier tracking loops in the satellite and small terminals. Suppressed carrier tracking loops are capable of providing signal to noise ratios orders of magnitude better than the signal to noise ratios required on the ST to ST traffic links. The effect of phase noise associated with the frequency reference and its derivations will be negligible on the traffic BER performance.

6.3.3 OPERATION AND MAINTENANCE

Real time operation of the communication system should be fully automated. Real time operation includes:

1. Supervisory and signalling for call initiation/termination
2. ST receive/transmit frequency assignments.

Long term operation of the communication system should be by human control. Long term operation includes:

1. New on line status changes
2. Satellite bandwidth reallocations per changing traffic demands.

Maintenance functions will be limited to unscheduled maintenance. The maintenance function includes:

1. Network fault diagnosis
2. Automated test equipment control
3. Beam status
4. Satellite TT&C
5. Small terminal status.

The maintenance function will be used to minimize system degradation caused by improper satellite or ST operation.

6.3.4 BILLING

Billing is a computational function. The following six inputs are required to accurately determine billing requirements:

1. Source (originating user)
2. Originating small terminal
3. Destimation (terminating user)
4. Terminating small terminal
5. Time the traffic path is established
6. Small terminal status.

The required inputs all exist within the orderwire structure and NCS station timing reference. Additional computations will also provide statistical data which may be used for satellite bandwidth reallocations. NCS billing will provide traceability to the small terminals and ST users.

6.3.5 NETWORK ROUTING MANAGEMENT

Network routing management will be used to control the long-term effects of traffic distribution and patterns. Intermediate frequency translations (programmable frequency synthesizers) as well as path rerouting (programmable switches) will be used to recongfigure the long-term traffic patterns. The programmable synthesizers and programmable switches located in the satellite's router will respond to commands from the NCS.

The network configuration and satellite TT&C link has not been addressed in detail. For baseline purposes, a link capacity of 250 kb/s has been assumed.

6.4 ST Orderwire Concept Summary

To minimize station small terminal costs, the order complexity should be concentrated in the NCS. A TDM/FDM method of multiplexing is used to reduce the required bandwidth needed for data transfer. The FDM is incorporated by transmitting all orderwire information necessary for a spot beam on one carrier frequency. Forty carriers (one per spot beam) will be used. TDM will be used to distinguish between terminals within a beam. Terminal differentiation within a beam will be performed by correlating address information contained within each time slot. Each time slot transmitted by the NCS is assigned to a unique small terminal. The small terminals will transmit to the NCS in an assigned time slot of the return orderwire link.

6.4.1 ST ORDERWIRE SYSTEM CONCEPT TRAFFIC MODEL A

The peak hour usage for the system was estimated to be 1200 calls/second. The estimate was based on a voice path being used for an average of 3 minutes. Total system channel capacity for Traffic Model A is 68176. The average call per second is:

$$\frac{68176 \text{ channels}}{180 \text{ seconds}} = 379 \text{ calls/second}$$

To properly size the orderwire system, a worst case peak usage was assumed to be:

$$3 \times 379 \text{ channels/second} \Rightarrow 1200 \text{ channels/second}$$

To initiate and terminate a call, the orderwire protocol outlined in paragraph 4.8 requires 6 ST communications with the NCS. The orderwire time slot capacity is then:

$$\frac{6 \text{ time slots}}{\text{Channel}} \times 1200 \text{ channels/second} = 7200 \text{ time slots/second}$$

The orderwire was size to 800 time slots. Including overhead bits the NCS must transmit 1900 bits to complete a call and each ST (two each) must transmit 950 bits to complete a call. The NCS transmit data rate is:

$$\frac{1900 \text{ bits}}{\text{call}} \times \frac{1200 \text{ calls}}{\text{second}} = 2.28 \text{ MBPS}$$

The NCS receive data rate is:

$$2 \times \frac{950 \text{ bits}}{\text{call}} \times \frac{1200 \text{ calls}}{\text{second}} = 2.28 \text{ MBPS.}$$

6.4.2 ST ORDERWIRE BEAM CONCEPT (NEW YORK BEAM TRAFFIC MODEL A)

The New York Beam represents the highest beam traffic density. The New York Beam must support 3610 channels:

Station Type	Quantity	Channels	Total Channels
E	3	278	834
F	12	68	816
G	140	14	1960
		Beam Total:	3610

The New York Beam peak traffic is estimated to be:

$$\frac{3610}{68176} \times 1200 \text{ calls/second} = 64 \text{ calls/second}$$

The complete a call, the NCS must transmit:

$$1900 \text{ bits/call} \times 64 \text{ calls/second} = 121.6 \text{ kb/s}$$

To complete a call, the NCS must receive (from the New York Beam):

$$950 \text{ bits/call} \times 64 \text{ calls/second} = 60.8 \text{ kb/s}$$

6.4.3 ST ORDERWIRE SYSTEM CONCEPT TRAFFIC MODEL B

The peak hour usage for the system was estimated to be 1000 calls/second. The estimate was based on a voice path being used for an average of 3 minutes. Total system channel capacity for Traffic Model B is 57000. The average call per second is:

$$\frac{57000 \text{ channels}}{180 \text{ seconds}} = 317 \text{ calls/second}$$

To properly size the orderwire system, a worst case peak usage was assumed to be:

$$3 \times 317 \text{ channels/second} \Longrightarrow 1000 \text{ channels/second}$$

The access time of the smaller ST stations is related to the available time slots. To keep access time low, the available time slots for the smaller stations (I & J) must be increased. The 200 slots per beam concept has been extended to Traffic Model B.

The orderwire was sized to 14200 time slots. Including overhead bits the NCS must transmit 1900 bits to complete a call and each ST (two each) must transmit 950 bits to complete a call. The NCS transmit data rate is:

$$\frac{1900 \text{ bits}}{\text{call}} \times \frac{1000 \text{ calls}}{\text{second}} = 1.90 \text{ MBPS}$$

The NCS receive data rate is:

$$2 \times \frac{950 \text{ bits}}{\text{call}} \times \frac{1000 \text{ calls}}{\text{second}} = 1.90 \text{ MBPS.}$$

The bandwidth requirements assume rate 1/2 encoding.

6.4.4 ST ORDERWIRE BEAM CONCEPT (NEW YORK BEAM TRAFFIC MODEL B)

The New York Beam represents the highest beam traffic density. The New York Beam must support 2638 channels:

Station Type	Quantity	Channels	Total Channels
E	5	36	180
F	32	9	288
G	78	11	858
H	78	7	546
I	119	5	595
J	171	1	171
		Beam Total	2638

The New York Beam peak traffic is estimated to be:

$$\text{calls/second} = 44 \text{ calls/second}$$

To complete a call, the NCS must transmit:

1900 bits/call × 44 calls/second = 83.6 kb/s

To complete a call, the NCS must receive (from the New York Beam):

950 bits/call × 44 calls/second = 41.8 kb/s

6.5 NCS Hardware Definition

Table 6.5-1 lists the hardware required by the trunking station.

Table 6.5-1. Additional Hardware Required by Trunking Station

Traffic Model A	Traffic Model B
40 Orderwire transmitters	71 orderwire transmitters
40 Orderwire receivers	71 orderwire transmitters
1 satellite control transmitter	1 satellite control transmitter
1 satellite control receiver	1 satellite control receiver
Timing and frequency reference	Timing and frequency reference
Station computer, associated processor	Station computer, associated processor
and associated peripheral equipment	and associated peripheral equipment

The NCS is to be incorporated into a trunking station. For cost effectiveness, the NCS should share the trunking station's antenna, LNA, down converters, up converters, HPA, and space diversity switches.

The transmitters and receivers required for the orderwire and satellite control links will be similar to the traffic transmitters and traffic receivers used in the small terminals. The magnitude of computer hardware and software required to perform the various functional requirements is yet undetermined. Significant software development and computer hardware will be required to implement the orderwire, system management, and satellite control functions.

6.6 NCS Power Dissipation

The NCS power dissipation, Table 6.6-1, is the additional power a trunking station will require. The individual subassembly power dissipations were extended to 41 (40 orderwire channels and 1 satellite control channel) for traffic Model A. Individual subassembly power dissipations were extended to 72 (71 orderwire channels and 1 satellite control channel) for traffic Model B.

Power estimates for the station computer, processors and peripherals is based on a PDP-11 computer with 512K bytes of memory and six peripherals:

Computer	: 1650 Watts
Memory	: 1320 Watts
Six peripherals	: 4620 Watts
Four processors	: 410 Watts

Table 6.6-1. NCS Power Dissipation

Subassembly	Assy (Watts)	Traffic Model A Total (Watts)	Traffic Model B Total (Watts)
OW xmtr/satellite control xmtr			
φ modulator	0.4	16.4	28.8
Coder (FEC)	0.2	8.2	14.2
Xmtr control		5	5
OW receiver/satellite control receiver			
φ demodulator	0.7	28.7	50.4
Decoder (FEC)	0.25	10.25	18.0
Receiver control		5	5
Station computer, processors, peripherals		8000	8000
Low voltage power supplies		73.6	121.4
	Total	8147 Watts	8243 Watts

SECTION 7

7. SMALL TERMINALS

The following section discusses the Small Terminals (ST) of the ACST FDMA system.

7.1 Small Terminal Functions

Refer to Figure 7.1-1 in the following description of the ST functions. The ST is the user's entry point into the communication system. As such, it must provide three basic functions:

- To link the user's phone lines to the ST hardware (Terrestrial Interface Subsystem)
- To effect a communication link (traffic channel) between the desired parties (Orderwire Subsystem)
- To provide a means of communicating between desired parties (Traffic XMT & REC subsystems)

The primary communication over the orderwire will include the destination address (telephone number supplied by calling party, ST →NCS) and the dedicated frequencies required to establish the communication link (NCS → calling and called ST). Signalling and supervisory information concerning the traffic channel will be handled over the orderwire. In addition, the orderwire subsystem is designed to receive and carry-out commands from the NCS via the orderwire communication link to:

- Adjust radiated power to combat uplink rain fades
- Initiate FEC coding and decoding to combat downlink rain fades.

The orderwire subsystem will also provide the system synchronization so that all small terminals are slaved to the NCS.

7.2 Small Terminal Organization

The single channel ST station (Station J, Traffic Model B) is comprised of five subsystems, (see Figure 7.2-1).

- TIU subsystem
- Traffic transmitter subsystem
- Traffic receiver subsystem
- Orderwire subsystem
- Antenna subsystem

These are standard subsystems common to all small terminals. The J class ST is designed to support one 32 kbps toll quality voice channel.

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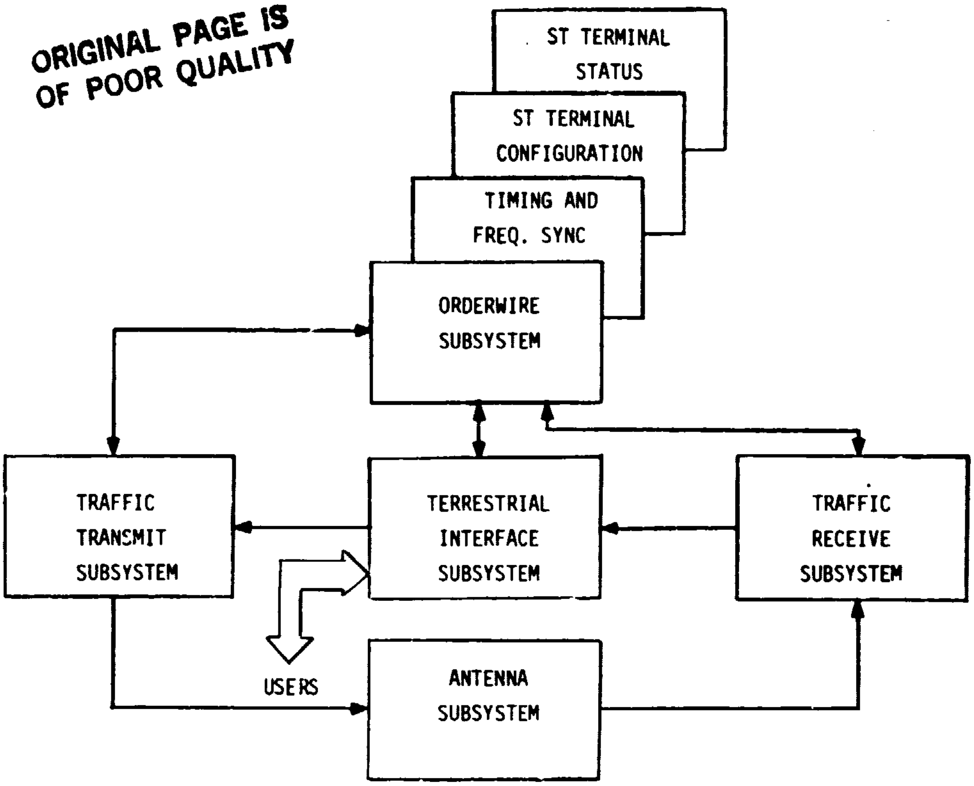

Figure 7.1-1. Small Terminal Functions

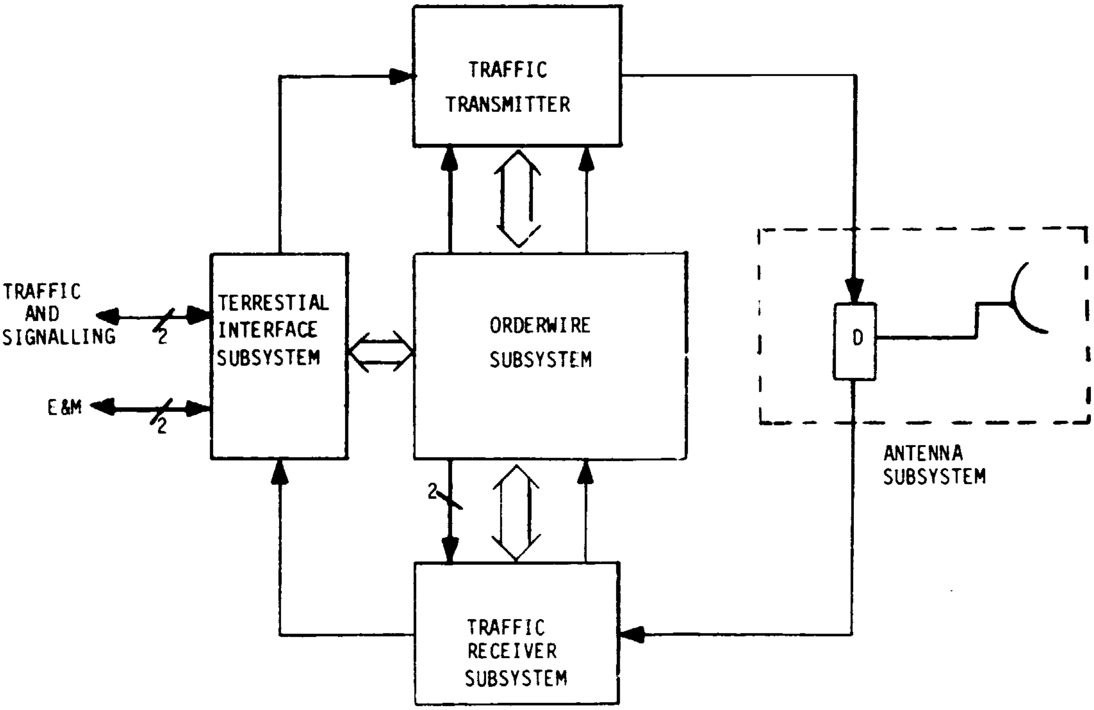

Figure 7.2-1. Signal Channel ST Station

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7.3 Multichannel ST Block Diagram

In the following description, refer to Figure 7.3-1. The multichannel ST is characteristic of the E, F, and G class terminals in Traffic Model A and the E, F, G, H, and I terminals of Traffic Model B. The multichannel small terminal is comprised of the same subsystems as the single channel small terminal. The TIU, traffic transmitters and traffic receivers will increase on a one for one basis as the channel capacity increases.

The TIU capacity may be increased by adding a module to the TIU subsystem main frame for each channel added. Complete subsystems (traffic receivers and traffic transmitters) must be added for each additional channel added. The orderwire subsystem will not change since all channels are controlled from a single bus structure.

Additional HPA's, different antenna sizes and antenna positioning control must be added as channel capacity increases (increased EIRP requirements). If necessary, the Ka-band outputs may be summed spatially in a Cassegrain feed structure at the antenna.

The high rate user interface is a direct hardwired interface over dedicated lines. The high rate data is inputted/outputted by the TIU. The TIU contains I/O buss circuitry and reclocking circuitry. The signalling and supervision signals are provided by a companion low rate traffic circuit.

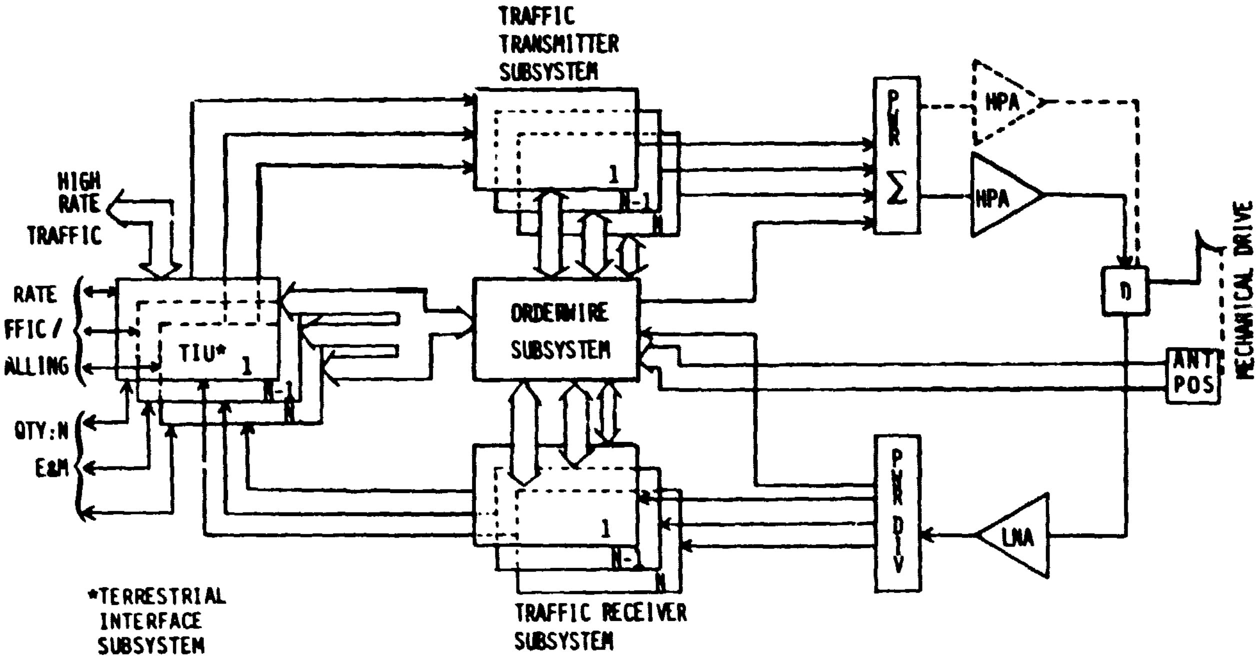


Figure 7.3-1. Multichannel ST Block Diagram

7.4 Terminal Capacity

Table 7.4-1 gives the ST capability in tabular form. The channels and bit rates are commensurate with those stated in the SOW with the exception that the voice channel bit rate is 32 kb/s instead of 64 kbps.

Table 7.4-1. Terminal Capability

	Traffic Model A Class				Traffic Model B Class					
	E	F	G		E	F	G	H	I	J
32 Kb/s channels	240	60	12		30	5	10	5	5	1
56 Kb/s channels	30	7	2		4	3	1	2	0	0
1.5 Mb/s channels	7	1	0		1	1	0	0	0	0
6.3 Mb/s channels	1	0	0		1	0	0	0	0	0
Total Capacity Mb/s	26.160	3.812	0.496		8.984	1.828	0.376	0.272	0.160	0.032
SOW Traffic Model Rates (Mb/s)	33.84	5.732	0.88		9.944	1.988	0.696	0.432	0.320	0.064
Power improvement (dB)	1.1	0.8	2.5		0.4	0.4	2.7	2	3	3

7.5 Small Terminal Equipment Characteristics Summary (BER 1 × 10^{-6})

The antenna size, HPA power, and LNA noise temperature for the Traffic Model A stations were determined through parametric analysis. The parametric analysis is presented in subparagraphs 7.12, 7.13, 7.14, and 7.15. Parametric analysis was not performed on Traffic Model B stations. The equipment characteristics for Traffic Model B stations are based on Traffic Model A stations of comparable capacities.

The HPA saturated power sizes the maximum power capability required. Normal operation (rain fade and clear conditions) will be backed off from the saturated power. The powers listed in Table 7.5-1 are intended only to show the range of power required for each class of station.

The LNA noise temperature listed includes the noise temperature of the antenna due to rain (290°K). Delta PSK modulation will be used on the traffic channels. The FEC characteristics as listed will provide the required signal to noise ratio (downlink rain fade) to achieve the required BER when the downlink is experiencing rain fade.

Table 7.5-1. ST Equipment Characteristics Summary (BER 1×10^{-6})

	Traffic Model A			Traffic Model B					
Equipment	E	F	G	E	F	G	H	I	J
Antenna Diameter (M)	6	5	4	6	5	4	4	4	4
HPA (saturated power)	200 W	50 W	10 W	100 W	25 W	10 W	5 W	5 W	1 W
Rain fade	≈75 W	≈15 W	≈3 W	≈25 W	≈7 W	≈2 W	≈1.5 W	≈1 W	≈200 mW
Clear (no rain)	≈3 W	≈0.5 W	≈0.1 W	≈0.7 W	≈0.2 W	≈75 mW	≈56 mW	≈30 mW	≈5 mW
LNA (max noise temperature in °K)	1621	1148	724	1621	1148	724	724	724	724

Modem: DELTA PSK

FEC CODEC: Rate 1/2, constraint length 5, 2 bit soft decision

7.6 ST Receive, Transmit, and Interface Characteristics

EIRP and G/T requirements (see Table 7.6-1) were determined by link budgets giving a total system EB/NO >10.6 dB (BER $\leq 10^{-6}$) when maximum rain fade occurs on the uplink and downlink.

The user interface functional requirements are based on the most common type of signalling anticipated in the 1987 time frame. As a baseline assumption, potential subscribers with unique interface requirements will provide the necessary interfacing equipment which will make their user interface compatible with the ST TIU. Commercial equipment is readily available to satisfy many unique interface requirements.

Table 7.6-1. ST Receive, Transmit and Interface Characteristics

	Traffic Model A Class			Traffic Model B Class					
	E	F	G	E	F	G	H	I	J
EIRP (With Rain Fade) dBm	109.8	101.3	92.6	105.1	98.5	91.4	90	87.7	80.7
Ant Gain (dB)	61.8	60.3	58.3	61.8	60.3	58.3	58.3	58.3	58.3
HPA (dBm)	46.0	41.0	34.3	43.3	38.3	33.1	31.7	29.4	22.4
G/T (dB/°K)	27	27	27	27	27	27	27	27	27
Ant Gain (dB Min)	59.1	57.6	55.6	59.1	57.6	55.6	55.6	55.6	55.6
Sys Noise Temp (Max, °K)	1621	1148	724	1621	1148	724	724	724	724
User Interface									
Low Rate and Voice	Standard two wire inband signaling interface. Baseline signaling is assumed to be dual tone (touch tone). Supervisory information provided by two wire E&M.								
High Rate	Bus compatible, bus standard and levels TBD. High rate user traffic, signalling, and supervision are assumed to be via dedicated leased lines.								

7.7 ST Orderwire Characteristics

(See Table 7.7-1.) The orderwire communication link between the NCS and ST should perform at better than the specified traffic BER (1×10^{-6}). As a baseline, the OW BER is established at 1×10^{-8}. The orderwire communication link shares the ST traffic link's HPA and LNA. To achieve the required OW BER, FEC will be implemented on a permanent basis.

Capacity for call initiation/termination is based on the worst case beam capacity (New York). Per protocol, each call will require 3 separate sets ST ↔ NCS data transfers. Each ST transmit requires 300 bits. Each ST receive requires 600 bits. As a minimum, 198 slots per second must be available (5 msec slot duration). The ST transmitted data in each slot must contain 300 bits.

The transmit data rate is:

$$\frac{300 \text{ bits}}{5 \text{ msec}} = 60 \text{ kb/s}$$

The receive data rate is:

$$\frac{600 \text{ bits}}{5 \text{ msec}} = 120 \text{ kb/s}$$

The bandwidth requirements include rate 1/2 encoding for FEC.

The capacity for the (Traffic Model B) I and J stations was increased by dedicating more time slots to those stations. Increasing the available time slots reduced the access time to effect a call.

Table 7.7-1. ST Orderwire Characteristics

	Traffic Model A Station			Traffic Model B Station					
	E	F	G	E	F	G	H	I	J
Capacity Required (calls/second)	5	1.2	0.25	0.6	0.183	0.117	0.117	.083	.0167
Capability (calls/second)	5	1.2	0.25	0.6	0.183	0.117	0.117	0.25	0.2

BER $\leq 10^{-8}$

FEC

Rate: 1/2

Constraint length: 5

Quantization: 2 Bit soft decision

Data Rate

Transmit: 300 bits per 5.0 msec slot (60 kb/s burst rate)

Receive: 600 bits per 5.0 msec slot (120 kb/s continuous)

RF Bandwidth

Transmit: 120 kHz (includes rate 1/2 encoding)

Receive: 240 kHz (includes kHz and rate 1/2 encoding)

7.8 Orderwire Subsystem Description

The Orderwire Subsystem (see figure 7.8-1) provides the ST with:

1. System timing
2. Frequency synchronization
3. User/system signalling and supervision
4. 1/2 duplex communication path with NCS

System timing relies on reconstructing the orderwire clock which is generated in the NCS. The ST processor computes the appropriate timeslot for orderwire transmission by comparing the known geographical location and the ST address correlation.

Frequency synchronization is effected by reconstructing the NCS carrier in a suppressed carrier track loop. The reconstructed carrier will be used in synthesizing all LO signals.

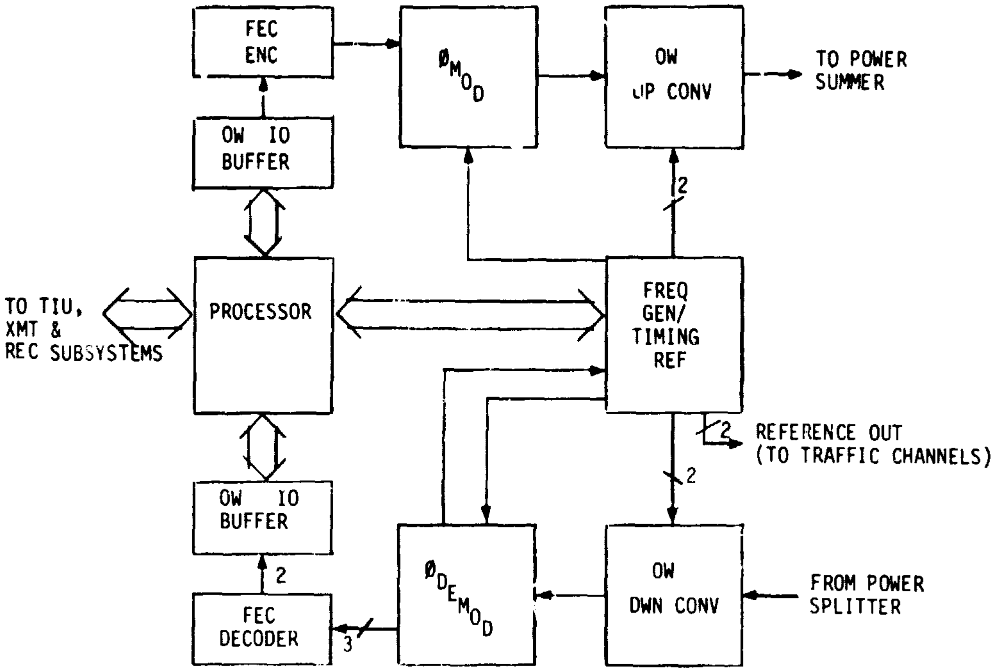


Figure 7.8-1. Orderwire Subsystem

Signalling and supervision are the necessary signals required to 1) determine destination address and 2) path status (busy, ringing reorder).

Half duplex communication includes:

1. Frequency assignments for path establishment
2. Small terminal status
3. Small terminal configuration
    a. Adaptive power to combat rain fade
    b. FEC encode/decode.

7.9 Terrestrial Interface Subsystem Description

The Terrestial Interface Unit (TIU) interfaces the user's two wire phone system and E&M supervisor lines (see figure 7.9-1). The baselines system is a DTMF (dual tone multi-frequency) inband signalling system. Other systems may be made compatible by introducing commercially available equipment at the user interface external to the ST station.

In-band signalling is effected over the traffic and signalling line via the signalling interface. The dual tone analog signalling is adapted to the orderwire service by using tone encoders and decoders whose outputs/inputs are controlled by the processor bus structure.

Low rate traffic is interfaced to the traffic transmitter or traffic receiver via the 2-4 wire hybrid conversion. Echo suppression or cancellation is included in the hybrid.

Coders/decoders provide the traffic A/D or traffic D/A of voice data. The codec digital rate for voice is 32 kb/s.

High rate data to/from the user is interfaced through the TIU. Each high rate data interface must have I/O buffers, bit sync circuitry for outbound traffic and relock circuitry for inbound traffic. The signalling and supervisory signals are provided by separate 2 wire interface and associated pair of E & M lines.

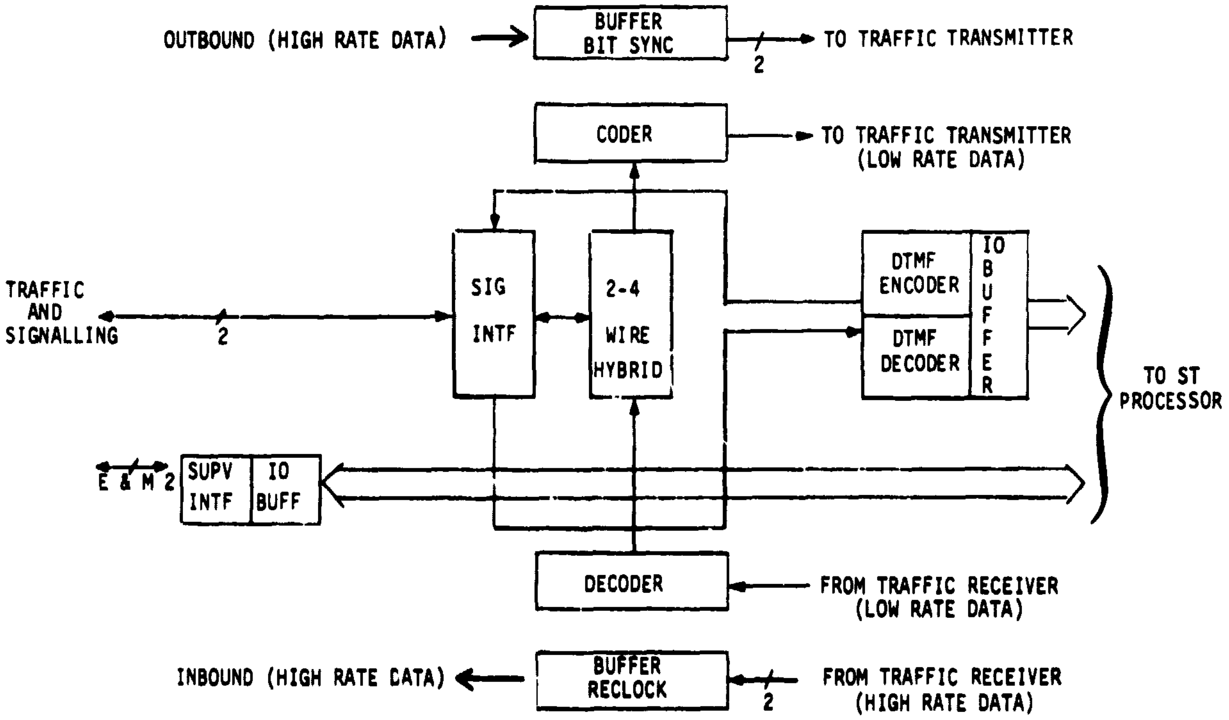


Figure 7.9-1. Terrestrial Interface Subsystem Description

7.10 Traffic Transmitter and Receiver Subsystems Description

Frequency conversion is to be performed by four translations: two fixed and two adjustable (both the transmit and receive paths). For the traffic transmitter, a VHF frequency is used to establish the carrier. A fixed frequency translation and two selectable frequencies provide the remaining translations to Ka-band. A similar but reverse process occurs for the traffic receiver (see figure 7.10-1).

