TWG

DOCUMENT 106-65

TELEMETRY STANDARDS
(REVISED JULY 1965)

TELEMETRY WORKING GROUP
INTER-RANGE INSTRUMENTATION GROUP
RANGE COMMANDERS COUNCIL

NATIONAL RANGES

WHITE SANDS MISSILE RANGE
KWAJALEIN TEST SITE
PACIFIC MISSILE RANGE
AIR FORCE EASTERN TEST RANGE
AIR FORCE WESTERN TEST RANGE

SERVICE RANGES

NAVAL ORDNANCE TEST STATION
AIR PROVING GROUND CENTER
AIR FORCE FLIGHT TEST CENTER

DOCUMENT 106-65

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Incorporating
"Frequency Standards for Telemetry"
prepared by the
Frequency Coordination Working Group
Inter-Range Instrumentation Group

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A standard in the field of telemetry for guided missiles was established in 1948 by the Research and Development Board and was thereafter revised and extended as the result of periodic reviews by that agency. The last official RDB revision of the standard was published as MTRI 204/6, dated 8 November 1951.[1]

Since then, the Inter-Range Instrumentation Group (IRIG) has prepared new standards in telemetry. The Steering Committee representing IRIG and the Department of Defense test ranges assigned the task of promulgating new or revised telemetry standards to the Telemetry Working Group (TWG). This publication contains the current combined standards and supersedes the following IRIG documents:

101-55	Testing for Speed Errors in Instrumentation Type Magnetic Tape Recorders
102-55	Telemetry Standards for Guided Missiles
103-56	Revised Telemetry Standards for Guided Missiles
101-57	Magnetic Recorder/Reproducer Standards
102-59	Standards for Pulse Code Modulation (PCM) Telemetry
101-60	Magnetic Recorder/Reproducer Standards
106-60	IRIG Telemetry Standards (November 1960)
106-60	IRIG Telemetry Standards (Revised June 1962)

Advances in the state of the art of telemetry are evidenced in the development of equipment and techniques which have enabled extended performance beyond that defined in prior revisions of these standards. It is the purpose of this revision to delineate the obtainable performance of modern telemetry systems within the limits of practical design and use. These standards, therefore, do not necessarily define the existing capability of any test range but rather constitute a guide of the implementation and orderly application of telemetry systems for both the ranges and range users within the limits of good design practice.

The broader range of capabilities attainable under these standards require more careful consideration of tradeoffs (e.g., frequency response versus accuracy) than heretofore. Guidance to the user in this consideration is provided in the appropriate appendices to these standards.

These telemetry standards were established to further the compatibility of airborne transmitting equipment and ground receiving and data-handling equipment at the test ranges. To this end, the Range Commanders recommend that telemetry equipment at the test ranges conform to the standards presented here.

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[1] In 1951, the RDB was succeeded by the Office of the Assistant Secretary of Defense (Research and Development).

The quality of terminal equipment in general will be raised by concentrating development on a minimum of system types. Research should be continued, however, on telemetry systems that may offer substantial improvements over those described in this document.

Agencies proposing to use equipment that deviates from these standards will be required to show that their proposed action is both technically necessary and economically feasible.

To ensure that the standards remain current, the Telemetry Working Group will review them at each meeting, and will revise them as required.

It is worthy of note that this revision of IRIG Telemetry Standards expands the capabilities in both frequency division Multiplex Systems and Recorder/Reproducers.

Frequency standards formerly contained in IRIG Recommendation Number 101-59 revised September 1961 have been revised by the Frequency Coordination Working Group with the assistance of the Telemetry Working Group and are included as Section I.

The Electronics Systems Division (ESD), USAF, is the responsible agency for preparation and future revision of a Military Standard for Aerospace Telemetry which is scheduled for completion by December 1965. The initial version will include many of the provisions of IRIG Document 106-65 and will be coordinated with IRIG and the Telemetry Standards Coordinating Committee (NTC-TSCC). The final document will be a Department of Defense approved standard issued as MIL-STD 442.

1. FREQUENCY STANDARDS

1.1 General

1.1.1 This section replaces IRIG Frequency Standards for Telemetry, as stated in IRIG Recommendation Nr 101-59, previously published as Appendix I to IRIG Document 106-60. These parameters and criteria were devised by the Frequency Coordination Working Group of the Inter-Range Instrumentation Group, with the assistance of members of the Telemetry Working Group and development groups of the three military services and aircraft industries. The purpose of these parameters is to provide development and coordination agencies with design specifications on which to base equipment development and modification; the specific intent being to insure interference-free operation for all concerned and an efficient utilization of the telemetry radio-frequency spectrum.

1.1.2 The frequency spectrum is a limited entity, a natural resource that must be conserved. Frequency utilization is a system problem; the transmitter-receiver link must be considered as a system. Efficiency of spectrum utilization must be a goal; susceptibility to interference must be minimized.

1.1.3 Wasteful use of the spectrum by any system using electromagnetic radiation and reception can have adverse effects on military and civil activities. Spectrum conservation must be recognized and applied by all agencies in the electronics field (designers, manufacturers, testers, and users).

1.1.4 Throughout this document, in specifying RF bandwidths, the transmitter and receiver shall be considered as a system. The designer will be required to adhere to rigid engineering design practices to conserve the frequency spectrum. Each system will be subjected to a critical review with respect to the amount of information contained in a given bandwidth versus the type of modulation. The user will be required to demonstrate and prove the system design to frequency management personnel to justify the use of the frequency spectrum.

1.1.5 These parameters and criteria have been devised for application at military test ranges where congestion of the usable frequency spectrum is a severe problem. It is hoped that, where applicable, these same principles will be applied to other fields outside the scope of instrumentation systems.

1.2 Frequency Parameters and Criteria for Design of Telemetry Transmitter and Receiver Systems (Covering all systems in this document)

1.2.1 Frequency Band 216 to 260 Megacycles:

1.2.1.1 216 to 225 Mc/s: Channel spacing is based on 0.5 Mc/s separation on the integral and one-half-megacycle channels; assignments are made on a non-interference basis to established services.

1.2.1.2 225 to 260 Mc/s: Forty-four 500 kc/s channels are allocated on a primary basis until 1 January 1970.

TABLE 1-1
RF TELEMETRY ASSIGNMENTS

Systems shall be capable of operating on any of the following frequencies without design modification (all given in Mc/s):[1]

216.5	223.0	228.2	237.8	248.6
217.0	223.5	229.9	240.2	249.1
217.5	224.0	230.4	241.5	249.9
218.0	224.5	230.9	242.0	250.7
218.5	225.0	231.4	243.8	251.5
219.0		231.9	244.3	252.4
219.5		232.4	244.8	253.1
220.0		232.9	245.3	253.8
220.5	225.7	234.0	245.8	255.1
221.0	226.2	235.0	246.3	256.2
221.5	226.7	235.5	246.8	257.3
222.0	227.2	236.2	247.3	258.5
222.5	227.7	237.0	247.8	259.7

[1] Telemetry assignments of TABLE 1-1 will be completely removed from this band by 1 January 1970.

1.2.1.3 Transmitter Systems

1.2.1.3.1 Frequency Tolerance: The transmitted RF carrier considering variables such as operating time, supply voltage, temperature, acceleration, vibration, and shock, will be within 0.01 percent of the assigned carrier frequency.

1.2.1.3.2 Power: The maximum allowable power shall be 100 watts; the power used should never be more than absolutely necessary for reliable telemetry transmission.

1.2.1.3.3 Spurious Emmission and Interference Requirements: (Using test methods and equipment in accordance with current MIL-I-26600)

1.2.1.3.3.1 Spurious Emission (Antenna Conducted or Antenna Radiated - 0.150 to 10,000 Mc/s): Emissions from the transmitter-antenna system are of primary importance. Spurious and harmonic outputs, antenna-conducted (i.e., measured in the antenna transmission line) or antenna-radiated (i.e., measured in free space), shall be limited to the values derived from the formula:

$$\text{db (down from unmodulated carrier)} = 55 + 10 \log_{10} P_t,$$

where P_t is the measured output power in watts

NOTES:
1. This limits all conducted spurious and harmonics to a maximum power level of -25 dbm.

2. Radiated tests will only be used when the transmission line is inaccessible for conducted measurements.

3. Conducted or radiated spurious emissions will be checked under modulated conditions.

1.2.1.3.3.2 Interference (Conducted or Radiated): All interference voltages (0.150 to 25 Mc/s) conducted by the power leads and interference fields (0.150 to 10,000 Mc/s), radiated directly from equipment, units, or cables, shall be within the limits specified by the current MIL-I-26600.

1.2.1.3.4 Bandwidth: The 40 db bandwidth of the modulated carrier, referenced to the unmodulated carrier shall not exceed 640 kc/s (±320 kc/s). Carrier components appearing outside a 1.0 Mc/s (±500 kc/s) bandwidth shall meet the limits for spurious and harmonic emissions, as stated in paragraph 1.2.1.3.3.1.

1.2.1.4 Receiver Systems:

1.2.1.4.1 Spurious Emissions (0.150 to 10,000 Mc/s): RF energy, both radiated from the unit and antenna-conducted, shall be within the limits specified in the current MIL-I-26600.

1.2.1.4.2 Interference Protection: Radio frequency interference protection will be provided only for systems using receivers which meet the following criteria:

1.2.1.4.2.1 Frequency Stability: Shall be 0.001 percent or better.

1.2.1.4.2.2 Spurious Responses (0.150 to 10,000 Mc/s): Shall be more than 60 db below the fundamental frequency response.

1.2.1.4.2.3 Flexibility of Operation: The system shall operate on any of the frequencies listed under paragraph 1.2.1 without design modification.

1.2.1.4.2.4 Bandwidth: A maximum bandwidth of 1.2 Mc/s (±600 kc/s) as referenced to the 60 db points will be permitted.

1.2.2 Frequency Bands 1435-1540 Mc/s and 2200-2300 Mc/s:

1.2.2.1 The band 1435-1540 Mc/s is nationally allocated to Government and non-Government telemetry use on a shared basis. Telemetry assignments will be made therein for flight testing[1] of manned and unmanned aircraft, missiles, space vehicles or major components thereof, as described below:

1.2.2.1.1 1435-1485 Mc/s: Narrowband channel spacing is in increments of 1 Mc/s beginning with the frequency 1435.5 Mc/s. Wideband channels are permitted. They will be centered on the center frequency of narrowband channels. Use of these channels is primarily for flight testing of manned aircraft, and secondarily for flight testing of unmanned aircraft and missiles or major components thereof.

1.2.2.1.2 1485-1535 Mc/s: Narrowband channel spacing is in increments of 1 Mc/s beginning with 1485.5 Mc/s. Wideband channels are permitted. They will be centered on the center frequency of narrowband channels. Use of these channels is primarily for flight testing of unmanned aircraft and missiles or major components thereof, and secondarily for flight testing of manned aircraft. Channels between 1525-1535 Mc/s may also be employed for space telemetry on a shared basis.

1.2.2.1.3 1535-1540 Mc/s: Channels in this band are for exclusive space purposes.

1.2.2.2 In the 2200-2300 Mc/s band, assignments will be made for telemetering other than flight testing of manned aircraft as described below:

1.2.2.2.1 2200-2290 Mc/s: Narrowband channel spacing is in increments of 1 Mc/s beginning with 2200.5 Mc/s. Wideband channels are permitted. They will be centered on the center frequency of narrowband channels. Use of these channels is on a co-equal shared basis with government fixed and mobile communications. Telemetering use of these channels includes telemetry associated with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles, irrespective of their trajectories.

1.2.2.2.2 2290-2300 Mc/s: Use of this band is for deep space telemetry exclusively.

1.2.2.3 Transmitter Systems:

1.2.2.3.1 Frequency Tolerance: The transmitted RF carrier, considering variables such as operating time, supply voltage, temperature, acceleration, vibration, and shock, will be within 0.005 percent of the assigned carrier frequency.

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[1] Flight testing telemetry is defined as telemetry which is used in support of research, development, test and evaluation, and which is not integral to the operational function of the system.

1.2.2.3.2 Power: The power shall be as directed by the intended use, never more than absolutely necessary.

1.2.2.3.3 Spurious Emission and Interference Requirements: (Using test methods and equipment in accordance with current MIL-I-26600.)

1.2.2.3.3.1 Spurious Emission (Antenna Conducted or Antenna Radiated - 0.150 to 10,000 Mc/s): Emissions from the transmitter-antenna system are of primary importance. Spurious and harmonic outputs, antenna-conducted (i.e., measured in the antenna transmission line) or antenna-radiated (i.e., measured in free space), shall be limited to the values derived from the formula:

$$\text{db (down from unmodulated carrier)} = 55 + 10 \log_{10} P_t,$$

where P_t is the measured output power in watts.

NOTES:
1. This limits all conducted spurious and harmonics to a maximum power level of -25 dbm.
2. Radiated tests will only be used when the transmission line is inaccessible for conducted measurements.
3. Conducted or radiated spurious emissions will be checked under modulated conditions.

1.2.2.3.4 Flexibility of Operation: The transmitter shall be capable of operating throughout the entire frequency band from 1435 to 1540 Mc/s and/or 2200 to 2300 Mc/s, without design modification.

1.2.2.3.5 Bandwidth:

1.2.2.3.5.1 For a nominal 1 Mc/s channel spacing, a maximum bandwidth of 1.2 Mc/s (± 600 kc/s) as referenced to the 60 db points will be permitted.

1.2.2.3.5.2 Wider band systems will be permitted to use transmitter bandwidths of 2.2, 3.2, 4.2, etc., Mc/s as referenced to the 60 db points. Assignments will be made on an individual requirement basis.

