International Standard ISO 6068

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Information processing — Recording characteristics of instrumentation magnetic tape (including telemetry systems) — Interchange requirements

Traitement de l'information — Caractéristiques d'enregistrement de la bande magnétique de mesure (y compris les systèmes de télémesure) — Spécifications d'échanges

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 6068 was prepared by Technical Committee ISO/TC 97, *Information processing systems*.

It cancels and replaces ISO 3413-1975 and ISO 3615-1976 of which it constitutes a technical revision.

Contents

Information processing — Recording characteristics of instrumentation magnetic tape (including telemetry systems) — Interchange requirements

1 Scope and field of application

This International Standard specifies the tape and recorder/reproducer characteristics and modes of recording to enable users of different systems to interchange information recorded on instrumentation magnetic tape.

Modulation patterns are described in clause 6.

Test procedures recommended for use in measuring performance parameters of magnetic tape recorder and reproducer systems are described in annex B.

Annexes C to F provide additional information but do not form part of this International Standard. The characteristics of unrecorded tape are specified in ISO 6371.

2 References

ISO 1858, *Information processing — General purpose hubs and reels, with* 76 mm (3 in) *centre hole, for magnetic tape used in interchange instrumentation applications.*

ISO 1860, *Information processing — Precision reels for magnetic tape used in interchange instrumentation applications.*

ISO 3802, *Information processing — General purpose reels with* 8 mm (5/16 in) *centre hole for magnetic tape for interchange instrumentation applications.*

ISO 6371, *Information processing — Interchange practices and test methods for unrecorded instrumentation magnetic tape.*

3 Definitions

The following terms have a special technical meaning in this International Standard, and no attempt is made to lay down definitive terminologies outside the specific context of this International Standard.

3.1 bi-phase (or Bi-Φ) : Form of representation for binary "1" and "0" in pulse code modulation (PCM). Three variants, known as "level", "mark" and "space", are defined in 6.3.3 and figure 1.

3.2 data azimuth[1] : Angle in the plane of the tape, at any instant in time, between a line perpendicular to the reference edge of the tape and either of the two parallel lines defining data scatter.

NOTE — Data azimuth may be expressed as the sum of static and dynamic components in the form :

$$A + Bf(t)$$

where

$$\int_0^t f(t)\, dt = 0$$

3.3 data azimuth (dynamic)[1] : Maximum angular deviation, over a period of time, of the data azimuth from its mean value as defined by data azimuth (static). For the purposes of this definition, the word maximum is interpreted as being at the 95 % probability level. For a Gaussian distribution, this is two standard deviations (2σ).

NOTE — Data azimuth (dynamic) is the maximum value of the quantity $Bf(t)$ in the note on data azimuth.

3.4 data azimuth (static)[1] : Mean value, over a period of time, of the data azimuth.

NOTE — Data azimuth (static) is the quantity A in the note on data azimuth.

3.5 data scatter[1] : Minimum distance between two parallel lines, in the plane of the tape, between which all data transitions recorded in the same head, at the same time, shall fall.

3.6 data spacing : Distance on the tape between simultaneous events recorded on odd and even numbered tracks, when interlaced heads are used.

NOTE — On recording, this is equal to the head spacing, but on reproducing is only exactly equal to head spacing when record and reproduce tensions are equal. Different record and reproduce tensions will give rise to small errors in time correlation between the signals from the two heads.

1) The errors in location and angular relation among transient data recorded simultaneously on all odd or even tracks are defined by the terms : data azimuth, data scatter, and individual track data azimuth difference. These are approximately equivalent to the terms : head azimuth, gap scatter and head segment gap azimuth difference; however, guiding misalignment is included in the data location error definitions.

3.7 duty factor (of a pulse) : Percentage occupancy of pulse duration within a pulse period or time-slot.

3.8 edge margin (M) : Distance between the outside edge of the highest numbered track and the tape edge (see figure 5).

3.9 edge margin, minimum (M_m) : Minimum allowable value of edge margin.

NOTE — This value places an additional constraint on track configurations since, in general, the simultaneous application of all worst case tolerances for track width, track location and tape width will result in a value of edge margin less than M_m.

3.10 frequency division multiplex (FDM) : Multiplexing technique in which modulated subcarriers are combined in such a way that each of a number of data channels occupies a unique and defined section of the available bandwidth.

3.11 frame, major : The minimum overall repetitive sequence of pulses, in which each input channel is sampled at least once. The period of the major frame is determined by the length of the longest submultiple frame(s).

3.12 frame, minor : A group of data pulses or samples; it includes and ends with a synch. pulse or pattern. The minor frame is an integral submultiple of the major frame and, in the absence of subcommutation, is repetitive and equal to the major frame.

3.13 frame, submultiple : A repetitive group of subcommutated data pulses. Supercommutation within a submultiple frame is possible (see figure 2).

3.14 gap length : Distance from the leading edge to the trailing edge of the head gap measured perpendicular to the track width (see figure 3).

3.15 gap scatter : Minimum distance between two parallel lines, in the plane of the tape, between which gap trailing edges in a recorder head shall fall (see figure 3).

3.16 head : Grouping of individual head segments in a fixed assembly with the gap lines on a common plane.

3.17 head azimuth : Angle formed, in the plane of the tape, between a line passing through the gap centres of the two outside head tracks and a line perpendicular to the head reference plane (see figure 3).

3.18 head numbering : Head 1 of a pair of heads is the first head over which an element of tape passes when moving in the normal operating direction.

3.19 head reference plane : The plane, which may be imaginary (for some head designers, it is the nominal head mounting surface), parallel to the reference edge of the tape and perpendicular to the plane of the tape (see figure 3). (For the purpose of the definition, the tape shall be considered as perfect.)

3.20 head segment : Single transducer which records or reproduces one track on magnetic tape (see figure 3).

3.21 head segment gap azimuth : The angle, in the plane of the tape, between a line perpendicular to the head reference plane and the gap trailing edge in a record head segment (see figure 3).

3.22 head segment gap azimuth difference : Angular deviation of the azimuth of head segment gaps, in a head, from the head azimuth (see figure 3).

3.23 head segment numbering : Numbering of a head segment shall correspond to the track number on the magnetic tape on which that head segment normally operates. Head 1 of a pair will contain all odd-numbered segments while head 2 will contain all even-numbered segments (see figures 3 and 4).

3.24 head spacing (S) : The distance along the tape path between the gap centre lines of head 1 and head 2, when interlaced heads are used (see figure 4).

3.25 head tilt : Angle, between the plane tangent to the front (active) surface of the head at the centre-line of the head segment gaps, and a line perpendicular to the head reference plane (see figure 3).

3.26 heads in-line : For in-line recording, only one record head and one reproduce head will be used.

3.27 heads interlaced : Head placement for interlaced recording is to locate the head segments (both record and reproduce) for alternate tracks in separate heads. Thus, to record on all tracks of a tape, two record heads will be used; to reproduce all tracks on a tape, two reproduce heads will be used.

The two heads of a pair of record or of reproduce heads for interlaced recording shall be mounted in such a manner that the centre-line through the head segment gaps of each head are parallel and spaced according to the head spacing (S) (see figure 4).

3.28 individual track data azimuth difference[1)] : Angular deviation of the data azimuth of individual odd or even recorded tracks from the data azimuth of all odd or even tracks.

The difficulty of making direct optical angular measurements requires this error to be expressed as the loss of signal amplitude permitted when the tape is reproduced on an ideal reproducing head, whose gap is aligned to coincide with the data azimuth of all odd or even tracks, as compared to the maximum signal amplitude obtainable by optimizing the reproduce head azimuth for the individual tracks (see figure 3).

3.29 mode : In telemetry systems, one of two techniques generally used for recording on a given track on magnetic tape; direct recording and single-carrier FM (frequency modulation).

NOTE — Single-carrier FM (and PCM) may itself be recorded by either direct recording (with bias) or saturation (without bias) techniques, and in other instrumentation systems may be regarded as a modulation pattern.

3.30 modulation pattern : Form in which data is encoded prior to transmission or recording, for example, multiple-carrier FM, PAM, PCM. See note accompanying the definition of mode on single-carrier FM (see 3.2.9).

3.31 NRZ (non-return-to-zero) : Form of representation for binary "1" and "0" in pulse-code modulation (PCM). Three variants, known as "level", "mark" and "space", are defined in 6.3.3 and figure 1.

3.32 pulse amplitude modulation (PAM) : Time Division Multiplexing (TDM) technique in which pulses in a sequence are amplitude-modulated, so that the pulse amplitudes represent samples of analogue-variable parameters.

3.33 PAM/FM : Frequency modulation of a radio-frequency carrier by a PAM waveform.

3.34 PAM/FM/FM : Frequency modulation of a radio-frequency carrier by an FDM set of subcarriers, which in turn are frequency-modulated by PAM waveforms.

3.35 pulse code modulation (PCM) : Time Division Multiplexing (TDM) technique in which samples of data are represented in binary form by a group of discrete pulses (words) (see figure 1).

3.36 PCM/FM : Frequency modulation of a radio-frequency carrier by a PCM waveform.

3.37 PCM/FM/FM : Frequency modulation of a radio-frequency carrier by an FDM set of subcarriers, which in turn are frequency-modulated by PCM waveforms.

3.38 pseudo-noise (PN) waveform : Non-random waveform having mean, variance, and other properties resembling random noise (see annex C).

3.39 reference edge : Edge of the tape nearest track 1 (see figure 5).

3.40 reference track location (G) : Location of the centre-line of track 1 relative to the reference edge of the tape (see figure 5).

3.41 standard tensile force : Reference longitudinal tensile force in magnetic tape in the vicinity of the head(s) during recording or reproducing.

3.42 subcommutation : Assigning more than one input channel (data source) to the same time-slot in successive minor frames. The sources assigned to such a time-slot recur in a repetitive sequence.

3.43 supercommutation : Assigning an input channel (data source) to more than one time-slot within each minor frame.

3.44 synchronization : Establishing the timing of a data sequence. A number of different synch formats may be required to identify minor frames, major frames (submultiple frames) and (in PCM) bits and words.

3.45 tape speed, actual (V_{act}) : Tape speed during recording or reproducing. In general the actual tape speed will not be equal to the standard tape speed.

3.46 tape speed, effective (V_{eff}) : Actual tape speed after applying corrections for the effects on the tape of differences between operating and standard conditions, i.e. tensile force, tape materials and thickness, and environment (temperature and humidity). The effective tape speed should be equal to one of the standard tape speeds.

NOTE — Environmental effects on the recorder/reproducer system are not included in this definition.

3.47 tape speed, standard (V_{std}) : Range of defined nominal tape speeds for tapes operating at the standard tensile force and in standard environmental conditions.

3.48 tape tensile force : Tape tensile force applied to the tape during operation. The value of this tensile force is not necessarily the standard tensile force but it is assumed to be applied uniformly across the width of the tape.

3.49 time division multiplex (TDM) : Multiplexing technique in which data samples are transmitted or recorded sequentially in time, each sample occupying a unique and defined period or time-slot within the sequence.

3.50 time-slot : A channel interval; the period allocated for each pulse or sample within a minor frame.

3.51 track location (H_n) : Distance from the centre-line of the reference track (track 1) to the centre-line of the recorded track (n) (see figure 5).

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1) The errors in location and angular relation among transient data recorded simultaneously on all odd or even tracks are defined by the terms : data azimuth, data scatter, and individual track data azimuth difference. These are approximately equivalent to the terms : head azimuth, gap scatter and head segment gap azimuth difference; however, guiding misalignment is included in the data location error definitions.

3.52 track numbering : Tracks on tape shall be numbered consecutively, starting with track 1, from top to bottom when viewing the magnetic surface of the tape with the earlier portion of the recorded signal to the observer's right (bottom to top if the earlier portion of the recorded signal is to the observer's left) (see figure 5).

3.53 track spacing (D) : Centre-to-centre distance between adjacent recorded tracks (see figure 5).

3.54 track width (W) : Mechanical width of the common interface of the record head segment at the gaps. This does not include the effects of fringing fields which will tend to increase the recorded track width by small amount (see figures 3 and 5).

4 Tape and recorder/reproducer characteristics

4.1 General

This clause specifies the tape and recorder/reproducer characteristics required to assure interchange, so that tapes recorded at one facility may be successfully reproduced at another. Recommended test procedures for magnetic tape recording/reproducing equipment are given in annex A.

4.2 Tape and reel characteristics

4.2.1 Tape widths

Standard tape widths are specified in table 1.

Table 1 — Standard tape widths

mm	in
$6{,}30\ ^{0{,}00}_{-0{,}06}$	$0.248\ ^{0.000\,0}_{-0.002\,5}$
$12{,}70\ ^{0{,}00}_{-0{,}10}$	$0.500\ ^{0.000}_{-0.004}$
$25{,}40\ ^{0{,}00}_{-0{,}10}$	$1.000\ ^{0.000}_{-0.004}$
$50{,}80\ ^{0{,}00}_{-0{,}10}$	$2.000\ ^{0.000}_{-0.004}$

4.2.2 Reels

Tapes shall be wound on hubs or reels complying with the requirements of ISO 1860, ISO 1858 or ISO 3802.

4.3 Tape speeds

4.3.1 Standard tape speeds

The standard tape speeds (V_{std}) for instrumentation magnetic tape recorders are as specified in table 2.

Table 2 — Standard tape speeds

mm/s	in/s
6 096	240
3 048	120
1 524	60
762	30
381	15
190,5	7 1/2
95,2	3 3/4
47,6	1 7/8
23,8	15/16

4.3.2 Effective tape speeds

The effective tape speed (V_{eff}) throughout a reel (in the absence of tape-derived servo speed control) shall be within ± 0,5 % of the required standard speed for low-band DR recorders and ± 0,2 % for intermediate-band and wide-band DR recorders (see 5.1.1.1). Tape speed errors are defined as departures of average speed from the standard value.

Recommended methods for measuring effective tape speed are given in A.2.2.

NOTE — Errors at frequencies above 0,5 Hz are known as flutter (see 4.6).

4.4 Track configurations

Track configurations are illustrated in figure 5 and specified in tables 2 to 9. It should be noted that although a tape reference edge is specified, edge guiding of the tape is not an implied requirement of the recorder/reproducer.

The head spacing for adjustable heads refers to equipment having facilities for adjusting the azimuth of reproduce heads; these are required for wide-band DR recorder/reproducers (see 5.1.1.1).

4.5 Recorder/reproducer characteristics

4.5.1 Data scatter

The maximum data scatter shall be as follows :

Tape width	Maximum data scatter
6,3 mm (0.25 in)	1,25 µm (50 µin)
12,7 mm (0.5 in)	2,5 µm (100 µin)
25,4 mm (1 in)	5,0 µm (200 µin)
50,8 mm (2 in)	10,0 µm (400 µm)

It is the responsibility of an equipment manufacturer to decide whether or not data scatter may be equated to gap scatter (see figure 3 and the footnote to 3.2).

4.5.2 Data azimuth (static)

Data azimuth (static) shall be not greater than ± 0,3 mrad (± 1′ of arc). It is the responsibility of an equipment manufacturer to decide whether or not data azimuth (static) may be equated to head azimuth (see figure 3 and the footnote to 3.2).

4.5.3 Data azimuth (dynamic)

Data azimuth (dynamic) shall be not greater than ± 0,3 mrad (± 1′ of arc) as determined from measurements of the dynamic interchannel time displacement error (ITDE) between outer tracks on the same head. It is the responsibility of an equipment manufacturer to decide whether or not data azimuth (dynamic) may be equated to the mechanical restriction placed on tape angular motion by the tape guides; the guides shall not cause damage to the tape. (See the footnote to 3.2.) A recommended method for the measurement of ITDE is given in A.2.4.

4.5.4 Individual track data azimuth difference

The maximum signal loss due to individual track data azimuth difference shall be not greater than 1 dB (excluding reproduce head error) at the shortest wavelength specified for the equipment. The overall record/reproduce error shall not be greater than 2 dB.

4.5.5 Head tilt

Head tilt shall be not greater than ± 0,9 mrad (± 3′ of arc) for low- and intermediate-band DR recorders (see 5.1.1.1) and ± 0,3 mrad (± 1′ of arc) for wide-band DR recorders (see figure 3).

4.5.6 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 (wide band).

4.5.7 Head polarity

(Refer to A.2.1 for a recommended polarity test and B.2 for further information.)

4.5.7.1 Record head

Each record head winding shall be connected to its respective amplifier in such a manner that a positive-going pulse with respect to system ground, at the record 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.

4.5.7.2 Reproduce head

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

4.5.8 Standard tensile force

For tapes using a polyethyleneterephthalate (PET) base, standard tensile force shall be 0,131 N/mm (12 ozf/in) of tape width. For ideal interchange, recorder/reproducer operating tape tensile forces should be equal to standard tensile force; as the operating tensile force departs from standard tensile force, the corrections to be applied to make the effective tape speed (V_{eff}) equal to the standard tape speed (V_{std}) become increasingly unreliable due to non-linearities, etc.

NOTE — It is current practice in some countries to use a standard tensile force of 0,175 N/mm (16 ozf/in) tape width. Interchange parties should exercise caution when defining tests involving this parameter.

4.6 Other characteristics

Reference has been made in 4.3.2 to flutter, and other related characteristics are time-base error (TBE) and pulse-to-pulse jitter. Requirements for these characteristics are not specified in this International Standard since they depend on the intended application, but recommended test methods for measuring such characteristics are given in A.2.3 (flutter), A.2.5 (TBE) and A.2.6 (pulse-to-pulse jitter).

Table 3 — Dimensions — Recorded tape format, 4 tracks in line on 6,3 mm (1/4 in) wide tape
(see figure 5)

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	0,686		0,584	0.025 ± 0.002
Track spacing (D)		1,778		0.070
Reference track location (G)	0,483		0,381	0.017 ± 0.002
Track location tolerance (H_n tolerance)	0,051		−0,051	± 0.002

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	1,829		1,727	0.070
3	3,607		3,505	0.140
4	5,385		5,283	0.210

Table 4 — Dimensions — Recorded tape format, 7 tracks interlaced on 6,3 mm (1/4 in) wide tape
(see figure 5)

Dimension	mm max.	mm nom.	mm min.	in
Track width (W)	0,660		0,610	0.025 − 0.001
Track spacing (D)		0,889		0.035
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Ajustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_n)		0,025		0.001
Reference track location (G)	0,470		0,394	0.017 0 ± 0.001 5
Track location tolerance (H_n tolerance)	0,038		−0,038	± 0.0015

Track number	Location for nth track (H_n) mm max.	mm nom.	mm min.	in
1 (reference)		0,000		0,000
2	0,927		0,851	0.035
3	1,816		1,740	0.070
4	2,705		2,629	0.105
5	3,594		3,518	0.140
6	4,483		4,407	0.175
7	5,372		5,296	0.210

Table 5 — Dimensions — Recorded tape format, 7 tracks interlaced on 12,7 mm (1/2 in) wide tape
(see figure 5)

Dimension	mm max.	mm nom.	mm min.	in
Track width (W)	1,40		1,14	0.050 ± 0.005
Track spacing (D)		1,778		0.070
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,127		0.005
Reference track location (G)	1,067		0,965	0.040 ± 0.002
Track location tolerance (H_n tolerance)	0,051		−0,051	± 0.002

Track number	Location for nth track (H_n) mm max.	mm nom.	mm min.	in
1 (reference)		0,000		0.000
2	1,829		1,727	0.070
3	3,607		3,505	0.140
4	5,385		5,283	0.210
5	7,163		7,061	0.280
6	8,941		8,839	0.350
7	10,719		10,617	0.420

Table 6 — Dimensions — Recorded tape format, 14 tracks interlaced on 12,7 mm (1/2 in) wide tape
(see figure 5)

Dimension	mm max.	mm nom.	mm min.	in
Track width (W)	0,660		0,610	0.025 ± 0.001
Track spacing (D)		0,889		0.035
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,127		0.005
Reference track location (G)	0,546		0,470	0.020 0 ± 0.001 5
Track location tolerance (H_n tolerance)	0,038		−0,038	± 0,001 5

Track number	Location for nth track (H_n) mm max.	mm nom.	mm min.	in
1 (reference)		0,000		0.000
2	0,927		0,851	0.035
3	1,816		1,740	0.070
4	2,705		2,629	0.105
5	3,594		3,518	0.140
6	4,483		4,407	0.175
7	5,372		5,296	0.210
8	6,261		6,185	0.245
9	7,150		7,074	0.280
10	8,039		7,963	0.315
11	8,928		8,852	0.350
12	9,817		9,741	0.385
13	10,706		10,630	0.420
14	11,595		11,519	0.455

Table 7 — Dimensions — Recorded tape format, 21 tracks interlaced on 12,7 mm (1/2 in) wide tape
(see figure 5).