Encoding and decoding of the digital data is provided to combat rain fade. The FEC is controlled by the transmitter control unit and the receiver control unit. The control units provide the interfacing circuitry for commands from the processor as well as providing telemetry to the processor. In addition, the transmitter control module provides power boost commands to the TWTA for combating rain fade.

The ϕ compensation network at the input to the HPA is a phase distorting circuit. The phase predistorting circuit compensates the phase change in the HPA. The compensation reduces the AM-PM distortion of the TWT.

No active gain blocks are shown in the transmit path. Based on preliminary gain budgeting, if the HPA is capable of 50 dB of gain and the output of the upconverter is nearly 0 dBm, no additional gain will be required.

7.11 ST Potential RF Technologies Description

The technologies defined are for a first order approximation aimed at minimizing station costs.

7.11.1 LNA TECHNOLOGY

FET technology at 20 GHz may be capable of providing the required noise temperatures for the smaller stations employing the 4 meter antenna. The low noise temperature LNA at 20 GHz is a potential candidate for advance technology for (ground applications).

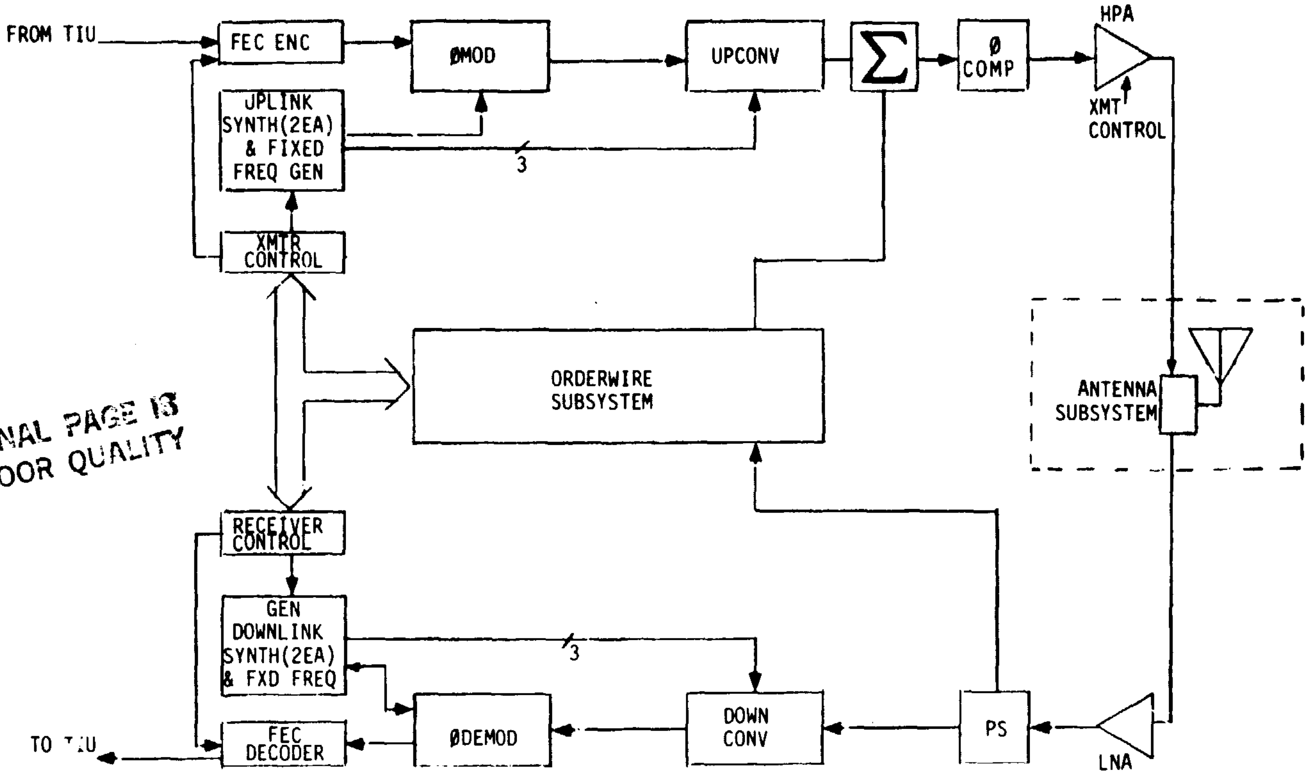


Figure 7.10-1. Traffic Transmitter and Receiver Subsystems

7.11.2 TRANSMITTER TECHNOLOGY

The higher power HPA requirements will most certainly have to be incorporated with TWTA's. Of the TWTA configurations, coupled cavity devices must be used for higher power while the helix type device can be used in the lower power region (≤5 watts). For the low range of HPA requirements, IMPATT solid state devices when operated as an amplifier may prove to be adequate. Stability poses a serious problem when considering IMPATT devices. At the present, FET devices at 30 GHz are not practical but may be capable of supplying the required power (≤2W) linearity in the 1987 time frame. The Varian VTA 6298A1 (30/20 GHz TWT development) is capable of meeting the high power requirements. The Hughes 914H is a potential candidate for the high power TWT. The 914H was developed for USA SATCOMA in 1979.

7.11.3 ANTENNA TECHNOLOGY

Cassegrain antenna design has been considered because of its ability to provide spatial power summing low aperature blockage, and minimization of insertion loss between feeds and receiver inputs/transmitter outputs.

7.11.4 ST LNR

The noise performance of the LNR should be optimized to simultaneously minimize the satellite RF power and the ground station cost. A high noise figure will require large satellite RF power and/or large ST receive antenna gains. By using a noisy ST LNR and a relatively small ST receive antenna, the satellite RF power requirements will become so high that the satellite is impractical. On the other hand, using a very expensive and high performance ST LNR with a large ST receive antenna will reduce the required satellite RF power, but will raise the smaller station costs to impractical levels. To make the system practical, a realistic satellite RF power should be established.

7.11.5 ST ANTENNA

The physical size of the antenna is limited by environmental considerations such as wind loading. The upper limit of the ST antenna has been arbitrarily set at 6 meters. Surface tolerancing of the antenna will significantly impact the gain as well as cost of the antenna.

The ST antenna impacts the ST LNR, ST HPA, as well as the satellite RF power. The parametric analysis that follows optimizes the ST antenna for minimum ST station costs at a practical satellite RF power.

7.12 Antenna Parametric Analysis

A family of curves are plotted in figure 7.12-1 as a function of antenna size (meters) versus units of cost. The curves for surface tolerances of $\epsilon = 0.25$ mm and $\epsilon = 0.75$ mm are published data. The curves for $\epsilon = 0.50$ mm and $\epsilon = 1.0$ mm are approximation based on the following assumptions:

1. As surface area increases for a fixed surface tolerance the cost increases linearly.
2. As surface tolerancing increases for a fixed area antenna the cost decreases linearly.

Efficiency of the antenna is a function of the surface tolerancing. Four constant gain contours (2 @ 20 GHz and 2 @ 30 GHz) are plotted to show the effects of surface tolerancing and antenna diameter as a function of cost. The Y axis (cost) is not intended to suggest the actual cost of the antenna. Cost figures are approximations based on 1981 information and quantities of 200.

7.13 HPA Parametric Analysis

The curve in figure 7.13-1 is a reproduction of a cost information for a 44 GHz TWTA proposed by Motorola in 1981. The minimum cost of 40 units is based on estimates provided by Hughes. The Y axis (cost) is not intended to suggest the actual cost of the TWTA. Units of cost are approximations based on 1981 information and quantities of 200.

7.14 LNA Parametric Analysis

The curve in figure 7.14-1 is a reproduction of cost information for a 20 GHz LNA. Data was obtained from a Motorola proposal prepared in 1981. The Y axis (units of cost) is not intended to suggest the actual cost of the LNA. Cost figures are approximations based on 1981 information and quantities of 200.

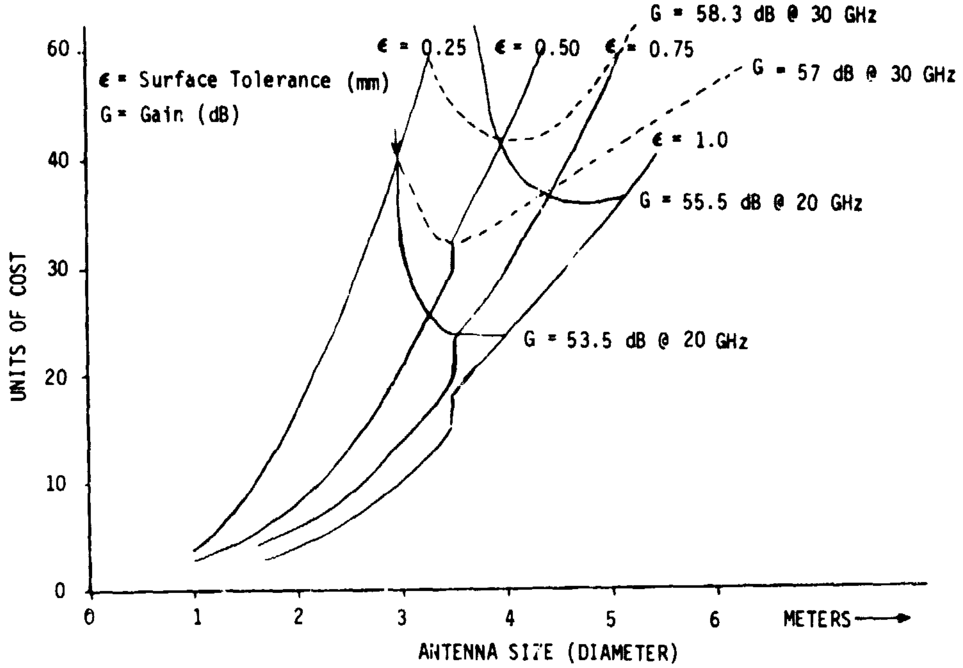


Figure 7.12-1. Antenna Parametric Analysis

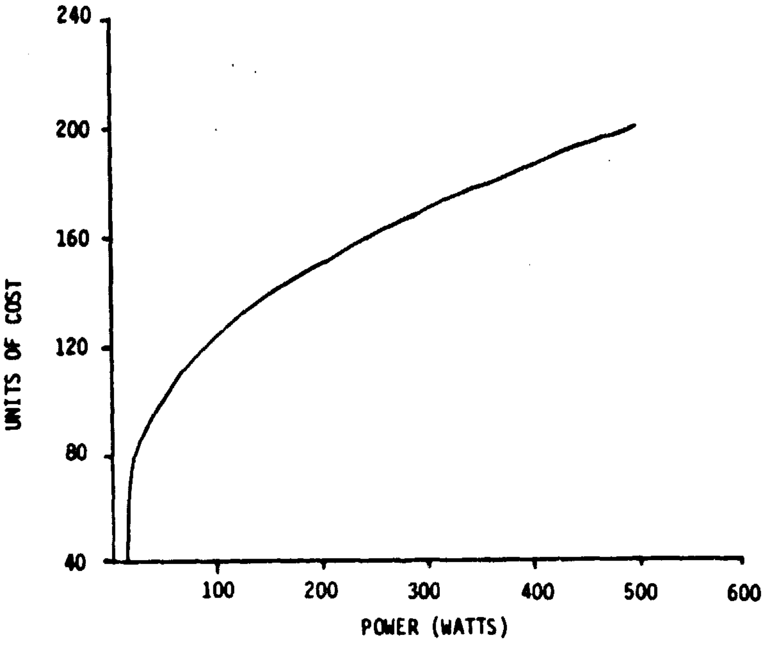


Figure 7.13-1. HPA Parameter Analysis

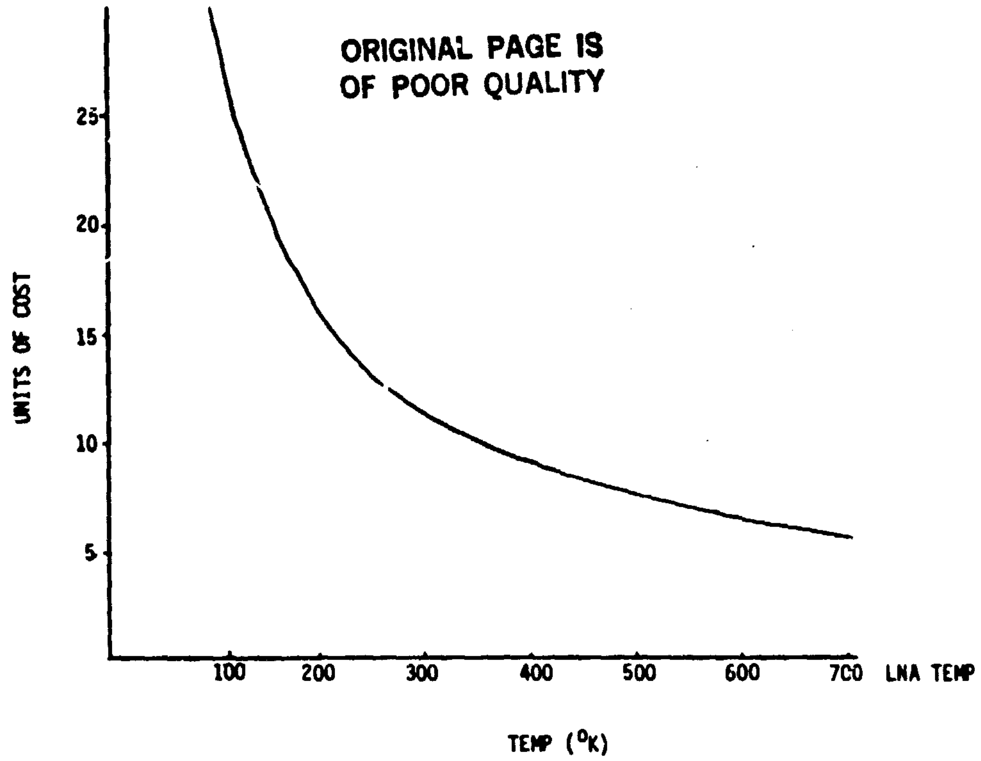


Figure 7.14-1. LNA Parametric Analysis

7.15 Composite Parametric Analysis for an LNA, HPA, and Antenna (Traffic Model A)

The cost curves in figure 7.15 1 were developed to determine the optimum ST antenna size. These cost curves apply for a fixed satellite transmit power based on the receiver parameter G/T. For a G/T of 27 dB/°K; a static antenna surface tolerance of 0.5 mm RMS and a satellite EIRP of 10 dBm/BIT, the minimum cost impact occurred for the parameters shown in table 7.15-1.

Table 7.15-1. Cost Impact Parameters

Station	Antenna Diam(m)	Receiver Noise Temp (°K)	TWTA (Watts)
E	6	1621 Max	200 (Sat.), 65 (Lin)
F	5	1148 Max	42 (Sat.), 12.6 (Lin)
G	4	724 Max	9 (Sat.), 2.7 (Lin)

No absolute cost significance is intended other than to show the minimum antenna diameter required to minimize impact on station cost.

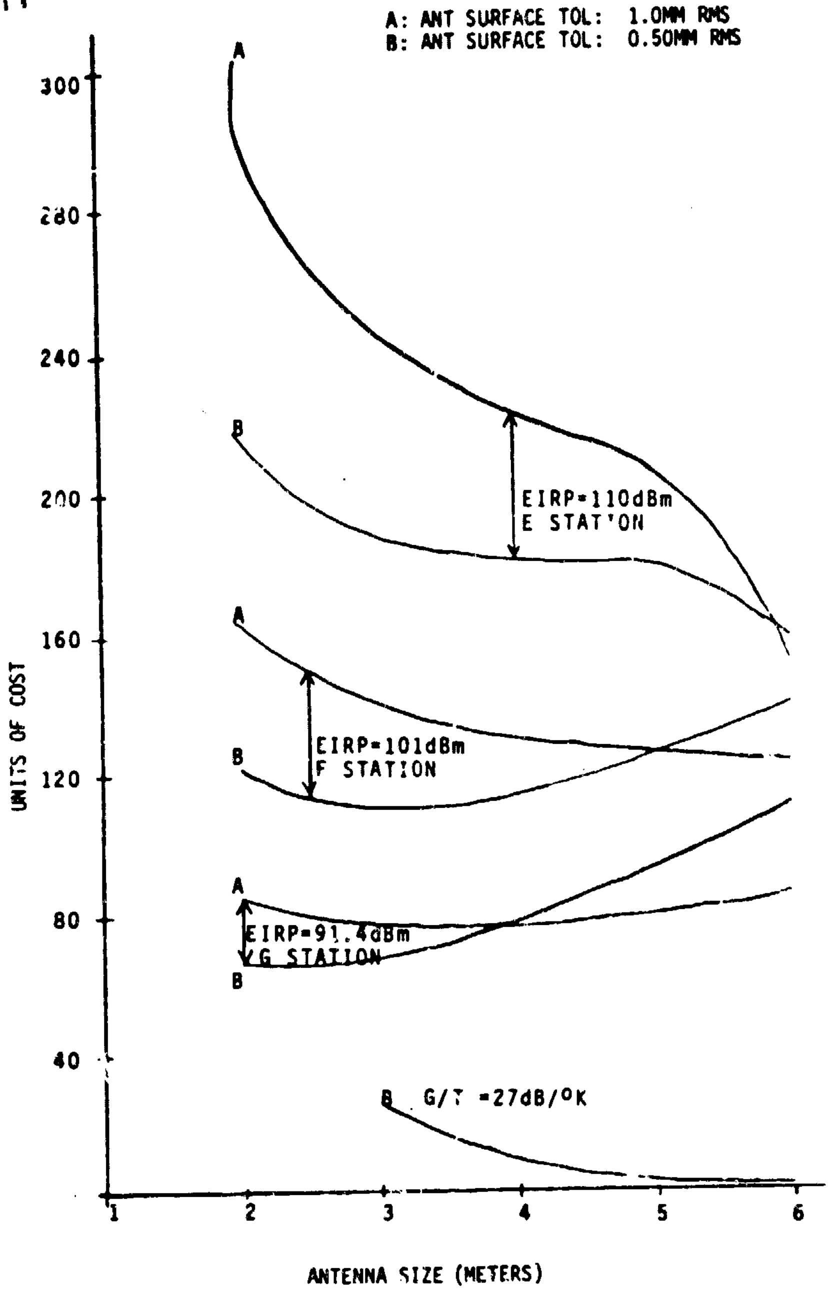


Figure 7.15 1. Cost Curves

7.16 O-QPSK Demodulation Serial Implementation Description

The serial detection scheme shown in figure 7.16-1 is used to maintain hardware simplicity while reducing the performance sensitivity to various sources of degradation. The received signal is detected in phase quadrature to permit the matched filtering to be performed at baseband. Matched filtering is done at baseband rather than at IF because the required frequency response is easier to obtain. The serial demodulator structure employs a Costas loop configuration to maintain carrier synchronization and clock synchronization is performed by the MSIC. A preset equalizer is used to offset amplitude and group delay distortions introduced by the transmitter and channel filtering. A preset rather than adaptive equalizer is employed for simplicity. The H9 demodulator MSIC, under development in the 30/20 GHz baseband processor program, performs the actual carrier phase detection, bit synchronization and data detection.

7.17 ST Power Requirements

In the following description refer to table 7.17-1. The HPA power consumption is based on 10% TWT efficiency and 50% HVPS efficiency, when the ST station is experiencing maximum uplink attenuation due to rain. The LVPS power is based on 50% efficiency of all circuitry excluding the HPA.

The traffic transmitter/traffic dissipations are based on extending the individual subassembly dissipations by the total number of channels on each station. The TIU power dissipations are based on extending the inidividual subassembly dissipations by the number of voice channels in each station. The breakdown of the various subassemblies shown in table 7.17-2 indicates those portions whose power consumption was included in table 7.17-1.

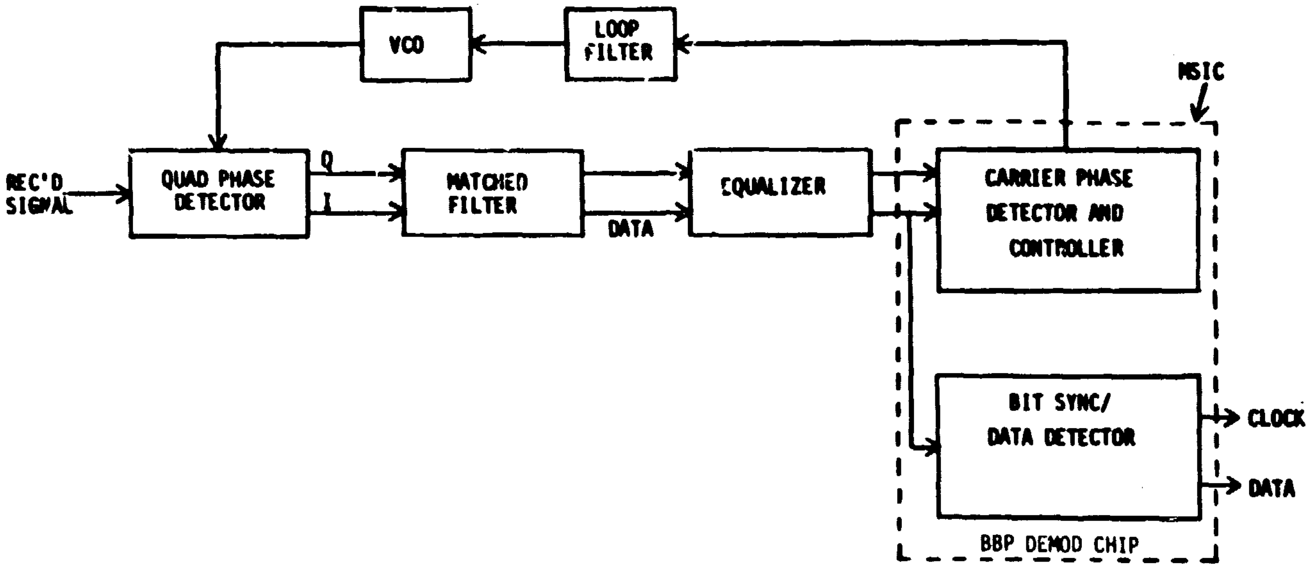


Figure 7.16-1. O-QPSK Demodulator Serial Implementation

Table 7 17-1. ST AC Power Requirements

Subassembly	Watts	Station Power (in watts)								
		Traffic Model A			Traffic Model B					
		E	F	G	E	F	G	H	I	J
HPA		1,500.00	300.00	60.00	500.0	140.0	40.0	30.0	20.0	4.0
Traffic XMTR	1.64	455.92	111.52	22.96	59	14.8	18	11.5	8.2	1.6
Traffic RCVR	1.99	553.22	135.32	27.86	71.6	17.9	21.9	13.9	10.0	2.0
TIU	1.20	288.00	72.00	14.4	36.0	6.0	12.0	6.0	6.0	1.2
Orderwire		250.0	65.0	24.0	45.0	19.0	21.0	17.0	15.0	11.0
LNA	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Low Voltage Power Supplies (LVPS)		1556.10	393.0	92.2	220.6	66.7	81.9	57.4	48.2	24.8
Approximate Total		4612.00	108.5	250.0	941.0	273.4	203.8	145.0	116.0	54.0

Table 7.17-2. Breakdown of Subassemblies

Traffic Xmtr	Traffic Rcvr	TIU	Orderwire
ϕ Modulator	ϕ Demodulator		Processor
Coder (FEC)	Decoder (FEC)		Freq gen/timing ref
Traffic Xmtr Control	Traffic rcvr control	Tone encoder	ϕ Modulator
Upconverter	Downconverter	Tone decoder	ϕ Demodulator
Uplink Synthesizer	Downlink synthesizer	Coder (CVSD)	Encoder (FEC)
		Decoder (CVSD)	Decoder (FEC)
		I/O buffers	Upconverter
			Downconverter

SECTION 8

8. ADVANCED TECHNOLOGY PROJECTIONS

The SS-FDMA router design for an operational system in the 1990's will use advanced technology available in 1987. It is expected that the router design will be based upon new mosiac, bipolar processes for linear signal processing through VHF. The dominant areas where low power, high frequency capability is required is in the router IF switches, the programmable synthesizers, and in small LSI functions for summing, distribution, and AGC amplifiers.

The SS-FDMA router satellite control and management functions will employ CMOS for digital processing. This will definitely include forward error correction decoders and CMOS microprocessors for router management and telemetry data processing. Paragraphs 8.1 and 8.3 depict the likely trends in these areas.

8.1 1987 Projections For Bipolar Random Logic

Research on advanced processing techniques indicates availability of two advanced versions of the mosaic process by 1987 (see table 8.1-1). Reduction in device geometry will yield higher maximum transistor operating frequency (f_t) and higher packing density resulting in an 84 percent lower speed-power product internally (see figure 8.1-1). At the system level, the net result forecasted is a 40 percent lower power consumption with a simultaneous 74 percent higher clocking rate possible. Additionally, the higher packing density and lower power consumption implies more complex functions can be built per chip.

Table 8.1-1. Projections for Bipolar Logic

Technology	Year	No. of Functions	Power X Speed Product (Raw Gate)	Gate Delay	Gate Power
MECL 10K	1971	50	50 PJ	2.0 ns	25 mW
MECL III	1970	15	54	0.9	60
MMT-LSI	1975	400	20	1.0	20
MECL 20K	1974	150	8	1	8
MOSAIC I	1978	750	3	0.75	4
....					
MOSAIC II	1981	2100	1.4	0.5	2.8
MOSAIC III	1984	6300	0.48	0.2	2.4

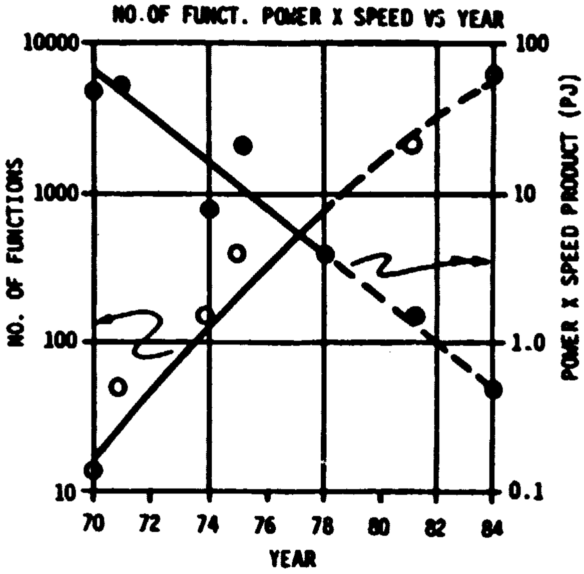


Figure 8.1-1. No. of Funct. Power X Speed Vs Year

8.2 1987 Projections For Improved Switch Performance

The projections for improved switch performance comprise:

- Technology: silicon bipolar integration
- Implementation: Custom LSI using latest processes
- Anticipated results:
  - Improved processing

    Allows reduction of device geometry and consequent improved F. Allows higher density and a reduction of overall chip size or increased capability per chip

    Both of these improvements should lead to increased isolation and bandwidth or reduced DC power for the switch, probably at the expense of RF power handling capability
  - Custom LSI

    Allows higher density and a reduction of overall chip size or increased capability per chip. This can be repeated to improve isolation in the ceramic substrate.

    Allows reduced DC power through availability of more optimum resistor values in control circuits

    Allows better separation of input/output lines on chip for improved isolation

8.3 1987 Projections CMOS Technology

Semiconductor manufacturers are projecting major advances in CMOS memories by 1987 (see figure 8.3-1). Reduction in device geometry is expected to decrease power requirements from 7 μW/MHz/bit for 1982 technology to 1 μW/MHz/bit for 1987 technology. At the system level this provides in 85 percent reduction in power for active memories. Reduced device geometry will allow higher memory density. One megabit IC and greater is projected for 1987. Also, reduced geometry will increase speed by a factor of five by 1987. Chip carrier technology for space applications is also expected to provide great pin-out capability allowing high density packaging.

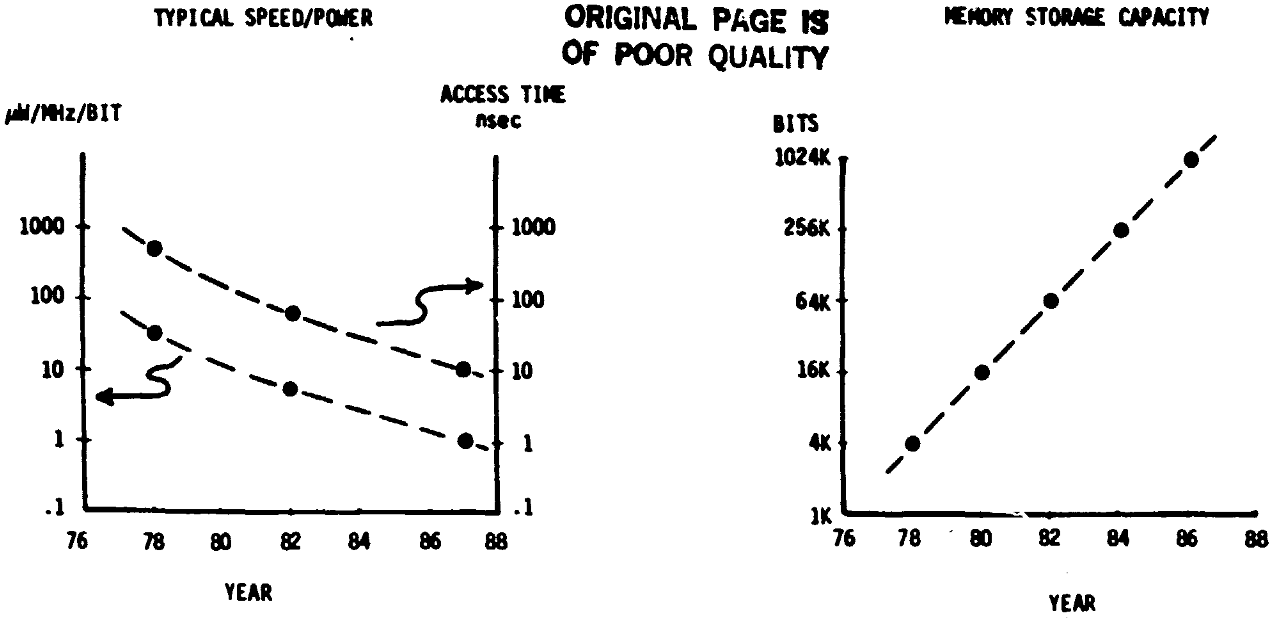


Figure 8.3-1. 1987 CMOS Technology Projections

8.4 CMOS Radiation Hardening

The projected radiation characteristics have been based upon existing state-of-the-art technology and the development rate of radiation hard CMOS processes. Current developments in silicon gate radiation hard processing have produced low density devices with 3×10^5 rad (Si) hardness. High density processes have been successful to a level of 10^4 rads (Si). By 1987, lithographic and processing techniques will be refined to a point where 1.5 μm minimum features will be possible. At this resolution, the packing of the current low density process would increase by a factor of four. This would be sufficient to enable the layout of a device as complex as the present rate 1/2 MCD chip or a 2K × 8 static RAM with the hardness of the present low density process ($\approx 3 \times 10^5$ rads (Si).

