MANNED SPACE FLIGHT NETWORK TELEMETRY SYSTEM

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Summary This paper discusses the Manned Space Flight Network (MSFN) Telemetry System as it has been developed through the Mercury, Gemini, and Apollo programs and is now being modified to meet Skylab, Earth Resources Technology Satellite (ERTS), and Apollo “J” mission (Apollo 16 and subsequent lunar missions) requirements. The existing telemetry system must be modified to meet the requirements of these future programs.

This modification will consist of the implementation of automated configuration switching, centralized control of telemetry subsystems, tunable FM and PSK modulators/demodulators, high frequency PCM signal conditioners, and the upgrading of both the wide band instrumentation magnetic tape recorders and the PCM decommutation capability.

The resulting telemetry system, which will be capable of supporting various manned and unmanned space missions, is described here. Data flow diagrams are delineated and equipment electrical characteristics are discussed.

Introduction The Manned Space Flight Network (MSFN) Telemetry System has been designed to meet the following major goals:

1. “Real Time” display of telemetry parameters.

2. “Man-rated,” which is interpreted as meaning that any single failure will not preclude the capability of providing the required mission support.

3. Flexibility for “quick-turnaround” due to changing requirements.

4. “State-of-the-art” design for telemetry systems and subsystems within budgetary considerations.

With an ultimate goal of providing data to a flight control team during manned flight missions, the Mercury network was implemented in 1960. Many changes have since been incorporated and new equipment implemented to meet the Gemini and Apollo program requirements. However, the prime requirement of providing data to a flight control team has not changed, although this team has moved from evaluating data on site to a central control center at the Manned Spacecraft Center, Houston, Texas.

An effort is now underway to provide support capability for ERTS, Skylab, and the Apollo “J” mission series. This capability represents a substantial effort in the implementation of new equipments on the MSFN. In this paper some of the new equipments are discussed, along with their eventual use in meeting these new requirements.

The present MSFN consists of tracking stations at Corpus Christi, Texas, Goldstone, California; Merritt Island, Florida; USNS Vanguard; Canary Islands; Acension Island; Bermuda; Madrid, Spain; Carnarvon, Australia; Honeysuckle Creek, Australia; Guam; Kauai, Hawaii; Guaymas, Mexico; and the Network Test and Training Facility at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland (Reference 4). During 1971, the tracking station at Grand Bahama Island will be moved to the Southern Hemisphere, to meet Skylab tracking requirements. Figure 1 shows the geographical locations of MSFN tracking stations (Reference 12).

For the purpose of this paper, the telemetry data system is defined by Figure 2.

History of the MSFN Telemetry Capabilities Due to the changing tracking and data requirements of the Mercury, Gemini, and Apollo programs, the MSFN has continually implemented new equipments. Some of the MSFN telemetry system capabilities since 1960 are listed below:

1960 and 1961 - Mercury Implementation

1. 100 kHz magnetic tape recording capability.
2. Five FM IRIG discriminator channels.
3. PAM decommutation.
4. Narrow band VHF receiving, with post detection space diversity combining capability.
5. Preamps with 4 db noise figure.
6. Pre-selector RF filter for three RF links.
7. Limited on-site display.
8. One kHz oscillograph capability.

1962

1. Additional IRIG discriminator capability at selected MSFN sites.
2. Wide bandwidth VHF receivers with post detection space diversity combining capability.
3. Pre-selector RF filter for five RF links.
4. Limited narrow band FM record capability.

1963 - Gemini Implementation

1. PCM decommutation capability, using patchboard acquisition and distribution techniques.
2. 1.5 MHz recording capability.
3. Local display expanded.

1964

1. Bermuda data remoted.
2. Biomed data remoted, using analog techniques from entire network.
3. Wide band multiplexing techniques used for data transmission.
4. PCM decoms interfaced to computer.

1965 - Apollo Implementation

1. PCM decommutation capability, using stored program techniques.
2. Wide bandwidth receivers using predetection polarization combining and predetection recording and playback techniques.
3. RF multicouplers vice pre-selectors.

1966

1. Expanded VCO multiplexing techniques for recording purposes.
2. On-site displays are driven from computer in addition to PCM decommutator.

1967

1. Complete IRIG proportional bandwidth FM discriminator capability.
2. PAM decommutation capability expanded and interfaced to computer system.
3. Automatic VHF receiver calibration equipment.
4. Flexible analog to digital conversion equipment interfaced to computer.
5. VHF receiver preamps with 1.7 db noise figure.

1968

1. Wide band tunable FM demodulation capability.
2. Frequency calibration equipment.
3. All telemetry data remoted to Houston.
4. One bps to one Mbs split-phase PCM bit synchronization.

1969

1. Expanded subcarrier spectrum analysis.
2. Five kHz oscillograph.
3. Wide band data transmission techniques applied to slow scan TV remoting.
4. Receiver AGC data digitized for remoting and automatic PCM bit error rate tests.

1970

1. Automatic video matrix switching system.
2. Video distribution amplifiers with 2 Mhz response.
3. Centralized telemetry control.
4. Two MHz recording capability.
5. Automatic monitoring of remoted PCM data.
6. Wide band tunable voltage controlled oscillator programmed from computer.

1971 - ERTS and Skylab implementation

1. 20 MHz PCM bit synchronization.
2. Five MHz PCM decommutation.
3. Tunable PSK demodulation and simulation capability to two MHz.
4. Digital biomed data remoting, using high accuracy A/D conversion.

Apollo Configuration for “H” Series Missions The proceedings of the Apollo Unified “S” Band Conference (Reference 3), held in June 1966, delineated the characteristics of various equipments to be implemented in support of the Apollo lunar landing program. The Apollo PCM decommutator was briefly described along with its interface with the computer and USB System.

A building block approach was used to implement this system, i.e., all equipments were not implemented at the same time, but were integrated into the Gemini telemetry system as requirements were finalized and equipments were delivered. This was possible because of the telemetry system organization.

The MSFN telemetry system consists of six subsystems:

1. Digital telemetry subsystem.
2. FM telemetry subsystem.
3. PAM/PDM telemetry subsystem.
4. Telemetry recorder subsystem.
5. RF telemetry subsystem.
6. Telemetry control subsystem.

The RF telemetry system consists of dual VHF (225-260 MHz) telemetry receivers with predetection combining, and predetection recording and playback capability. The RF signal is fed to the receivers from a low noise figure preamp (on the order of 1.7 db). The over-all system noise figure is on the order of 2.1 db, providing excellent VHF "predetect combined" video signals for recording and decommutation. The receivers are calibrated using a ten-channel VHF signal simulator which automatically sequences through seven signal levels, thus capable of calibrating ten receivers simultaneously. The receivers can demodulate narrow and wideband FM signals using a variety of IF band widths. Receiver output signals are made available to the digital subsystem for decommutation, to the recorder subsystem for magnetic recording and to the FM subsystem for further demodulation of FM multiplexes. Interfacing between subsystems is accomplished using 50-ohm coaxial cable and termination into coaxial patch panels and matrix switching systems for configuration flexibility. Equipment description and salient characteristics of the existing RF Telemetry subsystem equipments are found in Appendix 1 of this paper.

The telemetry recorder subsystem consists of multiple IRIG wide band group II instrumentation recorders, voice recorders, pressure fluid analog chart recorders, event monitoring chart recorders, and five-kHz oscillographic recorders. Flexible 50-ohm coaxial patch panels and matrix switching systems interface each of the recorders to the other telemetry subsystems. Each IRIG wide band group II recorder (Reference 2) has a 1.5 MHz direct record capability for 14 tracks (one-inch tape) at tape speeds from 3-3/4 to 120 inches per second. Up to seven tracks may be used for wide band FM recording. Salient characteristics of all existing recorder subsystem equipments are found in Appendix 2.