1.2.2.4 Receiver Systems:

1.2.2.4.1 Spurious Emissions (0.150 to 10,000 Mc/s): RF energy, both radiated from the unit and antenna-conducted, shall be within the limits specified in the current MIL-I-26600.

1.2.2.4.2 Interference Protection: Radio frequency interference protection will be provided only for systems using receivers which meet the following criteria:

1.2.2.4.2.1 Frequency Stability: Shall be 0.001 percent or better.

1.2.2.4.2.2 Spurious Responses (0.150 to 10,000 Mc/s): Shall be more than 60 db below the fundamental frequency response.

1.2.2.4.2.3 Flexibility of Operation: The system shall be tunable over the entire 1435 to 1540 Mc/s band and/or 2200 to 2300 Mc/s band, without design modification, and will have variable bandwidth selection.

1.2.2.4.2.4 Bandwidth:

1.2.2.4.2.4.1 For a nominal 1 Mc/s channel spacing, a maximum bandwidth of 1.2 Mc/s (±600 kc/s) as referenced to the 60 db points, will be permitted.

1.2.2.4.2.4.2 Wider band systems will be permitted to use bandwidths of 2.2, 3.2, 4.2, etc., Mc/s, as referenced to the 60 db points. Assignments will be made on an individual requirement basis.

Section 2

Section 2 of the standards is undergoing further revision, which is expected to be completed in approximately six months. Items under consideration are: the use of higher frequency subcarriers, the use of constant bandwidth subcarriers, and the use of greater subcarrier deviations.

2. FREQUENCY DIVISION MULTIPLEXING TELEMETRY STANDARDS (FM/FM and FM/PM)

2.1 General

In these systems one or more frequency modulated subcarriers, each at a different frequency, are employed to modulate a frequency modulated (FM) or phase modulated (PM) transmitter in accordance with the RF conditions specified in section 1.

Each of the subcarriers is frequency modulated in a manner determined by the intelligence to be transmitted by that channel. In order to greatly increase the number of data channels, one or more of subcarrier channels may be modulated by time division multiplex schemes such as PAM, PDM, or PCM as specified in sections 3, 4, or 5.

The required modulation baseband capability of FM/FM or FM/PM telemetry systems is from 340 c/s to 110 kc/s or better.

2.2 Subcarrier Channels

Table 2-1 lists nineteen standard FM subcarrier center frequencies that shall be used together with their maximum deviation and with their nominal frequency response and rise time. The theoretical maximum channel frequency response and minimum rise time that can be approached is also listed. (See Appendix II for the expected trade-offs of channel response for improved signal to noise ratio, reduced distortion, etc., by limiting the channel response to the nominal values indicated in Table 2-1.)

2.2.1 Channel Response Capability

While the use of subcarrier deviation ratios as low as one are possible as indicated in Table 2-1, lower deviation ratios are not considered practicable due to the excessive attenuation produced on the modulation frequencies in the discriminator bandpass filters. Deviation ratios of 5 as indicated for the nominal channel response will yield telemetered data that is less subject to dynamic distortion transmission system noise due to weak signals, and intermodulation occuring in the transmission and recording system. The choice of deviation ratio to be used in a given system should be based on the specific needs of its application. (See Appendix II)

TABLE 2-1 SUBCARRIER BANDS

±7.5% CHANNELS

Channel	Center Frequencies (c/s)	Lower Limit* (c/s)	Upper Limit* (c/s)	Nominal Frequency Response (c/s)	Nominal Rise Time (ms.)	Maximum Frequency Response** (c/s)*	Minimum Rise Time** (ms.)
1	400	370	430	6	58	30	11.7
2	560	518	602	8	42	42	8.33
3	730	675	785	11	32	55	6.40
4	960	888	1,032	14	24	72	4.86
5	1,300	1,202	1,398	20	18	98	3.60
6	1,700	1,572	1,828	25	14	128	2.74
7	2,300	2,127	2,473	35	10	173	2.03
8	3,000	2,775	3,225	45	7.8	225	1.56
9	3,900	3,607	4,193	59	6.0	293	1.20
10	5,400	4,995	5,805	81	4.3	405	.864
11	7,350	6,799	7,901	110	3.2	551	.635
12	10,500	9,712	11,288	160	2.2	788	.444
13	14,500	13,412	15,588	220	1.6	1,088	.322
See Paragraph 2.2.2							
14	22,000	20,350	23,650	330	1.1	1,650	.212
15	30,000	27,750	32,250	450	.78	2,250	.156
16	40,000	37,000	43,000	600	.58	3,000	.117
17	52,500	48,562	56,438	790	.44	3,938	.089
18	70,000	64,750	75,250	1050	.33	5,250	.067
19	93,000	86,025	99,975	1395	.25	6,975	.050
See Paragraph 2.2.3							

±15% CHANNELS

A***	22,000	18,700	25,300	660	.53	3,300	.106
B	30,000	25,500	34,500	900	.39	4,500	.078
C	40,000	34,000	46,000	1200	.29	6,000	.058
D	52,500	44,625	60,375	1575	.22	7,875	.044
E	70,000	59,500	80,500	2100	.17	10,500	.033
F	93,000	79,050	106,950	2790	.13	13,950	.025

* Rounded off to nearest c/s.

** The indicated maximum frequency response and minimum rise time is based upon the maximum theoretical response that can be obtained in a bandwidth between the upper and lower frequency limits specified for the channels. (See paragraph 2.2.1 and referenced discussion in Appendix II for determining practical transmission system accuracies.)

*** Bands A thru F are optional and may be used by omitting adjacent lettered and numbered channels. Channels 13 and A may be used together with some degradation in adjacent channel interference. The recording of channel A and the 17 kc/s tape speed control signal on a given tape track is not permitted. (See section 2.2.2 and 6.3.6.2)

2.2.2 Subcarrier Channel Spacing

The 19 subcarrier channels of Table 2-1 were chosen to make the best use of present equipment and the modulation base band capability. There is a ratio of approximately 1.33 to 1 between the center frequencies of adjacent bands, except between 14.5 kc/s and 22 kc/s where a larger gap is left to provide a 60 c/s amplitude modulated 17 kc/s carrier for capstan speed control of magnetic-tape recorders. (See Section 6.3.6.2 of these standards.) The use of an additional FM subcarrier between 14.5 kc/s and 22 kc/s is not considered practical or permissible.

2.2.3 Tape Speed Compensation

Tape speed error compensation systems capable of compensating for speed errors throughout the subcarrier data frequency range require a compensation channel at least as wide as the widest subcarrier data channel. For systems using subcarriers up to 70 kc/s, a 100 kc/s reference signal recorded on the tape is standard. Other compensation reference signals of 50 kc/s or 25 kc/s may be employed when sufficiently low frequency subcarriers are employed. A 200 kc/s reference signal shall be used when channel 19 or F is employed with an intermediate or wideband tape recorder. If channel 19 or F is to be recorded on a low band recorder, a 100 kc/s reference will be recorded on a separate tape track. (See Section 6.3.6.3) If the transmission system includes a tape recorder with 100 kc/s compensation reference, channel 19 (93 kc/s) cannot be used. If only a ground recorder is employed in the system, the compensation reference is normally recorded on a separate tape track from the data.

SECTION 3

Section 3 of the standards is undergoing revision which is expected to be completed in approximately six months.

3. PDM/FM OR PDM/PM OR PDM/FM/FM STANDARD

3.1 General

The pulse-duration-modulation (PDM) systems are intended for use where a time-division multiplex system can meet the bulk of the telemetry requirements of a given application. A relatively large number of information channels can be accommodated, but with a relatively low frequency response capability in comparison with the subcarrier channels of the FM/FM system.

3.2 PDM/FM or PDM/PM[1]

The following are the specifications for the PDM signal:

Number of samples per frame*	30	45	60	90
Frame rate (frames per second)	30	20	15	10
Commutation rate (samples per second)**	900	900	900	900

Notes: *The number of samples per frame available to carry information is two less than the number indicated, because the equivalent of two samples is used in generating the frame-synchronizing pulse.

**Frame rate times number of samples per frame.

The amplitude of the measurands being transmitted in each channel shall determine the duration of the corresponding pulses. The relation between measurands and pulse duration should, in general, be linear.

Minimum pulse duration (zero level information)	90 ± 30 microseconds
Maximum pulse duration (maximum level information)	700 ± 50 microseconds
Pulse rise and decay time (measured between 10% and 90% levels)	10 to 20 microseconds (constant to ± 1 microsecond for a given transmitting set)

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[1] Use of PDM/PM requires the use of equipment to reshape the receiver output signal for proper operation of many display scopes, decommutators and tape recorder/reproducers. PDM/FM is recommended over PDM/PM.

3.2.1 The time interval between the leading edges of successive pulses within a frame shall be uniform from interval to interval within ±25 microseconds. This time interval shall have a nominal period equal to 1 divided by the total sampling rate.

3.2.2 The commutator speed or frame rate shall not vary more than plus 5.0 percent to minus 15.0 percent from nominal.

A frame-synchronizing interval equal to two successive pulse time intervals shall exist in the train of pulses transmitted, to be used for synchronization of the commutator and the decommutator. A representation of the pulse train waveform is shown in Figure 3-1.

3.3 PDM/FM/FM

PDM systems may also be employed on the ±15 percent deviation channels of the standard FM/FM multiplex systems. When so used, they are designated PDM/FM/FM telemetry. It should be recognized that this application of PDM is wasteful of bandwidth and that it places three wide-band-modulation systems in cascade. Gaussian-type-output low-pass filters should be used at the subcarrier discriminator outputs for this application.

3.3.1 Subcarrier Channels: The recommended subcarrier channels for this application are bands B, C, D or E. Operating criteria for use of these specific bands are shown in Table 3-1. Satisfactory performance is contingent upon the use of optimum-output low-pass filters.

3.3.2 Time-Interval Variation Between Leading Edges of Successive Pulses: Section 3.2.1 shall apply.

3.3.3 Commutation Speed: Section 3.2.2 shall apply.

3.4 In-Flight Zero and Full-Scale Calibration

On all PDM commutators, channels 1 and 2, following the synchronizing pulse, are recommended for zero and full-scale calibration, respectively.

TABLE 3-1 PDM MODULATION OF FM/FM SUBCARRIER CHANNELS*

Samples per second	Channel allocation	FM/FM channel (kcps)	Deviation utilized (percent)	Recommended value of minimum pulse length (microseconds)
900	B	30.0	±7.5	200 + 30 - 0
900	C	40.0	±7.5	170 + 30 - 0
900	D	52.5	±7.5	150 + 30 - 0
900	E	70.0	±7.5	110 + 30 - 0

Note: *Institute of Radio Engineers, "The Transmission of Pulse Width Modulated Signals over Restricted Bandwidth Systems", IRE Transaction on Telemetry and Remote Control, Vol. TRC-3, No. 1, April 1957.

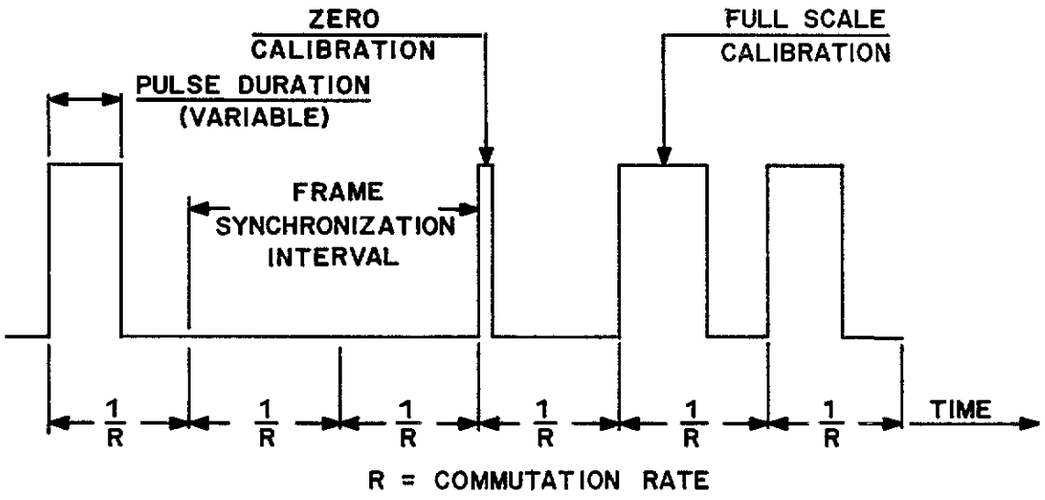

FIGURE 3-1 PDM PULSE TRAIN WAVEFORM

SECTION 4

Section 4 of the Standards is undergoing revision which is expected to be completed in approximately six months.

4. PAM/FM STANDARDS

4.1 General

Pulse amplitude modulation (PAM) data specified in these standards shall be transmitted as time division multiplexed analog sample pulses.

This standard defines recommended operating parameters and design practices insuring efficient and reliable performance for the implementation of Pulse Amplitude Modulation (PAM) telemetry systems. Reasonable latitude is provided for moderate variation about theoretical optimal configurations, where such is justified by practical considerations. Attention is also directed to Standards for PAM/FM/FM Systems in Section 4.9.

4.2 IF Bandwidth and Transmitter Deviation[1]

4.2.1 Selection of the design IF bandwidth (exclusive of the band shift factor) to be used should be guided by the permissible RMS error at minimum required receiver power. See Figure 4-1. A total sampling rate shall be used which lies in the range of 1/2-1/7 times the actual receiver IF bandwidth (3 db points) divided by the IF Bandshift factor (1.5 - 3.3).

4.2.2 The peak-to-peak frequency deviation shall not exceed 0.75 times the design IF bandwidth selected in accordance with paragraph 4.2.1.