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	0,483		0,432	0.018 ± 0.001
Track spacing (D)		0,584		0.023
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,178		0.007
Reference track location (G)	0,470		0,394	0.017 0 ± 0.001 5
Track location tolerance (H_n tolerance)	0,025		−0,025	± 0.001

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	0,610		0,559	0.023
3	1,194		1,143	0.046
4	1,778		1,727	0.069
5	2,362		2,311	0.092
6	2,946		2,896	0.115
7	3,531		3,480	0.138
8	4,115		4,064	0.161
9	4,699		4,648	0.184
10	5,283		5,232	0.207
11	5,867		5,817	0.230
12	6,452		6,401	0.253
13	7,036		6,985	0.276
14	7,620		7,569	0.299
15	8,204		8,153	0.322
16	8,788		8,738	0.345
17	9,373		9,322	0.368
18	9,957		9,906	0.391
19	10,541		10,490	0.414
20	11,125		11,074	0.437
21	11,709		11,659	0.460

Table 8 — Dimensions — Recorded tape format, 14 tracks interlaced on 25,4 mm (1 in) wide tape
(see figure 5)

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	1,40		1,14	0.050 ± 0.005
Track spacing (D)		1,778		0.070
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum(M_m)		0,279		0.011
Reference track location (G)	1,168		1,067	0.044 ± 0.002
Track location tolerance (H_n tolerance)	0,051		−0,051	± 0,002

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	1,829		1,727	0.070
3	3,607		3,505	0.140
4	5,385		5,283	0.210
5	7,163		7,061	0.280
6	8,941		8,839	0.350
7	10,719		10,617	0.420
8	12,497		12,395	0.490
9	14,275		14,173	0.560
10	16,053		15,951	0.630
11	17,831		17,729	0.700
12	19,609		19,507	0.770
13	21,387		21,285	0.840
14	23,165		23,063	0.910

Table 9 — Dimensions — Recorded tape format, 28 tracks interlaced on 25,4 mm (1 in) wide tape
(see figure 5)

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	0,660		0,610	0.025 ± 0.001
Track spacing (D)		0,89		0.035
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,229		0.009
Reference track location (G)	0,698		0,622	0.026 0 ± 0.001 5
Track location tolerance (H_n tolerance)	0,038		−0,038	± 0.001 5

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	0,927		0,851	0.035
3	1,816		1,740	0.070
4	2,705		2,629	0.105
5	3,594		3,518	0.140
6	4,483		4,407	0.175
7	5,372		5,296	0.210
8	6,261		6,185	0.245
9	7,150		7,074	0.280
10	8,039		7,963	0.315
11	8,928		8,852	0.350
12	9,817		9,741	0.385
13	10,706		10,630	0.420
14	11,595		11,519	0.455
15	12,484		12,408	0.490
16	13,373		13,297	0.525
17	14,262		14,186	0.560
18	15,151		15,075	0.595
19	16,040		15,964	0.630
20	16,929		16,853	0.665
21	17,818		17,742	0.700
22	18,707		18,631	0.735
23	19,596		19,520	0.770
24	20,485		20,409	0.805
25	21,374		21,298	0.840
26	22,263		22,187	0.875
27	23,152		23,076	0.910
28	24,041		23,965	0.924

Table 10 — Dimensions — Recorded tape format, 42 tracks interlaced on 25,4 mm (1 in) wide tracks
(see figure 5)

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	0,483		0,432	0.018 ± 0.001
Track spacing (D)		0,584		0.023
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,305		0.012
Reference track location (G)	0,737		0,660	0.027 5 ± 0.001 5
Track location tolerance (H_n tolerance)	0,025		−0,025	± 0.001

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	0,610		0,559	0.023
3	1,194		1,143	0.046
4	1,778		1,727	0.069
5	2,362		2,311	0.092
6	2,946		2,896	0.115
7	3,531		3,480	0.138
8	4,115		4,064	0.161
9	4,699		4,648	0.184
10	5,283		5,232	0.207
11	5,867		5,817	0.230
12	6,452		6,401	0.253
13	7,036		6,985	0.276
14	7,620		7,569	0.299
15	8,204		8,153	0.322
16	8,788		8,738	0.345
17	9,373		9,322	0.368
18	9,957		9,906	0.391
19	10,541		10,490	0.414
20	11,125		11,074	0.437
21	11,709		11,659	0.460
22	12,294		12,243	0.483
23	12,878		12,827	0.506
24	13,462		13,411	0.529
25	14,046		13,995	0.552
26	14,630		14,580	0.575
27	15,215		15,164	0.598
28	15,799		15,748	0.621
29	16,383		16,332	0.644
30	16,967		16,916	0.667
31	17,551		17,501	0.690
32	18,136		18,085	0.713
33	18,720		18,669	0.736
34	19,304		19,253	0.759
35	19,888		19,837	0.782
36	20,472		20,422	0.805
37	21,057		21,006	0.828
38	21,641		21,590	0.851
39	22,225		22,174	0.874
40	22,809		22,758	0.897
41	23,393		23,343	0.920
42	23,978		23,927	0.943

Table 11 — Dimensions — Recorded tape format, 84 tracks interlaced on 50,8 mm (2 in) wide tape
(see figure 5)

Dimension	mm			in
	max.	nom.	min.	
Track width (W)	0,483		0,432	0.018 ± 0.001
Track spacing (D)		0,584		0.023
Head spacing (S)				
Fixed heads	38,125		38,075	1.500 ± 0.001
Adjustable heads	38,151		38,049	1.500 ± 0.002
Edge margin, minimum (M_m)		0,711		0.028
Reference track location (G)	1,168		1,092	0.044 5 ± 0.001 5
Track location tolerance (H_n tolerance)	0,025		−0,025	± 0.001

Track number	Location for nth track (H_n)			
	mm			in
	max.	nom.	min.	
1 (reference)		0,000		0.000
2	0,610		0,559	0.023
3	1,194		1,143	0.046
4	1,778		1,727	0.069
5	2,362		2,311	0.092
6	2,946		2,896	0.115
7	3,531		3,480	0.138
8	4,115		4,064	0.161
9	4,699		4,648	0.184
10	5,283		5,232	0.207
11	5,867		5,817	0.230
12	6,452		6,401	0.253
13	7,036		6,985	0.276
14	7,620		7,569	0.299
15	8,204		8,153	0.322
16	8,788		8,738	0.345
17	9,373		9,322	0.368
18	9,957		9,906	0.391
19	10,541		10,490	0.414
20	11,125		11,074	0.437
21	11,709		11,659	0.460
22	12,294		12,243	0.483
23	12,878		12,827	0.506
24	13,462		13,411	0.529
25	14,046		13,995	0.552
26	14,630		14,580	0.575
27	15,215		15,164	0.598
28	15,799		15,748	0.621
29	16,383		16,332	0.644
30	16,967		16,916	0.667
31	17,551		17,501	0.690
32	18,136		18,085	0.713
33	18,720		18,669	0.736
34	19,304		19,253	0.759
35	19,888		19,837	0.782
36	20,472		20,422	0.805
37	21,057		21,006	0.828
38	21,641		21,590	0.851
39	22,225		22,174	0.874
40	22,809		22,758	0.897
41	23,393		23,343	0.920
42	23,978		23,927	0.943
43	24,562		24,511	0.966
44	25,146		25,095	0.989
45	25,730		25,679	1.012
46	26,314		26,264	1.035
47	26,899		26,848	1.058
48	27,483		27,432	1.081
49	28,067		28,016	1.104
50	28,651		28,600	1.127
51	29,235		29,185	1.150
52	29,820		29,769	1.173
53	30,404		30,353	1.196
54	30,988		30,937	1.219
55	31,572		31,521	1.242
56	32,156		32,106	1.265
57	32,741		32,690	1,288
58	33,325		33,274	1,311
59	33,909		33,858	1,334
60	34,493		34,442	1,357
61	35,077		35,027	1,380
62	35,662		35,611	1,403
63	36,246		36,195	1,426
64	36,830		36,779	1,449
65	37,414		37,363	1,472
66	37,998		37,948	1,495
67	38,583		38,532	1,518
68	39,167		39,116	1,541
69	39,751		39,700	1,564
70	40,335		40,284	1,587
71	40,919		40,869	1,610
72	41,504		41,453	1,633
73	42,088		42,037	1,656
74	42,672		42,621	1,679
75	43,256		43,205	1,702
76	43,840		43,790	1,725
77	44,425		44,374	1,748
78	45,009		44,958	1,771
79	45,593		45,542	1,794
80	46,177		46,126	1,817
81	46,761		46,711	1,840
82	47,346		47,295	1,863
83	47,930		47,879	1,886
84	48,514		48,463	1,909

5 Modes of recording

5.1 Direct recording (DR)

5.1.1 Bandwidths

5.1.1.1 Wavelengths on tape

For the purposes of this International Standard, four bandwidths are designated :

a) low-band DR : direct recording response to a minimum recorded wavelength of 15,2 µm (600 µin).

NOTE — For recording subcarrier bands above proportional bandwidth channel 18 or constant bandwidth channel 11 B, intermediate-band recorders are recommended (see 6.1.1 and 6.1.2).

b) intermediate band DR : direct recording response to a minimum recorded wavelength of 6 µm (240 µin);

c) wide-band 1,5 MHz DR : direct recording response to a minimum recorded wavelength of 2 µm (80 µin);

d) wide-band 2,0 MHz DR : direct recording response to a minimum recorded wavelength of 1,5 µm (60 µin).

NOTE — Interchange of tapes between wide-band DR and low- or intermediate-band DR machines is not recommended.

See B.1.1 for notes on extended wide-band DR recording.

5.1.1.2 Frequency response

The frequency response or passband of direct-recorded data as a function of tape speed is given in table 12. In measuring this response, signals throughout the specified pass-band shall be recorded at normal record level (see 5.1.3.4) and the reproduce output signal levels shall be referenced to the playback output at the record level set frequency. See A.3.2 for a recommended test procedure.

5.1.2 Bias

5.1.2.1 Wavelength

The high-frequency bias signal shall have a wavelength on tape not greater than the following :

DR band	Maximum bias wavelength µm (µin)
Low Intermediate }	1,6 (60)
Wide-band 1,5 MHz	0,6 (24)
Wide-band 2,0 MHz	0,45 (18)

5.1.2.2 Current

With an input signal at the record bias set frequency (see table 12) and at a level 5 to 6 dB below normal record level (see 5.1.3.4), the record bias current shall be adjusted for maximum reproduced output and then increased until the output falls by the following amounts :

DR band	Fall in output for optimum bias (overbias) dB
Low	3
Intermediate	3
Wide-band 1,5 MHz	1
Wide-band 2,0 MHz	2

See A.3.1 for a recommended test procedure.

5.1.3 Record parameters

5.1.3.1 Input impedances at all frequencies in the low- and intermediate-bands shall be 5 000 Ω minimum resistance shunted by 250 pF maximum, with or without meter. Input impedances for wide-band recorders shall be 75 Ω ± 10 % across the specified band.

5.1.3.2 Adjustments shall be provided to enable normal record level to be produced by input signals in the range 1 to 10 V peak-to-peak.

5.1.3.3 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 only for loss of record head efficiency with frequency. For the test described in A.3.9 (or equivalent), the difference in the response curves normalized to the 0,02 upper bandedge frequency shall be no greater than the figures given below :

Fraction of upper band edge frequency	Difference dB
0,1	0,5
0,5	1,0
0,8	1,6
1,0	2,0

It should be noted that the procedure above does not establish a uniform recorded flux density on the tape for different heads, see B.4 for further comments.

5.1.3.4 The level of recording shall be set at such a value that a reproduced signal of the record level set frequency indicated in table 12 measured at the output of the playback amplifier under the load specified in 5.1.4.2 shall contain 1 % third harmonic distortion after correction for allowable equalization variations (− 40 ± 1) dB referred to the output of a frequency three times the record level set frequency, recorded at normal record level; such distortion is a function of tape saturation, and not a function of record or reproduce amplifier characteristics. This level, the normal record level, is the 0 dB reference level for all other measurements. (See A.3.1 for a recommended test procedure).

5.1.3.5 Record head gap length for wideband recording shall be within the range from 1,65 µm (65 µin) to 2,7 µm (105 µin).

NOTE — In recording complex telemetry signals with varying crest factors, optimum record level should be determined for the particular signal to be recorded. See B.3.

5.1.4 Reproduce parameters

5.1.4.1 Output impedances for low- and intermediate-band recording shall be 100 Ω maximum across the pass bands specified in table 12. Output impedances for wide-band recorders shall be 75 Ω maximum across the specified pass band.

5.1.4.2 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 for low-band and intermediate-band recorders shall be a minimum of 3 V peak-to-peak with a third harmonic distortion of 1 % and a maximum second harmonic distortion of 0,5 % when measured across a resistive load of 600 Ω ± 10 % shunted by a maximum of 1 500 pF. The output level for wide-band recorders shall be a minimum of 2 V peak-to-peak with a third-harmonic distortion of 1 % and a maximum second harmonic distortion of 0,5 % when measured across 75 Ω ± 10 %. Lack of proper output termination shall not cause the reproduce amplifier to oscillate.

5.1.5 Other system parameters

A number of other parameters affecting system performance, such as signal-to-noise ratio, crosstalk etc., are not specified in this International Standard since requirements depend on the intended application, but recommended test methods for measuring such parameters are given in A.3.3 to A.3.8.

5.2 Single-carrier frequency modulation recording (FM)

5.2.1 Bandwidths

5.2.1.1 Wavelengths on tape

For the purposes of this International Standard, four bandwidths are designated :

a) low-band FM : carriers at centre frequency having a nominal recorded wavelength on the tape of 28,2 µm (1 110 µin);

b) intermediate-band FM : carriers at centre frequency having a nominal recorded wavelength on tape of 14,1 µm (555 µin);

c) wide-band I FM : carriers at centre frequency having a nominal recorded wavelength on tape of 7,1 µm (278 µin);

d) wide-band II FM : carriers at centre frequency having a nominal recorded wavelength on the tape of 3,4 µm (133 µin).

5.2.1.2 Frequency response

The FM carrier frequencies and data signal pass-bands (modulating frequencies) as a function of tape speed are given in table 13. See A.4.2 a) and A.4.3 for recommended test methods.

5.2.2 Carrier deviations

[See A.4.2 b) for a recommended test method.]

5.2.2.1 General

For low-band, intermediate-band, and wide-band I recording, the fullscale FM carrier deviation shall be ± 40 %.

For wide-band II recording, the fullscale FM carrier deviation shall be ± 30 %.

5.2.2.2 Effect of voltage on frequency

Increasing positive voltage shall give increasing frequency (but see 5.4).

5.2.3 Record characteristics

Single-carrier FM records may employ either direct-recording (see 5.1) or recording without bias (see 5.3) techniques.

5.2.4 Other system parameters

A number of other parameters affecting system performance, such as signal-to-noise ratio, linearity and drift etc., are not specified in this International Standard since requirements depend on the intended application, but recommended test methods for measuring such parameters are given in A.4.4 to A.4.10.

5.3 Recording without bias

5.3.1 General

In single-carrier FM recording, and pulse-code modulation (PCM) when the pulse stream is recorded directly on tape and not as a modulated FDM sub-carrier, information is not contained in the amplitude of the reproduced signal and a linear amplitude transfer function as provided by direct recording is not essential. Saturation recording without high-frequency bias is therefore permissible. The record signal level (see below) is higher than in direct recording, a higher reproduce head output level is obtained and the need for generating a high-frequency bias signal is avoided; however, guard tracks may be required when saturation and direct recordings are being made on the same head [see also 5.3.8 c)].

5.3.2 Optimum record level

Except at long recorded wavelengths, the reproduce head output level does not increase asymptotically to a maximum as the record level is increased, but reaches a peak and then falls again. As the recorded wavelength becomes shorter, the record level for peak output falls and the output falls more rapidly at record levels below and above that giving peak output. The procedures for setting optimum record level are as follows :

a) For single-carrier FM recording the optimum record level is that which gives a maximum reproduce head output for a recorded wavelength equal to that of the carrier at the upper end of its frequency deviation range (carrier plus deviation is given in table 13).

b) For PCM recording the same principle applies except that maximum output is determined at the maximum flux transition rate applicable to the bit representation.

5.4 Predetection recording

Predetection signals consist of frequency-modulated (or phase-modulated) intermediate-frequency (IF) carriers which have been translated in frequency to be compatible with wide-band DR recorder frequency response. These signals shall be recorded by direct recording. Parameters for predetection signals are given in table 14.

Because of the translation technique employed, the deviation direction (see 5.2.2.2) is reversed from the original modulation. Care shall therefore be exercised when interchanging predetection tapes with other tapes.

5.5 Timing signal recording

When recording modulated time-code signals, care shall be taken to ensure that low-frequency response down to 100 Hz is provided. For low-band DR recorders direct-record response down to 100 Hz is available but the low-frequency cutoff of wide-band DR recorders (and intermediate band DR recorders at the higher tape speeds) exceeds 100 Hz (see table 12). For systems using these recorders it is recommended that the time-code signals be recorded on a single-carrier FM track or on an FM subcarrier; in the latter case the highest subcarrier available should be used to minimize time delay.

5.6 Tape speed correction and flutter compensation

5.6.1 Types of control signals

Two types of sinusoidal speed-control signals are designated in this International Standard : amplitude-modulated and constant-amplitude, and either may be specified by a user; however, the constant-amplitude method is recommended for all applications where the appropriate hardware can be made available. Constant-amplitude signals may also be used for flutter compensation if required.

5.6.2 Amplitude-modulated speed-control signal

This shall have the following characteristics :

Carrier frequency	17,0 kHz ± 0,5 %
Bandwidth required	16,5 kHz to 17,5 kHz
Percentage modulation	45 to 55 %
Modulating frequency	60 Hz ± 0,01 %

In single-carrier FM recording, a separate track is always required for the speed-control signal. In multiple-carrier FM recording (see 6.1), the speed-control signal may be mixed with subcarriers on the same track, but shall be recorded 10 ± 0,5 dB below normal record level.

Proportional-bandwidth channel A or constant-bandwidth channel 1A cannot be used on the same track as the speed-control signal because they may interfere with the control signal. When recorded on a separate track, the amplitude-modulated speed-control signal shall be recorded at normal record level (see 5.1.3.4).

5.6.3 Constant-amplitude speed-control signal

Table 15 lists constant-amplitude speed-control signal frequencies as a function of tape speed. In single-carrier FM recording, a separate track is always required for the speed-control signal. In other types of recording, speed-control signals may be mixed with other signals if recording requirements so demand and system performance permits; table 15 shows the guard band about each signal frequency which shall be left free of other signals in order to give proper operation.

Mixing of the speed-control signal with certain types of signal may degrade system performance. When using high performance servo systems, signals higher than the control signal frequency should not be mixed with the control signal. The level of individual extraneous signals, including spurious harmonics and noise, shall be 40 dB or more below the level of the speed-control signal. For optimum servo speed correction, constant amplitude speed-control signals should be on a separate track.

For use on the same track as multiple-carrier FM subcarriers (see 6.1), the criteria given in table 16 apply to the speed-control signal (reference frequency).

5.6.4 Track allocation

Tape-speed correction and flutter compensation signals shall be recorded on the tracks defined in table 17.

Table 12 — Direct-record parameters

Tape speed mm/s	(in/s)	± 3 dB pass-band[1)] Hz	Record bias set frequency[2)] tolerance ± 10 % kHz	Record level set frequency tolerance ± 10 % kHz
Low-band DR				
1 524	(60)	100 — 100 000	100	10
762	(30)	100 — 50 000	50	5
381	(15)	100 — 25 000	25	2,5
190,5	(7 1/2)	100 — 12 000	12	1,2
95,2	(3 3/4)	100 — 6 000	6	0,6
47,6	(1 7/8)	100 — 3 000	3	0,3
23,8	(15/16)	100 — 1 500	1,5	0,15
Intermediate band DR				
3 048	(120)	300 — 500 000	500	50
1 524	(60)	300 — 250 000	250	25
762	(30)	200 — 125 000	125	12,5
381	(15)	100 — 60 000	60	6,0
190,5	(7 1/2)	100 — 30 000	30	3,0
95,2	(3 3/4)	100 — 15 000	15	1,5
47,6	(1 7/8)	100 — 7 500	7,5	0,75
23,8	(15/16)	100 — 3 800	3,8	0,38
Wide-band 1,5 MHz DR				
3 048	(120)	400 — 1 500 000	1 500	150
1 524	(60)	400 — 750 000	750	75
762	(30)	400 — 375 000	375	37,5
381	(15)	400 — 187 000	187	18,7
190,5	(7 1/2)	400 — 93 000	93	9,3
95,2	(3 3/4)	400 — 46 000	46	4,6
47,6	(1 7/8)	400 — 23 000	23	2,3
23,8	(15/16)	400 — 11 500	11,5	1,15
Wide-band 2,0 MHz DR[3)]				
3 048	(120)	400 — 2 000 000	2 000	200
1 524	(60)	400 — 1 000 000	1 000	100
762	(30)	400 — 500 000	500	50
381	(15)	400 — 250 000	250	25
190,5	(7 1/2)	400 — 125 000	125	12,5
95,2	(3 3/4)	400 — 62 500	62,5	6,25
47,6	(1 7/8)	400 — 31 250	31,2	3,12
23,8	(15/16)	400 — 15 625	15,6	1,56

1) Pass-band response reference is the output as the record level set frequency.

2) Procedures for setting optimum bias current are given in 5.1.2.2.

3) Some recorders provide 4,0 MHz DR sine wave capability at 6 069 mm/s (240 in/s) with ± 3 dB bandwidth 800 Hz to 4 MHz. The bias set frequency is 4 MHz and the record level set frequency is 400 kHz.

Table 13 — Single-carrier FM record parameters

Tape speed mm/s (in/s)			Carrier centre frequency	Carrier deviation limits		Modulating frequency	Response at band limits[1)]
Low-band FM	Intermediate-band FM	Wide-band I FM	kHz	Carrier plus deviation kHz	Carrier minus deviation kHz	kHz	dB
		3 048 (120)	432,0	604,8	259,2	0 to 80,00	± 1
	3 048 (120)	1 524 (60)	216,0	302,4	129,6	0 to 40,00	± 1
3 048 (120)	1 524 (60)	762 (30)	108,0	151,2	64,80	0 to 20,00	± 1
1 524 (60)	762 (30)	381 (15)	54,00	75,60	32,40	0 to 10,00	± 1
762 (30)	381 (15)	190,5 (7 1/2)	27,00	37,80	16,20	0 to 5,000	± 1
381 (15)	190,5 (7 1/2)	95,2 (3 3/4)	13,50	18,90	8,100	0 to 2,500	± 1
190,5 (7 1/2)	95,2 (3 3/4)	47,6 (1 7/8)	6,750	9,450	4,050	0 to 1,250	± 1
95,2 (3 3/4)	47,6 (1 7/8)	23,8 (15/16)	3,375	4,725	2,025	0 to 0,625	± 1
47,6 (1 7/8)	23,8 (15/16)		1,688	2,363	1,012	0 to 0,313	± 1
23,8 (15/16)			0,844	1,181	0,506	0 to 0,156	± 1
		Wide-band II FM					
		6 096 (240)	1 800,0	2 340,0	1 260 0	0 to 800,0	+1 − 3
		3 048 (120)	900,0	1 170,0	630,0	0 to 400,0	+ 1 − 3
		1 524 (60)	450,0	585,00	315,00	0 to 200,0	+ 1 − 3
		762 (30)	225,0	292,50	157,50	0 to 100,0	+ 1 − 3
		381 (15)	112,50	146,25	78,750	0 to 50,00	+ 1 − 3
		190,5 (7 1/2)	56,250	73,125	39,375	0 to 25,00	+ 1 − 3
		95,2 (3 3/4)	28,125	36,562	19,688	0 to 12,50	+ 1 − 3
		47,6 (1 7/8)	14,062	18,381	9,844	0 to 6,25	+ 1 − 3

1) Frequency response referred to 1 kHz output for FM channels 13,5 kHz and above, and 100 Hz for channels below 13,5 kHz.