The existing PCM decommutation technique consists of two types: patchboard and stored program. Either type can process PCM data coded NRZ-L, NRZ-S, NRZ-M, RZ and Bi-phase-Level (Split Phase). The MSFTP-1 uses patchboards to program the decommutation and distribution of data. The MSFTP-2 uses a core memory to store instructions for the decommutation and distribution of data. The MSFTP-2 core memory has a capacity of 4,096 words of 36 bits each, which can be programmed by manual entry, paper tape reader entry, or computer-system entry. Both decommutators have two computer buffers, and each buffer can transfer 30-bit words to the computer system. Each decommutator has digital to analog converters that can be used to distribute selected parameters in analog form to peripheral equipment (analog chart recorders or meters). The decommutators also can be programmed to distribute on/off event parameters or binary coded parameters to peripheral equipment (event recorders). Salient characteristics of all existing digital telemetry subsystems are given in Appendix 5.

The model DDF-13 PAM/PDM decommutator accepts serial PAM or PDM data for conversion to parallel and serial binary data. The input to the DDF-13 may be from a subcarrier discriminator or from an analog tape recorder. The equipment performs pulse synchronization on the data and can also decode main-frame and sub-frame synchronization patterns. The formatter measures the amplitude or duration of the input data pulses, and then converts it to a PCM NRZ-L format, with one eight-bit word corresponding to each input data pulse, and generates a 16-bit synchronization pattern for each frame of converted data. The DDF-13 accepts variable duty cycle PAM data or PDM data conforming to IRIG, or accepts data with non-IRIG standard coded PAM format having a duty cycle in the range between 30 and 90 percent. For PDM coded data, the duty cycle for the zero percent calibration level can be coded four to 15 percent of the fall bit length time, and the 100 percent calibration level can be coded from 45 to 70 percent of the full bit length time. The input data rates may range from one bps to 10 kbs for 100 percent duty cycle PAM format, or one bps to five kbs for PDM or 50 percent duty cycle PAM. The formatter has two converted outputs, each with one eight-bit binary word per input data pulse: one is compatible with the input to the computer system for transfer in parallel; the other is formatted in a PCM, NRZ-L serial format with a synchronization pattern as previously described. Salient characteristics of all existing PAM/PDM telemetry subsystems are given in Appendix 3.

The FM subsystem includes subcarrier discriminators with IRIG channel characteristics and subcarrier discriminators with variable center frequency and bandwidth characteristics for processing FM/FM multiplexed data channels. In addition, data converter/multiplexer equipment is available which can accept up to 36 channels of analog or converted digital-to-analog (D/A) data which can modulate IRIG subcarrier voltage controlled oscillators (Channels 1 through 18 and A through E), and then multiplex these subcarrier channels for off-station transmission and tape recording. Salient characteristics for existing FM telemetry subsystems are given in Appendix 4.

Apollo Configurations for “J” Series Missions The telemetry system is presently undergoing modifications to meet the Apollo “J” Mission requirements. Four major pieces of equipment will be implemented: a tunable PSK demodulator, tunable PSK simulator, tunable voltage controlled oscillator, and an Analog Multiplexer Quantizer. Figure 3 depicts the telemetry system configuration for the Apollo “j” missions.

1. Tunable PSK Demodulator The tunable PSK Demodulator is being implemented for support of the Particles and Fields Subsatellite and the Scientific Data System (SDS), each of which is flying PSK subcarriers modulated onto either an FM or PM transmitter. Figure 4 depicts the SDS spectrum.

For the purposes of this paper, PSK will be defined as the phase modulation of a carrier $\pm 90^\circ$ (Reference 1). The modulating waveform could be any of the IRIG PCM code formats, i.e., NRZ, RZ, and split phase (bi-phase).

A sinusoidal carrier that is phase-shifted $\pm 90^\circ$ by a binary sequence can be expressed as

$$e_{psk}(t) = -Am(t) \sin (w_c t + \phi_c$$

where

A is the carrier amplitude,
m(t) = ±1 is a switching function representing the binary sequence,
w_c is the carrier frequency,
ϕ_c is the initial phase of the carrier.

The two possible signal states of the PSK signal are

$$e_1(t) = A \sin (w_c t \phi_c), \text{ and } e_2 (t) = -A \sin (w_c t + \phi_c).$$

If the modulation process is phase-coherent, the bit transitions of the binary sequence always occur at the same point of a carrier cycle, i.e., the phase and frequency of the PCM modulating signal are related to the phase and frequency of the carrier. For phase-noncoherence, bit transitions occur at random with respect to carrier zero crossings and peaks, i.e., the subcarrier to data rate is nonintegral. The tunable PSK demodulator will separate coherent or noncoherent PSK-NRZ, RZ, or split phase modulated data from a frequency multiplex. Optimum demodulator performance at low input signal-to-noise ratios is the primary design objective. Salient features of the tunable PSK demod (Reference 6) are as follows:

a. DC Offset - Up to 100% of peak-to-peak signal amplitude.
b. Subcarrier Rate - Tunable from 1 kHz to 2.0 MHz.
c. Bit Rate - 1 bps to 1.00 Mbs.
d. Code Formats - PSK modulated by an NRZ-M, NRZ-L, RZ, Bi ϕ-L, Bi ϕ M, or Bi ϕ -S PCM data.
e. Carrier to Bit Rate Ratios - From 1 to 1000. Carrier frequency and bit rate need not be harmonically related.
f. Input Filtering - A tunable linear phase bandpass filter is employed at the signal input to separate the PSK subcarrier from the frequency multiplex. The tunable filter has selectable bandwidths of 1, 1.5, 2, 2.5, and 3 times the bit rate, with a roll-off characteristic of 18 db/octave. A fixed bandpass filter may be substituted for the internal tunable bandpass filter for selected PSK subcarriers.
g. Subcarrier Tracking Range - ±10% of carrier frequency.
h. Subcarrier Frequency Jitter - The phase lock loop will track variations in the subcarrier frequency up to ±10% of the nominal subcarrier frequency at a jitter rate of up to 10,000 Hz.
i. Threshold - The demodulator will provide optimum performance at low input signal-to-noise ratios.

2. PSK Simulator The PSK simulator will generate NRZ, RZ, or split-phase (bi-phase) modulated sub-carriers in the frequency range from 1.0 kHz to 2.0 MHz. The simulator will contain four PSK modulators and will be capable of mixing these PSK modulators together with external FM subcarriers to generate a multiplex of frequencies.

In general, the PSK simulator will exercise the tunable PSK demodulator and simulate, as a minimum, the SDS and Particles and Fields Subsatellite to be used during the Apollo "J" mission.

3. Tunable Subcarrier Oscillator A computer-programmable, tunable subcarrier oscillator will be implemented into the MSFN telemetry system as part of the Apollo "J" mission equipment updates. The oscillator will be used to simulate the SDS FM subcarriers, to provide expanded multiplexing capability for magnetic tape recording, and to provide a flexible frequency source for microwave transmission requirements. Salient features of the unit are listed below (Reference 8):

a. Input Signal Amplitude Range - ±1, ±2.5, or ±5 volts peak for full band-edge can be selected remotely, or locally. Variable inputs between ±1 volt and ±10 volts can be accommodated.
b. Center Frequency - Any center frequency between 100 Hz and 2.5 MHz can be selected locally, or by remote control.
c. Deviation Polarity - Positive or negative direction is selected locally or remotely.
d. Center Frequency Deviation - Center frequency deviations from ±5% to ±40% are programmable to three digits. This is selected locally or by remote control.
e. DC Offset - Zero, high bandedge, low bandedge, or variable offset may be selected locally or by remote control.
f. Center Frequency Stability - Center frequency drift does not exceed ±0.05% for 15 hours at constant temperature after a 15 minute warm-up.
g. Bandwidth Stability - Bandwidth drift is not greater than ±.2% of full scale deviation at constant temperature after a 15 minute warm-up.
h. Static Linearity - For center frequencies extending to one MHz, best straight line linearity is ±.1% of bandwidth for deviations not greater than ±15%, and is ±0.2% of bandwidth for deviations not greater than ±40%. For center frequencies of 1 MHz or more, best straight line linearity is within ±.5% for all deviations.
i. Frequency Response - The frequency response is within +1 db from dc to 500 kHz.
j. Amplitude Modulation - For any deviation, the amplitude modulation of the sine wave output is less than one db.
k. Subcarrier Distortion - At any deviation, the total subcarrier harmonic distortion of the sine wave output is less than 1%.

l. Remote Control and Computer Interface - The Programmable Tunable Subcarrier Oscillator's input range, positive or negative sense, dc offset, center frequency and center frequency deviation may be controlled by the computer system.
m. FSK Modulation Capability - The storage of a second set of three digits pertaining to a second programmed center frequency, together with a set of gates controlled by a status line input such that by switching the status line from "0" to "1" the VCO output can be switched back and forth from a first to the second stored frequency, thus generating FSK waveforms.
n. Output Mixing - An external signal may be inserted in the frequency range from dc to 10 MHz for mixing with the internally generated frequency.
o. Injection Locking - The insertion of a precision frequency at the nominal output frequency of the tunable VCO will phase lock the VCO output to the injected signal. Locking range is ±1% of the center frequency.

