

**IBM**

**Saturn Instrument Unit**

**Technical Manual**

MSFC No. III-5-509-8

IBM No. 67-966-0007

# Command System Description



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TECHNICAL MANUAL

**COMMAND SYSTEM DESCRIPTION**

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NOTE: The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page.

Page	Issue
Title . . . . .	Original
A . . . . .	Original
i thru ii . . . . .	Original
1-1 thru 1-2 . . . . .	Original
2-1 thru 2-5 . . . . .	Original
2-6 Blank . . . . .	Original
3-1 thru 3-9 . . . . .	Original
3-10 Blank . . . . .	Original
4-1 thru 4-5 . . . . .	Original
4-6 Blank . . . . .	Original
4-7 thru 4-9 . . . . .	Original
4-10 Blank . . . . .	Original
4-11 thru 4-15 . . . . .	Original
4-16 Blank . . . . .	Original
4-17 thru 4-21 . . . . .	Original
4-22 Blank . . . . .	Original
4-23 thru 4-30 . . . . .	Original

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# CONTENTS

Para	Page	Para	Page
<b>SECTION I INTRODUCTION</b>			
1-1	1-1	3-3	3-4
1-2	1-2	3-4	3-6
<b>SECTION II COMMAND SYSTEM DESCRIPTION</b>			
2-1	2-1	4-1	4-1
2-2	2-1	4-2	4-1
2-3	2-1	4-3	4-1
2-4	2-2	4-4	4-4
2-5	2-3	4-5	4-4
2-6	2-4	4-6	4-7
2-7	2-4	4-7	4-11
2-8	2-4	4-8	4-12
2-9	2-4	4-9	4-12
<b>SECTION III COMMAND PROCESSING</b>			
3-1	3-1	4-10	4-13
3-2	3-1	4-11	4-13
<b>SECTION IV COMPONENT DESCRIPTION</b>			
		4-11	4-14
		4-12	4-17
		4-13	4-17
		4-14	4-17
		4-15	4-19
		4-16	4-19
		4-17	4-19
		4-18	4-20
		4-19	4-20
		4-20	4-27

## ILLUSTRATIONS

Number	Page	Number	Page
1-1	1-2	4-2	4-3
2-1	2-2	4-3	4-4
2-2	2-3	4-4	4-5
3-1	3-2	4-5	4-7
3-2	3-3	4-6	4-8
3-3	3-5	4-7	4-9
3-4	3-7	4-8	4-12
3-5	3-8	4-9	4-12
4-1	4-2	4-10	4-15
		4-11	4-17

ILLUSTRATIONS (Cont)

Number	Page	Number	Page
4-12	CCS Power Amplifier. . . . .	4-17	
4-13	Traveling Wave Tube Schematic Diagram . . . . .	4-18	
4-14	CCS Power Amplifier Block Diagram . .	4-21	
4-15	Saturn Command Antenna Systems Block Diagram . . . . .	4-23	
4-16	Saturn V Command Antenna Configura- tion Block Diagram (UHF Equipment Removed) . . . . .	4-24	
4-17	Command System Antenna Positions. . .	4-25	
		4-18	CCS and PCM Antennas . . . . . 4-26
		4-19	CCS RF Components . . . . . 4-28
		4-20	Coaxial Switch Block Diagram. . . . . 4-28
		4-21	CCS Hybrid Ring Schematic Diagram . . 4-28
		4-22	Power Divider Schematic Diagram . . . 4-29
		4-23	Uprated Saturn I Command System RF Components . . . . . 4-29
		4-24	Command Directional Coupler Schematic Diagram . . . . . 4-29
		4-25	Uprated Saturn I Command Antenna . . . 4-30

# SECTION I

## INTRODUCTION

### 1-1 GENERAL DESCRIPTION

The Saturn Instrument Unit (IU) Command System has been designed to provide a reliable digital communications link between the Mission Control Center (MCC), Houston, Texas, and the onboard digital computer system. The actual communication with the vehicle is accomplished through message transmissions from earth-fixed ground stations of the Manned Space Flight Network (MSFN) and the Deep Space Network. These stations, strategically located about the earth, are tied directly to the MCC computer complex in Houston.

The IU Command System is one of three systems which provide a digital data up-link between the ground computers and the Saturn Vehicle. The other two systems are located in the Command Module and Lunar Module; they are referred to as the Apollo Uplink and the Lunar Module Digital Command Assembly, respectively. Although the three systems are similar, their operational usage varies.\* Each system has a specific mission and is related to a particular flight phase. Operation time will vary and is limited by the electromagnetic range and location of the ground stations, as well as the flight phase. The primary usage of the IU Command System will take place during earth parking orbit. During this period, data and commands are supplied to the IU computer system which may alter its stored data and programmed instructions. Flight environment, tests performed on the IU equipment, last-minute flight or navigation changes, etc., account for these up-link messages.

The information path, as illustrated in Figure 1-1, is from MCC, through one of several ground stations, to the Saturn Vehicle. Digital information, including addressing data, is sent from MCC to a

\* All three systems use the same MSFN ground stations and the same general coding and modulation schemes. In some cases, two of the systems may even share the same rf carrier frequency. However, the scope of this manual is limited to an explanation of the IU Command System only.

specified ground station for encoding and transmission. After being encoded into a special format, the message is then modulated onto an rf carrier and transmitted to the vehicle. Within the IU, receiving equipment demodulates the rf transmission and forwards the still-coded message format to a decoding device. This device, known as the Command Decoder, breaks the message down into its original digital components, verifies the vehicle address, and forwards the decoded message (now in digital form) to the IU computer system.

The command message (word) is composed of 35 digital bits of information. Of these 35 bits, 17 are used to "address" the message to the vehicle and decoder. The remaining 18 bits, which are the data portion of the command word, ultimately reach the IU computer system.

The IU computer system is made up of a Launch Vehicle Digital Computer (LVDC) and Data Adapter (LVDA). Acceptance of the message, after various computer checks, initiates and transmits an acceptance message (via telemetry) to the ground station computer. This message informs the ground command system that the original message was acceptable and that the cycle may be repeated if more up-link data is awaiting transmission. If, for some reason, the message was not acceptable, the ground computer will attempt to repeat the message until it is either accepted or a predetermined number of attempts have been made.

The digital command messages, which are transmitted to the IU, are used to either initiate certain LVDC program routines or to supplement or alter data already in the LVDC memory. The first "word" of a given transmission normally specifies the action to be performed (mode command) and any following words contain supplementary data (data commands) needed for the execution of the command. For example, if a command is given to update certain navigation parameters, the one-word mode command is followed by the navigation data needed to accomplish the update. (In this case, 35 data words from the

ground.) Details of the various command messages and data formats will be found in Section III.

## 1-2 COMMAND SYSTEM RELIABILITY

The application of the IU Command System and the information transmitted through the system require a high degree of reliability and accuracy. This high reliability is obtained by the use of several hardware and software safeguarding techniques.

The MSFN is designed to provide a high degree of data transmission accuracy from the originating station in Houston, Texas, to the ground station computer system which actually transmits the vehicle. Message encoding, through the use of a sub-bit

scheme, virtually eliminates transmission errors and transposition of individual bits. Onboard the vehicle, the Command Decoder checks each bit as part of the decoding process. It also checks for missing bits, timing, and correct message address. Any detected discrepancy is cause for immediate rejection of the whole message word. After decoding, the data portion of the word is presented to the LVDA/LVDC for several data processing tests before it is finally accepted as an authentic and accurate command word.

Hardware assurances of reliable Command System equipment include redundant telemetry lines and changeable code plug wiring within the Command Decoder, a dual antenna system, and the highest standards of manufacture and engineering throughout.

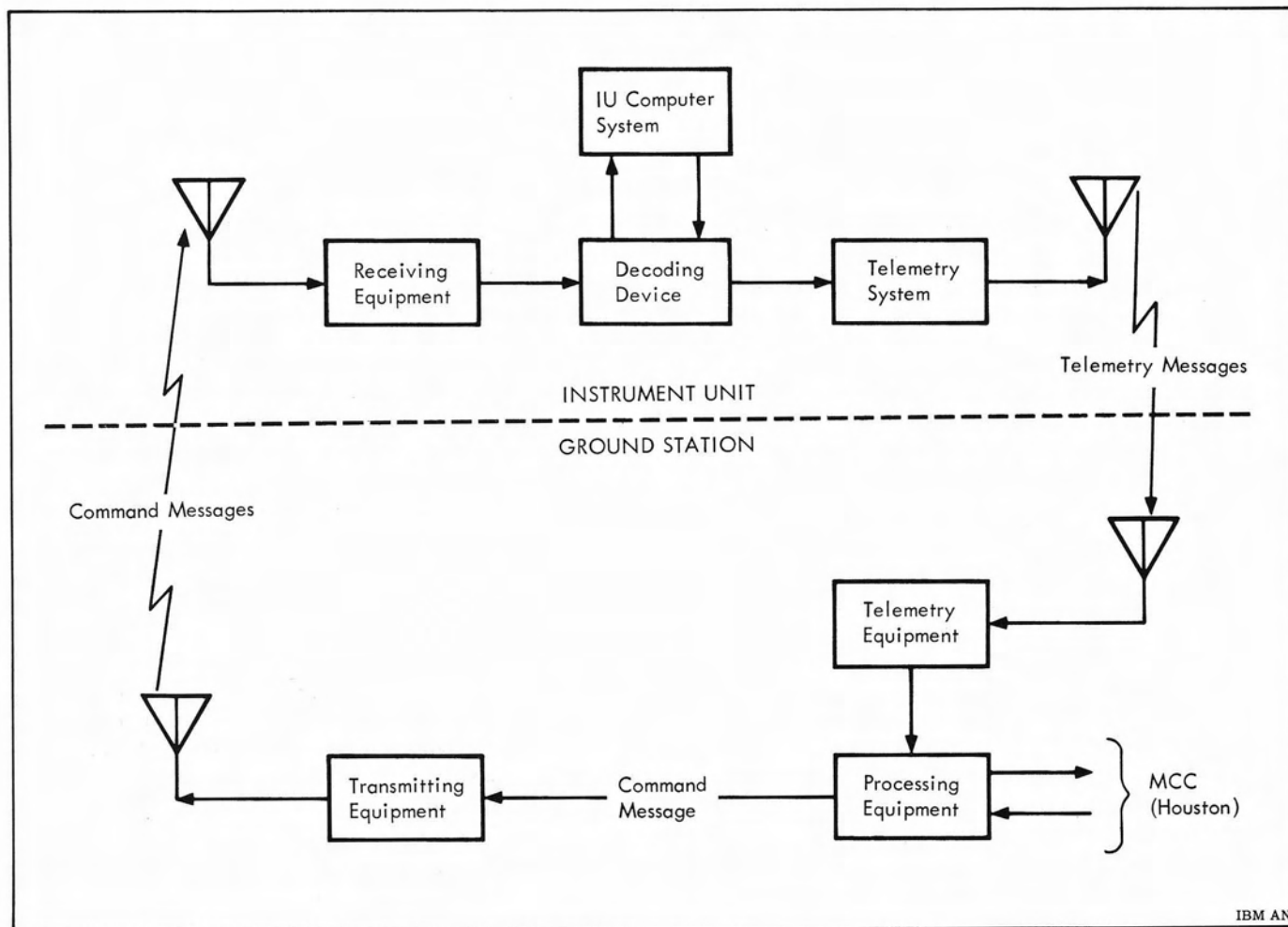


Figure 1-1. Command System Data Flow



## SECTION II

# COMMAND SYSTEM DESCRIPTION

### 2-1 UPDATED SATURN I (IU) COMMAND SYSTEM

The Updated Saturn I (IU) Command System consists of the equipment shown in Figure 2-1. Input commands and data are received by the MSFN ground station from MCC. After processing, temporary storage, and encoding within the digital command system, the message is transmitted (via a uhf carrier) to the vehicle. The command message is then received, demodulated, decoded, and either accepted or rejected by the vehicle's IU Command System before being passed on to the LVDC/LVDA computer system. Final verification and processing are accomplished within the LVDC. Acceptance and verification messages are returned to the ground equipment (via telemetry) to complete the cycle.

#### 2-2 UPDATED SATURN I COMMAND SYSTEM OPERATION

The flight components which make up the Updated Saturn I Command System are the Command Receiver (MCR-503B), its associated Antenna network, and the Command Decoder. Supplementary IU equipment which is utilized by the Command System includes a PCM (Pulse Code Modulation) telemetry system and the LVDA/LVDC computer system.

The command antenna network receives 450-megahertz command signals through two omnidirectional antennas which are mounted 180 degrees apart on the exterior of the IU structure. The two antennas are electronically isolated from each other by a Command Power Divider which transfers the signal power to a Command Directional Coupler. This coupler is designed to isolate the antenna inputs to the Command Receiver from test inputs of pre-launch ground equipment. The test inputs are routed through an umbilical connection.

The Command Receiver amplifies and demodulates the 450-megahertz, Phase Shift Keyed/

Frequency Modulated (PSK/FM) signal, and the resultant PSK audio signal (1 kHz and 2 kHz in composite form) are then supplied to the Command Decoder for further processing. The Command Decoder, which is the heart of the Command System, has the task of decoding the composite PSK audio waveform into its original digital message.

The command message transmission is made through a 32-bit word which is preceded by three vehicle address bits. After the decoding process is completed, 14 of the remaining 32 bits are checked for the correct decoder address. If the address is correct, the message is "accepted", and the remainder of the bits (18) are transferred to the LVDA in preparation for a final transfer to the LVDC. These 18 bits make up the data and control portion of the command message. Section III of this manual describes the command message and processing in greater detail.

### 2-3 SATURN V (IU) COMMAND SYSTEM

The Saturn V (IU) Command System consists of the equipment shown in Figure 2-2. As in the Updated Saturn I Command System, input commands and data are received by the MSFN ground station from MCC. After processing, temporary storage, and encoding within the digital command system the message is transmitted (via an rf carrier) to the vehicle. The command message is then received, demodulated, decoded, and either accepted or rejected by the Command System before being presented to the LVDC/LVDA computer system. Final acceptance and verification are accomplished within the LVDC by special program routines. Acceptance and verification messages are returned to the ground equipment (via telemetry) to complete the cycle.

The command frequency for Saturn V Vehicles is in the S-band frequency range. Up-link data is transmitted at 2101.8 MHz, and down-link data is transmitted at 2282.5 MHz. The Command System

operates as part of a Unified S-band System which is unique to the Saturn V Vehicle.

2-4 UNIFIED S-BAND SYSTEM

Before describing the Saturn V (IU) Command System in more detail, it is necessary to explain the completely new approach taken for the Saturn V tracking and communication scheme. This new approach was adopted because of the increased complexity of the equipment needed to support a lunar flight and the distances involved. Consequently, a system has been developed in which a single system, with a single carrier frequency, performs all the tracking and communication functions. This new system is referred to as the Unified S-Band (USB) System.

Since systems capable of operating to lunar distances (which employ the unified techniques) were already in operation, the USB scheme was adapted to

the Apollo Program rather than expand and modify the existing vhf and uhf network equipment. The USB system was considered to offer a superior technical solution with a minimum of new development and expense. In addition, and very significant, is the fact that the unified system also reduces the equipment required onboard the space vehicle.

The USB technique employs a single carrier frequency, in each direction, for all tracking and communication data between the vehicle and ground. Under the general USB scheme, voice commands, and updata are modulated onto subcarriers and then combined with ranging data. This composite information is used to phase-modulate the single transmitted carrier frequency. A vehicle transponder recovers and detects the subcarriers from the rf carrier for voice and command information. Earthbound information in the form of voice and telemetry data are modulated onto subcarriers, combined with the ranging signals, and then used to phase-modulate the

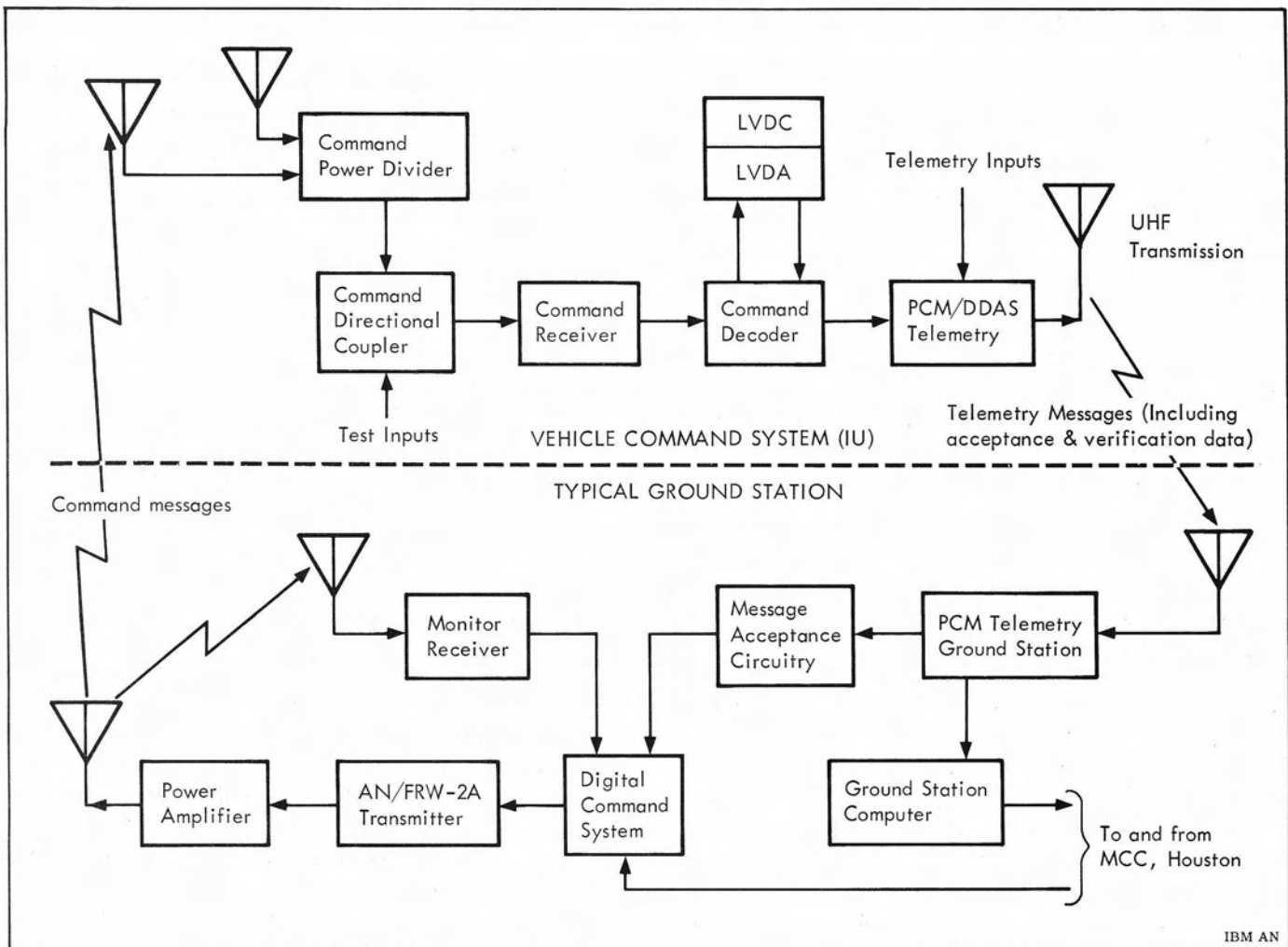


Figure 2-1. Uprated Saturn I (IU) Command System Block Diagram

downlink rf carrier frequency. The received and transmitted carrier frequencies are coherently related to allow measurement of the carrier doppler frequency by the ground station for accurate determination of space vehicle range and velocity.

It should be noted that in the case of the IU Command System (explained in the following paragraphs), voice and ranging capabilities of the USB system are not used. Instead, separate USB transponders, located in the Spacecraft, are used for these functions as well as the normal telemetry and updata requirements.

2-5 SATURN V COMMAND SYSTEM OPERATION

The flight components which comprise the Saturn V Command System include a CCS Transponder,

Command Decoder, CCS Power Amplifier, and its associated Antenna System. (CCS is the abbreviation for Command and Communication System.) Supplementary IU equipment which is utilized by the Command System includes a PCM Telemetry System and the LVDA/LVDC computer system.