Table 14 — Predetection carrier parameters

Tape speed mm/s (in/s)	Predetection carrier centre frequency kHz	Recommended predetection record/playback pass-band kHz
6 096 (240)	1 800	200 to 3 000
3 048 (120)	900	100 to 1 500
1 524 (60)	450	50 to 750
762 (30)	225	25 to 375
381 (15)	112,5	12,5 to 187,5

Table 15 — Constant-amplitude speed-control signals

Tape speed mm/s (in/s)	Frequency kHz	Minimum guard-band Hz
6 096 (240)	400 ± 0,01 %	—
3 048 (120)	200 ± 0,01 %	± 13 950
1 524 (60)	100 ± 0,01 %	± 10 500
762 (30)	50 ± 0,01 %	± 2 500
381 (15)	25 ± 0,01 %	± 2 000
190,5 (7 1/2)	12,5 ± 0,01 %	± 2 000
95,2 (3 3/4)	6,25 ± 0,01 %	± 2 000
47,6 (1 7/8)	3,125 ± 0,01 %	± 2 000
23,8 (15/16)	1,562 ± 0,01 %	± 2 000

Table 16 — Reference signal usage with multiple-carrier FM subcarriers
(reference and data signals on same track)

Reference frequency kHz	Subcarrier usage (see also 6.1)
240 ± 0,01 %1)	For use with all centre frequencies
200 ± 0,01 %	For use with all centre frequencies except channel H
100 ± 0,01 %	Use with centre frequencies up to and including 80 kHz
50 ± 0,01 %	Use with centre frequencies up to and including 40 kHz except channel C
25 ± 0,01 %	Use with centre frequencies up to and including 16 kHz
12,5 ± 0,01 %	Use with centre frequencies up to and including 7,35 kHz
6,25 ± 0,01 %	Use with centre frequencies up to and including 3,9 kHz
3,125 ± 0,01 %	Use with centre frequencies up to and including 0,960 kHz

1) For flutter compensation only, not for tape speed-control.

Table 17 — Allocation of tracks for tape-speed correction and flutter compensation signals

Track configuration (table number)	Track number for tape-speed correction and flutter compensation signal	Optional additional track number
3	2	—
4	4	5
5	4	5
6	7	8
7	11	12
8	7	8
9	13	14
10	21	22
11	TBD	TBD

6 Modulation patterns

6.1 Multiple-carrier FM recording (frequency-division multiplexing)

6.1.1 Proportional-bandwidth subcarrier channels

Table 18 lists 29 FM proportional-bandwidth subcarrier channels. The channels identified with letters permit ± 15 % subcarrier deviation rather than ± 7,5 % deviation, but use the same centre frequencies as the eight highest numbered channels; table 18 defines limitations on combinations of channels which may be used. The channels shall be used within the limits of maximum subcarrier deviation.

6.1.2 Constant-bandwidth subcarrier channels

Table 19 list 36 FM constant-bandwidth subcarrier channels. The letters A, B and C identify the channels for use with maximum subcarrier deviations of ± 2 kHz, ± 4 kHz and ± 8 kHz respectively, along with maximum frequency responses of 2 kHz, 4 kHz and 8 kHz respectively. The channels shall be used within the limits of maximum subcarrier deviation.

6.1.3 Subcarrier channel spacing

There is a ratio of approximately 1,33 to 1 between the centre frequencies of adjacent ± 7,5 % proportional bandwidth channels except between 14,5 kHz and 22 kHz where a larger gap is left to provide a 60 Hz amplitude-modulated 17 kHz carrier for tape speed control (see 6.1.4). The use of an additional FM subcarrier between 14,5 kHz and 22 kHz is not permissible. Combinations of both proportional-bandwidth and constant-bandwidth channels may be used, provided that adequate allowance is made for guard-bands.

6.1.4 Tape speed correction and flutter compensation

Tape speed correction and flutter compensation for multiple-carrier FM formats may be accomplished as indicated in 5.6. Use of the standard reference frequency shall be in accordance with the criteria of table 16 when the reference signal is mixed with data.

6.1.5 Recording mode

Direct recording shall always be used for recording multiple-carrier FM signals, since a non-linear transfer function will result in the generation of unwanted harmonics of the carrier frequencies.

6.1.6 Subcarrier tests

Recommended test methods are given in A.7.

6.1.7 Information for users

Applications notes and a discussion of performance tradeoffs will be found in annex E.

6.2 PAM recording

6.2.1 General

Pulse-amplitude modulated (PAM) waveforms, the characteristics of which are specified herein, consist of time-division multiplexed pulses whose amplitudes represent samples of analogue-variable parameters. For transmission, PAM waveforms may be used either to frequency modulate radio-frequency carriers directly (PAM/FM) or to modulate multiple-carrier FM subcarriers (PAM/FM/FM). For recording, the waveforms may be used to modulate multiple-carrier FM subcarriers or single-carrier FM carriers. PAM waveforms are not recorded directly on magnetic tape.

6.2.2 Waveform structure

6.2.2.1 Minor frame length

The PAM waveform consists of a sequence of minor frames (see figure 2), each of which comprises a constant number of time-sequenced channel intervals or time-slots. The maximum minor frame length shall be 128 channel time intervals or time-slots, including the intervals devoted to synchronization and calibration. The pulse and minor frame structure shall conform to either figure 6 or 7.

6.2.2.2 Commutation pattern

The information channels are allotted equal and constant time intervals within the PAM minor frame. Each interval or time-slot ("T" in figures 6 and 7) contains a sample pulse commencing at the start of the interval and having amplitude determined by the corresponding measurement and according to a fixed relationship (usually linear) between the minimum level (zero amplitude) and the maximum level (full-scale amplitude). For 50 % duty cycle (RZ-PAM), the zero level shall be 20 % of full amplitude level as shown in figure 6. The pulse width shall be the same in all time intervals (the intervals devoted to synchronization excepted). The duration shall be either 0,5 T ± 0,05 T, as shown in figure 6 or T ± 0,05 T, as shown in figure 7.

6.2.2.3 Calibration

It is recommended that calibration pulses of known level be inserted into each minor frame to permit the removal of scale and offset errors. Channels 1 and 2, immediately following the minor frame synchronization interval, shall be used for zero-and full-scale calibration, respectively.

6.2.2.4 Minor frame synchronization interval

Each minor frame shall be identified by the presence within it of a synchronization pattern :

a) 50 % duty factor (RZ-PAM). The synchronization pattern shall have a duration equal to two information channel intervals (2 T) and shall be full-scale amplitude for 1,5 T followed by the reference level for 0,5 T (see figure 6).

b) 100 % duty factor (NRZ-PAM). The synchronization pattern shall be, in the order given, zero level for a period T, full-scale amplitude for a period 3 T, and a level not exceeding 50 % full-scale amplitude for a period T (see figure 7).

6.2.3 Pulse and minor frame rate

6.2.3.1 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 (i.e. twice maximum pulse rate for 50 % duty factor) shall be not greater than one-fifth of the total (peak-to-peak) deviation specified in table 18 or 19 for the FM subcarrier selected.

b) PAM/FM (only applicable to radio-frequency telemetry systems). The reciprocal of the shortest interval between transitions in the PAM pulse train (i.e. twice maximum pulse rate for 50 % duty factor) shall be limited by whichever is the narrower of the following :

— One-half of the frequency for 3 dB attenuation of the premodulation filter, when employed (see 6.2.7).

— One-fifth of the intermediate frequency (IF) bandwidth (3 dB points) selected from the bandwidths listed in table 20.

6.2.3.2 Minor frame rate

The minor frame rate and pulse-rate values listed below may be used in any combination :

a) the minor frame rate shall be equal to or greater than 0,125 frames per second;

b) the minor frame rate shall be no greater than that corresponding to the maximum pulse rate specified in 6.2.3.1.

6.2.4 Accuracy and stability

6.2.4.1 Long term

During the period of desired data, the time between the occurrence of corresponding points in any two successive minor frame synchronization patterns shall not differ from the reciprocal of the specified nominal minor frame rate by more than 5 % of the nominal period.

6.2.4.2 Short term

During a measured period, P, for the occurrence of 1 000 channel intervals or time-slots, 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 $T_{ave} = P/1\,000$ by more than 1 % of the average interval.

6.2.5 Multiple and submultiple sampling

6.2.5.1 General

Data sampling at rates which are multiples and submultiples of the minor frame rate (supercommutation and subcommutation respectively as defined in 3.42 and 3.43 is permissible.

6.2.5.2 Submultiple frame synchronization

The beginning of the longest submultiple frame interval (equal to the major frame interval) shall be identified by the transmission of a synchronization pattern within the identified submultiple frame. All other submultiple frames shall have a fixed and known relationship to the identified submultiple frame. The following submultiple frame interval synchronization patterns shall be used :

a) 50 % duty factor RZ : a full-scale amplitude pulse in two successive minor frames of the same channel interval (time-slot) as that allocated to data channels of the identified submultiple frame, for example, channels 6-1 and 6-2 in figure 2. 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) 100 % duty factor (NRZ) : the presence of synchronization information in five successive minor frames of the same channel interval (time-slot) as that allocated to data channels of the identified submultiple frame, for example, channels 6-1 to 6-5 in figure 2. The amplitude of the data channels assigned for synchronization shall be as follows :

1) First minor frame — zero amplitude, for example, channel 6-1.

2) Second, third and fourth minor frames — full-scale amplitude, for example, channels 6-2 to 6-4.

3) Fifth minor frame — not more than 50 % of full-scale amplitude, for example, channel 6-5.

6.2.5.3 Maximum submultiple frame (major frame) interval

The interval of any submultiple frame, including the time devoted to synchronizing information, shall not exceed 128 times the interval of the minor frame in which it occupies a recurring position (i.e. the major frame length shall not exceed 128 times the minor frame length).

6.2.6 Frequency modulation

The maximum and minimum amplitude of a PAM waveform shall produce equal and opposite modulation frequency deviations about the assigned carrier or subcarrier frequency. The deviation shall be the same for all occurrences of the same level.

6.2.7 Premodulation filtering

Premodulation filtering is recommended to control the spectral occupancy of the modulated output signal. The filter shall be designed to provide maximally linear phase response and the amplitude response shall have an asymptotic negative slope at high frequencies corresponding to at least 36 dB per octave.

6.2.8 PAM test methods

The values of the modulation parameters recommended in this standard can be measured by oscilloscopic or oscillographic means. Recommended system test methods are given in A.5 (to be added).

6.3 PCM recording

6.3.1 General

Pulse-code modulation (PCM) data, the characteristics of which are specified herein, shall be transmitted or recorded as serial binary-coded time-division multiplexed words, most significant bit first (where applicable).

6.3.2 Word and minor frame structure

6.3.2.1 General

The PCM minor frame shall contain a known number of bit intervals, all of equal duration unless specially assigned identification bits within the bit stream are employed to indicate a change. The duration of the bit interval and the number of bit intervals per minor frame shall remain fixed from frame to frame.

NOTE — The definitions in 3.11, 3.12, 3.13, 3.42, 3.43 and 3.50 relate to words (see 6.3.2.4) or groups of bits, each of which is located within a time-slot or channel interval.

6.3.2.2 Minor frame length

The length of a minor frame shall not exceed 8 192 bit intervals, including intervals devoted to synchronization.

6.3.2.3 Minor frame synchronization

Frame synchronization information consists of a digital word not longer than 33 bits in consecutive bit intervals within the minor frame. Recommendations concerning synchronization are given in D.2.

6.3.2.4 Word length

Individual words shall not be less than 4 bits nor more than 64 bits in length but it is suggested that word lengths be chosen to be integral multiples of 8 bits. Within these limits, words of different length may be multiplexed in a single minor frame. However, the length of a word in any position within a minor frame shall be consistent from frame to frame, except during changes caused by special identification bits appearing in a bit stream.

6.3.2.5 Special words

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

6.3.3 PCM bit representations

Only one bit representation shall be used in a single PCM pulse train. The following conventions for representing binary "one" and "zero" are permissible (see figure 1 for graphic and verbal definitions).

NRZ-L **NRZ-M** NRZ-S **BI-Φ-L**
BI-Φ-M BI-Φ-S

NOTE — Bold representations are preferred, the other two are obsolescent and may be deleted in future revisions of this International Standard.

Other bit representations may be used with the agreement of interchange parties.

6.3.4 Minimum and maximum bit rates

6.3.4.1 Minimum bit rate

The minimum bit rate shall be one per second.

6.3.4.2 Maximum bit rate

a) PCM/FM/FM. The reciprocal of twice the shortest period between transitions in the PCM bit stream shall not exceed the maximum frequency response for the chosen subcarrier channel (see tables 18 and 19).

b) PCM/FM (only applicable to radio-frequency telemetry systems). The maximum bit rate is limited by the available system bandwidth and the selected bit representation. Receiver intermediate frequency (IF) bandwidth shall be selected from table 20. See also additional information in D.1.

6.3.5 Accuracy and stability

6.3.5.1 Long-term

During any period of desired data, the bit rate shall not differ from the specified nominal bit rate by more than 1 % of the nominal rate.

6.3.5.2 Short-term (bit jitter)

Any transition in the PCM waveform occurring within an interval P shall occur within 0,1 bit period of the time at which the 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 minor frames; i.e.

$$\text{Average bit period} = \frac{P}{\text{specified bits/frame}} \times \frac{1}{5}$$

6.3.6 Multiple and submultiple sampling

6.3.6.1 General

Data sampling at rates which are multiples and submultiples of the minor frame rate (supercommutation and subcommutation respectively as defined in 3.42 and 3.43 is permissible. When submultiple sampling is employed, the restrictions on minor frame length (see 6.3.2.2) and bit jitter (see 6.3.5.2) are also applicable to the submultiple frames, i.e. the length of the longest submultiple frame (words 6-1 to 6-N in figure 2) shall not exceed 2 048 bits (but see also 6.3.6.3) and for bit jitter the interval P shall be the measured time for five successive minor frames (five successive channel intervals within the submultiple frame, for example, words 6-1 to 6-5 in figure 2).

6.3.6.2 Submultiple frame synchronization

The beginning of the longest submultiple frame interval (equal to the major 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 frame. It is recommended that one of the following alternative methods be used for submultiple frame synchronization :

a) The beginning of a submultiple frame may be identified by a unique digital word in one minor frame, occupying the same word or channel interval (time-slot) as that allocated to data words of the identified submultiple frame, for example, word 6-1 in figure 2.

b) The beginning of a submultiple frame may be identified by a unique digital word replacing the minor frame synchronization word indicating the start of the submultiple sequence. For example, the minor frame synch words in figure 2 occupy time-slot n in each minor frame, and that in one minor frame, say N, is changed to identify the longest submultiple frame or major frame interval. The complement of the minor frame synch word is often used for this purpose.

c) Each word within the identified submultiple frame may be separately identified by the addition of identification bits to indicate the position of that word within the submultiple frame sequence, for example, bits may be added to each word in the sequence 6-1 to 6-N in figure 2.

6.3.6.3 Maximum submultiple frame (major frame) interval

The interval of any submultiple frame, including the time devoted to synchronizing of channel identification information, shall not exceed 256 times the interval of the minor frame in which it occupies a recurring position (i.e. the major frame length shall not exceed 256 times the minor frame length).

6.3.7 Premodulation filtering (not applicable when PCM waveforms are recorded directly on magnetic tape)

Premodulation filtering is recommended to control the spectral occupancy of the modulated output signal. The characteristics of the filter shall be as defined in 6.2.7.

6.3.8 PCM record characteristics

a) It is recommended that the bits forming a word or sample in a PCM pulse train be recorded serially on a magnetic tape track. Where the bits in a word represent a single sample of an input channel, the most significant bit shall occur first.

b) The inclusion of a word parity bit is optional; if included, it shall provide overall odd parity in the word and shall be the last bit in the word.

c) The pulse train may be recorded as a modulating input to a carrier (in radio-frequency telemetry systems this may be a predetection recording of a PCM/FM format or a remodulation by a post-detection signal), or recorded directly on tape using either direct recording (see 5.1) or recording without bias (see 5.3) techniques. If recording without bias (saturation recording) is used, guard tracks may be required between a saturated track and any adjacent direct record track so as to minimize crosstalk from the saturated recording.

d) When PCM signals are recorded directly on tape, provision must be made for the lack of reproduce low frequency response, for example, by constraining NRZ formats to ensure an adequate number of flux transitions, or by using a bi-phase format (see 6.3.3).

These techniques relate to longitudinal packing densities up to about 400 bits/mm (10 000 bits/in). See B.1.2 for comments on the use of higher packing densities.

6.3.9 PCM system tests

Recommended system test methods are given in A.6.

Table 18 — Proportional-bandwidth FM subcarrier channels

Channel	± 7,5 % channels						
	Centre frequency Hz	Lower deviation limit[1)] Hz	Upper deviation limit[1)] Hz	Nominal frequency response Hz	Nominal rise time Hz	Maximum frequency response[2)] Hz	Minimum rise time[2)] 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	886	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	0,864
11	7 350	6 799	7 901	110	3,2	551	0,635
12	10 500	9 712	11 288	160	2,2	788	0,444
13	14 500	13 412	15 588	220	1,6	1 088	0,322
14	22 000	20 350	23 650	330	1,1	1 650	0,212
15	30 000	27 750	32 250	450	0,78	2 250	0,156
16	40 000	37 000	43 000	600	0,58	3 000	0,117
17	52 500	48 562	56 438	790	0,44	3 938	0,089
18	70 000	64 750	75 250	1 050	0,33	5 250	0,067
19	93 000	86 025	99 975	1 395	0,25	6 975	0,050
20	124 000	114 700	133 300	1 860	0,19	9 300	0,038
21	165 000	152 624	177 375	2 475	0,14	12 375	0,029
Channel	± 15 % channels[3)]						
A	22 000	18 700	25 300	660	0,53	3 330	0,106
B	30 000	25 500	34 500	900	0,39	4 500	0,078
C	40 000	34 000	46 000	1 200	0,29	6 000	0,058
D	52 500	44 625	60 375	1 575	0,22	7 875	0,044
E	70 000	59 500	80 500	2 100	0,17	10 500	0,033
F	93 000	79 050	106 950	2 790	0,13	13 950	0,025
G	124 000	105 400	142 600	3 720	0,09	18 600	0,018
H	165 000	140 250	189 750	4 950	0,07	24 750	0,014

1) Rounded off to nearest hertz.

2) 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.

3) Channels A to 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 19 — Constant-bandwidth FM subcarrier channels

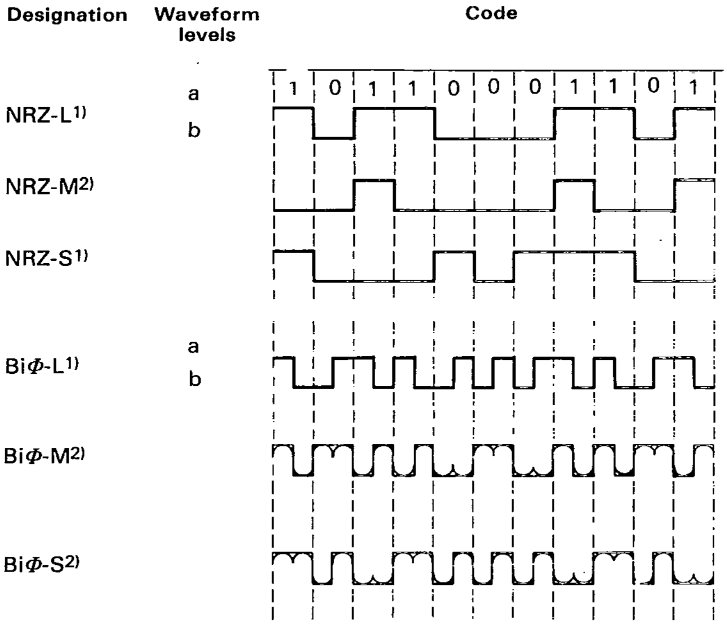
A channels		B channels		C channels	
Deviation limits = ± 2 kHz Nominal frequency response = 0,04 kHz Maximum frequency response = 2 kHz[1)]		Deviation limits = ± 4 kHz Nominal frequency response = 0,8 kHz Maximum frequency response = 4 kHz[1)]		Deviation limits = ± 8 kHz Nominal frequency response = 1,6 kHz Maximum frequency response = 8 kHz[1)]	
Channel	**Centre frequency** kHz	**Channel**	**Centre frequency** kHz	**Channel**	**Centre frequency** kHz
1A	16				
2A	24				
3A	32	**3B**	32	**3C**	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		

1) The indicated maximum frequency is based upon the maximum theoretical response that can be obtained in a bandwidth between deviation limits specified for the channel.

Table 20 — Receiver intermediate frequency bandwidths (3 dB)

12 500 Hz[1)]
25 000 Hz[1)]
50 000 Hz[1)]
100 000 Hz
300 000 Hz
500 000 Hz
750 000 Hz
1 000 000 Hz
1 500 000 Hz
3 300 000 Hz

1) System instabilities may limit the use of these bandwidths



NRZ-L[1)]: Non-Return-to Zero Level [or NRZ Change (NRZ-C)]
"One" is represented by level "a".
"Zero" is represented by the level "b".

NRZ-M[2)]: Non-Return-to-Zero Mark
"One" is represented by a change in level at the beginning of the bit period.
"Zero" is represented by no change in level.

NRZ-S[1)]: Non-Return-to-Zero Space
"One" is represented by no change in level.
"Zero" is represented by a change in level at the beginning of the bit period.

BiΦ-L[1)]: Bi-Phase Level [or Split Phase, Manchester II ± π rad (180°)]
"One" is represented by levels a, b within a bit period.
"Zero" is represented by levels b, a within a bit period.

BiΦ-M[2)]: Bi-Phase Mark
A transition occurs at the beginning of every bit period.
"One" is represented by a mid-bit level change.
"Zero" is represented by no mid-bit level change.

BiΦ-S[2)]: Bi-Phase Space
A transition occurs at the beginning of every bit period.
"One" is represented by no mid-bit level change.
"Zero" is represented by a mid-bit level change.

NOTES

1) In NRZ-L and Bi-phase-L formats it is not essential to define the sense of the waveform; levels "a" and "b" may be positive or negative at the users' discretion. However, the following voltage convention is recommended for use wherever possible; "a" always positive, "b" zero or negative, "sampling" or "data ready" pulse positive. Level "a" should always correspond to logic "1" and level "b" to logic "0" in digital equipment.

2) Since only transitions are significant for NRZ-M, NRZ-S, BiΦ-S and BiΦ-M, waveform levels need not be identified. Voltage levels for equipment interfacing shall be determined by the interchange parties.

