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NASA TECHNICAL
MEMORANDUM

NASA TM X-53350
October 22, 1965

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NASA TM X-53350

(NASA-TM-X-53350) SATURN INSTRUMENT UNIT COMMAND SYSTEM (NASA) 41 p
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SATURN INSTRUMENT UNIT COMMAND SYSTEM

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NASA

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TECHNICAL MEMORANDUM X-53350

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ABSTRACT

The Marshall Space Flight Center philosophies concerning the Saturn Instrument Unit command system are described and evaluated. The actual hardware is described in detail; its interfaces with other Saturn systems and with the Manned Space Flight Network are fully covered.

A specific point of interest is the phase-shift-keyed detection system in the decoder. Higher reliability is obtained by the use of fewer components. The problem of acquisition time has been eliminated by the absence of a phase lock loop.

The possibility of expanding the capabilities of the logic system is inherent in the use of more bits (fourteen) in each address than are actually required. This possibility is consistent with the philosophy of providing a system which will be compatible with any vehicle design changes.

At the earliest possible date, R-ASTR-IRC will publish an evaluation report which will describe the implementation of the philosophies discussed in this report.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

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October 22, 1965

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INSTRUMENTATION AND COMMUNICATION DIVISION
ASTRIONICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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UNUSUAL TERMS

Term	Definition
update data bit:	a binary data bit intended to alter the stored navigational program in the LVDC to improve mission accuracy
updata bit	a binary data bit intended for use in the vehicle but not necessarily to update the navigational program
updata link and data uplink	the communications system, including both ground and airborne equipment, intended for performance of functions within the vehicle by remote control

TECHNICAL MEMORANDUM X-53350

SATURN INSTRUMENT UNIT COMMAND SYSTEM

SUMMARY

The Instrument Unit command system for Saturn IB and Saturn V vehicles is fundamentally an evolution of a prior system which was flight tested on SA-6, SA-7, and SA-9. It consists of a command decoder, the launch vehicle digital computer and data adapter, a PCM/FM telemetering link, the MCR-503 command receiver on Saturn IB, and the command communications system transponder on Saturn V. The command system will be used to update guidance information or to command certain vehicle functions such as stage selector switch operations, review of data in certain locations of the launch vehicle digital computer memory, and out-of-sequence telemetering of S-IVB pressures, temperatures, etc., for orbital checkout. In every case, the Instrument Unit command system access to these functions is through the launch vehicle digital computer.

INTRODUCTION

Purpose

The purpose of the Saturn Instrument Unit (IU) command system is to provide a radio frequency/digital data transmission link from various Manned Space Flight Network stations to the onboard launch vehicle digital computer (LVDC). The LVDC uses the transmitted data to update the mission guidance parameters or to perform certain orbital (S-IVB/IU) checkout and stage switch selector functions.

Similar Systems

The Apollo vehicle contains two other digital data uplinks which are very similar in operation to those in the IU command system. The locations of these two systems and the names assigned to them are as follows.

Command Module — Apollo updata link*
Lunar Excursion Module — LEM digital command assembly

All three systems are similar in that they all receive data from the various earth-fixed stations of the Manned Space Flight Network (MSFC). They all use the same general encoding and modulation scheme, and even the same

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*Also referred to as the unified S-band system.

RF carrier frequency will be shared by the different systems on some flights. The block diagram of Figure 1 shows a general system configuration applicable to all three systems. The similarities between systems end with such a block diagram, however, for the operational philosophies (and thus the onboard hardware) necessarily diverge because each has a different mission to perform and a different phase of the earth-lunar round trip during which its mission is to be accomplished. The bulk of the IU command system's usage will take place during earth parking orbits prior to injection of the vehicle into a lunar transfer trajectory.

The Apollo updata link and the LEM digital command assembly are the responsibility of MSC in Houston, Texas, and will not be discussed further in this report. The IU command system is not to be confused with the secure range safety command system although both command systems are the responsibility of the Command Unit (R-ASTR-IRC), both are digital systems, and both may utilize the same RF carrier frequency and similar onboard equipment such as antennas and receivers on early flights. Information on the secure range safety command system is given in Reference 1.

Components of the IU Command System

The IU command system hardware development is divided into two programs, the Saturn IB version and the Saturn V version. This division is made necessary as the result of a decision to move the command carrier frequency from UHF (450 MHz) to S-band (2 GHz). Since the MSFN will not be fully implemented with S-band equipment in time for some of the S-IB flights, and since no MSFC-qualified S-band flight equipment is presently available, the S-IB IU command system (Fig. 2) will use the UHF network implemented for Gemini and the existing flight-qualified UHF receivers such as the MCR-503 (Fig. 9). This, however, does not preclude the possibility of using the S-V version on the late S-IB flights if it becomes feasible and desirable. The S-V IU command system (Fig. 3) will utilize the S-band-implemented MSFN and the flight hardware presently under development by MSFC. Although it is too early to know exact configuration details of the S-V command and communication system (CCS), it is being designed to be part of a larger system, i.e., the Saturn V IU (Fig. 3).

Acknowledgement

The author wishes to express his thanks to Mr. Charles W. Casey's office, I-MO-F, for contributing basic materials contained in this report.

SYSTEM DESCRIPTION

General

Figure 3 shows a block diagram of the overall command system for Saturn V. The commands and data to be transmitted to the vehicle will originate in the Mission Control Center (MCC) in Houston, Texas, and will be sent to the remote stations of MSFN where they will be transmitted to the vehicle. The command is transmitted in the S-band using a carrier frequency of 2101.8 MHz. The command is FM modulated on a 70 kHz subcarrier, which in turn is PM modulated on the 2101.8 MHz carrier. The signal from the ground station is received through the S-band transponder of the Saturn command and communications system in the IU. The receiver portion of the transponder separates the transmitted message from the carrier and subcarrier and feeds the resulting baseband signal to the IU command decoder where decoding is accomplished. From the decoder, the message is sent through the launch vehicle data adapter (LVDA) to the launch vehicle digital computer (LVDC). Verification of the message received is achieved by transmitting a signal over the IU-PCM (and on some vehicles the S-IVB-PCM simultaneously) telemetry system back to the ground station.

For the flights of the Saturn IB vehicles, the ground network will not be equipped for S-band operation. Therefore, the IU command system of Saturn IB uses a frequency-modulated carrier at 450 MHz. The IU carries the MCR-503 receiver for reception of the command signal. The same type of receiver is used also for the secure range safety command system. A block diagram of the Saturn IB IU command system is illustrated in Figure 2. The functional schemes of the Saturn IB and the Saturn V IU command system are identical, except for the carrier frequency and subcarrier.

Modulation Techniques

The technique employed by the ground stations for baseband modulation is phase-shift keying (PSK). A stable 1 kHz tone is generated in the modulator and used as a phase synchronizing signal. A coherent 2 kHz tone is then biphase modulated so that the binary digits are phase analogous. The 2 kHz tone is modulated at a 1 kHz rate. A binary "one" is being transmitted during the one millisecond period when the 2 kHz tone is in phase with the 1 kHz reference starting at the point where the 1 kHz waveform is crossing zero and has a positive slope (A of Fig. 4). The 1 kHz tone and the phase modulated 2 kHz tone are algebraically summed to produce the composite waveform shown in B of Figure 4. This composite waveform then modulates an RF carrier for transmission to the vehicle. In the Saturn IB IU command system, the 450 MHz RF carrier will be frequency modulated ± 60 kHz. In the Saturn V IU command system, the composite baseband waveform will frequency modulate an intermediate carrier (subcarrier) of 70 kHz, which will in turn phase modulate the 2101.8 MHz S-band carrier. The former modulation scheme is referred to as PSK/FM (at 450 MHz), and the latter is called PSK/FM/PM (at 2101.8 MHz).

The ground encoder/baseband modulator used with the IU command system will be either the digital command system (DCS) or the data processing equipment. Since the modulator portion of these two equipments performs the same function, use of the DCS will be assumed here. A brief description of the DCS will be given.

Mission Control Center

It is the basic function of MCC in Houston to assemble, analyze, and derive vehicle performance data from tracking and telemetry information. From these data variations, any performance parameter can be compared to tolerance limits for the parameter and a decision can be made as to whether a correction is required.

It is planned that MCC will, except in emergency situations, be responsible for origination and transfer of all vehicle messages to the MSFN ground installations.

In normal operation this transfer is made by way of a high speed data (HSD) communications system. A 100 word-per-minute teletype serves as a backup for the HSD system.

General Description of DCS Functions

The following very simplified description of the DCS operation is included to provide the reader with information for a better understanding of the MSFN/IU command system interface.

Input Subsystem. - The function of the input subsystem is to receive data from any one of four individually selectable sources: (1) HSD system, (2) 100 word-per-minute teletype lines, (3) high speed ground computer, or (4) manual input.

In addition, certain remote MSFN sites will have provisions for receiving data via a communications satellite, and the input subsystem at such sites will have provisions for receiving these data also.

This subsystem performs row and column parity checks as a part of its error detection routine before storage at the memory location contained in the message.

Memory Subsystem. - The function of this subsystem is to provide capability for (1) receipt of 512 command words (maximum of 40 bits per word), (2) storage of these words in a magnetic core memory, and (3) performance of error detection routines immediately following storage to check that the message stored is identical to the message received. When initiated by the operator, this subsystem will nondestructively shift the information stored in the operator-selected memory locations to the output system.

Output Subsystem. - In general, this subsystem functions to receive data from memory storage and performs the following operations:

(1) Generates phase-coherent 1 and 2 kHz subcarriers.

(2) Receives output from memory locations and encodes message into the chosen sub-bit pattern. The waveform thus produced is a clocked, non-return-to-zero (NRZ) pulse train.

(3) Utilizes the NRZ pulse train to biphase modulate the 2 kHz subcarrier at the rate of one kilobit per second.

(4) Following modulation, combines the 1 and 2 kHz signals in a linear adder.

(5) Feeds the composite signal to the RF subsystem.

(6) Performs extensive error detection and self-check routines. The DCS has a limited self-repair capability (substitution of alternate path circuitry).