During 1971 all biomedical telemetry data received at an MSFN tracking station will be remoted to the Houston control center via digital techniques. Biomedical data is defined as the astronauts' EKG's and impedance pneumograph information. At present, EKG's and impedance pneumograph data are frequency multiplexed using IRIG subcarriers and remoted via telephone lines. Under the new scheme, all LM and extravehicular biomed data will be digitized into eight-bit binary words, and remoted using 4.8k bit modems and compatible telephone lines. CSM biomed data is presently transmitted from the spacecraft in digital form. In order to achieve the high accuracy required, an Analog Multiplexer Quantizer (AMQ) will be implemented with the following features (Reference 12):

a. The AMQ is capable of accepting 128 individual analog inputs.
b. The input sample rate is selectable from one to 100,000 samples per second. The sample rate accuracy is ±.05%, and the stability is ±.001%.
c. The sample time is five microseconds.
d. The aperture time is 200 nanoseconds.
e. Analog to Digital Conversion
    (1) The resolution is 8 bits with an accuracy of ±1/2 the least significant bit.
    (2) Linearity - ±.05%.
    (3) Stability - ±.02% of full scale for short term (8 hours); ±.05% long term (30 days).
    (4) Crosstalk - ±.01% of full scale.
    (5) Offset and Noise - ±.01% of full scale.
    (6) Output Code

Input Analog Voltage	Output Binary Code
0.0 volts	00000000
+10.0 volts	11111111

f. Local/Remote System Control - The AMQ can be operated and controlled from the front panel (local control), or remotely (remote control) via instructions received from the computer system.

g. System Modes. The following system modes are selectable locally or through the proper computer instructions when in the remote mode:

   (1) Sequential/Addressable Mode. The sequential mode causes the channels to be sampled sequentially, starting at channel number 1 (Address 00000000) and recycling after the channel number in the recycle control has been reached. The rate at which the channels are sampled is a function of the sample-rate control. The addressable mode disables the sequential mode and causes the channel whose address is supplied by the "Channel Address" control or the computer input to be sampled.

   (2) Synchronous/Asynchronous Mode. The synchronous mode allows the internal sample rate to control the channel sampling rate in either the Local or Remote mode of operation. If the sequential mode is selected, the channels are sampled sequentially at the sample rate. If the addressable mode is selected, the channel whose address has been entered into the system is sampled at the sample rate. The asynchronous mode disables the synchronous mode and results in the following operation depending upon the Local/Remote control:

      (a) Local Operation. The asynchronous mode will cause the channels to be sampled at a rate determined by a pushbutton control.

      (b) Remote Operation. The asynchronous mode in the remote operation will have a sample rate determined by the computer.

Skylab A rehabilitation effort is underway to replace various equipments in the MSFN Telemetry System that cannot meet Skylab requirements. included in this group are a new data decommutation subsystem, wide band recorder subsystem, and receiver subsystem.

1. Digital Telemetry. A Stored Program Data Decommutation System will be implemented into the MSFN telemetry system in 1972. The following list itemizes features presently not incorporated into the MSFN decommutation system (Reference 5):

   a. One bps to five Mbs serial input.
   b. Store a minimum of 32 unique formats, using 8k of memory.
   c. Frame sync word lengths from six to 32 bits, and data word lengths from four to 32 bits.
   d. Digital pattern recognition for frame and subframe synchronization.
   e. Five subframe synchronizers, all of which can handle recycle or ID patterns.
   f. Memory Buffered Serial Data Output (modem compatible).
   g. Digital printer built in for data display.
   h. Data Redundancy Removal and data tagging.

i. Format instructions are designed to handle complex PCM formats with a minimum number of instructions.
j. 32 digital (binary) to analog converters,
32 ON-OFF outputs (digital stores),
32 bit data multiplex.
k. Two output data buffers for computer interface.
l. Memory load from computer.
m. Self-contained test equipment.
n. Automatic program change upon detection of a predetermined code.
o. Maximum of three equipment racks.
p. Remote control operation.

The decommutator, when implemented, will provide a minimum of four PCM handling systems at each MSFN site.

2. RF Telemetry. A minimum of eight dual-channel receiver systems win be available when new receiver systems are implemented in 1972 at each MSFN site. The new systems will augment the existing model 2074 receiver and model 5100 combiner system. Features to be included in the system are as follows:
   a. PM, FM, and AM demodulation.
   b. Tuning ranges from 130 MHz to 2300 MHz in selected ranges, including interfacing to “S” band down converter frequencies.
   c. IF bandwidths from 12.5 kHz to five MHz.
   d. Predetection and postdetection combining capability.
   e. Predetection. playback capability for all recorder speeds.
   f. AGC shaping at threshold.
   g. Combined AGC available for recording.
   h. Detected combined predetection signal available for further processing.

3. Wide Band Instrumentation Recorder Augmentation. A new IRIG wide band instrumentation recorder (model FR 1900A) is being implemented at each MSFN tracking station. The characteristics of the new recorder system are similar to those of existing recorders, except for the following salient features: Two MHz bandwidth; low time base error; bidirectional drive-capable of recording and reproducing tapes in two directions; selective track record capability; variable speed capability using an external oscillator; voice log record or monitor for voice annotations on any selected direct or FM track; footage counter to be used to cue tape; a reference frequency failsafe to stop the transport on loss of reference signal; data dubbing carrier output for FM; FM carrier squelch so that system can be calibrated without moving tape; tape width conversion capability for one inch or one-half inch tape. The additional recording system will provide for a back-up or off-line recorder at each site.

Earth Resources Technology Satellite (ERTS) Goddard Space Flight Center is preparing to launch an ERTS in 1972. The MSFN is now modifying the Corpus Christi tracking station and a portion of the Network Test and Training Facility at GSFC for ERTS tracking support. Included in the equipment for this support is a high frequency PCM bit synchronizer. The following list itemizes the salient input and performance characteristics of the high frequency bit sync. The design shall be such that discrete bit rates are selected by means of plug-in subunit. The unit shall be capable of operating with the following signal sources: PM receivers, FM demodulators, magnetic tape recorders, and PCM simulators (Reference 9).

a. Code types - NRZ-L.
b. Bit Rate - The unit will accept bit rates of from one Mbs to 20 Mbs using single frequency plug-ins.
c. Static Frequency Offset - Bit rate offset may be ±0.5% of the selected bit rate (Δ/f = ±0.5%).
d. Dynamic Frequency Offset - Bit rate may exhibit a ±15 kHz dynamic variation (sinusoidal) of up to +0.1% of center frequency ($\Delta f/f < \pm 0.1\%$) at modulating frequencies of up to 0.1% of bit rate ($f_m/f \leq 0.1\%$).
e. Amplitude - Signal amplitude (bipolar) may be from 0.2 volt to 6 volts peak-to-peak, with dynamic amplitude variations of up to 25% at frequencies up to 0.1% of bit rate.
f. Baseline Offset
   (1) Static - up to 5% of peak signal amplitude.
   (2) Dynamic - up to 1% of peak signal amplitude at frequencies up to 1% of bit rate.
g. Transition Density - 10% minimum (average) transitions (alternate ones and zeros = 100% transitions). Capable of up to 64 sequential missing transitions without bit slippage.
h. Group Delay Distortion - Group delay distortion could result in transition displacement of up to ±5% of a bit period.
i. Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR) - For random data and no jitter, the BER is within one db of Table 1 for SNR's. ≥ 5 db (rms/rms). The BER is within two db for any combination of worst case signal characteristics for SNR's > 10 db.
j. The bit sync acquisition occurs within an average of 1000 bit times for SNR's > 5 db and worst case signal characteristics.
k. The bit slippage averages less than:
   (1) SNR's ≥ 10 db, random data, no jitter - slippage ≤ 1×10^{-9}
   (2) SNR's ≥ 5 db to 10 db, random data, no jitter - slippage ≤ 1×10^{-7}.
   (3) SNR's ≥ 12 db, worst case signal characteristics (any combination) - slippage ≤ 1×10^{-9}.

