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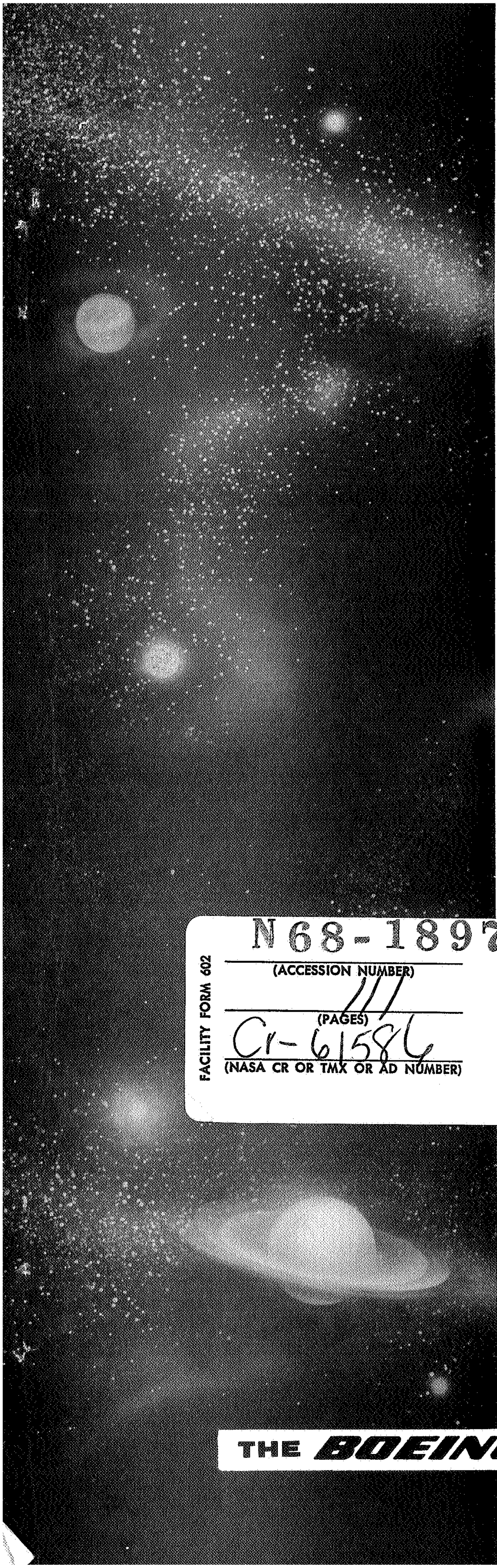

DEVELOPMENT OF CHECKOUT SPECIFICATIONS FOR NEW TELEMETER SYSTEMS

phase B

MARCH 5, 1968

THE BOEING COMPANY - SPACE DIVISION

DOCUMENT NO. D5-13402-1

TITLE PHASE B REPORT: DEVELOPMENT OF CHECKOUT SPECIFICATIONS FOR NEW TELEMETER SYSTEMS

MODEL NO. CONTRACT NO. NAS8-21205

TELEMETRY SYSTEMS

MARCH 5, 1968

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TELEMETRY SYSTEMS

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ABSTRACT AND LIST OF KEY WORDS

This document reports the work accomplished during the Phase period of performance of Contract NAS8-21205, "Development of Checkout Specifications for New Telemeter Systems". The purpose of this contract is to: study new and proposed new telemeter systems; and, develop the specifications for the checkout equipment required for post-manufacturing and prelaunch checkout of selected telemetry systems. During Phase B, information regarding operating parameters, checkout requirements and the checkout equipment for several specific systems selected by the Contracting Officers Technical Representative was gathered and evaluated in preparation for Phase C.

Apollo Applications Program (AAP) Telemetry
Checkout Equipment - Telemetry
Checkout - Telemetry
Command and Communications System (CCS)
Constant Bandwidth
FM Baseband Structure - Telemetry
Proportional Bandwidth
Pulse Amplitude Modulation (PAM)
Pulse Code Modulation (PCM)
Telemetry Systems
Unified Carrier; Telemetry, Tracking & Command
Unified S-Band (USB)

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SECTION 1

INTRODUCTION AND SUMMARY

1.0 PURPOSE

The purpose of this document is to report the results of Phase B of the contract titled "Development of Checkout Specifications for New Telemeter Systems", number NAS8-21205. This report contains a summary of the work to be accomplished during the contract with emphasis on this phase, results of this phase, a work plan for Phase C and a summary of accomplishments to date.

1.1 SCOPE OF THE CONTRACT

The scope of this contract includes the study, compilation, evaluation and development of checkout specifications for new data transmission techniques, new telemeter proportional bandwidth channels, constant bandwidth systems, higher transmission frequencies and other advanced telemetry techniques, and for the post-manufacturing and prelaunch checkout equipment. This study is divided into three phases in accordance with the program schedule shown on Figure 1-1.

Phase A consisted of a survey of new and proposed telemeter systems and techniques and for the preparation of a short description of each, specifying its state of development or its use and its prime developer and user. Phase A was of three months duration and the results were detailed in D5-13402.[1]

The intent of Phase B is to determine the following in regard to the systems approved by the customer: parameters to be measured to assure flight readiness; any peculiarities requiring special checkout data to be taken at the subsystem test level; if available standards sufficiently control development and implementation; and, if the developers' ground equipment is adequate for post-manufacturing and prelaunch checkout.

The task to have been accomplished during Phase C was to select, with MSFC approval, one or more systems from those studied during Phase B and develop the requirements for ground equipment changes necessary to provide adequate post-manufacturing and prelaunch checkout of these systems. The Phase C task recommendations have been changed at the request of MSFC. The new task objectives are detailed in Section 3.0.

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[1] D5-13402, "Phase A Report: Development of Checkout Specifications for New Telemeter Systems", The Boeing Company, October 12, 1967.

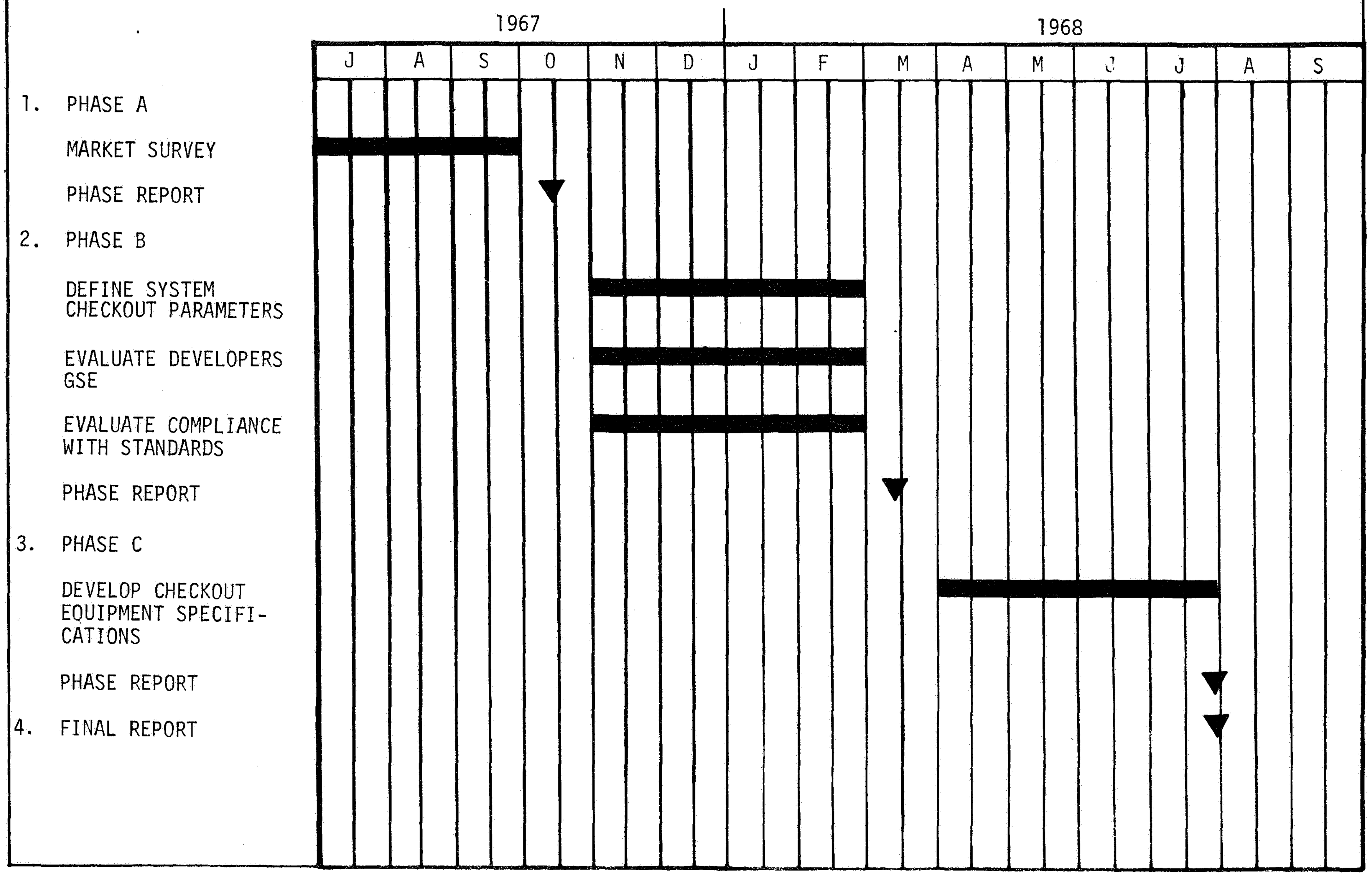

FIGURE 1-1. PROGRAM SCHEDULE

1.2 PHASE B SUMMARY

Phase B progressed according to the program schedule of Figure 1-1. It was determined during Phase A that the areas that should be studied during this phase include the following telemetry systems and techniques that have a high probability of application to MSFC responsible programs: Unified S-Band systems, constant and Proportional Bandwidth systems, PCM systems, and On-board Data Management systems.

Upon review of the Phase A report by the Contracting Officers Technical Representative, it was determined that more specific areas of study were to be the subject of the Phase B effort.[1] These more specific systems and techniques, selected by the contract Technical Supervisor, and the level of detail for each are as follows:

a. Unified S-Band and Saturn Command and Communication System

1. Determine those parameters which must be measured to assure the flight readiness of the subject system at the "systems checkout level".
2. Determine the existence of any pecularities of the system that indicate the need for special checkout data to be taken at the component or subsystem test level.
3. Evaluate the developers' proposed ground equipment and determine its abilities to acquire the parameters defined by (1) and (2).
4. Determine if available standards are sufficient to control further development and implementation. Suggest supplemental standards.
5. Determine the best configuration for a Checkout Ground Station in light of the integrated functions of this type of system.

b. Auxiliary Storage and Playback (ASAP)

Same as a. (1) through (4) above.

c. Experiment Data Acquisition System (EDAS)

Same as a. (1) through (4) above.

d. Constant Bandwidth

1. Same as a. (1) through (4) above.
2. Investigate optimum relationship between proportional and constant bandwidth systems checkout equipment.

---

[1] Letter PR-SC, Subject: "Contract NAS8-21205, Phase B Study", To: A. M. Vendettuoli (Boeing), From L. Garrison (NASA-MSFC Contracting Officer), January 11, 1968.

1.2 (Continued)

e. PCM and PAM

Explore possible checkout problems and their solutions, both in techniques and equipment, as higher pulse rates and special coding techniques are used.

f. Proportional Bandwidth

Review present MSFC and MSFC Contractor checkout techniques and determine if all that is needed is being done, if it is being done properly and, if any unnecessary tests are being conducted.

A detailed report of the results of the above areas of study are presented in Section 2.

The recommended program plan for Phase C is contained in Section 3. Some of the recommended tasks exceed the budget allocation for this contract; and, if all the tasks are desired additional effort must be negotiated.

SECTION 2

PHASE B STUDY RESULTS

2.0 INTRODUCTION

This section contains a detailed discussion of the areas of study for Phase B as requested by the Contracting Officer's Technical Representative after a review of the results of Phase A. In addition, a report on the market survey for new systems during this phase is given. A bibliography of the technical material used during this phase is contained in Appendix B.

2.1 APOLLO UNIFIED S-BAND AND SATURN COMMAND AND COMMUNICATION SYSTEMS

Unified S-Band (USB) carrier communications systems for transmission of information to and from the Manned Space Flight Network (MSFN) are employed on both the Saturn V launch vehicle and the Apollo spacecraft. Two USB systems are employed on the Apollo spacecraft; the Command and Service module, Unified S-Band (CSM-USB), part of the Communication and Data Subsystem, and the Lunar Module USB (LM-USB). The Saturn V system is the IU Command and Communication System (CCS). All three are built by Motorola. This section will primarily deal with those portions of the USB related to down-link transmission of telemetry data.

A unified carrier communications system transmits and receives several kinds of information such as tracking, ranging, voice, telemetry and commands on one RF carrier. The various data functions usually phase or frequency modulate subcarriers and then the frequency multiplexed combined signal is used to angle modulate the RF carrier. The subcarriers for all systems are selected to minimize mutual interference and be compatible with the MSFN stations. The angle-modulated signal from the ground station is received and demodulated by a carrier-lock phase detector. Subcarrier demodulators then coherently detect information associated with each subcarrier. The unified carrier system uses phase-locked loop techniques in the spacecraft to coherently relate the received and transmitted carriers. The psuedo-random noise (PRN) ranging code on the up-link carrier is demodulated in the receiver and directly used to modulate the down-link carrier. Thus the code is simply turned around. The spacecraft receiver-transmitter is a phase-locked transponder for tracking and ranging plus receiver demodulators to separate such information as up-voice and up-commands and a transmitter capable of also modulating voice and telemetry on the down-link carrier.

The ratio of down-link to up-link RF carrier frequencies (turn-around or offset ratio)[1] for all MSFC USB systems is $\frac{240}{221}$. The actual frequency

[1]Turn-around ratio is sometimes used to indicate the frequency ratio of down-link to up-link RF carrier, as here, while at other times it is used to indicate the ratio of down-link to up-link modulation index of the carriers.

2.1 (Continued)

received at the MSFN ground stations during a mission is (204/221) F_T + D where F_T is the actual transmitted frequency from the ground station and D is the two way doppler shift frequency, which has a maximum value during earth escape velocity of 200 KHz. In event of loss of phase-lock in the spacecraft receiver an auxiliary oscillator will determine the down-link frequency. The LM-USB and Saturn CCS share the same RF carrier frequencies but during a mission they will not be simultaneously transmitting.

The USB frequency spectrum for up-link communication to the spacecraft and launch vehicle is shown in Figure 2-1.[1] The spectrum includes the two RF carriers used for the CSM and for either the LM or the CCS. The sub-carriers are for voice and command data. The frequency spectrum of the various USB space borne transmitters is shown in Figure 2-2.[2] Only the two highest carriers are coherently related to the receiver frequencies. The RF carrier at 2277.5 MHz is the IU (S-IVB) S-Band transmission link sending PCM/FM only and is not a unified carrier. The lowest carrier is the CSM FM link primarily for wide band television data.

2.1.1 Unified S-Band Systems of the Manned Space Flight Network

The various USB systems employed by the MSFN have, of necessity, many similarities. These similarities are shown on Table 2-I. All the spaceborne systems must be compatible with the same ground stations. Not all the systems have the total capability that the CSM-USB has but each portion of the unified carrier that is employed by a system is the same for all systems.

2.1.1.1 Up-Link Communication Signals

The following three up-link information sources may modulate the RF carrier in any combination of one or more at a time.

a. Up-Link Command Data

The CSM and the CCS both accept command data for updating the on-board computer. The Digital Command System (DCS) in the MSFN stations is a Gemini type system. Each command word consists of 35 data bits. In order to ensure that each command message is decoded properly each data bit is divided into five sub-bits whose patterns are chosen

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[1] Proceedings of the APOLLO UNIFIED S-BAND TECHNICAL CONFERENCE, NASA SP-87, Goddard Spaceflight Center, July 14-15, 1965

[2] Manned Space Flight Network Ground Systems, MG401, February 1967, (NASA Contract NAS5-9870).

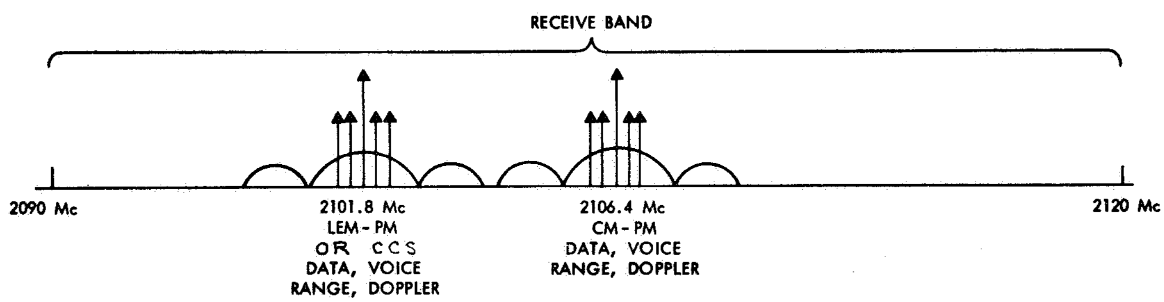

FIGURE 2-1 UNIFIED S-BAND SYSTEMS FREQUENCY SPECTRUM - UP-LINK LM, CSM AND CCS

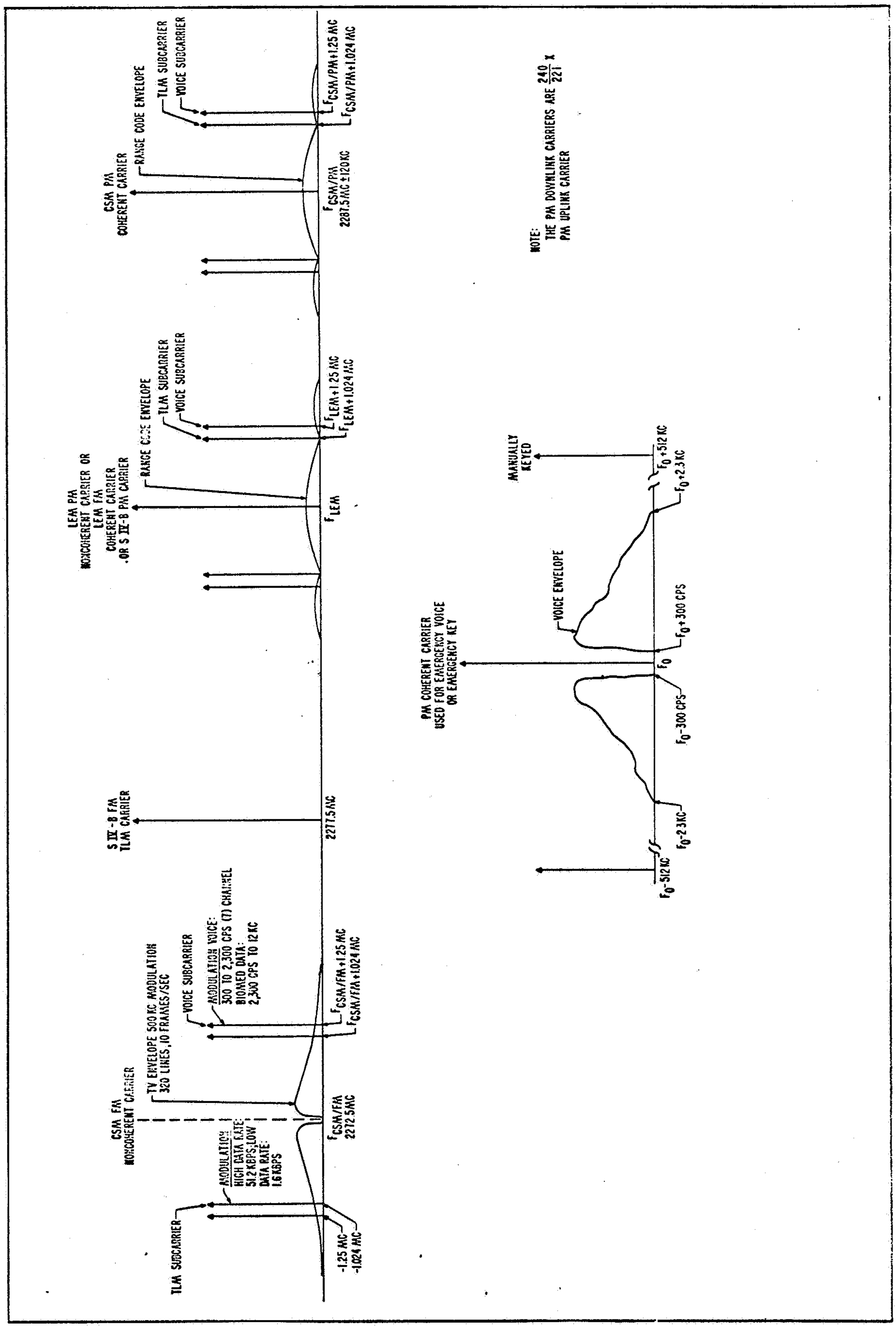

FIGURE 2-2 UNIFIED S-BAND SPECTRUM - CSM, LM AND CCS DOWN-LINK

TABLE 2-I USB SYSTEM SIMILARITIES

USB COMMUNICATION LINK CHARACTERISTIC	PARAMETER	USB SYSTEM CSM	LM	CCS
UP-LINK				
PM Coherent RF Carrier	2101.8 MHz		X	X
	2106.40625 MHz	X		
Command Data	70 KHz PM Subcarrier	X		X
Voice	30 KHz FM Subcarrier	X	X	
PRN Range Code	PM on RF Carrier	X	X	X
Transponder Frequency Turn-Around Ratio	240/221	X	X	X
DOWN-LINK				
PM Coherent RF Carrier	2287.5 MHz	X		
	2282.5 MHz		X	X
FM Non-Coherent RF Carrier	2282.5 MHz		X	
	2277.5 MHz			X
	2272.5 MHz	X		
PCM Telemetry	PM on 1.024 MHz Sub-carrier, PM on RF Carrier	X	X	X
Voice	FM on 1.25 MHz Sub-carrier, PM on Carrier	X	X	
	FM on Carrier	X	X	
	FM on 1.25 MHz Sub-carrier, FM on RF Carrier	X	X	
Ranging	PM on RF Carrier	X	X	X
Television	FM on RF Carrier	X	X	
Back-Up Voice	PM on RF Carrier	X	X	
Emergency Key	Keyed 512 KHz Sub-carrier on PM RF Carrier	X	X	
Biomedical Data	FM on 1.25 MHz Sub-carrier, FM on RF carrier - Relayed from LM	X		

2.1.1.1 (Continued)

a. (Continued)

for optimum differentiation between binary ones and zeros of the data bits. The sub-bit rate is 1000 bits per second. The modulation method used by the DCS is referred to as Phase shift keyed (PSK) baseband modulation.[1] The 1 kilobit NRZ digital command message is used to phase shift key a 2 KHz sine wave. This is also called bi-phase modulation. This PSK signal is summed with a 1 KHz reference signal to form a composite baseband waveform as shown on Figure 2-3. This baseband signal then frequency modulates a 70 KHz subcarrier which is combined with the voice subcarrier and ranging code to phase modulate the S-Band RF carrier (PSK/FM/PM).

b. Up-Link Voice Transmission

The voice baseband is an analog waveform with most of the energy between 300 Hz and 2300 Hz. The baseband signal frequency modulates a 30 KHz subcarrier which in turn is combined with the other up-link information to phase modulate the RF carrier. Only the CSM and LM receive voice.

c. Pseudo Random Noise (PRN) Range Code

Ranging measurements made by the MSFN employ the Mark I Ranging subsystem developed by JPL. This system measures the round trip propagation time of a signal from a MSFN ground station to a spacecraft transponder and back to the ground station. The range code employed by the MSFN is a combination of five codes which repeats approximately every 5.4 seconds. This corresponds to a range of over 800 million meters. The code will not repeat during the time of propagation from earth to the maximum range and back. This provides an unambiguous response from the spacecraft transponder that can be continuously evaluated. This code has a bit rate of 992.834 kbps. Each bit period corresponds to 300 meters of round trip distance or 150 meters of one way range. Further resolution of the range is accomplished using the doppler shift of the coherent carrier frequency. Due to the integral relationship of frequency and phase of the received and transmitted carriers, there is a theoretical ranging accuracy of one meter at lunar distance. The range code phase modulates the RF carrier to a peak phase shift of 0.6 radians. All three spacecraft transponders, CSM, LM and CCS receive and retransmit the ranging code. It is used only for backup, however, on the CCS.

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[1] COMMAND SYSTEM DESCRIPTION, MSFC 111-5-509-8, IBM 67-966-0007, June 1, 1967

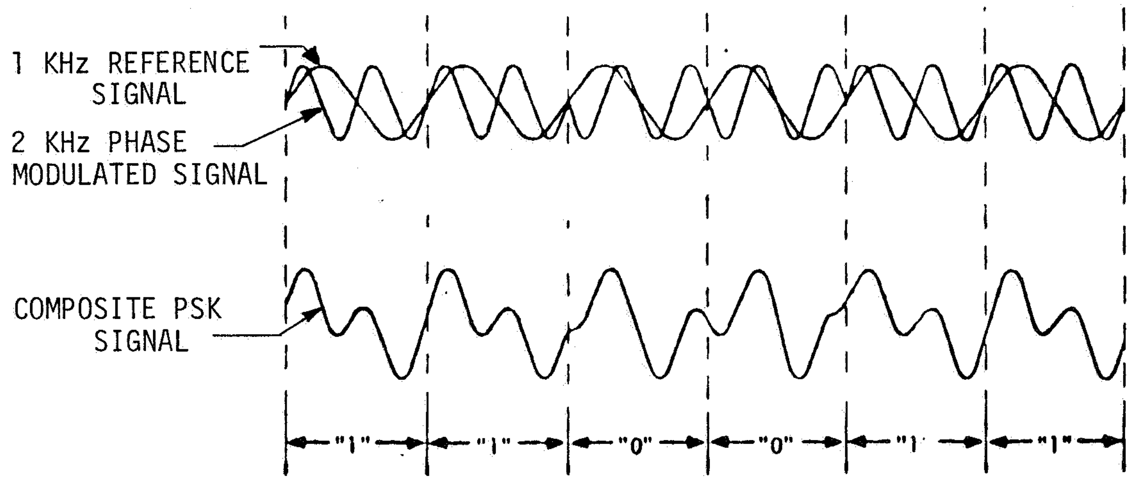


FIGURE 2-3 PHASE SHIFT KEYED COMMAND UP-DATA

2.1.1.2 Down-Link Communications Signals

The RF carrier is received by the spaceborne transponder in the coherent mode. The transponder generates an S-Band carrier for the down-link coherently related in phase to the up link carrier and related in frequency by a ratio of 240/221, down-link to up-link. There are nine sources of modulation intelligence which may modulate the down-link RF carriers. Some are primary communication links while others are for back-up only. They are:

a. PRN Range Code - The range code sent from the ground is received and retransmitted by the spacecraft transponder. The binary code is unchanged but the rate is changed slightly due to the doppler frequency shift (two way shift). This range code is summed with the other modulation sources to phase modulate the down-link RF carrier.

b. PCM Telemetry - The down-link telemetry data from the CSM, LM and CCS is PCM NRZ. The bit rate of the CCS is 72 kbps while the CSM & LM bit rate can be either 51.2 kbps (normal) or 1.6 kbps (reduced). For all systems, the serial digital data first bi-phase modulates a 1.024 MHz subcarrier which is then summed with other data and transmitted on either the PM carrier or the FM carrier.

c. Voice - The voice signal, like the up-link, contains most of its energy between 300 Hz and 2300 Hz. This signal first frequency modulates a 1.25 MHz subcarrier and is then summed with other information and transmitted via either the PM or FM carrier.

d. Emergency Voice - The voice baseband signal can also be used to directly phase modulate the PM carrier.

e. Biomedical Telemetry - During extra-vehicular activities, an FM/FM system in the extra-vehicular mobility unit sends seven channels of data back to earth using the CSM as a relay. The seven channels (4 KHz, 5.4 KHz, 6.8 KHz, 8.2 KHz, 9.6 KHz, 11.0 KHz and 12.4 KHz) are transmitted via VHF to the CSM where they are demodulated and then the summed FM baseband signal is summed with the baseband voice signal. This composite signal then frequency modulates the 1.25 MHz voice subcarrier which is then transmitted on the PM or FM link.

f. Television - The down-link transmission of TV from the CSM and LM, when used, is of non-standard frame rate and line format. The TV baseband is 500 KHz which frequency modulates the FM carrier.

g. Emergency Key - As a last resort communication link with the ground, a hand keyed Morse code signal can be sent from the CSM and LM. The baseband key signal is used to gate on and off a 512 KHz square wave which is filtered to produce a keyed 512 KHz subcarrier. This subcarrier then phase modulates the PM carrier.

2.1.1.2 (Continued)

h. Recorded PCM Telemetry and Voice - The CSM contains the only record capability but it can be used to receive and record LM PCM data along with its own data. The recorded PCM bi-phase modulates a 1.024 MHz subcarrier (different than the real time PCM subcarrier). This subcarrier can then be combined with other subcarriers for transmission on either the PM or FM link. Recorded and real time telemetry cannot be transmitted simultaneously on the same RF carrier. LM voice can also be stored on the CSM data storage equipment. The recorded voice can be played back at a higher speed (32:1) and frequency modulates a 1.25 MHz subcarrier (different subcarrier module than real time voice). This voice modulated subcarrier is then summed with other information and transmitted via either the FM or PM link. As with recorded PCM, the recorded and real time voice cannot simultaneously share the same RF carrier. In addition, due to the higher bandwidth of the played back voice, the EVA biomedical data cannot be summed with recorded voice.

i. Scientific Data - Three channels of scientific data frequency modulated on proportional bandwidth FM/FM subcarriers is available on the CSM down-link FM communication channel. This data would not be sent during the time TV is transmitted. The three proportional bandwidth channel center frequencies are 95 KHz, 125 KHz and 165 KHz.

2.1.2 Apollo Unified S-Band Systems

As mentioned previously both the CSM and LM employ unified (integrated) carrier S-Band systems. They are similar in many ways and will be discussed together.

The CSM Communication and Data Subsystem consists of ten components. Those components related to down-link telemetry only are shown in the block diagram of Figure 2-4. The CSM-USB can simultaneously transmit PM & FM on separate carriers while receiving the up-link carrier. Telemetry data may be transmitted on the PM or PM and FM links simultaneously. The CSM telemetry links to the ground stations are PCM/PM/PM, PCM/PM/FM, FM/FM scientific data and biomedical data, both FM/FM/PM and FM/FM/FM.