RF System

This system includes:

1. FM modulator, AN/FRW-2A transmitter, monitor receiver, and antenna system for the Saturn IB program.

2. A 70 kHz subcarrier generator with FM modulation capability, PM modulator, S-band RF transmitter, and antenna system for the Saturn V program.

Command Site Telemetry System

Each command site must have telemetry equipment capable of receiving, decommutating, and presenting in real time certain telemetry information from the vehicle.

For example, the DCS operation depends upon receipt of a message acceptance pulse (MAP) for each message transmitted. Receipt of an MAP advances the DCS to transmit the next message in the sequence; failure to receive an MAP causes the DCS to retransmit the same message.

The MAP for the IU command system is composed of an address verification pulse, generated in the decoder, and a computer reset pulse, generated by the LVDC. The LVDC will acknowledge receipt of a valid message, i.e., a message passing all LVDC tests for validity, by generating a pulse which resets the decoder outputs to zero and generates a telemetry signal (called the "computer reset pulse"). In the event that a message fails one or more of the LVDC validity tests, the reset pulse is not generated and therefore no MAP is received at the ground station. In this case the LVDC initiates a telemetry message indicating the cause for message "rejection" (Fig. 5). This "error" message must be decommutated and analyzed in real time to determine whether a retransmission is desirable.

Command Word Format

The command word in the IU command system (Fig. 6) is composed of 35 updata bits functionally grouped as follows.

Seventeen address bits (Fig. 7)

1. Three bits for vehicle address
2. Fourteen bits for decoder address

Eighteen information bits (Fig. 8(a) through (d))

1. Four bits for control information
    - (a) Two mode/data bits
    - (b) Two interrupt bits

2. Fourteen bits for computer data

The first three bits of the word are called vehicle address bits and are 111 for the IU command system on all Saturn flights. The 14 decoder address bits are distributed throughout the word as shown in Figure 5. These bits are compared with a prewired address in the decoder and are used to perform error checking.

The 18 information bits are used to convey binary data to the LVDC. (All data for the LVDC are processed by the LVDA, which is the input-output device for the LVDC.)

The LVDC data bits are divided into functional groups as shown in Figure 5. The first two bits are called "interrupt" bits and the next two are called "mode/data" bits. The remaining 14 bits are data to the LVDC. The interrupt bits are always binary "ones" and are combined in the LVDA to produce a single interrupt bit from the LVDA to the LVDC. The mode/data bits are binary "ones" or "zeros" depending on whether the particular command message is a mode command word or a data command word. The other 14 bits represent the binary coded data wherein the message will be presented in the "true" and "complement" form.

Bit Coding and Timing

Each of the 35 updata bits of the command word is encoded into 5 sub-bits (total of 175 sub-bits per command word). Each sub-bit is one millisecond in duration, which is exactly the period of the 1 kHz waveform. Each updata bit, consequently, is five milliseconds in duration because the system operates NRZ with no dead time between sub-bits. The total time for a 35-bit message transmission is 5 (ms) × 35 = 175 milliseconds since there also is no dead time between updata bits. The updata bit rate is, therefore, 200 bits per second.

Since each sub-bit has a binary coding potentiality, each updata bit can be coded in $2^5 - 1 = 31$ unique ways. The ways in which the sub-bits can be arranged in groups of five are referred to as "sub-bit patterns." Only 3 of the possible 31 sub-bit patterns are planned for use for the IU command system during a given flight. The encoder and decoder have provisions for changing (prior to flight) one, two, or all three of the sub-bit patterns. One of the three sub-bit patterns will be used solely for the first three updata bits of the command word, the vehicle address. These updata bits will be referred to as "X" bits and are utilized to distinguish between commands intended for the Apollo spacecraft and those intended for the IU. This is necessary since both updata links use the same baseband modulation and time-share a common carrier.

The other two sub-bit patterns are used for the remaining 32 message bits. Consequently, each updata bit can be coded in a binary fashion. These sub-bit patterns are chosen for optimum differentiation between ones and zeros, thus providing error detection capability at the updata-bit level.

Command Types

Only 14 updata bits out of each 35-bit command word can be utilized to carry data to the LVDC. It is sometimes necessary to transmit more than one command word to complete a given message (command).

Present plans call for the LVDC to be capable of receiving 10 different types of messages, although this can be expanded to many more if necessary. The 10 different message types (modes) are as follows:

1. LVDC Memory Update

    (a) Message requirements: 1 mode, 8 data/memory location, and 1 execute.

2. Navigation Update

    (a) Message requirements: 1 mode, 35 data

3. Sequence Table Update

    (a) Message requirements: 1 mode, 1 data

4. , Terminate Mode

    (a) Message requirements: 1 mode

5. Execute Mode

    (a) Message requirements: 1 mode

6. Switch Selector Mode

    (a) Message requirements: 1 mode, 2 data

7. LVDC Memory Sector Dump

    (a) Message requirements: 1 mode, 2 data

8. Single LVDC Memory Word Dump
    (a) Message requirements: 1 mode, 3 data

9. Systems Checkout
    (a) Message requirements: 1 mode

10. LVDC Closed Loop Initiate
    (a) Message requirements: 1 mode

In every case the type of command being transmitted is determined by the first 35-bit word of the message. This first word is always a mode command word and the most significant 7-bit slots of the 14-bit data group are coded to establish which one of the ten command types is being sent. The remaining 7-bit slots are coded to be complementary to the first seven. The data words, as differentiated from mode words, contain six data bits and their complements plus two counter bits.

Command Receiver

The Saturn IB IU command system uses the MCR-503 receiver with a frequency range of 406 to 450 MHz. In the Saturn V vehicle the IU command is received by the S-band transponder of the Saturn command and communication system.

A block diagram of the MCR-503 receiver is shown in Figure 9. The received RF signal is coupled from RF input J1 to a fixed-tuned, low-pass filter which has a cutoff frequency of approximately 570 MHz. 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 to 450 MHz. The bandpass filter output is amplified by the 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 -3 db bandwidth of the complete preselector assembly is approximately 4 MHz. The gain is approximately 5 db. The preselector RF amplifier output is coupled to the first mixer. Here the multiplied output of the local oscillator is heterodyned with the RF signal to produce the first IF signal. The first IF signal is amplified and applied to the second mixer, where it is heterodyned with a signal at the local oscillator frequency to produce the 10. 7 MHz second IF signal. The local oscillator is crystal controlled and has a tuning range of 100 to 120 MHz. During factory alignment, the oscillator, multiplier, first mixer, and IF amplifier are tuned to provide maximum sensitivity. The first and second mixer, first IF amplifier, crystal oscillator, and frequency multiplier are contained in the first IF assembly. The -3 db bandwidth of this assembly is approximately 1.5 MHz and the gain is approximately 43 db.

The 10.7 MHz output of the first IF assembly is coupled directly to the IF bandpass filter. The passive LC filter determines the overall receiver bandpass characteristics. The nominal -3 db bandwidth of the filter is 340 kHz and the -60 db bandwidth is 1200 kHz. The filter insertion loss is approximately 10 db.

The bandpass filter output is fed to the second IF assembly, which contains two feedback amplifier pairs. Each pair has a gain of approximately 30 db. The output of each pair is tuned to 10.7 MHz. 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 the back-to-back diodes in the transistor collector circuit. The second limiter limits by saturation and cutoff of the transistor and drives the Foster-Seeley discriminator. The discriminator sensitivity is approximately 4 millivolts rms per kHz of peak deviation. The emitter follower output stage is used for impedance isolation between the discriminator and the audio amplifier.

The audio amplifier consists of a voltage amplifier stage, a phase inverter, and a low impedance output stage. The nominal voltage gain of the amplifier is 14 db. The lower -3 db frequency is approximately 300 Hz and the upper -3 db frequency is approximately 250 kHz. The overall receiver -3 db audio bandwidth is approximately 600 Hz to 80 kHz. This is set by the output circuit of the discriminator. The amplifier output feeds two 47-ohm isolation resistors, each one of which feeds an output connector. These resistors allow one output to be shorted to ground without reducing the other output voltage more than 3 db. One of these outputs will be used as the input for the IU command decoder. The amplifier output also feeds a bandpass filter. This filter output is fed to an AGC-controlled amplifier and then to the high-level telemetry detector circuit. The telemetry voltage thus obtained will provide a useful measure of RF input signal up to 500 microvolts.

Characteristics of the MCR-503 receiver are given in Table I.

TABLE I. CHARACTERISTICS OF THE MCR-503 RECEIVER

MCR-503 Receiver Characteristics	
Frequency range	406 to 450 MHz
Frequency deviation	±60 kHz max.
Quieting	15 db at 10 μV
Maximum RF input	2.0 V rms
Input VSWR	1.5:1 maximum
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)	1 to 80 kHz
Audio distortion	Less than 5 percent
Audio output level	1.4 V rms into 75 ohms (with two tones, ± 30 kHz deviation per tone)
Input voltage	+22 V dc to +36 V dc
Weight	1.4 kg (3.1 lbs)
Power	3.5 W at 28 V dc
Outline dimensions:	
Height	8.6 cm (3 3/8 in.) (less connectors)
Width	13.4 cm (5 1/4 in.)
Depth	11.7 cm (4 9/16 in.)

Decoder Operation

The decoder is the interface unit between the command receiver and the LVDA. Data transmission is made through a 32-bit word which is preceded by three vehicle address bits ("X" bits).. Each data and address bit is composed of 5 sub-bits. The total 175 sub-bit message must be decoded into the original message configuration of 35 bits before the data can be transferred into the LVDA for computer acceptance.

The functions of the IU command decoder are as follows:

1. Demodulate the PSK baseband subcarriers.

2. Recover the original 175 sub-bits.

3. Compare each 5 sub-bit group against three prewired bit codes to recover the 35-bit command word.

4. Check that all 35 bits are received.

5. Check that 5 sub-bits are received within the 5-millisecond bit period.

6. Check that the 3-bit vehicle address and the 14-bit decoder address are correct.

7. Inhibit any further decoding if any of the checks are invalid.

8. Present the 18 information bits to the LVDA in parallel form.

9. Present an "address verification" signal to PCM telemetry.

10. Receive the "LVDC reset" signal from the LVDA and present this signal to PCM telemetry.

The operation of the decoder can best be explained by breaking the decoder into two logical functional parts as shown in Figure 10.

