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RCC

TELEMETRY STANDARDS
(REVISED FEBRUARY 1969)

TELEMETRY WORKING GROUP
INTER-RANGE INSTRUMENTATION GROUP
RANGE COMMANDERS COUNCIL

KWAJALEIN MISSILE RANGE
WHITE SANDS MISSILE RANGE

NAVAL WEAPONS CENTER
PACIFIC MISSILE RANGE
ATLANTIC FLEET WEAPONS RANGE

AIR FORCE EASTERN TEST RANGE
AIR FORCE FLIGHT TEST CENTER
AIR FORCE SATELLITE CONTROL FACILITY
AIR FORCE WESTERN TEST RANGE
ARMAMENT DEVELOPMENT AND TEST CENTER

In the compilation of data for these Telemetry Standards it is possible that an error or two may have escaped detection. It is also possible that experience factors may reveal information different from that included in this edition.

Correspondence pertinent to these Telemetry Standards should be addressed to:

Secretariat,
Range Commanders Council
ATTN: STEWS-SA-R
TM Standards
White Sands Missile Range,
New Mexico 88002

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TELEMETRY STANDARDS

1. SCOPE AND APPLICATION

1.1 A standard in the field of telemetry for guided missiles was established in 1948 by the Research and Development Board (RDB) 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), of the Range Commanders Council, has prepared and published 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, 106-69, Telemetry Standards 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)
106-65	IRIG Telemetry Standards (Revised July 1965)
106-66	IRIG Telemetry Standards (Revised March 1966)

These current standards were established to foster the compatibility of telemetry transmitting, receiving, and signal processing equipment at the test ranges under the cognizance of the members of the Range Commanders Council. To this end, the Range Commanders recommend that telemetry equipment operated at the test ranges, and telemetry equipment used by programs requiring test range support, conform to these standards.

The capability attainable within the guidelines of these standards will accommodate the majority of all telemetry requirements. Occasionally, deviations may be necessary to support some peculiar requirements. Agencies proposing to use equipment configurations or techniques which deviate from these standards will be required to show that the action is both technically necessary and economically feasible. When an agency proposes to deviate from these standards the sponsoring headquarters (NAVORDSYSCOM, NAVAIRSYSCOM, AFSC, AMC, etc.) should be immediately informed. The sponsoring headquarters should then coordinate with the affected range(s) to mutually decide on the validity of the deviation. There is a dual objective in the procedure just described: First, it should be ascertained that the support required cannot be provided within the limits of these standards. Second, it should be

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

determined that utilization of a non-standard measurement method can successfully interface with existing and available systems and components.

These standards do not necessarily define the existing capability of any given test range but constitute a guide for the orderly implementation and application of telemetry systems for both the ranges and range users. The range of capabilities attainable with the utilization of these standards requires careful considerations of tradeoffs. Guidance concerning these tradeoffs is provided in the appendices.

To insure that the standards remain current, the Telemetry Working Group will review the standards versus range requirements at each of its meetings and provide revisions as appropriate.

2. REFERENCE DOCUMENTS

2.1 Reference documents are identified at their point of reference.

3. DEFINITIONS

3.1 Definitions are contained in RCC Document 104-64 (Revised 1969) A glossary of Range Terminology.

4. GENERAL STATEMENTS OR REQUIREMENTS

4.1 The general statements or requirements are contained in each section of this document.

5. DETAILED REQUIREMENTS

5.1 Radio Frequency Standards for Telemetry

5.1.1 General: These standards are the result of a joint effort of the Frequency Coordination and the Telemetry Working Groups of IRIG after consultation with related groups of the military services and industry. The purpose of these standards is to provide development and coordination agencies with criteria on which to base equipment design and modification. The specific intent is to insure interference-free operation and efficient utilization of the telemetry radio frequency spectrum.

Frequency utilization is a system problem. Throughout this section, in specifying radio-frequency bandwidths, the transmitter and receiver shall be considered as a system. Systems not adhering to these standards 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 may be required to demonstrate and prove the system design to frequency management personnel to justify the use of the frequency spectrum.

These standards have been devised for application at military test ranges where congestion of the usable frequency spectrum is a severe problem. It is recommended that, wherever possible, these same principles be applied to other fields outside the scope of the instrumentation systems.

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

5.1.2.1 Frequency Band 216 to 260 MHz

5.1.2.1.1 216 to 225 MHz. Channel spacing is based on 0.5 MHz separation on the integral and one-half-megahertz channels; assignments are made on a noninterference basis to established services.

5.1.2.1.2 225 to 260 MHz. Forty-four 500 kHz channels are allocated on a primary basis until 1 January 1970, as shown in Table I which follows on the next page.

TABLE I RADIO FREQUENCY TELEMETRY ASSIGNMENTS

Systems shall be capable of operating on any of the following frequencies without design modification (all given in MHz)*

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

*Telemetry assignments of Table I will be completely removed from this band by 1 January 1970.

5.1.2.1.3 Transmitter System

(a) Frequency Tolerance. The transmitter radio-frequency carrier considering variables such as operating time, supply voltage, temperature, acceleration, vibration, and shock, will be within 0.01 percent of the assigned frequency. The specified frequency tolerance is applicable for any or all operations in which the conducted power level is greater than -25 dbm for a duration of one or more seconds. If radiated measurements become necessary for the determination of frequency, the 0.01 percent tolerance shall apply when a field intensity of greater than 150 microvolts per meter for one or more seconds is experienced at a distance of 100 feet from the transmitter antenna system.

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

(c) Spurious Emission and Interference Requirements (Using test methods and equipment in accordance with current MIL STD).

(1) Spurious Emission (Antenna Conducted or Antenna Radiated - 0.150 to 10,000 MHz). 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 on the following page.

db (down from unmodulated carrier) = $55 + 10 \log_{10} P_t$,
where P_t is the measured output power in watts.

NOTE

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 unmodulated conditions.

(2) Interference (Conducted or Radiated). All interference voltages (0.150 to 25 MHz) conducted by the power leads and interference fields (0.150 to 10,000 MHz) radiated directly from equipment, units, or cables, shall be within the limits specified by the current MIL STD.

(d) Bandwidth. The power level of any 3 kHz bandwidth between f_o + 320 kHz and f_o + 500 kHz; and between f_o -320 kHz and f_o - 500 kHz shall be at least 40 db down from the unmodulated carrier power. The power level of any 3 kHz bandwidth beyond $f_o \pm$ 500 kHz shall be at least X db down from the unmodulated carrier power where X is determined from the following formula and is applicable only for transmitter powers equal to or greater than 0.04 watts.

(Formula) $X = 55 + 10 \log_{10} P_t$,

where P_t is the measured output power in watts and f_o is the assigned frequency.

All bandwidth measurements (spectrum analysis) will be made with instruments having a bandwidth of 3 kHz.

5.1.2.1.4 Receiver Systems

(a) Spurious Emissions (0.150 to 10,000 MHz). Radio-Frequency energy, both radiated from the unit and antenna conducted, shall be within the limits specified in the current MIL STD.

(b) Interference Protection. Radio frequency interference protection shall be provided only for systems using receivers which meet the following criteria:

(1) Frequency Stability. Shall be 0.001 percent or better.

(2) Spurious Response (0.150 to 10,000 MHz). Shall be more than 60 db below the fundamental frequency response.

(3) Flexibility of Operation. The system shall operate on any of the frequencies in Table I, without design modification.

(4) Bandwidth. A maximum bandwidth of 1.2 MHz (±600 kHz), as referenced to the 60 db points, will be permitted.

5.1.2.2 Frequency Bands 1435-1540 MHz and 2200-2300 MHz

5.1.2.2.1 The band 1435-1540 MHz is nationally allocated to Government and nongovernment telemetry use on a shared basis. Telemetry assignments will be made therein for flight testing[2] of manned and unmanned aircraft, missiles, space vehicles or major components thereof, as described below:

(a) 1435-1485 MHz. Narrowband channel spacing is in increments of 1 MHz beginning with the frequency 1435.5 MHz. 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.

(b) 1485-1535 MHz. Narrowband channel spacing is in increments of 1 MHz beginning with 1485.5 MHz. Wideband 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 secondly for flight testing of manned aircraft. Channels between 1525-1535 MHz may also be employed for space telemetry on a shared basis.

(c) 1535-1540 MHz. Channels in this band are for exclusive space purposes.

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

(a) 2200-2290 MHz. Narrowband channel spacing is in increments of 1 MHz beginning with 2200.5 MHz. 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

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[2]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.

with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles, irrespective of their trajectories.

(b) 2290-2300 MHz. Use of this band is for deep space telemetry exclusively.

5.1.2.2.3 Transmitter Systems

(a) Frequency Tolerance. The transmitter radio frequency carrier considering variables such as operating time, supply voltage, temperature, acceleration, vibration, and shock, shall be within 0.003 percent of the assigned frequency.

(1) Measurement Note. Between 1 and 30 seconds after initial turn-on, the transmitter carrier frequency shall remain within 0.01 percent of the assigned frequency. After warm-up, the specified frequency tolerance is applicable for any and all operations in which the conducted power level is greater than -25 dbm for a duration of one or more seconds. If radiated measurements become necessary for the determination of frequency, the tolerance outlined in 5.1.2.2.3 (a) shall apply when a field intensity of greater than 500 microvolts per meter is experienced at a distance of 100 feet from the transmitter antenna system. The intent of paragraph 5.1.2.2.3 (a) and this paragraph is to describe transmitter carrier stability requirements; the effects of modulation are not included in this requirement.

(b) Power. The power shall be as directed by the intended use, and never more than absolutely necessary.

(c) Spurious Emission and Interference Requirements (Using methods and equipment in accordance with current MIL STD).

(1) Spurious Emission (Antenna Conducted or Antenna Radiated - 0.150 to 10,000 MHz). 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.

NOTE

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.

NOTE (Cont'd)

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

(d) Flexibility of Operation. The transmitter shall be capable of operating throughout the entire frequency band from 1435 to 1540 MHz and/or 2200-2300 MHz, without design modifications.

(e) Bandwidth

(1) For a nominal 1 MHz channel spacing, the power level of any 3 kHz bandwidth between f_o + 0.6 MHz and f_o + 1.0 MHz, and between f_o - 0.6 MHz and f_o - 1.0 MHz shall be at least 60 db down from the unmodulated carrier power. The power level of any 3 kHz bandwidth beyond $f_o \pm 1.0$ MHz shall be at least X db down from the unmodulated carrier power where X is determined from the following formula and is applicable only for transmitter powers equal to or greater than 4.0 watts.

(Formula) $X = 55 + 10 \log_{10} P_t$,

where P_t is the measured output power in watts and f_o is the assigned frequency.

All bandwidth measurements (spectrum analysis) will be made with instruments having a bandwidth of 3 kHz.

(2) Wideband systems will be permitted to use transmitter assigned bandwidths of 2.2, 3.2, 4.2, etc. MHz as referenced to the 60 db points. Frequency assignments will be made on an individual requirements basis. In all cases the X db bandwidth of the modulated carrier referenced to the unmodulated carrier shall not exceed the assigned bandwidth by more than 1.0 MHz ($\pm$0.5 MHz) where X is determined and measurements are made as stated in 5.1.2.2.3 (e) (1) above.

5.1.2.2.4 Receiver Systems

(a) Spurious Emissions (0.150 to 10,000 MHz). Radio-frequency energy, both radiated from the unit and antenna-conducted, shall be within the limits specified in the current MIL STD.

(b) Interference Protection. Radio-frequency interference protection will be provided only for systems using receivers which meet the following criteria:

(1) Frequency Stability. Shall be 0.001 percent or better.

(2) Spurious Responses (0.150 to 10,000 MHz). Shall be more than 60 db below the fundamental frequency response.

(3) Flexibility of Operation. The system shall be tunable over the entire 1435 to 1540 MHz band and/or 2200 to 2300 MHz band, without design modification, and will have variable bandwidth selection.

(4) Bandwidth. For a nominal 1 MHz channel spacing, a maximum bandwidth of 1.2 MHz (±600 kHz) as referenced to the 60 db points, will be permitted. Wide band systems will be permitted to use bandwidths of 2.2, 3.2, 4.2, etc. MHz as referenced to the 60 db points. Assignments will be made on an individual requirements basis.

5.2 FREQUENCY DIVISION MULTIPLEXING TELEMETRY STANDARDS (FM/FM AND FM/PM)

5.2.1 General. In these systems, one or more subcarriers, each at a different frequency, are employed to frequency modulate (FM) or phase modulate (PM) a transmitter in accordance with the radio-frequency conditions specified in Section 5.1.

Each of the subcarriers conveys measurement data in the form of frequency modulation. The number of data channels may be increased by modulating the subcarrier with a time division multiplex format such as PAM, PDM, or PCM (see Sections 5.3, 5.4, and 5.5), provided the limits of subcarrier deviation are not exceeded.

The selection and grouping of subcarrier channels depend upon the data bandwidth requirements of the application at hand, and upon the necessity to ensure adequate guard bands between channels. Combinations of both proportional-bandwidth channels and constant-bandwidth channels may be used.

AM baseband standards will be added to this section in future editions of this document.

5.2.2 Subcarrier Channels

Table II lists 29 FM proportional-bandwidth subcarrier channels. The channels identified with letters permit ±15 percent subcarrier deviation rather than ±7.5 percent deviation, but use the same center frequencies as the eight highest numbered channels. The channels shall be used within the limits of maximum subcarrier deviation. (See Appendix B for expected performance tradeoffs at selected combinations of deviation and modulating frequency.)

Table III lists 35 FM constant-bandwidth subcarrier channels. The letters A, B and C identify the channels for use with maximum subcarrier deviations of ±2 kHz, ±4kHz and ±8kHz respectively, along with maximum frequency responses of 2 kHz, 4kHz and 8 kHz respectively. The channels shall be used within the limits of maximum subcarrier deviation. (See Appendix B for expected performance tradeoffs at selected combinations of deviation and modulating frequency.)

5.2.2.1 Subcarrier Channel Spacing. There is a ratio of approximately 1.33 to 1 between the center frequencies of adjacent ±7.5 percent proportional bandwidth channels, except that 14.5 kHz and 22 kHz where a larger gap is left to provide a 60 Hz amplitude modulated 17 kHz carrier for capstan speed control of magnetic-tape recorders. [See paragraph 5.6.2.2.6 (b) (1).] The use of an additional FM subcarrier between 14.5 kHz and 22 kHz is not permissible.

5.2.3 Tape Speed Control and Flutter Compensation

Tape Speed Control and flutter compensation may be accomplished as indicated in paragraph 5.6.2.2.6. Use of the standard reference frequency shall be in accordance with the criteria of Table IV, when the reference signal is mixed with data.

TABLE II PROPORTIONAL SUBCARRIER CHANNELS

±7.5% CHANNELS

Channel	Center Frequencies (Hz)	Lower Deviation Limit* (Hz)	Upper Deviation Limit* (Hz)	Nominal Frequency Response (Hz)	Nominal Rise Time (ms)	Maximum Frequency Response*** (Hz)*	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 5.2.2.1							
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 5.2.3							
20**	124,000	114,700	133,300	1860	.19	9,300	.038
21**	165,000	152,625	177,375	2475	.14	12,375	.029

±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
G**	124,000	105,400	142,600	3720	.09	18,600	.018
H**	165,000	140,250	189,750	4950	.07	24,750	.014

* Rounded off to nearest Hz.

** Recommended for use in UHF transmission systems only.

*** The indicated maximum data 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 5.2.2 and referenced discussion in Appendix B for determining possible accuracy versus response tradeoffs.)

**** Channels A thru H may be used by omitting adjacent lettered and numbered channels. Channels 13 and A may be used together with some increase in adjacent channel interference.

TABLE III CONSTANT BANDWIDTH SUBCARRIER CHANNELS

A CHANNELS		B CHANNELS		C CHANNELS	
Deviation limits = ±2 kHz Nominal frequency response = 0.4 kHz Maximum frequency response = 2 kHz**		Deviation limits = ±4 kHz Nominal frequency response = 0.8 kHz Maximum frequency response = 4 kHz**		Deviation limits = ±8 kHz Nominal frequency response = 1.6 kHz Maximum frequency response = 8 kHz	
Channel	Center Frequency (kHz)	Channel	Center Frequency (kHz)	Channel	Center Frequency (kHz)
1A	16				
2A	24				
3A	32	3B	32		
4A	40				
5A	48	5B	48		
6A	56				
7A	64	7B	64	7C	64
8A	72				
9A	80	9B	80		
10A	88				
11A	96	11B	96	11C	96
12A	104				
13A	112	13B	112		
14A	120				
15A	128	15B	128	15C	128
16A*	136				
17A*	144	17B*	144		
18A*	152				
19A*	160	19B*	160	19C*	160
20A*	168				
21A*	176	21B*	176		

* Recommended for use in UHF transmission systems only.

** The indicated maximum frequency response is based upon the maximum theoretical response that can be obtained in a bandwidth between deviation limits specified for the channel. (See discussion in Appendix B for determining practical accuracy versus response tradeoffs.)

TABLE IV REFERENCE SIGNAL USAGE
Reference and Data Signals on Same Track

Reference Frequency kHz	Subcarrier Usage
*240 ± 0.01%	For use with all center frequencies
200 ± 0.01%	For use with all center frequencies except Channel H
100 ± 0.01%	Use with center frequencies up to and including 80 kc
50 ± 0.01%	Use with center frequencies up to and including 40 kc except Channel C
25 ± 0.01%	Use with center frequencies up to and including 14.5 kc
12.5 ± 0.01%	Use with center frequencies up to and including 7.35 kc
6.25 ± 0.01%	Use with center frequencies up to and including 3.9 kc
3.125 ± 0.01%	Use with center frequencies up to and including .960 kc

*for flutter compensation only, not for tape speed control.

If the reference signal is recorded on a separate track, any of the listed reference frequencies may be used, provided the requirements for compensation rate of change are satisfied.

Table IV shows that the 240 kHz reference frequency is the only permissible frequency when Channel H is included in the multiplex and the reference signal is mixed with the data. In addition, the 240 kHz reference signal may be used as a translation frequency in a constant-bandwidth format, provided the reference signal is suitably divided down, to 80 kHz for example.

In addition to the reference frequencies listed in Table IV, which are of the constant-amplitude type, an amplitude modulated signal centered at 17 kHz ± 0.5% may be used for servo speed correction. See paragraph 5.6.2.2.6 (b) (1). Channel 1A must be deleted if the 17 kHz signal is multiplexed with subcarrier signals.

5.3 PULSE DURATION MODULATION (PDM) STANDARD

5.3.1 General. Pulse Duration Modulation (PDM) data, the characteristics of which are specified herein, shall be transmitted as time-division multiplexed analog pulses with the duration of the information channel pulses being the analog-variable parameter.

This standard defines recommended pulse train structure and design characteristics for the implementation of Pulse Duration Modulation telemetry systems.

5.3.2 Frame and Pulse Structure. Each frame shall consist of a time-sequenced constant number of channel intervals and a frame synchronization interval. The maximum frame length shall be 128 channel time intervals per frame, including intervals devoted to synchronization and calibration. A representation of PDM waveform is shown in Figure 1 (A).

5.3.2.1 Commutation Pattern. The information channels are allocated equal and constant time intervals within the PDM frame. Each such interval ("T" in Figure 1) contains a variable duration information sample pulse commencing at the start of the interval and having a maximum duration less than "T" as defined in paragraph 5.3.2.5 below. The duration of each information pulse shall be determined by the amplitude of the measurand of the corresponding information channel according to a fixed relationship (usually linear) between the minimum zero-level pulse duration and the maximum full-scale-level pulse duration.

5.3.2.2 In-Flight Calibration. In-Flight calibration should be obtained from zero and full-scale calibration pulses, respectively, in channel time intervals 1 and 2 immediately following the frame synchronization interval.

5.3.2.3 Frame Synchronization Interval. Each frame shall be identified by the presence within it of one of the following:

(a) A full amplitude synchronization pulse, the duration of which is equal to 1.5 T in a time interval of two consecutive periods T (Figure 1 (A)). The pulse duration so defined is the period between the 50 percent amplitude levels (approximately) of the frame synchronization pulse measured at a point in the telemetry system prior to premodulation filtering.

(b) The absence of a pulse for a time interval equal to 2T (See Figure 1(B)).

5.3.2.4 Minimum Pulse Duration. The duration of the pulse shall be measured prior to the premodulation filter and at approximately the 50 percent level.

(a) PDM/FM/FM. The minimum duration PDM pulse shall be greater than 1.5 times the reciprocal of the peak-to-peak deviation of the frequency modulated subcarrier.