There are ten different carrier combinations of the CSM to MSFN phase modulated carrier.[1] These operating modes are shown in Table 2-II. Some of these modes are for emergency such as 6 and 10. The frequency modulated carrier for communication between the CSM and the MSFN has five carrier combinations which are shown in Table 2-III. Both the PM and FM link can be used to transmit the PCM data. Scientific data is transmitted

[1] COMMUNICATION AND DATA SUBSYSTEM, North American Rockwell Procurement Specification MC901-0712, February 7, 1967

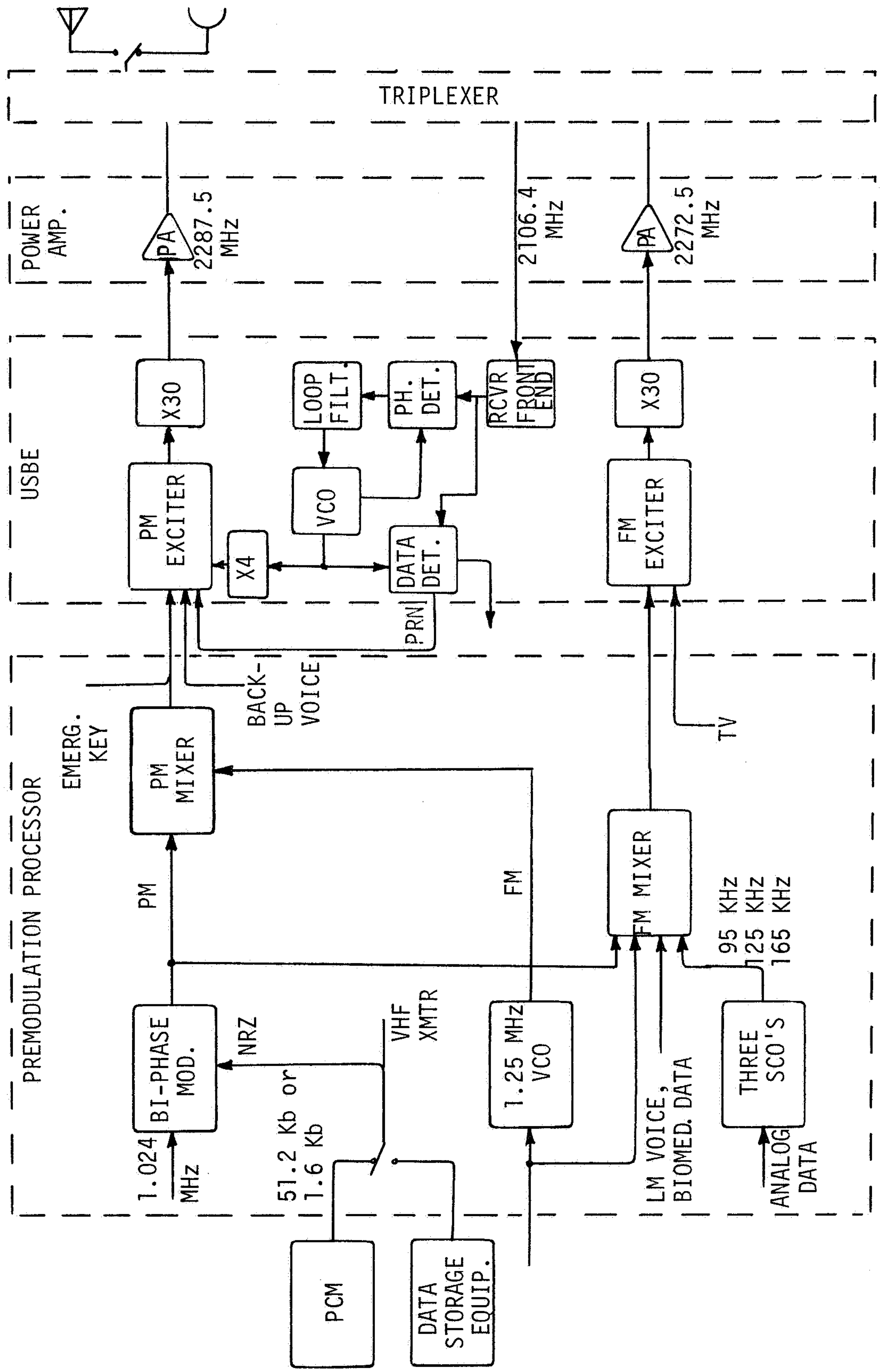


FIGURE 2-4 CSM UNIFIED S-BAND TELEMETRY DOWN-LINK BLOCK DIAGRAM

TABLE 2-II. CSM TO MSFN S-BAND TRANSMISSION COMBINATIONS (PM MODE)
(2287.5 MC CARRIER)

MODE	INFORMATION	MODULATION TECHNIQUE	SUBCARRIER FREQUENCY	PEAK CARRIER PHASE DEVIATION	DEVIATION TOLERANCE PERCENT
1	Carrier, Voice	FM/PM	1.250 MHz	0.7	+20, -10
	51.2 KBPS TM	PCM/PM/PM	1.024 MHz	1.2	+20, -10
2	Carrier, PRN	PM on Carrier		0.20*	+25, -25
	Voice	FM/PM	1.250 MHz	0.7	+20, -10
	CSM 51.2 KBPS TM	PCM/PM/PM	1.024 MHz	1.2	+20, -10
3	Carrier, PRN	PM on Carrier		0.20*	+25, -25
	Voice	FM/PM	1.250 MHz	1.2	+20, -10
	CSM 1.6 KBPS TM	PCM/PM/PM	1.024 MHz	0.7	+20, -10
4	Carrier, Voice	FM/PM	1.250 MHz	1.2	+20, -10
	CSM 1.6 KBPS TM	PCM/PM/PM	1.024 MHz	0.7	+20, -10
5	Carrier				
	CSM 1.6 KBPS TM	PCM/PM/PM	1.024 MHz	1.6	+20, -5
6	Carrier, Key	AM/PM	512 KHz	1.0	+15, -10
7	Carrier, PRN	PM on Carrier		0.20*	+25, -25
8	Carrier				
	Back-Up Voice	PM on Carrier		0.7	+15, -10
	CSM 1.6 KBPS TM	PCM/PM/PM	1.024 MHz	1.2	+20, -10
9	Carrier				
	PRN	PM on Carrier		0.20*	+25, -25
	1.6 KBPS TM	PCM/PM/PM	1.024 MHz	1.6	+15, -10
10	Carrier				
	Back-Up Voice	PM on Carrier	Baseband	1.2	+15, -10

*Down PRN ranging phase deviation is set with full up-link modulation in turn-around channel

TABLE 2-III. CSM TO MSFN S-BAND TRANSMISSION COMBINATIONS (FM MODES)
(2272.5 MHz CARRIER)

Carrier Combinations	Information	Modulation Technique	Subcarrier Frequency	Peak Carrier Frequency Deviation	Deviation Tolerance Percent
1	Playback Voice at 1:1	FM at Base band	-	100 KHz	+20, -40
	Playback CSM 51.2 KBPS TM at 1:1	PCM/PM/FM	1.024 MHz	600 KHz	+15, -15
	Playback Scientific Data at 1:1	FM/FM FM/FM FM/FM	95 KHz 125 KHz 165 KHz	75 KHz 110 KHz 170 KHz	+15, -15 +15, -15 +15, -15
2	Playback Voice at 32/1	FM at Baseband	-	100 KHz	+20, -40
	Playback CSM 1.6 KBPS TM at 32/1	PCM/PM/FM	1.024 MHz	600 KHz	+15, -15
	Playback Scientific Data 32/1	FM/FM FM/FM FM/FM	95 KHz 125 KHz 165 KHz	75 KHz 110 KHz 170 KHz	+15, -15 +15, -15 +15, -15
3	Playback LEM 1.6 KBPS Split-Phase TM at 32/1	FM at Baseband		200 KHz	+25, -50
4	Real-Time TV	FM at Baseband	-	1 MHz	+10, -10
5	Real-Time Scientific Data	FM/FM FM/FM FM/FM	95 KHz 125 KHz 165 KHz	75 KHz 110 KHz 170 KHz	+15, -15 +15, -15 +15, -15

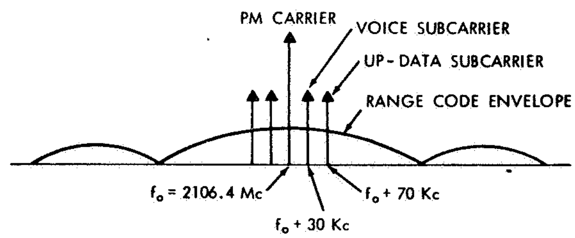
2.1.2 (Continued)

via the FM link on three proportional bandwidth subcarriers which are non-IRIG center frequencies of 95 KHz and 125 KHz and 165 KHz, IRIG. During EVA, seven FM channels of biomedical data are transmitted via VHF/AM from the LM to the CSM and then time shared with playback voice on the S-band FM link or combined with real time voice on the PM link. The seven SCO's are from 4 KHz to 12.4 KHz and are also non-IRIG frequencies. Some typical up-link and down-link spectrums for the various carrier combinations are shown in Figure 2-5. The following paragraphs describe the CSM components shown in Figure 2-4.

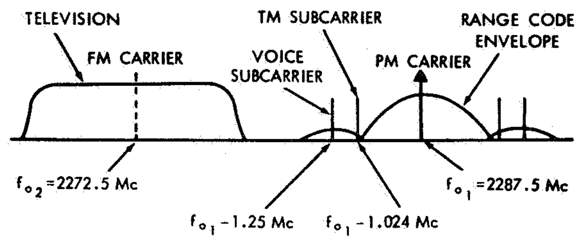
The PCM telemetry component provides outputs of 51.2 kilobits and 1.6 kilobits in NRZ-C (L) format consisting of 8 bit binary coded data words with the most significant bit first. A binary one in the least significant bit and all other bits zero indicates a zero voltage. The PCM system accepts only positive voltages. Each subsequent bit is weighted at 19.7 millivolts for a maximum output of binary 254 or 4.98 volts. A GSE output of serial RZ is provided with 95Ω output impedance: "1" = 4.5; + 2.0, - .5 VDC and a "0" = 0V; + .2, - 0.0 VDC. The long term stability of the 512 KHz clock is 2 parts per million and the short term stability is ± 19.5 nanoseconds. The bit jitter is .8% of a bit period. This 512 KHz clock is also sent to the premodulation processor to generate the 1.024 MHz subcarrier.

The PCM format synchronization code is 32 bits including 6 frame identification bits. An 8 bit format identification (51.2 kbps or 1.6 kbps) word is inserted every second. The normal format is 51.2 kbps and consists of 6400 eight bit words and is called a sub-frame. The sub-frame corresponds to the minimum number of words to sample all inputs. Thus, all data is contained in one sub-frame. Each sub-frame contains 50 prime frames containing 128 eight bit words each. The first 4 words (32 bits) of each prime frame contain the frame sync. The last 6 bits of the sync identify which of the 50 prime frames it is. The reduced format is 1.6 kbps consisting of 200 eight bit words which constitutes one frame and it repeats once per second. Again the first 4 words of the frame are frame sync.

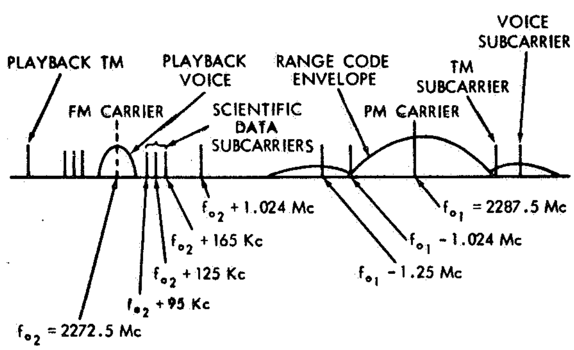
The Premodulation Processor (PMP) is the interface between all components of the Communication and Data Subsystem. The PMP contains all functions not directly related to any of the other subsystem components. The PMP contains most of the operating mode switching, sub-carrier oscillators, discriminators, mixers, modulators and other circuitry necessary to satisfy its varied interface requirements. The PMP accepts the NRZ-L PCM data from either the PCM telemetry or the Data Storage Equipment, bi-phase modulates a 1.024 MHz subcarrier with this data and is subsequently routed to either the PM or FM exciter. The 1.024 MHz telemetry subcarrier frequency is locked to the 512 KHz reference in the PCM



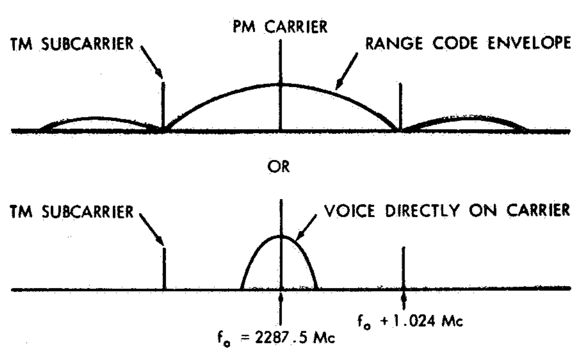
a —Full up-link spectrum with the range of code, voice, and up-data subcarriers.



b —Typical down-link spectrum.



c —Typical down-link spectrum with a normal PM mode.



d —Contingency down-link spectrum.

FIGURE 2-5 TYPICAL CSM RF SPECTRUMS FOR VARIOUS CARRIER COMBINATIONS

2.1.2 (Continued)

telemetry component. The modulation of this subcarrier is bi-phase with 180° ± 10° phase shift difference between a binary "0" and a "1". The signal-to-noise of the PCM processing circuits in the PMP are such that no more than 1 erroneous bit will occur in 10^7 bits.

The PMP also contains SCO's for three channels of real time analog scientific data. The SCO's accept 0 to 5V inputs. The subcarrier center frequencies are 95 KHz, 125 KHz (both non-IRIG) and 165 KHz with stability of ±0.15% and linearity deviation of less than 0.15% from the best straight line. The deviation sensitivity is 3% of center frequency per volt input. The modulation index is 2.5, and the subcarrier deviation is ±7.5%. The combined scientific data is transmitted on the FM link only.

The Unified S-Band Equipment (USBE) component provides reception, transmission, carrier modulation and demodulation capabilities required of the communications subsystem. The USBE also provides PRN ranging and tracking by receiving and transmitting in phase coherence. The USBE must operate in conjunction with an output power amplifier and an input premodulation processor.

The USBE component consists of two redundant PM transponders and an FM transmitter (for clarity only one transponder is shown on Figure 2-4). The receiver frequency is 2106.40625 MHz with a VCO stability of ±0.002%. The PM transmitter frequency is 240/221 times the received frequency in the phase lock mode or 2287.5 MHz ± 0.0015% in the auxiliary oscillator mode. The modulation sensitivity is 1 radian of peak carrier phase deviation for 1 volt input, up to 2.4 radians maximum deviation. The output power is 400 milliwatts (high) or 275 mw (reduced). The FM transmitter rest frequency is 2272.5 MHz ± 455 KHz. The modulation sensitivity is 1 MHz carrier deviation for 1 volt input for frequencies from 300 Hz to 1.2 MHz. The TV modulation input is 1 MHz/volt offset for 1.3 volt input for a center frequency from DC to 500 KHz.[1] The FM transmitter power output is 145 milliwatts (high and 100 milliwatts (reduced). The FM frequency stability is ± 0.02%.

The S-Band power amplifier provides RF power amplification of the USBE outputs. The phase modulated carrier power output is 11.2 watts, high power, or 2.8 watts, low power. The frequency modulated carrier power is 11.2 watts, high power, or 2.5 watts, low power. The power amplifier outputs are routed through a triplexer to selectable antennas. The triplexer enables simultaneous transmission of the PM & FM carriers while receiving the up-link PM carrier.

Data sheets describing the CSM-USB system parameters are included in Appendix A.

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[1] Collins Radio Co., Data Sheet, See Appendix A

2.1.2 (Continued)

The Lunar Module USB transponder also provides up-link voice, PRN turn-around ranging information, down-link telemetry, voice, emergency keying, TV or biomedical data transmission between the LM and earth. It consists of a phase-locked transponder, phase modulator, frequency modulator and RF power amplifier. The peak phase shift is ±4 radians for PM and the FM deviation is up to ±3.5 MHz. The various transmitted spectrums are shown in Figure 2-6.

The RF carrier stability in either FM or unlocked PM mode is ±0.0015%. It can be seen from Figure 2-6 that the subcarrier frequencies and the RF carrier turn-around ratio are the same as the CSM-USB. There is no requirement for the LM to simultaneously transmit PM and FM so there is only one time shared RF carrier at 2282.5 MHz. The PCM bit rates are the same as the CSM, 51.2 kilobits and 1.6 kilobits per second. The only FM telemetry is the seven biomedical subcarriers (4 KHz to 12.4 KHz, non-IRIG) that are contained in the extra-vehicular mobility unit, EMU. This information is time shared with voice on the 1.25 MHz subcarrier (part of the CSM down-link).

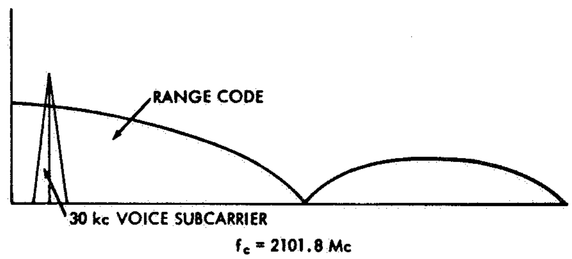
Data sheets providing a list of LM transponder parameters is included in Appendix A.

2.1.3 Saturn Command And Communication System

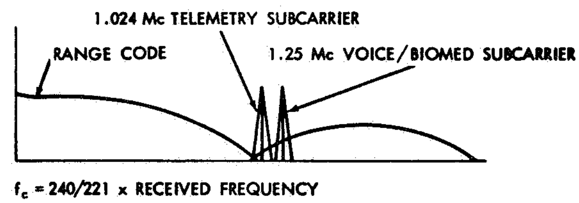
The CCS is a phase-coherent transponder for establishing a two way communication link between the instrument unit of the Saturn V launch vehicle and the USB ground stations. Its functions are to receive and demodulate command up data for guidance computer updating, transmit PCM mission control measurements originating in the S-IVB and IU to the USB ground stations and as a backup to the prime tracking and ranging equipment it will receive and transmit PRN ranging codes.

During the launch and earth orbit phases, VHF transmitters are the prime telemetry source and make CCS telemetry unnecessary. At distances of approximately 10,000 kilometers (5400 nautical miles) and greater, VHF transmission is inadequate primarily due to spacecraft and ground antenna gains. After injection into translunar trajectory, the CCS transponder and a UHF transmitter become the prime telemetry links. The mission control data from the S-IVB stage and the IU are interconnected so that both sources of data are available at both RF links. This makes the mission control data double-redundant during the launch and earth orbit phase. At a distance of approximately 20,000 kilometers (10,800 nautical miles), the S-IVB/IU separates from the spacecraft and is no longer needed for mission success. See Figures 2-1 & 2-2 for the up and down-link spectrums.

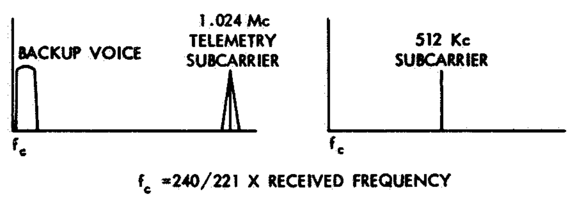
A block diagram of the CCS transponder is shown in Figure 2-7. The transmitter section of the transponder contains the circuitry necessary



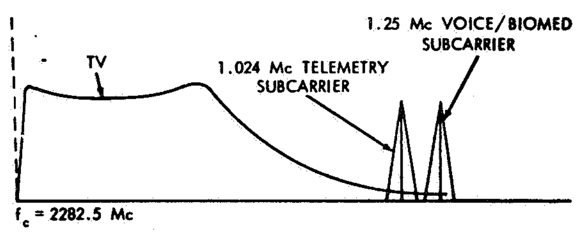
a —Full up-link PM spectrum.



b —Full down-link PM spectrum.



C —Down-link RF spectra for contingency modes (PM).



d —FM down-link spectrum.

FIGURE 2-6 TYPICAL LUNAR MODULE RF SPECTRUMS FOR VARIOUS CARRIER COMBINATIONS

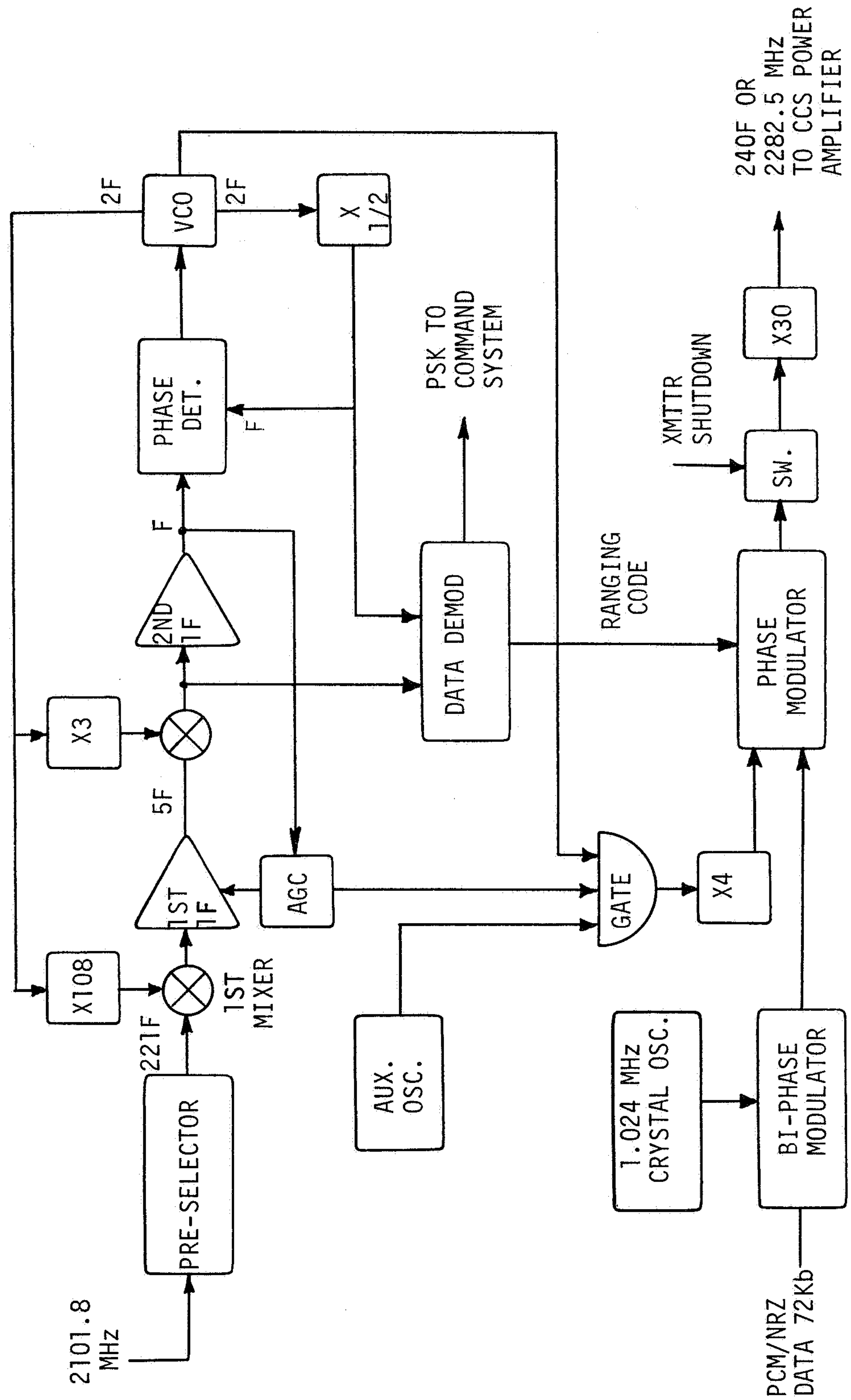


FIGURE 2-7 COMMAND AND COMMUNICATION TRANSPONDER

2.1.3 (Continued)

to combine the PRN ranging code and down-link telemetry (mission control measurements) and multiply the modulator output to S-Band.

The CCS transponder up-link consists of the PRN ranging code combined with the up-data commands which are frequency modulated on a 70 KHz sub-carrier. This combined signal phase modulates the RF carrier. The 70 KHz command subcarrier is frequency modulated by a combined signal consisting of a 1 KHz reference signal (the sub-bit rate of the commands) and a phase shift keyed (PSK) 2 KHz sine wave bi-phase modulated at the sub-bit rate of the command message. This subcarrier, in turn, phase modulates the RF carrier producing PSK/FM/PM at 2101.8 MHz.

The transponder receiver, through mixers and a reference frequency of approximately 9.51 MHz down converts the RF carrier to F, See Figure 2-7. The reference VCO frequency is then compared with F in a loop phase detector and any error is applied to the VCO to lock the VCO in phase and frequency relationship to the received carrier which will include a doppler shift. This VCO frequency will then determine the transmitter carrier frequency. In event of loss of phase lock the AGC of the receiver will gate out the VCO and allow an auxiliary oscillator to determine the transmitter carrier frequency. Therefore, telemetry data can be sent to the ground station without receiving an up-link carrier.

The transponder down-link carrier spectrum consists of the received ranging code phase modulating the down-link carrier which is 240/221 times the received frequency or 2282.5 MHz in the unlocked mode. In addition a 1.024 MHz subcarrier bi-phase modulated by the 72 kbps NRZ PCM telemetry also phase modulates the RF carrier. This telemetry data is compatible with the USB ground stations although its bit rate is different from the Lunar Excursion Module and Command and Service Module PCM bit rates. Either modulation input may be separately set to modulate the carrier to 2 radians for a peak modulation capability of 4 radians. The CCS transponder power output is 250 mw to 500 mw. The power amplifier raises this to 15 watts minimum.

Since the CCS and LM transponders have identical frequencies, a possibility of interference exists if the two are operated simultaneously at close range. The CCS transponder has the capacity to shut down the transmitter by an external command. This shut down command will be initiated before the LM spacecraft transponder is used. The CCS receiver will remain alive so that commands may be received at all times.

Appendix A provides a tabulation of the CCS transponder parameters. The test requirements for the CCS including parameters and tolerances are available in MSFC document 6753-P(TR).[1]

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[1] Saturn Instrumentation Systems Test Requirements, 6753-P(TR), MSFC-R-QUAL, May 22, 1967, Changed September 25, 1967

2.1.4 Unified S-Band System Comparison

The Saturn CCS, CSM & LM all communicate with the same MSFN ground stations and the same general coding and modulation schemes are employed. The CCS and the LM share the same RF carrier frequencies. A tabulation depicting the similarities of the various USB system functions and operating parameters was shown in Table 2-I. A comparison of transponder specifications is given on Table 2-IV. As can be seen from the tables the specifications and operating parameters are common in most instances. The RF carriers are different but the offset ratio is the same, therefore, any JPL Mark I type ranging system checkout station could be used to evaluate ranging. The command up-data bit rate, sub-bit coding and sub-carrier are the same. The PCM telemetry subcarrier frequency and modulation method are the same, although the bit rates and frame identification are different.

2.1.5 Unified S-Band Developers Proposed Ground Checkout Equipment

Both Motorola and Collins radio have developed checkout stations for Unified S-Band Systems. Motorola, the manufacturer of all the USB transponders, has separate checkout stations for each unit. The Collins Radio Co., system integrator for the Apollo Communication and Data (CAD) Subsystem, also assembled a checkout station for the CSM-USB.

Collins provides two separate stations to check out the complete CAD system, called bench maintenance equipment (BME). One station is required for the unified S-Band equipment and S-Band power amplifier, the other station is for the remainder of the CAD components including the premodulation processor but not including the PCM telemetry.

Both Collins stations consist of commercially available test equipment, a special test and maintenance unit (STMU) for each component to be checked out and some interface panels. The S-Band BME is used to perform acceptance tests, detect and isolate malfunctions and provide end to end tests of the unified S-Band equipment and power amplifier. It is a manually operated console consisting of six racks of equipment.

The Motorola equipment used at KSC and MSFC consists of four racks of equipment that can be used for: unit test; closed loop system test; and, in conjunction with a frequency measuring rack, open loop system test. This equipment is manually operated and consists largely of standard test equipment.[1]

The Motorola test set provides a ranging subsystem that can generate and evaluate actual range codes as used by the MSFN.

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[1] Preliminary Handbook for Command and Communication System Test Set, Motorola No. 68-26647H, May 1966

TABLE 2-IV USB TRANSPONDER SPECIFICATION COMPARISON

	CSM-USB	LM-USB	CCS-USB
Up-Link Carrier	2106.40625 MHz	2101.8 MHz	2101.8 MHz
Up-Data Subcarrier	70 KHz	N/A	70 KHz
Up-Voice Subcarrier	30 KHz	30 KHz	N/A
VCO Stability	±0.002%		
Down-Link Carrier PM Transmitter-Phase Locked	$\frac{240}{221}$ X Rcvd Freq.	$\frac{240}{221}$ X Rcvd. Freq.	$\frac{240}{221}$ X Rcvd. Freq.
PM Transmitter-Not Locked	2287.5 MHz	2282.5 MHz	2282.5 MHz
FM Transmitter	2272.5 MHz	2282.5 MHz	N/A
Auxiliary Oscillator Stability	±0.0015%	±0.0015%	
FM Transmitter Stability	±0.02%	±0.0015%	N/A
Telemetry Subcarrier	1.024 MHz (PM)	1.024 MHz (PM)	1.024 MHz (PM)
Voice Subcarrier	1.25 MHz (FM)	1.25 MHz (FM)	N/A
Transmit/Receive Frequency Ratio (Turn-Around Ratio)	204/221	204/221	240/221
Receiver Dynamic Range	-50 to -127 dbm	-50 to -127 dbm	-15 to -125 dbm
RF Loop Bandwidth 2 BL	800 Hz	800 Hz	800 Hz
Receiver Command Bandwidth	10 to 100 KHz demodulated PM	10 to 100 KHz modulated PM	70 KHz Subcarrier Demodulator
Receiver Tracking Range	±90 KHz	±90 KHz	±180 KHz
Turn-Around Ranging	PN Code	PN Code	PN Code
Down-Link Information	Ranging, Doppler, Voice, Telemetry & Video (FM)	Ranging, Doppler Voice, Telemetry & Video (FM)	Ranging, Doppler, & Telemetry
Transmitter Minimum Power	250 mw PM 100 mw FM	750 mw	250 mw
Transmitter Modulation Bandwidth	FMTV-DC to 500 KHz FMWB-300 Hz to 1.2 MHz PMWB-300 Hz to 1.5 MHz PM voice 300 Hz to 10 KHz	FMTV-10 Hz to 500 KHz FMWB-300 Hz to 1.5 MHz PM -300 Hz to 1.5 MHz PM -300 Hz to 10 KHz	1.024 MHz Subcarrier with input mod response from dc to 72 KBs
Modulation Sensitivity and Deviation	FM-1 MHz/volt PM-1 rad/volt ±4 rad	FMWB-1.5 MHz/V-peak FMTV-8.8 MHz/V-peak PM -2 rad/V-peak	±4 rad
Power Required	16 w	38 w	35 w

2.1.6 Unified S-Band Standards and Specifications

The RF carriers employed by the USB systems are within the band allotted to launch vehicles and spacecraft in the IRIG telemetry standards. The channel center frequencies are also per IRIG standards. The channel bandwidths of 5 MHz (wideband) are permitted although the standard channel spacing is 1 MHz. The transmitter frequency stability specified by IRIG is $\pm 0.003\%$ of the assigned channel. The USB down-link phase modulated carrier, locked or unlocked is better than this, however, the Apollo CSM FM transmitter carrier stability is $\pm 0.02\%$ of the rest frequency. Only the CSM employs frequency division multiplexing of telemetry data for transmission at S-band. There are seven channels of biomedical data at low subcarrier frequencies (4 KHz to 12.4 KHz). The deviations and center frequencies are non-IRIG standard. There are three scientific data channels employing high subcarrier frequencies (95 KHz and 125 KHz which are non-IRIG and 165 KHz). The deviations from IRIG standards are due to the development timing. The communication system requirements of the MSFN were established prior to addition of the new higher proportional bandwidth and constant bandwidth frequencies to the IRIG standard.

All three unified S-Band systems (CSM, LM and CCS) were designed for NASA programs and are therefore controlled by NASA fabrication and environmental specifications.

2.1.7 Unified S-Band Checkout Ground Station

The unified S-Band components of the Apollo and Saturn are similar in many ways, being built for communication with the same ground station network and by the same manufacturer, Motorola. It is therefore entirely feasible for one checkout ground station to be employed for checkout of both Apollo systems and the Saturn system. Due to the integrated functions of these systems it is recommended that this checkout station not be used exclusively for telemetry data acquisition but be capable of verifying the many varied functions of these systems. The checkout station configuration discussed here, however, will include the equipment required to verify the down-link telemetry with minor emphasis on the ranging and command functions.