PSK Demodulation and Sub-Bit Decoding. The onboard receiver demodulates the RF carrier and presents the composite baseband signal (A of Fig. 4) to the IU command decoder. The purpose of the PSK demodulator is to separate the 1 and 2 kHz signals, compare the phase of the 2 kHz tone with the 1 kHz reference tone once each millisecond, and generate a pulse on the "1" output circuit or the "0" output circuit, as the case may be. Figure 11 is a simplified block diagram of the PSK demodulator.

The composite audio input signal is filtered by a low-pass filter whose response is 40 db down at 4 kHz. The low-pass filter output goes to two places: a summing network and a 1 kHz bandpass filter. The bandpass filter recovers the 1 kHz component, which is subsequently amplified, delayed in phase to compensate for filter response, and also applied to the summing network. The summing network essentially acts to linearly subtract the two signals, thus recovering the 2 kHz component.

The 1 kHz sine wave is capacitively coupled to a shaper circuit which acts to "square up" the positive half cycle of the input waveform. This waveform is differentiated and the positive pulse is used to trigger a monostable multivibrator. The trailing edge of this monostable output is differentiated, shaped and amplified, and fed as one input to each of two AND gates. The output of the amplifier is a very narrow pulse appearing at a 1 kHz rate and will be referred to as the sampling pulse.

The output of the summing network (the 2 kHz waveform) is capacitively coupled to a shaper circuit. The shaper output is applied to two places: first it is applied to an inverter stage, and second it is applied to the "1" AND gate.

When the 2 kHz waveform is positive and time coincident with the sampling pulse, the "1" AND gate will produce an output pulse. This pulse will trigger the "1" monostable multivibrator to the "on" state. The time period of this monostable is 200 microseconds ±10 percent. The monostable output is fed to the input of the main decoder.

The output of the inverter is applied to the "0" AND gate along with the sampling pulse. In a manner similar to that described previously, the "0" AND gate will produce an output pulse and trigger the "0" monostable. Note that both AND gates cannot have an output at the same time.

To provide maximum insensitivity to relative phase differences between the two recovered components, the timing resistor of the sampling monostable is selected so that the sampling pulse falls as closely as possible to the center of the positive portion of the second cycle of the 2 kHz shaped waveform. This timing is accomplished under conditions as near ideal as possible; namely the use of a modulator known to be in good phase alignment, a properly operating signal generator, and a flight qualified receiver. Such a procedure ensures that any relative phase difference caused by the equipment during flight will occur only from uncontrollable sources (such as differences in ground equipment).

Main Decoder. -The operation of the main decoder is best explained by the use of the block diagram in Figure 12 and the flow diagram in Figure 13. During dead time between messages, a continuous stream of sub-bit "1's" is being transmitted. These sub-bits are fed to the sub-bit decoder where they are written into the 5-bit shift register. Each sub-bit, as it leaves the sub-bit demodulator, is 200 microseconds in duration. The leading edge of this 200-microsecond waveform is differentiated and used as the shift pulse for the 5-bit shift register. The bits are written into the register by the differentiated trailing edge.

The shift register has 10 outputs (two for each position) resulting in 2^5 (32) possible sub-bit patterns. Each of 3 sub-bit comparators "X," "1," and "0" have 5 wires connected to the 5-bit shift register, one wire to each position. If, for example, the sub-bit code for a data "1" is chosen as "11010," the sub-bit code for a data "0" is chosen as the data "1's" complement, and the "X" sub-bit code is chosen to be "11000," then the wiring between the sub-bit comparators and the 5-bit shift register will be as shown in Figure 14.

During intervals when no messages are being transmitted, all sub-bit "1's" are transmitted; however, the comparators have no output. 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 sub-bits are bracketed by continuous sub-bit "1's," the "X" comparator is initially enabled by the output from OR 6 through OR 3 and the 5-bit counter is inhibited by AND 1; permitting an "X" comparison at any time the 5-bit shift register pattern is correct.

The first "X" bit comparison generates a 1 millisecond pulse which is differentiated; the leading edge passes through AND 2 and resets the 5-bit counter and the 3-bit counter. The trailing edge of the pulse advances the 3-bit counter one count and starts the missing-bit clock.

The missing-bit clock is essentially two monostable multivibrators which, if a proper message is being received, will provide a continuous output from OR 6. This is accomplished by alternately triggering the multivibrators. The "on" cycle of the multivibrators (5.4 ms) is adjusted to be slightly greater than the duration of each data bit (5.0 ms). Thus the "off" multivibrator is triggered "on" 400 microseconds before the "on" multivibrator completes its cycle, and OR 6 will always have at least one input. When the missing-bit clock starts, the output of OR 6 will: (1) open AND 1 enabling the 5-bit counter, (2) inhibit AND 2 preventing the next "X" comparison from generating a reset, and (3) inhibit through OR 3 the "X" comparator.

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 OR 3, thus enabling an "X" comparison. A valid "X" comparison will generate a 200 microsecond pulse. The trailing edge of 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 (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. 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 AND 3 and AND 4. As long as this signal is present, AND 3 and AND 4 are "open"; that is, they will allow valid "0" and "1" bits to pass through.

The next 32 bits will be coded with "0's" and "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." If it is a "0" or a "1," a pulse will be produced at the output of OR 5, 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, a 1-millisecond monostable multivibrator is triggered "on." This signal opens AND 5 and allows an address comparison to be made. If the address is correct, a signal will pass through AND 5 and trigger the output gate flip-flop (a bistable multivibrator) to its "set" state. In addition, the two 60-millisecond monostable multivibrators will be triggered "on," providing an indication to telemetry that the address was valid. Two multivibrators are used for reliability.

The "set" output of the flip-flop also resets the 3-bit counter (through OR 4) and provides an enabling voltage to the 18 data output drivers. 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 accepts these data bits from the LVDA, a reset pulse acknowledging receipt is sent through the LVDA to the decoder. This pulse will pass through OR 8 and will clear the 32-bit shift register, reset the output flip-flop (thus disabling the 18 data-output drivers), and trigger two 60-millisecond monostable multivibrators. The outputs of these two multivibrators are sent to telemetry 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.

Data Verification

The application of the IU command system and the information transmitted through the system require a high probability that a correct command message will be received in the vehicle. This high probability is obtained by the use of several different techniques throughout the system.

First of all, the Manned Space Flight Network is designed to provide a high degree of data transmission accuracy from the originating station in Houston, Texas, to the MSFN DCS unit, or data processing computer, which actually transmits the message to the vehicle. Secondly, to transpose a "1" bit to a "0" bit or vice-versa, every one of the five sub-bits of an updata bit must be transposed to its complement; and this must be done in multiples of five in synchronism with the bit rate (200 bits per second) or the message will be rejected. Thirdly, 17 bits of each 35-bit transmission must be correct (there is no possibility of an undetected error here) before the 18 information bits are presented to the LVDA. Last of all, a verification loop utilizing telemetry as a downlink is employed to verify the 18 information bits for critical commands (the LVDC update commands).

The verification loop works as follows. If the 14-bit address is correct, an address verification pulse is sent to telemetry. This pulse is decommutated in real time at the ground station and presented to the message acceptance pulse circuitry (Fig. 15). A second pulse is also derived in the vehicle and sent to telemetry. This is the LVDC reset pulse which signifies that the LVDC has received the 18 information bits. This pulse is also decommutated in real time and routed to the message acceptance pulse circuitry. The address verification pulse triggers a 200-millisecond monostable multivibrator to the "on" state. The LVDC reset pulse will occur a short time thereafter and trigger a 60-millisecond monostable multivibrator to the "on" state. If the LVDC reset pulse does not appear during the "on" time of the address verification pulse, then it will not appear at all for a given transmission. The two outputs are logically combined in an AND gate, which will have an output only when both multivibrators are "on" at the same time.

The 10-millisecond pulse thus produced is called the message acceptance pulse and is fed to the DCS. The DCS uses this message acceptance pulse as a "next-message-transmit" signal. Upon receipt of this pulse, the DCS will transmit the next message (if any). If the message acceptance pulse does not appear within a certain length of time, the DCS will then retransmit the message. A dead time between messages is needed to ensure that the DCS does not retransmit prior to receipt of the message acceptance pulse. The delay takes into account all processing and loop delays, including propagation time (a maximum two-way trip of 28,000 kilometers for the S-IVB/IU).

To complete the data verification, the LVDC stores all LVDC update messages (as many as 40 18-bit groups) and nondestructively reads out these data bits to telemetry. Upon receipt by the ground station, these bits are sent to Houston via MSFN and compared with those originally transmitted. If all bits are verified, an "execute update" command is sent to the DCS and thence to the vehicle. Only upon receipt of this message will the LVDC act upon the "update" data bits.