In general, speed and power for CMOS devices are scaled by $1/L^2$ and $1/L$, respectively, as critical dimensions of a layout are reduced.

$$L = \frac{\text{old minimum dimension}}{\text{new minimum dimension}}$$

For 1987, the new minimum dimension of 1.5 μm, as compared to the present size of 3 μm, will result in an $L = 2$ and $L^2 = 4$. Therefore, since the present device operates at a maximum data rate of 8 Mb/s, a 1987 version will be capable of 32 MBPS in a nonradiation environment. At a total dose of 3×10^5 rads, there is sufficient dislocation damage and mobility reduction that the final operation speed of a device is cut in half. This means a 1987 rad hard MCD would operate at a maximum frequency of 16 Mb/s. The power scale factor is based upon the device operating at its maximum frequency. It can be shown that for CMOS devices $P_{AVE} \simeq C_T V^2 f$ where C_T = total capacitive load driven, V = supply voltage, and f = maximum clocking speed. A 1987 device would operate at about 1/2 $(l = 2)$, the average power of the 1981 technology device. The same type of scale factors have been used in projecting the 1987 memory devices (see table 8.4-1).

Table 8.4-1. CMOS Radiation Hardening

	1982	1987
1. Convolution Decoder		
Max Data Rate	8 Mb/s	16 Mb/s
Min Feature	3 μM	1.5 μM
RAD Hardness	2×10^4 RADS (Si)	3×10^5 RADS (Si)
Power Consumption	200 mW	100 mW
2. Custom LSI (CMOS)		
Max Clock Speed	15 MHz	30 MHz
Min Feature	3 μM	1.5 μM
RAD Hardness	3×10^5 RADS (Si)	3×10^5 RADS (Si)
3. Memories		
Access Time	100 ns	50 ns
Size	$2\,K \times 8$	$2\,K \times 8$
Power	5 μW/BIT/MHz	1.0 μW/BIT/MHz
RAD Hardness	2×10^4 RADS (Si)	3×10^5 RADS (Si)

SECTION 9

9. SS-FDMA TECHNICAL CONCLUSIONS

The SS-FDMA technical conclusions are:

1. 32 KBPS CVSD is efficient and effective for voice links.
2. Zoning frequency plan reduces router complexity.
3. Router sectorization allows systematic and dramatically reduced complexity.
4. Row-column switching is adequate for required flexibility.
5. Ground Station TWTA linearization potentially saves satellite power.
6. Ground stations may require antenna tracking for large stations.
7. Large ground station TWTA dictated by satellite characteristics.
8. Small ground station G/T dictated by low satellite power.
9. No satellite power boost required for 6 dB downlink rain fade.
10. Estimated router size 15,900 cu in, wt 360 lbs, and power 200 watts can provide a practical small terminal routing system for traffic model A.
11. Satellite small terminal routing system radiated power 360 watts is practical.
12. Router is naturally beam-to-beam path oriented.
13. FDMA SCPC is naturally station-to-station oriented.
14. CONUS coverage inefficient for small station.

The above technical conclusions have been explained rather thoroughly in the previous presentation. The importance of the zoned frequency plan, the sectorized router, and row-column switching can not be understated. These three in combination made a realistic FDMA system architecture. Switch point were reduced from 2.5 million or more to the order of 200. The router power was reduced by an order of magnitude or more. The interconnection topology became manageable. Yet there has been little of any significant reduction in capability. This structure provides insight to even more capability without increased complexity.

The router path orientation and FMDA channel orientation have been noted but not presented in the previous analysis. However, their significance should not be overlooked in further review and analysis of the router structure to enhance greater flexibility and involve simplier multichannel FDMA ground stations.

The SS-FDMA Task I program conclusions are:

- SS-FDMA system architecture dramatically improved by
  - new frequency zoning plan
  - sectorized router organization
- Architectural approach yields insight to even better structure
  - improved organization for wideband video
  - simplified ground stations using path multiplexing
- Key design building blocks
  - analog 8 × 8 switch
  - compact SAW filter construction with good isolation
  - three dimensional structural design

The results of the TASK I 1982 technology SS-FDMA system architecture study have produced a dramatic simplification in the system architecture. The combination of a zoned frequency plan and a sectorized router have made possible a practical FDMA small terminal system. What was an unrealistic and impractical satellite router configuration has become both attractively flexible and realistically practical. This has been realized through a dramatic reduction in number of switch points and in frequency synthesis. This has been the result of this effort.

Further this evolution has yielded insight into possibilities for still further improved structures, probably at no further reduction in size, weight, and power, but with significantly improved throughput flexibility for wideband video and possibly better and simpler multichannel ground stations.

The keys to this structure are the 8 × 8 analog switch development, compact, well isolated, SAW filters, and a practical three dimensional structural design.

SECTION 10

10. RECOMMENDATIONS

10.1 SS-FDMA Technical Recommendations

The SS-FDMA technical recommendations are as follows:

1. Use zoning frequency plan.
2. Use sectorized router.
3. Use row-column switching.
4. Modify frequency plan to accommodate inter-sector switching.
5. Reconsider separate "router" for wideband video.
6. Evaluate single carrier per path impact on ground stations (TDMA/FDMA).

The first three recommendations are a natural result of the conclusions of the analysis. In the process of assembling the final report to TASK I a possible frequency plan modification with no increased ground complexity would allow complete intra-sector column switching. This should be pursued to its logical end as it offers significantly increased router flexibility.

Also not readily apparent in the previous system architecture development is the full role played by the wideband video. Unlike the other channels whose interconnect potential greatly exceeds the number paths, potential wideband video channels represents perhaps only 10% of the number of potential paths. A router reorganization that reflects this could significantly increase the router throughput capability and reduce reaction time to changing traffic. This too should be pursued.

Finally serious consideration should be given to time division multiplexing ground station traffic by paths using TDM/FDMA. Considerably simpler larger FDMA stations are possible.

10.2 SS-FDMA Program Conclusion

The results of the TASK I 1982 technology SS-FDMA system architecture study have produced a dramatic simplification in the system architecture. The combination of a zoned frequency plan and a sectorized router have made possible a practical FDMA small terminal system. What was an unrealistic and impractical satellite router configuration has become both attractively flexible and realistically practical. This has been realized through a dramatic reduction in number of switch points and in frequency synthesis. This have been the key result of this effort.

Further, this evolution has yielded insight into possibilities for still further improved structures, probably at no further reduction in size, weight, and power, but with significantly improved throughput flexibility for wideband video and possibly better and simplier multichannel ground stations.

The keys to this structure are the 8 × 8 analog switch development, compact, well isolated, SAW filters, and a practical three dimensional structural design.

10.3 Recommended SS-FDMA Planning Objectives

The SS-FDMA system architecture design study has resulted in a significantly changed architecture and particularly different router configuration than that first presented in Motorola's original technical proposal. The truly key role played by the 8 × 8 switch, the SAW filters, and the three dimensional architecture have been made evident. In addition the basic subassembly of the router is the sector. A successful demonstration of the three technologies in this subassembly is key and dominant in a demonstration of an SS-FDMA router capability. This in conjunction with the input and output circuitry of one beam would demonstrate the router and its technology. This is recommended as essential to pursue. Likewise this leads to a restructuring of the STE for path evaluation rather than channel testing. Finally there are truly significant advantages that can be pursued for better organization of the router for full row-column switching and to better handle wideband video.

SECTION 11

11. SUPPORT STUDIES (APPENDIXES A THRU J)

A number of support studies have been conducted which provided principle input data to the overall system architecture and to the preliminary organization of the satellite ST Router. The principle studies are listed below as Appendixes A through J:

APPENDIX A	**HIGH POWER AMPLIFIERS**
APPENDIX B	**ROUTER ANALOG SWITCH**
APPENDIX C	**FREQUENCY SYNTHESIZER**
APPENDIX D	**ROUTER SURFACE ACOUSTIC WAVE (SAW) FILTERS**
APPENDIX E	**MODULATION ANALYSIS**
APPENDIX F	**DEMODULATOR EVALUATION**
APPENDIX G	**ERROR CORRECTION CODING/DECODING**
APPENDIX H	**TRAFFIC MODELS**
APPENDIX I	**TRAFFIC MODEL REFINEMENT**
APPENDIX J	**SIGNALLING INTERFACE**

APPENDIX A
HIGH POWER AMPLIFIERS

APPENDIX A
HIGH POWER AMPLIFIERS

A1. EHF HIGH POWER (20GHz) AMPLIFIER CONSTRAINTS

- SOLID-STATE (ADVANCED DEVELOPMENT FOR 30/20 GHz PROGRAM)
  - IMPATT
  - FET
- VACUUM TUBE (ADVANCED DEVELOPER FOR 30/20 GHz PROGRAM)
  - TWT

IMPATT and FET devices are the only solid state devices capable of approaching the required operating frequency (20 GHz). The TWT is the only vacuum tube device capable of supporting the required bandwidth.

A2. TRANSMITTER TECHNOLOGY SUMMARY

Technique	Freq. (GHz)	Gain (dB)	Sat. Power	Eff. (%)	Bandwidth (GHz)
GaAs Power FET	20	5	2w	20–40	
Multi-Stage GaAs	17–20	40	40w	20	2–3
FET Amplifiers*	17–20.2	30	13.5w	15	2–3
Si-IMPATTS	40–50		~2w	~10	
GaAs IMPATTS	40–50		0.5–2.0w	6–18	
TnP IMPATTS	35		~1w	16	
Multi-Stage	41	12	400 mw	10	0.2
IMPATT	37	33	5w	8	0.7
Amplifier	37	13	200 mw	3.5	2.6
	60	23	100–200 mw	6	1.3
	60	21	1w	NA	6.0
*	20	30	20w	20	0.5

*30/20 GHz Program Advanced Technology

The GaAs FET as a power device is severely limited above 20 GHz. In addition, efficiency of the FET when operated linearly is significantly reduced below its saturated efficiency of 15 percent. The bandwidth capability of the IMPATT severely limits its usefulness. In addition, the IMPATT device is typically operated as an ILO. To achieve some degree of linearity, it must be operated in the reflex mode degrading even further inherently low DC-RF efficiency.

The TWT is the most efficient of the three possible devices discussed. It is inherently a high power device. A high cost is associated with the EHF TWT because of severe machining and assembly problems.

A3. TWT TRANSMITTER TECHNOLOGY

- Hughes 918A

P_o	75 watts saturated (high mode) 7.5 watts saturated (low mode)
η(%)	>40% at saturated power (high mode)
BW	>2.5 GHz (17–20 GHz)
Gain	>40 dB (high mode)

- WJ-3712

P_o	25 watts saturated
η(%)	>39.5% at saturated power
BW	>4 GHz (18–22 GHz)
Gain	>49 dB

- VTA 6298A1

P_o	200 watts saturated
η(%)	10–15% at saturated power
BW	1.5% of F_o (F_c = 29 GHz)
Gain	TBD

The table above lists important features of the Hughes TWT (model 918A) being developed for NASA Lewis Research Center.

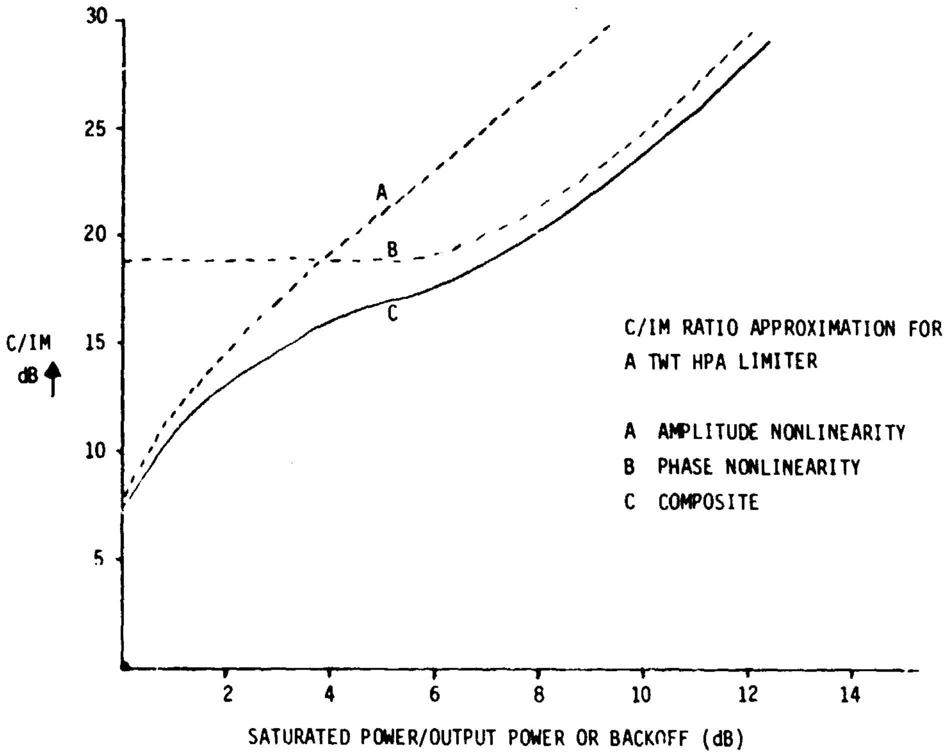
Watkins Johnson is currently performing an IR&D program to develop a TWT capable of operating in the 18–20 GHz range. The WJ-3712 TWT is also included in the table.

The Varian TWT (VTA 6298A1) is being developed as 30/20 GHz advanced technology. The VTA 6298A1 preliminary data is compatible with the ST requirements for the larger classes of ground stations.

A4. CARRIER TO INTERMODULATION PERFORMANCE FOR A TWT

The IM distortion presented in the table below was predicted using the following constraints:

- The input power spectrum to the TWT is composed of many unmodulated equal amplitude carriers. In the limit, the input spectrum may be modeled by white noise.
- The carrier to IM ratio plotted on the Y axis is for a centralized carrier component. The C/IM ratio at band center represents the worst case C/IM.

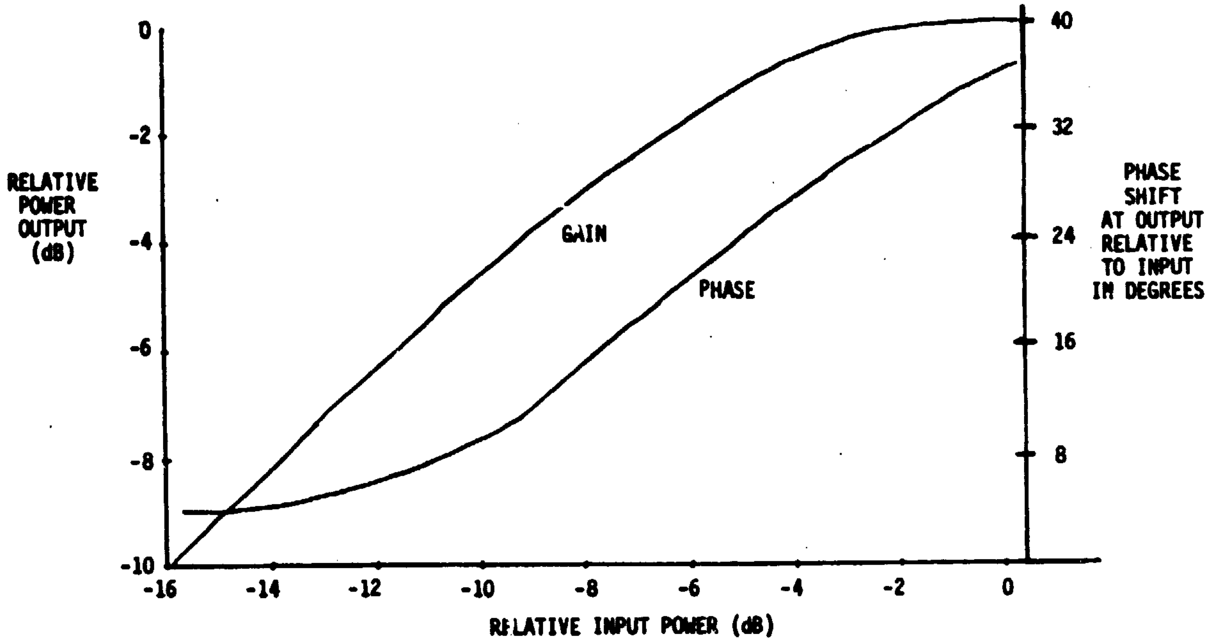


A5. PHASE/GAIN TRANSFER FUNCTION APPROXIMATION FOR TWTA HPA

The gain transfer characteristic is modeled by the error function defined as:

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

The phase transfer characteristic is rather typical of TWT performance and is defined as $0_{out}(\mathrm{deg}) \approx .602[1 - \exp(-3.54P_{in})] + .05P_{in}$. The gain transfer characteristic is used to predict the IM distortion due to amplitude nonlinearities. The phase transfer characteristic is used to predict the AM-PM IM distortion. The phase and gain transfer characteristics are required to predict IM performance.



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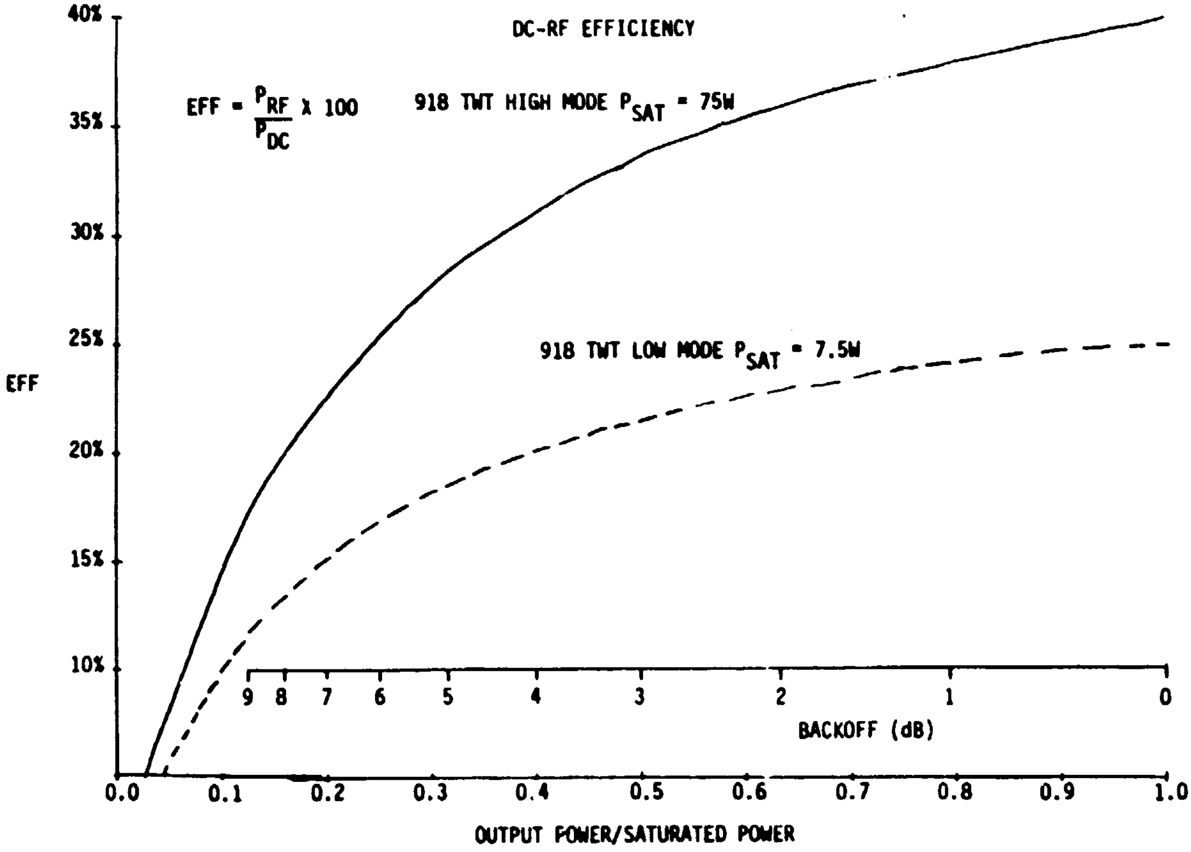
A6. DC-RF EFFICIENCY FOR HUGHES 918A TWT

The high and low model efficiency of the Hughes 918A TWT is plotted below. The efficiency was calculated from the following equations:

$$\text{High Mode} \quad P_{DC}(\text{Watts}) \approx 36.4 + 2P_{RFout}$$

$$\text{Low Mode} \quad P_{DC}(\text{Watts}) \approx 4.9 + 3.4P_{RF\ out}$$

$$\text{where Efficiency} = \frac{P_{RFout}}{P_{DC}}$$



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A7. TWT LINEARIZATION CANDIDATES

- Ground station TWT phase characteristic
- Ground station TWT amplitude characteristics
- Satellite TWT phase characteristics
- Satellite TWT amplitude characteristics

Conclusion: Linearize ground station TWT phase characteristics

Linearization of the ground station TWT phase characteristic was chosen because of the following process of elimination:

- Predistortion/linearization circuitry requires periodic alignment (once or twice a year). As a conclusion, no attempt to linearize the satellite TWT is contemplated.
- Amplitude linearization requires predistortion of the input envelope to the TWT. The input envelope is not easily represented nor is it predictable. In addition, attempts to linearize the transmit envelope could lead to corruption of E^b/N^o at the receiver. The possible corruption is introduced by adding more amplitude nonlinearities and consequently, more potential uncertainty.

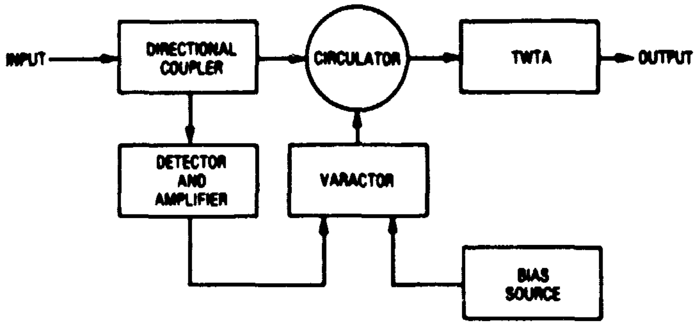
A8. GROUND STATION TWT AM/PM EQUALIZER

Conclusion: Three dB improvement in TWTA's AM-PM conversion

Equalization of TWTA amplitude and phase nonlinearities has been practical over the last 5 years. Although theoretical predictions indicate significant improvements are possible, practical laboratory experiments have yielded less than ideal performance. The equalization circuits are difficult to align and need periodic readjustment (1 to 2 times per year). Practical circuits requiring no adjustment are being built by NEC. An achievable C/IM improvement for AM/PM conversion has been assumed to be at least 3 dB.

The proposed AM/PM equalizer operates as follows:

The amplitude of the multicarrier signal is detected and the bias of a varactor is modulated by this detected amplitude. The change of the varactor is modulated by this detected amplitude. The change of the varactor bias changes the phase of the input signal to the TWTA to cancel the AM/PM distortion.



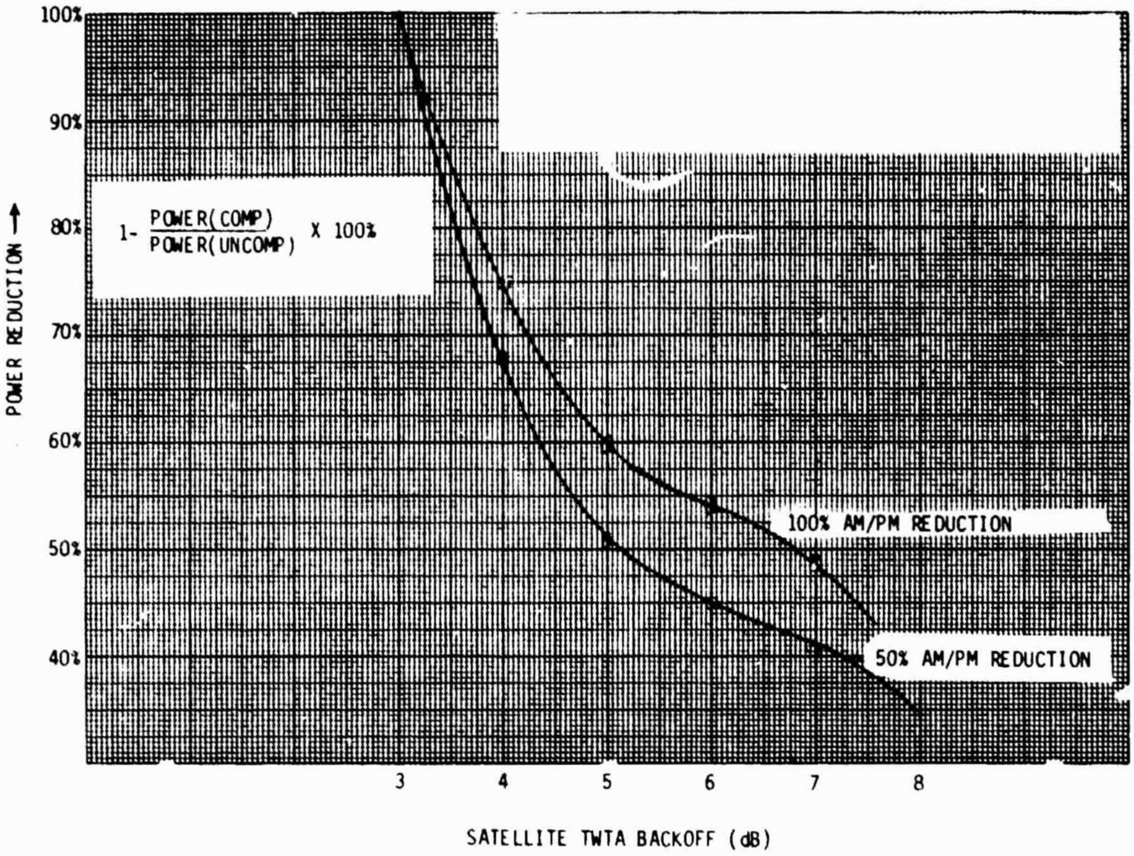
CONCLUSION: THREE dB IMPROVEMENT IN TWTA's AM-PM CONVERSION

A9. TWTA POWER REDUCTION RESULTING FROM GROUND STATION EQUALIZATION OF AM-PM

The curves shown below depict the resulting satellite power reduction when the TWTA at the ground stations are equalized. Two cases of equalization are shown:

- CASE 1 — The AM/PM IM products are completely cancelled out at the ground station (ideal case)
- CASE 2 — The AM/PM IM products are reduced 50% at the ground station (practical case)

The uncompensated satellite TWTA DC power at 3 dB BO is very large (in excess of 100,000 Watts). At 5 dB back off, the uncommpensated TWTA satellite DC power is typically 2500 watts. At 5 dB backoff, the equalization reduces the power requirement to 1200 Watts.



APPENDIX B
ROUTER ANALOG SWITCH

APPENDIX B
ROUTER ANALOG SWITCH

B1. IF SWITCH CONCEPT DESCRIPTION

The IF switch matrix is an essential element of the SS-FDMA system providing interconnection flexibility between the various spot beams and SAW band limiting filters. In analog applications the crosspoint switch configuration offers superior isolation, bandwidth and intermodulation performance over the other non-blocking switches since signals flow through only one switch closure and signal interconnections are straight forward.

The building block concept provides flexibility through the use of one monolithic IC switch element for a variety of switch size and redundancy requirements. The number of elements which may be connected to form a large matrix is limited only by isolation, bandwidth and ceramic substrate size considerations.

The monolithic building block elements are configured to allow fully redundant 8 × 8 switch comprised of four 8 × 8 elements. Switches with only redundant inputs or redundant outputs require two 8 × IC elements.

Multilayer ceramic substrates offer a mature technology capable of isolating the large number of interconnection lines required between densely packed monolithic IC die. The multiple layers are usually alternating depositions of thick film gold and special insulating glass, allowing some layers to form ground planes separated from signal lines by thin dielectric. The proximity of the ground plane provides line to line isolation.

The selection of a basic switch approach which offers low size, weight and power is important in the SS-FDMA system since the total number of switches is high and the DC switch power consumed can be a significant portion of total payload power.

B2. FUNCTIONAL DIAGRAM OF MODULAR SWITCH MATRIX

The functional diagram shown is for a 48 × 48 switch matrix consisting of 36 monolithic IC 8 × 8 elements. In this case each input line is connected to six 8 × 8 elements in parallel. Similarly each output is derived from the outputs of six 8 × 8 elements. Each output may be switched to any one of forty-eight inputs. Forty-eight inputs may be simultaneously connected to forty-eight different outputs.

Immunity to single point failures is achieved on the input by using spare SAW filters and spare switch inputs. On the outputs redundant lines each service three 8 × 8 elements.

The current limitation on multilayer ceramic substrate size (typically 2-1/4 by 2-1/4 in) probably will not allow an entire 48 × 48 matrix to be implemented on one substrate. A substrate containing one half the matrix appears feasible.

Ideally the switch control would be implemented so that any signal path could be changed without disturbing other paths, the number of control bits would be the minimum number possible to specify the switch, and the number of control lines would be small. These mutually exclusive goals can be approached through use of row/column addressing of individual 8 × 8 elements with a single 8 bit data bus to all elements.

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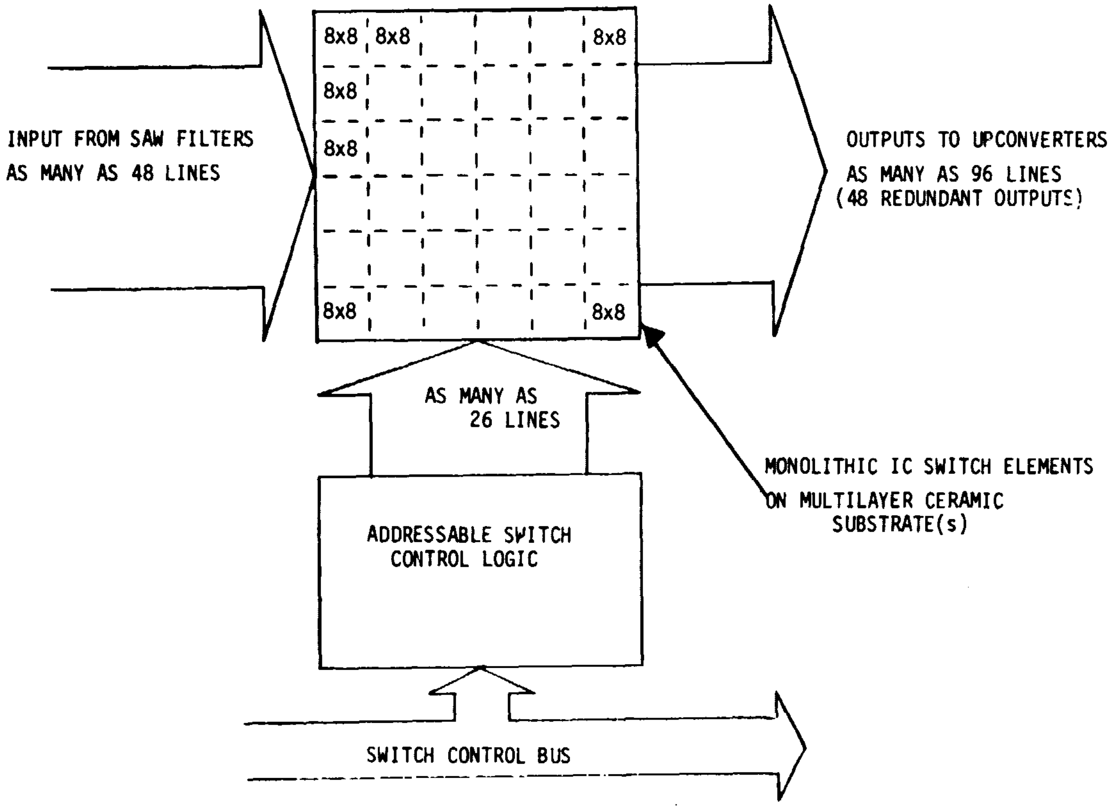


B3. SUMMARY OF PREDICTED SWITCH PERFORMANCE CHARACTERISTICS

Parameter	Proposal		Present Prediction (for Motorola GB6 Gate Array)
	Requirements	Prediction	
Size	48 × 48	48 × 48	8 × 8 to 48 × 48 in multiples of 8
Input Bandwidth	20 MHz per ch.	---	48 × 48: 25 MHz (−1 dB) 16 × 16: 160 MHz (−1 dB)
Output Bandwidth	200 MHz	200 MHz (−3 dB)	48 × 48: 200 MHz (−3 dB) 16 × 16: 300 MHz (−3 dB)
Upper Frequency	300 MHz	300 MHz (−3 dB)	48 × 48: 300 MHz max. 16 × 16: <300 MHz, <400 MHz
Isolation:		---	48 × 48: 23 dB at 270 MHz
Worst Case	20 dB		16 × 16: 40 dB at 270 MHz
Switch Elements Alone	---	48 × 48: 100 dB at 270 MHz	---
Nominal Signal Level	−30 dBm	---	−30 dBm
Setup Time	1 msec	---	100 μsec with 1 MHz clock.
Intermodulation Distortion	−30 dB	3rd order −60 dB	3rd order −40 dB
Gain	0 dB	+3 to +6	0 dB
DC Power Consumption	---	8 × 16 chip: 174 mW 48 × 48 chip: 3132 mW	8 × 8 chip: 306 mW 48 × 48: 5300 mW (pwr managed)
Dimensions	---	2 in × 2 in	48 × 48: 2.5 × 2.5 min substrate 16 × 16: 1.0 × 1.0 substrate

The present performance predictions are the preliminary results of analysis for monolithic 8 × 8 switch elements mounted on a multilayer ceramic substrate. A control concept for the switch elements has been devised, preliminary schematics for array cells have been generated and the limitations imposed by available intercell interconnect space have been assessed. These efforts have resulted in preliminary values for power consumption, maximum IC switch dimensions (8 × 8) and setup time.