The USB transponder can be used as a down-link phase modulated transmitter without the need for the up-link carrier. The down-link RF carrier frequency is normally derived from the up-link RF frequency. If it is not desirable to generate an up-link carrier the transponder will operate on an internal oscillator to develop the down-link carrier. Operating in this manner would allow for checkout of the PCM/RF link with a minimum of ground station equipment.

A list of typical tests to be performed on the CCS-USB are given in Table 2-V for the various levels of checkout. The USB systems provide several outputs to the measurement and telemetry systems for evaluation

TABLE 2-V TESTS PERFORMED ON THE CCS-USB

TEST DESCRIPTION	LEVEL OF TESTING			
	BENCH	SYSTEM LEVEL ACCEPTANCE TEST	LAUNCH AREA CLOSED LOOP	LAUNCH AREA OPEN LOOP
Receiver Center Frequency	X	X	X	X
Receiver AGC Vs Signal Level over Dynamic Range	X*	X	X*	
Receiver Threshold	X	X	X	X
Receiver Tracking Range and SPE Vs Frequency	X*	X	X*	X(Two Points)
Receiver Tracking Rate	X	X	X	
70 KHz Subcarrier Demod. Performance	X	X	X	X
Transmitter Frequency; In-Lock	X	X	X	X
Transmitter Frequency; Auxiliary Oscillator	X	X	X	X
Spurious Output	X	X	X	
1.024 MHz SCO	X	X	X	X(and PCM)
Range Delay Vs Received Signal Level	X	X	X	X
Transmitter Power	X	X	X	X
Telemetry Output Verification		X		X
Command Decoder		X		X
Antenna Switching and Power Output		X		X
PRN				X
Carrier Mod. Index Rcvr. & Xmittr	X	X		

*Sufficient data taken to plot curves. (Received power level Vs AGC & Frequency Vs Static Phase Error).

2.1.7 (Continued)

of the USB performance. The tests to be performed on the CSM-USB are similar to those of the CCS transponder. Table 2-VI indicates the various types of telemetry outputs available. Each of the CCS test points should be terminated with a 100 KΩ resistive load.

The telemetry and bench test output provision of the PCM Telemetry component of each of the USB systems is shown on Table 2-VII as an indication of the available test points for evaluating USB system readiness.

The unified S-band checkout station capabilities required to be compatible with the integrated functions of the Saturn CCS and the CSM-USB are described in this section. The optimum station for checkout of the NASA S-band systems would include the capability of receiving and demodulating the four FM and/or PM channels employed on Saturn and Apollo. This would include both the unified carriers and the single modulation source carrier. The station would also be capable of communicating with the transponders on both up-link channels employed with carriers modulated by both subcarrier and baseband signals. A block diagram of a typical station for post-manufacturing stage level checkout of the USB transponder is shown in Figure 2-8. Simplified block diagrams of the Saturn CCS and Apollo CSM-USB systems are shown on Figure 2-9.

Although it is possible to receive PCM telemetry on the down-link without generating an up-link carrier, this is not recommended. With no up-link carrier the auxiliary oscillator determines the down-link frequency but the receiver AGC, static phase error, turn-around ratio (both modulation indices and frequency ratio) and ranging capability can not be checked. Therefore, a transmitter should be included in the station.

For open or closed-loop checkout of the CSM-USB a diplexer and antenna coupler are required since the spacecraft employs one antenna for both transmission and reception. The Saturn CCS uses separate receive and transmit antennas and no diplexer would be required. The diplexer receive bandwidth must be 2270 MHz to 2290 MHz and the transmit bandwidth should be 2090 MHz to 2120 MHz to cover the range of RF carriers employed by the CSM and LM.

The checkout station transmitter should have separate VCO's to provide RF outputs of 2101.802 MHz and 2106.40625 MHz. There must be access to the VCO outputs for frequency measurement. The frequency of each VCO must be adjustable about the center frequency to check the transponder receiver static phase error (SPE) while phase locked. The transmitter in conjunction with the power amplifier must provide an RF power level between -15 dbm and -127 dbm at the CCS transponder receiver and -50 dbm to -127 dbm at the CSM-USB receiver. The transmitter will be phase modulated with two separate signals; a 70 KHz subcarrier which is phase modulated by the composite command data waveform shown in Figure 2-3, and a clock rate of up to 500 KHz (square wave) to simulate the range code clock. A clock rate of 500 KHz at a peak phase shift of 0.3 radians is

TABLE 2-VI UNIFIED S-BAND SYSTEM TELEMETRY/TEST PROVISIONS

PARAMETER	APOLLO CSM-USB	SATURN CCS-USB	IP&C MEAS. NUMBER
Transponder Tracking Loop Static Phase Error (SPE)	Receiver SPE Telemetry output Provided	Analog voltage with mid-scale representing rest frequency. Data for curve taken during various ground tests.	VJ75-603
Transponder Receiver AGC	AGC voltage analog output provided	Analog voltage proportional to received signal strength. Data for curve taken during various ground tests.	VJ76-603
Transponder In-Lock	Not Provided	Digital Voltage	VJ77-603
PM Transmitter Detected Power Output	Analog Signal Provided	Not Provided	
FM Transmitter Detected Output Power	Analog Signal Provided	N/A	
Up-Link Command Subcarrier (70 KHz) In-Lock	Not Provided	Digital Voltage	VJ78-603
Power Amplifier Regulator Output	Not Provided	Analog Voltage	J79-603 R&D Only
Power Amplifier Anode-Helix Voltage	Not Provided	Analog Voltage	J80-603 R&D Only
Power Amplifier Cathode Current	Not Provided	Analog Voltage	J81-603 R&D Only
Power Amplifier Helix Current	Not Provided	Analog Voltage	J82-603
Power Amplifier Collector Voltage	Not Provided	Analog Voltage	
Transmitter Temperature	Analog Voltage	Not Provided	
Power Amplifier Temperature	Analog Voltage	Not Provided	
Transponder and P.A. "Power On"	Not Provided	Discrete (0 or 28V)	VK150-601
Transmitter & P.A. Inhibit	Not Provided	Discrete (0 or 28V)	VK153-601

TABLE 2-VII PCM TELEMETRY AND TEST OUTPUT PROVISIONS

PARAMETER	APOLLO CSM-USB	SATURN CCS-USB
GSE		
Serial Data	PCM RZ	PCM/FM (600 KHz carrier)
Data Timing Rate	Square Wave at the Data Rate (1.6 kb or 51.2 kb)	
Subcarrier Reference	512 pps	
Subframe rate Pulse	One pulse at beginning of each sub-frame	
ACCEPTANCE CHECKOUT EQUIPMENT		
Failure Detection of redundant circuits	Up to eight Bi-level signals	
TELEMETRY OUTPUTS		
PCM Clock Source	Discrete indication of internal or external source	
High and Low Calibration Checkpoint Voltages	15% and 85% of high level & low level channels	
BENCH TEST POINTS		
Bit Rate Indication	Discrete	
High Level, High Checkpoint Calibration Voltage	Analog	
All internal Power Supplies	Analog	
PCM Clock Source	Discrete indicating internal or external	
Prime Frame Rate	Pulse Rate	
NRZ Serial Data	Serial PCM/NRZ	
Reset Coincidence	Discrete	

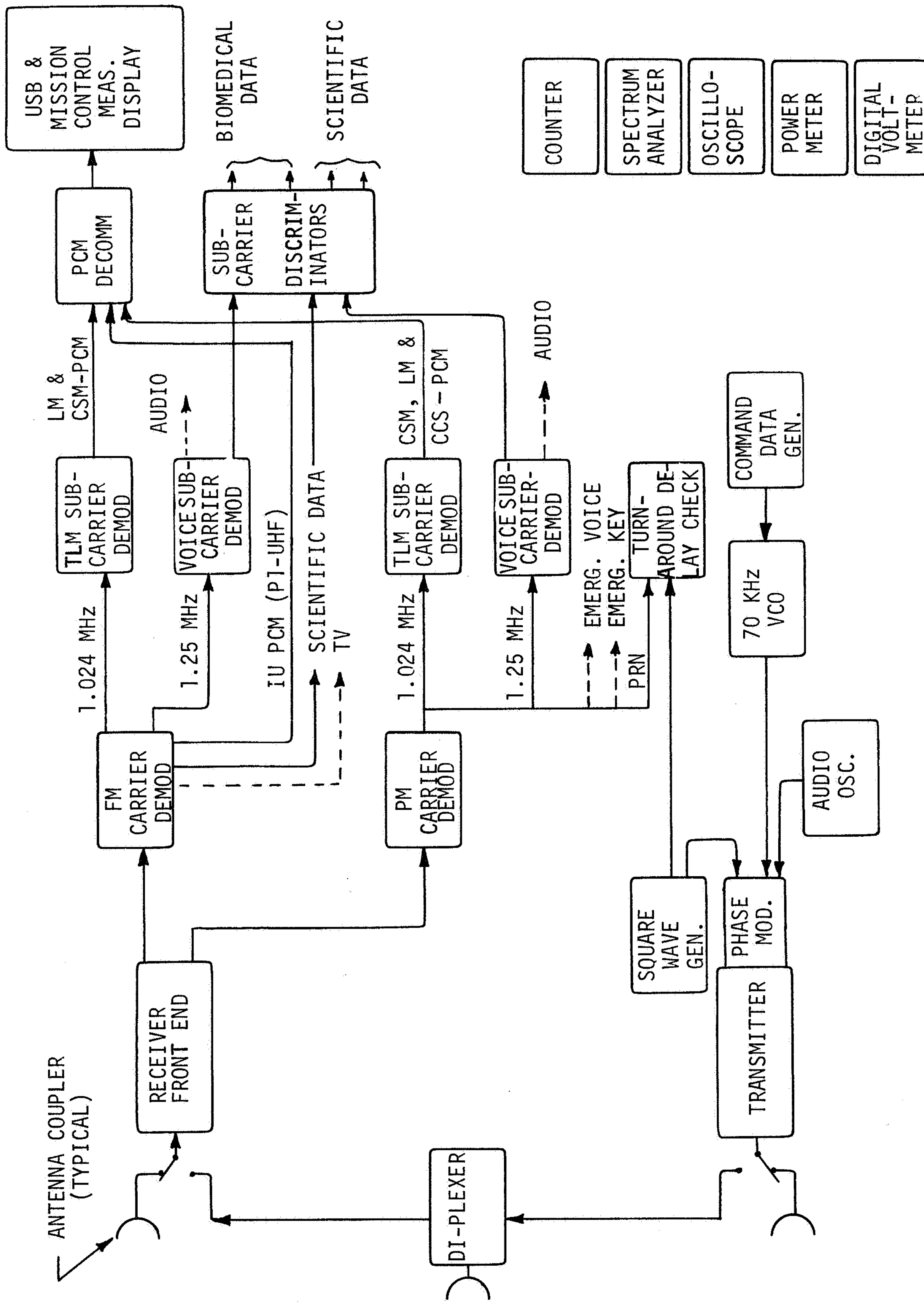
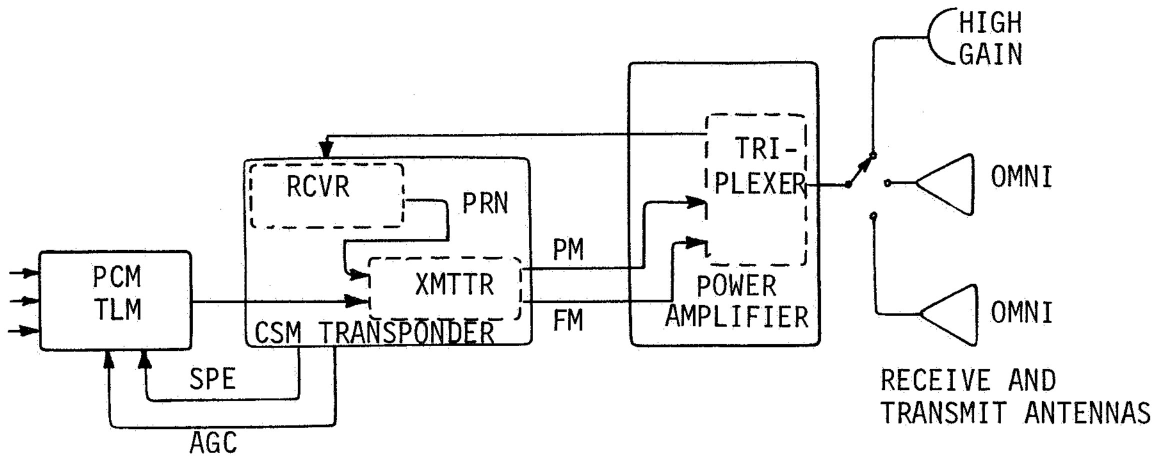
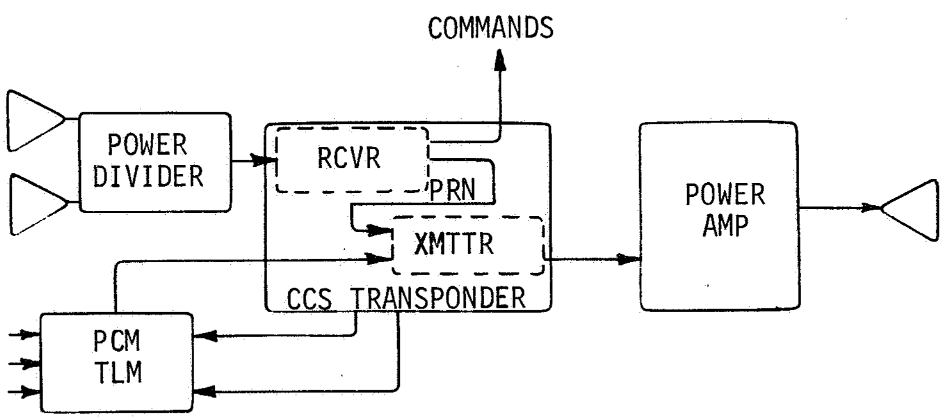


FIGURE 2-8 UNIFIED S-BAND STAGE LEVEL CHECKOUT STATION BLOCK DIAGRAM



a. CSM UNIFIED S-BAND



b. CCS UNIFIED S-BAND

FIGURE 2-9 UNIFIED S-BAND SIMPLIFIED BLOCK DIAGRAMS

2.1.7 (Continued)

used to check the turn-around deviation ratio and a clock rate with a period no less that 2.5 microseconds is required to check the system delay of the range code at various signal levels. In addition, the up-link RF carriers must be deviated up to ±120 KHz at a rate up to 65 KHz to verify that the transponder receiver can acquire and maintain phase lock during the extremes of doppler shift.

The checkout station receiver must receive the four RF carriers shown in Figure 2-2. The carriers contain both wideband FM data and phase coherent data. The CSM-USB can simultaneously transmit FM and PM on independent carriers but simultaneous reception and demodulation by the checkout station is not required.

The transmitter and receiver in the checkout station must provide access to the VCO's, which are around 22 MHz in the Motorola CCS test set. A counter will measure the VCO frequencies as an accurate method of determining the UHF carrier frequencies.

A spectrum analyzer will be used to verify that all spurious outputs of the transponder, both in-band and outside the passband are below the required value.

The FM carrier demodulator provides the demodulated FM baseband of the CSM-USB which includes TV at baseband and a 1.024 MHz subcarrier modulated by the spacecraft PCM telemetry. It also separates out the Saturn IU UHF PCM/FM data. The CSM FM baseband also contains three FM channels of scientific data. Some of the latest information obtained on the MSFN ground station fails to mention this scientific data. If it is used, some non-IRIG standard discriminators will be required for the 95 KHz and 125 KHz subcarriers.

The PM carrier demodulator should be a phase-lock loop type. The demodulator output includes the PM telemetry data on the 1.024 MHz subcarrier, FM biomedical data on the voice subcarrier and the range code or clock pulses. One of the measurements, primarily related to the ranging capability, that must be made is the turn-around system delay of the range code in the transponder. This can be done with a low clock rate (less than 40 KHz). A measurement of the modulation indices of the up and down link basebands must also be made and a 500 KHz square wave modulating the up-link is used.

The telemetry subcarrier demodulators for both the phase and frequency modulated 1.024 MHz subcarrier are the same. The PCM bit rate at the output will be either 1.6 kbps or 51.2 kbps from the CSM or 72 kbps from the CCS. The bandpass of the telemetry subcarrier demodulators should be remotely selectable at approximately three times the data rate or 6 KHz, 150 KHz and 220 KHz.

2.1.7 (Continued)

The voice subcarrier demodulators for FM and PM are the same for the 1.25 MHz subcarrier which also contains the biomedical FM data relayed from the LM (seven channels).

The PCM bit synchronizer and data processor must be very versatile to accept the various bit rates and formats employed by NASA. These are essentially three bit rates and three formats to be decommutated and evaluated.

Some of the measurements of the transponder made during stage level checkout are made by the PCM telemetry and transmitted on the USB carrier. These measurements will be routed to digital to analog converters and made available for measurement and display.

2.2 AUXILIARY STORAGE AND PLAYBACK (ASAP) SYSTEM

The purpose of this portion of the study is to determine a set of test requirements which will assure the flight readiness of the ASAP at a system checkout level. The study shall determine if available standards are sufficient to control further development and implementation and evaluate the developers' proposed ground equipment to determine its ability to acquire the necessary checkout parameters.

2.2.1 ASAP Functional Description

The ASAP is designed to decode, format and store experimental data over a ninety minute time period, the time required for one earth orbit, after which time the data is available for acquisition (playback) upon command from a switch selector playback command.

A typical system application of ASAP is shown in Figure 2-10. This represents a functional block diagram as proposed for the X-Ray Astronomy Experiment S-027 (MSFC Experiment No. 49). The experiment package consists principally of Saturn telemetry equipment (Model 270 multiplexer, Model 410 Multiplexer, and PCM/DDAS Model 301 Assembly) with the addition of ASAP. The ASAP has three functions. The first is to collect and store programmed data on magnetic tape. The second is to play back the data upon command. The third function is to supply sync and clock data for time correlation of experimental data.

The ASAP is also employed in the AAP-2, Apollo Telescope Mount (ATM) experiment. A functional block diagram of ASAP as proposed for ATM is shown in Figure 2-11. This defines the interfaces which are applicable to ASAP as a functioning system. A functional flow chart which depicts an operational sequence of the system is shown in Figure 2-12. Upon receiving a "TM Clock and Counter Set" command from the command system networks, a "Data Request" command is generated in the Auxiliary Storage and Playback Interface Unit (AIU) to the Computer Interface Unit (CIU). This command causes a write pulse to be generated. The write pulse advances the non-destructive readout (NDRO) Register to the first word in

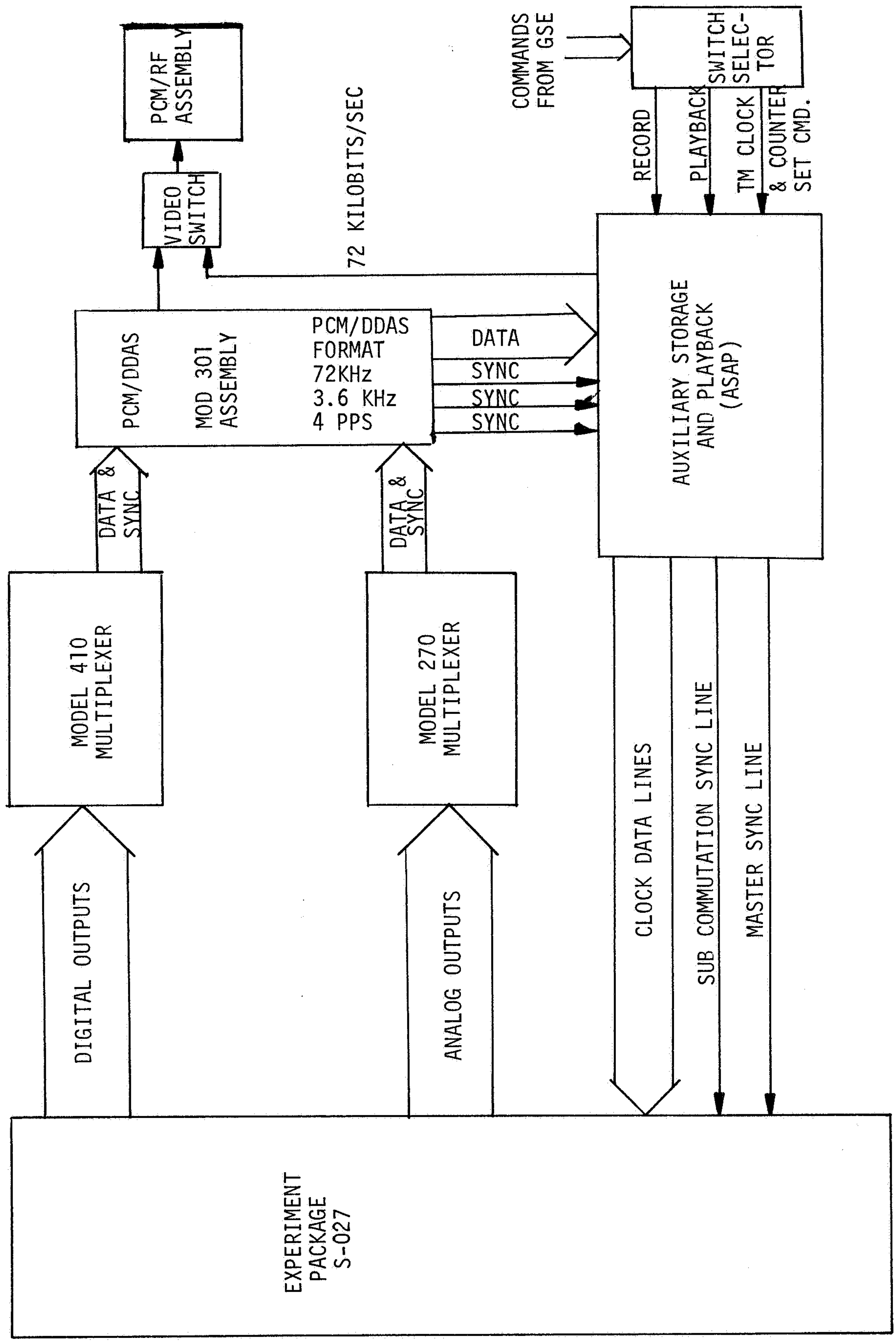


FIGURE 2-10 TYPICAL ASAP APPLICATION

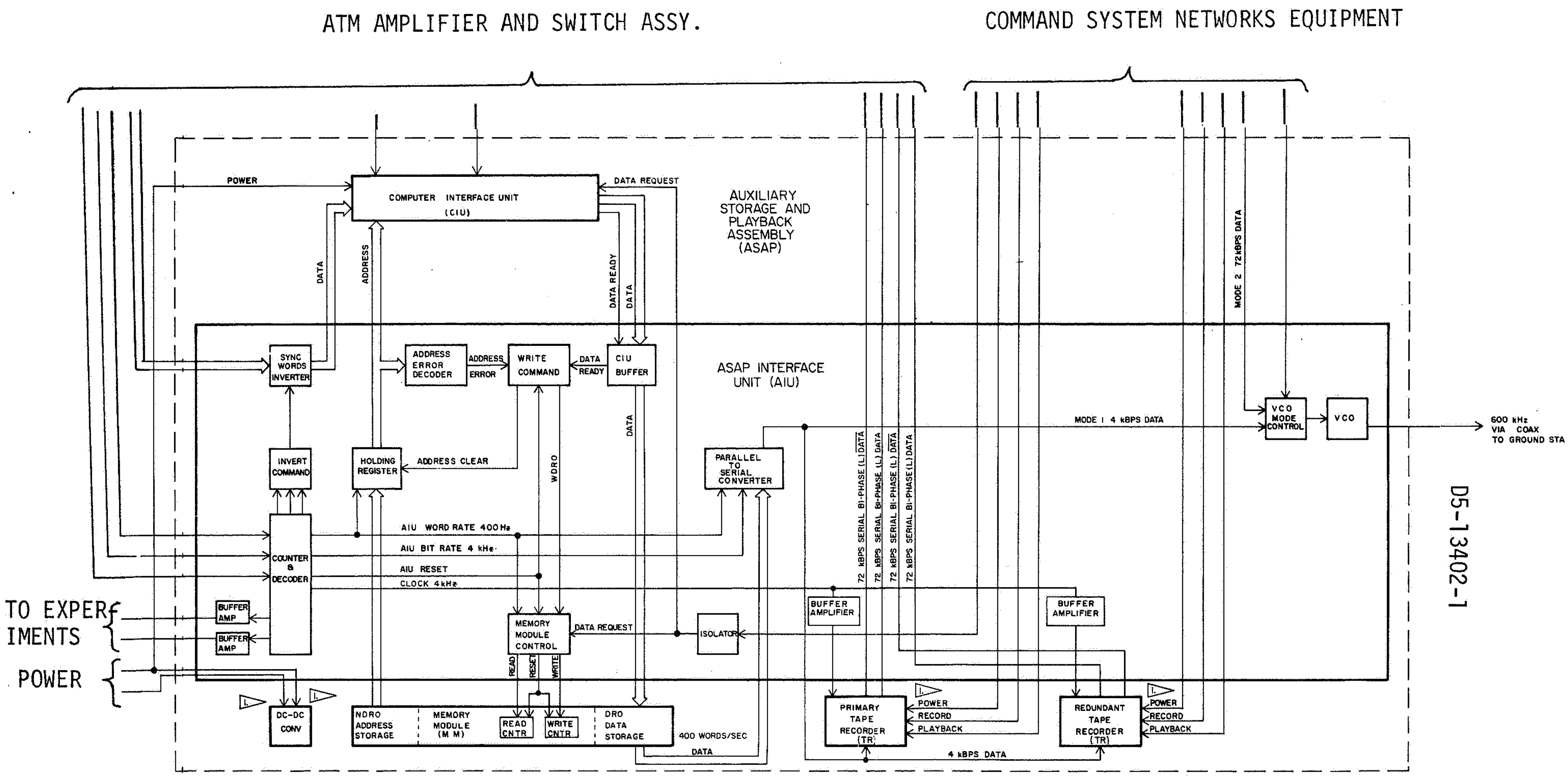
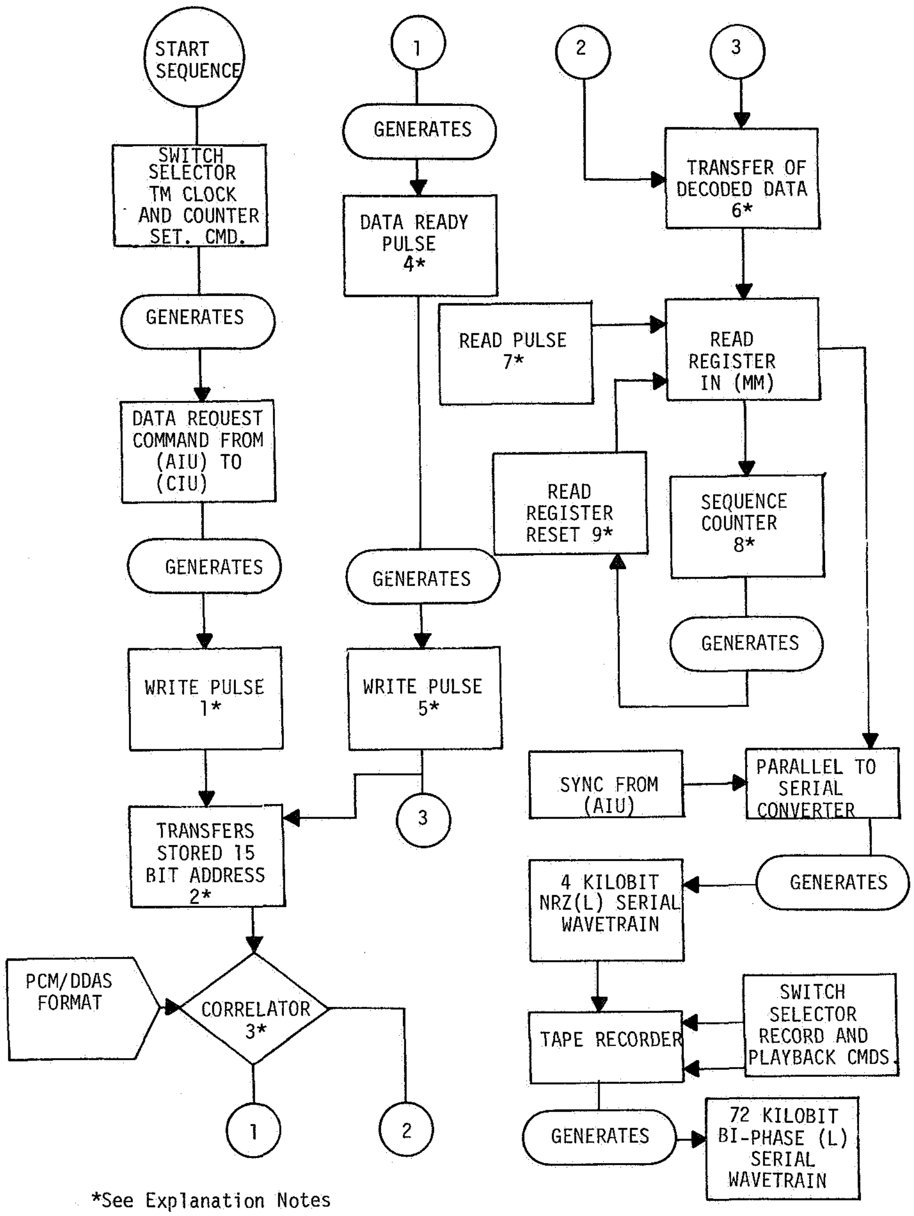


FIGURE 2-11 ATM TELEMETRY ASAP SYSTEM FUNCTIONAL BLOCK DIAGRAM

FIGURE 2-12 ASAP FUNCTIONAL FLOW CHART



*See Explanation Notes

1. Write pulse advances the non-destructive readout (NDRO) Register to the first word in the programmed sequence of 400 twenty-five bit in the MM.
2. Transfers the stored 15 bit address from the NDRO register in the MM to a holding register in the AIU.
3. Correlates address in the holding register to the corresponding address in the PCM/DDAS format at the CIU.
4. Generated by the CIU when data is ready for acquisition by the AIU.
5. Advances the NDRO register to the next programmed address word location in the MM.
6. Transfer of decoded data from PCM/DDAS format to the MM Destructive Readout (DRO) register.
7. Transfers data from the MM to the parallel to serial converter in the AIU at a 400 pps rate.
8. Sequence counter generates a read register reset command for updating the read register from the DRO register after all 100 memory locations have been sequenced.

2.2.1 (Continued)

the programmed sequence of up to 400, twenty five bit words in the memory module (MM). With advancement of the NDRO register, this transfers the first stored 15 bit address from the NDRO register in the MM to a holding register in the AIU. The CIU then must correlate the address in the holding register to the corresponding address in the PCM/DDAS Format at the CIU. When correlation is reached by the CIU, a "Data Ready" pulse is generated by the CIU saying data is ready for acquisition by the AIU. Decoded data is then transferred to the MM upon receiving the next write pulse. At the same instant the NDRO register is advanced to the next programmed word in the sequence. A "read" pulse transfers data from the MM Destructive Readout (DRO) register to a parallel to serial converter in the AIU where data is generated in a non-return-to-zero level NRZ (L) at a 4 kilobit per second rate and made available to the input of a 4 track tape recorder. The tape recorder can then be commanded by the command system networks to reproduce the stored data at a 72 kilobit (bi-phase level) rate.