Onboard the space vehicle, the command message is received and demodulated by the multi-purpose CCS Transponder. The command message output of the CCS Transponder is identical to the output format of the Command Receiver used in the Uprated Saturn I scheme. The command messages are also processed in a similar manner. The Command Decoder translates the message into its original intelligence and feeds the resultant binary

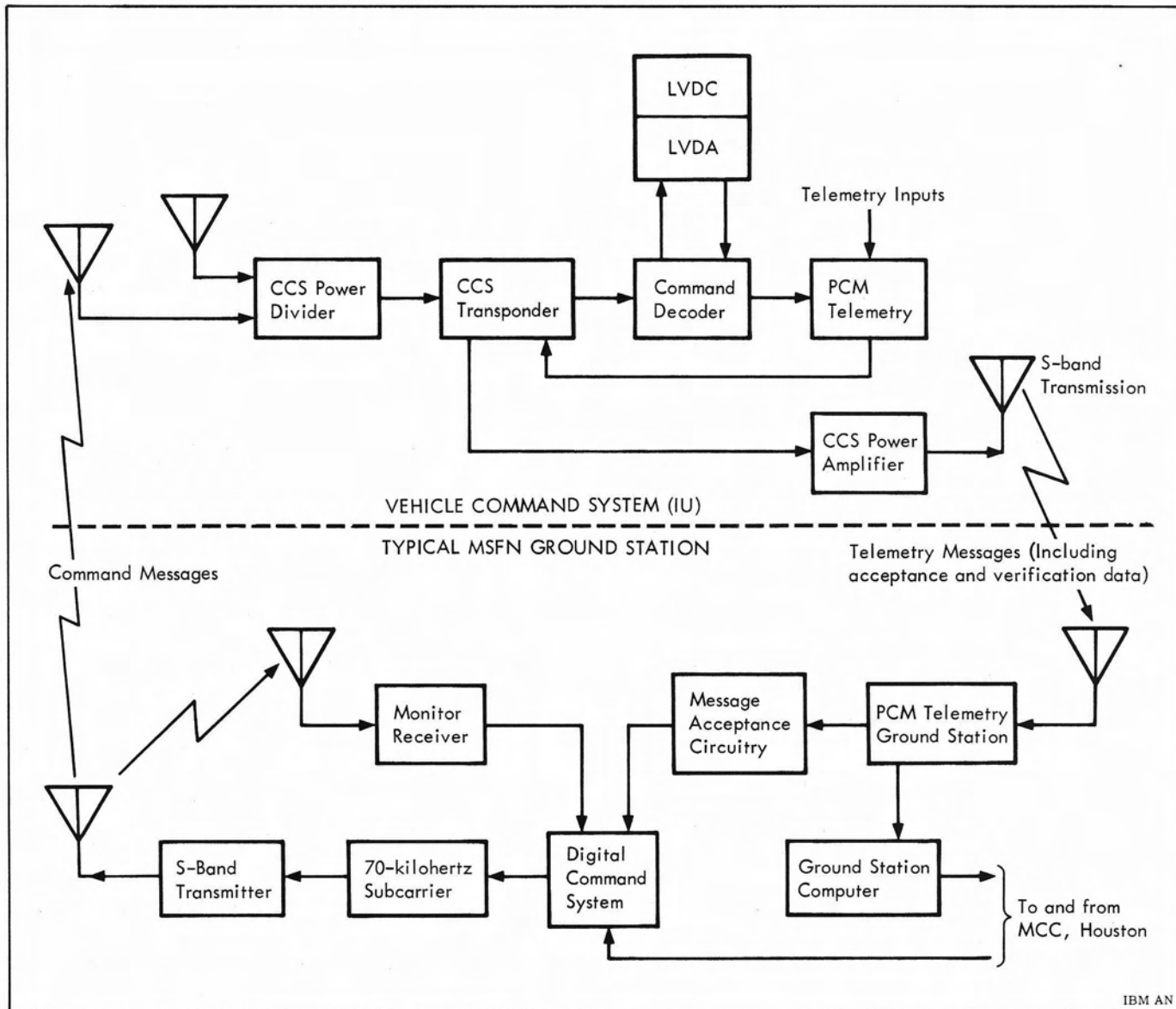


Figure 2-2. Saturn V (IU) Command System Block Diagram

message to the LVDA/LVDC. Address verification and computer acceptance messages are returned to the ground via the IU telemetry system. Since the Saturn V Vehicle utilizes the USB scheme, the telemetry messages are transmitted via the CCS Transponder. The rf output, at the S-band frequency, is amplified by the CCS Power Amplifier before being routed through a dual antenna network.

The antenna network, while not detailed in the figure, consists of two omnidirectional antennas for short-range transmissions and one directional antenna with multigain capabilities for longer ranges. Two separate antennas feed the updata rf messages to the receiver portion of the CCS Transponder through a Power Divider.

On the ground, telemetry messages are recovered and processed in a manner similar to the method used in the Uprated Saturn I command scheme. Message acceptance circuitry uses the verification and computer acceptance messages (recovered from telemetry) to inform the digital command system equipment of the command message status.

## 2-6 GROUND STATION DESCRIPTION

### 2-7 DIGITAL COMMAND SYSTEM

A Digital Command System (DCS) is located at each MSFN ground station. The DCS is a digital processing computer which receives, stores, encodes, and transfers the command messages originating at MCC. The system also monitors outgoing messages by utilizing a monitor receiver input.

For purposes of discussion, the DCS may be divided into three major subsystems: input, memory, and output. The DCS is represented by one block in Figures 2-1 and 2-2.

The function of the input subsystem is to receive MCC data from any one of four sources --

- High-speed data system
- High-speed ground computer
- 100-words-per-minute teletype line
- Manual input.

As part of its function, the input subsystem performs certain parity-check and error detection routines before transferring the intelligence into memory storage.

The memory subsystem is capable of receiving and storing 512 command words (40 bits per word) within its magnetic core memory. After storage, error detection routines perform checks to insure that the stored word is identical to the received word. Upon command, this subsystem will transfer the stored information from selected memory locations to the output system.

The output subsystem receives data from memory storage and performs several operations which include:

- Generating phase-coherent 1-kilohertz and 2-kilohertz subcarriers,
- Encoding the message into a predetermined sub-bit pattern – the output produced is a non-return-to-zero (NRZ) pulse train,
- Modulating the 2-kilohertz subcarrier by utilizing the NRZ pulse train,
- Combining the 1-kilohertz and 2-kilohertz signals in a linear adder and feeding the composite signal to the rf system,
- Performing error detection and self-check routines.

### 2-8 GROUND STATION RF SYSTEM

The Uprated Saturn I ground station rf system includes an AN/FRW-2A Transmitter, power amplifier, monitor receiver, and associated antenna systems. The transmitter/power amplifier combination frequency modulates the encoded composite sinewave, (which was generated in the DCS) onto a 450-megahertz carrier. This is the rf message which is transmitted to the onboard command equipment.

The monitoring receiver, as its name implies, is used by the ground system to monitor the strength and quality of the outgoing transmission. The output of the monitor receiver is returned to the DCS for verification and monitoring.

### 2-9 COMMAND TELEMETRY SYSTEM

The Uprated Saturn I ground station telemetry system includes the equipment necessary for the reception, decommutation, and presentation of real-time PCM telemetry information from the vehicle.

Acceptance of a command message by the vehicle Command System is signalled to the ground via PCM telemetry. Receipt of this acceptance message signals the DCS that another word may be transferred. In the event a message fails one or more of the onboard (LVDC) validity tests, a telemetry message is initiated by the LVDC to inform the ground station the reason for the rejection. The telemetry system then becomes an invaluable aid in analyzing and diagnosing possible trouble areas in the Command System loop.

Included with the ground telemetry equipment is a Message Acceptance Pulse (MAP) circuit which is unique to the Command System operation. The MAP circuit monitors and times the interval between address verification signals and message acceptance signals from the IU Command Decoder. If the time between signals is within preset tolerances, an output from this circuit informs the DCS of this condition so that another command message may be transmitted. However, if one or both of the Command Decoder signals fails to arrive, the MAP circuit logically assumes that the command message was not accepted by the LVDC, and by the signal it presents to the DCS, the MAP requests that the message transmission be repeated.

## SECTION III

# COMMAND PROCESSING

### 3-1 BASIC ENCODING AND MODULATION TECHNIQUE

The command word, as developed by the ground station DCS, must be encoded into a particular digital sub-bit format before transmission to the vehicle. Each of the 35 digital updata bits of the command word is encoded into 5 sub-bits (for a total of 175 sub-bits per command word). Duration time for each sub-bit is 1 millisecond for a total of 5 milliseconds per bit. Therefore, the updata rate is 200 bits per second. It should be noted that the system operates on an NRZ scheme and consequently has no deadtime between either sub-bits or bits.

The arrangement of the sub-bit groups into specific patterns determines whether the bit represented is a binary "1", "0", or "X" (vehicle address). \* Only 3 of a possible 32 ( $2^5$ ) bit configurations are used for a given flight. The ground encoder and vehicle decoder have provisions for changing these patterns (prior to flight) by means of changeable code plugs. The sub-bit patterns are chosen for optimum differentiation between binary ones and zeros to provide a better error detection capability in point-to-point transmission.

As stated earlier, one pattern is used to represent a binary "1", another a binary "0", and the third to represent "X" bits. The "X" bits are always the first 3 bits of each command word and are used solely as a vehicle address. Addressing is needed to distinguish between command words intended for the Apollo Spacecraft and those intended for the IU since both command systems use the same baseband modulation and actually time share a common rf carrier.

The method of modulation used by the DCS is referred to as Phase Shift Keyed (PSK) baseband modulation. A 1 kHz sinewave (corresponding to the 1-millisecond sub-bit rate) is generated within the

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\* As an example of binary encoding, the sub-bit patterns used might be:

"X"	=	01110
"1"	=	11111
"0"	=	00000

DCS output subsystem and is used as a phase synchronizing signal. (See A of Figure 3-1.) A 2 kHz waveform is then biphase modulated (at the 1 kHz rate) so that the binary bits are phase analogous. (See B of Figure 3-1.) A binary "1" is encoded during the period when the 2 kHz waveform is in phase with the 1 kHz reference waveform (starting at the point where the 1 kHz waveform crosses the zero reference and has a positive-going slope). The 1 kHz waveform and phase-modulated 2 kHz waveform are then algebraically summed to produce the composite waveform illustrated in C of Figure 3-1. This composite waveform is then used to modulate the rf carrier transmitted to the vehicle.

In the Uprated Saturn I Command System, the rf carrier is frequency modulated (PSK/FM). However, in the Saturn V Command System, the composite waveform is first used to frequency modulate a subcarrier (intermediate) which, in turn, is used to phase modulate the S-band rf carrier (PSK/FM/PM).

The characteristics of the command message are:

- Message Length - 175 sub-bits
- Sub-bit Rate - 1000 bits per second
- Encoding Scheme - 5 sub-bits per data bit
- Data Bit Rate - 200 bits per second
- Command Word Length - 35 bits
- Modulation Scheme
  - Uprated Saturn I - PSK/FM
  - Saturn V - PSK/FM/PM

### 3-2 COMMAND WORDS AND FORMAT

The LVDC is programmed to receive two types of command words from the Command System; these

are mode commands and data commands. A mode command will determine which of several command program routines is to be run. A data command, as the name implies, furnishes the necessary data for the commanded routine. Generally, each mode command must be followed by one or more data commands. The particular routine will determine the amount of data that must be received.

The full command word, as decoded by the IU Command System, is made up of 35 digital bits. Both mode and data command words utilize the same command word format. A breakout of the command word format is shown in Figure 3-2. The Command Decoder uses 17 of the 35 bits for address decoding and verification. The remaining 18 bits are routed to the LVDA for further processing before being forwarded to the LVDC. Ultimately, 14 information bits reach the LVDC as either mode or data command messages. Two interrupt lines, A and B, are logically ANDed together by the LVDA, and the resultant signal is presented to the LVDC as a Command Decoder (CD) interrupt signal. The 2 bits labelled OM/D "A" and OM/D "B" are processed in a similar manner and are presented to the LVDC as a single Orbital Mode/Data (OM/D) bit. The bit is used to identify the type of message as either a mode command or data command.

The 14 information bits make up the full LVDC command word and will appear as bits sign(s) through 13 in the LVDC accumulator. As an assurance of complete accuracy and bit transfer, the "true" command word is found in bits 14 through 8 of the command word,

and bits 7 through 1 contain the same command in complement form.\* Flight program routines are used to check the true number against the complementary number in a final verification before the mode or data command is stored in an LVDC memory location. If, during the check routine, the information bits do not complement each other, the program assumes an erroneous transfer of bits and rejects the whole word. After rejection, an error message is telemetered to the ground, and the command is again transmitted. Seven such attempts are made before that particular command is bypassed.

As a final check, bit 8 of the true command is used as a "sequence" bit. This bit will always be a logic "0" for a mode command, but will alternate between logic "1" and "0" for consecutive words in a data command transmission. This check assures that the data words are received in sequential order. Thus, if two consecutive words have a "0" in bit 8 position, the program assumes that a word is out of sequence or a word has been either omitted or lost.

Therefore, of the original 35-bit command word which was transmitted from the ground, only 7 bits (20 percent) actually contain the mode command or data command transmittal. The 80-percent bit attrition is justified from the standpoint of maximum accuracy and reliability.

\* A complement of a binary or digital number appears in the original number's opposite form; e.g., the complement of binary number 1100011 is 0011100.

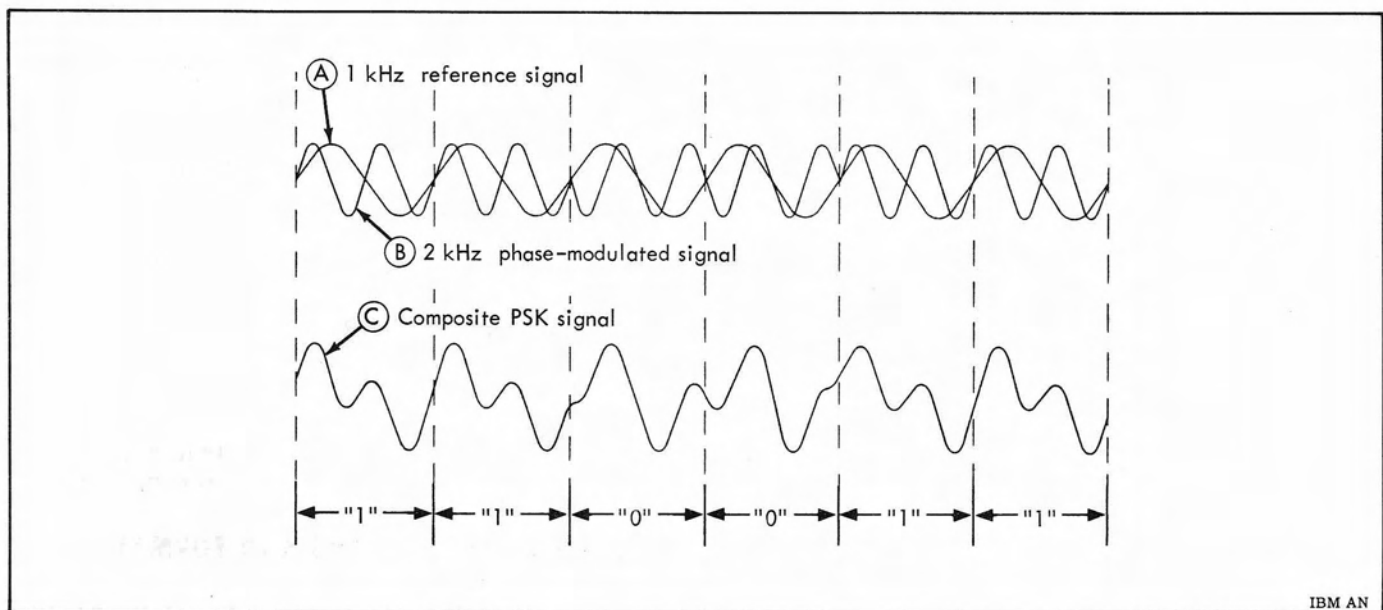


Figure 3-1. Phase Shift Keyed Signals

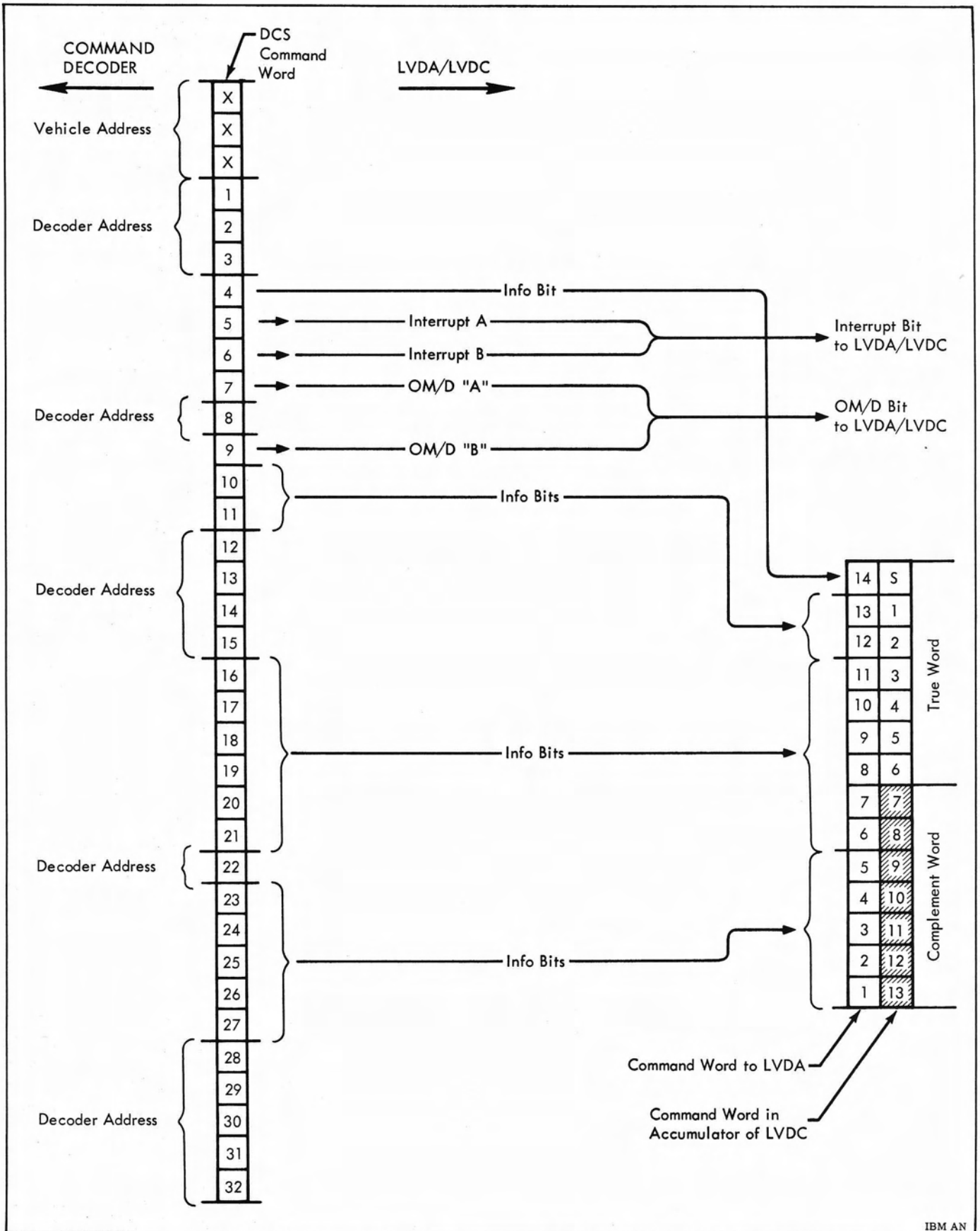


Figure 3-2. Command Word Format



### 3-3 ORBITAL MODE/DATA COMMANDS

As stated previously, the command words are either of two types, mode commands or data commands. The LVDC flight program differentiates between the two by interrogating the OM/D bit (Orbital Mode/Data bit). If the OM/D bit is a logic "1", a mode command is indicated; conversely, if the bit is a logic "0", a data command is indicated. It should be noted that in earlier documentation, the OM/D bit was referred to as the "sync" bit.

#### MODE COMMANDS

Mode commands are accepted by the Command Decoder interrupt routine of the flight program. (The mechanics of this routine will be explained in a later paragraph.) The mode commands are "key" or trigger words which permit the flight program to operate already-programmed (pre-stored) routines. Several of these routines are standard for each vehicle; others are unique to a particular flight test or vehicle. Mode commands and their associated codes are shown in Figure 3-3 for Vehicle AS-503. Mode commands which are standard for the early Saturn Vehicles are:

- Update sequence time base
- Navigation update
- Generalized Switch Selector
- Sector dump
- Telemeter Single Memory Location
- Terminate
- Target loading (variable azimuth).

A brief description of these common mode command routines follows:

Update Sequence Time Base - This routine provides the ground stations with the capability to alter the orbital time base. This mode requires one data command word. When the data has been received, the routine will: (a) format the data for the main orbital program, (b) indicate to the main program that the time base is to be incremented or decremented with the new data, and (c) return to the main orbital program prepared to receive a new mode command.