4.2.3 The actual receiver IF bandwidth shall be between three (3) and twenty-three (23) times the total sampling rate. This includes a system IF band shift factor (1.5 - 3.3). Selection of receiver intermediate frequency (IF) bandwidth (3 db points) shall be from the set of discrete bandwidths listed in Table 4-1.

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[1] See Appendix IV, Section 1, for additional information.

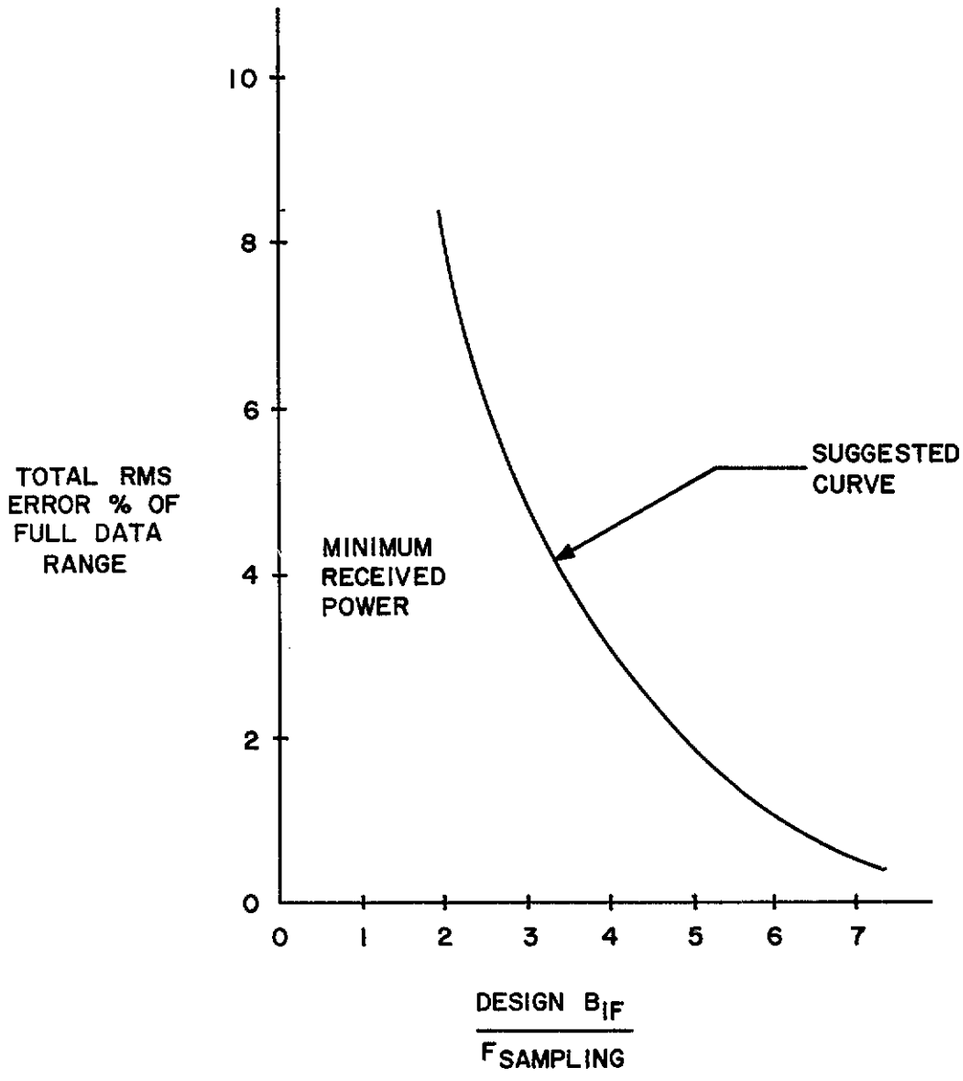

FIGURE 4-1 DESIGN IF BANDWIDTH
SAMPLING FREQUENCY VS ERROR AT MINIMUM REQUIRED RECEIVER POWER

TABLE 4-1
PAM/FM RECEIVER IF BANDWIDTHS

List of Receiver IF Bandwidths (3 db points; c/s)

12,500*
25,000*
50,000*
100,000
300,000
500,000
1,000,000**
1,500,000**

*For use only under special conditions. See Appendix V, Section 1.2.

**For use in the 1435-1535 Mc/s and 2200-2300 Mc/s telemetry frequency bands only.

4.3 Sampling Rate Stability

The long term stability of the sampling rate shall be one percent or better of the specified nominal sampling rate measured over any consecutive N samples, where N is the number of samples closest to 1000 within an integral number of frames. Within any period of N consecutive samples, no data pulse shall deviate from its average position, measured over that period, by more than five percent of a PAM sample period (T). See Figure 4-2.

4.4 Frame and Pulse Structure

4.4.1 The number of primary channels, including those assigned to synchronization signals shall not exceed 130 (frame length).

4.4.2 The sample pulses generated for transmission shall have a duty cycle of either 50 percent ±5 percent or 100 percent ±5 percent. See Figures 4-2, 4-3, 4-4 and 4-5, and Appendix IV, Section 2 for additional information.

4.5 Synchronization

Each frame shall be identified uniquely by the transmission of a pulse amplitude assigned to synchronization, or by means of a binary code word as illustrated in Figures 4-2, 4-3, 4-4, and 4-5. See Appendix IV, Section 3, for additional information and discussion of binary code words.

The maximum length of the code word when used shall not exceed 33 times the period of time defined by the duration of the individual pulses comprising the code word. The time duration of the pulses comprising the synchronizing code word shall evenly divide the duration of the one or more PAM sample pulse periods occupied by the code word. The minimum duration of the pulses comprising the code word is defined as 1/M times the data sampling period, where M is the largest integer not in excess of the design IF bandwidth divided by the total sampling rate.

4.6 Super-Commutation and Sub-Commutation

4.6.1 Super-commutation and sub-commutation are acceptable methods of exchanging the number of measurements and sampling rates. A unique synchronization pattern shall be used to indicate the beginning of the longest sub-commutated frame. All other sub-commutated frames with shorter lengths shall be integral sub-multiples of the longest frame and shall have a fixed and known relative phase with respect to the longest sub-commutated frame.

4.6.2 The longest sub-commutated frame shall not exceed 130 channels, including the channels used for synchronization.

4.7 Pre-Modulation Filtering

Pre-modulation filtering shall be used in the transmitter to obtain an overall radiated spectrum which does not exceed the system design IF bandwidth. The amplitude of the power spectrum of the radiated signal outside the design IF bandwidth shall not exceed one percent of the unmodulated carrier amplitude.[2]

4.8 RF Carrier Modulation

Frequency modulation of the radio frequency carrier shall be used. Transmission of frame and channel synchronizing code pulses when used shall be such that the carrier is deviated to the higher frequency deviation limit to transmit a "one" and to the lower frequency deviation limit to transmit a "zero". Once a frequency deviation limit is reached for either a "one" or a "zero", the resulting frequency shall remain essentially constant for consecutive like bits. See Figures 4-3 and 4-5.

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[2] See Appendix IV, Section 4, for recommended filter characteristic. The requirements of the Frequency Standards shall be met. (See Section 1)

4.9 PAM/FM/FM Commutation

Commutation (time-division multiplexing) may be used in one or more subcarrier bands. A nearly limitless variety of commutation schemes could be devised, but a few relatively simple methods will satisfy most telemetry needs. The specifications listed below for commutation were chosen to give maximum flexibility consistent with presently available equipment and techniques, and it is intended that, in order to limit the varieties that must be handled at test ranges, the following restrictions on commutation be observed:

4.9.1 The total number of samples per frame (number of segments of a mechanical commutator) and the frame rates shall be one of the combinations shown in Table 4-2. If a higher commutation rate is required for certain information, two or more samples per frame (equally spaced in time) can be used to represent one telemetered function at the expense of the total number of information channels. This process is referred to as cross-strapping or supercommutation.

4.9.2 The commutation pattern in the subcarrier frequency vs. time domain shall be as shown in Figure 4-6.

4.9.3 A frame-synchronizing pulse of full-scale amplitude and duration equal to two "on" periods plus one "off" period shall be provided once every frame, as shown in Figure 4-6.

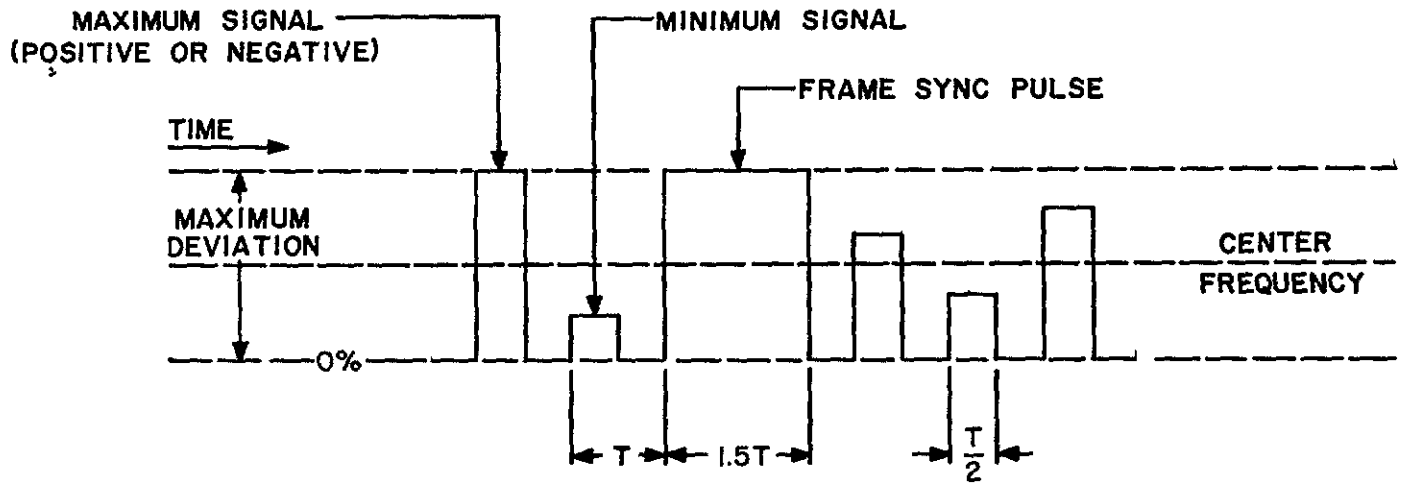
4.9.4 The commutator speed (or frame rate) shall not vary more than +5.0 percent to -15 percent from the nominal values given in Table 4-2.

4.9.5 The duty cycle shall be 40 percent to 65 percent.

4.9.6 A channel synchronization pedestal is required for automatic decommutation (See Figure 4-6).

4.10 In-Flight Zero and Full-Scale Calibration

On all pulse-amplitude-modulation (PAM) commutators, channels one and two, following the synchronizing pulse, are recommended for zero and full-scale calibration, respectively.



20 to 25% of deviation is reserved for channel synchronization.

Channel synchronization is recommended but not required.

If the 20 to 25% deviation is not used for synchronization, minimum signal would correspond to the opposite deviation extreme from maximum signal.