Figure 1 — PCM definitions

Time-slot numbers in each minor frame

Frame numbers in each major minor frame	1	2	3	4	5	6	7	8	9	10		*n*-4	*n*-3	*n*-2	*n*-1	*n*
1	1	2	3-1	4	5	6-1	7	8	1	9-1	Sub-commutation					
2	1	2	3-2	4	5	6-2	7	8	1	9-2						
3	1	2	3-1	4	5	6-3	7	8	1	9-3						
4	1	2	3-2	4	5	6-4	7	8	1	9-4						
5	1	2	3-1	4	5	6-5	7	8	1	9-1						
6	1	2	3-2	4	5	6-6	7	8	1	9-2						
N-4	1	2	3-2	4	5	6-(*N*-4)	7	8	1	9-4						
N-3	1	2	3-1	4	5	6-(*N*-3)	7	8	1	9-1						
N-2	1	2	3-2	4	5	6-(*N*-2)	7	8	1	9-2						
N-1	1	2	3-1	4	5	6-(*N*-1)	7	8	1	9-3						
N	1	2	3-2	4	5	6-*N*	7	8	1	9-4						

Supercommutation (time-slots 1 and 9)

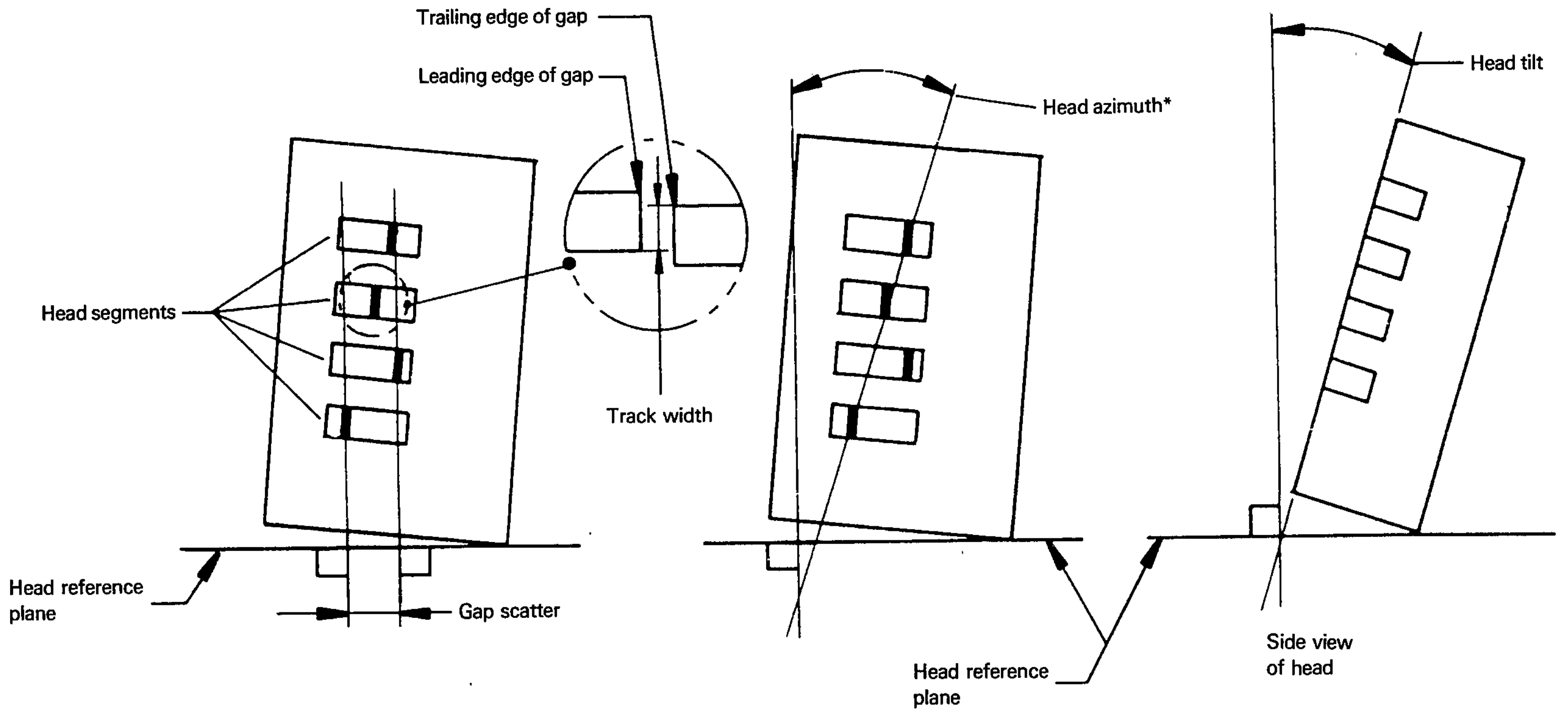
Calibrations may occupy these time-slots (time-slots 1 and 2)

Longest submultiple frame (time-slot 6)

Frame synch. occupies last time-slot in each minor frame (may also occupy adjacent slots)

Typical input channel (or word) allocations within a major frame

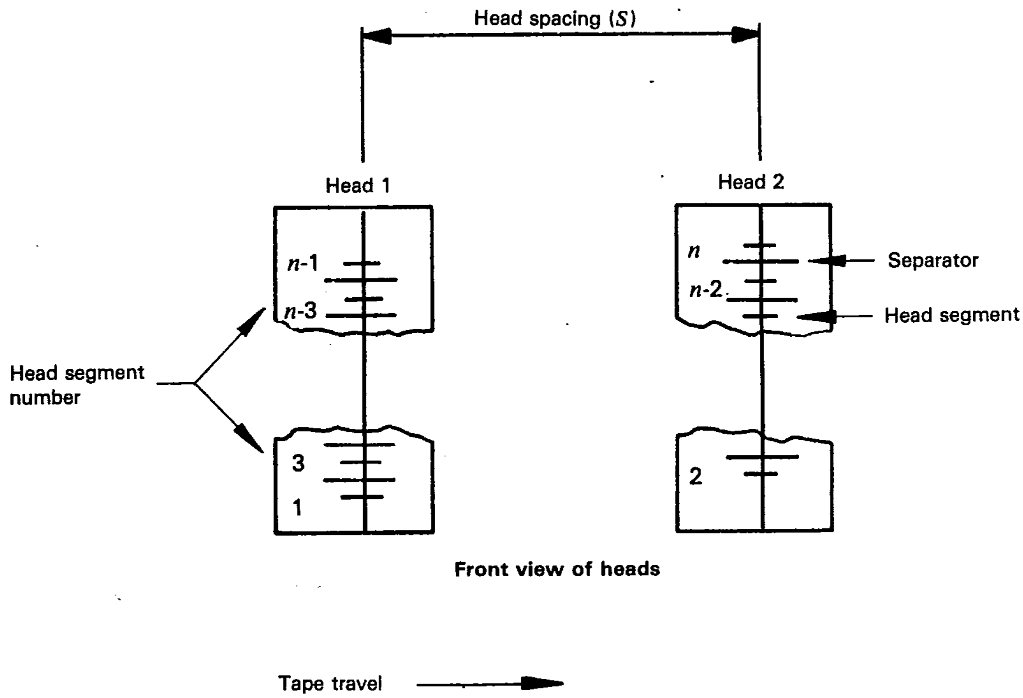
Figure 2 — Time-division multiplexing definitions (PAM and PCM)



Forward direction of tape travel ⟶

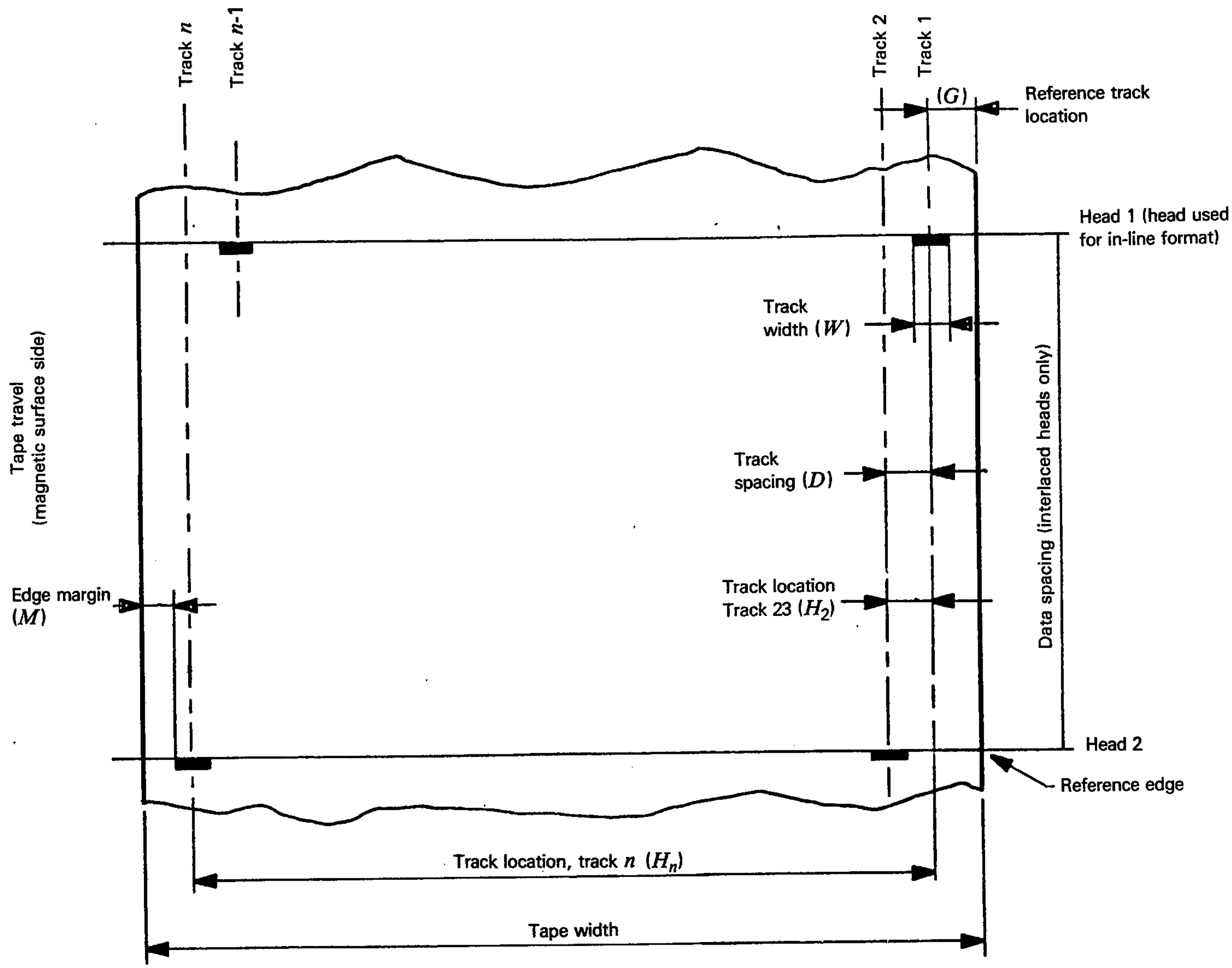
* The head azimuth line passes through the gap centres of the two outside tracks.

Figure 3 — Head mechanical parameters



NOTE — With formats to tables 4, 5 and 7, head segments *n*, *n*-2, etc. are in Head 1 and head segments *n*-1, *n*-3, etc. are in Head 2.

Figure 4 — Heads interlaced, *n*-track system

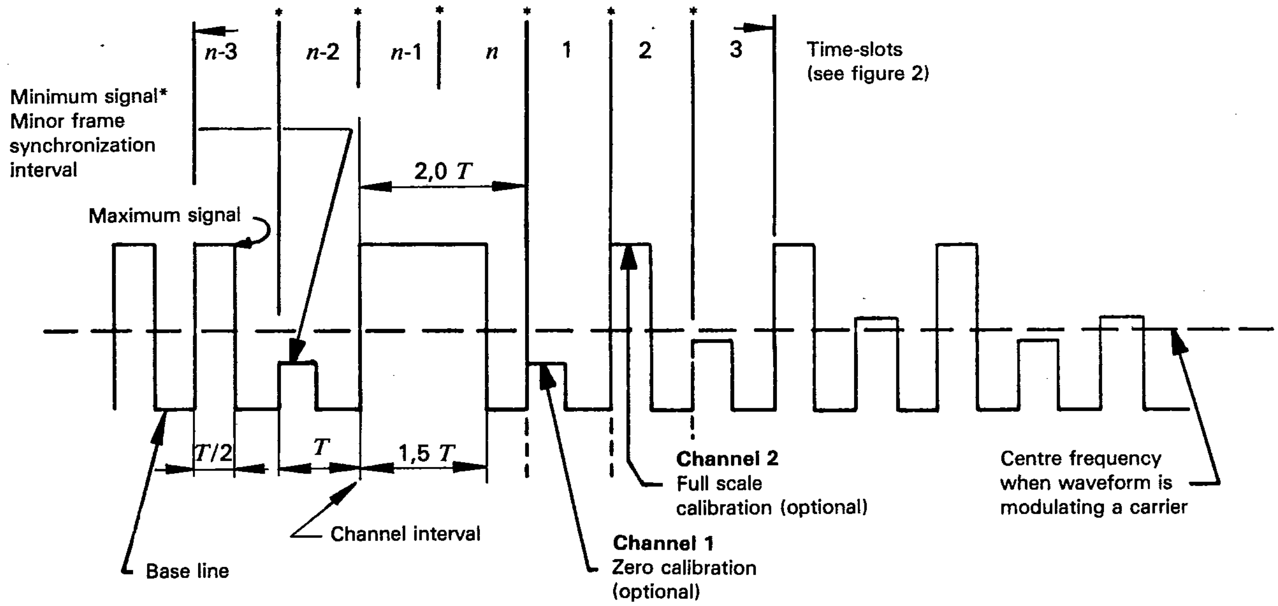


NOTES

1 With an in-line format, all tracks are in the Head 1 position.

2 With formats to tables 4, 5 or 7, track n is in the Head 1 position and track n-1 in the Head 2 position.

Figure 5 — Recorded tape format



* 20 to 25 percent of full amplitude reserved for pulse synchronization is recommended.

Figure 6 — Fifty percent duty factor PAM with amplitude synchronization

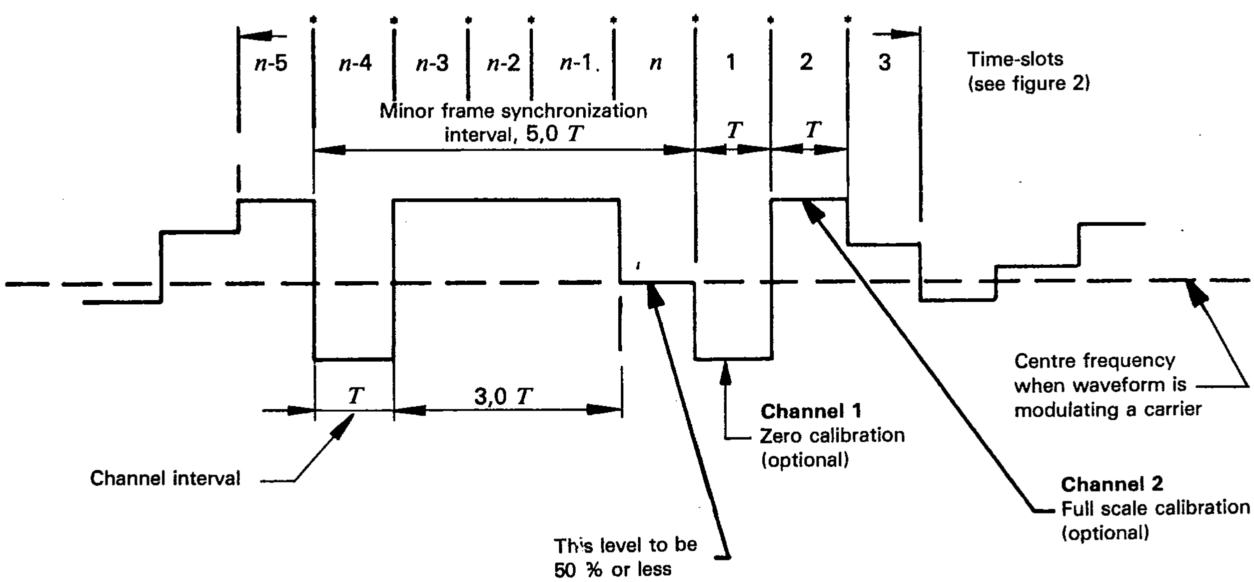


Figure 7 — One-hundred percent duty factor PAM with amplitude synchronization

Annex A

Recommended procedures for testing recorder/reproducer systems

(This annex does not form part of the standard.)

A.0 Introduction

This annex describes test procedures recommended for use in measuring performance parameters of magnetic tape recorder and reproducer systems. Performance limits are not generally specified in this International Standard since these depend greatly upon the intended application of the equipment and have a direct bearing on equipment cost.

Where measurement techniques are not defined, 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.

Some additional and alternative test procedures are described in annex C.

A.1 General

Before starting performance tests, the recorder/reproducer shall be aligned and adjusted in accordance with this International Standard and the appropriate instruction manual.

It is recommended that a qualitative test be conducted to ensure 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.

Although tests may be made in the simultaneous record/reproduce mode to save time, the machine must be capable of meeting all applicable specifications in any available mode of operation.

A.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 (for example, test oscillators) should be an order of magnitude better than the performance specification to be measured, and in any case shall be taken into account when a performance specification is being verified.

A.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 north-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 (see 4.5.7). 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 an erased 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 0,15 to 0,36 mm (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 shall give a positive-going pulse at the output when the magnetized section crosses the reproduce heads (see figure 8 for a typical waveform);

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

A.2.2 Tape speed

These tests measure effective average tape speed for recording or reproducing without a tape speed control signal, as required in 4.3.2. Two methods are described. 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.

Tape speed variations having frequency components above 0,5 Hz are defined as flutter and are treated in A.2.3. The following test methods provide an estimate of average tape speed and may not adequately measure some speed variations having frequency components between 0 and 0,5 Hz.

Further notes on the measurement of tape speed are given in C.6.

A.2.2.1 Introduction

The precise measurement of a given length of magnetic tape requires standardizing the environmental conditions of temperature, humidity, and tape tensile force in order to establish a standardized tape elongation.

After tape length or pulse spacing calibration measurement of a tape, the methods described make use of the calibrated tape as a transport tape speed measurement tool giving results independent of tensile force, temperature and humidity. Specifically, the calibrated tapes may be field used at any constant temperature, humidity or tensile force without correction factors for nonstandard conditions. A tape transport which has been adjusted to operate correctly with a test tape under a given set of temperature, humidity, and tensile force conditions must, however, be readjusted for any changes in these conditions.

A.2.2.2 Explanation

The intent of the tape speed measurement methods is the standardization of the "effective" rather than the actual or "absolute" tape speed. Absolute tape speed is relatively meaningless because it does not consider the operational elongation of the tape, which must be considered if a true or effective velocity measurement is to be achieved.

As used herein, actual tape speed, V_{act}, is defined as the peripheral velocity of the capstan minus any tape slip, regardless of tensile force and environment.

$$V_{act} = V_c (1 - s/100) \qquad \ldots (1)$$

where

V_c is the capstan peripheral velocity;

s is the tape slip in percent.

Effective tape speed, V_{eff}, is defined as the actual tape speed modified by tensile force and environmental differences from standard conditions.

$$V_{eff} = k_t \, k_{temp} \, k_{hum} \, V_{act} \qquad \ldots (2)$$

where all k s are the same basic form, for example,

$$k_t = 1 - E^{-1} (t_0 - t_s) \qquad \ldots (3)$$

where

E is the modulus of elasticity × tape cross-sectional area, in newtons (pound force);

t_0 is the operating tensile force in newtons (pound force);

t_s is the standard tensile force in newtons (pound force).

In the corresponding equations for k_{temp} and k_{hum}, E^{-1} is replaced by the appropriate coefficient of expansion and the t s by the appropriate temperatures or humidities.

Standard temperature and standard humidity are defined and specified in ISO 6371, viz :

temperature : 23 ± 3 °C

humidity : 45 to 55 % relative humidity

Equations (2) and (3) reveal that two recorder systems operating at different tensile forces must have different actual tape speeds if their effective tape speeds are to be identical. Similar statements can be made with respect to the temperature constant, k_{temp} and the humidity constant, k_{hum}.

Both methods I and II following are measurements of effective tape speed under the conditions of measurement and require no correction factors if the recorder is operating at nonstandard tensile forces and environment. New measurements would be required if the operating conditions changed.

Example

Consider two recorders at the same temperature and humidity, but one with twice the tensile force of the other.

Speed measurement of the two recorders via method II must result in both systems displaying a count of 25 000 µs at 1 524 mm/s (60 in/s) even though the calibration tape is elongated a greater amount by the higher tensile force recorder. Since the higher tensile force recorder elongates the tape more than the other recorder it must transport the tape faster in order to maintain correct effective tape speed. Stated differently, the actual tape speed of the higher tensile force recorder must be greater by an amount just equal to the greater elongation, at which point the counter will read 25 000 µs.

Similar examples can be constructed to show that both methods I and II correctly measure effective tape speed without requirement of correction factors.

A.2.2.3 Tape speed — Laboratory use, method I

This test establishes the speed interchangeability of tapes between recorders, per 4.3.2, under controlled conditions of environment for the type of tape base most commonly used in recording. Since differences in operating tape tensile force are taken into account, the measured effective tape speed is based on constancy of recorded wavelength rather than absolute velocity.

A.2.2.3.1 Equipment required

Tape conforming to a forthcoming International Standard. Sample tape length to be greater than 2 m. Steel rule, 2 m, non-flexible. Marking means optional; capable of translating rule reading and marking tape within ± 0,1 mm. For marking fixture, see figure 9, for electronic instruments, see figure 10.

The test may also be carried out using approximately equivalent inch measurements.

A.2.2.3.2 Procedure

For testing proceed as follows :

a) Age the required length(s) of tape off the reel in an unstressed (tension-free) condition for a period of at least 24 h in a controlled environment of 23 ± 1 °C (73 + 2 °F) and 45 to 55 % relative humidity. This environment is to be maintained for steps b) to d). Temperature for subsequent steps 23 ± 3 °C (73 ± 5 °F), relative humidity 45 to 55 %.

b) Clamp tape in fixture (see figure 9) so that tape naturally lies along edge of rule and is free of kinks and bends.

c) Apply standard tensile force (as defined in 4.5.8) ± 2 % as shown in figure 9.

Caution : Apply load gradually. Allow tape to stand tensile force for a period of at least 10 minutes to allow initial creep to take place.

d) Scribe two marks on oxide side, 1 500 ± 0,1 mm apart, taking care to avoid damaging tape base. If additional marks or lengths are required, repeat as necessary. However, all markings on a sample shall be complete within 30 min.

e) Splice at least three test samples into a full reel of tape at the beginning (first 10 %), middle (40 to 60 %), and end (last 10 %) 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 tensile force condition. Store tape on the supply reel for at least 2 h and not more than 24 h.

f) Record tape test sections with a high-frequency carrier, square wave (wavelength approximate 10 µm), or dc 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. Ensure that no control track signals are present.

h) Adjust the detector/electronic counter (see figure 10) to detect the pulses which will appear at the output of the reproducer when the leading (or trailing) edge of the scribe marks pass over the reproduce head gap. Reproduce tape test sections with equipment. Test section at least five times and obtain average reading of elapsed time between marks in microseconds.

j) Determine effective speed by

$$V_{eff} = \frac{1\,500}{T} \text{ mm/s}$$

where T is the elapsed time of the test section in seconds.

