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MODULAR

space station

PHASE B EXTENSION

INFORMATION MANAGEMENT ADVANCED DEVELOPMENT FINAL REPORT

Volume II: Communications Terminal Breadboard

PREPARED BY PROGRAM ENGINEERING
JULY 31, 1972

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

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TECHNICAL REPORT INDEX/ABSTRACT

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ABSTRACT

THIS DOCUMENT IS VOLUME II OF THE FINAL REPORT OF THE MODULAR SPACE STATION ADVANCED DEVELOPMENT STUDY, HARDWARE DESIGN AND TEST PROGRAM WHOSE FINAL OBJECTIVE WAS TO DEMONSTRATE A TECHNIQUE FOR INTEGRATING THE MODULAR SPACE STATION (MSS) EXTERNAL COMMUNICATIONS EQUIPMENT WITH A HIGH GAIN PARABOLIC ANTENNA AND TO DEMONSTRATE ITS CAPABILITY TO PERFORM THE MSS COMMUNICATIONS OPERATIONS. THIS PROGRAM INCLUDED PRELIMINARY ANALYSIS TO DEFINE THE DESIGN OF AN MSS CONCEPT THAT WOULD BE COMPATIBLE WITH OTHER PROGRAM ELEMENTS SUCH AS THE EARTH ORBITAL SHUTTLE AND THE TRACKING AND DATA RELAY SATELLITE. DETAILS OF THIS ANALYSIS, THE DESIGN CONCEPT OF AN OVERALL COMMUNICATIONS TERMINAL BREADBOARD AND THE DESIGN DETAILS AND TEST RESULTS OF THE DELIVERED EXTERNAL RF PACAKGE ARE INCLUDED.

FORM M 131-V REV. 1-68

FOREWORD

This document is one of a series required by Contract NAS9-9953, Exhibit C, Statement of Work for the Phase B Extension - Modular Space Station Program Definition. It has been prepared by the Space Division, North American Rockwell Corporation, and is submitted to the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, in accordance with the requirements of the Data Requirements List (DRL) MSC-T-575, Line Item 72.

This document is Volume II of the Modular Space Station Information Management System Advanced Development Technology Report, which has been prepared in the following five volumes:

I	IMS ADT Summary	SD72-SA-0114-1
II	IMS ADT Communications Terminal Breadboard	SD72-SA-0114-2
III	IMS ADT Digital Data Bus Breadboard	SD72-SA-0114-3
IV	IMS ADT Data Processing Assembly	SD72-SA-0114-4
V	IMS ADT Software Assembly	SD72-SA-0114-5

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DP-103	DPA Processor Performance Requirements (Preliminary), August 1971
DP-103	DPA Processor Final Description, May 1972
DP-104	EEM DMS Processor Development Plan, June 1972
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DP-110	DBCU Acceptance Report (to be published)
EL-277	Bulk Storage Development Plan
IB-101	DPA Internal Flow and Traffic Pattern, May 28, 1971
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ICD #AN 26465	Interface Control Document - Data Bus Controller Unit to Buffer I/O, Revision January 21, 1972
MD-101	Mass Memory Parametric Data
RF-101	Modular Space Station Communications Terminal Breadboard Preliminary System Specification, October 1971

SA-101	Central Processor Operational Analysis, September 30, 1971
SA-102	Central Processor Memory Organization and Internal Bus Design, December 30, 1971
SD 71-227	Automatic Control and Onboard Checkout Final Study Report

ABBREVIATIONS

ADS	Advanced Data System
ADT	Advanced Development Technology
ADTX	Advanced Development Technology Extension
AFC	Automatic Frequency Control
AGC	Automatic Gain Control
AN	Autonetics (Division of North American Rockwell Corporation)
BPF	Bandpass Filter
bps	Bits Per Second
CAIRS	Computer-Assisted Interactive Resource Scheduling
CCIR	International Radio Consultative Committee
CDR	Critical Design Review
CEI	Contract End Item
CLASP	Computer Language for Aeronautics and Space Programming
CM	Command Module (Apollo)
COMPOOL	Common Pool (of Data)
CP	Central Processor or Circular Polarization
C.P.	Computer Program
CPCEI	Computer Program Contract End Item
CPCI	Computer Program Configuration Item
CPDF	Computer Program Development Facility
CPIC (A)	Computer Program Integration Contractor (Agency)
CPT&E	Computer Programming Test and Evaluation
CR	Change Report
CRT	Cathode-Ray Tube (Display)
CSS	Crew Subsystem
CTB	Communications Terminal Breadboard
CTF	Central Test Facility
DACS	Data Acquisition and Control Subassembly
dB	Decibel
DBCU	Data Bus Control Unit
dBm	Decibel Referred to One Milli-Watt
dBW	Decibel Referred to One Watt
DCR	Design Change Request
DDB	Digital Data Bus
Demux	De-Multiplex(er)
DMS	Data Management System
DPA	Data Processing Assembly
DPSK	Dual Phase Shift Keying
DRSS	Data Relay Satellite System

ECP	Engineering Change Proposal
EDF	Experiment Data Facility
EEM	Engineering Evaluation Model
EEMP	Engineering Evaluation Model Processor
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatability
EMI	Electromagnetic Interference
EOS	Earth Orbital Shuttle
EOSS	Earth Orbital Space Station
EPS	Electrical Power Subsystem
ETC/LSS or ECLSS	Environment Control and Life Support Subsystem
EVA	Extra-Vehicular Activity
EXT	External
E_b/N_o	Energy Per Bit to Noise Density Ratio
FACS	Facsimile
FDM	Frequency-Division Multiplex
FM	Frequency Modulation
FQT	Formal Qualification Test
G&CS	Guidance and Control Subsystem
GFE	Government Furnished Equipment
GHz	Giga-Hertz
GOA	Gated Operational Amplifier
HAL	Higher-Order Aerospace Programming Language
HOL	Higher-Order Language
HOLM	Higher-Order Language Machine
Hz	Hertz
IF	Intermediate Frequency
IFRU	In-Flight Replaceable Unit
IM	Intermodulation Products
IMS	Information Management System
IMSIM	Information Management Simulation
IOC	Initial Operational Capability
IOCB	Input-Output Control Block
IOU	Input-Output Unit
I/O	Input-Output
IPA	Intermediate Power Amplifier
IQL	Interactive Query Language
IR	Infra-Red
ISS or IMS/S	Information (Management) Subsystem
ITT	International Telephone and Telegraph
K-words	Thousands of (Computer) Words
K-EAPS	Thousands of Equivalent-Add Operations Per Second
K-bps	Thousands of Bits Per Second
KH_z	Kilohertz

LEM	Lunar Excursion Module
LM	Lunar Module
LNA	Low Noise Amplifier
LO	Local Oscillator
LPF	Low Pass Filter
M1, M2	(Computer) Memory Designation
Mbps	Megabits Per Second
MCB	Module Control Block
MHz	Megahertz
MOF	Mission Operations Facility
MOL	Manned Orbiting Laboratory
MSC	Manned Spacecraft lenter
MSFN	Manned Space Flight Network
MSS	Modular Space Station
MUX	Multiplexer
mW	Milli-Watts
MW	Microwave
mV	Milli-Volts
NF	Noise Figure
OBCO	On-Board Checkout
OCC	Operations Control Center (On-Board)
ODM	Operational Data Management
OM	Operating Memory
PA	Power Amplifier
PCM	Pulse Code Modulation
PDR	Preliminary Design Review
PL/1	Procedure Language
PM	Phase Modulation
PN (PRN)	Pseudo Random Noise
ppm	Parts Per Million
POT	Preliminary Qualification Tests
PSK	Phase Shift Keying
RAM	Research and Applications Module
RACU	Remote Acquisition and Control Unit
RCS	Reaction Control Subsystem
RF	Radio Frequency
RHCP	Right-Hand Circular Polarization
RPU	Remote Processing Unit
Rx	Receive
S&C	Standards and Conventions
SCCB	Software Configuration Control Board
SCN	Specification Change Notice
SD	Space Division (of North American Rockwell Corporation)
SDC	Systems Development Corporation

S/N	Signal to Noise Ratio
SOW	Statement of Work
SPL	Space Programming Language
SRD	Step-Recovery Diode
SSCB	Solid-State Circuit-Breaker
SSS	Structures Subsystem
STE	Support Test Equipment
TAV	Test and Validation (Programs)
TBD	To Be Determined
TCXO	Temperature-Controlled Crystal Oscillator
TDA	Tunnel Diode Amplifier
TDM	Time Division Multiplexing
TDRS	Tracking and Data Relay Satellite
TIP	Test and Integration Plan
TLM, TM	Telemetry
TOOL	Test Operations Oriented Language
TRW	Thompson Ramo Woolridge Corporation
TT&C	Telemetry, Tracking and Control
TWT	Traveling Wave Tube
TWTA	Traveling Wave Tube Amplifier
Tx	Transmit
USB (E)	Unified S-Band (Equipment)
UV	Ultra-Violet
VDD	Version Description Document
VHF	Very High Frequency
VSB	Vestigal Side Band
VSWR	Voltage Standing Wave Ratio

1.0 COMMUNICATIONS TERMINAL BREADBOARD

1.0 COMMUNICATIONS TERMINAL BREADBOARD

This report delineates the results of an 18-month program whose final objective is to demonstrate a technique for integrating the Modular Space Station external communications equipment with a high gain parabolic antenna and demonstrating its capability to perform the MSS communications operations. This program includes preliminary analysis to define the design of an MSS concept that would be compatible with other program elements such as the EOS and the TDRS. Details of this analysis, the design concept of an overall Communications Terminal Breadboard (CTB) and the design details and test results of the delivered external RF package are included.

1.1 SUMMARY

The MSS total communications terminal includes a complex of equipment operating in three frequency bands - VHF, S and Ku. Each band is used to provide specific communications links with a multiplicity of external terminals and a complex of baseband signals. These links and their signal transfer requirements are defined in Table 1-1 and Figure 1-1.

Operation of the communications system to provide the capability for multiple link, multiple frequency performance is proposed by a design that incorporates RF and baseband switching. This is based on the MSS Phase B concept to mount the K and S-band RF power amplifiers and RF receiver preamplifiers as close to their antennas as possible. In the case of the K-band system this involves the location of these equipments on the external, steerable, parabolic antenna. By providing up and down conversion to the K-band transmitter and receiver from S-band, low level RF signals can be routed from the internal S-band equipment over coaxial cables. In a similar manner, S-band power amplifiers and receiver front ends are mounted close to each semi-directive antenna. Efficiency of the overall systems are thus improved by avoiding the RF cable losses at the higher powers and higher frequencies. Figure 1-2 displays this physical concept.

These concepts required the development of a K-band transmitter/receiver package capable of being operated in a Space Environment and of being mechanically and electrically interfaced with a 5-foot parabolic antenna. It also requires the development of a concept for multiple RF link mechanization.

The first task resulted in a concept for the Multiple RF Link Mechanization. Provision is made to switch between the five separate duplex RF channels which link the MSS to:

1. Tracking and Data Relay Satellite (TDRS)
2. Earth Orbital Shuttle (EOS)
3. Two Research Application Modules (RAM)
4. Ground Stations of the MSFN

Table 2-1. External Communication Data Characteristics

		RF Channel	Voice	Television	System TLM	Computer Data	Experiment Data	Text/ Graphics	Command Data	EVA TLM	Facsimile	Ranging Measure	Ranging Respond
From Space Station To	Detached RAM	S-band	(1) 300-4000 Hz						10 kbps			0.5 mbps	
	Shuttle orbiter	S-band	(1) 300-4000 Hz		50 kbps							0.5 mbps	0.5 mbps
	MSFN ground terminal direct	S-band	(3) 300-4000 Hz	4.5 MHz	500 kbps	500 kbps	2.0 mbps	1.0 kbps		200 bps			0.5 mbps
	Ground terminal via TDRS	VHF	(1) 300-4000 Hz		10 kbps								
	Ground terminal via TDRS	K-band	(3) 300-4000 Hz	4.5 MHz	500 kbps	500 kbps	2.0 mbps	1.0 kbps		200 bps	0.5 MHz		0.5 mbps
	EVA	VHF	(1) 300-4000 Hz										
To Space Station From	Detached RAM	S-band	(1) 300-4000 Hz	2.9 MHz	50 kbps	500 kbps	Part of system TLM						0.5 mbps
	Shuttle orbiter	S-band	(1) 300-4000 Hz						1.0 kbps			0.5 mbps	0.5 mbps
	MSFN Ground Terminal Direct	S-band	(4)* 300-4000 Hz			500 kbps		1.0 kbps	1.0 kbps			0.5 mbps	
	Ground Terminal via TDRS	VHF	(1) 300-4000 Hz						1.0 kbps				
	Ground Terminal via TDRS	K-band	(4)* 300-4000 Hz			500 kbps		1.0 kbps	1.0 kbps				
	EVA	VHF	(1) 300-4000 Hz							200 bps			

*One of the four voice channels - ground to MSS - is a high-fidelity channel 30-10,000 Hz for entertainment.

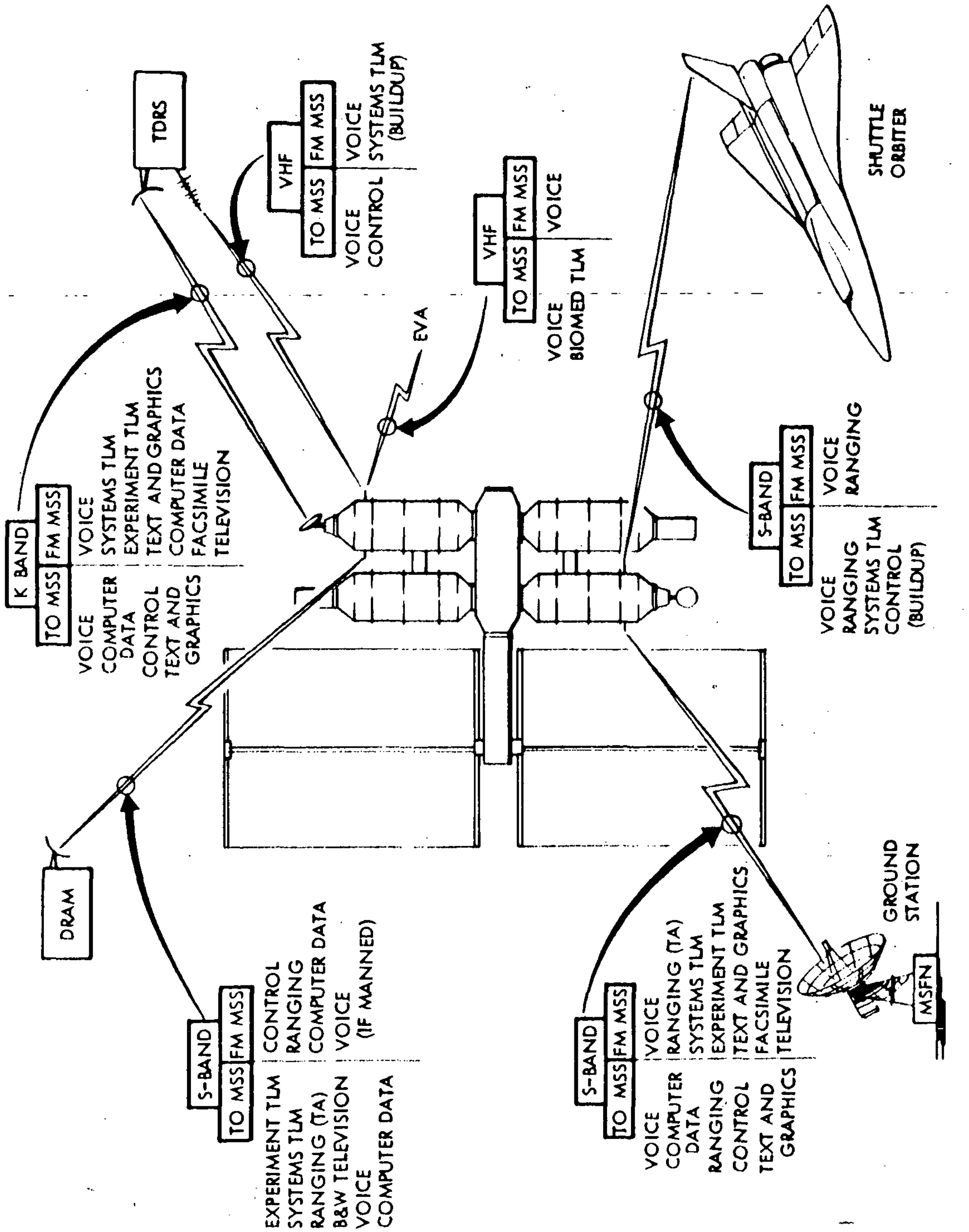

Figure 1-1. External Communication Link Requirements

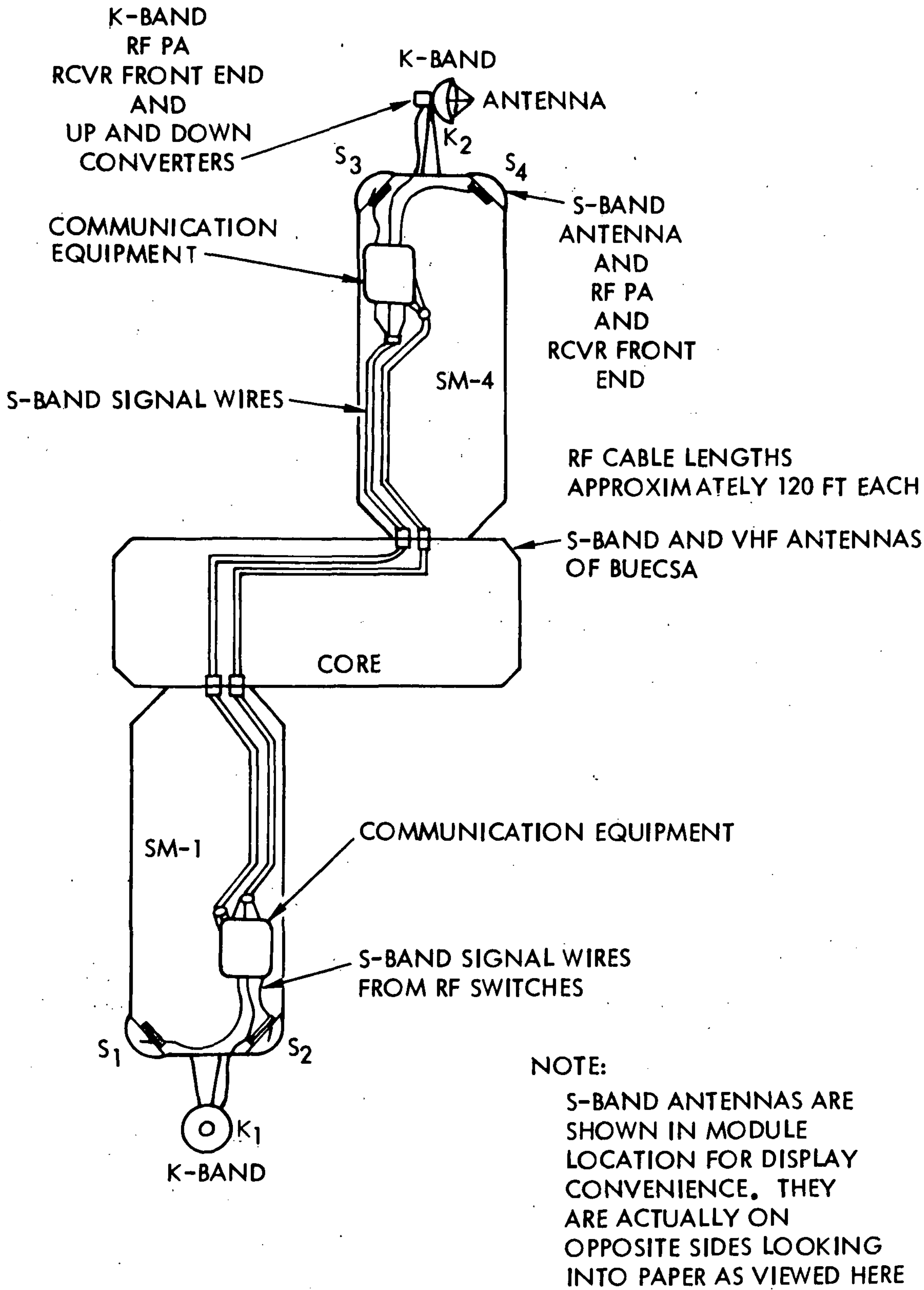

Figure 1-2. Physical Concept for RF Communication Link Equipment

Both baseband and RF switching were considered necessary to provide proper data to the desired link. Utilization of a PIN diode RF switching matrix results in a design concept for a lightweight, compact, reliable RF switching system with presently available hardware. Baseband switching and multiplexing concepts were also analyzed and recommended systems defined.

1.2 CTB GENERAL DESCRIPTION

A complete Communications Terminal Breadboard including both externally and internally mounted equipment was defined. The external Antenna Mounted Electronics Subassembly, Display-Control Unit and the Internal to External interconnect cables are deliverable hardware. Other equipment necessary to implement a complete breadboard terminal is to be furnished and assembled by the customer.

The Antenna Mounted Electronics Subassembly contains a K-band (14.65 GHz) transmitter and a K-band (13.6 GHz) receiver mounted in an enclosure designed for operation in a Space Environment. The K-band equipment is designed to interface with S-band frequencies, specifically compatible with the LEM transceiver. Thus a complete operating breadboard at K-band can be assembled by connecting and mounting the antenna mounted electronics subassembly to an antenna and connecting the K-band transmitter input to the LEM transmitter output at 2.2825 GHz and the K-band receiver output to the LEM receiver input at 2.1018 GH_z. Up and down conversion and the necessary amplification are provided in the K-band equipment package.

The antenna mounted RF electronics subassembly has the following major characteristics:

Transmitter

Output frequency -	14.65 GHz
RF power output (1) -	6 watts (one TWT); 20 watts (two TWT's)
RF bandwidth -	200 MHz
Input frequency -	2.2825 GHz
Input RF drive required -	1 MW
Input RF impedance -	50 ohms

(1) When one TWT power amplifier is used. When two are connected in parallel, power output will be a minimum of 20 watts. Single TWT operation operated in the two tube circuit results in a 3 db loss in the hybrid circuit.

Receiver

Input frequency -	13.6 GHz
Input RF signal level -	83 dBm
RF bandwidth -	200 MHz

Receiver (Continued)

Receiver System Noise Figure -	<7 dB
Output frequency -	2.1018 GHz
Output S-band power level -	-33 dBm (min.)
Output RF impedance -	50 ohms

1.3 HISTORY

At the inception of this program, the Communications Terminal Breadboard was conceived as an S-band system with a solid-state 20 watt transmitter power amplifier. With the development of the TDRS concept as the high-data rate relay satellite for MSS to ground, it was decided to change the emphasis for operational frequency to K-band - the TDRS frequency band. S-band equipment of the type proposed was available off-the-shelf type equipment. K-band equipment with a 20-watt rf transmitter power output and low noise K-band receiver equipment needed to be developed and evaluated. These decisions were made after the statement of work had been negotiated with ITT for the Communications Terminal Breadboard. Final negotiations with MSC and ITT resulted in reduction of analyses tasks and complete emphasis on the development, design, production, test and delivery of the K-band antenna mounted RF electronics assembly. Full use was made of the concept development activity in the specification of K-band hardware. This more closely followed the intent of the program - the demonstration of required new technologies.

2.0 REQUIREMENTS ANALYSIS

2.0 REQUIREMENTS ANALYSIS

2.1 SIGNAL SOURCES

The MSS communications terminal will service five external links at various times. Two are to the ground either directly or through a relay satellite, but because ranges and pointing problems are different, these were considered as distinct. The remaining links are unique; to the shuttle, to the research applications module, and to an EVA. The links will carry voice, telemetry, command or control, television, facsimile, experimental data, high rate computer data, and entertainment audio, but no all types of source material are required by each link. The services described originate from or are returned to one of three communications buses. These are the voice bus, the digital data bus, and the video entertainment bus. The reasons for employing a system of three buses with functions divided between voice, digital data, and video are discussed in Appendix Section 5.2.2, Baseband Switching Concepts.

The communications terminal will appear to be an ordinary subscriber to any bus. Thus, voice service will be taken off or put on the voice bus via the internal communications paging scheme. Digital data such as telemetry, command and control, and experimental and computer data originate from and are returned to the digital data bus via a number of RACUs. Television, facsimile, and entertainment audio will be taken from or inserted on the television-entertainment bus according to it's particular routing-management scheme.

Television, facsimile, and entertainment audio are in analog on the video and entertainment bus. They are therefore inserted or removed by analog filtering and multiplex techniques. Voice signals are digital on the internal communications bus but are ordinarily digitally removed and processed to produce analog voice for the subscriber. It will therefore be economical to use the same technique for the communications terminal. The data from the digital data bus will enter the communications terminal via RACU and will remain digital until modulation for transmission. Radio signals received from outside the communications terminal will be demodulated and then proceed in the opposite direction as they are transmitted to the three communication buses.

2.2 BREADBOARD DESIGN

The external communication system for the modular space station is expected to consist of direct links between the station and logistic vehicles, detached modules, ground, and a relay satellite to ground. Two kinds of antennas are being considered for these links. The first is a set of semi-omni antennas arranged to give essentially spherical coverage, and the second is a high-gain cassegrain-type parabolic reflector provided for the relay satellite link, and other applications requiring directivity and high gain such as angle tracking and detached module TV reception. Although the breadboard design is directed toward the high-gain antenna with regard to packaging concept, the design is directly applicable to the semi-omni antenna.

The system concept will afford flexibility in directing the functions described to any one of the five external links by switching.

Transmission and reception are implemented by placing the transmitting power amplifier, receiving low noise amplifiers, and associated diplexer at the antenna to eliminate feed cable losses. The low level RF to the transmitting amplifier and from the receiving amplifier are fed over about 50 feet of cable from the electronics inside the space station.

The electronics inside the space station include the modulators, frequency and baseband switching apparatus, local oscillators, and modulation processor.

The physical separation of functions eliminates the leakage, pickup, and loss problems associated with routing high power transmit and low level receive signals on long cables. As proposed, the transmit signals are routed at 10 mw and the receive signals are 30 db above the received antenna power.

2.3 RECOMMENDED APPROACH

Based on the tradeoff studies in the Appendix, it has been concluded qualitatively on the basis of cost, reliability, flexibility, maintainability, complexity, size, and weight, that the preferred communications switching system concept of the two considered is that shown in block form in Figure 2-1. This diagram illustrates the entire system for the final station configuration. The basic operation involves baseband switching combinations of information sources for the different links to the appropriate multiplexers and switching the outputs of the demultiplexers to the appropriate internal bus inputs. The multiplexers assemble the combinations of information into basebands which are used to frequency modulate the corresponding link carriers. The demultiplexers disassemble the basebands from the demodulators into the different information sources. Any of the multiplexer-modulator or demultiplexer-demodulator pairs can be used to assemble or disassemble the information for any of the links since the modulators and demodulators have the capability to generate and operate with any of the link carriers. The RF switching matrices switch the different link signals to or from any of the station antennas.

Figure 2-2 shows a functional block diagram of the communications terminal breadboard as it is now conceived. The information sources that will be processed are three analog voice channels, one digital data channel, and one TV channel. The baseband switching matrix will demonstrate the ability to switch any of the inputs to the outputs and the capability of switching any of the three input voice channels to any of the three voice inputs of the multiplexer and the voice outputs of the demultiplexer to any of the outputs of the matrix.

The baseband switching matrix, the multiplexer and the demultiplexer compose the modulation processor of the system. The design of the muliplexer and demultiplexer is a function of the analog or digital form and TDM or FDM format of the information sources from the MSS and the type of processing that the signals will undergo as determined by the tradeoff studies of Section 5.1.

Assuming the signals are in the form noted previously, block diagrams of the proposed multiplexer and demultiplexer are shown in Figures 2-3 and 2-4. The multiplexer operates on the different signals so that they are frequency multiplexed into one baseband, which is used to frequency modulate the carrier.

Signal conditioning is performed on the analog TV with its baseband spectrum position left unchanged. The three analog voice signals are frequency multiplexed in a position above the TV, and the digital data is used to PSK a subcarrier so that its spectrum position is above the TV and voice. Figure 2-5 shows the baseband spectrum at the output of the multiplexer.

The demultiplexer performs the reverse operation on the baseband at the output of the demodulator. Filtering is employed to separate the three signals. The TV signal is amplified, the three voice channels are frequency demultiplexed, and the digital data are removed from the subcarrier.

The frequency modulator and demodulator will be designed to demonstrate the capability to switch carriers as required by the recommended system. The output of the modulator and the input to the demodulator will be connected to the RF switching matrix.

The RF switching matrix could be a greatly reduced version of the final matrix. It will be built with two inputs and two outputs for the transmit and receive portions so that its isolation, insertion loss, and coupling properties can be verified. For demonstration, a suitable noise generator could be connected to the extra inputs of the matrix shown in Figure 2-2 to illustrate the switching operation and isolation.

2.4 RELATION TO ULTIMATE SYSTEM

Figure 2-2 shows effectively one transmit and receive channel of the total system (Figure 2-1.). It includes all the functions that are required in the ultimate system and therefore serves as a means to demonstrate the operation and performance of all the system functions. It also illustrates how the total system can be evolved from the breadboard.

The evolution of the final system is a simple procedure. As the number of channels increases, the baseband and switching matrices must be expanded so that they can switch these added links, and an identical multiplexer, demultiplexer, modulator, and demodulator must be added for each new channel.

To add pseudo-random ranging, the baseband switching matrix must be expanded to accommodate the extra information source, a PSK modulator must be added to each multiplexer and a filter must be added to each multiplexer. A capability for turnaround ranging can be included by a simple addition to the baseband switching matrix.

The addition of more antennas to the system involves adding diplexers, transmitters and receivers, and the expansion of the RF switching matrix.

The description of system buildup shows that the difference between the breadboard and the ultimate system is only in the number of components and the number of inputs and outputs of the switching matrices. The functions involved in the system operation are the same.

2.5 FAILURE MODE CONSIDERATIONS

The question arises: How flexible is the recommended communications system in an emergency? Can communications with the ground continue in a greatly decreased capability? For example, can one voice channel or possibly just a telegraph key be used if there is a power failure at the space station with only batteries as an auxiliary power source?

Since there might be an extreme power shortage in this situation, communications of any kind must be carried on with as little equipment operating as possible. The recommended RF switching system has this capability of transmitting over any link with only a small percentage of the total system operating.

Provisions for an emergency could be built into the communications system. For example, a manually operated switch to bypass the switching matrix and connect the transmitter associated with the appropriate antenna directly to the modulator, with emergency lines to power the transmitter from the auxiliary power; an input to the modulator for a microphone and multiplexer; and a similar arrangement on the receive channel. This would allow transmission and reception with a minimum amount of equipment and a minimum amount of power consumption.

All the equipment at present, conceived for this emergency communications, could be operated with a consumption of approximately 10 watts.

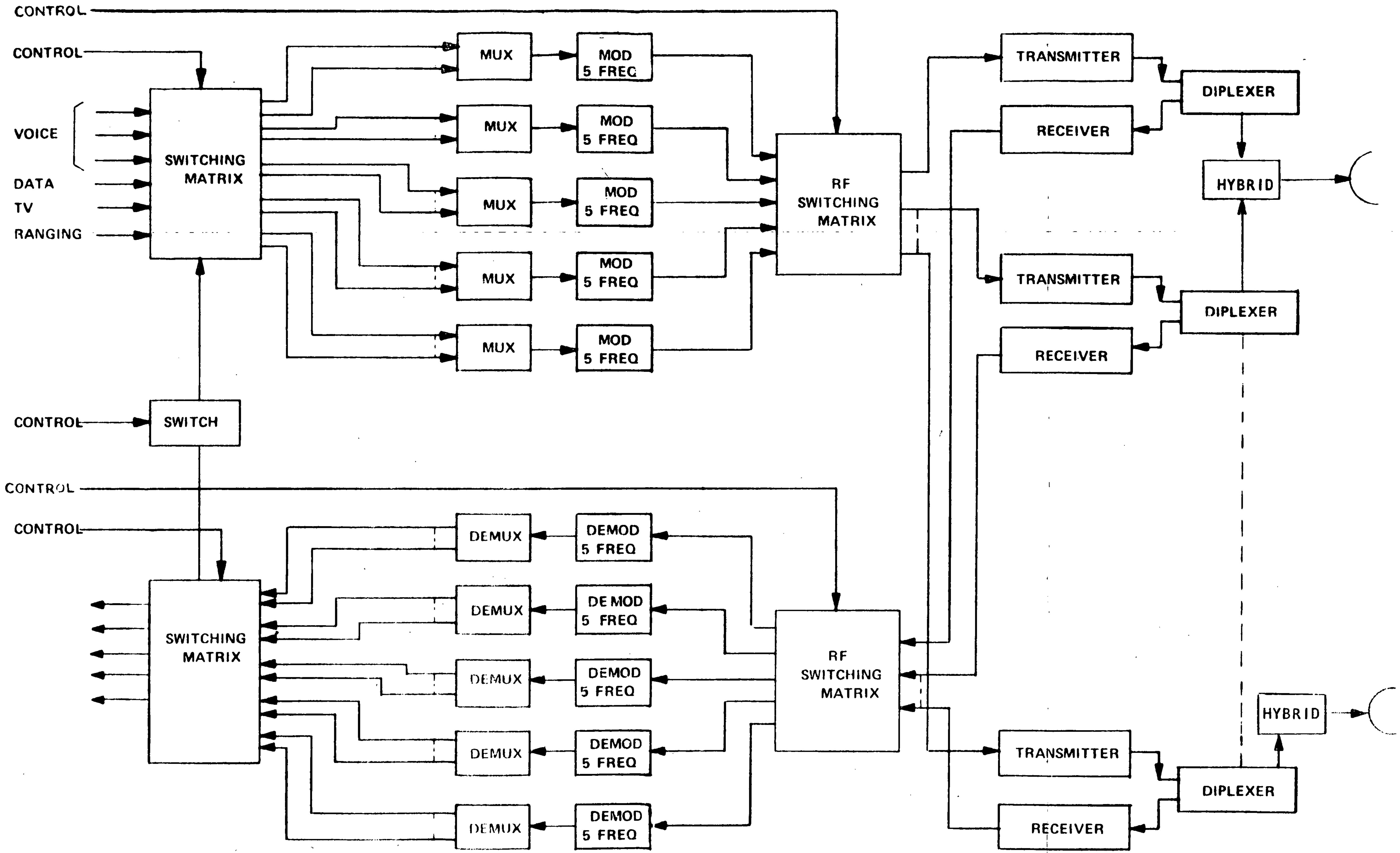

Figure 2-1. Recommended Communication System

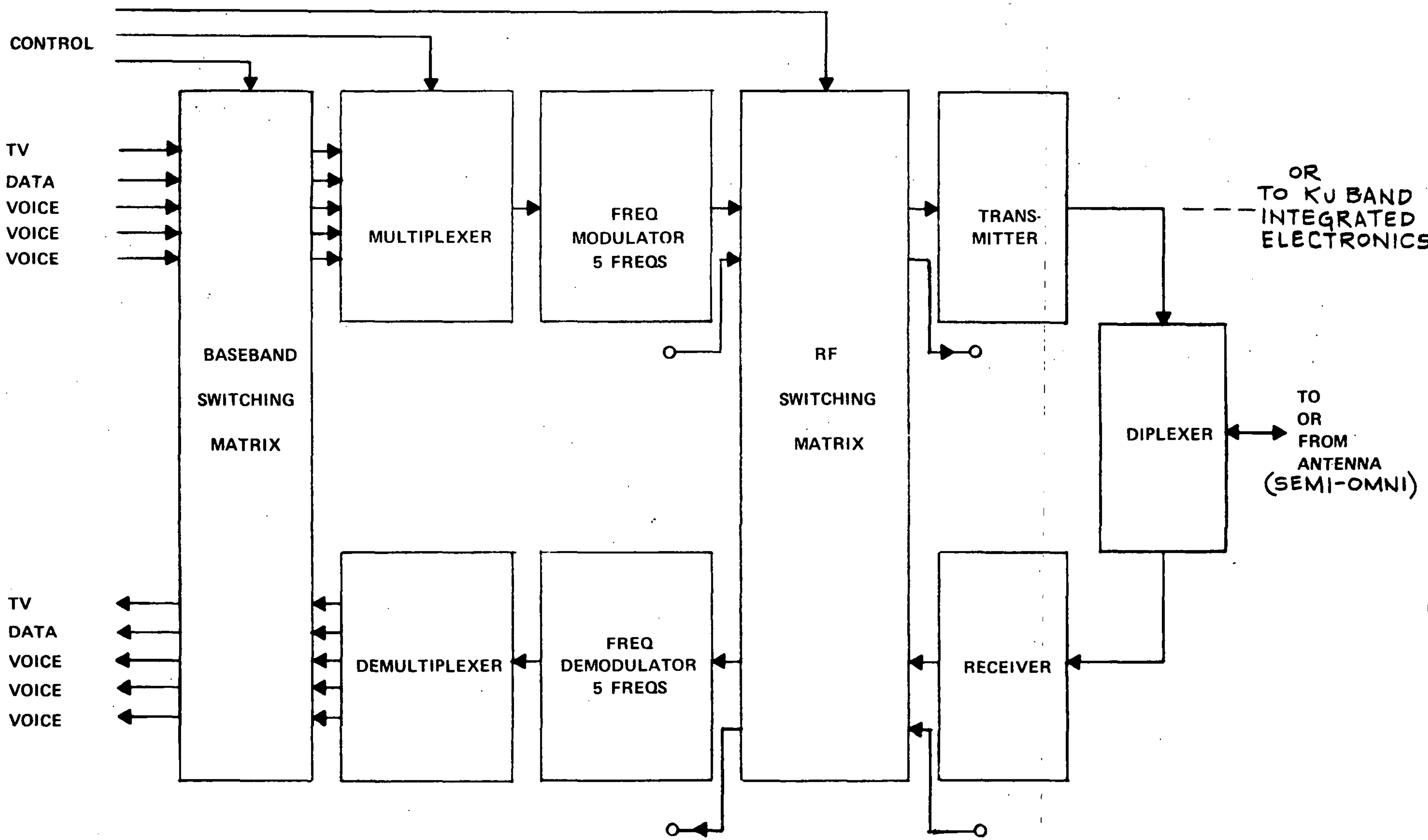

Figure 2-2. Communications Terminal Breadboard

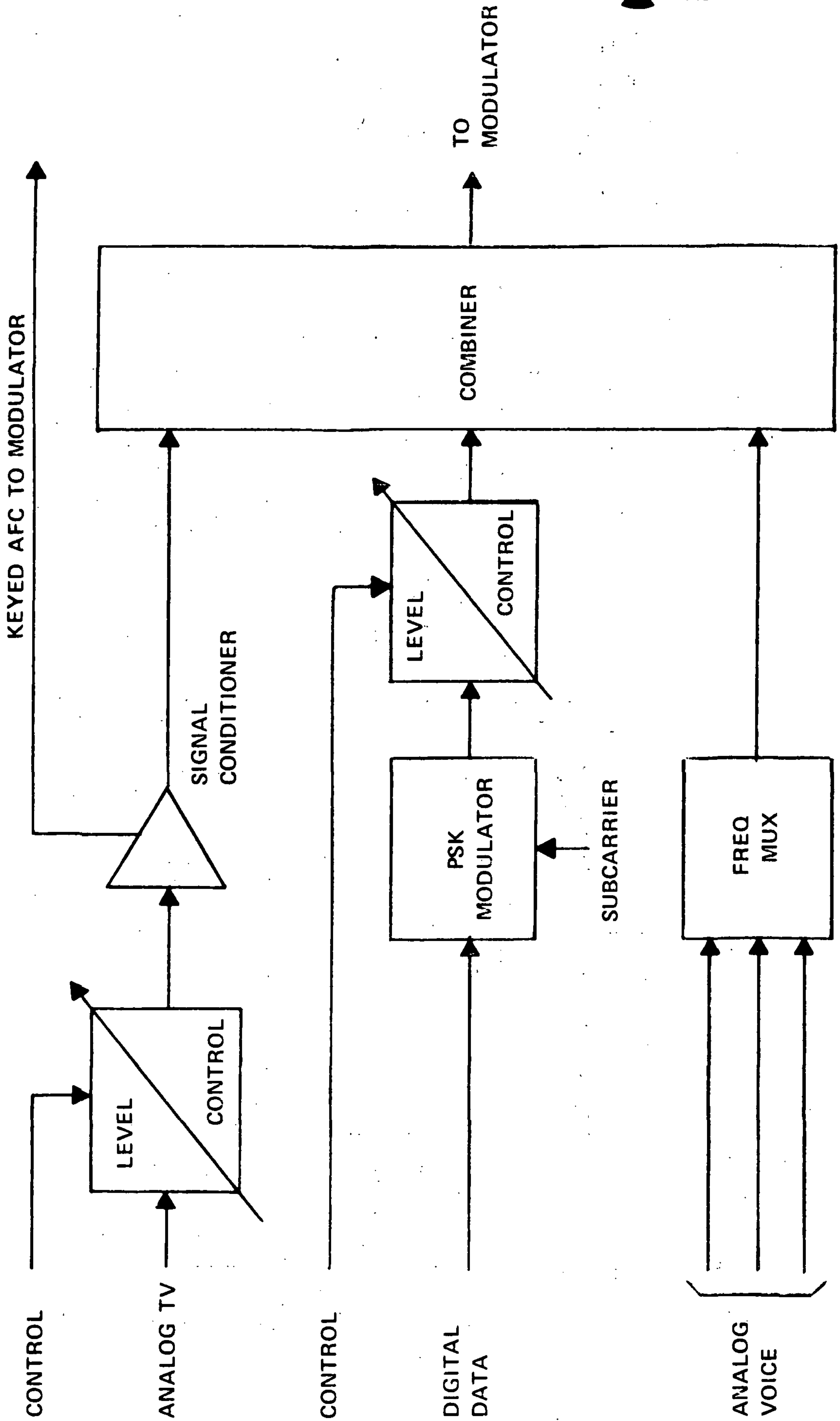

Figure 2-3. Multiplexer for Communication Terminal Breadboard

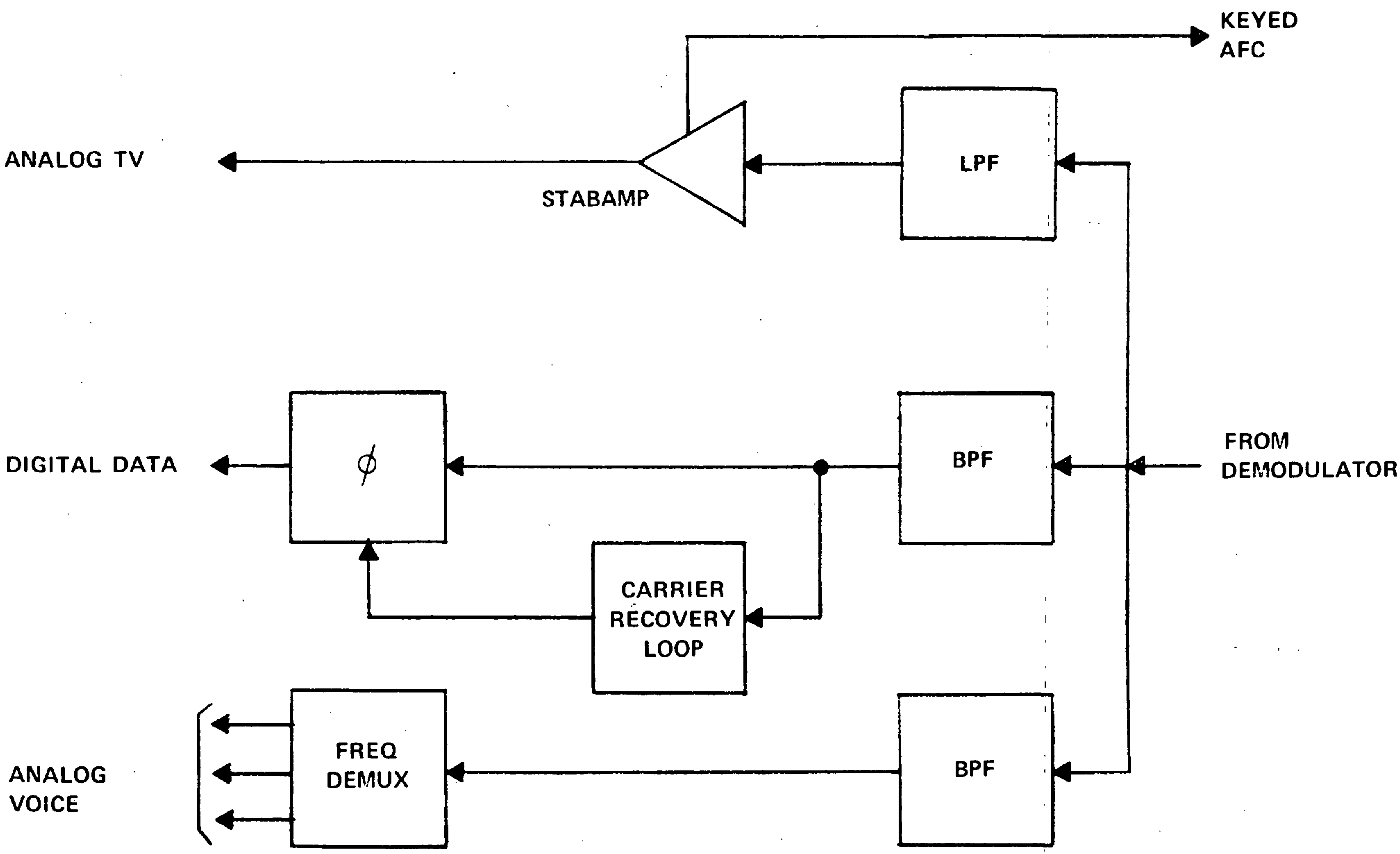

Figure 2-4. Demultiplexer for Communication Terminal Breadboard

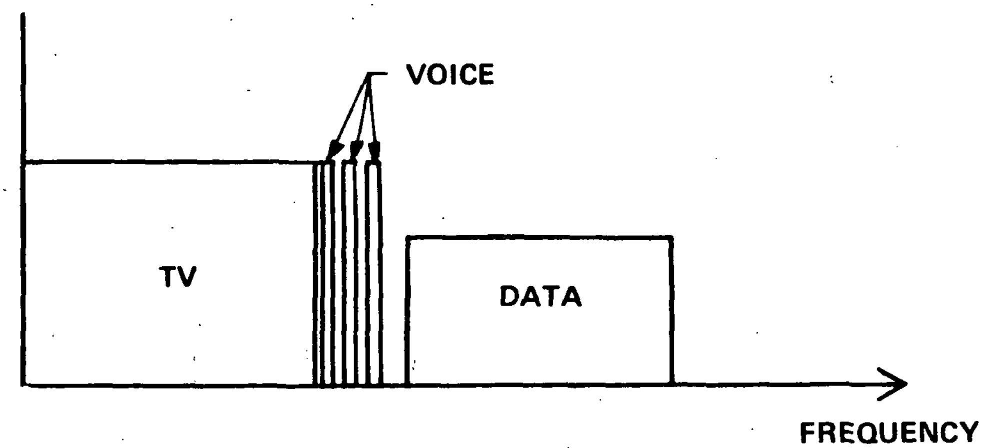

Figure 2-5. Baseband Spectrum at Multiplexer Output

3.0 BREADBOARD DEVELOPMENT AND DESIGN

3.0 BREADBOARD DEVELOPMENT AND DESIGN

3.1 CTB DEVELOPMENT AND DESIGN

A complete set of requirements were developed for a Communications Terminal Breadboard that can be used as a test bed for evaluation of the MSS terminal concept. Figure 3-1 shows the block diagram of this overall Communication Terminal Breadboard. The antenna-mounted electronics subassembly was designed, developed and delivered as an operating unit to these requirements. Implementation of a complete system requires the mechanization and interconnection of other subassemblies that include an antenna system, S-band converters to and from baseband, multiplexing and demultiplexing equipment and a baseband switching system. Requirements for all of these subassemblies were developed and can be used to obtain available hardware. The antenna-mounted electronics subassembly is supplied with the necessary interconnect cables and control display unit to operate with this equipment. Figure 3-2 identifies all of this hardware. A concept of the overall breadboard configuration is displayed in Figure 3-3. The overall CTB requirements definitions form the basis for ensuring that the ultimate CTB will represent a logical development of requirements and concepts. It should be emphasized that the characteristics and definitions are by no means frozen. They may vary to reflect any changes in the station concept as it evolves.