FIGURE 4-2 PAM PULSE TRAIN WAVEFORM, CONVENTIONAL FRAME SYNCHRONIZATION 50 PERCENT DUTY CYCLE

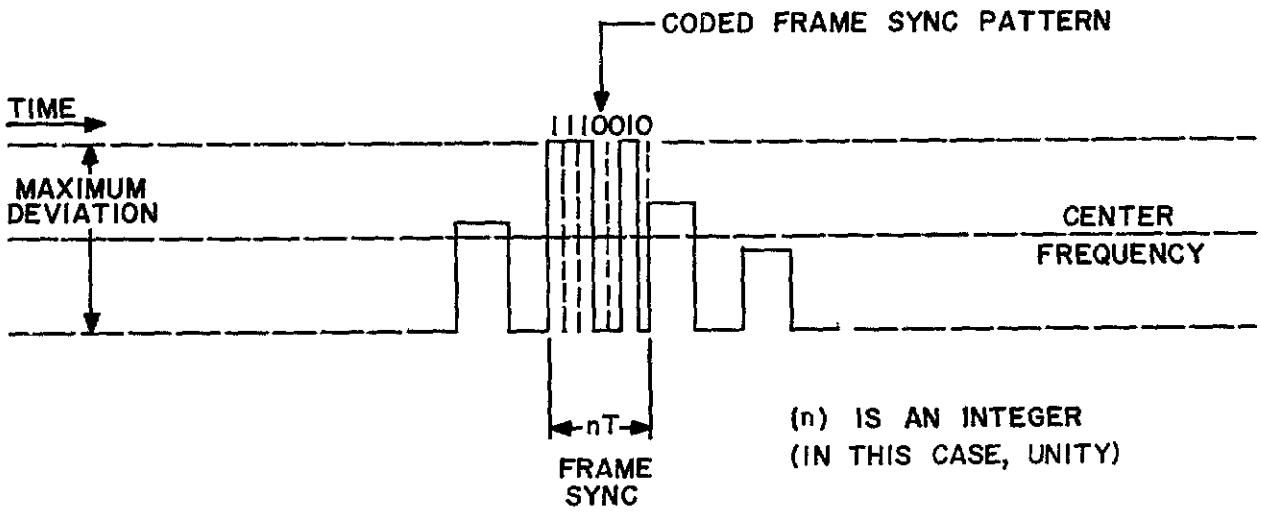


FIGURE 4-3 PAM PULSE TRAIN WAVEFORM, CODED FRAME SYNCHRONIZATION 50 PERCENT DUTY CYCLE

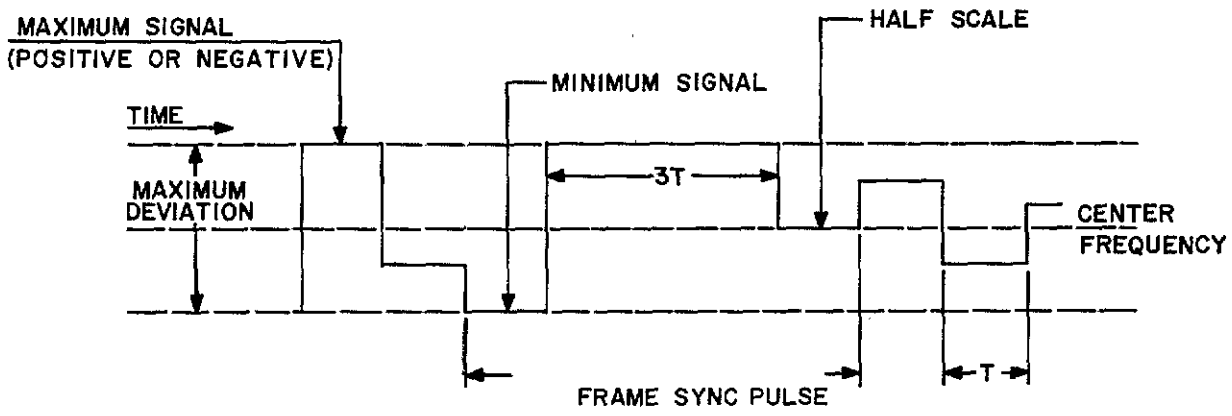


FIGURE 4–4 CORRECTED PAM PULSE TRAIN WAVEFORM, CONVENTIONAL FRAME SYNCHRONIZATION 100 PERCENT DUTY CYCLE

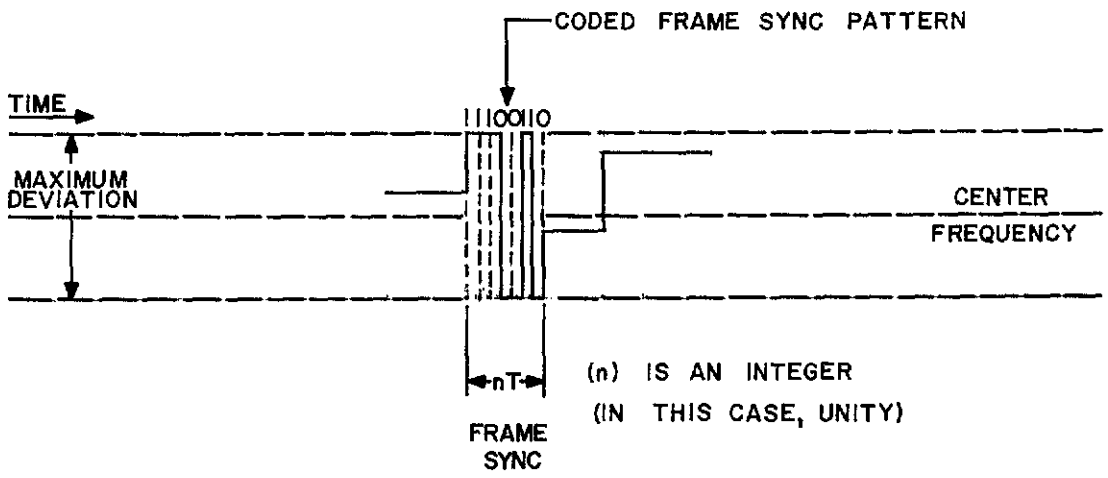


FIGURE 4–5 PAM PULSE TRAIN WAVEFORM, CODED FRAME SYNCHRONIZATION 100 PERCENT DUTY CYCLE

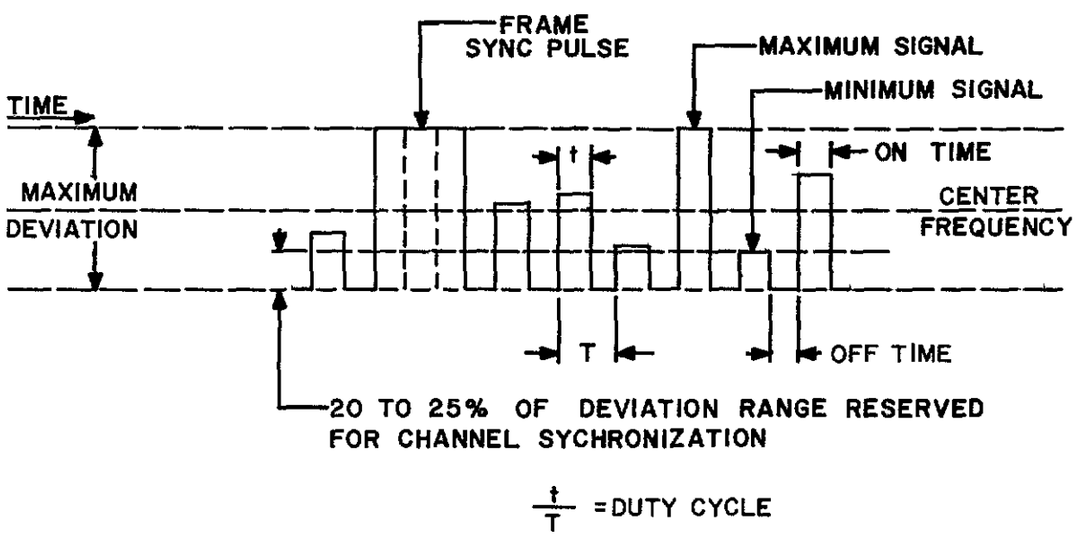


FIGURE 4-6 PAM PULSE TRAIN WAVEFORM

TABLE 4-2 COMMUTATION SPECIFICATION FOR AUTOMATIC DECOMMUTATION

No. of samples per frame*	Frame rate (frames per sec)	Commutation rate** (samples per sec)	Lowest recommended subcarrier bands (cps)
18	5	90	14,500
18	10	180	22,000 (±15%) or 30,000 (±7.5%)
18	25	450	30,000 (±15%) or 70,000 (±7.5%)
30	2.5	75	10,500
30	5	150	22,000 (±7.5%)
30	10	300	22,000 (±15%) or 40,000 (±7.5%)
30	20	600	40,000 (±15%)
30	30	900	70,000 (±15%)

NOTES: *The number of samples per frame available to carry information is 2 less than the number indicated, because the equivalent of 2 samples is used in generating the frame-synchronizing pulse.

**Frame rate times number of samples per frame.

SECTION 5

Section 5 of the Standards is undergoing revision which is expected to be completed in approximately six months.

5. PCM/FM OR PCM/PM STANDARDS

5.1 General

Pulse-code-modulation (PCM) data specified in these standards shall be transmitted as serial-binary-coded, time-division multiplexed samples.

5.2 Bit Rate Vs. Receiver IF Bandwidth (3-db points)

Selections of bit rates and corresponding receiver intermediate-frequency (IF) bandwidth shall be made from those listed in Table 5-1. Only those discrete receiver IF bandwidths listed shall be used (optional below 12,500 c/s). The selections in Table 5-1 have been made on the consideration that automatic tracking of radio-frequency (RF) carrier drift or shift will be used in the receiver.

It is recommended that, for practical design considerations, a bit rate equal to the receiver IF bandwidth (3-db points), divided by a factor ranging from 1.5 to 3.3, be used. The bandwidth/bit-rate relationships in Table 5-1 were selected on this basis. See Appendix V, Section 1 for additional information.

5.3 Bit-Rate Stability

The change in bit rate shall not exceed 1.0 percent of the nominal bit rate. In addition, spurious time displacement of bit phase in an interval "T" relative to the frequency and phase established by an average over the preceding interval "T" shall not exceed 0.1 bit period. The interval "T" shall be taken as 10 times the maximum period between assured bit transitions. Such transitions or changes in state may be provided by appropriate parity, fixed programming, the guarantee that all data will not simultaneously go to zero or full scale, etc.

The allowable change in bit rate given above accommodates the use of magnetic drums. When drums are not involved, crystal-controlled clock frequency is recommended.

5.4 Word and Frame Structure

The number of bits per frame shall not exceed 2,048, including those used for frame synchronization. The frame length selected for a particular mission shall be kept constant. (See Appendix V, Section 2, Word and Frame Structure.) Word length for any given word position can range from 6 to 64 bits but shall be kept constant for that position for a particular mission. It is recommended that an odd parity bit be included where a higher order of confidence in bit transmission is desired.

5.5 Synchronization

Frames shall be identified by a single frame-synchronization word, which shall be limited to a maximum length of 33 adjacent bits. (See Appendix V, Section 3, for suggested PCM synchronization patterns.)

5.6 Supercommutation and Subcommutation

5.6.1 Supercommutation and subcommutation are acceptable methods of exchanging the number of measurements and sampling rate. A selected coded word shall be used to indicate the beginning of the longest subcommutated frame. All other subcommutated frames with shorter lengths, shall be submultiples of the longest frame and shall have a fixed and known relative phase with respect to the longest subcommutated frame.

5.6.2 The longest subcommutated frame shall not exceed 130 channels, including the channel used for synchronization.

5.7 Premodulation Filtering

Filtering shall be used before the transmitter modulator. (See Appendix V, Section 4, for recommended filter characteristics.)

5.8 RF Carrier Modulation

5.8.1 The RF carrier modulation method shall be either FM or PM.

5.8.2 Frequency modulation of the carrier, when used, shall be of the type in which the carrier is deviated to the higher frequency deviation limit to transmit a "one" and to the lower frequency deviation limit to transmit a "zero". Once a frequency deviation limit is reached for either a "one" or a "zero", the resulting frequency remains essentially constant for consecutive like bits.

5.8.3 Phase modulation of the carrier, when used, shall be of the type in which the carrier is deviated to the leading phase-deviation limit to transmit a "one" and to the lagging phase-deviation limit to transmit a "zero". Once a phase-deviation limit is reached for either a "one" or a "zero", the resulting phase remains essentially constant for consecutive like bits.

TABLE 5-1 PCM BIT RATE AND RECEIVER IF BANDWIDTH
(3 db Points)

System Type	Bit Rate (bits per sec)*	Receiver IF Bandwidth (c/s)
A	8,000 and lower **	12,500 (and as required for lower bit rates)
B	8,000 to 65,000	25,000 - 50,000 - 100,000
C	50,000 to 330,000	100,000 - 300,000 - 500,000
D	320,000 to 800,000	500,000 - 1,000,000 *** - 1,500,000 ***

In the 225- to 260- Mc/s band, bit rates that require bandwidth in excess of those prescribed in Paragraph 1.2.1.3.4 shall not be used.

NOTES: *See restrictions imposed by section 6, "Magnetic Tape Recorder/ Reproducer Standards."

**Systems in this category may require special consideration and nonstandard hardware; these systems will be handled separately, as required by the test ranges concerned.

***For use only in 1435 to 1540 Mc/s and 2200 to 2300 Mc/s telemetry bands.

6. MAGNETIC-TAPE RECORDER/REPRODUCER STANDARDS

6.1 General

These standards define terminology and specify the configuration and operating characteristics of magnetic tape recording/reproducing devices used for telemetry data storage. They are also intended to serve as a guide in the procurement of airborne magnetic tape recording equipment so that standard reproducing equipment on the ground may be used. Standards applying to magnetic tapes used by magnetic tape recording/reproducing devices are referenced.

6.2 General Requirements

In order to allow maximum interchange of telemetry magnetic tape records and recording equipment between the test ranges, standard recording techniques and tape configurations are required. Any one of the several methods of information storage set forth here may be used, or any compatible combination may be used simultaneously.

6.2.1 Tape Speeds: The standard tape speeds for instrumentation magnetic tape recorders are 1-7/8, 3-3/4, 7-1/2, 15, 30, 60, and 120 inches per second (i/s).

6.2.2 Record/Reproduce Bandwidths: For purposes of the standards, three bandwidths are designated. They are:

(1) Low Band: Direct record response to 100,000 c/s nominal at 60 i/s. For recording subcarriers bands above Band 18, intermediate-band recorders are recommended.

(2) Intermediate Band: Direct record response to 250,000 c/s nominal at 60 i/s or 500,000 c/s nominal at 120 i/s.

(3) Wide Band: Direct record response to 1.5 Mc/s and above at 120 i/s.

6.3 Direct Recording

Direct recording is widely used for recording FM/FM derived telemetry signals. It is also used for airborne applications and other closed loop telemetry. Although serial PCM and PDM telemetry data may be recorded by this method, it is not recommended.

Wideband direct recording will be used primarily for predetection recording of the IRIG standard telemetry RF signals. It can be used for postdetection recording, but due to the wide bandwidth employed, signal-to-noise ratios may be worse than would be obtained using low or intermediate bandwidth recorders.

6.3.1 Tape and Reel Characteristics: The recorder/reproducer must meet performance criteria of these standards using any of the tapes qualified under the appropriate section of Interim Federal Specification W-T-0070(NAVY-Ships), when wound on reels qualified under Interim Federal Specification W-R-00175 (NAVY-Ships).

6.3.1.1 Tape Widths: The standard nominal tape widths for direct recording are 1/2 and 1 inch, with tolerance on all widths as specified in Specification W-T-0070. The 1/2-inch tape recorders are most widely available at the ranges and 1/2-inch tape should be used whenever it is compatible with program requirements.

6.3.1.2 Tape Specifications:

6.3.1.2.1 Low Band: Any tapes qualified under Specification W-T-0070/4 shall be used for this band.

6.3.1.2.2 Intermediate Band: Any tapes qualified under Specification W-T-0070/4 shall be used for this band.

6.3.1.2.3 Wideband: Tapes qualified under Specification W-T-0070/5 shall be used for wideband recording.

6.3.1.3 Track Geometry: (See Figure 6-1, Analog Tape Geometry)

6.3.1.3.1 Track Width: The track width for multiple-track recording shall be 0.050±0.005 inch. Track width is defined as the physical width of the magnetic head that would be used to record any given track. The actual width of the recorded track may be somewhat greater because of the magnetic fringing effect around each record head.