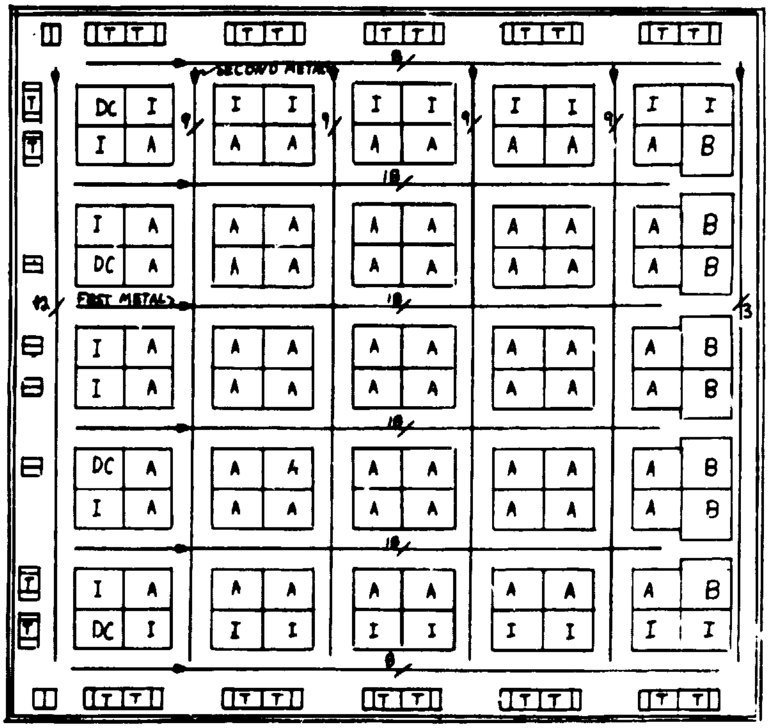
The use of groundplane layers in the multilayer ceramic substrate for isolation between RF lines has been investigated resulting in computer models for stripline and microstrip approaches. Results shown are for microstrip. Interconnection lines and other elements of the monolithic ICC switch element have also been modeled. Values for bandwidths and isolation have been generated by combining the models.

B4. MOTOROLA GEG GB6 CELL ARRAY LAYOUT

The GB6 cell array was developed for large scale ECL integrated circuit applications. Each cell in the array contains a number of unconnected transistors and resistors. The final steps of wafer processing, where first and second metal are applied, provide the interconnection patterns. Thus, wafers preprocessed through deposition of first metal may be used for various devices which differ only in interconnect patterns. Since each cell contains isolated transistors and resistors, applications are not limited to ECL functions.

The number of resistors and transistors and the resistor values and transistor current carrying capabilities vary among the various cell types. The bias networks in each cell are designed for proper temperature compensation with a −4 volt supply. The bias networks are fairly flexible; current may be adjusted to minimize power consumption.

Resistive level translators allow internal ECL to operate from 0 to +5 volt CMOS logic level inputs. ECL may be implemented with low operating currents to provide necessary on-chip logic functions for the monolithic IC switch.



DIE SIZE 251 x 229 MILS

NUMBER OF BOND PADS 72

WAFER PROCESSING: MICARL

CHIP CONTROL: GEG

INTERCONNECT CONTROL: GEG

TOTAL CELLS	100
INPUT (I)	24
ARRAY (A)	64
OUTPUT (B)	8
BUFFER (DC)	4

CMOS-ECL INPUT TRANSLATORS 24

BIAS INTERNAL TO EACH CELL

B5. POWER BUDGET FOR 8 × 8 SWITCH CHIP USING THE GB6 CELL ARRAY

Power Budget for 8 × 8 switch chip using the GB6 Cell Array

Cell Description	All Outputs Operating		Reduction Per Off Output
	Contributors to Current	Total at $V_{CE} = -4$ VDC	
CMOS-ECL	0.2 mA/Input × 12 Inputs	240 mA	—
Data Latch	0.21 mA/Latch × 8 Latches Plus 0.32 mA/Bias × 2 Bias Circuits	2.32 mA	—
Output Buffer	0.284 mA/Power Control × 8 Controls	2.27 mA	2.62 mA/Buffer
	3.70 mA/Buffer × 8 Buffers	29.6 mA	
Master-Slave	0.458 mA/M-S × 3 × 8 Master-Slave	11.0 mA	—
Dual Decoder	0.114 mA/Dual × 4 × 8 Dual Decoders	3.65 mA	0.114 × 4 mA/Output
	0.14 mA/Bias × 8 Bias Circuits	1.12 mA	0.14 mA/Bias Circuit
Switch	2.16 mA/Switch × 8 Switches	17.28 mA	2.16 mA/Switch
	0.52 mA/V_B × 8 Switches	4.16 mA	0.52 mA/Output
Clock Driver	1.30 mA/Driver × 2 Drivers	2.60 mA	—
Total Chip Current		Outputs On: 76.40 mA	Reduction: 5.9 mA/Output Off
Total Chip Power		305.60 mW	23.6 mW/Output Off

Power consumption for a 48 × 48 switch: (305.6 mW × 36)-(23.6 × 8 × 30) = 5335 mW

Power consumption for a 16 × 16 switch: (305.6 mW × 4)-(23.6 × 8 × 2) = 845 mW

The power budget values are calculated from preliminary schematics of each array cell type. The schematics were based on the available transistor and resistor values of the GB6 cell array. Power management is implemented to controlling current sources which supply the dual decoder cells, the switch cells and the output buffer associated with each output. The reduction shown is that caused by disabling one output. The eight data latches store the on/off control data for the power management circuits.

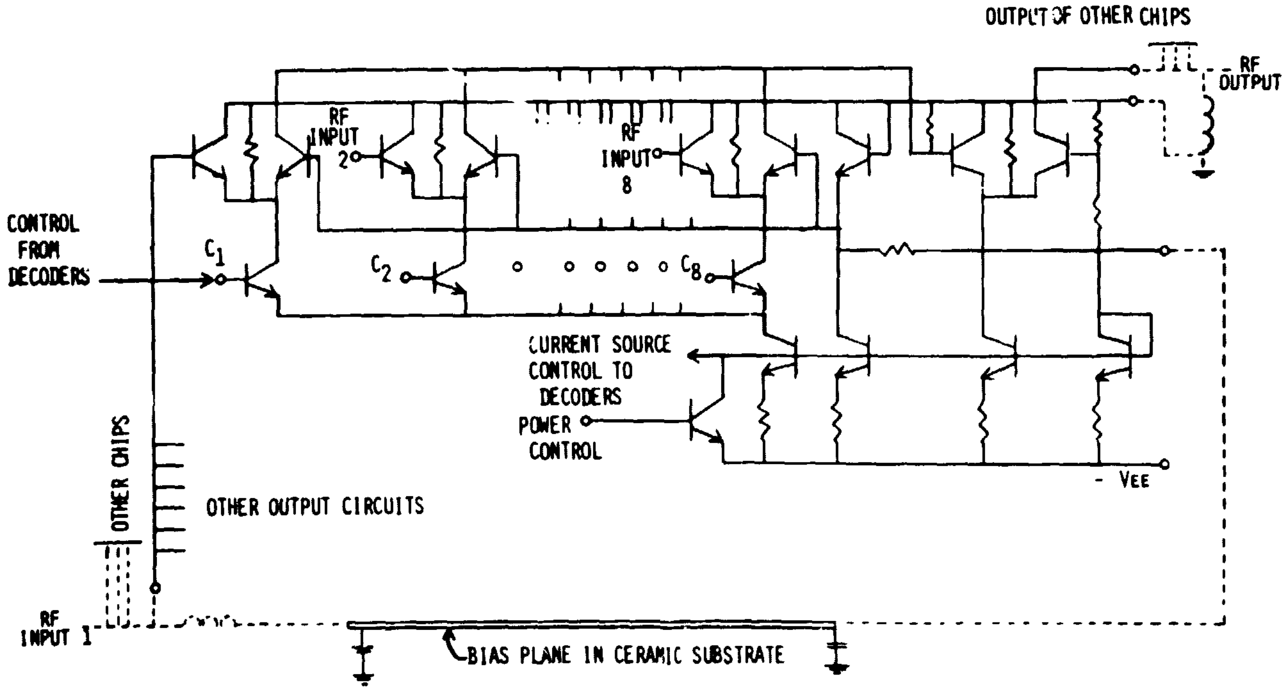
A further reduction of total switch power is possible by disabling the current sources which supply master-slave shift registers. This imposes the operational constraint that desired outputs must be enabled prior to shift register loading; however, total power for a 48 × 48 switch will fall to 4.1 watts from 5.3 watts.

B6. DIFFERENTIAL TRANSISTOR PAIR SWITCH, OUTPUT BUFFER, AND BIASING

The differential transistor pair switches shown in this conceptual schematic drive the single differential pair buffer to form one output of an 8 × 8 switch. Control voltages C1 through C8, one of which is high, steer current to the desired switch. When the desired output is from another IC, the power control disables the current sources and thus disables eight switches and the buffer in the IC shown.

Several measures are depicted which have been determined through analysis to improve RF characteristics. The differential switch pair is driven single ended so that the output may be isolated by two reverse biased base-emitter junctions when off. Each of the eight IC outputs has its own separate collector return exiting the device to off chip ground. This is necessary to isolate the base bias of each differential pair output transistors from voltages induced in resistive ground metallization by other output switches and buffers. A resistor in each switch pair provides predictable base emitter reverse bias and thus low input capacitance when the switch is OFF. Inputs are biased off chip from the same voltage used to bias the switch pair output transistor. Attempts to devise on-chip bias networks with high isolation have proven futile due to the conflict of low bias source resistances required to maintain balance with high source resistance required for isolation. A sufficient quantity of high value resistors in unavailable in the cells for on-chip bias.

The primary advantages of the differential pair switch are that it can provide high isolation, is compatible with existing MOSAIC processing and existing cell arrays and that is provides flat unilaterial gain over a wide bandwidth with low current drain.

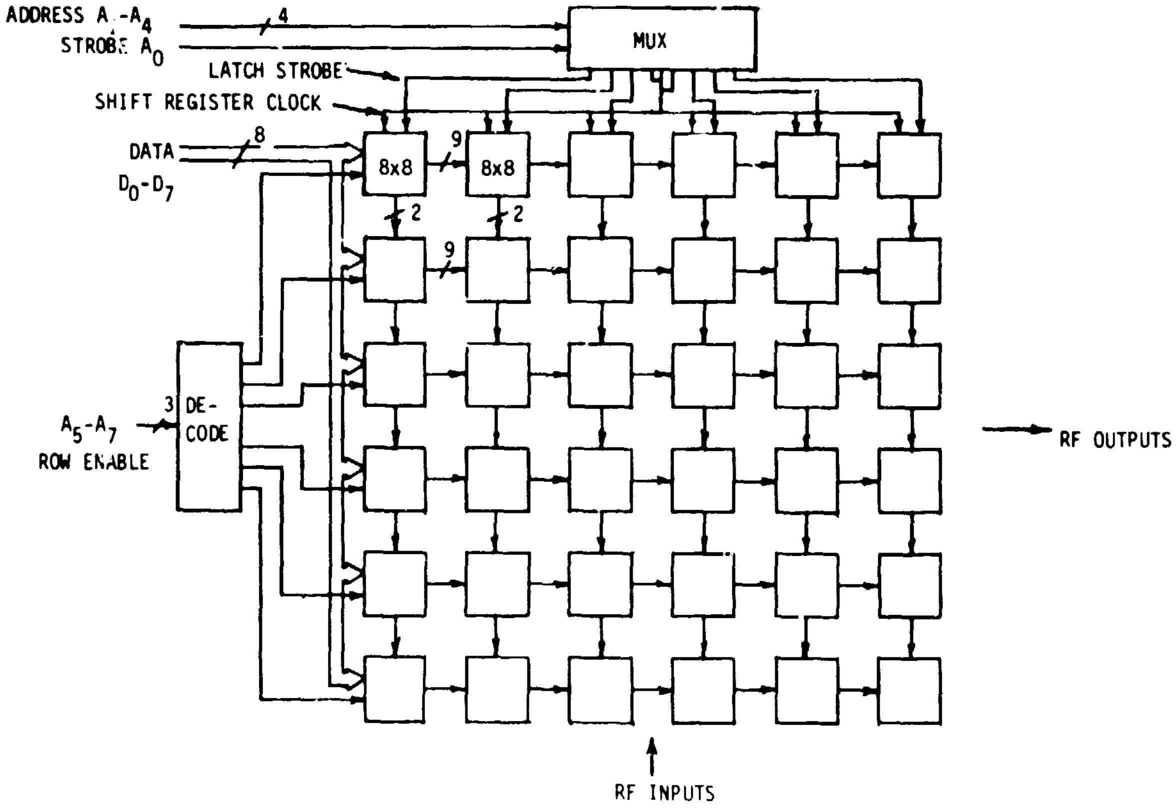


B7. BASIC CONTROL CONCEPT

Control input functions

- Enable line for each row of 8 × 8 switches
  - Enables both shift register clock and power control latch strobe.
- Shift register clock to all 8 × 8 switches
  - Simultaneously clocks data to all 8 × 8 switches occupying a row which has its clock inputs enabled. Drives eight 3-bit shift registers in each 8 × 8. All shift registers in one row recieve the same data.
- Latch strobe for each column of 8 × 8 switches
  - Power control latches are strobed in a single 8 × 8 switch in the row which has its latch strobe inputs enabled. Simultaneously strobes eight latches in an 8 × 8, one for each output.
- Data bus to all 8 × 8 switches (8-bit parallel)
  - Provides shift register input data over one line for each of eight 3-bit registers per 8 × 8. The same data is simultaneously received by registers in all 8 × 8's in a row; however, the data is used only in the one 8 × 8 per row which will have a particular output powered through use of power latches.

    The data bus also provides power latch input data over the same lines for each of eight latches per 8 × 8. An 8-bit word is strobed into each 8 × 8, powering only the desired outputs from that chip.

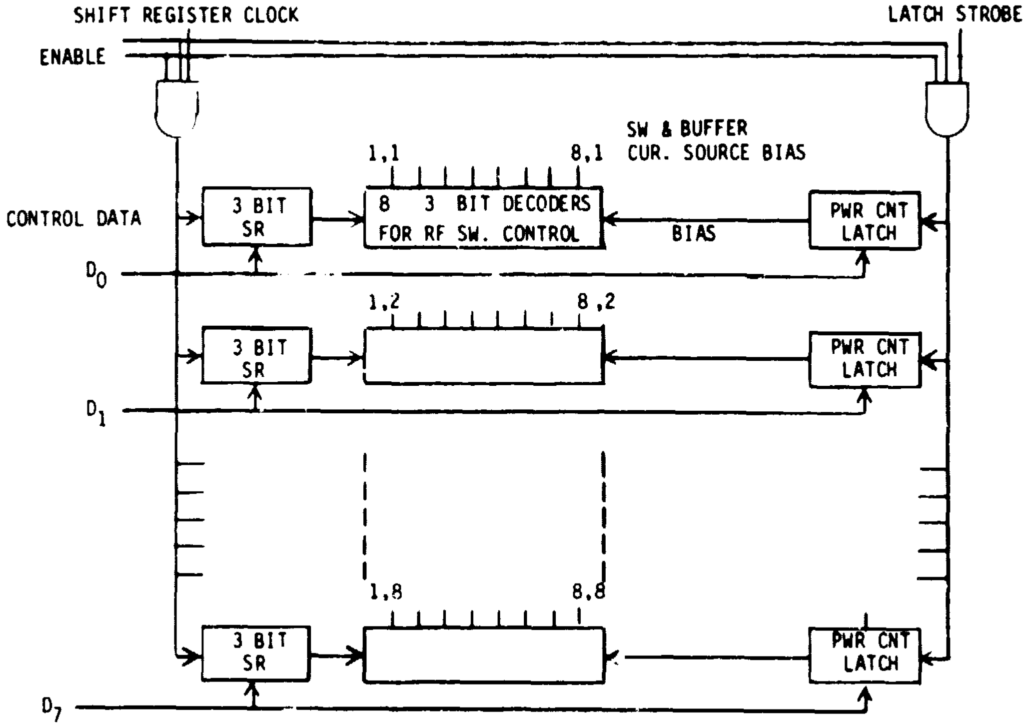


This approach allows the switch to be specified with very nearly the lowest number of control bits possible. The compexity of on-chip logic is minimized as are on-chip interconnections. A disadvantage is that changing one output will momentarily disturb other outputs of the same 8 × 8 while new serial data is being clocked to registers. A similar approach using latches exclusively is being investigated as an improvement which may eliminate this characteristic.

B8. 8 × 8 SWITCH CONTROL LOGIC AND POWER MANAGEMENT

The control logic provides control word storage and routing necessary to specify the state of each crosspoint of the 8 × 8 switch IC. The memory is included in the IC so that control words may be transferred sequentially over a reasonably small number of lines to the switch. The configuration shown is within GB6 array complexity limits. It provides flexibility for a range of compromises between the number of control lines, switch setup time and the size of the minimum portion of the matrix which may be updated independently without momentarily disrupting other portions.

For example, the control arrangement shown on a previous cell for a 48 × 48 switch requires that a full row of 8 × 8 switches be updated simultaneously. Twenty-one control lines are required for the full switch which can be completely updated in 54 clock cycles, nine cycles per row. With 22 lines and slightly more complex external logic, 8 × 8 switch elements may be updated independently by enabling both row and by column of ICs. The same 54 clock cycle setup time for a 48 × 48 switch may be retained by enabling all columns simultaneously during shift register loading when a full switch update is desired. In contrast, the originally proposed concept of a single long shift register in each switch chip with one data input and one clock input per chip would require 72 control lines and 160 clock cycles if eight chips are loaded in parallel in a 48 × 48 switch.



When a much smaller 16 × 16 switch is used, the control arrangement shown requires 14 control lines to the switch matrix and a complete update can occur in ten clock cycles. The originally proposed concept would have required eight control lines and 32 clock cycles for a full update if the four chips are loaded in parallel.

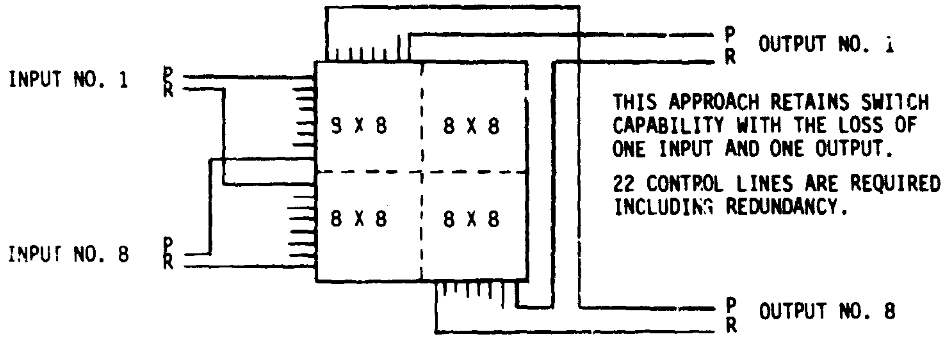
A modification of the present switch concept requires evaluation. Replacing the three bit shift register with three latches will allow one output of the switch to be updated without disturbing any other output. Whether the increased number of on-chip interconnect lines may be accommodated and power impact are primary concerns in the full latch approach. The control approach shown is the best one devised to date which can clearly be accommodated in the GB6 cell array.

B9. REDUNDANT 8 × 8 SWITCH CONCEPT

Two redundancy approaches are shown since a small increase in hardware appears to produce substantially increased redundancy, at a price in DC power.

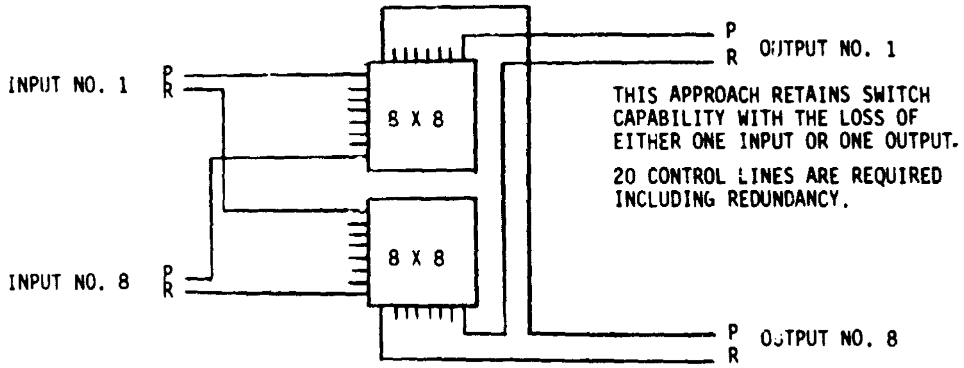
The upper diagram shows a switch which requires no external power division or summing to preclude single point failures when used with redundant source and load units. Loss of a switch input or source unit will not degrade operation of the other switch input with either output. Similarly, loss of a switch output or load unit will not degrade use of either the primary of redundant input.

The lower diagram shows a switch which requires cross-strapping at either the input or output to prevent single point failures. Passive hybrid coupler cross-strapping of sources or loads with the switch will prevent loss of a pair of source and load units with failure of one 8 × 8 element.



THIS APPROACH RETAINS SWITCH CAPABILITY WITH THE LOSS OF ONE INPUT AND ONE OUTPUT.

22 CONTROL LINES ARE REQUIRED INCLUDING REDUNDANCY.



THIS APPROACH RETAINS SWITCH CAPABILITY WITH THE LOSS OF EITHER ONE INPUT OR ONE OUTPUT.

20 CONTROL LINES ARE REQUIRED INCLUDING REDUNDANCY.

B10. CHARACTERISTICS OF THE SELECTED MONOLITHIC IC SWITCH DESIGN

- Silicon bipolar technology - well established, low risk, low impedance signal paths, better isolation
- Motorola MOSAIC I monolithic integrated circuit process - high density, high performance
- Motorola GEG cell array (GB6), MICARL processing, flexibility, high performance, low development time
- Differential transistor pairs as switch elements - good isolation, lower power, simple control, wide bandwidth, linear unilaterial gain
- On chip storage of switch configuration (shift reg, latches) - necessary for reasonable number of control lines
- Power management - power reduction in switch elements having inactive outputs

Several alternatives to silicon bipolar technology exist including GaAs FETs, CMOS Silicon on Sapphire and PIN diodes. The desired switch RF characteristics are attainable with all of these approaches. The only notable disadvantage of the silicon bipolar approach over the most likely alternative CMOS-SOS is that silicon bipolar power consumption will be higher. In favor, the unilateral transfer function of silicon bipolar switches provides the isolation necessary to stabilize passband characteristics against possible VSWR variations due to switching.

The features of the Motorola GB6 cell array which provide flexibility include a large number of unconnected resistors with a range of values, interconnect alleys run both directions across the chip so that both layers of metal can be used for connections internal to cells. In addition the option exists for future process changes in pre-metal layers if desirable since wafer processing is under Motorola GEG control.

Power management is desirable for the switch design since the total switch power is a significant portion of total SS-FDMA power for some possible configurations and the potential savings are substantial (i.e., 50% reduction for a 48 × 48 switch and 30% for a 16 × 16 switch).

The breadboard design studies listed below are intended to refine the switch concept in key areas prior to detailed design efforts.

- Complete on-chip isolation model:

  Analysis to date used estimates for resistive coupling in the substrate below parallel input and output lines. A more exact model is now available. Some unavoidable input to input line cross-overs were not included in the initial analysis.

- Perform further analysis and trade-off studies of isolation in the multilayer ceramic substrate to which monolithic switches will be mounted:

  The version of compact used for line-to-line coupling evaluation must be verified for accuracy at the line dimensions being used.

  Trade-off isolation vs bandwidth in selecting line dimensions and microstripline vs stripline structure in the layers. (Preliminary data presented is for microstripline).

- Further study of latch and shift register control concepts is needed:

  Prefer latches since each output could be updated without interrupting other outputs.

  The number of on-chip interconnect lines may prohibit the latch approach. The latch approach may consume more power.

- Attempt a preliminary metal layout on a few critical cells.
- Continue to refine preliminary cell schematics.
- Refine switch redundancy concept.

APPENDIX C
FREQUENCY SYNTHESIZER

APPENDIX C
FREQUENCY SYNTHESIZER

C1. SYNTHESIZER REQUIREMENTS

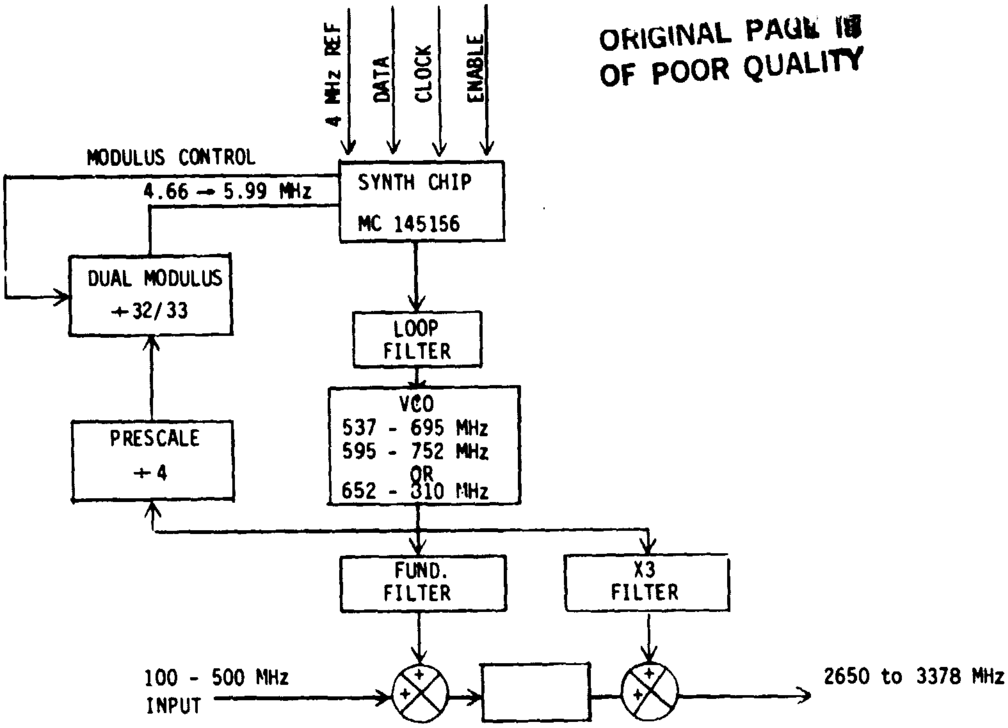
- Synthesizers are required for carrier frequency generation both at the ST and the satellite.
- The synthesizers must cover a wide range of frequencies.
- The synthesizer phase noise is a major constraint on the design and must be minimized.
- Switching and settling times are not of prime concern up to a reasonable fraction of a second.
- The burden of long term stability can be transferred to the synthesizer reference.

Although the concept of the frequency plan does not require the use of programmable frequency synthesizers in the router, it does not remove the requirements for frequency synthesis as the receive bands must be broken into lesser bandwidth sections for processing. The concept of system frequency control requires that all signals used for translating a received channel be coherently derived from a satellite replica of the system master oscillator at the network control station. Although that master oscillator could have been located in the satellite, it appears more logically placed at the network control station where long-term drifts can be corrected, and it adds no complexity to either the satellite or to the CPS equipment.

The synthesis in the router is, however, greatly simplified as only a few (~15) frequencies need to be synthesized and the synthesized frequencies can be relatively widely separated. This permits a high reference frequency to be used with a wideband phase locked loop in an indirect frequency synthesizer. Although the synthesizers can be programmable, for this application the desired frequencies can be hardwired.

C2. SYNTHESIZER CONCEPT

The synthesizer concept is that of an indirect synthesizer in which the output frequencies are derived in a voltage controlled oscillator which after frequency division is compared against a stable reference. In this case the reference is derived in the network control receiver. The principle design problem with this type of synthesizer, that of added phase noise originating in the VCO, is greatly relieved for this application because the wide spac-



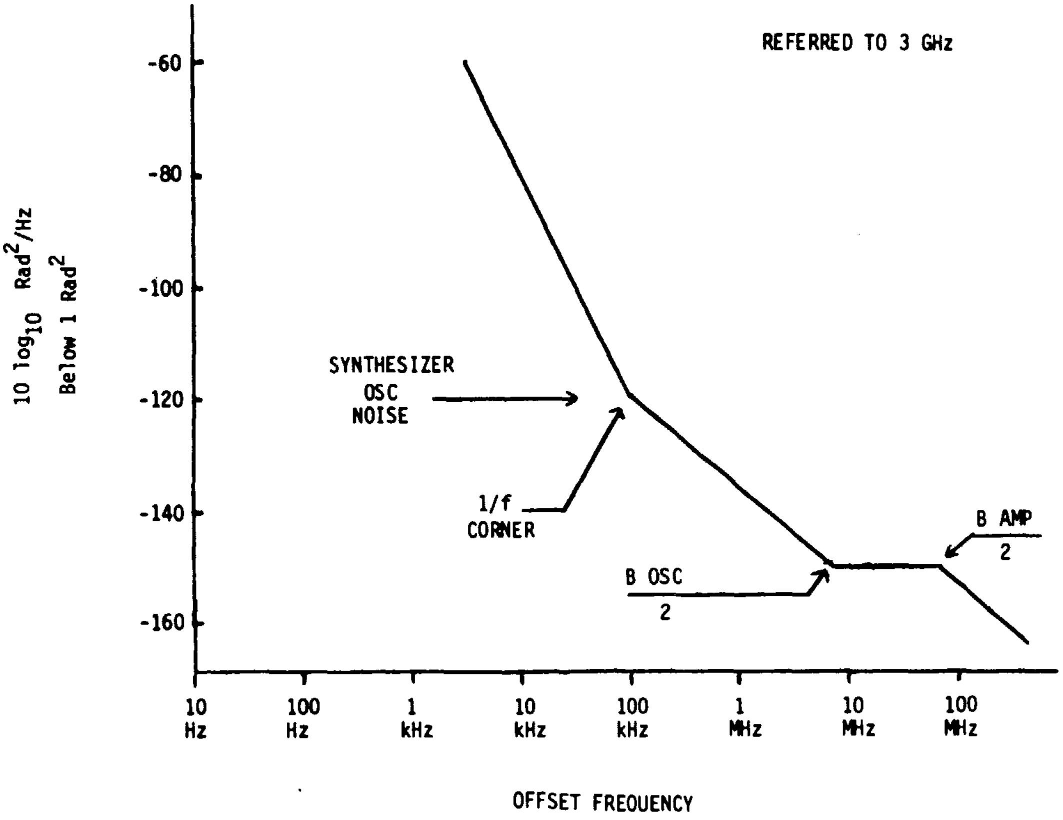
ings of the desired output frequencies do not require high division ratios. This permits a relatively high phase comparison frequency in the synthesizer and a correspondingly wide closed loop bandwidth for the synthesizer. The synthesizer feedback then cancels the low frequency part of the noise spectrum. As the noise spectrum is expected to be modeled as:

$$S\phi = \sum_{n-o}^{n} \frac{K_n}{f^n} = K_o + \frac{K_1}{f} + \frac{K_2}{f^2} + \frac{K_3}{f^3}$$

the majority of the noise will be at the lower frequency offsets from the output carrier.