The remaining portions of this section present the detailed design of the delivered antenna-mounted electronics subassembly and the requirements definitions of the remaining subassemblies.

3.2 TECHNOLOGY GOALS

Detailed design of the antenna-mounted electronics subassembly was based on the performance requirements that were structured from a set of prioritized technological goals. Table 3-1 lists these goals in priority order. Those addressed in the resultant design are enclosed in the table box. Evaluation of this equipment and its operation will define the adequacy of these concepts for application to the MSS communications terminal design. An effective laboratory and operational test program and the resultant evaluation will provide data for avoidance of future design and operational problems.

The total CTB can be expanded to address other technical and operational problems associated with future concepts and practices for the MSS communication terminal. Addition of RF switching, S-band terminals and the associated baseband switching would allow evaluation of frequency spectrum management, simultaneous multiple links and the EMI problems.

As indicated in the Technology Goals, CTB/antenna compatibility and techniques for automatic checkout and control can be investigated utilizing the equipment specified herein.

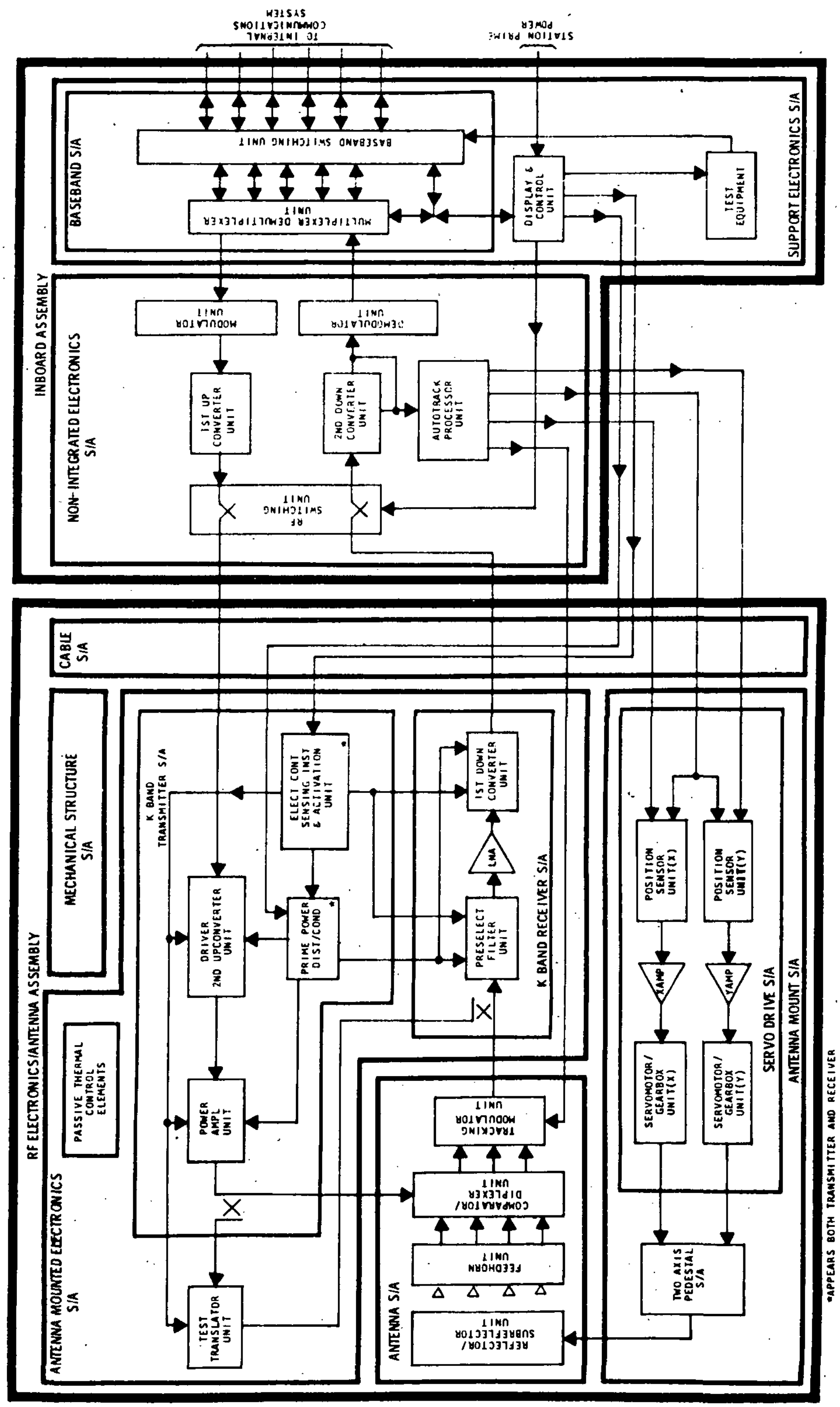

Figure 3-1. Communications Terminal Breadboard Block Diagram

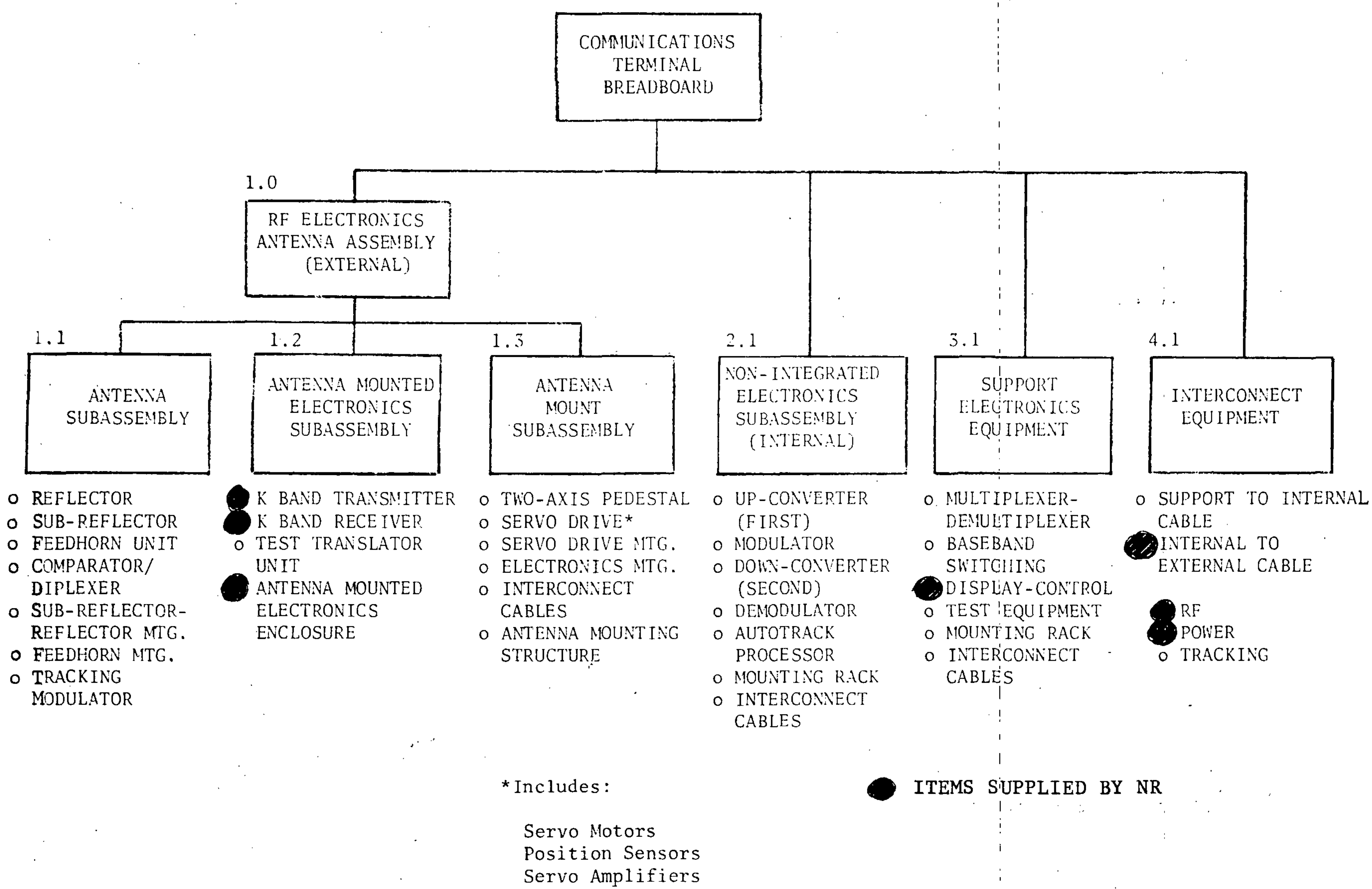

Figure 3-2. CTB Hardware Identification

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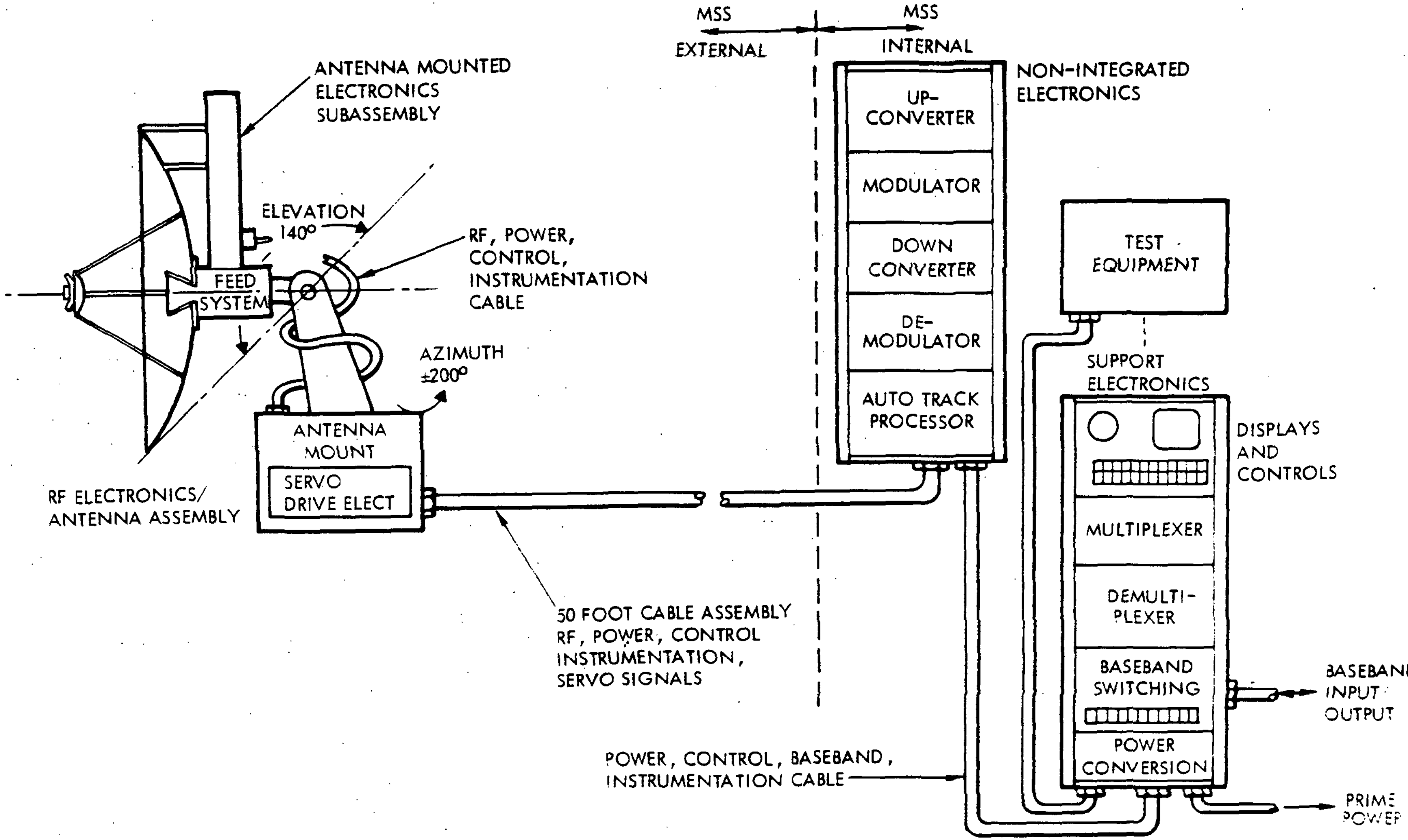

Figure 3-3. Communications Terminal Breadboard

Table 3-1. CTB Technology Goals

- Power amplifier prime power and control signal application
- Power amplifier packaging and passive thermal control techniques
- Paralleling power amplifier outputs with graceful degradation
- RF power output of 20 watts
- RF bandwidth of 100 mhz
- Pre-amplifier noise figure less than 7 db
- Pre-amplifier performance evaluation instrumentation
- Pre-amplifier graceful degradation
- RF combining element with adequate thermal and electrical isolation between final and pre-amplifier
- Structural configuration and associated RF efficiency of the optical system and feedhorns as an integrated subassembly
- Low cost fabrication techniques
- Mechanical and electrical integration of the primary and secondary reflectors and feed system with the antenna-mounted electronics
- Feedhorn design for support of antenna tracking
- Feedhorn capable of handling 25 watts RF
- Performance evaluation instrumentation for power amplifier
- Long life capability of components
- Incorporation of simultaneous ranging, voice, and tv transmission
- Phase coherent operations of exciter-receiver
- Angle tracking data extraction
- Computer aided antenna acquisitions
- Gimbal angle pickoffs to support vehicle tracking

3.3 DETAILED PERFORMANCE SPECIFICATIONS

The detailed specification of the antenna-mounted electronics is based on developing the key factors of power output, bandwidth, and receiver sensitivity. To establish these, characteristics of the other elements of the link were identified; specifically, TDRS, the expected path loss, and the maximum channel capacity required for the link. The following parameters have been identified for the TDRS terminal:

Receiving band, GHz	14.4 to 15.35
Transmitting band, GHz	13.4 to 14.2
Receiver system effective noise temperature	1200°K
EIRP, dbw	52
Path loss, db	207 to 208

Using these parameters, transmit and receive center frequencies for the modular space station K-band radio were chosen as 14.65 GHz (f_T) and 13.6 GHz (f_R), respectively.

The determine the maximum instantaneous bandwidth required of the link, the highest communication capacity mode is employed. The mode baseband is shown in Figure 3-4. The RF bandwidths are found to be

$$B_{RF\ (Transmit)} = 27.2\ \text{MHz}$$

$$B_{RF\ (Receive)} = 42\ \text{MHz}$$

These are based on

$$S/N_{TV} = 64\ \text{db P-P/rms (CCIR weighting and preemphasis)}$$

$$S/N_{voice} = 45\ \text{db}$$

$$E_b/N_{o\ data} = 10\ \text{db}$$

The principal parameters of the MSS were defined as

Antenna diameter, feet	5
Transmit power, watts	20
Receiver noise figure, db	7
B_{RF}, MHz max	200

The first three parameters were chosen iteratively, considering component capability and system performance. The last represents a reasonable spectrum within which the actually occupied band, 42 MHz, can be established.

Using these parameters, the resultant calculations of expected link performance and margin are shown in Table 3-2. It is seen that for the TDRS to MSS link, a comfortable margin of 3.9 db is expected, while in the opposite direction, a margin of at least 11.6 db can be obtained even without the use of a threshold extension demodulator.

GROUND VIA TDRS LINK

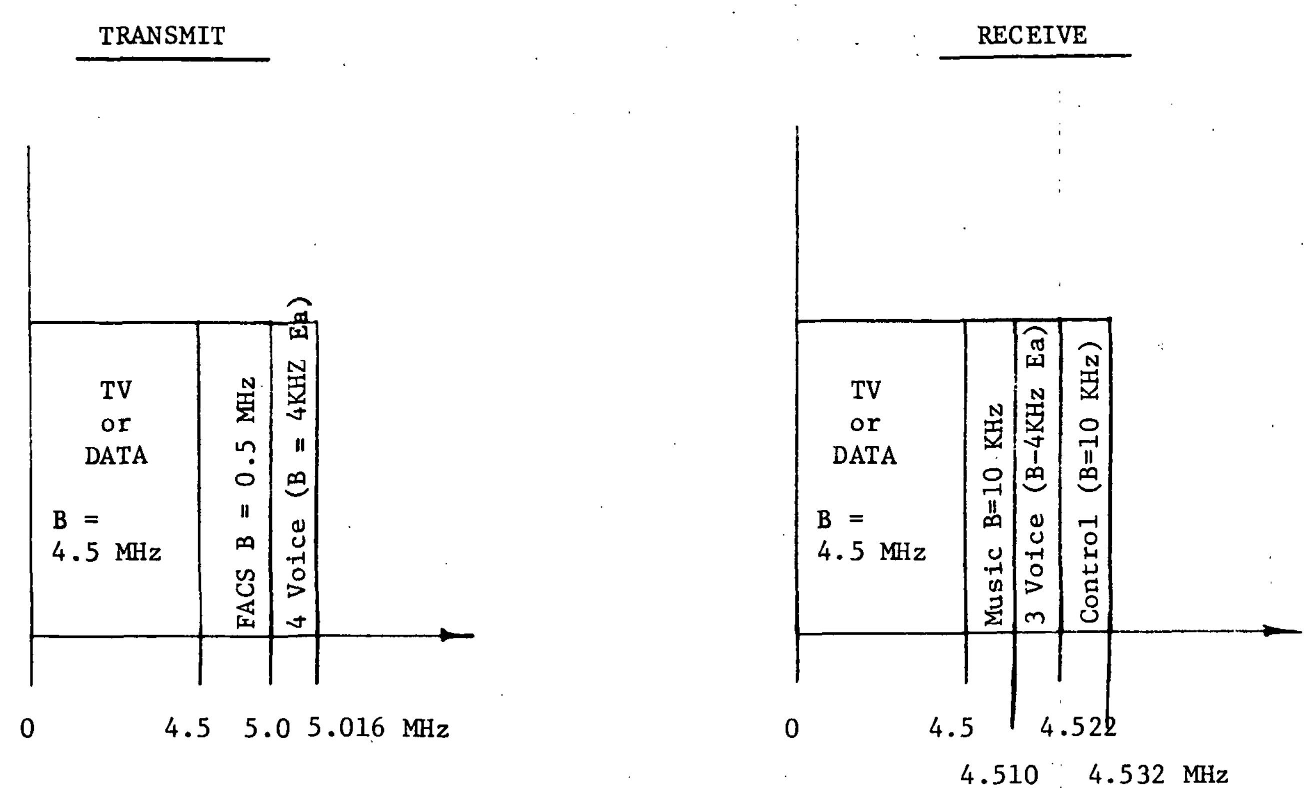

Figure 3-4. K-Band Maximum Capacity Baseband Spectra

Table 3-2. K-Band Link Calculations

FACTOR		TDRS TO MSS	MSS TO TDRS
Carrier Frequency	GH_z	13.6	14.65
EIRP, Transmitted Power	dBW	52.0	58.0
Path Loss	dB	207.6	208.2
Misc. Loss	dB	1.0	1.0
Antenna Gain	dB	44.5	45.0
Received Power (P_R)	dB	-112.0	-106.2
Receiver System Noise Temp. (1200°K) (N_t)	dB	30.8	30.8
Noise Density (N_o)	dB/H_z	-197.8	-197.8
P_R/N_o	dB/H_z	85.8	91.6
RF Bandwidth	MH_z	42.0	27.2
RF Bandwidth	dB	76.2	74.3
P_R/N	dB	9.6	17.3
FMFB Threshold	dB	5.7	5.7
Margin	dB	3.9	11.6

3.3.1 Performance Specifications, Antenna-Mounted Electronics

The antenna-mounted electronics consist of the K-band transmitter; passive thermal control elements; the K-band receiver; the control, sensing, and activation unit; and the frequency translator, integrated into a common package.

The overall performance specifications for the antenna-mounted electronic subassembly (as delivered to MSC) are listed in Table 3-3.

Table 3-3. Antenna-Mounted Electronics Specifications

Characteristic		Performance
Transmit Power	w	6*
Receiver Noise Figure	dB	7
Transmit Frequency	GH_z	14.65
Receive Frequency	GH_z	13.6
Transmit R-F Bandwidth	MH_z	200
Receive R-F Bandwidth	MH_z	200
Modulation	-	FM
Transmit I-F to R-F Gain	dB	38*
Receive R-F to I-F Gain	dB	50
Operating Temperature	^oC	0 to 50
Stability (transmit & receive)	-	1 part in 10^6/day
Transmitter Input Frequency	GH_z	2.2825
Receiver I-F Output Frequency	GH_z	2.1018

*Single travelling wave tube operation

3.3.1.1 Antenna-Mounted Electronics Subassembly Description

The entire K- to S-band up and down converter subsystems, including their associated power supplies are contained in the antenna-mounted housing shown in Figure 3-5. This housing contains all pertinent electronic hardware to receive and transmit K-band signals when interfaced with proper S-band transmit/receive hardware. Photographs of this antenna-mounted electronics subassembly are shown in Figures 3-6, 3-7, and 3-8. Table 3-4 defines the major mechanical and thermal characteristics of this package.

The layout provides for the second final power amplifier to be added in the future. The necessary mounting interface and thermal control are already included. To install and connect the second travelling wave tube, it will be necessary to add another circulator and waveguide connections. A phase shifter will be used to adjust the tube outputs into exact coherence.

The layout is based on passive thermal control which requires three radiating surfaces. Two faceted sides provide the area required for the final power amplifiers. The remaining surface, at the top, radiates the balance of transmitter component dissipations as well as the receiver wattage.

A three-inch cubic volume has been set aside for the test translator. Due to the projected dissipation of three watts, heat sink area has been allotted on the top surface radiator.

The thermal elements are designed to

- Minimize thermal impact due to solar radiation and internal dissipation
- Provide supplemental heating with heat plugs
- Provide thermal isolation between transmit and receive components by separate radiators
- Minimize radiator surface deterioration to maintain proper electronics operation over system life

Following subsections describe the units that are assembled and integrated to make the total package.

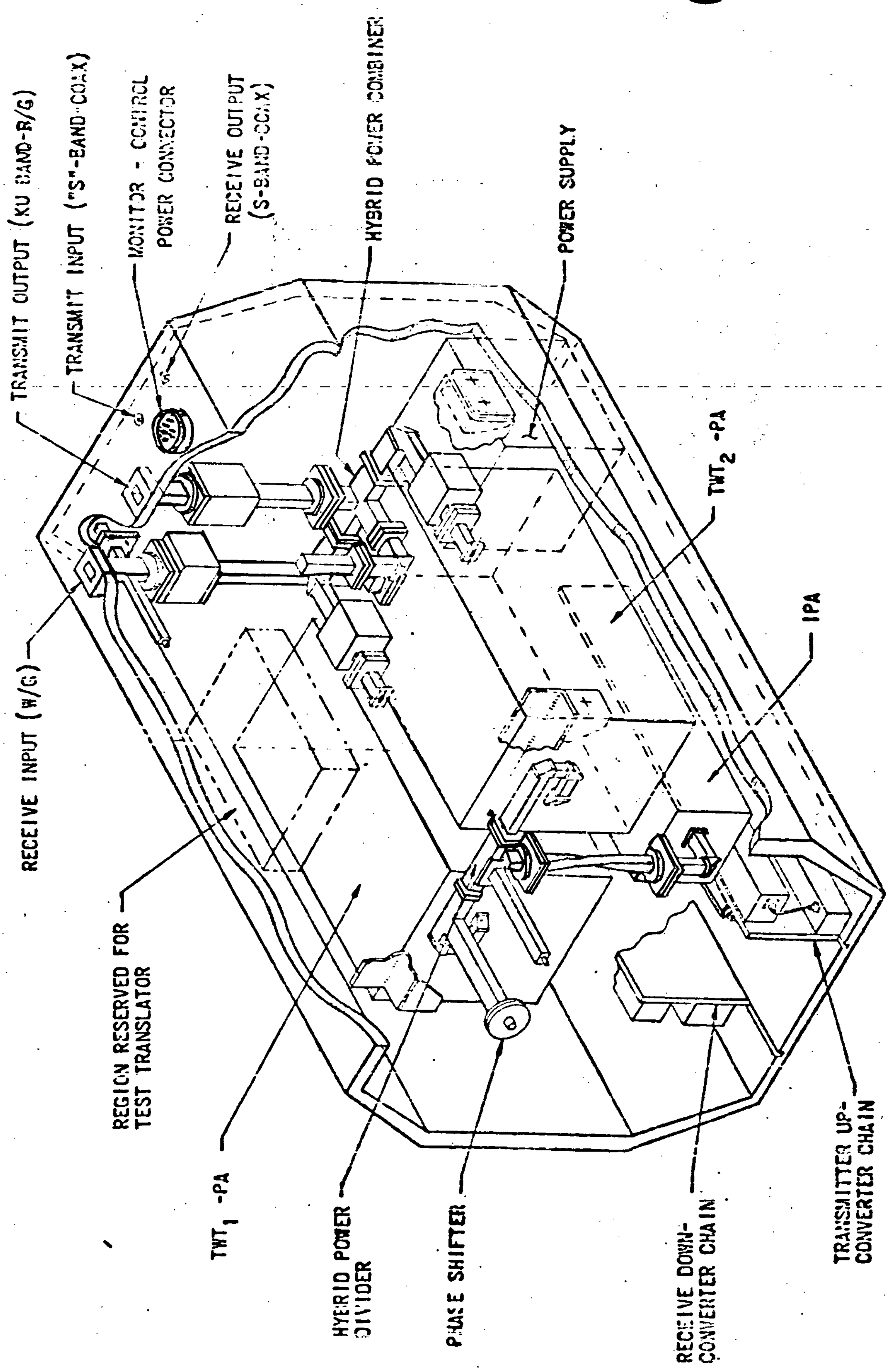

Figure 3-5. Antenna-Mounted Electronics Subassembly

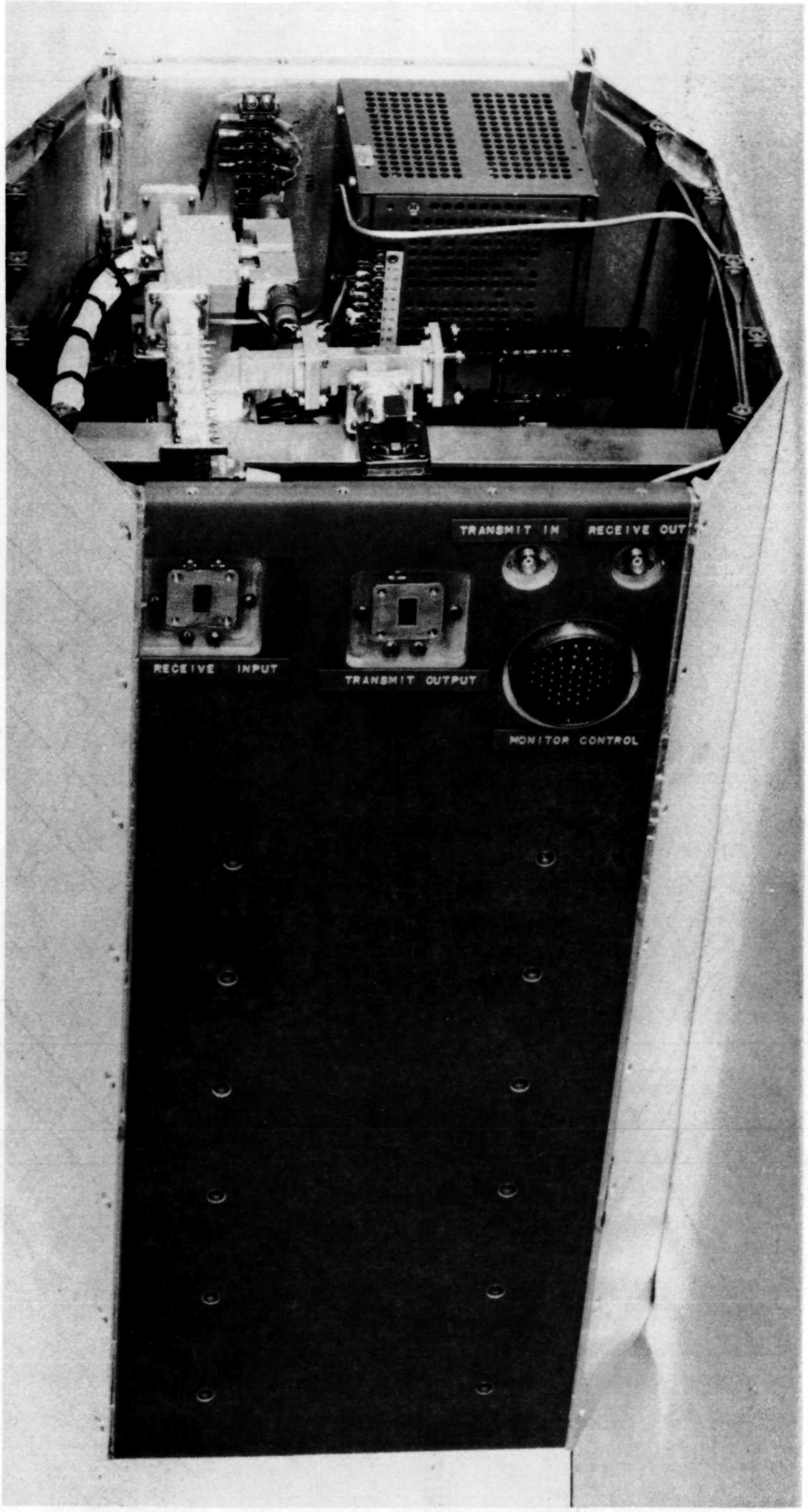

Figure 3-6. CTB Antenna Mounted Electronics Subassembly Package - Oblique View, Mounting and Interconnect Face

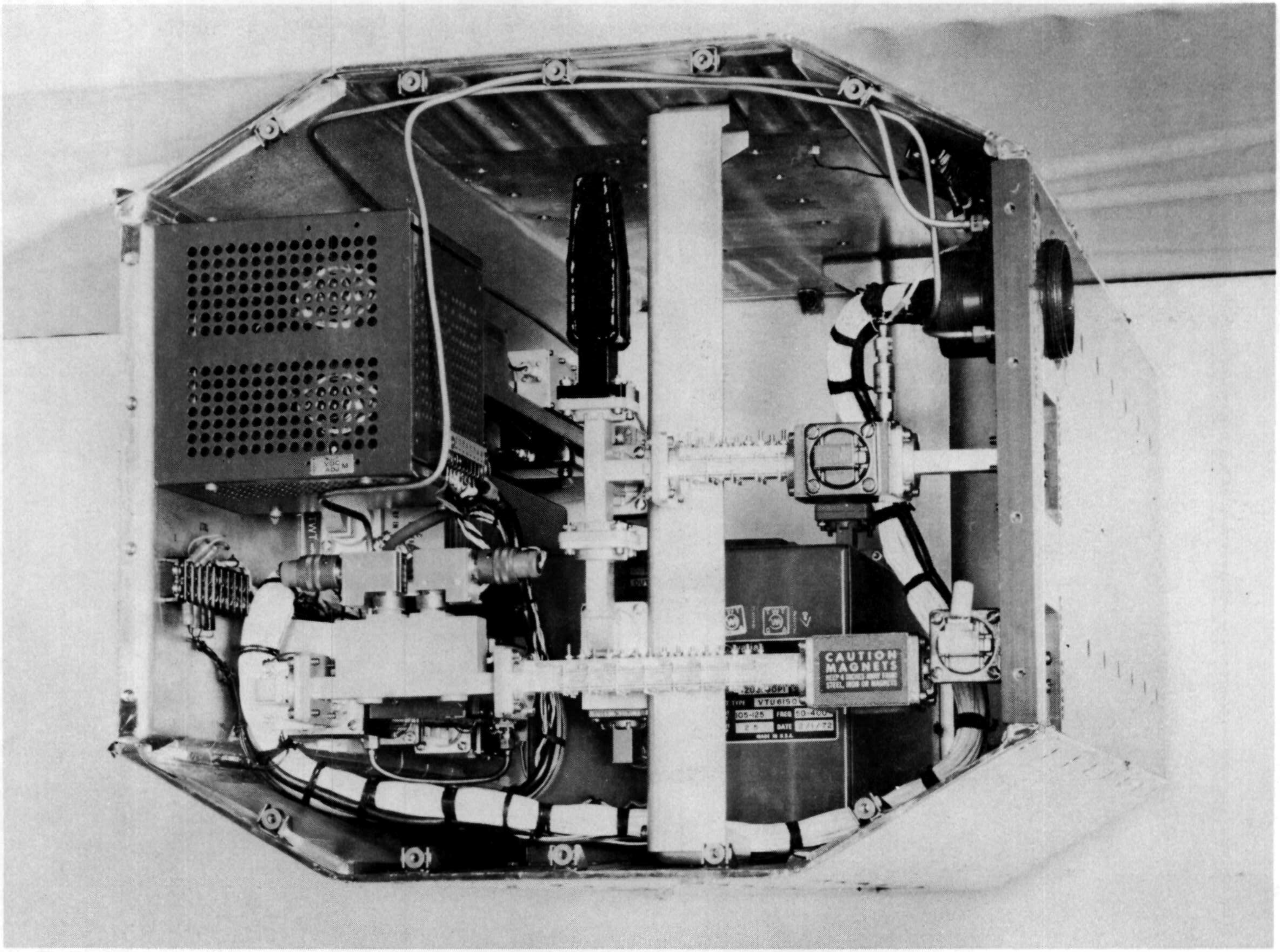

Figure 3-7. CTB Antenna-Mounted Electronics Subassembly Package - Internal View - Input/Output End

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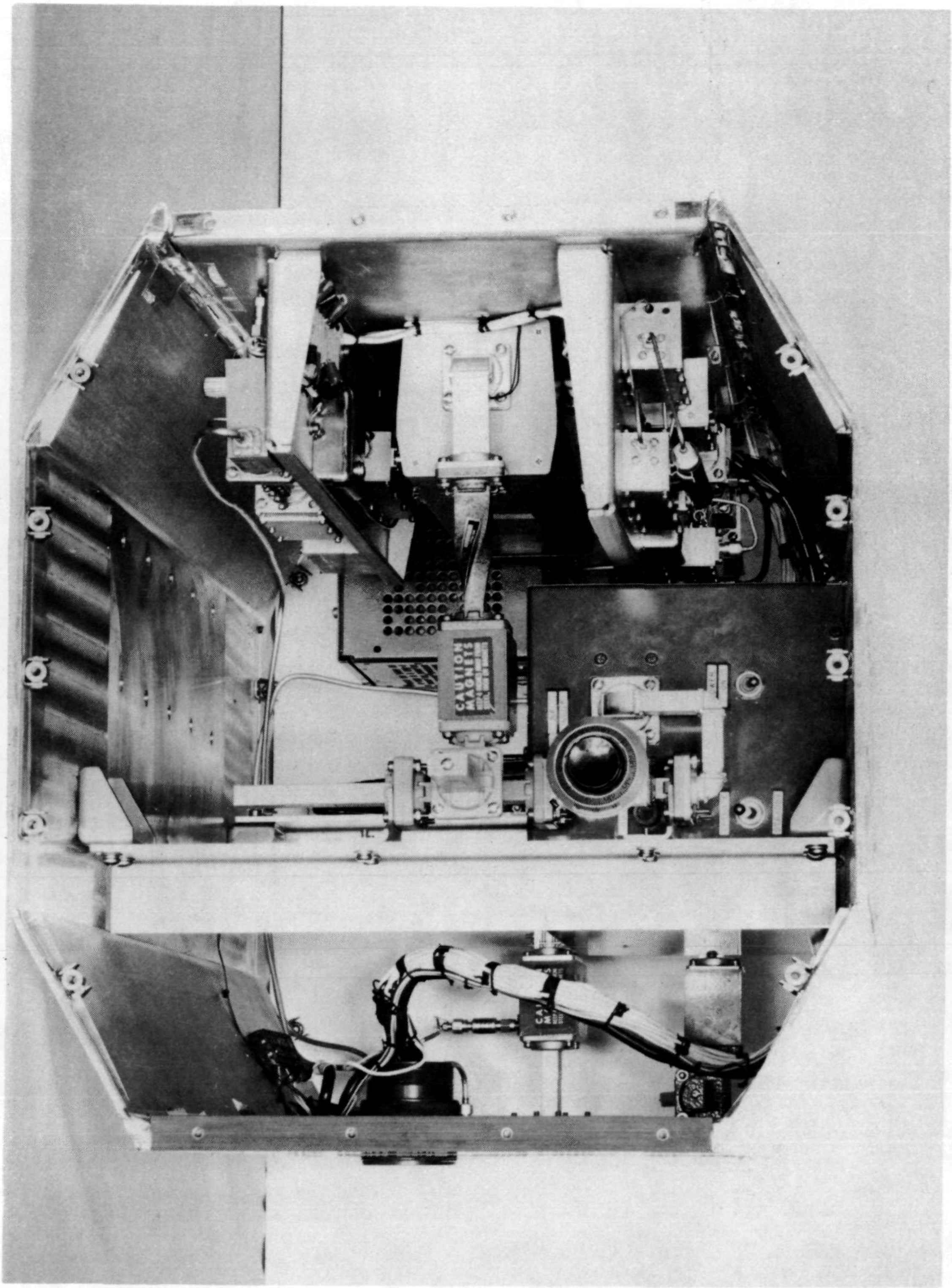


Figure 3-8. CTB Antenna-Mounted Electronics Subassembly Package - Internal View

Table 3-4. Mechanical Description and Specifications

Physical characteristics:

Dimensional	Length	26.0 inches
	Width	15.0 inches
	Height	17.0 inches

Weight (Single TWT PA-actual)	102	pounds
(Dual TWT PA-estimated)	120	pounds

Electrical interface (mounting surface):

Receive	to station	Type N coax
	to antenna feed	UG-419/U W/G
Transmit	to station	Type N coax
	to antenna feed	UG-419/U W/G
Power, control, monitor		Unit MS 3102-A-36-7P
		Mate MS 3106-A-36-7S

Mounting interface:
Matrix of 12 1/4-20 inserts
(See outline drawing for dimensional relationship Figure 5-14 in the Appendix)

Thermal control:

Type	100% passive/independent of mounting interface
Exterior film	Silvered Teflon - Teflon .005 thick
	Absorbtivity $\alpha = 0.08$
	Emissivity $\epsilon = 0.77$

Adapted for 250 mile earth orbit exposure

Input Power:

110 Volts, 60 H_z, Single Phase
200 Watts (Single TWT PA)
375 Watts (Dual TWT PA)

3.3.1.2 THERMAL MANAGEMENT

Heat is dissipated solely by passive techniques; internally by conduction and radiation and externally by radiation and reflection.