6.3.1.3.2 Track Spacing: Tracks shall be spaced 0.070 inch center-to-center across the tape and, as a group, shall be centered on the width of the tape. Therefore, the one-half inch tape would contain seven tracks with one track located at the center of the tape, and one-inch tape would contain 14 tracks with the center of the tape equidistant between 7 and 8.

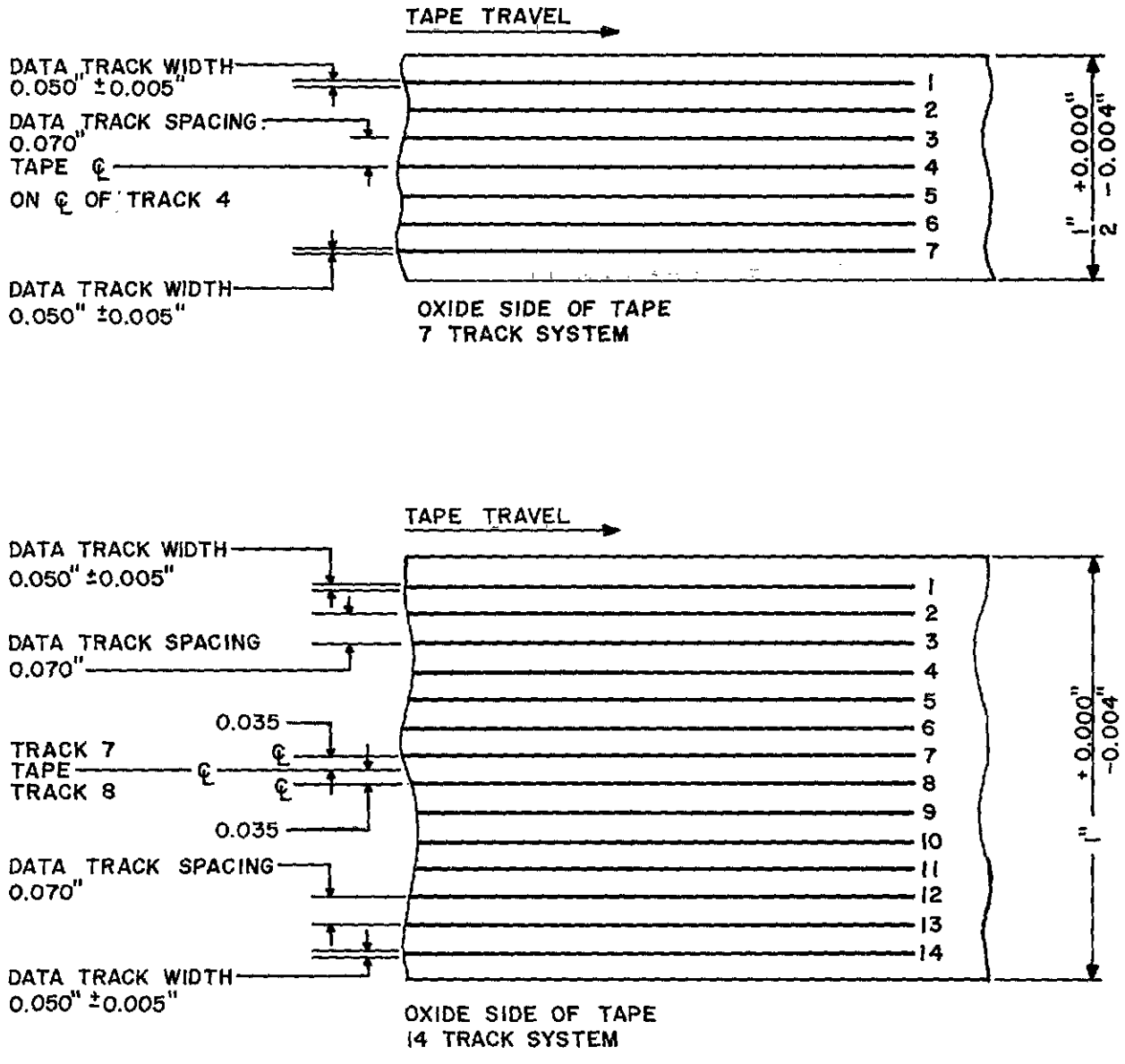


FIGURE 6–1 ANALOG TAPE GEOMETRY

6.3.1.3.3 Track Numbering: The tracks on a tape shall be numbered consecutively, starting with track number 1, from top to bottom when viewing the oxide-coated side of a tape with the earlier portion of the recorded signal to the observer's right.

6.3.2 Head and Head-Stack Configuration (See Figure 6-2)

6.3.2.1 Head Placement: The standard placement is to locate the heads (both record and playback) for alternate tracks in separate head stacks. Thus, to record on all tracks of a standard-width tape, two record-head stacks will be used; to reproduce all tracks of a standard-width tape, two playback-head stacks will be used.

6.3.2.2 Head-Stack Placement: The two stacks of a head pair (record or reproduce) shall be mounted in such a manner that the centerlines through the head gaps of each stack are parallel and spaced 1.500 ± 0.001 inches apart for fixed head stacks. For intermediate-band or wideband heads where azimuth adjustment of the reproduce head stacks is required, the stack spacing shall be 1.500 ± .002 inches between gap centerlines including maximum azimuth adjustment required to allow meeting system performance requirements.

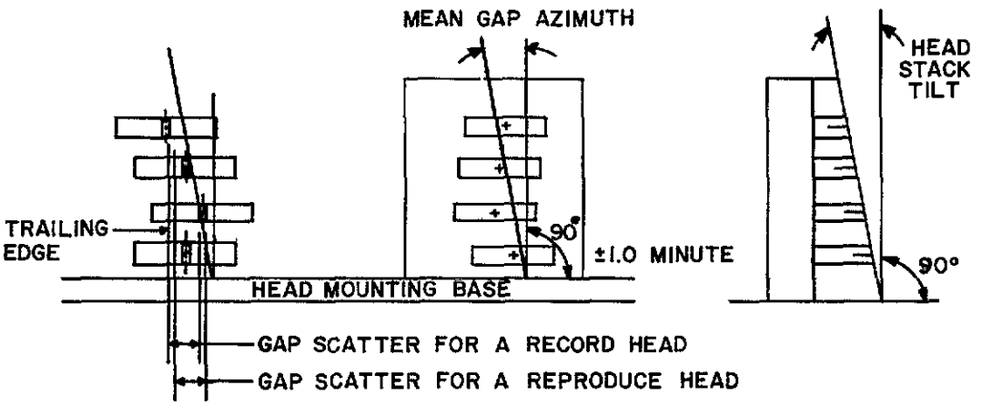
6.3.2.3 Head-Stack Numbering: Head stack number 1 of a pair of stacks (record or reproduce) is the first stack over which an element of tape passes when moving in the normal record or reproduce direction.

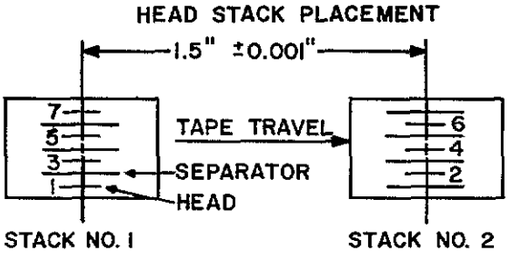
6.3.2.4 Head and Stack Numbering: Numbering of a record or reproduce head shall correspond to the track number of the magnetic tape which that head normally records or reproduces. Stack number 1 of a pair will contain all odd-numbered heads, while stack number 2 will contain all even-numbered heads.

6.3.2.5 Head-Stack Tilt: The plane tangent to the front surface of the head stack at the centerline of the head gaps shall be perpendicular to the head-mounting plate within ±3 minutes of arc.

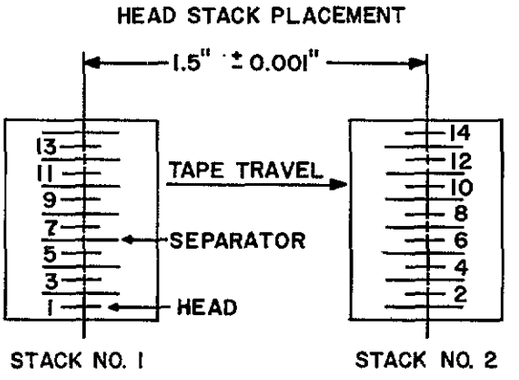
6.3.2.6 Gap Scatter: Gap scatter shall be 0.0001 inch or less.

6.3.2.7 Mean Gap Azimuth Alignment: The mean gap azimuth shall be perpendicular to the head mounting plate to within ±1 minute of arc.





7 TRACK ANALOG HEAD
AND STACK CONFIGURATION



14 TRACK ANALOG HEAD
AND STACK CONFIGURATION

FIGURE 6-2 ANALOG HEAD CONFIGURATION

6.3.2.8 Head Location: Any head in a stack shall be located within ±0.002 inch of the nominal position required to match the track location set forth in paragraph 1.3.1.3.

6.3.2.9 Head Interchangeability: Where rapid interchangeability of heads is specified, the method of head mounting, locating, and securing shall ensure that all alignment and location requirements are satisfied without shimming or mechanical adjustment, except for azimuth adjustment of the reproduce head stack which may be required for intermediate band recorder/reproducers and is required for wideband recorder/reproducers. Where azimuth adjustment is provided the output of each track at the upper frequency limit at the optimum azimuth alignment position for the head assembly shall be within 1 db of the output at the optimum position for the individual track.

6.3.3 Head Polarity.

6.3.3.1 Record Head: Each record-head winding shall be connected to its respective amplifier in such a manner that a positive-going pulse with respect to system ground, at the amplifier input, will result in the generation of a specific magnetic pattern on a segment of tape passing the record head in the normal direction of tape motion. The resulting magnetic pattern shall consist of a polarity sequence of south-north-north-south. (See Appendix VI for method of measurement.)

6.3.3.2 Reproduce Head: Each reproduce-head winding shall be connected to its respective amplifier in such a manner that a segment of tape exhibiting a south-north-north-south magnetic pattern will produce a positive-going pulse, with respect to system ground, at the output of the reproduce amplifier.

6.3.4 Tape Guiding: The tape guides shall provide accurate guidance of the tape across the heads without damaging the tape.

6.3.5 Record/Reproduce Parameters: All recorder/reproducer electrical performance characteristics shall be met simultaneously during the "Record/Reproduce" and the "Reproduce Only" modes of direct record operation.

6.3.5.1 Bias: The high-frequency bias signal shall be approximately five times the highest direct record frequency for which the recorder/reproducer system is designed. (Note: Tapes recorded on machines employing a bias frequency approximately three times the highest record frequency response and reproduced on higher bandwidth machines, will exhibit bias signal output which may interfere with recorded data signals.)

6.3.5.1.1 Bias Leakage: Less than 30 millivolts rms bias leakage signal shall occur during the record mode on any properly terminated input or output signal line, including both amplifier gain settings.

6.3.5.2 Frequency Response: The frequency response or pass band of direct-recorded data as a function of tape speed is given in Table 6-1. In measuring this response, signals throughout the specified pass band are recorded at Normal Record Level and the reproduce output signal levels are referenced to the playback output at the Record Level Set Frequency. Bias leakage and record/reproduce cross-coupling shall not be of sufficient magnitude to mask this measurement.

*6.3.5.3 Signal-to-Noise: (See Appendix VI for method of measurement.)

6.3.5.3.1 Low Band: Signal-to noise ratio for signals in the specified pass-band recorded at Normal Record Level shall be 35 db minimum at 15 ips or above and 30 db minimum below 15 ips.

6.3.5.3.2 Intermediate Band: Signal-to-noise ratio for signals in the specified pass-band recorded at Normal Record Level shall be 28 db minimum at 15 ips or above and 25 db minimum below 15 ips.

6.3.5.3.3 Wide Band: Signal-to-noise ratio for signals in the specified pass-band recorded at Normal Record Level shall be 25 db minimum at 15 ips or above and 22 db minimum below 15 ips.

Note: *Paragraphs 6.3.5.3, 6.3.5.4, 6.3.5.6, and 6.3.6.1.2 apply to reproduce systems to be used for real-time data display and/or accurate data reduction systems. For record-only installations or rough data analysis applications, less restrictive performance parameters may be adequate. Equipment specifications in these areas must be adequate to delineate the performance required for the intended application.

6.3.5.4 Phase Response.

6.3.5.4.1 Intermediate Band Recorders: Record/reproduce phase response shall be such that a square wave whose frequency is 1/5 the maximum frequency specified in Table 6-1 shall be reproduced with no more than 20% overshoot compared to the flat portion of the square wave. (See Note on Page 6-7.)

6.3.5.4.2 Wideband Recorders: The maximum envelope delay variation shall be ±0.3 microsecond from 100 kc/s to 1.5 Mc/s at 120 ips with inversely proportional delay variations at lower tape speeds. (See Appendix VI)

6.3.5.5 Record Parameters:

6.3.5.5.1 Input Impedance: Input impedance at all frequencies in the low and intermediate bands shall be 5,000 ohms minimum, with or without meter. Input impedance for the wideband recorders shall be 75 ohms ±10% across the specified band.

6.3.5.5.2 Input Level: Input signals of 0.5 to 20.0 volts peak-to-peak shall be adjustable to produce Normal Record Level and meet all performance criteria of these standards.

6.3.5.5.3 Transfer Characteristics: A constant flux record characteristic is required. The record amplifier shall provide a transfer characteristic that is basically a constant current versus frequency characteristic, upon which is superimposed a compensation characteristic to correct only for loss of record-head efficiency with frequency. (See Appendix VI for recommended method of measurement.)