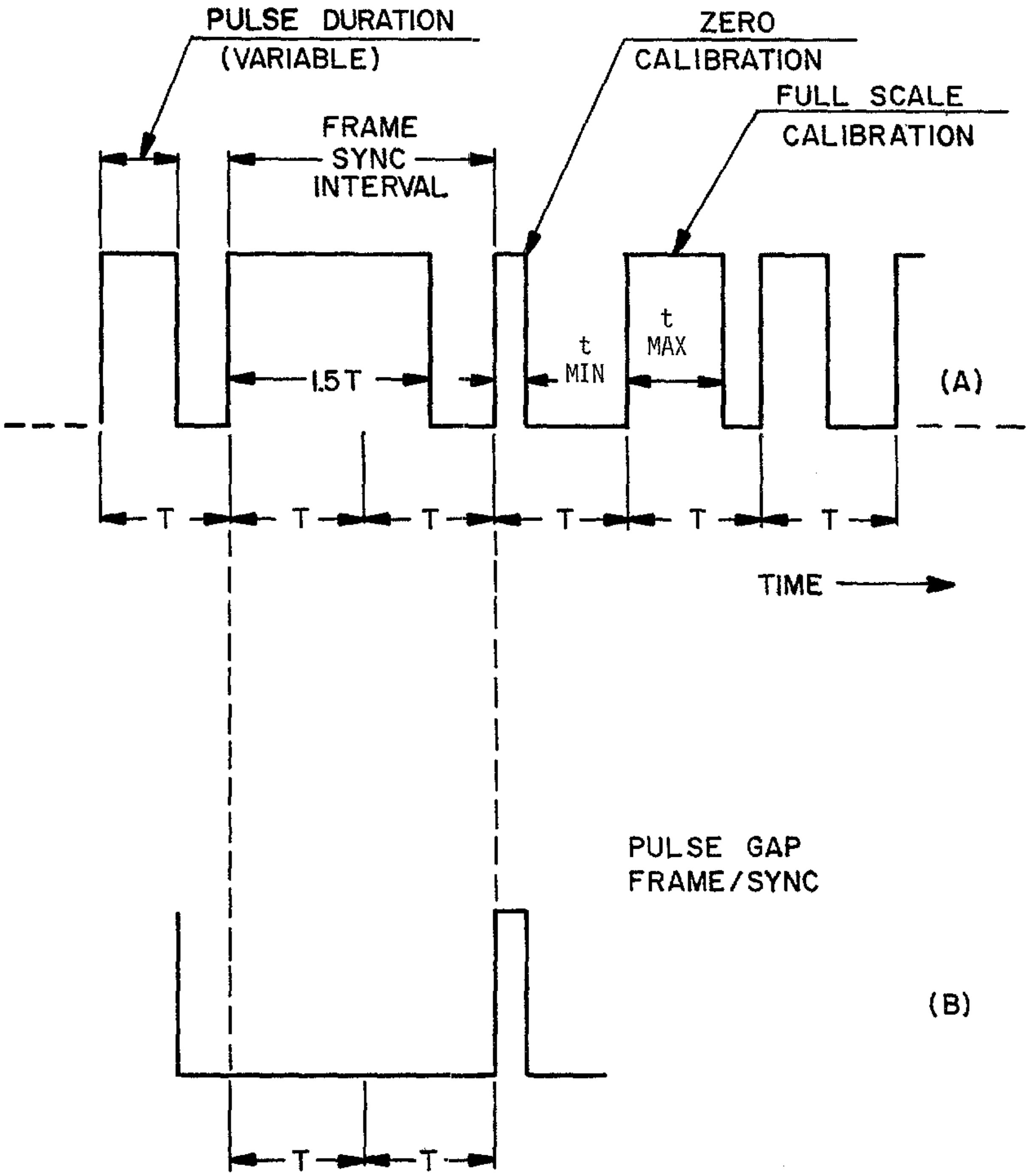


FIGURE 1 PDM PULSE TRAIN WAVEFORM

(b) PDM/FM and PDM/PM. The minimum pulse duration shall be greater than 1.33 times the reciprocal of the 3 db frequency of the premodulation filter when employed, or greater than 1.5 times the reciprocal of the 3 db intermediate frequency (IF) bandwidth selected from Table V, whichever is more constricting.

5.3.2.5 Maximum Pulse Duration. The duration of the pulse shall be measured prior to the premodulation filter and at approximately the 50 percent level.

(a) PDM/FM/FM. The maximum duration of any PDM pulse shall be such that the shortest interval between successive pulses is not less than 2.5 times the reciprocal of the peak-to-peak deviation of the frequency modulated subcarrier. (See Appendix C)

(b) PDM/FM and PDM/PM. The maximum duration of a PDM pulse shall be such that the shortest interval between successive pulses is not less than 2.5 times the reciprocal of the intermediate frequency (IF) bandwidth (3 db points) listed in Table V.

5.3.3 Frame and Pulse Rate. The frame structure parameters listed below may be used in any combination:

(a) A minimum rate of 0.125 frames per second.

(b) A maximum pulse rate of 3600 pulses per second.

5.3.3.1 Long-Term Accuracy and Stability. The time between the occurrence of corresponding points of two successive frames shall not differ from the reciprocal of the specified nominal frame rate by more than 5 percent of the nominal frame period.

5.3.3.2 Short-Term Stability. During a measured period, P, for the occurrence of 1000 channel intervals, the time between the occurrence of the 50 percent amplitude levels of the leading edge of any two successive pulses (synchronization pulses excepted) shall not differ from the average channel interval established by the formula $T_{ave} = \frac{P}{1000}$ by more than 1 percent of the average interval.

5.3.4 Multiple and Submultiple Sampling Rates. Data Multiplexing at sampling rates which are multiples and/or submultiples of the frame rate is permissible.

5.3.4.1 Submultiple Frame Synchronization. The beginning of the longest submultiple frame interval shall be identified by a synchronization pattern consisting of the absence of a pulse in two successive occurrences of the same frame channel interval allocated to data channels of the identified submultiple frame. All other submultiple frames shall have a fixed and known relationship to the identified submultiple frame.

5.3.4.2 Maximum Submultiple Frame Length. The interval of any submultiple frame, including the time devoted to synchronizing information, shall not exceed 128 times the interval of the frame in which it occupies a recurring position.

5.3.5 Radio Frequency or Subcarrier Modulation

5.3.5.1 Frequency Modulation. The frequency deviation of an FM carrier or subcarrier which represents the maximum or minimum amplitude of a PDM waveform shall be equal and opposite with respect to the frequency of the unmodulated carrier or subcarrier. The deviation shall be the same for all occurrences of the same level.

5.3.5.2 Phase Modulation. The phase deviation of a PM carrier which represents the maximum or minimum amplitudes of a PDM waveform shall be equal and opposite with respect to the phase of the assigned carrier frequency. The deviation shall be for all occurrences of the same level.

5.3.6 Premodulation Filtering. Premodulation filtering is recommended to restrict the radiated spectrum as specified in paragraphs 5.1.2.1.3 (d) and 5.1.2.2.3 (e). Recommended filter characteristics are given in Appendix C.

5.4 PULSE AMPLITUDE MODULATION (PAM) STANDARDS

5.4.1 General. Pulse Amplitude Modulated (PAM) data, the characteristics of which are specified herein, shall be transmitted as time division multiplexed analog pulses with the amplitude of the information channel pulse being the analog-variable parameter.

This standard defines recommended pulse train structure and design characteristics for the implementation of Pulse Amplitude Modulation telemetry systems.

5.4.2 Frame and Pulse Structure. Each frame shall consist of a constant number of time-sequenced channel intervals. The maximum frame length shall be 128 channel time intervals per frame, including the intervals devoted to synchronization and calibration. The pulse and frame structure shall conform to either Figure 2 or 3.

5.4.2.1 Commutation Pattern. The information channels are allocated equal and constant time intervals within the PAM frame. Each interval ("T" in Figures 2 and 3) contains a sample pulse commencing at the start of the interval and having amplitude determined by the amplitude of the measurand of the corresponding information channel according to a fixed relationship (usually linear) between the minimum level (zero amplitude) and the maximum level (full-scale amplitude). For 50 percent duty cycle (RZ PAM), the zero calibration level shall be 20 percent to 25 percent of full amplitude level as shown in Figure 2. The pulse width shall be the same in all time intervals (the intervals devoted to synchronization excepted). The duration shall be either 0.5T ± 0.05T, as shown in Figure 2, or T ± 0.05T, as shown in Figure 3.

5.4.2.2 In-Flight Calibration. It is recommended that in-flight calibration be used and Channels 1 and 2, immediately following the frame synchronization interval, be used for zero and full-scale calibration, respectively.

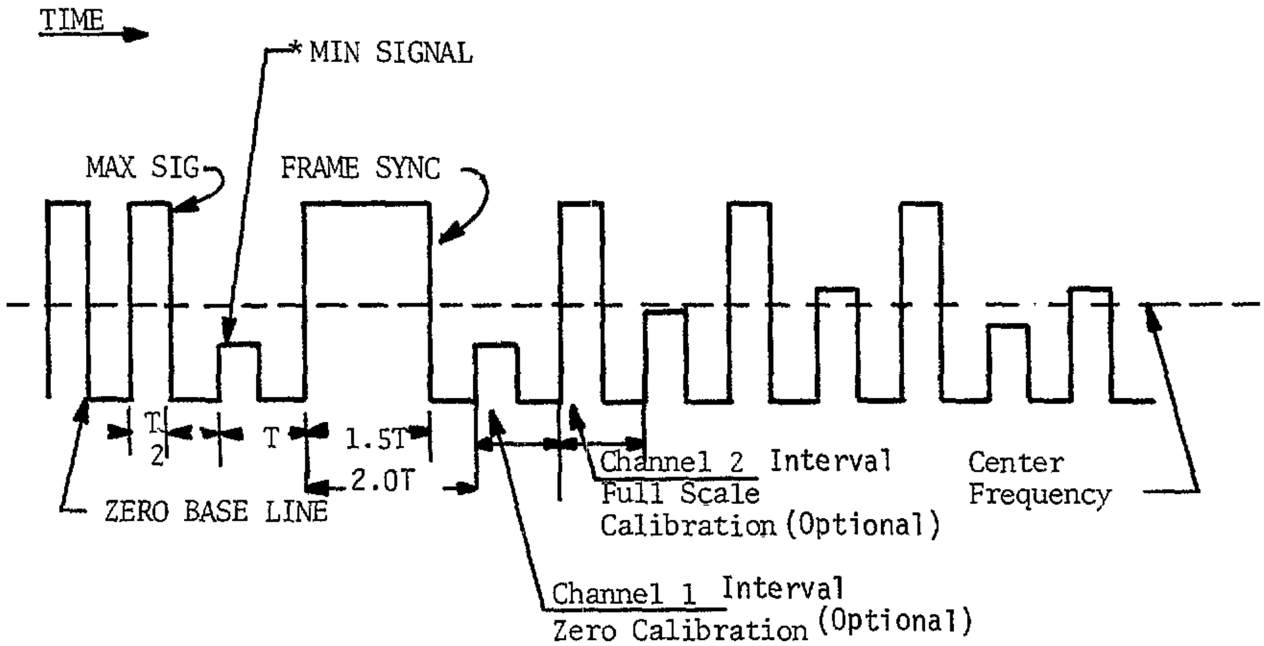
5.4.2.3 Frame Synchronization Interval. Each frame shall be identified by the presence within it of a synchronization interval.

(a) Fifty Percent Duty Cycle (RZ-PAM). The synchronization pattern interval shall have a duration equal to two information channel intervals 2T and shall be full-scale amplitude for 1.5T followed by the reference level for 0.5T (See Figure 2).

(b) One-Hundred Percent Duty Cycle (NRZ-PAM). The synchronization pattern shall be, in the order given, zero level for a period T, full-scale amplitude for a period 3T, and a level not exceeding 50 percent full-scale amplitude for a period T (See Figure 3).

5.4.2.4 Maximum Pulse Rate. The maximum pulse rate shall not be greater than that permitted by the following:

(a) PAM/FM/FM. The reciprocal of the shortest interval between transitions in the PAM pulse train shall be not greater than one-fifth of the total (peak-to-peak) deviation specified in paragraph 5.2, Tables II and III, for the FM Subcarrier selected.



*20 to 25 percent deviation reserved for pulse synchronization is recommended

FIGURE 2 50 PERCENT DUTY CYCLE PAM WITH AMPLITUDE SYNCHRONIZATION

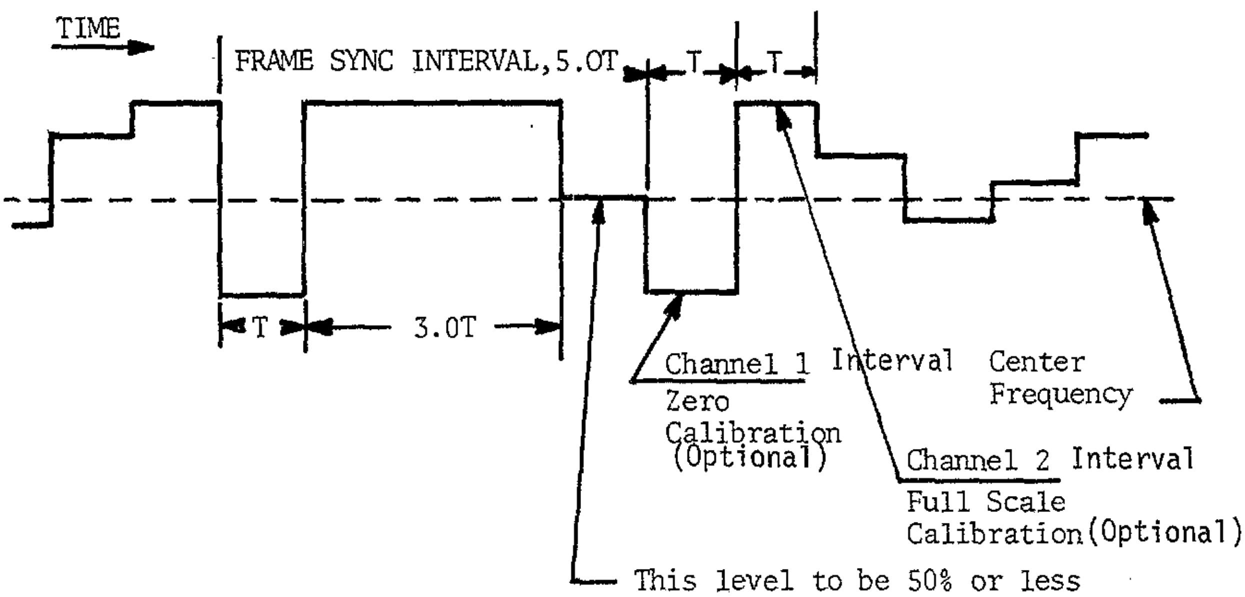


FIGURE 3 100 PERCENT DUTY CYCLE PAM WITH AMPLITUDE SYNCHRONIZATION

(b) PAM/FM. The reciprocal of the shortest interval between transitions in the PAM pulse train shall be limited by whichever is narrower of the following:

(1) One half of the 3 db frequency of the premodulation filter when employed.

(2) One fifth of the intermediate frequency (IF) bandwidth (3 db points) selected from the IF bandwidths listed in Table V.

5.4.3 Frame and Pulse Rate. The frame structure parameters listed below may be used in any combination:

(a) A minimum rate of 0.125 frames per second.

(b) A maximum pulse rate as specified in paragraph 5.4.2.4.

5.4.3.1 Long Term Accuracy and Stability. The time between the occurrence of corresponding points in any two successive frame synchronization intervals shall not differ from the reciprocal of the specified nominal frame rate by more than 5 percent of the nominal period.

5.4.3.2 Short Term Stability. During a measured period, P, for the occurrence of 1000 channel intervals, the time between the start of any two successive channel intervals (synchronization intervals excepted) shall not differ from the average channel interval established by the formula $T_{av} = \frac{P}{1000}$ by more than 1 percent of the average interval.

5.4.4 Multiple and Submultiple Sampling Rates. Data multiplexing at sampling rates which are multiples and submultiples of the frame rate is permissible.

5.4.4.1 Submultiple Frame Synchronization. The beginning of the longest submultiple frame interval shall be identified by the transmission of a synchronization pattern. All other submultiple frames shall have a fixed and known relationship to the identified submultiple frames.

(a) Fifty Percent Duty Cycle (RZ). The presence of a full scale amplitude pulse in two successive occurrences of the same frame channel interval allocated to data channels of the identified submultiple frame. The first such pulse shall have a duration equal to the channel interval; the second pulse shall have a duration nominally one-half the channel interval.

(b) One-Hundred Percent Duty Cycle (NRZ). The presence of synchronization information in five successive occurrences of the same frame channel interval allocated to data channels of the identified submultiple frame.

The amplitude of the data channels assigned for synchronization shall be as follows:

(1) First Occurrence - Zero amplitude

(2) Second, Third, and Fourth Occurrences - Full-scale amplitude.

(3) Fifth Occurrence - Not more than 50 percent of full-scale amplitude.

5.4.4.2 Maximum Submultiple Frame Length. The interval of any submultiple frame, including the time devoted to synchronizing information, shall not exceed 128 times the interval of the frame in which it occupies a recurring position.

5.4.5 Frequency Modulation. The frequency deviation of an FM carrier or subcarrier, which represents the maximum and minimum amplitude of a PAM waveform, shall be equal and opposite with respect to the assigned carrier or subcarrier frequency. The deviation shall be the same for all occurrences of the same level.

5.4.6 Premodulation Filtering. Premodulation filtering is recommended to restrict the radiated spectrum as specified in paragraphs 5.1.2.1.3 (d) and 5.1.2.2.3 (e). Recommended filter characteristics are given in Appendix D.

5.5 PULSE CODE MODULATION (PCM) STANDARDS

5.5.1 General. Pulse Code Modulation (PCM) data, the characteristics of which are specified herein, shall be transmitted as serial binary-coded time-division multiplexed samples using the sequence of pulses within each sample to represent a discrete magnitude of the data.

The standard defines recommended pulse train structure and design characteristics for the implementation of Pulse Code Modulation telemetry systems.

5.5.2 Word and Frame Structure. The PCM frame shall contain a known number of bit intervals, all of equal duration, unless special identification bits within the bit stream indicate a change. The duration of the bit interval and the number of bit intervals per frame shall remain fixed from frame to frame.

5.5.2.1 Frame Length. The length of a frame shall not exceed 2048 bit intervals, including the intervals devoted to synchronization.

5.5.2.2 Frame Synchronization. The frame synchronization information shall consist of a digital word not longer than 33 bits in consecutive bit intervals within the frame. Recommendations concerning synchronization patterns are given in Appendix E.

5.5.2.3 Word Length. Individual words shall not be less than 6 bits nor more than 64 bits in length. Within these limits, words of different length may be multiplexed in a single frame. However, the length of a word in any position within a frame shall be constant from frame to frame, except during changes caused by special identification bits appearing in the bit stream.

5.5.2.4 Special Words. The assignment of word positions to convey special information on a programmed basis in designated frames is permissible. The number of bits in the substituted words, including identification and padding bits, shall exactly equal the number of bits in the replaced words.

5.5.2.5 Binary Bit Representation. The following conventions for representing binary "one" and "zero" are permissible:

NRZ-L	RZ	BIØ-L
NRZ-M		BIØ-M
NRZ-S		BIØ-S

Graphic and verbal descriptions of these conventions are given in Figure 4. Only one convention shall be used in a single PCM pulse train.

5.5.3 Maximum Bit Rate. The maximum bit rate is limited only by the requirements of paragraph 5.1.2.2.3(e). Receiver intermediate frequency (IF) bandwidths should be selected from Table V. The minimum bit rate shall be 1 pps.

5.5.3.1 Bit Rate Accuracy and Stability. During any period of desired data, the bit rate shall not differ from the specified nominal bit rate by more than 1 percent of the nominal rate.

TABLE V

RECEIVER INTERMEDIATE FREQUENCY BANDWIDTH (3db)

12,500 Hz*
25,000 Hz*
50,000 Hz*
100,000 Hz
300,000 Hz
500,000 Hz
750,000 Hz
1,000,000 Hz**
1,500,000 Hz**
3,300,000 Hz**

* System instabilities may limit the use of these bandwidths

** For use in the 1435-1535 MHz and 2200-2300 MHz Telemetry Frequency Bands only.

5.5.3.2 Bit Jitter. Any transition in the PCM waveform occurring within interval P shall occur within 0.1 bit periods of the time at which such transition is expected to occur based upon the measured average bit period as determined during the immediately preceding interval P. The interval P for the purpose of this requirement, shall be equal to the measured time for five successive frames.

$$\text{Average Bit Period} = \frac{P}{\text{Specified Bits per frame X 5}}$$

5.5.4 Multiple and Submultiple Sampling. Data sampling at rates which are multiples or submultiples of the frame rate is permissible. When submultiple sampling is employed, the restrictions on frame length (paragraph 5.5.2.1 above) and bit jitter (paragraph 5.5.3.2 above) are applicable to the submultiple frame.

5.5.4.1 Subframe Synchronization Methods. Recommended methods for identifying subframe channels are as follows:

(a) The beginning of a submultiple frame may be identified by a unique digital word within the submultiple frame and occupying the same word interval as the submultiple frame. Each submultiple sequence will have a fixed and known relationship to the submultiple frame identification word.

(b) The beginning of a submultiple frame may be identified by a unique digital word replacing the frame synchronization word indicating start of the submultiple sequence.

(c) Each word within the submultiple sequence may contain identification bits to indicate the position of that word.

5.5.4.2 Maximum Submultiple Frame Length. The interval of any submultiple frame, including the time devoted to synchronizing or channel identification information, shall not exceed 128 times the interval of the frame in which it occupies a recurring position.

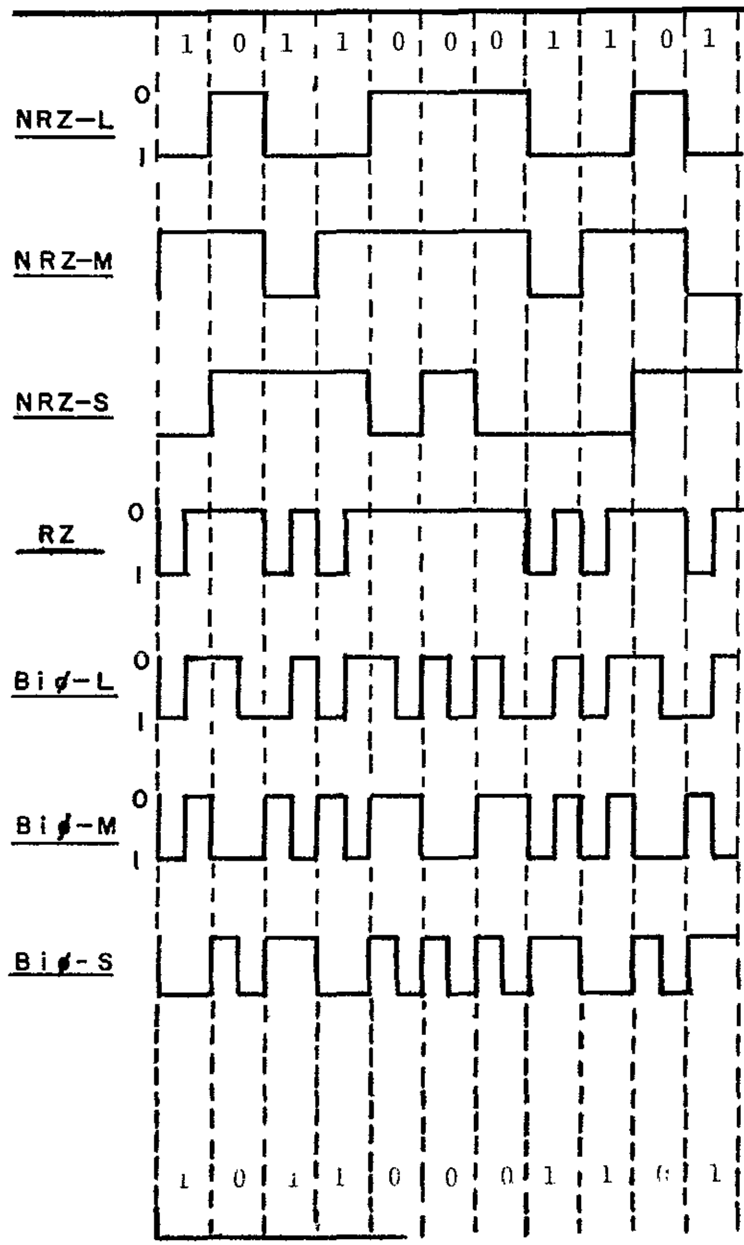
5.5.5 Radio Frequency and Subcarrier Modulation

5.5.5.1 Frequency Modulation (FM). The frequency deviation of an FM carrier or subcarrier shall be symmetrical about the assigned carrier or subcarrier frequency. The deviation shall be the same for all occurrences of the same level.