Figure 3-9 identifies the heat sources. Primary control is effected by area, relative dissipation density, material conductivities. Thickness and webbing is also employed to isolate heat sources as required.

Externally, thermal control is provided by the application of silvered teflon to the surfaces, as shown in Figure 3-10. The absorbtivity-emissivity characteristics of silvered teflon ($\alpha/\varepsilon = 0.1$) permit exceptional control of solar influence with little impact on the dissipative path. Silvered teflon technique has been successfully employed with minor degradation over a two-year flight history in more severe orbits. Further data are to be collected with the flight of OSO-H. The optimal thickness of teflon is .005 inch.

The sizing of radiator areas is reflected in Table 3-5. The two three-faceted sides relate to transmitter power amplifier requirements. The area required under full solar exposure and internal dissipation to provide a maximum of 160°F average sink temperature is 3.25 square feet per tube using a Varian tube. Eliminating the solar influence, the temperature would drop to 128°F. The use of the Hughes tube either as backup or future availability will result in temperatures of 76°F and 88°F without case modification. The Hughes TWT is a more efficient tube that could be used but was not available in the time required for this program. Final flight hardware using the more efficient Hughes tube could foreshorten the 17.0-inch dimension with minimal impact to the balance of the system. Only the pre-Tunnel Diode Amplifier (TDA) receive chain would have to be rerouted which is independent of thermal control.

The TDA area is selected to minimize solar impact and minimize thermal swing while limiting the maximum temperature to 100°F. This results in 0.34 square feet required. The balance of dissipative elements will be mounted on webs which conduct heat to the radiative surface, for which 0.98 square feet is provided. Thermal response and transmit duty cycle characteristics will cause the sink surface temperatures to conform to the tabulated limits.

Preliminary configuration of the thermal characteristics of the antenna electronics were demonstrated by vacuum radiation simulation to an elevated space sink temperature. The subassembly was placed within a shroud refrigerated to -100° F, all of which is, in turn, within a vacuum system. Neither solar nor other external heat sources were simulated in the test. The results verify the dissipation path of internal heat sources, both conductive and radiative contributions.

Table 3-5. Antenna-Mounted Electronics Thermal Table

	RECEIVER	TRANSMITTER		
			POWER AMPLIFIER	
	TDA	DRIVER STAGES	VARIAN	HUGHES
Area, sq. ft.	0.34	0.98	3.25	3.25
Full power no external influence dissipation avg surf temp	30.9 BTU/HR 33 F	88.7 BTU/HR 33 F	597 BTU/HR 128 F	283 BTU/HR 28 F
Full power solar, albedo and space-craft i-r dissipation avg surf temp	51.9 BTU/HR 100 F	148.7 BTU/HR 100 F	737 BTU/HR 160 F	423 BTU/HR 78 F

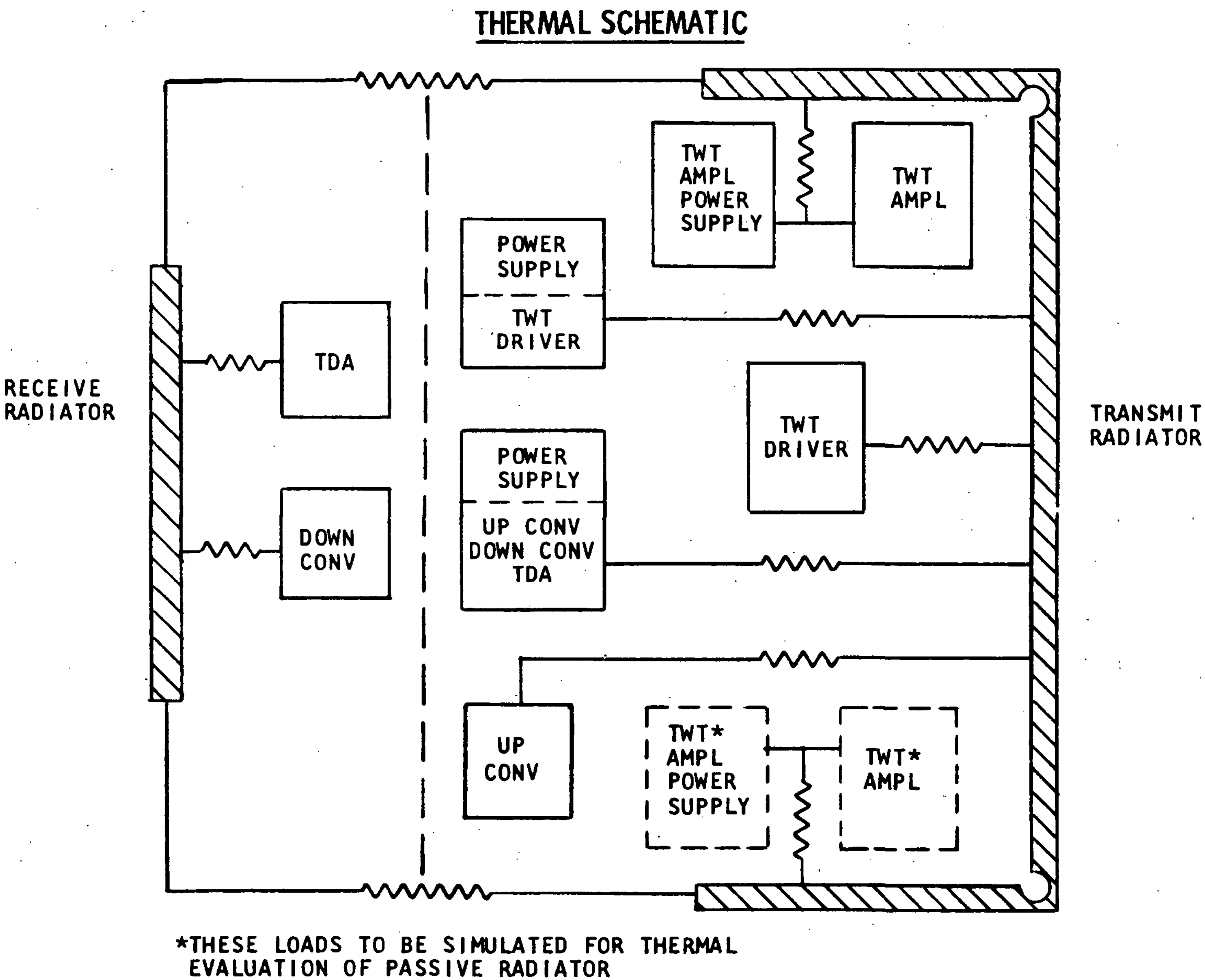
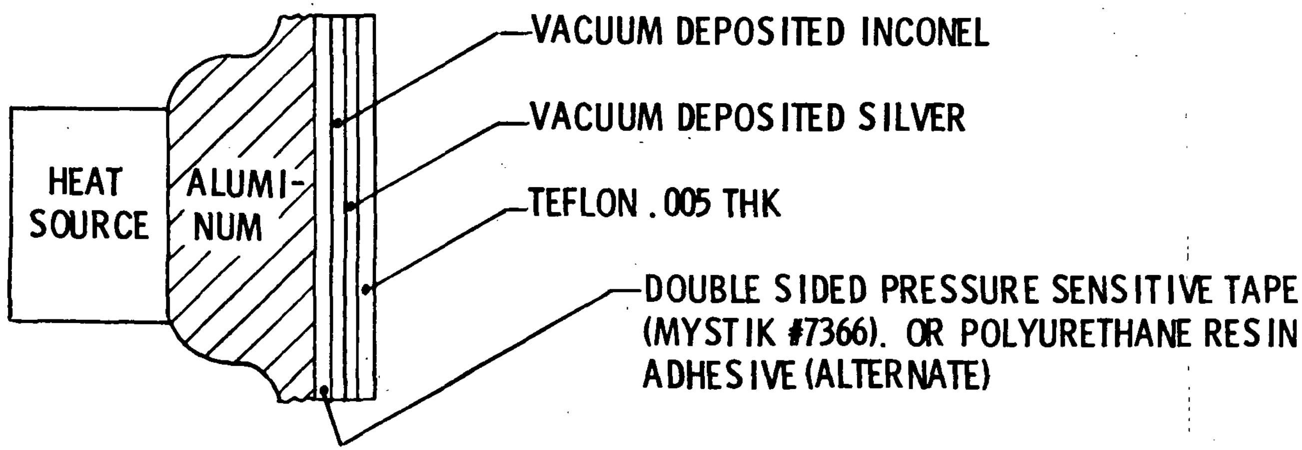


Figure 3-9. Thermal Schematic Diagram

THERMAL CONSTRUCTION



CHARACTERISTICS

- $\frac{A}{E}$ OF 0.1
- THERMAL RANGE (NOMINAL) $+50^{0}C$ TO $-150^{0}C$
- HIGHEST TEMPERATURE $80^{0}C$ MAY INDUCE BLISTERING OR CRACKING DUE TO THERMAL EXPANSION
- FURTHER DATA DUE WHEN OSO-H COMPARES SURFACES TREATMENTS IN SEPT. 1971. (300 NAUTICAL MILE ORBIT PLANNED).
- SUCCESSFULLY APPLIED WITH POLY-URETHANE RESIN ADHESIVE (THIOKOL-SOLITHANE)
- PROPOSED MATERIAL NOW FLYING ON OGO-6 POLAR ORBIT (370 TO 680 MILES) FOR TWO YEARS WITH NO THERMAL TRANSFER IMPACT.

Figure 3-10. Thermal Construction, Analysis Diagram

3.3.1.3 Transmitter Subassembly Description

The transmitter subassembly consists of the second up-converter, driver, final amplifier, monitor and control, and the prime power distribution units.

The overall block diagram for the S- to K-band transmitter equipment is shown in Figure 3-11. The system accepts a 0 dbm S-band drive signal and up-converts it to final frequency by using the sum component of a diode mixer's output. The K-band local oscillator signal operates at 12.3675 GHz and is obtained from a 45.8056 MHz TCXO followed by a X270 multiplier chain.

The desired 14.65 GHz signal is filtered prior to application to the low-level Ku-band TWT amplifier (IPA). A variable waveguide attenuator is provided on the input to the IPA in order to adjust the overall transmitter gain. The IPA output signal is applied to a 3 db waveguide hybrid and provides two equal amplitude drive signals for the two final power stages. (Note: One TWTA is supplied with the delivered unit.) A waveguide phase shifter is provided in one input signal path to adjust the phase balance between the two tubes and obtain proper power addition. The same type hybrid is used on the TWTA outputs to sum the two signal paths. High power isolators (20-watt internal loads) are used on both TWTA outputs and provide positive load protection due to any high VSWR reflection.

A bandpass filter and high power output isolator are used on the transmitter's output to shape the operating bandwidth and reduce harmonic and spurious output levels below specification limits.

RF monitor circuits are provided on the LO chain and transmitter outputs and use detector diodes to produce dc output voltages. Control relays are used to turn prime power on/off to the IPA and two final TWTA tubes. The operation of these relays are monitored and dc output voltages are supplied to indicate their status. In addition, separate controls for both high power TWTA helix currents are provided.

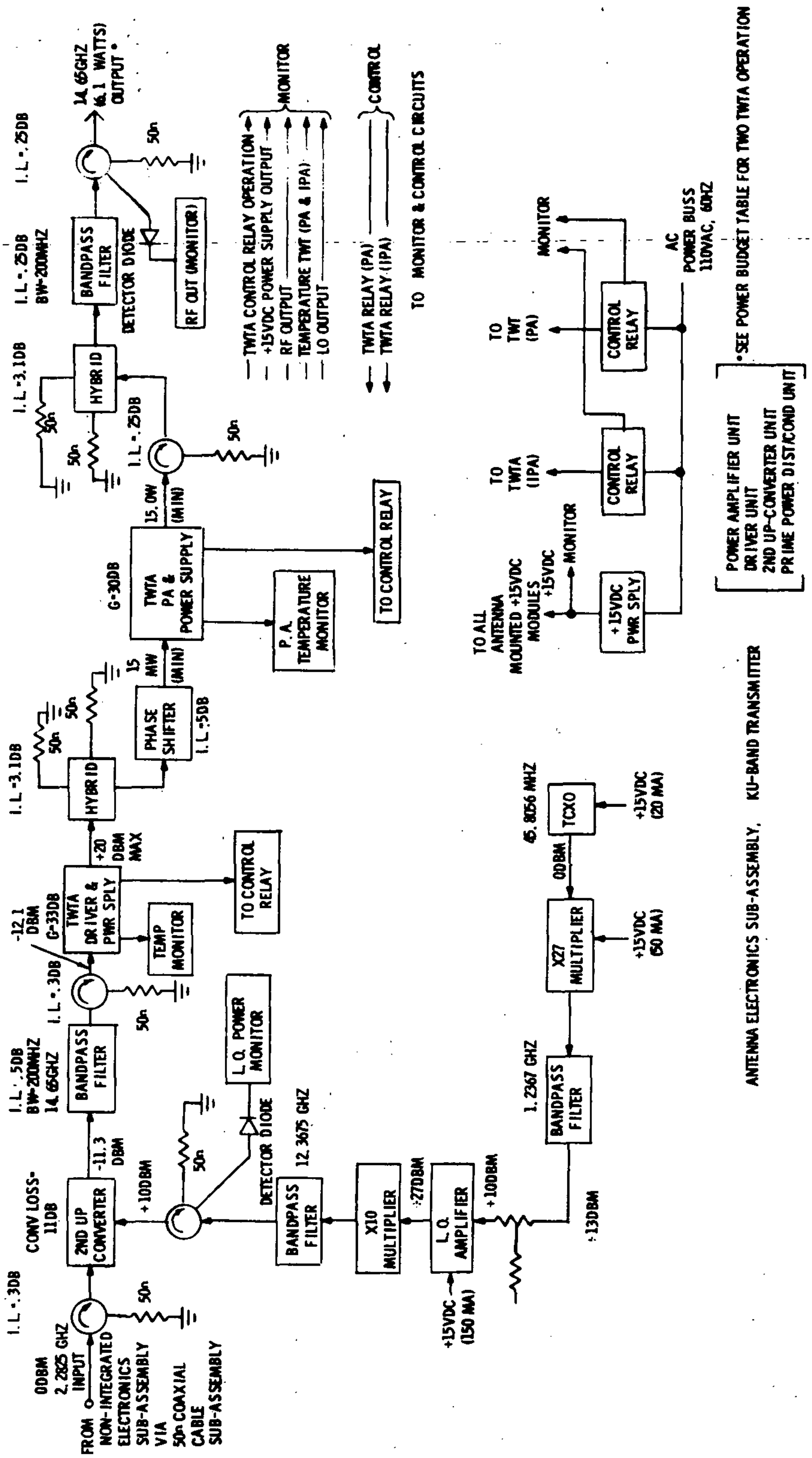


Figure 3-11. K -Band Transmitter

Thermistor sensor elements are used to monitor the temperature of the IPA and both final TWTAs. DC output voltages proportional to temperature are obtained for all three monitored areas.

All monitor and control functions are remoted via a 50 foot cable to the "control panel" via the housing's bulkhead connector and cable assembly.

The overall transmitter specifications are shown in Table 3-6.

Table 3-6. Transmitter Subassembly Specifications

Characteristic		Performance
Output Frequency	GH_z	14.65
Power Output	Watts	
1 Final Amplifier		6.0
2 Final Amplifiers		23.0
Instantaneous 1 db Bandwidth	MH_z	200
Duty Cycle c-w	%	100
AC to RF Efficiency (All T_x Antenna Mounted Electronics)		
1 Final Amplifier	%	3.1
2 Final Amplifiers	%	6.8
Total Dissipated Heat		
1 Final Amplifier	Watts	193
2 Final Amplifiers	Watts	344
Spurious Outputs		
Non Harmonic below carrier	dB	-60
Harmonic below carrier	dB	-50
Residual FM	dB	-35
Output VSWR		1.25:1
Output Isolator Load Capability	Watts	25
Frequency Stability	ppm/ day	1
Frequency Control Element		TCXO, Antenna Mounted

Table 3-6. Transmitter Subassembly Specifications (Cont)

Characteristic		Performance
Upconverter IF Input (single conversion)		
Frequency	GH_z	2.2825, ±50 MH_z
Power	dBM	0
IF Bandwidth, 1 db	MH_z	200
Impedance	Ohms	50
Standing Wave Ratio, max		1.25:1
IF to RF Gain (One travelling wave tube)	dB	37.8
Power Amplifier Configuration		
Initial CTB		1 travelling wave tube
Final CTB		2 travelling wave tubes (hybrid added)
Transmitter Failure Mode		Graceful Degradation, (Hybrid-added power amplifiers)
Monitor Circuits		
Function		Transmitter RF output Control Relay operation Upconverter LO output Travelling wave tube temperature (IPA) Travelling wave tube temperature (PA) Power Supply + 15 vdc
Output Format		0.5 to 5.0 vdc across 5K ohm
Control Circuits		Power supplies turn on and off (TWT)

3.3.1.3.1 Up-Converter

Referring to Figure 3-11, the up-converter system consists of 4 basic components, namely the S-band input circuit, the up-converter mixer, the K-band L.O. chain and output bandfilter.

The physical layout of the assembly is shown in Figure 3-12. The 0 dbm, 2.2825 GHz S-band drive signal enters the assembly via a coaxial isolator seen at the left side of the photo. The signal passes through the isolator with less than 0.3 db loss and is applied to the doubly-balanced diode mixer. The input isolator provides greater than 20 db isolation across a 200 MHz band centered on 2.250 GHz and thereby minimizes the mixers input match at the S-band interface. A 12.3675 GHz L.O. signal is applied via coax isolator to the mixer's L.O. port. The + 10 dbm L.O. signal level results in a -11 dbm, 14.65 GHz signal at the output of the mixer. The K-band L.O. signal is sampled by a 10 db probe mounted in the L.O. isolator. A detector diode produces a dc output voltage and monitored level is remoted to the "Control Panel" via the housings' bulkhead connector and external cable assembly.

The mixer's output signal is applied to a waveguide, manually adjustable attenuator prior to connection to the up-converter output filter assembly The attenuator has up to 30 db attenuation and is used to provide low level adjustment of the transmitters overall S to K-band gain. The control is factory adjusted and does not require any periodic adjustment or maintenance.

The 14.65 GHz signal leaves the attenuator and is then applied to a combination filter, consisting of a 5 pole band pass filter and 8 section waffle-iron type low pass filter which is used to select the sum component of the mixer output. The filter shapes the desired K-band and signal bandwidth and suppresses the LO and all other spurious signals greater than 75 db below the desired signal level. The resultant signal is applied to a wave-guide isolator and leaves the up-converter assembly for transmission to the IPA.

The K-band LO chain consists of a low noise, temperature compensated crystal oscillator (TCXO) operating at 45.8056 MHz. Its schematic is shown in Figure 3-13. The TCXO output drives a 3 stage transistor multiplier which increases the TCXO frequency 27 times to result in a 1.2367 GHz signal. The X 27 multiplier is shown in Figure 3-14 with its associated output filter. The narrowband, 6 pole tubular bandpass filter results in all spurious levels down greater than 85 db below the + 10 dbm output signal. The schematic for the X 27 module is shown in Figure 3-15.

The + 10 dbm, 1.2367 GHz signal is applied to a two stage power amplifier prior to application to the X 10 step recovery diode (SRD) multiplier for final multiplication to K-band. The amplifier is shown in Figure 3-14 and its schematic in Figure 3-15. The amplifier develops over 900 milliwatts output when driven by the X 27 module and its transfer characteristic, bandwidth and input return loss are shown in Figures 3-16 and 3-17.

69915

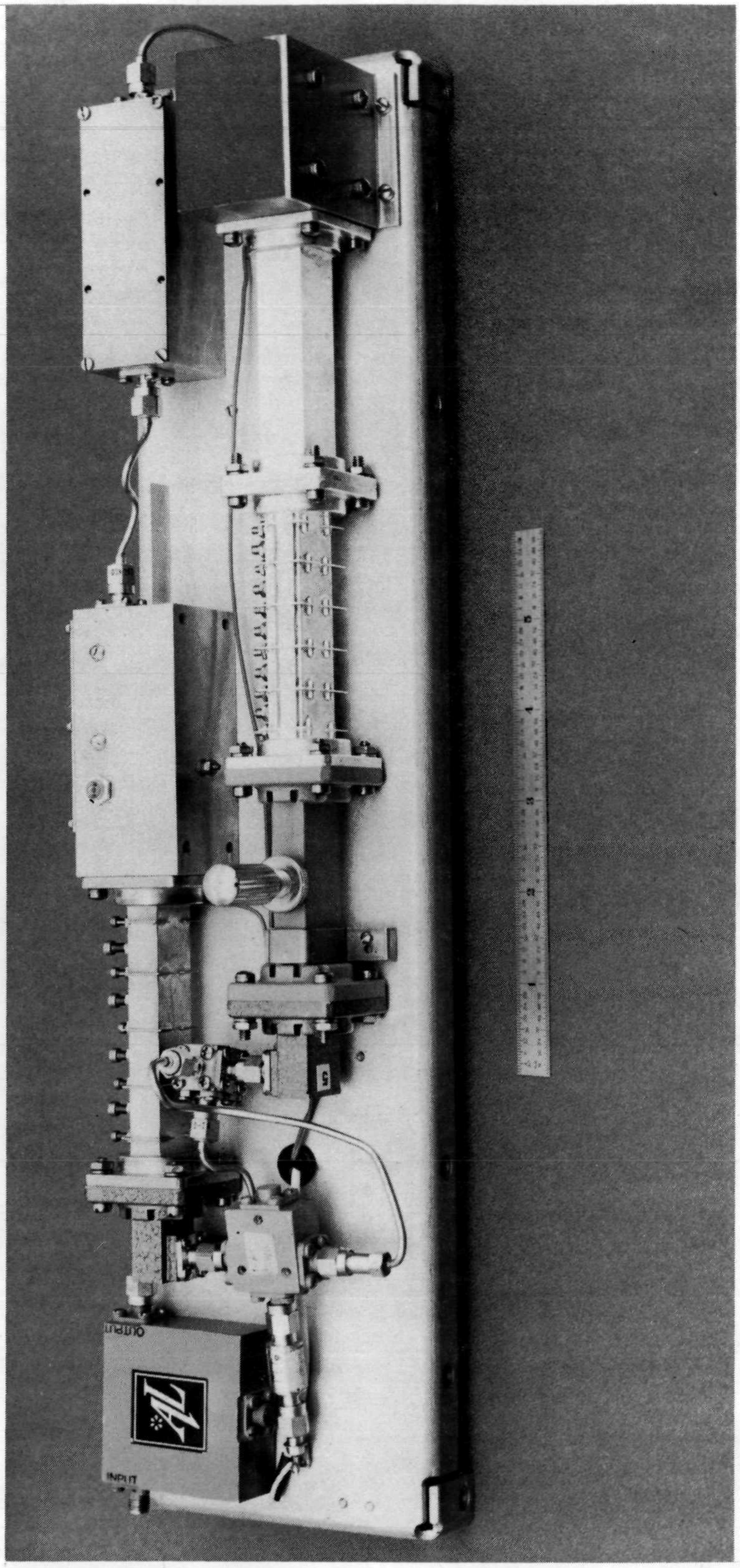


Figure 3-12. Up-Converter Subassembly

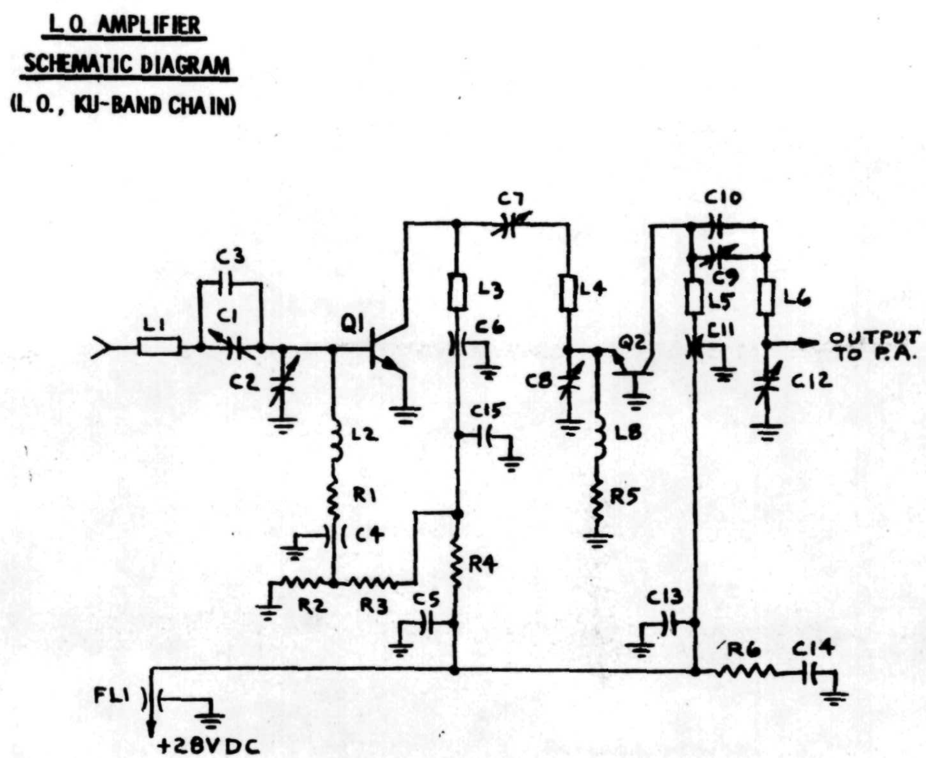


Figure 3-13. Local Oscillator, Schematic Diagram

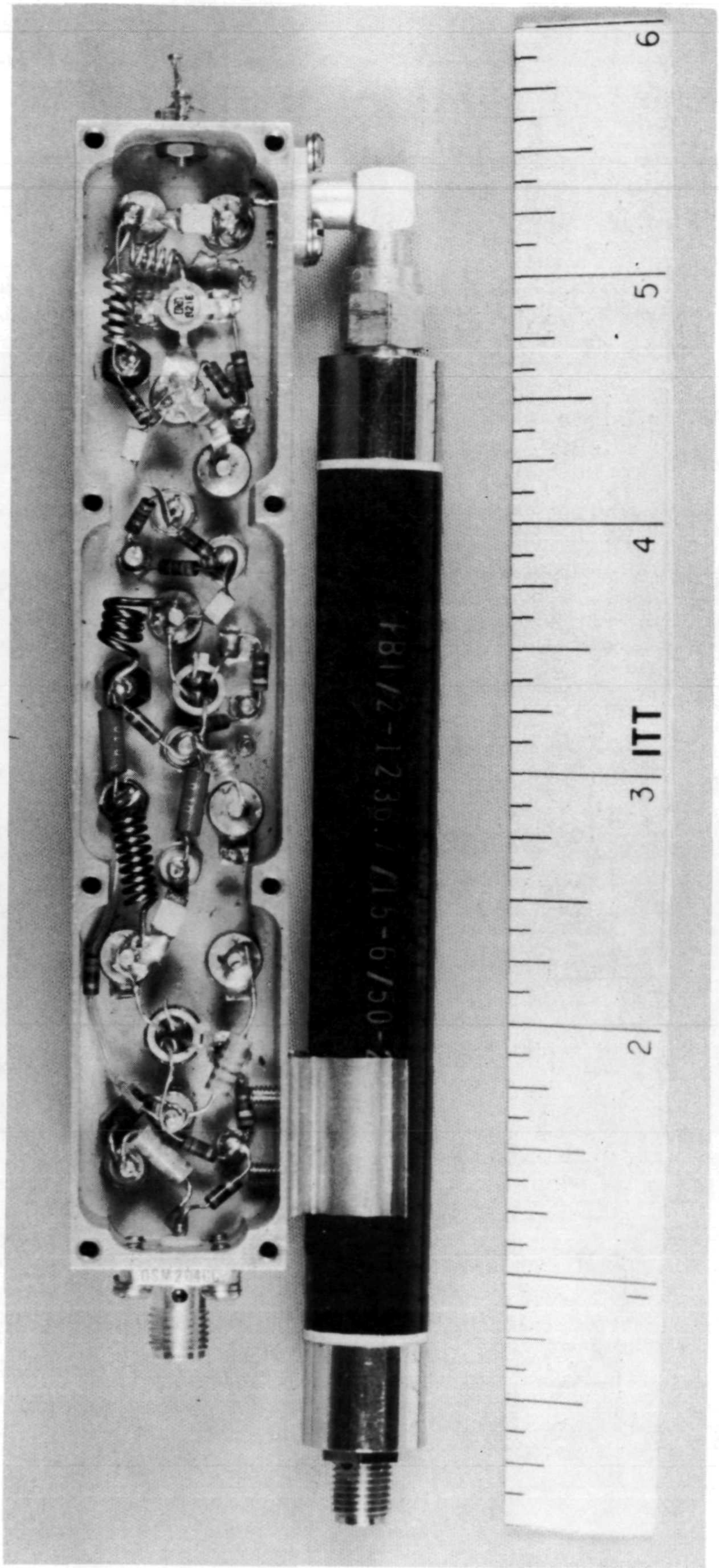


Figure 3-14. Photograph - X27 Multiplier Plus Output Filter

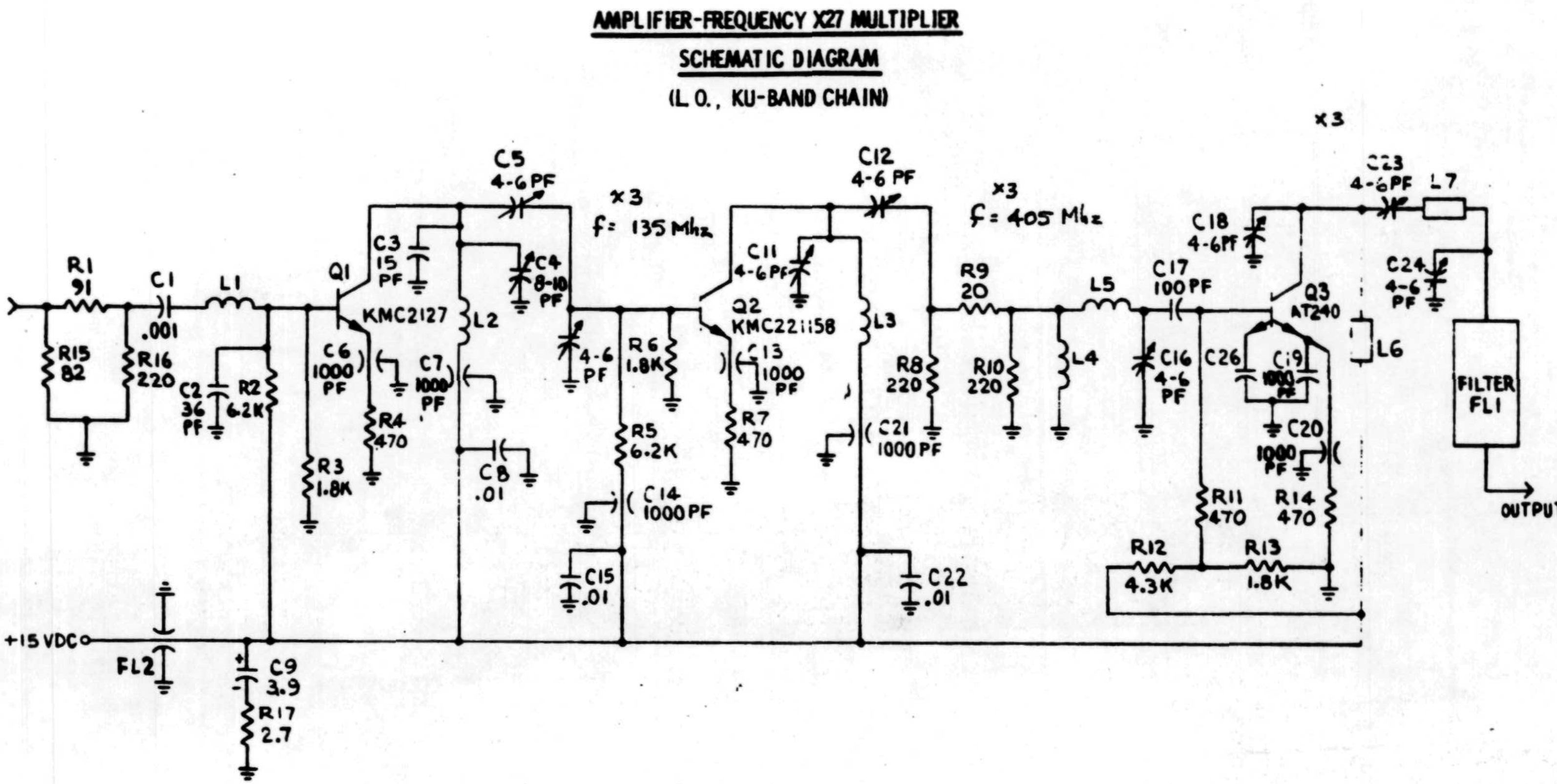


Figure 3-15. Amplifier- X27 Frequency Multiplier, Schematic Diagram

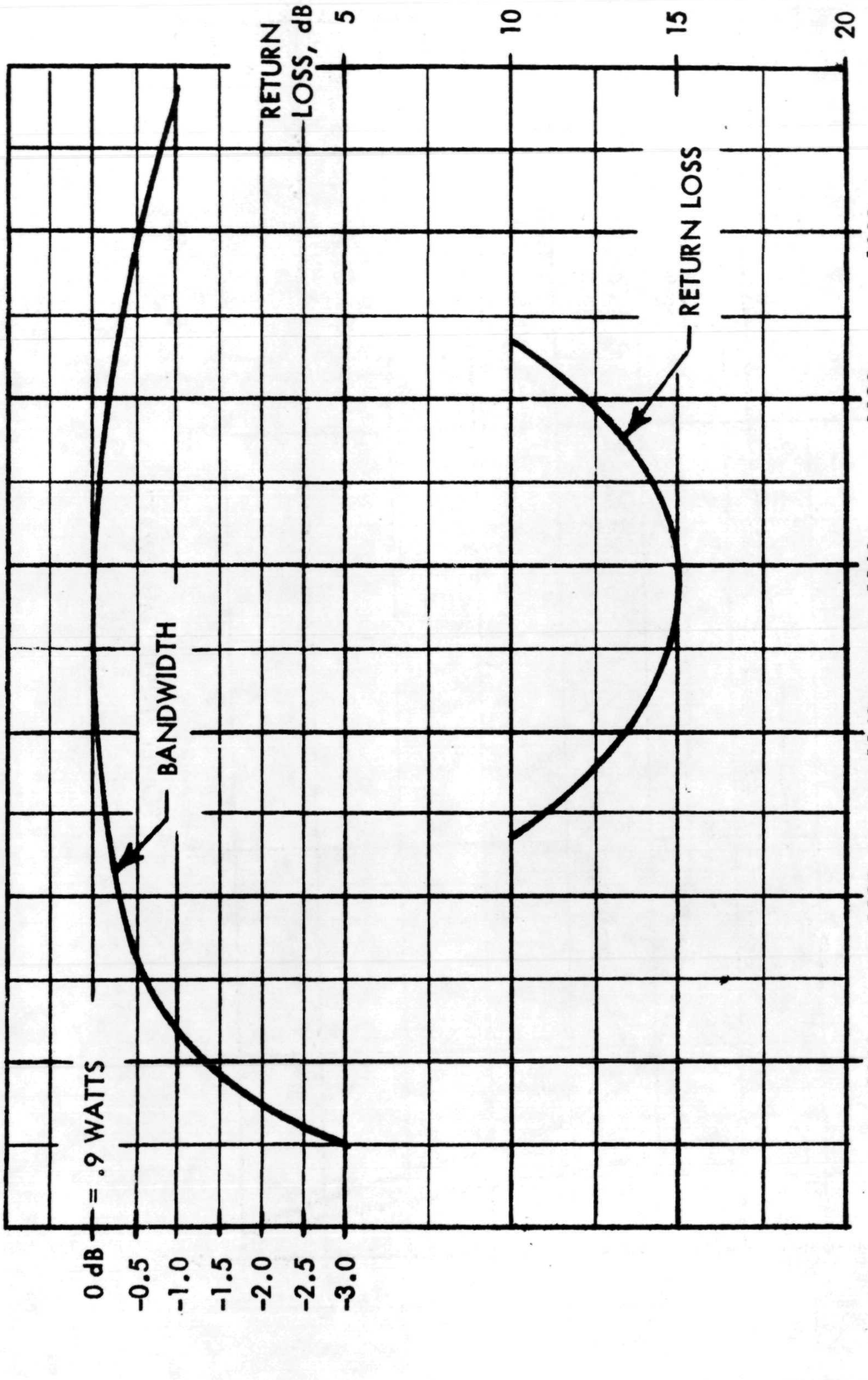


Figure 3-16. Bandwidth & Return Loss, Local Oscillator Amplifier

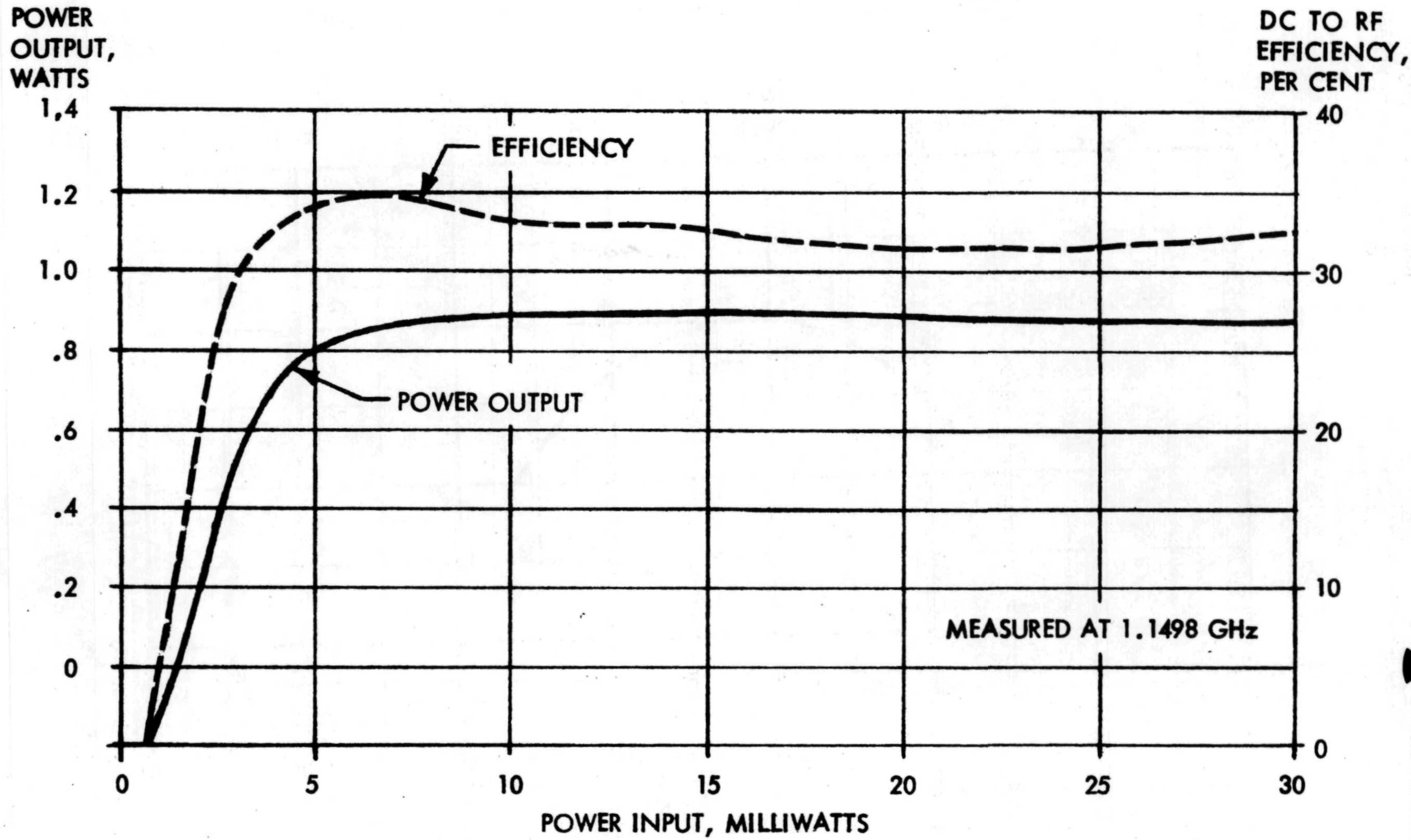


Figure 3-17. Gain Transfer Characteristic, Local Oscillator Amplifier

The LO amplifiers output drives the X 10 Step Recovery Diode (SRD) multiplier directly. No isolator is required due to the input match of the X 10 multiplier. The multiplier's input circuit is constructed with lumped element components and the output bandfilter with waveguide. The diode is an HP5082-0335 and is self-biased by the drive signal and bias resistor. The multiplier and its filter are shown in the photograph of Figure 3-12. It provides greater than +10 dBm output into the mixer's LO port via the LO isolator.

Prime power for the entire up-converter assembly is +15 vdc and is obtained from the 15 volt power supply mounted within the housing.

3.3.1.3.2 Intermediate Power Amplifier (IPA)

The intermediate power amplifier (IPA) is a self-contained traveling wave tube and power supply and operates directly from the 110 vac, 60 Hz prime power source. The amplifier is shown in photograph in Figure 3-18 (top center) and measures 3.5" x 3.5" x 12" and weighs less than 6.5 pounds.

The up-converter output signal drives the IPA directly and the IPA produces a +17 dbm (50 mW) into the 3 db hybrid. The instantaneous bandwidth of the IPA is far in excess of the system requirements and thereby transparently reproduces the up-converter's band shape.

Prime power to the IPA is controlled by a latching relay connected in series with the 115 vac line. The relay status is monitored and remoted to the "Control Panel."

Additional specifications for the IPA are listed below:

Table 3-7. IPA Characteristics

Specification		Performance
Center frequency	GHz	14.65
Bandwidth, 0.5 db	GHz	13.4 to 15.35
Power output	dBm	+17
Duty cycle, CW		100%
Noise figure	dB	10
Gain at rated power output	dB	40
Spurious output, below rated output	dB	-100
Residual AM and FM below rated output	dB	-60
AM to PM conversion		3° per dB
Input to output VSWR (hot)		1.5:1
Prime power		110 vac, 60 Hz @ 16 watts
Operating temperature		0 to +60°C
Cooling		Conduction
Tube life (expected)	hours	10,000
Size		3.5" x 3.5" x 12"
Weight	pounds	6.5

69484

Figure 3-18. RF Components, Antenna-Mounted RF Electronics

3.3.1.3.3 Power Amplifier (PA)

The ultimate configuration for the final power amplifier will consist of two 15-watt TWTA's hybrid combined to produce a minimum 20-watt K-band power output. The deliverable P.A. as shipped, contains only one TWTA. All other power combining components are installed. Only a second tube is required to obtain the 20 watt level.