6.3.5.5.4 Record Bias Setting: See Table 6-1 for bias adjustment procedure.

6.3.5.5.5 Record-Level Setting: The level of recording shall be set at a value that yields one percent third-harmonic distortion from the tape when measured at the output of the playback amplifier during playback. This level, the Normal Record Level, shall be set while recording the Record Level Set Frequency indicated in Table 6-1. "0db" reference level is the Normal Record Level (See Glossary). (In recording complex telemetry signals with varying crest factors, optimum record level must be determined for the particular signal to be recorded.)

TABLE 6-1

Direct-Record Parameters

Low Band

Tape Speed ips	±3-db Pass Band c/s (1)	Record Bias Set Frequency c/s overbias 3db (2)	Record Level Set Frequency c/s
60	100 - 100,000	100,000 ±10%	1000 ±10%
30	100 - 50,000	50,000 ±10%	1000 ±10%
15	100 - 25,000	25,000 ±10%	1000 ±10%
7-1/2	100 - 12,000	12,000 ±10%	500 ±10%
3-3/4	100 - 6,000	6,000 ±10%	500 ±10%
1-7/8	100 - 3,000	3,000 ±10%	500 ±10%

Intermediate Band

Tape Speed ips	±3-db Pass Band c/s (1)	Record Bias Set Frequency c/s overbias 3db (2)	Record Level Set Frequency c/s
120	300 - 500,000	500,000 ±10%	1000 ±10%
60	300 - 250,000	250,000 ±10%	1000 ±10%
30	200 - 125,000	125,000 ±10%	1000 ±10%
15	100 - 60,000	60,000 ±10%	1000 ±10%
7-1/2	100 - 30,000	30,000 ±10%	500 ±10%
3-3/4	100 - 15,000	15,000 ±10%	500 ±10%
1-7/8	100 - 7,500	7,500 ±10%	500 ±10%

Wideband

Tape Speed ips	±3-db Pass Band c/s kc/s (3)	Record Bias Set Frequency kc/s (overbias) (3)	Record Level Set Frequency kc/s
120	500 to 1500	1,500	150 ±10%
60	500 to 750	750	75 ±10%
30	500 to 375	375	37.5 ±10%
15	500 to 187	187	18.7 ±10%
7-1/2	500 to 93	93	9.3 ±10%
3-3/4	500 to 46	46	4.6 ±10%

Notes: (1) Passband response is referenced to the output at the Record Level Set Frequency.

(2) Record Bias current is adjusted for maximum reproduce output at a signal level 6 db below Normal Record Level and then increased until an output level 3 db below the maximum value is obtained.

(3) Record Bias current is adjusted for maximum reproduce output at a signal level 6 db below Normal Record Level and then increased until an output level 1 db level below the maximum value is obtained.

6.3.5.6 Reproduce Parameters.

6.3.5.6.1 Output Impedance: Output impedance for low and intermediate-band recording shall be 100 ohms maximum across the pass bands specified in Table 6-1. Output impedance for wideband recorders shall be 75 ohms maximum across the specified pass band.

6.3.5.6.2 Output Level: When reproducing a signal at any frequency in the Pass Band recorded at an input voltage equivalent to that required for Normal Record Level, the output level shall be a minimum of 3 volts peak-to-peak with a maximum third harmonic distortion of one percent when measured across a resistive load of at least 600 ohms shunted by a maximum of 1500 pf for low-band and intermediate-band recorders, and across 75 ohms for wideband recorders. Lack of proper output termination shall not cause the reproduce amplifier to oscillate.

6.3.5.6.3 Transfer Characteristics: The reproduce amplifier shall provide signal equalization as a function of frequency, which will provide the overall Recorder/Reproducer System Frequency Response set forth in Table 6-1 upon playback of a signal recorded as set forth in paragraphs 6.3.5.5.3 and 6.3.5.5.5.

6.3.5.6.4 Crosstalk: The signal to crosstalk ratios shall be at least 6 db greater than the signal-to-noise ratios of Section 6.3.5.3 for wavelengths on tape less than .060 inch. (See Appendix VI for method of measurement.)

6.3.6 Speed Control and Flutter Compensation: The average or long-term Record and Reproduce Tape speeds shall be sufficiently close to the standard speed to insure the capability to adequately control and correct the reproduce tape speed on other recorders. Signals may be recorded for servo playback speed control and for sub-carrier discriminator flutter compensation systems.

6.3.6.1 Tape Speed and Flutter.

6.3.6.1.1 Record Speed: Tape throughout the reel or in any portion of the reel shall be recorded at a speed within ±0.5 percent of the standard speed for low-band recorders and ±0.2 percent for intermediate-band and wideband recorders.

6.3.6.1.2 Flutter: Maximum peak-to-peak cumulative flutter over the indicated pass band shall not exceed the value shown in Table 6-2. (See Appendix VI for method of measurement; see also note on page 6-7.

TABLE 6-2

Permissible Flutter

Tape Speed ips	Pass Band, c/s	Flutter Percent
120	0.2 to 10,000	.25
60	0.2 to 10,000	.25
30	0.2 to 5,000	.35
15	0.2 to 2,500	.45
7 1/2	0.2 to 625	.50
3 3/4	0.2 to 313	.70
1 7/8	0.2 to 160	1.0

Note: For measurement of flutter with standard FM/FM discriminators, the 10.5 kc/s, 5.25 kc/s, 2,100 c/s, 790 c/s, 330 c/s and 160 c/s Low-pass filters may be employed.

6.3.6.2 Speed Control Signals: Speed Control Signals are recorded on the tape for the purpose of servo control of tape speed during playback. Either type of speed-control signal, Amplitude-Modulated or Constant Amplitude, may be selected by the range user. Operating level for Speed Control Signals shall be 10±0.5 db below Normal Record Level, when mixed with other signals, or Normal Record Level when recorded on a separate track.

6.3.6.2.1 Amplitude-Modulated Speed-Control Signal: The Amplitude-Modulated Speed-Control Signal shall have the following characteristics:

Carrier Frequency	17.0 kc/s ±0.5%
Bandwidth Required	16,500 c/s to 17,500 c/s
Percentage Modulation	45 to 55%
Modulating Frequency	60 c/s ±0.01%

Note: FM/FM Channel A should not be used on the same track with the 17 kc/s Speed-Control Signal because it interferes with the Speed-Control Signal.

6.3.6.2.2 Constant-Amplitude Speed-Control Signal: Constant-amplitude speed-control signals may be used on a separate track for optimum servo speed correction capability or may be mixed with other signals if recording requirements are too great to allow a free track for the control signal. Table 6-3 lists constant-amplitude speed control signal frequencies and the band-width about the signal frequency which must be left free of other signals in order to give proper servo and/or compensation operation. The constant-amplitude signal should also be used as a flutter correction signal if required.

TABLE 6-3

Control Signal Frequencies

Frequency, kc/s		Bandwidth, c/s
*200	±0.01%	±10,000
*100	±0.01%	± 5,000
* 50	±0.01%	± 2,500
* 25	±0.01%	± 1,250
12.5	±0.01%	± 1,000
6.25	±0.01%	± 1,000
3.125	±0.01%	± 1,000

*May also be used for discriminator flutter correction.

6.3.6.2.3 Playback Speed: Playback tape speed without servo speed control shall be within ±0.5 percent of the Standard Speed for low-band recorders and ±0.2 percent for intermediate band and wideband recorders. With servo speed control, the reproduced time base (or servo control signal) shall vary no more than ±0.025 percent from its average frequency value and the average frequency shall be within ±0.02 percent of an independent time standard of ±0.01 percent accuracy. Use of the servo speed control shall not result in an increase in cumulative flutter over that obtained without servo speed control. (See Appendix VI for method of measurement.)

6.3.6.3 Flutter Compensation: Signals to be used for discriminator flutter correction systems are as follows:

TABLE 6-4

Compensation Signals

Frequency	Maximum Bandwidth
200 kc/s ±0.01%	±13,950 c/s
100 kc/s ±0.01%	±10,500 c/s
50 kc/s ±0.01%	± 2,500 c/s
25 kc/s ±0.01%	± 1,250 c/s

See Section 6.3.6.2.1 and Section 2.2.3 for restrictions on use of flutter-correction signals.

6.3.7 Predetection Recording: Predetection signals consist of frequency-modulated or phase-modulated IF carriers which have been translated in frequency to be compatible with wideband recorder frequency response. These signals will be recorded by direct (high-frequency bias) recording.

6.3.7.1 Predetection Carrier Parameters:

TABLE 6-5

Conversion Frequencies

Tape Speed (i/s)	Predetection Carrier Center Frequency c/s	Recommended Predetection Record/Playback Pass Band kc/s
120	900,000	100 to 1,500
60	450,000	50 to 750
30	225,000	25 to 375
15	112,500	12.5 to 187.5

6.3.7.2 Intermodulation Distortion: Individual intermodulation products of any two frequencies above 10 kc/s in the pass band recorded simultaneously, with each signal at one-half the normal record level, shall be less than 2.0 percent for each intermodulation component referred to the output of a signal recorded at Normal Record Level. The $F_1 \pm F_2$, and $2F_1 \pm F_2$, and $2F_2 \pm F_1$ products shall be measured.

6.4 Single-Carrier FM Record and Wideband FM Record Systems

Single-Carrier FM record systems may employ saturation recording or direct recording techniques on low-band and intermediate-band recorders. For wideband FM systems, direct recording with an external FM system is recommended.

6.4.1 Tape and Reel Characteristics: Section 6.3.1 shall apply.

6.4.1.1 Tape Width: Paragraph 6.3.1.1 shall apply.

6.4.1.2 Tape Specifications: Paragraph 6.3.1.2 shall apply.

6.4.1.3 Track Geometry:

6.4.1.3.1 Track Width: Paragraph 6.3.1.3.1 shall apply.

6.4.1.3.2 Track Spacing: Paragraph 6.3.1.3.2 shall apply.

6.4.1.3.3 Track Numbering: Paragraph 6.3.1.3.3 shall apply.

6.4.2 Head and Head-Stack Configuration:

6.4.2.1 Head Placement: Paragraph 6.3.2.1 shall apply.

6.4.2.2 Head-Stack Placement: Paragraph 6.3.2.2 shall apply.

6.4.2.3 Head-Stack Numbering: Paragraph 6.3.2.3 shall apply.

6.4.2.4 Head and Stack Numbering: Paragraph 6.3.2.4 shall apply.

6.4.2.5 Head-Stack Tilt: Paragraph 6.3.2.5 shall apply.

6.4.2.6 Gap Scatter: Paragraph 6.3.2.6 shall apply.

6.4.2.7 Head Location: Paragraph 6.3.2.7 shall apply.

6.4.2.8 Head Interchangeability: Paragraph 6.3.2.8 shall apply.

6.4.3 Tape Guiding: Paragraph 6.3.4 shall apply.

6.4.4 Tape Speeds and Corresponding FM Carrier Frequencies:

(See Table 6-6)

6.4.5 FM Record/Reproduce Parameters:

6.4.5.1 FM Record System Voltages:

For single-carrier FM record systems, input voltage shall be ±1.4 volts DC.

For wideband FM record systems, input voltage of 0.5 to 20 volts peak-to-peak shall be adjustable to produce full frequency deviation. Output voltage of FM record channel shall be 1.0 volts rms nominal and 1.0 volt peak-to-peak minimum.

Deviation direction: Increasing positive voltage gives increasing frequency.

6.4.5.2 FM Record System Impedance:

Single-carrier FM record systems input impedance, 5,000 ohms minimum.

Wideband FM record systems: Input and output impedances shall be 75 ohms ±10 percent at all frequencies in the specified pass band.

6.4.5.3 FM Reproduce Systems:

A signal of increasing frequency on the input of a single-carrier or wideband FM reproduce system shall give a positive-going signal at the output.

Output levels for signals recorded at full deviation.

6.4.5.4 Single-Carrier FM Systems: 3 volts peak-to-peak minimum with maximum total harmonic distortion of 2 percent across a load of 10,000 ohms minimum, from DC to the maximum specified frequency.

TABLE 6-6

Single-Carrier and Wideband FM Record Parameters

Tape Speed ips			Carrier Center Frequency c/s	Carrier Deviation Limits*			
Low Band	Intermediate Band	Wide Band		Carrier Plus Deviation c/s	Carrier Minus Deviation c/s	Modulation Frequency c/s	Response at Band Limits db ***
1 7/8			1,688	2,363	1,012	DC 313	± 1
3 3/4	1 7/8		3,375	4,725	2,025	DC 625	± 1
7 1/2	3 3/4		6,750	9,450	4,050	DC 1,250	± 1
15	7 1/2	3 3/4	13,500	18,900	8,100	DC 2,500	± 1
30	15	7 1/2	27,000	37,800	16,200	DC 5,000	± 1
60	30	15	54,000	75,600	32,400	DC 10,000	± 1
	60	30	108,000	151,200	64,800	DC 20,000	± 1
	120	60	216,000	302,400	129,600	DC 40,000	± 1
		120	432,000	604,800	259,200	DC 80,000	± 1

Tape Speed ips	Wideband Group 2** Carrier Center Frequency c/s	Carrier Plus Deviation c/s	Carrier Minus Deviation c/s	Modulation Frequency c/s	Response at Band Limits db **
120	900,000	1,170,000	630,000	DC 400,000	± 3
60	450,000	585,000	315,000	DC 200,000	± 3
30	225,000	292,500	157,500	DC 100,000	± 3
15	112,500	146,250	78,750	DC 50,000	± 3
7 1/2	66,250	73,125	39,375	DC 25,000	± 3
3 3/4	33,125	36,562	19,688	DC 12,500	± 3

* Input voltage levels per Paragraph 6.4.5.