Navigation Update - This routine enables the ground stations to load six navigation parameters and the

execution time into the LVDC. The parameters are transmitted in the following order:  $\dot{X}_S$ ,  $\dot{Y}_S$ ,  $\dot{Z}_S$ ,  $X_S$ ,  $Y_S$ ,  $Z_S$ , and time. After verification, they are stored in pre-determined LVDC memory locations. Since only six\* information bits are transmitted in one data command, it takes five transmissions to formulate one 26-bit LVDC word. Therefore, it takes 35 data words to complete the 7-word requirement.

Generalized Switch Selector - This routine will provide the ground station with the capability of executing any S-IVB or IU Switch Selector function on command. Two data commands are needed for this routine.

Sector Dump - This routine provides the capability for commanding the LVDC to telemeter the entire contents of one LVDC memory sector or a series of memory sectors within the same memory module. Two data commands are needed to specify the memory sector(s) involved.

Telemeter Single Memory Location - This routine enables the ground station to command the telemetering of a single memory location. Three data commands are needed to complete the addressing scheme of this routine.

Terminate - This routine provides the ground station with the capability to terminate certain LVDC-DCS programs before they have been normally completed. The terminate mode command will also prepare the LVDC to accept a new mode command. Normally, the terminate mode command may interrupt and terminate any of the other mode command routines if they have not completed their data acquisition.

Target Loading - This routine shall provide the capability to load nine targeting parameters into the LVDC. A total of 45 data commands are needed to complete this routine. Five 6-bit words make up one parameter, and each parameter requires one 26-bit LVDC word.

#### DATA COMMANDS

Data commands contain the information required by mode command routines. Generally, each mode command requires one or more data messages before the routine can be run to completion. (The terminate mode command is an exception to this and requires no data.)

---

\* The 7th bit of a data command (in bit position 8) is the sequence bit and does not contain data for the LVDC.

14-Bit Command Word Transferred to LVDA/LVDC								Mode Command Names (AS-503)		
	14	13	12	11	10	9	8	7	1	
1	0	0	0	0	0	1	0	Complement of Bits 14 thru 8		Spare
2	0	0	0	0	1	0	0		Spare	
3	0	0	0	0	1	1	0		Spare	
4	0	0	0	1	0	0	0		Spare	
5	0	0	0	1	0	1	0		Spare	
6	0	0	0	1	1	0	0		Spare	
7	0	0	0	1	1	1	0		Spare	
8	0	0	1	0	0	0	0		Update Sequence Time Base	
9	0	0	1	0	0	1	0		Navigation Update	
10	0	0	1	0	1	0	0		Generalized Switch Selector	
11	0	0	1	0	1	1	0		Sector Dump	
12	0	0	1	1	0	0	0		Telemeter Single Memory Location	
13	0	0	1	1	0	1	0		Spare	
14	0	0	1	1	1	0	0		Spare	
16	0	1	0	0	0	0	0		Terminate	
17	0	1	0	0	0	1	0		Spare	
18	0	1	0	0	1	0	0		Spare	
19	0	1	0	0	1	1	0		Alternate TB4	
20	0	1	0	1	0	0	0		Alternate TB7	
21	0	1	0	1	0	1	0		Spare	
22	0	1	0	1	1	0	0		Spare	
23	0	1	0	1	1	1	0		Spare	
24	0	1	1	0	0	0	0		Spare	
25	0	1	1	0	0	1	0		Target Loading (Variable Azimuth)	
26	0	1	1	0	1	0	0		Spare	

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Figure 3-3. Mode Command Format

The data command word is made up of 14 bits: 6 true bits, 1 sequencing bit, and 7 complementary bits. Bits 14 through 9 contain the true bits, and bits 7 through 1 are the complement bits. Bit 8 is used as a sequencing bit and, in the case of multiple-word transmissions, will alternate from a logic "1" to "0" to "1", etc. This sequencing assures correct continuity of consecutive data word commands.

A specific data format is required for each type of data command. The description of these formats is beyond the scope of this manual.\* However, Figure 3-4 is used as an example of one of the formats. It shows the layout of a navigation update data word format. In this case, 35 such words must be processed before the routine's requirements are fulfilled.

### 3-4 COMPUTER PROCESSING

During the orbital flight, the major loop of the flight program consists of telemetry executive routines (when over receiving stations) and a hardware evaluation program (when out of receiving station range). All other functions, such as navigation, guidance, and control, are processed on an interrupt basis during this flight phase.

The interrupt feature of the LVDC/LVDA is an essential part of the flight program. An interrupt signal stops the computer processing at a convenient point and transfers LVDC control to the activity indicated by the interrupt. Some interrupts are caused by external sources or events and usually start time bases or inform the computer of communications from the ground. Other interrupts are self-generated and are used in control and sequencing functions.

When the computer recognizes an interrupt, it systematically determines the source of the interrupt by examining bits in a special interrupt storage register. Once the interrupt is defined, program control is given to a special routine concerned with the identified interrupt. When processing of the interrupt is completed, program control is returned to the main program at the original point of interruption. Provision has been made for 12 interrupts in the LVDA/LVDC. These interrupts are listed in Table 3-1 in order of decreasing priority. The

\* These formats are defined in the LVDC Equation Defining Document which is distributed by IBM for each vehicle.

Command Decoder routine, called for by bit 8 of the interrupt storage register, will be examined in detail in the following paragraphs.

Once the interrupt is recognized as a Command Decoder interrupt, program control is switched to a specialized processing routine. A typical word flow diagram of this Command Decoder interrupt routine is shown in Figure 3-5. Starting at block 1, validity checks are made on the 14-bit word. This check includes a true-complement test in which bits 14 through 8 are compared with bits 7 through 1. If any of the tests fail (block 2), the computer will disregard the message, send a telemetry error message to the ground, and step an error counter. In addition, the Computer Reset Pulse (CRP) will not be sent to the Command Decoder. A check (block 3) is made of the error counter, and if count has reached a value of 7, the counter is reset to zero and the routine is prepared for a new mode word. However, if the count is less than 7, the routine prepares itself for another attempt (block 7) at receiving the same word from the ground station.

If the word is valid, a check is made to determine if the command word is a mode word or a data word (block 5). Assuming a mode word is received, the routine (blocks 6 and 8) will then:

- Send a CRP to the Command Decoder
- Verify the sequence bit
- Decode bits 14 through 9 and validate the mode
- Reset the error counter
- Telemeter (twice) a status code indicating to the ground that the LVDC has entered the commanded mode routine
- Prepare to receive data (if necessary) to support the routine.

However, if the commanded routine requires no data words, a CRP will not be issued until all program tests have been successfully performed. If the routine requires data, the LVDC will issue a CRP as soon as the program has been set up to accept the correct number of data words.

Once the LVDC is ready to accept data, a Command Decoder interrupt will be able to initiate the following sequence (blocks 9, 10, 11, 12, and 13):

- Establish that the word is a data word
- Send a CRP to the Command Decoder
- Verify the sequence bit
- Temporarily store the data
- Determine if more data is required, and if so, prepare for its reception

- Return to the main program until the next interrupt.

After the LVDC flight program has entered a commanded routine, it will not recognize or accept another mode command (except terminate) until it has finished receiving the required data commands and has executed all of the routine's functions. However, seven consecutive errors on a given data command word will also cancel the routine. The terminate mode command will instruct the LVDC to immediately terminate the routine in operation, clear the error counter, and return to the main orbital program.

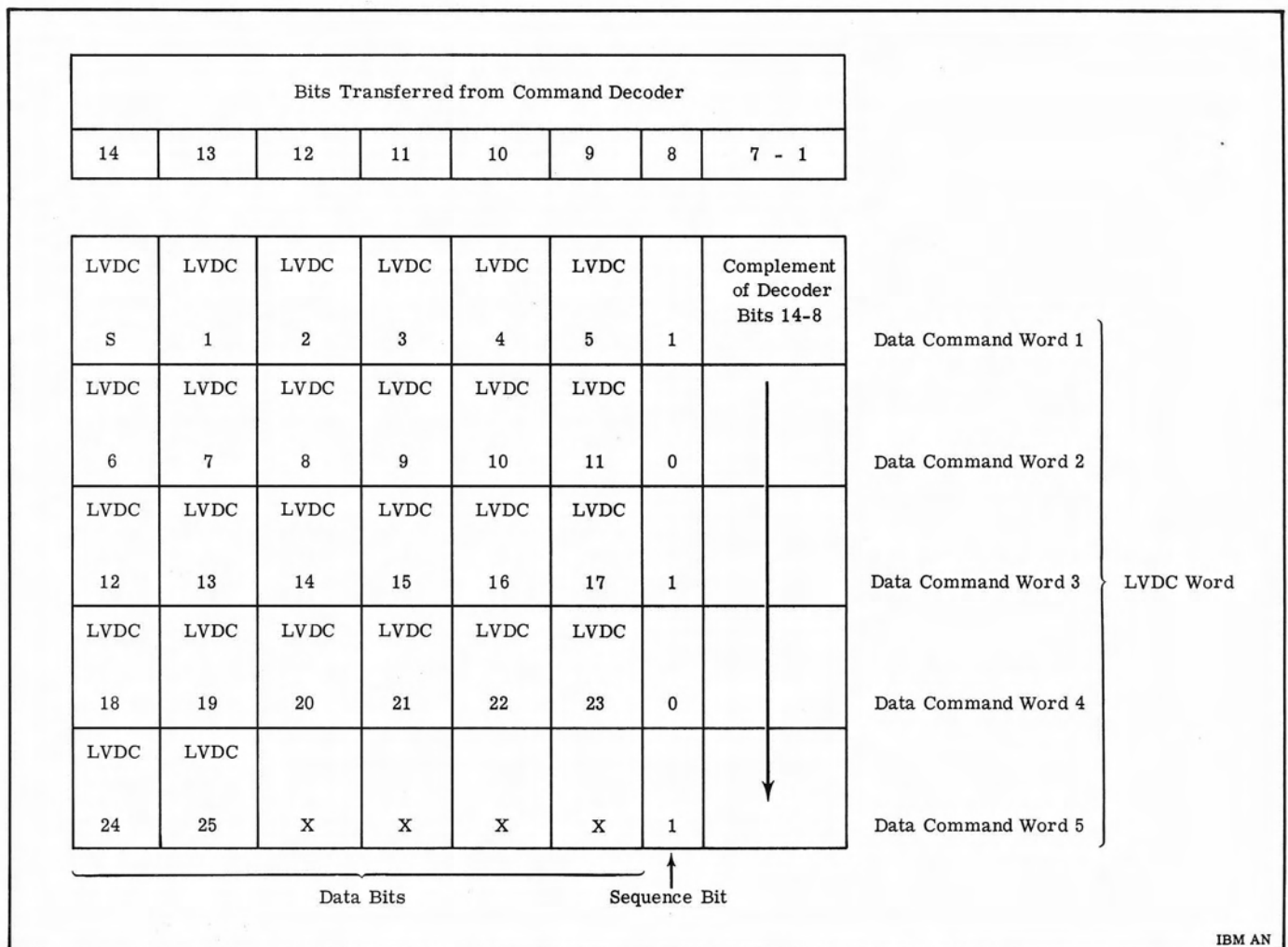


Figure 3-4. Data Word Format for Navigation Update

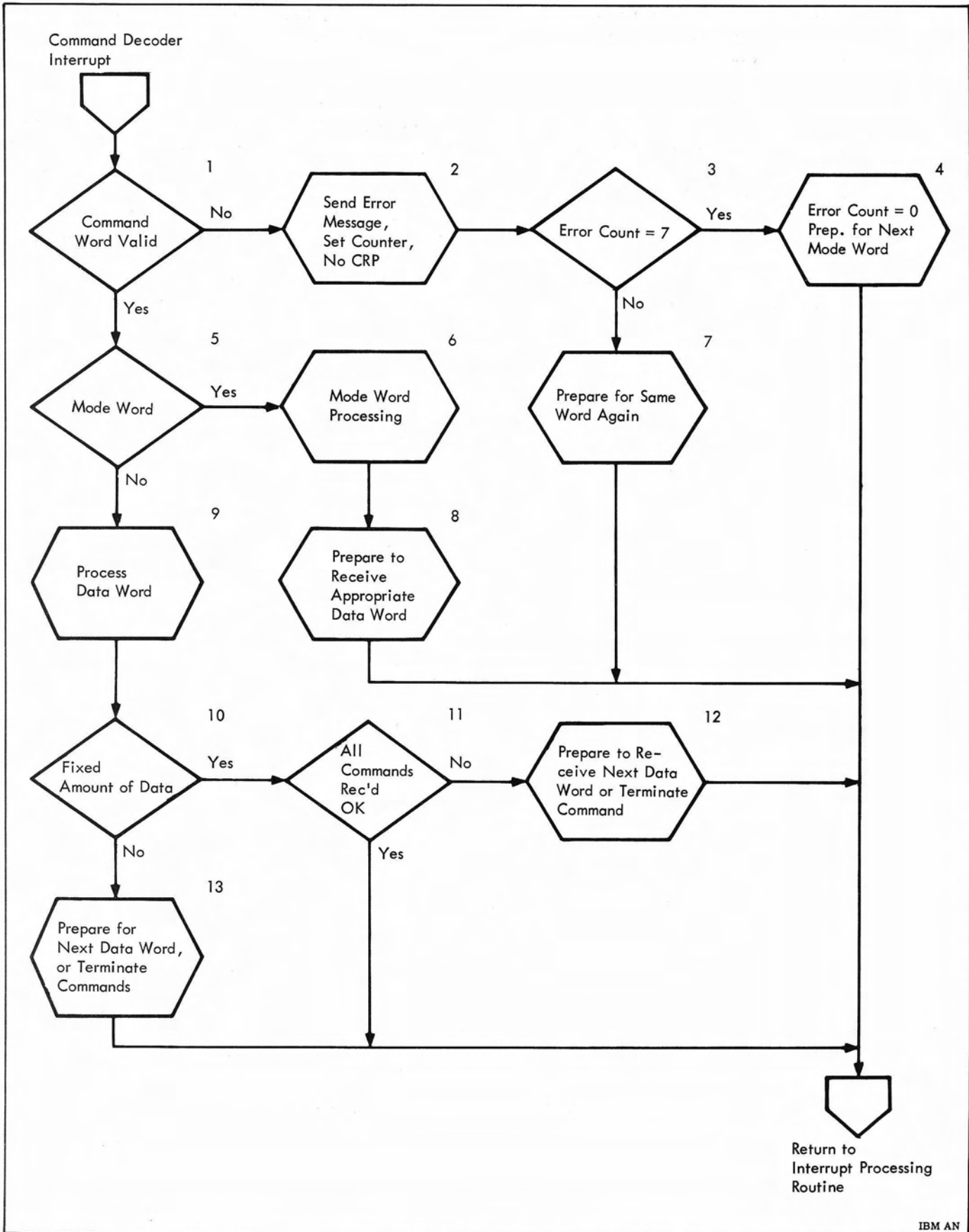


Figure 3-5. Command Decoder Interrupt Flow Chart

Table 3-1. Interrupts

Interrupt Storage Register Bit	LVDC Data Word Bit Position	Function	Vehicle Series	
			200	500
12	Sign	Minor Loop Interrupt	200	500
11	1	Switch Selector Interrupt	200	500
10	2	Computer Interface Unit Interrupt	200	500
9	3	Temporary Loss of Control (TLC)	200	500
8a	4	Command Decoder Interrupt "A"	200	500
8b	4	Command Decoder Interrupt "B"	200	500
7	5	Guidance Reference Release	200	500
6	6	S-II Propellant Depletion/Engine Cutoff	—	500
		Spare	200	—
5	7	S-IC Propellant Depletion/Engine Cutoff	—	500
		S-IB Propellant Depletion	200	—
4	8	S-IVB Engine Out "B"	200	500
3	9	RCA-110A Interrupt	200	500
2	10	S-IC Inboard Engine Out	—	500
		S-IB Low-Level Sense	200	—
1	11	Command LVDA/RCA-110A Interrupt	200	500

## SECTION IV

# COMPONENT DESCRIPTION

The following paragraphs contain a general description of each of the components which make up the IU Command System. For detailed descriptions, refer to the documents which are listed in the List of Related Documents.

The flight equipment presented in this section is in the following order:

- Command Receiver
- Command Decoder
- CCS Transponder
- CCS Power Amplifier
- Command Antenna Systems

The physical positions of these components within the IU are shown in Figures 4-1 and 4-2 for the Uprated Saturn I and Saturn V Vehicles, respectively. The illustrations are typical and may vary with changing vehicle configurations.

### 4-1 COMMAND RECEIVER

#### 4-2 INTRODUCTION

The Command Receiver, shown in Figure 4-3, receives, amplifies, and demodulates the rf command signals transmitted from the various ground stations. The input signals (450 MHz) are coupled from a single command antenna which is mounted on the outside of the IU structure near Position I of the vehicle. The output of the Command Receiver is fed directly to the Command Decoder. The Command Receiver is used only on the Uprated Saturn I Vehicles and is replaced on the Saturn V Vehicles by the multipurpose CCS Transponder which operates in the S-band frequency range.

Characteristics of the Command Receiver are given in Table 4-1.

#### 4-3 DETAILED OPERATION

A block diagram of the Command Receiver is shown in Figure 4-4. The received rf signal is coupled from the rf input, J1, to a fixed-tuned, low-pass filter. The output of the low-pass filter is connected to a critically coupled, double-tuned bandpass filter, which is tunable over the required frequency range of 406 MHz to 450 MHz. The bandpass filter output is amplified by an rf amplifier stage. This amplifier provides additional rejection to signals outside the receiver passband and is tunable over the required frequency range. The low-pass filter, bandpass filter, and rf amplifier are contained in the preselector assembly.

The preselector rf amplifier output is coupled to the first mixer. Here the multiplied output of the local (crystal) oscillator is heterodyned with the rf signal to produce the first IF signal. The first IF signal is amplified by the first IF amplifier and applied to the second mixer, where it is heterodyned with a signal at the local oscillator frequency to produce the second IF signal. The local oscillator is crystal controlled. The first and second mixer, first IF amplifier, crystal oscillator, and x3 frequency multiplier are contained in the first IF assembly.

The output of the first IF assembly is coupled directly to an IF bandpass filter. This passive LC filter determines the overall receiver bandpass characteristics.

The bandpass filter output is fed to the second IF assembly, which contains two feedback amplifier pairs. The output of the second amplifier pair feeds both the limiter-discriminator assembly and the signal strength telemetry circuit. The low-level signal strength telemetry output is a dc voltage that is proportional to the receiver rf input signal.