5.5.5.2 Phase Modulation (PM). The phase deviation of a PM carrier shall be symmetrical about the unmodulated carrier. The deviation shall be the same for all occurrences of the same level.

5.5.5.3 PCM/FM/FM. The subcarrier channel shall be chosen such that the maximum frequency response for the channel (as given in Tables II and III, Section 5.2) is greater than the reciprocal of twice the shortest period between transitions in the PCM waveform.

5.5.6 Premodulation Filtering. Premodulation Filtering is recommended to confine the radiated RF spectrum as required in paragraphs 5.1.2.1.3 (d) and 5.1.2.2.3 (e). Recommended filter characteristics are given in Appendix E.



NRZ-Level (or NRZ Change)
"One" is represented by one level
"Zero" is represented by the other level

NRZ-Mark
"One" is represented by a change in level
"Zero" is represented by no change in level

NRZ-Space
"One" is represented by no change in level
"Zero" is represented by a change in level

RZ
"One" is represented by a half-bit wide pulse
"Zero" is represented by no pulse condition

Bi-Phase-Level (or Split Phase, Manchester 11 + 180°)
"One" is represented by a 10
"Zero" is represented by a 01

Bi-Phase Mark
A transition occurs at the beginning of every bit period.
"One" is represented by no second transition.
"Zero" is represented by a second transition one-half bit period later.

Bi-Phase Space
A transition occurs at the beginning of every bit period.
"One" is represented by a second transition one-half bit period later.
"Zero" is represented by no second transition.

FIGURE 4 PCM WAVEFORMS

5.6 MAGNETIC-TAPE RECORDER/REPRODUCER STANDARDS

5.6.1 General. These standards define terminology, standardize the recorder/reproducer configuration to achieve compatibility and specify test procedures for 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. The provisions of this standard and measurement methods described herein apply to a single machine only. Machine-to-machine tolerance accumulations are not implied.

5.6.2 Compatibility Requirements - Fixed Head Recorder/Reproducers

5.6.2.1 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.

5.6.2.1.1 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 (ips).

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

(a) Low Band. Direct record response to 100,000 Hz nominal at 60 ips.[3]

(b) Intermediate Band. Direct record response to 250,000 Hz nominal at 60 ips or 500,000 Hz nominal at 120 ips.

(c) Wideband. Direct record response to 1.5 MHz nominal at 120 ips.[4]

5.6.2.2 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 radio-frequency signals. It can be used for postdetection recording, but due to the wide bandwidth employed,

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[3]For recording subcarrier bands above Proportional Bandwidth Channel 18 or Constant Bandwidth Channel 11B, intermediate-band recorders are recommended.

[4]Interchange of tapes between wideband machines and low-or intermediate-band machines is NOT recommended.

signal-to-noise ratios may be worse than would be obtained using low or intermediate bandwidth recorders.

5.6.2.2.1 Tape and Reel Characteristics. Magnetic tape characteristics are specified in Interim Federal Specification W-T-0070 (NAVY-Ships).[5] Reel characteristics are specified in Federal Specification W-R-00175 (NAVY-Ships).[6] Tapes and reels qualified under the appropriate section of these specifications are adequate for many applications, but additional supplementary procurement specifications may be required on an interim basis to meet a particular operational requirement of the Ranges pending updating of the Federal Specifications.[7]

(a) Tape Widths. The standard nominal tape widths for direct recording are 1/2 and 1 inch, with tolerances on all widths as specified in Interim Federal Specification W-T-0070. The 1/2-inch tape recorders are most widely available at the ranges.

(b) Tape Specifications

(1) Any tapes qualified under Interim Federal Specification W-T-0070/4 shall be used for low-band recording.

(2) Tapes qualified under Interim Federal Specification W-T-0070/4 shall be used for intermediate-band recording.

(3) Tapes qualified under Interim Federal Specification W-T-0070/5 shall be used for wideband recording.

(c) Track Geometry. See Figure 5, Analog Tape Geometry.

(1) 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 recorder track may be somewhat greater because of the magnetic fringing effect around each record head.

(2) 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,

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[5]W-T-0070 (NAVY-Ships) Interim Federal Specifications, Tapes, Recording, Sound and Instrumentation, Magnetic Oxide Coated, General Specification For, 26 Apr 63.

[6]W-R-00175 (NAVY-Ships) Interim Federal Specification, Reels and Hubs for Magnetic Recording Tape, General Specifications For, 26 April 1963.

[7]See MAGT-F001 (USAF) Air Force Systems Command Supplementary Specification, "Wideband Instrumentation Magnetic Tape/Recorder Interface Compatibility Specification," 1 October 1968.

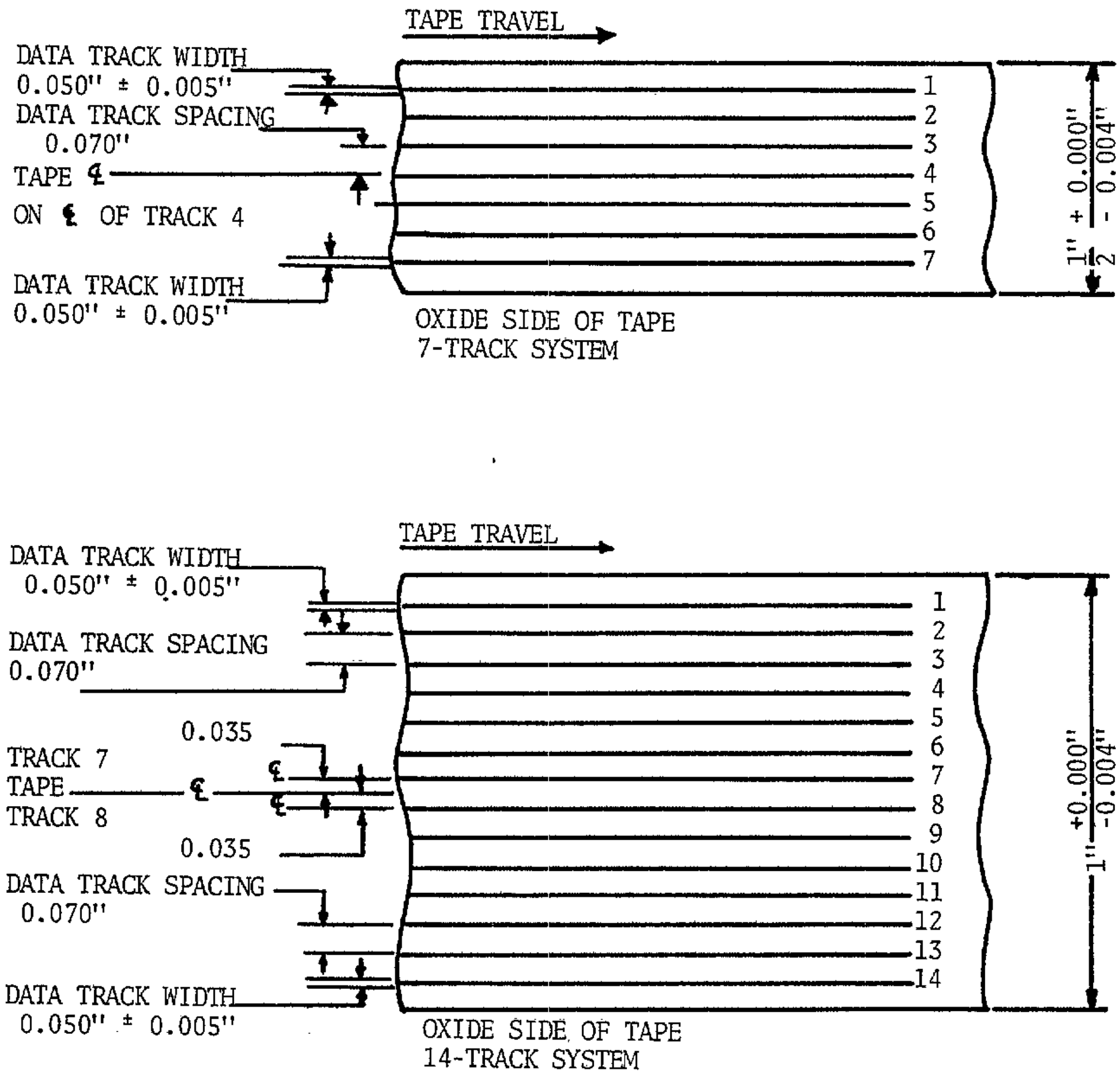


FIGURE 5 ANALOG TAPE GEOMETRY

the 1/2-inch tape would contain seven tracks with one track located at the center of the tape, and 1-inch tape would contain 14 tracks with the center of the tape equidistant between 7 and 8.

(3) 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.

5.6.2.2.2 Head and Head-Stack Configuration. See Figure 6.

(a) 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.

(b) 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 required to allow meeting system performance requirements.

(c) 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.

(d) Head and Stack Numbering. Numbering of a record or reproduce head shall correspond to the track number on 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.

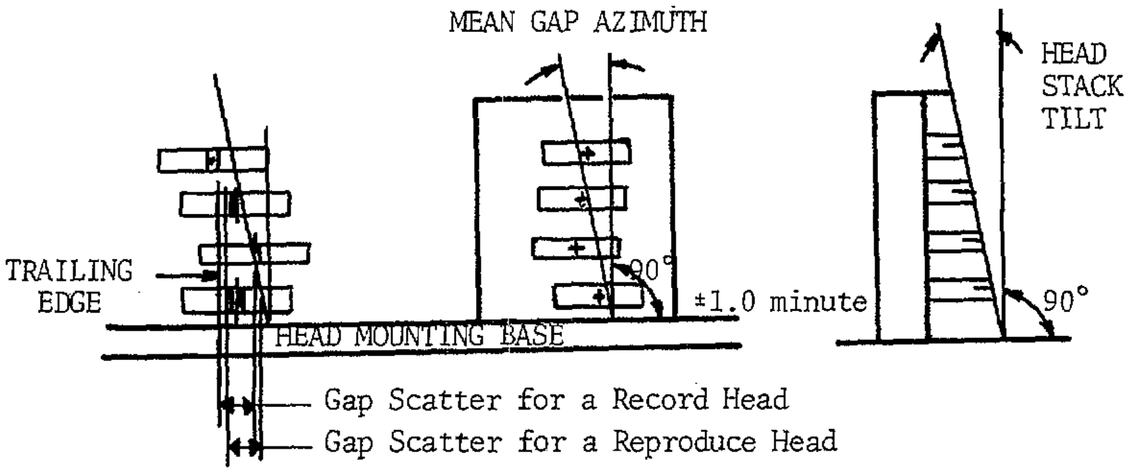
(e) Head-Stack Tilt. The plane tangent to the front surface of the head stack at the centerline of the head gaps shall be perpendicular to the head-mounting plate within ±3 minuts of arc.

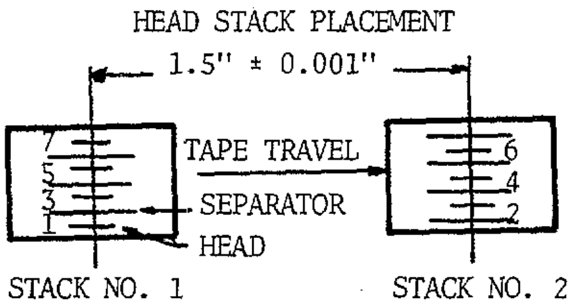
(f) Gap Scatter. Gap scatter shall be 0.0001 inch or less.

(g) Mean Gap Azimuth Alignment. The mean gap azimuth shall be perpendicular to the head-mounting plate to within ±1 minute of arc.

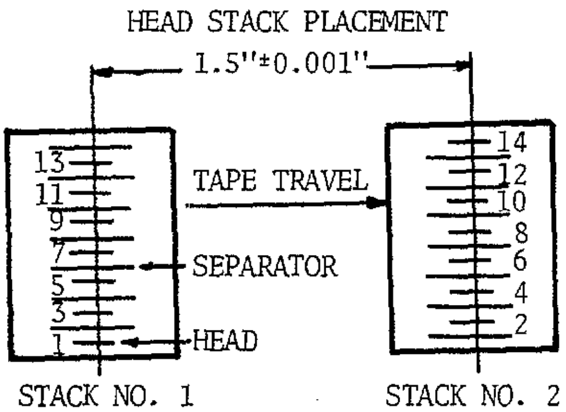
(h) Head Location. Any head in a stack shall be located within ±0.002 inch of the nominal position required to match the track location set forth in paragraph 5.6.2.2.1 (c).

(i) 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





7-TRACK ANALOG HEAD
AND STACK CONFIGURATION



14-TRACK ANALOG HEAD
AND STACK CONFIGURATION

FIGURE 6 ANALOG HEAD CONFIGURATION

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 2 db of the output at the optimum position for the individual track.

5.6.2.2.3 Head Polarity

(a) 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 paragraph 5.6.3.2.1 for method of measurement)

(b) 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-south magnetic pattern will produce a positive-going pulse, with respect to system ground, at the output of the reproduce amplifier.

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

5.6.2.2.5 Record/Reproduce Parameters

(a) The high-frequency bias signal for low- and intermediate-band recorders shall have a wavelength on tape less than 60 microinches. For wideband recorders the bias frequency shall be greater than 3.4 times the highest direct record frequency for which the recorder/reproducer system is designed. (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.)

(b) The frequency response or pass band of direct-recorder data as a function of tape speed is given in Table VI. 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 of mask this measurement.

(c) Record Parameters

(1) Input impedance at all frequencies in the low and intermediate bands shall be 5,000 ohms minimum resistance shunted by 250 pf. max. with or without meter. Input impedance for the wideband recorders shall be 75 ohms ±10 percent across the specified band.

(2) Input signals of 1.0 to 10.0 volts peak-to-peak shall be adjustable to produce Normal Record Level.

(3) A record characteristics which provides constant signal flux on the tape for all frequencies in the passband is required. The record amplifier shall provide a transfer characteristic which is basically a constant current versus frequency characteristic upon which is superimposed a compensation characteristic to correct for loss of record-head efficiency with frequency. For the test described in 5.6.3.3.9, the difference in the response curves normalized to the 0.02 band edge frequency shall be no greater than the figures given below:

Fraction of Band Edge Frequency	db difference
0.1	0.5
0.5	1.0
0.8	1.6
1.0	2.0

(4) Information for record bias setting is contained in Table VI.

(5) The level of recording shall be set at a value that results in a signal from the tape having one percent third-harmonic distortion from the tape of the record level set frequency when measured at the output of the playback amplifier under the load specified in paragraph 5.6.2.2.5 (d) (2) during playback. This level, the Normal Record Level, shall be set while recording the Record Level Set Frequency indicated in Table VI. Zero db reference level is the Normal Record Level. (In recording complex telemetry signals with varying crest factors, optimum record level must be determined for the particular signal to be recorded.)

(d) Reproduce Parameters

(1) Output impedance for low- and intermediate-band recording shall be 100 ohms maximum across the pass bands specified in Table VI. Output impedance for wideband recorders shall be 75 ohms maximum across the specified pass band.

(2) When reproducing a signal at the Record Level Set Frequency 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 1.0 percent when measured across a resistive load of 600 ohms ±10 percent shunted by a maximum of 1500 pf. for low-band and intermediate-band recorders, and 2 volts peak-to-peak with a maximum third harmonic distortion of 1.0 percent when measured across 75 ohms ±10 percent for wideband recorders. Lack of proper output termination shall not cause the reproduce amplifier to oscillate.

5.6.2.2.6 Speed, Speed Control and Flutter Compensation. The average or long-term record tape speed shall be sufficiently close to the standard speed to ensure the capability to adequately control and correct the reproduce tape speed on recorders equipped with servo playback speed control, or to reproduce a recorded tape without servo speed control with sufficient frequency accuracy to permit recovery of recorded information.

TABLE VI DIRECT - RECORD PARAMETERS

Low Band

Tape Speed ips	±3-db Pass Band Hz*	Record Bias Set Frequency Hz overbias 3 db**	Record Level Set Frequency Hz
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 Hz*	Record Bias Set Frequency Hz overbias 3 db**	Record Level Set Frequency Hz
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%	500 ±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 Hz*	Record Bias Set Frequency, kHz ***	Record Level Set Frequency kHz
120	500 - 1,500,000	1,500 ±10%	150 ±10%
60	500 - 750,000	750 ±10%	75 ±10%
30	500 - 375,000	375 ±10%	37.5 ±10%
15	500 - 187,000	187 ±10%	18.7 ±10%
7-1/2	500 - 93,000	93 ±10%	9.3 ±10%
3-3/4	500 - 46,000	46 ±10%	4.6 ±10%

* Passband response is referenced to the output at the Record Level Set Frequency.

** Record Bias current is adjusted for maximum reproduce output at a signal level 5 to 6 db below Normal Record Level and then increased until an output level 3 db below the maximum value is obtained.

*** Record Bias current is adjusted for maximum reproduce output at a signal level 5 to 6 db below Normal Record Level and then increased until an output level 1 db below the maximum value is obtained. For systems with 2 MHz response, bias should be set at 2 MHz for 120 ips operation or corresponding submultiple frequencies for lower tape speeds.

(a) The effective tape speed throughout the reel or any portion of the reel (in the absence of tape derived 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 as measured by the procedures described in paragraph 5.6.3.2.2.

(b) Sinusoidal 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 specified 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.

(1) The Amplitude-Modulated Speed-Control Signal shall have the following characteristics:

Carrier Frequency	17.0 kHz ± 0.5%
Bandwidth Required	16,500 Hz to 17,500 Hz
Percentage Modulation	45 to 55%
Modulating Frequency	60 Hz ± 0.01%

NOTE

FM Proportional Bandwidth Channel A or Constant Bandwidth Channel 1A can not be used on the same track with the 17 kHz Speed-Control Signal because it interferes with the Speed-Control Signal.

(2) Constant-amplitude speed-control signal shall be used on a separate track for optimum servo speed correction. The constant-amplitude speed-control signal may be mixed with other signals if recording requirements so demand and system performance permits. Mixing of the constant-amplitude speed-control signal with certain types of signals may degrade system performance for tapes which are to be reproduced on tape transports with low time base error capstan drive systems. (Refer to manufacturer.) Table VII lists constant-amplitude speed-control signal frequencies and the bandwidth about the signal frequency which must be left free of other signals in order to give proper compensation operation. The constant-amplitude signal should also be used as a flutter correction signal if required.

TABLE VII
CONSTANT-AMPLITUDE SPEED-CONTROL SIGNALS
(Reference Signal on a Separate Track)

Frequency (kHz)	Minimum Guard Band (Hz)*	Tape Speed (ips)** Pre-Detect	Post-Detect
*200 ± 0.01%	±13,950		60
*100 ± 0.01%	±10,500	120	30
* 50 ± 0.01%	± 2,500	60	15
* 25 ± 0.01%	± 2,000	30	7.5
12.5 ± 0.01%	± 2,000	15	3.75
6.25 ± 0.01%	± 2,000	7.5	1.875
3.115 ± 0.01%	± 2,000	3.75	-

*When using high performance servo systems, signals higher than the reference frequency should not be multiplexed with the reference signal. The level of individual extraneous signals, including spurious, harmonics, and noise, must be 40 db or more below the level of the speed control signal.

**The listed tape-speed/frequency relationships are the ones most widely employed at the Ranges. Other combinations are used, but should be coordinated with the cognizant Range.

(c) Signals to be used for discriminator flutter correction systems are listed in Table VII. In addition, 240 kHz ± 0.01 percent with ± 13,950 Hz minimum guard band is used with constant bandwidth FM systems. See paragraph 5.6.2.2.6 (b) (2) and Section 5.2.3 for restrictions on use of flutter-correction signals.

5.6.2.2.7 Predetection Recording. Predetection signals consist of frequency-modulated or phase-modulated intermediate-frequency 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. Parameters for these signals are in Table VIII.

TABLE VIII
PREDETECTION CARRIER PARAMETERS

Tape Speed ips	Predetection Carrier Center Frequency kHz	Recommended Predetection Record/Playback Passband, kHz
120	900	100 to 1,500.0
60	450	50 to 750.0
30	225	25 to 375.0
15	112.5	12.5 to 187.5

5.6.2.3 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 is recommended.

(a) Tape and Reel Characteristics. Paragraph 5.6.2.2.1 shall apply.

(1) Paragraph 5.6.2.2.1 (a) shall apply for tape width.

(2) Paragraph 5.6.2.2.1 (b) shall apply for tape specifications.

(3) Track Geometry. Paragraph 5.6.2.2.1 (c) (1) shall apply for track width, paragraph 5.6.2.2.1 (c) (2) for track spacing, and paragraph 5.6.2.2.1 (c) (3) for track numbering..