- The bit detector is balanced so as to offer an equal probability of correct decision for both "ones" and "zeroes." The difference in BER for "ones" and "zeroes" shall not exceed 10%. Table 1 shows the BER to be expected from varying SNR's.

Table 1
Bit Error Rate Probability

$$SNR = 20 \log \frac{\text{signal (Vrms)}}{\text{noise (Vrms)}},$$

Actual noise bandwidth = 5 × bit rate,
Noise is measured in 1/2 bit rate bandwidth for SNR.

Signal to Noise Ratio, SNR (db)	Bit Error Rate, BER
-1	1.867×10^{-1}
0	1.586×10^{-1}
1	1.313×10^{-1}
2	1.038×10^{-1}
3	7.927×10^{-2}
4	5.705×10^{-2}
5	3.754×10^{-2}
6	2.329×10^{-2}
7	1.253×10^{-2}
8	6.037×10^{-3}
9	2.401×10^{-3}
10	7.889×10^{-4}
11	1.926×10^{-4}
12	3.450×10^{-5}
13	4.100×10^{-6}
14	2.722×10^{-7}
15	9.500×10^{-9}

Telemetry Control Sub-System Implementation is presently underway for a Data Systems Control Console (DSCC). This console will centrally control all the operations of the MSFN telemetry system, and is intended to provide the capability for changing configurations and controlling system operations for the Apollo "J" missions and Skylab. The following functions will be included:

- Control of the telemetry matrix switching system.
- Monitoring capability of all telemetry data remoted to GSFC and MSC.
- Control of all PCM decommutators and simulators.
- Operations control of all wide band instrumentation recorders.
- Monitoring capability for all recorded and PCM input/output data. Tape search control.

Figure 5 d:picts the telemetry interface for the DSCC.

1. Telemetry Configuration Matrix Switching System. The Telemetry Matrix Switching System is a versatile and flexible matrix switching assembly which is capable of accommodating a wide variety of input signals. It is employed as a building block to solve telemetry switching problems. The switching systems will augment existing coaxial patch panels.

   Activated either by local or remote control, the salient characteristics of the switching assembly (Reference 11) are:

   a. Saturable core, magnetically latched reed crosspoints retain a selected interface upon loss of primary power or remote control input.
   b. Both the center conductor and shield of the coaxial signal line are switched separately and simultaneously. Cross-point latching is confirmed by an independent reed.
   c. Frequency response to 10 MHz at 50 db crosstalk isolation.
   d. Three individual 14 x 14 switching matrixes expandable to either a single 42 x 14 matrix, or a 14 x 14 and a 28 x 14 matrix.
   e. A pre-programming operational mode which instantly activates any one of three predetermined 42 x 14 input/output configurations.
   f. A front panel display which presents a visual identification of the entire input/output switching status.
   g. Provisions for preserving an input/output matrix configuration while test signals are inserted to the 14 outputs. In this disable position, the matrix outputs are open circuited.
   h. Front panel monitor switches which enable an operator to select any input signal or output signal for monitoring.

   The remote control panels will be installed in the DSCC and have an identical capability of the local panel on the matrix switch itself. Individual switching systems will be implemented for the recorder subsystem, digital subsystem, and the testing interface.

2. Remoted Data Monitor. An integrated circuit PCM data monitor decommutation, which will provide a continuous monitor of the 2.4 kbs or 4.8 kbs data remoted from each Manned Space Flight Network station, will be implemented into the DSCC. The decom will display up to three data words at any instant, requiring only a knowledge of word, Format ID and frame location to display a data point. The decommutator functions are performed by logic cards programmed by an internal patchboard and associated front panel contro (Reference 10).

   A signal conditioner capable of processing the incoming bit rates is included.

   The PCM monitor decom performs the following functions:

   a. Accept a preconditioned 4.8 kbs LSB first NRZ-L serial PCM data stream and the associated bit rate clock.
   b. Perform word, Format ID, and frame synchronization of incoming PCM data.
   c. Display up to three data words at any instant of time in binary form.

d. Decommutate two 2.4 kb output formats interleaved to form a 4.8 kbs format, as illustrated in Figure 6.
The monitor decommutator will also process single 2.4, 4.8, 7.2, 9.6 kbs formats.

3. The DSCC remote control operation of the stored program PCM decommutators will include the following functions:
   a. Mode Switch - Load/Operate.
   b. Remote Control Enabling indicator.
   c. Format Selector Switch; visual indication of format selected; format change push button.
   d. Input Selector Switch Control for the PCM Simulators and the PCM Signal Conditioners.
   e. Sync Status Indicators for frame and subframe synchronizers.
   f. Computer Buffers will have Enable/Inhibit transfer control, Tape Playback Bit Set/Reset Switch and indicators for both functions, and a "No Input Acknowledge Indicator" for each computer buffer.

   The DSCC remote control operation of the stored program PCM simulators will include the following functions:
   a. Mode Switch - Load/Operate.
   b. Remote Control Enabled Indicator.
   c. Bit Rate Selector Switch.
   d. Format Selector Switch with a visual indication of the format selected and a format change push button.
   e. Systems Reset Push Button.
   f. Code Type Selector Switch.
   g. Stored/Manual Clock Enable/Disable Switch and indicator.

1. The DSCC instrumentation wide band recorder remote control panel will include the following features:
   a. Mode Select Capabilities - Run, Record, Forward, Rewind, Standby, Stop.
   b. Speed Selector Capability.
   c. Automatic Recorder Transfer Capability with an Enable/Disable Switch.
   d. Transport Servo System Indicator.
   e. Timer, to indicate the amount of tape remaining on the supply reel. This timer will compensate for different tape speeds as well as tape lengths.
   f. End of Tape Sensor, to indicate end of reel or torn tape.
   g. Cycle Lock Switch.
   h. Power Supply Failure Indicator.

5. Data Monitoring Capabilities. Binary/Decimal displays will be implemented into the console for display of spacecraft-transmitted PCM parameters. The units to be installed in the DSCC will have simultaneous binary, decimal, and analog displays for the selected parameters.

In addition to the data monitors, a sophisticated test select capability will be implemented into the system. This will consist of 14 recorder monitor oscilloscopes, capable of displaying data from the reproduce ampliffers of each instrumentation recorder for validation of recorded data. A selection switching matrix will precede the small monitoroscilloscopes to select which recorder will drive the display. Augmenting the monitor oscilloscopes is a four-channel oscilloscope preceded by a 5 x 30 test select matrix, which is interfaced to the 42 X 14 data matrix. Each 42 x 14 matrix has a separate reed matrix for test purposes, capable of providing any signal to the 5 x 30 matrix and ultimately to the four-channel oscilloscope. A four-channel oscilloscope and associated test select matrix will be implemented for support to the PCM system and the recorder system.

Two clock parameters from the Lunar Module (LM) and Command/Service Module (CSM) (Central Timing Equipment (CTE) and Mission Elapsed Time (MET) clocks) will be monitored using display clocks interfaced directly to the PCM decommutators. The display of these clocks will assist in the tape recorder search for particular time segments of critical parameters from either the LM or CSM. The control of recorder tape search equipment is included on the console.