Limiting is accomplished in the first limiter by back-to-back diodes in the limiter's collector circuit. The second limiter limits by saturation and

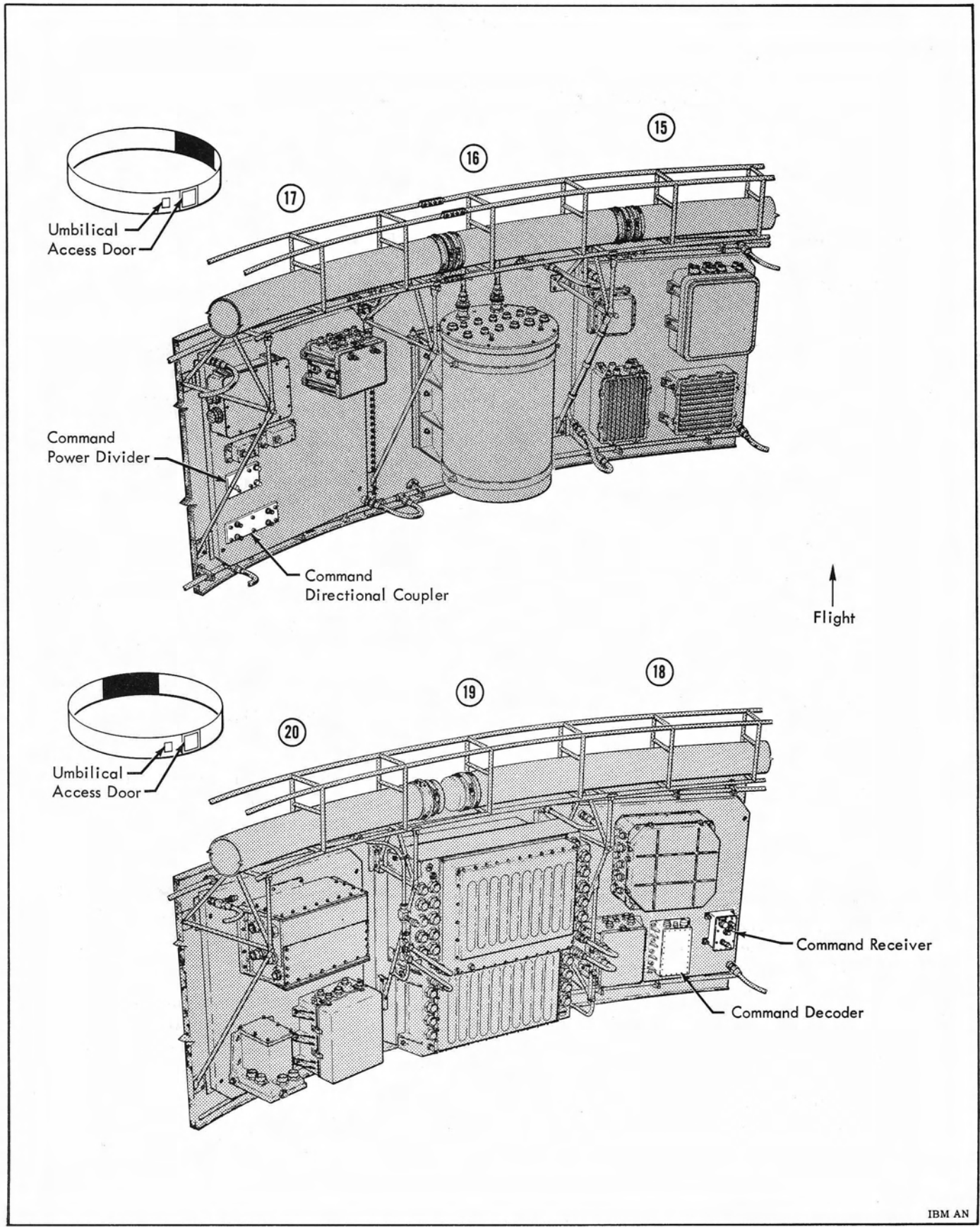
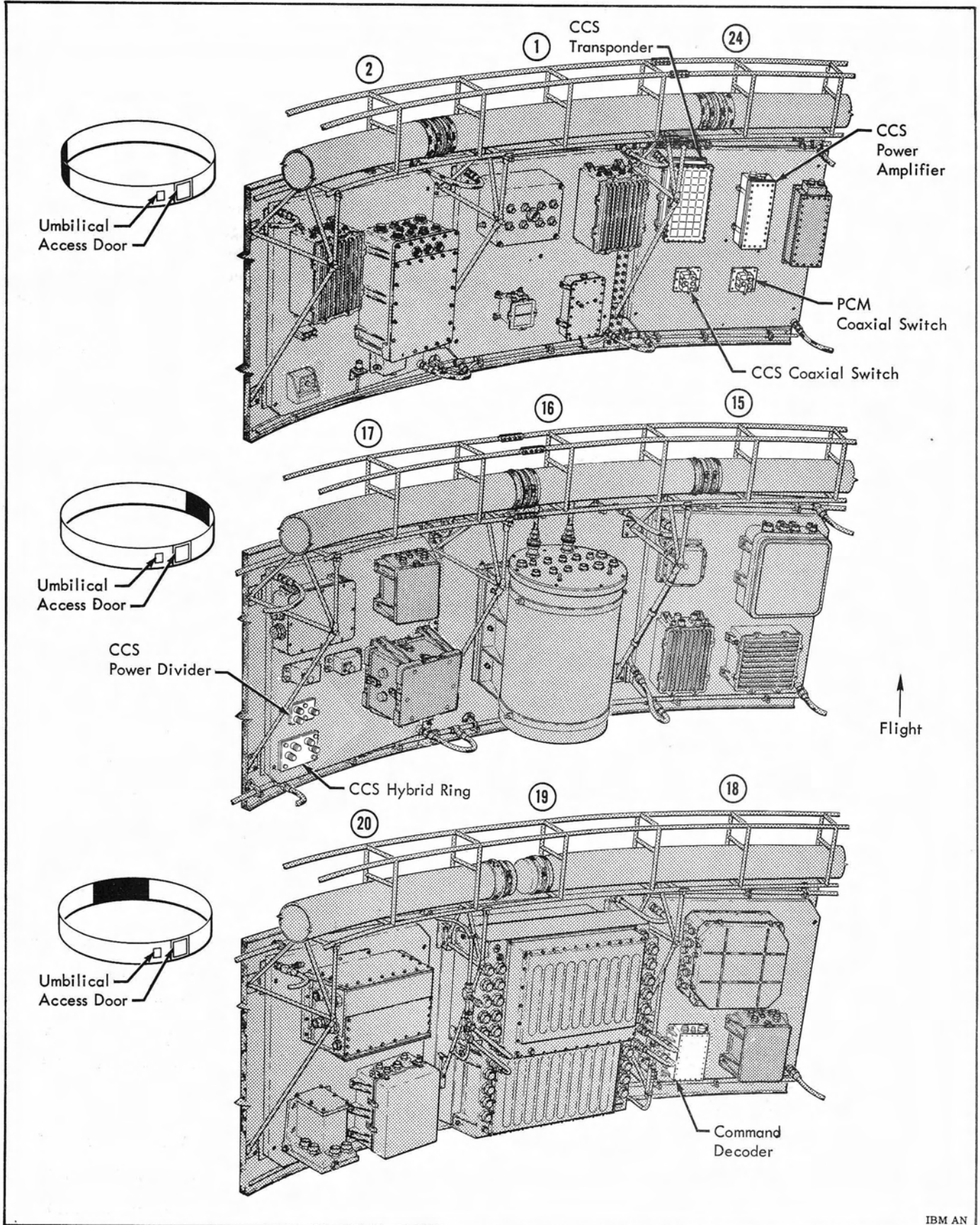


Figure 4-1. Uprated Saturn I Command System Equipment Layout





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Figure 4-2. Saturn V Command System Equipment Layout

cutoff of the circuit and drives a Foster-Seeley type discriminator. An emitter follower output stage is used for impedance isolation between the discriminator and the audio amplifier.

The audio frequency amplifier consists of a voltage amplifier stage, a phase inverter, and a low-impedance output amplifier stage. The amplifier output feeds two isolation resistors, each one of which feeds an output connector. These resistors allow one output to be shorted to ground without appreciably reducing the other output voltage. One of these outputs is used as the input signal to the IU Command Decoder. The amplifier output also feeds a band-pass filter. This filter output is fed to an AGC-controlled amplifier and then to a high-level telemetry detector circuit. The telemetry voltage thus obtained will provide a useful measure of rf input signal.

The low-level dc telemetry output provides a measurement of rf input signals in the threshold region, which is between 0 and 10 microvolts. The high-level dc telemetry output provides a measurement of rf input signals between 0 and 500 microvolts.

The input power leads and the output telemetry leads are filtered to meet rfi requirements. This filtering is accomplished in an rfi filter and regulator assembly. The voltage regulator converts a nominal +28 Vdc input voltage to a fixed +15.5 Vdc output. A single +15.5 Vdc voltage is used for all assemblies requiring power.



Figure 4-3. Command Receiver

## 4-4 COMMAND DECODER

### 4-5 INTRODUCTION

The data flow for the Saturn IU Command System is from the command receiving equipment, through the Command Decoder, to the LVDA/LVDC computer system. The information is routed through the Command Decoder for decoding and preliminary verification tests. If a transmission error occurs (e.g., a bit is missed), the message is rejected. If all bits are received and they are in their proper order and sequence, the Command Decoder then verifies the address, transfers the command portion to the LVDA,

Table 4-1. Characteristics of the Command Receiver

ELECTRICAL	
Frequency Range	406 to 450 MHz
Frequency Deviation (for 1 Vrms output)	± 30 kHz
Quieting	15 db at 10 microvolts
Maximum RF Input	2.0 Vrms
Input VSWR (max)	1.5:1
Tuning Stability	± 30 kHz
Oscillator	Crystal controlled, single crystal
RF Bandwidth (-3 db)	340 ± 30 kHz
RF Bandwidth (-60 db)	1200 kHz
Type of Output	Audio, two isolated outputs
Audio Bandwidth (-3 db)	100 Hz to 80 kHz
Audio Distortion	Less than 5 percent
Audio Output Level	1 Vrms into 75 ohms
Input Voltage	+24 Vdc to +36 Vdc
Power	3.5 watts at 28 Vdc
PHYSICAL	
Height	11.1 cm (4.3 in.)
Width	13.4 cm (5.3 in.)
Depth	11.9 cm (4.7 in.)
Weight	1.4 kg (3 pounds)

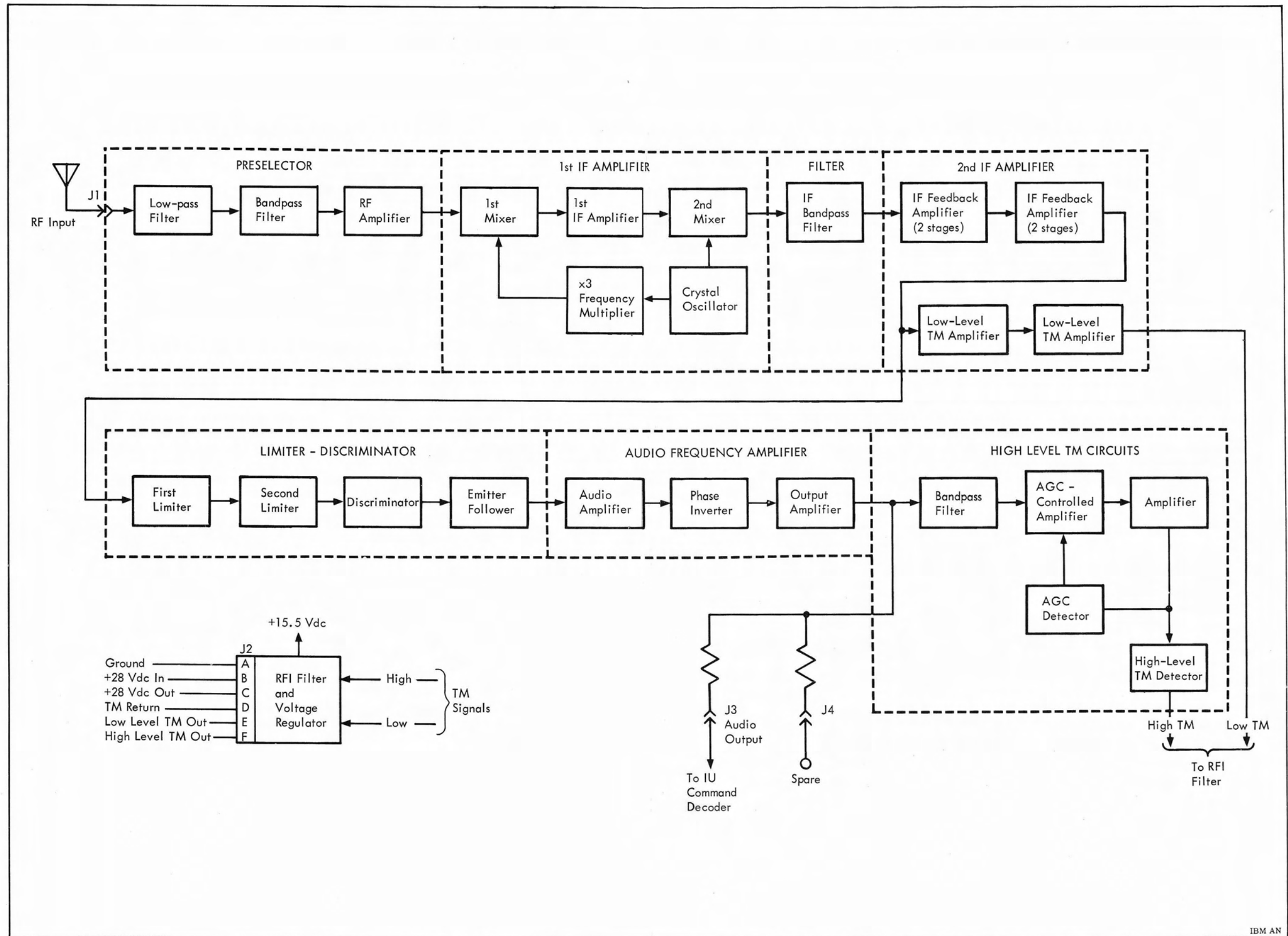


Figure 4-4  
Command Receiver Block Diagram  
4-5/4-6

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and generates telemetry discrettes to indicate that the above functions have occurred.

The Command Decoder, shown in Figure 4-5 is common to both the Uprated Saturn I and the Saturn V Vehicles. The physical and electrical characteristics of the Command Decoder are given in Table 4-2.

#### 4-6 LOGIC DESCRIPTION

A detailed description of the Command Decoder operation is given in the following paragraphs. Figures 4-6 and 4-7 supplement the text. Figure 4-7 is a block diagram of the circuitry discussed. An explanation of the logic symbols used is found with the figure.

#### PSK DETECTOR

The PSK data signals from the Command Receiver are first routed through two filters—a band-pass filter and a narrow band filter not shown on figure 4-7—before being applied to the PSK sub-bit detector. The detector is shown in the upper left-hand portion of the figure.

The PSK sub-bit detector amplifies and shapes the 1 kHz and 2 kHz signals from the filter to determine the phase of the 2 kHz signal with respect to the 1 kHz signal. The relative phase of the signals determines the sub-bit "1's" and "0's" as required. The detector output is then applied to the appropriate (set or reset side) of a 5-bit shift register and is also used to step a 5-bit counter circuit.

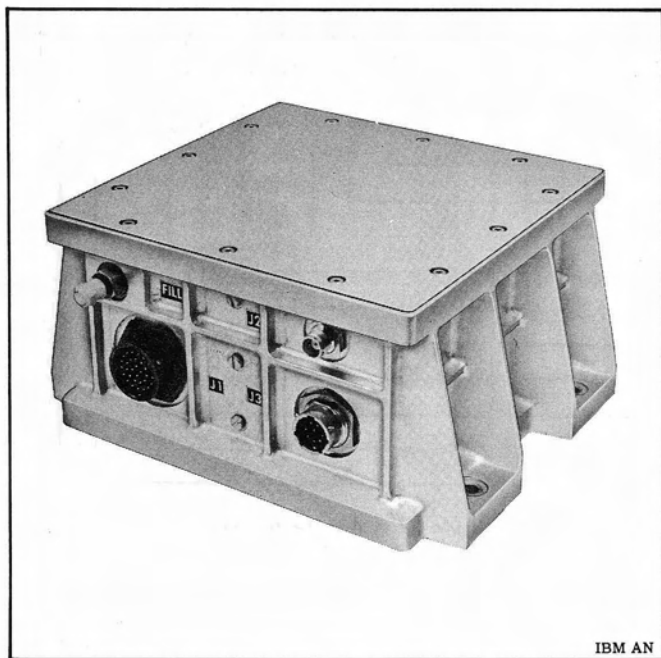


Figure 4-5. Command Decoder

#### 5-BIT COUNTER AND SHIFT REGISTER

The sub-bit "1's" and "0's" from the sub-bit detector are written into the 5-bit shift register as required and routed to code plug J4. From the code plug, the appropriate sub-bit "1's" and "0's" are connected to their respective AND circuit comparators. Figure 4-6 shows a typical wiring scheme of code plug J4.

As each group of 5 sub-bits is written into a 5-bit shift register, they are counted by the 5-bit counter. When the counter reaches a count of five, a positive pulse is produced and used to open gates AND5, AND6, and AND10 (through OR3) to provide a "1" code enable, "0" code enable, or an "X" bit count pulse only when the correct sub-bit pattern is written into the 5-bit shift register.

The shift register has 10 outputs (2 for each position) resulting in  $32(2^5)$  possible sub-bit patterns. Each of the 3 sub-bit comparators, "X", "0", and "1", (AND10, AND8, AND9) have 5 wires connected to the 5-bit shift register, via code plug J4, 1 wire to each position. Hence, gate AND10 will have an output when the correct 5-bit code is written into the 5-bit shift register, thereby generating an "X" code bit. The same is true for AND8 and AND9, thereby generating a "0" code or a "1" code, respectively. For example, the sub-bit code for a data

Table 4-2. Command Decoder Characteristics

ELECTRICAL	
Primary Voltage	+22 to +38 Vdc
Operating Current	70 to 90 ma
Audio Input	0.65 to 2.25 Vrms
Binary Output Functions	
"One"	+25 to +28 Vdc
"Zero"	-0.5 to +0.5 Vdc
Data Output Impedance	Less than 1000 ohms
PHYSICAL	
Weight	3.85 kg (8.5 pounds)
Height	10.79 cm (4.25 in.)
Length	22.60 cm (8.90 in.)
Width	18.39 cm (7.24 in.)

"1" may be chosen as "11010", the sub-bit code for a data "0" may be chosen as the data "1's" complement, (00101), and the "X" sub-bit code may be chosen to be "11000".

During intervals when no messages are being transmitted, all sub-bit "1's" are transmitted. However, the comparators have no output since there is no code pattern. The first three data bits of a transmitted message are designated as "vehicle address" and are sub-bit coded as "X's." Since the message is bracketed by continuous sub-bit "1's," the "X" comparator is initially enabled by the output from OR3, permitting an "X" comparison at any time the 5-bit shift register pattern is correct. The "X" bits are counted in a 3-bit counter referred to as the "X" counter. The "count of three" output of this 3-bit counter enables AND3 and AND4 only after three "X" bits have been counted.

The input to the missing-bit clock (center of the figure) is the output from OR5. The composite signal is therefore the "X" bit count, "1" code enable, or "0" code enable. During normal message decoding the pulse spacing is 5 milliseconds (200 bps). The missing-bit clock is essentially two monostable multivibrators which, if a proper message is being received,

will provide a continuous output from OR6. This is accomplished by alternately triggering the multivibrators. The ON cycle of the multivibrators (5.4 milliseconds) is adjusted to be slightly greater than the duration of each data bit (5.0 milliseconds). Thus, the OFF multivibrator is triggered ON, 400 microseconds before the ON multivibrator completes its cycle. Under normal operating conditions and with no bit missing, OR6 will always have at least 1 input.

The output from AND2 at the first "X" bit will reset the 5-bit counter and will pass through OR4 to reset the 3-bit counter. The 3-bit counter is also reset through OR4 by the pulse from OR6 when the absence of a bit is detected by the missing-bit clock or when the computer reset pulse occurs at the completion of a data transfer to the LVDA.

32-BIT SHIFT REGISTER

The 32 bits following the three "X" bits are coded "0's" or "1's" as required. Each time a count-of-five state is reached by the 5-bit counter a comparison is made to determine if the bit is a "0" or a "1". These 32 bits are written into a 32-bit shift register.