(b) Head and Head-Stack Configuration. Paragraph 5.6.2.2.2 (a) shall apply for head placement, paragraph 5.6.2.2.2 (b) for head-stack placement, paragraph 5.6.2.2.2 (c) for head stack numbering, paragraph 5.6.2.2.2 (d) for head and stack numbering, paragraph 5.6.2.2.2 (e) for head-stack tilt, paragraph 5.6.2.2.2 (f) for gap scatter, paragraph 5.6.2.2.2 (g) for mean gap azimuth alignment, paragraph 5.6.2.2.2 (h) for head location, and paragraph 5.6.2.2.2 (i) for head interchangeability.

(c) Tape Guiding. Paragraph 5.6.2.2.4 shall apply.

(d) Tape Speeds and Corresponding FM Carrier Frequencies. See Table IX.

(e) FM Record/Reproduce Parameters

(1) For FM record systems, input voltage of 1.0 to 10.0 volts peak-to-peak shall be adjustable to produce full frequency deviation.

Deviation Direction: Increasing positive voltage gives increasing frequency.[8]

(2) Single carrier FM record systems minimum input impedance, 5000 ohms resistance shunted by 250 pf.

Wideband FM record systems: Input impedance shall be 75 ohms ± 10 percent at all frequencies in the specified passband.

(3) FM Reproduce Systems. Output levels are for signals recorded at full deviation.

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[8]Predetection recorded tapes are recorded with reverse deviation direction because of the translation techniques employed. Care should be exercised when interchanging predetection tapes with conventional wideband FM systems.

TABLE IX SINGLE-CARRIER AND WIDEBAND FM RECORD PARAMETERS

Tape Speed (ips) Low Band	Intermediate Band	Wide Band Group I	Carrier Center Frequency kHz	Carrier Deviation Limits* Carrier Plus Deviation kHz	Carrier Minus Deviation kHz	Modulation Frequency kHz	Response at Band Limits db ***
1-7/8			1.688	2.363	1.012	DC to 0.313	±1
3-3/4	1-7/8		3.375	4.725	2.025	DC to 0.625	±1
7-1/2	3-3/4		6.750	9.450	4.050	DC to 1.250	±1
15	7-1/2	3-3/4	13.50	18.90	8.100	DC to 2.500	±1
30	15	7-1/2	27.00	37.80	16.20	DC to 5.000	±1
60	30	15	54.00	75.60	32.40	DC to 10.00	±1
	60	30	108.0	151.2	64.80	DC to 20.00	±1
	120	60	216.0	302.4	129.6	DC to 40.00	±1
		120	432.0	604.8	259.2	DC to 80.00	±1

Wide Band Group II**	Carrier Center Frequency kHz	Carrier Deviation Limits* Carrier Plus Deviation kHz	Carrier Minus Deviation kHz	Modulation Frequency kHz	Response at Band Limits db ***
3-3/4	28.125	36.562	19.688	DC to 12.50	+1, -3
7-1/2	56.250	73.125	39.375	DC to 25.00	+1, -3
15	112.50	146.25	78.750	DC to 50.00	+1, -3
30	225.0	292.50	157.50	DC to 100.0	+1, -3
60	450.0	585.00	315.00	DC to 200.0	+1, -3
120	900.0	1,170.0	630.0	DC to 400.0	+1, -3

* Input voltage levels per paragraph 5.6.2.3(e)(1).

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

*** Frequency response and signal to noise referred to 1 kHz output for FM channels 13.5 kHz and above, and 100 Hz for channels below 13.5 kHz.

(4) Single-Carrier FM Systems. Three volts peak-to-peak minimum across a resistance of 10,000 ohms minimum, from dc to the maximum specified frequency. 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.

(5) Wideband FM Systems. Two volts peak-to-peak minimum across a load impedance of 75 ohms $\pm$ 10 percent. Increasing input frequency gives a positive-going output voltage.

(f) Speed Control and Compensation. Paragraph 5.6.2.2.6 shall apply except that a separate track is always required for speed-control and flutter compensation signals with single-carrier FM systems.

5.6.2.4 PCM Recording. PCM may be successfully recorded by several different methods. The major PCM recording formats in use are listed in Table X.

TABLE X PCM FORMATS

		Recording Format	
Method	Signal Type	Bit Placement	Electronic Mode
1	Pre-Detection	Serial	Direct
2	Post Detection	Serial	Direct
3	Post Detection	Serial	FM
4	Post Detection	Parallel	Saturation
5	Post Detection	Serial	Saturation

Methods 1 and 3 result in similar signals if the predetection carrier is in a PCM/FM form. Both are acceptable for serial recording prior to use of a bit synchronizer and signal conditioner.

Method 2 is acceptable if adequate provision is made for the lack of reproducer low frequency response. Any method which adequately controls the low frequency content of the signal may be used, e.g., constraint of format to insure an adequate number of transitions, or use of Bi-phase Modulation (See Section 5.5 Pulse Code Modulation (PCM) Standards.) The last method is preferred but requires approximately double the bandwidth of NRZ modulation.

Method 4 is the only standard format for instrumentation parallel PCM recording after bit decisions have been made (i.e., after the data has become synchronous binary digital data).

Method 5 is not recommended unless several guard tracks can be placed between the saturated PCM track and the nearest analog track to minimize crosstalk from the saturated digital track.

5.6.2.4.1 Tape. For saturation PCM recording, W-T-0070 does not provide a special tape. Instrumentation tape may be satisfactory, but for critical applications digital type tape may be required.

5.6.2.4.2 Parallel PCM. 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.

5.6.2.4.2.1 Track Geometry. See Figure 7.

(a) 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 systems shall be 0.010 ± 0.002 inch.

(b) 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.

(c) Spacing between track centers on 16-track systems shall be 0.060 inch. Optional tracks A and B shall be centered on 0.035 inch from the centerlines of tracks 1 and 16, respectively.

(d) Spacing between track centers on 31-track systems shall be 0.030 inch, including optional tracks A and B.

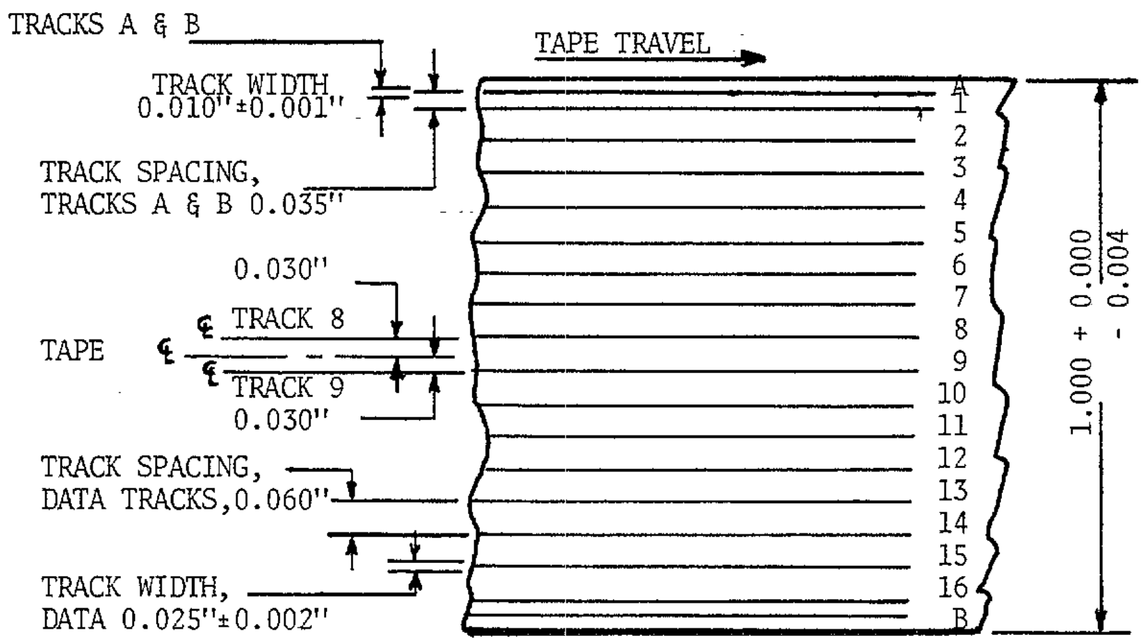
(e) On 16-track systems, the center of the tape shall be centered between tracks 8 and 9.

(f) On 31-track systems, the center of the tape shall be centered on the centerline of track 24.

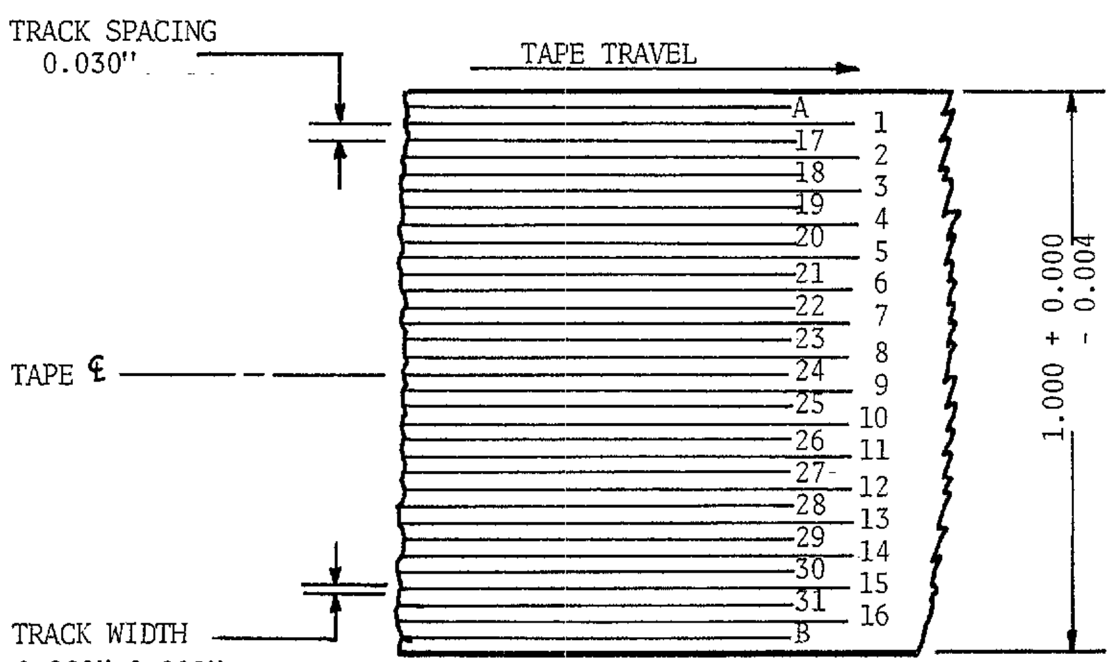
(g) For track numbering See Figure 7.

Paragraph 5.6.2.2.1 (c) (3) shall apply for 16-track systems and for 31-track systems, except that for 31-track systems the numbering from top to bottom shall be A (optional) 1, 17, 2, 18, 3, 19 ...31, 16 B (optional).

5.6.2.4.2.2 Head and Head-Stack Configuration. See Figure 8.

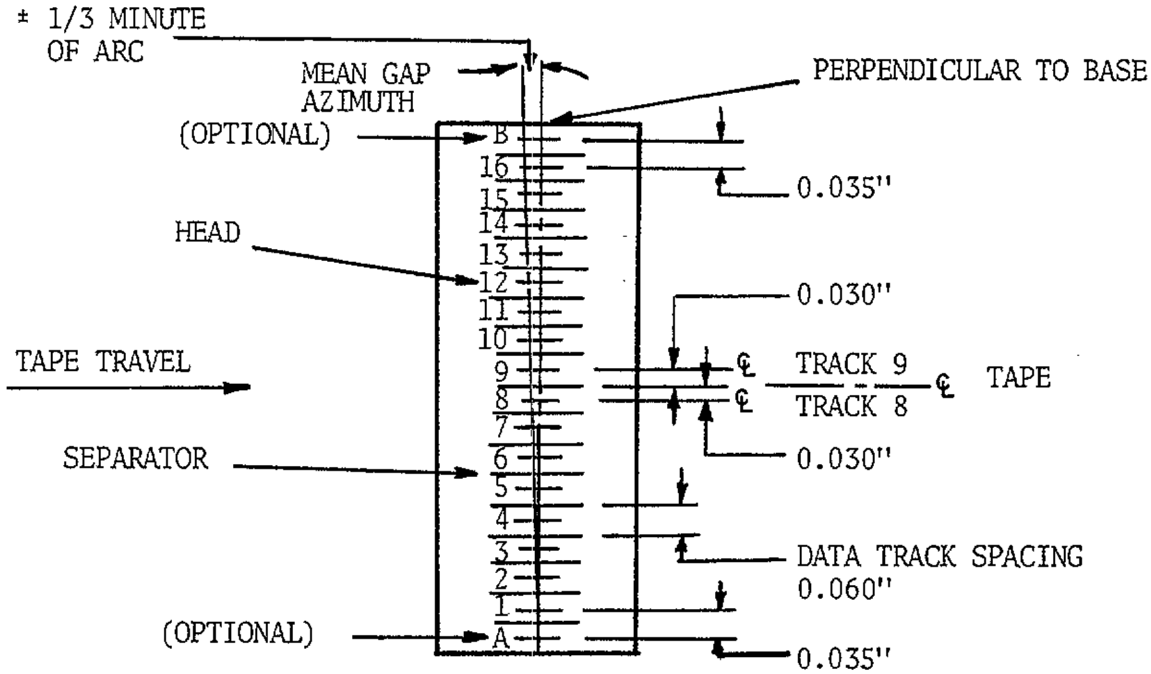


OXIDE SIDE OF TAPE
16-TRACK SYSTEM

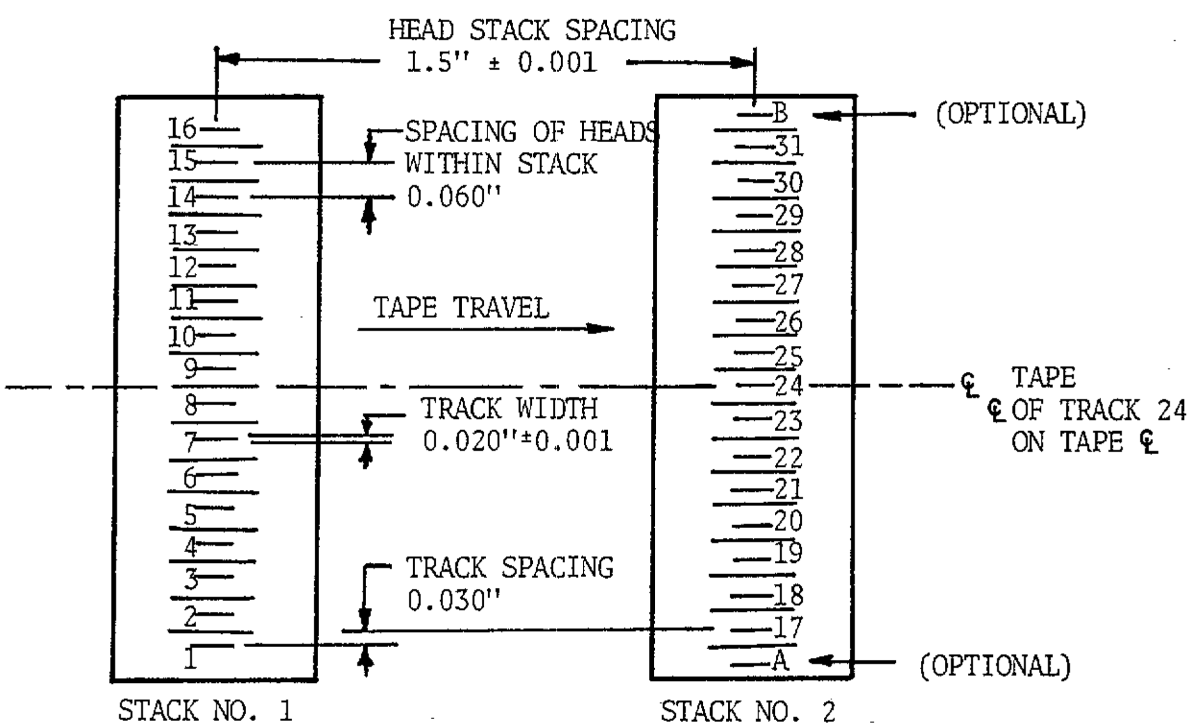


OXIDE SIDE OF TAPE
31-TRACK SYSTEM

FIGURE 7 PCM TRACK SYSTEM



16-TRACK SYSTEM



31-TRACK SYSTEM

FIGURE 8 PCM HEAD CONFIGURATION

(a) Paragraph 5.6.2.2.2 (b) shall apply for head-stack placement (31-track system).

(b) Paragraph 5.6.2.2.2 (c) shall apply for head-stack numbering (31-track system).

(c) 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.

(d) Mean Gap azimuth error shall not exceed ± 1/3 minute of arc.

(e) Paragraph 5.6.2.2.2 (e) shall apply for head-stack tilt.

(f) Paragraph 5.6.2.2.2 (f) shall apply for gap scatter.

(g) 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 5.6.2.4.2.1 (c), 5.6.2.4.2.1 (d), 5.6.2.4.2.1 (e), and 5.6.2.4.2.1 (f).

5.6.2.4.2.3 Head Polarity. Section 5.6.2.2.3 shall apply.

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

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

5.6.2.4.2.6 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.

5.6.2.4.2.7 Total Bit Spacing Error. This shall not exceed 650 microinches, peak-to-peak, with respect to the clock(s), from record to reproduce and from machine to machine.

5.6.2.4.2.8 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 5.6.2.4.2.10 (c) and 5.6.2.4.2.11 (c).

5.6.2.4.2.9 Timing. Track 16 shall be reserved for range timing.

5.6.2.4.2.10 Recorder Input Characteristics.

(a) Input impedance shall be 20,000 ohms resistive minimum, shunted by 250 pf. max.

(b) Input voltage shall be 2 to 20 volts plus, minus, or symmetrical about ground, and polarity selectable.

(c) Input format shall be parallel input, nonreturn-to-zero (NRZ level).

5.6.2.4.2.11 Output Characteristics.

(a) Reproduce output format shall be parallel output, nonreturn-to-zero (NRZ Level). Reproducer output shall compensate for all recorder/reproducer-induced time-displacement errors to within 5.0 percent of the word interval, or 1.6 microseconds, whichever is greater.

(b) Output impedance shall be 100 ohms maximum.

(c) Output voltage 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.

5.6.2.5 PDM Recording.[9] See Section 5.3. 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.

5.6.2.6 Record Amplifier

(a) Input impedance shall be 20,000 ohms resistive minimum, shunted by 250 pf. maximum.

(b) Normal input level shall be 1.0 volt, peak-to-peak.

(c) 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.

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[9]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.

5.6.2.7 Reproduce Amplifier

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

(b) Output impedance shall be 100 ohms maximum

TABLE XI PDM RECORD PARAMETERS

Minimum Tape Speed ips			Minimum Pulse Duration (Microseconds)
Low Band	Intermediate Band	Wideband	
60	30	15	75
30	15	7-1/2	75
15	7-1/2	3-3/4	100

(c) Nominal output level shall be 8 volts, peak-to-peak, across 1,000 ohms resistance shunted by no more than 250 picofarads capacitance.

(d) Rise and decay time of the output rectangular pulses shall be less than 2 microseconds from 10 to 90 percent amplitude levels.

(e) The reproduce amplifier shall incorporate circuitry to detect defective pulses during the reproduce process and provide automatic resetting to preclude loss of subsequent data.

5.6.3 Procedures for Testing Recorder/Reproducer Systems

This section describes test procedures to be used in measuring performance parameters of magnetic tape recorder and reproducer systems. Performance limits are not specified since these depend greatly upon the intended application of the equipment and have a direct bearing on equipment cost.

Where measurement techniques are not specified, it is assumed that commonly accepted measurement methods for mechanical and/or electrical characteristics will be employed.

Not all of the following tests are required for any one system, and tests other than those indicated may be required for a given system.

5.6.3.1 General: Before starting performance tests, the Recorder/Reproducer should be aligned and adjusted in accordance with these standards and the appropriate instruction manual.

It is recommended that a qualitative test be conducted to assure that the system will transport tape and will record and/or reproduce upper-band edge signals without large amplitude fluctuations.

After the recorder has been aligned, adjustments shall not be changed for the duration of the performance testing, unless otherwise noted in the test procedure.

Tests may be made in the simultaneous record/reproduce mode to save time, but the machine must be capable of meeting the specifications in the reproduce-only mode.

5.6.3.2 Transport and Head Tests

NOTE

Tests associated with transport operation involve the elements of precisely determining time base accuracies through the record/reproduce system; therefore, accuracy/stability of associated test equipment (e.g., test oscillators) should be an order of magnitude better than the performance specification to be measured.

5.6.3.2.1 Head Polarity. In order to maintain signal polarity from record to playback, it is required that a positive-going pulse applied to the input of a direct-record amplifier produce a magnetic flux pattern on the tape whose polarity sequence is south-north-noth-south. Likewise, a magnetic flux sequence of south-north-north-south polarity passed across a reproduce head must produce a positive pulse at the output of a direct reproduce amplifier. The test for head polarity is as follows:

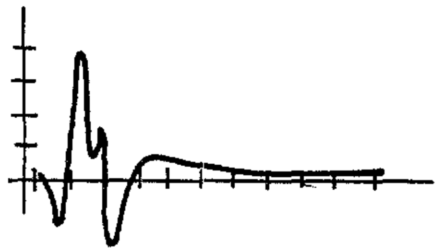
(a) Obtain a small rectangular bar magnet and a compass.

(b) Determine the polarity of the magnet with the compass. (The North-seeking pointer of the compass will be attracted to the South Pole of the magnet.) Mark the South Pole of the bar magnet.

(c) Using a degaussed tape of the appropriate width for the machine being tested, draw a corner of the South Pole of the magnet across the width of the tape on the oxide side of the tape. Withdraw the magnet. Since the sharpness of the recorded pulse is a function of the mechanical definition of the corner of the magnet, some difficulty may be encountered in obtaining an adequate output signal. In this case, a thin (0.006 to 0.014 in.) transformer lamination of soft iron or Permalloy may be extended from the South Pole of the bar magnet to form a narrow South Pole, and hence, a sharper pulse.