REFERENCE

1. Marshall Space Flight Center: "Secure Range Safety Command System for Saturn." NASA TM X-53162, Nov. 9, 1964.

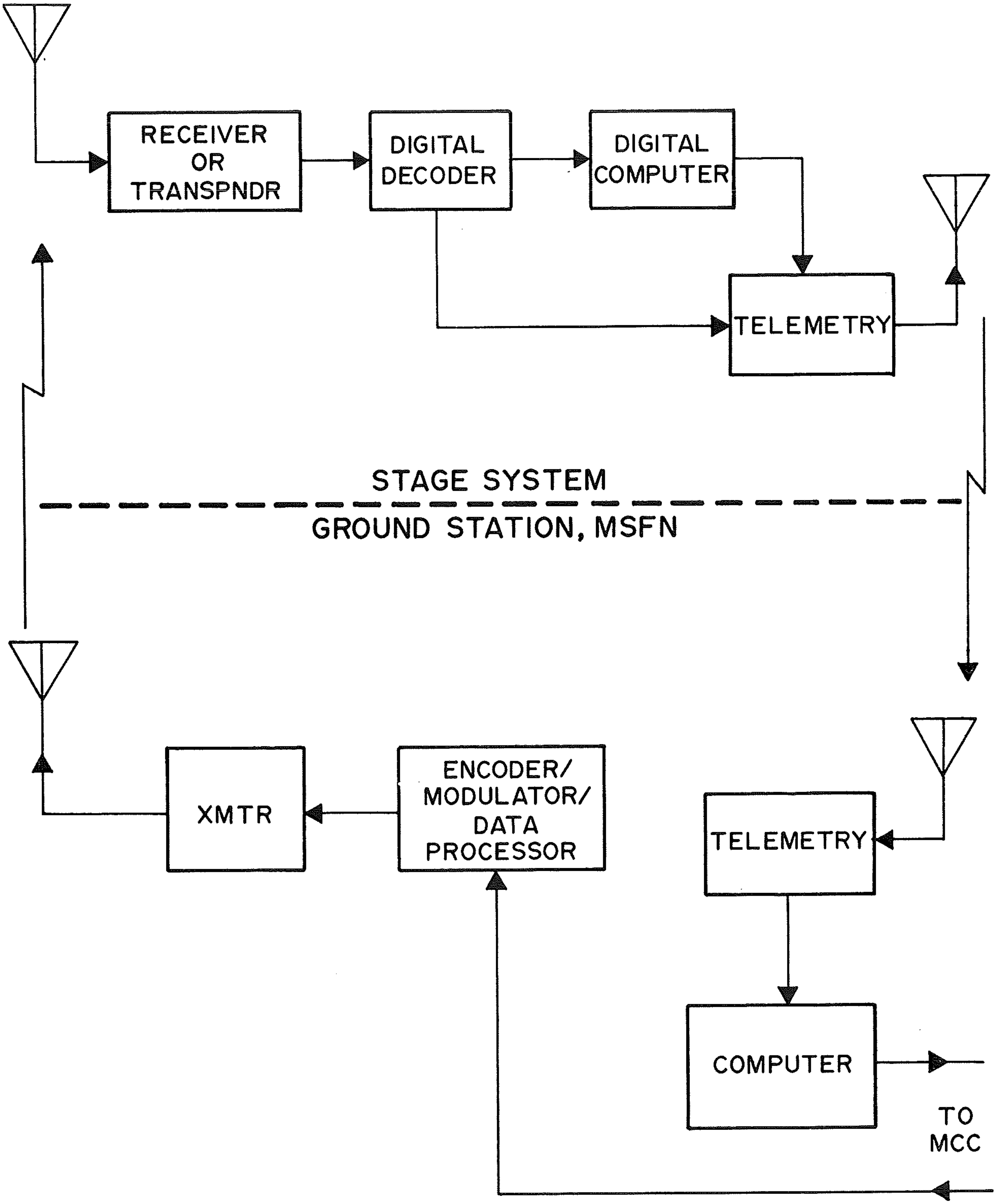
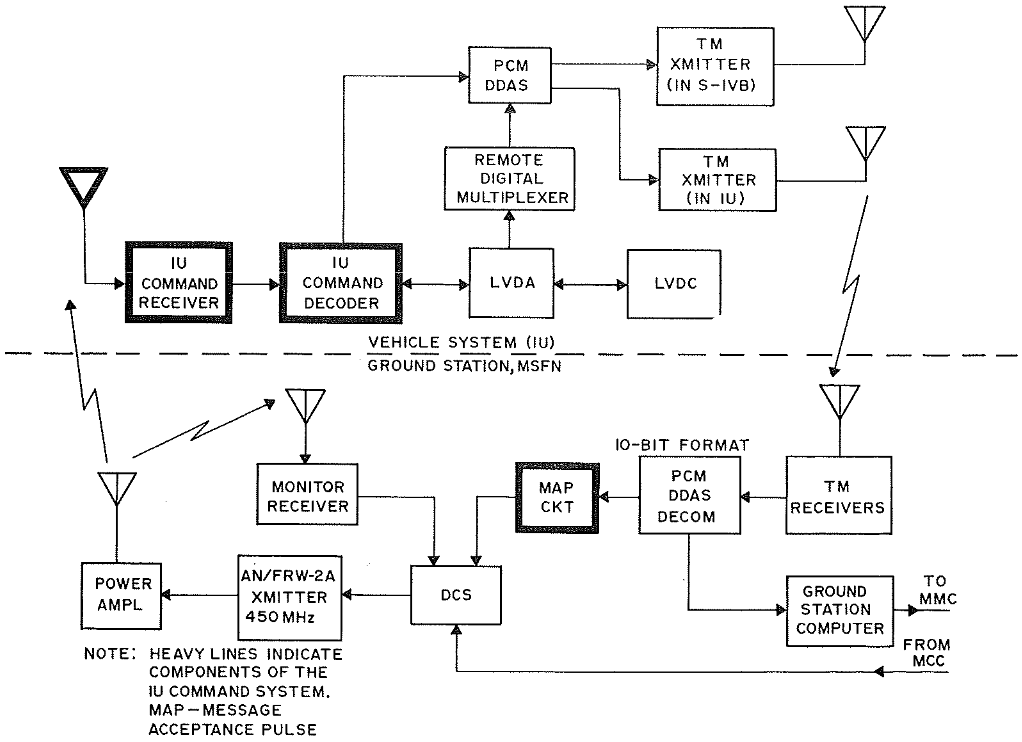
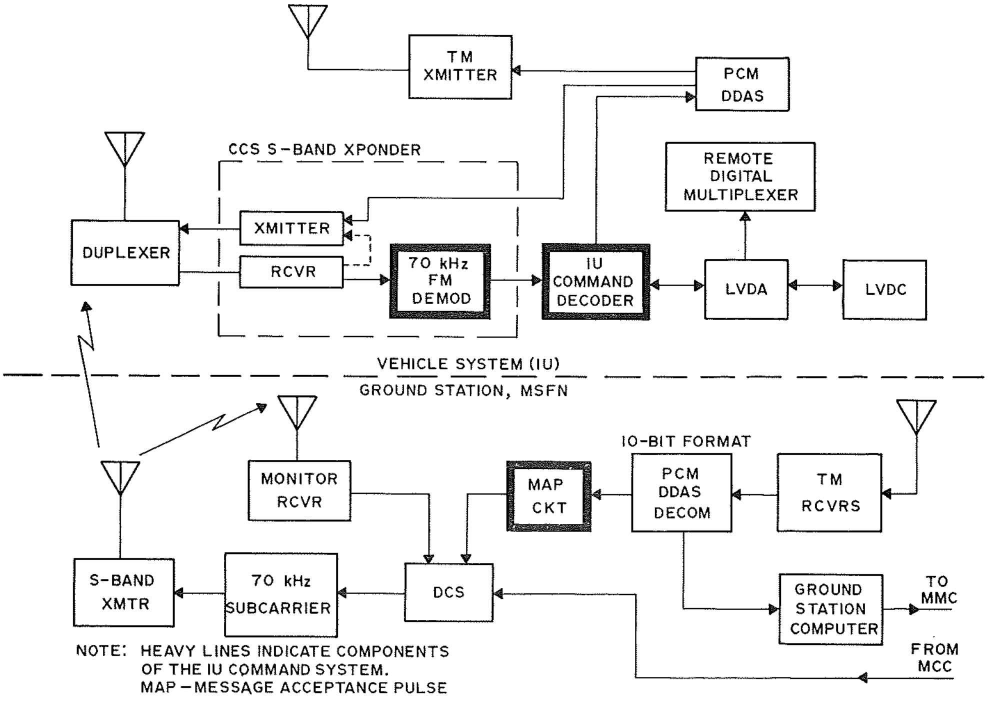


FIGURE 1. GENERAL SYSTEM CONFIGURATION



NOTE: HEAVY LINES INDICATE COMPONENTS OF THE IU COMMAND SYSTEM.
MAP – MESSAGE ACCEPTANCE PULSE

FIGURE 2. S-IB IU COMMAND SYSTEM



NOTE: HEAVY LINES INDICATE COMPONENTS OF THE IU COMMAND SYSTEM.
MAP – MESSAGE ACCEPTANCE PULSE

FIGURE 3. S-V IU COMMAND SYSTEM

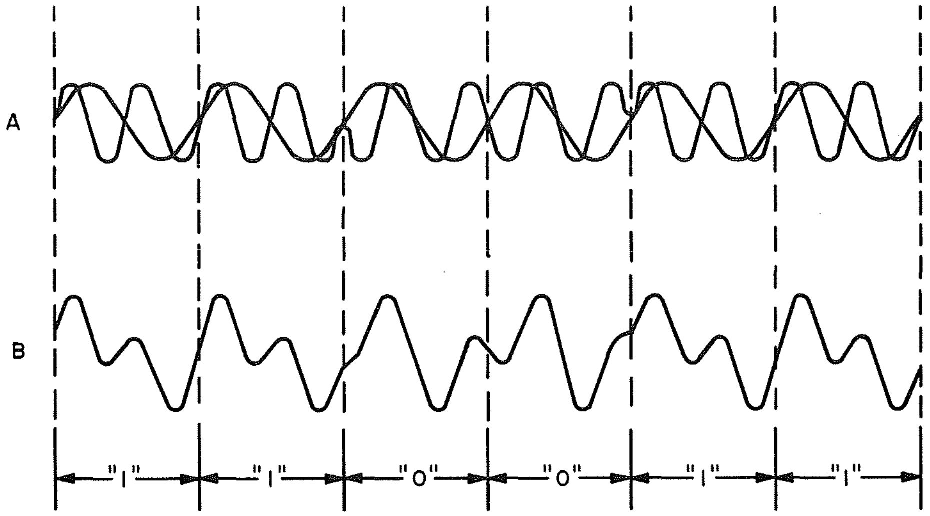


FIGURE 4. COMPOSITE WAVEFORM

DCS HISTORY WORDS FORMAT

(LVDC) DCS STATUS WORD

		40 27	26 18	17 15	14 8	7 1
# TIME		* 14 TAG BITS	9 ERROR CODE BITS	3 ERROR CTR BITS	** ERROR EVALUATION	ERROR EVALUATION
GMT	GET					

* TAG BITS UNIQUE FOR ERROR & NONERROR WORDS.