A.2.2.4 Tape speed — General and field use, method II

The method of tape-speed measurement defined in A.2.2.3 is an accurate method of determining tape speed. However, for maintenance and operational testing the method is very time-consuming. The following method is recommended for those cases where a quick method of checking tape speed is required.

A.2.2.4.1 Equipment required

This method uses commercial or laboratory-prepared, prerecorded tapes which have been recorded with saturated pulses having a pulse-to-pulse separation distance of 38,1 mm (1.5 in) to an accuracy of ± 0,02 % under controlled tensile force and environment. These tapes are prepared under a tensile force of 0,175 N/mm (1 lbf/in) of tape width ± 2 % under temperature and relative humidity conditions of A.2.2.3.2 a).

A.2.2.4.2 Procedure

For testing proceed as follows :

a) Connect a counter to the output of the recorder, disable the bias and control track signals, short the input to the record amplifier, and place the recorder in the reproduce mode.

b) Place the test tape on the transport and start the machine at 1 524 mm/s (60 in/s). On an oscilloscope, verify the approximate pulse period operation of the counter. At 1 524 mm/s, (60 in/s), the spacing will be 25 000 µs, 12 500 µs at 3 048 mm/s (120 in/s), 50 000 µs at 762 mm/s (30 in/s), 100 000 µs at 381 mm/s (15 in/s), etc. Measure the period using the counter in a ten-period averaging mode. Measurements are to be made near the beginning, middle, and end of the reel.

c) The exact tape speed may be calculated by the following equation :

$$\text{tape speed} = 38{,}1 \text{ mm}/T_c = 1.5 \text{ in}/T_c$$

where T_c is the period displayed by the counter in seconds.

d) Accuracy of the tape, including questions of misuse or abuse, can be checked visually by developing the pulses using a carbonyl iron dispersion and measuring the displacement between pulses under the controlled tensile force and environmental conditions.

e) The user should select a specific reel diameter for compatibility with his data-acquisition tapes. Optimum compatibility will be realized when the test tape reel diameter is the same as the diameter of the data-acquisation reels. The prerecorded tape shall be of the same thickness and elastoplastic characteristics as the data-acquisition tapes.

A.2.3 Flutter measurement

Variations in tape speed occurring at frequencies greater than 0,5 Hz are defined as flutter, and the tests described herein cover instrumentation and procedures for the measurement of flutter in instrumentation magnetic recording equipment. Methods for operational tests and acceptance tests are included. In addition, recommendations and guidelines are included for performing application information tests. These three types of tests are outlined as follows :

a) operational tests : basic tests suitable for field use to verify that equipment performance is within required limits;

b) acceptance tests : detailed tests to verify that the equipment meets specifications;

c) application information tests : tests intended to determine specialized performance characteristics. Information from these tests in intended for systems analysis and design.

Further notes on flutter measurements are given in C.2 to C.5.

Timing errors may be derived from flutter measurement but may also be measured directly; recommended test procedures for measuring TBE are given in A.2.5, and for pulse-to-pulse jitter in A.2.6.

A.2.3.1 Method of measurement

Since instantaneous differences between the effective record and reproduce tape speeds result in modulation of the frequency of a recorded carrier, the basic method used to measure flutter is to determine the amount of frequency modulation caused by the record/reproduce process. Therefore, to measure flutter a precision reference carrier is recorded and subsequently reproduced. The reproduced signal is applied to an FM discriminator. The output of the discriminator is a continuous electrical signal proportional to the variation between the record and reproduce speeds.

A.2.3.2 Equipment required to measure flutter (see figure 11)

The following are listed as separate components in order to indicate the required functions. it is recognized that these functions may be combined in one or in several instruments in actual practice :

A.2.3.2.1 Recorder/reproducer

The recorder/reproducer to be measured shall be equipped with suitable record/reproducer amplifiers.

NOTE — If record or reproduce heads and/or electronics are not available on a particular system, a cross play between two machines will be required, and a composite measurement will result. Such measurements may be considerably less accurate than recording and reproducing on the same tape transport.

A.2.3.2.2 Precision signal generator

The generator must be capable of supplying a signal of the required frequency and amplitude to a high degree of both stability and resolution. A sine wave is preferred for recording with bias. The residual frequency-modulation must be negligible compared to the flutter amplitude anticipated.

A.2.3.2.3 Band-pass filter, carrier

A band-pass filter may be inserted in the system ahead of the discriminator to limit system noise. The amplitude response of this filter must be flat ± 3 dB from $f_c - (af_c + f_f)$ to $f_c + (af_c + f_f)$, where f_c is the frequency of the reference carrier, f_f is the highest frequency flutter component to be measured, and af_c is the fractional flutter. A roll-off of 18 dB/octave beyond band-edge is suggested. The phase response of the filter should be sufficiently smooth to ensure satisfactory performance and avoid excessive overshoot in the presence of transients.

A.2.3.2.4 Frequency discriminator

The discriminator must accept the reproduced reference carrier which has been modulated by flutter and produce an output signal proportional to the modulation.

In general, 60 dB amplitude limiting must precede the frequency-sensitive portion of the discriminator in order to meet the dynamic range requirements of the system.

A.2.3.2.5 Band-pass filter, flutter (see table 21)

A band-pass filter follows the discriminator. Its purpose is to limit the frequency band of the flutter signal and to reject carrier frequency components. The filter shall be down no more than 3 dB at 0,5 Hz and at the upper flutter frequency being measured, and it shall fall off at a rate of 18 dB per octave outside the pass-band.

A.2.3.2.6 Magnetic tape

The tape shall be completely degaussed (bulk erased), in excellent condition and of a type meeting the requirements of a forthcoming International Standard, which is recommended for the recorder being tested.

A.2.3.2.7 Indicators and analyzers

The flutter signal from the band-pass filter following the discriminator is a complex one which will, in general, be a random function but may additionally contain discrete components. In order to measure this signal adequately statistical techniques shall be used.

Table 21 — Flutter band-pass filter characteristics

Tape speed mm/s (in/s)	Pass-band of filter Hz
23,8 (15/16)	0,5 to 156
47,6 (1 7/8)	0,5 to 313
95,2 (3 3/4)	0,5 to 625
190,5 (7 1/2)	0,5 to 1 250
381 (15)	0,5 to 2 500
762 (30)	0,5 to 5 000
1 524 (60)	0,5 to 10 000
3 048 (120)	0,5 to 10 000

a) Acceptance tests

The indicator used for acceptance tests shall be a direct-reading instrument designed to read the peak-to-peak amplitude and to ignore occasional random peaks, provided that the value read is exceeded less than 5 % of the time. That is, the peak-to-peak flutter is within the value read 95 % of the time. It is recognized that this measurement can be made in several different ways. A block diagram describing one method is shown in figure 12. Also, statistical voltmeters which accomplish this result are commercially available. Furthermore, if it is known that the flutter signal follows a Gaussian amplitude probability distribution, the peak-to-peak measurement described above is four times the rms value.

Frequency response : 0,5 Hz to 10 kHz

Meter averaging time : 5 s

b) Operational tests

An oscilloscope may be used as an indicator for operational tests.

Frequency response : 0,5 Hz to 10 kHz

Sweep speed : 100 mm/s

A.2.3.3 Calibration of test system

The flutter-measuring system shall be calibrated by simulating the flutter-modulated reproduced carrier signal. The simulated flutter signal shall be obtained from a frequency-modulated oscillator, and shall consist of a sine-wave carrier, frequency modulated by a sine-wave modulating signal. The level of the modulated carrier shall be equivalent to that expected from the recorder/reproducer output. The percentage of modulation shall be accurately determined and compatible with the expected flutter amplitude.

a) Accuracy

The system shall be accurate within ± 3 % of full scale.

b) Frequency response

The frequency response of the system shall be uniform within ± 3 dB over the flutter bandwidth.

c) Noise susceptibility (see figure 11)

The output noise caused by linear addition of the output noise of the tape-recorder/reproducer system and a stable reference carrier at the same level as would be derived from the tape-recorder/reproducer system shall be less than 5 % of the specified flutter.

d) Susceptibility to amplitude modulation of the carrier (see figure 11)

The system shall be subjected to an amplitude-modulated sine-wave carrier at the same level as would be derived from the tape-recorder/reproducer system. The sine-wave modulating freqency shall be varied from 0,5 Hz to the highest flutter frequency of interest. The level of modulation shall be 30 % for modulating frequencies from 0,5 Hz to 1 kHz. For frequencies above 1 kHz, the percentage of modulation shall vary inversely with frequency to 3 % at 10 kHz. The system output noise for any single frequency shall be less than 5 % of the specified flutter.

A.2.3.4 Test procedure

This test is to determine the magnitude of total cumulative flutter over a specified pass-band. Measurements are conducted at one or more points of tape supply reel loading for the specified tape speed. Results are expressed as the percentage change of a recorded frequency during the reproduce process.

a) Connect the equipment as shown in figure 11.

b) Adjust the precision signal generator and the discriminator to a carrier frequency suitable for the tape speed used. The frequency used shall not be less than five times the maximum flutter frequency.

c) Place the erased tape on the machine, select the tape speed to be used and place machine in RECORD mode.

d) Adjust record level above normal to optimize the ratio of carrier-to-noise level. A value of approximately 13 dB above normal is suggested. (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, i.e. using saturation recording, which may be used in any case.)

e) Record test signals :

1) Acceptance tests : record test signals on three tracks : the two outside tracks, and a track on or nearest to the centre of the tape. Record at three points : near the beginning, middle and end of reel. Each recording shall be three minutes minimum in length.

2) Operational tests : record one three minute recording on one track at any convenient point in the reel.

f) Rewind the tape, place machine in REPRODUCE mode, and adjust carrier band-pass filter and flutter band-pass filter to the proper values for the tape speed used. (The reproduce speed shall be nominally the same as the record speed.)

g) Read the peak-to-peak flutter output :

1) Acceptance tests : observe the flutter on the indicator described in A.2.3.2.7 a).

2) Operational tests : observe the flutter as displayed on the oscilloscope at a sweep speed of 100 mm/s. The observation time shall be five seconds minimum. In reading the peak-to-peak amplitude, occasional random peaks which exceed the value read shall be ignored provided that the value is not exceeded more than 5 % of the time.

A photograph of the oscilloscope trace may be used to supplement the visual observation.

A.2.4 Dynamic interchannel time displacement error (ITDE) (see 4.5.3)

The ITDE shall be measured as outlined in the following procedure. See figure 13 for test equipment connections.

The measured ITDE shall be considered to include all fluctuations within 95 % 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 the band of interest.

Procedure :

a) Set the test oscillator frequency (f_c) in accordance with table 22.

Table 22 — Test oscillator frequencies for ITDE, TBE and Jitter tests

Tape speed mm/s (in/s)	f_c kHz
3 048 (120)	100
1 524 (60)	50
762 (30)	25
381 (15)	10
190,5 (7 1/2)	5
95,2 (3 3/4)	2,5
47,6 (1 7/8)	1,0
23,8 (15/16)	0,5

b) Record the test oscillator signal on two tracks within the same head (for example, 3 and 5). At high transport speeds, the entire reel of tape may be recorded. With lower speeds, a recording of 1 to 2 min at beginning, middle and end of reel is satisfactory.

c) 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 10 mm (horizontal).

d) 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.

e) Visually observe or photograph the CRT display over ten-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.

A.2.5 Time base error (TBE)

The TBE shall be measured as outlined in the following procedure. See figure 14 for test equipment connections.

The measured TBE shall be considered to include all fluctuations within 95 % 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 the band of interest.

Procedure :

a) Set the reference oscillator frequency (f_c) in accordance with table 22.

b) Record the test signal in accordance with manufacturer's instruction manual.

c) 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.

d) Rewind the recorded tape and place the instrument in the REPRODUCE mode. Select the transport tape servo system to the TAPE mode.

e) Adjust oscilloscope time base and trigger to display a single leading edge with the TBE component occupying a minimum of 10 mm (horizontal).

f) 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.

g) 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.

Further notes on TBE are given in C.3 and C.4.

A.2.6 Pulse-to-pulse jitter

Jitter, both with or without servo, shall be measured as outlined in the following procedure. See figure 15 for test equipment connections.

The measured jitter shall be considered to include all fluctuations within 95 % 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 the band of interest.

Procedure :

a) Set the test oscillator frequency (f_c) in accordance with table 22.

b) Record the test signal in accordance with manufacturer's instruction manual.

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

d) 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 10 mm (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 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.

A.3 Direct recording system tests

This clause defines test procedures for direct recording. The bias and record level adjustment below 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 (refer to manufacturer's instructions). See table 23 for required test equipment.

A.3.1 Bias and record level

This test estabishes bias and record level settings as specified in 5.1.2.2 and 5.1.3 d).

Procedure :

a) Set up equipment, instruments, and loads as indicated in figure 16 using the reference tape.

b) With the signal source set to the record bias set frequency and the input level set 5 to 6 dB below the estimated normal record level, record and simultaneously reproduce a tape, and adjust the bias level for proper overbias (see 5.1.2.2).

c) With signal source set to record level set frequency, increase the input level until 1 % third harmonic distortion is obtained at the reproduce output as indicated by the wave analyzer. Before measuring third harmonic distortion, check and adjust the reproduce amplifier response equalization at the third harmonic frequency so that it is within $\pm$ 1 dB of the response at the record level set frequency prior to setting for the 1 % level.

d) Reduce level and repeat step b) to recheck bias setting. The final settings for bias and record level are the operating bias and normal record level, and constitute standard record conditions.

A.3.2 Frequency response-direct recording (see 5.1.1.2)

Procedure :

a) Set up equipment, instruments, and loads as indicated in figure 16. No external band-pass filter shall be used in this test.

b) Perform initial adjustment of bias and record level per A.3.1 and manufacturer's instructions.

Table 23 — 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 % over frequency range under test.
Voltmeter	True rms reading AC VTVM calibrated to an accuracy of ± 1/2 dB over frequency range under test.
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.) Bandwith shall be sufficiently wide to avoid erroneous reading due to recorder flutter. (It is unlikely that a single instrument can be used over the entire frequency range.)
Mixing network	Linear mixing network (resistor). Design to match source and load impedances.
Electronic counter	Time base and reading accuracy shall 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 frequencies (see table 12 of this International Standard), spurious signals and noise at least 10 dB below equipment specification, 18 dB per octave rolloff.
NPR (noise power ratio) test set (see annex C)	Baseband high pass filter : 12 kHz. Baseband low pass filters : 60, 108, 204, 552, 1 052, 2 540 kHz. Notches : 14, 34, 70, 105, 185, 342, 695, 1 248 kHz.
Spectrum analyzer (see annex C)	To be compatible with the NPR test set, the important parameters including frequency range, precision of frequency and level setting, resolution and dynamic range.

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 in decibels, the maximum and minimum excursions of the reproduce output level, V_2, with respect to the reading obtained in step d).

For further notes on the measurement of frequency response see C.7.

A.3.3 Signal-to-noise ratio

Pass bands in A.3.2 and in this clause may not be identical and should not be compared directly. Filter characteristics shall be known or verified before running the signal-to-noise test.

This test determines the ratio of normal record level rms signal plus noise output voltage to the zero signal rms noise and spurious signal output voltage. (Zero signal noise is the noise arising when reproducing a tape recorded with no signal into the record head but with bias energized). Measurements shall be conducted while simultaneously recording and reproducing with bias.

Procedure :

a) Set up equipment, instruments, and loads as indicated in figure 16, using a band-pass filter as listed in table 23.

b) Perform initial adjustment of bias and record level per A.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.

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

e) Observe and log the output level, V_2. Use a true rms voltmeter.

f) Determine the difference in decibels between the reading obtained in step c) and the reading obtained in step e).

A.3.4 Intermodulation distortion

Procedure :

a) Set up equipment, instrument, and loads as indicated in figure 17.

b) Perform initial adjustment of bias and record level per A.3.1 and manufacturer's instructions.

c) Determine the input voltage required to give normal record level, using the wave analyzer with the switch in position 1 (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 each equal to half 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 pass band may be logged, if required.

e) Check harmonic and intermodulation component frequency input voltages with the wave analyzer (switch in position 1) and determine that all components listed in table 24 (other than f_1 and f_2) 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 in position 2) at the frequencies listed in table 24 in decibels relative to normal record level output. Additional component frequencies may be present in the pass band if other frequencies are used for f_1 and f_2.

For further notes on intermodulation measurements see C.8.

Table 24 — 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

A.3.5 Crosstalk

The following test procedure measures the crosstalk of a signal in one channel to all other channels.

Procedure :

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 1,5 mm (0.06 in) through the band corresponding to the tape speed being used.

d) Rewind and reproduce the tape. Observe the output of all tracks without input 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.

e) Stop the tape and repeat for the other track.

A.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 1,0 V rms.

Procedure :

a) Place bulk erased tape of the appropriate type onto the recorder.

b) At the highest available tape speed, record and reproduce the record level set frequency 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 1,0 V rms.

c) Reduce the input level to zero while continuing to record only the bias signal. With a tunable voltmeter 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.

NOTE — Chassis ground should be properly connected to the local instrumentation ground during this test.

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.

A.3.7 Group delay variation and transient response

A.3.7.1 General

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 directly recording pulse waveforms. Optimum group delay performance is required for recording certain multiplexed signals, predetection signals, etc.

A.3.7.2 Group delay variation test procedure for wide-band recorders

The following test indicates specific equipment which is now being used by several bodies. Other compatible equipment of this type may be used when available.

A.3.7.2.1 Test equipment

The following minimum equipment or equivalent 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 display or group delay variation measurement.

Wandel and Goltermann CRO Indicator, model SG-1;

Wandel and Goltermann CRO Plug-in, model SGE-3.

A.3.7.2.2 General procedure

a) 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 Ω load resistance of the LDE-1 receiver.

b) The group delay measurements shall be made over the bandwidths shown in table 25 and shall be referenced to a delay reference frequency between 200 kHz and 1 MHz.

Table 25 — Group delay measurements

	Tape speed mm/s (in/s)	Measurement bandwidth	Delay reference frequency
Wide band 1,5 MHz	3 048 (120)	100 kHz to 1,5 MHz	Optional
	1 524 (60)	100 kHz to 750 kHz	Optional
	762 (30)	100 kHz to 375 kHz	Optional
Wide band 2,0 MHz	3 048 (120)	100 kHz to 2,0 MHz	Optional
	1 524 (60)	100 kHz to 1,0 MHz	Optional
	762 (30)	100 kHz to 500 kHz	Optional

NOTE — The group delay variation tests may also be extended to single-carrier FM recorder systems at 3 048 mm/s (120 in/s) over the bandwidth of 100 to 400 kHz.

c) Group delay variation measurements may be performed in either the point-to-point (see A.3.7.2.3), or sweep (see A.3.7.2.4) modes and shall conform to the test set manufacturer's instruction procedures as modified herein.

A.3.7.2.3 Point-to-point mode

Procedure :

a) 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.

b) The output of the TFPS-42 shall be set to – 10 dB as indicated by the front panel level meter.

c) Each frequency point measured shall be recorded for at least 20 s in order to permit sufficient time for reading.

d) 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. (Verification of readings may be desirable and the range may be temporarily switched to the next higher scale.)

A.3.7.2.4 Sweep mode

Procedure :

a) 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.

b) The output of the TFPS-42 shall be set to – 10 dB as indicated by the front panel level meter.

c) Each track measured shall be repetitively swept for at least 60 s to permit adequate observation time.

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

e) 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.

f) Documentation may be obtained by oscilloscope camera. Figure 18 depicts a typical result and shows less than ± 200 ns delay from 100 kHz to 1,5 MHz. Group attenuation is also shown against a common frequency axis.

A.3.7.3 Transient response

The phase performance of a record/reproduce system which is measured by the square-wave method shall have the parameters of the square wave measured in accordance with descriptions in figure 19. 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 ten times the lower band-edge frequency. It should be noted that these conditions cannot be met simultaneously at tape speeds below 190,5 mm/s (7 1/2 in/s). Measurements can be made at lower tape speeds but with lower precision as the repetition frequency approaches the band edge.

A.3.8 Multispeed reproduce transfer levels

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 meet the above requirement.

Procedure :

a) Place bulk erased tape of the appropriate type on the recorder.

b) At any convenient tape speed, record at normal record level a signal having a wavelength of 47,6 µm (1.875 milli-inch); 500 Hz at 23,8 mm/s (15/16 in/s), 1 kHz at 47,6 mm/s (1 7/8 in/s) 2 kHz at 95,2 mm/s (3 3/4 in/s), . . ., 64 kHz at 3 048 mm/s (120 in/s).

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.

For further notes on the measurement of multispeed reproduce transfer levels, see C.9.

A.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 [see section 5.1.3 c)].

Procedure :

a) Place bulk erased tape of the appropriate type on the recorder.

b) Record and reproduce at 1/8th 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 upper 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. Frequencies eight times as high as those used in step b) shall 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). Each frequency shall be recorded approximately 1/8th as long as in step b).

d) Reproduce the tape recorded in step c) at 1/8th the highest tape speed of the machine. On machines with azimuth-adjustable reproduce heads, adjust azimuth for maximum upper 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.

For further notes on measurements of record transfer characteristics, see C.10.

A.4 Single carrier FM system tests

A.4.1 General

All FM tests except drift and dc 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. Except where otherwise stated all percentages shall be referred to full positive to negative deviation as 100 %. This procedure is intended to test those systems described in table 13 only.

A.4.2 Centre frequency, deviation and polarity check (see 5.2.1 and 5.2.2)

a) The centre frequency shall be checked by shorting the input of the amplifier and monitoring the carrier frequency with an electronic counter. The centre frequency shall be adjusted to conform to values specified in table 13 within 1 %.

b) The deviation and polarity shall be checked as follows :

Apply the positive peak dc input signal to a tolerance appropriate to the specified performance of the equipment under test and verify a full positive deviation in carrier frequency and a corresponding positive output voltage from the reproduce amplifiers. Apply the negative peak dc input signal and verify a full negative deviation in carrier frequency and a corresponding negative output voltage from the reproduce amplifier.

A.4.3 Frequency response (see 5.1.2.2)

Procedure :

a) Set an input sine-wave signal to the reference frequency (as defined in the footnote to table 13) and an amplitude equal to that giving full peak-to-peak deviation.

b) Maintain this input amplitude and measure the reproduce output signal amplitude at various frequencies up to and including the maximum modulation frequency (see table 13).

c) Observe the maximum and minimum excursions of the reproduce output level from that at the reference frequency, and log them in decibels.