(d) Reproduce the magnetized portion of the tape. All reproduce amplifiers should give a positive-going pulse at the output when the magnetized section crosses the reproduce heads. (See Figure 9)

(e) Record positive pulses on the tape through the record amplifiers. Reproduction of these pulses should give positive pulses at the output of the playback amplifiers.



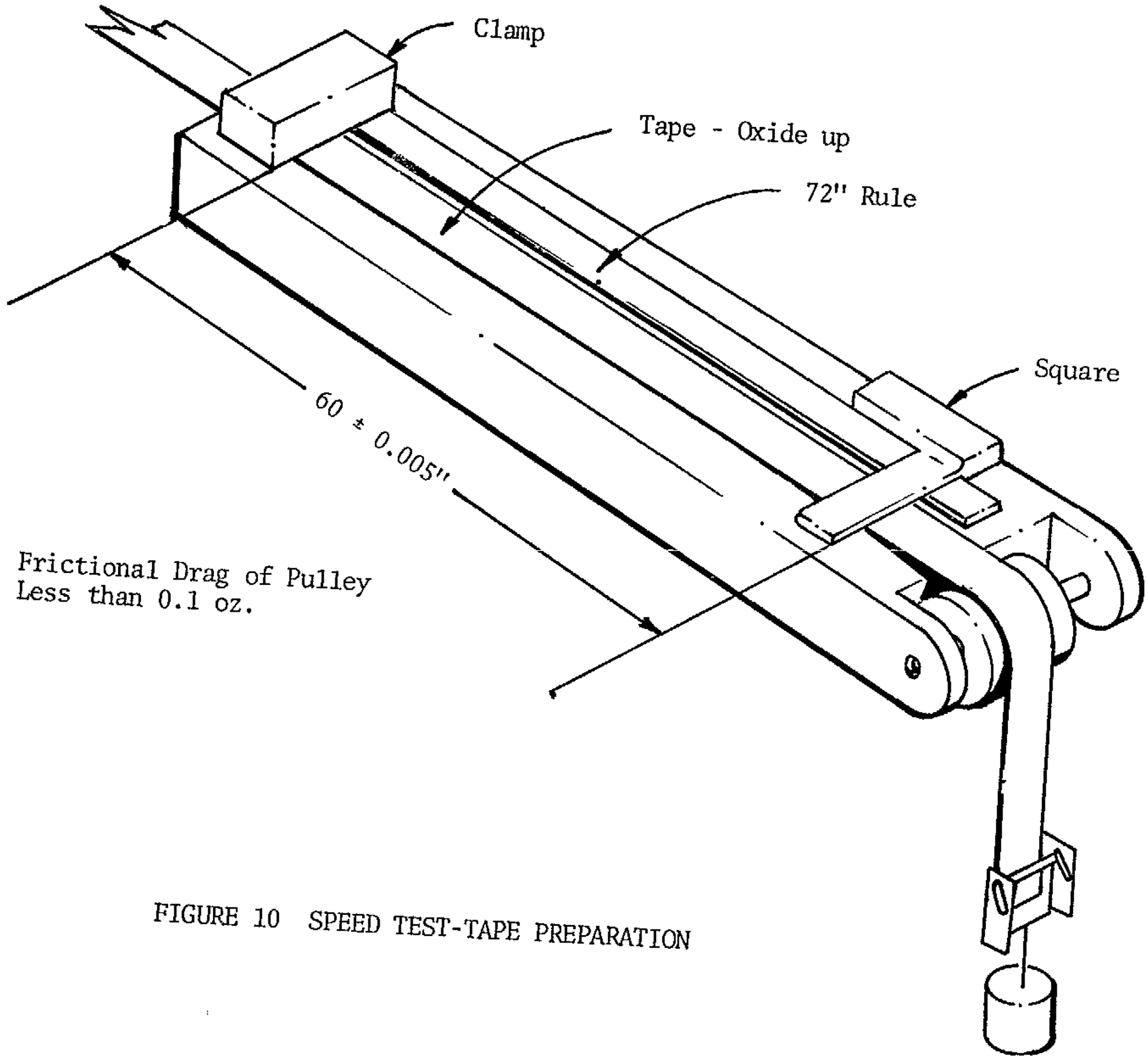
0.5 volt/cm
5 microsec/cm
Positive polarity up

FIGURE 9 WAVEFORM OBTAINED FROM HEAD POLARITY TEST

5.6.3.2.2 Tape Speed: This test measures tape speed for recording or reproducing without a tape speed control signal per paragraph 5.6.2.2.6. Tape speed errors are defined as departures from the nominal tape speed occuring at frequencies below 0.2 Hz. Two methods are specified. The first method is intended as a laboratory or factory standard and may be used for tape testing or checking of working standards. The second method describes a working standard. Other working standards may be used. Neither method requires extended storage of a test tape, since the error due to dimensional changes of commonly employed tape base (backing) materials as a result of environment (temperature and humidity) and aging may exceed the tape speed accuracy required.

(a) Tape Speed - Laboratory Use - Method I: This test measures the "effective" tape speed of the equipment under test. It establishes the speed interchangeability of tapes between recorders per paragraph 5.6.2.2.6 (a) under controlled conditions of environment for the type of tape base most commonly used in telemetry recording. Since differences in operating tape tension are taken into account, the measured effective tape speed is based on constancy of recorded wavelength rather than absolute velocity.

(1) Equipment Required: Tape per Interim Federal Specification W-T-0070/4 and/or W-T-0070/5. Sample tape length to be greater than 6 feet long. Steel Rule, 6 feet (non-flexible) (Lufkin C2416, 72 inches; Starrett C416R, 72 inches or equivalent). Marking means: optional - capable of translating rule reading and marking tape within ± .005 inch. (Suggested: tool-makers square, 10X to 20X machinist's microscope, scriber; or Gem Centering Gage, Tool Components, Inc.) Marking Fixture - See Figure 10. Electronic Instruments - See Figure 11.



Note: Frictional Drag of Pulley Less than 0.1 oz.

FIGURE 10 SPEED TEST-TAPE PREPARATION

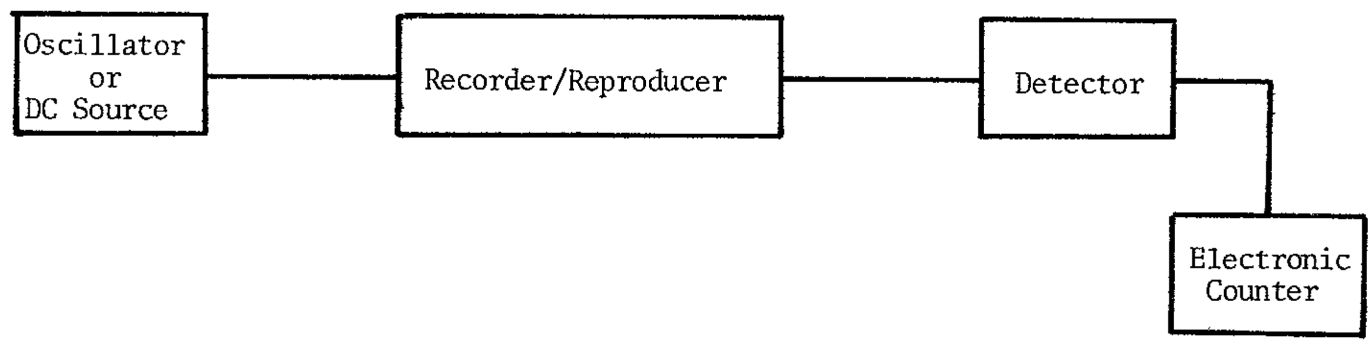


FIGURE 11 TAPE SPEED - METHOD I

(2) Procedure is as follows:

a. Age required length(s) of tape off the reel in an unstressed (tension free) condition for a period of at least 24 hours in a controlled environment of 70 ± 2° F and 50 ± 5 percent relative humidity. This same environment is to be maintained for steps b. through d. Temperature for subsequent steps 70 ± 5° F, RH, 50 ± 5 percent.

b. Clamp tape in fixture (See Figure 10) so that tape naturally lies along edge of rule and is free of kinks and bends.

c. Attach a weight of 16 oz. ± 2.0 percent for 1" tape and 8 oz. ± 2.0 percent for 1/2" tape as shown.

CAUTION

Apply load gradually. Allow tape to stand under tension for a period of at least 10 minutes to allow initial creep to take place.

d. Scribe two marks on oxide side 60 ± .005 inches apart, taking care to avoid damaging tape base. If additional marks or lengths are required, repeat as necessary. However, all markings on a sample should be completed within 30 minutes.

e. Splice at least three test samples into a full reel of tape at the beginning (first 10 percent), middle (40-60 percent) and end (last 10 percent) of reel. Shuttle tape from take-up reel to supply reel, and reverse, on equipment to be tested at least five times to establish normal tension condition. Store tape on the supply reel for at least 2 hours and not more than 24 hours.

f. Record tape test sections with a high frequency carrier (wavelength approximately 0.5×10^{-3} inch) or d-c signal through record head. Alternatively, the tape may be saturated with a permanent magnet.

g. Immediately before making speed measurement, shuttle tape test section from supply reel to take up reel at operating speed. Rewind.

h. Reproduce tape test sections with equipment and test instruments connected as shown in Figure 11. Repeat measurement of each test section at least five times and obtain average reading of elapsed time between marks in microseconds.

i. Determine effective speed by:

$$V = \frac{60 \times 10^6}{t} \text{ ips}$$

The maximum error of this test method is approximately 0.05 percent when performed as described. This error may be greatly exceeded if the calibrated test tape is exposed to elevated temperatures or stored for extended periods before use, due to release of internal stress.

If greater accuracy is required, individual test tape samples may be calibrated for elongation, and temperature and humidity coefficients. The appropriate correction factors may then be applied to the test data to relate the results to the calibration conditions.

(b) Tape Speed - General and Field Use - Method II: This test determines the tape speed of the equipment under test on an absolute basis. Since the differences in operating tension between types of backing material, and length changes due to temperature and humidity are not taken into account, the accuracy of this method for determining interchangeability per paragraph 5.6.2.2.6 is necessarily limited. If the test conditions specified in paragraph 5.6.3.2.2 (a) are approximated, the accuracy of measurement will approach that of Method I.

(1) Equipment Required: Steel tape 100 feet (Keufel & Esser 7335, 7385 or equivalent). Pulse Generator (Time Base accurate to 0.01 percent). Tensioning Means (spring scales: 20 lb. full scale, and 2 to 5 lb full scale). Thermometer.

(2) Procedure is as follows:

a. Record two pulses at a time interval of:

$$t = \frac{1200}{V} \text{ seconds,}$$

where V is the nominal tape speed in inches per second. This produces a nominal 100-ft test section.

b. Remove tape from reel and develop pulses (marks) in magnetic oxide or carbonyl iron dispersion.

c. With test tape lying beside the steel measuring tape on a flat surface, determine the difference between the nominal 100 ft (steel tape) and the test tape. During this measurement the steel tape should be under a tension of 10 lbs. and the test tape under the nominal operating tension of the recorder ± 2 oz.

NOTE

The 16 oz. of Method I may be substituted to approximate the effective machine tension, if desired. If the temperature varies greatly from 68° F, a correction factor of -7.74×10^{-3} in/°F/100 ft may be applied to correct the steel tape length. (Ref: K. & E. Catalog.)

Percent speed error = 0.0825 X length difference, inches.

5.6.3.2.3 Flutter: Two methods of measuring flutter are described. Each method calls for use of an FM discriminator such as may be supplied by the recorder manufacturer in his equipment as an FM reproduce amplifier or such as those used in FM/FM telemetry. The discriminator monitors a signal recorded at constant frequency and amplitude. A test procedure is included to eliminate or to account for the apparent flutter caused by amplitude modulation noise, signal dropouts or preamplifier random noise since many discriminators are sensitive to such effects.

The measured flutter shall be considered to include all the discriminator output fluctuations within 95% limits, excluding low frequency speed change components below 0.2 Hz.

The first flutter test procedure uses an oscilloscope display (which may or may not be photographed) to give an average measurement of flutter in a selected passband.

In the second test procedure, a level detector is used in addition to, or instead of, the oscilloscope record. The detector provides a digital display of the amount of time during a predetermined period that the positive and negative flutter peaks exceed a preselected level.

The procedures to be used for measuring flutter are as follows:

(a) Equipment for the measurement of flutter is shown in Figure 12.

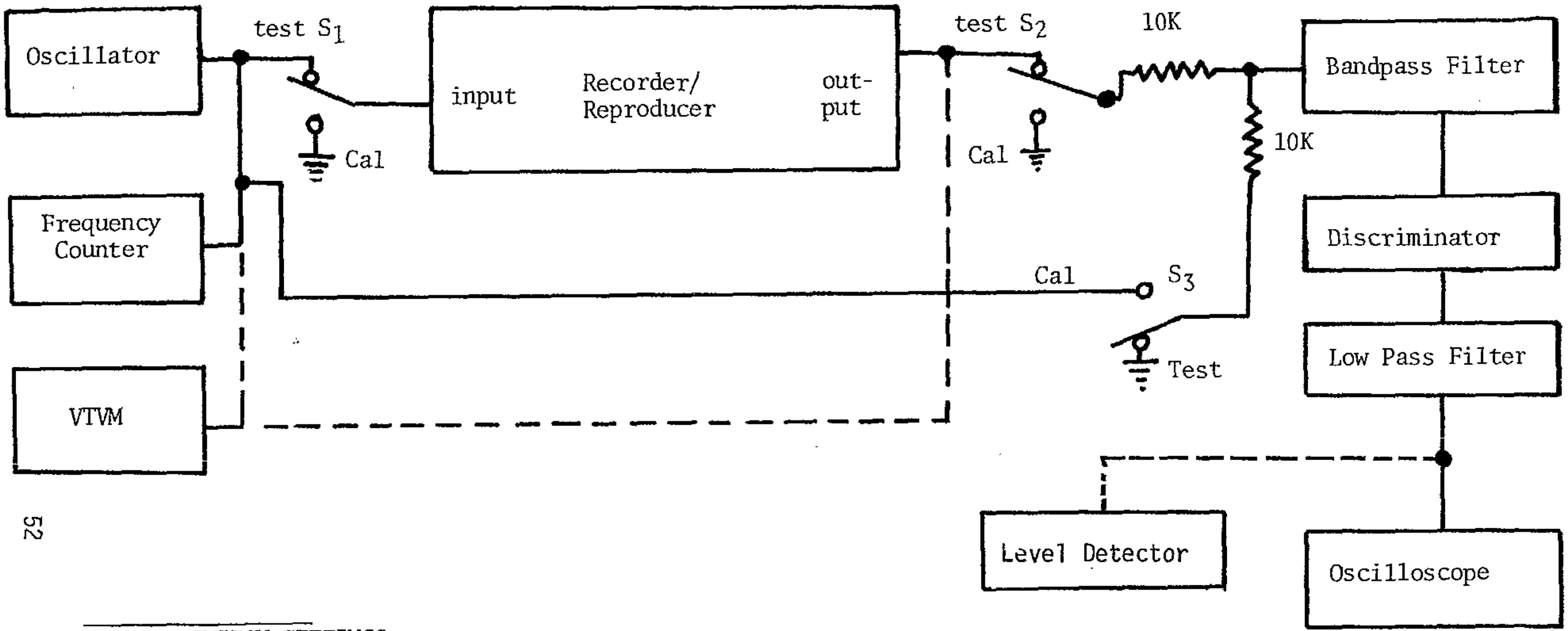
(b) The discriminator used for flutter measurements shall meet the following performance requirements:

(1) The discriminator output noise caused by 30 percent amplitude modulation of the reference carrier by any single frequency from dc up to the flutter upper band limit should be less than 10 percent of the specification flutter signal.

(2) The discriminator output noise caused by linear addition of the output noise of the tape system and a stable reference carrier at the same level as would be derived from the system should be less than 5.0 percent of the specification flutter signal. The system setup is shown in Figure 12. The tape system will be in the record mode (bias on) with input shorted.

(3) Band-Pass Filter: A band-pass filter may be used to limit system noise. However, the 3 db bandwidth of the filter cannot be less than two times the flutter bandwidth being measured and must be symmetrical about the reference carrier frequency used.

(4) Low-Pass Output Filter: The low-pass output filter may have either a flat or gaussian response shape. The flat filter system (including



NOTES: SWITCH SETTINGS

	Discriminator Amplitude Calibration	Discriminator Noise Calibration	Flutter Test
S_1	CAL	CAL	Test
S_2	CAL	Test	Test
S_3	CAL	CAL	Test

FIGURE 12 FLUTTER TEST

discriminator) shall be down no more than 3 db at the upper flutter frequency being measured. The Gaussian filter system shall be down no more than 6 db at the upper flutter frequency being measured.

(5) In the event that the discriminator used in the test fails to meet paragraphs 5.6.3.2.3 (b) (1) and 5.6.3.2.3 (b) (2) when using the appropriate filter in paragraphs 5.6.3.2.3 (b) (3) and 5.6.3.2.3 (b) (4), the value of the noise obtained in paragraphs 5.6.3.2.3 (b) (1) and 5.6.3.2.3 (b) (2) shall be subtracted from the 95% level flutter measurement. The permissible correction shall not exceed 25 percent of the flutter specification of the machine under test.

TABLE XII FILTER CHARACTERISTICS FOR FLUTTER MEASUREMENT

Tape Speed (ips)	Minimum Bandwidth of Band-Pass Filter at 3 db points kHz	Passband of the Low-Pass Filter* Hz
1-7/8	0.625	0.2 to 313
3-3/4	1.250	0.2 to 625
7-1/2	2.500	0.2 to 1,250
15	5.000	0.2 to 2,500
30	10.00	0.2 to 5,000
60	20.00	0.2 to 10,000
120	20.00	0.2 to 10,000

* No more than 3 db for flat filter.
No more than 6 db for Gaussian filter.

(6) Any center frequency may be used provided it meets paragraphs 5.6.3.2.3 (b) (1) and 5.6.3.2.3 (b) (2) and is at least 5 times the maximum flutter frequency.

(c) Steps

(1) Adjust the test oscillator and the discriminator to the frequencies suitable to the machine speeds. This adjustment shall be capable of an accuracy of 0.01 percent of the carrier, or better.

(2) Calibrate the oscilloscope such that full-scale deflection is equal to 1.0 percent of the oscillator frequency. Adjust the horizontal time to 1 second per centimeter.

(3) Degauss the tape and place on the transport. Place the machine in Record mode and select the tape speed to be measured.

(4) Turn equipment from calibrate condition to test condition and adjust input signal level above normal, approaching saturation. (Suggested value +13 db relative to normal record level.) Record test signals on the two

outside tracks and the center track. A 3-minute minimum recording at the beginning, middle, and end of the reel shall be made. (See paragraph 5.6.3.1)[10]

(5) The flutter as displayed on the oscilloscope in the playback mode, with servo if available at the beginning, mid, and end of reel may be photographed. Each photograph will cover a 10-second period.

(6) The flutter shall be considered to include all the flutter data appearing on the oscilloscope or camera record except random peaks and drift components below 0.2 Hz. The 95% limit on flutter shall be equal to the specification limit which means the random peaks will not exceed the specification limit more than 5.0 percent of the time. A direct reading instrument to measure this condition is described in Figure 13. If the random noise exceeds the specification 5.0 percent of the time, the cause of the noise must be determined and eliminated before the test continues.

5.6.3.2.4 Dynamic Interchannel Time Displacement Error (ITDE): ITDE shall be measured as outlined in the following procedure. Refer to Figure 14 for test equipment connections.

The measured IDTE shall be considered to include all fluctuations within 95 percent limits.

The reproduced waveforms for this measurement must have a signal-plus-noise to noise ratio of at least 34 db for precise definition of the zero axis crossings. Optional band-pass filtering of the reproduced waveform serves to remove all noise components except those existing within this narrow band.

Steps

(a) Record the test oscillator signal on two adjacent head tracks within the same head stack (e.g., 3 and 5). At high transport speeds the entire reel of tape may be recorded. With lower speeds, recording of 1 - 2 minutes at beginning, middle, and end of reel is satisfactory.

(b) Rewind the recorded tape and place the instrument in the reproduce mode with servo, if available. Adjust oscilloscope time base and trigger to display a single leading edge using the minimum delay necessary to get the required display, with the ITDE component occupying a minimum of 1 cm (horizontal).

(c) Set the vertical gain so that upper and lower portions of the waveform touch the outer graticule lines. Adjust scope intensity to a level which prevents trace blooming but still displays individual transient excursions.