2.2.2 Functional Test Requirements Which Will Assure the Flight Readiness of the ASAP

2.2.2.1 Sub-System Test Requirements

At the component and sub-assembly level tests, the functional performance of the component or "black box" is controlled by a Design procurement or specification control drawing which delineates a set of functional tests that will verify a unit is performing within its design specifications. These specifications and standards are sufficient in determining quality assurance of the unit as to flight rated performance and reliability; however, a data package or the performance history as to how a particular test specimen rated on each functional test requirement during the acceptance test performance could be of some benefit to a systems' checkout engineer. During post-manufacturing or prelaunch checkout, these tests results could be used as a deciding factor in making corrections to a failure mode. A failure analysis and synthesis of the entire system could be made based upon the acceptance tests performance report of each sub-assembly. Parameters which were of a border-line character as to acceptance or rejection of a unit could be impacted as a failure mode and the effect upon the entire system predicted.

2.2.2.2 System Checkout Requirements

The following system parameters should be verified during checkout:

a. Ground station or digital receiving station (DRS)

1. Verify that the digital-to-analog converters (DAC) are calibrated,

2. Verify proper programming for ASAP format at the correlator patch panel,

2.2.2.2 (Continued)

3. Verify proper programming of the data switch patch panel, and,

4. Verify that the DRS simulator (calibrator) and quick look are operating properly.

b. Experiments (ATM, S-027, etc.)

1. Verify that the experiment PCM/DDAS system is operating properly:

(a) 72 kilobit NRZ (L) serial wavetrain

(b) Sync Generation

(1) 72 kilohertz

(2) 3.6 kilohertz

(3) 4 pulses per second

(c) Calibration of all analog PCM/DDAS words

2. Verify data routing and control to ASAP through the Amplifier and Switch Assembly.

3. Verify that the command systems network is supplying control commands to ASAP.

c. ASAP

1. With a TM calibration stimulus (analog, discrete, clock, etc.) applied to each programmed PCM/DDAS word location address in the PCM/DDAS masterframe that is programmed for decommutation by ASAP, record the calibration data on the ASAP tape recorder. Place the ASAP tape recorder in a playback mode and at the ASAP digital receiving station verify that each programmed channel is being decoded properly and that the calibration response is within the assigned tolerance at each stimulus calibration level.

2. Verify (1) through both the ASAP and PCM/DDAS RF Data links and the 600 KHz hardwire to the checkout ground station. Note: The 4 kbps tape recorder input data can also modulate the 600 KHz subcarrier to fault isolate between the tape recorder and the AIU.

3. Verify (1) and (2) with both the primary and redundant tape recorders.

4. Verify that the master sync and sub-commutation sync are being generated in the proper time domain with respect to the data package multiplexer sampling rates.

2.2.2.2 (Continued)

5. Verify that the clock is supplying proper time and format over a 90 minute record cycle (if applicable).

2.2.3 Evaluation of Developers' Proposed Ground Equipment

Presently Astrionics (R-ASTR) and the Quality and Reliability Assurance Lab. (R-QUAL) at MSFC, are jointly developing a checkout station for ATM which will handle ASAP. The basic configuration or concept of the digital receiving station (DRS) is similar to those developed for Saturn applications for the PCM/DDAS system. The PCM/DDAS format consists of 30 sub-frames, each containing sixty 10 bit words totaling 1800 words per masterframe. The masterframe is 250 milliseconds in duration which results in a word rate of 7200 words per second or a bit rate of 72 kilobits per second (kbps). The ASAP tape recorder reproduce rate is identical to this, 72 kbps bi-phase (L).

With the masterframe synchronization logic being identical, this makes the DRS synchronization equipment compatible between the PCM/DDAS format and the ASAP format. The difference in format lies in the number of sub-frames and the number of 10 bit words in each sub-frame. The ASAP format has 60 sub-frames in one master frame with one hundred 10 bit words per sub-frame which gives a total of 6000 words per masterframe. The masterframe is 15 seconds in duration during the record mode and 15/18 seconds during the playback mode. This means sixty PCM/DDAS masterframes equals one ASAP masterframe, or one sub-frame in an ASAP masterframe will occupy the same time domain as a PCM/DDAS masterframe. Design modifications of a Saturn PCM/DDAS Digital Receiving Station with respect to the correlator, data switch and simulator are required to accommodate the 6000 word/masterframe ASAP format. Interface equipment such as digital-to-analog converters (DAC) and a computer interface unit (if automatic data reduction is desired) will have to be designed around peripheral checkout equipment.

The DRS is adaptable to either a manual or automatic checkout capability. As an example, the DRS could be made to operate with a computer interface unit which would give fully automatic checkout capability when interfaced with a general purpose digital computer (this is desirable since correlation of events during checkout with real time and data measurements as to sequence, elapsed time between events, response time, etc., become important checkout parameters); or the data switch can output programmed data channels to DACS for data acquisition by recorders or displays by panel meters.

2.2.4 Status of Standards, Specifications and Manuals

At the writing of this report all documentation releases have been preliminary; however, coordination efforts with R-ASTR and R-QUAL have

2.2.4 (Continued)

produced very good results in determining system configuration through the use of sketches, and proposed or preliminary requirements and documentation. The following documents concerning the ASAP are available for the ATM experiment:

a. Preliminary ATM, Telemetry Systems Description (GC110416)

b. CIU (50M60273) Specification Document

c. MM (GC110405) Specification Document

d. AIU (GC110403) Specification Document

e. DC-DC Converter Power Supply (GC110157) Specification Document

f. Tape Recorder (GC11037) Specification Document

g. IP&C List 50M12711

h. ATM Telemetry Ground Station Specifications, November 1, 1967, Revised January 25, 1968

2.2.5 Conclusions

This delineates the necessary system and sub-system checkout requirements which are applicable in determining the system performance of the ASAP. The system is being developed using present MSFC Saturn telemetry control specifications, so standards are sufficient to control further development and implementation, if a need or requirement should arise in expanding the usage of ASAP.

2.3 EXPERIMENT DATA ACQUISITION SYSTEM (EDAS)

The EDAS has been cancelled at the writing of this report. It was designed to support the following Apollo Application Program (AAP) Missions: AAP - 1, -2, -3 and -4, and record data from experiments M018, M050, M051, M508 and M509 and T020, which are biomedical measurements of the astronaut to be made while he is performing the various work functions in the Orbital Workshop.

The EDAS consisted of five wideband data channels (FM/FM) and one narrowband or commutated channel (PAM) providing a total of 88 multiplexed channels and five continuous data channels. The composite video output was to be recorded on tape for storage until a dumping command was given for playback and time sharing of a RF data link.

All measurements which were to have been assigned to the low response data channels (commutated channels) are presently scheduled for integration into the Airlock Module PCM Instrumentation System as shown in

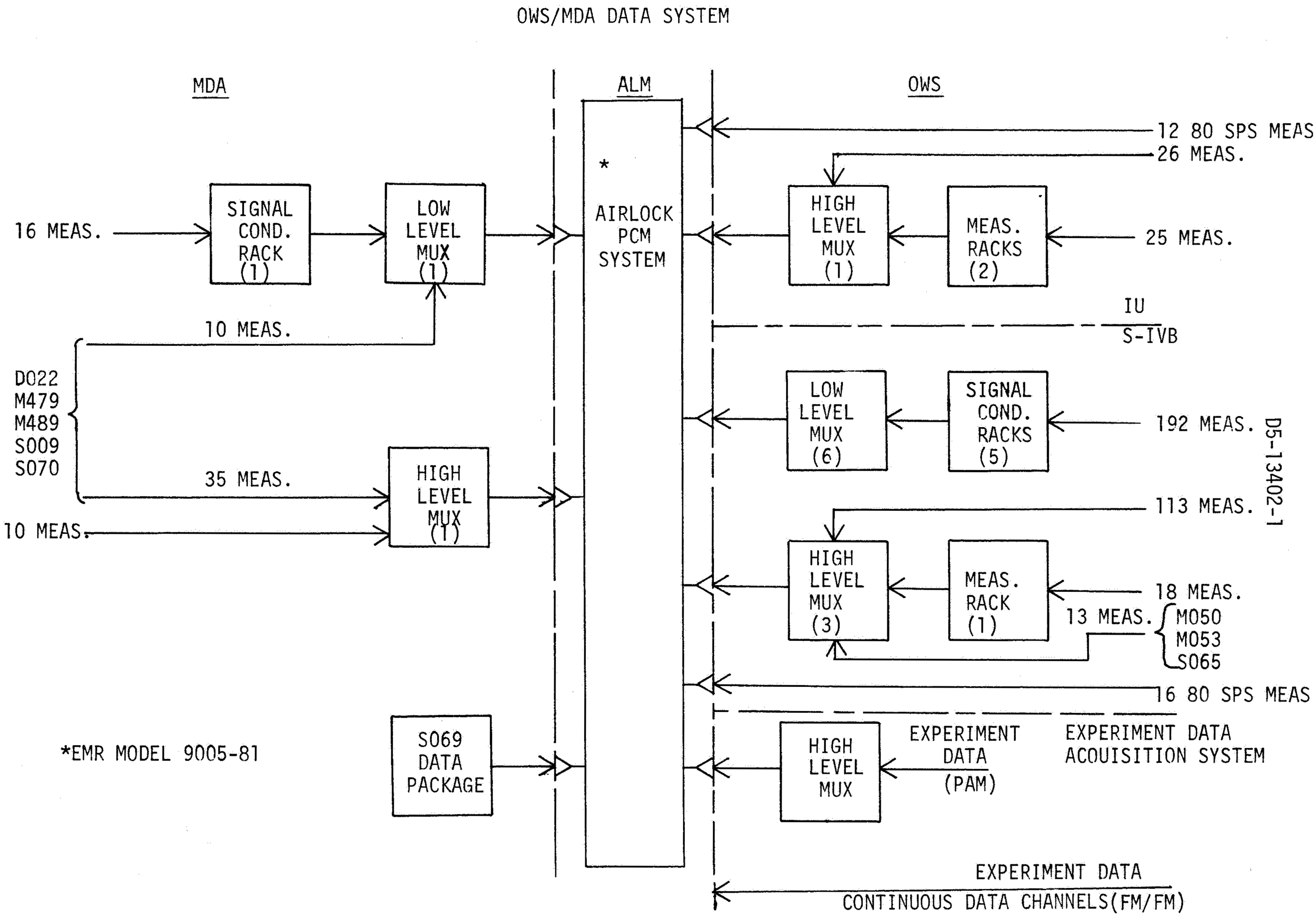


FIGURE 2-13 ORBITAL WORKSHOP/MULTIPLE DOCKING ADAPTER TELEMETRY SYSTEM

2.3 (Continued)

Figure 2-13; however, those measurements which required a wideband or continuous data channel are still being pondered by MSC and the AAP contractors.

Performance features of the EDAS Commutator compared to those of the high level multiplexer (HLM) used in the Airlock Module PCM Instrumentation System are as follows:

	PERFORMANCE FEATURES					
	Number of Channels/Unit	Type of Signal	Sample Rate (SPS)	Source Impedance	Accuracy	Input Power
EDAS	88	(0-5) VDC	1.25	10 Kilohms	±30 MV	28 ± 4 VDC at 100 MA
HLM***	32	(0-5) VDC	1.25	10 Kilohms	±20 MV*	**24 ± 0.5 VDC at 625 MA

*System incorporates analog-to-digital (A/D) conversion (8 bits) which has a resolution of ±20 millivolts for the least significant bit.

**System will withstand a supply voltage to 30 VDC, maximum.

***The EMR Model 9005-81 high level multiplexer (HLM) encoder is a medium-speed data encoding system.

The airlock module PCM system is to be assembled using hardware employed during the GEMINI program. This equipment is to have an operating life of up to one year in earth orbit. It is, of course, compatible with the manned spaceflight network ground stations.

2.4 CONSTANT BANDWIDTH SYSTEM

2.4.1 Constant Bandwidth-General

Data bandwidths and quanity requirements have expanded and attained a degree of commonality such that within the frequency multiplex transmission technique the method of maintaining a constant bandwidth for individual data channels has become feasible. Consequently, the standards guiding agencies of IRIG and AIA have had studies conducted by Electro-Mechanical Research Inc. of Sarasota, Fla.[1] and by Data Control Systems Co.

[1] Telemetry FM/FM Baseband Structure Study, Contract DA-29-040-AMC-746 (R) Volume I Final Report For White Sands Missile Range, New Mexico, 1965

2.4.1 (Continued)

of Danbury, Conn.,[2] respectively, of the baseband to establish a constant bandwidth structure. The results of these studies were very similar, and differ only in minor detail. The structure has some incompatibility with equipment capability due to stability related to the small percent of deviation of the subcarrier frequencies at the spectrum upper end. Also, at present no provisions are made for translation techniques to circumvent upper spectrum equipment limitations. As further users experience is acquired, these incompatibilities will be dissipated by establishment of realizable requirements through feedback from these agencies.

The constant bandwidth method has the same theoretical premise as the presently employed proportional bandwidth technique. But, as a comparison, constant bandwidth differs from proportional in that each subcarrier deviation is constant for all subcarriers and is not a proportional function of the subcarrier frequency. Figure 2-14 illustrates the general differences in baseband channel designation, as presently established by IRIG, for constant and proportional bandwidth. Constant bandwidth is not a replacement for proportional but rather adds extended utilization of the baseband spectrum. Proportional bandwidth is designed to accommodate an increasing progression of data bandwidths, wherein, constant bandwidth accommodates a constant data bandwidth for two or more channels. Constant bandwidth does provide better channel time correlation and a larger number of channels in the FM baseband due to the formulation difference of these methods. These methods can, by use in an optimized combinational configuration, enhance baseband utilization efficiency for varying data bandwidths and quanity requirements.

The present capability of industry can readily provide constant bandwidth systems that comply with any users particular requirements. Industry has systems available that provide data bandwidths other than the IRIG standard of 400 Hz, 800 Hz, and 1.6 KHz; and, that circumvent the upper spectrum equipment incompatibility by translation of the lower end spectrum. Also, these systems can extend below the 16 KHz center frequency limit as established in the IRIG structure.

The discussion following herein will pertain to constant bandwidth system's areas of baseband structure, system limitations, and system error to establish system checkout parameters.

2.4.2 Baseband Structure

As noted in the preceeding, the standards agencies have had studies and tests conducted of FM baseband applications. These included investigations

[2] Development of a Constant Bandwidth FM Standard, ATC Report No. ARTC-39, Aerospace Industries Association of America Incorporated, 1725 DeSales Street, N.W. Washington, D.C. 20036, 1964

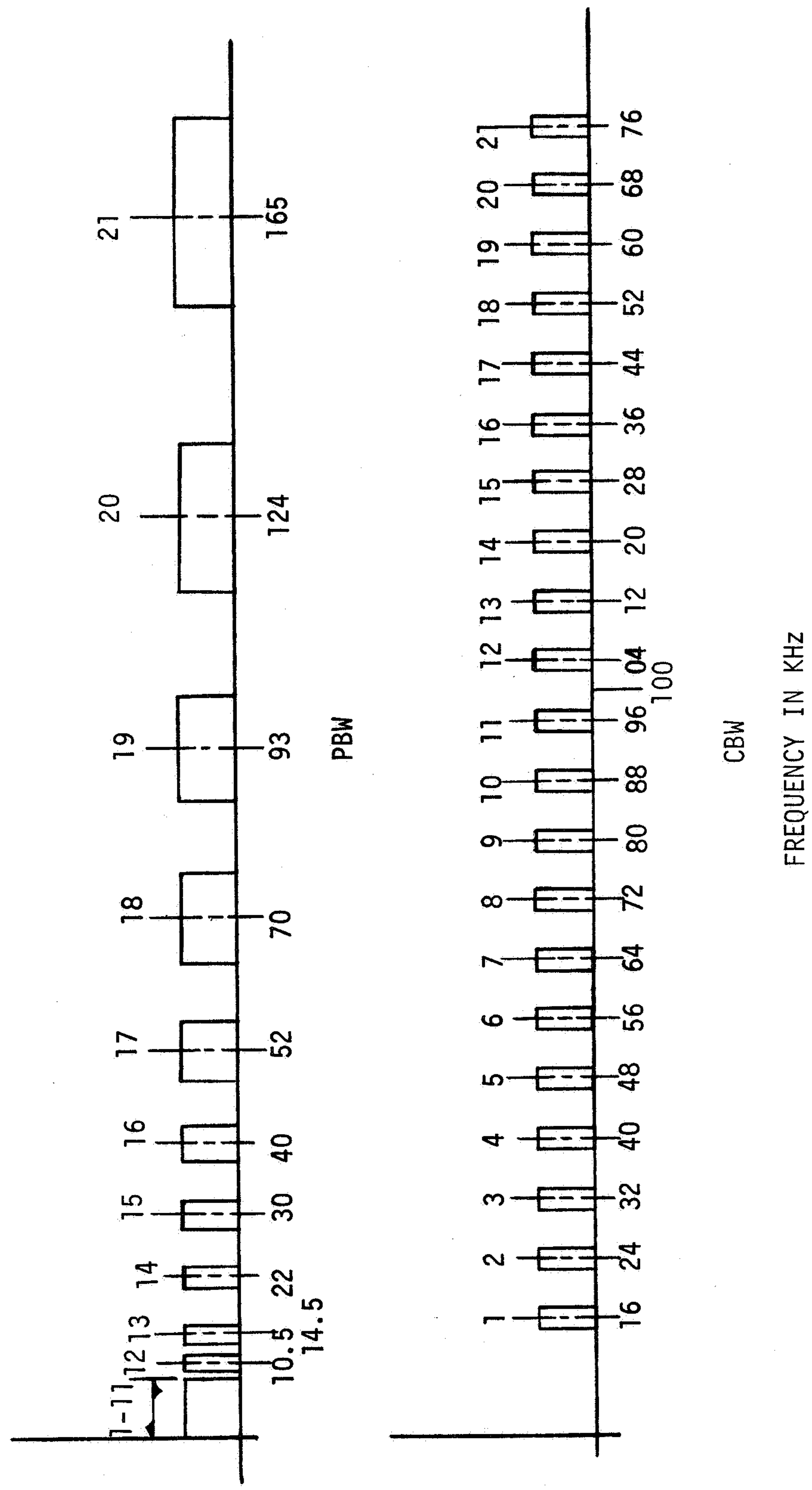


FIGURE 2-14 IRIG PROPORTIONAL AND CONSTANT BANDWIDTH BASEBAND STRUCTURE

2.4.2 (Continued)

of the FM baseband extension and of parameters influencing spectrum limitations. The extension investigation was based on the move of telemetry from VHF frequencies to UHF frequencies, which provides approximately twice the available RF bandwidth, and was required to determine how the added noise, due to increased bandwidth, would affect the data accuracy. In essence the parameters of primary concern were the designation of the channel's center frequencies, determination of guard bands, modulation indexes, pre-emphasis, threshold, signal-to-noise ratio (SNR) and equipment limitations. Figure 2-15 shows the technique parameters and relationship of these parameters to establish a constant bandwidth structure.

The presently established baseband has been extended from the existing 100 KHz area to approximately 200 KHz. This was deemed feasible from the results of the studies-tests. Within this spectrum IRIG has established constant bandwidth channel assignments and guard bands with a binary relationship, reference Figure 2-16. The binary relationship was established, basically, as a result of providing compatibility with the binary relationship of tape recorder speeds. Thus, if composite data is recorded at one speed and played back at another the resultant center frequencies would not be transformed to center frequencies that would require a non-standard demodulator.

The subcarrier frequency structure is based on the baseband frequency spectrum available, interaction effect of the individual channels and inherent noise. The allowable RF bandwidth controls the permissible baseband spectrum. For VHF and UHF this is 0 to 100 KHz and 0 to 200 KHz, respectively. Interaction is a function of deviation, modulation index, subcarrier amplitude, and frequency distance between subcarriers. Inherent noise increases as the baseband frequency spectrum increases. Consequently, the subcarrier frequency structure of channel designation and spacing becomes limited from the contribution of these parameters.

A total of 35 channels have been assigned within the 0 to 200 KHz spectrum with deviations of ±2 KHz, ±4 KHz and ±8 KHz, which provides data bandwidths of 400 Hz, 800 Hz and 1.6 KHz, respectively, for a mod index of 5. The basic channel assignment starts at 16 KHz and ends at 176 KHz and each channel is assigned according to 16 + 8 (+M-1) = fc in KHz, for +M of 1 through 21 and where fc is the channel center frequency. This provides 21 channels, of 400 Hz data bandwidth, spaced 8 KHz apart with a 4 KHz guard band at the required ±2 KHz deviation. Larger data bandwidths use appropriate binary channel center frequencies and guard bands selected from the basic channel center frequency assignments. This gives 9 channels for 800 Hz data bandwidths and 5 channels for 1.6 KHz data bandwidths. Figure 2-17 illustrates the IRIG channel assignment structure. This structure is based primarily on the premise of the maximum number of channels versus system SNR tradeoff and RF bandwidth limitations.

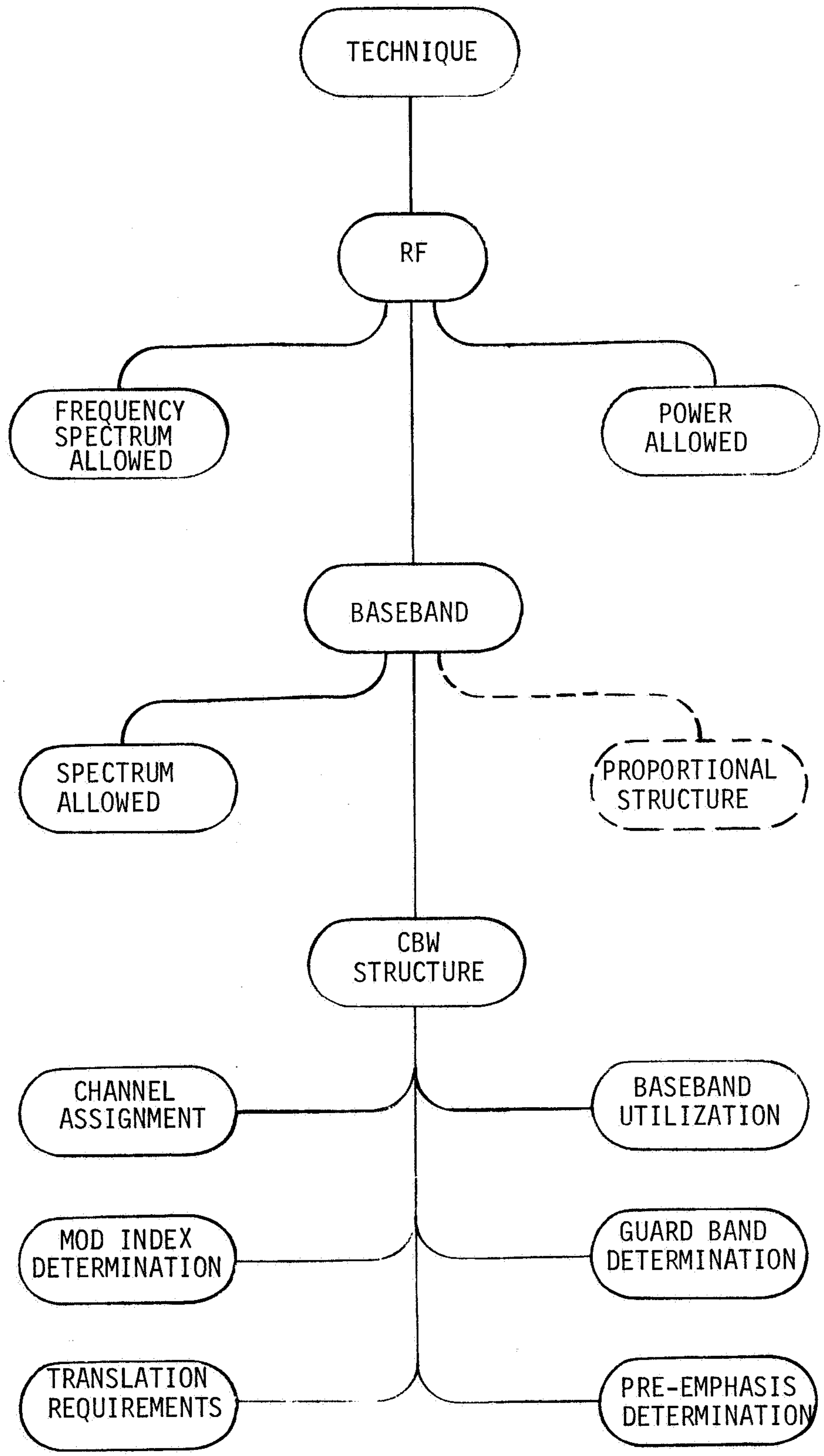
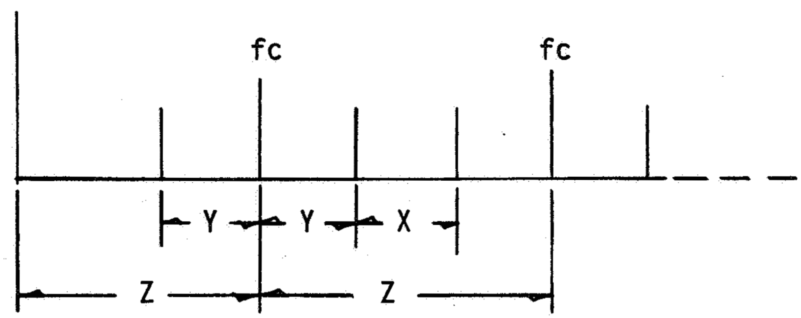


FIGURE 2-15 CONSTANT BANDWIDTH ESTABLISHMENT PARAMETERS



Z = Channel center frequency placement

Y = Subcarrier deviation

X = Guard band

Binary Relationship

$Z = 2^{N_1} + 2^{N_2}\,(M-1)$; $[4 \leqq N_1 \leqq 6,\ 3 \leqq N_2 \leqq 5]$ in KHz

$Y = 2^{N_3}$; $[1 \leqq N_3 \leqq 3]$ in KHz

$X = 2^{N_4}$; $[3 \leqq N_4 \leqq 5]$ in KHz

N_1 --- N_4 and M: Numerical relationship for 2, 4, 8 KHz Deviation

IRIG Channels	N_1	N_2	N_3	N_4	M
A $\pm$ 2 KHz dev. Z_1, Y_1, X_1	4	3	1	3	1-21
B $\pm$ 4 KHz dev. Z_2, Y_2, X_2	5	4	2	4	1-10
C $\pm$ 8 KHz dev. Z_3, Y_3, X_3	6	5	3	5	1-4

FIGURE 2-16 IRIG CONSTANT BANDWIDTH BINARY RELATIONSHIP

CBW SUBCARRIERS

Channel ±2 KHz Dev.	Fc, KHz Center Frequency	Channel ±4 KHz Dev.	Fc KHz	Channel ±8 KHz Dev.	Fc KHz
1A	16				
2A	24				
3A	32	3B	32		
4A	40				
5A	48	5B	48		
6A	56				
7A	64	7B	64	7C	64
8A	72				
9A	80	9B	80		
10A	88				
11A	96	11B	96	11C	96
12A	104				
13A	112	13B	112		
14A	120				
15A	128	15B	128	15C	128
16A	136				
17A	144	17B	144		
18A	152				
19A	160	19B	160	19C	160
20A	168				
21A	176	21B	176		

FIGURE 2-17 IRIG CONSTANT BANDWIDTH CHANNEL PLACEMENT

2.4.3 System Limitations

The constant bandwidth system discussed here will include carrier transmission-reception (RF), subcarriers processing (video) and modulation-demodulation (data), but excludes signal conditioning, antennas and data processing subsequent to demodulation (ref. Figure 2-18). These functional parts are excluded because they do not contribute significantly to system limitation. The included functional parts do contribute significantly to system limitation that results from both data transmission technique and equipment. The data transmission technique imposes system limitation of available RF and baseband frequency spectrum and signal power reduction at the upper baseband frequency spectrum due to low modulation ratio of the subcarrier frequency to RF modulator deviation. The equipment imposes system limitations of stability, non-linearity, inherent noise, and deviation due to physical restrictions.

2.4.3.1 RF Limitations

The limitations due to the RF link are the spectrum utilization restraints, as established by the FCC and IRIG. These restraints are in the form of specific frequency spectrum blocks assigned to telemetry, reference Figure 2-19, bandwidth criteria for assigned center frequencies, reference Figures 2-20 and 2-21, and maximum allotted transmission power. RF equipment limitations come from the practical limits of frequency stability in the transmitter oscillator and receiver local oscillators, of the transmitter modulation and receiver demodulation linearity and of the distortion introduced by filters.

2.4.3.2 Video Processing Limitations

The video portion of the constant bandwidth system is from the subcarrier oscillator to the RF modulator and from the RF receiver to the subcarrier demodulator, reference Figure 2-18. The limitations are from technique in the baseband structure and from the equipment. The baseband process is determined from the pass band of the RF requirements. These requirements limit the base band spectrum and the amount of deviation each subcarrier can deviate the transmitter. Channel interaction becomes the most prohibitive influence in determining the number of channels to be used in the base band. This interaction is the result of the power spectrum of each channel as related to the subcarrier modulation index. The larger the modulation index is made the more the actual data power will be contained in a practical band spectrum about the subcarrier, the reverse is true of modulation index reduction. The passable data bandwidth is limited by present techniques to prevent data power of a channel from being added to another during demodulation.