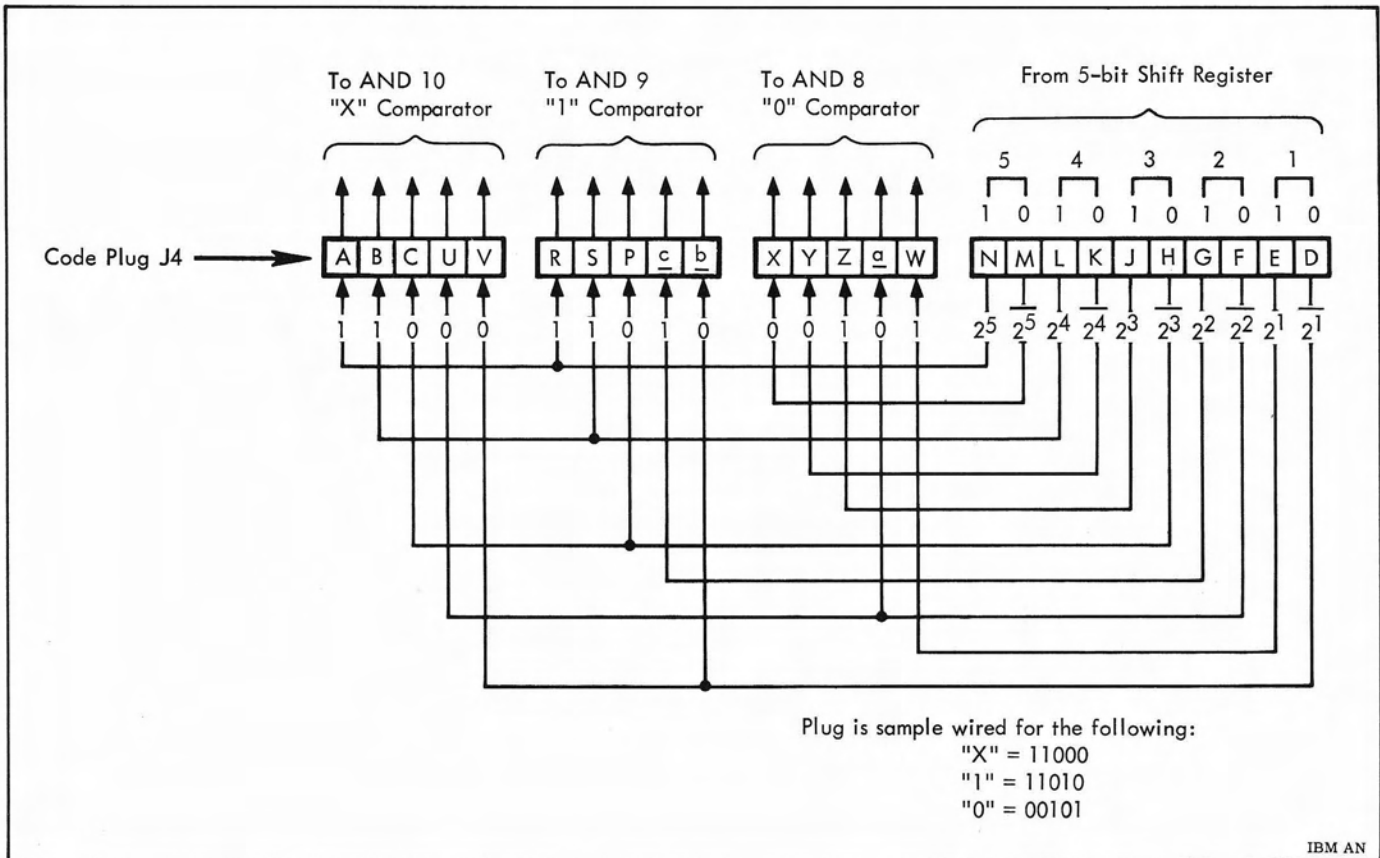


Figure 4-6. Sample Wiring of Code Plug J4

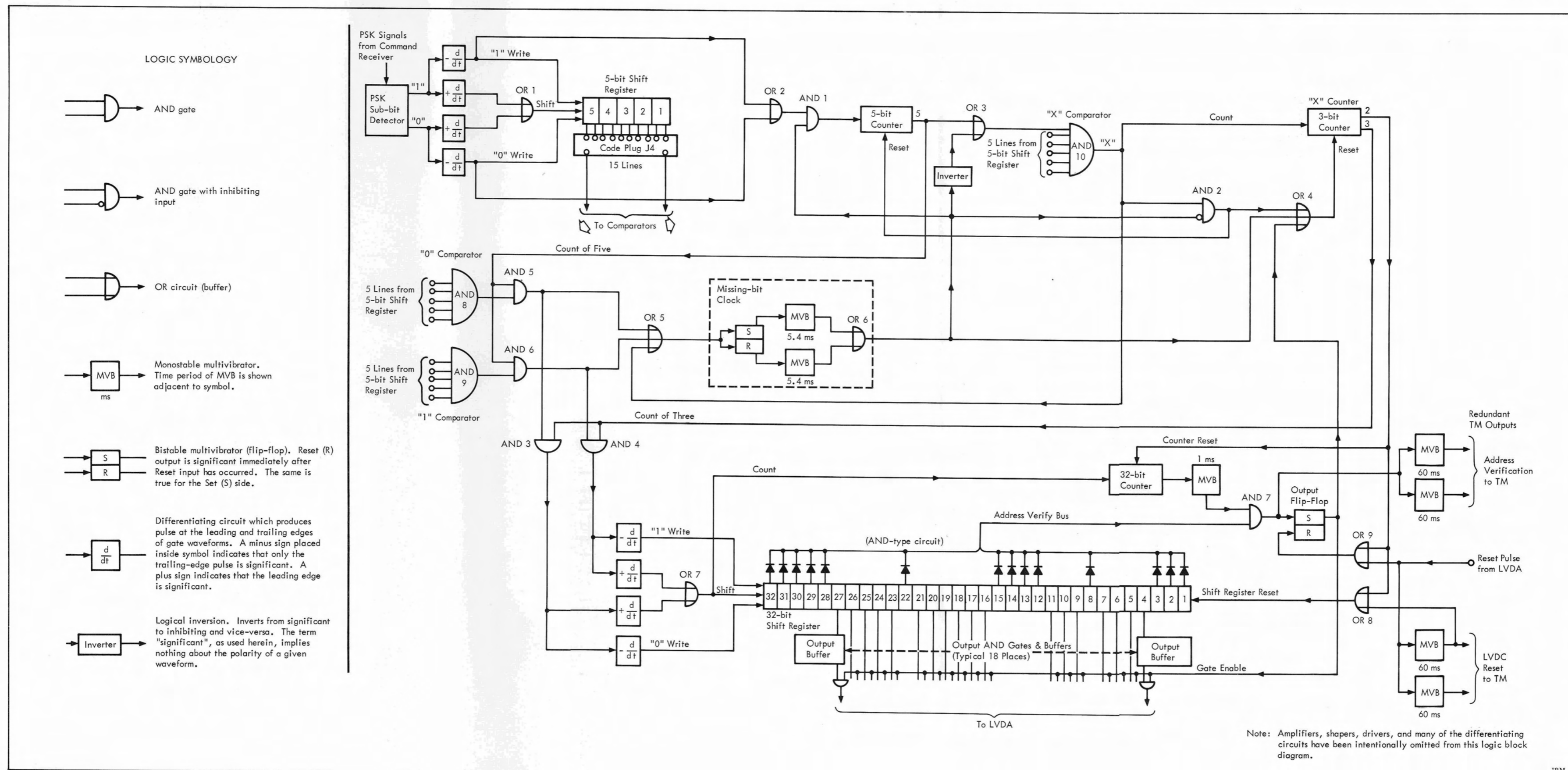


Figure 4-7  
Command Decoder Logic Diagram  
4-9/4-10

The decoder address is prewired and composed of 14 of the 32 bits of the shift register. These 14 bits must be true to have an output on the address verify bus. The diodes of the bus may be connected to the set or reset side of each shift register stage as prescribed by the decoder address desired.

The 18 data bits are buffered and sent to the LVDA for processing. For simplicity, the complete buffering and gating logic is not shown in the figure.

#### SHIFT OUT AND 32-BIT COUNTER

The input shift pulses to the 32-bit shift register are counted by the 32-bit counter. At a count of 32, a multivibrator (MVB) is triggered, strobing gate AND7. At this time, the 32 data bits have been completely written into the 32-bit shift register. If the decoder address in the register is correct, gate AND7 is opened and the output pulse is used to:

- Set the output flip-flop to enable the output buffer gates
- Reset the 3-bit counter
- Trigger the address verify MVB's

The computer reset pulse, which occurs after computer acceptance of the command message, resets the output flip-flop through OR9, thus disabling the output AND gates. The computer reset pulse also triggers two computer return MVB's. Their output is returned to OR8 to reset the 32-bit shift register.

#### OUTPUT MONOSTABLES

The address verify pulse from the address verify bus (via AND7) is routed to two redundant MVB's. The output pulse width on the MVB's is set to 60 milliseconds and is sent to the telemetry system to denote decoder address verification. As mentioned in the preceding paragraph, the computer reset pulse from the LVDA is used to trigger another pair of redundant MVB's (60 milliseconds). These MVB's acknowledge receipt of the computer reset pulse. Although not shown, the outputs of the MVB's are buffered to meet the required input voltage levels of the IU telemetry system.

#### 4-7 DETAILED OPERATION

The first "X" bit comparison in the command message generates a 1-millisecond pulse which passes through AND2 and resets the 5-bit counter and through OR4 to reset the 3-bit counter. The pulse also advances the 3-bit counter by one count and starts the

missing-bit clock. When the missing-bit clock starts, the output of OR6 will: (1) open AND1, enabling the 5-bit counter, and (2) inhibit AND3, preventing the next "X" comparison from generating a reset.

As the next 5 sub-bits are written into the 5-bit shift register, they are counted by the 5-bit counter. When the counter reaches a count of five, the output passes through OR3, thus enabling a second "X" comparison. A valid "X" comparison will generate a 200-microsecond pulse. This pulse will advance the 3-bit counter to the count-of-two state and will also keep the missing-bit clock running. The count-of-two output from the 3-bit counter will (1) clear the 32-bit shift register through OR8 (the cleared state of this register is when there is a "0" stored in the "0" side of all 32 stages), (2) send a reset pulse to the 32-bit counter, and (3) send a reset pulse to the output flip-flop through OR9. After the third "X" bit has been recognized, the count-of-three output from the 3-bit counter will provide a direct-coupled signal to AND3 and AND4. As long as this signal is present, AND3 and AND4 are "open"; i. e., they will allow valid "0" and "1" bits to pass through.

The next 32 bits will be sub-bit coded with "0's" and "1's" as received. Each time a count-of-five state is reached by the 5-bit counter, a comparison is made to determine if the bit is a "0" or a "1". A pulse will be produced at the output of OR5, thus keeping the missing-bit clock running. These 32 bits will also be shifted and written into the 32-bit shift register and counted by the 32-bit counter. Upon the count of 32, the 1-millisecond monostable multivibrator is triggered ON. This signal opens AND7 and allows an address comparison to be made. If the address is correct, a signal will pass through AND7 and trigger the output gate flip-flop to its set state. In addition, two 60-millisecond monostable multivibrators will be triggered ON by AND7 to provide an indication to the telemetry system that the address was valid. Redundant multivibrators are used for reliability.

The set output of the output gate flip-flop also resets the 3-bit counter (through OR4) and provides an enabling voltage to the 18 data-output AND gates. The binary information stored in the 18 data stages of the 32-bit shift register is thus transferred in parallel form to the LVDA. When the LVDC data processing routines accept these data bits, a reset pulse (acknowledging receipt) is sent through the LVDA to the decoder. This pulse will pass through OR9 to reset the output flip-flop (disabling the 18 output AND gates). The same pulse will also trigger two 60-millisecond monostable multivibrators and

thus clear the 32-bit shift register through OR8. The outputs of these multivibrators are sent to the telemetry system to indicate receipt of the LVDC reset pulse. If, for some reason, the LVDC reset pulse does not arrive prior to the beginning of the next message, the second "X" bit of vehicle address will provide an output from the 3-bit counter to reset the decoder circuits.

## 4-8 CCS TRANSPONDER

### 4-9 INTRODUCTION

The CCS Transponder is a continuous-wave, phase-coherent transponder which operates in the S-band frequency range. As its name implies, the CCS Transponder is capable of receiving and retransmitting an encoded ranging and tracking signal. In addition to this conventional "turn-around" function, the unit has two other primary functions. First, it is able to receive and demodulate PSK command signals transmitted from MSFN ground stations, and second, it is able to transmit PCM telemetry signals originating in the Saturn V telemetry system.

The CCS Transponder, herein referred to as Transponder, is shown in Figure 4-8. Characteristics of the Transponder are listed in Table 4-3.

Although the transponder has a turn-around capability, this function is not utilized in the present IU/CCS configuration since two similar transponders (located in the Spacecraft) are used for that purpose. However the CCS tracking system may be used in case of a failure of the other transponders or if a cross check is desired.

The Transponder's capability consists of being able to coherently receive and transmit a Pseudo-Random Noise (PRN) code. The unique code originates

at the ground ranging stations and is used to measure range and position at lunar distances (or less). Because of these long ranges and the propagation time involved, the signals must be encoded to avoid any chance of ambiguity. A later paragraph will briefly describe the ranging techniques and code.

During launch and earth orbit, the CCS telemetry feature will not be used. The vhf telemetry transmitter system is used instead. However, at greater distances (10,000 kilometers or 5400 nautical miles) from the ground stations, vhf antenna gains become inadequate and IU telemetry signals are then transmitted from the CCS/UHF S-band systems.

Figure 4-9 is a simplified block diagram of the Transponder. Input signals to the Transponder include rf signals from the antenna system and PCM telemetry data from the IU telemetry system. Output signals include rf signals to the CCS Power Amplifier, phase-shift keyed command data to the Command System, and telemetry measurements and discretets to the telemetry system. The Transponder consists of 2 sections—a receiver and transmitter section. Physically, the various receiver and transmitter modules are contained in separate sections of the Transponder case to decrease circuit interaction. The modules, in turn, are isolated to individual functions; i.e., first IF amplifier, frequency divider, command demodulator, etc. Fifteen separate modules with various subassemblies are used in the Transponder.

The receiver section, shown in the figure, accepts the up-link rf signal from the IU antenna system, converts the S-band frequencies to a usable IF signal, and then recovers the PRN ranging code and/or command data.

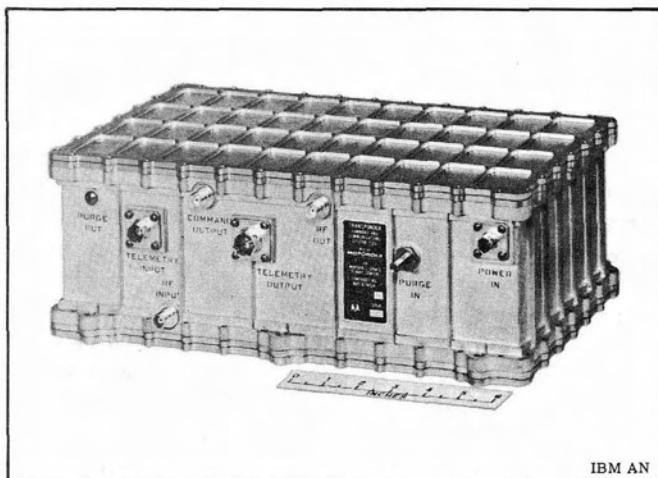


Figure 4-8. CCS Transponder

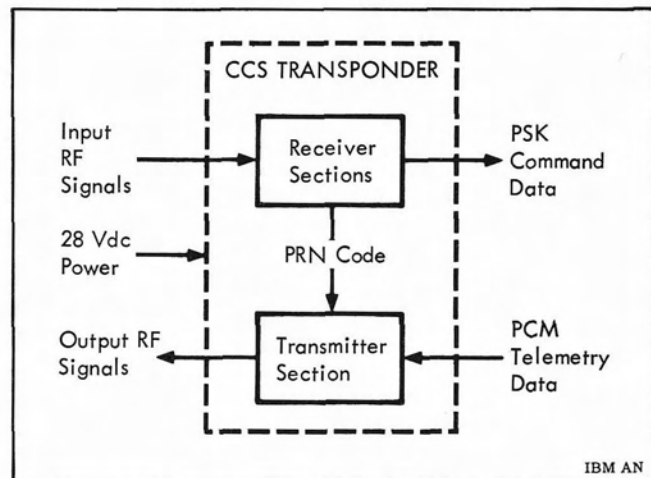


Figure 4-9. CCS Transponder Simplified Block Diagram



The transmitter section contains a phase modulator that reacts to the PRN ranging code from the receiver and/or biphas modulated 1.024 MHz telemetry subcarrier. This telemetry subcarrier is generated by a crystal-controlled oscillator in the transmitter section. In turn, the subcarrier is bi-phase modulated with telemetry data from the IU telemetry system. The transmitter may be disabled (by external command) to permit the Transponder to function only as a receiver.

Discrete digital telemetry outputs indicating receiver lock status and 70 kHz subcarrier presence are provided. Analog outputs are also provided to indicate tracking loop phase error and received signal level (agc voltage).

A variable duty factor power supply provides the operating voltages for the Transponder. The power supply operates from a nominal 28 Vdc input source and provides regulated 28 Vdc, 15 Vdc, and -15 Vdc for the solid-state circuits within the Transponder.

#### 4-10 DETAILED TRANSPONDER OPERATION

The S-band signals received by the IU CCS Omnidirectional Receiving antennas are coupled to

Table 4-3. CCS Transponder Characteristics

ELECTRICAL	
Frequency Received	2101.8 MHz
Frequency Transmitted	2282.5 MHz
VCO Frequency	19.02 MHz
Receiver Bandwidth	12 MHz
Transmitter Bandwidth	25 MHz
Transmitter Output Power (min)	250 mW
Input Power (max)	35 W
Input Voltage	24 to 32 Vdc
PHYSICAL	
Height	13.7 cm (5.4 in.)
Length	37.8 cm (14.9 in.)
Depth	24.9 cm (9.8 in.)
Weight	9.75 kg (21.5 pounds)

a preselector circuit in the Transponder (Figure 4-10). A preselector eliminates most of the unwanted frequencies and permits the desired frequencies to pass to the first mixer.

A first mixer stage receives a local oscillator signal frequency from a x108 frequency multiplication circuit. The 2 signals are combined in the mixer to produce the usual superheterodyne frequencies at its output.

Following the first mixer is a preamplification stage that includes a bandpass filter, which passes only the difference-frequency component of the mixer output. The amplifier gain of this circuit is controlled by an agc voltage.

The output of the preamplifier, the first IF frequency, is applied to the first IF amplifier. This amplifier provides gain for the first IF signal, with gain control again being a function of agc voltage, before application to the second mixer.

The second mixer receives a second local oscillator signal frequency from a x3 frequency multiplication circuit. The superheterodyne frequency output of the second mixer is applied to a bandpass filter and a demodulation circuit.

The second IF output signal from the bandpass filter is applied simultaneously to a linear IF amplifier and to a limited IF amplifier. The second IF signal that is amplified by the linear amplifier is applied to the agc circuit. The second IF signal that is amplified by the limited amplifier is applied to a phase-lock loop.

The signal applied to the demodulation circuit is phase demodulated, leaving a PRN ranging code and a frequency-modulated 70 kHz subcarrier. The PRN ranging code is sent to the transmitter section for modulating the down-link signal. The subcarrier is demodulated by a detector circuit into a composite audio signal that contains phase-shift-keyed digital information. This signal is then applied to the command Decoder for decoding and ultimate use by the IU Command System. The demodulator circuit is disabled if the receiver is not in phase lock.

When the receiver is in phase lock with the received signal, a voltage-controlled oscillator in the phase-lock loop provides a signal to a control amplifier in the transmitter section. If the receiver is not in phase lock, this signal is disabled by the control amplifier before reaching the Transmitter

x4 frequency multiplier. Instead, the auxiliary oscillator is enabled to provide a signal to the x4 multiplier at the same frequency. In this manner, a carrier signal is applied to the x4 frequency multiplier regardless of whether the receiver is in or out of phase lock.

The x4 frequency multiplier provides an input to the modulation circuit that is the fourth harmonic of the voltage-controlled oscillator or auxiliary oscillator signal frequency. This carrier signal is applied to a modulation circuit where it is phase modulated by the biphasic modulated subcarrier (generated in a subcarrier oscillator and biphasic modulator circuit). Also, if the receiver is in phase lock, the PRN ranging code is similarly modulated on the carrier. The phase-modulated carrier is then given x30 frequency multiplication, amplification, and filtering before leaving the Transponder as the down-link signal. The output signal from the transmitter, however, may be disabled by a command input signal, and the Transponder will then function only as a receiver.

The Transponder also provides four isolated telemetry output signals for the vehicle telemetry system. Signal strength and in-lock status telemetry outputs are derived from the AGC loop; a static phase error telemetry output is derived from the phase-lock loop; and 70 kHz subcarrier status is derived from the demodulation circuit.

#### 4-11 UNIFIED S-BAND RANGING SYSTEM AND CODE

##### NOTE

Although the unified S-band ranging system is not directly related to the IU Command System, a brief description of the system is included at this point because of the turnaround ranging capabilities of the CCS Transponder.