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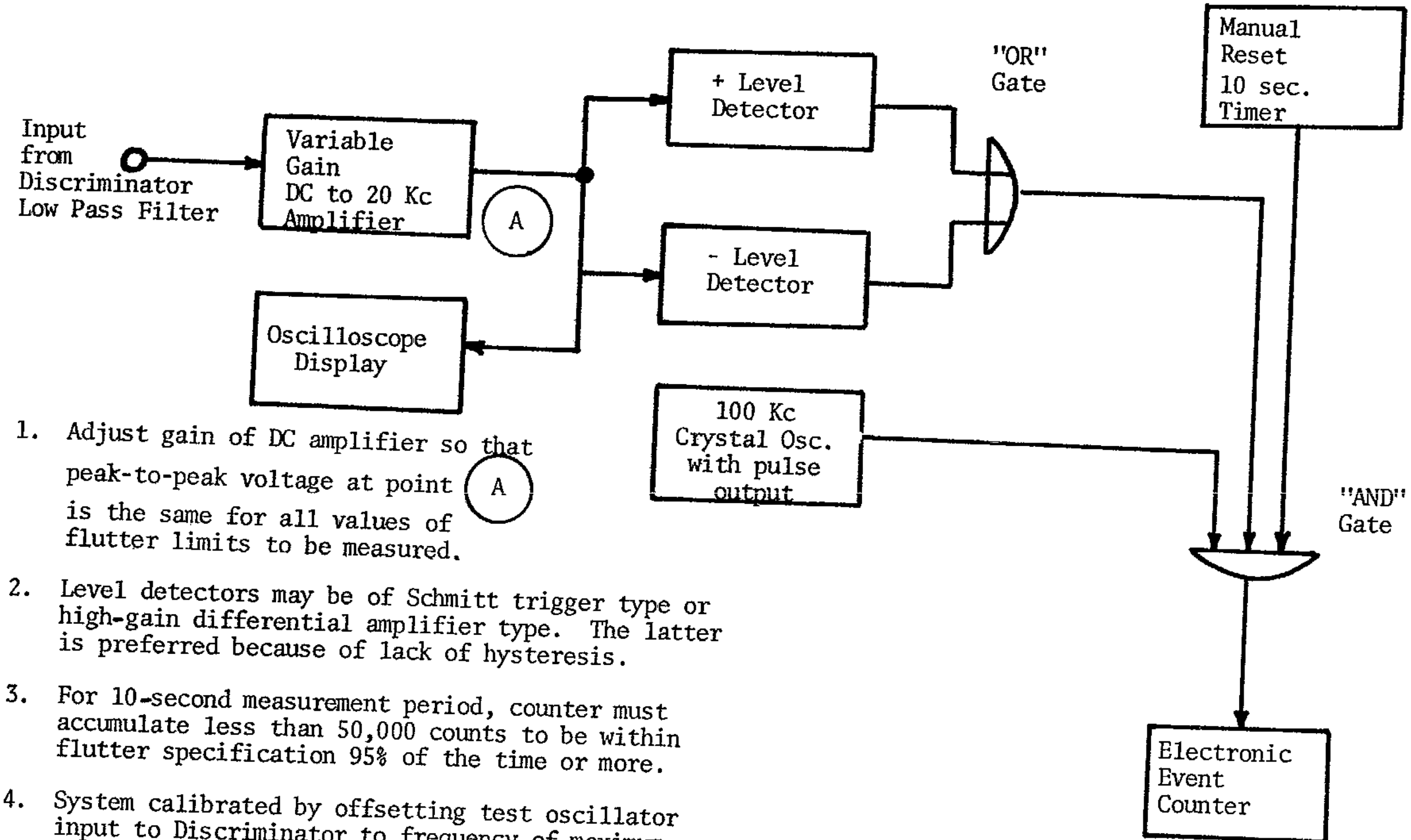
[10] If record amplifier is power limited, it may be necessary to drive the heads directly from an oscillator having adequate output or from an auxiliary amplifier.



1. Adjust gain of DC amplifier so that peak-to-peak voltage at point (A) is the same for all values of flutter limits to be measured.

2. Level detectors may be of Schmitt trigger type or high-gain differential amplifier type. The latter is preferred because of lack of hysteresis.

3. For 10-second measurement period, counter must accumulate less than 50,000 counts to be within flutter specification 95% of the time or more.

4. System calibrated by offsetting test oscillator input to Discriminator to frequency of maximum allowable flutter deviation. Set gain of DC amplifier so that counter just begins to trigger on maximum allowable deviation.

5. Variable gain DC amplifier must have capability to produce gains of less than one as well as gains greater than one.

FIGURE 13 BLOCK DIAGRAM, LEVEL DETECTOR FOR DIGITIZED FLUTTER MEASUREMENT

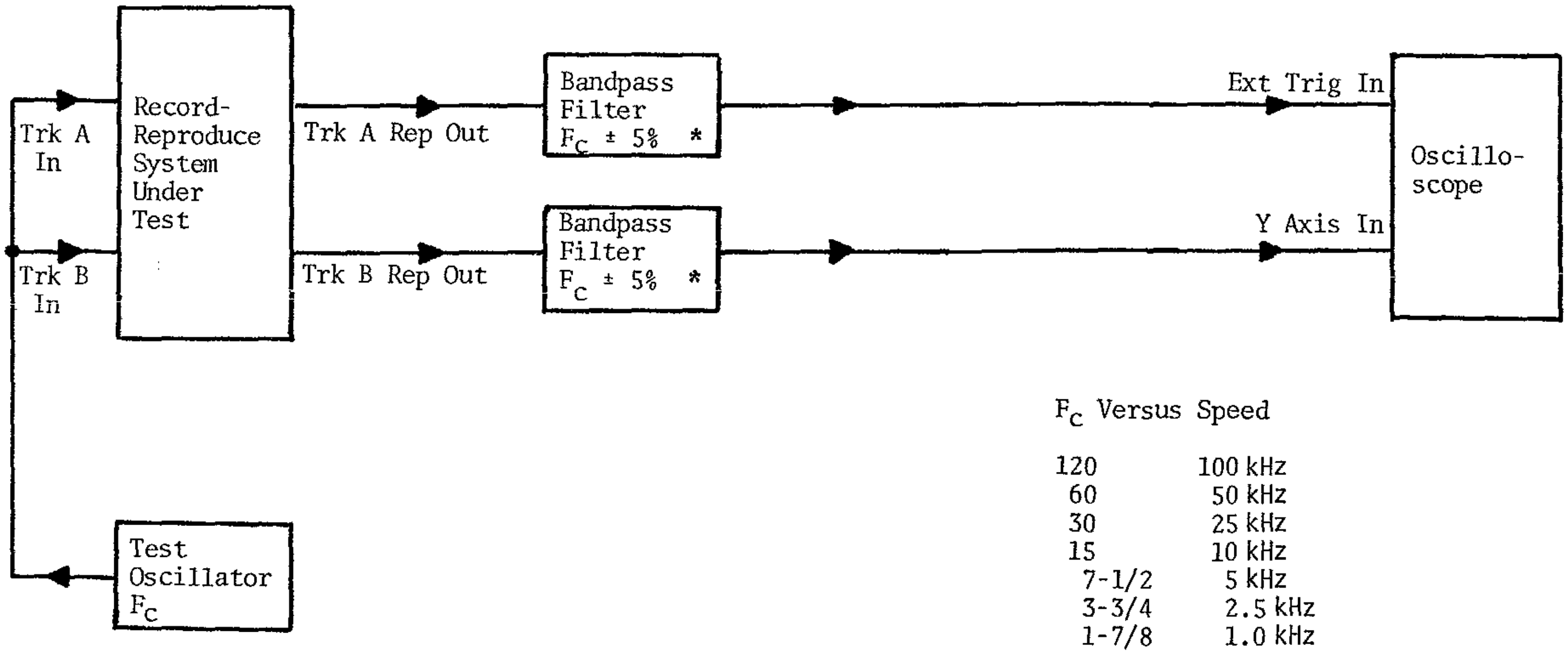


FIGURE 14 ITDE MEASUREMENT

(d) Visually observe or photograph the CRT display over 10-second sample periods at the beginning, middle, and end of reel. The ITDE displayed on the oscilloscope shall be converted to units of time based upon the horizontal width of the solid portion of the display. Occasional crossovers occurring not more than 5% of the time shall be ignored.

5.6.3.2.5 Time Base Error (TBE): TBE shall be measured as outlined in the following procedure. Refer to Figure 15 for test equipment connections.

The measured TBE shall be considered to include all fluctuations within 95 percent limits.

The reproduced waveform for this measurement must have a signal-plus-noise to noise ratio of at least 34 db for precise definition of the zero axis crossings. Optional band-pass filtering of the reproduced waveform serves to remove all noise components except those existing within this narrow band.

Steps

(a) Set up equipment and record test signal in accordance with manufacturer's instruction manual.

(b) Depending upon operational speed selected, record a sufficient length of tape at beginning, middle and end of reel to provide adequate time for tape speed servo acquisition and lockup prior to performance measurements.

(c) Rewind the recorded tape and place the instrument in the reproduce mode with servo, if available. Select the transport tape servo system to the Tape Mode.

(d) Adjust oscilloscope time base and trigger to display a single leading edge with the TBE component occupying a minimum of 1 cm (horizontal).

(e) Set the vertical gain so that upper and lower portions of the waveform touch the outer graticule lines. Adjust scope intensity to a level which prevents trace blooming but still displays individual transient excursions.

(f) Visually observe or photograph the CRT display over 10-second sample periods at the beginning, middle, and end of reel. The TBE displayed on the oscilloscope shall be converted to units of time based upon the horizontal width of the solid portion of the display. Occasional crossovers occurring not more than 5% of the time shall be ignored.

5.6.3.2.6 Pulse to Pulse Jitter: Jitter, both with or without servo shall be measured as outlined in the following procedure. Refer to Figure 16 for test equipment connections.

The measured jitter shall be considered to include all fluctuations within 95 percent limits.

The reproduced waveform for this measurement must have a

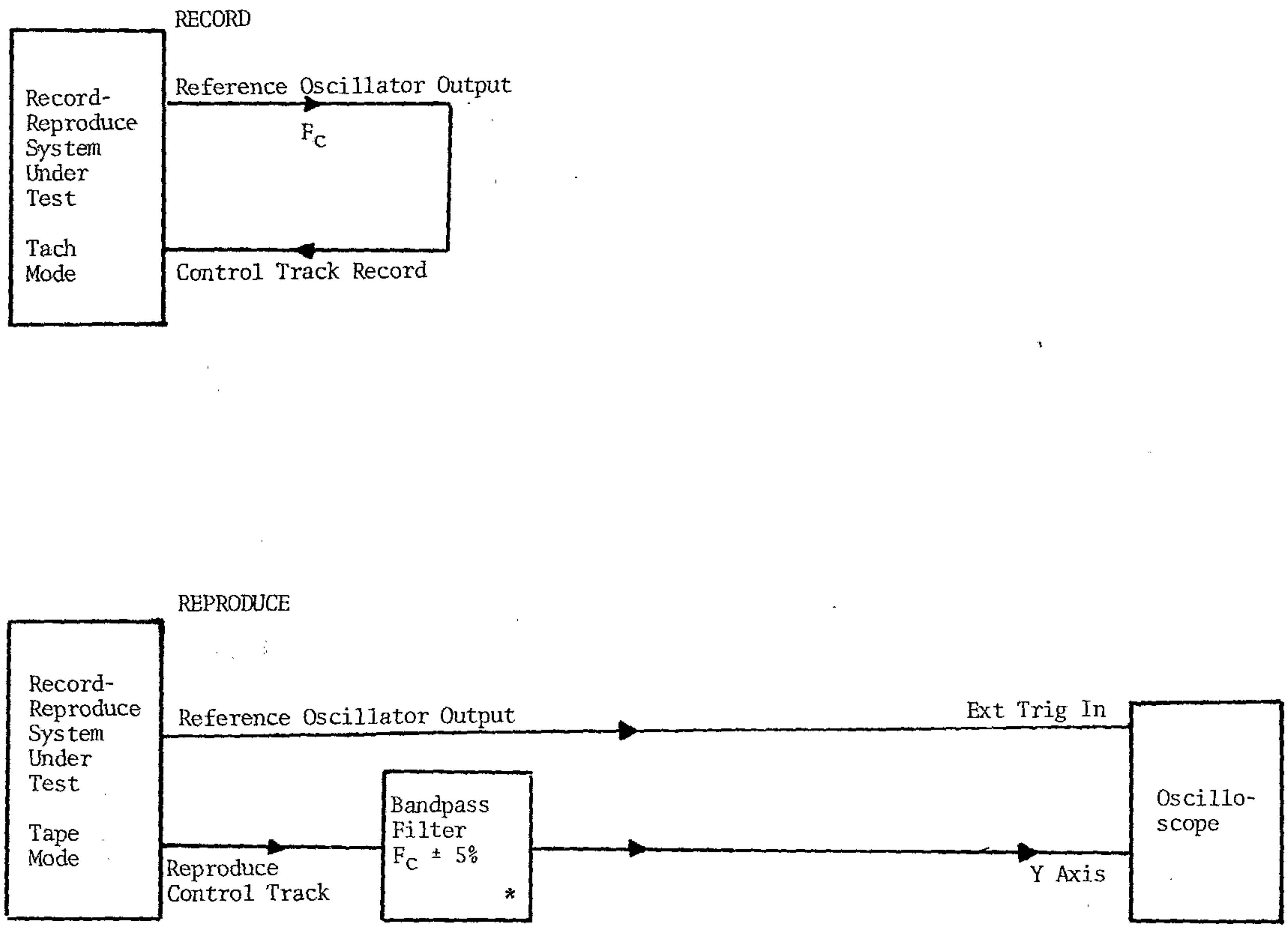


FIGURE 15 TBE MEASUREMENT

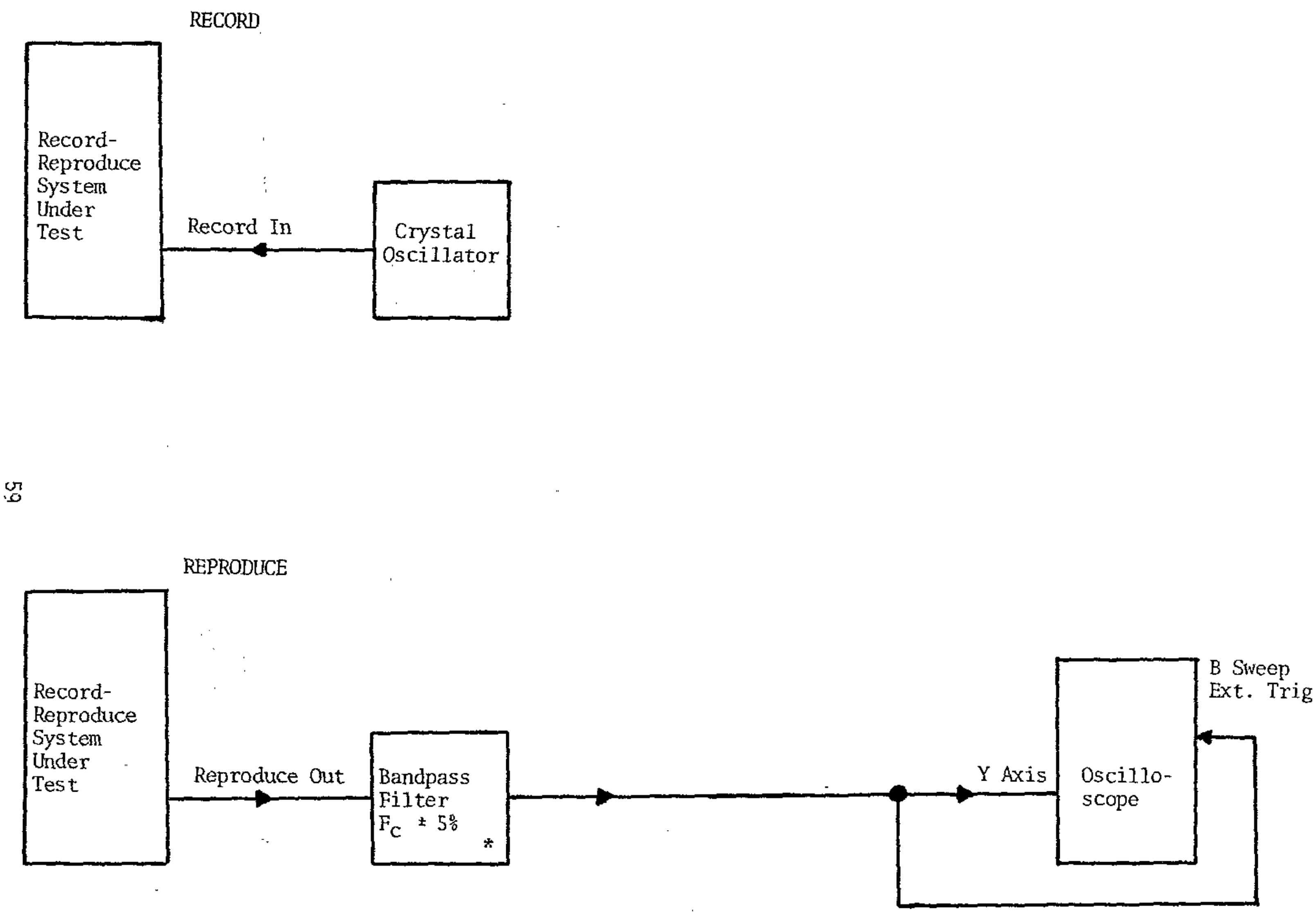


FIGURE 16 JITTER MEASUREMENT

signal-plus-noise to noise ratio of at least 34 db for precise definition of the zero axis crossings. Optional band-pass filtering of the reproduced waveform serves to remove all noise components except those existing within this narrow band.

Steps

(a) Set up equipment and record test signal in accordance with manufacturer's Instruction Manual.

At high transport speeds, the entire reel of tape may be recorded. With lower speeds, recording of 1 - 2 minutes at beginning, middle, and end of reel is satisfactory.

(b) Rewind the recorded tape and place the instrument in the reproduce mode with servo, if available. Adjust oscilloscope time base and trigger to display a single leading edge using the minimum delay necessary to get the required display with the jitter component occupying a minimum of 1 cm (horizontal).

(c) Set the vertical gain so that upper and lower portions of the waveform touch the outer graticule lines. Adjust scope intensity to a level which prevents trace blooming but still displays individual transient excursions.

(d) Visually observe or photograph the CRT display over 10-second sample periods at the beginning, middle, and end of reel. The jitter displayed on the oscilloscope shall be converted to units of time based upon the horizontal width of the solid portion of the display. Occasional crossovers occurring not more than 5% of the time shall be ignored.

5.6.3.3 Direct System Tests: This section defines test procedures for direct recording. The bias and record level adjustment (paragraph 5.6.3.3.1) may only be performed once during a sequence of tests. Bias and record level settings will normally be established at the highest operating tape speed unless individual adjustments are provided for each speed. (Refer to manufacturer's instructions.) See Table XIII for required test equipment.

5.6.3.3.1 Bias and Record Level: This test establishes bias and record level settings as specified in Table VI.

Steps

(a) Set up equipment, instruments and loads as indicated in Figure 17. The optional band-pass filter shall not be used. Refer to manufacturer's instructions for detail instructions pertaining to adjustments.

(b) With signal source set to the Record Bias Set Frequency and the input level set 5 to 6 db below Normal Record Level, record and simultaneously reproduce a tape and adjust bias level for proper overbias (Table VI).

TABLE XIII TEST EQUIPMENT REQUIREMENTS FOR DIRECT RECORDING

OSCILLATOR:	Sinusoidal oscillator or signal generator to meet impedance and level requirements of equipment under test. Noise, distortion and spurious components to be below 0.2 percent over frequency range under test.
VOLTMETER:	True RMS reading AC VTVM calibrated to an accuracy of ±1/2 db over frequency range under test. (Hewlett Packard 3400A, Ballantine 320, or equivalent.) Average reading RMS calibrated meters may be substituted except as noted in 5.6.3.3.3.
WAVE ANALYZER:	(Frequency Selective Voltmeter) Calibrated to an accuracy of ±1/2 db. Dynamic range of at least 50 db. (No internal spurious signal generation or noise for full amplitude signal present at input and instrument set to measure frequency components 50 db below full amplitude.) Bandwidth shall be sufficiently wide to avoid erroneous reading due to recorder flutter. (Typical instruments: Hewlett Packard 302A, 310A; Wandel and Goltermann TFPM 43 and 76; General Radio 1900A, Sierra 125B. No single instrument will cover entire frequency range.)
MIXING NETWORK:	Linear mixing network (resistor). Design to match source and load impedances.
ELECTRONIC COUNTER:	Time base and reading accuracy should be sufficient to avoid degrading the measurement of equipment performance.
BAND-PASS FILTER:	Passive or active linear filter, down no more than 3 db at the band edge frequency (See Table VI), spurious signals and noise at least 10 db below equipment specification, 18 db per octave rolloff.

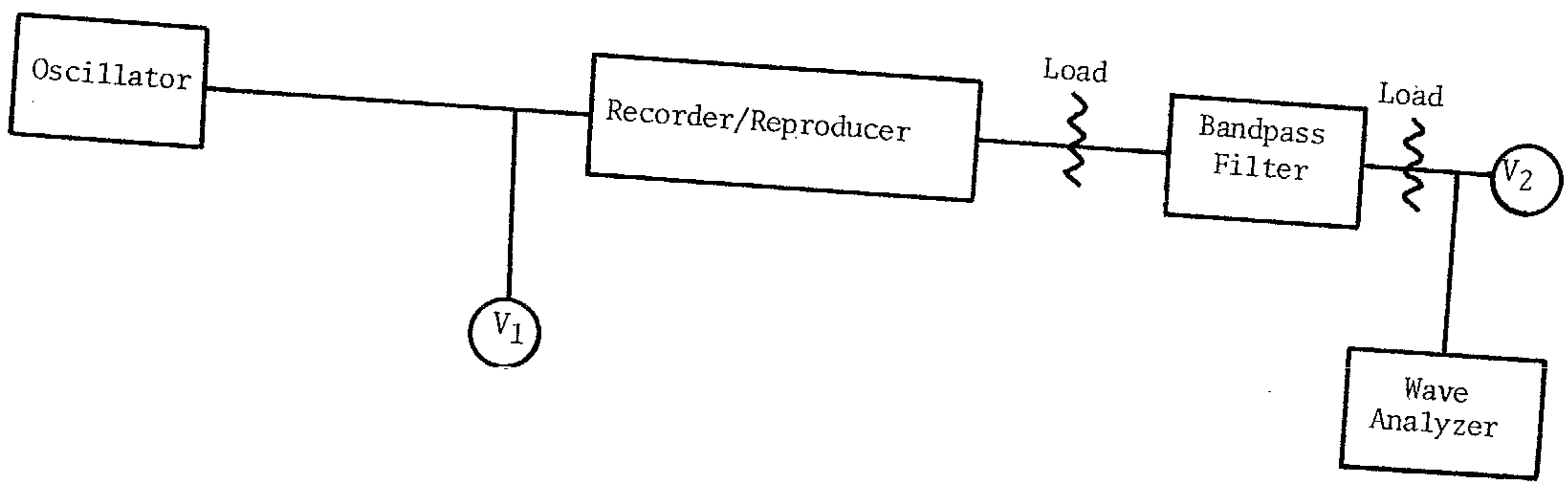


FIGURE 17 FREQUENCY RESPONSE AND SIGNAL TO NOISE RATIO

(c) With signal source set to Record Level Set Frequency, increase the input level until 1.0 percent 3rd harmonic distortion is obtained at the reproduce output as indicated by the wave analyzer. This establishes Normal Record Level.

(d) Reduce level and repeat Step (b) to recheck bias setting.

5.6.3.3.2 Frequency Response - Direct Recording

Steps

(a) Set up equipment, instruments and loads as indicated in Figure 17. No external band-pass filter shall be used in this test.