The typical system video processing equipments are mixer amplifiers, translators, pre-emphasis units, and associated filters for the modulation and, de-emphasis, detranslators, tape recorders, tape speed compensation, and associated filters for demodulation. The physical

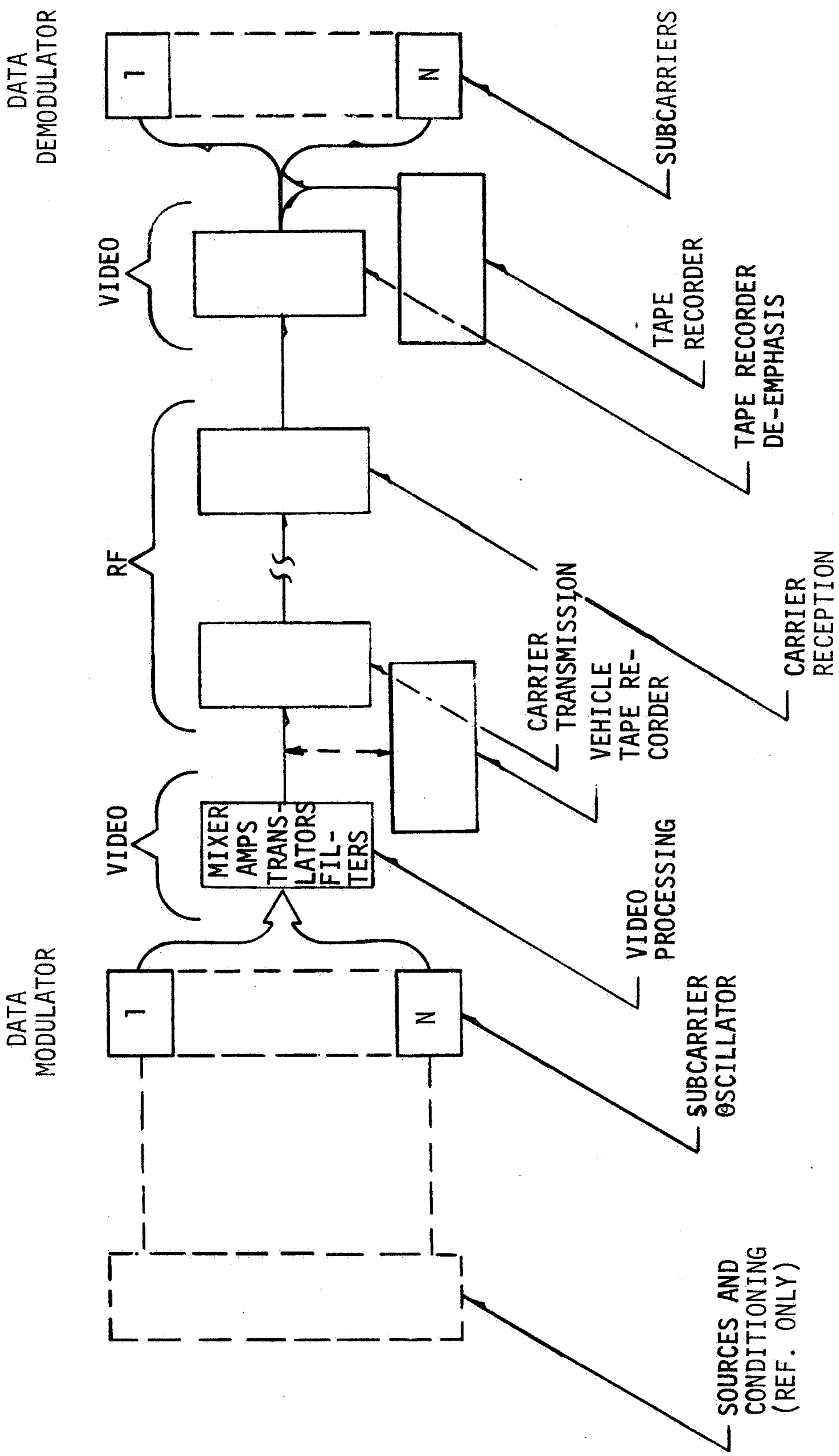
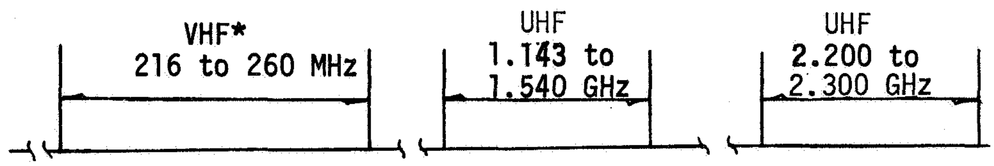
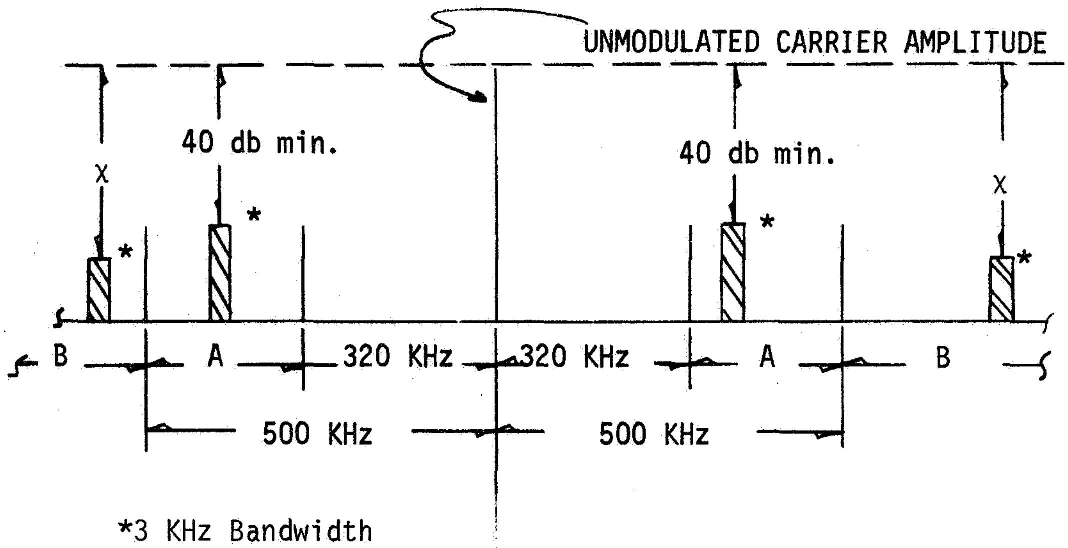


FIGURE 2-18 TYPICAL CONSTANT BANDWIDTH SYSTEM



*To be vacated by 1970

FIGURE 2-19 FCC ALLOTTED FREQUENCY BANDS

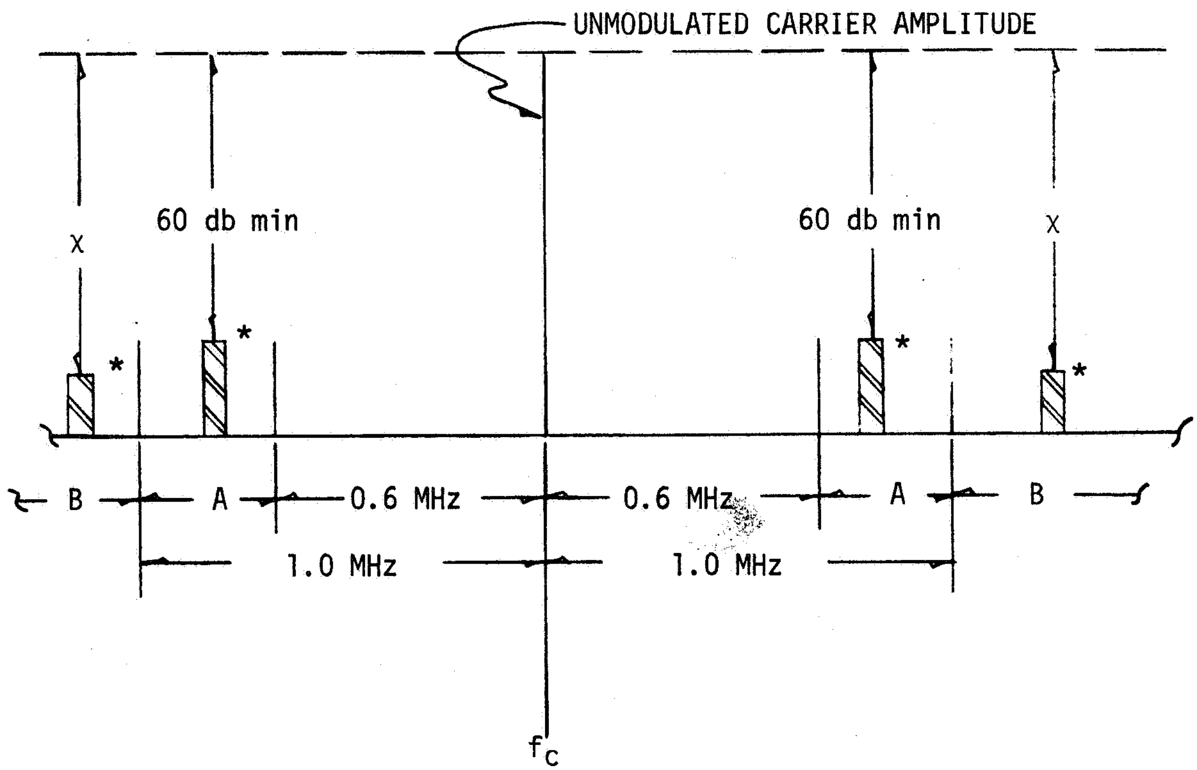


*3 KHz Bandwidth

1. The IRIG requirement of the 3 KHz bandwidth power level for area A is as noted: 40 db min down from the unmodulated carrier amplitude.

2. The IRIG requirement of the 3 KHz bandwidth power level for area B is as noted: χ where χ = 55 + 10 log (measured carrier power output) and is for carrier power levels greater than 40 milliwatts.

FIGURE 2-20 IRIG CARRIER POWER BANDWIDTH REQUIREMENTS - VHF



*3 KHz Bandwidth

1. The IRIG requirement of the 3 KHz bandwidth power level for the area A is as noted: 60 db min down from the unmodulated carrier amplitude.

2. The IRIG requirement of the 3 KHz bandwidth power level for the area B is as noted: χ, where χ = 55 + 10 log (measured carrier power output) and is for carrier power levels greater than 4 watts.

3. Exceptions are made of the above for wider carrier bandwidths ref. IRIG spec. 106-66, Paragraph 5.1.2.2.3 (e) (2).

FIGURE 2-21 IRIG CARRIER POWER BANDWIDTH REQUIREMENTS - UHF

2.4.3.2 (Continued)

restraint limitations of the equipments are the distortions introduced by the non-linearities of the mixer amplifiers, pre-emphasis, de-emphasis, and filters, instability of the translator and detranslator, and tape speed instability of the tape recorder.

2.4.3.3 Data Modulator - Demodulator Limitations

Subcarrier modulators and demodulators contribute to system limitation by non-linearity of the modulator voltage to frequency transfer function and non-linearity of the demodulator frequency to voltage transfer function, subcarrier frequency instability, DC shifts and filters. Non-linearity and instability limitations become most severe at the lower and upper baseband spectrum, respectively. With a constant deviation for all subcarriers and a reduction in channel frequency the deviation becomes an appreciable fraction of the channel frequency causing the modulator and demodulator to have much larger excursion range. This results in linearity limitations of the physical unit. At the upper baseband spectrum the subcarrier center frequency increases such that the deviation becomes an increasingly smaller fraction causing modulator and demodulator stability requirements that become physically limited. These limitations are primarily the result of the data transmission technique and are graphically illustrated in Figure 2-22. The normal equipment contributors to system limitation are the DC shifts and distortion introduced by modulator-demodulator filters.

2.4.4 System Error

System error and system limitation are different in that system limitation pertains to the theoretical and actual physical limitations of a system and system error pertains to the inaccuracies due to equipment. System equipment errors can be generally categorized as linearity, stability, DC shifts and distortion (harmonic-intermodulation). System error can be expressed as average error, root-mean-square error, or peak error. The method used depends on the particular system requirement. The normally accepted system error of constant bandwidth is 2 to 5 percent. Two percent corresponds to a modulation index of 5 and five percent corresponds to a modulation index of 2.

2.4.4.1 RF Error

RF errors as described here pertain to the errors contributed by the RF equipment. The RF equipment consist of the transmitter, power amplifiers, preselector and receiver. Of these equipment errors the most significant contributors are the non-linearity of the transmitter modulator and receiver local oscillators, DC shift of DC response transmitter modulator and receiver demodulator, and distortion introduced by the transmitter filters and receiver RF - IF demodulator filters.

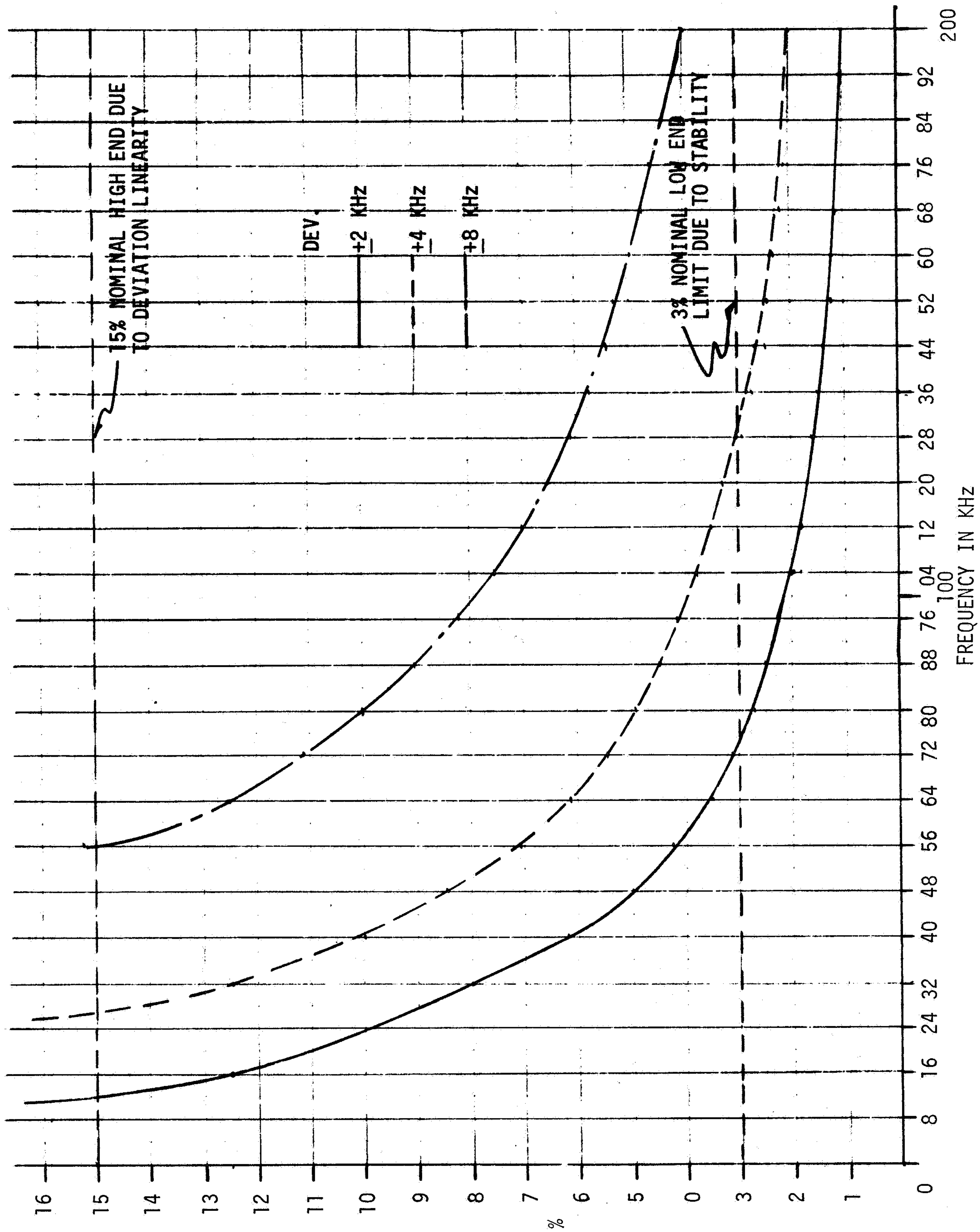


FIGURE 2-22 RATIO OF DEVIATION TO CENTER FREQUENCY IN PERCENT

2.4.4.2 Video Errors

Video processing is from the subcarrier modulator to the transmitter modulator and from the receiver demodulator to the subcarrier demodulator.

The error contributors of this portion of the data flow are the mixer amplifiers, translators, filters, preconditioners of the transmitters, tape recorder de-emphasis and detranslators.

2.4.4.3 Subcarrier Modulator - Demodulator Error

These units contribute errors of DC shifts, sensitivity instability, non-linearity and distortion. Unique errors of these units are modulation data feed-through and demodulation carrier feed-through.

2.4.5 Checkout Parameters

The following parameters are those necessary to check out an operational constant bandwidth vehicle system. The parameters and the typical values are in tabular form in the succeeding system areas.

2.4.5.1 RF

Transmitters

Parameter	Value
Center Frequency Stability	IRIG
Power	IRIG
Modulated Bandwidth (Function of Mod Sensitivity)	IRIG

2.4.5.2 Video

Translators

Parameter	Value
Frequency Stability	0.015%
Frequency Accuracy	0.005%
Spurious Output Signal	-46 db or less from referenced center carrier amplitude

2.4.5.2 (Continued)

Pre-Emphasis

Parameter	Value
Schedule: 1. Subcarrier Amplitude	IRIG
2. Transmitter Deviation/Subcarrier	IRIG

2.4.5.3 Modulator

Parameter	Value
Center Frequency Accuracy	0.1%
Center Frequency Stability	0.1%
Linearity	0.1%

2.4.5.4 System

Parameter	Value
Accuracy: MI 5	2%
MI 2 (Normalized/Amplitude)	5%
Distortion	1%
S/N (full scale rms signal to rms noise)	30 db min.

2.4.6 Optimization of Proportional and Constant Bandwidth System Checkout Equipment

2.4.6.1 General

Proportional bandwidth (PBW) and constant bandwidth (CBW) are particular forms of FM modulation. Both have similar system functional identities in that each requires FM modulators and demodulators that are basically identical, differing only in compliance with system parameters of center frequency, deviation, and data bandwidth. The major systems difference is that constant bandwidth uses a frequency translation technique to effectively utilize the baseband spectrum.

2.4.6.2 Optimization

Optimization of ground equipment of these systems are somewhat realizable through the basic commonality of the demodulator equipment. But, since a demodulator has to comply with the center frequency, deviation and data bandwidth of a channel per either system, optimization becomes restricted in that either manual or automatic means must be incorporated to change the tuning and filter elements of the demodulator such that a

2.4.6.2 (Continued)

demodulator may be used in either system and for different channels within a system. Determining whether manual or automatic methods are best depends on factors of time required to switch between systems and cost of automation. When time required for system changeover is not a prime factor, then the change over can be accomplished by manual replacement of the tuning and filter element modules. When time is a prime factor, the demodulator must have provisions for automatically switching over these elements internally. Obviously cost becomes greater with this facility.

A cursory discussion follows of present industry capability of methods for a typical 21 channel system of combined PBW and CBW. Note that detranslation equipment is a separate item of non-commonality.

2.4.6.3 Methods

Manual - The manual method requires a sufficient number of tuning and filter plug-in modules to accommodate the channels of both systems. For 21 channels this needs, as a minimum,42 tuning units, which include the bandpass filter elements, and 42 lowpass filter units plus additional units for constant amplitude or linear phase requirements. Adjustment of the demodulator is required after changes of the tuning and filter element units. Patching provisions or manual switching is required for the detranslation equipment to remove and apply this function during PBW and CBW operation, respectively. Thus, manual operation will have less complex equipment, larger module stores quantity, longer transition time, more operator involvement, be more reliable, and should be a more economical system when time is not a prime factor.

Automatic - The automatic method requires demodulators that can be automatically switched to different channels within a system and to the different systems without removal and replacement of plug-in modules or adjustments, also automatic switching of the detranslation equipment is required. An automatically switchable demodulator generally costs an order of magnitude higher than a manual discriminator. With this cost and inclusion of automatic control, the total cost should be from 10 to 15 times that of a manual system. Thus, when time is a prime factor, the additional cost will be offset by the short transition and set up time. Present industry systems can switch and set up in milliseconds, whereas, manual time is in the realm of 0.5 to 1.5 hours.

2.5 PCM AND PAM CHECKOUT PROBLEMS AND SOLUTIONS

This investigation of PAM/PCM checkout problems and solutions is directed to those encountered in higher pulse rates and special coding techniques, as related to system techniques and equipment.

2.5.1 Theoretical Considerations

The first source of information which should be considered when approaching new techniques in data transmission and retrieval is the theory behind the process. The parameters in question are higher data (pulse) rates and special coding techniques. Accepted presently as a useful expression for data rate transmission, under the conditions of constant average power and gaussian noise distribution function, is the Shannon equation:

$$Rmax = W \log \left(1 + \frac{S}{N}\right)$$

R = data rate in bits per second

W = bandwidth

S = average signal power

N = average noise power

Therefore, most of the problems of digital data transmission can be stated as follows: What is going to happen to the relationship between the channel, characterized by its bandwidth and inherent noise, the maximum allowable signal level, (a fixed or variable signal to noise ratio) and the data, is described solely by the number of information bits per unit time to be processed, and the expected probability of error.[1]

2.5.2 Errors and Problems Encountered from the use of Higher Pulse Rates in PCM Modulation and Demodulation Techniques

It is assumed that errors in a bit stream occur in an independent or random fashion. Random bit errors that occur in PCM data will not only add a component of mean square error to the data, but introduces a biasing effect. The bias being defined as the deviation from the mean of an expected (probability of error) value.[2] Between each N data words a sync word is placed consisting of m bits. The purpose of the sync word is to detect errors, due to bit slippage, bit error rate, signal blanking in the processing line, etc. The data rate should be used to determine the type of coding techniques which will yield a reliable synchronization pattern. One technique utilizes an autocorrelation (a count of the number of mismatches or errors) of the pre-set sync word pattern with the trans-

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[1] Bernfeld, Marvin, "Pulse Compression Techniques", IEEE Proceedings, Volume 51, September 1963.

[2] Rechtin, E., "Lunar Communications", John Wiley and Sons, Inc., 1964

2.5.2 (Continued)

mitted sync word pattern. A high autocorrelation indicates low noise or proper hardware performance while a low autocorrelation indicates a probable loss of sync.[1] The higher the bit rate the more intricate the correlation becomes. Most present day demodulators consider one bit of each word at a time; therefore, making no statistical dependence between data samples. Thus, as higher data rates are encountered there is less time for interrogation on the transmitting end and the time to distinguish between data and errors on the receiving end is reduced.[2]

A coding technique which lies midway between error detection coding and error correction coding is block coding. In this technique, the block of received digits is subdivided into an integral number of mutually exclusive and exhaustive sub-blocks. Then errors that occur within particular sub-blocks are detected at the receiver, and in addition, the receiver is able to specify which particular sub-blocks contain errors.[3] This scheme is similar to that employed on the Mariner spacecraft where data is transmitted over a high speed data link using double error correcting.[4] The technique has been sometimes referred to as Burst transmission which infers that data is assembled into a discrete unit and transmitted as a block. A block could be defined as containing all parameters selected from a single telemetry link in one master frame.

As the investigation continued it became apparent, principally from the literature, that as data rates were increased the associated checkout and reliability problems with respect to data synchronization, noise and accuracy, also increased. The correlation technique started to become more elaborate regardless of the coding technique employed in the bit stream (NRZ, MNRZ, Bi-Phase, Mark or Space, etc.). Special coding techniques were employed to hopefully yield a higher reliability in data acquisition at the ground station. The most popular of these codes being

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[1] Kuhn, B. G., Morey, K. H., and Smith, W. B., "The Orthomatch Data Transmission System", IEEE Transactions on Space Electronics and Telemetry, Volume Set-9, September 1963.

[2] Miyauchi, K., "Experiments on Binary Pulse Regeneration at Bit Rates of 160 and 320 MC in the 11-GC Region", IEEE Proceedings, Volume 51, September 1963.

[3] Barnard, G. A., Cox, W. R. and Yoshikawa, T., "Design and Operation of a Digital Simulation for the NASA Data Network", International Electronics Conference, 1964.

[4] Schomburg, R. A., "Computer Simulation of Data Compressor for Aerospace Telemetry Systems", Institute of Radio Engineers, October, 1962.

2.5.2 (Continued)

a low cross correlation technique using orthogonal and biorthogonal coding schemes. An added feature being phase coherence.

It appears that an optimum system from the viewpoint of transmission efficiency would be one which employs a phase coherent biorthogonal scheme transmitting digital data with a generated transition on all bits of information. The data rate would be a function of Shannon's equation and it would be variable to adjust for changes in the ratio of S to N. If phase coherence is sacrificed, then the complexity in the correlator schemes are increased at the ground station to obtain sync reliability.

Pattern (code) recognition to obtain synchronization uses the pattern, (binary representation of a sync word) the pattern complement, the pattern mirrors, and mirror complement. Matrix generation of these codes based upon orthogonal and biorthogonal coding yields a programmed (one possibility in a unit matrix) matrix to obtain a comparison for sync recognition.[1] On a baseband channel of limited bandwidth and perturbed by white noise, polynominal codes (non random binary) have also been shown to be quite efficient in producing a low error probability at a given information rate and signal to noise ratio.[2]

In checking out PCM systems with higher bit rates, the synchronization reliability is the key to the accuracy of the information being received. Adequacy of frame sync codes to synchronize specific length frames under anticipated signal to noise conditions should be thoroughly tested.

2.5.3 Errors and Problems Encountered from use of High Pulse Rates in PAM Modulation and Demodulation Techniques

Shannon Rate Distortion function gives the telemetry rate necessary to transmit data from a source with a given level of distortion. It is known that a gaussian process with a given spectrum requires a larger rate than any other process with the same spectrum; further, the rate-versus-distortion curve for a gaussian process with a given spectrum is easily evaluated.[3] Distortion destroys the absolute magnitude of the information being processed over a PAM channel.

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[1] Boeing document T2-113458-1, "Performance Potential of Biorthogonal (16,5) Coding in Space Telecommunications", 1966, Flint, C. C.; Meerdink, K. J.; Ritchey, O. W.; and Reeves, M. L.

[2] Kautz, W. H., "Nonrandom Binary Superimposed Codes:, IEEE Transactions on Information Theory, Volume IT-10, October 1964.

[3] Bendick, M., "The Functional Time Diagram Method of Command and Control System Analysis", International Convention on Military Electronics, September 1963.

2.5.3 (Continued)

As the PAM data rate is increased the rise and fall times must become short such that the absolute magnitude of the channel being sampled is interrogated over the worst sampling period. This increases the pass band of the data channel. To obtain faster rise and fall times, depicts higher currents which generate a higher ambient noise level within the system. Sufficient time must be allowed for the fall time of the preceding channel pulse to let its transient virtually disappear before the gate is open for the next channel to be sampled; otherwise, the amplitude of the first channel pulse will influence the magnitude of the next giving rise to crosstalk between channels. At the receiving end there is not much time for an analog-to-digital converter (ADC) to interrogate, encode the data in the same real time domain that data is received, and output the data for interpretation.

Synchronization problems are the same as with PCM.

Noise superimposed upon data will be the largest expected problem encountered during checkout, and trying to determine the amount of quantization and the analog to digital encoding technique required to offset this condition could become a real task.

2.5.4 Checkout Problems & Solutions

Some checkout problems due to higher pulse rate PCM and PAM are summarized in Table 2-VIII along with solutions and the impact on the checkout equipment.

2.5.5 Conclusions

The present trends in data acquisition are directed toward programming the data commutators, digitizing, quantizing and performing data reduction and checkout processes within the vehicle systems. This is established by the fact that work on such systems as: Addressable Time Division Data System (ATDDS), Experiment Data Acquisition Systems (EDAS), On-Board Vehicle Checkout Systems (OVCS), Computer Control Communication Systems (CCCS), which are only a few that are space related, are in a development phase. With the new technological advancements in integrated circuits, all these systems are practical. This helps to reduce the requirements for increased pulse rates, because a priority can be assigned to transmitted data, which is to be analyzed by the ground station, with respect to programmed mission events.

2.6 SATURN PROPORTIONAL BANDWIDTH CHECKOUT TECHNIQUES

The present MSFC and MSFC Contractor Checkout techniques on Proportional Bandwidth Systems were reviewed to verify:

TABLE 2-VIII HIGH PULSE RATE PCM AND PAM CHECKOUT PROBLEMS AND SOLUTIONS

PROBLEMS	SOLUTIONS	EFFECTS ON CHECKOUT HARDWARE
A. Sync Errors 1. Random Bit Errors a. Bit Slippage b. Bit Error Rate c. Bit Jitter	A. Verify through functional testing and evaluation that the system synchronizers, and correlators bounded by worst case conditions are adequate.	A. More intricate synchronization processes than in lower pulse rate systems presently employed in space environments to obtain the desired reliability.
B. Wider Bandwidths with higher radiated power makes the system more vulnerable to a lower signal to noise ratio.	B. Verify through functional testing and evaluation that all passbands and bandpass filters are performing their task at the sub-assembly level.	B. More elaborate filtering will be required to offset the lower signal to noise ratio at increased data rates.
C. Higher ambient noise level within the system: 1. Due to faster rise and fall times (at higher currents) to obtain required system response. 2. Crosstalk (PAM).	C. Same as B.	C. Filtering requirements will be a function of the noise generated within the ground station checkout equipment at increased pulse rates.
D. Less overall system accuracy 1. Sacrifice speed for accuracy 2. Less time to interpret and encode data at the ground station without more intricate coding techniques.	D. 1. More rigid calibration procedures at sub-assembly level. 2. Implementing quantization practices using automatic checkout equipment at system level. 3. Compounding Encoders	D. Depicts automatic checkout equipment due to overall system response.

2.6 (Continued)

a. That all tests required to determine the component's or sub-system's performance are being performed.

b. That all tests are being performed properly.

c. That no unnecessary tests are being conducted.

2.6.1 General Review of the Parameters Which Contribute to FM/FM System Errors

The overall system accuracy of the Saturn FM/FM and FM/FM/FM (FM^3) systems should be verified to within 3 percent of the full scale voltage required to deviate each subcarrier oscillator (SCO) from one bandedge limit to the next when measured at the checkout station subcarrier discriminator output.[1] To attain this accuracy, tests must be performed on each piece of hardware within the system to determine that those parameters which contribute to total system error are within pre-determined tolerances. The system tests should include sub-assembly test results for optimization of errors throughout the complete system - i.e. flight, ground, and checkout equipment. To define a complete set of parameters which contribute to total system error without first defining the entire system would be ambiguous; however, few errors which usually make their contribution in an FM/FM system are transmitter and SCO dynamic linearity, transmitter and SCO pre-emphasis, harmonic distortion or crosstalk in the discriminator or multiplex system and tape recorder system, spurious products outside the maximum deviations assigned to each SCO and transmitter carrier frequency, incidental FM and errors in the demodulator reference frequency. These parameters are not to be confused with errors which are contributed by test and checkout equipment calibration accuracies which are always present in any system. All errors, regardless of the source, add in some algebraic expression to make up the total system error.

The best method of reducing system error is through sub-assembly testing and evaluation where special tests and calibration curves unique to the test specimen are run.[2] Then predicted results or contributed error from each assembly within the system is known. A typical Saturn proportional bandwidth system broken down into a sub-assembly level is shown in Figure 2-23. All assemblies shown to be on the vehicle have test requirements and procedures which verify the performance of each at the sub-system level, so each assembly has been required to pass through a tolerance window before installation is made at the next assembly

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[1] S-IC STAGE END ITEM TEST PLAN, 66B10901, October 29, 1964.

[2] Space Vehicle Stage Analysis and Checkout Guidelines, SR-QUAL-64-13, May 1, 1964

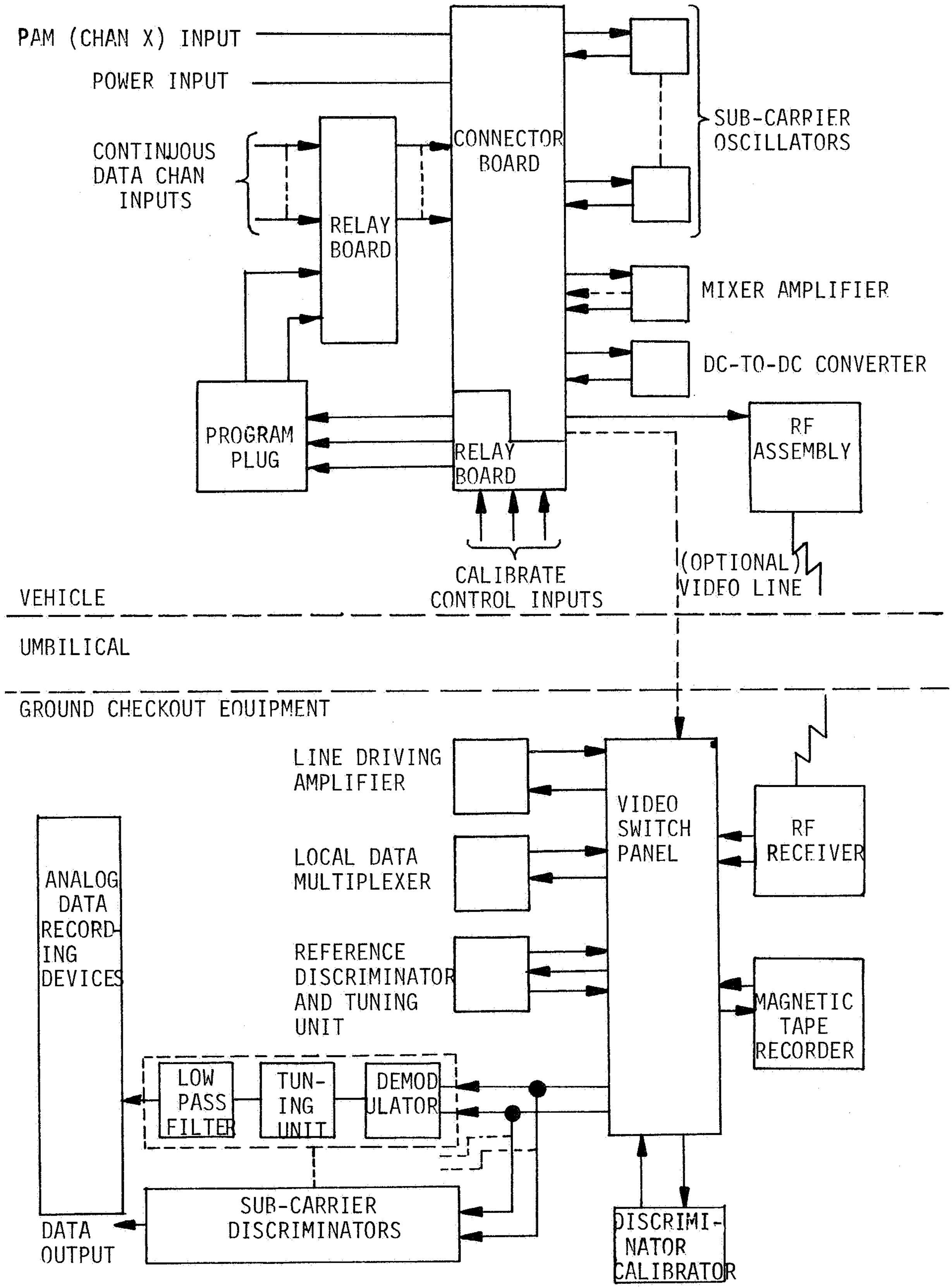

FIGURE 2-23 TYPICAL SATURN FM/FM OR FM^3 TELEMETER SYSTEM

2.6.1 (Continued)

level.[1] The receiving station is calibrated based on the accuracy of the discriminator calibrator; vehicle calibration data is then compared against the discriminator calibrator to obtain the system error. Through this method of testing, a high confidence level and predicted accuracy can be achieved.