For further notes on frequency response measurements see C.11.

A.4.4 Signal-to-noise ratio

Procedure :

a) Record a sine-wave signal set as defined in A.4.3 a) above,

b) Short-circuit the input and record the undeviated carrier.

c) The signal-to-noise ratio is defined as the ratio of the reproduce output signals obtained from the recordings made at a) and b), expressed in decibels.

d) The output signals shall be measured with an average reading, rms calibrated voltmeter; the meter shall be down no more than 3 dB at 10 Hz. No external filters shall be used in the measurements.

A.4.5 Distortion

A.4.5.1 Single component distortion

Record a signal at full deviation ± 5 % and a frequency 50 % of the maximum modulation frequency specified in table 13. The output of the FM reproduce amplifier shall be measured with a wave analyzer which measures the second harmonic.

A.4.5.2 Intermodulation distortion

IM distortion shall be measured by recording two mixed signals, each at a level sufficient to provide half full deviation of the carrier. The reproduce output shall be monitored with a wave analyzer and the intermodulation 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 $f_1 = 0{,}45$ and $f_2 = 0{,}55$ of the maximum modulation frequency specified in table 13.

A.4.6 Spurious components (wide-band FM)

These shall be measured by recording the maximum modulation frequency as specified in table 13 at a level sufficient to provide full deviation ± 5 %. The reproduced output shall be monitored with a wave analyzer.

A.4.7 Group delay and transient response

See A.3.7 (particularly the note to table 25).

A.4.8 Dc linearity (see figure 20)

A.4.8.1 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 (i.e. frequency in A.4.8.2, voltage in A.4.8.3).

A.4.8.2 Record amplifier linearity (procedures for systems without reproduce capability)

Inject signals into the record amplifier of the specified levels to provide zero, full positive, and full negative deviation of the carrier. The levels must be accurate to 0,01 % or better. Monitor the frequency output with a counter having 0,05 % resolution. The percent nonlinearity shall be determined from the following formula.

$$Y\,\%\ \text{nonlinearity} = \frac{e_{max.}}{f_u - f_L} \times 100 \qquad \ldots (6)$$

where $e_{max.}$ is the maximum value of the error function [see d) below].

A Y % p-p specification is interpreted as $\pm\ Y/2$ % and conversely.

NOTE — If the form of the linearity curve has not previously been determined, a number of additional measurements should be made at intermediate levels.

A.4.8.3 System linearity (includes procedure for measuring record amplifier linearity)

Proceed as in step b). Monitor the record amplifier frequency and the reproduce amplifier output voltage. Voltage shall be measured with an integrating dc voltmeter which does not respond to the noise in the output of the FM system. Voltage nonlinearity shall be determined from equation 6.

A.4.8.4 Determination of error function e

The method outlined below measures the dc linearity as a departure from a reference line through zero. The reference line is only an approximation to the mathematical best straight line having least mean square error, but 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.

The reference line is a straight line mathematically constructed to pass through the output f_0 for zero input and the actual output f_L for full negative input. The departure of the actual output at all points from the reference line is then given by the formula

$$e = \mathrm{f}_x + F_L x - (1 + x) f_0 \qquad \ldots (7)$$

where

f_x is the output for input x;

f_L is the output for full negative input ($x = -1$);

f_0 is the output for zero input ($x = 0$);

x is the fraction of full input ($-1 \leqslant x \leqslant +1$ only).

The value of e is then plotted graphically as a function of x. All points on this curve must be inside 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 20 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 20 a). Critical examination will show that for this shape, only the end points need be measured. Maximum error always occurs at $x = +1$, and substitution in equation (7) gives

$$e_{max.} = f_u + f_L - 2f_0 \qquad \ldots (8)$$

A less common type of curve is shown in figure 20 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).

A.4.9 Dc drift at centre frequency

a) Record amplifier centre frequency drift (procedure for systems without reproduce capability)

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

b) System zero drift (includes procedure for measuring record amplifier zero drift)

Proceed as in step a). In addition, monitor the dc output voltage change versus other parameters as specified (time, temperature, line voltage, etc.). All changes in the frequency band 0 to 0,5 Hz shall be included.

c) An x-percent p-p specification is interpreted as $\pm x/2$ % and conversely.

A.4.10 Multispeed reproduce transfer levels

These shall be measured by recording the reference frequency specified in table 13, 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.

For further notes on measurements of multispeed reproduce transfer level see C.12.

A.5 PAM system tests

(See 6.2). PAM system tests may be included in a future revision of this International Standard.

A.6 PCM system tests

(See 6.3).

NOTE — The tests described below are generally only applicable to radio-frequency telemetry systems but some of the information may be relevant or adaptable to other PCM instrumentation systems.

A.6.1 Test procedure

For testing the performance of a PCM ground data receiving system, the following procedure shall be used :

a) Determine the carrier predetection bandwidth, PCM waveform patterns, type and depth of modulation, bit rate, and range of bit error probability (P_e) values to be tested.

b) The test configuration shall be as shown in figures 21, 22 or 23 (see also A.6.2.2). The specific system parameters, listed in step a) above, shall be documented and included with the resultant test data.

c) Point the antenna at the quiet sky, at least three antenna beamwidths from any radio sources, and set up in the application configuration.

d) Vary the output power (P_s) of the RF test signal generator. Plot or tabulate P_e versus E_b/N_0 where E_b is the signal energy per bit and N_0 is the noise power density. A typical plot is shown in figure 24.

A.6.2 Application notes (see also C.4)

A.6.2.1 Bit error probability test

a) The test pseudo-noise (PN) sequence shall be 2 047 bits in length.

b) The PN generator shall include an internal clock continuously variable over the range of 10 bits/s to 10^6 bits/s. The stability shall conform to 6.3.5. Provisions for acceptance of external clock shall be included.

c) Provision shall be made for including in the test format an arbitrary word of not more than 33 bits at selectable integer multiples of the PN sequence period.

d) Two pulse waveforms shall be selectable, namely NRZ and Bi-ϕ (see figure 1).

e) The PN test receiver shall include a PN sequence synchronizer, error comparator, and error counter of capacity at least 1 000 errors.

f) The PN test receiver shall provide PN sequence pattern and bit clock outputs.

g) The PN test receiver shall use an integrate-and-dump bit detector using bit clock from f).

h) RF signal generators covering appropriate telemetry bands shall be provided with :

1) base-band response from 0 to 1 MHz, flat to ± 2 dB;

2) peak-to-peak frequency modulation capability adjustable from 700 Hz to 7 MHz;

3) peak frequency deviation meter to cover this range with an error not more than 10 % of meter reading;

4) peak-to-peak carrier phase modulation from $\pi/2$ to π radians continuously adjustable;

5) peak phase deviation meter to cover this range with not more than 3 % error.

j) The closed loop tracking bandwidth of the PN sequence synchronizer shall be variable in steps including 10, 100, 500 and 1 000 Hz.

k) The PN receiver shift register clock shall be derived by efficient utilization of the auto-correlation of the PN waveform.

m) Provision shall be made to indicate the time required to accumulate the bit error count.

A.6.2.2 PCM test method

a) Where a PCM simulator, bit synchronizer, error comparator, and error counter exist, the closed-loop configuration in figure 21 or 22 can easily be accomplished and P_e determined in real time utilizing the procedures described in A.6.1. If the PCM test pattern is predetection or postdetection recorded and played back through the system bit synchronizer as shown in figure 22, a PCM pattern regenerator must be utilized. This regenerator could be the same PCM simulator utilized for generating the PCM test pattern, provided a clock input and frame synchronization input to the simulator are available for loading and synchronization purposes (see figure 23).

b) It is recommended that a pseudo-noise (PN) test pattern be utilized whenever possible. One reason for this is that a PN sequence can be generated and synchronized economically by a shift register with feedback configured for a maximum length sequence. Since the number of positions in the shift register and the feedback connections uniquely determine the test pattern, it is convenient to specify the pattern in terms of these parameters. Another reason is that a standard test pattern, adopted by all users, allows the exchange of test data without ambiguity. In this connection, an eleven-position shift register is recommended with feedback summed modulo two from positions 9 and 11.

The sequence will be 2 047 bits long which corresponds roughly to frame lengths in use which, for NRZ, exercises the low frequency response of elements of the system. This is important because with NRZ, lack of dc response causes baseline variation of the bit stream in accordance with the fractional amount of near-dc-power lost. In addition, the sequence will contain eleven binary ones followed by nine binary zeros thus exercising the bit synchronizer with only one NRZ transition in 19 bits, three in 29 bits, five in 39 bits, seven in 49 bits, etc.

c) The synchronization of the PN-PCM test pattern regenerator is shown in figure 25. Because of the autocorrelation properties of a PN sequence, it is possible to synchronize a slave shift register to an incoming PN bit stream (plus noise) by cross correlation. This can be carried out by coherent or non-coherent methods. Test data indicate that the non-coherent method is adequate for tests in which the bit error probability (P_e) is less than 0,01.

d) The non-coherent method of synchronization makes use of the clock from a data bit synchronizer. Since data bit transitions occur at random, a non-linear operation is required in the data bit synchronizer in order to generate discrete frequency components at the bit rate and its harmonics. Figure 25 is a schematic of the non-coherent PN synchronizer. The clock from the bit synchronizer is used to drive the shift register. The NRZ bit stream out of the bit detector is used to load the shift register when the switch is thrown to the load position. The switch is then thrown to the feedback position, and, if there are no errors in the loaded bits, the shift register is in lock with the input PN waveform. It will stay in lock until bit slippage occurs in the bit synchronizer. If one or more errors are loaded into the register, the shift register is not locked, and because of the auto-correlation properties of the PN sequence, the error rate is nearly 50 %. Thus if the error rate is 0,01 for example, the register is locked. If it is not locked, i.e. error rate approximately 0,5, the switch is returned to the load position and the process repeated until lock is obtained. In operational hardware, the whole loading operation can be done automatically.

e) The spectrum of an NRZ-PN sequence consists of a Fourier series of sinusoids with a fundamental frequency equal to the sequence repetition rate with power values inscribed within the random PCM NRZ power spectrum of figure 26. Such a spectrum for a PN sequence of length seven bits is shown in figure 27. The fraction of the total power in each component near zero frequency is approximately $2/m$, where m is the number of bits in the sequence. Thus, when m is large, such as 2 000, the spectrum is nearly continuous and has the same shape as random NRZ. Similarly, for a Bi-ϕ PN sequence, the Fourier component frequencies are multiples of the sequence rate with power value inscribed within the random Bi-ϕ spectrum of figure 26.

f) Statistics of the accumulated bit error sample need to be considered. It may be assumed that the bit errors are Poisson distributed. Thus, the sample variance may be taken as the number of errors accumulated; i.e. the standard deviation, σ, is given by the square root of the error count. The percent σ is thus $100/\sqrt{N}$, where N is the number of errors counted. Thus, if the desired percent σ is 10 %, N shall be 100 or more.

A.7 Multiple-carrier FM subcarrier tests

A.7.1 General

A.7.1.1 Range of tests

a) The tests described in sections A.7.2 to A.7.12 include measurements to determine the following performance characteristics of multiple-carrier FM sub-carrier oscillators :

1) Control range(s) (see A.7.2)

2) Non-linearity (see A.7.3)

3) Amplitude modulation (see A.7.4)

4) Output distortion (see A.7.5)

5) Effect of source impedance (see A.7.6)

6) Effect of grounding input (differential-input models only) (see A.7.7)

7) Output loading (see A.7.8)

8) Modulation feedthrough (see A.7.9)

9) Stability versus time (see A.7.10)

10) Effect of supply voltage variation and ripple (see A.7.11)

11) Common-mode rejection (see A.7.12)

b) It is recommended that the performance tests be conducted in the order in which they are presented, except that tests which may be destructive or cause permanent degradation of performance should be included in the last part of the schedule.

c) It is recommended that performance tests be carried out in the following four bands as defined in table 18 :

7 (2,3 kHz ± 7,5 %), 14 (22 kHz ± 7,5 %),
A (22 kHz ± 15 %) and E (70 kHz ± 15 %).

A.7.1.2 Test equipment

To minimize measurement errors, test equipment should be energized from a regulated line and the tests conducted in a room where ambient temperature variations are small. When tests require the measurement of voltages or currents with a high order of precision, or when the measurement of low-level voltages or currents are required, care must be given to the design of the test configuration to avoid the error-producing effects of ground-loop currents. The use of an isolation power transformer is desirable. Observe the practice of bringing all ground leads to one common point.

A.7.1.3 Test procedures

a) The basic test procedures described in A.7.2 to A.7.12 should satisfy the performance information requirements of the majority of telemetry sub-carrier oscillator users. The tests could be conducted in much greater detail, and this may be done at the discretion of the testing facility when such a requirement arises.

b) Some performance characteristics are temperature-dependent and additional measurements at ambient temperatures covering the operating range may be required for particular applications. Measurements under other specific environments (for example, vibration) may also be required.

c) The block diagrams given in figures 28 to 39 are included for descriptive purposes and are not intended to provide detailed information on test equipment interconnections.

d) To assure uniformity of testing, the following procedures and preliminary adjustments should be completed before the individual tests are conducted.

1) Initial procedures

— Place the sub-carrier oscillators under test in a temperature-controlled chamber, and maintain the chamber at + 30 ± 1 °C unless otherwise indicated in the test schedule. If a temperature chamber is not available, ambient temperature variations must be kept as small as possible so that the effect of controlled test parameter variations are not influenced by temperature variations.

— The supply voltages for the sub-carrier oscillators under test must be carefully adjusted and regulated.

— The output impedance of signal sources used in the tests should be low (i.e. approximately 10 Ω maximum for dc signal sources and approximately 600 Ω maximum at the operating frequency, for ac sources). This is especially important when testing sub-carrier oscillators employing solid-state design, where reverse leakage currents may be present at the input terminals.

2) Preliminary adjustments

— Adjust the supply voltage(s) to the level(s) recommended by the manufacturer, and allow a 15-minute warmup.

— Adjust the appropriate controls on the sub-carrier oscillator so that the input signal voltage level and excursion recommended by the manufacturer will produce full deviation output frequency excursion, centred at the appropriate centre frequency.

— Adjust the amplitude control to produce the maximum output signal amplitude.

— Apply the maximum output load recommended by the manufacturer, or apply a 10 kΩ load if the manufacturer makes no recommendation.

NOTE — During the tests described in the following procedures, controls are frequently varied from the settings established during these preliminary adjustments. Care should be taken to ensure that in each case the correct control settings are re-established before proceeding with any further performance tests.

A.7.2 Control range(s)

a) Purpose : to determine the ranges of the controls which are provided to adjust :

1) deviation sensitivity

2) reference frequency

3) output level.

b) The sensitivity control adjusts the magnitude of input-voltage excursion required to produce full deviation output frequency excursion. The reference-frequency control adjusts the output frequency which is produced when the input signal terminals are shorted. Depending upon the manufacturer's design, the nominal reference frequency may correspond to the centre frequency or to either of the deviation limits. The output level control adjusts the amplitude of the sub-carrier output signal.

c) Certain models may feature all three of the controls, while other models may have only one or two controls. Still other models may have a control to adjust each of the deviation limit frequencies but no reference-frequency control.

d) Test procedure

The following test procedure applies to models which include the three controls listed above.

1) Set up as per figure 28.

2) Measure the input voltage excursion required to produce a full deviation range output frequency excursion with the sensitivity control set first to the maximum position and then to the minimum position.

3) Short-circuit the input terminals, and measure both the minimum and maximum frequency produced by adjusting the reference frequency control through its full range.

4) Apply a dc input voltage to produce an output frequency equal to the centre frequency. Measure the output signal amplitude for both minimum and maximum settings of the output level control.

A.7.3 Non-linearity

a) Purpose : to determine the departure of the output frequency versus the input-voltage characteristics from a reference straight line drawn through the points corresponding to centre frequency and low deviation limit. See also A.4.8.

b) Two methods of measurement are described. In one method an analogue plot of departure from linearity is automatically produced by an X-Y recorder, while in the other method data is acquired through a point-by-point procedure of measurement and then plotted manually. Method No 1 is the more rapid of the two, but accuracy is limited to the order of 0,1 %; it should also be noted that the measurements will include the effect of any non-linearities in the sub-carrier discriminator as well as those in the oscillator under test. Accuracy in method 2 is limited only by the precision and resolution of the voltmeter and the frequency counter.

c) Test procedure (Method No 1)

1) Set up as per figure 29.

2) Adjust the sensitivity of the X-axis of the recorder to produce a convenient excursion when full scale input voltage excursion is applied to the sub-carrier oscillator.

3) Adjust the mixer network so that the output voltage excursion of the sub-carrier discriminator and the input voltage excursion applied to the sub-carrier oscillator produce a nominal null (within a few per cent) at the Y input to the recorder.

NOTE — If the inputs to the mixer network are A and B and the network applies gains of G_A and G_B respectively, then the magnitude of the output shall be $G_A \cdot A - G_B \cdot B$.

4) Adjust the sensitivity of the Y-axis so that the mixer network output produces a convenient excursion, and calibrate the Y-axis in per cent of full deviation range. To calibrate the Y-axis, set the dc signal source to the voltage corresponding to zero volts from the discriminator and disconnect temporarily the dc signal source input to the mixer and the X-axis. Vary the dc signal source in small percentile increments of full scale and note the corresponding Y deflections.

5) Slowly change the input voltage through the full scale range (equivalent to sub-carrier oscillator output frequency change from one deviation limit to the other). Avoid rapid input voltage changes, because they will produce phase shifts in the sub-carrier oscillator and the discriminator which will lead to measurement errors.

6) Establish a reference straight line through the points representing centre frequency and lower deviation limit.

7) Departure of the plot drawn by the X-Y recorder from the established reference straight line represents departure from linearity.

8) Departure from linearity is expressed as a percentage of full deviation range and is given a positive sign when, for a selected input voltage level, the output frequency is greater than the corresponding point on the reference line.

d) Test procedure (Method No. 2)

1) Set up as per figure 30.

2) Measure the output frequencies corresponding to eleven equally spaced input voltage levels covering the sub-carrier range as determined in A.7.2, using the precision voltmeter and the frequency counter.

3) An alternative method of measurement, shown in figure 30, employs a high-stability dc voltage source and a precision decade voltage divider. However, it must be determined that the linearity of the voltage divider is not significantly degraded by the loading effect of the input impedance of the sub-carrier oscillator.

4) The measured data can be plotted on a scale with greatly increased resolution if an arbitrary slope (approximating the data slope) is first subtracted from the data. Then a reference line as defined above can be established and the departure of each data point from the reference line can be determined with much higher resolution.

5) Departure from linearity is expressed as a percentage of full deviation range and is given a positive sign when, for a selected input voltage level, the output frequency is greater than the corresponding point on the reference line.

A.7.4 Amplitude modulation

a) Purpose : to determine the change of output signal amplitude as the sub-carrier frequency is changed through the deviation range from one limit to the other.

b) Test procedure

1) Set up as per figure 31.

2) Vary the dc input signal to cause the output frequency to cover the full excursion from one deviation limit to the other, and measure the minimum ($E_{min.}$) and the maximum ($E_{max.}$) output signal amplitudes within the deviation range.

3) Calculate percentage amplitude modulation from the equation :

$$\text{\% Amp. Mod.} = [(E_{max.} - E_{min.})/(E_{min.} + E_{min.})] \times 100 \qquad \ldots (9)$$

4) Adjust the output frequency to centre frequency and reduce the output signal amplitude to 70 % of its former value. Repeat the measurements of amplitude modulation as outlined above.

A.7.5 Output distortion

a) Purpose : to determine the distortion of the output subcarrier waveform at selected output amplitudes and output loads (sine wave outputs only). See also A.7.8.

b) Two methods can be used to measure output distortion, using either a distortion analyzer or a wave analyzer. If a distortion analyzer is used, the effects of all of the distortion-producing components (within the bandwidth of the test instrument) are lumped together. If a wave analyzer is used, it is necessary to search for and measure the amplitude of the individual distortion components and then calculate the distortion, using the same algorithm as would be applied by the distortion analyzer.

c) Test procedure

1) Set up as per figure 32. Care should be taken to use short, unshielded leads between the output terminals and the measuring instruments, since capacitive loading is one of the test parameters.

2) Apply dc input voltages to produce output frequencies corresponding to centre frequency, lower deviation limit, and upper deviation limit respectively. Measure the output distortion at each of these frequencies.

3) Reduce the output subcarrier amplitude to 70 % of maximum amplitude and repeat the measurements outlined in 2) above.

4) Readjust the output amplitude to maximum, and apply a 100 pF capacitive load to the output terminals (in addition to the resistive load).

5) Perform distortion measurements at the three frequencies corresponding to centre frequency, lower deviation limit and upper deviation limit.

6) In the same manner, make distortion measurements with capacitive loads of 500 pF and 1 000 pF.

A.7.6 Effect of source impedance

a) Purpose : to determine the change of output frequency as a function of source impedance variations and to determine the current that is fed back from the input terminals into the source.

b) This test is particularly important on solid-state models which will receive input signals from variable-resistance transducers; the effects are also temperature-dependent [see A.7.1.3 b)].

c) Test procedure

1) Set up as per figure 33.

2) Short the input terminals and measure the output frequency.

3) Adjust the variable resistance decade to 100 Ω. Measure the voltage appearing at the subcarrier oscillator input terminals (use a null voltmeter), and measure the output frequency.

4) In the same manner, measure the input voltages and output frequencies with the following resistance values applied to the input : 1 kΩ, 5 kΩ, 50 kΩ, 100 kΩ and 1 MΩ.

5) Use the frequency measured with the input shorted as a reference for calculations, and express frequency changes in per cent of full deviation range. Calculate the feedback current for each of the input resistance levels, taking into account the impedance of the voltmeter if necessary.

6) If the input voltage versus output frequency characteristics of the sub-carrier oscillator are already known, they can be used to determine the input voltage for each source resistance without the need to use a dc voltmeter.

A.7.7 Effect of grounding input (differential-input models only)

a) Purpose : to measure the effects of grounding the input terminals separately, on the sub-carrier output frequency and amplitude.

b) Test procedure

1) Set up as per figure 34. Confirm that any common-mode voltages present on the output terminals of the dc signal source do not exceed the common-mode capabilities of the sub-carrier oscillator.

2) Ground the chassis of the sub-carrier oscillator.

3) Apply the input voltages recommended by the manufacturer for sub-carrier frequencies corresponding to lower deviation limit, centre frequency, and upper deviation limit. Neither input terminal shall be grounded. Measure the output sub-carrier frequencies and amplitudes corresponding to each of these inputs.