(b) Perform initial adjustment of bias and record level per paragraph 5.6.3.3.1 and manufacturer's instructions.

(c) With signal source set to produce Normal Record Level at the Record Level Set Frequency, observe the actual input level V_1. (This voltage shall be considered the nominal 0 db input reference.)

(d) Record and reproduce a tape and observe the reproduce output level V_2.

(e) Record and reproduce a tape, varying the input frequency over the specified frequency band while maintaining input V_1 at the reference level.

(f) Observe and log the maximum and minimum excursions in db of the reproduce output level, V_2 - with respect to the reading obtained in Step (d).

5.6.3.3.3 Signal to Noise Ratio: This test determines the ratio of Normal Record Level RMS signal plus noise output voltage to the zero modulation RMS noise[11] and spurious signal output voltage. Measurements shall be conducted while simultaneously recording and reproducing with bias.

Steps

(a) Set up equipment, instruments and loads as indicated in Figure 17. The use of a band-pass filter is optional.

(b) Perform initial adjustment of bias and record level per paragraph 5.6.3.3.1 and manufacturer's instructions.

(c) With signal source set to produce Normal Record Level at the Record Level Set Frequency, observe and log the output level, V_2.

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[11] Zero modulation noise is the noise arising when reproducing a tape recorded with no signal into the record head but with bias energized. Bias leakage is not included.

(d) Remove the input signal and substitute a short circuit.

(e) Observe and log the output level, V_2. Apply correction factor if an average reading meter is used.[12]

(f) Determine the difference in db between the reading obtained in Step (c) and the reading obtained in Step (e).

5.6.3.3.4 Intermodulation Distortion

Steps

(a) Set up equipment, instruments and loads as indicated in Figure 18.

(b) Perform initial adjustment of bias and record level per paragraph 5.6.3.3.1.

(c) Determine the input voltage required to give Normal Record Level with Wave Analyzer (second oscillator disconnected and replaced with equivalent generator impedance).

(d) Set oscillators 1 and 2, to give input voltages for f_1 and f_2 equal to 1/2 the voltage determined in Step (c). Recommended test frequencies for general purpose testing are $f_1 = 0.45$ and $f_2 = 0.55$ of the upper-band edge frequency. Other frequencies may be substituted, as necessary. Components outside the passband may be logged if required.

(e) Check harmonic and intermodulation component frequency input voltages with Wave Analyzer (Switch Position 1) and determine that all components listed in Table XIV are at least 10 db lower than the required equipment performance specification.

(f) Record and reproduce a tape. Observe and log intermodulation component frequency output voltages (Switch Position 2) as listed in Table XIV in db relative to Normal Record Level output. Additional component frequencies may be present in the passband if other frequencies are used for f_1 and f_2.

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[12] An average reading, RMS calibrated meter may be used for V_2, provided it can be demonstrated that the correction factor required to convert the noise reading obtained on the average reading meter to the reading obtained on a true RMS reading meter is less than 3 db for the particular equipment/instrument combination under test.

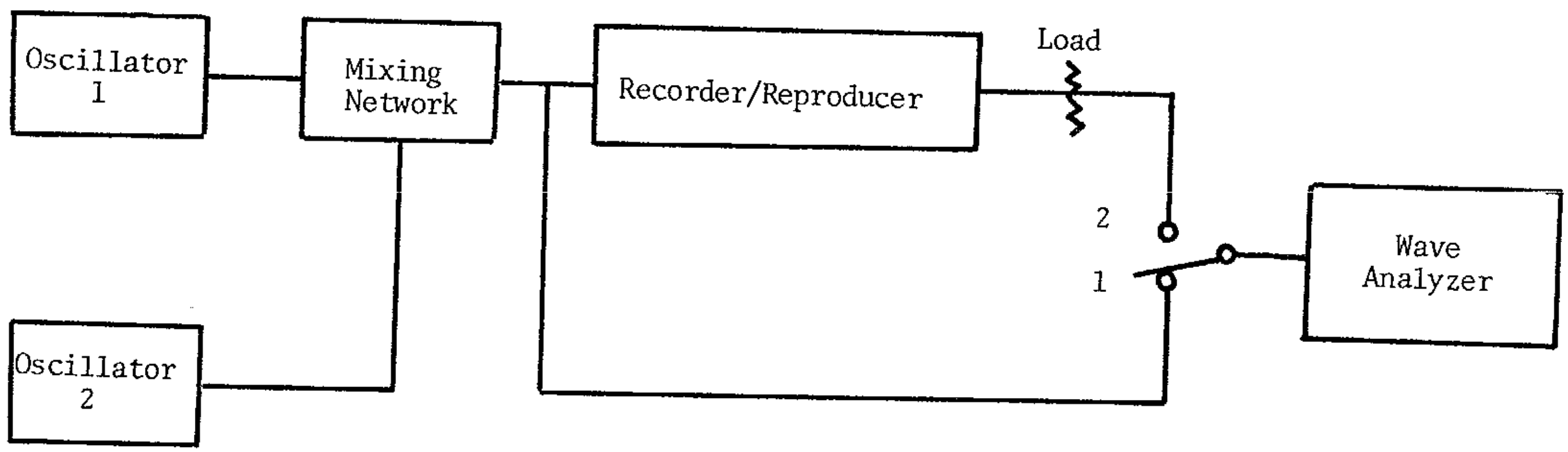

FIGURE 18 INTERMODULATION DISTORTION TEST

TABLE XIV INTERMODULATION TEST FREQUENCIES

The second column gives test frequencies for general use as a function of the upper-band edge frequency (f = 1.0).

Component	Frequency
f_1	0.45
f_2	0.55
$f_2 - f_1$	0.10
$2f_1 - f_2$	0.35
$2f_2 - f_1$	0.65
$2f_1$	0.90
$f_1 + f_2$	1.00

5.6.3.3.5 Crosstalk: The following test procedure measures the cross-talk of a signal in one channel to all other channels.

Steps

(a) Connect an oscillator to the input of the track being measured. Set the input at Normal Record Level.

(b) Short the input to the record amplifier of all other tracks.

(c) Record selected frequencies with wavelength less than 0.060 inches through the band of the tape speed being used.

(d) Rewind and reproduce the tape. Observe the output of all tracks without signal relative to the output at the record level set frequency set at Normal Record Level, using a frequency selective voltmeter having a dynamic range at least 10 db greater than the specification limit for crosstalk. Correction for frequency response of the channel at the test frequency is permissible.

(e) Stop the tape and repeat for the other tracks.

5.6.3.3.6 Bias Leakage: The purpose of this test is to establish the level of bias leakage during the record mode on any properly terminated input or output signal line, with signal levels adjusted to 1.0V RMS.

Steps

(a) Place bulk degaussed tape of the type recommended by the manufacturer onto the recorder.

(b) At the highest available tape speed, record and reproduce the record level set frequency (Table VI) on at least one odd and one even tape track. Terminate both input and output in rated impedances and adjust input and output levels to 1.0V RMS.

(c) Reduce the input level to zero while continuing to record only the bias signal. With a tunable voltmeter (Sierra Model 158A or equivalent) measure the bias leakage voltage at the following circuit points:

(1) Odd track output signal line, high side to low side.

(2) Even track output signal line, high side to low side.

(3) Odd track output signal line, high side to a convenient front panel chassis ground.[13]

(4) Even track output signal line, high side to a convenient front panel chassis ground.

(5) Odd track output signal line, low side to chassis ground.

(6) Even track output signal line, low side to chassis ground.

5.6.3.3.7 Group Delay and Transient Response Measurements: The phase characteristics of a record-reproduce system affect the transient response and the group delay characteristics of the system. Optimum transient response is required when recording pulse waveforms directly. Optimum envelope delay performance is required for recording certain multiplexed signals, predetection signals, etc. Optimum transient and envelope delay performance are generally not simultaneously attainable.

(a) Group Delay Variation Test Procedure for Wideband Recorders: The following test indicates specific equipment which is now being used by several manufacturers and ranges. Other compatible equipment of this type may be used when available.

(1) Test Equipment: The following minimum equipment is required:

Wandel and Goltermann Transmitting Unit, Model LDS-1.
Wandel and Goltermann Level Transmitter, Model TFPS-42.
Wandel and Goltermann Receiver, Model LDE-1.

Although not mandatory, the following additional equipment is recommended as convenient for obtaining oscilloscope displays of group delay variation:

Wandel and Goltermann CRO Indicator Model SG-1
Wandel and Goltermann CRO Plug-In Model SGE-3.

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[13] Chassis ground must be properly connected to the local instrumentation ground during this test.

(2) Procedure: Group Delay Variation may be measured either simultaneously during the record tape pass or during a separate reproduce pass. Recording and reproduction shall always occur at the same speed. Recordings shall be made at normal record level and reproduce measurements shall be made by connecting the reproduce amplifier directly to the 75-ohm load resistance of the LDE-1 Receiver.

The group delay measurements shall be made over the following bandwidths and shall be referenced to a delay reference frequency between 200 kHz and 1 MHz.

Tape Speed	Measurement Bandwidth	Delay Reference Frequency
120 ips	100 kHz to 1.5 MHz	Optional
60 ips	100 kHz to 750 kHz	Optional
30 ips	100 kHz to 375 kHz	Optional

NOTE

The Group Delay Variation tests may also be extended to single-carrier FM recorder systems at 120 ips over the bandwidth of 100 kHz to 400 kHz.

Group Delay Variation measurements may be performed in either the point-to-point or sweep modes and shall conform to the test set manufacturer's instruction manual procedures, page 19, as modified herein.

A Point-to-Point Mode

Steps

1. The mode selector switch (upper left portion of the LDS-1) shall be positioned fully clockwise in order to permit measuring frequency selection on the high resolution dial of the TFPS-42.

2. The output of the TFPS-42 shall be set to a level of -10 db as indicated by the front panel level meter.

3. Each frequency point measured shall be recorded for at least 20 seconds in order to permit sufficient time for reading.

4. The receiver delay range selector switch (lower right portion of the LDE-1) shall be positioned to the most convenient range which will encompass the desired specifications.[14]

[14] Verification of readings may be desirable and may be temporarily switching to the next higher scale.

B Sweep Mode

Steps

1. The mode selector switch (upper left portion of the LDS-1) shall be positioned fully counterclockwise, and the sweep velocity control (LDS-1) positioned fully counterclockwise.

2. The output of the TFPS-42 shall be set to -10 db as indicated by the front panel level meter.

3. Each track measured shall be repetitively swept for at least one minute to permit adequate observation time.

4. The receiver delay range selector switch (lower right portion LDS-1) shall be positioned to a convenient range which will encompass the desired specification.

5. The value of delay shall be read as the average displacement curve of the oscilloscope display. The peak-to-peak noise envelope associated with the delay presentation shall not be considered as a group delay error component.

Documentation may be obtained by oscilloscope camera. Figure 19 depicts a typical result and shows less than ± 200 nanoseconds delay from 100 kHz to 1.5 MHz. Group attenuation is also shown against a common frequency axis.

(b) Transient Response: The phase performance of a record-reproduce system which is measured by the square wave method shall have the parameter of the square wave measured in accordance with descriptions on Figure 20. Parameters to be measured shall be Rise Time, Tilt, and Overshoot. Square wave repetition frequency shall be 0.05 of upper-band edge frequency, but never less than 10 times the lower-band edge frequency.

5.6.3.3.8 Multispeed Reproduce Transfer Level: In multispeed, automatically equalized machines recording at one speed and playing back at another is a common operation. It is sometimes desirable to maintain the reproduce output at approximately constant level for a given wavelength independent of speed without resorting to manual readjustment of reproduce gain controls. The purpose of this test is to determine a system's capability to do this.

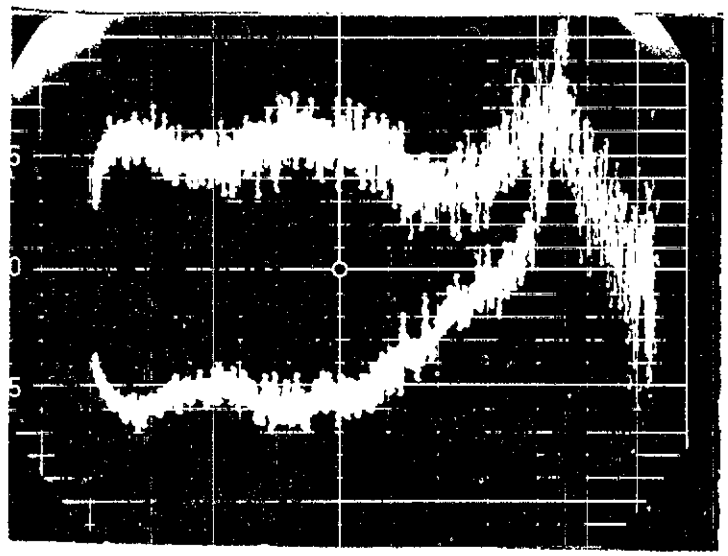
Steps

(a) Place manufacturer recommended bulk erased tape on the recorder.

(b) Record at normal record level a signal having a wavelength of $1.875\ (10)^{-3}$ inches, (1 kHz at 1-7/8 ips, 2 Hz at 3-3/4 ips.... 64 Hz at 120 ips) at any convenient speed.

Group Delay

Group Attenuation



Vertical Delay Scale: 100 nanoseconds/small division

Vertical Attenuation Scale: 0.2 db/small division

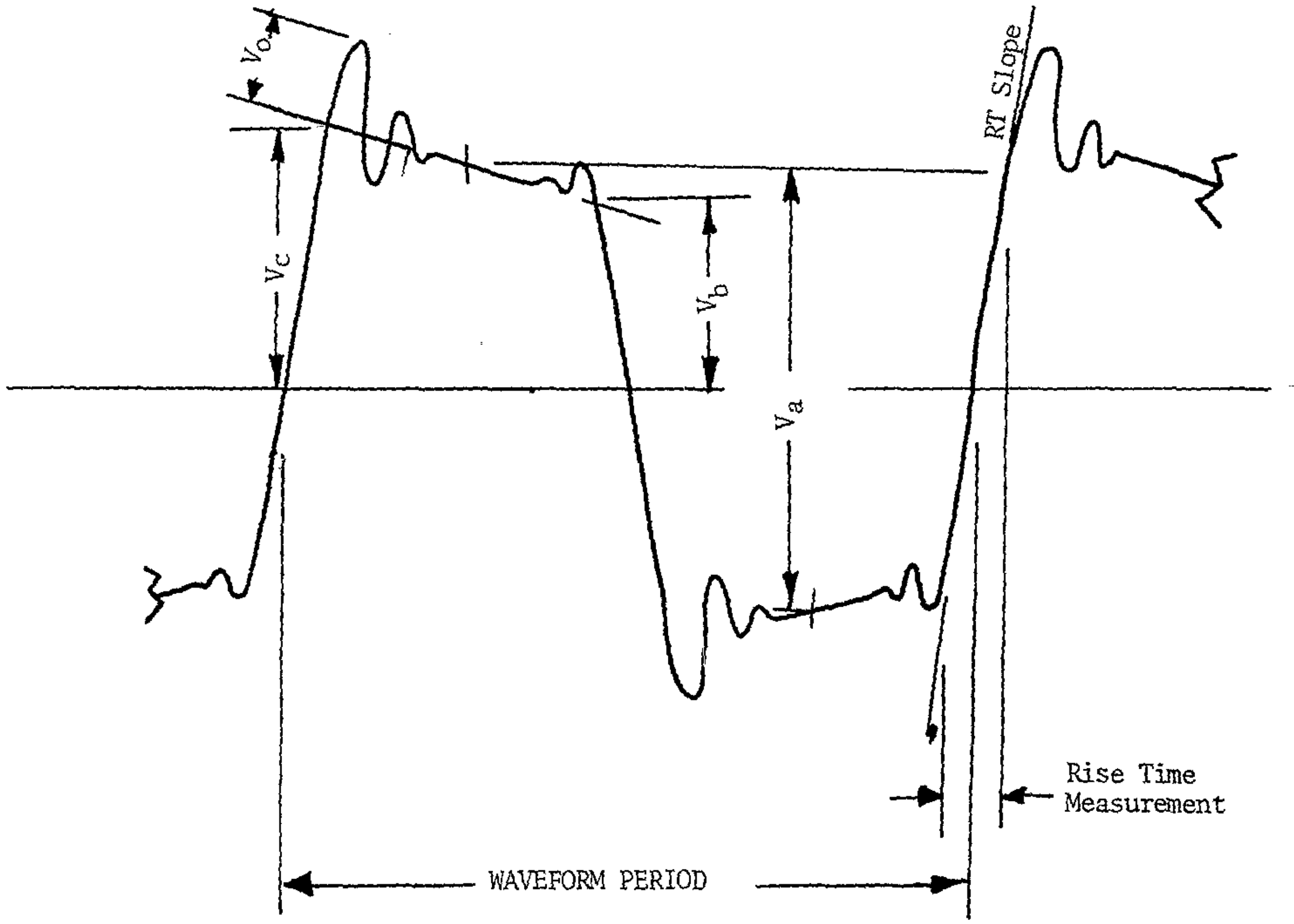
Horizontal Scale: 200 kHz per division, traces beginning at 100 kHz

Zero Delay Grid: +5 divisions

Zero Attenuation Grid: -5 divisions

Polarity: A falling delay curve indicates phase lag, a rising attenuation curve indicates an increase in attenuation.

FIGURE 19 GROUP DELAY VARIATICN TEST PROCEDURE FOR WIDEBAND RECORDERS



Signal peak-to-peak amplitude - V_a

% overshoot - $\frac{V_o}{V_a}$ X 100

% tilt - $\frac{V_c - V_b}{V_a}$ X 100

Note: Conventional Rise Time - 40% of time required for amplitude of RT slope to increase by V_a

FIGURE 20 WAVEFORM PARAMETERS
FOR TRANSIENT RESPONSE MEASUREMENT

(c) Rewind and play back at all specified speeds of the machine without repositioning the output level control. Note the output level at each speed.

5.6.3.3.9 Record Transfer Characteristics: The purpose of this test is to establish that the record head losses at high frequencies are compensated by the record amplifier. Low-frequency signals are recorded and reproduced at the lowest tape speed on the machine. High frequency signals are then recorded at the highest tape speed on the machine and reproduced at the lowest tape speed. Frequencies recorded in the two tests are chosen to be at the same wavelength on the tape. Insofar as possible, the procedure is designed to eliminate the variation in response of the tape, the frequency losses in the reproduce system, and azimuth misalignments which might arise from the test method.

Steps

(a) Place recorder manufacturer recommended bulk degaussed tape on the recorder.

(b) Record and reproduce at 1/8 the highest tape speed of the machine, frequencies of 0.02, 0.1, 0.5, 0.8, and 1.0 times the maximum specified bandwidth for that speed. The input shall be at normal record level On machines with azimuth adjustable reproduce heads, adjust azimuth for maximum output of the band edge frequency. Note the absolute output level of all frequencies. Reproduce level shall be adjusted so that level changes between speeds will not cause the reproduce amplifier to saturate.

(c) Rewind the tape and erase it. Frequencies 8 times as high as those used in Step (b) above should be recorded at the highest speed of the machine. Take reasonable care to record the same wavelength signals at the same place and in the same direction on the tape as in Step (b) above. Each frequency should be recorded approximately 1/8 as long as in Step (b).

(d) Reproduce the tape recorded in Step (c) at 1/8 the highest tape speed of the machine. On machines with azimuth adjustable reproduce heads, adjust azimuth for maximum band edge output. Note the absolute output level of all frequencies.

(e) The deviation from ideal recording is defined as the difference between the response curves obtained in Steps (b) and (d) when the curves have the 0.02 frequency point in common.

5.6.3.4 FM System Tests

5.6.3.4.1 General: All FM tests except Drift and d-c Linearity shall be run through the tape. The FM Record/Reproduce System shall be capable of meeting specifications of all the following parameters simultaneously, without readjustment. Allow equipment to warm up the specified length of time. In the absence of a warm-up specification, the warm-up time shall be in accordance with the manufacturer's recommendation. All percentages shall be referred to full positive to negative deviation as 100 percent. This procedure is intended to test those systems described by Table IX only.

5.6.3.4.2 Deviation, Center Frequency and Polarity Check: The center frequency shall be checked by shorting the input of the amplifier and monitoring the carrier frequency with an electronic counter. The center frequency shall be adjusted to conform to values specified in Table IX within 1.0 percent. The deviation and polarity shall be checked as follows:

Apply the positive peak d-c input signal and verify a full positive deviation in carrier frequency and a corresponding positive output voltage from the reproduce amplifiers. Apply the negative peak d-c input signal and verify a full negative deviation in carrier frequency and a corresponding negative output voltage from the reproduce amplifier.

5.6.3.4.3 Frequency Response: Shall be measured by maintaining the input sine wave signal at constant amplitude (100 percent carrier modulation level at the reference frequency). Monitor the reproduce output signal amplitude at various frequencies in the passband specified in Table IX, including the maximum modulation frequency. Observe the maximum and minimum excursions of the reproduce output level and log in db.

5.6.3.4.4 Signal/Noise Ratio: Shall be measured by recording a sine wave signal at sufficient level to provide full deviation ±5 percent at the reference frequency per Table IX. The input to the amplifier shall then be shorted and the carrier recorded on the tape. The signal-to-noise ratio shall be defined as the ratio of the reproduced output signals under the above conditions measured with an average reading, RMS calibrated voltmeter. No external filters shall be used in the measurements. The VTVM employed shall be down no more than 3 db at 10 Hz.

5.6.3.4.5 Distortion

(a) Single Component Distortion: Record a signal at full deviation ±5.0 percent and a frequency 50 percent of the maximum modulation frequency specified in Table IX. The output of the FM reproduce amplifier shall be measured with a wave analyzer which measures the second harmonic.

(b) Inter-Modulation Distortion: Shall be measured by recording two mixed signals, each at a level sufficient to provide 1/2 full deviation of the carrier. The reproduce output shall be monitored with a wave analyzer and the inter-modulation distortion components of $(F_2 \pm F_1)$, $(2F_1 - F_2)$ and $2F_2 - F_1)$ measured as a percent of the full deviation RMS output voltage. Test frequencies shall be 45 and 55 percent of the maximum modulation frequency specified in Table IX.