The single TWTA consists of a self-contained power supply and traveling wave tube as as in the case of the IPA, operates directly from the 110 VAC prime power bus. The amplifier produces greater than 15 watts output and has over 37 dB gain. The entire TWTA consumes 165 watts of prime power. The unit measure 6" x 6 1/2" x 12" and weighs 18.5 pounds. The photograph of Figure 3-19 shows an exposed internal view of the amplifier and Figure 3-20 shows its block diagram.

The +13 dbm drive signal from the IPA output hybrid, drives the tube to full saturated power output and bandwidth. The 1 db output bandwidth is greater than 300 MHz centered on 14.65 GHz.

Prime power to the TWTA is controlled by a latching relay connected in series with the 110 VAC power line as in the case of the IPA and second TWTA. The relays operation is controlled from the "Control Panel" and its status is also monitored there. In addition, separate and independent control of each TWTA helix current is provided locally as well as at the "Control Panel".

The TWTA output is protected by an isolator prior to connection to the summing hybrid. The isolator's load provides protection to the tube in the event a high VSWR is presented to the tubes output terminals due to any cause. The isolator load is capable of dissipating 20 watts. Both TWTA's are isolator protected and the deliverable equipment includes the second TWTA isolator (not installed).

Additional specifications for the TWTA are listed in Table 3-8.

Table 3-8. PA Characteristics

Specification		Performance
Center frequency	GH_z	14.65
Bandwidth, 1.0 db	GH_z	14.5 to 14.8
Power output across operating bandwidth	Watts	15.0 (min)
Duty cycle		100%, cw
Noise figure	dB	29.4
Gain at rated output	dB	37.5
Spurious output	dB	-70 dB below rated output
Residual AM and FM	dB	-60 dB below rated output
AM to PM conversion		80 per db
Input/output VSWR (hot)		2.0:1
Prime power		110 VAC, 60 Hz, @ 165 watts
Prime power to RF output efficiency	%	9
Operating temperature	^{o}C	0 to 50
Cooling		Conduction
Expected tube life, hours	Hours	1000
Size		6" x 6 1/2" x 12"
Weight	Pounds	18.5

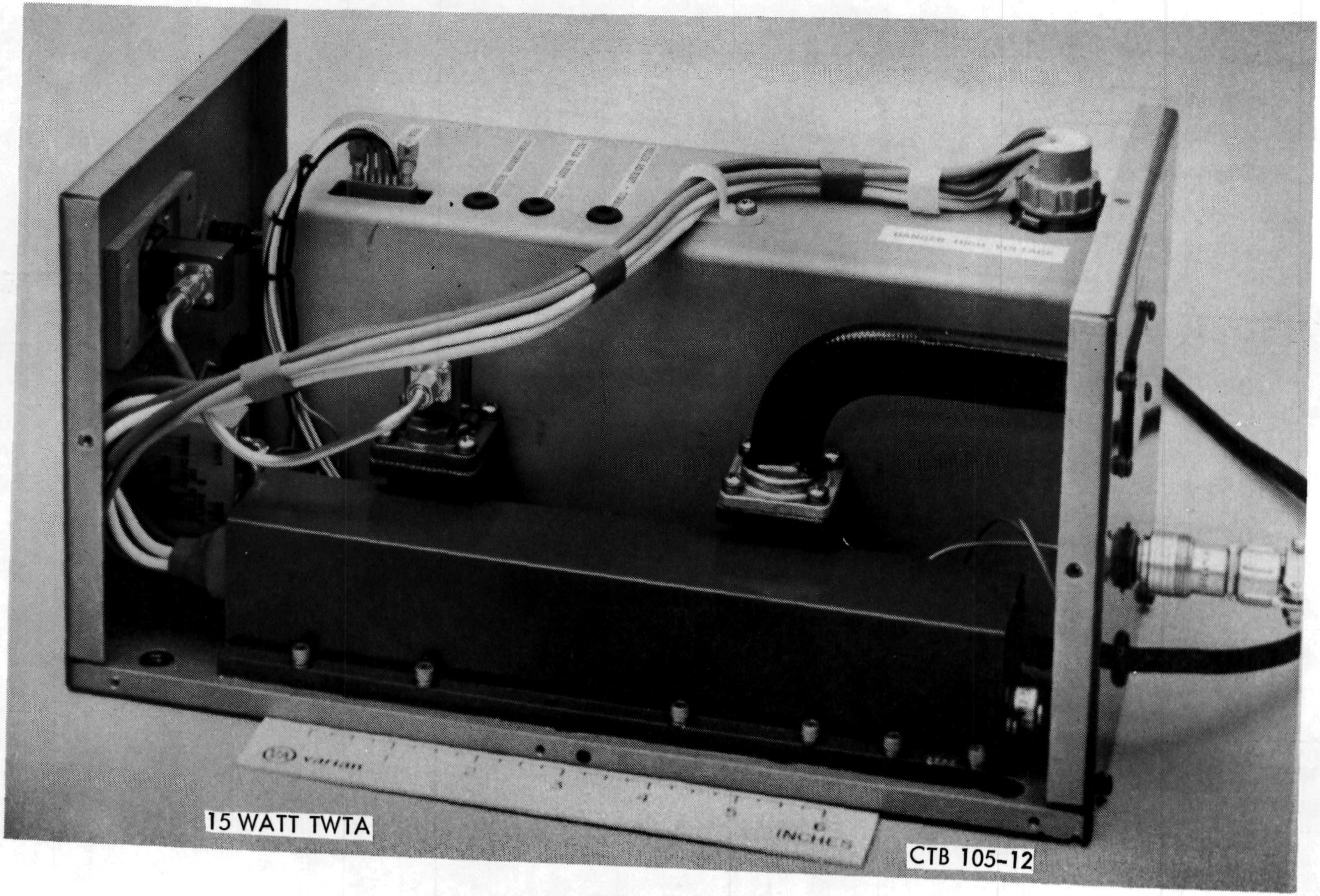


Figure 3-19. Power Amplifier, Internal View

BLOCK DIAGRAM - 15 W K-BAND TWTA

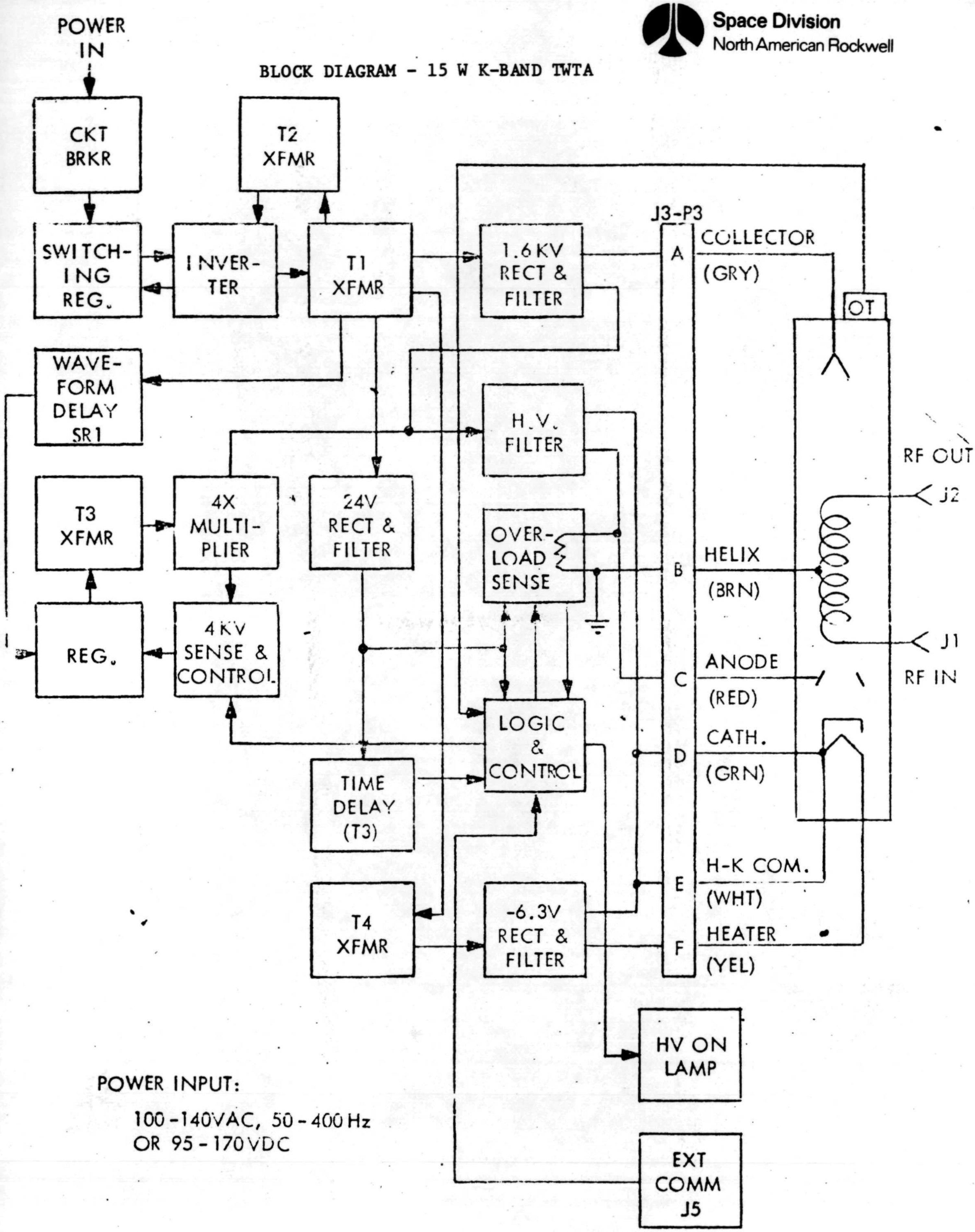


Figure 3-20. Power Amplifier, Block Diagram

3.3.1.4 Receiver Subassembly Description

The receiver subassembly consists of the preselect filter unit, low noise amplifier, and first down converter unit. The receiver subassembly is mechanically integrated with the transmitter subassembly but electrically and thermally isolated. The receiver accepts a 13.6 GH_z signal from the output of the diplexer in the antenna subassembly and after amplification, down converts it to 2.1018 GH_z for delivery to the non-integrated electronic subassembly.

The overall block diagram for the K- to S-band receiver front end is shown in Figure 3-21 and its photograph in Figure 3-22. The assembly consists of four basic circuits, namely the pre-select filter assembly, the low noise K-band pre-amplifier, the K to S-band down converter and the K-band LO chain.

The receiver is designed to interface directly to the K-band antenna via a 20 db circulator and does not need any other diplexer filtering. The receiver accepts the 13.6 GH_z signal and down-converts it to S-band (2.1018 GH_z) by using the difference IF component of the diode mixer's output. The K-band local oscillator signal operates on 11.4982 GH_z and is obtained from a 42.5859 MHz TCXO followed by a X270 multiplier of the same design used in the transmitter. Low noise amplification is provided by a tunnel diode amplifier (TDA) and achieves an overall K to S-band system noise figure of less than 7 db including all input losses (input directional coupler, isolator and pre-select filter). The overall receiver instantaneous 1 db bandwidth is greater than 200 MHz and has over 65 db RF to IF gain.

The 13.6 GH_z signal bandwidth enters the receiver via a waveguide directional coupler with a 20 db coupled arm. The coupled arm provides a coax entrance point and is designed to interface with the future test translator. A photograph of the coupler is shown in Figure 3-23. The signal leaves the coupler and is applied to an isolator before going into the pre-select filter. The isolator presents an excellent source impedance to the pre-select filter and thereby minimizes pass band ripple. In addition it provides the receiver with an input VSWR of less than 1.2:1 across its operating bandwidth.

The preselect filter is a 7 pole wave guide design and shapes the system operating bandwidth and also provides rejection to the co-located transmitter frequency. The insertion loss of the filter is a key design factor since its loss directly degrades the receiver's noise figure. The filter achieves the required system bandwidth and rejection with less than 0.8 db loss. A photograph of the filter is shown in Figure 3-24.

The signal passes through the filter and is then applied to the Low Noise Amplifier (LNA) for amplification prior to down-conversion. No isolator is required between the filter and LNA since the TDA input contains one already. The TDA is a 2 stage design and achieves less than 4.9 db noise figure in an uncooled, room ambient environment. The gain is greater than 33 db and essentially establishes the overall system noise figure. A 3 pole filter is used between the TDA output and mixer input for two reasons:

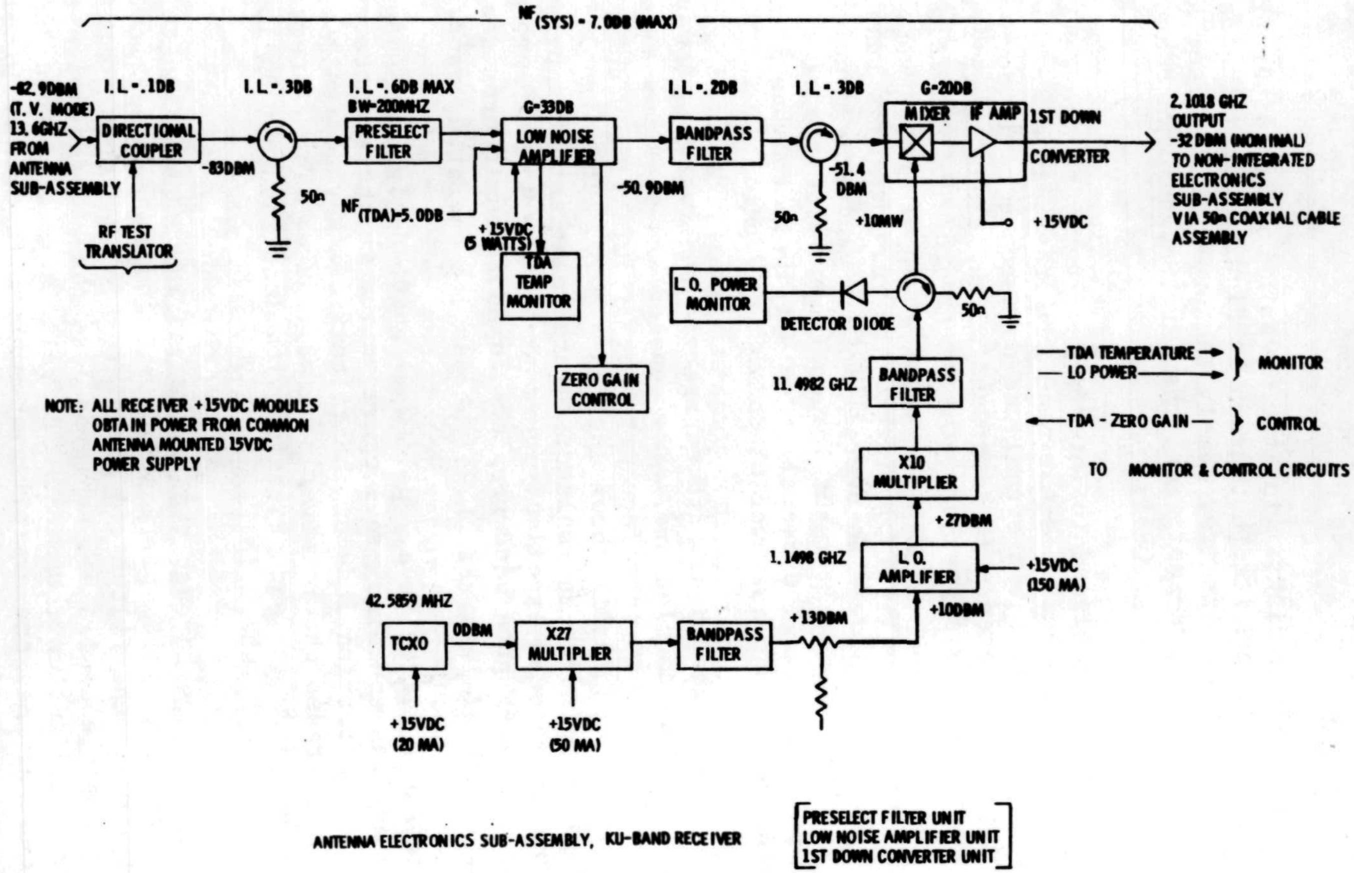


Figure 3-21. K-Band Receiver, Block Diagram

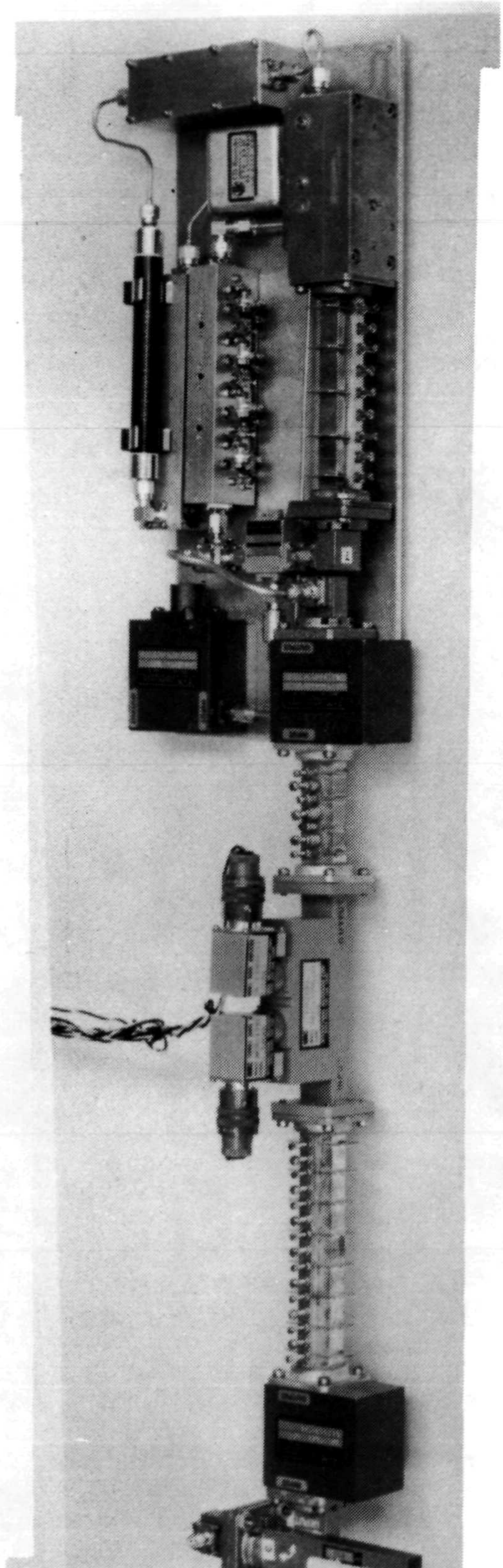


Figure 3-22. Receiver Subassembly

ITT 69441

Figure 3-23. Receiver Input Directional Coupler

ITT 69440

Figure 3-24. Receiver Pre-Select Filter

- o Eliminates image noise from entering mixer
- o Prevents LO signal leakage into TDA and possibly being radiated by the antenna

The K-band signal is applied to the mixer input via an isolator in order to prevent the mixer's input VSWR from effecting the post TDA filters characteristics. The signal enters the mixer and mixes with the 11.4982 GH_z LO signal. The resultant difference frequency IF signal is applied to the 4-stage low noise 2 Ghz IF amplifier.

The 2 GH_z IF signal leaves the receiver via an output isolator and is connected to the housings' bulkhead connector for interconnection to the external S-band receiver hardware.

The LO chain is the same design as used in the transmitter. The only difference is the operating frequency. Refer to Section 3.3.1.1.1 for additional information.

All receiver modules operate from the internally mounted + 15 VDC power supply. As in the transmitter, the K-band LO signal is detector monitored and remoted to the "Control Panel". In addition the TDA temperature monitor and "ZERO Gain" control are also remoted to the "Control Panel" for system analysis.

The overall receiver specifications are shown in Table 3-9.

3.3.1.4.1 Low Noise Preamplifier (LNA)

The low noise amplifier is realized using a 2 stage tunnel diode amplifier which has a measured noise figure less than 4.9 db at 13.6 ghz. The instantaneous 1 db bandwidth is greater than 300 MHz and provides greater than 33 db gain. The entire amplifier consumes only 0.5 watt from the + 15 VDC power supply. A photograph of the unit is shown in Figure 3-25.

The unit exhibits absolutely stable operation over any source/load VSWR condition and temperature. Its noise figure is essentially uneffected over 0 to + 50 degrees C and thereby easily maintains the receiver's noise figure of less than 7.0 db over the operating environment.

The TDA is designed with a bias network for reducing the amplifier's gain to zero. The function is controlled from the "Control Panel" and can be used for system analysis. A thermistor element is mounted on the input waveguide flange to monitor the TDA temperature. The sensors output voltage is displayed at the "Control Panel".

Additional specifications for the TDA are listed below in Table 3-10.

Table 3-9. Receiver Subassembly Specifications

Specification		Performance
RF input,	GHz	13.6
Instantaneous 1 db (RF input) bandwidth	MHz	200
Noise figure	dB	7
Tunnel diode amplifier		
Noise figure	dB	5.0
Gain,	dB	33
1.0 db compression point,	dBm	-27
RF input		
Standing wave ratio, 50 ohms		1.25:1
Waveguide connector		WR-62
Spurious response, below signal level		
In band,	dB	-40
Out-of-band	dB	-70
Transmit band, 14.4 to 15.35 GHz	dB	>90
Down converter IF, GHz		2.1018
Bandwidth, 1 db,	MHz	200
Output, TV mode,	dBm	-33
Output impedance,	OHMS	50
Output VSWR, max.		2.0:1
RF to IF gain	dB	50
RF to IF gain variation with frequency; over 100 MHz Bandwidth	dB	± 0.75
Operating temperature	^{o}C	0 to 50
Frequency stability,	ppm/day	1
Frequency control element		TCXO, antenna mounted
Receiver failure mode		Graceful degradation, tunnel diode amplifier
Monitor circuits		
Function		TDA temperature LO output power
Output format		Voltage 0.5 to 5.0 vdc across 10K ohms
Control circuits		TDA-zero gain
Power requirements		+15 vdc at 10 watts
Size, volume, and weight		Receiver in the same physical package as the power amplifier and other antenna-mounted electronic components. See transmitter specification.

ITT 69849

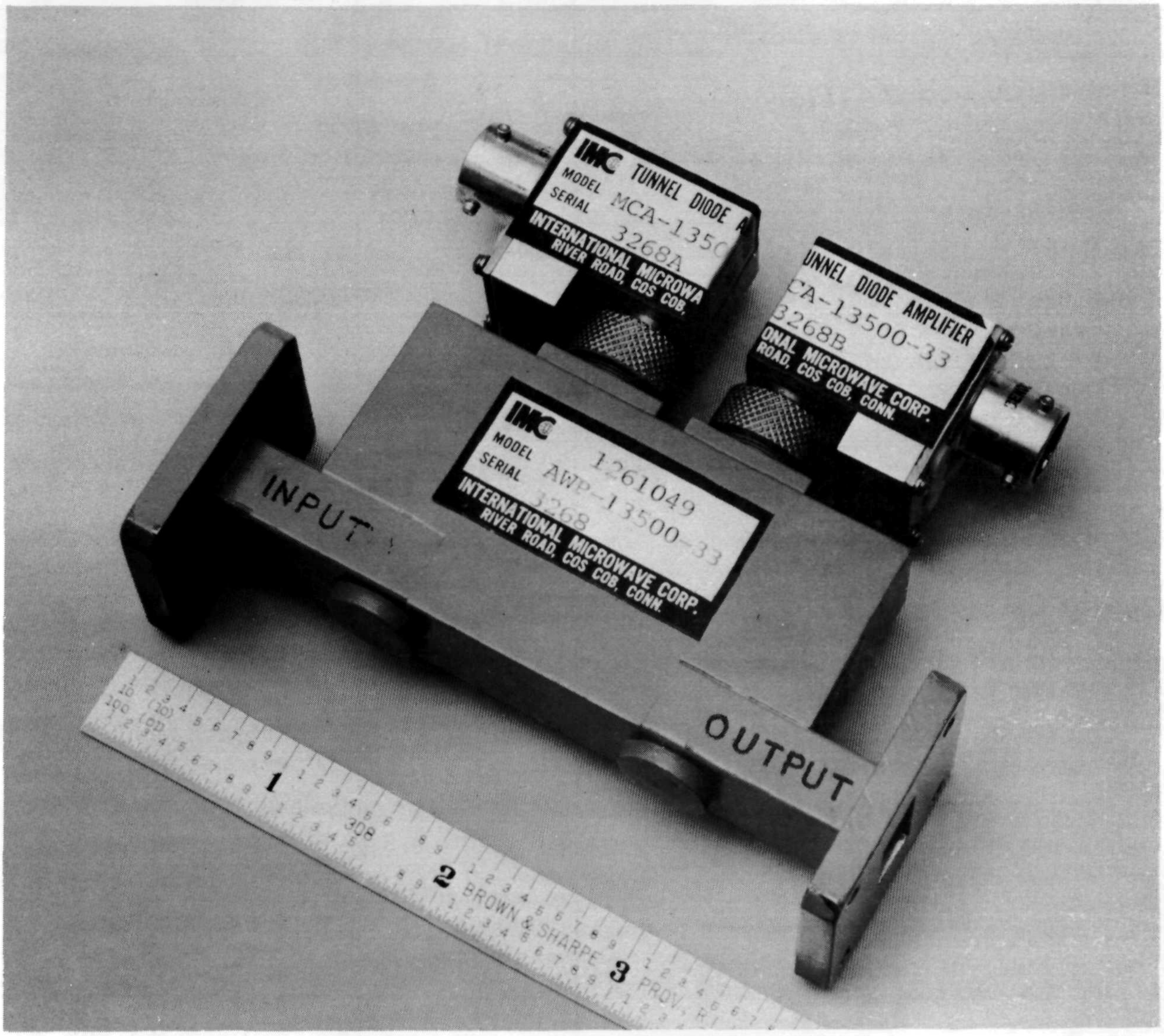


Figure 3-25. Receiver Low-Noise Preamplifier

Table 3-10. Receiver TDA Characteristics

Specification		Performance
Center frequency	GH_z	13.6
Bandwidth, 1 dB	GH_z	13.45 to 13.75
Gain	dB	33
Gain variation with temperature	dB	+0.5
1 db compression (output)	dBm	-25
DC input power		0.5 watt @ + 15 VDC
Input/output VSWR		1.15:1
Maximum input power into RF input port	mw	50
Diode maintenance		Field replaceable
Weight	ounces	8
Size		4-1/2" x 4-1/2" x 1-1/2"

3.3.1.4.2 Down Converter

Referring to Figure 3-21, the overall down-converter system consists of 4 basic components, namely the mixer input filter, K- to S-band mixer, 2 GH_z IF amplifier and K-band LO chain.

The physical layout of the assembly is shown in photograph in Figure 3-24. The -51.1 dbm signal enters the down-converter from the TDA output and is applied to the assembly's 3 pole post TDA filter prior to down-conversion to S-band. The filter is used primarily to eliminate the TDA image noise. The filter is a waveguide design and exhibits extremely flat amplitude response across the receiver bandwidth due to the image noise being 4 GH_z away. The filter has less than 0.2 dB insertion loss and essentially no passband ripple due to its wideband design.

The signal passes through the filter and is applied to the mixer via a waveguide isolator. The isolator is used between the filter and mixer in order to eliminate the mixers input VSWR effects on the filter's characteristics. A waveguide to coax adapter is used on the isolator's output to interface with the mixer's coax input.

The mixer is the same design used in the up-converter and is a doubly-balanced coaxial design. It's measured conversion loss at 13 dB GH_z is

10 db when driven by a + 10 dbm LO source. The LO power is deliberately kept high to minimize the Intermodulation (IM) products and the mixer achieves very linear mixing. The measured 3rd order intercept point is greater than + 10 dbm and equates to the 3rd order IM products being greater than 120 db below the desired test tone signal.

The K-band LO source is obtained from a X270 multiplier chain of the same design as used in the up-converter. The only difference is the exact operating frequency. As in the case of the up-converter, a coax isolator with a detector diode is used between the LO chain and mixer's input port. The isolator minimizes VSWR effects between the components and also provides LO power monitoring. The final operating frequency of the LO chain is 11.4982 GHz and is derived from a 42.5859 MHz TCXO multiplied 270 times. The difference IF of the mixer output is selected and is 2.1018 GHz. The LO frequency was selected to be on the low side of the 13.6 GHZ signal instead of on the upper side in order to avoid frequency inversion between the transmitter and receiver. Additional information on the X270 multiplier chain is presented in Section 3.3.1.1.1.

The 2.1018 GHz IF signal leaves the mixer and is applied to a 4 stage, lumped element circuit, transistor amplifier. A photograph of the amplifier is shown in Figure 3-26 and its schematic in Figure 3-27. The amplifiers noise figure, bandwidth, gain and gain transfer characteristics are shown in Figures 3-28 and 3-29. The amplifier achieves a 3.25 db noise figure over an instantaneous 1 dB bandwidth of 200 MHz and provides over 37 dB gain. The measured 1 dB compression is + 11 dbm when operating at rated noise figure.

All down-converter modules obtain operating power from the housing mounted 15 VDC power supply. As in the up-converter, the K-band LO power is detected at the mixer input and the rectified voltage is displayed at the "Control Panel" for monitoring purposes.

3.3.1.5 Control Panel

The physical layout of the "Control Panel" is shown in Figure 3-30. The panel is designed to mount into a standard 19 inch relay rack and has cut-outs on its edges to facilitate mounting.

The "Control Panel" is the central point for performing all the operating and monitoring functions for the electronics hardware mounted in the housing. A rear mounted bulkhead connector is used to interconnect the panel to the housing via an interconnecting cable. Two cables are supplied with the deliverable hardware. One is 10 feet; the other 50 feet. 110 VAC, 60 Hz prime power for the housing electronics hardware is obtained by connecting the Control Panel's AC line cord to a standard AC wall outlet. All control functions are located in the central area of the panel and are identified as follows:

Table 3-11. Control Panel Functions

Control	Function
o TDA Gain	TDA zero gain control
o IPA	Turn ON/OFF ac power
o PA-1 Main Power	Turn ON/OFF ac power
o PA-1 Helix Power	Turn ON/OFF tubes' helix current. Conserve tube life. Control power level and heat.
o PA-2 Main Power	Same function as PA-1 (Future 2nd TWTA)
o PA-2 Helix Power	Same function as PA-1 (Future 2nd TWTA)

The "Control Panel" is fully equipped for installation of the second TWTA. No additional hardware is required in the panel to accommodate the future tube. Similarly, all cables are contained within both interconnecting cables.

The various receiver and transmitter monitor functions are indicated in the photograph and are located in two distinct separate groups. Tip jacks for each section are provided and are used for interconnecting an external high impedance dc voltmeter for display.

Schematic diagram shown in Figures 3-31 and 3-32 detail the wiring interconnections of the "Control Panel" to the various receiver/transmitter circuits.

Prime power to the "Control Panel" is fused for safety and a neon lamp shows when 110 VAC prime power is on to power "Control Panel" circuits.

A calibration curve for temperature versus output voltage is shown in Figure 3-33 to aid temperature measurements for the monitored points detailed above.

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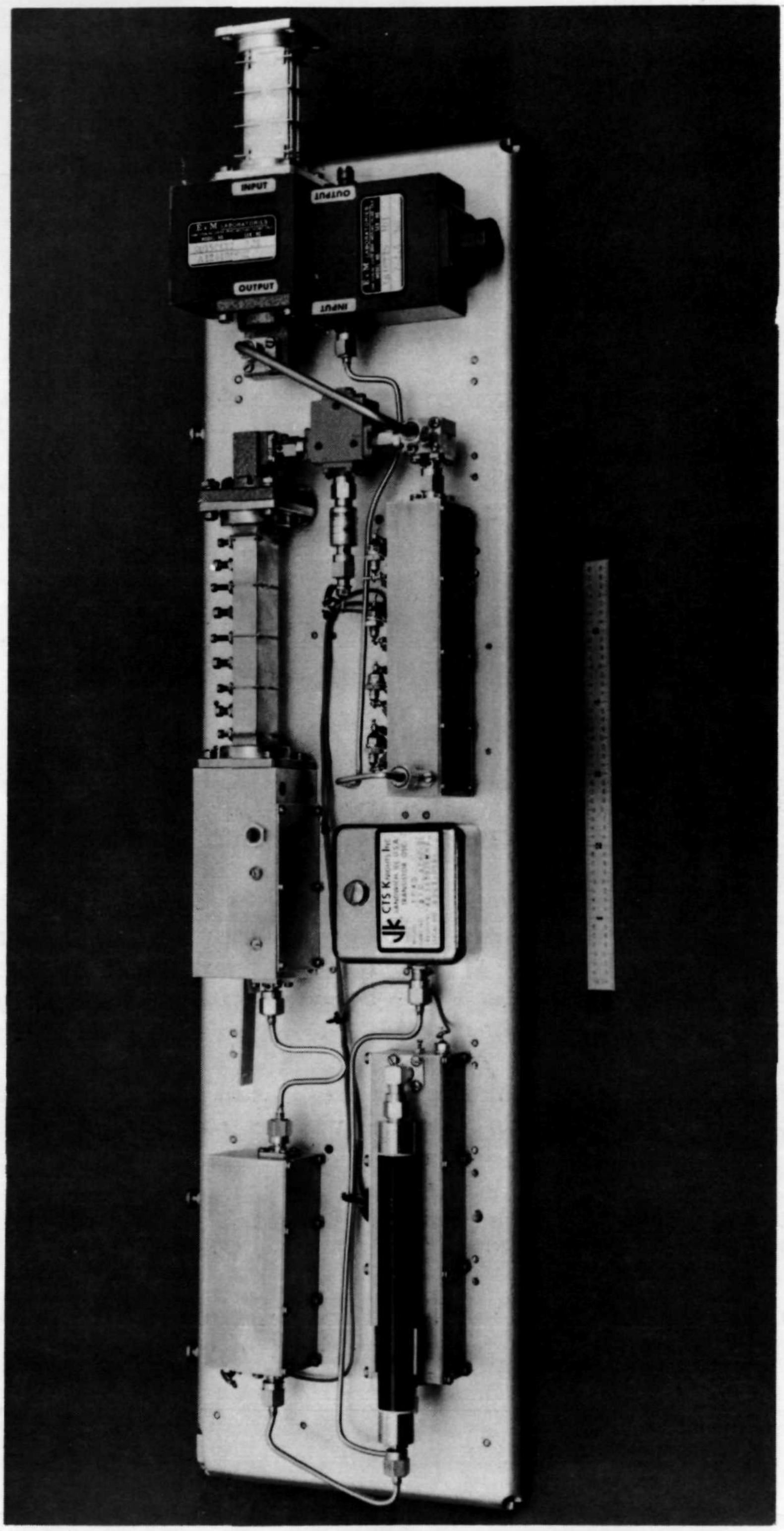

Figure 3-26. Receiver Down-Converter Subassembly

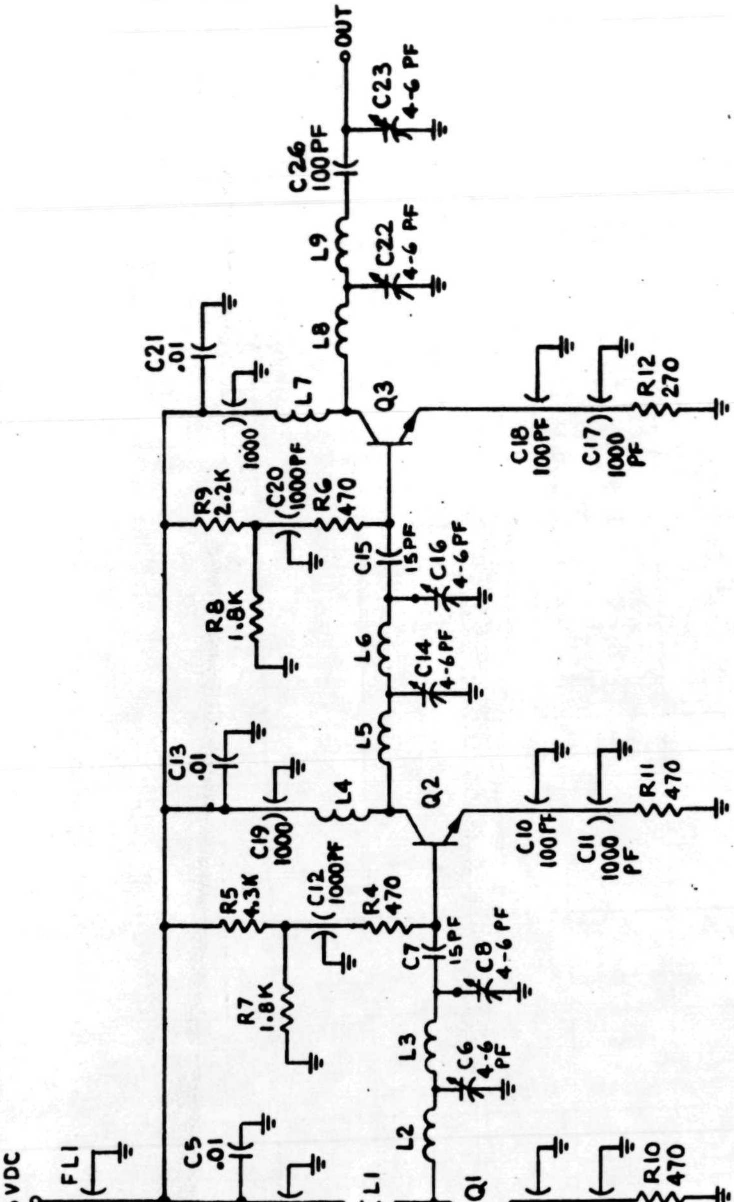

Figure 3-27. 2-GHz Low-Noise Amplifier, Schematic Diagram

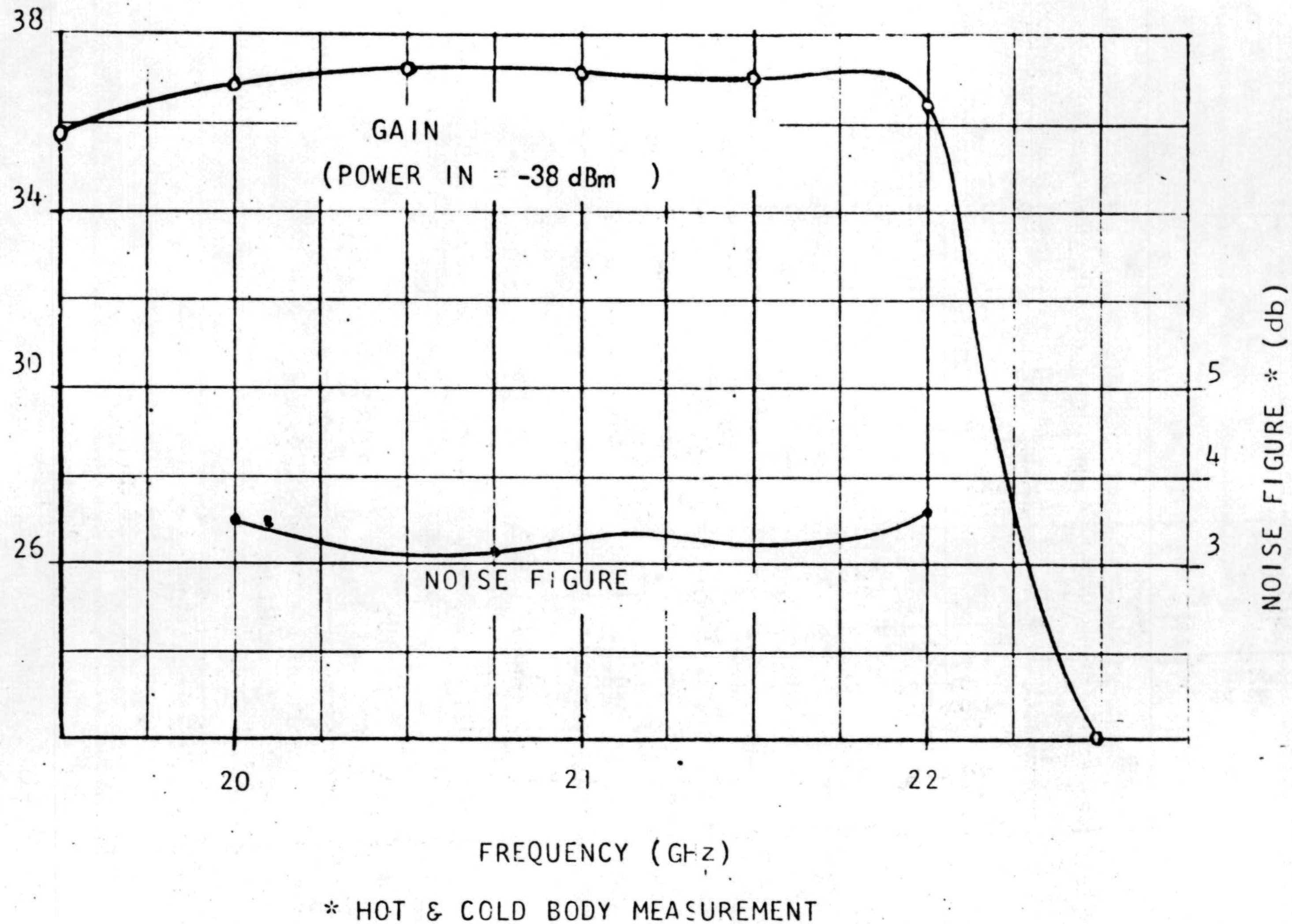

Figure 3-28. 2.1018 GHz Amplifier, Frequency Response and Noise Figure

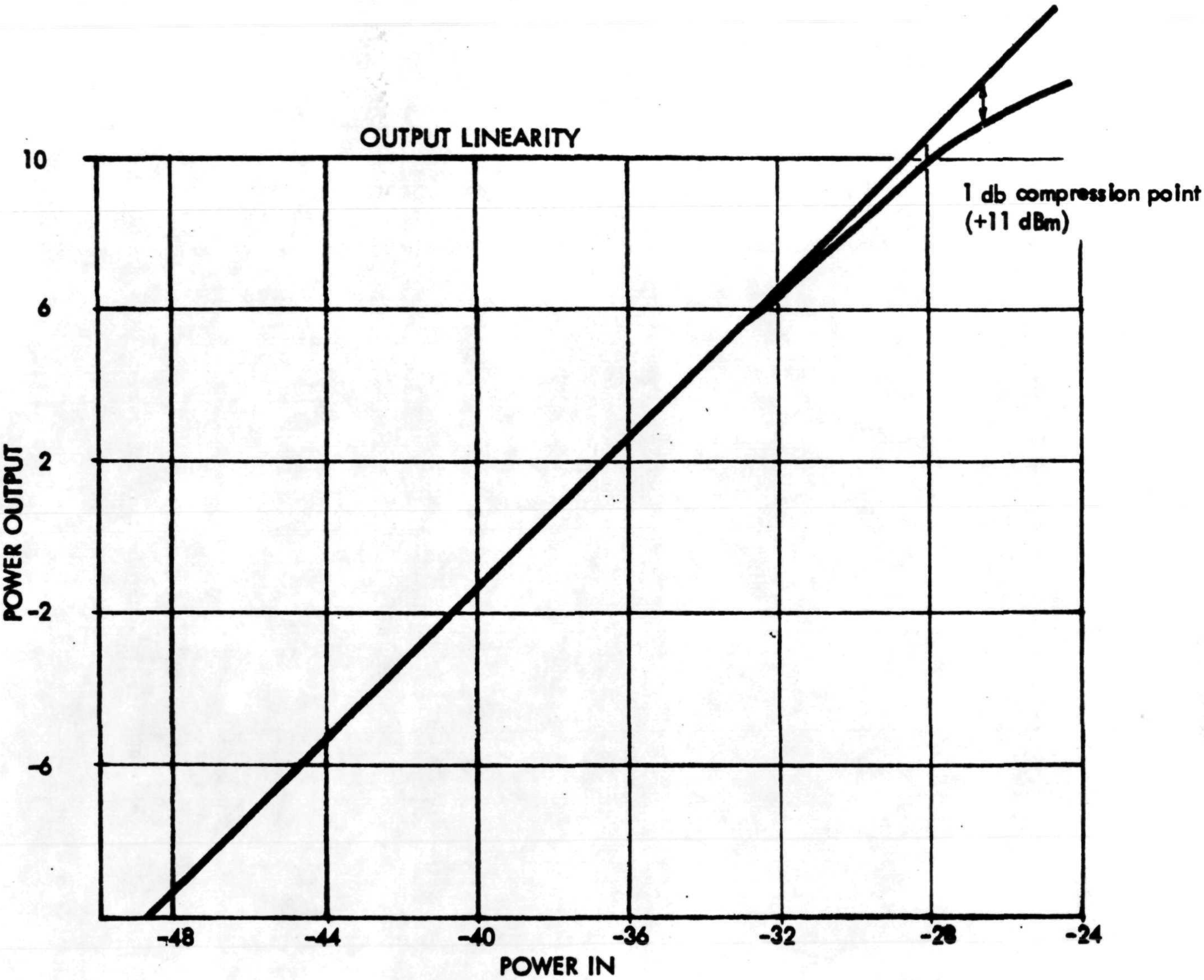

Figure 3-29. 2.1018 GHz Amplifier, Output Linearity

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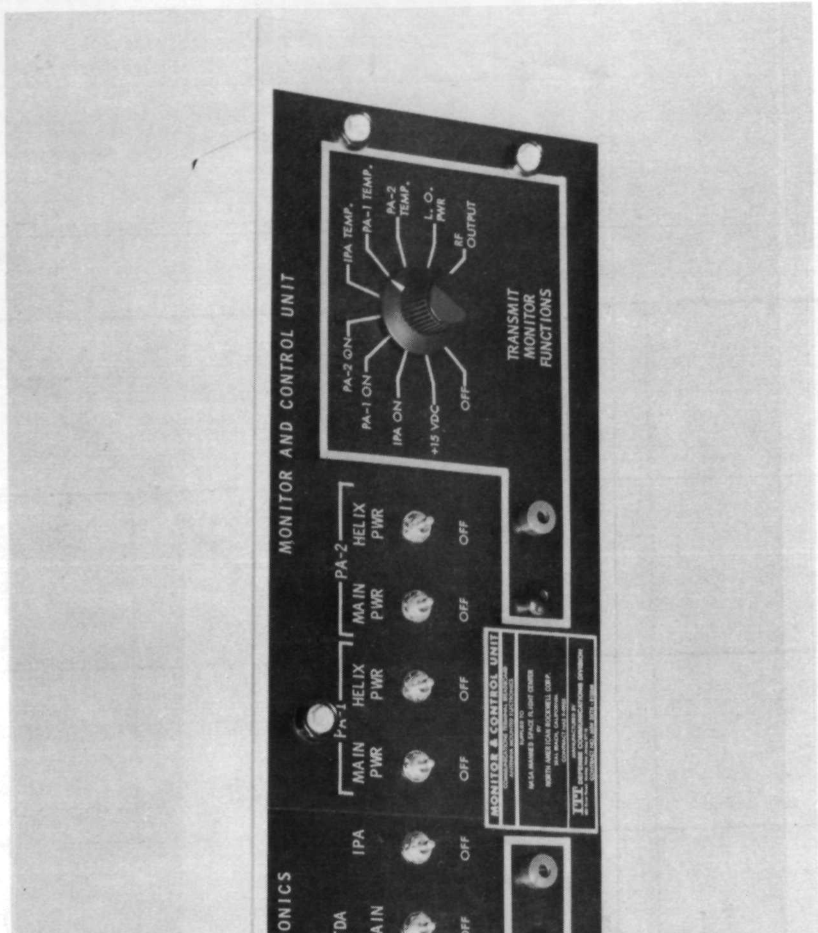