4) Ground one input terminal and apply the same input voltages used in 3) above and again measure the output frequencies and amplitudes.

5) Repeat 4) above with the other input terminal grounded.

6) Using the frequencies and amplitudes measured in 3) above as references for calculations, express the frequency changes as percentages of full deviation range, and express amplitude changes directly in per cent.

A.7.8 Effect of output loading

a) Purpose : to determine the effects of output loading, both resistive and capacitive, on the amplitude and frequency of the output signal.

NOTE — This test may be conducted concurrently with measurements of output distortion (see A.7.5).

b) Test procedure

1) Set up as per figure 35.

2) Adjust the dc input signal to a level that will produce an output frequency equal to the centre frequency.

3) Measure the frequency and amplitude of the output signal with no load applied to the ouput.

4) Using the same input level applied in 2) above, measure the output frequencies and amplitudes for resistive output loads of 2 kΩ, 5 kΩ, 10 kΩ, 20 kΩ and 50 kΩ, excluding any loads in excess of the manufacturer's recommended limit.

5) Remove the resistive load and recheck the output frequency and amplitude; readjust the dc input signal if necessary (i.e. if any drift has occurred) to produce centre frequency.

6) Using the same input level applied in 5) above, measure the output frequencies and amplitudes for capacitive ouput loads of 100, 500 and 1 000 pF.

7) Use the frequencies and amplitudes measured under no-load conditions as references for calculations; express frequency changes as a percentage of full deviation range and express amplitude changes directly in per cent.

A.7.9 Modulation feedthrough

a) Purpose : to determine the amplitude of the modulation-frequency component appearing at the sub-carrier oscillator output.

b) Test procedure

1) Set up as per figure 36.

2) Measure the amplitude of the unmodulated sub-carrier output, i.e. with zero input signal.

3) Adjust the frequency of the signal source to correspond to the maximum modulation frequency for a modulation index of 1, i.e. maximum frequency response as given in table 18. Adjust the peak-to-peak amplitude of the ac signal to produce full sub-carrier deviation; depending on the manufacturer's design it may also be necessary to provide a dc offset signal [see A.7.2 b)].

4) Measure the amplitude of the modulation-frequency component appearing at the sub-carrier oscillator output terminals, using a wave analyzer or similar frequency-selective voltmeter.

5) Repeat 4) above at a modulation frequency of one-half of that selected in 3) above, and then repeat 4) above again at a frequency one-tenth of that selected in 3).

6) Modulation feed-through is expressed in decibels below the sub-carrier and is calculated from the ratio of unmodulated sub-carrier component to modulation component appearing at the output terminals.

A.7.10 Stability versus time

a) Purpose : to determine warming up, reference frequency variations, and sensitivity variations as a function of time.

b) Measurements shall be conducted over a period of 8 h and elapsed time is measured from cold start. Nominal settings of the sensitivity control and the reference frequency control should approximate those which will produce full deviation range output frequency excursion, centred at the appropriate centre frequency, after 30 min or more of operation. Initial tests to make these nominal control settings shall be followed by an adequate cooling time before the start of the main tests.

c) Test procedure

1) Set up as per figure 37. The configuration includes a programmer which switches the sub-carrier oscillator input voltages and provides a count command to the electronic counter. A printer is also shown associated with the counter. Although the

test can be conducted without these two items of test equipment, the uniformity of measurement procedure which they provide is desirable to minimize measurement errors due to human judgment and fatigue.

2) Adjust the reference voltages to the preselected levels for output frequencies corresponding to the lower deviation limit, centre frequency and the upper deviation limit.

3) Energize the sub-carrier oscillator and measure the output frequencies for each of the three input voltages at the end of one minute elapsed time. Make similar measurements at one-minute intervals for the first 10 min.

4) After 10 min make measurements at 5-minute intervals until an elapsed time of 1 h has occurred.

5) After 1 h, make measurements at 30-minute intervals until an elapsed time of 8 h has occurred.

6) Sensitivity instability is defined as the variation of full scale output frequency excursion (resulting from full-scale input voltage excursion) expressed as a percentage of full scale ouput excursion measured at an elapsed time of 30 min. Reference frequency shift is defined as the variation of output frequency for zero input, expressed as a percentage of full scale output frequency excursion measured at an elapsed time of 30 min. Sensitivity change is given a positive sign when full scale output excursion is greater than that measured at the reference time of 30 min. Reference frequency shift is given a positive sign when the output frequency is greater than that measured at the reference time of 30 min.

A.7.11 Effects of supply voltage variation and ripple

a) Purpose : to determine the effect of supply voltage changes and ripple on output frequency and amplitude.

b) Test procedure

1) Set up as per figure 38.

2) Adjust the supply voltage to the nominal value recommanded by the manufacturer (do not apply a ripple voltage).

3) Adjust the dc input signal to the sub-carrier oscillator to produce first the lower deviation limit frequency, then centre frequency, and finally upper deviation limit. Note the input voltages required to produce each of the three output frequencies, and measure the sub-carrier output amplitude at each of these frequencies.

4) Reduce the supply voltage by 10 % of the nominal level and again measure the output frequencies and amplitudes for each of the three input signal voltage levels used in the previous measurement.

5) Make similar measurements with the supply voltages changed by −5 %, + 5 %, + 10 %, and back to nominal level again. (The measurement range may be expanded if required for specific system applications.)

6) Using the frequencies and amplitudes measured in 3) above as references, calculate the frequency changes as a percentage of full deviation range and calculate the amplitude changes directly in per cent. The changes are given a positive sign when they represent an increase in magnitude.

7) Apply nominal supply voltage to the sub-carrier oscillator, adjust the dc input signal to produce centre frequency output, and superimpose a sinusoidal signal of 60 Hz on the supply voltage. Adjust the rms value of the ripple to 2 % of the nominal supply voltage, and measure the frequency deviation of the sub-carrier oscillator (the output excursion of the sub-carrier discriminator is proportional to the sub-carrier oscillator frequency deviation).

8) Conduct similar measurements at ripple frequencies of 200, 400, 600, 800 and 1 000 Hz.

9) Express the peak-to-peak frequency deviations as percentages of full deviation range.

A.7.12 Common-mode rejection (for differential-input models only)

a) Purpose : to determine the effect on output frequency resulting from application of a common signal to both input terminals.

b) Test procedure

1) Set up as per figure 39.

2) With the sub-carrier oscillator terminals shorted together and connected to ground, measure the sub-carrier output frequency.

3) Connect the shorted input terminals to a dc voltage (reference to ground) and adjust the dc voltage to equal the magnitude of the full scale common-mode input recommended by the manufacturer.

4) Measure the sub-carrier output frequency, first, with a positive polarity applied to the input, and then with a negative polarity applied to the input.

5) Connect an ac voltage source to the shorted input terminals, and adjust the peak-to-peak amplitude of the ac signal to equal the magnitude of the full scale common-mode input recommended by the manufacturer.

6) Adjust the frequency of the ac input signal to that which would produce a modulation index of 1 for the band under test, i.e. maximum frequency response as given in table 16. Use a low-noise sub-carrier discriminator and ac voltmeter to determine the frequency deviation of the sub-carrier oscillator output caused by the common-mode signal. Repeat the measurement at frequencies of 60 Hz and 400 Hz, if these frequencies fall within the modulation-frequency range of the sub-carrier oscillator under test.

NOTE — The discriminator must be calibrated at each of the modulation frequencies.

7) Compare the frequencies measured in 4) above with that measured in 2) above and calculate the output frequency deviations. Frequency deviations in 6) above are obtained from measurements of the output of the calibrated discriminator. Convert these deviations to the ones which would have been produced by the recommended full scale differential input, i.e. multiply the calculated deviations by the factor

$$\frac{\text{full scale differential input}}{\text{full scale common-mode input}}$$

neglecting any effects due to non-linearity.

8) Common-mode rejection is the ratio of full scale sub-carrier deviation to converted deviations as determined in 7) above, expressed in decibels.

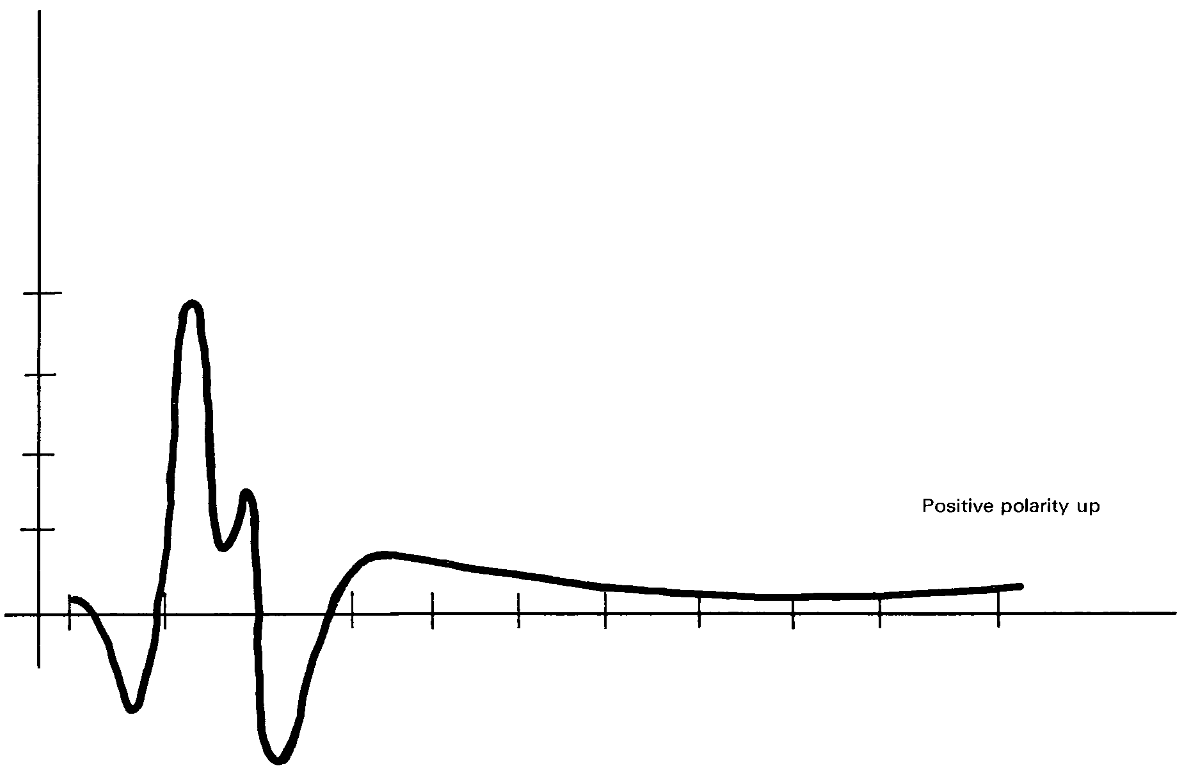
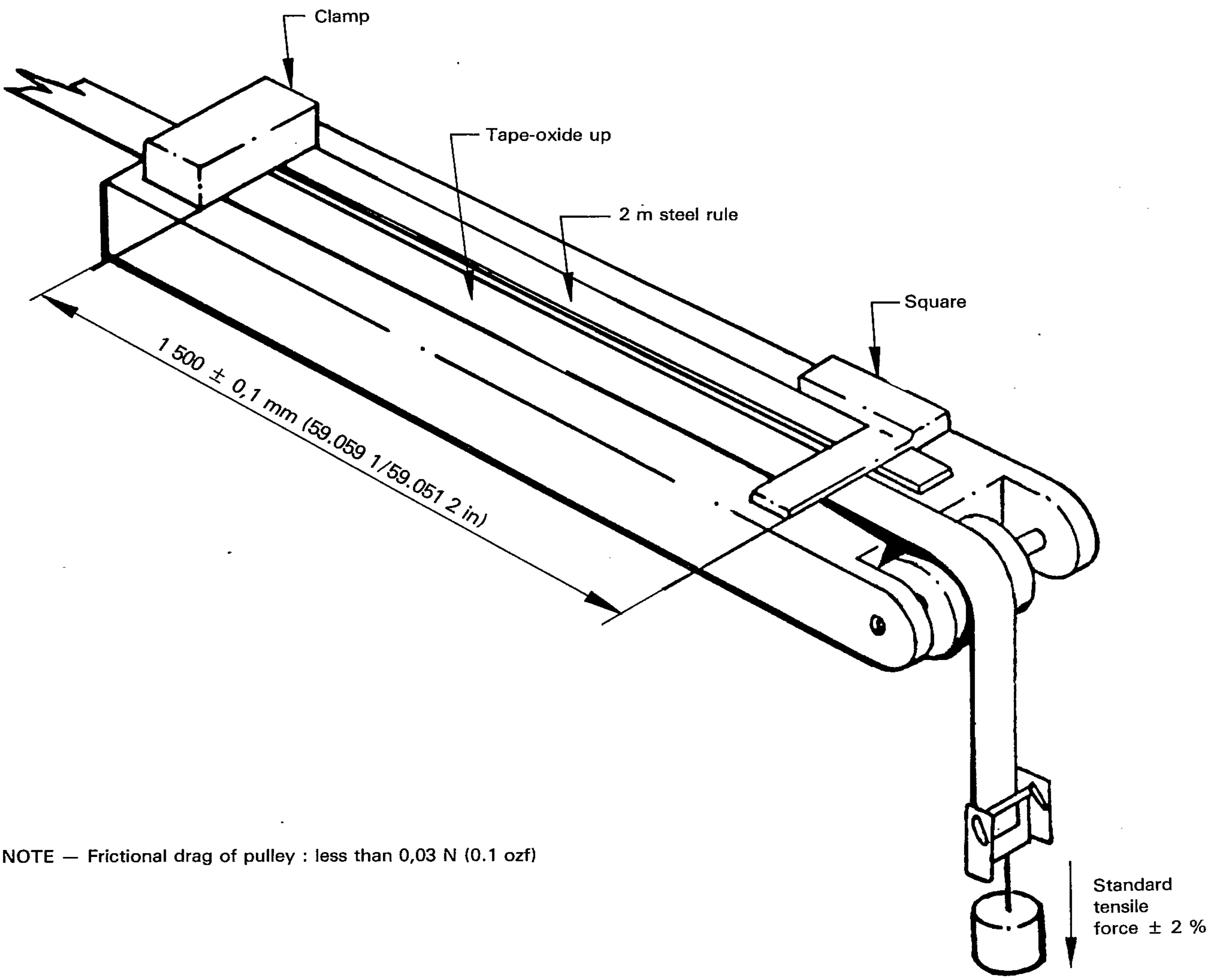


Figure 8 — Typical waveform obtained from head polarity test



NOTE — Frictional drag of pulley : less than 0,03 N (0.1 ozf)

Figure 9 — Speed test-tape preparation

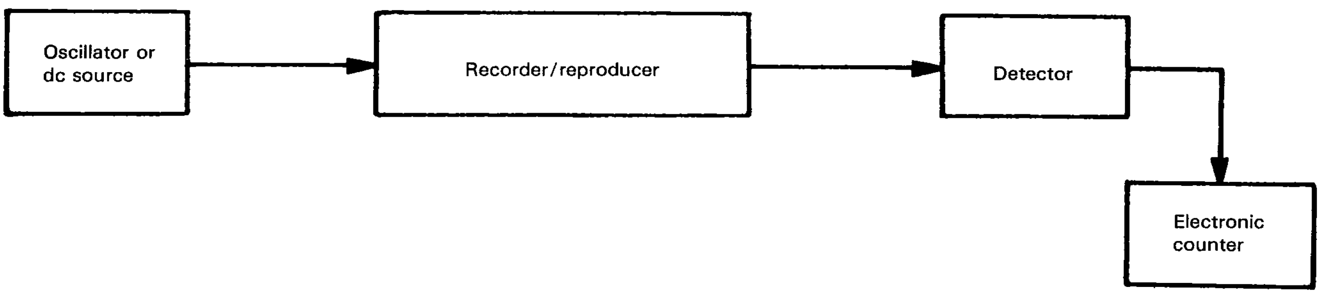
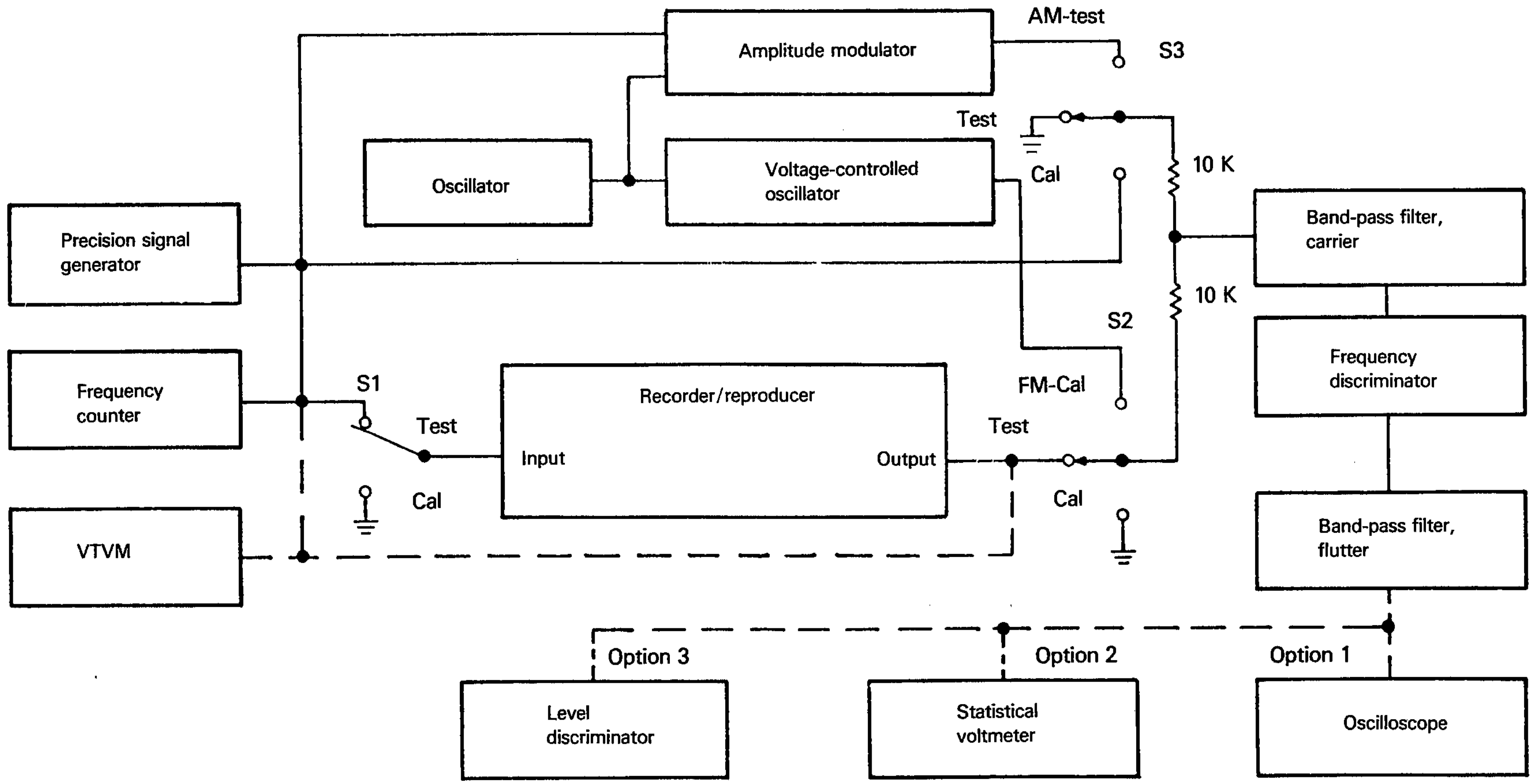


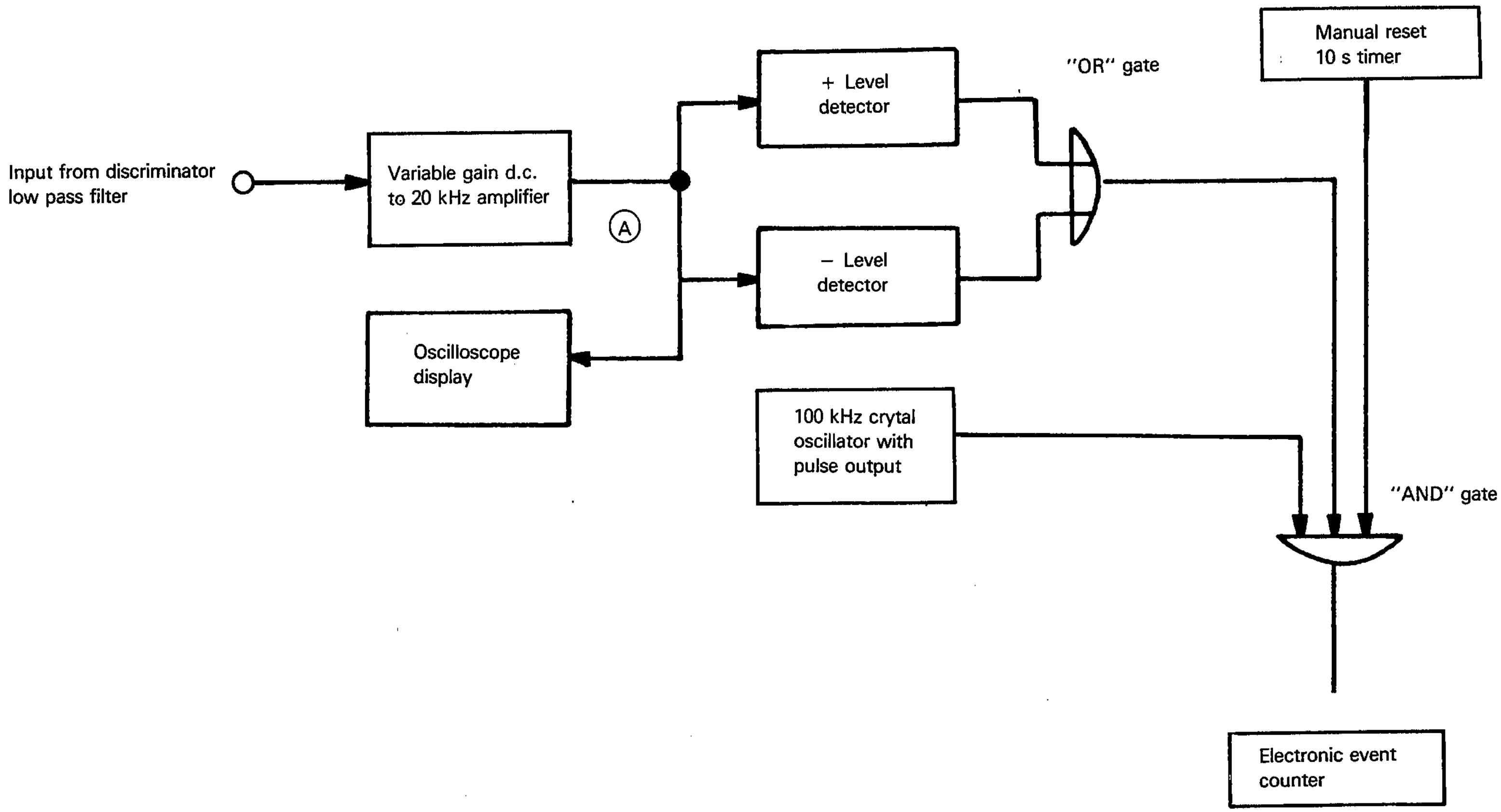
Figure 10 — Tape speed — Method I



Switch setting

	Discriminator calibration Static	Discriminator calibration Dynamic	Discriminator noise calibration	Discriminator AM susceptibility calibration	Flutter test
S1	Cal	Cal	Cal	Cal	Test
S2	Cal	FM-Cal	Test	Cal	Test
S3	Cal	Test	Cal	AM-test	Test

Figure 11 — Flutter test



a) 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.