Acknowledgments The author wishes to acknowledge the encouragement and helpful advice from D. Dalton, Head of the GSFC Digital Data Systems Branch; J. Taylor, Head of the GSFC Telemetry Engineering Section; and M. Levine, C. Dudley, and R. Orff of the GSFC Telemetry Engineering Section.

Acronyms

ACN - Ascension Island, MSFN Tracking Station
AMQ - Analog Multiplexer Quantizer
BDA - Bermuda MSFN Tracking Site
CRO - Carnarvon, Australia, MSFN Tracking Station
CYI - Canary Islands, MSFN Tracking Station
DSDU - Decommutation System Distribution Unit
FM - Frequency Modulation
GBM - Grand Bahama Island, MSFN Tracking Station
GDS - Goldstone, California, MSFN Tracking Site
GSFC - Goddard Space Flight Center
GWM - Guam, MSFN Tracking Station

GYM - Guaymas, Mexico, MSFN Tracking Site
HAW - Kokee Park, Hawaii, MSFN Tracking Site
HSK - Honeysuckle Creek, Australia, MSFN Tracking Station
MAD - Madrid, Spain, MSFN Tracking Station
MIL - Merrit Island, Florida, MSFN Tracking Station
MSFN - Manned Space Flight Network
MSFTP-1 - Manned Space Flight Telemetry Processor - 1
MSFTP-2 - Manned Space Flight Telemetry Processor - 2
MTR - Magnetic Tape Recorder
NTTF - Network Test and Training Facility at Goddard Space Flight Center
PAM - Pulse Amplitude Modulation
PCM - Pulse Code Modulation
TEX - Corpus Christi, Texas, MSFN Tracking Station
VCO - Voltage Controlled Oscillator
VDA - Video Distribution Amplifiers
WBMTR - Wideband Magnetic Tape Recorder

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11. "Specification for Switching Matrix Assembly, GSFC Document S-812-P-28, Goddard Space Flight Center, November 1969.
12. Specification for Analog Multiplexer Quantizer, GSFC Document S-812-P-36, Goddard Space Flight Center, May 1, 1970.

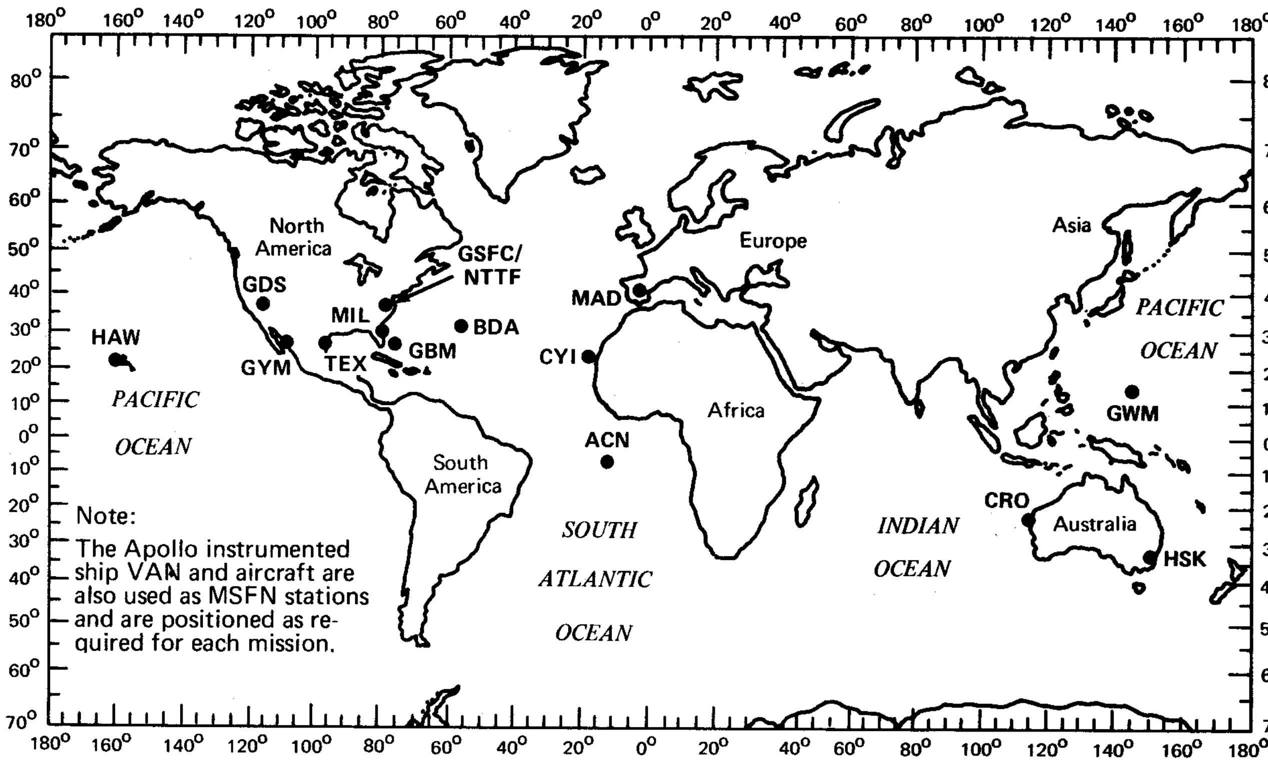


Figure 1-Geographic Location of MSFN Facilities.

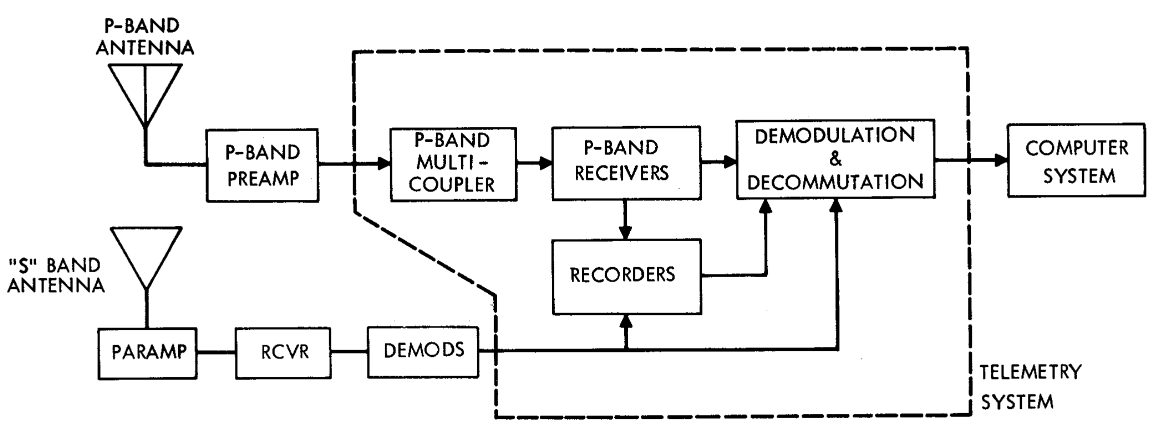


Figure 2-MSFN Telemetry System.