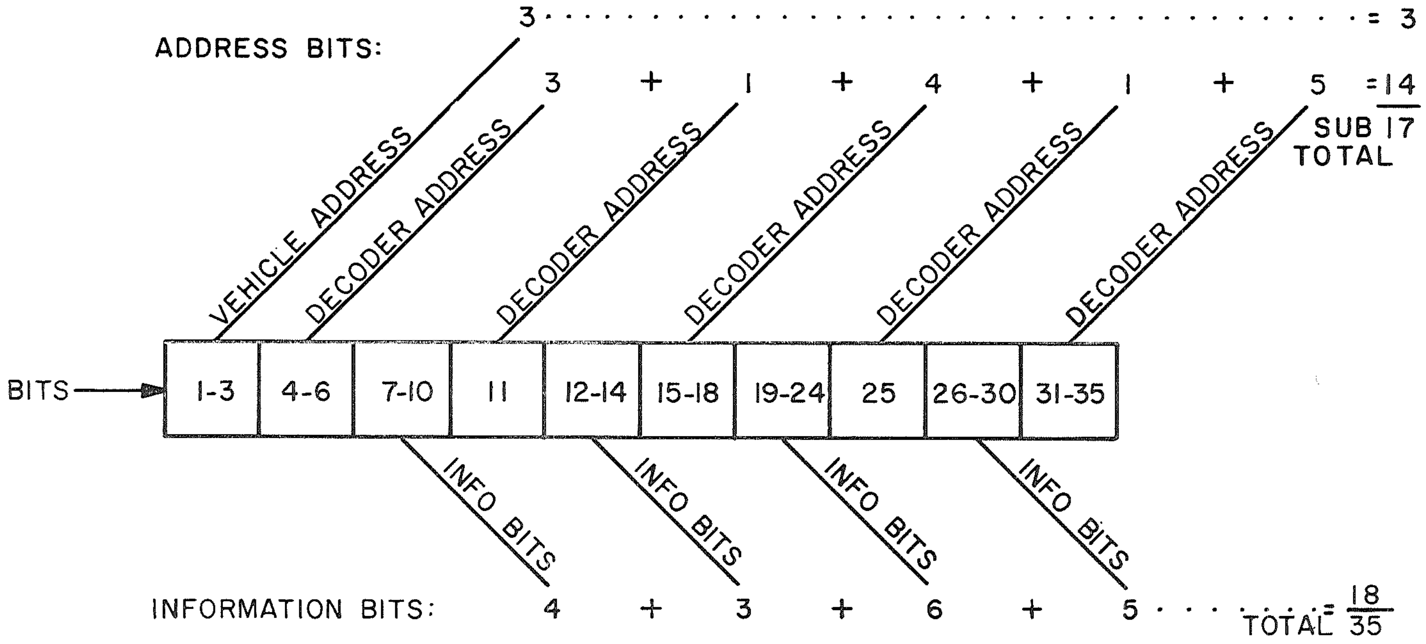
** COMMAND DATA BITS EXCEPT WHEN REQUIRED TO SUPPLEMENT ERROR CODE BITS.

\# ADDED BY GROUND EQUIPMENT

VEH.	TIME		CMD #	RETR	MAP # 1	MAP # 2	EVENT	REQ'ING CONSOLE	CMD (IN OCTAL)
	GMT	GET							

HISTORY SUMMARY

FIGURE 5. MESSAGE REJECTION



NOTE: BITS ARE NUMBERED IN ORDER OF TRANSMISSION

FIGURE 6. COMMAND WORD IN IU COMMAND SYSTEM

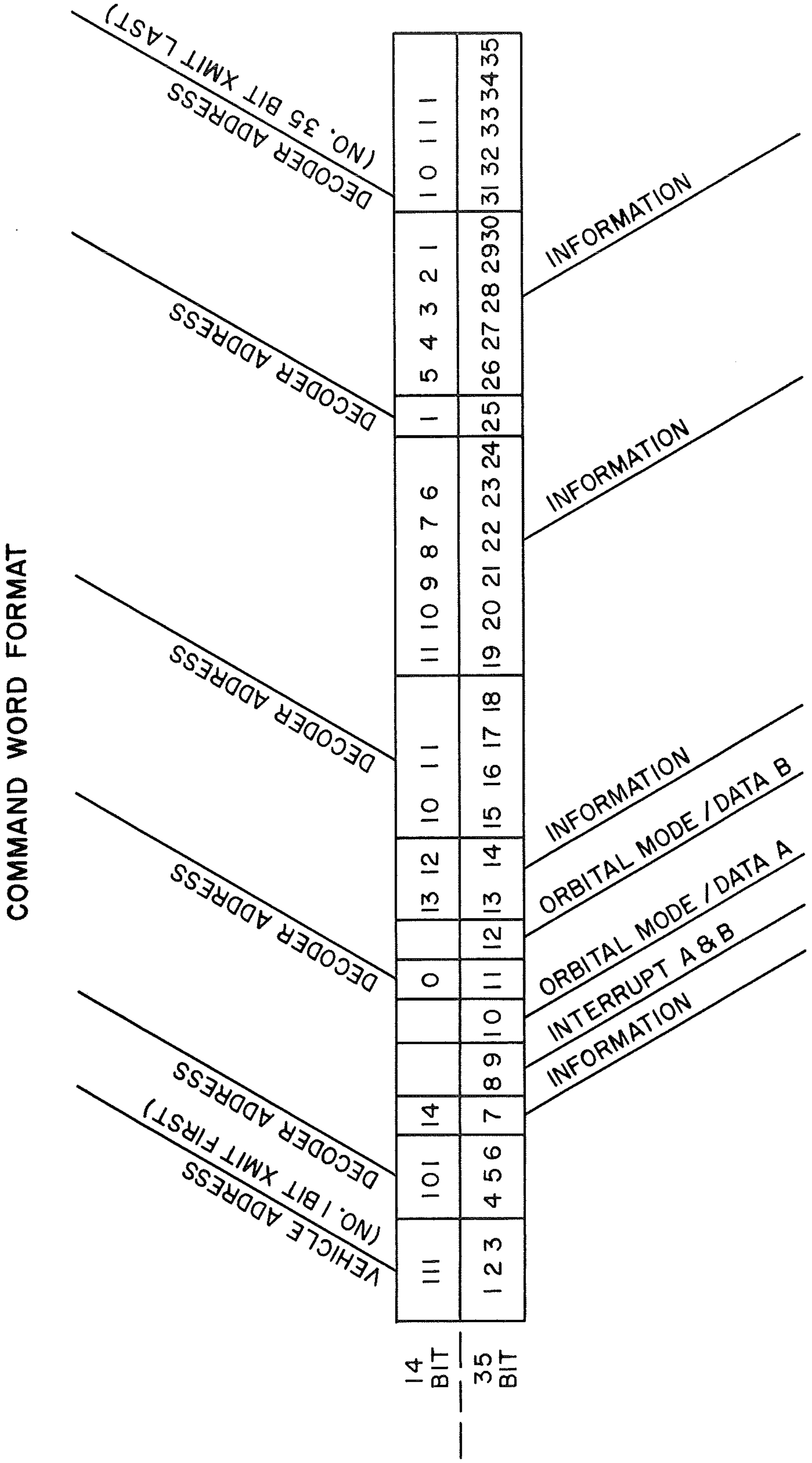


FIGURE 7. SEVENTEEN ADDRESS BITS

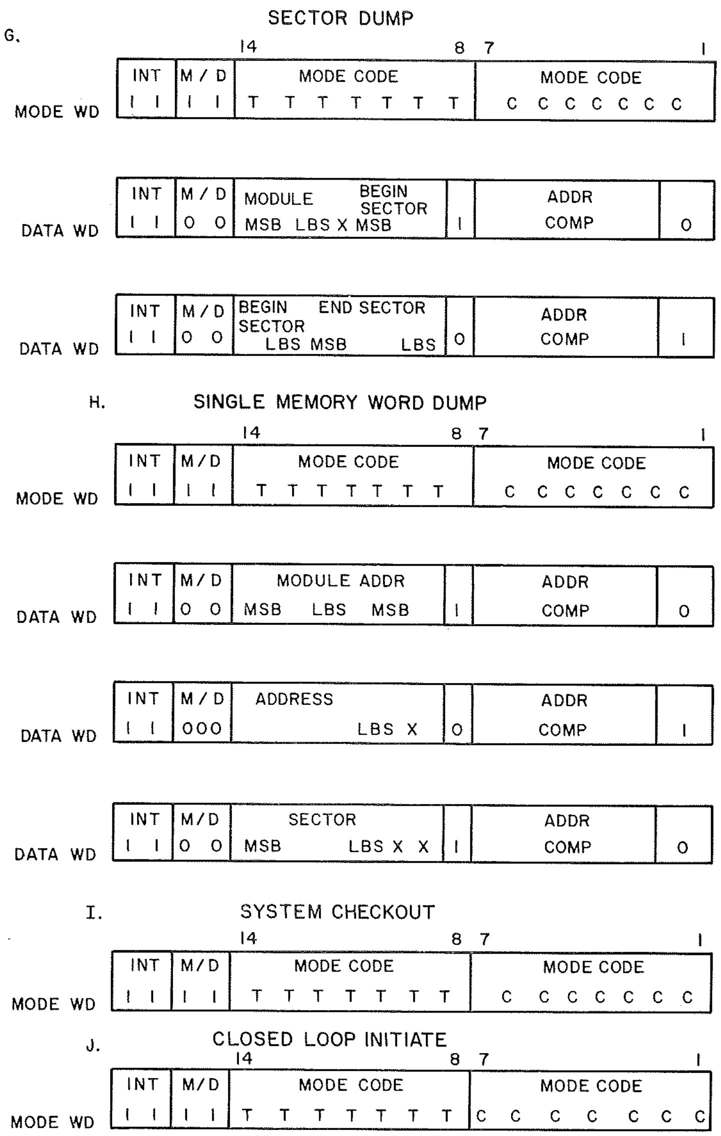


FIGURE 8(a). EIGHTEEN INFORMATION BITS

SEQUENCE TABLE UPDATE

MODE WORD

		14 8	7 1
INT	M/D	MODE CODE	MODE CODE
1 1	1 1	T T T T T T T	C C C C C C C

DATA WORD

INT	M/D	DATA TRUE		DATA	
1 1	0 0	S MSB LSD	1	COMP	0

D. TERMINATE MODE

MODE WORD

		14 8	7 1
INT	M/D	MODE CODE	MODE CODE
1 1	1 1	T T T T T T T	C C C C C C C

E. EXECUTE MODE

MODE WORD

		14 8	7 1
INT	M/D	MODE CODE	MODE CODE
1 1	1 1	T T T T T T T	C C C C C C C

F. SWITCH SELECTOR

MODE WORD

		14 8	7 1
INT	M/D	MODE CODE	MODE CODE
1 1	1 1	T T T T T T T	C C C C C C C

DATA WORD

INT	M/D	IU IVB ADDR		ADDR	
1 1	0 0	X MSB	1	COMP	0

DATA WORD.