C3. SYNTHESIZER NOISE SOURCES

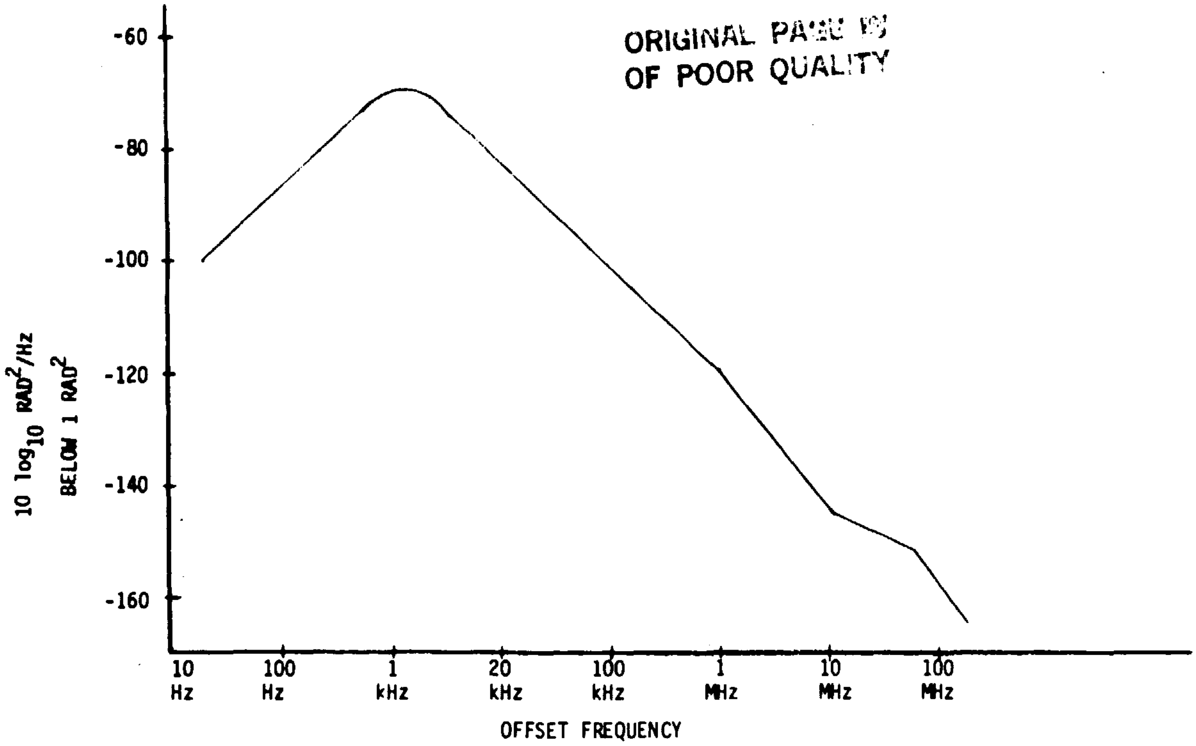
The projected phase noise spectral density, as a function of offset frequency is expected to be dominated by three terms. There will be a frequency insensitive phase noise density at a level which is determined by the noise figure of the oscillator amplifier and it will extend out to the half bandwidth of that amplifier (or any succeeding amplifier). Next there is a noise spectral density which falls at 6 dB/octave due to the equipartition noise in the oscillator tuned circuit. At frequencies beyond the half bandwidth this component will fall at a higher rate. Finally there is the flicker frequency noise falling at 9 dB per octave which is present in all physical oscillators. This noise extends from very low offset frequencies out to a corner frequency which is related to the class of oscillator.



For the satellite synthesizers the amplifier bandwidths will exceed 100 MHz, the oscillator tuned circuit "Q" will be about 200 in a distributed component tuned circuit. The corner frequency for the flicker noise is expected to be about 100 kHz for this class of oscillator. The levels shown include the effective frequency multiplication by four.

C4. PROJECTED SYNTHESIZER NOISE

The projected phase noise at the synthesizer output will be the portion of the phase noise in its reference frequency input which lies within the synthesizer phase locked loop bandwidth, and the portion of the noise generated within the synthesizer which is outside its loop bandwidth. As the reference is highly filtered in a narrow band crystal con-



trolled phase locked loop, the synthesizer output phase noise will be dominated by that noise generated by itself and it in turn is primarily the reactance control noise. The resultant mean square phase

$$\sigma^2 = \left(\frac{K^3}{\sqrt{2\epsilon(1-\epsilon^2)}\,\omega_n^2}\right)\tan^{-1}\left(\frac{\sqrt{(1-\epsilon^2)}}{\epsilon}\right)$$

where $K_3 = (6.25 \times 10_4)$ rad^4/sec^2 from the synthesizer noise source chart and ω_n is the loop natural frequency and is 1.89×10^4 radians/sec for this analysis:

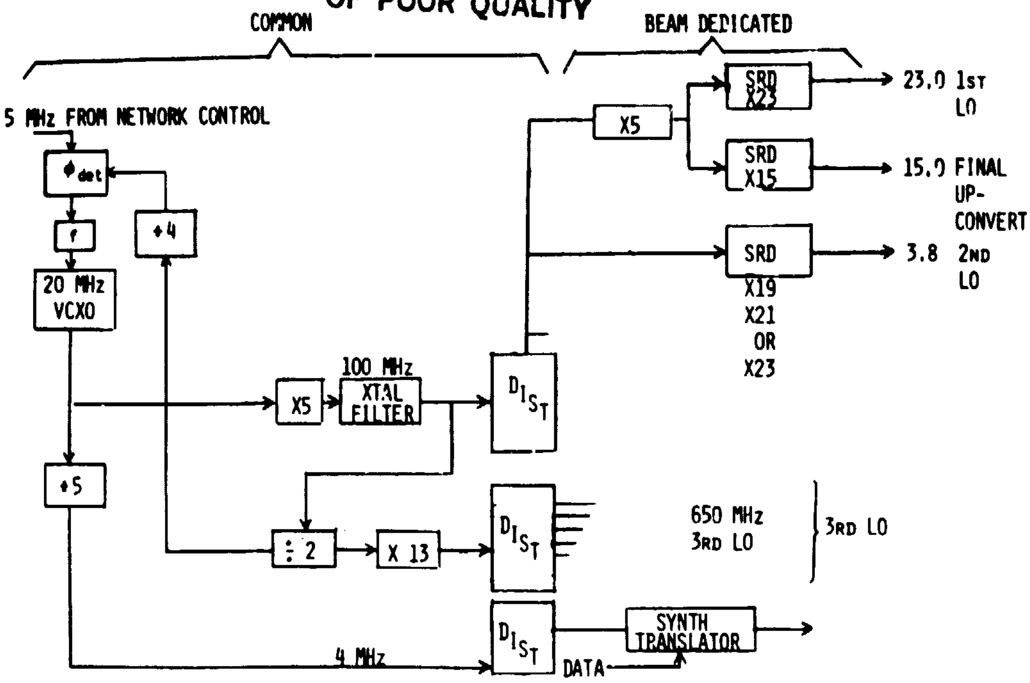
then $\sigma^2 = 1.37 \times 10^{-4}$ rad^2

or $\sigma = 0.67$ degrees RMS

This is the predicted synthesizer loop contribution to the carrier frequency stability.

C5. SATELLITE REFERENCE FREQUENCY GENERATOR

The signal path through the router requires a number of frequency translations, both down and up in its course from an input beam to an output beam. To perserve frequency coherence it is necessary that all of the translations be against a known multiple (perhaps fractional) of the master oscillator in the network control station. This is done by erecting a satellite reference by way of coherent phase lock to the network control carrier.



The required local oscillator and upconverter signals are then generated for the satellite reference by appropriate frequency multiplication, division, or other means of coherent synthesis and then distributed to the sections of the router where they are required.

This centralized reference generation greatly reduces the amount of hardware over the generation of each signal at the place where it is to be used, but a failure in either the network control receiver or the reference generator would disable a large part of the system. They both should be highly redundant to prevent this from happening.

C6. PROJECTED POC SYNTHESIZER TRANSLATOR

	Power (mW)	Size (in)	Weight
Voltage Controlled Oscillator	60	1.00 × 0.60 × 0.25	
Tripler	30	0.80 × 0.50 × 0.25	
Prescale ÷2 ÷2	42	1.60 × 0.50 × 0.20	
Dual Modulus ÷8/9	70	0.75 × 0.25 × 0.20	
Modulus Extender	40	0.23 dia × 0.19	
Synthesizer	25	1 × 0.4 × 0.20	
Mixers (2)	–	1 × 0.21 × 0.25	
Bandpass filters (3)	–	3.0 × 1.0 × 0.25	
		1.338 in^3	0.10 lb

Asembled volume = 2.0 in^3

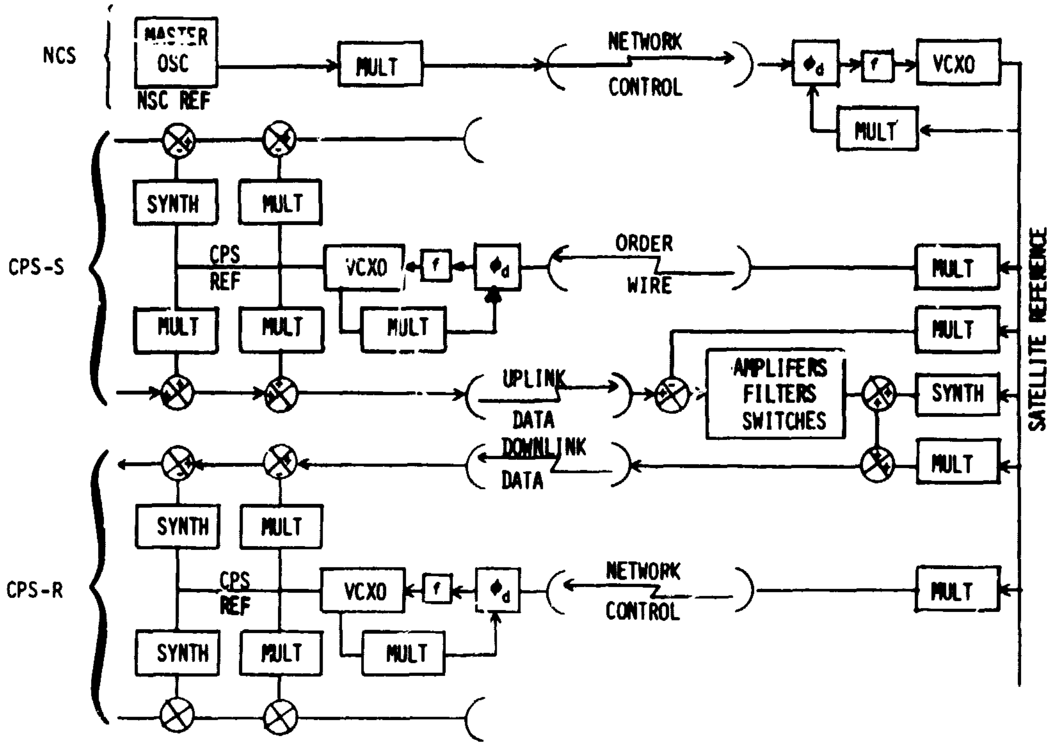
Assembled Weight 0.14 lb

As the number of frequency synthesizers required in the satellite has been reduced from 1600 to about 40, the incentive for extreme miniaturization has been correspondingly reduced. It may still be economically advantageous to apply some degree of custom LSI to the basic design, however, as each ST station will need a minimum of two synthesizers.

The accompanying chart is for a current design using available components. The major difficulty in meeting these projections will be in achieving the desired VCO "Q" in the allotted volume.

C7. CLOSED LOOP NETWORK CONTROL

The SS-FDMA system must accommodate tightly packed 1 Bit/Hz narrowband channels. To do this successfully without requiring excessive carrier frequency guard bands necessitates good frequency stability. The recommended approach is to distribute a system frequency reference from NCS.This "master oscillator" can be recovered at the satellite over the network control link using a long loop phase locked loop shown as a simple loop in the diagram below. This signal provides the reference for all the satellite local oscillators.



The outboard orderwire signal over the network control channels is sent to each ST. Here it is received again in a long loop phase locked loop to provide a frequency reference for the ST. This signal then provides a frequency reference for the ST data communications uplinks so that when received by another ST a fully coherent signal control has been achieved throughout.

This method requires little to no additional hardware. It simply utilizes the information that is contained in the signals throughout the system to achieve a high stability frequency reference at a nominal ST cost.

APPENDIX D
ROUTER SURFACE ACOUSTIC WAVE (SAW) FILTERS

APPENDIX D
ROUTER SURFACE ACOUSTIC WAVE (SAW) FILTERS

D1. SAW FILTER PREDICTED PERFORMANCE VS REQUIREMENTS

Item	Proposal						Present Freq Plan					
	Reqmts	Predicted					Reqmts	Present Prediction				
Center Frequency Range (MHz)	100-267	100	140	200	270	270	TBD	50	50	90	180	270
Passband Widths, B (MHz)	1,2,4,8,15	1	2	4	8	15	1,2,4,8,15	1	2	4	8	15
Transition Band (1 dB-20 dB) (MHz)	<1.5B	.25	.5	1.0	2.0	3.75	<1.5B	.25	.5	1.0	2.0	3.75
Stop Bands	<2.0B						<2.0B					
Insertion Loss	MIN	20	18	18	20	22	MIN	20	18	18	20	25
Group Delay Deviation	<10%	<540 nsec	<270 nsec	<140 nsec	<70 nsec	<40 nsec						
Amplitude Ripple (dB, Pk to Pk)	<1.0	<1.0 dB					<1.0 dB					
Phase Deviation (Deg, Pk to Pk)	<6.0	<6.0										
Rejection Level (dB)	>45	>45 dB					>45 dB					
Temperature (°C)	−20 to +55	−20 to +55					−20 to +55					

Detailed predictions of SAW filter performance requires a design exercise using a definitive set of filter requirements. Such an exercise will be performed once the frequency plan is more firm than at present. The performance limitations of this and paragraph D2 will serve to guide the final frequency plan definitions.

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D2. LIMITS OF QUARTZ SAW FILTER BANDWIDTH VS CENTER FREQUENCY

The range of practical Quartz substrate SAW bandpass filter bandwidths as a function of center frequency is constrained for the given shape factor and amplitude ripple:

By loss in the case of maximum percent bandwidth

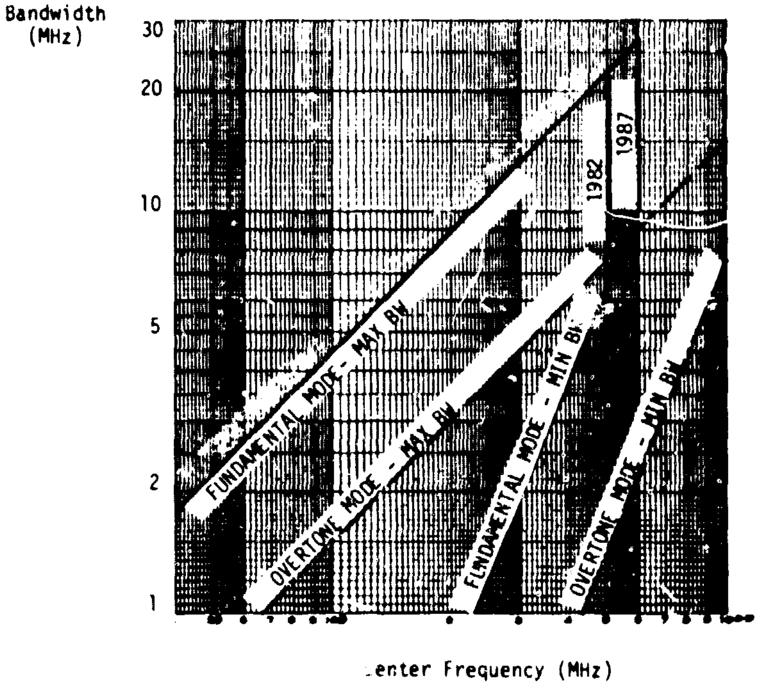
By the size of the minimum dimension which must be replicated (i.e. mask and photolithic resolution) in the case of maximum center frequency

By high order effects associated with the large number of transducer fingers required at higher center frequencies in the case of minimum bandwidth.

In addition, the SAW filter substrate length is primarily a function of bandwidth. A 1 MHz bandwidth will be accommodated by a 1 inch long substrate, a practical length.

The technology improvement for 1987 is in the area of mask and photolithograhic resolution. Optically generated masks are presently usable to 400 MHz while electronic beam generated masks are used to 500 MHz fundamental mode center frequencies.

As shown, wide bandwidth filters are limited to the upper IF frequencies. Due to switch frequency limitations, some SS-FDMA applications may require wide bandwidths at frequencies as low as 100 MHz. For these requirements Lithium Niobate SAW filters can be used. They provide several times the percent bandwidth of quartz filters; however, their center frequency temperature coefficient is −90 ppm/°C. For wide bandwidth filters (i.e., 5 to 12% BW) this coefficient is acceptable.



Conditions -

-20dB/-1dB Shape Factor:

1.5: 1

Amplitude Ripple:

1dB pk to pk

Loss:

22dB maximum

APPENDIX E
MODULATION ANALYSIS

APPENDIX E
MODULATION ANALYSIS

E1. TRADE-OFF CURVES

Trade-Off Curves. The modulation trade-off curves shown in the figure below and the results presented in this section are in support of material presented in Section 4.6. This data is based on a four pole Butterworth transmission filter, an ideal matched filter (zero distortion), and a bit error rate (BER) of 10^{-6}. The investigation is being expanded to more fully investigate filter types and filter order vs. carrier to noise power (CNR) degradation as well as investigating the employment of a nonideal receiver detector (i.e., an optimized raised cosine rolloff filter placed in the receiver).

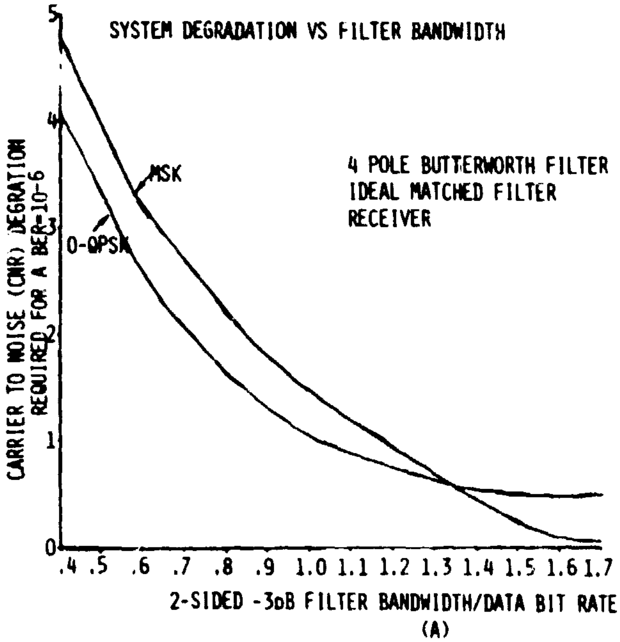
The trade-off curve of normalized bandwidth efficiency (BT) in bits/sec/Hz vs. CNR degradation is presented in A below.

Minimum Traffic Channels Separation vs. Filter Bandwidth. The curve is generated from:

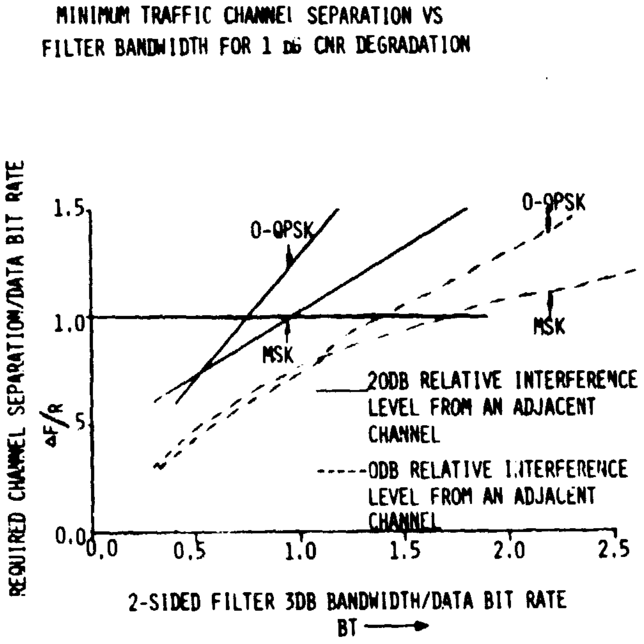
$$\text{CNR Degradation} = \int_{-\infty}^{\infty} H_{TF}(f)|^2 M(f)df \Bigg/ \int_{-\infty}^{\infty} M(f)df$$

where: $H_{TF}(f)$ is the transfer function of the transmitting filter, and
$M(f)$ is the power spectrum of the modulation waveform

BT is related to minimum channel separation within the satellite wideband SAW filters in the curve presented in B below. This curve follows the procedure defined in Kalet [IEEE Comm, Sept. 77] and White [IEEE Comm, Sept 77]



(A)



(B)

where the measure of adjacent channel interference is the mean square crosstalk between channels. Following the design goals appearing in paragraph 4.6.1, the curve is derived for the maximum allowable CNR degradation due to crosstalk of 1 dB. Further, 20 dB relative adjacent channel interference level inferred is from the uplink and downlink rain fade control (power adjustment, plus coding) as a worst case condition, and is used as a critical performance parameter.

E2. BANDLIMITED PERFORMANCE COMPARISON

Modulation Format	Filter BW	Adjacent Channel In Level (dB)	Channel Separation	Degradation (dB) "A"	Degradation Due to Signal Loss in Filt (dB) "B"	Total Degradation (dB) A + B
O - QPSK	1.35R	0	0.97R	1	0.5	1.5
	1.05R	0	0.79R	1	1.0	2.0
	1.35R	20	1.55R	1	0.5	1.5
	1.05R	20	1.25R	1	1.0	2.0
MSK	1.35R	0	0.89R	1	0.5	1.5
	1.17R	0	0.84R	1	1.0	2.0
	1.35R	20	1.25R	1	0.5	1.5
	1.17R	20	1.13R	1	1.0	2.0

RESULTS:

For the 4 pole butterworth transmitting filter, the receiver ideal matched filter and the BER = 10^{-6} considered in this report.

1. The limit on CNR degradation due to filtering losses of 1 dB is seen in the table above to restrict the filter bandwidth. For MSK to be 1.175 R (where R = data bit rate) O-QPSK to be 1.05 R.

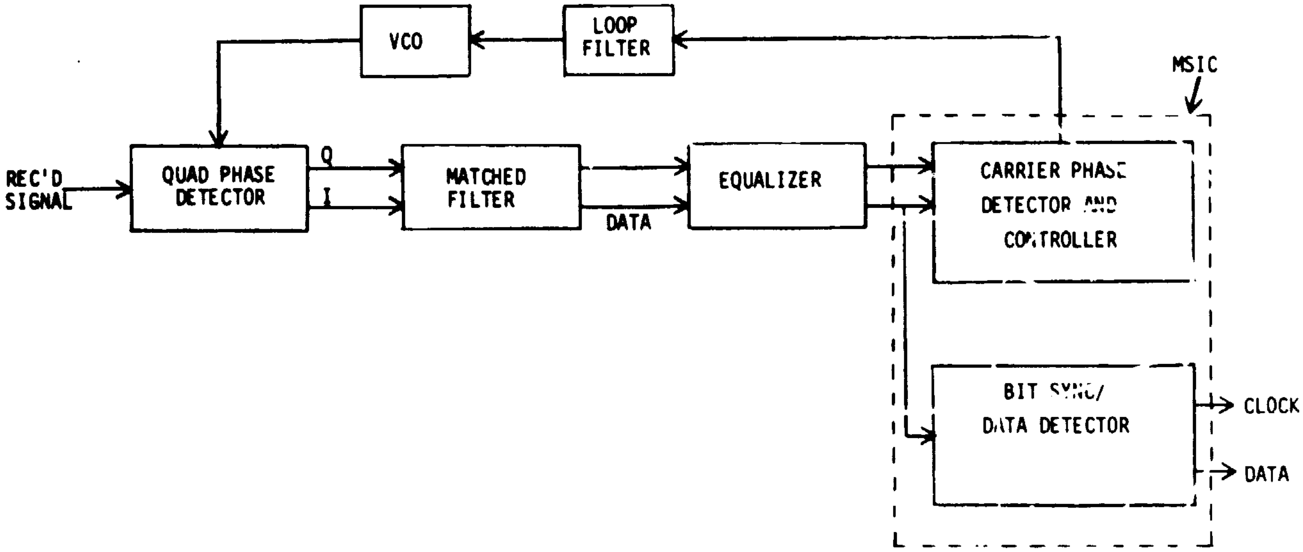
2. The line drawn horizontally for ΔF/R = 1 channel separation, defines the maximum filter bandwidths allowed which satisfy a 1 BIT/SEC/Hz bandwidth efficiency design goal. For 0 dB Adj channel interference level MSK bandwidth must be ≤1.6 R and O-WPSK bandwidth must be ≤1.42 R.
   For 20 dB Adj channel interference level MSK bandwidth must be ≤0..95R and O-WPSK bandwidth must be ≤0.8R.
3. From these considerations the bandlimited performance of O-QPSK and MSK, it is seen that the overall required bandwidth for either modulation technique is 1 BIT/SEC/Hz for an adjacent channel interference level of 0 dB (the nominal no rain fades condition), and 1 BIT/SEC/Hz for an adjacent channel interference level of 20 dB (the worst case condition; uplink and downlink rain fade)

APPENDIX F
DEMODULATOR EVALUATION

APPENDIX F
DEMODULATOR EVALUATION

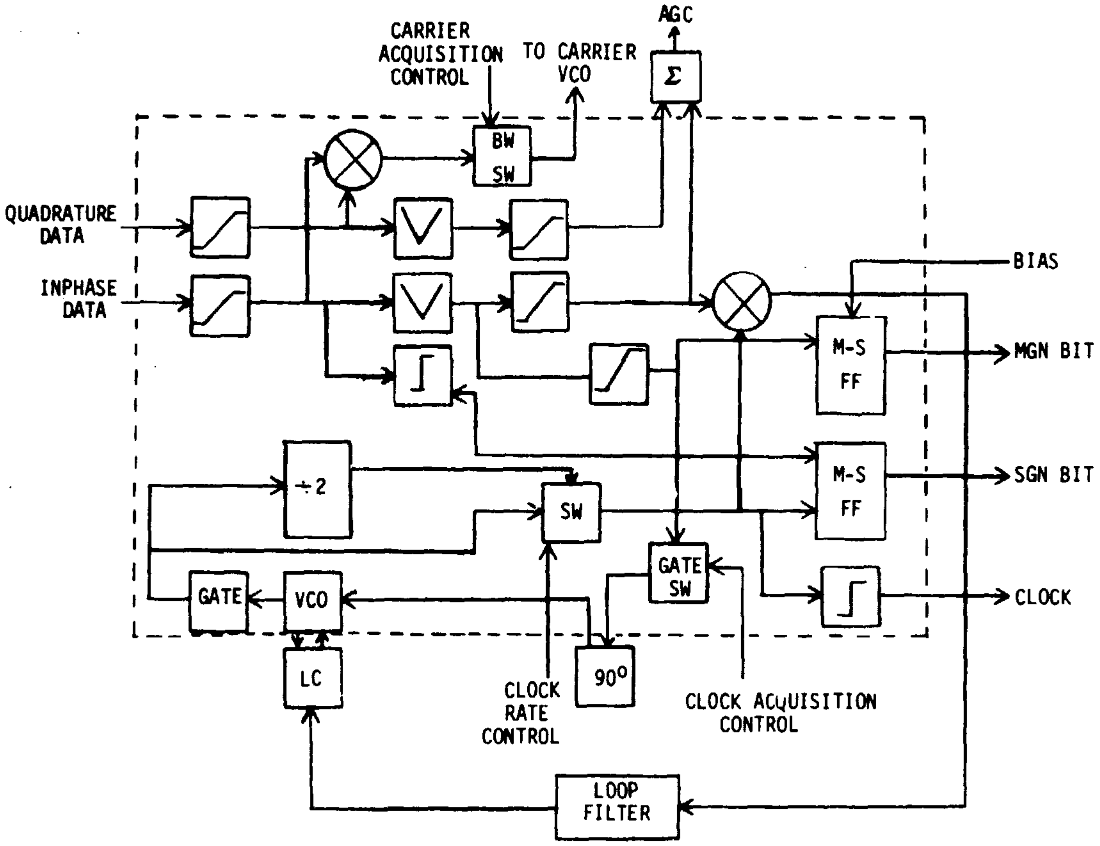
F1. O-QPSK DEMODULATOR SERIAL IMPLEMENTATION

The demodulator employs one HF9 demodulator MSIC in the serial detection of O-QPSK modulated signals. Inphase and quadrature data inputs to the IC are used for carrier phase error detection, clock regeneration, AGC generation, and data detection. In addition to the received modulated signal, the demodulator inputs a sync signal and a symbol rate select signal, both of which are supplied by the ST terminal processor. The sync signal precedes the received signal and is used to reconfigure the carrier and clock loops to enhance their acquisition characteristics. The symbol rate select input is provided to set the rate at which the data is sampled which is dependent upon whether or not FEC coding was performed at the transmitting site. The bias input sets the threshold decision level for the MGN bit when 2 bit soft decisions are desired.



F2. HF9 DEMODULATOR MSIC

The HF9 demodulator MSIC is implemented on Motorola's GEG's HF9 gate array developed on the Baseband Processor Subsystem project funded by NASA. MOSAIC I technology was utilized in the fabrication process in conjunction with emitter coupled logic design techniques to optimize the speed-power tradeoffs. The primary functions performed by the HF9 demodulator MSIC are carrier phase detection, clock regeneration and phase acquisition, two bit soft decision, and AGC. Nominal logic levels are 0V and −0.5V and maximum power consumption is 360 mW at V_{EE} = −4.0V.