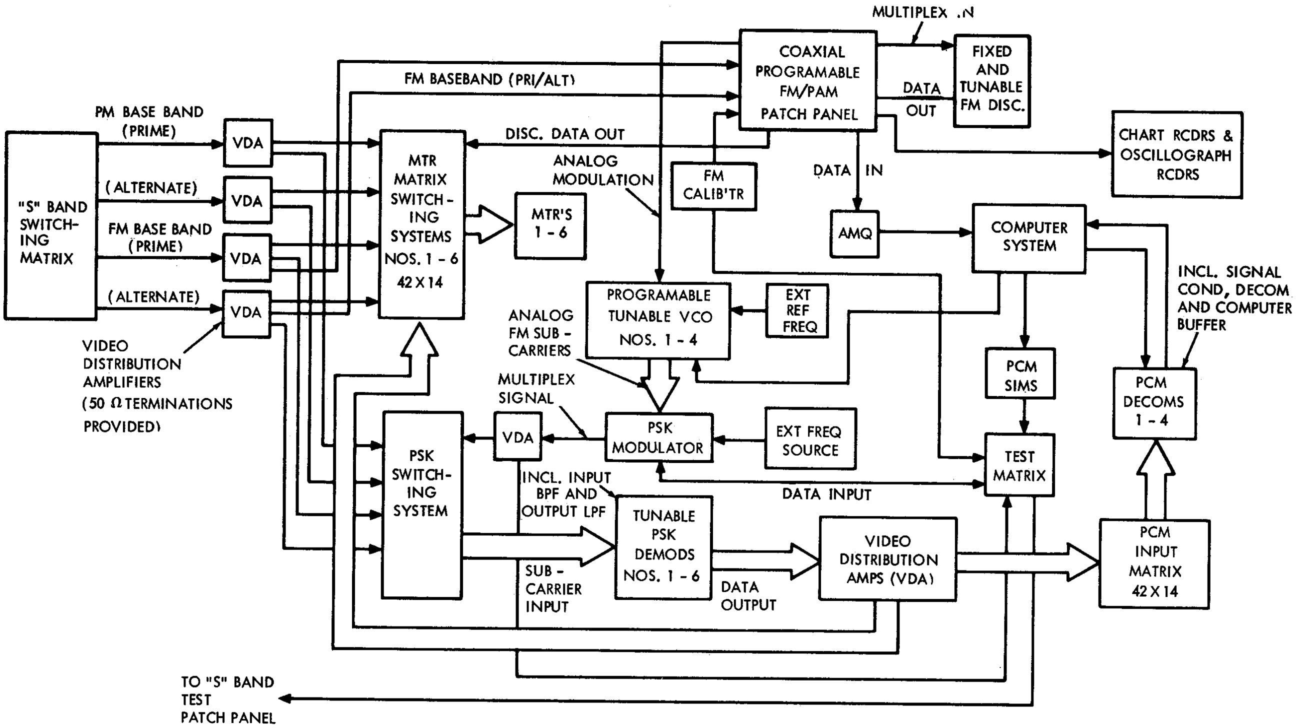
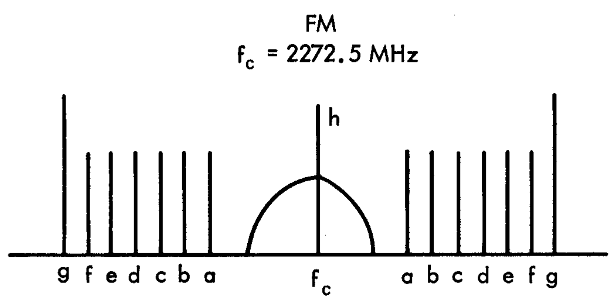


Figure 3-MSFN Telemetry System Configuration for the SDS and the Particles and Field Subsatellite



a = 165 kHz SDS DATA SUBCARRIER (1:1 DATA PLAYBACK) (4 kbs/biϕ- L/FM)

b = 225 kHz REAL-TIME SDS DATA SUBCARRIER (4 kbs/bi ϕ- L/FN)

c = 300 kHz SDS DATA SUBCARRIER (1:1 DATA PLAYBACK)

d = 400 kHz REAL-TIME SDS DATA SUBCARRIER

e = 576 kHz PLAYBACK OF 64 Kbps SDS PCM TELEMETRY AT 1:1 RATIO (PSK)

f = 768 kHz REAL-TIME SDS 64 kbs PCM TELEMETRY SUBCARRIER (PSK)

g = 1.024 MHz PLAYBACK OF 51.2 kbs CSM PCM TELEMETRY AT 1:1 RATIO (PSK)

h = PLAYBACK CM VOICE AT BASEBAND (1:1 PLAYBACK)

Figure 4-Scientific Data System (SDS) Frequency Spectrum

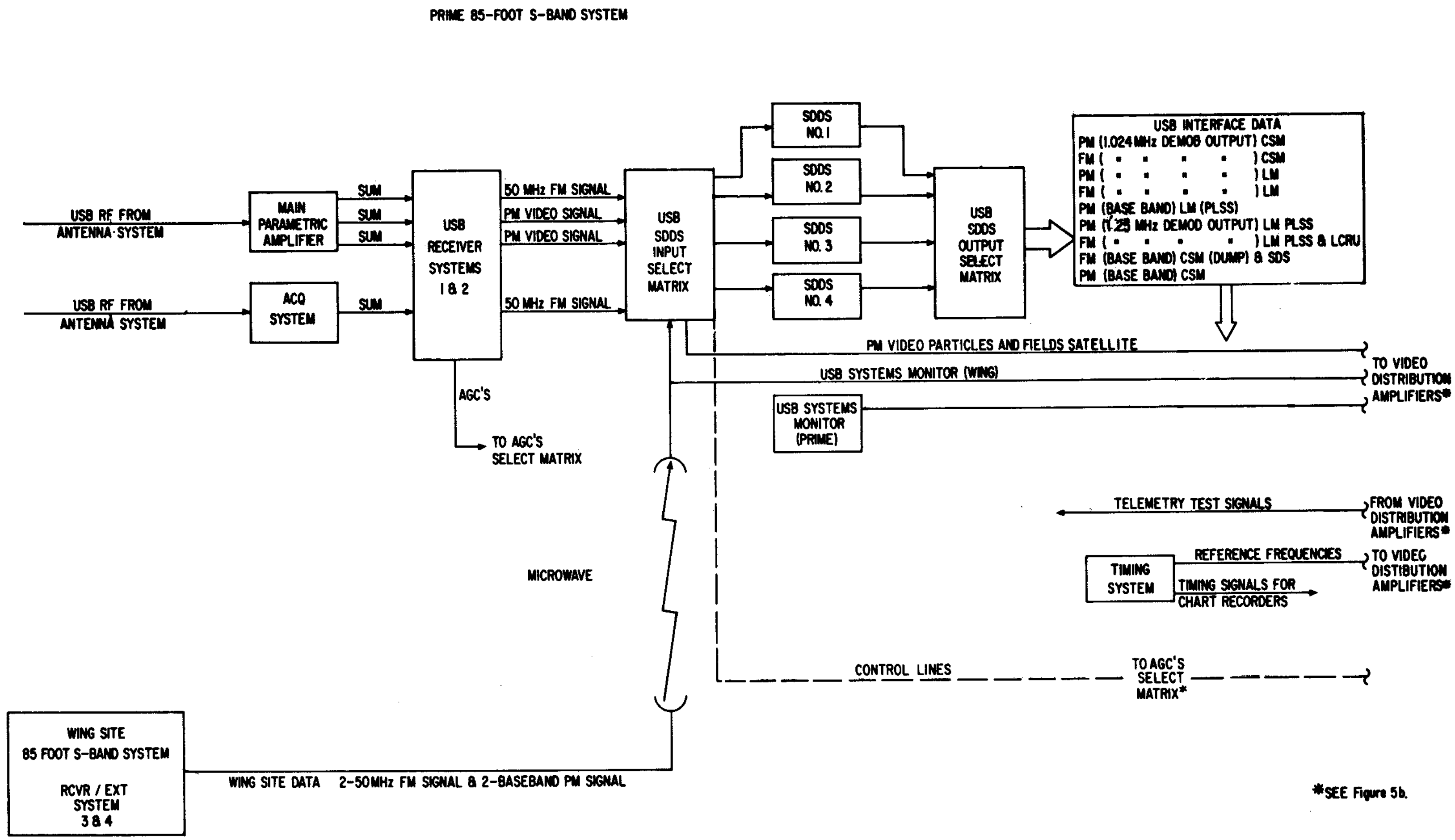
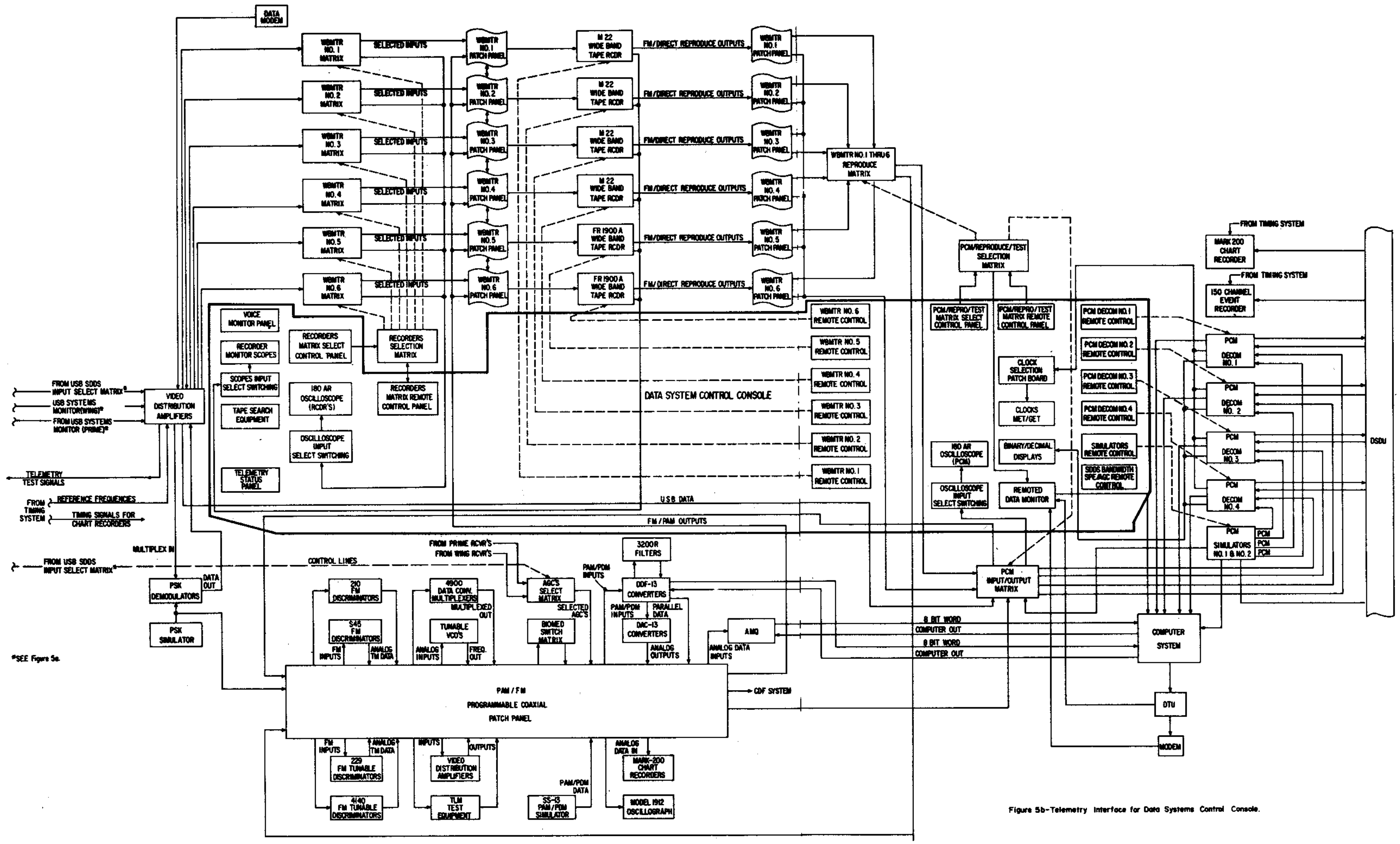