INT	M/D	ADDRESS		ADDR	
1 1	0 0	LBS X	0	COMP	1

FIGURE 8(b). EIGHTEEN INFORMATION BITS

B. NAVIGATION UPDATE

(5 DATA WORDS FOR EACH LOCATION UPDATED)
(TOTAL LOCATIONS TO BE UPDATED = 7)

MODE WORD

INT	M/D	MODE CODE	MODE CODE
1 1	1 1	T T T T T T T	C C C C C C C

DATA WORD

INT	M/D	DATA		DATA	
1 1	0 0	MSB	1	COMP	0

DATA WORD

INT	M/D	DATA		DATA	
1 1	0 0		0	COMP	1

DATA WORD

INT	M/D	DATA		DATA	
1 1	0 0		1	COMP	0

DATA WORD

INT	M/D	DATA		DATA	
1 1	0 0		0	COMP	1

DATA WORD

INT	M/D	DATA		DATA	
1 1	0 0	LBS X X X X	1	COMP	0

REPEAT DATA WORDS FOR TOTAL OF 35 SEQUENCE BITS ARE CONSECUTIVE

FIGURE 8(c). EIGHTEEN INFORMATION BITS

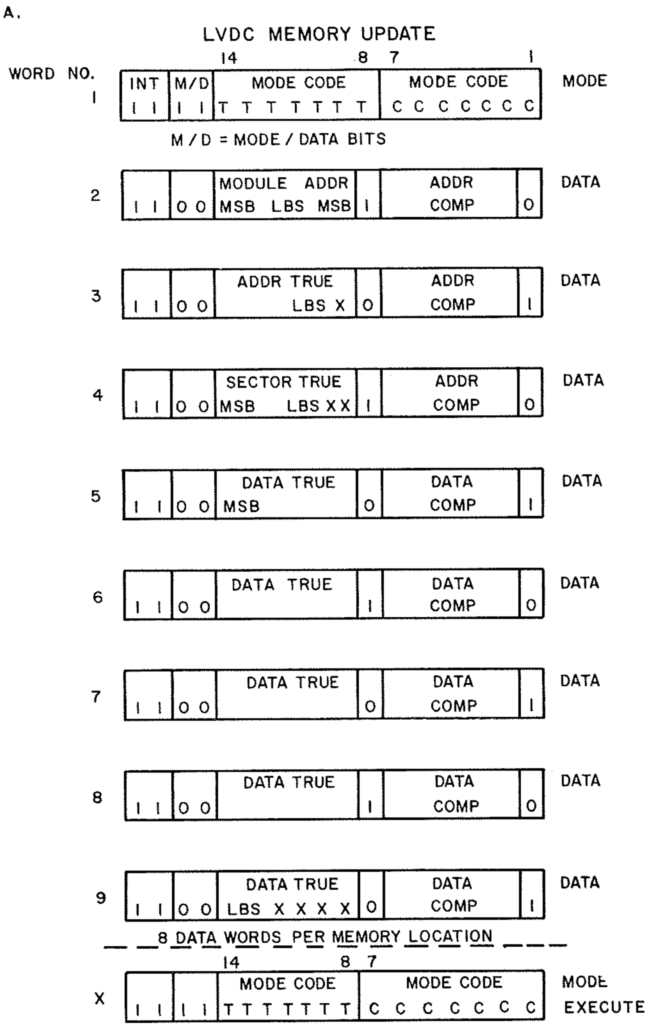


FIGURE 8(d). EIGHTEEN INFORMATION BITS

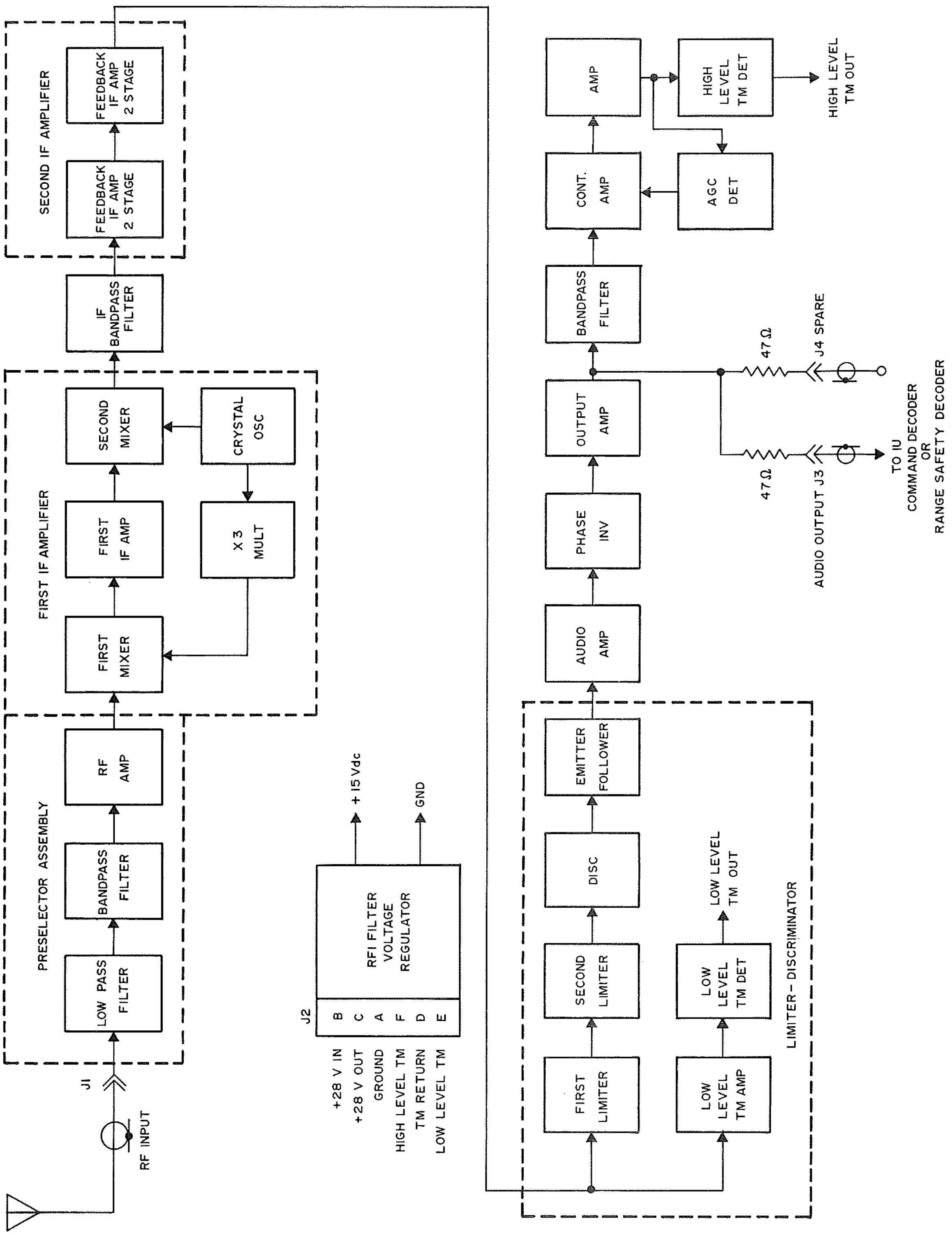


FIGURE 9. BLOCK DIAGRAM OF THE MCR-503 RECEIVER

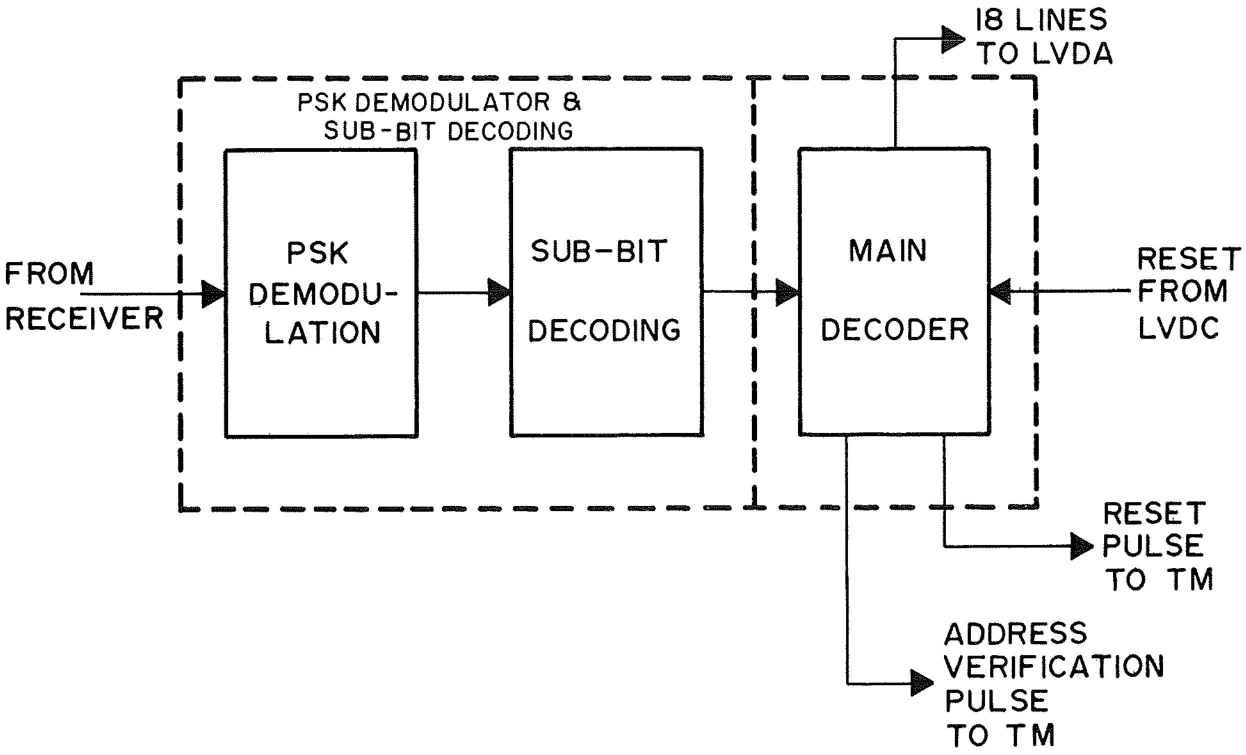


FIGURE 10. FUNCTIONAL BLOCK DIAGRAM OF THE DECODER

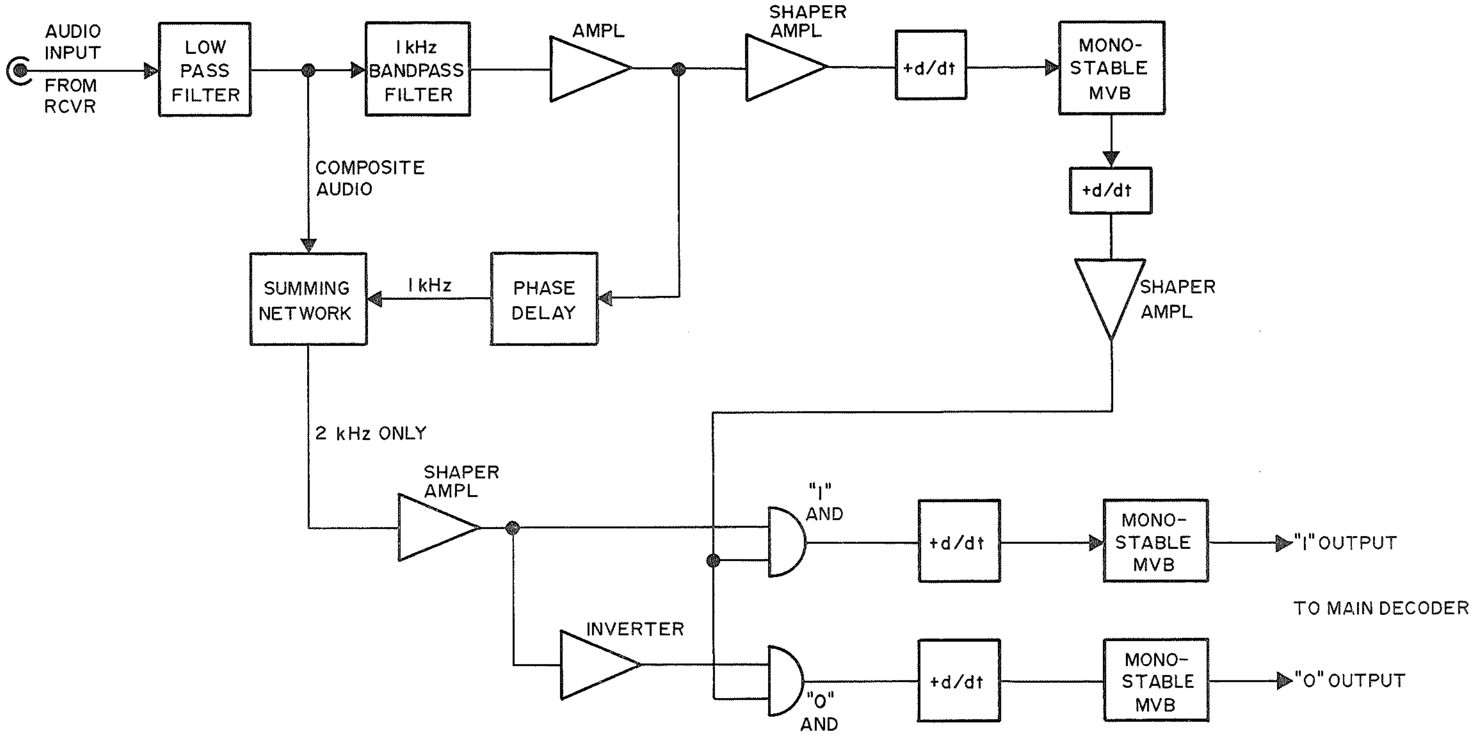


FIGURE 11. PHASE SHIFT KEYING DEMODULATOR

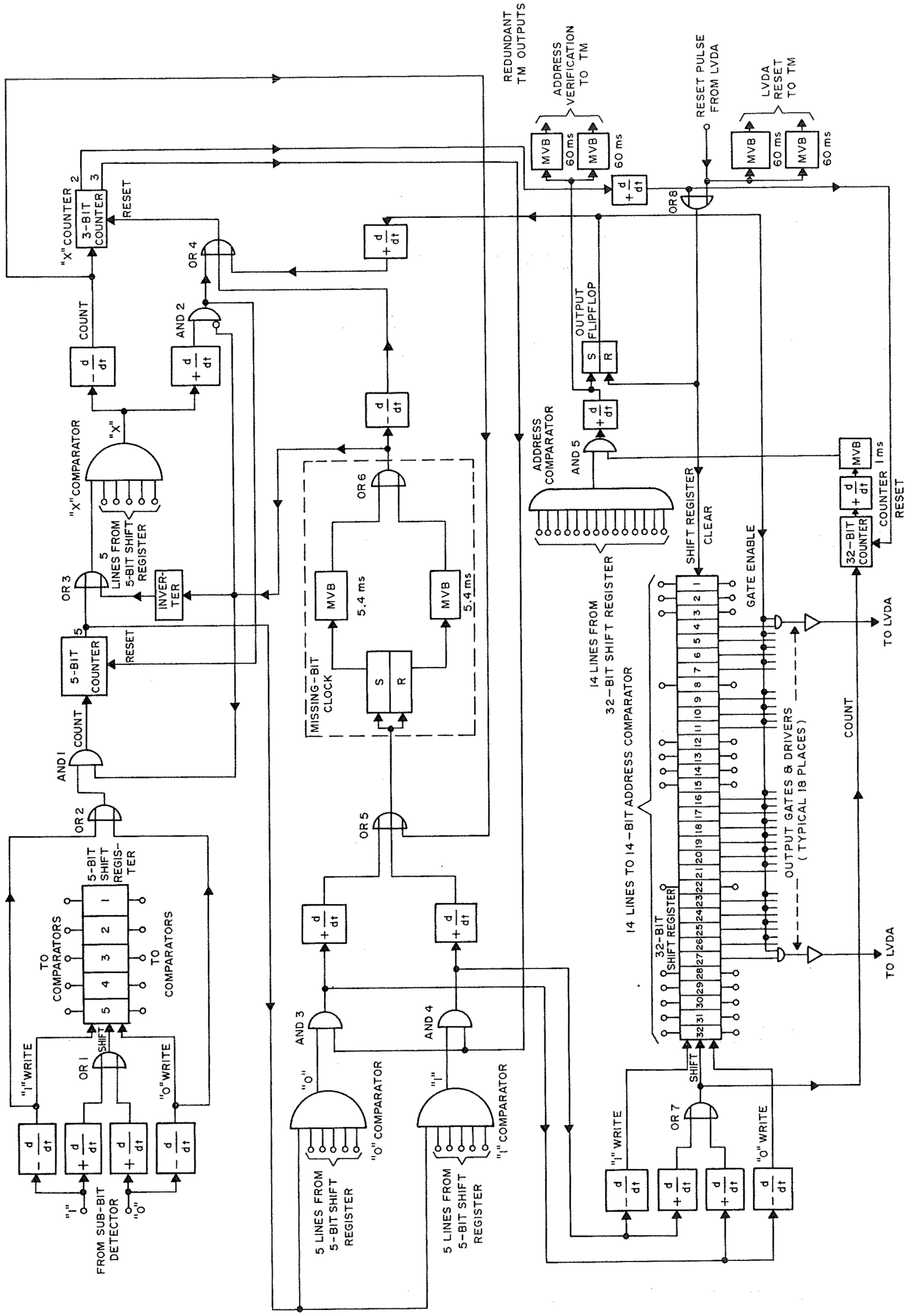


FIGURE 12. BLOCK DIAGRAM OF THE MAIN DECODER