F3. DEGRADATION BUDGET FOR PARALLEL AND SERIAL Q-QPSK MODEMS

Source of Error	Error Magnitude	Modem Degradation Parallel (dB)	Modem Degradation Serial (dB)
Modulator Amplitude Unbalance	0.10 dB	0.15	
Phase Unbalance	2.0°	0.05	
Channel Passband Ripple	0.10 dB	0.05	0.05
Demod Quadrature Phase Error	2.5°	0.10	0.05
Demod Phase Error	6.5°	0.10	0.05
Matched Filter Misalignment	2-Pole Butterworth	0.50	0.90
Bit Sync Timing Uncertainty	5.0%	0.05	0.05
Bit Sync Threshold Uncertainty	5.0%	0.05	0.05
Total Degradation (Sum)		1.55	1.40

The various sources of degradations listed represent the primary contributors to the sub-optimum performance exhibited by the modem. The associated values of degradation are a result of previous experience with similar modems that have been built and tested and various theoretical analyses that have been performed in the past. While the serial modem appears to have a minimal advantage over the parallel approach, it is important to note that it is much less sensitive to variations in the magnitude of the degradation sources than is the parallel structure. In other words, the increase in the total degradation for a serial modem will be substantially less than that of the parallel modem for a given increase in one of the source degradations.

F4. O-QPSK MODULATION DETECTION USING THE HF9 DEMODULATOR MSIC

- Simple demodulator configuration
- Decreased hardware complexity
- Reduced sensitivity to conventional sources of degradations
- Employes the technology developed on the baseband processor effort

O-QPSK modulation detection is performed in serial fashion with the HF9 demodulator MSIC. The serial structure is no more complex than a biphase demodulator yet provides better overall performance over the conventional parallel approach to O-QPSK modems when married with a serial modulator structure. This is a result of the simple hardware configuration and the corresponding reduced sensitivity to the typical sources of degradations. These sources of degradation include quadrature phase misalignment, static carrier phase error, and channel amplitude imbalances. In addition, the serial provides full rate data and clock without the need to multiplex as is typical of parallel detection schemes. Another driver in this type of detection scheme is that it takes advantage of the MSI circuit technology developed on the Baseband Processor Subsystem effort funded by NASA.

APPENDIX G
ERROR CORRECTION CODING/DECODING

APPENDIX G
ERROR CORRECTION CODING/DECODING

G1. FORWARD ERROR CORRECTION CODING/DECODING OPTIONS

Convol Code Rate	K	Sym Rate R_s	Data Rate R_b	E_b/N_0 (Min) (dB)	E_s/N_0 (Min) (dB)	Rel Band Width	Availability
Uncoded		1	1	10.6	10.6	1	Yes
1/3	5	3	1	5.6	0.8	3	Yes
1/2	5	2	1	6.0	3.0	2	Yes
1/2	5	2	1	7.0	3.0	2 (Q=4)	Yes
2/3	6	3/2	1	4.4	2.6	3/2	New Dev Req

Baseline Conv. Code R = 1/2, K = 5 2 Bit Soft Dec. (BBP-MCD and Demod Comb)

$P_b < 10^{-6}$

$\frac{E_s}{N_0}$ (Minimum) Relative to Uncoded Value

Relative Bandwidth Required Compared to Uncoded for Full Throughput

Availability as a Result of 30/20 GHz Program Tech. Dev.

Forward error control can be enhanced by the use of error detection and correction coding. The SS-FDMA message format lends itself best to convolutional encoding and maximum-likelihood decoding. This is the most efficient and powerful method except perhaps for higher coding or concatenated routing methods. The above table lists the practical capability of several convolutional codes referenced to an uncoded channel.

Although greater potential gain exists using some of the other listed methods, a rate 1/2, constraint length 5, four level soft-decision coding method was chosen for the baseline. This permits the use of the Maximum-Likelihood Convolutional Decoder (MCD) currently under development on the 30/20 GHz Baseband Processor program. The decoder can provide either rate 1/2 or rate 1/3 decoding, but a rate 1/3 code requires excessive bandwidth. It can also use 1, 2, or 3 bit soft-decision. However, the baseband processor demodulator chip provides a two-bit soft-decision intrinsically.

APPENDIX H.
TRAFFIC MODELS

APPENDIX H
TRAFFIC MODELS

H1. TRAFFIC MODEL OVERVIEW

- Traffic Model A: 2204 ST Stations located in 45 major metropolitan areas—BBP TDMA Model
- Traffic Model B: 10,000 ST Stations distributed among the 277 standard metropolitan statistical areas (U.S. Statistical Abstract, 1979) — potential FDMA operational model
- Voice, video, and data signals are transmitted using independent carriers
- Changes in the traffic matrix occur slowly
- Intra-spot traffic not handled by this system
- Satellite in geosynchronous orbit at approximately 100° W Longitude

Traffic Models A and B of the NASA FDMA SOW essentially are designed with two purposes in mind. Traffic Model A is similar to the traffic model used for the SS-TDMA system.

Traffic Model B, however, represents a likely FDMA market. It features several thousand single-channel ground stations whoses simplicity will compete with the terrestrial network for long distance communications. This low-cost terminal is the main selling point of the FDMA system.

Traffic Model A specifies 2204 ST stations distributed among 45 major metropolitan areas. These cities and their total ST traffic are the same as for the TDMA system.

Traffic Model B specifies 10,000 ST stations distributed among the 277 standard metropolitan statistical areas as defined in the U.S. Statistical Abstract for 1979. These stations are distributed among the SMSA's in direct proportion to population. The total ST traffic handled by model B is defined to be the same as that handled by Traffic Model A.

Motorola has made several reasonable assumptions regarding both traffic models. The first of these is that voice, video, and data signals are transmitted using independent carriers. Motorola also assumes that changes in the traffic matrix occur slowly. Sufficient bandwidth will be allocated for projected peak loads, but any additional changes in loading which may require swapping of bandwidths will occur witn time scales on the order of minutes and hours, not milliseconds.

It is likely that the SS-FDMA system can compete economically with terrestrial networks within a particular spot beam area. Thus, intra-spot traffic will not be handled by this system. The final position of the satellite has yet to be chosen by NASA; however, for CONUS coverage, the satellite will be located at approximately 100° W longitude.

H2. TRAFFIC MODEL BASELINE

- Traffic models are based on Western Union, ITT, and TRW studies, along with NASA refinement.
- Models are statements of terminal capacities, numbers of stations, and quantity of traffic from metropolitan areas.
- ST-TRUNK and TRUNK-ST cross-traffic interconnect occurs on the ground at the trunking stations.
- Hardwired paths result in router simplification, but the amount of switched traffic versus hardwired traffic will evolve out of Motorola's system study.

The traffic models stated in the NASA FDMA SOW have been culled from studies done by Western Union, ITT, and TRW. NASA itself has also provided some input, especially in relation to Traffic Model B. These models are essentially only statements of terminal capacities, numbers of stations, and quantity of traffic from major metropolitan areas.

Motorola was mandated by the NASA SOW to ignore trunking traffic, with the exception of providing bandwidth for it in the frequency plan. However, there is a certain amount of "cross-traffic" which must be handled, i.e., traffic from a ST station to a trunking station, and vice versa. The most economical solution to this problem is to place the interconnect burden on the few trunking stations, not on the more numerous ST stations. The trunking stations would thus have the equivalent of a ST terminal on their premises.

A requirement of the SOW stated that 40% of the traffic originating and ending among the 18 largest cities be routed by hardwired paths within the ST routing assembly. Hardwired paths reduce the router complexity, but also reduce the flexibility of the system. The amount of switched versus hardwired traffic will evolve out of the system study.

H3. SALIENT FEATURES OF TRAFFIC MODEL A

- Total ST traffic load of 3.8 Gb/S distributed among 45 cities in proportion to the amount of generated traffic
- Forty-five cities covered by 40 spot beams; each spot beam is 0.3° HPBW (approximately 150 miles in diameter)
- In spots with no trunking stations, the trunking band could carry ST traffic
- Carrying ST traffic in the trunking band would double the effective frequency reuse (normal reuse = six times)
- Voice channels dominate the traffic model (87 percent) and 50-65 percent of the data rate.

There are 45 cities specified in Traffic Model A, with a total amount of ST traffic of 3.8 Gb/s. The traffic destined for a particular city is in proportion to the amount of traffic generated by that city. The 45 cities are covered by 40 antenna spot beams (five of the spots cover two cities each); each spot beam has a 0.3° half-power beamwidth. Projected onto the surface of the earth from geosynchronous orbit, each spot beam has a diameter of approximately 150 miles.

There are 22 cities out of the 45 which carry trunking traffic. The other 23 do not. In these 23 locations, the 1.5 GHz-wide trunking band could be used to carry ST traffic. By using the trunking band in those locations without trunks, a doubling of the available spectrum would be possible (based on a normal frequency reuse factor of six).

Voice channels dominate the ST traffic. Wideband channels (1.5 Mb/s and 6.3 Mb/s) use 1.3% of the channels but represent 29% of the data rate.

H4. TRAFFIC MODEL A DEFINITION OF TERMINAL CLASSES (64 Kb/s VOICE CHANNELS)

ST Terminal Class	Number of Channels	Channel Data Rate (Bps)	Use	Maximum Composite Data Rate (Mbps)
E	240	64K	Voice	33.84
	2	1.5M	Date	
	20	56K	Data	
	1	6.3M	Video	
	5	1.5M	Video	
	10	56K	Video	
F	60	64K	Voice	5.732
	5	56K	Data	
	1	1.5M	Video	
	2	56K	Video	
G	12	64K	Voice	0.88
	1	56K	Data	
	1	56K	Video	

There are three classes of ST terminals in Traffic Model A. Type E terminals have a composite data rate of 33.84 Mb/s; there are 80 such terminals distributed among the 45 cities. Type F terminals have a composite data rate of 5.732 Mb/s; there are 300 such terminals among the 45 cities. Type G terminals have a composite data rate of 0.88 Mb/s; there are 1824 such terminals distributed among the 45 cities of Traffic Model A.

H5. TRAFFIC MODEL A STATION AND CHANNEL SUMMARY FOR ST TRANSMITTED TRAFFIC

Station Type	Data Rate (Mb/s)	No. of Stations	Number of Channels					
			Voice (64K)	Data (56K)	Data (1.5M)	Video (56K)	Video (1.5)	Video (6.3)
E	33.84	80	19,200	1600	160	800	400	80
F	5.732	300	18,000	1500		600	300	
G	0.88	1824	21,888	1824		1824		
Total		2204	59,088	4924	160	3224	700	80
Percent			(87%)	(7%)	(0.2%)	(5%)	(1%)	(0.1%)
Total Data Rate (Mb/s)			3,782	275	240	181	1050	504
Percent			(63%)	(5%	(4%)	(3%)	(17%)	(8%)

Total Number of Stations = 2,204
Total Number of Channels = 68,176
Total ST-ST & ST-Trunk Data Rate (Mb/s) = 6,032
Total Number of ST Centers = 45
Total Trunk - ST Data Rate (MB/s) = 801
(not included in above total data rate)

The figures shown here represent a composite traffic record for Traffic Model A. These numbers represent the total available number of stations, channels, and data rate. They are not adjusted for NASA's peak loading.

Voice channels are seen to dominate. As shown, 87% of the channels and 63% of the data rate are devoted to voice. Wideband channels (1.5 Mb/s and 6.3 Mb/s) use only 1.3% of the channels, but 29% of the data rate.

Using NASA's peak loading per beam and assuming the peak load occurs simultaneously, there are 1110 stations active, with 30,000 channels active, resulting in about 3 Gb/s total traffic.

It is likely that NASA's 50% of the stations on is more likely to be 50% of the channels in use. It is also likely that most of the stations will be on, but with varying channel loading. This means a higher polling requirement but probably a lower peak load.

H6. SALIENT FEATURES OF TRAFFIC MODEL B

- Total ST traffic load of 3.8 Gb/S distributed among 277 cities in proportion to population
- Two hundred and seventy-seven cities covered by 71 spot beams; each spot beam is 0.3° HPBW (approximately 150 miles in diameter)
- In spots with no trunking stations, the trunking band could carry ST traffic
- Voice channels dominate the traffic model (85%)

There are 277 cities specified in Traffic Model B, with a total amount of ST traffic defined as being equal to that in Traffic Model A, or 3.8 Gb/s. The amount of traffic originated from and destined to a particular city is in proportion to the population of that city. The 277 cities are covered by 72 antenna spot beams; each spot beam has a 0.3° half-power beamwidth. Projected onto the surface of the earth from geosynchronous orbit, each spot beam has a diameter of approximately 150 miles.

As with Traffic Model A, there is a large number of spots which do not originate trunking traffic. In these spots, the 1.5 GHz-wide trunking band could be used to carry ST traffic.

Voice channels dominate the ST traffic load. Wideband channels (1.5 Mb/s and 6.3 Mb/s) use 1.5% of the channels but represent 41% of the data rate.

In order to handle traffic to and from the 71 spots without enormously increasing the size of the routing switch over and above the 40 × 40 switch required for Traffic Model A, some of the 71 spot beams may be combined onboard the satellite. This scheme would reduce the size of the routing switch to something manageable, but would also result in increased downlink power and reduced spectral efficiency.

H7. TRAFFIC MODEL B DEFINITION OF TERMINAL CLASSES (64 Kb/s VOICE CHANNELS)

ST Terminal Class	Number of Channels	Channel Data Rate (Bps)	Use	Maximum Composite Data Rate (Mbps)
E	30	64K	Voice	9.944
	1	1.5M	Data or Video	
	2	56K	Data	
	1	6.3M	Video	
	2	56K	Video	
F	5	64K	Voice	1.988
	2	56K	Data	
	1	1.5M	Data or Video	
	1	56K	Video	
G	10	64K	Voice	0.696
	1	56K	Data	
H	5	64K	Voice	0.432
	1	56K	Data	
	1	56K	Video	
I	5	64K	Voice	0.320
J	1	64K	Voice	0.064

There are six classes of ST terminals in Traffic Model B. Type E terminals have a composite data rate of 9.944 Mb/s; there are 200 such terminals distributed among the 277 cities of Traffic Model B. Type F terminals have a composite data rate of 1.988 Mb/s; there are 600 such terminals in Traffic Model B. Type G terminals have a composite data rate of 0.696 Mb/s; there are 1600 such terminals in Traffic Model B. Type H terminals have a composite date rate of 0.432 Mb/s; there are 1600 such terminals in model B. Type I terminals handle five 64 Kb/s voice channels, for a composite data rate of 0.320 Mb/s; there are 2400 such terminals in Traffic Model B. Type J terminals consist of a single 64 Kb/s voice channel; there are 3600 such terminal in Traffic Model B.

H8. TRAFFIC MODEL B STATION AND CHANNEL SUMMARY FOR ST TRANSMITTED TRAFFIC

				Number of Channels			
Station Type	Data Rate (Mb/s)	No. of Stations	Voice (64K)	Data (56K)	D/V (1.5M)	Video (56K)	Video (6.3M)
E	9.944	200	6,000	400	200	400	200
F	1.988	600	3,000	1,200	600	600	
G	0.696	1,600	16,000	1,600			
H	0.432	1,600	8,000	1,600		1,600	
I	0.320	2,400	12,000				
J	0.064	3,600	3,600	3,600			
TOTAL		10,000	48,600	4,800	800	2,600	200
	Percent		(85%)	(8%)	(1%)	(5%)	(0.4%)
	Total Data Rate (Mb/s)		3,110	269	1,200	146	1,260
	Percent		(52%)	(4%)	(20%)	(2%)	(21%)

Total Number of Stations = 10,000
Total Number of Channels = 57,000
Total ST-ST & ST-Trunk Data Rate (Mb/s) = 5,985
Total Number of Centers = 277
Total Trunk-ST Data Rate (Mb/s) = 801
(Not included in above total data rate)

The figures shown here represent a composite traffic record for Traffic Model B. These numbers represent the total available number of stations, channels, and data rate. They are not adjusted for NASA's peak loading.

Voice channels are seen to dominate. As shown, 85% of the channels and 52% of the data rate are devoted to voice. Wideband channels (1.5 Mb/s and 6.3 Mb/s) use only 1.5% of the channels, but 41% of the data rate.

Using NASA's peak loading per beam and assuming the peak load occurs simultaneously, there are about 5000 stations active, with 24,000 channels active, resulting in about 3 Gb/s total traffic.

It is likely that NASA's 50% of the stations on is more likely to be 50% of the channels in use. However, station type J is either on or off — a single channel. This might also be nearly true of types H and I as well. The number of active stations might be 6200 or 62% of the total. In this case, the 50% NASA criterion is not too far off.

H9. TRAFFIC MODEL REFINEMENT

- Change from 64 Kb/s PCM to 32 Kb/s CVSD voice channels
  - Number of voice channels stays the same
  - Overall data rate reduced to 2.8 Gb/s, a saving of some 25%
  - For same BER, radiated power required is reduced by 3 dB
  - CVSD voice can tolerate higher error rates for an equallay high quality channel
- Time zone effects on traffic flow
  - Load peaks mid-morning
  - Smaller peak mid-afternoon, gradual fall-off
  - For inter-time-zone traffic, the load pattern changes in detail, but general shape remains the same
- Seasonal effects unimportant; believe their impact to be minimal
- Population shifts scoped through year 2000.
  - Model B — Several small cities in the northeast lose their ST stations because of migration to the sunbelt.

Acting under subcontract to Motorola, Western Union has made refinements to the NASA traffic models as summarized above. A major recommendation involves a change from 64 Kb/s PCM voice channels to 32 Kb/s continuously variable slope delta modulation for all the ST voice link traffic.

Using 32 Kb/s CVSD, the number of voice channels would remain the same, but the overall data rate required would be reduced to 2.7 or 2.8 Gb/s, an overall savings of some 25 percent. The radiated power required would be reduced by 3 dB for an equal bit error rate when using 32 Kb/s CVSD instead of 64 Kb/s voice.

A CVSD voice channel can tolerate higher error rates for an equally high quality channel, certainly to 10^{-3} for an additional saving of 3.5 dB when using coherent phase detection. Indeed, error rates as high as 10^{-2} can often be tolerated for still an additional 2.5 dB savings.

Traffic flow variations due to time zones were examined, showing a traffic peak during mid-morning, with a second, slightly smaller peak during mid-afternoon. This pattern did not undergo gross changes when inter-time-zone traffic was taken into account.

Population studies show a trend of migration to the sunbelt. Scoped through the year 2000, these population shifts indicate that several small cities in the Northeast (Connecticut, Massachusetts) might lose their ST stations (model B), based upon the present method of distributing ST terminals in proportion to population.

H10. REVISED TRAFFIC MODEL A DEFINITION OF TERMINAL CLASSES (32 Kb/s VOICE CHANNELS)

ST Terminal Class	Number of Channels	Channel Data Rate (Bps)	Use	Maximum Composite Data Rate (Mbps)
E	240	32 k	Voice	26.16
	2	1.5M	Data	
	20	56 k	Data	
	1	6.3M	Video	
	5	1.5M	Video	
	10	56 k	Video	
F	60	32 k	Voice	3.812
	5	56 k	Data	
	1	1.5M	Video	
	2	56 k	Video	
G	12	32 k	Voice	0.496
	1	56 k	Data	
	1	56 k	Video	

Changing from 64 Kb/s PCM to 32 Kb/s CVSD voice channels has changed Model A terminal classes in the following way. Numbers of channels have remained the same, but the composite data rates have changed.

- Terminal Type E has changed from 33.84 Mb/s to 26.16 Mb/s, a reduction of 23 percent.
- Terminal Type F has changed from 5.732 Mb/s to 3.812 Mb/s, a reduction of 33 percent.
- Terminal Type G has changed from 0.88 Mb/s to 0.496 Mb/s, a reduction of 44 pecent.

H11. REVISED TRAFFIC MODEL B DEFINITION OF TERMINAL CLASSES (32 Kb/s VOICE CHANNELS)

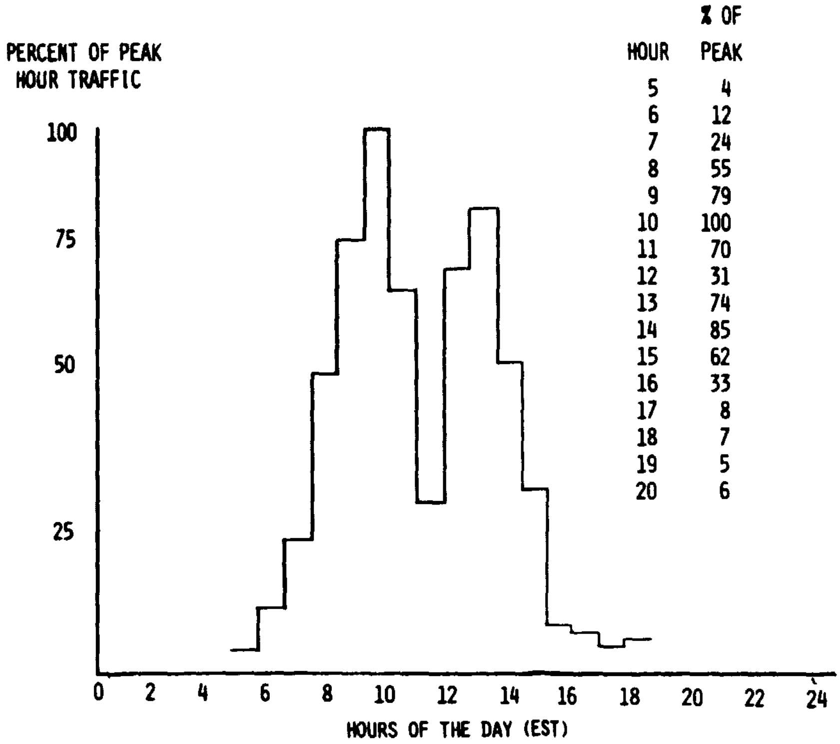
ST Terminal Class	Number of Channels	Channel Data Rate (Bps)	Use	Maximum Composite Data Rate (Mbps)
E	30	32 k	Voice	9.044
	1	1.5M	Data or Video	
	2	56 k	Data	
	1	6.3M	Video	
	2	56 k	Video	
F	5	32 k	Voice	1.828
	2	56 k	Data	
	1	1.5M	Data or Video	
	1	56 k	Video	
G	10	32 k	Voice	0.376
	1	56 k	Data	
H	5	32 k	Voice	0.272
	1	56 k	Data	
	1	56 k	Video	
I	5	32 k	Voice	0.160
J	1	32 k	Voice	0.032

Changing from 64 Kb/s PCM to 32 Kb/s CVSD voice channels has changed Traffic Model B terminal classes in the following way. Numbers of channels have remained the same, but the composite data rates have changed.

- Terminal Type E has changed from 9.944 Mb/s to 9.044 Mb/s, a reduction of 9 percent.
- Terminal Type F has changed from 1.988 Mb/s to 1.828 Mb/s, a reduction of 8 percent.
- Terminal Type G has changed from 0.696 Mb/s to 0.376 Mb/s, a reduction of 46 percent.
- Terminal Type H has changed from 0.432 Mb/s to 0.272 Mb/s, a reduction of 37 percent.
- Terminal Type I has changed from 0.320 Mb/s to 0.160 Mb/s, a reduction of 50 percent.
- Terminal Type J has changed from 0.064 Mb/s to 0.032 Mb/s, a reduction of 50 percent.

H12. BELL BUSINESS LONG DISTANCE

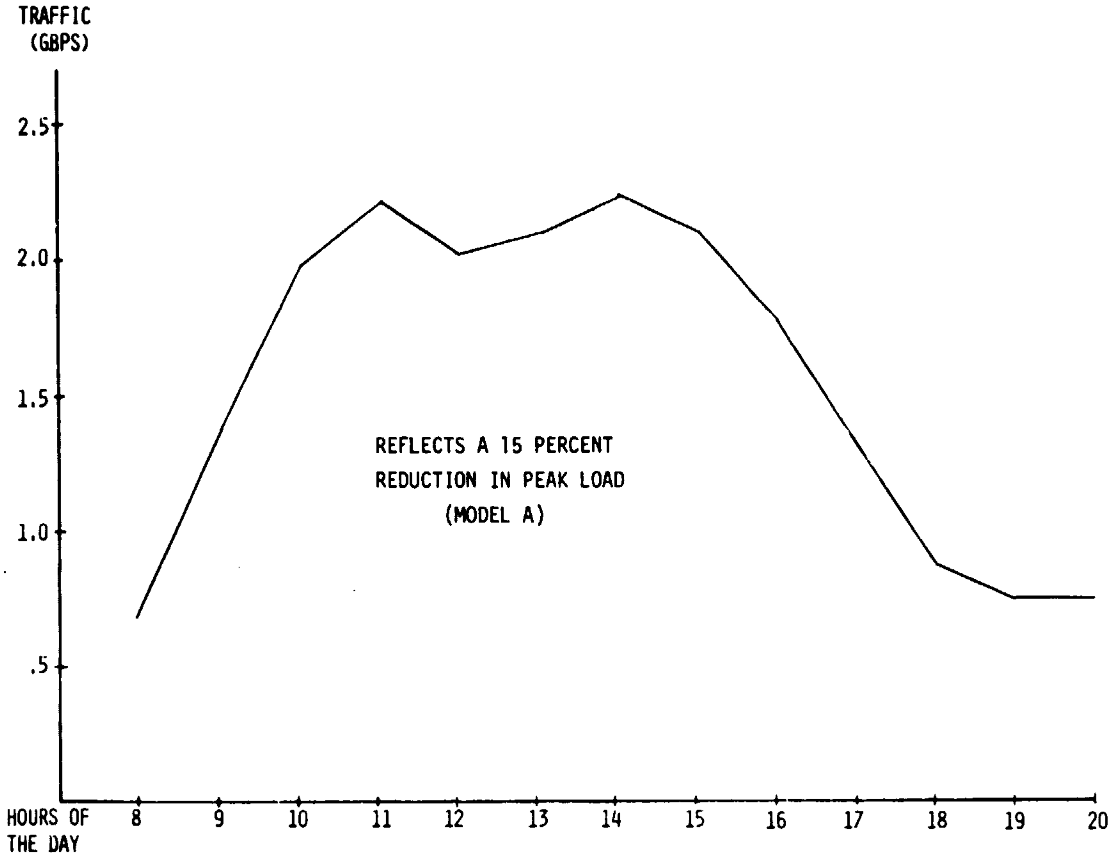
One of the inputs used by Western Union when considering the temporal variations of voice traffic was a composite of Bell business long distance calls. The graph shows a very pronounced peak at about 10 a.m. (Eastern time), then a sharp drop during lunch hour, followed by an equally sharp rise to a second, smaller peak at about 2 p.m. The late-afternoon decrease in traffic seems to fall off more gradually than the rise in traffic in early morning.



HOUR	% OF PEAK
5	4
6	12
7	24
8	55
9	79
10	100
11	70
12	31
13	74
14	85
15	62
16	33
17	8
18	7
19	5
20	6

H13. U.S. PEAK HOUR TRAFFIC CONSIDERING TIME ZONES

The composite peak hour traffic graph by Western Union shows two pronounced peaks. The first peak, at about 10:30 Eastern time, is due mainly to peak mid-morning traffic from the East coast. The second peak, at about 2 p.m. Eastern time, is nearly as large as the first. This is due to two contributions. A large portion of the traffic comes from East coast mid-afternoon traffic, while the rest of it comes from West coast mid-morning traffic. As the business day winds down, from east to west, there is a gradual decrease in late afternoon traffic.



H14. TASKS TO BE COMPLETED

- Refine Traffic Models A and B
    - Redistribute 6.3 Mb/S and 1.5 Mb/S channels
    - Recalculate traffic matrices
- Refine year 2000 projections of population growth and migration.
- Select method of combining 71 spot beams for Traffic Model B.

With regard to the traffic models, Motorola's major task is to assess the impact of changing from 64 Kb/s PCM to 32 Kb/s CVSD voice channels. This directly affects the overall station and spot data rates, and thus influences the frequency plan, switch parameters, filter bandwidths, and synthesizer frequencies.

Western Union's major task is refining the traffic models so as to treat high-rate (56 Kb/s and 32 Kb/s) channels separately. This will result in new spot-to-spot traffic matrices, and will illuminate the roles of the medium and high-rate channels.

A lesser task for Western Union is to refine its year 2000 projections of population growth and migration, in order to provide some means of determining year 2000 ST terminal distribution.

APPENDIX I.
TRAFFIC MODEL REFINEMENT

APPENDIX I
TRAFFIC MODEL REFINEMENT

I1. PRESENTATION OUTLINE

TRAFFIC MODEL OVERVIEW

- Purpose
- Models
- Definitions
- Assumptions—Model A
- Assumptions—Model B

TRAFFIC MODEL REFINEMENT—MODEL A

- Effects of Time Zones
- Effects of Population Shifts
- Effects of Time Zones, after Population Shifts
- Peak Hour Traffic
- Peak Hour Traffic by Time Zone
- Trunking Station Configuration

TRAFFIC MODEL REFINEMENT—MODEL B

- Effects of Time Zones
- Peak Hour Traffic
- Peak Hour Traffic by Time Zone
- Trunking Station Configuration

The presentation on Traffic Model Refinement includes an overview, the major findings for Model A and the major findings for Model B.

The overview includes an outline of the purpose, models, definitions and assumptions.

The results for Model A include the effects of time zone, the effects of population shifts, the effects of time zones after population shifts, peak hour traffic, peak hour traffic by time zone and trunking station configurations.

The results for Model B include the effects of time zone, peak hour traffic, peak hour traffic by time zone, and trunking station configurations.

I2. TRAFFIC MODEL OVERVIEW PURPOSE

CONFIGURE SPACECRAFT SWITCH
↑
ARRIVE AT REQUIRED CAPACITY FOR EACH SPOT BEAM
↑
EXPECTED TRAFFIC FLOW ON EACH UPLINK
↑
PEAK HOUR TRAFFIC BETWEEN EACH PAIR OF AREAS
↑
EFFECTS OF TIME ZONES, TYPE OF TRAFFIC, SEASONAL/POPULATION SHIFTS
↑
EXPANSION/REFINEMENT OF TRAFFIC MODELS

In order to configure the spacecraft switch, arrive at the required capacity for each spot beam, etc., it is necessary to obtain detailed information on the expected traffic flow on each uplink.

To determine the traffic flow on each uplink, it is necessary to determine the peak hour traffic between each pair of metropolitan areas.

To gain an accurate understanding of the peak hour traffic between metropolitan areas, it is necessary to examine the effects of time zones, type of traffic, seasonal shifts and population shifts.

The examination of these effects was the purpose of Item 2.1: Expansion and Refinement of Traffic Model A and Item 2.2: Expansion and Refinement of Traffic Model B.

I3. TRAFFIC MODEL OVERVIEW MODELS

- Two possible traffic models (i.e., Models A and B)
- Distillation of models generated by other studies and NASA
- Statement of terminal capacity, number of stations, quantity of traffic
- Expansion and refinement desired

NASA Lewis provided two possible traffic models, Models A and B, that might pertain to Customer Premise Service in the 1990s.

Traffic Model A specifies 2204 ST stations distributed among 45 major metropolitan areas while Traffic Model B specifies 10,000 ST stations distributed among 275 standard metropolitan statistical areas.

The models were a distillation of the traffic models generated by Western Union, ITT and TRW and involved further independent inputs from NASA, itself.

The models were only statements of terminal capacities, likely numbers of stations, and the quantity of traffic expected to arrive from specified geographical locations or spots.

The intent of the NASA SOW was not to challenge these models, per se, but to augment and refine them.

14. TRAFFIC MODEL OVERVIEW DEFINITIONS

- Low rate channels = 32 Kbps voice and 56 Kbps data/video less than 1.5 Mbps channels
- Medium rate channels = 1.5 Mbps data/video
- High rate channels = 6.3 Mbps video

In the expansion of refinement of Traffic Models A and B, three channel rates were defined.

Channels with rates less than 1.5 MBPS, that is, 32 KBPS voice and 56 KBPS data/video, were called low rate channels.

The 1.5 MBPS data/voice channels were called medium rate channels.

The 6.3 MBPS video channels were called high rate channels.