Figure 3-30. Control Panel Subassembly

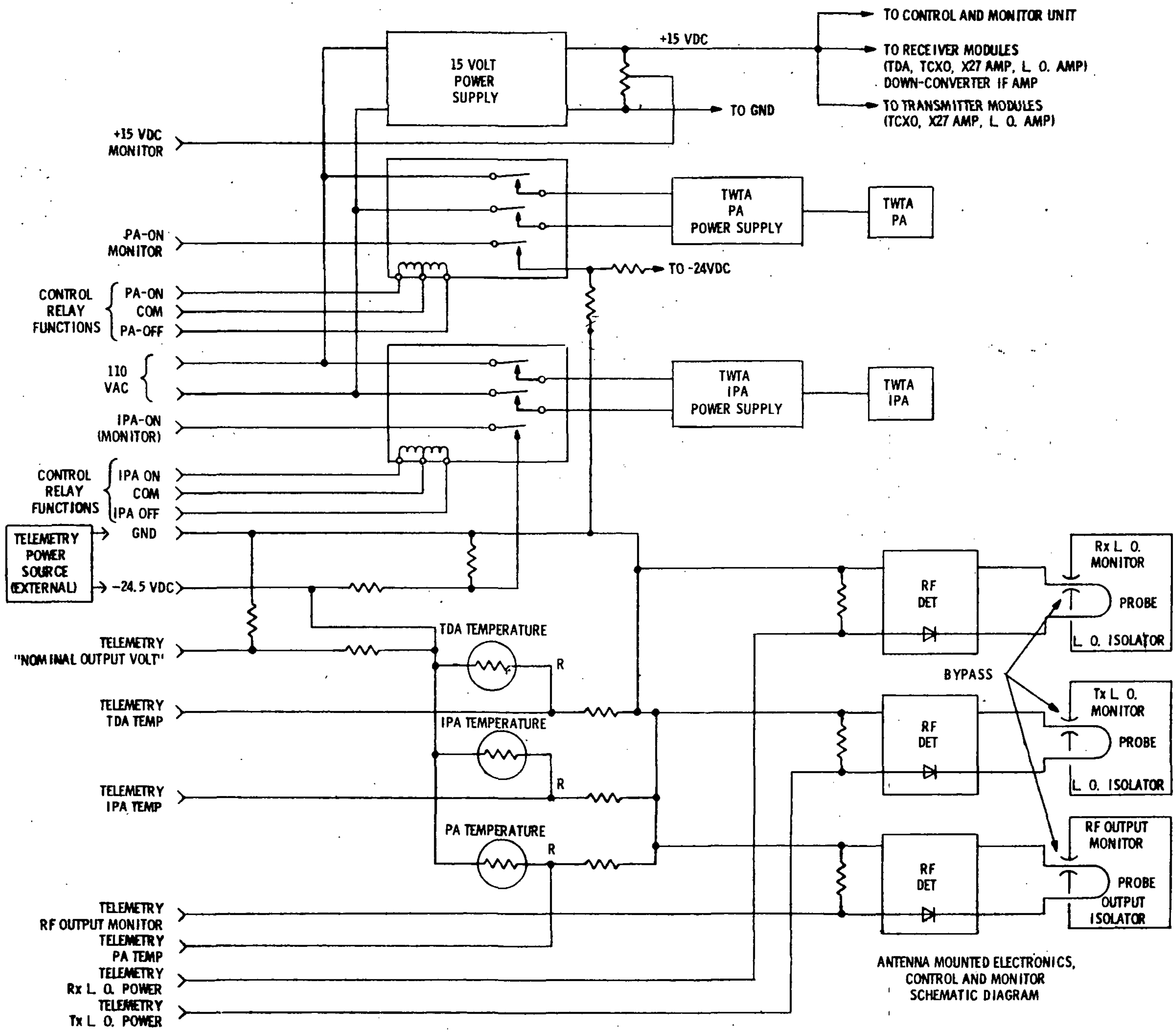

Figure 3-31. Monitor and Controls, Schematic Diagram

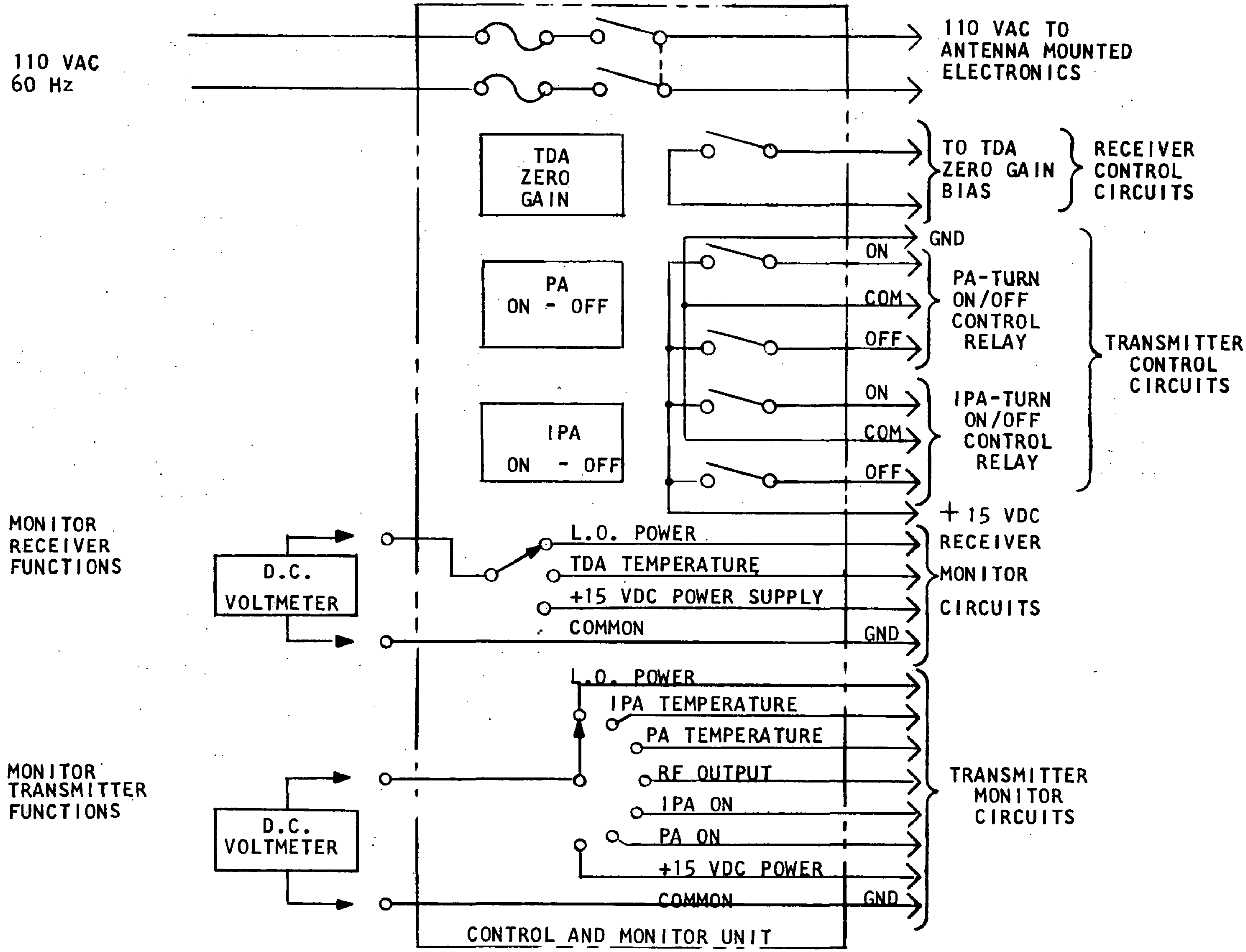

Figure 3-32. Cable Connections, Monitor and Control System

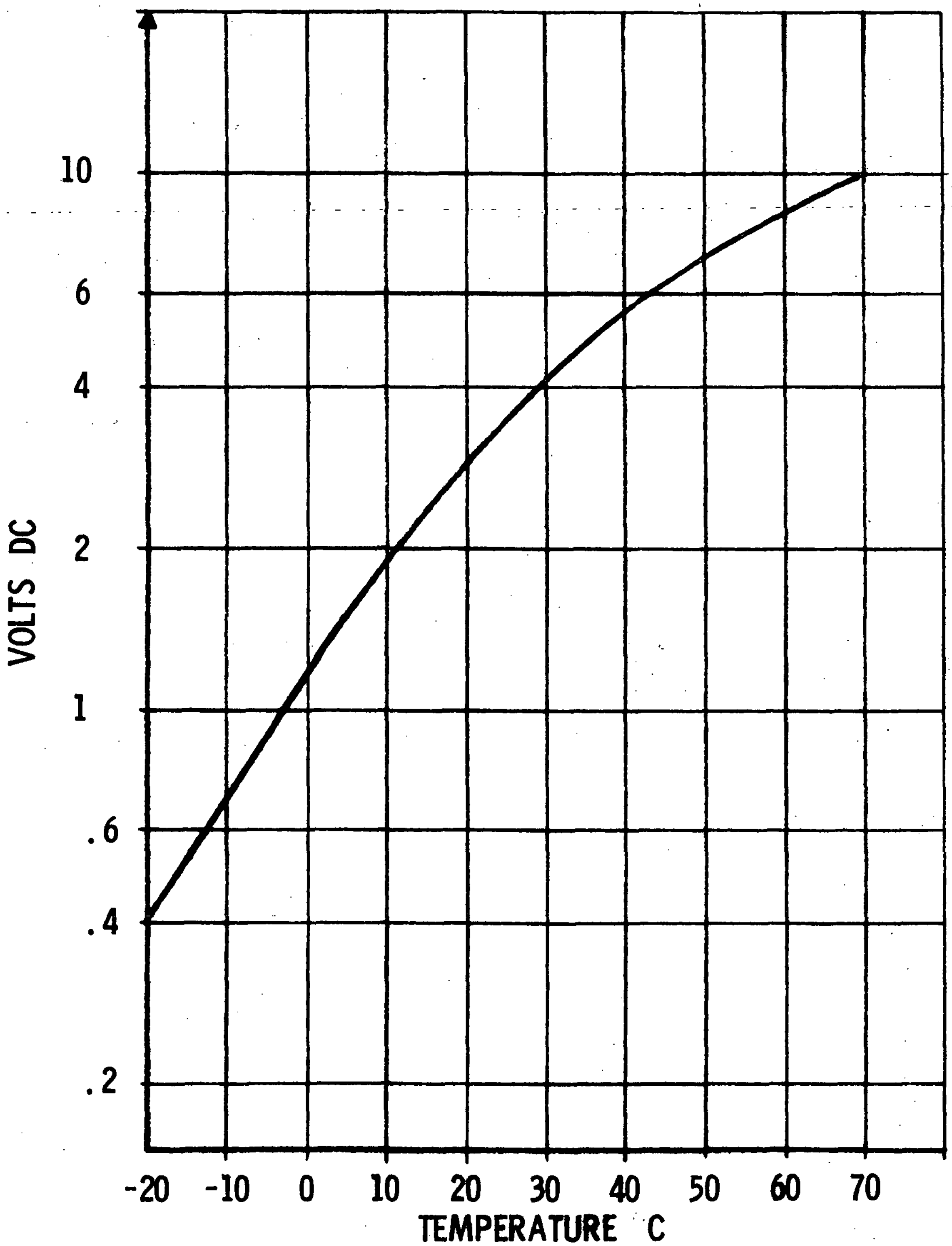

Figure 3-33. Calibration Curve, Thermistor Output vs Temperature C

Monitor and Control Circuits

TDA Temperature Monitor - The temperature is monitored with a thermocouple mounted to the unit. The thermocouple is biased, and a change in temperature will cause a change in output voltage. The voltage analog of temperature can be read in°F or°C at the Control and Monitor Unit.

Receive L-O Power Monitor. The output circulator of the LO chain has a coupling probe, so that the output can be sampled. A diode detector is used to convert the RF to d-c voltage, which is fed back to the "Control Panel" voltmeters.

Driver Amplifier Control Relay Monitor - The relay that switches the prime 115 vac for the power amplifier has an additional contact for an indicator. If the relay is on: i.e., energized, then the indicator contact is closed energized and a d-c voltage can be read at the Control and Monitor Unit.

Final Amplifier Control Relay Monitor - This is identical to the Control Relay Monitor described above for the driver amplifier.

+15 VDC Power Supply Output Monitor - A resistive power divider is placed across the power supply output to develop a d-c voltage proportional to the power supply output. The sampled voltage is sent to the voltmeter at the Control and Monitor Unit.

R-F Output Monitor - The output circulator has a probe to monitor transmit power; diode detector converts the sampled signal to a d-c analog voltage, which is read on the voltmeter on the Control Panel.

Driver Amplifier Temperature Monitor - The same as the Tunnel Diode Amplifier Temperature Monitor.

Final Amplifier Temperature Monitor - The same as the Tunnel Diode Amplifier Temperature Monitor.

Transmit L-O Output Monitor - The same as the Receive Local Oscillator Output Monitor.

TDA Zero Gain Control - The tunnel diode amplifier gain can be set to zero db by back biasing the diodes. This test can be used as a go-no-go indication of normal amplifier performance. The diodes are back biased by turning the control switch on allowing voltage to back bias the diodes.

Driver Amplifier Relay Control - The 115 vac prime power for the power amplifier is switched by a normally open relay. When the control switch is turned on, the relay is energized, switching prime power to the amplifier.

Final Amplifier Relay Control - This is identical to the relay described above.

3.3.1.6 Cable Assembly

The lead assignments and designations within the 50 foot cable assembly are shown in Table 3-12.

The EMC plan followed to minimize any potential interference problems consists of treating the following areas:

1. Eliminate pick-up of radiation leaks within the Cable Assembly

2. Eliminate pick-up or transmission on the S-band interface cables

3. Eliminate 60 hz power line hum and noise into control and monitor cable leads.

K-band pick-up was eliminated by using shielded leads on all control and monitor circuits. In addition, S-band signals are transmitted over coaxial cables to eliminate the entrance of K-band radiation into these signals paths.

The 60 hz powerlines are shielded and, except for the cable wraps, are physically separated from the other leads in the cable assembly.

All temperature and rf power monitor lines, including the common return lead, are electrically isolated from ground. Only cable shields are single-point grounded within the Antenna Mounted Electronics package. In addition, single-point grounding occurs for all other shields within the antenna package and thus presents floating lines at the Control Box end.

Table 3.12 that follows shows the operating levels of all leads contained in the cable assembly. Potential interference areas are discussed in the comments column.

NOTE: Due to low levels on LO and rf power monitor circuits (3), low output impedance line drivers amplifier may be required. These will be incorporated if required after future tests are conducted.

3.3.1.7 Prime Power Distribution and Conditioning

The prime power bus is 115 vac, single phase, 60 hz. The following distribution and conditioning are provided:

1. Turn on and off + 15 vdc power supply
2. Turn on and off 115 vac power supply to the driver amplifier
3. Turn on and off 115 vac power supply to final amplifier

Table 3-12. 50-Foot Cable Assembly Levels and Functions

CIRCUIT FUNCTION		OPERATING POWER CURRENT OR IMPEDANCE	OPERATING VOLTAGE	NUMBER OF LEADS*	COMMENTS
110 vac 60 hz Power		200 watts (one TWT)	110 vac	2	Shielded pair, seperated 1 foot from all control and monitor leads No interference to other leads anticipated
TDA Zero Gain Control		< 100 ohms	2 vdc	2	Shielded pair, low impedance, high operating voltage. No interference anticipated
IPA (ON-OFF) Control		100 ma	15 vdc	3	Shielded 3 leads, high current and voltage No interference anticipated
PA (ON-OFF) Control		100 ma	15 vdc	3	Same comments as IPA (ON-OFF) Control
RECEIVER	L. O. Power Monitor	5K ohms	.5-1 vdc	1 + com	Shielded lead, low-voltage, high impedance possible interference. Low output impedance line driver may be required
RECEIVER	TDA Temperature Monitor	5K ohms	5-10 vdc	1 + com	Shielded lead, high voltage and impedance No interference anticipated
RECEIVER	+15 vdc Power	5K ohms	10 vdc	1 + com	Same comment as TDA temp monitor
TRANSMITTER	L-O Power Monitor	5K ohms	.5-1 vdc	1 + com	Same comment as receiver L.O. power monitor
TRANSMITTER	IPA Temperature Monitor	5K ohms	5-10 vdc	1 + com	Same comment as receiver TDA temperature monitor
TRANSMITTER	PA Temperature Monitor	5K ohms	5-10 vdc	1 + com	Same comment as IPA temperature monitor
TRANSMITTER	R-F Out Monitor	5K ohms	1-3 vdc	1 + com	Same comment as receiver L.O. power monitor
TRANSMITTER	IPA -ON Monitor	5K ohms	5-10 vdc	1 + com	Same comment as receiver TDA temperature monitor
TRANSMITTER	PA -ON Monitor	5K ohms	5-10 vdc	1 + com	Same comment as IPA-ON
1st Down Converter Out		50 ohm	-30 dbm	1 coax	Coaxial cable, can be double shielded No interference anticipated
2nd Up Converter In		50 ohm	+3 dbm	1 coax	Same comment as 1st down converter out

*Common return leads (com) on receiver and transmitter monitor and control circuits are isolated relative to 60 hz power source

The +15 vdc power supply is of modular construction; weight, 4 pounds. It has sufficient capacity for all receiver and transmitter functions at maximum operating temperature and has an efficiency of 55%. The power supply has built in over voltage and short circuit protection.

3.3.1.8 Translator

Provision is made to mount a frequency translator in the antenna-mounted electronics housing to turn-around test K-band transmitter and receiver during MSS missions. This will obviate the necessity of EVA to check transceiver performance. Laboratory set-ups will be available for terrestrial test, so the expense of the test translator need not be incurred for the present model. The block diagram of the test translator can be seen in Figure 3-34.

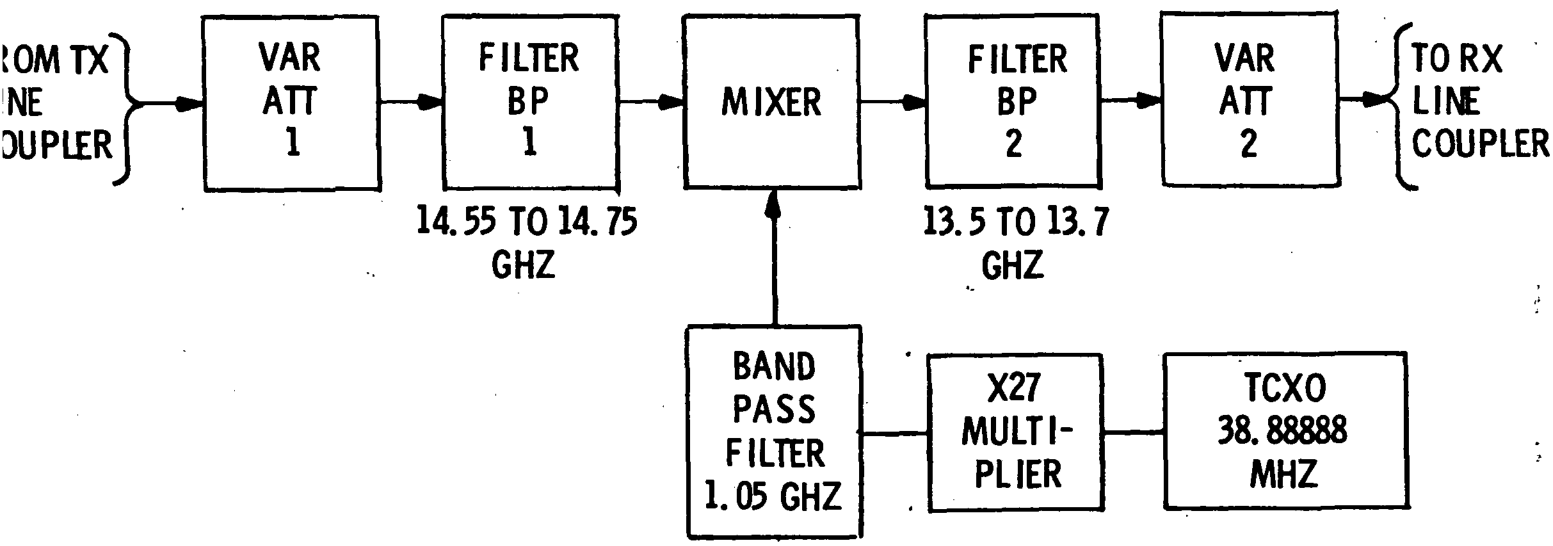

Figure 3-34. Test Translator, Block Diagram

3.3.2 ANTENNA SUBASSEMBLY REQUIREMENTS

The antenna subassembly is part of the outboard CTB equipment but not supplied as part of the deliverable contract items. As shown on the ultimate system block diagram, the antenna subassembly will consist of those components necessary to a high efficiency high gain antenna with simultaneous transmit and receive capability, right hand circular polarization for both receiving and transmitting, and monopulse tracking capability. The antenna shall be designed to withstand handling and launching. It should operate at designed efficiency when subjected to maximum slew rates of 10 degrees per second over the entire pointing volume while subjected to induced differential thermal conditions of the near-earth space environment.

The Antenna Subsssembly is to consist of a cassegrainian reflector system, a feed horn unit to illuminate the reflectors, a comparator and diplexer to produce sums and differences and to separate transmit and receive channels, and a tracking modulator to multiplex the direction finding signals onto the receive channel of the communications terminal. These tracking signals will ultimately reach an autotrack processor in the inboard assembly via the cable subassembly and parts of the non-integrated electronics subassembly.

3.3.2.1 Antenna Optics

The antenna optics are to provide an efficiency of at least 65 percent referred to the feed horn aperture. This should be confirmed by gain measurements at the comparator sum port with due allowance for comparator, transducer, polarizer, and matching section attenuations. The 65 per cent efficiency includes allowances for feedhorn spillover beyond the secondary reflector, illumination taper to control sidelobes, aperture blockage by the secondary and its support spars, rms surface tolerances on the reflectors, and tolerance for the mechanical alignment of the secondary and feed relative to the main reflector. A dual shaped cassegrain reflector system forms the basis of the optic design.

3.3.2.2 Feed System and Waveguide Circuitry

Figure 3-35 shows the block diagram of the feed system and associated waveguide circuitry. The comparator provides the sum and two difference signals needed for tracking. A transducer section launches the transmit signal to a four channel polarizer or, on receive, directs the four channel receive signals to the appropriate comparator input ports. The polarizer produces right hand circular polarization in each channel. A waveguide matching section permits the sum and difference signals to exist as the principal and higher order waveguide modes so that all signals may share a larger common feed horn aperture and thus produce a narrower confocal feed pattern.

The comparator sum port conducts both the transmit and receive signals, consequently a diplexer must be used to isolate the receiver from the transmitter power and to conduct the received signal to its own channel. The comparator difference signals are also filtered to reject transmitter signals

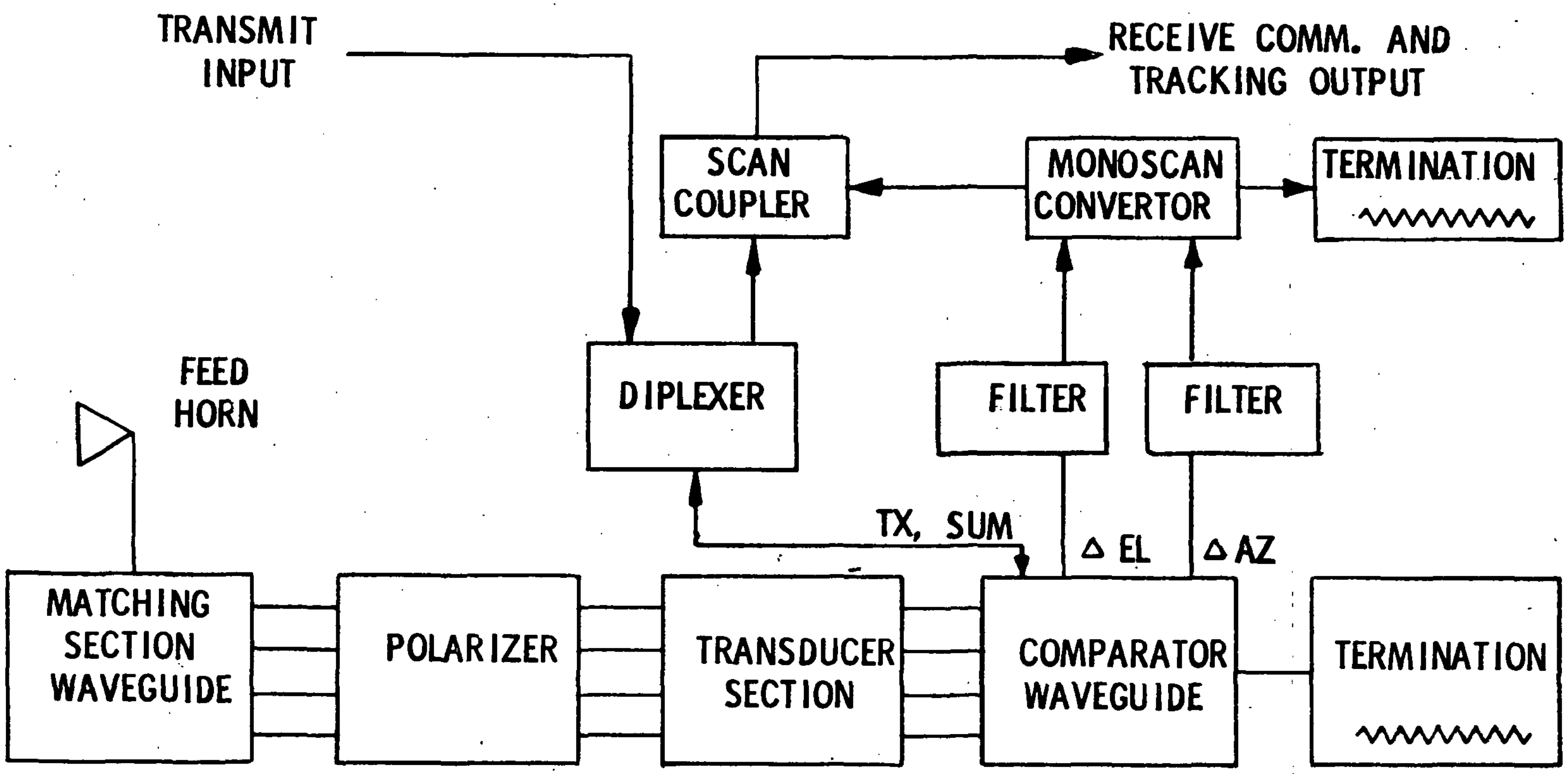

Figure 3-35. Feed Assembly, Block Diagram

and then are multiplexed into the receiver channel by the monoscan converter which feeds a scan directional coupler in the receive channel transmission line.

3.3.2.3 Antenna Subassembly Performance Requirements

The performance requirements of the antenna subassembly are presented in Tables 3-13 and 3-14.

These requirements are to be met with an earthbound brassboard system which does not experience thermal distortion.

3.3.2.4 Antenna Mount Subassembly Requirements

The Antenna Mount Subassembly positions and points the Antenna Subassembly to any support satellite or vehicle so that full station antenna gain may be available to these communications links. The mount subassembly uses tracking signals received from the autotrack processor in the non-integrated electronics subassembly. It is able to point the antenna to within ± 0.05 degrees of the peak gain of the antenna. The mount is capable of slewing the antenna at 10 degrees per second within its scan volume.

The Antenna Mount Subassembly supports the Antenna, the Antenna Mounted Electronics Subassembly and the Servo Drive Subassembly. These subassemblies are powered by, and transmit and receive all signals from, the inboard assembly over a cable subassembly which consists of straight sections and cable wraps about the rotation axes. The antenna mount subassembly consists of a two axis pedestal and a servo drive subassembly. The latter consists of two servomotor-gear box units, one for each axis, two amplifiers for driving the motors and two position sensor units which both receive the autotrack processor signals and sense the actual positions of the pedestal axes. The latter information is used during blind pointing for acquisition.

A standard antenna positioner sized to rotate the combined antenna electronics package in both elevation and azimuth provides the capability to perform antenna pattern measurements, tracking and communication with a data relay satellite (if desired) or demonstration of auto track capability.

3.3.2.5 Graceful Degradation

One of the technology goals that needs special discussion is that of graceful degradation. Both transmitter and receiver designs inherently exhibit such graceful degradation. Due to the use of a parallel TWT power amplifier stage and a two-stage TDA receiver pre-amplifier, partial failures of any of these amplifiers result in continued operation but in degraded modes. Such operation for these stages is discussed below.

<u>Tunnel Diode Amplifier</u>

The tunnel diode amplifier is a two stage cascade circuit with 33 db gain. Each stage consists of a low loss, three port circulator with the low noise diode connected to Port 2. Since a diode subjected to high power overload fails reactive, the signal enters the stage at Port 1, proceeds to

Table 3-13. Antenna Subassembly Requirements

Parameter	Scale	Receive	Transmit
Operating Band	GHz	13.4-14.2	14.4-15.35
Polarization	--	CP	CP
Axial Ratio	dB	2	2
VSWR	--	1.5:1	1.5:1
Aperture Efficiency	%	65-70	65-70
Gain (Aperture)	dB	44.5	45.0
Sidelobe Levels	(*)		
1st Order	dB	-16 dB	
2nd Order	dB	-20 dB	
Higher Order	dB	>-25 dB	
Diplexer Rejection			
No. of Poles	--	7	5
Band	GHz	13.5-13.7	14.55-14.75
Rejection Freq.	GHz	14.55	13.7
Rejection	dB	90	80

(*) Sidelobes result from:

- Illumination fucntion
- 4-1/2" SPARS
- Secondary Reflector Diameter - 9.2" and RMS Surface Error of 0.006"
- Main Reflector Diameter = 60" and RSM Surface Error of 0.020"

Table 3-14. Interface Between Antenna and Other Elements Definition

MECHANICAL	
Main Reflector	5 ft diameter
Secondary	9.2 inch maximum
RMS Surface Error	Main Reflector 0.020"
Secondary Support	Secondary 0.006" 4-1/2 in. Spars
Feed Dimensions	Length 18 inches Height 12 inches Width 10 inches
Number of microwave external connections	2 (one Transmit, one Receive)
Number of jacks to monoscan converter	5
Monoscan jack connector type	4 TNC Coax M39012/ 31-1-MS3114E-14-125
Microwave Flange Connections	UG 419/U Aluminum
ELECTRICAL	
Apperture Efficiency to Feed Horn Input (Receive Mode)	65 to 70 percent
Loss through feed system. (To output of Diplexer Receive Mode)	TBD
Antenna Beam collimation relative to mechanical boresight	± 0.05 degrees

Port 2, and is totally reflected there if the diode has failed, and thus proceeds on to Port 2 where it leaves the stage. The failure of a diode stage will degrade the signal by about 17 db, which will be compensated by the agc circuits prior to limiting before detection either at S-band or at i-f in the non-integrated electronic subassembly.

The system noise figure would degrade no more than 1.0 db if the first diode fails, and no more than 0.5 db if the second diode fails. If both diodes fail, the system noise will be dominated by the mixer in the first downconverter, and the bandwidth would have to be reduced to several hundred kilohertz.

Travelling Wave Tube Amplifiers

The two final power amplifiers are driven by the intermediate power amplifier, the output of which is divided in phase by a hybrid. The two components are connected in-phase, to the inputs of the two 10 watt final power amplifiers. A phase shifter is inserted in one path to adjust the phase coherence of the two components into perfect phase match. The outputs of the two final amplifiers are added in combiner to produce the stipulated 20 watts.

The second hybrid is a 4-Port passive network; the two output ports deliver electric fields proportional to the phasor sum and difference of the two common frequency signals at the input ports. When the two signals are in-phase and equal in magnitude (as they will be when both travelling wave tubes are operating) there is no phasor difference and all of the power comes out of the sum port; the difference port is terminated in a resistive load. If one travelling wave tube fails, the 10 watt output of the remaining tube is divided between the two output ports. Half is dissipated in the load at the difference port; the other half is delivered to the antenna system. The system can thus perform with less power output if one of the PA tubes should fail.

3.3.3 Non-Integrated Electronics Subassembly Requirements

The Non-Integrated Electronics Subassembly is part of the Inboard Electronics. It is connected by the multichannel Cable Subassembly to the RF Electronics Antenna Assembly. It receives the S-band signals from the K-band Receiver Subassembly and transmits others to the K-band Transmitter aubassembly over two coaxial cables. It also transmits autotrack processor unit signals to the tracking modulator and the position sensor units. The Non-Integrated Electronics Subassembly also accepts and delivers baseband signals from and to the Baseband Subassembly.

The Non-Integrated Electronics Subassembly consists of an S-band switching unit, a modulator and first upconverter unit, a second down converter and demodulator unit, and the autotrack processor. The RF switching unit connects the inboard assembly to one of several electronics antenna assemblies.

3.3.3.1 First Upconverter and Modulator

The baseband, up to 10 MHz, enters each modulator unit via the Multiplexer Unit located in the support electronics assembly. The modulator output is at 70 MHz and is applied to the first upconverter unit.

An internal oscillator and multiplier chain provide local oscillator power to the first Upconverter unit. The output signal from the first upconverter is at S-band and is applied over coaxial cable to the second upconverter unit in the antenna electronics subassembly for subsequent transmission. A block diagram of the first Upconverter and modulator is given in Figure 3-36. Its interfaces are listed in Table 3-15.

3.3.3.2 Second Downconverter and Demodulator

The 2 GHz IF output from the receiver section of the antenna electronics subassembly is transmitted to the second downconverter over a coaxial cable. A 2 GHz amplifier and bandpass filter are employed at the input of the second downconverter mixer for band shaping and level adjustment. An internal oscillator and multiplier chain provide local oscillator power to the second downconverter unit. The resultant second IF signal is at 70 MHz and is applied to the demodulation unit. The demodulator unit provides a baseband output video signal and is applied over a coaxial cable to the demultiplexer unit in the support electronics subassembly for final distribution to the internal communications systems.

Part of the 70 MHz IF signal is sampled and applied to the autotrack processing unit. A block diagram of the second downconverter-demodulator is shown in Figure 3-37.

3.3.3.3 Auto-Track Processor, Description

The auto-track processor unit accepts the 70 IF signal from the second downconverter unit and supplied trigger pulses to the Track-Modulator in the antenna subassembly to determine the scan cycle. The processor develops three output signals. Two are error voltages to drive the servos in the servo-drive subassembly and the third output is used to indicate that a valid signal is present. The error voltages are developed by synchronously detecting the scan-coded amplitude modulation present in the 70 IF signal. The primary performance characteristics of the unit are:

Scan frequencey: 200 Hz

Randomness: Pseudo random polarity variations of scan cycle

Scan modulation sensitivity: 20 percent modulation per degree

Figure 3-38 shows the processor unit in block diagram.

Table 3-15. Interface Definitions, First Upconverter and Modulator

Characteristic		Performance
Output frequency	GHz	2.2825
Output impedance	ohms	50
Output connector		Coaxial, Type TBD
Output, dbm		5
Input frequency, baseband	MHz	
Input impedance	dBm	0
Input connector		Coaxial, TBD
Modulation		FM and PM

Table 3-16. Interface Definitions Second Downconverter Demodulator

Parameter		Value
Input frequency	GHz	2.1018
Input power	mw	TBD
Input impedance	ohms	50
Input connector		Coaxial, TBD
Output frequency, baseband	MHz	10 MHz
Output	dBm	0
Output impedance	ohms	TBD
Output connector		Coaxial, TBD
Demodulation		FM and PM

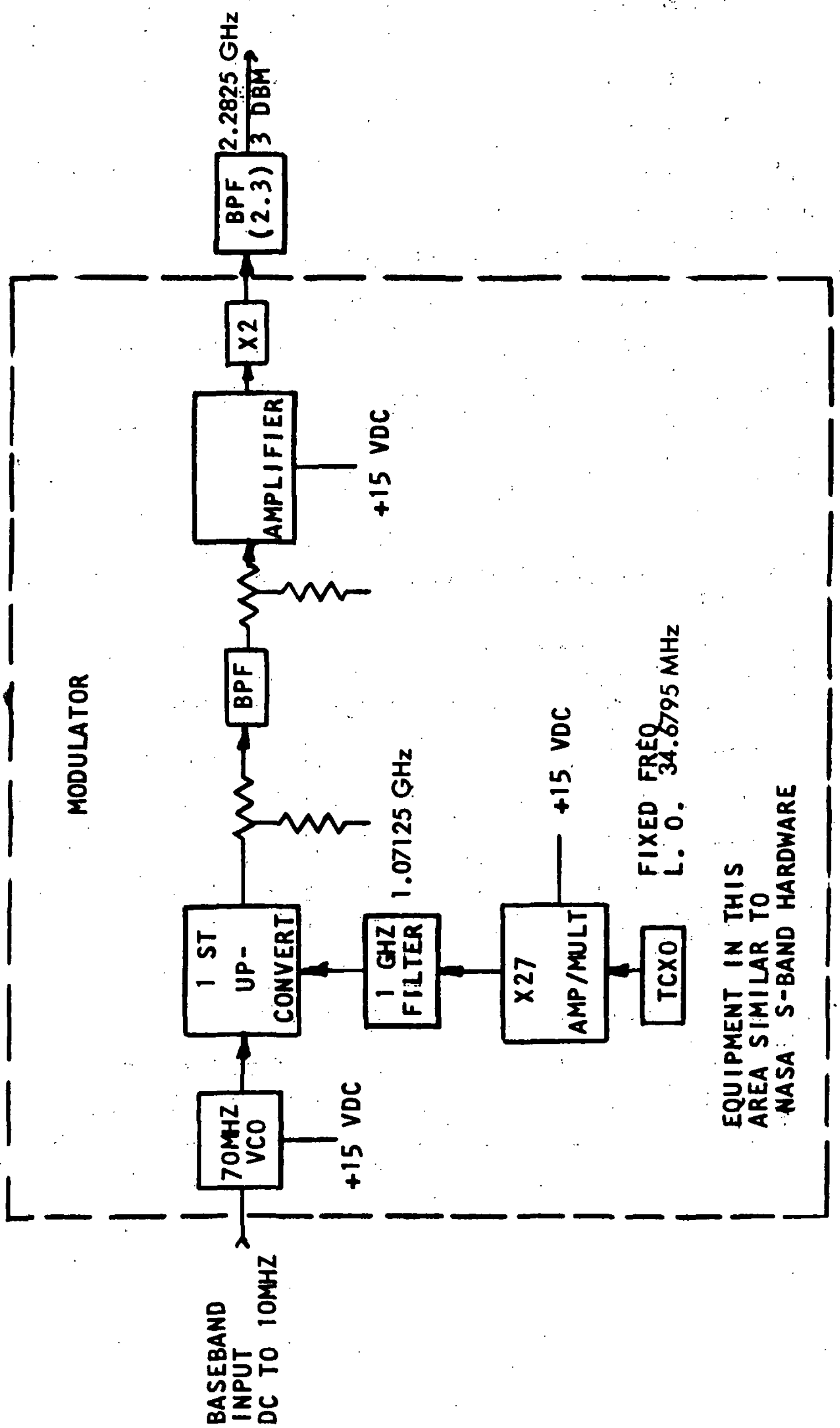

Figure 3-36. 1st Upconverter - Modulator, Block Diagram

Operating Modes:

1. Command pointing only, monoscan bypassed or ignored

2. Augmented command pointing; autotrack error signals used by computer to update pointing parameters

3. Autotrack, scan modulation is nulled by servo loop

4. Automatic acquisition, computer commands predetermined scan pattern. When signal is detected in threshold detector, mode (2) or (3) becomes operative. Sidelobe avoidance procedures may be programmed.