Figure 5a- Simplified Block Diagram of the Unified S-Band System, Showing the Telemetry Interfaces.

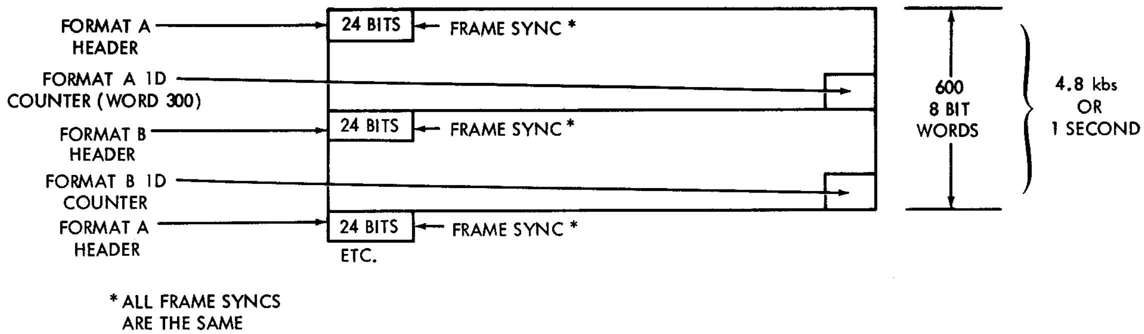


*SEE Figure 5a.

Figure 5b-Telemetry Interface for Data Systems Control Console.

Figure 6-MFSN Data Remoting Format.

Appendix 1



Description of RF Telemetry Equipment

Model R-1071A (Single Channel RF Telemetry Subsystem VHF Receiver). The R-1071A-1 has the following characteristics:

Tuning Range:	225 to 260 MHz.
Operating Modes:	Crystal, VFO, AFC, predetection record.
IF Bandwidth:	12.5 to 750 kHz.
Plug-ins:	IF units, demodulators, tuning heads, predetection down converters for FM and AM signals.
Signal Reception Capability:	All IRIG signals.

Model R-2074A-1 (Dual Channel for Diversity Reception). The characteristics of the R-2074A-1 are as follows:

Tuning Range:	225 to 260 MHz.
Operating Modes:	Crystal, VFO, AFC, predetection record and playback.
IF Bandwidth:	12.5 to 750 kHz.
Plug-ins:	IF units, demodulators, tuning heads, predetection playback converters for FM and AM signals.
Signal Reception Capability:	All IRIG signals.

VHF Signal Simulator Model TSS-507B This unit generates a composite VHF signal of one to ten discrete VHF frequencies in the IRIG telemetry band from 225 to 260 MHz. Variable attenuation of the combined frequency spectrum is available, with automatic stepping through preselected attenuation levels at known time intervals. The frequency stability is ±0.01% (within 20 seconds); the absolute accuracy is ±0.005% (within five minutes).

Diversity Combiner Model 5100A-1   This predetection/postdetection diversity combiner is capable of combining either two IF (pre-D) signals, or two video (post-D) signals. It provides down conversion of the two IF input signals to standard pre-D recording frequencies and a combined output at a pre-D recording frequency, as well as a complete up-converter/demodulator capability for either real-time monitoring of the recording process or subsequent playback of the recorded data. The signal-to-noise improvement is 2.8 db at high input signal levels.

Spectrum Display Unit Type 362B   This unit, designed to be used with the VHF telemetry receiver model R-2074, provides a visual.display of frequency versus relative amplitude of receiver signals on a cathode-ray tube, and aids in identifying and locating various interference sources. The response is variable to 4.0 MHz wide. Internal markers are provided.

Appendix 2
Description of the Telemetry Recorder Equipment

Recorder/Reproducer Model FR-1100/GS-80   This unit, used primarily for voice recording, can record and reproduce up to 14 tracks of data between 100 Hz and three kHz at 1-7/8 inches per second; and between 100 Hz and six kHz at 3-3/4 inches per second. The maximum recording time is six hours.

Magnetic Tape Recorder/Reproducer Model VR-3600   A multitrack IRIG wide band group H recorder/reproducer system. Each channel can be used for data. storage in the 400 Hz to 1.5 MHz frequency range using direct recording; or dc to 500 kHz using FM recording. Up to 14 channels can be utilized simultaneously. The available tape speeds are 120, 60, 30, 15, 7-1/2, and 3-3/4 inches per second.