2.6.2 A Review of Present MSFC Test Requirements at the Sub-System and System Levels

A prerequisite to assembled end-item checkout is that all component tests be made to MSFC approved checkout guidelines. The test philosophy has been to have several levels of testing whereby all functional test parameters have been thoroughly evaluated by the time the system is ready for an end-item checkout. The tests range from component testing, wherein tolerance specifications are verified before installation into the next higher assembly, to system evaluation or post-manufacturing checkout were the performance of the entire system is verified. The only reason to require such a thorough set of test requirements is to obtain the highest possible level of confidence in the system, because each component and each assembly is purchased or manufactured to some type of specification and control requirements which depict functional performance requirements.

With this test philosophy it appears that several tests during the lower test levels could perhaps be re-iterated several times; however, it is out of the scope of this task to determine where the saturation point on a curve of reliability predictions versus operating (test) time will lie. At the component and sub-system level of checkout the following tests are required by MSFC to verify operational status of a typical Saturn type (FM/FM) Proportional Bandwidth System: (The following tests and tolerances were specified in MSFC Document 6753-P(TR)[2] and are listed as typical examples).

a. Bandedge Limits

The bandedge limits to which each SCO is deviated is determined by ± 1.0 hertz or $\pm$ 1.0 percent of data bandwidth, whichever is greater using standard IRIG specifications. This tolerance should have some clarification since the IRIG telemetry standards were revised March 1966 and the data bandwidth is given in both a nominal and maximum

[1] S-IC Stage and GSE Test Tolerance Guide, D5-11148.

[2] Saturn Instrumentation Systems Test Requirements, 6753-P (TR), MSFC-R-QUAL, May 22, 1967, Changed September 25, 1967.

2.6.2 (Continued)

a. (Continued)

frequency response.[1] For a modulation index of 5, the nominal frequency response would be the data bandwidth. Maximum frequency response (modulation index of 1) should only be used when data quantity is the primary emphasis rather than data quality. This tolerance value is directed more at a sub-assembly level test requirement and could be difficult to measure at the system level.

b. Linearity

The SCO linearity is specified as ± 1.0 percent of the design bandwidth of a theoretical straight line representing the input voltage versus output frequency of the SCO. Several methods are used to define the theoretical line with one of the best being the method of Least Squares Approximation. The method is usually determined around the ground station checkout capability. The least squares approximation method requires automatic (computer controlled) ground station checkout equipment in order to obtain a fast solution response. A simple method is to assign a tolerance band around each calibration point which represents a go or no-go type test.

c. Pre-Emphasis

The pre-emphasis of each SCO is adjusted such that the output amplitude deviates the RF carrier frequency a pre-determined amount, ± 10%. The pre-emphasis adjustments require that the output level control of each affected SCO be used. These are adjusted to a pre-determined pre-emphasis schedule. The gain control on the mixer amplifier is then used for adjustment of the total FM multiplex level. The multiplex levels are adjusted to deviate the transmitter such that the radiated spectrum does not exceed a specified limit over a pre-determined percent of a given time interval.

At this point something must be said about pre-emphasis optimization. Ideally, one might think that the pre-emphasis scheduled is optimized such that the transmitter never exceeds its specified deviation limit; however, this doesn't have to be, and for optimum bandwidth efficiency is not the case. The time period for which the transmitter deviation can be exceeded over an operating period with all FM channels deviating the transmitter carrier is fixed at a maximum i.e., there is a possibility of all FM components adding in phase such that the transmitter deviation exceeds ± 125 K hertz deviation. The amount of time which the transmitter is allowed to over deviate such that spurious products exist outside its assigned spectrum, due

[1] IRIG Telemetry Standards, 106-66, Revised March 1966.

2.6.2 (Continued)

c. (Continued)

to the fixed pre-emphasis schedule, might be a parameter which would be of interest to know from a radio frequency interference view point.

d. Channel Verification

Channel verification is used to identify each data channel by applying a stimuli and monitoring an expected response. This test is integrated into the calibration tests. A five point calibration stimulus is applied to each SCO and the response is verified by ground station discriminators. All test parameters listed herein can be verified by monitoring the discriminator response.

All of these tests are applicable in determining the performance of a proportional bandwidth system. The test requirements should be complete and directed toward obtaining a required system accuracy. There should be procedures for performing each test and these procedures should be proven capable of validating the test tolerances for each performance parameter.

2.6.3 Present MSFC Contractor Checkout Techniques

All contractors are performing all the tests which are presented in paragraphs 2.6.2 at the component and system checkout level.[1,2,3] The techniques or checkout procedures vary only in the configuration and types of hardware employed to perform the same tests. The end result is the same, conformity by all contractors is finally reached at the launch complex where system checkout procedures are standardized as much as possible with respect to tolerances, methods or procedures, and time required in performing the programmed checkout requirements.[4]

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[1] S-IC STAGE END ITEM TEST PLAN, 66B10901, October 29, 1964

[2] Test and Checkout Specifications and Criteria for S-IU-502, MSFC No. 111-4-405-10, IBM No. 67-257-0005, August 1, 1967.

[3] Saturn S-II Integrated Test Requirements Report, SID-65-292, North American Aviation, September 1, 1965.

[4] Launch Vehicle Test Catalog Saturn V Apollo/Saturn 501, John F. Kennedy Space Center NASA Section I Test Procedure GP-307 January 15, 1967. Revision C - July 13, 1967, prepared by BATC for Saturn V Test Integration and Planning Branch LV-TOM-3.

2.6.3 (Continued)

The key to reducing the number of unnecessary tests and the amount of time required in performing each test has been the documenting of test requirements and checkout procedures. The checkout procedures are written around the available checkout equipment at the several contractor's plants and Government test sites; and dry runs which verify that the procedures are capable of validating each test requirement in the shortest time interval possible are made.[1]

2.6.4 Conclusions

All tests which are presently required by MSFC on Proportional Bandwidth Systems are applicable in determining system performance. The test philosophy is set up to obtain a high confidence level while obtaining a required system accuracy. All tests are performed to documented test requirements and procedures. Thus, the susceptibility of the test conductor to human error is reduced while performing each test. At the same time the number of unnecessary test are reduced to a minimum because tests are not being repeated.

2.7 NEW TELEMETER SYSTEM SURVEY

Due to the late response of some telemetry manufacturers during Phase A and the constant research in the field of telemetry it was necessary to continue the Phase A new telemeter system survey effort during Phase B.

2.7.1 Manufacturers Survey

During this phase, responses to the request for data from manufacturers, sent during Phase A, were still being received. Four additional telemetry manufacturers responded after submittal of the Phase A report. In addition, information from one new company not originally solicited was received. Five companies have not responded at all. No new systems or techniques were described in the literature received from manufacturers during this phase.

2.7.2 New Techniques

Although no new techniques were uncovered, some additional details on a technique, new to MSFC, and previously mentioned in the Phase A report, "Millimeter Wave Carrier", are included here. The NASA Goddard Space Flight Center is planning to include a millimeter wave communication system as an experiment in the Applications Technology Satellite, ATS-E,

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[1] Launch Vehicle Test Catalog Saturn V Apollo/Saturn 501, John F. Kennedy Space Center NASA Section II GP-307, Operational Procedures. Prepared by BATC for Saturn V Test Integration and Planning Branch LV-TOM-3.

2.7.2 (Continued)

to be launched in early 1969. The objective of the experiment, built by the Martin Marietta Corp., is to study the propagation variables that affect communication links in the 15 and 30 GHz region.[1] Millimeter waves are more subject to absorption, refraction and dispersion than lower frequencies. Absorption through the atmosphere is one of the most severe problems to be resolved. There are certain frequencies or windows where atmospheric absorption is relatively low. These regions occur below 20 GHz, 30 to 40 GHz and at 90 to 100 GHz. The system to be flown on ATS-E will employ an up-link carrier at 31.65 GHz and a down-link carrier at 15.3 GHz. The satellites down-link transmitter delivers 300 mw and will be phase modulated by the satellite telemetry system.

Bell Telephone has recently completed a repeater which operates at 51.7 GHz and transmits data at 306 megabits per second.

[1] "Milliwave Systems Make Solid Advances", Electronic Design, Page 25, February 1, 1968

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

3.0 INTRODUCTION

This section contains a discussion of the conclusions reached during the Phase B study, a recommended plan and schedule for Phase C and a report of the progress of the contract to date.

3.1 PHASE B CONCLUSIONS

Each of the requested areas of study was examined in depth to obtain the information required for this phase and in preparation for the development of checkout equipment specifications for these systems during Phase C.

3.1.1 Unified S-Band Systems

In regard to the checkout ground station for the Saturn and Apollo unified S-Band systems, it was determined that one station could be employed to transmit to, and receive and demodulate data from each of these three Saturn and Apollo transponders. The receiver could also receive the Saturn IU PCM/FM S-Band data. The demodulated PCM would be sent to a separate universal PCM decommutation station capable of accepting the various bit rates and frame formats. The station should also contain the digital command generator and tracking and ranging evaluators so that more efficient use could be made of the ground RF equipment. The Apollo systems would also require several other specialized checkout capabilities such as voice and FM/FM discriminators not specifically related to vehicle or spacecraft telemetry measurements.

3.1.2 Auxiliary Storage and Playback

The Auxiliary Storage and Playback, ASAP, equipment is being developed by MSFC-Astrionics and is for the most part compatible with the existing Saturn digital receiving equipment with the exception of the frame format.

3.1.3 Experiment Data Acquisition System

The Experiment Data Acquisition System (EDAS) scheduled for the S-IVB Orbital Workshop has been cancelled and an existing PCM system previously employed on Gemini will be used.

3.1.4 Constant Bandwidth

The present capability of industry can readily provide constant bandwidth systems that comply with any users particular requirements. Industry has systems available that provide data bandwidths other than the IRIG standard of 400 Hz, 800 Hz and 1.6 KHz, and systems that circumvent the upper spectrum equipment incompatibility by translation of the lower end spectrum. Also, these systems can extend below the 16 KHz center frequency limit as established in IRIG structure.

3.1.5 PCM and PAM

The investigation of possible problem areas that may occur as a result of increased PCM bit rates and higher PAM sampling rates revealed that more complex synchronization and noise rejection circuitry would be required if this trend was followed. However, it was also pointed out that there is a trend toward on-board data reduction and/or evaluation thereby reducing the quantity of data to be recovered by ground stations and hence negating the need for higher bit rates.

3.1.6 Proportional Bandwidth

The review of MSFC and contractor checkout techniques for proportional bandwidth systems verified that the test requirements dictated by MSFC are being adhered to by the stage contractors and that the tests performed are all applicable in verifying equipment readiness.

3.1.7 New Telemeter System Survey

No significantly new systems or techniques were uncovered as a result of the continued market survey.

3.2 PHASE C PLAN AND SCHEDULE

The recommended work to be accomplished during Phase C, as presented here, is based on discussions with the Contract Technical Supervisor during several meetings toward the end of Phase B. It was stated, during one of the meetings, that due to the contractual obligations of the AAP Systems Integrator and the program applications of those systems studied during Phase B, none of the areas of study for this phase would be approved for Phase C. Further, there are no new systems or techniques for which ground equipment change specifications are desired. It was therefore proposed that the scope of Phase C be changed and a revised set of objectives and work plan be presented in the following paragraphs.

The revised objective for Phase C, as requested by the Contract Technical Supervisor, is the performance of an error analysis of the four Saturn V stage contractor telemetry checkout stations. Only that portion of the checkout station required to check out PCM, PAM and FM/FM will be studied. To perform all the tasks associated with this analysis would exceed the funding originally allocated to Phase C. Therefore, the description of the tasks will be divided into; the work that can be done with the authorized manpower, the work that is directly related to the new objective but requiring additional funds, and a suggestion for an expanded equipment accuracy evaluation outside the scope of this contract.

3.2.1 Saturn V Telemetry Checkout Station Equipment Review and Accuracy Analysis

The tasks described here can be accomplished with the manpower presently

3.2.1 (Continued)

allocated to Phase C. The schedule is shown on Figure 3-1, task numbers 2 through 6.

The Saturn V telemetry checkout station equipment review, task 2 of figure 3-1, consists of a review of documentation describing the station equipment of each of the four contractors as used at each of the contractor checkout locations as shown below to determine that the individual contractors employ the same or equivalent equipment at each location. The documentation will be provided by MSFC-R-QUAL-PIT and consist of block diagrams of each station and identification of each item of equipment as to commercial model number, or in the case of an in-house design, complete specifications. Due to the limited funds remaining, trips to each contractor or checkout location will not be possible. Should this be determined to be necessary for the successful performance of this task, additional travel funds will be required.

The locations of the various telemetry checkout stations where contractor responsible equipment is used is as follows:

STAGE	TEST AND CHECKOUT LEVEL		
	POST-MANUFACTURING	STATIC TEST	POST-STATIC
IU	Huntsville, Ala.	-	-
S-IVB	Huntington Beach, California	Sacramento, California	Sacramento, Cal.
S-II	Seal Beach, Cal.	Mississippi Test Facility	Mississippi Test Facility
S-IC	Michoud	Mississippi Test Facility	Michoud

After it has been determined whether or not each contractor uses essentially the same equipment at each location, an accracy analysis will be performed on one (1) station of each of the four contractors. Significant differences between stations of individual contractors will be also analyzed. This theoretical accuracy will be determined by assuming a normal equipment error distribution and will include the effect of other contributed errors such as noise and human error. To arrive at the overall system accuracy, error distributions for each functional block of the block diagram will be determined and then each signal path will be analyzed. Wherever significant errors can be contributed by the operator, this area will be positively identified, and where possible, an assessment of this error on the overall accuracy will be made. These operator errors could be due to: inadequate (not incorrect) procedural instructions, controls with insufficient resolution, readouts or adjustments with ambiguous meanings, measurements dependent on

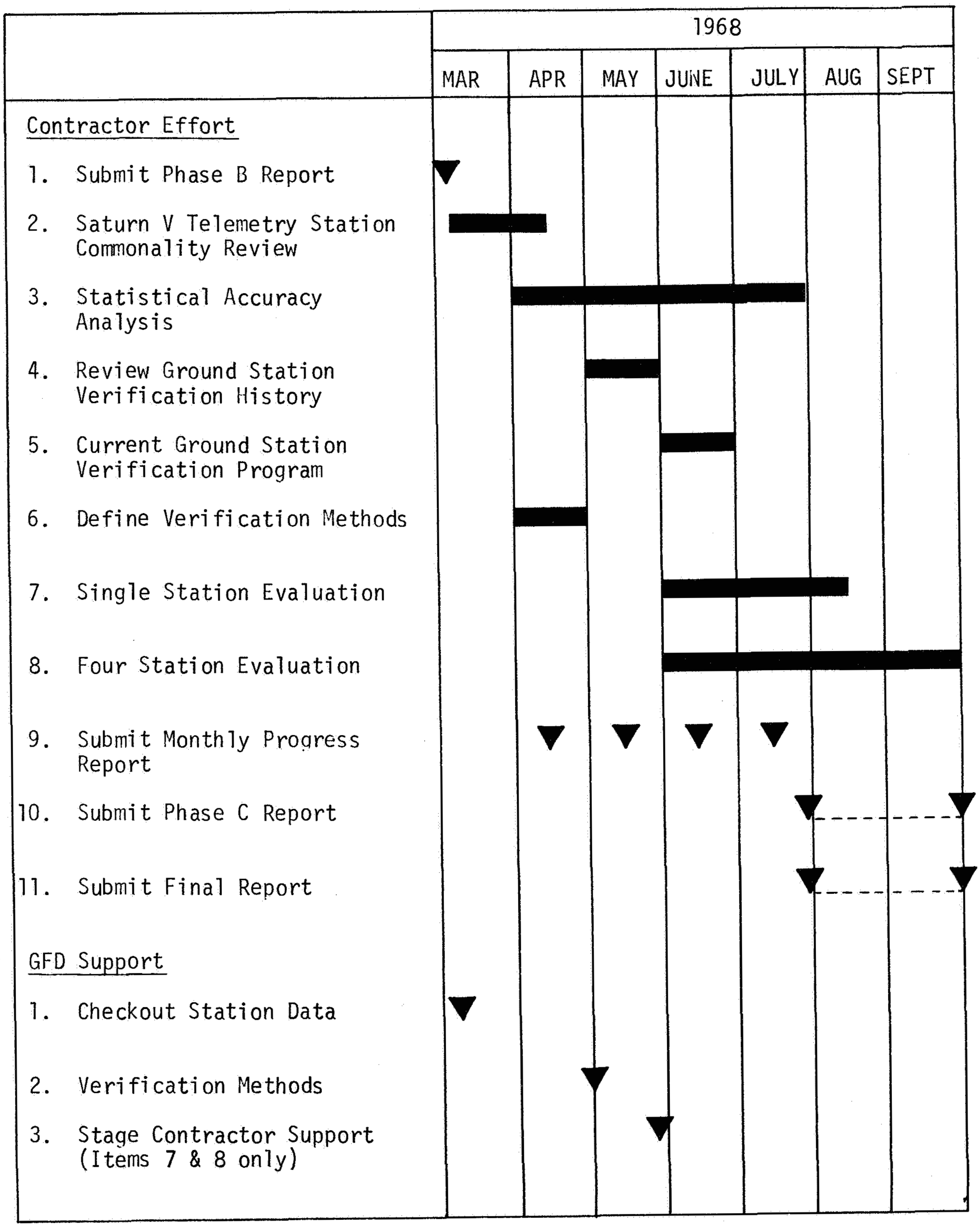


FIGURE 3-1 PHASE C PLAN AND ALTERNATES

3.2.1 (Continued)

operator evaluation or patience, etc. The overall system on which the error analysis is calculated will include all signal paths from the receiver through the demodulators and decommutators but will not include peripheral equipment used for evaluating or displaying the processed data.

For each data link (PCM, PAM and FM/FM) of each selected ground station the operating conditions, assumptions and limitations of both the equipment and operator will be established.

The past and present methods of ground station verification will be studied to determine the methods that were employed to certify it and what method is currently being employed to verify the station accuracy prior to use. Documentation from the S-II, S-IVB and IU stage contractors will be supplied by R-QUAL.

A method of verifying the calculated error of the three data links of each ground station will be defined. This definition will be in the form of a general test procedure listing the test equipment required and the basic method of accomplishing it.

A verification of the calculated error analysis on one ground station is desired. This task, Figure 3-I item 7, definitely cannot be performed with the present funding of this contract. This is due to the lack of a firm commitment as to which station would be used and the amount of cooperation provided by that contractor. If no travel costs and no station operating costs were incurred by The Boeing Company, it would be possible to perform this verification with a modest increase in labor, computer charges and contract extension.

The task documentation will include monthly progress reports and a phase report. All drawings, schedules, diagrams, procedures, specifications, etc. required to perform the task will be included in either the monthly progress reports or the phase report as applicable. Monthly progress reports will be submitted as indicated on Figure 3-1. The Phase C report containing the results of the theoretical error study, the review of station verification history and procedures and a method of verifying station error will be delivered prior to the end of the period of performance.

A final report containing a summary of each of the contract phases will also be provided.

Since the objective for this phase was previously discussed with the Contract Technical Supervisor and due to the ambitious schedule established, work will begin immediately after submittal of this report rather than pending approval of the report recommendations by MSFC.

3.2.2 Telemetry Checkout Station Evaluation

The performance of this task, which is presented as either a single station evaluation or a four station (one per contractor) evaluation on figure 3-1,

3.2.2 (Continued)

tasks 7 and 8, would require more significant additional funding; but, is directly related to the objective of the phase.

The work to be accomplished on each station would be to verify the statistical accuracy analysis through actual station operation. This would include observation of the calibration and maintenance operations as well as the processing of data through all the signal paths; and the analysis of these data for related statistical properties.

If either of the performance verification tasks are desired, the contract funding must be renegotiated to take into account the additional costs due to operating the stations, technician time, travel costs and computer time to analyze the data. If the station is that of a Saturn V contractor other than The Boeing Company, additional negotiation with the supporting contractor will be required to secure the cooperation of that contractor.

3.2.3 Expanded Equipment Accuracy Evaluation

A task outside the scope of this contract is mentioned here primarily for information only. Although, it is consistent with the new objective of Phase C. This task would entail the evaluation of all Saturn V telemetry checkout stations at all locations, from factory, through static firing and prelaunch checkout to determine the level of uniformity in test capability as each stage progresses through the checkout sequence. The task is out of the scope of this contract since: very significant stage contractor support, a large increase in manpower, addition of a rather large computer budget, and a significant increase in travel funds would be required.

As Saturn V Systems Integrator, The Boeing Company performs preflight and postflight evaluations of all Saturn V telemetry links (Task 4.2.7 of the Systems Engineering and Integration Support Contract) for the purpose of evaluating on board telemetry system performance only. During the performance of this evaluation for the first three launch vehicles it became evident that there was a significant difference in the quality of the data acquired by the various checkout stations. As the individual stages progressed through the various checkout stages from post-manufacturing, through static firing and post-static firing tests to the various MILA checkout phases the quality increased. This low quality at post-manufacturing and static test could be due to such factors as: inadequate procedures, differences in the checkout stations, defective or improperly calibrated vehicle hardware, or the fact that the stage is not completely fabricated when the checkout begins. A complete station by station evaluation could determine the expected level of uniformity of data.

If a task of this nature is desired a formal request for proposal should be initiated.

APPENDIX A

UNIFIED S-BAND SYSTEM MANUFACTURERS DATA SHEETS

This Appendix contains data sheets describing the Apollo Command and Service Module Unified S-Band Equipment and associated hardware of the PCM telemetry down-link and data sheets on the Saturn Command and Communications transponder. Data sheets from Collins Radio and Motorola are including.

The inclusion of these specific manufacturers names and data sheets does not constitute an encorsement of any kind, but rather, are included here for completeness and convenience.

The data sheets include descriptions of:

Communication and Data Subsystem	Collins	Page A-2
Apollo PCM Telemetry	Collins	Page A-5
Apollo Pre-Modulation Processor	Collins	Page A-9
Apollo Unified S-Band Equipment	Collins	Page A-15
Apollo S-Band Power Amplifier	Collins	Page A-18
Saturn CCS Transponder	Motorola	Page A-21
Lunar Module Unified S-Band Transponder	Motorola	Page A-23
Apollo Unified S-Band Transponder	Motorola	Page A-25

COLLINS COMMUNICATIONS AND DATA SUBSYSTEM

APOLLO (BLOCK II)

The essential link between spacecraft and earth during NASA's Apollo moon expedition is accomplished by one of the most intricate subsystems aboard the Command Module — the Communications and Data Subsystem.

Through this subsystem pass voice communication, tracking and ranging information, telemetry, television and recovery beacon signals. It is operative throughout all mission phases.

Development of the subsystem challenged existing technology because of mission complexity; multiple system interrelationships; size, weight and power constraints; and the requirement for utmost reliability.

Spacecraft tasks performed by the Communications and Data Subsystem include:

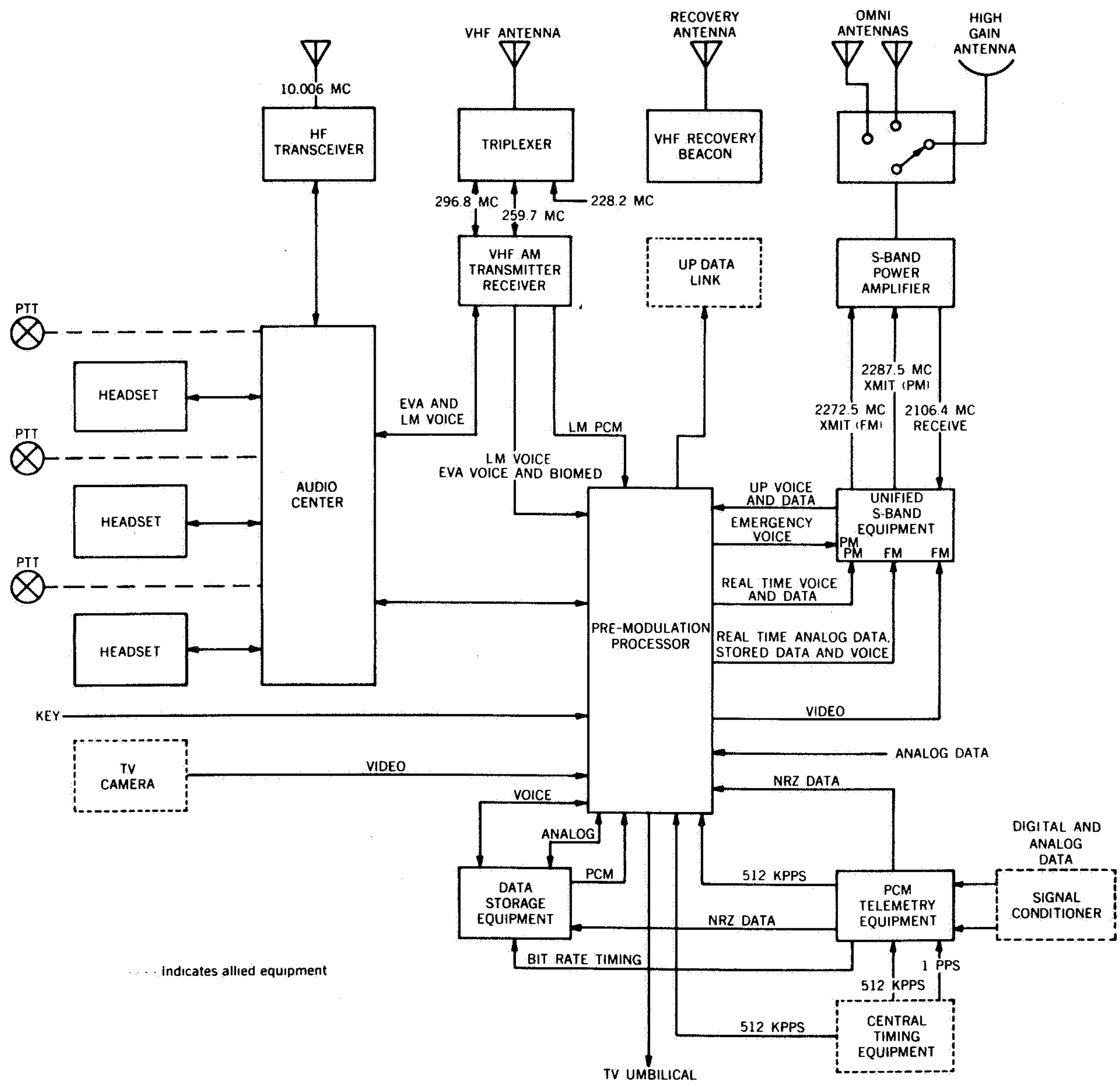
1. Transmission of voice, telemetry and television data from the Command Module to the Manned Space Flight Network on earth.
2. Reception and demodulation of voice transmission from earth.
3. Reception and retransmission of a coded signal from earth, enabling earth stations to derive spacecraft range and velocity.
4. Reception and response to C-band radar signals for tracking during the first earth orbital missions of the program.
5. Data processing to time multiplex, encode and assemble data for transmission to earth.
6. Intercommunication between astronauts.
7. Two-way voice communication between the Command and Service Modules and the Lunar Module (LM) or Extra Vehicular Astronaut (EVA).
8. Relay of voice and data from the LM or EVA to earth.
9. Reception, demodulation, decoding and routing of Manned Space Flight Network digital data for control and updating of spacecraft systems.

Under contract to North American Aviation, Collins is systems manager for the Communications and Data Subsystem, directing the efforts of five subcontractors. In addition to program management and systems planning, engineering and test, Collins is also designing and manufacturing many of the equipment units.

The current Apollo configuration is designated Block II. The earlier configuration, Block I, was produced for the early earth orbital missions. Block II replaces it in later missions leading to the lunar flights.

Basically there are two major differences between the two configurations. The C-Band Transponder is deleted in the Block II subsystem because of the NASA decision to expand the Unified S-Band ground network to provide S-band tracking and communication for near earth as well as deep space phases. An FM Telemetry Transmitter is also eliminated, since this function is now performed by the S-band network.

Secondly, the hardware philosophy has been updated to add redundancy, operational flexibility and reliability and to reduce weight. This has been accomplished by discarding the inflight module replacement concepts of Block I, which required numerous internal connectors and additional support and cooling complexity.



Communications and Data Subsystem Block Diagram

The subsystem units, which are installed in the Command Module's lower equipment bay beneath the astronauts' instrument panel, include:

1. *Audio Center* — Provides each astronaut with a communication link with other crew members. Includes selection, isolation and amplification of audio for all transmitters and receivers.

2. *VHF/AM Transmitter-Receiver* — Dual transmitters and receivers enable simplex or duplex operation. The units provide voice communication between Command Module and earth during near-earth and recovery phases. Also used for Command Module communication with LM and EVA. Data from LM and EVA may also be received over these channels.

3. *HF Transceiver* — Employed for direction finding and voice communication over long ranges during the post landing phase. Operates on single sideband, compatible AM or CW.

4. *VHF Recovery Beacon* — Transmits a VHF direction finding signal to aid recovery forces in locating the Command Module after splash-down.

5. *VHF Triplexer* — Allows up to three VHF Transmitter-Receivers to share a single antenna on the Command Module.

6. *PCM Telemetry* — Receives and samples bio-medical, operational and scientific data — both analog and digital — and converts it to a single serial pulse code modulated output.

7. *Data Storage Equipment* — Data and voice information which cannot be transmitted in real time may be stored in this 14 track (including 4 spares) tape unit for later transmittal. This equipment is especially useful when the spacecraft is behind the moon or when communication to earth is otherwise temporarily interrupted.

8. *Pre-Modulation Processor* — Serves as the central interface between the radio equipment and the audio, data and TV equipment. It selects and multiplexes information for modulation of transmitting equipment. In reception it demodulates and separates the incoming composite signal, and routes the information to the proper equipment.

9. *Unified S-Band Equipment* — Combines voice and data communication, tracking, ranging and telemetry on a unified RF system. Includes two phase locked transponders and one FM transmitter. The Unified S-Band Equipment is employed in duplex operation throughout the flight phases, providing the sole communications link after the spacecraft leaves the vicinity of the earth.