** The second group of wideband FM carrier frequencies are primarily for use with pre-detection recorders where one or more analog channels are also required.

*** Frequency response referred to 1 kc/s output for FM channels 13.5 kc/s and above, and 100 c/s for channels below 13.5 kc/s.

6.4.5.5 Wideband FM Systems: 3 volts peak-to-peak minimum across a load of 75 ohms ±10 percent. Individual harmonic components shall not exceed 3 percent.

A wideband FM reproduce system external to the recorder/reproducer shall operate properly on an input signal of 1 volt rms nominal and 1 volt peak-to-peak minimum. Input impedance shall be 75 ohms ±10 percent across the specified pass band.

6.4.6 Speed, Control and Compensation: Section 6.3.6 shall apply except that a separate track is always required for speed-control and flutter compensation signals with single-carrier FM systems and wideband FM systems.

6.4.7 Drift: After 30 minutes warmup, the FM record and/or reproduce electronics shall exhibit less than ±1 percent of full bandwidth drift over a period of 7 hours at an ambient temperature of +25°C.

6.4.8 Overall System Signal-to-Noise Ratio:

6.4.8.1 Single Carrier FM Systems: The signal-to-noise ratio of a signal of 0.1 the maximum modulation frequency listed in Table 6-6 recorded at full deviation shall be 40 db minimum.

6.4.8.2 Wideband FM Systems: The signal-to-noise ratio for a signal of 0.1 the maximum modulation frequency listed in Table 6-6 recorded at full deviation shall be 25 db minimum for tape speeds 15 ips and above, and 22 db minimum for tape speeds below 15 ips. These values shall be achieved with the wideband recorder operating at the minimum signal-to-noise ratios listed in paragraph 6.3.5.3.3.

6.4.9 Phase Response:

6.4.9.1 Single-Carrier FM Systems: Maximally linear phase response output filters shall be employed.

6.4.9.2 Wideband FM Systems: For 120 ips operation, maximum envelope delay variation shall be ±0.3 microsecond from 100 kc/s to 400 kc/s with inversely proportional delay variation at lower tape speeds.

6.5 PCM Recording

PCM data may be recorded directly in serial form by single-carrier FM techniques; by direct recording if adequate low-frequency and high frequency response is available on the recorder/reproducer; by saturation recording techniques; or by predetection recording. It may also be converted into a parallel form and recorded on a multitrack recorder. Serial PCM signals are sometimes converted to parallel computer tape format when bit rates and computer tape recorder response are compatible. This allows direct use of computers for data separation and analysis without an intermediate conversion. Predetection recording, FM recording, and parallel saturation recording are the recommended methods for recording PCM telemetry signals.

This section deals specifically with standards for recording PCM telemetry signals on 1-inch tape in parallel form.

There are two standard systems--a 16-track system and a 31-track system. The 31-track system consists of interleaved 16-track and 15-track stacks. The two stacks are employed as independent record/reproduce systems. Track spacing and location of tracks 1 through 16 in the 31-track system are identical to the 16-track system. Additional optional tracks A and B, located beyond tracks 1 and 16, may be used. Performance standards specified herein shall not apply to the optional tracks.

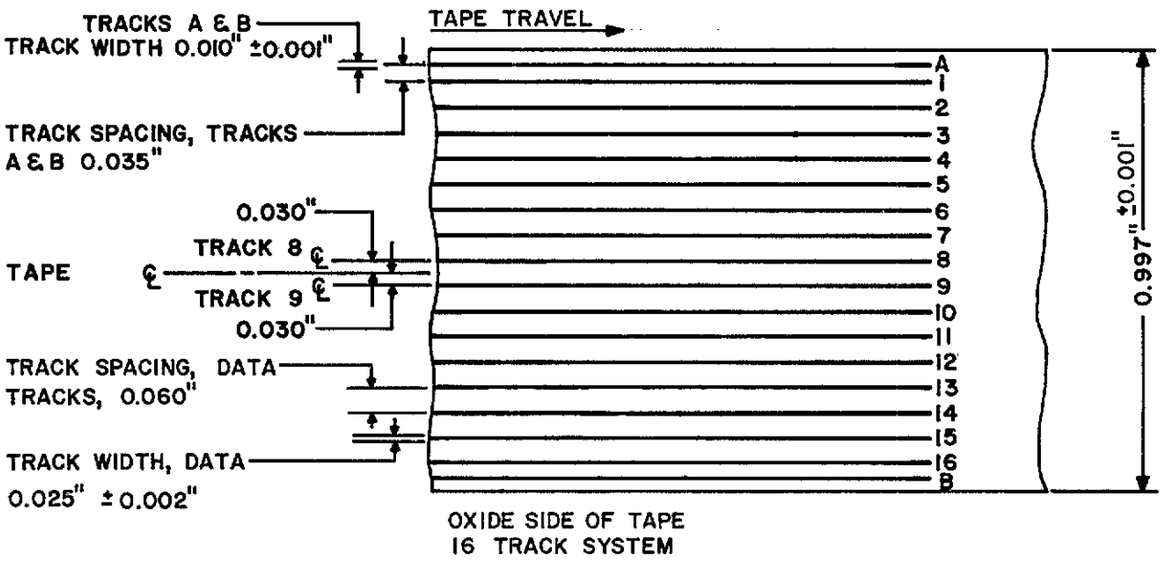
6.5.1 Tape: Interim Federal Specification W-T-0070 shall apply when available.

6.5.1.1 Tape Width: Standard tape width for PCM use is a nominal 1 inch.

6.5.2 Track Geometry: (See Figure 6-3)

6.5.2.1 Track Width:

6.5.2.1.1 Sixteen-Track System: Track width for 16-track systems shall be 0.025±0.002 inch. Track width is defined as the physical width of the head that would be used to record or reproduce any given track, although the actual width of the recorded track may be somewhat greater because of the magnetic fringing effect around each record head. Track width for optional tracks A and B for the 16-track system shall be 0.010±0.002 inch.



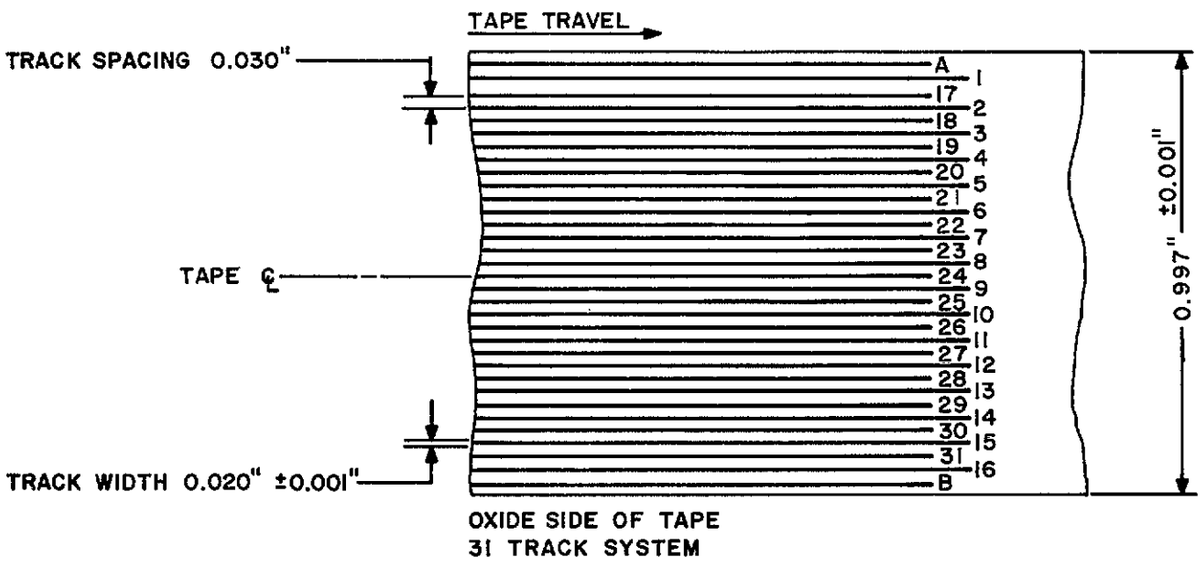


FIGURE 6-3 PCM TRACK SYSTEM

6.5.2.1.2 Thirty-One Track System: Track width for 31-track systems shall be 0.020±0.001 inch. Track width is defined as the physical width of the head that would be used to record or reproduce any given track, although the actual width of the recorded track may be somewhat greater because of the magnetic fringing effect around each record head. Optional tracks A and B, when employed, shall also be 0.020±0.002 inch in width.

6.5.2.2 Track Spacing:

6.5.2.2.1 Sixteen-Track System: Spacing between track centers on 16-track systems shall be 0.060 inch. Optional tracks A and B shall be centered 0.035 inch from the centerlines of tracks 1 and 16, respectively.

6.5.2.3 Track Location:

6.5.2.3.1 Sixteen-Track System: On 16-track systems, the center of the tape shall be centered between tracks 8 and 9.

6.5.2.3.2 Thirty-One Track Systems: On 31-track systems, the center of the tape shall be centered on the centerline of track 24.

6.5.2.4 Track Numbering: (See Figure 6-3)

6.5.2.4.1 Sixteen-Track System: For 16-track systems, paragraph 6.3.1.3.3 shall apply.

6.5.2.4.2 Thirty-One Track System: Paragraph 6.3.1.3.3 shall apply, except that the numbering from top to bottom shall be A (optional), 1, 17, 2, 18, 3, 19, ... 31, 16, B (optional).

6.5.3 Head and Head-Stack Configuration:

6.5.3.1 Head-Stack Placement: (31-track System) Paragraph 6.3.2.2 shall apply.

6.5.3.2 Head-Stack Numbering: (31-track System) Paragraph 6.3.2.3 shall apply.

6.5.3.3 Head and Stack Numbering: Heads shall be numbered to correspond to the track on the tape that they normally record or reproduce. For 31-track systems, stack number 1 of a pair will contain heads numbered 1 through 16, and stack number 2 will contain heads numbered 17 through 31, and, optionally, tracks A and B.

6.5.3.4 Mean Gap Azimuth Alignment: Mean gap azimuth error shall not exceed ±1/3 minute of arc.

6.5.3.5 Head-Stack Tilt: Paragraph 6.3.2.6 shall apply.

6.5.3.6 Gap Scatter: Paragraph 6.3.2.7 shall apply.

6.5.3.7 Head Location in Stack: The location of any head in a stack shall be within ±0.001 inch, nonaccumulative, of the nominal position required to match the track location, as set forth in paragraphs 6.5.2.1.1, 6.5.2.1.2, 6.5.2.2.1, and 6.5.2.2.2.

6.5.4 Head Polarity: Section 6.3.3 shall apply.

6.5.5 Tape Guiding: Tape guides shall provide accurate guidance of the tape across the heads without damaging the tape.

6.5.6 Tape Speeds: The standard speeds for instrumentation type magnetic-tape recorder/reproducers shall be employed.

6.5.7 Bit-Packing Density: The playback device shall be capable of playing back data recorded at bit-packing densities of 1,000 bits per linear inch per track maximum. The nominal maximum bit-packing density at the test ranges shall be 1,000 bits per linear inch per track.

6.5.8 Cross Talk and Transverse Sensitivity: Peak cross talk to peak signal ratio between any two PCM channels and transverse sensitivity between any two PCM tracks shall be less than 25 db for 16-track systems and 20 db for 31-track systems.

6.5.9 Record/Reproduce Reliability: The maximum allowable error shall be 1 bit in 100,000.

6.5.10 Skew and Differential Flutter: This shall not exceed 250 micro-inches, peak-to-peak.

6.5.11 Type of Recording: Nonreturn-to-zero ("NRZ MARK") recording shall be employed, wherein a change in magnetization of the tape from maximum level of one polarity to maximum level of the opposite polarity is used to indicate the digit "one," and no change in magnetization during a bit interval indicates a "zero." Recorder/reproducer electronics shall be designed to meet the requirements of paragraphs 6.5.13.3 and 6.5.14.3.

6.5.12 Timing: Track 16 shall be reserved for range timing.

6.5.13 Recorder Input Characteristics:

6.5.13.1 Input Impedance: This shall be 20,000 ohms minimum.

6.5.13.2 Input Voltage: This shall be 2 to 20 volts plus, minus, or symmetrical about ground, and polarity-selectable.

6.5.13.3 Input Format: This shall be parallel input, nonreturn-to-zero, ("NRZ Level").

6.5.14 Output Characteristics:

6.5.14.1 Reproduce Output Format: This shall be parallel output, nonreturn-to-zero ("NRZ Level"). Reproducer output shall compensate for all recorder/reproducer-induced time displacement errors to within 5 percent of the word interval, or 1.6 microseconds, whichever is greater.

6.5.14.2 Output Impedance: This shall be 100 ohms maximum.

6.5.14.3 Output Voltage: This shall be 10 volts, peak-to-peak, minimum across 1,000 ohms resistance shunted by no more than 250 picofarads capacitance, one polarity for "one," opposite polarity for "zero," selectable polarity.

6.6 PDM Recording[1]

In PDM recording, the duration-modulated rectangular waveform input signal is differentiated and the record head is driven with the resulting positive and negative spikes which correspond in time to the leading and trailing edges of the input pulses. The tape is thereby magnetically marked in such a manner that the pulses during the reproduce process may be used to trigger pulse reconstruction circuitry. Although recorded PDM data may be reproduced through a direct-record data-reproduce amplifier and pulse reconstruction performed later, the PDM reproduce amplifier reconstructs the original duration-modulated rectangular waveform.