15. TRAFFIC MODEL OVERVIEW ASSUMPTIONS—MODEL A

- Voice channels—32 KBPS
- Traffic peak hour loading based on availability of channels
- *All high rate channels on during peak hour
- *50% of all other channels on during peak hour
- Traffic on high (medium) rate channels can pass only among areas that have stations with high (medium) rate channels
- Traffic on low rate channels can pass among all areas
- Full duplex for all channels
- Traffic distributed on a proportional basis
- Matrices of traffic between city pairs developed separately for each rate
- Voice circuit behavior used to modify models
- Seasonal shifts need not be considered
- *Population shifts should be considered.

Twelve major assumptions were made when expanding and refining Traffic Model A. Nine of these assumptions were also made for Traffic Model B; the three that were not are noted with an asterisk.

Voice channels should be 32 KBPS, not 64 KBPS as indicated in the NASA Models; the number of voice stations.

Traffic peak hour loading should be based upon the availability of channels, not the availability of stations.

*All high rate channels (i.e., 6.3 MBPS) should be considered on at 100 percent of capacity during the peak hour.

*Fifty percent of all other channels (i.e., medium and low rate channels) should be considered on at 100 percent of capacity during the peak hour.

Traffic on high (medium) rate channels can pass only among metropolitan areas that have stations with high (medium) rate channels.

Traffic on low rate channels can pass among all metropolitan areas.

There is full duplex for all channels, i.e., a video link, a FAX link, etc., is exactly matched by return link.

The amount of traffic from one metropolitan area terminating at a second metropolitan area is proportional to the amount of traffic originating at the second area.

Matrices of CPS traffic between city pairs should be developed separately for each channel rate.

Voice circuit behavior (not different traffic patterns for each type of traffic) should be used to modify the traffic models.

Since reductions of traffic during various periods of the year will not affect a system designed for peak hour traffic loads, the effects of seasonal shifts need not be considered.

*Since population shifts are anticipated, the effects of these shifts should be considered in Model A.

16. TRAFFIC MODEL OVERVIEW ASSUMPTIONS—MODEL B

- Voice channels—32 KBPS
- Traffic peak hour loading based on availability of channels
- *50% of all channels on during peak hour
- Traffic on high (medium) rate channels can pass only among areas that have stations with high (medium) rate channels
- Traffic on low rate channels can pass among all areas
- Full duplex for all channels
- *Terminal types allotted to areas:
  E to 45 areas
  F to 100 areas
  G to J to all 275 areas
- Traffic distributed on a proportional basis
- Matrices of traffic between city pairs developed separately for each rate
- Voice circuit behavior used to modify models
- Seasonal shifts need not be considered
- *Effects of population shifts need not be considered

Twelve major assumptions were made when expanding the refining Traffic Model B. Three of these assumptions were not made for Traffic Model A; they are marked with an asterisk.

Voice channels should be 32 KBPS, not 64 KBPS as indicated in the NASA Models; the number of voice channels should not change.

Traffic peak hour loading should be based upon the availability of channels not the availability of stations.

*Fifty percent of all channels (i.e., high, medium and low rate channels) should be considered on at 100 percent of capacity during the peak hour.

Traffic on low rate channels can pass among all metropolitan areas.

There is full duplex for all channels, i.e., a video link, a FAX link, etc., is exactly matched by a return link.

*Terminal types should be allotted to metropolitan areas in the following manner:

- E class terminals allotted, one each to the 45 areas in Model A, with the remaining allotted proportionally to these 45 areas according to the number of E terminals (plus one) allotted to these 45 areas in Model A.
- F class terminals allotted, one each, to the top 100 areas and the rest distributed by Market Distribution Model—MDM over the same 100 areas.
- G through J terminals distributed by the MDM to all 275 areas.

The amount of traffic from one metropolitan area terminating at the second metropolitan area is proportional to the amount of traffic originating at the second area.

Matrices of ST traffic between city pairs should be developed separately for each channel rate.

Voice circuit behavior (not different traffic patterns for each type of traffic) should be used to modify the traffic models.

Since reductions of traffic during various periods of the year will not affect a system designed for peak traffic load, the effect of seasonal shifts need not be considered.

*Since the effect of population shifts on peak hour traffic were found to be insignificant in the refinement of Traffic Model A, these effects should not be considered in the refinement of Traffic Model B.

17. TRAFFIC MODEL REFINEMENT MODEL A EFFECTS OF TIME ZONES

Not Considering Population Shifts				
	Mbps	%	Areas	%
Channel Rates				
High—6.3	−75.6	12	12	
Med—1.5	−108.0	13	31	69
Low—<1.5	−200.8	13	45	100
Total	−384.4	13	88	65

A consideration of time zones resulted in a change in peak hour traffic amounts from 2.96 GBPS to 2.58 GBPS or a reduction of about 13 percent.

The reduction affected metropolitan areas and the number of each type of channel in the following ways:

- 12 areas loss a total of 75.6 MBPS of 6.3 MBPS channels
- 31 areas loss a total of 108 MBPS of 1.5 MBPS channels
- 45 areas loss a total of 200.8 MBPS of less than 1.5 MBPS channels

I8. TRAFFIC MODEL REFINEMENT MODEL A EFFECTS OF POPULATION SHIFTS

Number/Percent of Mbps and
Number/Percent of Areas Affected

	Mbps	%	Areas	%
Channel Rates				
High — 6.3	(±) 12.6	2	2	4
Med — 1.5	(±) 72.0	9	18	40
Low — <1.5	(±) 140.4	9	45	100
Total	(±) 225.0	8	65	48

A consideration of population shifts caused a total of 225 Mbps, or about 8 percent, of the peak hour traffic to shift among the 45 metropolitan areas.

This shift of traffic affected each type of channel and metropolitan areas in the following ways:

- 12.5 Mbps of 6.3 Mbps channels shifted between two areas
- 72.0 Mbps of 1.5 Mbps channels shifted among 18 areas
- 140.5 Mbps of less than 1.5 Mbps channels shifted among 45 areas

I9. TRAFFIC MODEL REFINEMENT MODEL A EFFECTS OF TIME ZONES

After Considering Population Shifts Peak Hour Traffic Reduced: 2.96 to 2.58 Gbps

	Mbps	%	Areas	%
Channel Rates				
High — 6.3	−75.6	12	11	24
Med — 1.5	−111.0	14	28	62
Low — <1 5	−202.3	13	45	100
Total	−388.9	13	81	60

The effects of considering time zones, after considering population shifts, were nearly identical to the effects before considering population shifts:

- Change in peak hour traffic amount: 2.96 Gbps to 2.58 or 13 percent
- 11 areas loss 75.6 Mbps of 6.3 Mbps channels
- 31 areas loss 111.0 Mbps of 1.5 Mbps channels
- 45 areas loss 202.3 Mbps of less than 1.5 Mbps channels

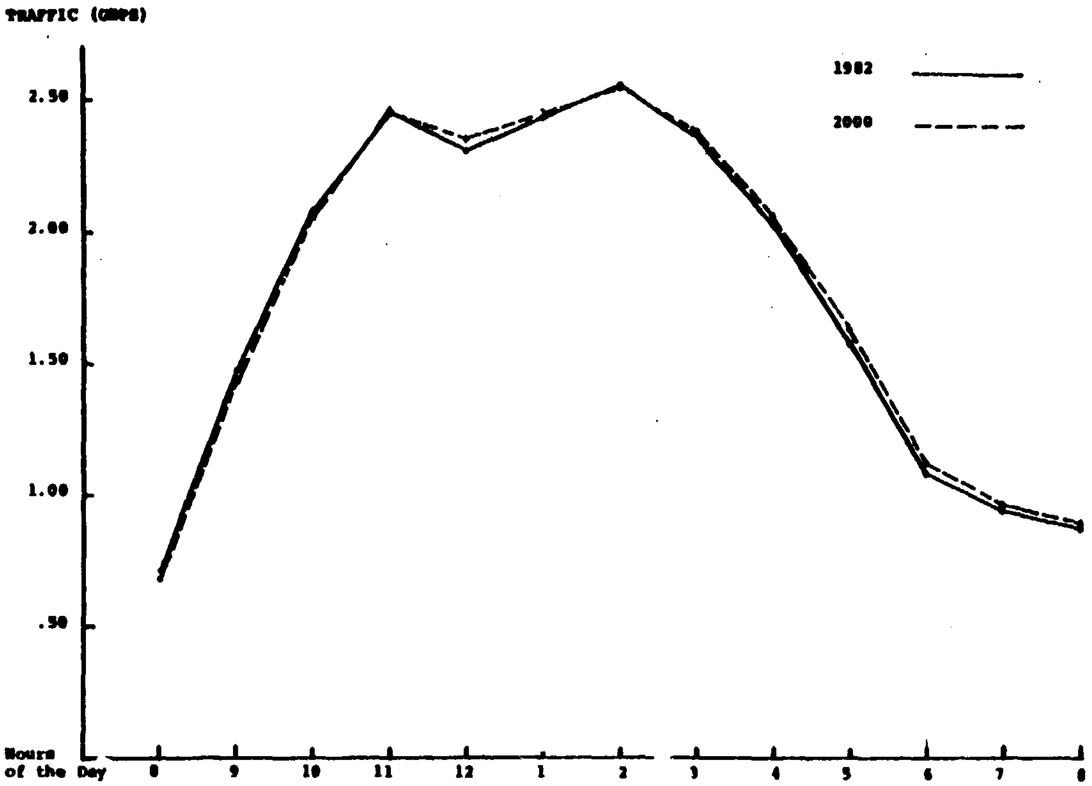
I10. TRAFFIC MODEL REFINEMENT MODEL A PEAK HOUR TRAFFIC

By changing 64 Kbps voice channels to 32 Kbps voice channels and assuming 100%, rather than 50%, of the 6.3 Mbps channels on, the data rate throughput was reduced from 3.78 Gbps to 2.96 Gbps or by about 22 percent.

When not considering (i.e., 1982) and when considering (i.e., 2000) population shifts, two major peak hours of the day were found:

- the hour when the traffic was the greatest was 2:00 P.M.; traffic amount = 2.58 Gbps
- a second peak was found at 11:00 A.M.; traffic amount was 2.46 Gbps

A comparison of the two peak hour curves (i.e., not considering and considering population shifts) indicated that population shifts had very little effect on peak hour traffic for each hour of the day.



COMPARISON OF U. S. PEAK HOUR TRAFFIC CONSIDERING TIME ZONES
MODEL A YEARS - 1982, 2000

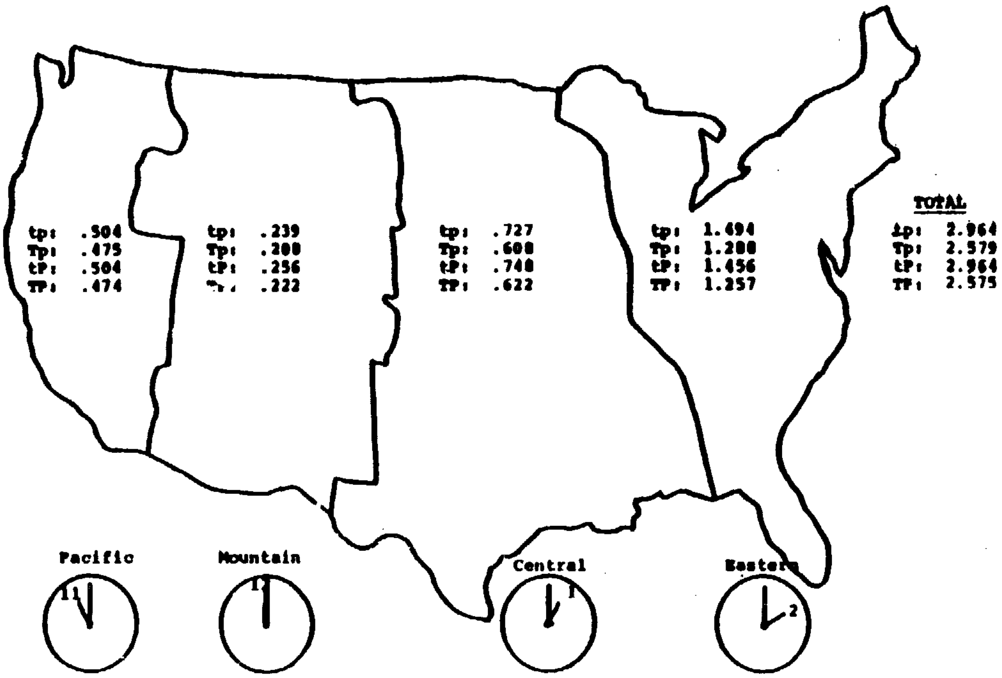
III. TRAFFIC MODEL REFINEMENT MODEL A PEAK HOUR TRAFFIC BY TIME ZONE

The reduction due to a consideration of time zones affected total generated traffic in each time zone in the following ways:

- Eastern Time Zone loss 14 percent
- Central Time Zone loss 16 percent
- Mountain Time Zone loss 13 percent
- Pacific Time Zone loss 6 percent

The shift of traffic due to population shifts affected total generated traffic in each time zone in the following ways (before considering time zones)

- Eastern Time Zone loss 2.6 percent
- Central Time Zone gained 2.9 percent
- Mountain Time Zone gained 7.1 percent
- Pacific Time Zone did not change



U. S. TIME ZONES AND PEAK HOUR GENERATED TRAFFIC

- Not considering time zones or population shifts (tp)
- Considering time zones, but not population shifts (Tp)
- Not considering time zones, but considering population shifts (tP)
- Considering time zones and population shifts (TP)

A consideration of both time zones and population shifts affected total generated traffic in each time zone in the following ways:

- Eastern Time Zone loss 14 percent
- Central Time Zone loss 17 percent
- Mountain Time Zone loss 13 percent
- Pacific Time Zone loss 6 percent

I12. TRAFFIC MODEL REFINEMENT MODEL A TRUNKING STATION CONFIGURATION

	Voice 32 Kbps	Data			Video	
		1.5 Mbps	56 Kbps	6.3 Mbps	1.5 Mbps	56 Kbps
Number of Channels	7209	26	600	26	98	372

In order to determine the type of equipment needed at trunking stations for ST service (i.e., the number of voice, data and video terminations at each and their bit rates) the split between ST → ST traffic sources and ST → Trunking traffic sources (i.e., the number of channels of each) was calculated. This was done by taking the percentage of each type of traffic as part of the total ST traffic and applying it to the satellite terminal make up for the region. This procedure was employed for each type of channel for each of the 45 metropolitan areas. Then, for each type of channel the numbers of such channels allotted to ST → T were summed across metropolitan areas and this sum was allotted to the trunking terminals in proportion to the amount of traffic carried (i.e., T → ST traffic).

I13. TRAFFIC MODEL REFINEMENT MODEL B EFFECTS OF TIME ZONES

Not Considering Population Shifts

Peak Hour Traffic Reduced: 2.83 to 2.46 Gbps

	Mbps	%	Areas	%
Channel Rates				
High — 6.3	88.2	11%	11	4%
Med — 1.5	99.0	13%	50	18%
Low — <1.5	169.5	13%	275	100%
Total	356.7	13%	336	41%

A consideration of time zones resulted in a change in peak hour traffic amounts from 2.83 Gbps to 2.47 Gbps or a reduction of about 13 percent.

The reduction affected metropolitan areas and the number of each type of channel in the following ways:

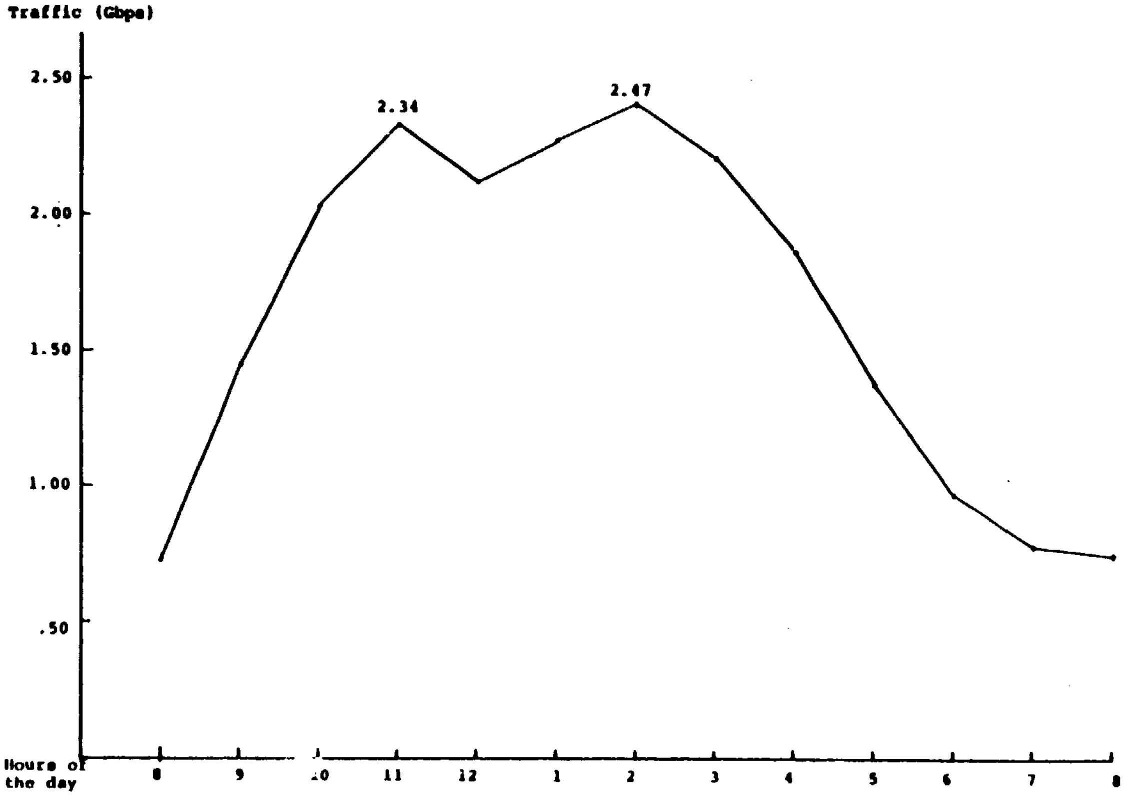
- 11 areas loss a total of 88.2 Mbps of 6.3 Mbps channels
- 50 areas loss a total of 99 Mbps of 1.5 Mbps channels
- 275 areas loss a total of 169.5 Mbps of less than 1.5 Mbps channels

I14. TRAFFIC MODEL REFINEMENTS MODEL B PEAK HOUR TRAFFIC

By changing 64 Kbps voice channels to 32 Kbps voice channels the data rate throughput, before considering time zones, was reduced from 3.78 Gbps to 2.83 Gbps or by about 25 percent.

After considering time zones, two major peak hours of the day were found:

- the hour when the traffic was the greatest was 2:00 P.M.; traffic amount = 2.47 Gbps
- a second peak was found at 11:00 A.M.; traffic amount was 2.34 Gbps

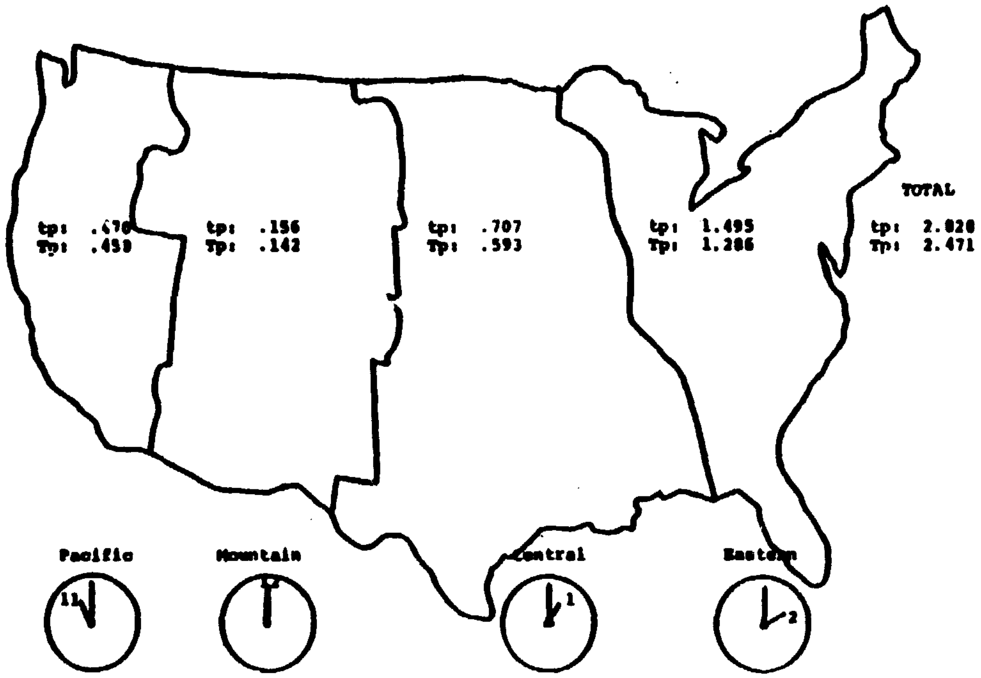


U. S. PEAK HOUR TRAFFIC CONSIDERING TIME ZONES
MODEL B Year = 1982

I15. TRAFFIC MODEL REFINEMENT MODEL B PEAK HOUR TRAFFIC BY TIME ZONE

The reduction due to a consideration of time zones affected total generated traffic in each time zone in the following ways:

- Eastern Time Zone loss 14 percent
- Central Time Zone loss 16 percent
- Mountain Time Zone loss 9 percent
- Pacific Time Zone loss 4 percent



U. S. TIME ZONES AND PEAK HOUR GENERATED TRAFFIC
- Not considering time zones or population shifts (tp)
- Considering time zones, but not population shifts (Tp)

I16. TRAFFIC MODEL REFINEMENTS MODEL B TRUNKING STATION CONFIGURATION

	Voice	Data		Video		
	32 Kbps	1.5 Mbps	56 Kbps	6.3 Mbps	1.5 Mbps	56 Kbps
Number of Channels	6597	56	643	28	57	356

In order to determine the type of equipment needed at trunking stations for ST service (i.e., the number of voice, data and video terminations at each and their bit rates) the split between ST → ST traffic sources and ST → Trunking traffic sources (i.e., the number of channels of each) was calculated. This was done by taking the percentage of each type of traffic as part of the total ST traffic and applying it to the satellite terminal make up for the region. This procedure was employed for each type of channel for each of the 275 metropolitan areas. Then, for each type of channel the numbers of such channels allotted to ST → T were summed across metropolitan areas and this sum was allotted to the trunking terminals in proportion to the amount of traffic carried (i.e., T → ST traffic).

APPENDIX J
SIGNALLING INTERFACE

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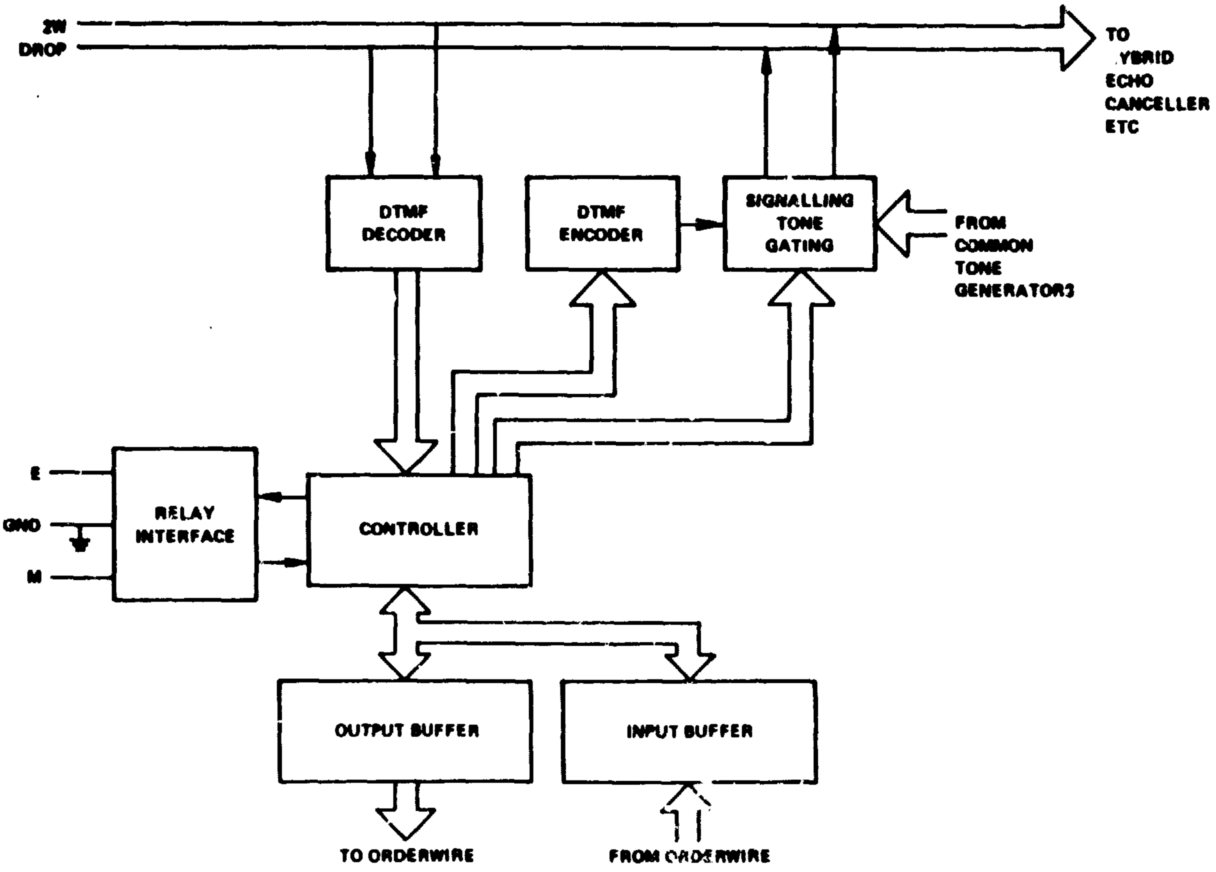
SIGNALLING INTERFACE

J1. SIGNALLING INTERFACE

The function of the Signalling Interface is to translate between the digital format of the ST terminal orderwire circuit which communicates with the NCS and the hybrid digital/analog format required by the PABX or other telephone circuit connected to the terminal. There are two types of information that pass through the interface: supervisory and signalling.

Supervisory information refers to the status of the PABX or the terminal—whether it is active (signalling or talking) or inactive. This information is carried over the "E" and "M" leads by DC signals. The E lead carries the state of the terminal to the PABX and the M lead the state of the PABX to the terminal.

Signalling information consists of status defining tones—dial tone, busy tone, and reorder tone—and network address information (called party number). The network address can be carried by the talking circuit using DTMF ("touch-tone") tones or by DC pulsing the E and M leads. In the latter case the address information is distinguished from the supervisory information by its timing characteristics; i.e., address pulses are 10 Hz square waves, while supervisory state changes must persist at least 140 millisec.



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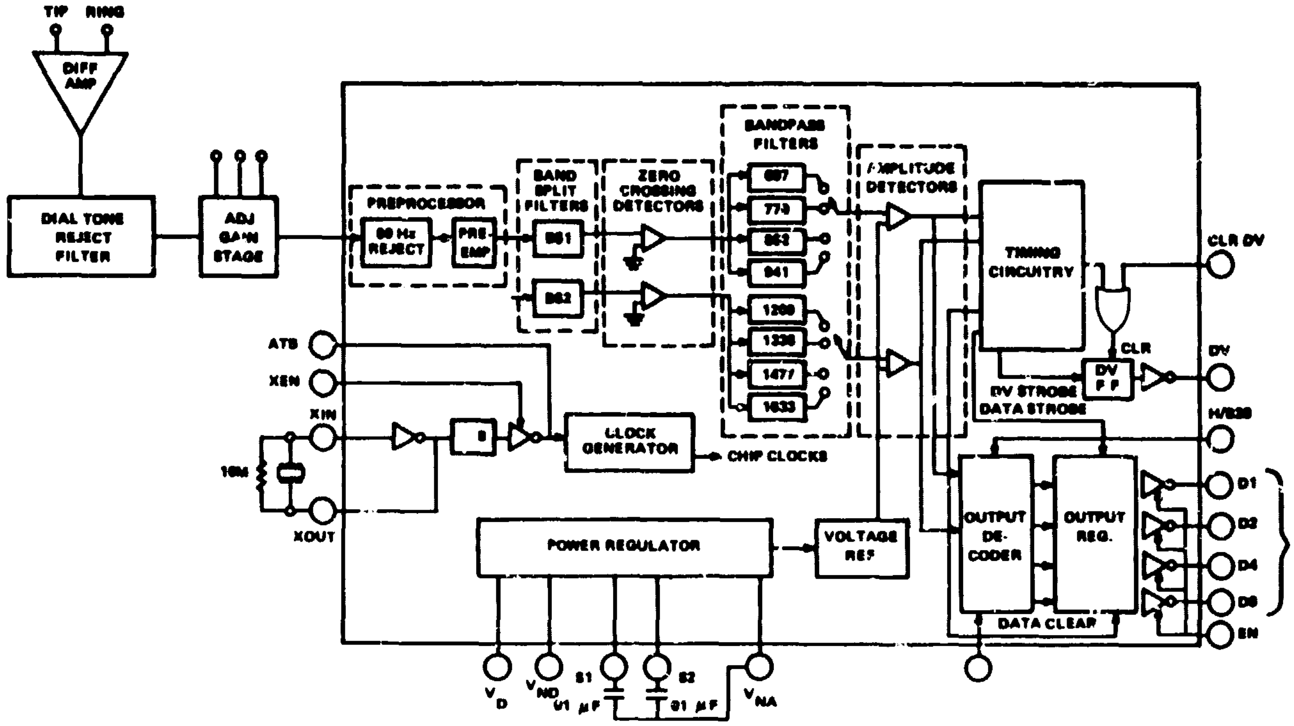
The design of the signalling interface has been based on a microprocessor controller, which handles all digital input and output, controls timing of signals, etc., together with external tone generating and detecting circuits. A common set of tone generators is used for the status tones, while the DTMF coder and decoder are provided one per interface.

J2. DTMF DECODER

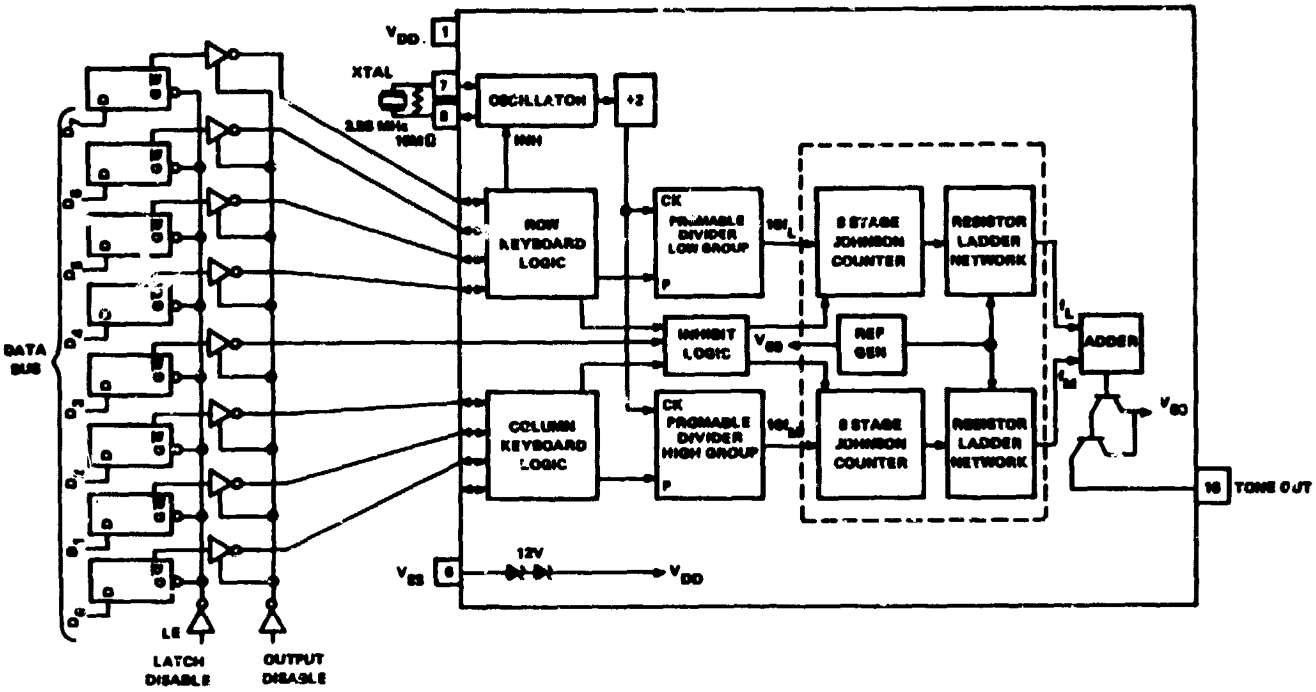
DTMF signals consist of a pair of tones selected from two groups of four (actually 1:4 and 1:3 because the fourth tone of the second group is not normally used). The DTMF decoder must recognize the presence of two simultaneous tones of a given minimum duration (23 millisec.) with a wide range of relative levels between the high and low tones ("twist" up to 4 dB). This must be done in the presence of dial tone. Single tone, triple tones, voice signals, etc. must be rejected.