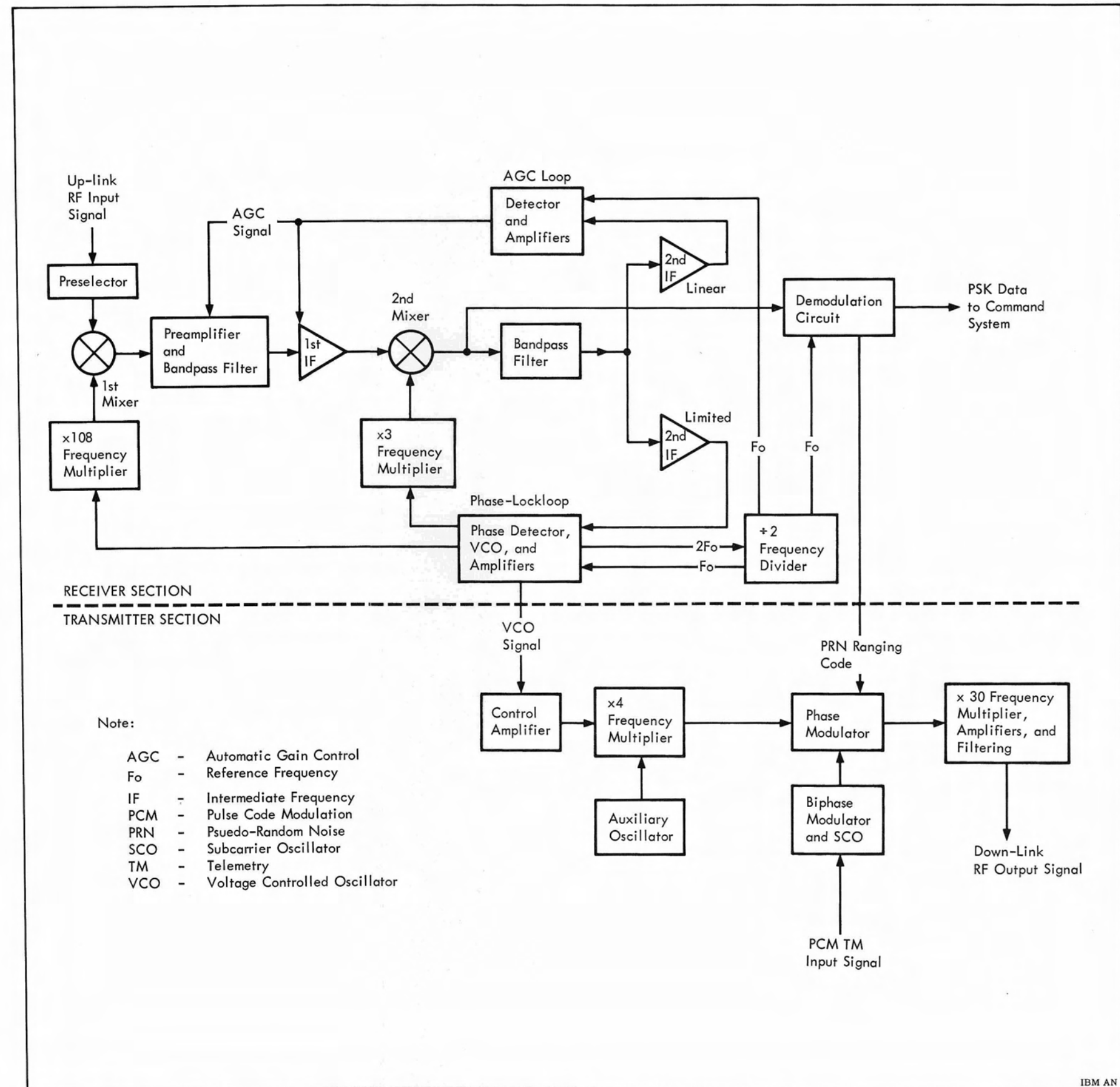
The unified S-band ranging system measures the distance between the ground station and space vehicle. As with most ranging schemes, this system depends upon an extremely accurate measurement of the round-trip travel time for some signal or code generated by the ranging station. Mission requirements call for measurements at maximum lunar distances of 0.8 million kilometers (0.4 million nautical miles) with a theoretical accuracy approaching  $\pm 1$  meter (3.28 feet) at this lunar range.

The ranging station transmits an S-band carrier which is modulated by a unique Pseudo-Random Noise

(PRN) ranging code. The signal is received and demodulated by the spacecraft transponder, and the same PRN code is used to modulate a down-link S-band carrier that is phase coherent with the received carrier signal. A difference between up-link and down-link carrier frequencies provides a simultaneous transmission and reception capability. At the tracking station, the return (received) signal is demodulated, and the recovered code is then effectively compared with a facsimile of the transmitted code. The time difference between the occurrence of corresponding transmitted code pulses and received code pulses is recorded in a tally device. The unit of measure is referred to as a range unit, and the range data output is in binary units.

The PRN code is composed of binary "1's" and "0's" combined by a code generator in such a manner that repetition of the resulting pattern occurs only after a length of several million bit periods. By utilizing such a code, the chances of ambiguous return signals is eliminated. In essence, any given portion of the code is returned to the ground before it is repeated. The actual code is generated by combining, bit by bit, several repetitive shorter subcodes in accordance with a particular Boolean logical relationship. Five subcode components are used with bit lengths of 2, 11, 31, 63, and 127. The length (in bits) of the total composite code is the product of the lengths (in bits) of the individual subcodes, or 5, 456, 682 bits. Since each bit period is approximately 1 microsecond in length, enough time elapses to complete the round trip before the lengthy pattern repeats itself. One microsecond corresponds roughly to 300 meters (984 feet) of round-trip distance or 150 meters (492 feet) of one-way range.

A simplified block diagram of the S-band ranging system is shown in Figure 4-11. In the actual ranging scheme, two code generators are used. One generator, the transmitter code, supplies the original code. A second generator, the receiver coder, is originally synchronized with the transmitter codes to establish a "zero" reference and is then delayed or offset (in time) by enough of the 5 million bits to exactly match, bit for bit, the returning code as it is being recovered in the receiver. A range tally device keeps track of this amount of offset (range units). After the initial correlation of the two sets of code patterns, a finer resolution of range is obtained by tallying fractional parts of each doppler cycle of the carrier frequency. This method ultimately results in a resolution of approximately  $\pm 1$  meter.



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Figure 4-10  
CCS Transponder Detailed Block Diagram

## 4-12 CCS POWER AMPLIFIER

### 4-13 INTRODUCTION

The CCS Power Amplifier, shown in Figure 4-12, is used on Saturn V Vehicles to amplify the modulated S-band signal originating within the CCS Transponder. Input signal power required to drive the amplifier is 250 to 500 milliwatts at the center frequency of 2282.5 MHz. Nominal power gain of the unit is 17 db. Characteristics of the CCS Power Amplifier are given in Table 4-4.

Operation of the CCS Power Amplifier is controlled by commands received from ground stations via IU Command System up-link commands. Both standby (warmup) and operational modes are provided for in the unit design. Three status signals of internal power supply functions are generated and fed to the IU telemetry system for ground-monitoring of the unit. The CCS Power Amplifier is functionally divided into 2 sections—an rf channel and a power supply section.

### 4-14 DETAILED OPERATION

Figures 4-13 and 4-14 supplement the following text as each section of the CCS Power Amplifier is described in detail.

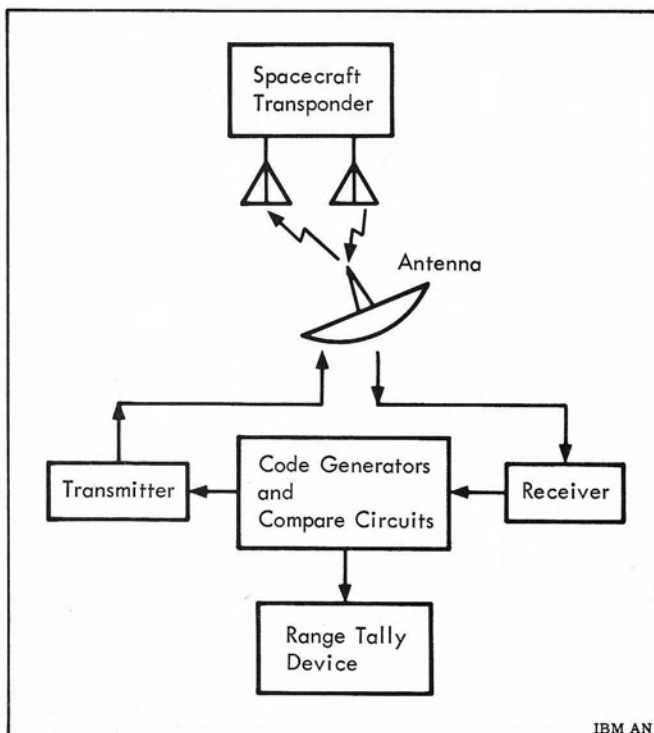


Figure 4-11. Unified S-Band System Simplified Block Diagram

### RF CHANNEL

The rf channel, shown on the upper half of Figure 4-14, consists of an attenuator, Travelling-Wave Tube (TWT), harmonic suppression filter, rf isolator, and bandpass filter.

The rf input at J1 is applied to the attenuator which limits the input power to the TWT. The TWT amplifies the rf signal and applies the amplified signal to the harmonic suppression filter. The output of the filter is then applied to the rf isolator. This circuit prevents damage to the TWT that may be caused by possible mismatches present at the output of the CCS Power Amplifier. The output signal is then filtered in a bandpass filter and applied to the rf output jack J2 for connection to the CCS antenna system.

### TWT DESCRIPTION

The TWT, shown in Figure 4-13, is a high-efficiency amplifier that utilizes the forward travelling-wave principle to provide amplification of the microwave input signal.

The heater, cathode, focus electrode, and anode function as an electron gun. Focusing of the electron beam is accomplished by a focus electrode and maintained by a force field established by permanent magnets that are mounted externally along

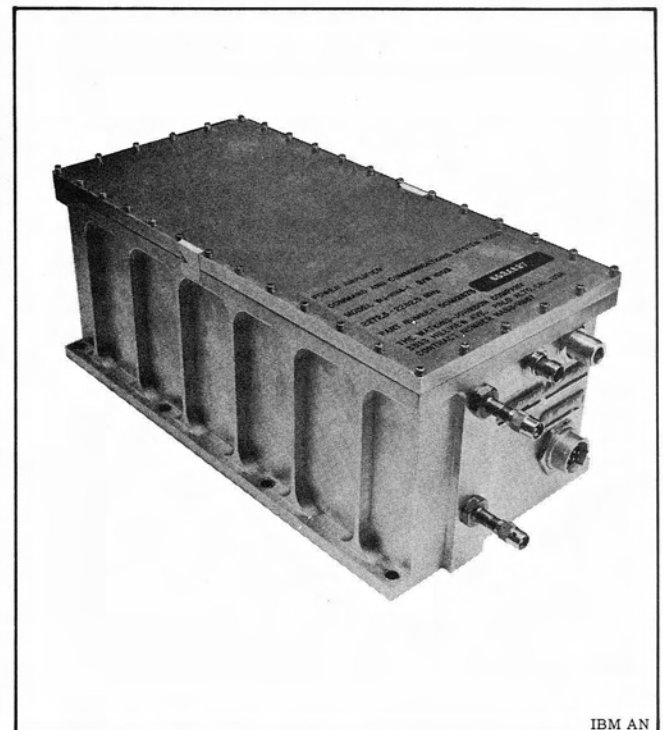


Figure 4-12. CCS Power Amplifier

the barrel of the tube. The beam passes through the center of a helix assembly (parallel to the axis) to a collector. Additional electron beam acceleration is accomplished by operating the helix at a potential of 1650 volts positive with respect to the cathode. The collector operates at 1200 volts positive with respect to the cathode. The collector functions to collect the electrons carried in the beam and operates in a manner similar to the plate in a conventional vacuum tube.

The helix assembly consists of two helical-wound coils. The input helix is directly coupled to the TWT rf input jack and the output helix is directly coupled to the TWT rf output jack. The 2 helices are connected to a metal envelope which is held at chassis ground (1650 Vdc). The envelope is insulated from the electron gun and collector elements.

The attenuators on each of the helices consist of carbon deposits on the helix windings. The purpose of the attenuators is to decouple the input signal from the output, which prevents the amplifier from oscillating.

The rf input is directly coupled to the helix assembly which acts as a delay line to the signal. The result of the delaying action is to synchronize the speed of wave propagation with the speed to which the electron beam has been accelerated. The input signal sets up a force field as it travels down the helix. The force field interacts with the electrons in the beam, and as the field cuts across the beam, electrons are accelerated and decelerated to form electron "bunches". These bunches are shown in the TWT waveform included on Figure 4-13. In addition, as the beam cuts the force field, energy is induced into the helix that adds to the strength of the field. This mutual interaction between the traveling wave and electron beam continues as the wave travels down the helix toward the attenuators. The attenuators decrease the signal on the helix, but do not affect the electron "bunches". After the wave passes the attenuator, the electron bunches start induction of a new wave onto the output helix and mutual interaction starts again. The mutual interaction continues to build the signal as the wave travels toward the end of the output helix. The resultant output is an amplified signal formed by energy from the bunched electrons. The output signal is directly coupled out of the

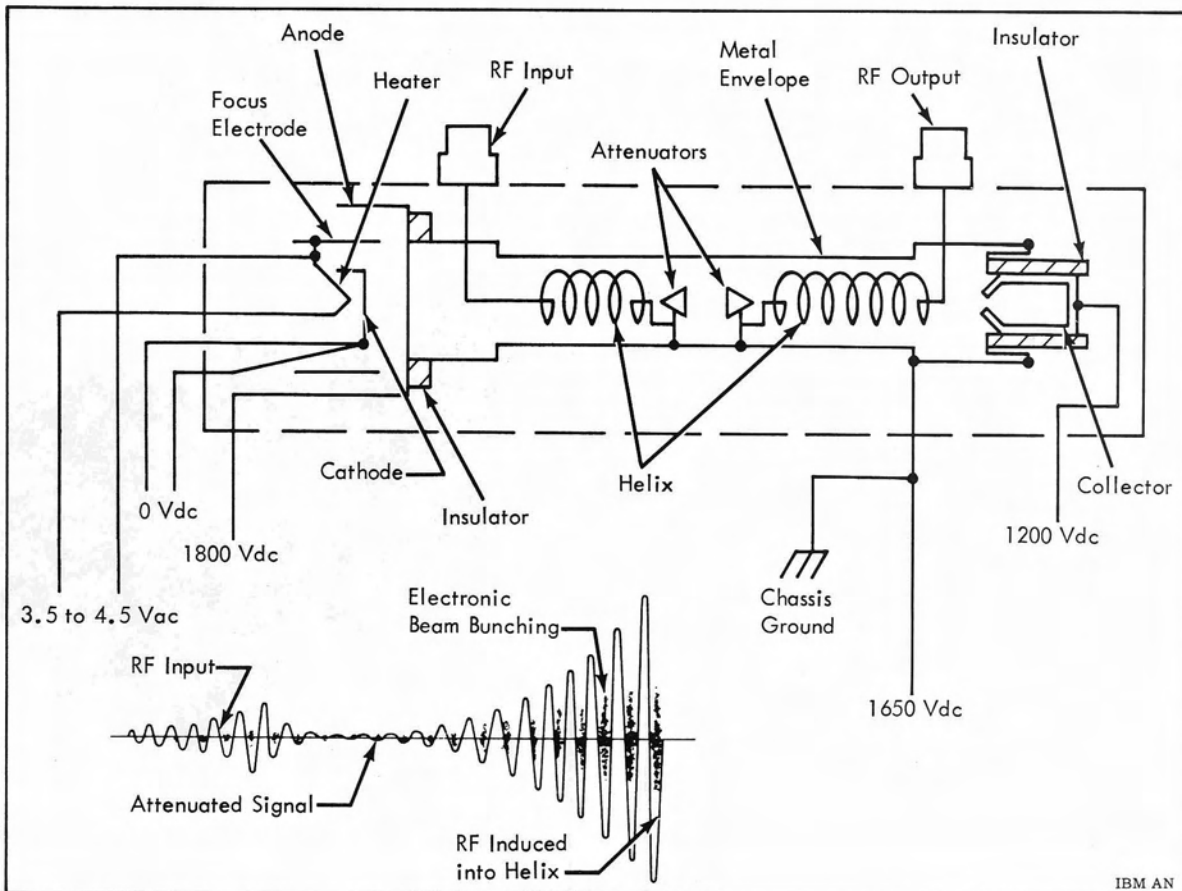


Figure 4-13. Traveling Wave Tube Schematic Diagram

TWT. The original signal coupled to the input signal is effectively lost in the attenuators, and the output signal is a new signal induced into the output helix by the electron bunches.

#### POWER SUPPLY SECTION

The power supply section, shown in the lower half of Figure 4-14, consists of an rfi assembly, voltage regulator, collector converter, helix converter, and a timing circuit. The rfi assembly filters the incoming 28-volt dc power before it enters the voltage regulator. In addition, the rfi assembly filters the telemetry status signals provided by the CCS Power Amplifier and the high-voltage control signal that is received as a command signal from the ground.

The 28 Vdc input power is applied to the voltage regulator which provides regulated 20 Vdc power for the collector and helix converters. The collector converter provides a cathode reference of 0 Vdc and a

Table 4-4. CCS Power Amplifier Characteristics

ELECTRICAL	
Voltage Required	24 to 32 Vdc
Power Consumption	
Operate mode	95 watts
Disable mode	20 watts
Center Frequency	2282.5 MHz
Bandpass	20 MHz Flat $\pm$ 1 db
Drive Power	250 to 500 mw at 2282.5 MHz
Output Power (min)	15 watts
Input Terminal Impedance	50 ohms nominal at a VSWR $\leq$ 1.3:1
Output Terminal Impedance	50 ohms nominal at a VSWR $\leq$ 1.5:1
Output Isolation (min)	20 db
Output Spurious Response	No greater than negative 95 dbm at 2104 MHz $\pm$ 5 MHz
PHYSICAL	
Length	41.11 cm (14.19 in.)
Width	16.77 cm (6.60 in.)
Depth	13.65 cm (5.38 in.)
Weight	9.07 kg (20 pounds)

collector operating voltage of 1200 Vdc for the TWT. The helix converter provides anode and helix voltages of 1800 Vdc and 1650 Vdc, respectively, for operation of the TWT.

The telemetry status signals developed in the CCS Power Amplifier allow the ground stations to monitor TWT helix current, TWT cathode current, and the operating mode (ON-OFF) of the high-voltage circuits.

### 4-15 COMMAND ANTENNA SYSTEMS

#### 4-16 INTRODUCTION

The command systems for the Uprated Saturn I and Saturn V Vehicles each have their own antenna configuration. On the Uprated Saturn I Vehicles, a simplified IU command antenna system is used. It consists of two omnidirectional receiving antennas which are connected to the command system through a Command Power Divider and Command Directional Coupler. The system is shown at the top of Figure 4-15. PCM telemetry is used to relay command messages back to the ground stations.

The Saturn V IU command antenna system is more complex because the commands are received through the multipurpose CCS Transponder and is involved in greater ranges. The Saturn CCS antenna arrangement is shown in the lower portion of the figure. Two omnidirectional antennas are used for receiving the S-band CCS signals, and two omnidirectional and two directional antennas are used for transmission. The particular usage of the transmitting antennas depends upon vehicle position and range at the time of transmission.

Although this is a Command System manual, the complete CCS/PCM antenna scheme is shown because of the complex way in which the telemetry system is tied in with the CCS and PCM-UHF systems.\* Hereinafter the PCM-UHF telemetry scheme will be referred to as the PCM system.

#### 4-17 CCS RECEIVING ANTENNA SYSTEM

The CCS receiving antenna system receives and transfers a 2101.8 MHz signal from the antennas

\* As defined for this manual, the CCS and PCM-UHF systems are parallel transmission paths for PCM telemetry data. The CCS operates at 2282.5 MHz, and the PCM-UHF system operates at 2277.5 MHz. Under certain operating conditions, both systems will use a common antenna network.

to the CCS Transponder. This system consists of a pair of omnidirectional antennas, a CCS Power Divider, and interconnecting coaxial cables. A block diagram of this system is shown in the lower portion of Figure 4-15. As shown in the figure, two coaxial cables from the antenna are joined at the CCS Power Divider. Thus, the incoming signals (which are of unequal strength) are coupled to a common input to the CCS Transponder. The CCS Power Divider also provides isolation between the antennas and the CCS Transponder.

#### 4-18 CCS/PCM TRANSMITTING ANTENNA SYSTEM

The Instrument Unit CCS/PCM transmitting antenna system, used in the Saturn V Vehicles, consists of two omnidirectional antennas, two directional antennas, a hybrid ring, two coaxial switches and interconnecting cables. Depending upon which system (CCS or PCM) is transmitting, the antenna system operates at either 2277.5 MHz or 2282.5 MHz. The components are arranged in the system as shown in the center of Figure 4-15.

Three modes of operation are available to the CCS/PCM transmitting scheme. They are:

- A low-gain, short-range mode in which PCM and CCS rf signals share two omnidirectional antennas.
- A medium-gain, medium-range mode in which the PCM and CCS signals each use their respective directional, multi-gain antenna.
- A high-gain, long-range mode in which the PCM and CCS signals each use their respective directional, multi-gain antenna.

A dc switching signal from the IU Switch Selector positions each coaxial switch to one of its three output positions. For CCS transmissions of relatively short range, the transfer path of the CCS Coaxial Switch routes the rf signals to the two CCS/PCM antennas, via the CCS Hybrid Ring. These antennas use an omni- or dispersed-radiation pattern to propagate the rf energy earthward.

For medium ranges, the CCS coaxial Switch is switched to the medium position. The rf signal is then routed to the CCS antenna which is directional and has 2 sets of radiating elements for medium and high-gain radiation. Long-range transmissions utilize the high-gain element of the antenna and are routed through the third position of the CCS Coaxial Switch.

Summarily, the same general scheme is followed for the rf signal flow from PCM telemetry to either the CCS/PCM omnidirectional antennas or the directional PCM antenna. As in the CCS signal path, an IU Switch Selector signal switches the three-way coaxial switch. The CCS Hybrid Ring allows the PCM signal to use the same pair of low-gain, omnidirectional CCS/PCM antennas as the CCS system.

In later Saturn V Vehicles the PCM-UHF system may be eliminated. Therefore, the antenna scheme will appear as shown in Figure 4-16. A Power Divider will replace the CCS Hybrid Ring to equally divide the output power between the two omnidirectional CCS Transmitting Antennas.