10. *S-Band Power Amplifier* — Amplifies the signal from the Unified S-Band Equipment to provide the necessary communication power during translunar coast and lunar operations. Two selectable power output levels are available from two selectable power amplifiers.

Pulse Code Modulation Telemetry Equipment

APOLLO (BLOCK II)

51.2 kilobits per second serial NRZ output is provided, derived from parallel analog, parallel digital and serial digital inputs.

Reduced format of 1600 bits per second may be selected to conserve transmission bandwidth.

High reliability *is obtained by block and quad redundancy,* fail-safe and majority logic circuit design.

The Apollo Block II Pulse Code Modulation (PCM) Telemetry Equipment receives and samples analog and digital spacecraft data, converting it to a single serial PCM output. It provides two fixed programs for sampling rate and sequence which supplies a non-return-to-zero (NRZ) PCM output of either 51,200 or 1600 bits per second.

The system is switched externally to "NORMAL" or "REDUCED" format. Data output in the NORMAL mode is 51.2 kbps in the form of 6400 8-bit words per second. Input data consists of 365 high level (0-5 v) analog inputs, 304 parallel digital inputs and one 40-bit serial digital input word. A 32-bit sync/ID word and an 8-bit format identification word is generated inside the PCM Telemetry Equipment.

The data output in the REDUCED mode is 1.600 kbps in the form of 200 8-bit words per second. Input data for this operating mode consists of 100 high level (0-5 v) analog inputs, 288 parallel digital inputs, and one 40-bit serial digital input word. Internally generated words are of the same type as those generated for the NORMAL operating mode. These inputs are sampled at various rates from 0 to 200 samples per second.

The system is designed as a high level system; however, it will synchronize and accept data from an external low level (0-40 mv) subsystem. The necessary timing signals required to operate the low level amplifier and multiplexer circuitry are generated in the high level telemetry unit. Fifty 1 sps low level channels are multiplexed in the external unit and fed to the high level unit as a 50 pps high level pulse amplitude modulation (PAM) input.

Equipment Description

The programmer contains the basic timing and control circuits for controlling the sequence of analog signal multiplexing, coding digital data multiplexing, controlling external data sources (serial digital data), and transferring data from the PCM system.

The basic subsections of the programmer are the oscillator, counters (period, bit, word and frame), and prime and sub-prime matrices. Normally, an external 512 kc input signal is used as the system clock. If this signal is absent, detection circuitry in the PCM switches the timing source to an internal clock (this is returned to the external timing upon return of the external 512 kc clock).

When the PCM is using the external clock, a 1 pps external signal is used to synchronize the programmer counters. The 1 pps signal is inhibited when using the internal clock. Counters and matrices within the programmer permit the forming of various time interval combinations required to provide the specific format and program sequencing commands required by the PCM and external equipment.

Format change from NORMAL to REDUCED mode is accomplished in the programmer by the activation of a switch to ground external to the PCM system. No data is lost during the transition between formats.

The analog multiplexer is used to sequentially sample a number of transducers into a fixed format. Each input is a single-ended 0-5 v signal. A typical gate consists of five channel gates fed to a sequencer gate. The sequencer gate is used for further multiplexing, for reduction of capacitance, and to prevent the failure of one channel gate from degrading more than five channels.

The outputs of the sequencer gates are further multiplexed into three quad-redundant high speed gates. The use of the high speed gates also reduces wiring capacitance and simplifies the timing requirements.

The outputs of the high speed gates are routed to the sample and hold circuitry. To achieve a high input impedance to the transducers and to minimize the droop on the charging capacitor, unity gain buffer amplifiers preceed and follow the sample and hold capacitor.

The output of the sample and hold circuitry is then fed to a half-split type analog-to-digital converter. The analog-to-digital conversion is accomplished by eight successive comparisons providing an 8-bit output to the digital multiplexer. With a zero volt input the converter generates the binary equivalent of the decimal one (00000001). The code is increased by a binary equivalent of a decimal one for each 19.7 millivolts of input voltage up to 4.98 volts, which produces a binary equivalent of decimal 254 (11111110). All input levels below zero volt will produce a binary code of 00000001, and all input levels above 4.98 volts will produce a binary code of 11111110.

The function of the digital multiplexer is to sample each parallel digital channel in the sequence determined by the programmer. The sampled 8-bit parallel digital word is read into the output register each time its digital multiplexer gate is enabled.

The eight parallel bit words, from the digital multiplexers, and serial data binary inputs, from an external source, are received by the output shift register. The output register converts the serial and parallel data into an NRZ and RZ form synchronous with the system bit rate. NRZ data is used for the spacecraft output and RZ is used for checkout of the telemetry system by ground support equipment (GSE).

Data transfer buffers are provided to supply redundant and nonredundant system outputs having specified characteristics. These signals consist of serial data control pulses, GSE data and timing signals, and spacecraft data and timing signals. All GSE drivers are transformer isolated and are powered by an external dc source to reduce power consumption during flight.

A calibrator is included in the PCM telemetry equipment. This calibrator provides precision voltages ($\pm 0.2\%$) which may be routed to other spacecraft equipment or reinserted into the PCM system for checking the coding of the PCM analog channels.

Reliability and Quality Assurance

The probability of the PCM Telemetry Equipment performing successfully for 200 hours of operation is required to be R=0.9997. The numerical reliability shall be met with a loss of no more than five analog channels and eight digital bits. To achieve this reliability, various combinations of quad redundancy, block redundancy, majority logic and fail-safe logic were used in the PCM design.

Parts and material have been selected and tested to ensure the highest practical equipment reliability. Circuit performance has been assured by extensive electrical and environmental testing and by the use of analysis techniques such as failure effect evaluation, parameter variation analysis, and stress analysis.

Equipment is qualification tested for manned space flight.

The Communications and Data Subsystem for the Apollo Spacecraft was designed and developed by the Collins Radio Company under contract for North American Aviation, Space and Information Systems Division. As Subsystem Manager, Collins Radio established all equipment specifications for both Collins developed and subcontracted equipments, coordinated all technical, reliability, quality, documentation and fiscal requirements to ensure a complete, well integrated system. The PCM Telemetry Equipment was designed, developed and manufactured under Collins direction by Radiation, Inc., Melbourne, Florida.

Specifications

Electrical Specifications

POWER:

Input voltage — 115/200 v, 3 phase, 400 cps; 11 v dc source for GSE drivers. Input power — 21 watts maximum for 115 v; 2.2 watts peak for dc source.

INPUT SIGNALS:

Analog data channels — 365 (0-5 v). Digital parallel data — 304 (bits). Digital serial data — one 40-bit word. Timing signals — 512 kc clock, 1 pps synchronization pulse.

SPACECRAFT OUTPUTS:

Digital Serial Data Control Pulses

Bit Sync — 51.2 kbps in NORMAL, 1.6 kbps in REDUCED.

Start Pulse — 50 pps in NORMAL, 10 pps in REDUCED.

Stop Pulse — 50 pps in NORMAL, 10 pps in REDUCED.

Serial Data

2 non-return-to-zero (NRZ-C).

Data Rate Timing

51,200 pps in NORMAL, 1,600 pps in REDUCED; in phase with NRZ outputs.

Subcarrier Reference

512,000 pps.

Data Rate Indicator

Positive voltage indicates NORMAL format. Zero voltage indicates REDUCED format.

GROUND EQUIPMENT CHECKOUT OUTPUTS:

Serial Data — Return-to-Zero (RZ). Data Rate Timing — 51,200 pps in NORMAL, 1,600 pps in REDUCED in phase with RZ output. Subcarrier Reference — 512,000 pps. Subframe Rate Timing — 1 pps. Test Points — all test points are made accessible.

PROGRAMMING:

Format — fixed format for NORMAL (51.2 kbps) and REDUCED (1.6 kbps). Format Selection — controlled by an external switch (not a part of PCM). Synchronization Code — 32 bits (last 6 bits are frame identification). Format Identification — special 8-bit word inserted once per second.

Environmental Specifications

VIBRATION:

Non-destructive (not required to meet above specifications) — 10-70 cps, linear increase from 0.008 g^2/cps to 0.06 g^2/cps; 70-2000 cps, 0.06 g^2/cps. Operating — 10-70 cps, linear increase from 0.002 g^2/cps to 0.015 g^2/cps; 70-2000 cps, 0.015 g^2/cps.

VACUUM:

1 x 10^{-4} mm Hg for 100 hour period.

TEMPERATURE:

0° F (base temperature 35° F); 150° F (base temperature 118° F); 140° F with no base coolant for a period of 15 minutes, capable of withstanding non-operating exposure from −45° F to +150° F.

ACCELERATION:

20 g acceleration for 5 minutes in each of three axes.

Mechanical Specifications

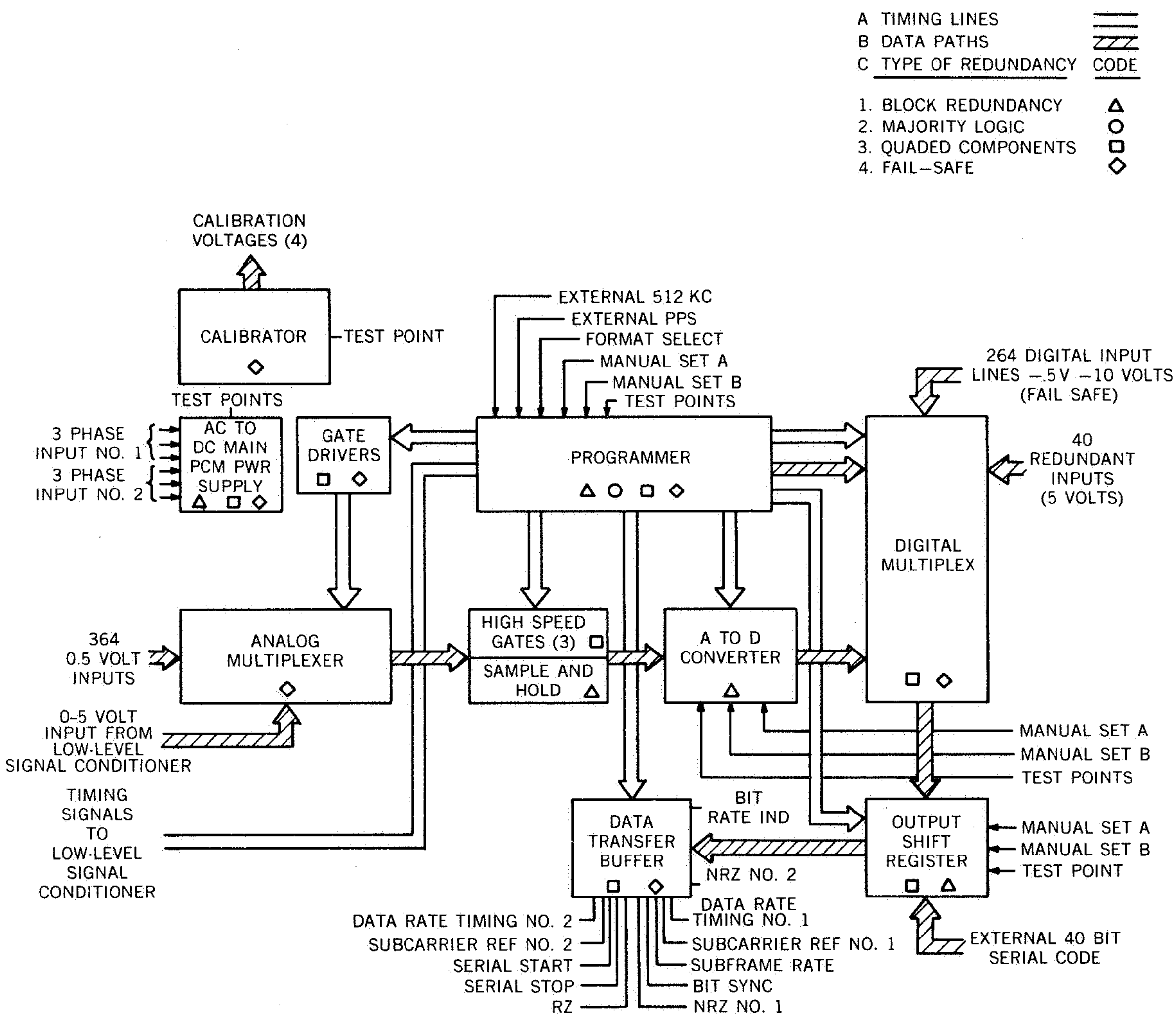
SIZE:

13.3" W, 7.0" H, 14.2" D (33.78 cm W, 17.78 cm H, 36.07 cm D).

WEIGHT:

44 lbs. (19.9 kg).

Specifications subject to change without notice.



Pulse Code Modulation Telemetry Equipment Block Diagram

Pre-Modulation Processor

APOLLO (BLOCK II)

Modular construction permits broad modification of mission and communication capabilities without extensive system changes.

High reliability is obtained by solid state design, generous component derating, and use of redundant, simplified circuitry.

Emergency communication capability is provided by switching signal processing circuits for voice and/or by keying the 512 kc clock input.

Low power consumption results from energizing only the circuits required for the selected transmission mode and by use of solid state active circuitry.

The Apollo Pre-Modulation Processor (PMP) provides the signal processing and interfaces between the voice, data and recording equipment and the RF transmitting and receiving equipment.

Because it combines in a single package several functions usually common to several spacecraft equipment units, the Pre-Modulation Processor permits broad modification of mission data transmission and communication capabilities without extensive modification of the interface equipment. Its modular construction enhances this capability by permitting substitution of new modules for functions which may be required.

Equipment Description

The PMP performs the following functions:

1. *NORMAL OPERATING MODES (DOWN LINK — PM)*

The following signal processing is performed prior to PM transmission via the Unified S-Band Equipment (USBE):

(a) *CM Voice Signal Processing*
Provides pre-emphasis, clipping, filtering and mode switching of real time Command Module (CM) voice which frequency modulates a 1250 kc subcarrier. Filtering and associated switching is performed to band limit the signal when time sharing with the Extra Vehicular Astronaut (EVA) signal to prevent interference with the EVA biomedical data.

(b) *LM/EVA Signal Processing*
Provides automatic gain control (AGC), over a wide dynamic range, of voice signals received from the Lunar Module (LM) or voice and bio-medical signals from the EVA.

(c) *Down Voice Relay and Conference Capability*
Provides for voice relay and conference capability by linearly mixing (time sharing) real time CM voice, LM voice or EVA voice and bio-medical data for frequency modulation of a 1250 kc subcarrier. Mode switching is provided to allow for transmission of real time LM/EVA signals only in the RELAY mode and to provide for filtering the CM voice signal in the RELAY/EVA mode to prevent interference with the EVA bio-medical data.

(d) *CM PCM Telemetry (Real Time — Normal)*
Provides biphase modulation of a 1024 kc subcarrier by real time, high or low rate, CM Pulse Code Modulation (PCM) data.

(e) *Voice and CM PCM Telemetry Multiplexing*
Provides mode switching and frequency multiplexing of the PCM telemetry signal (1024 kc subcarrier) and the voice/bio-medical signal (1250 kc subcarrier) for PM transmission via the USBE.

2. *NORMAL OPERATING MODES (DOWN LINK — FM)*

The following signal processing is performed prior to baseband FM transmission via the USBE. All data or voice signals transmitted via FM are recorded signals played back from the Data Storage Equipment (DSE), except for scientific data which can be transmitted in real time.

(a) *INTERCOM/LM Voice to DSE*
Provides for linear mixing (time share) of real time INTERCOM and LM voice signals to be recorded. Wide range AGC of the LM voice signal controls the level. Mode switching permits only the mixing of LM, but not EVA, voice signals with INTERCOM voice for recording.

(b) *LM PCM Channel to DSE*
Provides limiting circuitry to process LM PCM data (1.6 kbps) to be recorded.

(c) *Analog Telemetry to DSE (Switching)*
Provides switching of real time analog scientific data signals to be recorded or to frequency modulate a subcarrier oscillator (SCO) in real time. Three such channels are provided. The three subcarriers, which are generated in the

PMP equipment, are 95 kc, 125 kc and 165 kc.

(d) *CM PCM Telemetry (Recorded — Auxiliary)*
Provides PCM telemetry by biphase modulation of a second 1024 kc subcarrier with recorded CM PCM data. The PCM data is either high bit rate (51.2 kbps) at a playback/record ratio of one or low bit rate recorded at 1.6 kbps and a playback/record ratio of 32.

(e) *FM Channel Multiplexing*
Provides mode switching and frequency multiplexing of recorded signals for baseband FM transmission via the USBE for each of the following combinations:

TAPE/PCM ANALOG MODE
Recorded INTERCOM/LM voice (32:1 playback); three channels of analog telemetry with recorded scientific data frequency modulated on subcarriers of 95 kc, 125 kc and 165 kc; and recorded CM PCM telemetry (51.2 kbps) on a 1024 kc subscriber.

TAPE/LM PCM MODE
Recorded LM PCM data only. The LM PCM data is recorded at 1.6 kbps and transmitted baseband FM via the USBE at a playback to record ratio of 32.

SCIENTIFIC DATA MODE
Three channel analog telemetry with real time scientific data frequency modulated on subcarriers of 95 kc, 125 kc and 165 kc.

(f) *Television Channel*
Provides a hard-wire channel through the PMP of a video signal from a television camera for FM transmission via the USBE. An output is provided, through isolation circuitry, to the spacecraft umbilical for pre-launch monitoring.

3. *BACK UP MODES (DOWN LINK — PM)*

(a) *CM Voice Channel*
Provides pre-emphasis, clipping and mode switching of real time CM voice for baseband PM transmission via USBE. Mode switching is performed such that Normal and Back Up CM voice cannot be transmitted simultaneously. Mode switching provides for changing the Back Up CM voice level and resulting PM modulation index as a function of the CM PCM data rate.

(b) *CM PCM Telemetry Channel*
Redundant, identical biphase modulators and associated mode switching circuitry provides for modulation of either modulator with CM PCM data (1024 kc subcarrier) for PM transmission via the USBE.

(c) *Emergency Key and Sidetone*
Provides for keying the 512 kc subcarrier for PM transmission via the USBE. The 512 kc signal is derived by amplifying and filtering the Central Timing Equipment (CTE) clock input and providing it as an output whenever the KEY mode is selected and the Emergency Key is depressed. A 400 cps sidetone signal is also provided at this time as an audible tone to the astronaut headset.

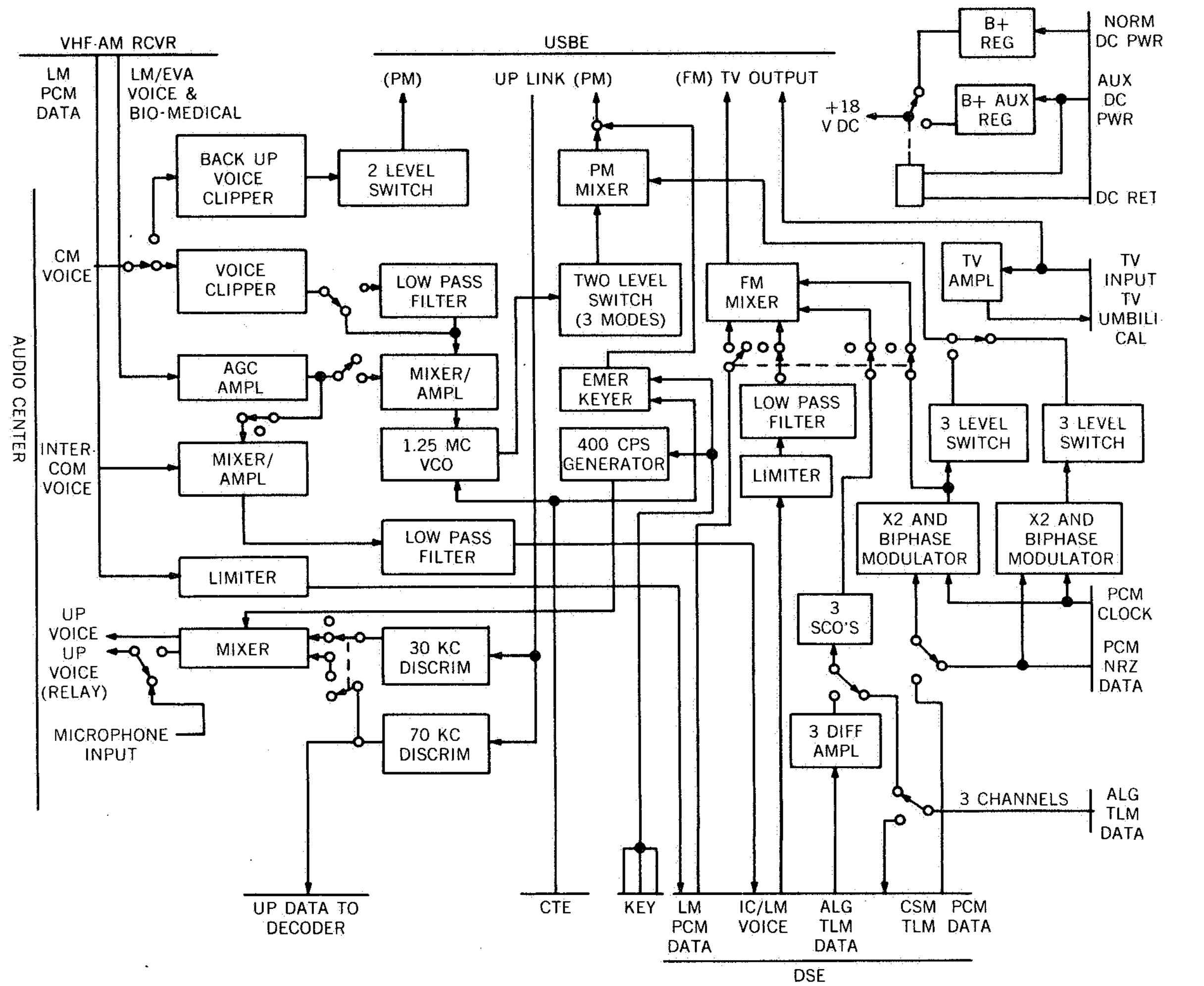
4. *NORMAL OPERATING MODES (UP — LINK)*

(a) *Normal Up Voice and Up Data Detection*
Provides separation and detection of a multiplexed up link signal consisting of a 30 kc subcarrier, frequency modulated with voice, and a 70 kc subcarrier, frequency modulated with data.

(b) *Up Voice Relay*
Provides for relay of detected up voice for re-transmission to LM via the VHF/AM Transmitter. When not in the RELAY mode (VOICE mode) a microphone input is conducted through the PMP to the Audio Center equipment.

5. *BACK UP OPERATING MODES (UP — LINK)*
Provides for mode switching and back up detection of up voice using the 70 kc up data detector. Relay of back up voice is provided when the RELAY mode is selected. In the VOICE mode the microphone input is again conducted through the PMP to the Audio Center equipment.

6. *POWER SUPPLY REGULATOR OPERATION AND SWITCHING*
The PMP contains two identical, switchable power supply regulators which operate from an input of +28 v dc and provide an 18 ±0.18 v dc output to power all active circuitry including mode switching, except for the relay required to switch regulators in the AUXILIARY mode. This relay operates from the primary +28 v dc input. All other mode switching is performed using the regulated 18 v dc output which is conducted to the Communication Control Panel, switched through appropriate mode control switches, and conducted back to the PMP to operate relays or power active mode switching circuitry.



Pre-Modulation Processor Block Diagram.

Reliability and Quality Assurance

High reliability is achieved through use of high reliability components which are qualified to rigid Apollo requirements, generous component derating, use of solid state proven circuitry, and incorporation of circuit redundancy for several functions. High reliability has been demonstrated by successful qualification testing to the rigid requirements of the Apollo program.

The predicted probability of success ranges from R=0.999702 to R=0.999999 for the several functions described for this equipment. These probabilities of success relate to the specified mission times which range up to 214 hours.

Equipment is qualification tested for manned space flight.

The Communications and Data Subsystem for the Apollo Spacecraft was designed and developed by Collins Radio Company under contract for North American Aviation, Space and Information Systems Division. As Subsystem Manager, Collins Radio established all equipment specifications for both Collins developed and subcontracted equipments and coordinated all technical, reliability, quality, documentation and fiscal requirements to ensure a complete, well integrated system. The Pre-Modulation Processor was designed, developed and manufactured by Collins.

Specifications

Electrical Specifications

INPUT POWER:

12.5 watts maximum, from a source of 24-30 v dc.

CM VOICE CHANNEL:

Input Impedance — 600 ohms ±20% balanced (audio input) 100 ohms ±10% (CTE clock input).

Input Signal — Voice to a maximum level of 5 v p-p.

Signal Processing — Pre-emphasis, 6 db/octave; clipping, 0 db nominal for NORMAL mode and 12 db nominal for BACK UP mode at 1 kc and 2.2 v p-p input.

Minimum Bandwidth — After correction for pre-emphasis EVA mode, 300 cps to 2.3 kc (4 db); NOT EVA mode, 300 cps to 3 kc (4 db); BACK UP mode, 300 cps to 2.3 kc (3 db).

Deviation Sensitivity — EVA mode, 3.63 kc/v below clipping; NOT EVA mode, 6.82 kc/v below clipping; BACK UP mode, N/A (baseband PM).

Distortion — Below clipping, less than 8% for the detected audio signal; BACK UP mode, less than 3%.

S/N Ratio — 26 db minimum at a nominal 2.2 v p-p input.

LM/EVA CHANNEL:

Input Impedance — 5,000-10,000 ohms balanced.

Input Signal — Voice/data from 0.11 to 9.0 v p-p.

Signal Processing – AGC to 3 db over a 38 db range.

Minimum Bandwidth (2 db) — 300 cps to 13 kc.

Deviation — 8.55 kc, nominal peak deviation.

Distortion — Less than 6% for the detected signal.

S/N Ratio — 32 db minimum.

INTERCOM VOICE CHANNEL (RECORD):

Input Impedance — 9,400-15,000 ohms balanced.

Input Signal — Voice to a maximum level of 5 v p-p.

Signal Processing — Isolation; insertion loss, 0-6 db.

Minimum Bandwidth (2 db) — 300 cps to 2.3 kc.

Distortion — Less than 6%.

INTERCOM/LM VOICE CHANNEL (PLAYBACK):

Input Impedance – 10,000 ohms minimum, balanced.

Input Signal — Voice to a maximum level of 6 v p-p.

Signal Processing — Peak clipping, 0 db nominal for a 1.5 v p-p input. Insertion loss below clipping is 18 db nominal.

Bandwidth (1 db) — 300 cps to 73.6 kc.

Distortion (below clipping) — Less than 5%.

S/N Ratio — 30 db, minimum at 6 v p-p input.

CM PCM TELEMETRY CHANNEL (NORMAL AND AUXILIARY):

Input Impedance — 9,000-50,000 ohms (data input); 10,000 ohms minimum (clock input).

Input Signal — PCM NRZ data, 0-6 v, up to 51.2 kbps.

Signal Processing — Biphase modulation of a 1024 kc subcarrier.

PCM Clock Signal — 512 kc square wave at 6.0 v p-p.

Bandwidth (3 db) – 150 kc, nominal, centered about 1024 kc.

LM PCM CHANNEL (RECORD):

Input Impedance — 5,000-10,000 ohms balanced.

Input Signal — Split bit PCM NRZ data at 1.6 kbps and 0.14 to 8.77 v p-p.

Signal Processing — Symmetrical limiting to an output level of 4-5 v p-p open circuit.

Minimum Bandwidth (1 db) — 600 cps to 2.8 kc below 1 limiting.

S/N Ratio — 30 db minimum, at limiting threshold.

LM PCM CHANNEL (PLAYBACK):

Input Impedance — 10,000 ohms minimum, balanced.

Input Signal — Split bit PCM NRZ data at 51.2 kbps to a maximum level of 6.3 v p-p.

Signal Processing — Isolation; insertion loss, 22.8-24.6 db.

Bandwidth — Flat to 1 db from 15 kc to 90 kc.

Distortion – Less than 2%.

S/N Ratio — 30 db minimum, at maximum input.

SCIENTIFIC DATA CHANNEL — THREE CHANNELS (REAL TIME):

Input Impedance — 300,000 ohms minimum.

Input Signal — Analog input from 0 to 5 v.

Signal Processing — Frequency modulation of a subcarrier at 95 kc, 125 kc and 165 kc.

Subcarrier Frequency Stability — ±0.15% of center frequency.

Linearity — Deviation from best straight line is less than 0.15% of center frequency.

Deviation Sensitivity — 3% of center frequency per volt.

Minimum Bandwidth (2 db) — DC to 3% of center frequency.

S/N Ratio and Crosstalk — 30 db, minimum (detected signal) for maximum input.

SCIENTIFIC DATA — THREE CHANNELS (PLAYBACK):

Input Impedance – 10,000 ohms minimum, balanced.

Input Signal — AC to a maximum of 8 v p-p.

Signal Processing — Frequency modulation of a subcarrier at 95 kc, 125 kc and 165 kc.

Subcarrier Frequency Stability — ±0.45% of center frequency.

Minimum Bandwidth (2 db) — 12.5 cps to 3% of center frequency.

Deviation Sensitivity — 1.86% of center frequency per volt.

Distortion — Less than 4.5% at maximum input.

S/N Ratio and Crosstalk — 30 db minimum (detected signal) for 5 v p-p input.

TV CHANNEL — HARD WIRED THROUGH THE PMP:

Insertion Loss — Less than 0.5 db.

Minimum Bandwidth (0.5 db) — DC to 500 kc.

TV UMBILICAL CHANNEL:

Input Impedance – Determined by TV channel load impedance.

Input Signal — Unipolar to a level of 1.9 v p-p.

Signal Processing — Isolation: Insertion loss, 0-5.6 db across 100 ohm load.

Minimum Bandwidth (3 db) — 10 cps to 500 kc.

UP VOICE CHANNEL:

Input Impedance — 5,000 ohms minimum, balanced over band from 20 kc to 40 kc.

Input Signal — Multiplexed voice and data subcarriers. FM voice subcarrier at 30 kc from 0.4 to 17 v p-p; 7.5 kc maximum deviation.

Signal Processing — FM detection and mode switching for NORMAL, RELAY and BACK UP VOICE.

Minimum Bandwidth (2 db) — 300 cps to 3 kc.

Limiting — Greater than 10 db at minimum input.

Distortion — Less than 7% for maximum deviation.

S/N Ratio – 35 db minimum, for maximum deviation.

UP DATA CHANNEL:

Input Impedance — 5,000 ohms minimum, balanced over band from 60 kc to 80 kc.

Input Signal — Multiplexed voice and data subcarriers. FM data subcarrier at 70 kc from 0.4 to 17 v p-p; 5 kc peak deviation (7.5 kc for back up voice).

Signal Processing — FM detection and mode switching for UP DATA and BACK UP VOICE.

Limiting — Greater than 10 db at minimum input.

Time Delay — Constant to within 20 microseconds.

Linearity — 2% of full scale from best straight line up to peak deviation of 5 kc.

Minimum Bandwidth (3 db) — 300 cps to 4 kc.

S/N Ratio — 30 db minimum, for 5 kc peak deviation.

MICROPHONE CHANNEL:
Output directly connected to input through switchable relay contacts.

EMERGENCY KEY CHANNEL:
Input Impedance (CTE Clock) — 100 ohms ±10%.
Input Signal — 512 kc square wave, unipolar, 3 v p-p.
Signal Processing — Mode switching and on-off keying of the filtered 512 kc subcarrier. Insertion loss, 2.9-3.7 db for keyed signal.