5. Manual, antenna pointing angle determined manually

Tracking jitter due to thermal noise: Negligible (no decrease in antenna gain).

Table 3-17. Interface Definitions, Auto-Track Processor

Trigger pulses to tracking modulator (part of antenna subassembly) Frequency: 800 pulses/second Number of wires: TBD Pulse sequences: TBD Pulse amplitude and shape: TBD
Error voltages to servos drive subassembly, two outputs (X and Y), volts per degree error to be determined.
Logic output to servo drive subassembly indicating acquisition, 0 and 1 logic levels to be determined.

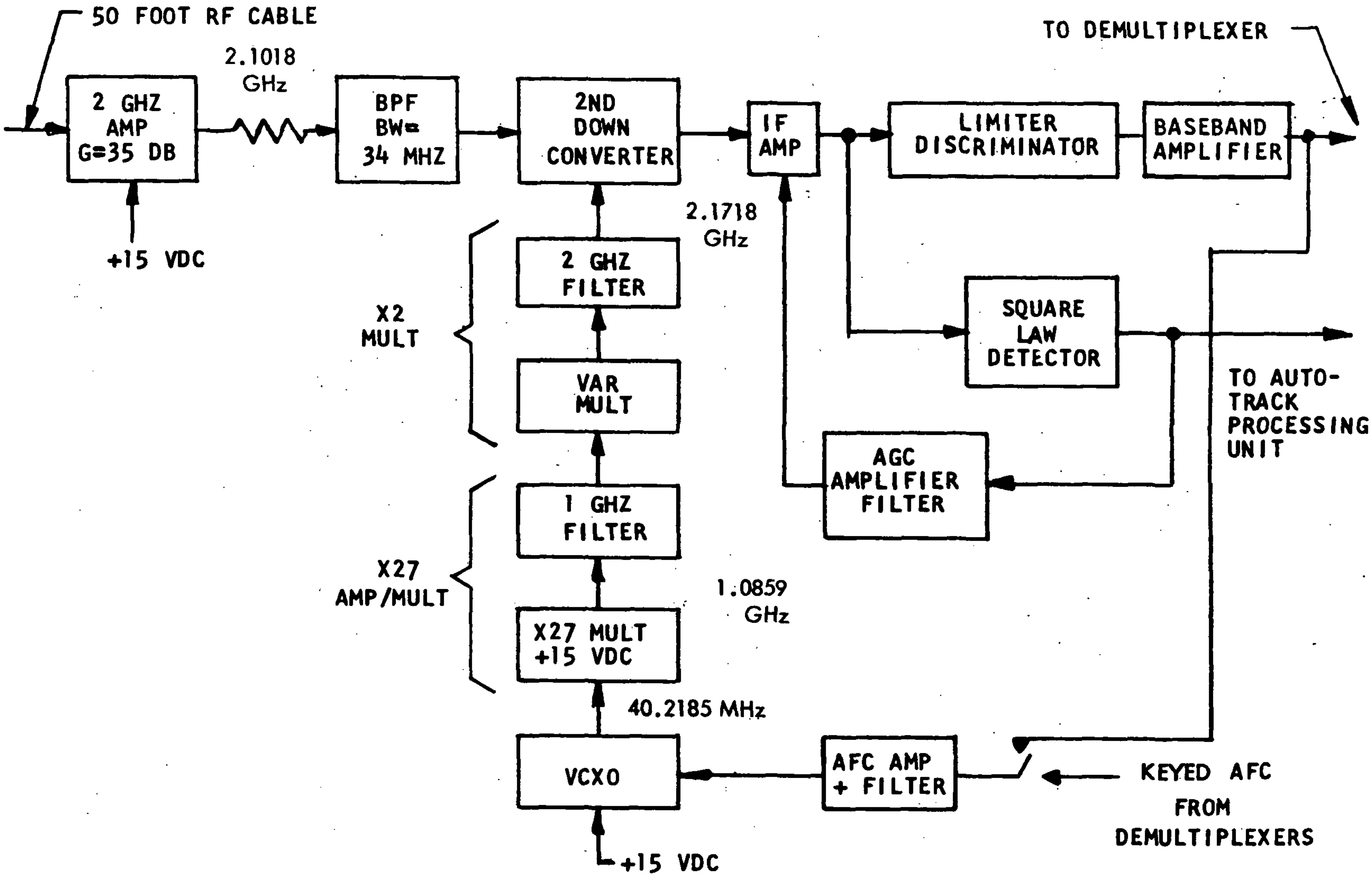

Figure 3-37. S-Band Receiver and Demodulator, Block Diagram

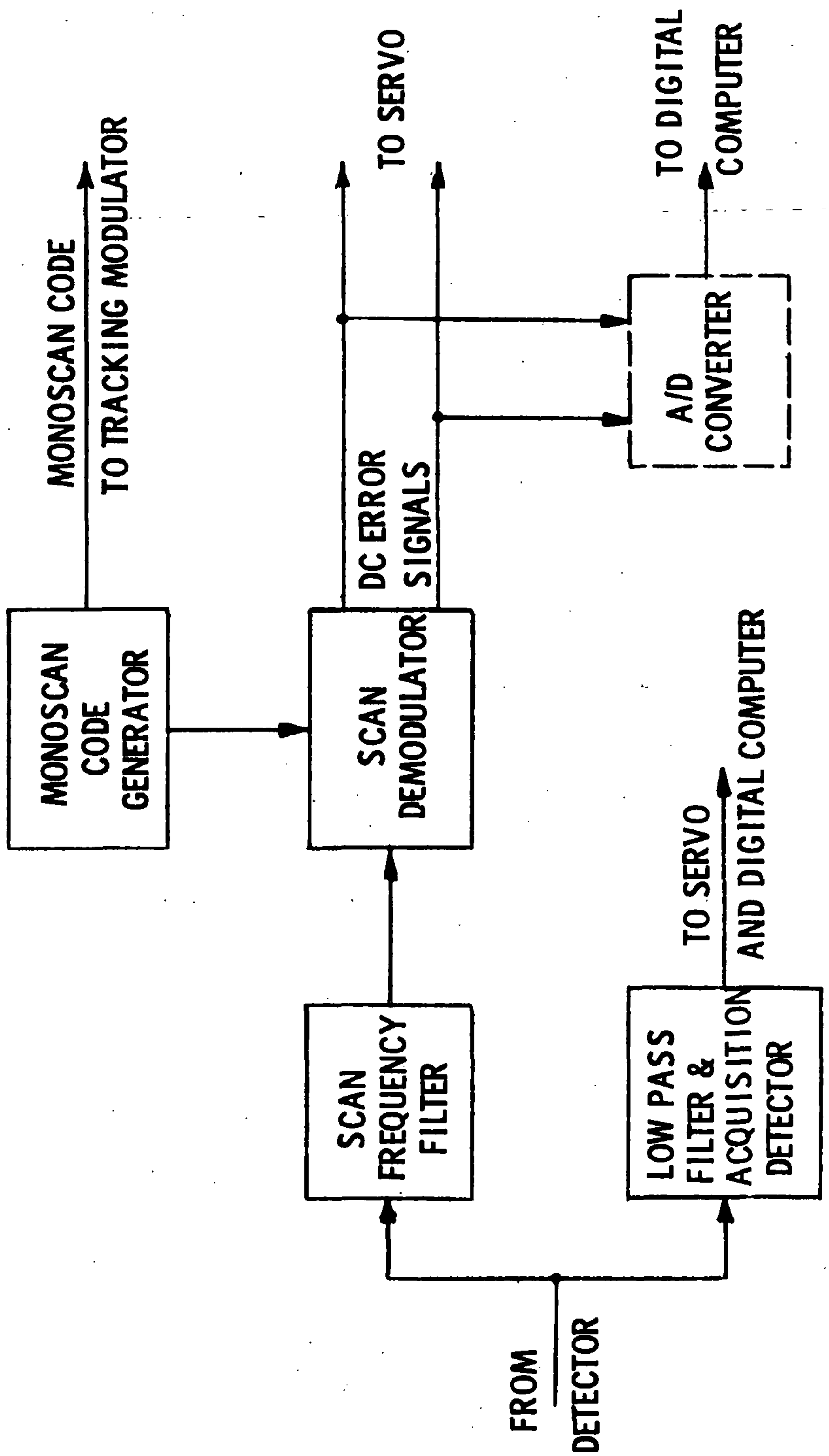

Figure 3-38. Auto-Track Processing Unit, Block Diagram

3.3.4 Support Electronics Subassembly Requirements

Support electronics includes all those equipments necessary to switch, multiplex, and demultiplex the transmitted and receive signals, to display all monitoring instrumentation, to control the operation of the CTB, to provide laboratory test facilities and to mount and interconnect the equipment. These equipments are:

- Baseband
  - Multiplex
  - Demultiplex
  - Switching
- Display and Control
- Test Equipment
- Mounting Rack
- Interconnect Cables

3.3.4.1 Baseband Equipment

The baseband subassembly consits of two units; the baseband switching unit and the mux-demux unit. The baseband switching unit either selects the desired combination of information sources from the internal communications subsystem for input of the mux or it takes the combination of information sources from the output of the demux and inputs them to the appropriate internal subsystem inputs. The mux-demux unit assembles or disassembles using frequency multiplexing or demultiplexing the baseband spectrum which is composed of the various information sources.

Baseband Switching Matrix

This units provides the ability to switch any information source to any multiplexer unit and the ability to switch any demultiplexer output to appropriate internal communications subsystem inputs.

Multiplexer

The multiplexer assembles the various information sources into a baseband signal using frequency division multiplexing. The relative levels of the signals are adjusted by level controls and the TV signal waveform is cleaned up by a signal conditioner. The several voice signals are frequency multiplexed and the digital ranging and data are each used to psk modulate subcarriers which place these signals in the desired locations in the baseband.

The ranging code could alternatively be used to modulate the main carrier in conformity to the USB requirements.

Table 3-18. Input Signals Format

Date Type		Base Bandwidth
Voice, Analog	Hz	300-4000
Music, Analog	Hz	30-10,000
Facsimile Analog	MHz	0.5
TV Color Analog	MHz	4.5
TV B&W Analog	MHz	2.9
Ranging Digital	Mbps	0.5
Data Digital	Mbps	≤10

Demultiplexer

The demultiplexer disassembles the complex baseband signal into the various information sources by using low-pass filters. The TV signal is conditioned by a stabamp. The voice signals are demultiplexed by a frequency demultiplexer and the digital data signal is recovered from its subcarrier by demodulating with a carrier recovery loop.

Figures 3-39 and 3-40 show the multiplexer and demultiplexer, respectively, in block diagram form. Figure 3-41 shows the baseband transmit switching matrix block diagram.

3.3.5 Cable Wrap Configurations

The antenna mounted electronics is delivered with a 10 and a 50 foot flexible cable that represents the cable subassembly, and provides the means to interconnect inboard electronics signals, controls, and monitor functions.

In the ultimate system however, the cable subassembly must undergo some form of cable wrap to allow for the axial motions of the antenna. The means for providing this is considered here at the conceptual level, to ensure consideration of the impact of cable wrap constraints on the overall external communication system design.

From information obtained in bending and twisting tests on twisted shielded pair cables, there appears to be no problem in the present application. However, data collected to date demonstrates the inadequacy of braided coax for 2 GHz signals after flexing several thousand cycles. As the life span may require 200,000 flexures over 10 years per axis, "Plaxial" cable is proposed. Plaxial cable is a flexible coax which will survive this requirement if bent no tighter than 12 inches in radius, and no twist occurs. Twist may be

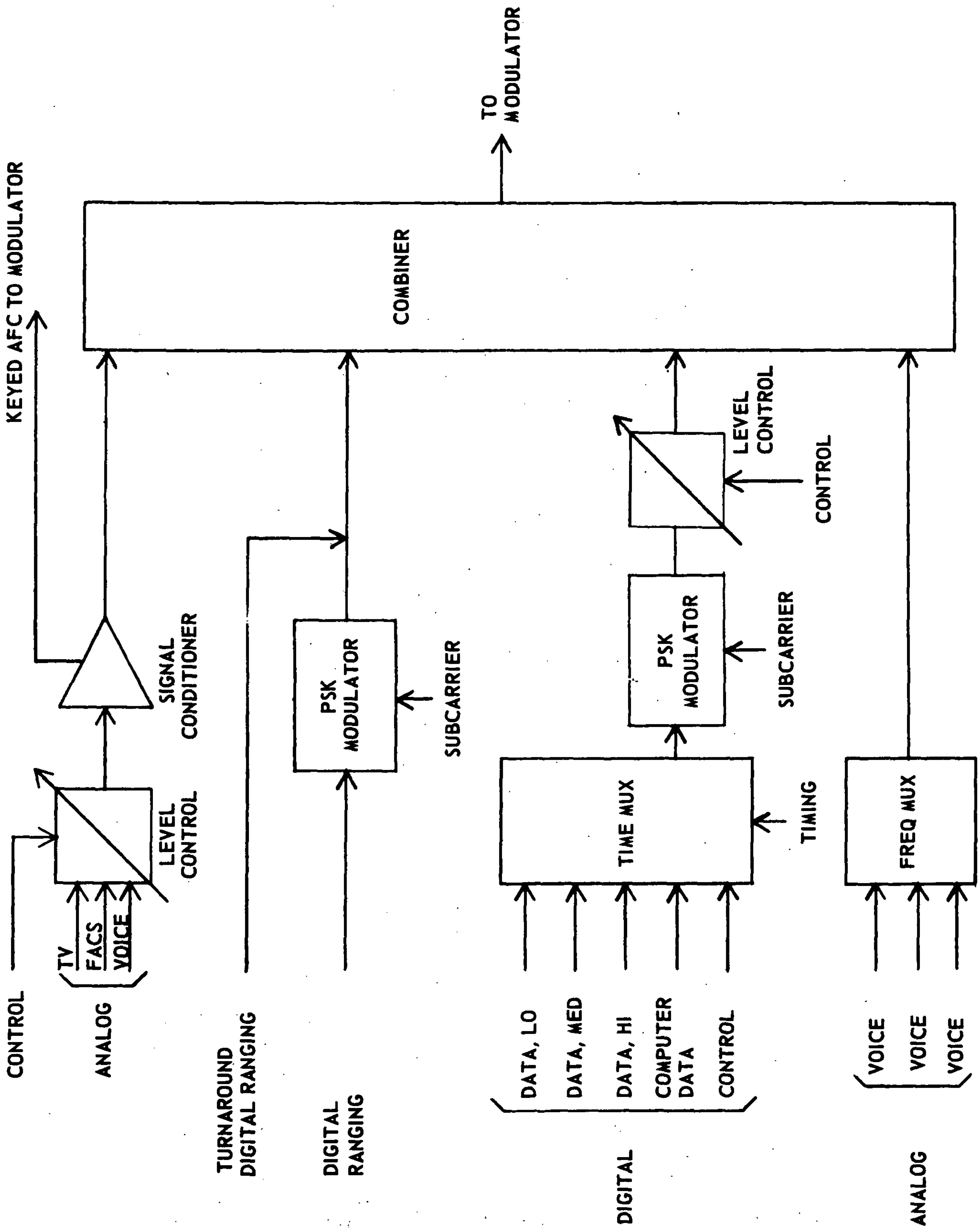

Figure 3-39. Multiplexer, Block Diagram

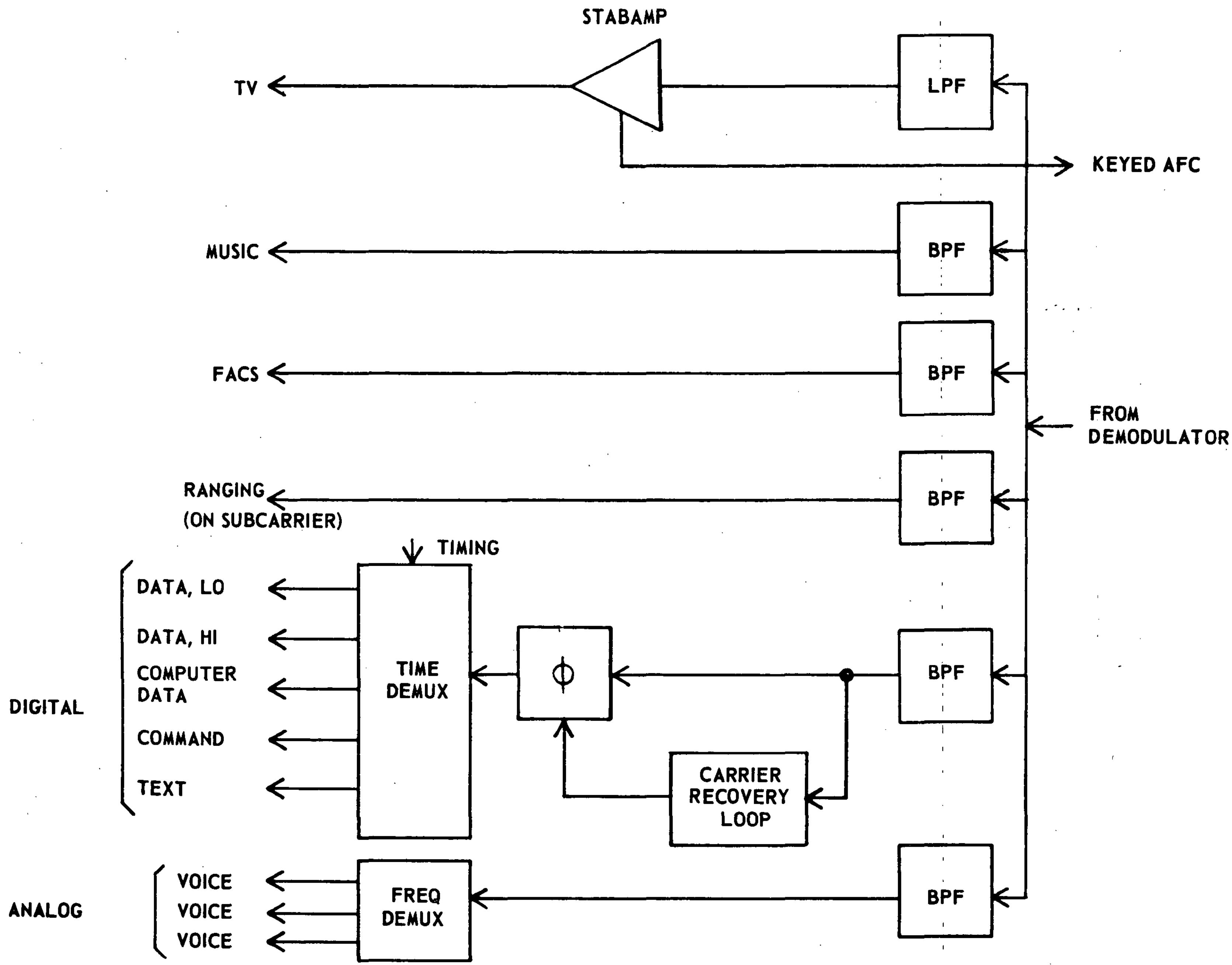

Figure 3-40. Demultiplexer, Block Diagram

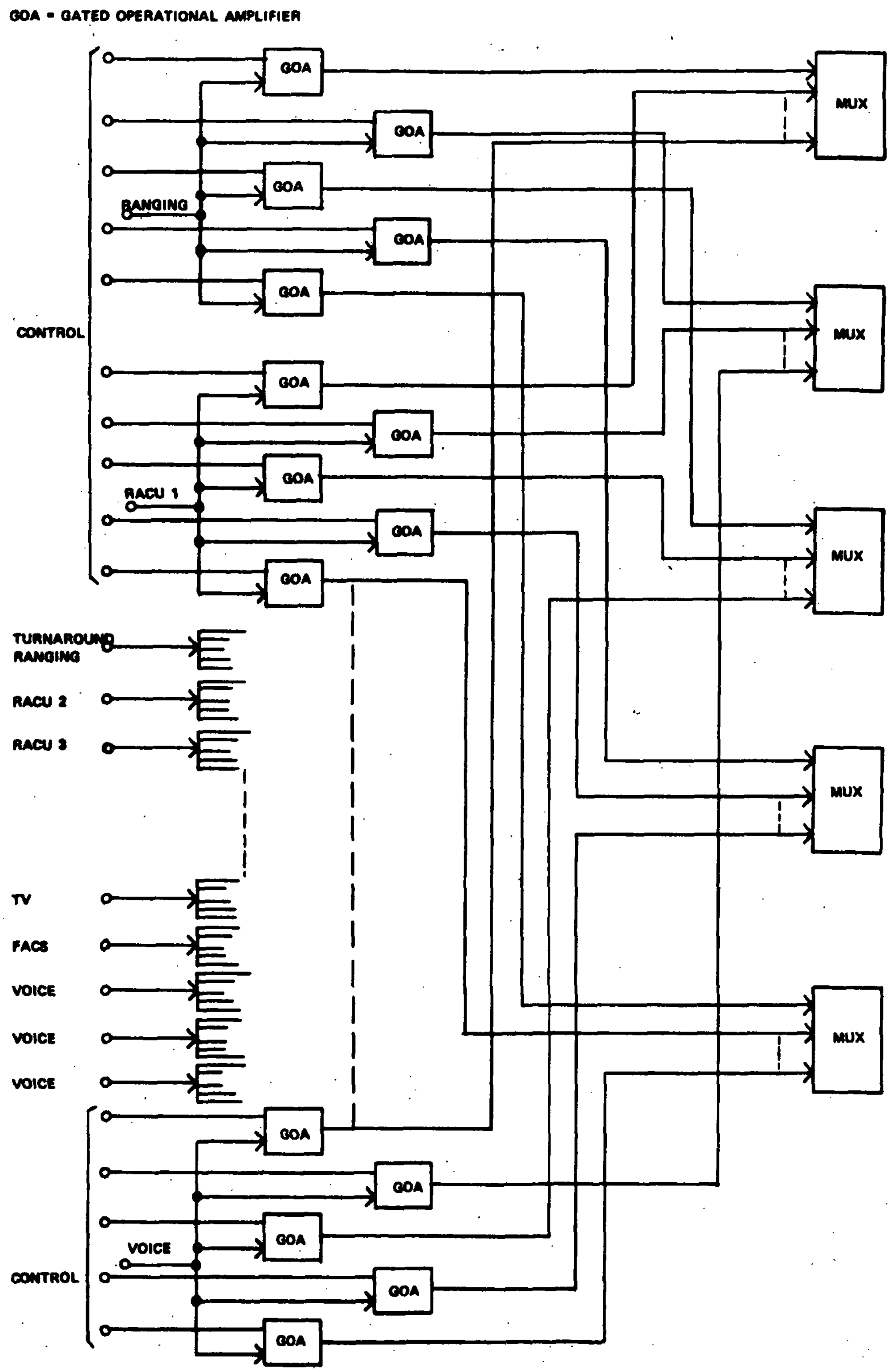

Figure 3-41. Baseband Transmit Switching Matrix, Block Diagram

Table 3-19. Interface Definitions, Baseband Equipment

Data Type	Impedance between Internal Communications Subsystem & Switching Unit
Voice Music Facsimile	600 ohms
TV Color TV B&W Ranging Data	75 ohms
Impedance between mux-demux unit and mod-demod unit: 50 ohms Signal levels: TBD Frequency band: baseband Unit Packaging configuration: TBD Connector types: TBD	

eliminated by control of cable cross section and wrap configuration to affect planar movement. Figure 3-42 illustrates two schemes of wrap configuration applied to an altazimuth mount, wherein the cables are assembled as a ribbon. The elevation wrap is limited to 120 degree coverage, and the azimuth wrap spiral permits greater than 120 degree motion. The cable cross section, shown on the right, may be fabricated by bonding adjacent conductors or weaving with nylon thread into a ribbon. The interwoven technique, for which there are several suppliers, is preferred due to its flexibility, and stiffness against twisting. It is simply controlled by the frequency and tightness of stitch. The ribbon configuration is also applicable to the X-Y mount configuration. Both the altazimuth and X-Y mounts are candidates for the tracker system associated with this program.

3.3.6 Mount Configuration

A preliminary study has been made to identify and assess the factors affecting the choice of mount configuration. The results of this study indicate that, as regards the tracking function itself, the X-Y mount is preferable. This is because no tracking singularities; i.e., points of high angular velocities, are experienced. With the altazimuth mount, TDRS tracking may result in high angular rates in azimuth albeit rather infrequently.

The effect of having to cope with this involves such things as increased motor size and more complex computer tracking programs.

Of even greater significance are the thermal implications. Figure 3-43 shows the modular space station and its coordinate system. Figure 3-44 shows the altazimuth antenna mount with the azimuth axis along the ±Z axis direction of the station. It the antenna is pointed in the Y-Z plane, then it is clear that one side of the electronic package, a principle radiating surface, will be facing the solar array. This is true regardless of elevation angle. This will significantly reduce the effective radiating area of that surface and consequently cause a significant increase in package temperature. Because of the fourth power temperature relationship, this effect will be most pronounced when the array is most nearly normal to the X axis, causing maximum blockage.

The X-Y mount shown in Figure 3-45 causes a much less severe effect.

Since only rotations about the X and Y axis are allowed, the only radiating surface that can be thermally affected by the solar array blockage is the top, which is not a principal radiating surface. Rotation about the X axis will cause one of the side surfaces to see portions of the station. However, the subtended angle will be relatively small, and it is expected that the surfaces will have significantly lower infra-red than the solar array due to the surface painting. Rotation about the X axis while tracking TDRS will also cause one of the side surfaces to partially see the earth radiation briefly during each earth orbit. However, because of the rotation of the X axis at about 4 degrees per minute, and the partial exposure, the thermal load of earth radiation on the passive radiation is expected to be small.

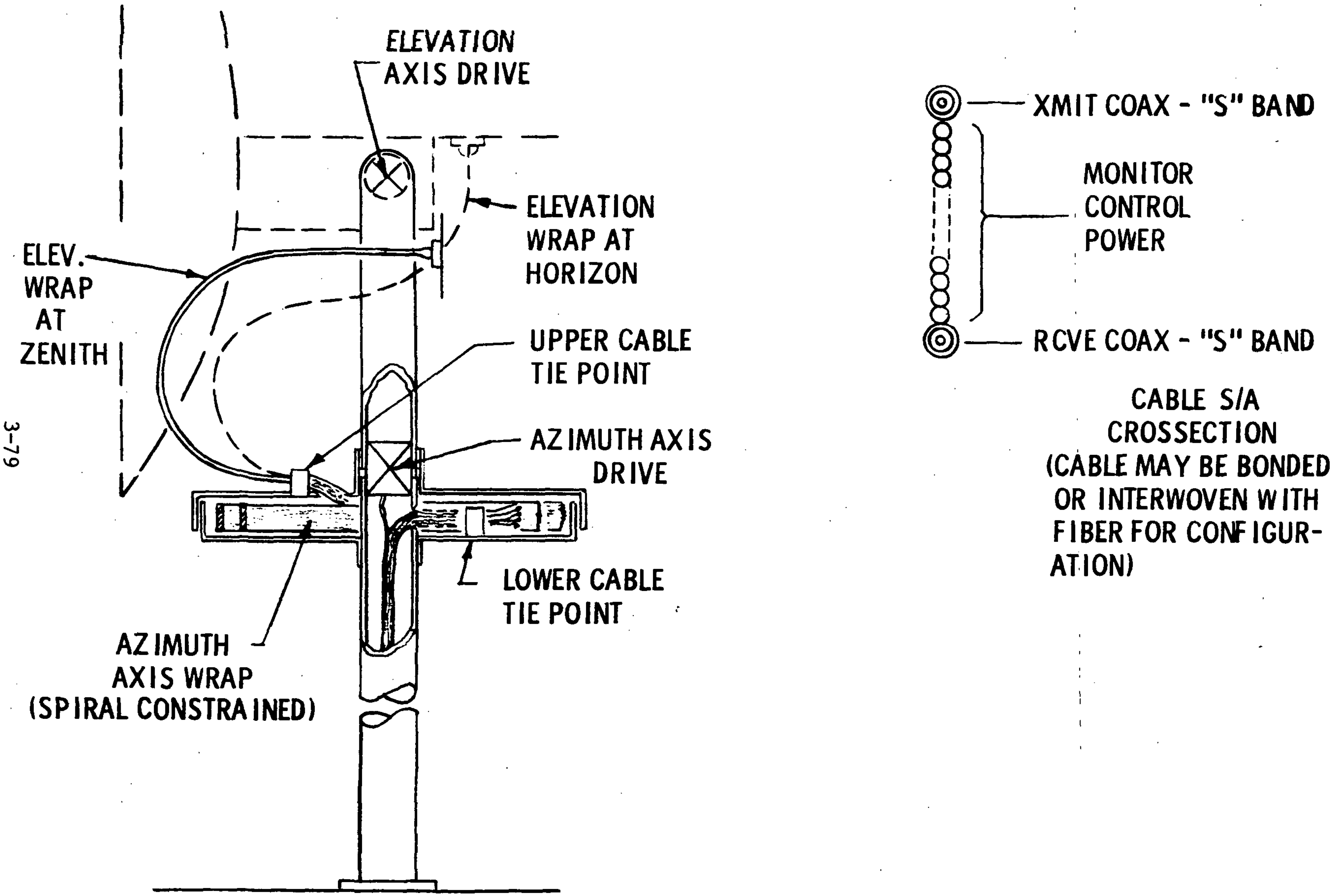

Figure 3-42. Cable and Wrap Details

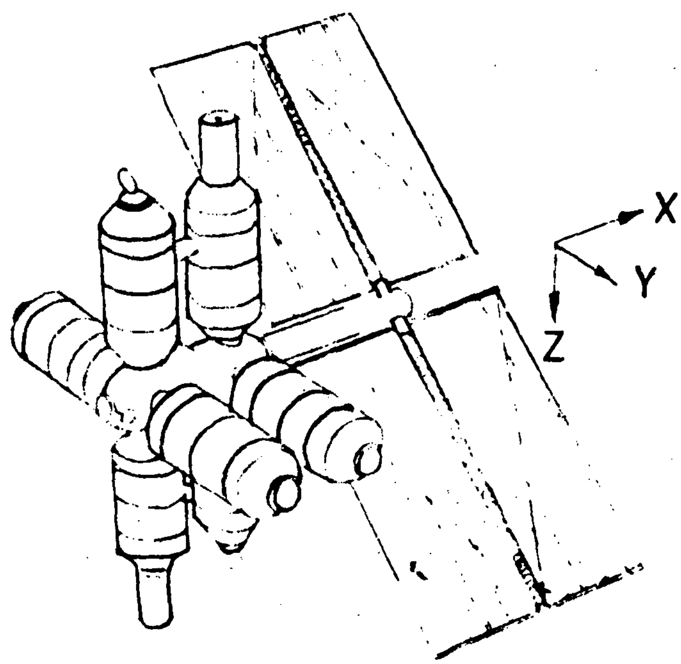

Figure 3-43. Sketch of Modular Space Station

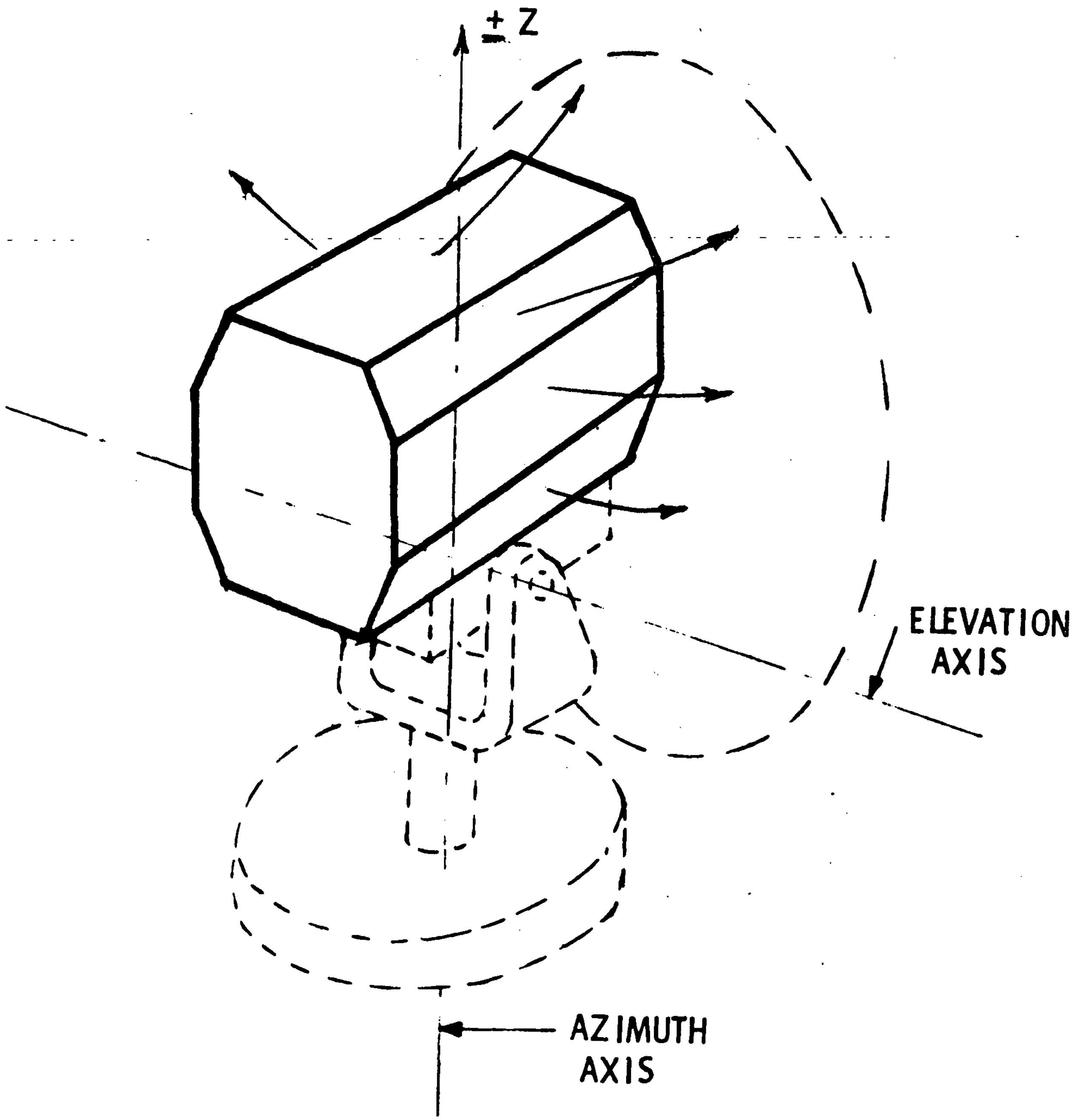

Figure 3-44. Two-Axis Altazimuth Mount

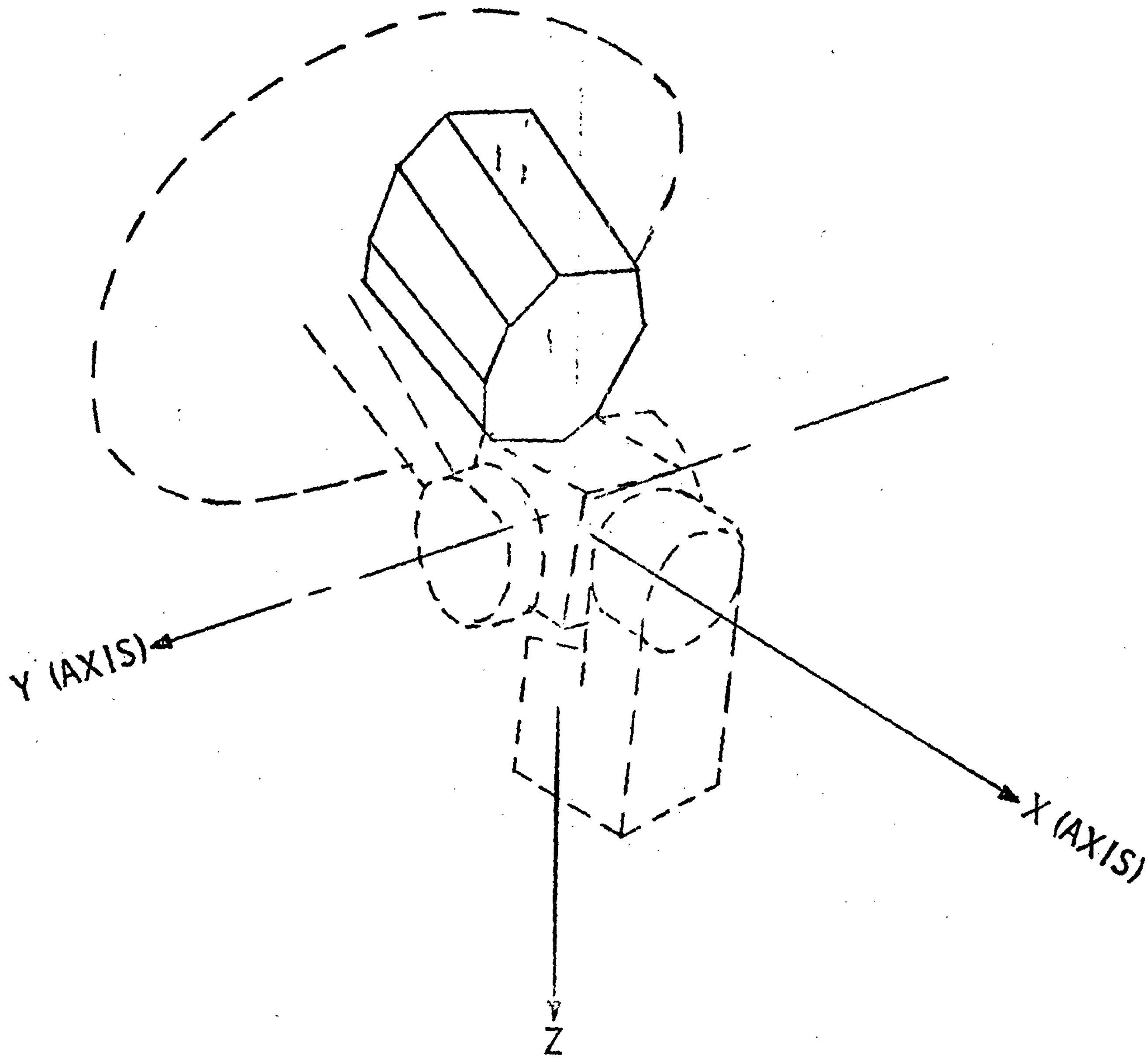

Figure 3-45. X-Y Two-Axis Mount

4.0 CTB INTEGRATION TESTS

TESTS

4.0 CTB INTEGRATION TESTS

Following performance testing of the delivered K-band transceiver, a series of loop back tests involving available GFE equipment to supply modulated S-band signals would be of great value in evaluating the ultimate capabilities of the CTB. In particular, elements of the Universal S-band system such as the Lunar Module transceiver and system test units including receiver, exciter, subcarrier oscillators, and data demod could be considered for use.

The current universal S-band system combines and processes ranging, data, and voice in a way that does not lend itself directly to simple loop back testing wherein the modulated carrier is translated in frequency and looped back to the receiver. This is apparent from an examination of the up and down link spectra shown in Figure 4-1. The up link (ground to LM) phase modulates the carrier directly with a pseudo random ranging code, and modulated subcarriers at 30 KHz and 70 KHz for voice and data, respectively. The LM system is designed to turn the ranging signal around and add voice and data subcarriers at 1.25 MHz and 1.024 MHz, respectively. The simple mechanism of translation and loop back of the LM signal is clearly not possible. However, there are a number of alternatives that are available. The basic philosophy underlying these alternatives is minimum or no modification to GFE. Alternatives I and II require no modification, but do require availability of both LM and USB equipment. Alternative III requires only LM equipment, but does require some modification in transmit subcarrier frequencies. Specifically, it is recommended that the subcarriers on the down link be shifted from 30 and 70 KHz to 1.024 and 1.25 MHz. The alternatives are shown in Figure 4-2.

The results of the CTB integration tests using any one of the alternatives mentioned above would have great significance, especially in an evolutionary development of the modular space station external communication subsystem. Interface definitions and test procedures should be a joint effort between NR/SD, ITT/DCD and NASA/MSC to ensure smooth integration. The extent of this effort would depend on the availability of GFE.