5.6.3.4.6 Spurious Components (Wideband FM): Shall be measured by recording the maximum modulation frequency as specified in Table IX at a level sufficient to provide full deviation ±5.0 percent. The reproduced output shall be monitored with a wave analyzer.

5.6.3.4.7 Group Delay and Transient Response: See paragraph 5.6.3.3.7.

5.6.3.4.8 D-C Linearity: See Figure 21.

(a) General: The following tests are to be used for production acceptance testing. In each case percent nonlinearity shall be referred to the full deviation values of f_u-f_l where f(X) is the output function being measured.

(b) Record Amplifier Linearity: (Procedures for systems without reproduce capability).

Inject signals into the record amplifier of sufficient level to provide zero, full positive, and full negative deviation of the carrier. The levels must be accurate to 0.01 percent or better. Monitor the frequency output with a counter having 0.05 percent resolution. The percent nonlinearity shall be determined from the following formula:

$Y\%$ nonlinearity = $\frac{e}{f_u - f_l} \times 100$ the peak-to-peak nonlinearity allowed by the specification. A Y% p-p specification is interpreted as $\pm \frac{Y}{2}$ and conversely.

(c) System Linearity: Including procedure for measuring record amplifier linearity.

Proceed as in 5.6.3.4.8 (b). Monitor the record amplifier frequency and the reproduce amplifier output voltage. Voltage shall be measured with an integrating d-c voltmeter which does not respond to the noise in the output of the FM system. Voltage nonlinearity shall be determined from the following formula:

$Y\%$ nonlinearity = $\frac{e}{f_u - f_l} \times 100$ the peak-to-peak nonlinearity allowed by the specification. A Y% p-p specification is interpreted as $\pm \frac{Y}{2}$ and conversely.

(d) Determination of e:

The method outlined below measures the d-c linearity as a departure from the best straight line (BSL) through zero. The BSL is, however, only an approximation of BSL in the rigorous mathematical sense of least mean square error. This approach is taken to reduce the computation time an order of magnitude below that which would be required for a least mean square error calculation.

An arbitrary straight line is mathematically constructed which passes through the actual output f_c for zero deviation (input shorted or set to center frequency) and the actual output for full negative deviation f_l. The departure of the actual output at all other points from the arbitrary line is then given by the formula:

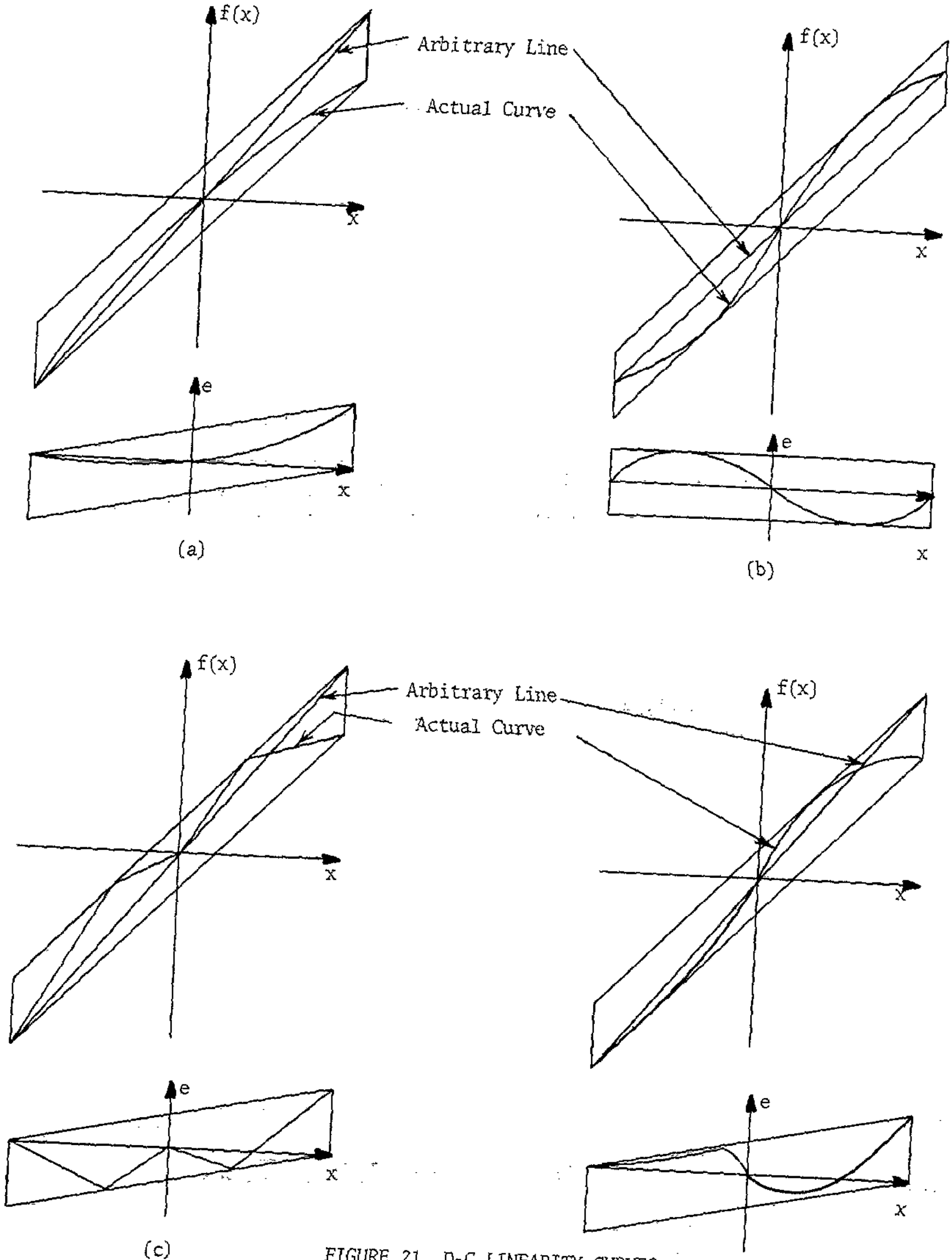


FIGURE 21 D-C LINEARITY CURVES

$e = f_x + f_1 X - (1 + X) f_c$ where

f_x = output for deviation X

f_1 = output for full negative deviation

f_c = output for zero deviation

X = fraction of full deviation - X has values

$-1 \leq X \leq +1$ only.

e is then plotted graphically as a function of X. All points on this curve must be inside of a parallelogram bounded by $X = \pm 1$ and having a p-p height equal to the allowable p-p error. In some cases this parallelogram will become a rectangle.

Several different types of output versus input and e versus X curves are plotted in Figure 21 to show that this computation forms the necessary and sufficient conditions to determine that the linearity is indeed within specification.

The most common type of curve found in FM systems is shown in Figure 21 (a). Critical examination will show that for this shape only the end points need be measured. This reduces the error function to $e = f_u + f_1 - 2f_c$ where

f_u = output for full positive deviation.

A less common type of curve is shown in Figure 21 (b). Once the maximum error points are determined as a function of X, a three-point computation of linearity will suffice for production testing purposes - assuming the S shape is characteristic of the class of equipment being tested.

5.6.3.4.9 D-C Drift at Center Frequency.

(a) Record Amplifier Center Frequency Drift: (Procedure for systems without reproduce capability).

Short the input to the record amplifier and monitor the output frequency versus other specified parameter (time, temperature, line voltage, etc.).

(b) System Zero Drift: (Including procedure for measuring record amplifier zero drift).

Proceed as in 5.6.3.4.9 (a). In addition, monitor the d-c output voltage change versus other parameter as specified (time, temperature, line voltage, etc.). All changes in the frequency band dc - 0.2 Hz shall be included.

(c) An X percent P-P specification is interpreted as $\frac{\pm X}{2}$ percent.

5.6.3.4.10 Multispeed Reproduce Transfer Levels: Shall be measured by recording the reference frequency specified in Table IX at a level sufficient to provide full deviation of the carrier at the highest tape speed of the system. The tape shall be rewound then reproduced at each tape speed of the system specified for FM operation and the output voltage monitored in each case. The output amplitude variation shall be expressed as a percent of the full deviation output voltage.

5.7 TRANSDUCER STANDARDS

5.7.1 General: The vast variety of transducers currently available for use in telemetry systems makes it impractical to develop a standard universally applicable to all transducers, except in the areas of terminology and definitions. Professional societies and similar groups have promulgated a number of standards and recommended practices pertaining to particular classes of transducers. These documents, which are referenced below, shall be used to the maximum extent possible, in order to achieve the goal of uniformity in the field of telemetry.

5. 7. 2 Terminology and Definitions: Terminology and definitions pertaining to transducers are contained in RCC Document 104-64 "A Glossary of Range Terminology," Revised 1969.

A more complete listing, from which the transducer terms in 104-64 were derived appears in RP 37.1 "Nomenclature and Specification Terminology for Aerospace Test Transducers with Electrical Output," April 1963, Instrument Society of America, 530 Willaim Penn Place Pittsburgh, Pennsylvania 15219

5.7.3 Transducer Characteristics and Performance: The Instrument Society of America has issued a number of documents dealing with specific transducer types. Additional documents are being prepared by committees of the Society. The published documents are subject to continuing review and users are urged to contact the Society for the most up-to-date printing.

Documents published to date and pertaining to transducers with electrical output are as follows:

RP 31.1 "Terminology and Specifications for Turbine-Type Flow Transducers" (Volumetric), 1961

RP 37.2 "Guide for Specifications and Tests for Piezoelectric Acceleration Transducers for Aerospace Testing," January 1964

RP 37.3 "Guide for Specifications and Tests for Strain Gage Pressure Transducers for Aerospace Testing," April 1964

S 37.6 "Specifications and Tests of Potentiometric Pressure Transducers for Aerospace Testing," May 1967

ISA "ISA Transducer Compendium"

APPENDIX A

The following is a copy of the MCEB-M 92-65 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

APPENDIX 1	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.
APPENDIX 2	1435-1540 Mc/s Telemetering Frequency Assignment Plan for Flight Testing of Manned and Unmanned Aircraft, Missiles and Space Vehicles (or Major Components Thereof)
APPENDIX 3	2200-2300 Mc/s Telemetering Frequency Assignment Plan for other than Flight Testing of Manned Aircraft.

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 (500Kc/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.

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* 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.

APPENDIX B

USE CRITERIA FOR FREQUENCY DIVISION MULTIPLEXING

10 General

The successful application of the Frequency Division Multiplexing Telemetry Standards depends upon recognition of performance limits and performance tradeoffs which may be required in implementation of a system. The use criteria included in this appendix are offered in this context, as a guide for orderly application of the standards which are presented in Section 5.2. The significant difference between existing standards and previous standards is the addition of three proportional-bandwidth channels, the inclusion of 35 constant-bandwidth channels, and the listing of maximum frequency response for a deviation ratio of one in the tables. Maximum frequency response (deviation ratio of 1) should never be used when data quality is the primary emphasis rather than data quantity.

It is the responsibility of the system designer to select the range of performance that is commensurate with his requirements and which permits him to operate within the limits of the standards. At the same time he must recognize the fact that even though the standards encompass a broad range of performance limits, performance tradeoffs such as data accuracy for data bandwidth may be necessary. Nominal frequency response is listed to indicate the majority of expected uses. It is not to be interpreted as an operational maximum frequency response. Nominal and minimum rise times are included in the same context. It must be remembered that system performance is influenced by other things such as hardware performance capabilities and upon differences in definitions of terms. In summary, the scope of the standards together with the use criteria are intended to offer flexibility of operation and yet provide realistic limits.

20 Background

The nominal and maximum frequency response of the subcarrier channels listed in Tables II and III is 10 percent and 50 percent, respectively, of the maximum allowable deviation bandwidth. The nominal frequency response of the channels employs a deviation ratio of five. The deviation ratio of a channel is defined as one-half the defined deviation bandwidth divided by the cutoff frequency of the discriminator output filter.

The use of other deviation ratios for any of the subcarrier channels listed may be selected by the range users to conform with the specific data response requirements for the channel. As a rule, the rms signal to noise ratio of a specific channel varies as the three-halves power of the subcarrier deviation ratio employed.

The nominal and minimum channel rise times indicated in Table II have been determined from the equation which states that rise time is equal to 0.35/(frequency response) for the nominal and maximum frequency response, respectively. The equation is normally employed to define the 10 percent to 90 percent rise time for a step function of the channel input signal; however, deviations from these values may be due to variations in subcarrier components in the system.

30 Performance Tradeoffs

The number of subcarrier channels which may be used simultaneously to modulate a radio-frequency carrier is limited by the radio-frequency channel bandwidth, and by the output signal/noise ratio that is acceptable in the application at hand. As channels are added, it is necessary to reduce the transmitter deviation allowed for each individual channel, to keep the overall multiplex within the radio-frequency channel assignment. This lowers the subcarrier-to-noise performance at the discriminator inputs, and the problem is to recognize acceptable tradeoffs between the number of subcarrier channels and acceptable subcarrier-to-noise ratios.

Background information relating to the level of performance and the tradeoffs that may be made is included in the "Telemetry FM/FM Baseband Structure Study," Volumes I and II, DDC Document Nos. AD-621139 and AD-621140, which was completed under a contract administered by the Telemetry Working Group of IRIG. The results of the study show that proportional bandwidth channels with center frequencies up to 165 kHz and constant-bandwidth channels with center frequencies up to 176 kHz may be used within the constraints of these standards. The test criteria included the adjustment of the system components for approximately equal signal-to-noise ratio at all of the discriminator outputs with the receiver input near radio-frequency threshold.

With subcarrier deviation ratios of four, channel data errors in the order of 2.0 percent rms were observed. Data channel errors in the order of 5.0 percent rms of full-scale bandwidth were observed when subcarrier deviation ratios of two were employed. When deviation ratios of one were used, it was observed that channel data errors exceeded 5.0 percent. Typical peak-to-peak errors of 10 percent of full bandwidth were observed when operating with a deviation ratio of one. Some channels showed peak-to-peak errors as high as 30 percent. It must be emphasized, however, that the results of the tests performed in this study are based upon specific methods of measurement on one system sample and that this system sample represents a unique configuration of components. Other components with other performance characteristics will not necessarily yield the same system performance.

System performance may be improved, in terms of better data accuracy, by sacrificing system data bandwidth. That is, if the user is willing to limit the number of subcarrier channels in the multiplex, particularly the higher frequency channels, the input level to the transmitter can be increased. The signal-to-noise ratio of each subcarrier is then improved through the increased per channel transmitter deviation. For example, the baseband structure study indicated that when the 165 kHz channel, the 124 kHz channel, and the 93 kHz channel were not included in the proportional-bandwidth multiplex, performance improvement in the remaining channels equivalent to approximately 12 db increased transmitter power can be expected.

Likewise, elimination of the five highest frequency channels in the constant-bandwidth multiplex allowed a 6 db increase in performance.

A general formula which can be used to estimate the performance of an FM/FM channel above threshold is as follows:[15]

$$\left(\frac{S}{N}\right)_d = \left(\frac{S}{N}\right)_c \left(\frac{3}{4}\right)^{1/2} \left[\frac{B_c}{F_{ud}}\right]^{1/2} \frac{f_{dc}}{f_s} \times \frac{f_{ds}}{F_{ud}}$$

where

$\left(\frac{S}{N}\right)_d$ = discriminator output signal-to-noise ratio (rms voltage ratio)

$\left(\frac{S}{N}\right)_c$ = receiver carrier-to-noise ratio (rms voltage ratio)

B_c = carrier bandwidth (Receiver intermediate-frequency bandwidth)

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[15] K. M. Uglow, "Noise and Bandwidth in FM/FM Radio Telemetry," IRE Transactions of Telemetry and Remote Control, May 1957, pp. 19-22.

F_{ud} = subcarrier discriminator output filter - 3 db frequency

f_s = subcarrier center frequency

f_{dc} = carrier peak deviation due to the particular subcarrier of interest

f_{ds} = subcarrier peak deviation

This relation provides estimates accurate within a few decibels, especially for the higher frequency channels where intermodulation is not a problem and where the receiver output noise is triangular in character.

The FM/FM multiplex used to modulate the radio-frequency carrier may be a proportional-bandwidth format, a constant bandwidth format, or a combination of the two types, providing that adequate guard bands are observed. It is recommended that the guard bands allowed for channels used in a mixed format be equal to or greater than the guard band allowed for that channel in an unmixed format.

40 System Component Considerations

System performance is dependent upon essentially all components in the system. Neglecting the effects of the radio-frequency and recording system, data channel accuracy is primarily a function of the linearity and frequency response of the subcarrier oscillators and discriminators employed. Systems designed to transmit data frequencies up to the nominal frequency responses indicated in Tables II and III have generally well-known response capabilities, and reasonable data accuracy estimates can be easily made. For data channel requirements approaching the maximum frequency response of Tables II and III, oscillator and discriminator characteristics are less consistent and less well defined, making data accuracy estimates less dependable.

The effect of the radio-frequency system on data accuracy is primarily in the form of noise due to intermodulation at high radio-frequency signal conditions well above threshold. Under low radio-frequency signal conditions, noise on the data channels is increased due to the degraded signal-to-noise ratio existing in the receiver.

Intermodulation of the subcarriers in a system is due to characteristics such as amplitude and phase nonlinearities of the transmitter, receiver, or other system components required to handle the multiplex signal under the modulation conditions employed. In systems employing appreciable pre-emphasis of the upper subcarriers, the lower subcarriers may receive appreciable intermodulation interference due to difference frequencies of the high frequency (and high amplitude) channels.

The use of magnetic tape recorders for the recording of the subcarrier multiplex may degrade the data channel accuracy primarily due to tape speed differences or variations between recording and playback. These speed errors can normally be compensated for in present discriminator systems when the nominal response rating of the channels are employed.

50 Range Capability

50.1 Receiver and Tape Recorders

The use of the 93, 124, 165 kHz proportional channels or the constant bandwidth channels may require receivers or tape recorders of a greater capability than are in current use at some ranges. It is recommended that users who anticipate using any of the above channels at a range check the range's capability at a sufficiently early date to allow procurement of necessary equipment if required.

50.2 Discriminator Channel Selection Filters

Inclusion of the higher frequency proportional-bandwidth channels and the new constant-bandwidth channels will require the ranges to acquire additional band selection filters. In those cases where minimum time delay variation within the filter is important, such as tape speed compensation, or high rate PAM or PCM, constant-delay filter designs are recommended.

50.3 Discriminator Output Filters

If a range facility were to stock discriminator output filters corresponding to each of the channel frequency responses listed in Tables II and III, it would be necessary to accommodate 64 separate cutoff frequencies. This number must be multiplied if more than one roll-off slope is required. In order to place a more modest requirement on the range facilities, output filters with the following cutoff frequencies are recommended:

> A filter for each of the frequencies listed under Nominal Frequency Response in Table III, plus 6500 Hz, 8500 Hz, 11,000 Hz, 15,000 Hz, 19,000 Hz, and 25,000 Hz. In addition, filters are recommended corresponding to each of the Nominal Frequency Responses and each of the Maximum Frequency Responses listed in Table III. For other data frequency requirements, compromises should be made by selecting one of the filter frequencies already listed.

APPENDIX C

PDM STANDARDS
ADDITIONAL INFORMATION AND RECOMMENDATIONS

10 Intermediate-Frequency Bandwidth and Transmitter Deviation

10.1 The appropriate receiver final intermediate-frequency bandwidth and transmitter deviation depend primarily on the total pulse rate, system noise and distortion tolerance.

20 Premodulation Filtering

20.1 It is recommended that the premodulation filter specified in Section 5.3.6 exhibit a final attenuation slope of 36 db per octave and shall have a maximally linear phase response.

30 Maximum Pulse Duration

30.1 The accuracy of a PDM system is a direct function of the timing measurement errors (jitter) on the leading and trailing edges of the pulses. The full-scale accuracy will improve as the duration of the maximum length pulse is increased.

30.2 The minimum Pulse Gap Time interval must be larger than the minimum pulse duration in order to avoid transient interference between successive data pulses (See Telemetry System Study Final Report Aeronutronics U743, 18 December 1959, Vol. 1 Section 2, page 36)

APPENDIX D

PAM STANDARDS

10 Intermediate-Frequency Bandwidth and Transmitter Deviation

10.1 The appropriate receiver final intermediate-frequency bandwidth and transmitter deviation depend primarily on the total pulse rate, system noise, and distortion tolerance.

10.2 Transmitter and receiver instability (Refer to Section 5.1 for Frequency Tolerance) may cause frequency drifts as high as ±39 kHz in the VHF band. Instabilities of this magnitude preclude the use of the three lower receiver intermediate-frequency bandwidths, unless a special technique such as automatic frequency control, capable of accommodating PAM waveforms, is applied.

20 Premodulation Filtering

20.1 It is recommended that the premodulation filter specified in Section 5.4.6 exhibit a final attenuation slope of 36 db per octave and shall have a maximally linear phase response.

APPENDIX E

PCM STANDARDS
ADDITIONAL INFORMATION AND RECOMMENDATIONS

10 Bit Rate Versus Receiver Intermediate-Frequency Bandwidth (3 db Points)

10.1 Receiver intermediate-frequency (i-f) bandwidth should be made from those listed in Table V. Only those discrete receiver intermediate-frequency bandwidths listed should be used for data channel (optional below 12,500 Hz). The selections in Table V have been made on the consideration that automatic tracking of radio-frequency (r-f) carrier drift or shift will be used in the receiver, however, doppler shift considerations may require wide Intermediate-Frequency/Discriminator Bandwidths for the AFC System.

10.2 For reference purposes in a well designed system, a receiver intermediate-frequency 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.

10.3 It is recommended that the period between assured bit transitions be a maximum of 64-bit intervals to assure adequate bit synchronization.

20 Suggested PCM Synchronization Patterns

20.1 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.

30 Premodulation Filtering

30.1 The premodulation filter recommended in paragraph 5.5.6 shall exhibit a final attentuation slope of 36 db per octave and shall have a maximally linear phase response.

AFLC/HAFB, Ogden