OUTPUT IMPEDANCES:
PM Channel — 110 ohms maximum.
FM Channel — 150 ohms maximum.
Back Up CM Voice Channel — 600 ohms ±20% balanced.
TV Channel — 100 ohms ±5%.
TV Umbilical Channel — 100 ohms ±5%.
Intercom LM Voice (Record) — 600 ohms ±20% balanced.
LM PCM (Record) — 600 ohms ±20% balanced.
Scientific Data (Record) — Equal to scientific data source impedance.
Up Voice Channel – 600 ohms ±20% balanced.
Microphone/Up Voice Relay Channel — Relay, 600 ohms ±20% balanced. Microphone, equal to microphone source impedance.
Up Data Channel — 600 ohms ±20% balanced.

OUTPUT LEVELS:
PM (Unmodulated subcarriers) —

MODE	*PCM TLM*	*VOICE*
PCM/HI RATE/VOICE	2.52 v p-p ±5%	1.46 v p-p ±5%
PCM/LO RATE/VOICE	1.46 v p-p ±5%	2.52 v p-p ±5%
PCM only	3.40 v p-p ±5%	
VOICE only		2.52 v p-p ±5%
BACK UP CM VOICE/PCM	2.52 v p-p ±5%	

UP VOICE — Normal, 0.8 ±0.07 v rms into 18,000 ohms. Relay, 0.707 v rms ±3 db into 600 ohms. Back up, 0.8 ±0.07 v rms into 18,000 ohms.
UP DATA — 0.99 v rms ±10% into 600 ohms.

Environmental Specifications

RANDOM VIBRATION:
10-70 cps — Linear increase in level from 0.0025 g^2/cps to 0.0187 g^2/cps (linear refers to a straight line plotted on log-log paper). 70-2000 cps — Constant at 0.0187 g^2/cps.

THERMAL:
Continuous operation with average coldplate temperature of +118° F. Equipment subjected to transient reentry simulation with no coolant flow in coldplate for 15 minutes.

VACUUM:
100 hours at 1 x 10^{-4} mm Hg.

SHOCK:
78 g, 11 millisecond pulse (non-operation).

Mechanical Specifications

ENVELOPE SIZE:
4.69" W, 5.977" H, 10.58" D (11.91 cm W, 15.18 cm H, 26.87 cm D) maximum.

WEIGHT:
11.3 lbs. (5.12 kg) maximum.

Specifications subject to change without notice.

FM (Unmodulated subcarriers) —

MODE	*PCM TLM*	*SCIENTIFIC SUBCARRIERS (Each)*		
		95 kc	*125 kc*	*165 kc*
TAPE/PCM ALG	1.2 v p-p ±5%	0.15 v p-p ±8%	0.22 v p-p ±8%	0.34 v p-p ±8%
SCIENTIFIC	None	0.15 v p-p ±8%	0.22 v p-p ±8%	0.34 v p-p ±8%

Unified S-Band Equipment

APOLLO (BLOCK II)

Unified S-band system combines voice and data communication, tracking, ranging and telemetry on a single radio frequency in the S-band range.

Dual transponders, either one of which can operate simultaneously with a frequency modulated transmitter, offer operational flexibility and redundancy.

Compact construction enables packaging of both transponders and the frequency modulated transmitter in a single, gasket-sealed, machined-aluminum case, with hermetically sealed connectors.

Phase locked transponders generate their transmission frequency coherently with the received signal, or, when the phase lock loop is not closed, utilize an auxiliary oscillator.

The Unified S-Band Equipment is utilized for a primary communications link in space communications systems. This highly versatile unit provides a completely redundant transponder and simultaneous FM transmitter capabilities in the S-band frequency range.

When this unit is used in conjunction with Collins' Pre-Modulation Processor (which performs the functions of subcarrier generation, modulation, mixing and detection), it is capable of simultaneously performing many communication functions which ordinarily would require separate receivers and transmitters.

The transponder receives and coherently detects a phase modulated carrier and transmits a phase modulated carrier coherently related to the received carrier. When no receive frequency is present, the transponder transmits a phase modulated carrier generated from an auxiliary oscillator.

Coherent detection and turnaround circuitry allows reception and retransmission of ranging signals in the PM modes. With proper design of the modulation, subcarrier channels may be received and transmitted simultaneously with the ranging channels. These subcarriers in turn may be modulated with voice or both digital and analog data. The down-link carrier also has baseband modulation capability.

The FM transmitter provides the capability of frequency modulation for transmitting voice or analog and digital information via subcarriers or wideband information such as television.

Equipment Description

The receiver accepts a 2106.4 mc phase modulated signal and converts it to a frequency of 9.5 mc at the output of the second mixer.

A narrowband amplifier provides the input to the receiver phase-lock loop which in turn generates the reference signal for conversion of the IF spectrum to baseband and coherent AGC control of the first IF amplifier. The coherent amplitude detector has an output that is sent to the antenna mechanism for tracking purposes.

The output of the second mixer is also fed through a wideband amplifier and limiter and mixed with the reference signal in the phase detector. An output from the detector is provided for extraction of the up-link information, including undetected subcarriers if present. The ranging signal, if present, is sent to the phase modulator for retransmission.

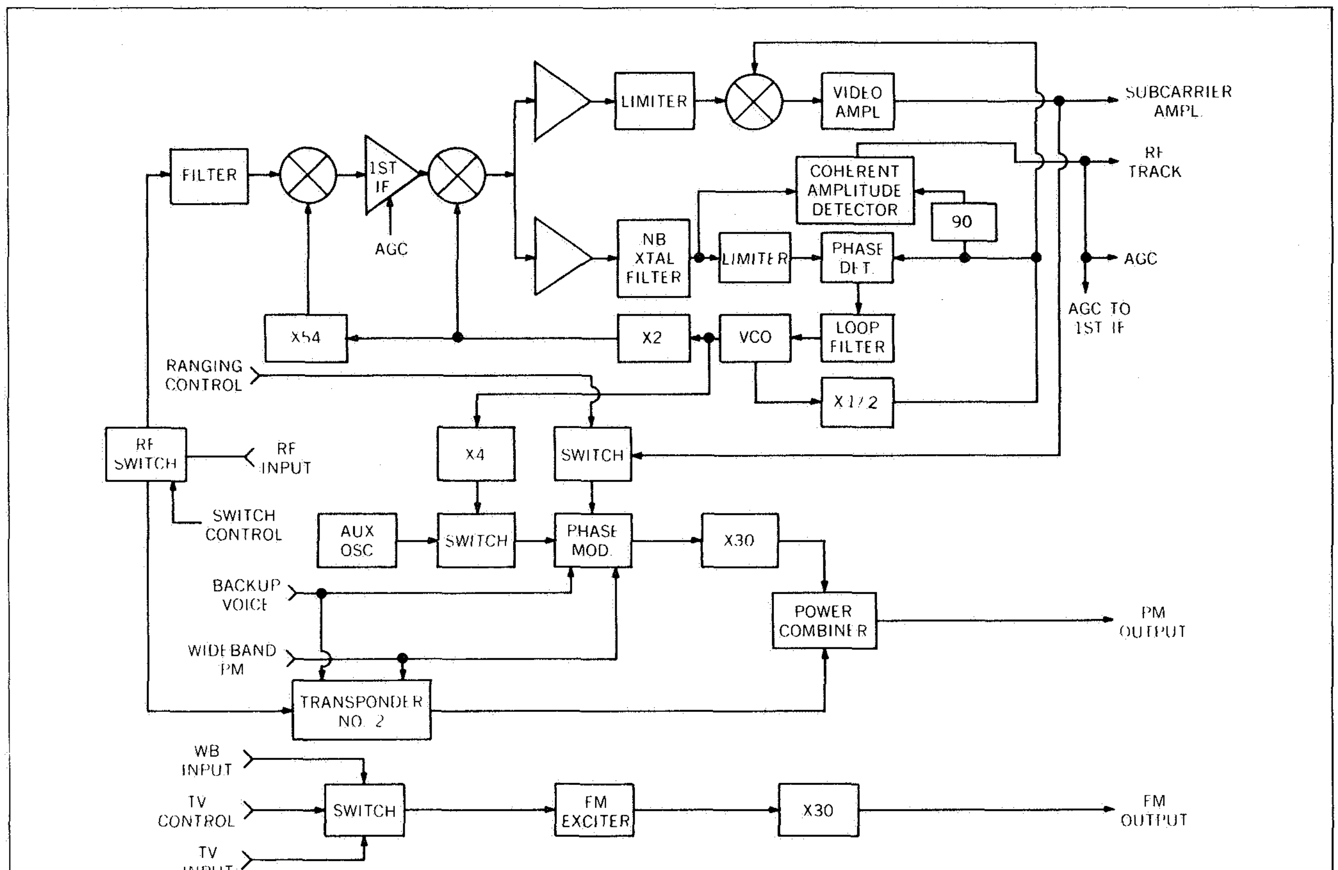
The transponder down-link carrier is derived from the coherent voltage controlled oscillator, or from the auxiliary oscillator. The phase modulator combines the wideband (subcarrier), ranging turnaround, and voice modulation inputs and phase modulates the carrier. The phase modulator's output is then connected to the transmitter amplifiers and multipliers.

Both transponders are connected to a power combiner, eliminating the necessity of RF switching between units.

The FM transmitter operates simultaneously with the PM transponder. The FM exciter has two modulation inputs — either a wideband input (subcarriers and analog or digital data) or an offset TV input. The FM exciter connects to the transmitter amplifier and frequency multiplier and an isolation network.

Reliability and Quality Assurance

The probability of success for the dual transponder and FM transmitter for 200 hours of operation in the Apollo mission is R=0.999965 for the transponder and R=0.997998 for the FM transmitter. Parts and material have been selected



Unified S-Band Equipment Block Diagram.

and carefully tested to ensure high reliability, and reliable circuit performance has been assured by extensive electrical and environmental testing and analysis techniques such as failure effect evaluation and parts stress analysis.

This equipment is developed to a quality assurance program incorporating the provisions of NASA Quality Publication NPC 200-2, Quality Assurance Provisions for Space Systems Contractors.

Equipment is qualification tested for manned space flight.

The Communications and Data Subsystem for the Apollo spacecraft was designed and developed by Collins Radio Company under contract for North American Aviation, Space and Information Systems Division. As Subsystem Manager, Collins established all equipment specifications for both Collins developed and subcontracted equipment, coordinated all technical, reliability, quality, documentation and fiscal requirements to ensure a complete, well integrated system. The Unified S-Band Equipment was designed, developed and manufactured under Collins direction by Motorola Aerospace Center, Scottsdale, Arizona

Specifications

Electrical Specifications

POWER SOURCE:
3 phase, 115 v ac, 400 cps and +28 v dc.

INPUT POWER:
Less than 34 watts ac and 2.4 watts dc.

Receiver (double heterodyne, phase lock loop)

FREQUENCY:
2106.40625 mc.

VCO STABILITY:
±0.002%.

TRACKING THRESHOLD:
Less than −157 dbw (nominally −165 dbw).

DYNAMIC RANGE:
To 76 db above threshold.

ACQUISITION RANGE:
Capable of acquiring when the received frequency is swept at a rate of 35 kcps/s or less out of ±90 kc at −144 dbw.

RANGING TURNAROUND CHANNEL BANDWIDTH:
10 kc to 1.2 mc.

INFORMATION CHANNEL BANDWIDTH:
10-100 kc.

WIDEBAND PHASE DETECTOR SENSITIVITY:
1 v peak out for 1 radian peak carrier deviation.

DEMODULATION CAPABILITY:
Linear from 0.2 radian to 1.5 radians carrier deviation.

RF TRACK OUTPUT:
0.5 v rms 1% amplitude modulation at 50 cps.

PM Transmitter

FREQUENCY:
240/221 times received frequency or 2287.5 mc ±0.0015% in the auxiliary oscillator mode.

POWER OUTPUT:
275-400 milliwatts into a 1.3:1 load at any phase angle.

MODULATION SENSITIVITY:
1 radian carrier deviation for 1 v input. Capable of 2.4 radians carrier deviation.

WIDEBAND MODULATION BANDWIDTH:
300 cps to 1.5 mc.

FM Transmitter

REST FREQUENCY:
2272.5 mc ±455 kc.

POWER OUTPUT:
100-145 milliwatts into 1.3:1 load at any phase angle.

MODULATION SENSITIVITY:
1 mc carrier deviation for 1 v input for frequencies from 300 cps to 1.2 mc.

TV MODULATION INPUT:
1 mc per volt offset for 1.3 v input for center frequency from dc to 500 mc.

Environmental Specifications

RANDOM VIBRATION:
Linear increase in level from 0.008 g^2/cps at 10 cps to 0.06 g^2/cps at 70 cps. Constant level of 0.06 g^2/cps, 70 cps to 2000 cps. Time duration 2.5 minutes in each of three major axes.

TEMPERATURE/VOLTAGE:
Continuous operating test conducted with average coldplate temperature of 35° F, surrounding air and wall temperature of 0° F and input voltage set at 113 v ac. Continuous operating test conducted with average coldplate temperature of 118° F, surrounding air and wall temperature of 150° F and input voltage set at 117 v ac. Equipment subjected to reentry simulation with no coolant flow with air and surrounding wall at 140° F and input voltage set at 117 v ac.

VACUUM:
100 hours of operation at 1 x 10^{-4} mm Hg.

Mechanical Specifications

SIZE:
9.5" W, 6" H, 21" D (24.13 cm W, 15.24 cm H, 53.34 cm D).

WEIGHT:
Less than 38 lbs. (17.22 kg).

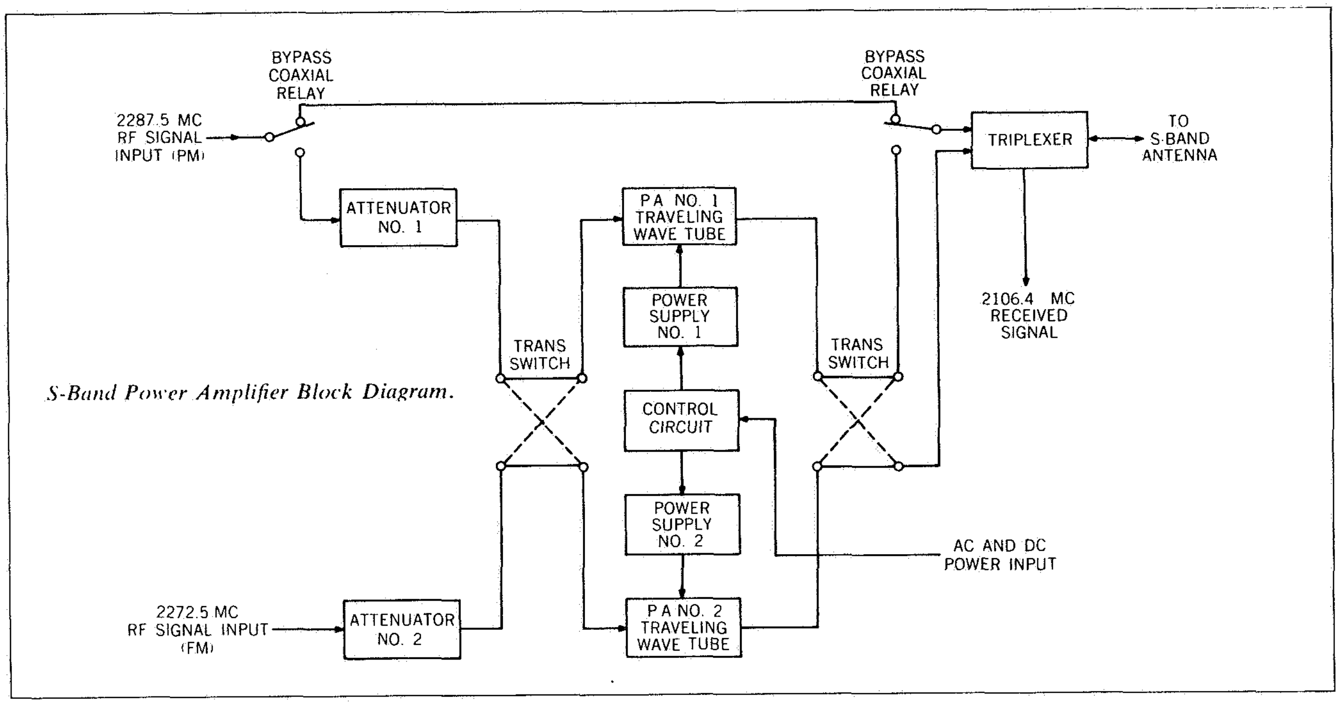
Specifications subject to change without notice.

COMMUNICATION/COMPUTATION/CONTROL

COLLINS

S-Band Power Amplifier

APOLLO (BLOCK II)



S-Band Power Amplifier Block Diagram.

Simultaneous amplification of two frequencies is possible by use of two independent power amplifiers.

Flexibility is achieved through use of coaxial transfer switch which allows either power amplifier to amplify either frequency.

Power economy is realized by bypassing the phase modulated signal around the power amplifier directly to the antenna when amplification is not required. High or low level amplification may be selected depending on communication distance.

Simultaneous transmit and receive functions are provided by a triplexer.

The S-Band Power Amplifier uses a traveling wave tube (TWT) power amplifier to provide high power amplification of the low level outputs of the spacecraft Unified S-Band Equipment. The unit contains two independent power amplifiers for amplification of the 2287.5 mc phase modulated (PM) and the 2272.5 mc frequency modulated (FM) input frequencies.

Either TWT may be selected for amplification of the PM or FM signal. The PM input signal is bypassed (without amplification) to the antenna jack whenever PM amplification is not required. No bypassing capability is provided for the FM signal.

The S-Band Power Amplifier provides two power levels (11.2 and 2.8 watts) of the PM signal, plus the bypass mode, and two power levels (11.2 and 2.5 watts) of the FM signal. The unit also contains a triplexer to allow use of a single antenna for simultaneous transmission and reception.

The S-Band Power Amplifier is packaged in a single sealed and pressurized case.

Equipment Description

The S-Band Power Amplifier, operating at both 2272.5 mc and 2287.5 mc, provides two selectable operating modes: reduced power and full rated power.

A bypass mode is provided for the PM signal. During the PM bypass mode, the 230-365 mw input drive signal is routed past the TWT to the triplexer and is attenuated approximately 2.6 db at the antenna connector.

The reduced power mode permits TWT operation at reduced input power and will produce a minimum of 2.5 watts for FM and 2.8 watts for PM at the antenna connector. The full rated power mode enables maximum output of the TWT and increases the output signal to a minimum of 11.2 watts for both FM and PM channels.

Should the loss of one or more phases of the 400 cycle primary power occur, automatic protection circuits activate, immediately switching the power amplifiers off and bypassing the PM drive signal to the antenna jack.

The modes of operation are selected remotely on the Communication Control Panel. One control switch, PRI-

MARY/SECONDARY, operates the transfer switches to select the TWT to be used for amplification of the PM signal. The FM drive signal is automatically routed to the TWT not selected for the PM signal.

Another control switch is used to select FULL POWER, OFF, or REDUCED POWER for the TWT selected for PM amplification. When this control switch is in the OFF position, the PM drive signal is bypassed around the TWT, through the triplexer and out the antenna connector.

A third control function applies power to the TWT not selected for PM use and selects the full power mode or the reduced power mode for FM signal amplification.

The S-Band Power Amplifier contains a triplexer to put both the transmit (PM and FM) carriers on one transmission line and allow a receive output from the antenna via the same transmission line. The receive channel of the triplexer is centered on 2106.4 mc.

The S-Band Power Amplifier requires sources of +28 v dc and 115 volt line to neutral, 400 cps, 3 phase power for operation and utilizes a maximum of 180 watts with both TWT amplifiers in full power mode. The dc power is used for switching and control purposes only.

Reliability and Quality Assurance

The probability of success of the S-Band Power Amplifier is R=0.999931 for 200 hours of operation in the Apollo lunar mission. Parts and material have been selected carefully, tested, and inspected thoroughly to ensure the highest practical equipment reliability. Circuit performance has been assured by extensive electrical and environmental testing and by the use of analysis techniques such as failure effect evaluation, parameter variation analysis, and stress analysis.

This equipment is being developed to a quality assurance program incorporating the provisions of NASA Quality Publication NPC 200-2, Quality Assurance Provisions for Space System Contractors.

Equipment is qualification tested for manned space flight.

The Communications and Data Subsystem for the Apollo spacecraft was designed and developed by Collins Radio Company under contract for North American Aviation, Space and Information Systems Division. As Subsystem Manager, Collins Radio established all equipment specifications for both Collins developed and subcontracted equipments, and coordinated all technical, reliability, quality, documentation and fiscal requirements to ensure a complete, well integrated system. The S-Band Power Amplifier was designed, developed and manufactured by Collins.

Specifications

Electrical Specifications

POWER REQUIREMENTS:
115/200 v ac, 3 phase — 180 watts with both TWT amplifiers in full power mode; 80 watts with both TWT amplifiers in reduced power. 28 v dc — 5 watts steady state and 350 watts during switching for 0.5 second maximum.

INPUT RF DRIVE POWER:
2287.5 mc (PM) — 230-365 mw; 2272.5 mc (FM) — 83-132 mw.

INPUT IMPEDANCE:
50 ohms (all ports).

INPUT VSWR:
1.6:1 maximum (all ports).

OUTPUT POWER:
2287.5 mc (PM) — 11.2 watts minimum.
2272.5 mc (FM) — 11.2 watts minimum.

REDUCED OUTPUT POWER:
2287.5 mc (PM) — 2.8 watts minimum.
2272.5 mc (FM) — 2.5 watts minimum.

DUTY CYCLE:
Continuous.

OUTPUT IMPEDANCE:
50 ohms nominal.

PHASE STABILITY:
Shall not add more than 0.05 radians rms phase jitter to the RF signal.

PM BYPASS ATTENUATION:
2.6 db maximum.

TRANSMISSION BANDWIDTH (0.5 db POINTS):
2287.5 mc — ±2.0 mc; 2272.5 mc — ±2.5 mc.

RECEIVE CENTER FREQUENCY:
2106.4 mc.

RECEIVE BANDWIDTH (0.5 db POINTS):
2106.4 mc — ±2.0 mc.

RECEIVE INSERTION LOSS:
2.5 db maximum.

RECEIVE ISOLATION:
60 db minimum between PM or FM signal frequencies and the receiver output connector.

Environmental Specifications

RANDOM VIBRATION:
10-70 cps — Linear increase in level from 0.0025 g^2/cps to 0.0187 g^2/cps (linear refers to a straight line plotted on log-log paper). 70-2000 cps — Constant at 0.0187 g^2/cps.

THERMAL:
Continuous operation with average coldplate temperature of +118° F. Equipment subjected to transient reentry simulation with no coolant flow in coldplate for 15 minutes.

VACUUM:
100 hours at 1 x 10^{-4} mm Hg.

SHOCK:
78 g, 11 millisecond pulse (non-operating).

Mechanical Specifications

ENVELOPE SIZE:
5.75" W, 5.95" H, 22.2" D (14.61 cm W, 15.11 cm H, 56.39 cm D) maximum.

WEIGHT:
32 lbs. (14.5 kg) maximum.

Specifications subject to change without notice.

COMMUNICATION/COMPUTATION/CONTROL

COLLINS

saturn command & communications s-band transponder

Under Contract NAS 8-14024 to NASA/MSFC Motorola is developing the S-band transponder used for command and communications in stage three (S-IVB) of the Saturn V booster for the Apollo mission. It is a phase-coherent receiver-transmitter for establishing a communication link between the Unified S-Band ground station and the Instrument Unit of the Saturn V launch vehicle. It functions to:

- Receive and demodulate command up-data for updating the guidance computers.
- Transmit pulse code modulated mission control measurements originating in the S-IVB and the IU to the USB ground stations.
- Coherently retransmit the pseudo-random noise range code that is received from the ground station.

features

- Integral up link command demodulator and down link telemetry subcarrier oscillator/bi-phase modulator
- Dynamic operating range greater than 100 db
- Coherent AGC
- Operates over $-50^{\circ}C$ to $+85^{\circ}C$ temperature environment
- Modular design
- Built to NASA QA specifications

MOTOROLA / AEROSPACE CENTER
8201 East McDowell Road, Scottsdale, Arizona 85252 (602) 947-8111

SATURN COMMAND AND COMMUNICATIONS S-BAND TRANSPONDER

Receiver Noise Figure	13 db maximum
Dynamic Range	Greater than 100 db
Threshold Noise Bandwidth	$2\beta_{L_o}$ 800 H_Z
Strong Signal Noise Bandwidth	2940 H_Z
Loop Gain (Strong Signal)	5×10^6 sec^{-1}
Phase Multiplication	110-1/2
Transponder Turn Around Ratio	240/221
Tracking Range	±180 H_Z
Receiver R-F Bandwidth	Transponder includes a four-cavity preselector for over 100 db rejection at frequencies more than 150 MH_Z from receiver center frequency. Minimum information bandwidth is 3 MH_Z.
Input Power	28 ±4 volts d-c at 32.5 watts maximum
Physical Characteristics	
Size	5.4 x 9.8 x 14.9 inches maximum - 6 mounting holes on multiples of 2-inch centers.
Weight	20-1/2 pounds maximum
Unit is designed to be mounted to a flat surface cold plate.	
Environment	
Temperature	Mounting surface (-50^{o} to $+85^{o}$C)
Vibration	Random Wave - 18g rms
Shock	50g
Acceleration	100g
Acoustic Noise	140 db
Radio Frequency Interference	MIL-I-6181D
Vacuum Pressurization	15 psig - provisions for dry nitrogen purging
Humidity	100%

apollo lunar excursion module (lem) s-band transponder

features

Primary Communication Link

The LEM Transponder provides the primary means of communicating voice, telemetry, television, and biomedical data from LEM to earth. In addition, it provides ranging and emergency keying functions.

Standby Redundancy

Either of the two receiver transmitters can be selected by a single switch.

Frequency Stability

The carrier with either FM or PM modulation is referenced to a stable quartz crystal which provides a 0.0015% stability figure.

Rapid Acquisition

The transponder will lock to input signals which may have sweep rates up to 35 kc/sec/sec.

Designed under NASA prime contract 9-1100, the LEM transponder provides up-link voice, and pseudo-random noise (prn) turnaround ranging information. The down-link provides phase-coherent prn ranging, telemetry, voice, emergency keying, television, or biomedical data transmission between the LEM and Earth for the Apollo mission. It consists of a phase-locked receiver, phase modulator, frequency modulator, and an r-f power amplifier plus frequency multiplier chain, all powered by a dc-to-dc converter.

Except for input and output switching, signal processing circuits, and the frequency modulator, all elements of the transponder are redundant and comprise two receiver-transmitters, either of which may be selected for operation and the other placed at standby.

The receiver operates at approximately 2100 Mc and exhibits a tracking signal threshold of -127 dbm (or lower) and a strong signal (-50 dbm) tracking loop noise bandwidth of 3500 cps maximum. It is capable of receiving phase-modulated signals within a bandwidth extending from 10 kc to 1.5 Mc. The transmitter supplies a minimum output power of 0.75 watt at approximately 2280 Mc. The phase modulation capabilities are ±4 radians with a modulation bandwidth from 100 cps to 1.5 Mc. When frequency modulated, the transmitter can be deviated ±3.5 Mc and will accept modulation frequencies from 10 cps to 1.5 Mc.

The transponder prime power drain is 36 watts maximum.

The transponder is packaged and interference shielded as an independent LEM Electronic Replaceable Assembly, with approximately 5-1/8 x 8 x 16-3/4 inch outline dimensions, exclusive of mounting flange conduction. The weight is approximately 20 pounds.

MOTOROLA / AEROSPACE CENTER
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LUNAR MODULE S-BAND TRANSPONDER

Transponder Operating Frequencies	**MSFN S-Band**
Receiver Dynamic Range	**-50 to -127 dbm**
R-F Tracking Loop BW (Threshold $2B_1$)	**800 cps**
Received Information	**Subcarrier Channel**
Receiver Tracking Range	**±90 kc**
Transmitter Power Output	**750 milliwatts (mim)**
Transmitter Modulation	
PM - Wideband	
Bandwidth	**100 cps to 1.5 Mc**
Sensitivity	**2 radians/volt peak**
Deviation	**±4 radians peak**
PM Narrow Band	
Bandwidth	**300 to 3000 cps**
Sensitivity	**4 radians/volt peak**
Deviation	**2 radians peak**
FM	
Bandwidth	**10 cps to 1.5 Mc**
Sensitivity	**1.5 Mc volt peak**
Deviation	**±3 Mc peak**
Power Requirements	
Voltage	**24 to 32 volts dc**
Power	**36 watts maximum**
Weight	**20 pounds**
Dimensions	**8 x 5.125 x 16.75 in.**

apollo csm unified s-band equipment - block II

Motorola's CW Transponder Section developed the Block II Unified S-Band Equipment for the Apollo command module under contract to Collins Radio Company, Cedar Rapids, Iowa. The unified S-band equipment provides the only r-f link connecting the spacecraft to earth for all portions of the mission except near-earth. This equipment receives and recovers uplink voice and command subcarriers, ranging and coherent carrier information. It transmits a PM coherent carrier, turn-around ranging, telemetry, and voice subcarrier signals. Alternate downlink voice and telemetry capability without coherent carrier operation, and a separate wideband FM transmitter for downlink TV and data transmission is provided.

The unified S-band equipment reliability is extremely high, since it is configured as remotely switchable, redundant transponders and power supplies with a separate single FM transmitter and associated power supply. This all solid state unit is packaged in a sealed housing with provisions for mounting the unit on a spacecraft cold plate.

features

THIS TRANSPONDER IS THE ONLY LINK CONNECTING THE APOLLO ASTRONAUTS TO EARTH FROM INJECTION INTO TRANSLUNAR ORBIT THROUGH LUNAR LANDING AND RETURN.

- Ultra High Reliability through design, configuration, components, and workmanship.
- Modulation capabilities include television, voice, and telemetry.
- Two redundant transponders in one package.

MOTOROLA / AEROSPACE CENTER
8201 East McDowell Road, Scottsdale, Arizona 85252 (602) 947-8111

UNIFIED S-BAND TRANSPONDER

block II apollo

Multiplication Ratio (Xmt/Rec)	240/221
PM Transmitter Frequency	2287.5 MHz
FM Transmitter Frequency	2272.5 MHz
Receiver Frequency	2106.40625 MHz

PM TRANSMITTER

R-F Power Output	0.250 watt to 0.40 watt
Modulation Frequency Range	
Wideband	PM: 300 Hz to 1.5 MHz
Voice	PM: 300 Hz to 10 kHz
Peak Deviation Capability	±4 radians
Deviation Sensitivity	1 radian/volt
Deviation Linearity	10%/2 radians

FM TRANSMITTER

R-F Power Output	0.100 to 0.145 watts
Modulation (FM)	
TV	DC to 500 kHz
Wideband	300 Hz to 1.2 MHz
Modulation Range	
TV	±1 MHz Peak Dev.
Wideband	±3 MHz Peak Dev.
Modulation Sensitivity	1 MHz/volt
Frequency Stability	±0.02%

RECEIVER

Tracking Range	±90 kHz
Predetection Bandwidth	15 kHz
Threshold Noise Bandwidth	$2B_{LO} = 800$ Hz
Strong Signal Noise Bandwidth	$2B_{LSS} = 3000$ Hz
Noise Figure	10.5 db
Carrier Tracking Sensitivity	-37 to - 134 dbm
AGC Time Constant	0.3 sec
Antenna Track AM Output	2 volts rms/% A.M. modulation

GENERAL

Input Voltage	115 VAC, 400 cycle, three phase
Input Power	
Transponder	16 watts
FM Transmitter	7 watts
Weight/Cubage (Approximate)	32 lb/1200 cu in.
Configuration/Dimensions (Approximate)	9 1/2 x 6 x 21 in.
Temperature: Operating (Coldplate)	+32°F to +118°F
Storage	-45°F to +150°F

Remarks	High Reliability. Turnaround PRN Ranging, wideband uplink demodulation, TV and wideband FM modulation.

APPENDIX B

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