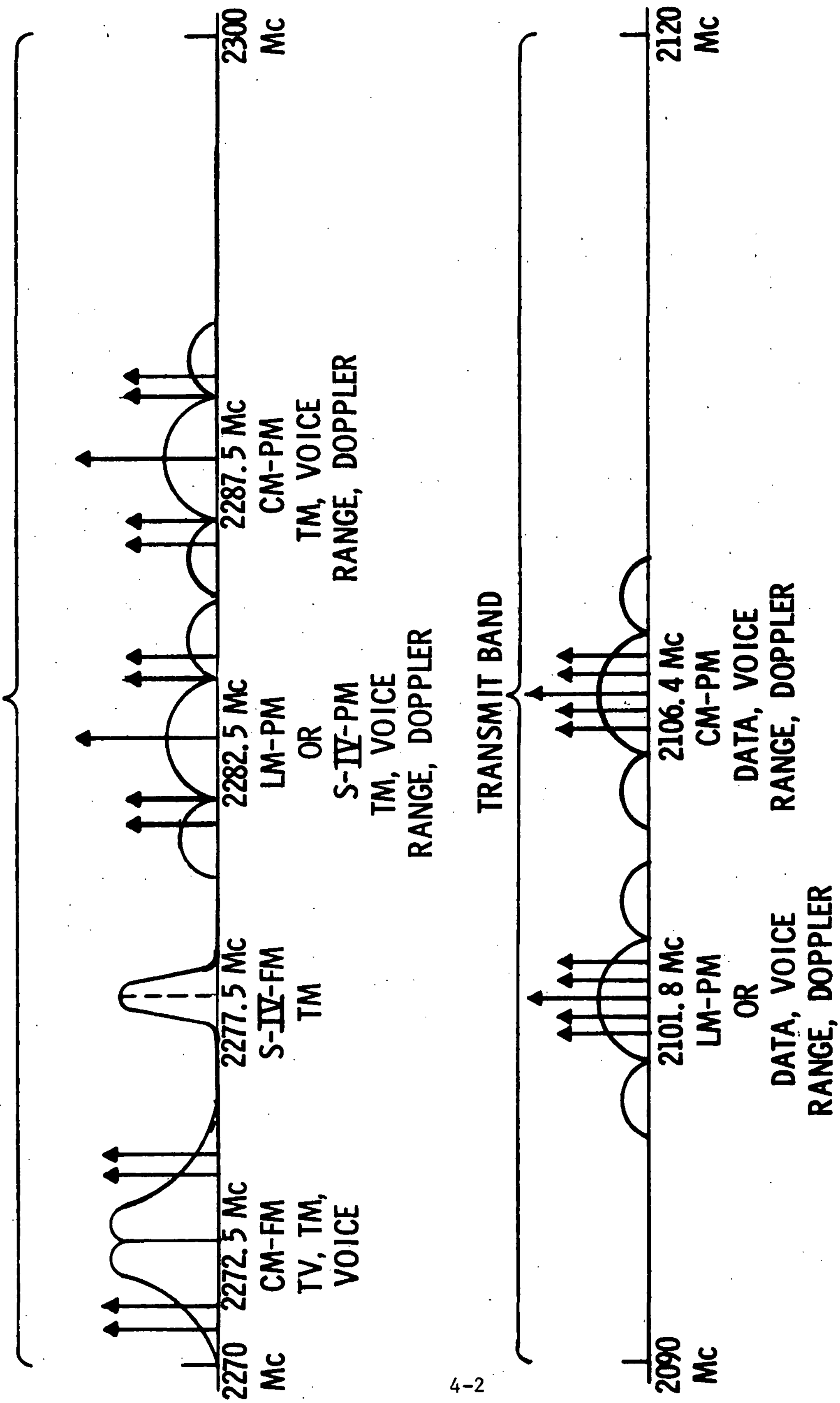

Figure 4-1. Universal S-Band System Spectra

CTB INTEGRATION ALTERNATIVES

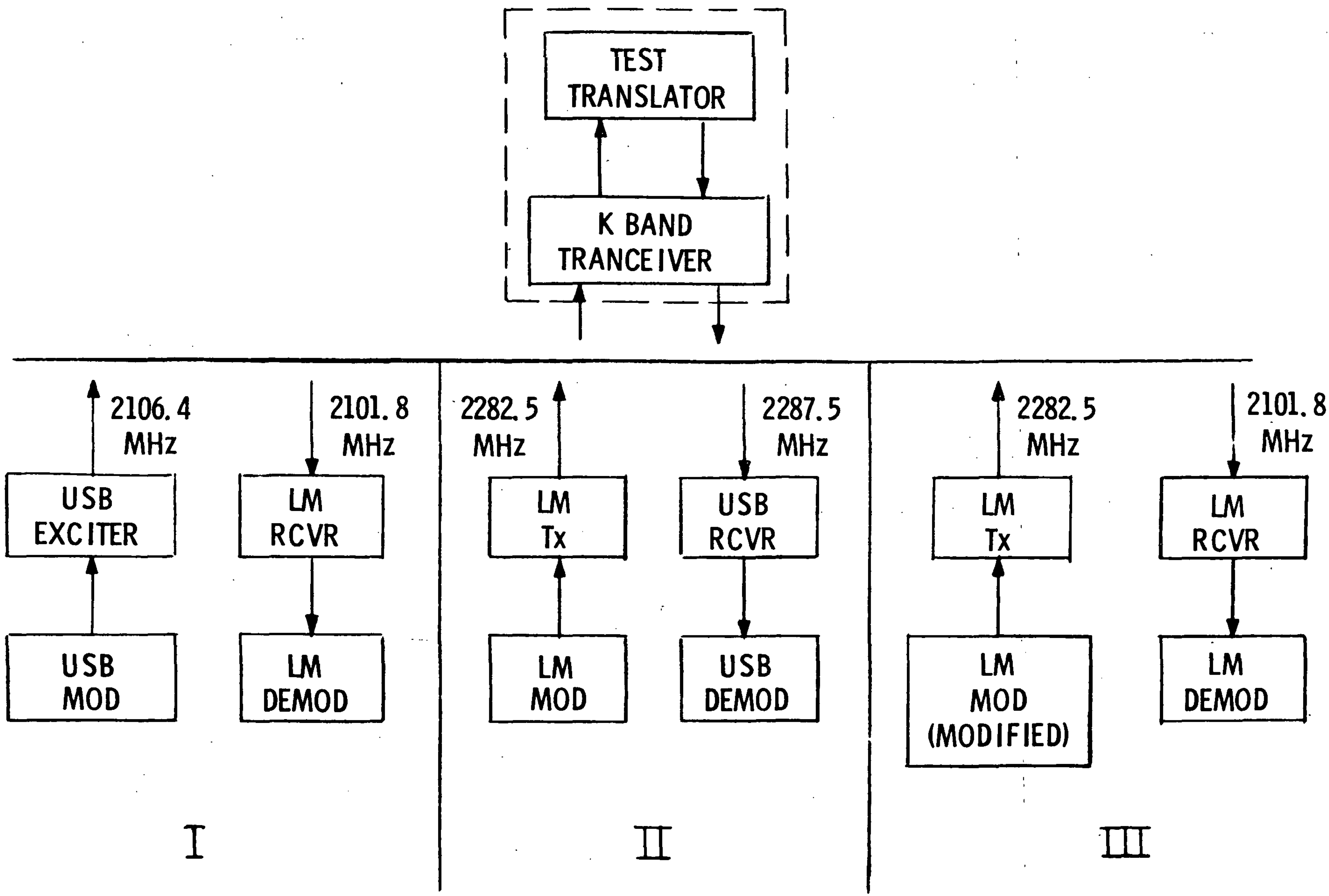

Figure 4-2. CTB Integration Alternatives

5.0 APPENDIX

5.0 APPENDIX

5.0 APPENDIX

A few key tradeoffs and other general information were considered of sufficient importance and interest to extract from the interim report. These are included as part of this appendix. Further details can be gathered, if desired, from the reports produced during the conduct of the Advanced Development task. A list of these reports and their location is included at the end of the Foreword.

5.1 MULTIPLEXING AND MODULATION CONCEPTS

There are a variety of tradeoff studies involved in the establishment of a design concept for the communications terminal. The basic requirement is to establish any one of five separate duplex RF channels which link the space station to the communications relay satellite system, the space shuttle, the manned space flight network, and the detached modules. It must be capable of switching voice, video, data, and commands multiplexed from several sources to any of the five RF channels. Therefore, among the major areas for tradeoff and optimization are those of multiplexing and modulation method. Table 5-1 lists these and other areas that must be considered in the design. In the following sections, the results of trade studies performed at ITT to date will be briefly discussed, indicating some of the advantages and disadvantages of the different approaches.

Table 5-1. Configuration and Concept Trade Studies

- Multicarrier links versus single carrier links
- FDM versus TDM
- Analog versus digital TV
- Analog versus digital voice
- FM versus DPSK

5.1.1 Multicarrier Links Versus Single Carrier Links

Each link is required to carry a variety of independent information elements; e.g., voice, data, TV, ranging. One could provide a carrier for each, thus optimizing the modulation for each information element on the link. Furthermore, in a multicarrier link the failure of a carrier degrades but does not break the link as it would for a single carrier link. This approach could require as many modems and transceivers as there are independent information elements leading to a system of higher cost and complexity than the single carrier system. There is also the problem of loss due to intermodulation products of a multicarrier signal if a common power amplifier is used for each link, especially if high efficiency saturated power amplifier operation is desired. In such an operation, about 20 percent of the power capability of the amplifier would be lost to intermodulation products.

The higher cost and complexity of the multicarrier approach favors the single carrier multiplexed links.

5.1.2 FDM Versus TDM

In addressing the signal format requirement, TDM has the inherent attractiveness of digital circuitry and transmission techniques. Specifically, digital transmission allows for such niceties as coherent detection, coding to improve channel efficiency, correlation detection, and so on. Furthermore, large-scale integration techniques can lead to small and low cost physical configurations for reasonable logic speeds. However, the requirement for high quality TV necessitates conversion to a high data rate, on the order of 60 mb/s. The circuitry and technology for this high speed data are complex and costly. In addition, the minimum bandwidth required for a given signal-to-noise ratio with digital transmission is limited by quantizing noise. This is most significant as regards a direct ground TV link where RF spectrum is at a premium. As seen in Figure 5-1, a signal-to-noise ratio of 45 db rms to rms requires a transmission bandwidth of 90 MHz.

An advantage to FDM is that it is more flexible and adapts to a variety of signal forms in combination; e.g., analog TV, binary digital data, voice, and digital ranging. Although ranging will not be incorporated, provision for its inclusion through later modifications will be made. Therefore, it must be considered in the basic design.

The requirement for turnaround ranging on nearly all links coupled with a TDM system would require that the ranging signal structure be a function of the particular link bit rate. Different pulse widths and ranging repetition rates would be involved thereby complicating the system.

A general rule can be evolved here: Since the ranging process is essentially time-dependent, the transmission process should be time-independent so that these two processes do not interact. In the FDM approach, the digital ranging signal can be placed on an angle-modulated subcarrier, which then becomes a constituent of the FDM baseband, thus the bit rate is independent of whatever other information is contained in the baseband. A single ranging equipment can then be used for all links, since ranging on any one detached module or advanced logistics vehicle is an intermittent process. Therefore, with respect to the given system requirements, FDM seems to be a better choice than TDM.

The baseband format has been arranged to provide minimum total RF bandwidth for the modulated signal. For FM systems which produce output noise spectra having a triangular distribution, the minimum bandwidth criterion requires that the signal with the largest product of signal-to-noise ratio times bandwidth be located in the lowest part of the baseband. For PM or AM systems with flat noise distributions, location in the baseband is immaterial.

Since the bit rate of digital voice is on the order of only 2 Mbps for 32 channels, it does not involve any of the high rate circuitry problems of digital TV. Although digital voice would have all the advantages of digital transmission, output voice from the bus will be analog, and would have to be converted to transmit in digital form. Therefore, voice should be analog.

5.1.3 FM Versus DPSK

Analog FM, although generally less efficient than coherent techniques, is best suited for the FDM approach, since the modulating waveform is already a frequency multiplexed analog voltage wave. Any change would unnecessarily complicate the system. Furthermore, it has been shown[1] that for high P_r/N_o (typical of the direct ground TV link which operates in a bandwidth-limited environment) and for low P_r/N_o (typical of the relay satellite TV link which operates in a power-limited environment) analog FM is better than PCM as shown in Figure 5-1. Since bandwidth, especially in the direct ground link, is of major concern, and since TV requirement is controlling as regards data rate, analog FM would seem to be indicated at the present time.

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[1] J. C. Balan, M. A. Epstein, L. Feit, "PCM Television via Satellite Relay." 1969 IEEE International Conference on Communications, 69 CP 381-COM, pp 37-1 through 37-9

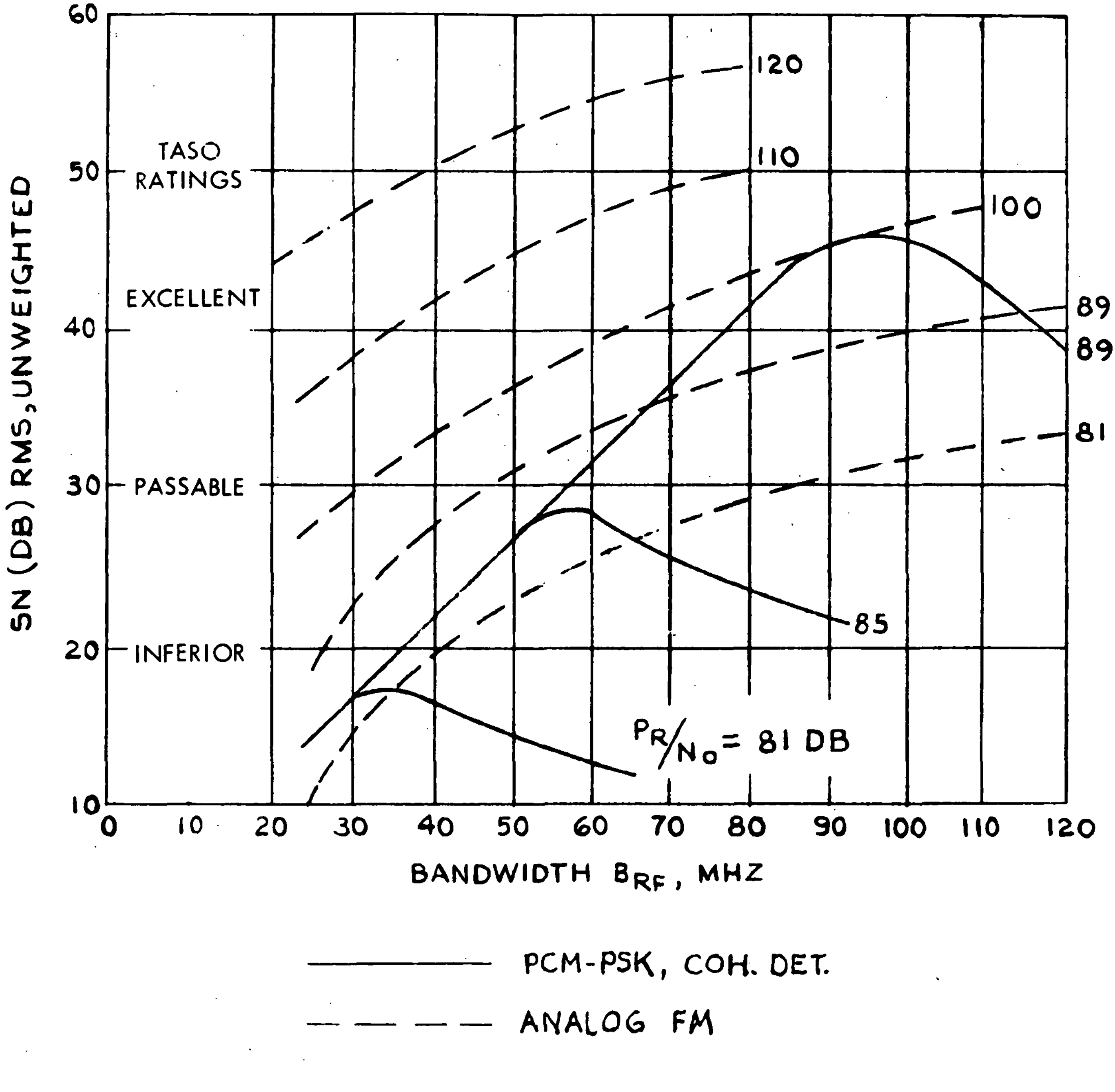

Figure 5-1. Signal to Noise Ratio vs Quantizing Levels as a Function of Received Power

5.2 CHANNEL SWITCHING APPROACHES AND TRADEOFFS

There are basically two different configurations for the ultimate system to switch between the five separate duplex RF channels which link the modular space station (MSS) to the Tracking and Data Relay Satellite System (TDRSS), the space shuttle, the manned space flight network (MSFN), and the detached modules (RAM). Several internal system designs are feasible depending on system requirements for each of the two basic switching configurations. The principal difference between the two systems is that RF switching is used in one system and not in the other. Figures 5-2 and 5-3 show the two basic configurations with different internal designs; i.e., in the RF switching system of Figure 5-2, each of the modulators and demodulators can generate any one of the five different carrier link frequencies and in the other system there are five local oscillators for the modulators and five for the demodulators with appropriate circuits to choose the required frequency for each modulator and demodulator. Either of these two designs can be employed in either of the two basic systems. Besides the two systems shown, there are other variations of the basic configurations, all having advantages and disadvantages that will be discussed in later sections of this report.

There are several similarities between the two fundamental systems. The requirement to switch voice, video, data, and any of the five RF links in various combinations dictates the need for baseband switching in either of the systems. The multiplexing and modulation techniques chosen through the tradeoff studies discussed in Section 5.1 impose the same basic design of the multiplexers, demultiplexers, modulators, and demodulators on both systems. The requirement that any of the five RF links be capable of using any of the N RF channels on the MSS requires that the transmitters, receivers and diplexers shown in Figures 5-2 and 5-3 be operable over the entire communications spectrum. The basic difference between the terms "link" and "channel" as used above is that a link refers to the path of communication between the MSS and the ground, satellite, RAM, or shuttle, while a channel is the path in the communications system between the modulator or demodulator and an antenna.

In general, it will be necessary to radiate through one of a number of antennas to obtain spherical coverage. Therefore, the number of channels required will be greater than five. The number of antennas required to obtain spherical coverage is a function of the geometry of the MSS, which is variable, especially during the buildup sequence. Each antenna may be required to radiate from 1 to 5 RF channels, depending upon the redundancy necessary.

Either of the systems could embody the concepts of five frequencies for each modulator and demodulator or two sets of local oscillators for all modulators and demodulators as illustrated in Figures 5-2 and 5-3, respectively. The choice depends on system reliability requirements. In the RF switching system it is completely feasible to have each modulator and demodulator set at one carrier frequency, and therefore be constrained to operate as one link. There is also the possibility of having five sets of transmitters, receivers, and diplexers for each antenna, one set per channel, thereby making it unnecessary to operate over the entire RF bandwidth, although redundancy requirements might modify this.

To evaluate these and other system approaches, results of tradeoff studies are shown in the following sections to choose the optimum switching system configuration. However, before tradeoff studies can be conducted, meaningful criteria must be established upon which to base the studies. These criteria must reflect the overall system concept, environment, and performance. The following is a list of tradeoff criteria which are an outgrowth of these considerations.

Tradeoff Criteria

Cost
Reliability
Functional flexibility
Maintainability
Equipment complexity
EMI-EMC
Size and weight

5.2.1 RF Switching Concepts

The object is to switch any one of the five RF links to or from any one of the N RF channels as shown in Figure 5-2. This is quite different from that of Figure 5-3 where no switching is needed since each RF channel is coupled to a complete communication system. These two methods lead to an interesting result. In the system without RF switching, the number of multiplexers, demultiplexers, modulators and demodulators is directly proportional to the number of antennas and channels. In the RF switching network, the quantity of these components is only proportional to the maximum number of simultaneously operating channels. This point is illustrated in Figure 5-4, where the difference in the number of system components of the nonswitched system compared to the switched system is plotted versus the total number of channels, when the number of simultaneous links is fixed at five. With five RF channels the total switching system has two more components than the system without switching (the two RF switching matrices). For a system with more than five channels the situation is reversed and the difference in the number of components grows linearly.

As a direct result of this behavior a comparison of the two systems may be made with respect to size, weight, cost, complexity, and reliability. Since most components of the two systems are identical, the relative size, weight, and cost will increase as the number of components increase. Figure 5-5 shows the relative cost of the nonswitched system compared to the system with switching as a function of the total number of channels; for this comparison, five links are used. This figure also shows that for six or more channels the system without switching is increasingly more costly.

One of the most important parameters in a space environment is reliability because of safety and the cost of repair. Reliability, which is a function of system complexity, depends in part upon the number of system components. It is to be expected that the probability of a component failure will increase as the number of components increases. There are three types of component failures in either of the two basic systems which can affect link operation.

An antenna failure in either system can lose a link unless there is overlapping antenna coverage that can be used for backup. A failure in a diplexer assembly (transmitter, receiver, and diplexer) will lose an RF channel unless there are backup diplexer assemblies on the antennas in the switched system or backup diplexer assemblies and modem assemblies on the antenna in the nonswitched system. A modem failure in the nonswitched system will lose a channel and possibly an antenna if there are no backup modem and diplexer assemblies on the corresponding antenna, while a modem failure in the switched system will not affect channel or antenna capability. The result of a modem failure in the switched system will be the loss of the capability of simultaneous use of all links unless there is a backup modem available. Therefore, for equivalent reliability the switched system needs less components than the system without switching.

The preceding discussion implies that the switching system is more reliable than the system without switching. This, however, depends on the ability to build a highly reliable switching matrix. An investigation into this problem has shown that an RF switching matrix operating with low power ($\approx$ 4 mw) signals at 1 GHz can be built with at least 50 db isolation, less than 1/2 db insertion loss, and 150 MHz bandwidth. The large bandwidth is necessary because each switch in the matrix must be capable of switching any of the five links.

The matrix can be built with either solid-state devices such as pin diodes or mechanical switches as shown in Figures 5-6 and 5-7, respectively. Both these figures show a matrix with inputs for the five channels and outputs for N transmitters. The bias lines are used to turn the switches on and off.

Using microstrip techniques with pin diodes, a highly reliable matrix (pin diode failure rate is 1 failure per million hours) can be constructed which is small in size, light in weight, and can meet typical EMI-EMC specifications (at least 50 db coupling isolation). Figure 5-8 shows a possible mechanical configuration for such a switch. Each substrate contains the switches between the input of one link and all the outputs. Properly shielded output buses go through all the substrates and have output connections on top of the matrix.

For control, a matrix, shown in Figure 5-9, switching dc to the various bias points could be used. In figure 5-9, the notation 1, 1; 2, 1;....; X, Y refers to the control switch that connects link X to antenna Y.

5.2.2 Baseband Switching Concepts

It was previously noted that baseband switching in the ultimate system will be required to switch voice, video, data, and commands in various combinations to the five RF links. The configuration of this baseband switching network is a function of the format of the input signals. There are a total of 12 different types of information sources which could supply signals to the switching system. Each of these sources originate or terminate at one of three information buses: digital data, digital voice, and entertainment.

The three-bus concept is a direct outgrowth of the characteristics of the information sources. The need for a digital data bus is an obvious requirement when there are many different digital data sources. The digital voice bus is an integral part of a novel internal telephone network. In the digital voice bus system, there is no central processing unit as normally appears in telephone networks. Instead, a closed bus circuit transmits information in a time multiplexed digital form along the bus until it reaches its destination where it is picked out of the bit stream. The interface between the bus and telephone converts the digital voice to an analog signal. The need for an entertainment video bus is due to the large bandwidths necessary for TV signals. It would be highly impractical to digitize the TV since it would require an extremely high data rate. Therefore, a bus to transmit TV in analog form is the logical conclusion. This is the purpose of the entertainment bus.

The following discussion considers two different approaches to assembling and extracting the digital information from the digital data bus. The first approach involves multiplexing of the digital information by the external communication system and the second approach gives multiplexing control to the central processor. Figure 5-10 shows the three buses and the 12 types of information. The arrows in the figure show whether the information is only received by the MSS, only transmitted, or both. The ranging, data-lo, data-med, data-hi, computer data, control, command, and text are all in digital form when they are removed or inserted on the digital data bus. The TV, music, facsimile, and voice channels are inserted and removed from the entertainment video and voice buses in analog form. The voice signals are digital on the voice bus, but when outputted or inputted to the bus they are analog.

The information outputs and inputs from the interfaces with the buses, as shown in Figure 5-10, would be the inputs or outputs of the baseband switching matrices of Figures 5-2 and 5-3. The interface between the matrices and digital data bus are RACUs. Between the matrices and entertainment bus are filters to select the different signals which are frequency multiplexed on the bus. Between the matrices and digital voice bus is circuitry to select the required voice channels and change them to analog. It is assumed that the voice inputs to the matrices are the same bus outputs which drive the MSS phones, therefore supplying analog signals. Since the voice channels are analog, one method for external transmission is to frequency multiplex these signals after the baseband switching and frequency modulate with the remaining information sources. It is also possible to digitize these voice channels and time multiplex them with the rest of the digital data in the multiplexer following the baseband switching matrix. This would require that a/d converters interface the output of the voice bus with the rest of the system.

For the configuration of Figure 5-10, where each digital source has its own RACU interface with the data bus, the transmit and receive baseband switching matrices must have a separate input or output for each of these digital sources. Figures 5-11 and 5-12 show the forms of these matrices when there are five multiplexers and five demultiplexers in the system. The switching element in the matrix is a gated operational amplifier since some of the signals to be switched are baseband analog. It is shown that there must be a time multiplexer and demultiplexer to process the digital data.

Another configuration for baseband switching, which involves fewer and simpler hardware and is therefore the recommended approach, is shown in Figure 5-13. In this case, there is one RACU to interface the data bus with the switching matrix for each communication link rather than a separate one for each digital data source. The interfaces for the other buses are the same as Figure 5-10. The central processor assembles the appropriate combination of digital data for each link and then outputs it through the appropriate RACU. The switching matrices of Figures 5-11 and 5-12 need less inputs and outputs since there are fewer RACUs and the multiplexer and demultiplexer do not need the time multiplexer and time demultiplexer, since in effect the central processor performs these operations. In this case the digital data would be fed into the PSK modulator of the multiplexer in a single data stream and outputted from the recovery loop of the demultiplexer in a single data stream. The MSS preliminary design deletes the need for an RACU by providing dedicated line from the central processor (CP) to the modulation processor (MP).

5.2.3 Discussion of Tradeoffs

The two basic communications systems with several variations of their internal design were described. It was pointed out that the principal difference between the basic systems is that one employs RF switching and the other does not.

Section 5.2.1 showed that for six or more antennas the RF switching system has less components and is therefore smaller, weighs less, and is less costly than the system without switching. Since there are less components, the switching system is not as complex as the other. It was found that RF switching matrix could be built to meet typical EMI-EMC specifications with high reliability. Therefore, as discussed in Section 5.2.1, the system with switching is more reliable than the system without switching.

It was previously noted that in the switching system (Figure 5-2), each modulator and demodulator could be set at one carrier frequency and therefore be constrained to operate as one link, or each modulator and demodulator could be designed to operate with circuitry that generates any of the five carrier frequencies and therefore be used for any of the links. Another possibility is to have a total of five local oscillators for the modulators with circuitry to select the carrier frequency for each.

In the first and third configurations a single equipment failure could cause the complete loss of a link because there is no provision for backup. However, in the second design each modulator or demodulator can be used for any link; in effect, each is a backup for the others. Although this scheme employs more equipment than the others,its greatly increased reliability makes it a much better choice to satisfy the reliability requirements.

Since the RF switching system possesses the capability of switching any of the modulators or demodulators to or from any of the antennas and the antennas have some overlap in their coverage, there is an inherent backup capability for the receivers, transmitters, diplexers, and antennas. If any of these components fail, incapacitating the associated antenna, the RF switch allows the link to use one of the other overlapping antennas. It is obvious from this discussion that the RF switching system has a high degree of flexibility.

The scheme involving the use of five transmitters, receivers, and diplexers, one set per link, for each antenna does not seem to be practical or necessary for the RF switching system since it involves a large increase in equipment for a relatively small increase in flexibility. It may be desirable to have more than one transmitter, receiver, and diplexer assembly per antenna to allow more than one link to simultaneously use the same antenna and as a backup. A possible scheme may be to have three diplexer assemblies on one antenna and two assemblies on another antenna whose pattern overlaps the first. This will provide the capability of transmitting all five links in the same direction without complete dependence on one antenna. The exact configuration will depend on the desired redundancy.

Since all the identically labeled components of Figure 5-2 are, in fact, also identical in operation, maintainability of the system is a simple matter. It is only necessary to keep one mux, demux, mod, demod, transmitter, receiver and diplexer on board the MSS as backup units. If an occasion arises that requires replacement of a system component, the backup unit can be used and then it can be replaced when the shuttle returns to the station. If more components fail than can be replaced by backup units, the system has enough inherent redundancy to take care of all the necessary communication needs of the station until the shuttle delivers the required equipment.

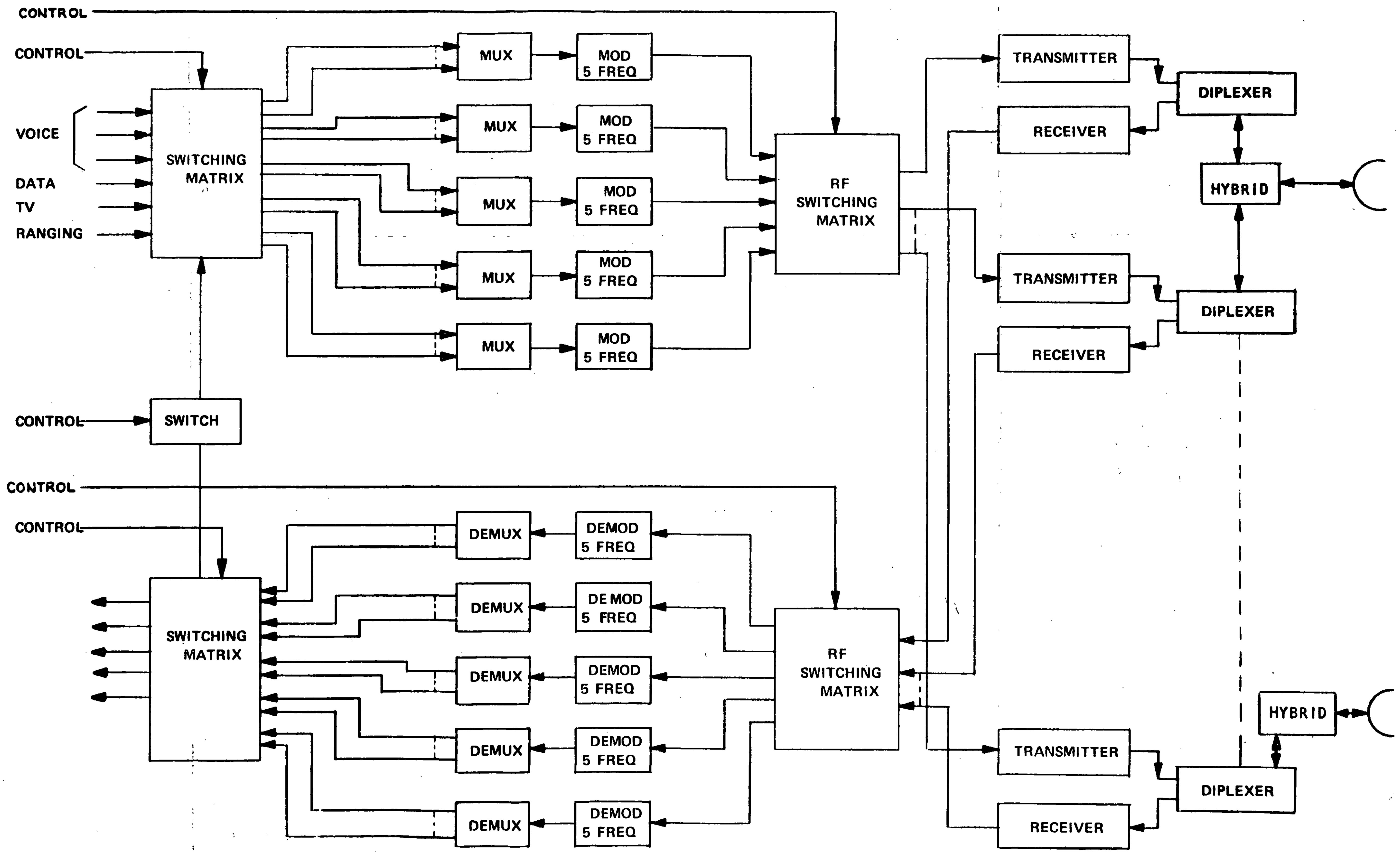

Figure 5-2. Communication System Using R-F Switching

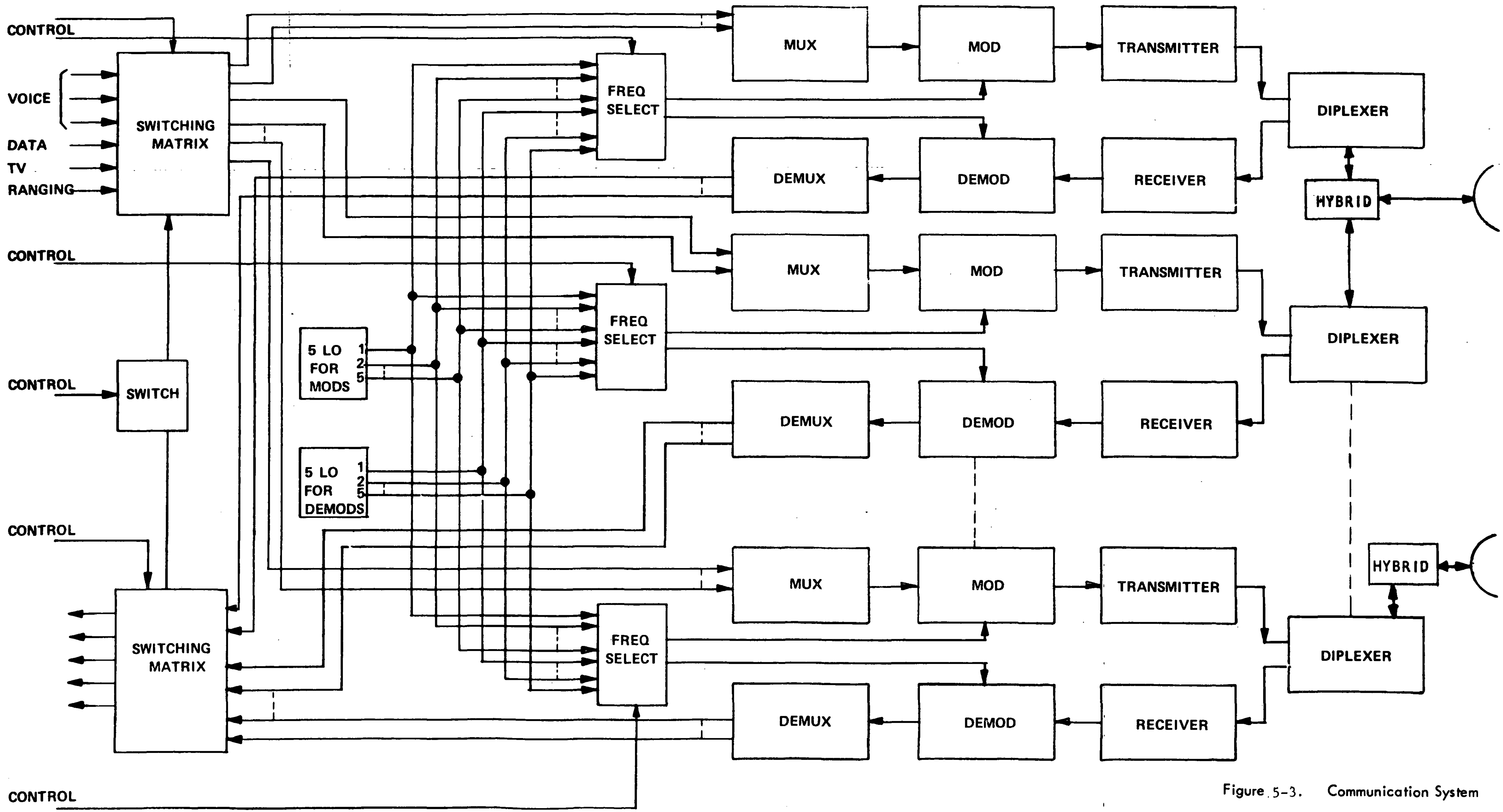

Figure 5-3. Communication System Without R-F Switching

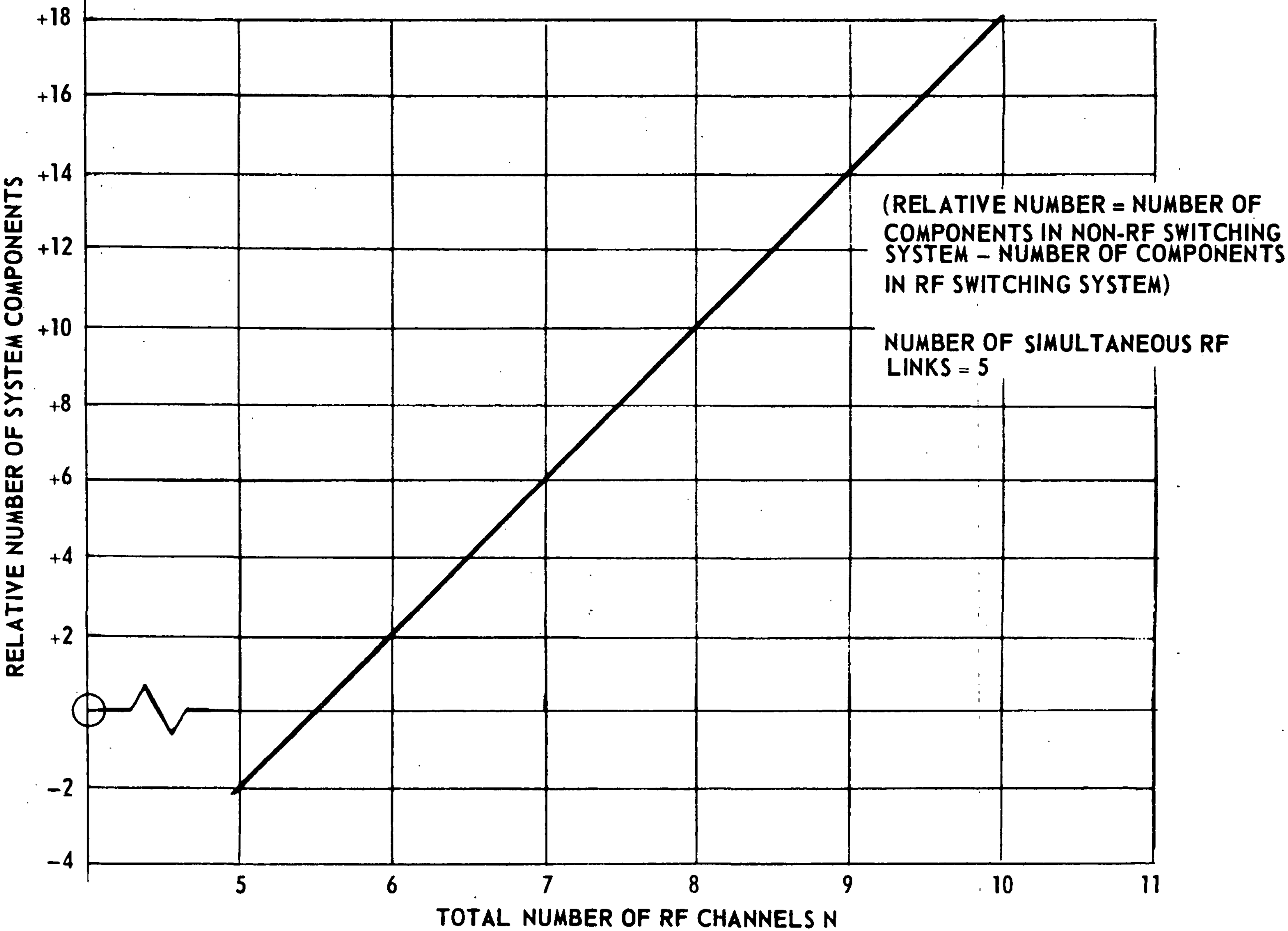

Figure 5-4. Relative Number of System Components vs Number of MSS Channels

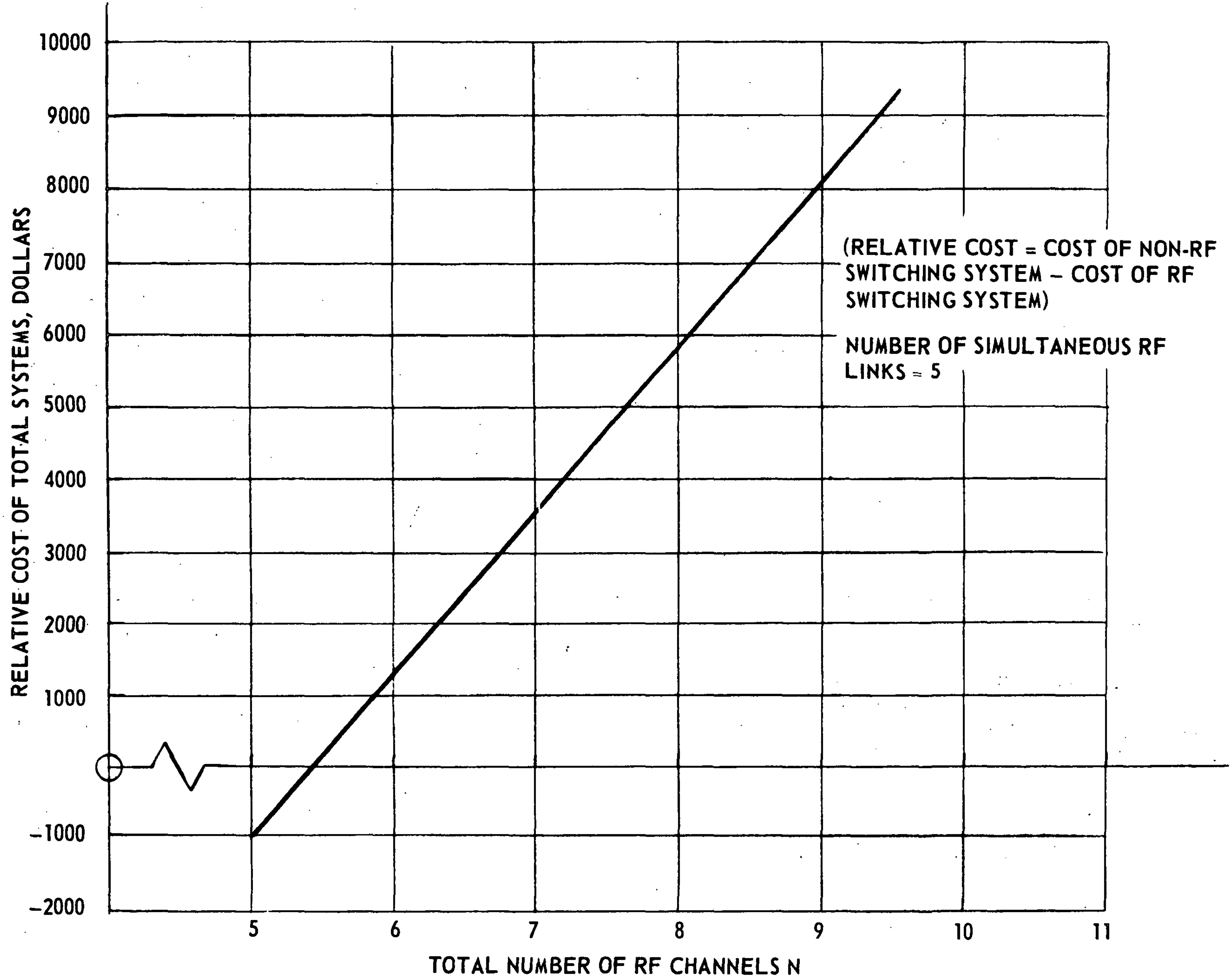

Figure 5-5. Relative Cost of Total System vs Number of MSS Channels

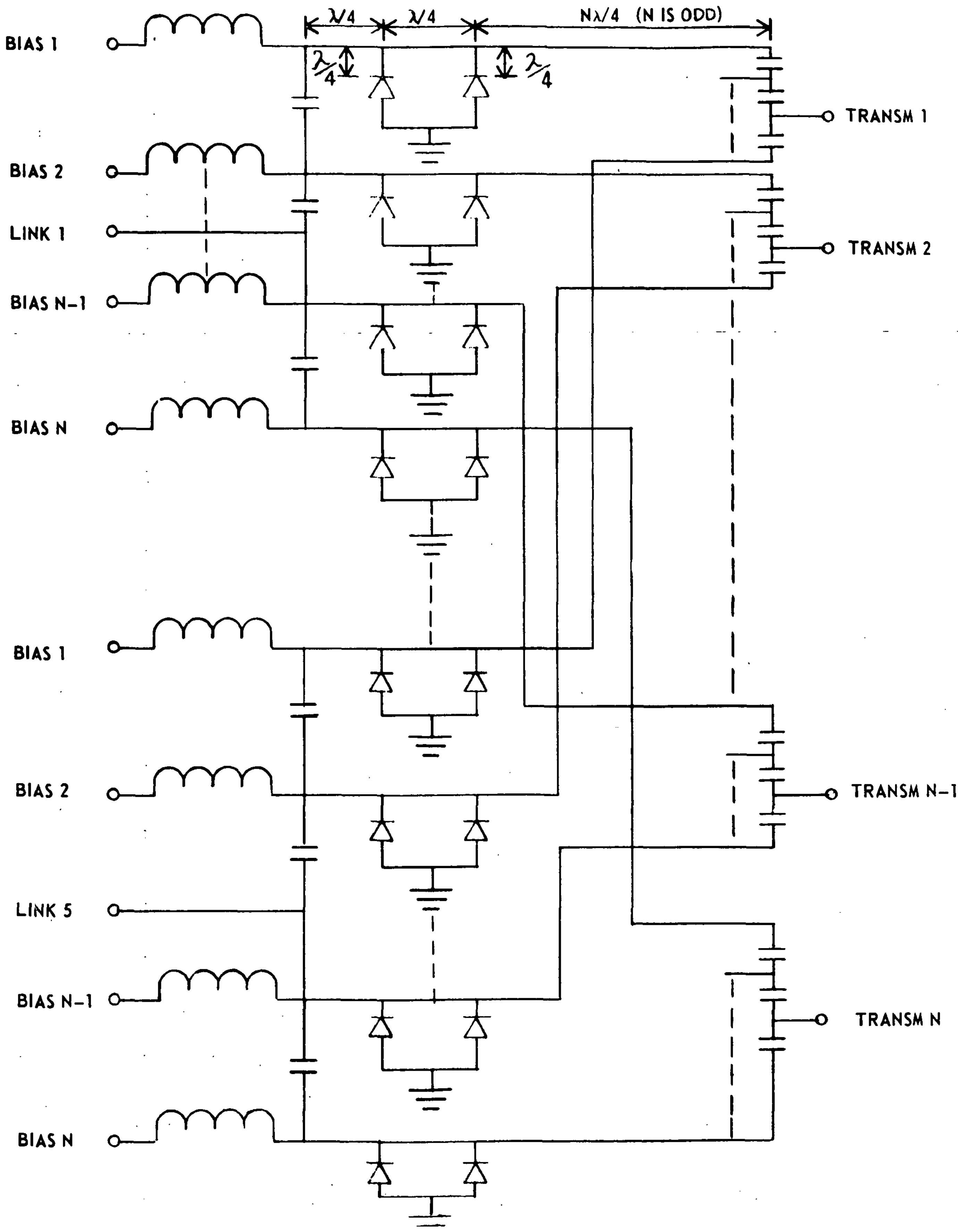

Figure 5-6. R-F Switching Matrix Using Pin Diodes

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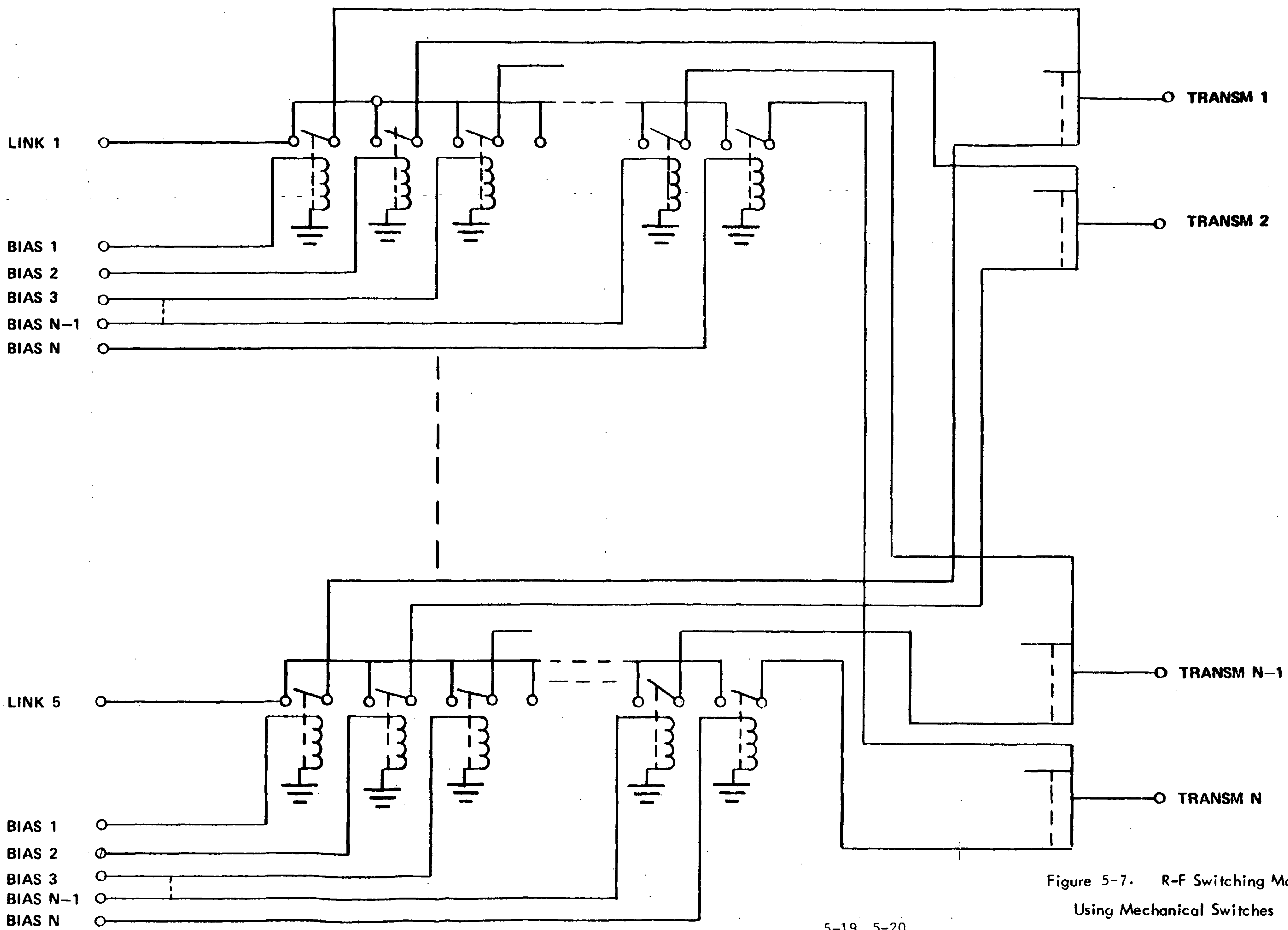