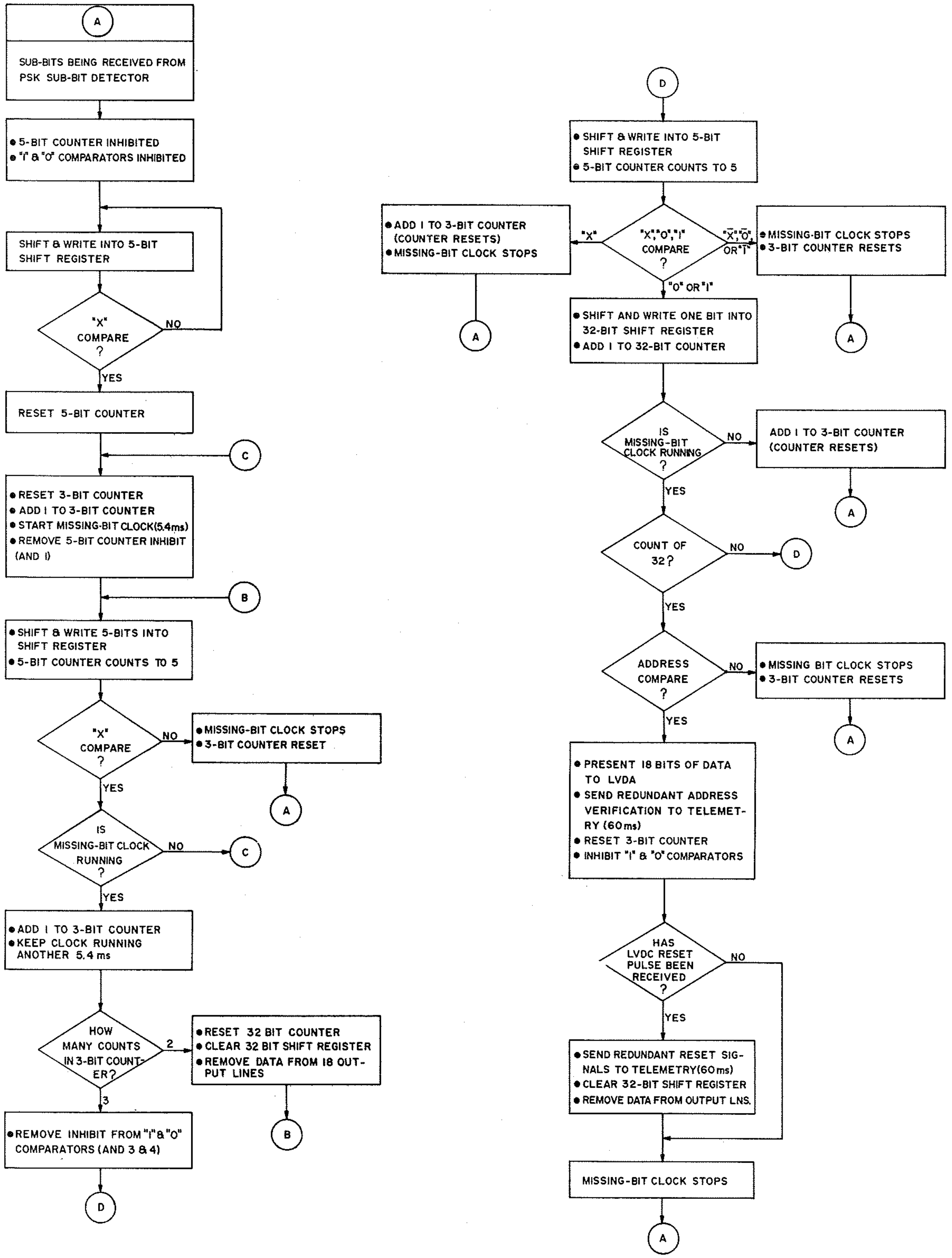


FIGURE 13. FLOW DIAGRAM OF THE MAIN DECODER

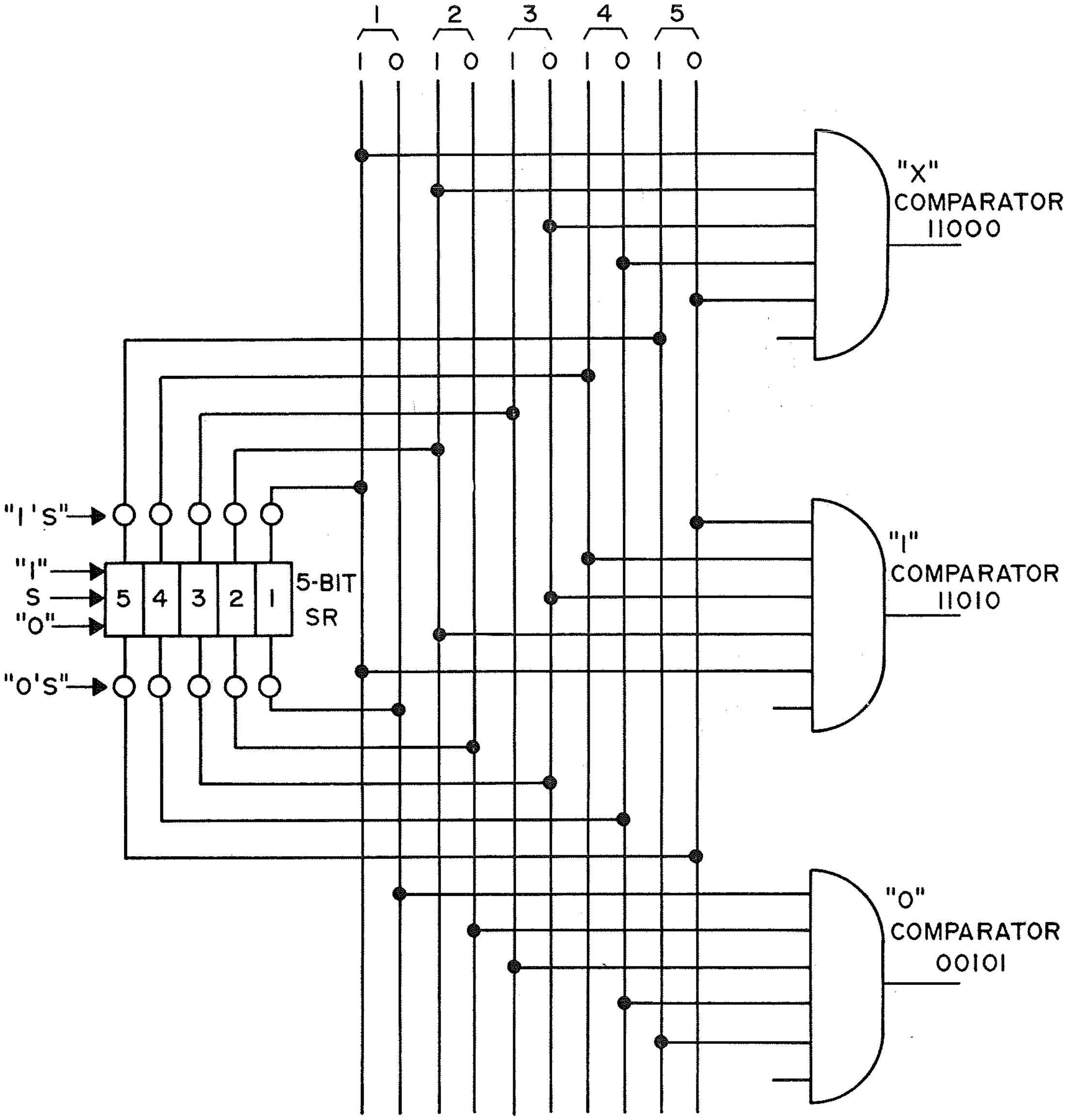


FIGURE 14. SUB-BIT DECODER WIRING

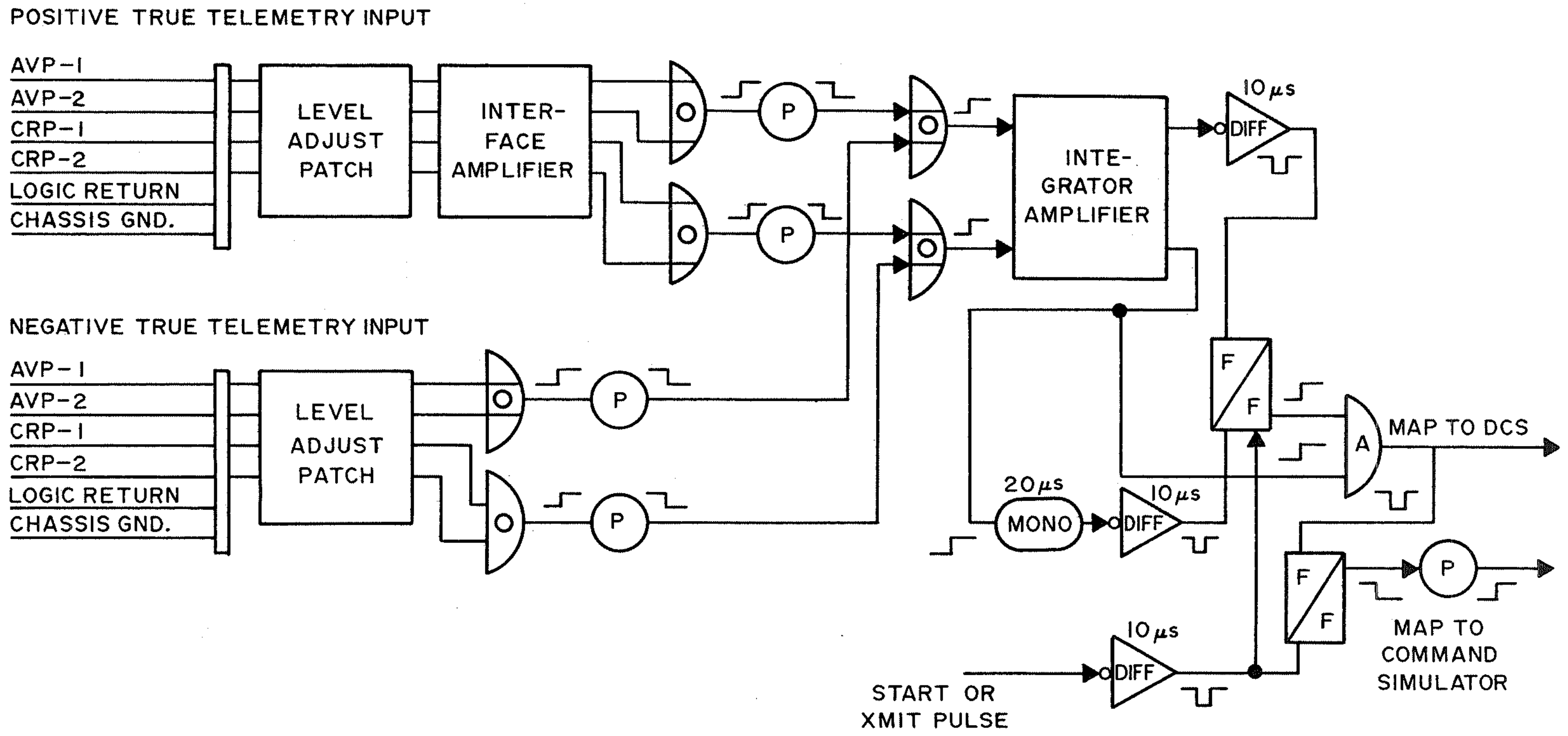


FIGURE 15. MESSAGE ACCEPTANCE PULSE CIRCUITRY

NASA TM X-53350 APPROVAL October 22, 1965

SATURN INSTRUMENT UNIT COMMAND SYSTEM

By H. R. Lowery

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report has also been reviewed and approved for technical accuracy.

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