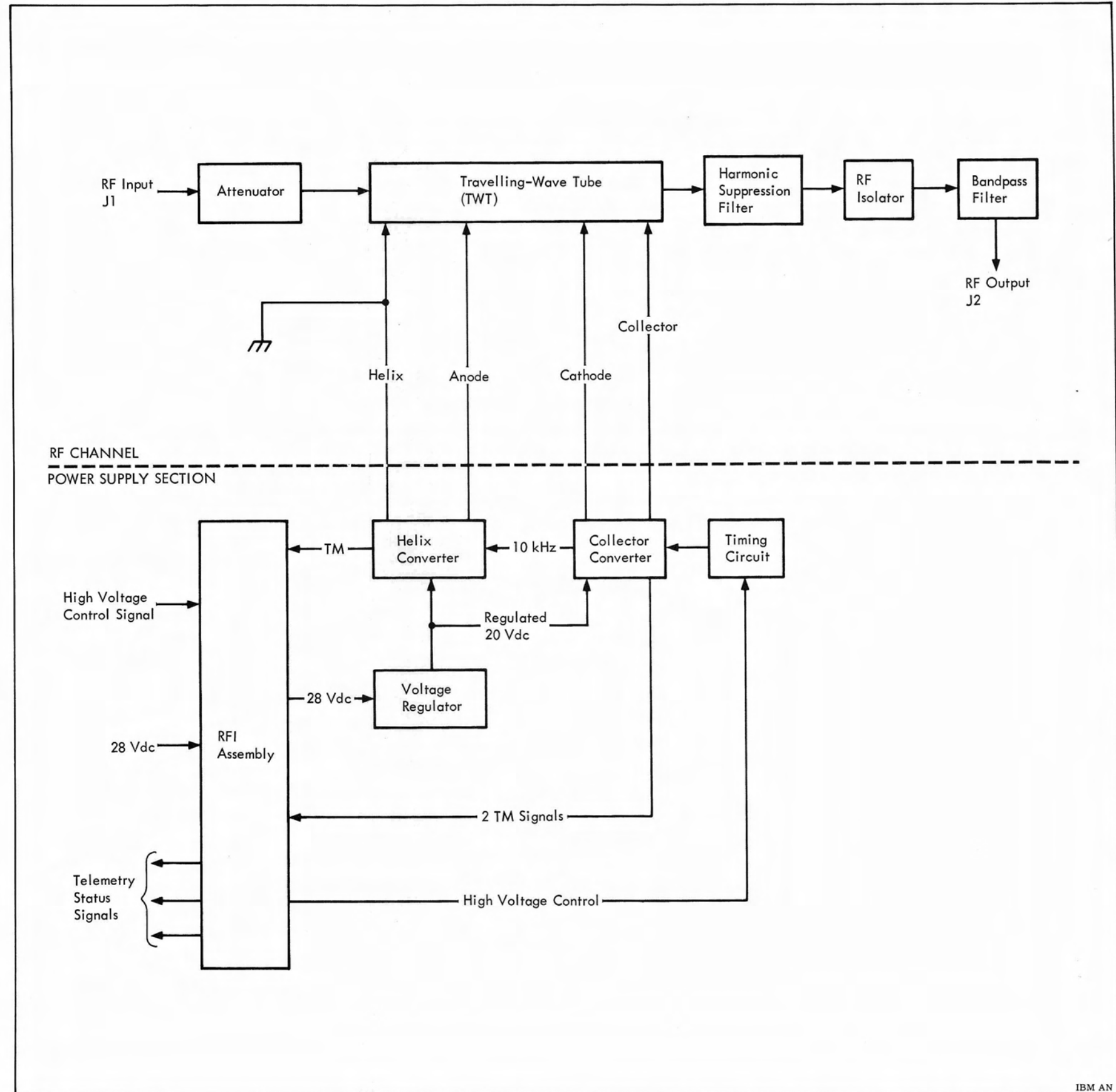
#### 4-19 COMMAND ANTENNA SYSTEM COMPONENTS

The physical location of the components which make up the IU command antenna systems are shown in Figure 4-17. Redundant omnidirectional antennas are located on opposite sides of the vehicle for maximum electromagnetic coverage. Single directional antennas are located near position I of the vehicle since this position will normally be oriented toward earth. The antennas are located on the outside (exterior) skin of the IU and are connected to their respective components by coaxial cables not shown on the figure. The following paragraphs describe the various Command System antennas and associated components.

##### CCS/PCM TRANSMITTING ANTENNA (OMNIDIRECTIONAL)

The CCS/PCM Transmitting Antenna is shown in Figure 4-18. The internal view of the antenna shows a half-loop radiating element encased in foam. A single coaxial connector ties the element to the remainder of the antenna system. Flight orientation of the antenna has the ramp-like side of the case pointed in the flight direction. The antenna is omnidirectional and is used to transmit CCS and PCM signals during low-level flight. Characteristics of the antenna include:

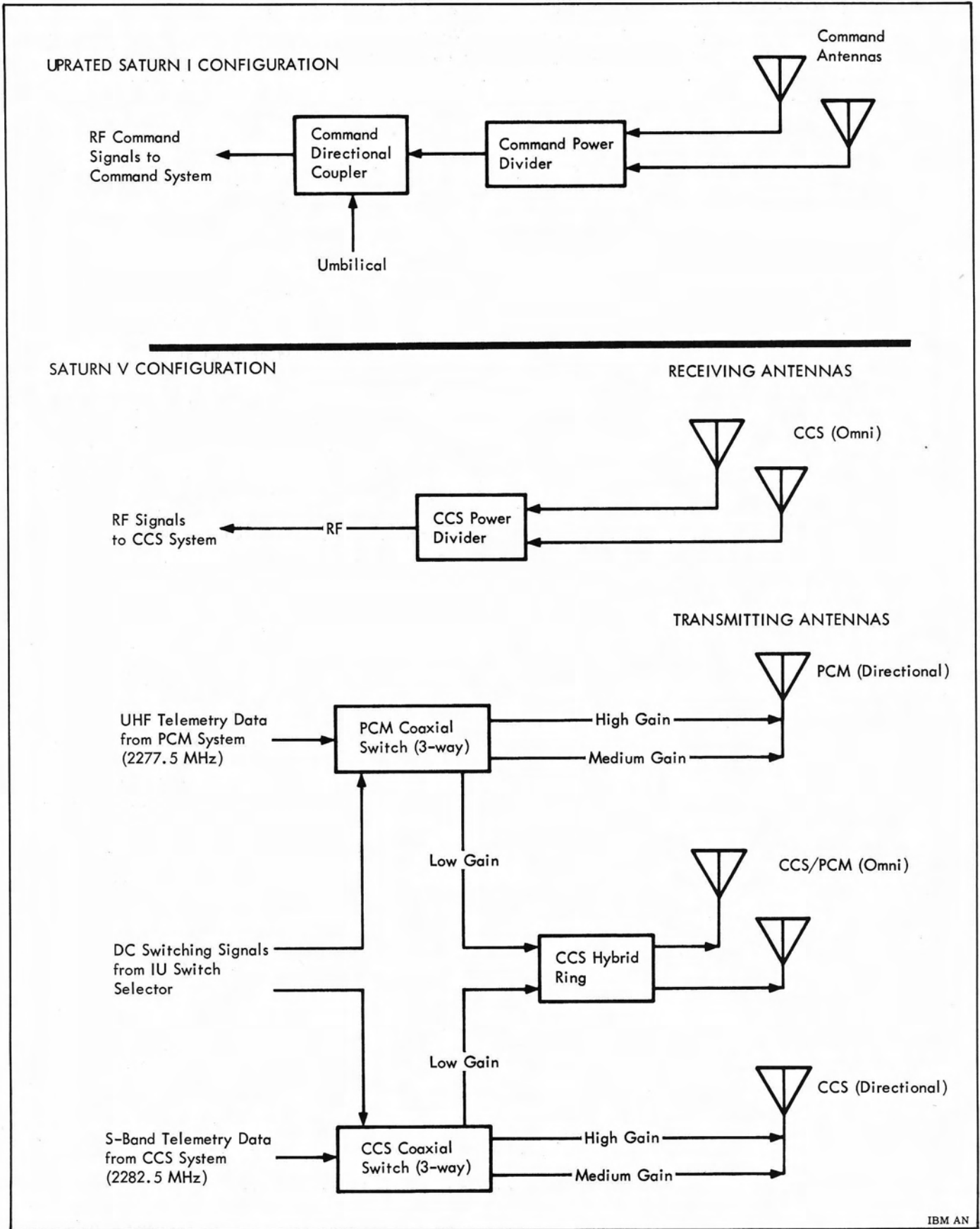
- Type: Half-loop
- Number Required: 2
- Frequency Range: 2.25 to 2.29 GHz
- Weight: 0.55 kg (approx)  
(1.2 pounds)
- Dimensions: 26.7 by 7.6 by 5.8 cm  
(10.5 by 3.0 by 2.3 in.)



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Figure 4-14  
CCS Power Amplifier Block Diagram





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Figure 4-15. Saturn Command Antenna Systems Block Diagram

It should be noted that this antenna is physically identical to the CCS Receiving Antenna. Both antennas are linearly polarized with a rectangular half-loop radiating element.

#### CCS RECEIVING ANTENNA (OMNI)

The CCS Receiving Antenna, which is physically identical to the CCS/PCM Transmitting Antenna, is shown in Figure 4-18. Characteristics of the antenna are:

- Number Required: 2
- Frequency Range: 2.09 to 2.11 GHz
- Type: Half loop
- Weight: 0.55 kg (approx)  
(1.2 pounds)
- Dimensions: 26.7 by 7.6 by 5.8 cm  
(10.5 by 3.0 by 2.3 in.)

The antenna is omnidirectional and is used to receive rf signals from the CCS ground stations.

#### CCS AND PCM TRANSMITTING ANTENNAS (DIRECTIONAL)

The CCS and PCM Transmitting Antennas are identical. The antenna is directional and has a multi-gain feature. Two independent sets of elements are encased in foam and then inclosed in a common outer covering. Referring to Figure 4-18, the single element has an average gain of 7 db, and the four-element helix array has an average gain of 11 db. A separate coaxial cable connects each array with a coaxial switch. Selection of either set of antenna

elements (via the coaxial switch) accounts for the multigain feature. Characteristics of the directional antenna are:

- Type: Helix array
- Number Required: 1
- Frequency Range: 2275 to 2285 MHz
- Polarization: Right circular
- Weight: 4.1 kg (approx)  
(9.0 pounds)
- Dimensions: 60.9 by 21.8 by 11.7 cm  
(24.0 by 8.6 by 4.6 in.)

#### COAXIAL SWITCH (PCM or CCS)

The coaxial switch is a single-pole, triple-throw switch. Three modes of CCS transmission can be selected by the switch. The CCS or PCM-UHF rf assemblies can be connected to either the high or low side of its associated directional antenna or to the combined CCS/PCM omnidirectional antennas through a hybrid ring. Characteristics of the coaxial switch are:

- VSWR: Less than 1.40 to 1
- Insertion Loss: Less than 0.3 db  
(from 1700 to 3000 MHz)
- Frequency Range: 1700 to 3000 MHz
- Power Rating (avg): 100 watts
- Voltage Breakdown: 500 Vdc
- Operating Power: 24 to 32 Vdc  
(at less than 1 ampere)

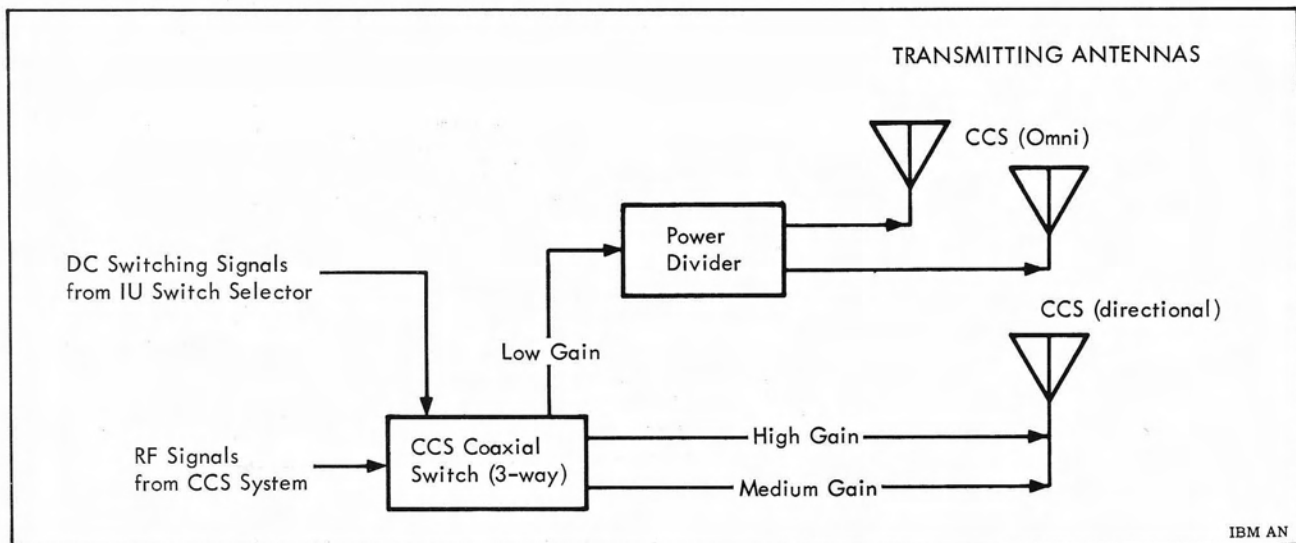


Figure 4-16. Saturn V Command Antenna Configuration Block Diagram (UHF Equipment Removed)

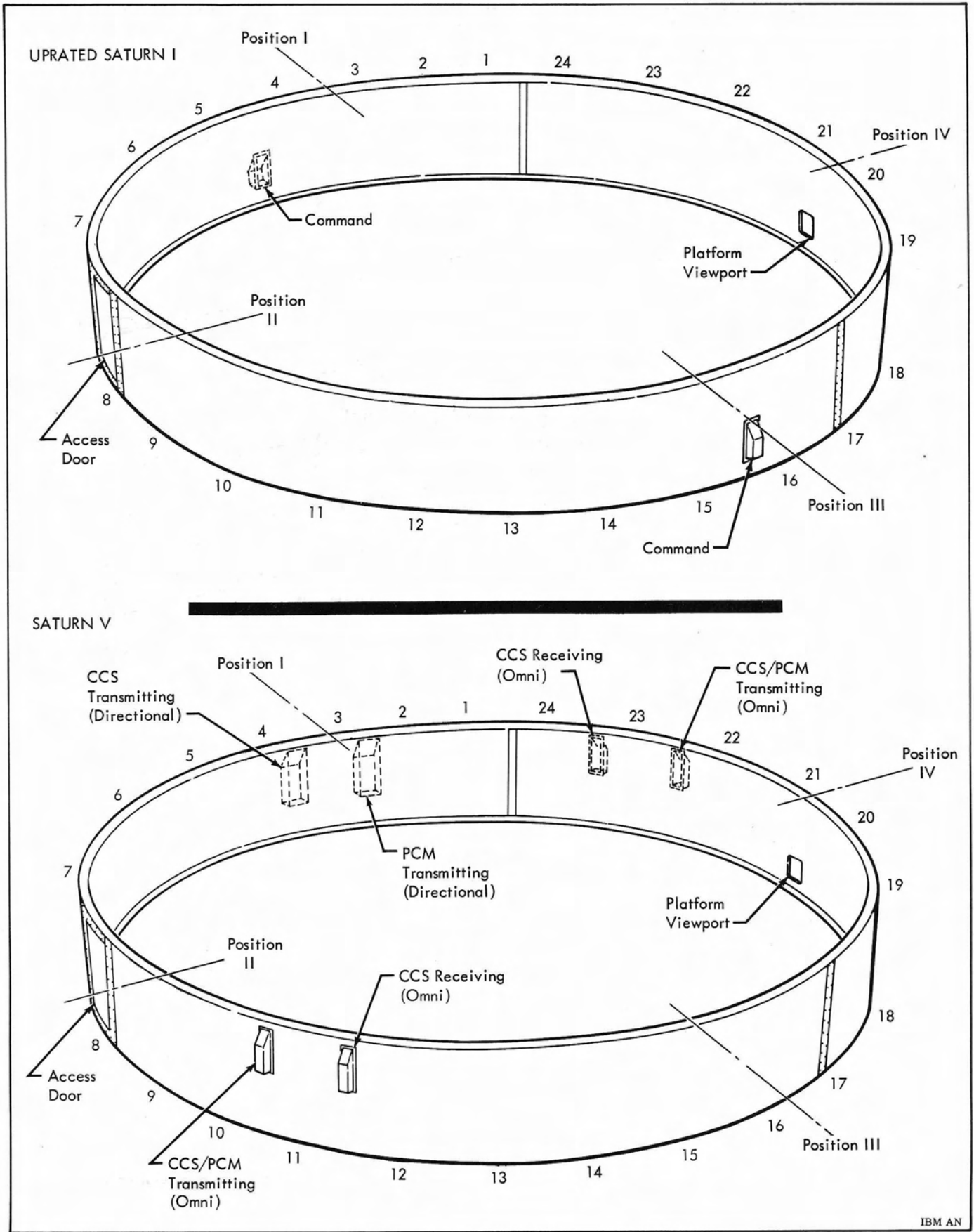


Figure 4-17. Command System Antenna Positions

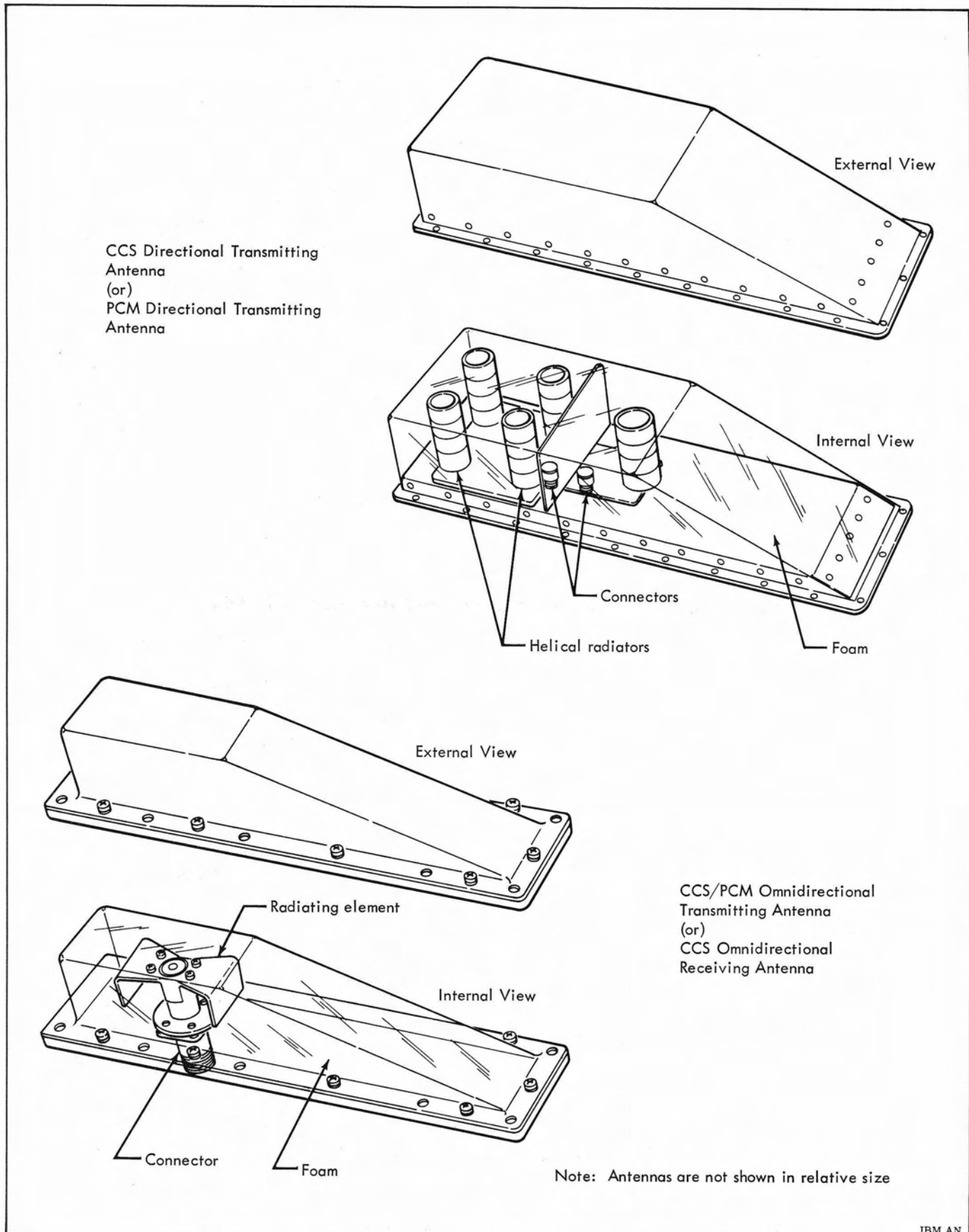


Figure 4-18. CCS and PCM Antennas

- Number Required: 1 for CCS, 1 for PCM
- Weight: 0.45 kg (approx)  
(1.0 pound)
- Dimensions: 12.8 by 12.8 by 7.0 cm  
(5.0 by 5.0 by 2.75 in.)