The circuitry that accomplishes this is shown in the figure. After conversion from balanced to signal ended, filters are used to reject dial tone and power line noise. The two frequency bands are then separated and the resulting signals hard limited. Two groups of bandpass filters then look for a pair of tones. Digital logic then insures correct tone recognition—minimum time present, proper number of tones, etc. The output is a BCD digit corresponding to the tone pair. This is gated onto the microprocessor bus when the enable line is activated.



J3. DTMF ENCODER

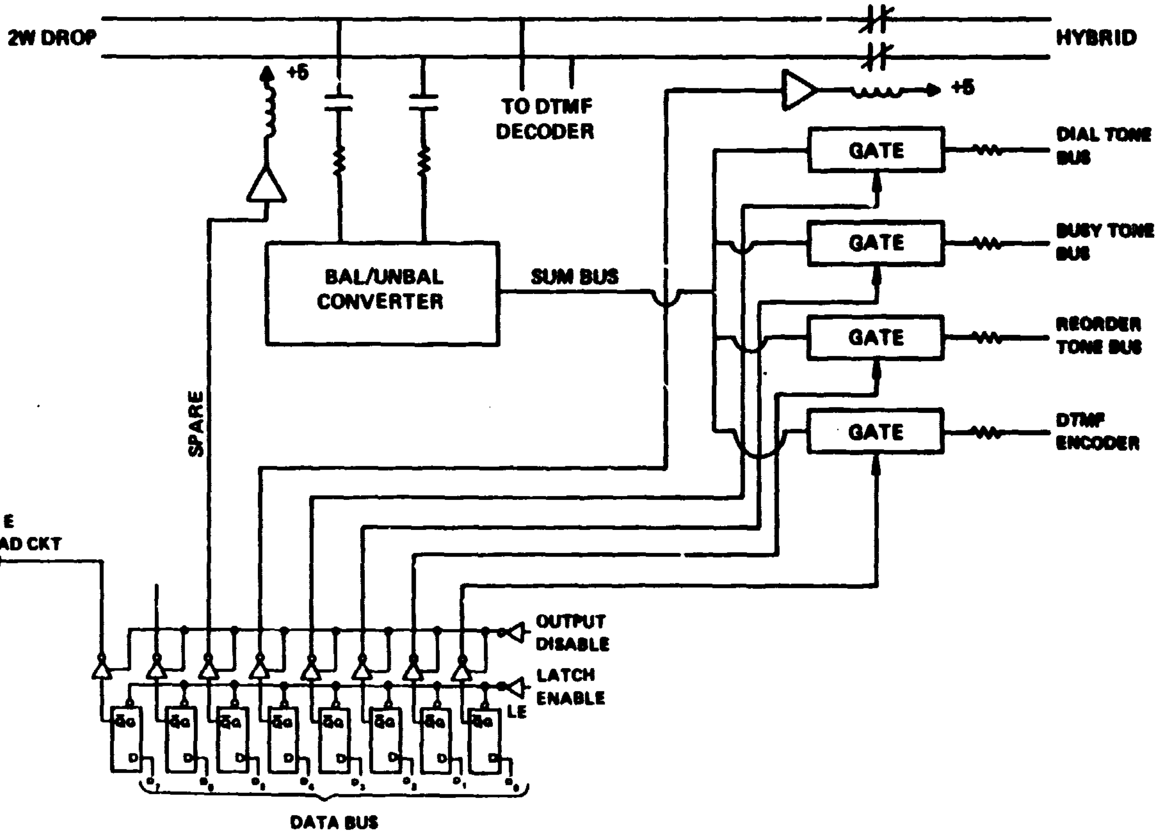
The DTMF encoder generates a pair of tones under command of the microprocessor controller. An eight bit input word is used, seven bits to select the tone pair (1:4 and 1:3) and the eighth to gate the encoder on and off. The tones are digitally generated to insure accuracy, and shaped by a resistor network to approximate a sine wave and minimize harmonics.



J4. TONE GATING

The tone gating circuit is used to select an appropriate tone on the DTMF coder for transmission to the PABX. Relays are used to connect the tones to the talking path toward the PABX, and disconnect the rest of the TIM. An eight bit word from the microprocessor bus is read into the latches and controls the state of the relays and gates. The tones are converted from unbalanced to balanced in a buffer circuit. The output resistors from this buffer provide the required 600 ohm termination for the line.

Separate relays have been used for tone insert and disconnecting the voice processing circuits of the TIM. This makes possible a test mode in which tones can be sent to the NCS (or other monitoring station) as a complete test of the tone generating, coding, decoding and voice processing portions of the terminal.

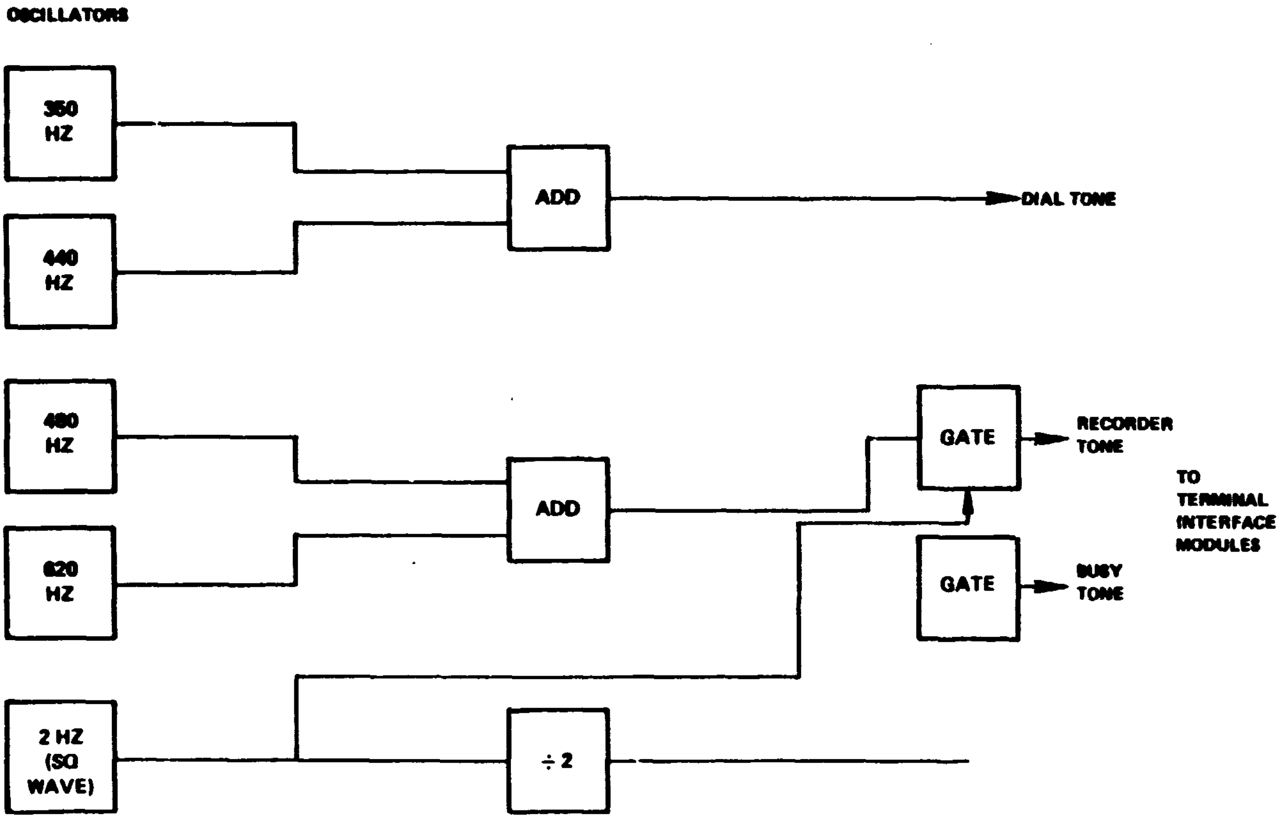


J5. TONE GENERATOR SYSTEM (COMMON EQUIPMENT)

The status tones are used by any individual TIM only a small percentage of the time. Consequently they are being provided by a common circuit and bussed to each channel unit. Dial tone and busy tone are familiar to every telephone user. Reorder tone is used to inform a caller that the number he dialed cannot be reached because it is not on the system, wrongly formatted, etc.

Dial tone consists of 350 Hz and 440 Hz sine waves, mixed at equal levels. Busy and Reorder tones are made up of 480 Hz and 620 Hz sine waves mixed at equal levels and gated at one Hz for Busy tone and two Hz for Reorder tone.

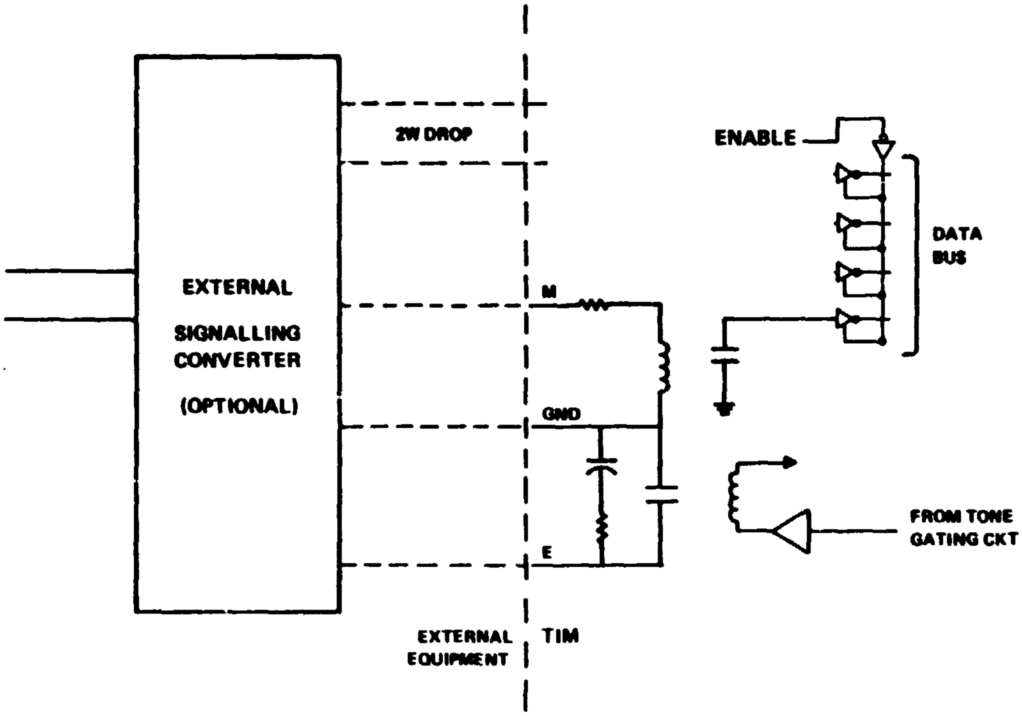
Standard low frequency oscillator circuits, opamp adders and transission gates are used in this system.



J6. E&M INTERFACE CIRCUIT

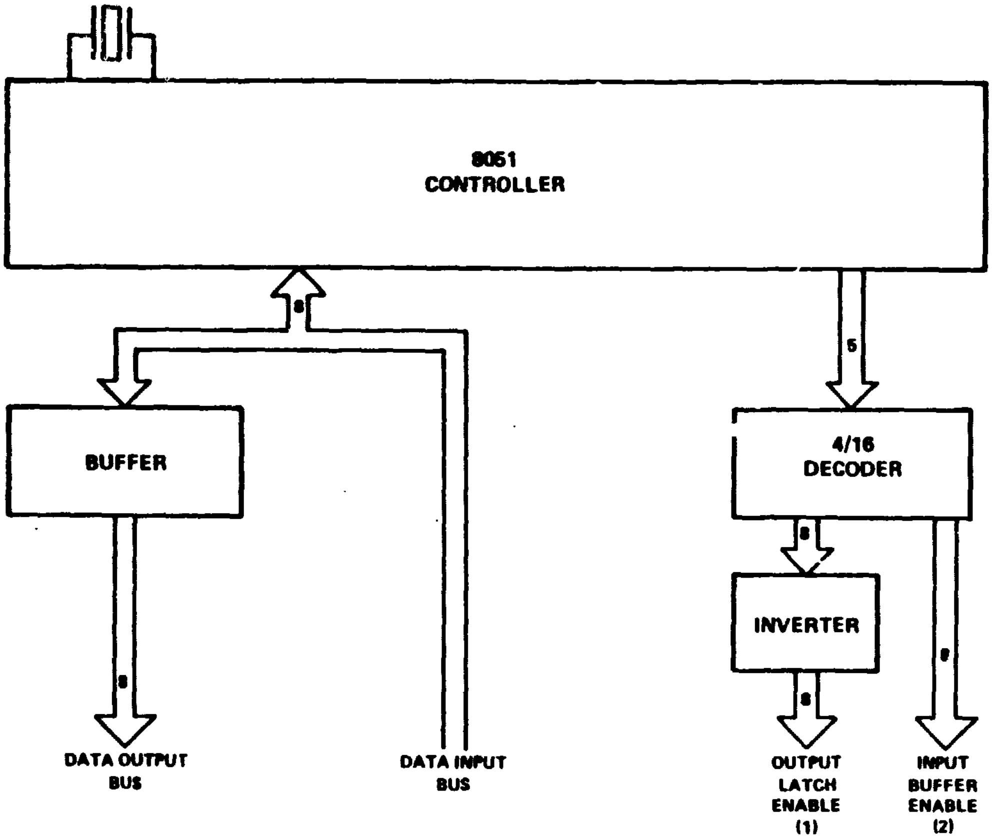
E&M leads are used to communicate supervisory and DC (pulse) signalling between the ST terminal and a PABX. The M lead carries information from the PABX to the terminal and the E lead carries information from the terminal to the PABX. Relays are used to provide ground and power isolation between the PABX and the terminal. Since the fastest pulsing rate is 10 pps, reed relays are used to prevent relay operating time from affecting operation.

When another interface (not E&M) is required to match the external PABX or other user equipment, an external conversion unit will be used. This is industry standard equipment.



J7. MICROPROCESSOR CONTROLLER

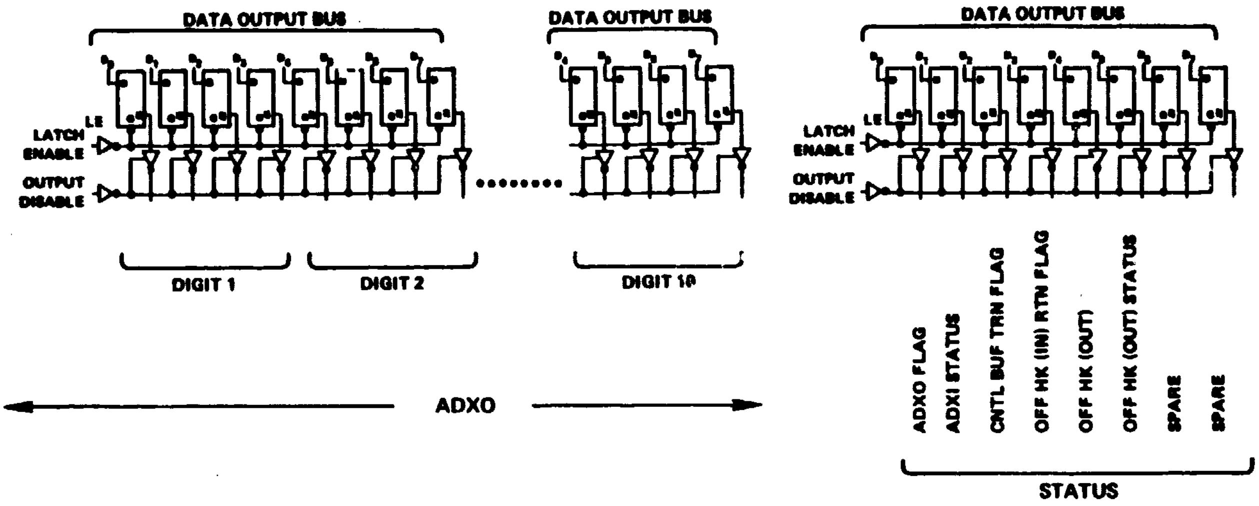
A microprocessor controller will be used to handle the supervisory and signalling information passing between the PABX and the ST terminal. An 8051 single chip controller has been selected. This contains 4 kbytes of program store and 128 bytes of data store, which should be more than adequate for this application. Two of its general purpose input/output ports will be used for a data bus and the port selection function. A 4:16 line decoder generates the 16 possible selection signals (8 input and 8 output). Miscellaneous logic for timing functions, etc. has not been shown.



(1)	ADXO	5
	STATUS	1
	TONE CTL	1
	DTMF ENC	1
(2)	ADXI	4
	STATUS	1
	DTMF DEC	1
	MISC	1
	SPARE	1

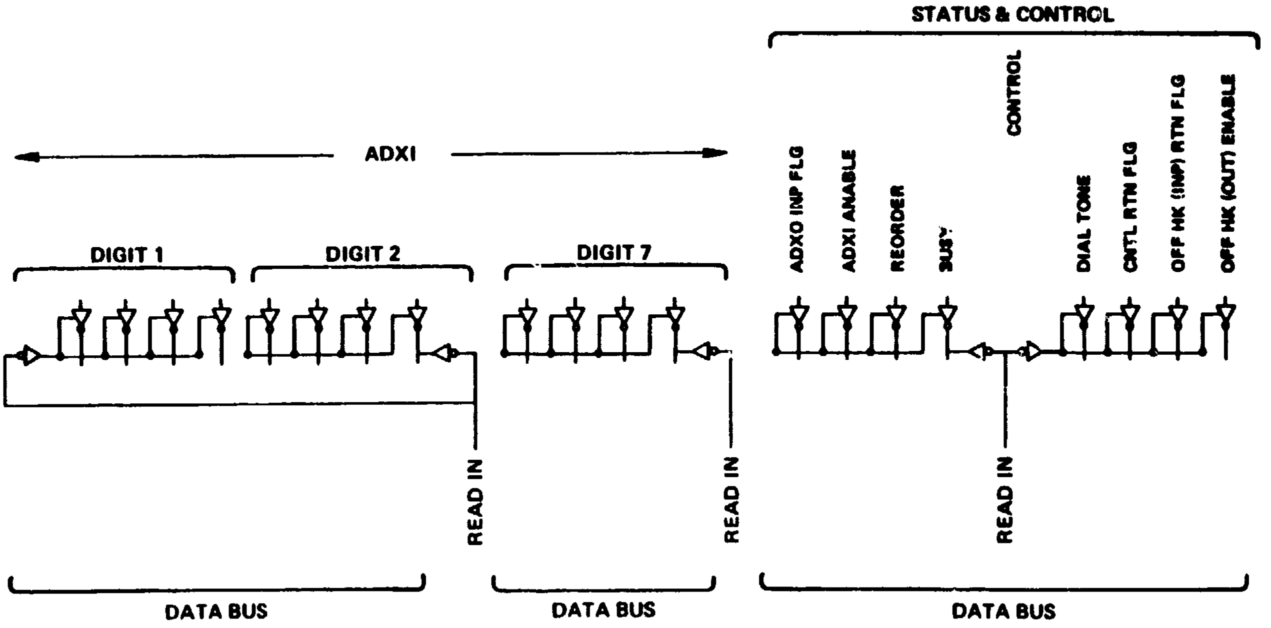
J8. OUTPUT BUFFER

The output buffer stores the customer dialed number (ADXO) and various status bits to make them available asynchronously to the orderwire. Groups of 8 bits consisting of two BCD dialed digits or 6 bits of status information are read into latches from the microprocessor controller data bus under control of latch enable signals from the controller. Three-state outputs have been provided which may be used by the orderwire system if desired.



J9. INPUT BUFFER

Input data from the orderwire to the signalling interface will consist of 7 BCD digits called party address (ADXI) and 8 bits of status information, presented in parallel format. These will be read into the microprocessor controller, via its data bus, 8 bits at a time, under control of enable signals from the controller.



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J10. MICROPROCESSOR PROGRAMMING

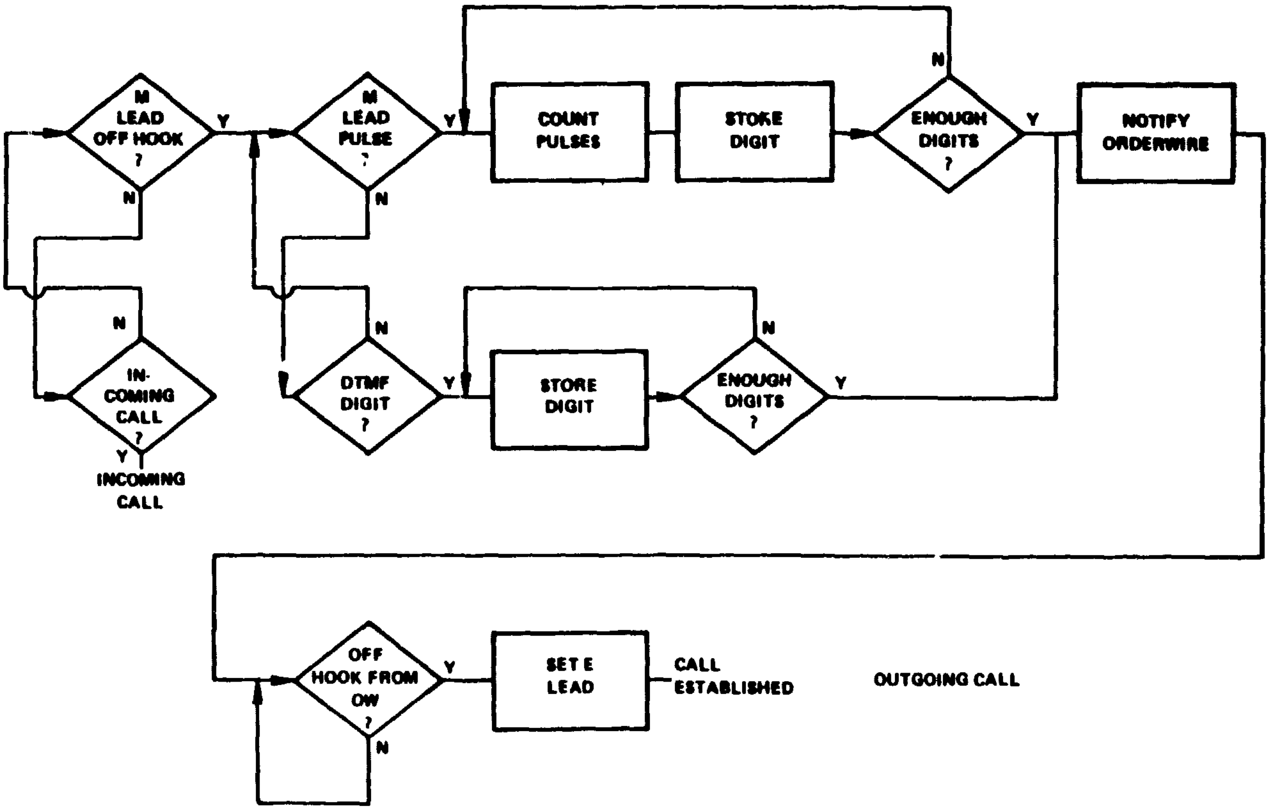
There are two possible processes occurring in the signalling interface—an incoming call or an outgoing call. These are basically complimentary process—only one occurs at a time—except for a possible overlap when both processes start simultaneously. This latter situation is called "Glare" and requires some special precautions to avoid system lock-up.

Because the microprocessor controller operates at microsecond speed while supervisory and signalling signals occur at millisecond speed, the program can be designed to operate in a polling mode, checking each input (M leads and orderwire input status word) alternately and branching to the appropriate subroutine depending on which becomes active.

J11. OUTGOING CALL

A simplified flow chart for an outgoing call is shown in the figure. When an M-lead OFF HOOK signal is recognized, the controller begins to hunt for either dial pulses or a DTMF signal. When it finds one it enters the appropriate subroutine to accumulate the called number and sends it to the orderwire output buffer (ADXO). When the number is complete the appropriate orderwire status flag is set. The controller then awaits a far-end off-hood signal from the orderwire to complete the call establishment sequence.

The above describes a normal call. There are many abnormal sequences, such as insufficient numbers dialed, glare, etc., which must be allowed for. The exact sequence of communication with the NCS must also be determined.



OUTGOING CALL

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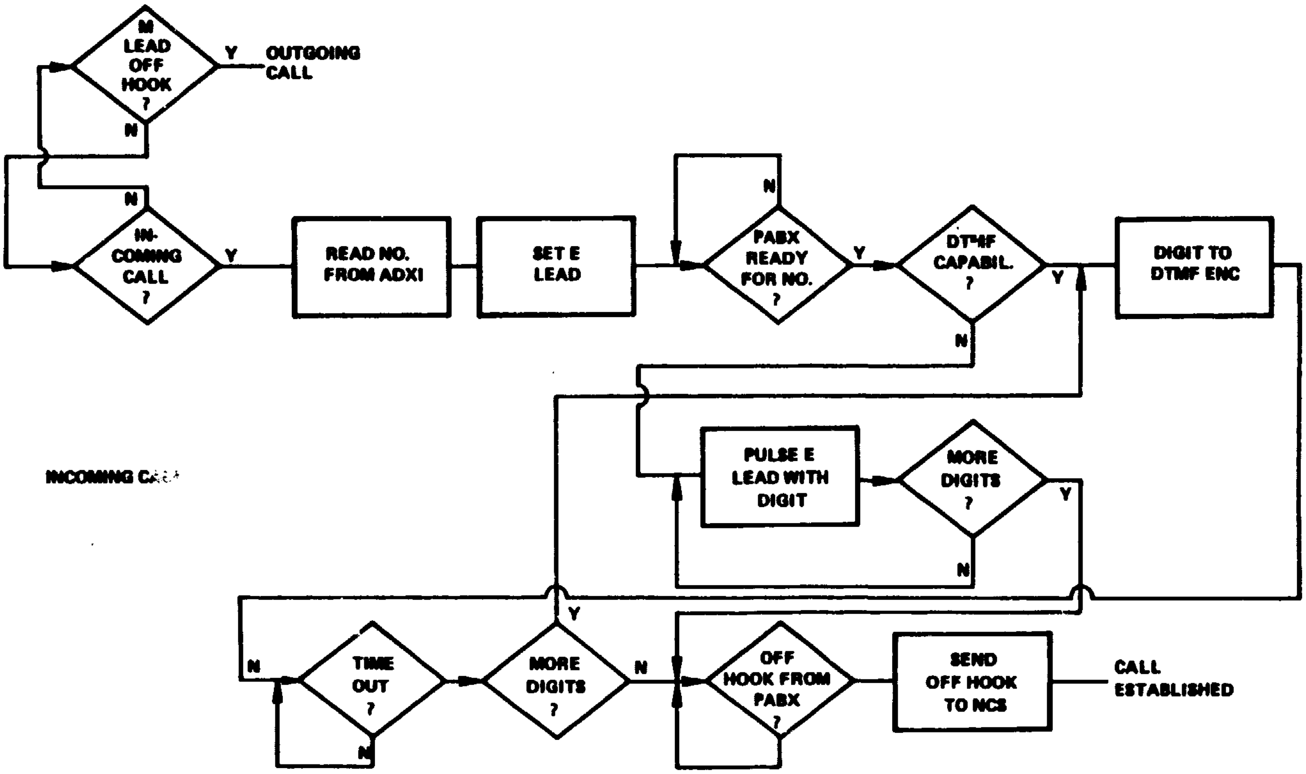
J12. INCOMING CALL

A simplified flow chart for an incoming call is shown in the figure. When the orderwire status line shows an incoming call, the called party address (ADXI) is read in. The terminal then signals OFF HOOK to the PABX, waits for a ready to accept dialing signal, and outpulses the number either as DTMF tones or as dial pulses. When number transmission is complete, the controller waits for an answer signal from the PABX. When this is transmitted to the NCS, the call establishment sequence is complete.

Again abnormal events have not been shown.



INCOMING CALL

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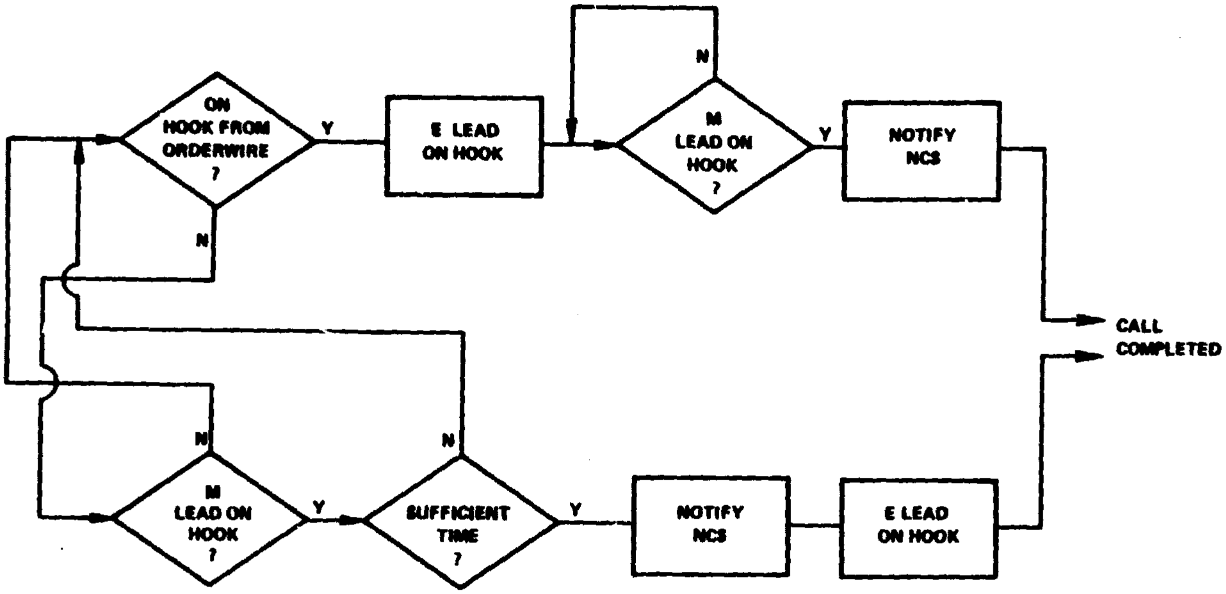
J13. CALL DISCONNECT

A simplified flow chart for call disconnect is shown in the figure. The initial disconnect signal may come from either end.



SUBJECT INDEX

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)

SUBJECT INDEX (Cont)