Figure 5-7. R-F Switching Matrix Using Mechanical Switches

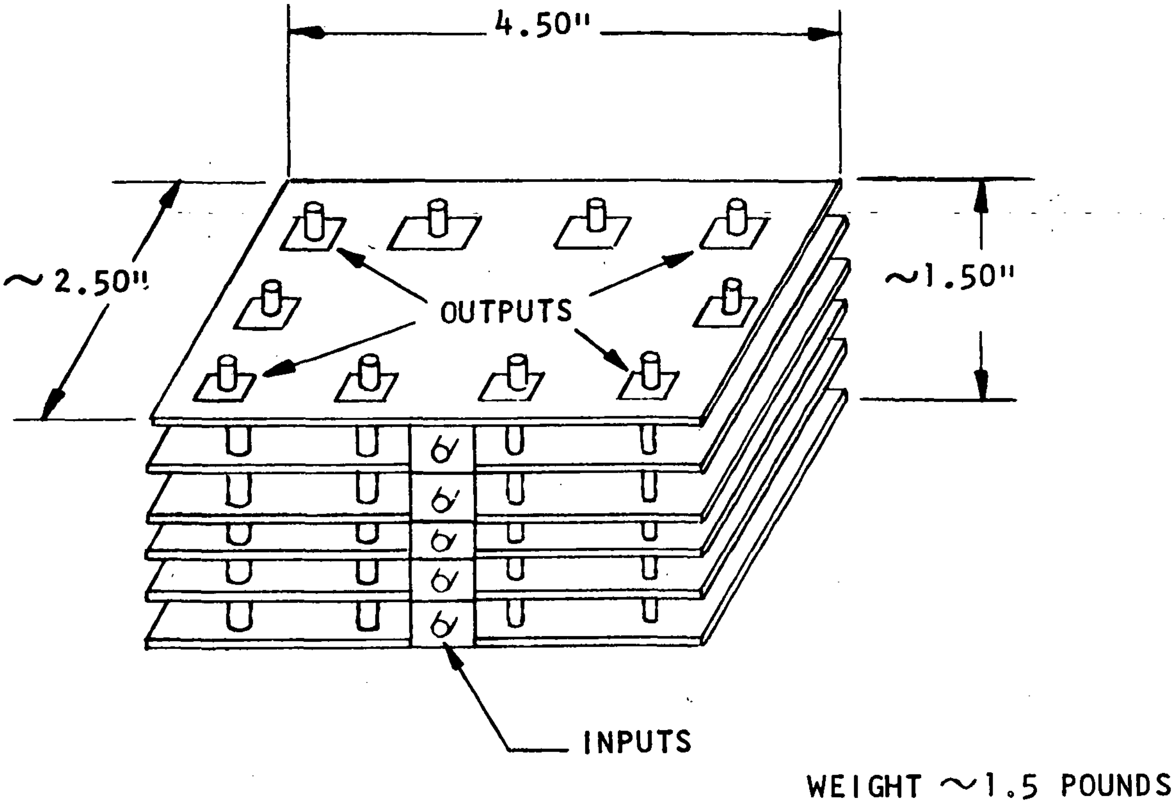

Figure 5-8. R-F Switching Matrix Using Microstrip Technique

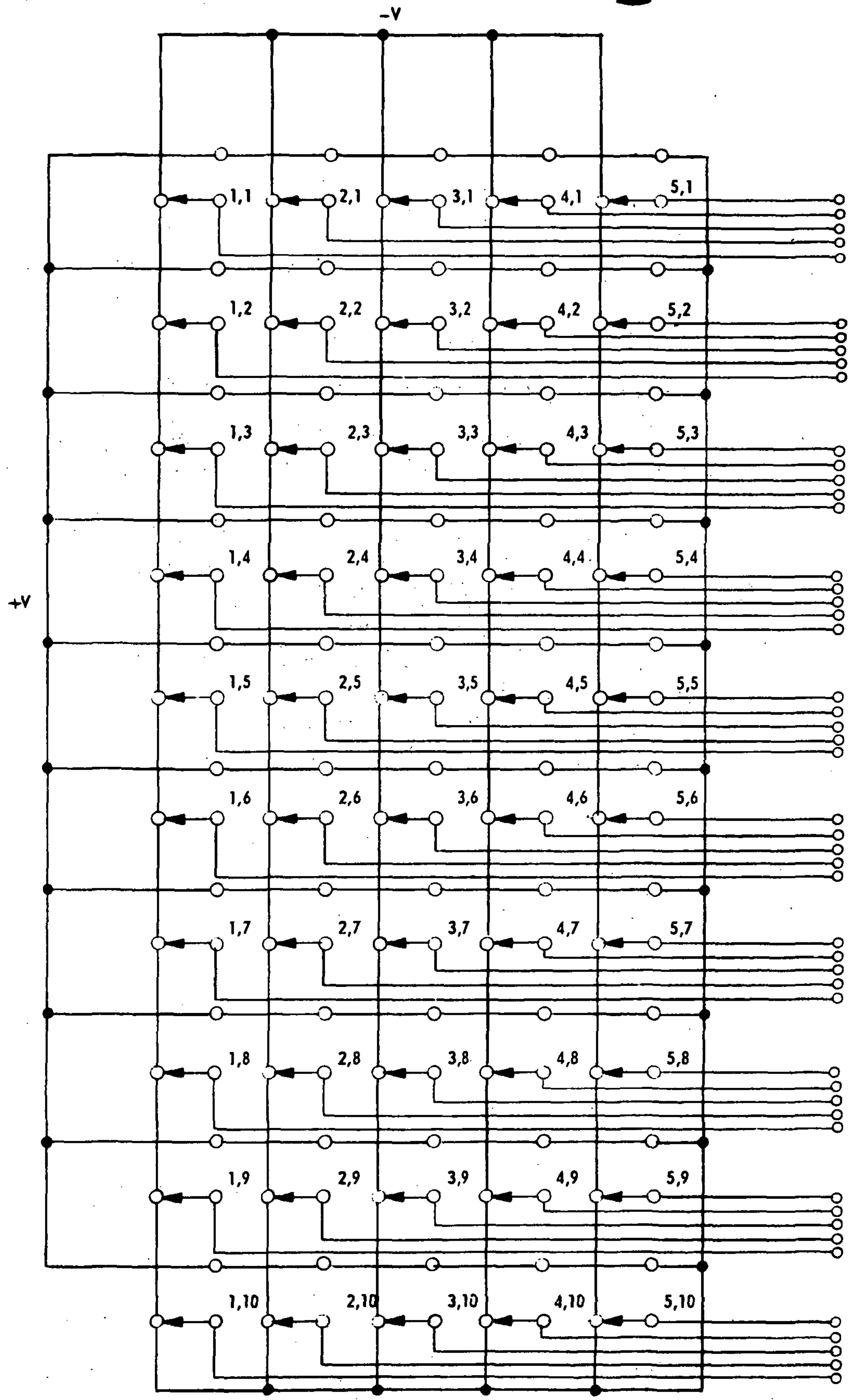

Figure 5-9. Control Matrix for R-F Switching

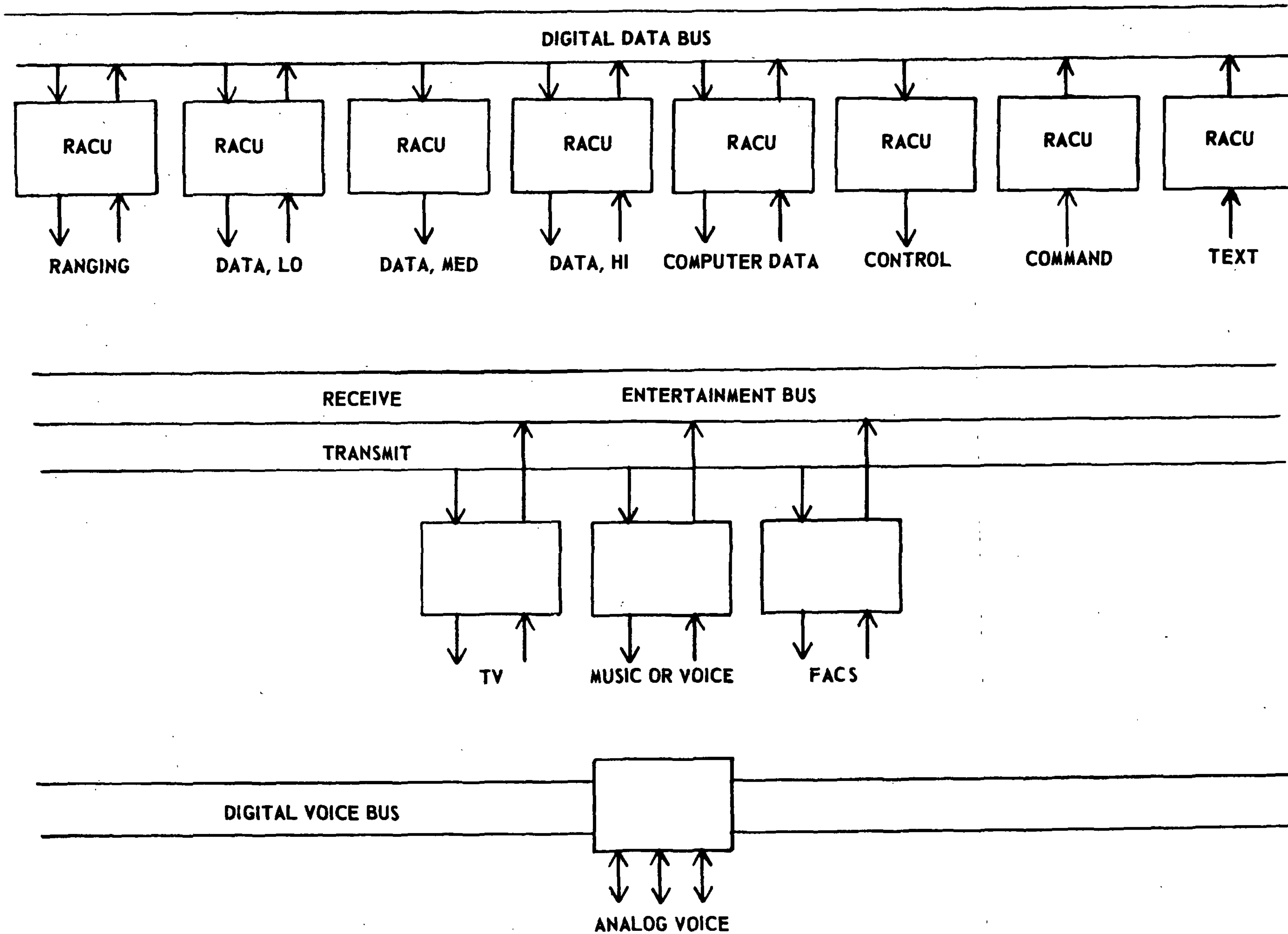

Figure 5-10. Information Busses and Sources

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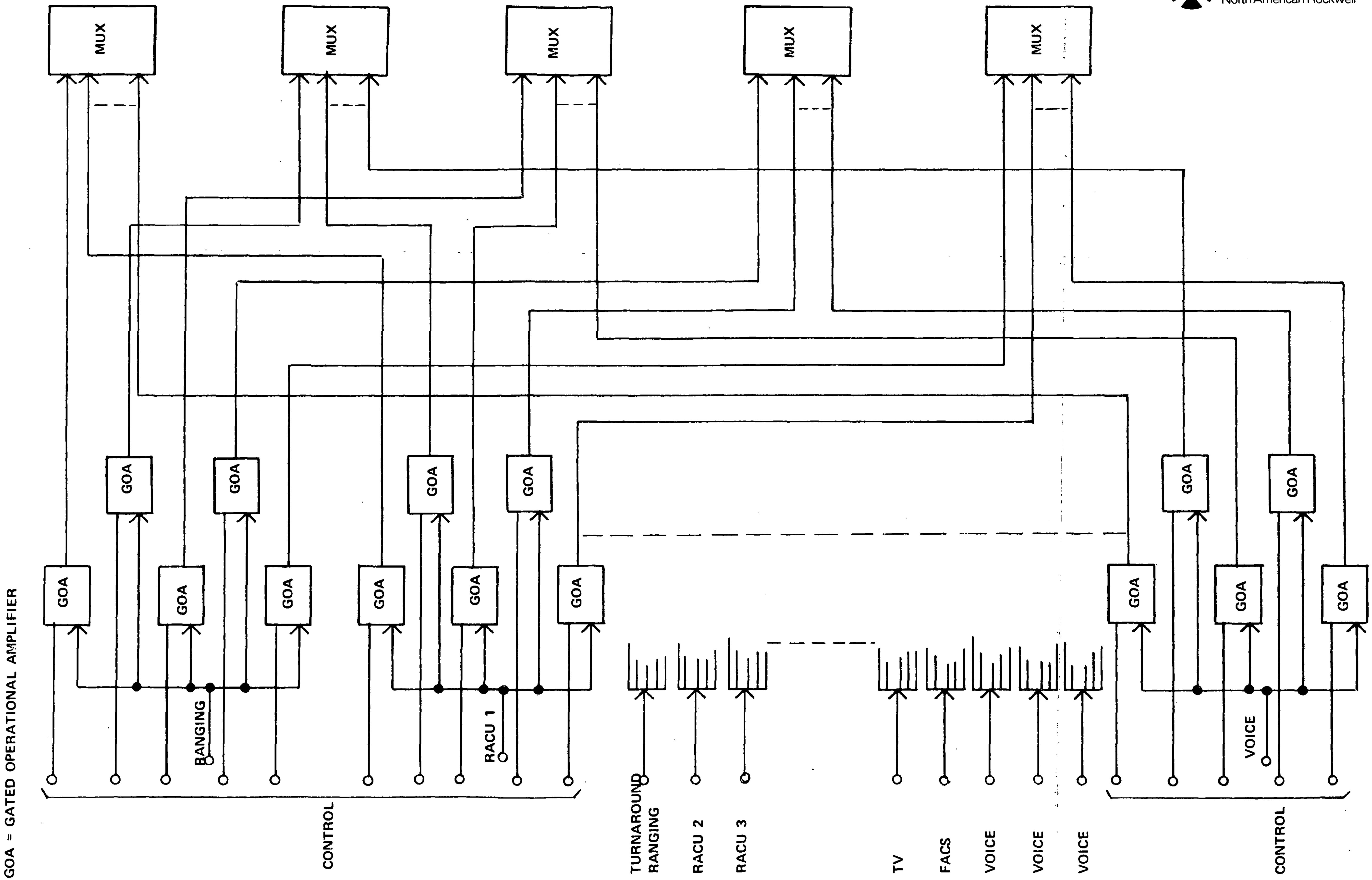

Figure 5-11. Transmit Baseband Switching Matrix

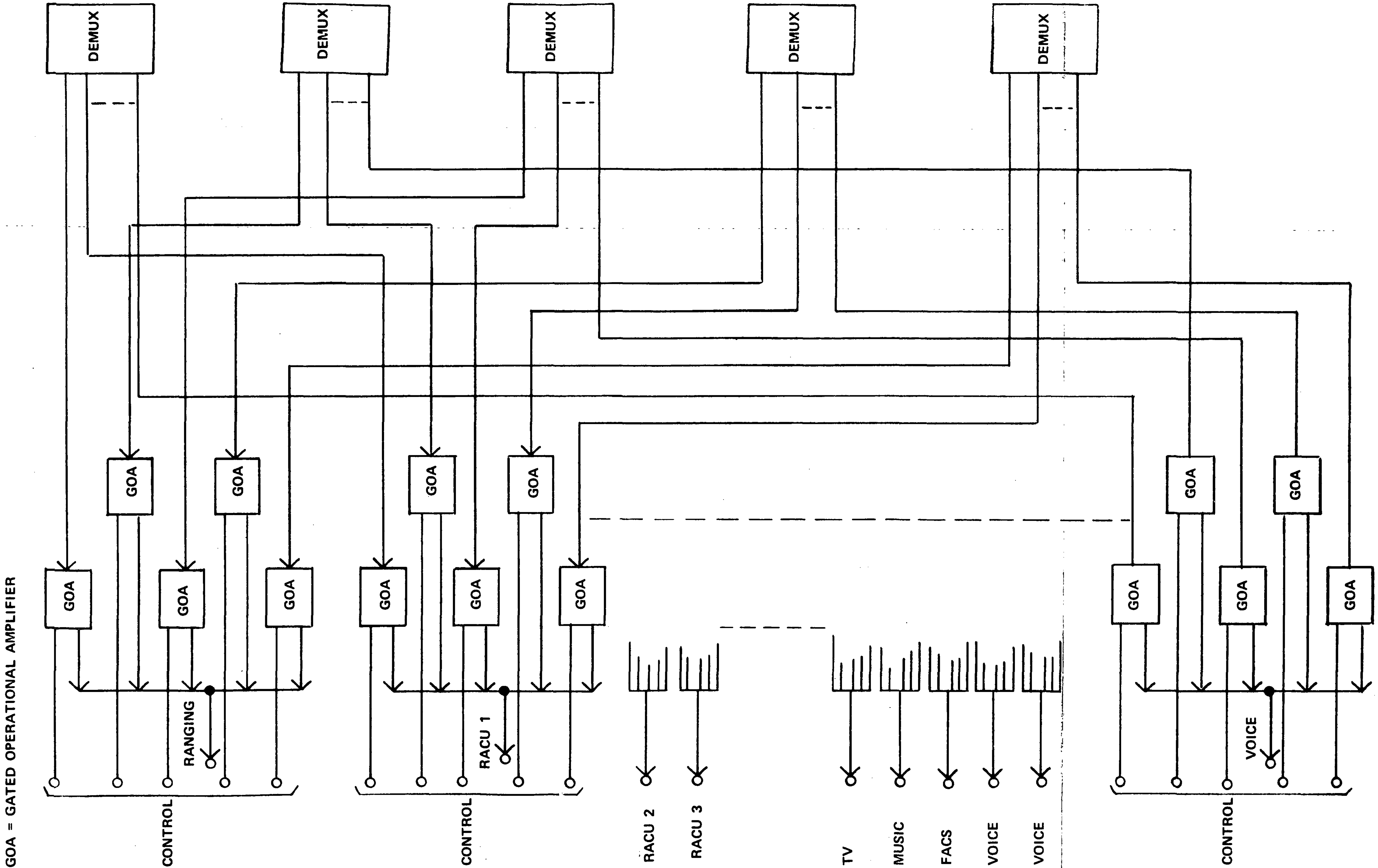

Figure 5-12. Receive Baseband Switching Matrix

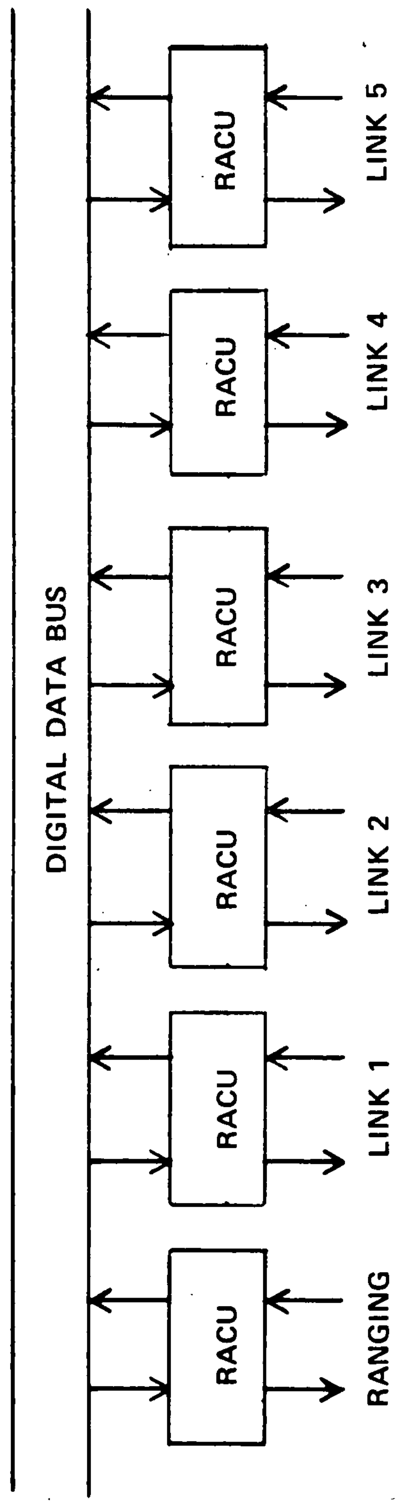

Figure 5-13. Recommended Interface Arrangement for Digital Data Bus

5.3 PASSIVE THERMAL CONTROL

The prime mechanical design philosophy is to provide a configuration which when subjected to the environment of the manned space station in a 250 mile earth orbit and various modes of operation shall be thermally controlled by passive means only.

5.3.1 Design

With electrical system design defined schematically, the receiver and transmitter components were resolved to physical configuration, thermal dissipation, and temperature ranges, both storage non-operate, and preferred operational. The transmitter associated components account for 97% of the internally generated heat.

The duty cycle of circuit operation combined with configuration requirements results in two basic classifications:

- The low level RF and constant dissipation elements, and
- The high power RF components of varying heat source.

This segregation will also permit a more desirable thermal exposure of the frequency generation circuitry for stability. Thus, the low level, constant dissipation items are mounted on a heat sink which is characterized by minimum thermal fluctuation. This is accomplished by independence from either travelling wave tube internally and minimum exposed area externally. Due to the symmetry of the power amplifier stage and the weight of the amplifier with integral power supply, opposite enclosure walls are used. While providing the necessary structural support, each wall becomes an independent sink responsible only to its associated tube. This permits a lighter weight construction, operational flexibility (should a tube fail), simplicity of maintenance and the ability to operate optimally with minimum influence due to antenna tracking position relative to the exterior thermal environment.

The Antenna Mounted Electronics Subassembly is previously illustrated in section 3.3.1, Figure 3-5. Each travelling wave tube with power supply is mounted on a three faceted sink. The third heat sink mounts and thermally controls the receiver components, up and down converter chain panels, the power supply and distribution, and intermediate power amplifier. The surface opposite the heat sink three provides mounting and interconnection interfaces. The details of which are illustrated in Figure 5-14. Twelve inserts of 1/4-20 thread size are installed to attach the antenna feed structure. The remaining surfaces double in application as structural bulkheads thermally isolating heat flow in or out of the enclosure.

The weight of the antenna mounted electronics subassembly, fully complimented with two TWT power amplifiers is 130 pounds, of which the electronics and enclosure housing account for 82 and 48 pounds respectively. The center of gravity is calculated to be coincident with the physical center.

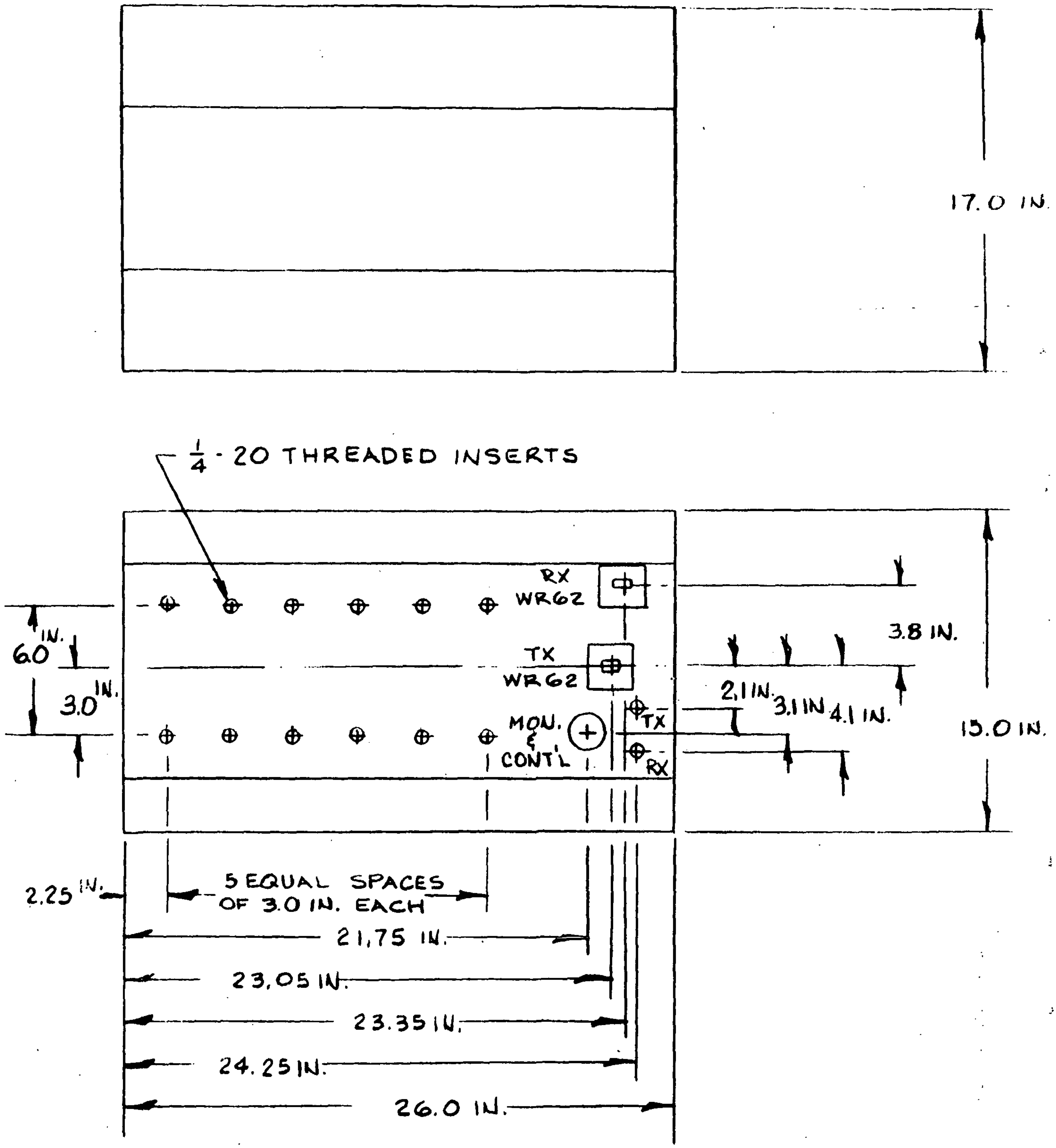

Figure 5-14. Mounting and Electrical Interface Details

The materials employed were selected for space mission compatibility. Aluminum alloys 1100H12 and 5052H32 served for TWT heat sink and sheet metal fabrication. The mounting panel and end covers are laminated epoxy fiberglass sheet, NEMA GRADE G10. Hardware selection was centered upon standard stainless steel. Except where mounting pressure was essential for thermal conductivity; i.e. TWT applications, hardware size was selected for ease of maintenance.

Thermal control is accomplished in respective areas by the application of silvered teflon to selected exterior surfaces while household aluminum foil is attached to the inside of the end covers only.

5.3.2 Thermal Mechanical

In the interest of weight control and reliability, the containing structure provides the required passive thermal management. The internally generated heat is transferred between components from the interior to the exterior by both radiation and conduction and is dissipated from the external surfaces by radiation into space. In addition, the sun, earth, and spacecraft will present thermal impacts upon the package exterior. These are functions of the intended orbit and associated seasonal influences of the enclosure mounting relative to the antenna and the antenna's tracking requirements.

The confirmed component dissipations are listed in the following tabulation with heat sink assignment.

Table 5-1. Component Dissipations

SOURCE	INTERNAL DISSIPATION, MAXIMUM WATTS	PREFERRED OPERATING RANGE °F	HEAT SINK LOCATION
TWT-PA 1	160.0	0 - 185	1
TWT-PA 2	160.0	0 - 185	2
TWT-IPA	14.0	0 - 185	3
Up Converter	4.0	50 - 100	3
Down Converter	4.0	50 - 100	3
Power Supply	11.0	50 - 100	3
TDA	0.5	50 - 100	-
Misc. Loads	5.0	___	-

To minimize external influence, thereby limiting thermal fluctuation, silver teflon was selected as the exterior control coating. The characteristics of low absorbtivity (α = 0.08), high emissivity (ϵ = 0.77) and durability are especially suited to the intended orbit. Data substantiating the stability of the coating characterisitics and method of application have been measured after extended exposure on OGO-6 spacecraft. "The temperature of the test panel is being monitored and has shown no increase, when comparable sun modes are repeated after almost two years in orbit."(1) A 5 mil teflon thickness was specified for optimum emissivity and environmental survival both temperature and abrasion. The silvered, teflon was obtained in strip from 1 and 2 inches wide for ease and accuracy of application with pressure sensitive adhesive backing. G. T. Schjeldahl Co., Northfield, Minnesota, supplied this tape as part number G4019.

Considering the antenna mounted electronics housing, illustrated in Figure 5-15, as basically a rectangular prism, the relation of surfaces to the antenna and associated tracking requirements were reviewed. The end covers and mounting panel are designed to be as thermally isolating permitting heat to flow neither in nor out of the housing. In this way the remaining control and mounting surface are definable according to associated heat loads internal and external. Furthermore, except for internal radiation and low conductance, assembly interfaces permit near independence of panel configuration and sizing.

A cylindrical heat sink profile would optimize radiating surface while presenting a minimum normal area to the sun or exterior heat influence, the three faceted configuration was selected for minimum weight impact. The TWT power amplifier procurement specification required a mounting interface of 12.0 x 6.5 inches with fifteen 1/4-20 inserts. The integral tube plate is 0.38 thick aluminum to achieve the required mounting while distributing internal local dissipations of the tube and supply. Thus a nominal 2.15 watts per square inch occurs. The footprint interface between aluminum surfaces of 32 microinch finish and less than 0.001 inch/inch flatness is compressed by 1/4-20 hardware torque to 60 inch pounds yielding a 4°F interface drop.(2) (3) The need for indium or other interface materials is thereby avoided. Using the recognized solar load of 130 watts/square foot, and earth albedo and emitted radiation of 0.30 $\pm$ 0.02 and 237 $\pm$ 7 watts/square meter respectively, (4) the required TWT radiator area is 3.25 square feet. Isotherms were described on the radiator area and a calculation performed to derive the necessary radiator crossection. Aluminum alloy 1100H12 was selected for its high thermal conductivity (128 btu/hr. sq. ft. °F/ft) and fabrication characteristics. While the conductivity of other alloys suffer from work hardening, the 1100 alloy is unaffected avoiding design compensation of the formed interface. With 175 watts as the maximum allowable dissipation per Power Amplifier, the baseplate reference temperature would range from 160° to 185°F when subjected to external loads of 0 to 40 watts. The received tube data reflects a 160 watts maximum thermal load.

Heat sink three controls the thermal exposure of the power supply, TWT IPA and up and down converter chains. The basic radiator is configured .12" thick aluminum sheet stock having a radiation area 25.5 x 9.8 inches. The resulting temperature range is 47° to 100°F as the influence heat load increases from 0 to 23 watts.

5.3.3 Thermal Test Procedure

The antenna mounted electronics subassembly was subjected to testing within a vacuum to simulate the conductive and radiative thermal transfer experienced in space (less solar radiation). The actual performance when

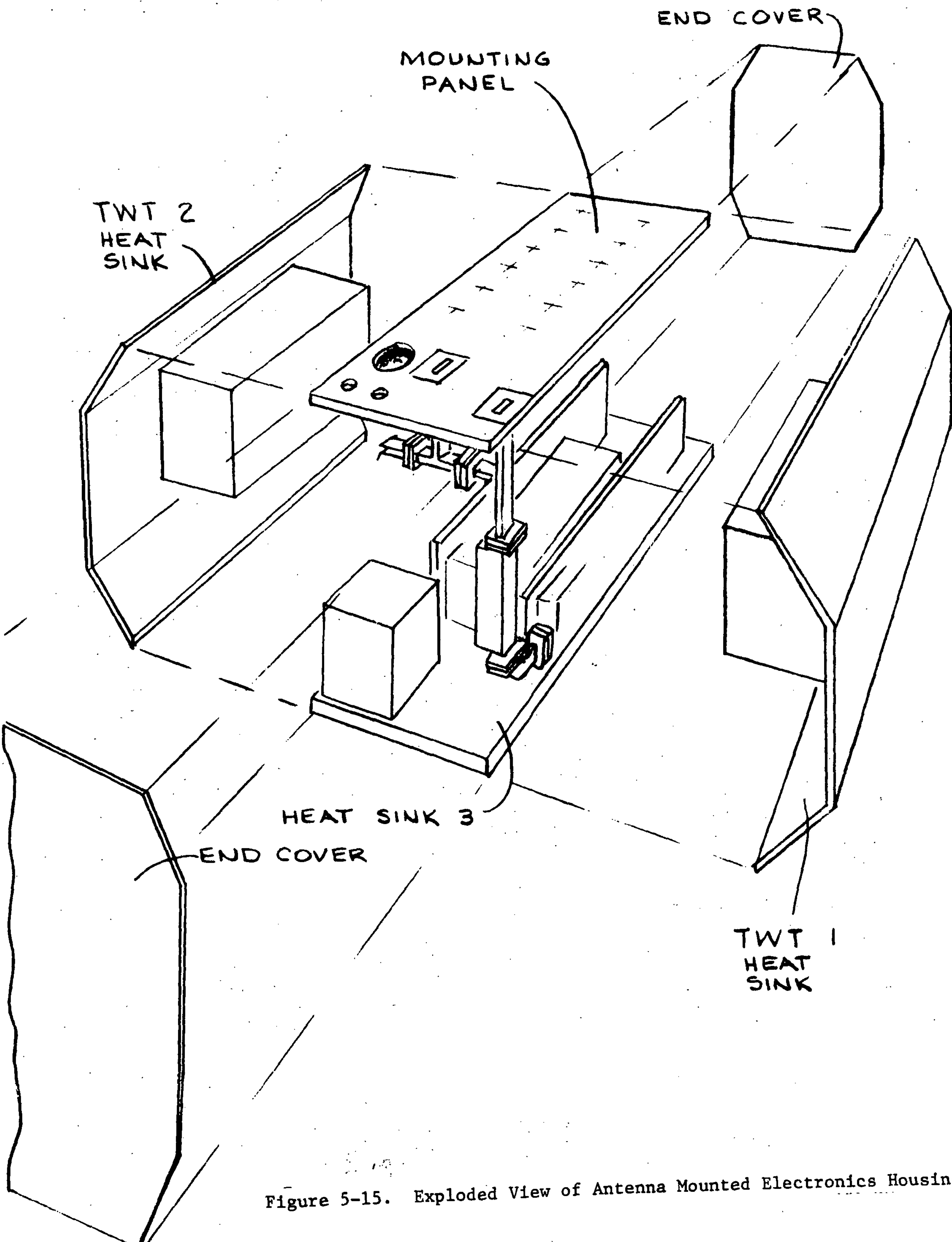

Figure 5-15. Exploded View of Antenna Mounted Electronics Housing

radiating to a shroud at less than -50°F was extrapolated to the temperature of space and compared with the analytical techniques to determine the adequacy of the design and the corrections, if any, necessary to achieve passive thermal management of the subassembly.

The test was performed in a vacuum chamber with a refrigeration shroud which encircled the subassembly. Except for the absence of solar spectrum radiation, the actual radiative and conductive characteristics may be evaluated with the least introduction of error. Internally, dummy heat sources are employed with external control of their dissipations. Source temperatures are monitored as well as heat sink interfaces temperatures. Other thermocouples were located internally to sense the interaction of heat sinks upon components due to radiation. Thus, the efficiency of the designed conductive paths may be verified and the interaction via radiation be studied. With thermocouples placed about the housing exterior, surface temperatures may be monitored to determine the heat sink and control coating performance. The shroud temperature is also monitored at a number of locations.

Five series of temperature tests were performed. Two of these tests simulated the total solar load, (1) incident upon TWT #1 PA and (2) incident to the maximum normal area. A third run simulated the condition of no external load and equal PA dissipations. Run number four was the same except for lower PA dissipations, approximately 160 watts. Run number five simulated actual orbital conditions and the timed exposure to solar radiation with time. Details of these tests, the procedures and results can be found in report CTB105/CTB106.

5.3.4 Test Results

Details of the results can be found in report CTB105/106. Significant unreduced data indicates ranges of temperature within limits specified in Table 5-1. Table 5-2 reflects the recomputed and translated to indicate estimated space environment temperatures. All temperatures indicate that the components will be well within their temperature ratings.

Table 5-2. Temperatures Translated to 0°R Space Sink

RUN	TWT 1 °F	TWT 2 °F	IPA/PS °F	Up Conv. °F	Down Conv. °F
No Sun/Earth (Run 4)	109	116	66	73	69
Failure of TWT 2	83	-68	+9	+1	24
Orbital Mode	141/129	126/138	66/66	73/73	69/69

5.3.5 Conclusions

Passive thermal control is provided for in the basic design with minimal mutual coupling between primary sink radiators and corresponding components. Should it be necessary to either conserve power or a failure occur, one TWT-PA may be inoperative without upsetting the thermal balance required for continued operation.

The use of aluminum foil will be extended to include internal coverage of end covers and the lower portions of the heat sinks opposite converter panels. The former will reduce transmissions through the covers, while the latter further decouples the converter componentry from dissipations. Converter panels will have less thermal excursion and perform at a higher more desirable temperature should a TWT become inoperative.

The configuration is rugged while weight conscious and employs durable space qualified materials and an exterior control coating particularly suited to the intended manned space station orbit.

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