The coaxial switch is operated by control signals from the IU Switch Selector and is used to achieve optimum antenna gains at greater-than-orbital ranges. Figure 4-19 includes a three-quarter view of a CCS Coaxial Switch. A block diagram of the unit is given in Figure 4-20.

#### CCS HYBRID RING

The CCS Hybrid Ring, shown in Figure 4-19, electronically couples two rf signals to the omnidirectional CCS/PCM Transmitting Antennas. The 2 signals are the outputs of the CCS and PCM Coaxial Switches. The hybrid ring arrangement provides signal coupling, impedance matching, and signal isolation. A schematic representation of the unit is shown in Figure 4-21. Characteristics of the CCS Hybrid Ring are:

- VSWR: Less than 1.5 to 1
- Frequency Range: 2277.5 to 2282.5 MHz
- Power Division: 3.00 ( $\pm 0.33$ ) db
- Number Required: 1
- Weight: 0.34 kg (approx)  
(0.75 pound)
- Dimensions: 11.5 by 9.0 by 3.1 cm  
(4.5 by 3.5 by 1.2 in.)

#### CCS POWER DIVIDER

The CCS Power Divider, shown in Figure 4-19, accepts rf input signals from the two omnidirectional CCS Receiving Antennas, couples the input signals, and routes them to the CCS Transponder. The power divider arrangement also provides impedance matching. A schematic representation of the unit is given in Figure 4-22. Characteristics of the CCS Power Divider are:

- Frequency Range: 2.10 to 2.30 GHz
- VSWR: 1.2:1
- Number Required: 1
- Weight: 0.28 kg (approx)  
(0.6 pound)
- Dimensions: 8.5 by 7.7 by 3.0 cm  
(3.4 by 3.0 by 1.2 in.)

#### 4-20 UPRATED SATURN I COMMAND ANTENNA SYSTEM

The command antenna system for the Uprated Saturn I Vehicles consists of two omnidirectional antennas, a Command Power Divider, Command Directional Coupler, and the interconnecting coaxial cables. The Command Antennas are mounted on opposite sides of the IU exterior surface for maximum coverage. The remainder of the equipment is mounted on cold plates which are fastened to the interior surface of the IU. Coaxial cables, which run along an overhead cable rack, connect the components.

A block diagram of the command antenna system is shown at the top of Figure 4-15. As in the CCS receiving antenna system, a power divider isolates the two omnidirectional receiving antennas from one another and combines their signal power as an input rf signal to the Command Receiver. A Command Directional Coupler is located (electronically) between the Command Power Divider and the Command Receiver. Its purpose is to isolate inputs to the Command Receiver from prelaunch ground equipment test inputs which are routed through an umbilical connection.

The following paragraphs describe the individual components in more detail.

#### COMMAND POWER DIVIDER

The Command Power Divider, shown in Figure 4-23, performs the same functions as the CCS Power Divider. It couples the rf input signals from the omnidirectional Command Antenna and routes them to the Command Receiver. The power divider arrangement also provides impedance matching. A schematic representation of the unit is given in Figure 4-22. Characteristics of the Command Power Divider are:

- Type: Stripline
- Number Used: 1
- Frequency Range: 445 to 455 MHz
- VSWR: 1.2:1
- Input Impedance: 50 ohms
- Weight: 0.3 kg (approx)  
(0.7 pound)
- Dimensions: 13.9 by 7.6 by 1.0 cm  
(5.5 by 3.0 by 0.4 in.)

#### COMMAND DIRECTIONAL COUPLER

The Command Directional Coupler, shown in Figure 4-23, isolates the rf antenna inputs to the

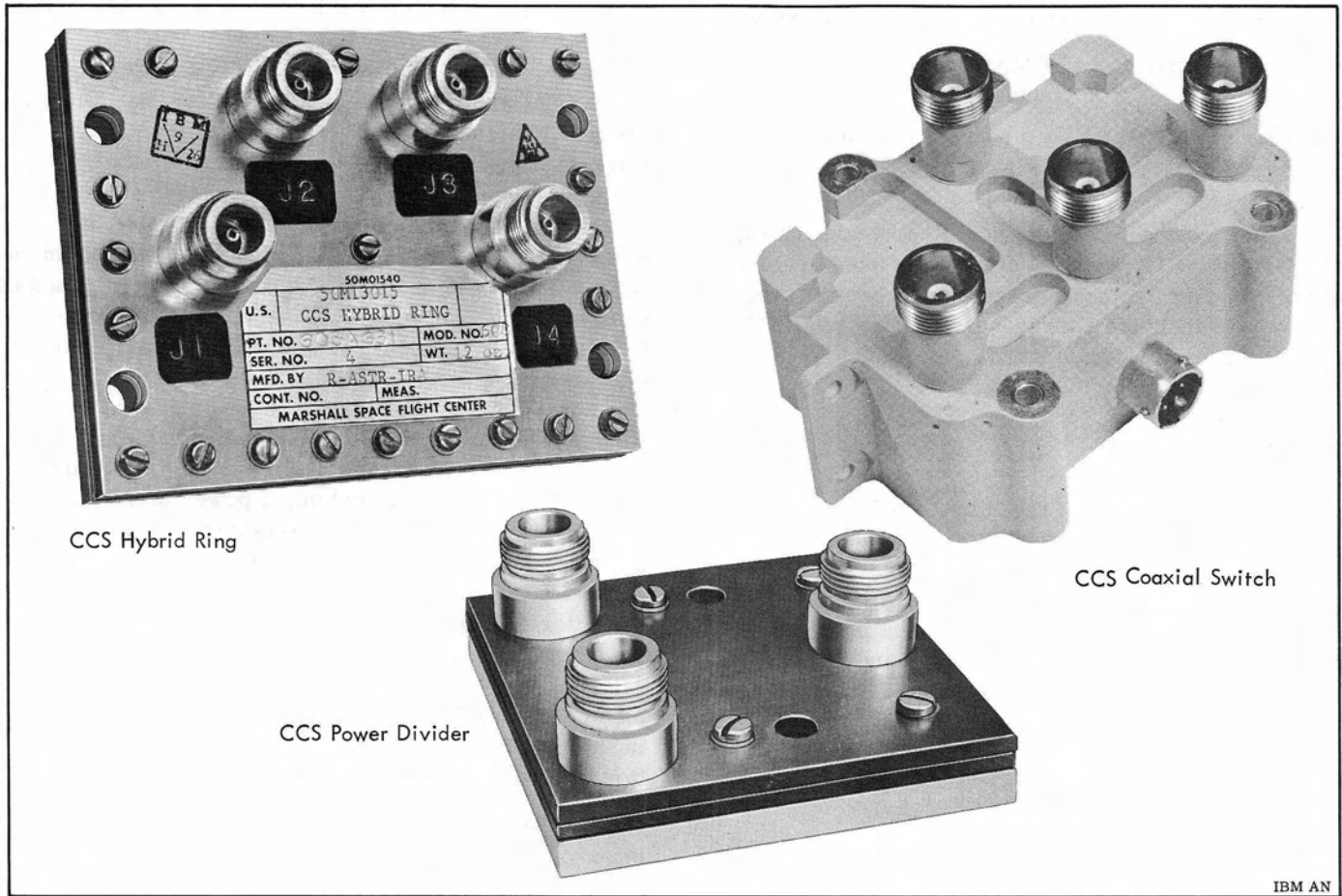


Figure 4-19. CCS RF Components

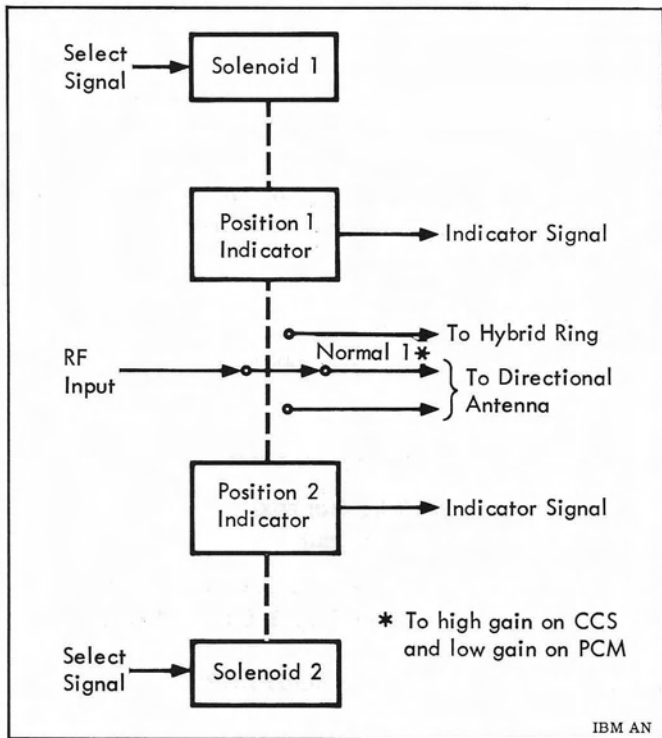


Figure 4-20. Coaxial Switch Block Diagram

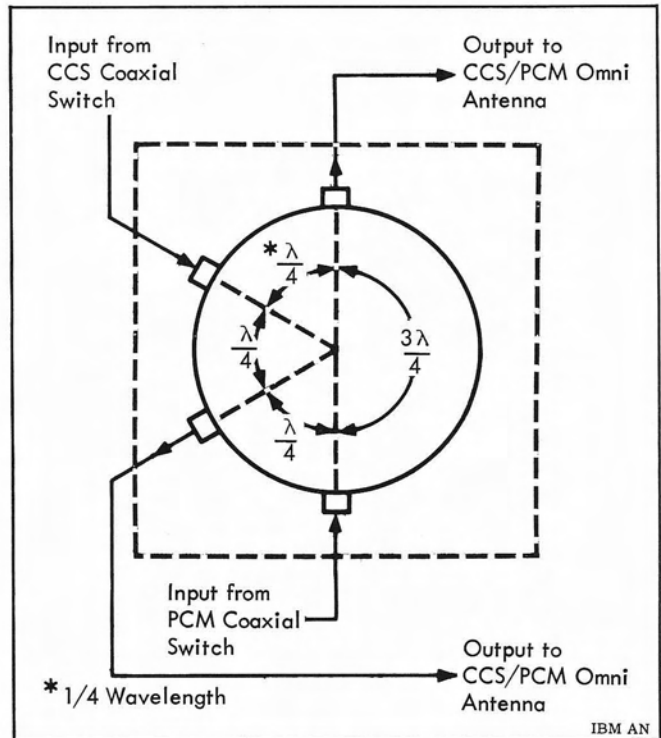


Figure 4-21. CCS Hybrid Ring Schematic Diagram

Command Receiver from the test inputs which are routed through the umbilical from the prelaunch ground equipment. A schematic representation of the unit is given in Figure 4-24. Characteristics of the Command Directional Coupler are:

- Number Used: 1
- Type: Stripline
- Frequency Range: 445 to 455 MHz
- VSWR: 1.25:1
- Input Impedance: 50 ohms
- Insertion Loss: 0.25 db
- Coupling: 17.5 (±3) db
- Directivity: 17 db or greater

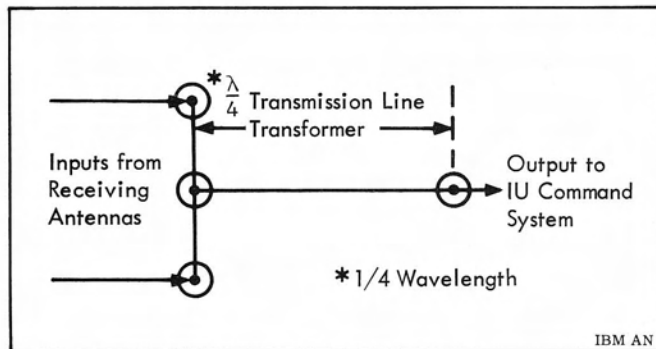


Figure 4-22. Power Divider Schematic Diagram

- Weight: 0.5 kg (approx)  
(1.1 pounds)
- Dimensions: 24.1 by 7.4 by 1.3 cm  
(9.5 by 2.9 by 0.5 in.)

COMMAND ANTENNA

The Command Antenna, shown in Figure 4-25, is one of two such antennas used to receive command signals from the ground stations. The antenna is designed (with spacing and phasing) to give omnidirectional coverage. Characteristics of the Command Antenna are:

- Type: Cross-looped antenna
- Number Required: 2

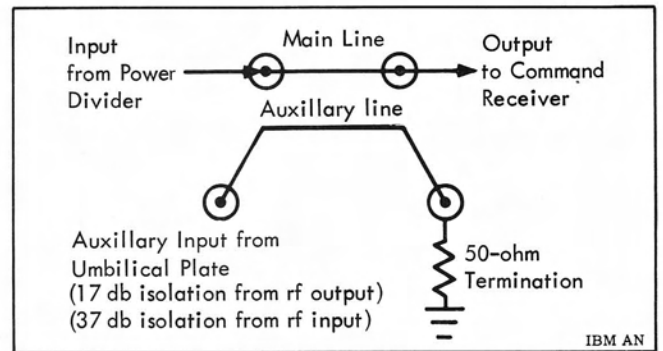


Figure 4-24. Command Directional Coupler Schematic Diagram

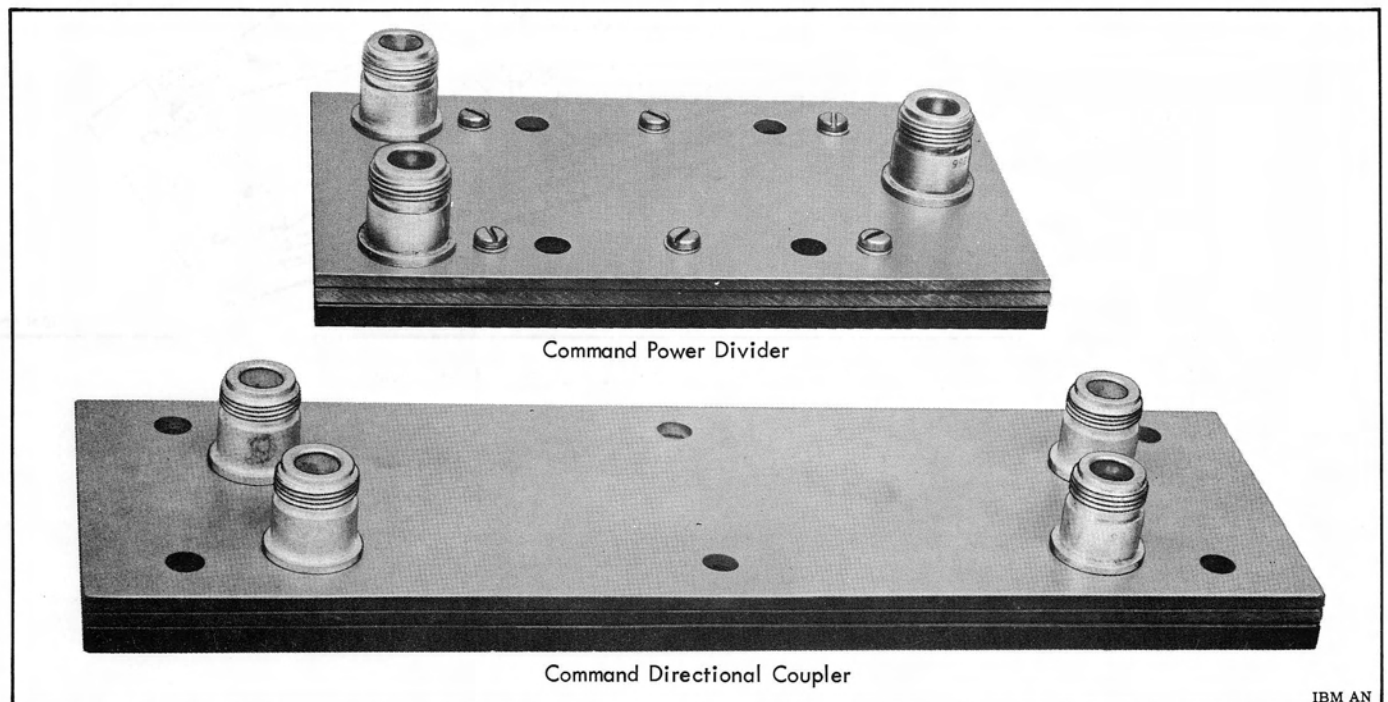


Figure 4-23. Uprated Saturn I Command System RF Components

Command System Description  
Section IV

- Frequency Range: 445 to 455 MHz
- Bandwidth: 16 MHz for 1.5:1 VSWR
- Polarization: Left circular
- Weight: 2.16 kg (approx)  
(4.75 pounds)
- Dimensions: 36.6 by 19.1 by 7.4 cm  
(14.4 by 7.5 by 2.9 in.)

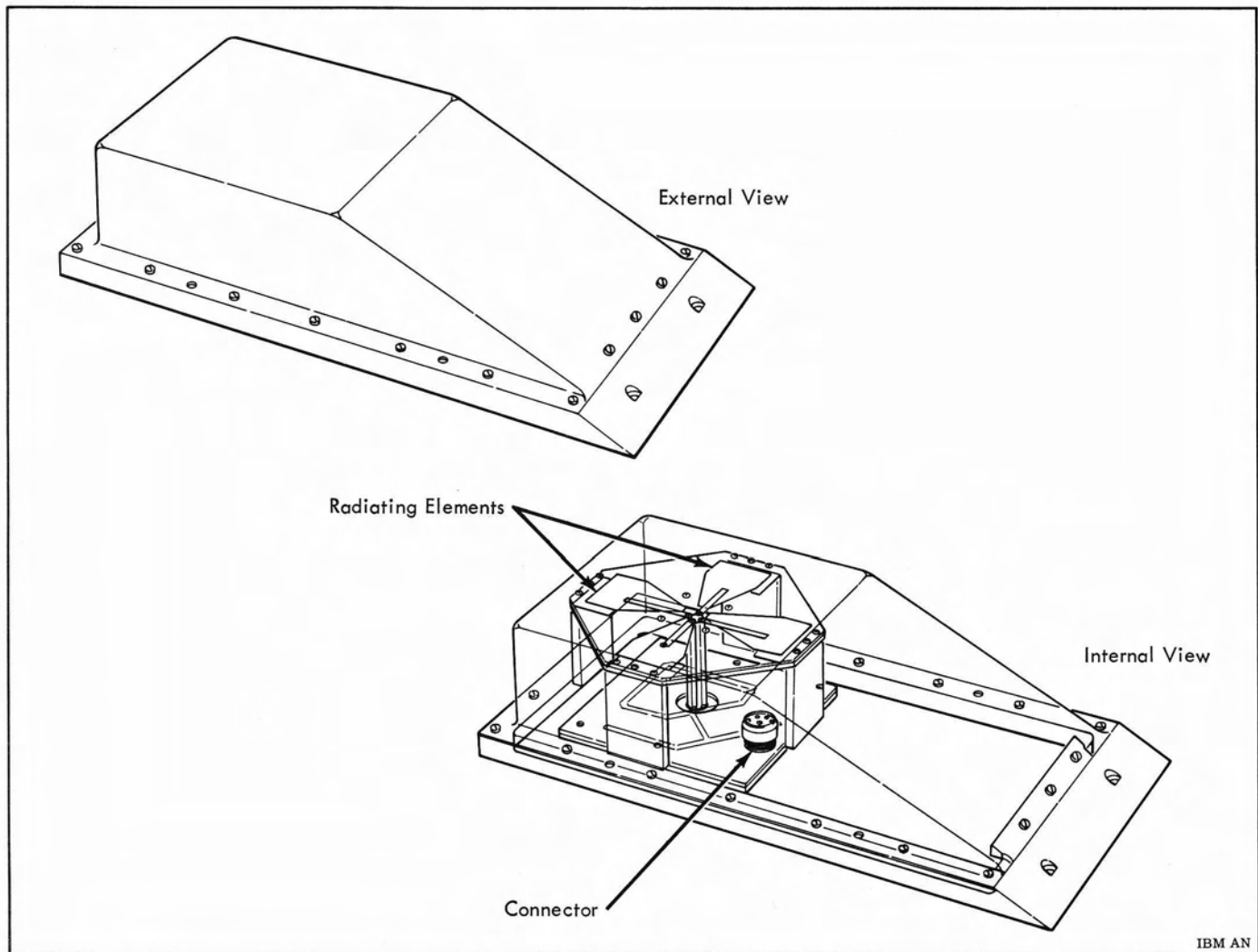


Figure 4-25. Uprated Saturn I Command Antenna





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