Operations Monitor, 150-Channel   This unit accepts and displays 150 channels of “on-off” type data. Response is instant to 1.25 msec at maximum chart speed. The electric writing method uses a stationary metal stylus which remains in contact with electrosensitive chart paper; it is instantaneous, dry, and permanent.

Analog Recorder Model Mark 200   This unit is a 17-pen recorder with eight analog and nine digital event pens. The linear accuracy is ±0.5%; frequency response is flat to 55 Hz full scale; to 100 Hz at reduced amplitude. Chart speeds from 0.05 to 200 millimeters per second are available. System sensitivity is 50 millivolts per division maximum, and five volts per division minimum. The dc and ac linearity is 0.5%. Chart speed accuracy is 0.25%.

Tape Recorder/Reproducer Model M-25 This is a combined direct and FM record/reproduce system, capable of recording 14 tracks of analog data. Operating speeds are 60, 30, 15, and 7-1/2 inches per second. For the FM record/reproduce system, bandwidth limits are 0 to 2 kHz to 0 to 20 kHz ±.5 db; signal-to-noise ratio is 46 db, and the FM carriers are from 13.5 kHz to 108 kHz. For the direct record/ reproduce-system, signal-to-noise ratios are from 25 to 30 db, and frequency responses are from 150 Hz to 250 kHz, ±3 db.

Wideband Tape Recorder/Reproducer Model M-22 This is a multitrack IRIG wide band group II recorder, capable of recording and reproducing 14 channels of analog data from dc to 1.5 MHz. Tape speeds are 120, 60, 30, 15, 7-1/2, and 3-3/4 inches per second. The bandwidth limits are from 0 to 500 kHz, plus three db for the FM record/reproduce system, with a signal-to-noise ratio of 25 db and carriers from 28 to 900 kHz. For the direct record/reproduce system, the signal-to-noise ratio is 20 db, and frequency responses vary from 400 Hz to between 46 kHz and 1.5 MHz, ±3 db.

Appendix 3
Equipment Description of the PAM/PDM Telemetry Subsystem

The Model DDF-13 operates in conjunction with the 320OR filter, an adjustable, low-pass filter which operates with the DDF-13 signal-conditioning circuits for reducing high frequency noise that may be superimposed on the input signal. The DDF-13 is basically a telemetry synchronizer and data formatter. It receives analog time-division-multiplexed telemetry data (PAM/RZ, PAM/NRZ, or PDM) from subcarrier discriminators, signal simulators, or analog tape units; provides pulse, main frame, and subframe synchronization, and generates and formats digital outputs for various applications. An ancillary output (analog) is provided for oscillograph or bargraph display of the input telemetry pulse train.

The digital outputs generated by the DDF-13 are supplied to a PCM system, a computer, and a digital-to-analog converter. The serial PCM output is in NRZ format and contains a 16-bit synchronization code for channel correlation in the PCM system. Computer outputs consist of parallel data and status flags, designed for electrical compatibility with the MSFN computer system. Digital-to-analog converter outputs consist of parallel data accompanied by channel identification information, designed for compatibility with the DAC-13 digital-to-analog converter.

The DAC-13, operating in conjunction with the Model DDF-13 Digital Data Formatter, displays any DDF-13 main frame or subframe channel through each of the ten digital-to-analog converter channels. Binary data bits 1 to 512 from the DDF-13 are converted to analog outputs in the data conversion process. The DAC-13 can process main frame, subframe, and supercommutated data.

Signal Simulator SS-13   This unit generates PAM-RZ, PAM-NRZ, and PDM time-conditioned signals. These are in IRIG and special telemetry formats for checkout and calibration of the DDF-13 digital data formatter. The generated signals comprise a simulated telemetry pulse train whose channel rates are controllable from one pulse per second (pps) to 10,000 pps. The pulse train may be up to 999 channels long, with a subcommutated channel providing a subframe of up to 999 channels. Timing for all logical operations is based upon clock-generated pulses; clock rate is adjusted within a range of one pps to 10,000 pps.

Appendix 4
Systems Description of the FM Telemetry Subsystem

Data Converter/Multiplexer Model 4900 and Model FMT 500   This data converter/multiplexer system accepts analog voltage inputs and multiplexes these into groups of FM subcarrier frequencies for application to the recording or FM remoting equipment. Complete IRIG proportional bandwidth VCO's are available.

Tunable Discriminator Model 229   Model 229A-01 covers a range of frequencies from 300 Hz to 300 kHz. Subcarrier frequency deviation from the 300-11z to 300-kHz ranges are 7.5% and 15%.

Discriminator Model 210A   Electrical specifications are the same as for Model 229. Model 210A-04, with switchable deviation polarity, is used.

Discriminator Model S-45   The discriminator is designed to demodulate FM signals in the frequency range from 300 Hz to 300 kHz. It provides fixed-channel, pulse-averaging detection. Deviation polarity is switchable. Percentage deviation is shown on a meter; a lamp indicates a low input level. Carrier deviation is ±7.5 or 15%. Complete IRIG proportioned bandwidth frequencies are available.

Programmable Tunable Discriminator Model 4140   This discriminator is designed to process analog- or pulse-type intelligence contained in an FM subcarrier channel. Subcarrier center frequencies between 100 Hz and 1.5 MHz are selectable. Deviations of ±7.5, 15, 20, 30, and 40% are available with output frequencies from dc to 300 kHz, using a 7-pole filter.

Frequency Calibrator Model 8812   The frequency calibrator is designed to provide a complete frequency multiplex of IRIG channels, plus various non-IRIG frequencies. All channels within the multiplexes can be set to any one of five calibration points, or they can be sequenced through the five calibration points. Channel frequency range is 400 Hz to 1.6 MHz. Accuracy is to within ±0.001%.

Appendix 5
Equipment Description of the Digital Telemetry Subsystem

PCM Decommutator Model 200 (MSFTP-2)   This unit is a PCM data-handling system, whose major subsystems are: (1) a program controller subsystem, (2) a synchronization subsystem, (3) an output subsystem, and (4) signal conditioners. The unit accepts PCM input from telemetry receivers, PCM signal simulators, subcarrier discriminators, and magnetic tape recorder/reproducers. The input consists of information channels containing data that has been sampled (commutated) and encoded into a serial bit stream (binary coded digits). This serial bit stream experiences some degeneration in the transmission link and therefore must be regenerated in noise-free form before being decommutated. The unit regenerates the serial stream, and (1) synchronizes with the incoming data bit rate, (2) identifies word, frame, and subframe synchronization patterns, (3) checks parity of incoming data, and finally (4) decommutates the PCM data and presents selected data (in parallel) to the telemetry computer for processing. Stored program decommutation techniques provide this capability and the variety of formats and processing operations required. The unit provides reconstructed serial data and bit rate outputs suitable for recording on magnetic tape recorders.

The signal conditioner and bit synchronizer accept video PCM signal inputs of RZ, NRZ, and split-phase code forms. The unit accommodates bit rates from 1.0 bits per second (bps) to 1.0 megabit per second for NRZ codes, and from 150 to 500,000 bps for RZ and split-phase codes.

The synchronizer provides serial PCM output data, clock, and control signals compatible with the serial-to-parallel converter.

A serial-to-parallel converter receives compatible output signals from the signal conditioner and bit synchronizer unit, and operates directly with the stored program decommutator.

PCM Simulator Model 100   This unit generates PCM formats with known noise and distortion parameters and data content such as might be received from a telemetry receiver or from a magnetic tape recorder. The PCM data output may be conditioned to simulate noise, jitter, frequency deviations, dc offset, or baseline wander. PCM formats may be selected from ten programs stored in a magnetic core memory, or they may be manually programmed; they may test PCM data decommutation systems directly or remotely. Code types available: non return to zero common (NRZ-C); non return to zero mark (NRZ-M); non return to zero space (NRZ-S); return to zero (RZ); and split phase.

Analog Multiplexer Quantizer Model 101   An analog to digital converter with multiplexer, this unit is used to time-multiplex a maximum of 128 channels of data and to convert analog channels to equivalent eight-bit binary words. Analog input voltage range is from 0 to +10 volts.