6.6.1 Tape: Standards for tape used in PDM recording are the same as for direct recording (Section 6.3.1).

6.6.2 Head and Head-Stack Configuration: Standards for PDM recording are the same as for direct recording (Section 6.3.2).

6.6.3 Head Polarity: Standards for PDM recording are the same as for direct recording (Section 6.3.3).

6.6.4 Tape Guiding: Standards for PDM recording are the same as for direct recording (Section 6.3.4).

6.6.5 Record/Reproduce Performance Parameters: The record/reproduce system shall be capable of recording and subsequently reproducing and reconstructing pulses whose minimum duration as a function of tape speed is given in Table 6-7. The maximum peak-to-peak pulse jitter measured at the half-amplitude points of the leading edges of successive pulses shall not exceed 2 microseconds, or 0.1 percent of the pulse period, whichever is greater, with servo playback speed control.

6.6.6 Record Amplifier:

6.6.6.1 Input Impedance: Input impedance shall be 20,000 ohms resistive minimum.

6.6.6.2 Normal Input Level: This level shall be 1.0 volt, peak-to-peak.

[1] PDM systems may be available with pulse rates not accommodated by these recording standards. For such signals the use of wideband FM or single-carrier FM recording techniques is recommended.

6.6.6.3 Transfer Characteristic: The record amplifier shall drive the record head with a pulse signal that is obtained by differentiation of the input duration-modulated rectangular pulse train. The time constant of the differentiation shall be 10 microseconds.

6.6.7 Reproduce Amplifier:

6.6.7.1 Function: The PDM reproduce amplifier will amplify the pulse output of the reproduce head and reconstruct the basic duration-modulated rectangular pulse train.

6.6.7.2 Output Impedance: Output impedance shall be 100 ohms maximum.

TABLE 6-7

PDM Record Parameters

Minimum Tape Speed ips			Minimum Pulse Duration (Microseconds)	Adjacent Pulse Jitter (u-secs, P-P) Note 1
Low Band	Intermediate Band	Wide Band		
60	30	15	75	2
30	15	7 1/2	75	2
15	7 1/2	3 3/4	100	2

Note 1: The indicated jitter tolerance applies to only that component of jitter introduced by tape record/reproduce.

6.6.7.3 Nominal Output Level: This level shall be 8 volts, peak-to-peak, across 1,000 ohms resistance shunted by no more than 250 picofarads capacitance.

6.6.7.4 Pulse Rise Time: Rise and decay time of the output rectangular pulses shall be less than 2 microseconds from 10 to 90 percent amplitude levels.

6.6.7.5 Missing Pulse Protection: The reproduce amplifier shall incorporate circuitry to detect defective pulses during the reproduce process and provide automatic resetting to preclude loss of subsequent data.

APPENDIX I

The following is a reproduction of the MCEB letter. It is included here for information only and may not be considered part of these standards.

THE JOINT CHIEFS OF STAFF
Washington, D.C. 20301

Military Communications-
Electronics Board

MCEB-M 92-65
19 February 1965

MEMORANDUM FOR: Chief of Communications-Electronics, USA
Director, Naval Communications, USN
Director of Command Control and Communications, USAF

Subject: Frequency Provisions for Telemetering

References: a. MCEB 563/11 dated 19 February 1965
b. MCEB-M 16-63 dated 24 January 1963

Enclosure: Frequency Assignment Plan for Air/Space-Ground Telemetering Operations

1. By reference a, the US MCEB approved the enclosure.

2. By reference b, essential air-ground telemetering in connection with guided missile, upper atmosphere research and space was accommodated on a primary basis, for an interim period, on 44 (500 Kcs) channels in the 225-260 Mc/s portion of the military communications band 225-400 Mc/s.

3. Under national allocation planning subsequent to the International Telecommunications Union Conferences, Geneva, 1959 and 1963, frequency allocation provisions have been made for telemetering in the 1435-1540 Mc/s and 2200-2300 Mc/s bands. By reference b certain military telemetering requirements were to be reaccommodated in the bands 1435-1535 Mc/s and 2200-2300 Mc/s.

4. By reference a, it was determined that air/space-ground telemetering must be restricted to these higher frequency bands of 1435-1540 Mc/s and 2200-2300 Mc/s in order to permit unrestricted use of the 225-400 Mc/s band for military communications. Further telemetering services must be completely removed from the 225-260 Mc/s portion of the 225-400 Mc/s band by 1 January 1970.

5. The military departments shall:

a. Initiate action to effect the orderly transfer of telemetering operations from the 225-260 Mc/s band to the two higher bands, 1435-1540 Mc/s and 2200-2300 Mc/s as appropriate.

b. Ensure that air/space-ground telemetering operations will be completely removed from the 225-260 Mc/s band by 1 January 1970.

c. Accelerate R&D action to provide for the development and installation of air/space-ground telemetry equipment in the 1435-1540 Mc/s and 2200-2300 Mc/s bands to operate within applicable Inter-Range Instrumentation Group and Military Standards.

d. Ensure that necessary coordination is accomplished in order to avoid harmful interference between telemetry operations in the 1435-1540 Mc/s and 2200-2300 Mc/s bands.

e. Ensure that air/space-ground telemetering operations under their respective cognizance comply with the Enclosure.

6. This memorandum supersedes reference b.

FOR THE MILITARY COMMUNICATIONS-ELECTRONICS BOARD:

A.I. J-122

/s/ Jack A Albright
JACK A. ALBRIGHT
Lt Colonel, USA
Secretary

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ENCLOSURE

FREQUENCY ASSIGNMENT PLAN FOR AIR/SPACE-GROUND TELEMETERING OPERATIONS

Contents

Enclosure

APPENDIX 1 TO ENCLOSURE

225-260 Mc/s

TELEMETERING FREQUENCY ASSIGNMENT PLAN FOR GUIDED MISSILES, UPPER ATMOSPHERE RESEARCH AND SPACE VEHICLES ON A PRIMARY BASIS AND MANNED AND UNMANNED AIRCRAFT ON A SECONDARY BASIS.

1. The following 44 (500 Kc/s) channels, centered on the listed frequencies are available for telemetering on a primary basis until 1 January 1970.

225.7 Mc/s	235.5 Mc/s	247.8 Mc/s
226.2 Mc/s	236.2 Mc/s	248.6 Mc/s
226.7 Mc/s	237.0 Mc/s	249.1 Mc/s
227.2 Mc/s	237.8 Mc/s	249.9 Mc/s
227.7 Mc/s	240.2 Mc/s	250.7 Mc/s
228.2 Mc/s	241.5 Mc/s	251.5 Mc/s
229.9 Mc/s	242.0 Mc/s	252.4 Mc/s
230.4 Mc/s	243.8 Mc/s	253.1 Mc/s
230.9 Mc/s	244.3 Mc/s	253.8 Mc/s
231.4 Mc/s	244.8 Mc/s	255.1 Mc/s
231.9 Mc/s	245.3 Mc/s	256.2 Mc/s
232.4 Mc/s	245.8 Mc/s	257.3 Mc/s
232.9 Mc/s	246.3 Mc/s	258.5 Mc/s
234.0 Mc/s	246.8 Mc/s	259.7 Mc/s
235.0 Mc/s	247.3 Mc/s	

2. Telemetering services will be completely removed from the 225-260 Mc/s band by 1 January 1970.

APPENDIX 2 TO ENCLOSURE

1435-1540 Mc/s

TELEMETERING FREQUENCY ASSIGNMENT PLAN FOR FLIGHT TESTING* OF MANNED AND UNMANNED AIRCRAFT, MISSILES AND SPACE VEHICLES (OR MAJOR COMPONENTS THEREOF). The band 1435-1540 Mc/s is nationally allocated for Government/Non-Government use on a shared basis.

Frequency Mc/s	Restrictions
1435 to 1485	Narrow band channel spacing is in increments of 1 Mc/s beginning with the frequency 1435.5 Mc/s. Wide band channels are permitted. They will be centered on the center frequency of narrow band channels. Use of these channels is primarily for flight testing* of manned aircraft, and secondarily for flight testing* of unmanned aircraft and missiles or major components thereof.
1485 to 1535	Narrow band channel spacing is in increments of 1 Mc/s beginning with the frequency 1485.5 Mc/s. Wide band channels are permitted. They will be centered on the center frequency of narrow band channels. Use of these channels is primarily for flight testing* of unmanned aircraft and missiles or major components thereof, and secondarily for flight testing* of manned aircraft. Channels between 1525-1535 Mc/s may also be employed for space telemetering on a shared basis.
1535 to 1540	Channels in this band are for exclusive space use.

*Flight testing telemetry is defined as telemetry which is used in support of research, development, test and evaluation, and which is not integral to the operational function of the system.

APPENDIX 3 to ENCLOSURE

2200-2300 Mc/s

FREQUENCY ASSIGNMENT PLAN FOR TELEMETERING OTHER THAN FLIGHT TESTING OF MANNED AIRCRAFT.

Frequency Mc/s	Restrictions
2200 to 2290	Narrow band channel spacing is in increments of 1 Mc/s beginning with the frequency 2200.5 Mc/s. Wide band channels are permitted. They will be centered on the center frequency of narrow band channels. Use of these channels is on a co-equal shared basis with government fixed and mobile communications. Telemetering use of these channels, includes telemetry associated with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles, irrespective of their trajectories.
2290 to 2300	Use of this band is for deep space TM exclusively.

This Page is Reserved for
APPENDIX II

The Appendix to Section 2 is in preparation and is expected to be completed in approximately six months.

This Page is Reserved for
APPENDIX III

The Appendix to Section 3 is in preparation and is expected to be completed in approximately six months.

APPENDIX IV

PAM STANDARDS

ADDITIONAL INFORMATION AND RECOMMENDATIONS

1. IF Bandwidth and Transmitter Deviation

1.1 The appropriate receiver final IF bandwidth and transmitter deviation depend primarily on the total sampling rate (including provision for synchronization) and system noise and distortion tolerances.

1.2 Transmitter and receiver instabilities (refer to Section I for frequency tolerances) may cause frequency drifts as great as ±39,000 c/s in the VHF band. Instabilities of this magnitude preclude the use of the three lower receiver IF bandwidths, 12,500; 25,000; and 50,000 c/s unless special techniques, such as automatic frequency control capable of accommodating PAM waveforms, are applied.

2. Frame and Pulse Structure

2.1 It is recommended that ground system equipment be capable of decommutating both 50 percent and 100 percent duty cycle pulses, and that new systems applications recognize that 100 percent duty cycle pulses improve the radio frequency (RF) spectrum utilization.

3. Synchronization

3.1 The amplitude type synchronization format for the 100 percent duty cycle pulse structure provides: (1) A synchronizing pulse at full scale amplitude and duration 3 times that of individual channel pulses, giving good discrimination between synchronizing and channel pulses; (2) specific modulation levels at the beginning and end of the synchronization period (zero and half-scale levels); (3) assured full scale signal at least once per frame, thus permitting use of full scale clamp circuitry. These levels, zero half scale, and full scale permit automatic calibration correction in the receiving stations.

3.2 Binary code patterns should be selected that have a high probability of recognition in a random PAM pulse train. It is pointed out that the amplitude synchronization formats described in Figures 4-2 and 4-3 of the PAM standards can be considered as specific binary codes. (The 100 percent duty cycle case may be 0111.)

3.3 It is recommended that a flexible shift-register type pattern recognizer be used to accommodate possible variation in binary code patterns.

4. Pre-Modulation Filtering

4.1 It is recommended that the pre-modulation passband exhibit a final attenuation slope of 36 db per octave beyond the bandwidth specified in Section 4.7 of the PAM/FM Standards.

APPENDIX V

PCM STANDARDS

ADDITIONAL INFORMATION AND RECOMMENDATIONS

1. Bit Rate Vs. Receiver IF Bandwidth (3-db Points)

1.1 For reference purposes, in a well-designed system, a receiver IF signal-to-noise ratio (power) of approximately 15 db will result in a bit error probability of about 1 bit in 10^6. A 2 db change (increase or decrease) in this signal-to-noise ratio will result in an order-of-magnitude change (10^7 or 10^5 from 10^6, respectively in the bit error probability.

1.2 It should be recognized that the range of factors 1.5 to 3.3 recommended in section 5.2 of the IRIG Telemetry Standards may result in a compatibility problem when using current FM receivers for standard IRIG FM/FM and PDM/FM systems, as well as PCM/FM systems designed in accordance with the standard given here. Modifications to video amplifier stages and other circuitry may be required.

2. Word and Frame Structure

2.1 The assignment of word positions to convey special information in designated frames on a programmed basis is acceptable. The substituted words, including the necessary identifier and padding bits, shall exactly match the replaced word or words in total number of bits.

3. Suggested PCM Synchronization Patterns

3.1 It is suggested that an n-bit frame-synchronization pattern be selected under the criterion that the probability of displacement of the pattern by ±1 bit be minimized, at the same time restricting the probability of pattern displacement by 2 to (n-1) bits below a prescribed maximum. A 31-bit synchronization pattern satisfying this criterion is:

0101011010100101101001101010111

3.2 An analysis leading to the selection of this criterion and resulting synchronization patterns is presented in Technical Memorandum 73-53, "Synchronization Methods for PCM Telemetry," Naval Ordnance Laboratory, Corona, Calif.

3.3 Other synchronization patterns will be suggested when their suitability has been established.

3.4 It is recommended that a flexible shift-register type pattern recognizer be used to accommodate possible variations in patterns.

4. Premodulation Filtering

4.1 For a well-designed system, it is recommended that a premodulation low-pass filter with the following characteristics be used:

(1) Cutoff frequency (3 db) equal to the nominal bit rate.
(2) Maximally linear phase response.
(3) Final slope of 36 db per octave.

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APPENDIX VI

The Appendix to Section 6 is in preparation and is expected to be completed in approximately six months.