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

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

d) 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.

e) Variable gain dc amplifier must have capability to produce gains of less than one as well as gains greater than one.

Figure 12 — Block diagram, level detector for digitized flutter measurement

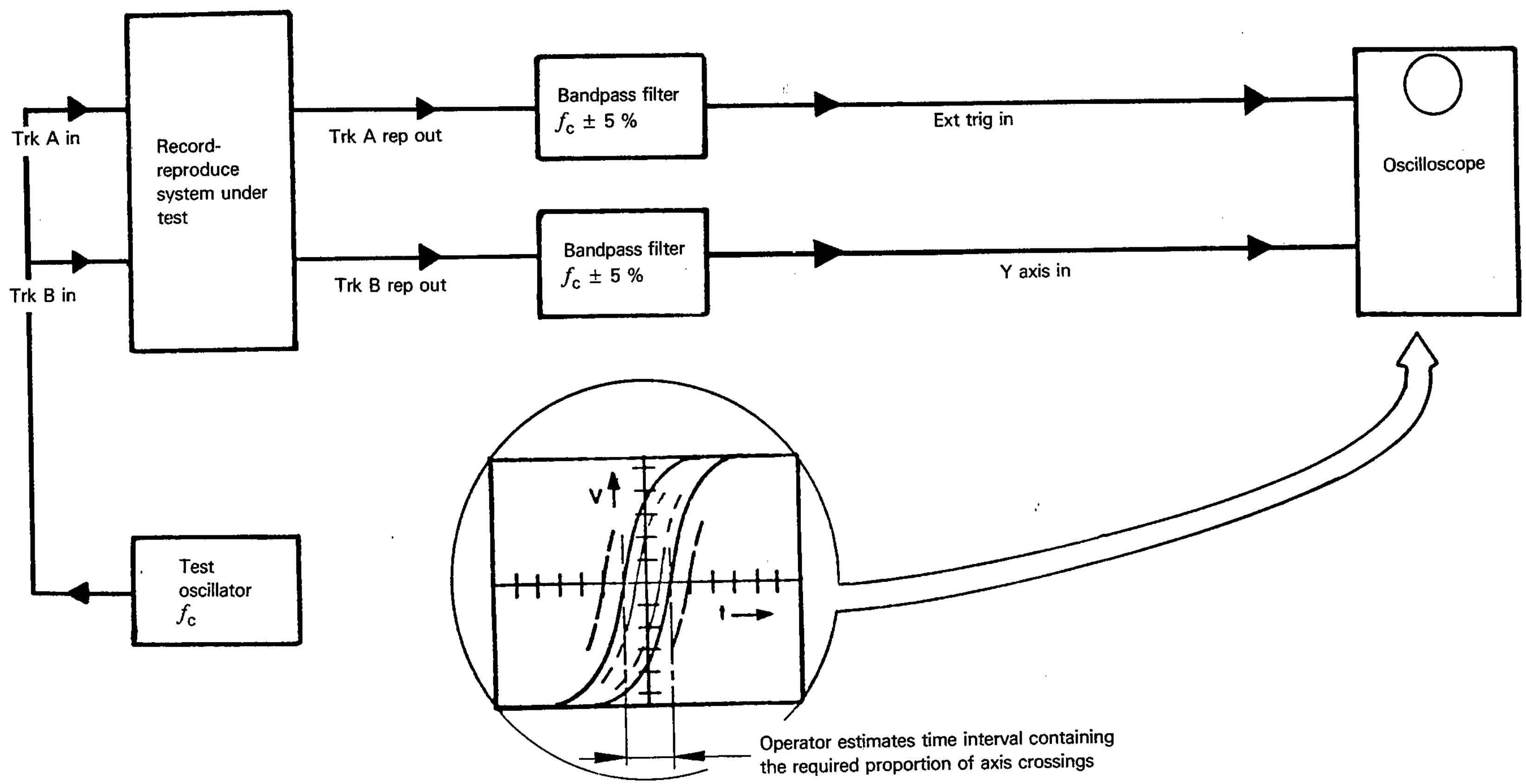


Figure 13 — ITDE measurement

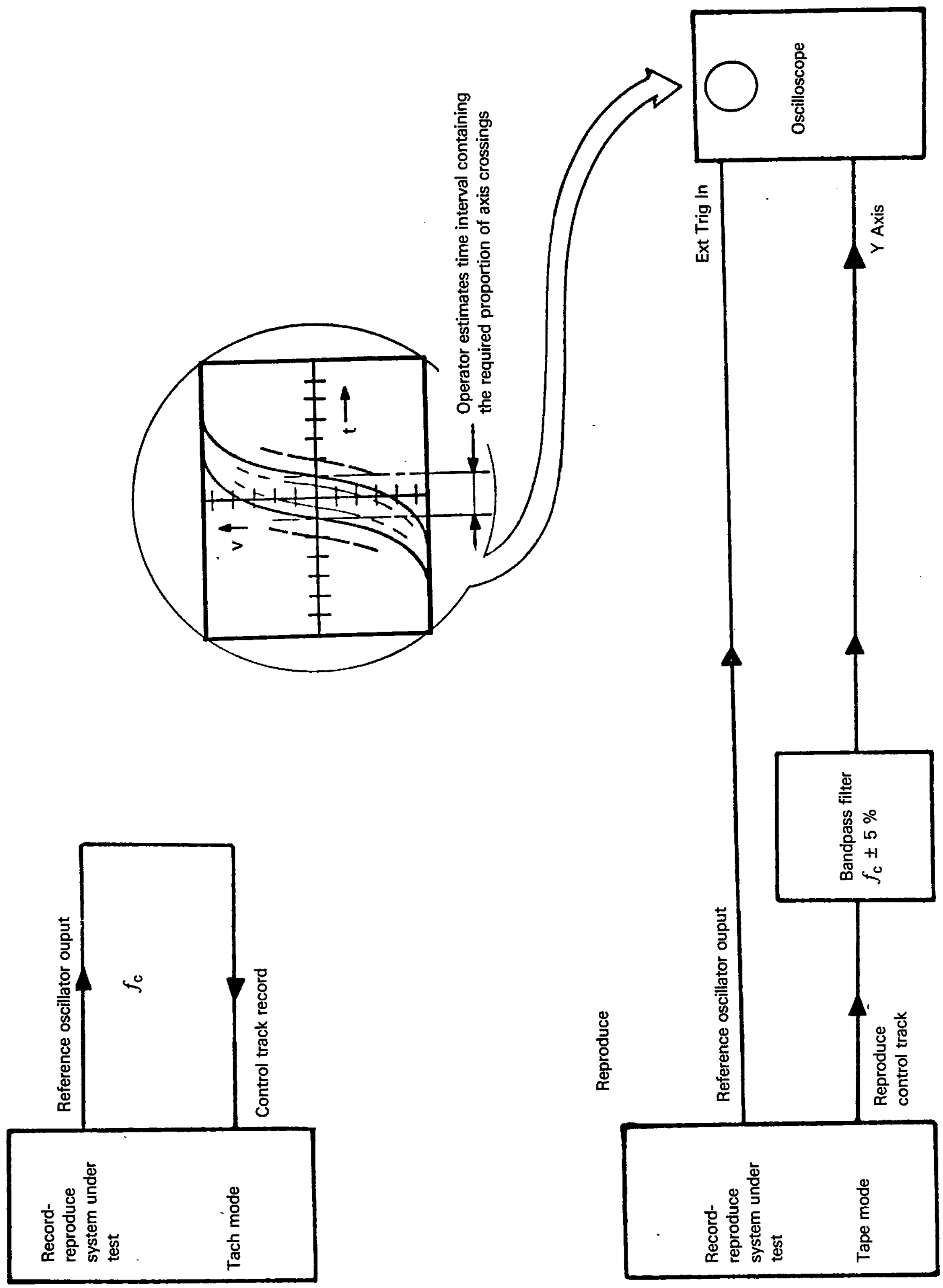


Figure 14 — TBE measurement

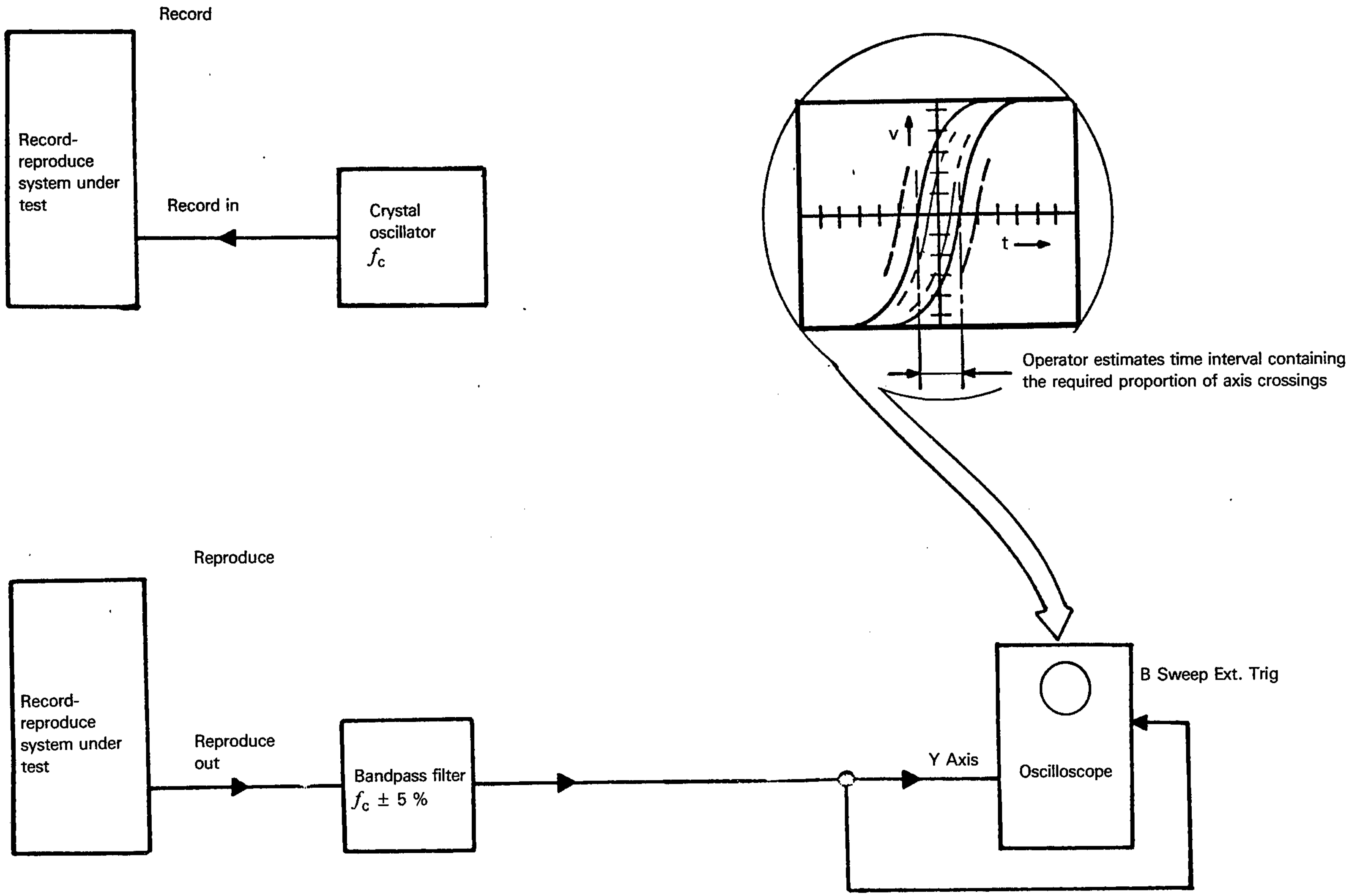


Figure 15 — Jitter measurement

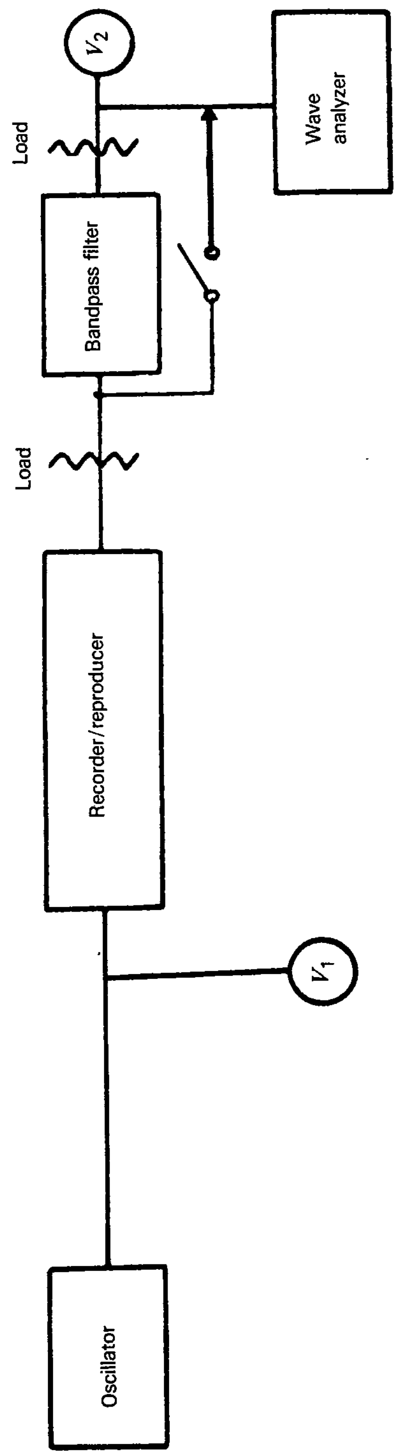


Figure 16 — Frequency response and signal-to-noise ratio

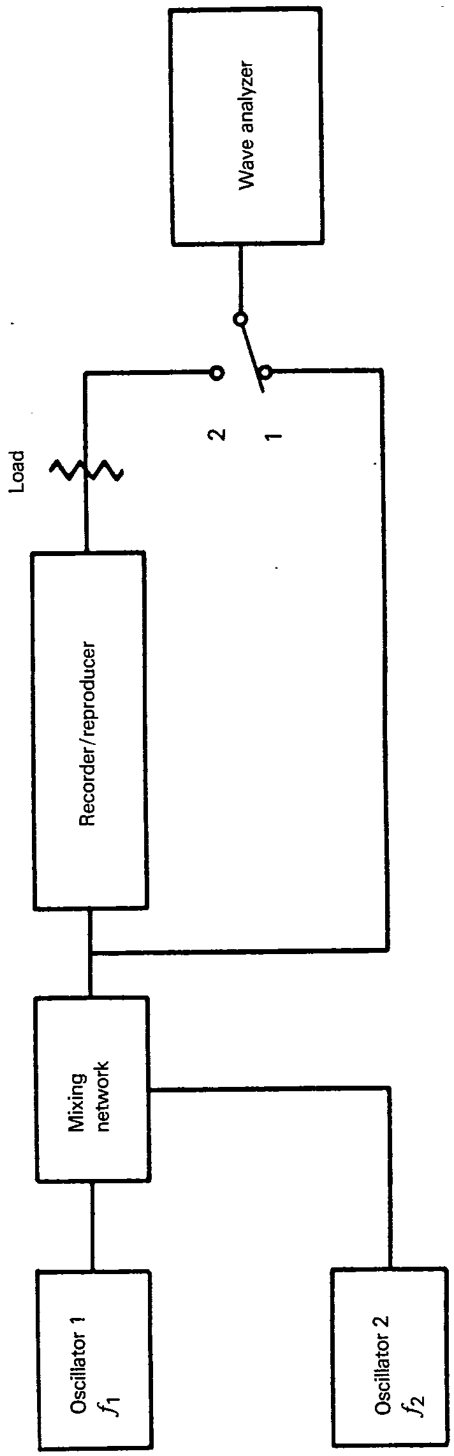
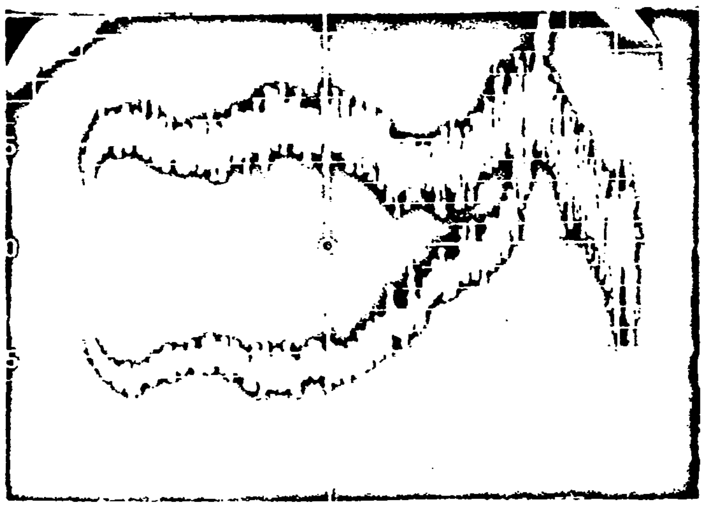


Figure 17 — Intermodulation distortion test

Group delay

Group attenuation



Vertical delay scale : 100 ns/small division

Vertical attenuation scale : 0,2 dB/small division

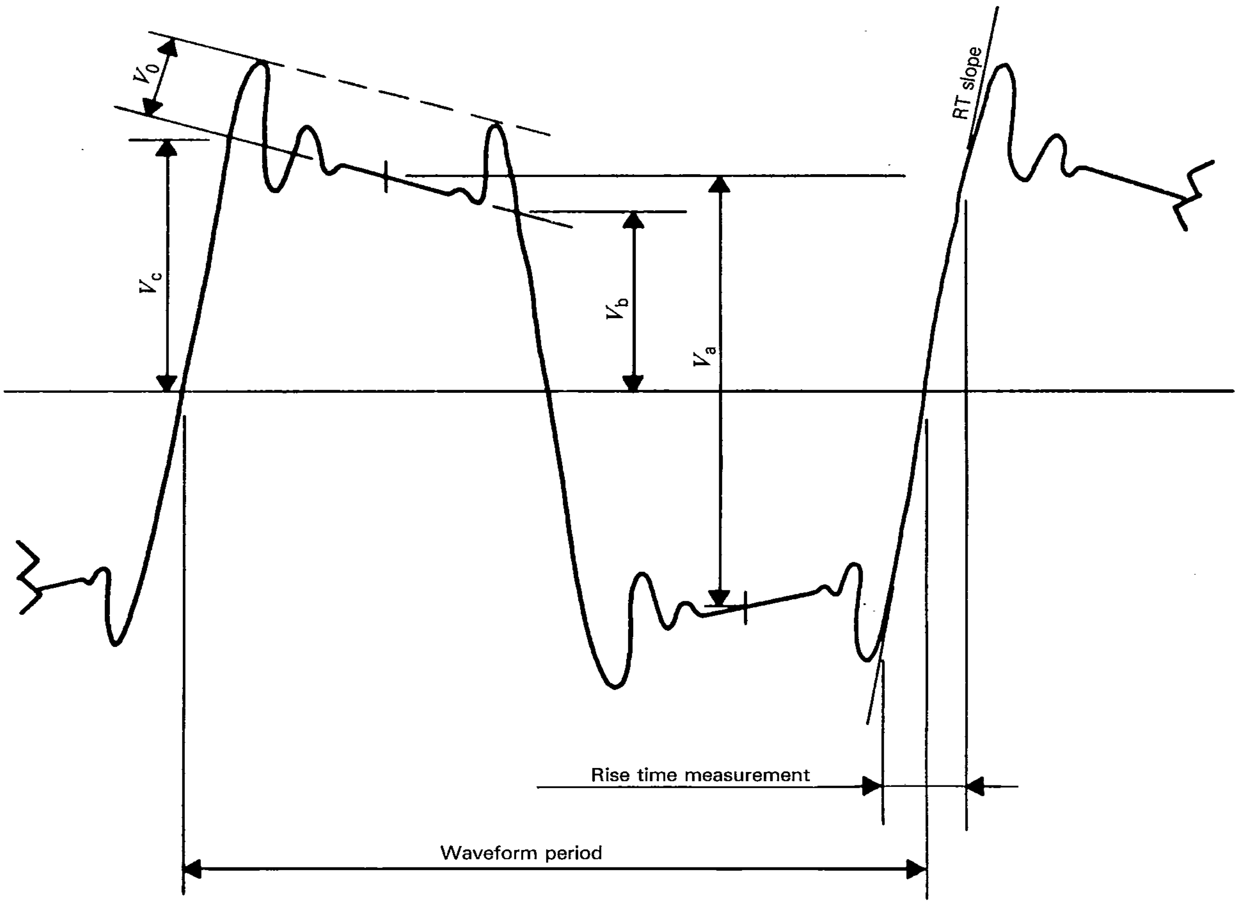
Horizontal scale : 200 kHz per division, traces beginning at 100 kHz

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 18 — Group delay variation test for wideband recorders



Signal peak-to-peak amplitude : V_a

% overshoot : $\left(\frac{V_0}{V_a}\right) \times 100$

% tilt : $\left(\frac{V_c - V_b}{V_a}\right) \times 100$

NOTES

1 Conventional rise time : 40 % of time required for amplitude of RT slope to increase V_a.

2 Overshoot or preshoot may occur on leading or trailing edge portion of pulses. Largest amplitude of overshoot is measured.

Figure 19 — Waveform parameters for transient response measurement

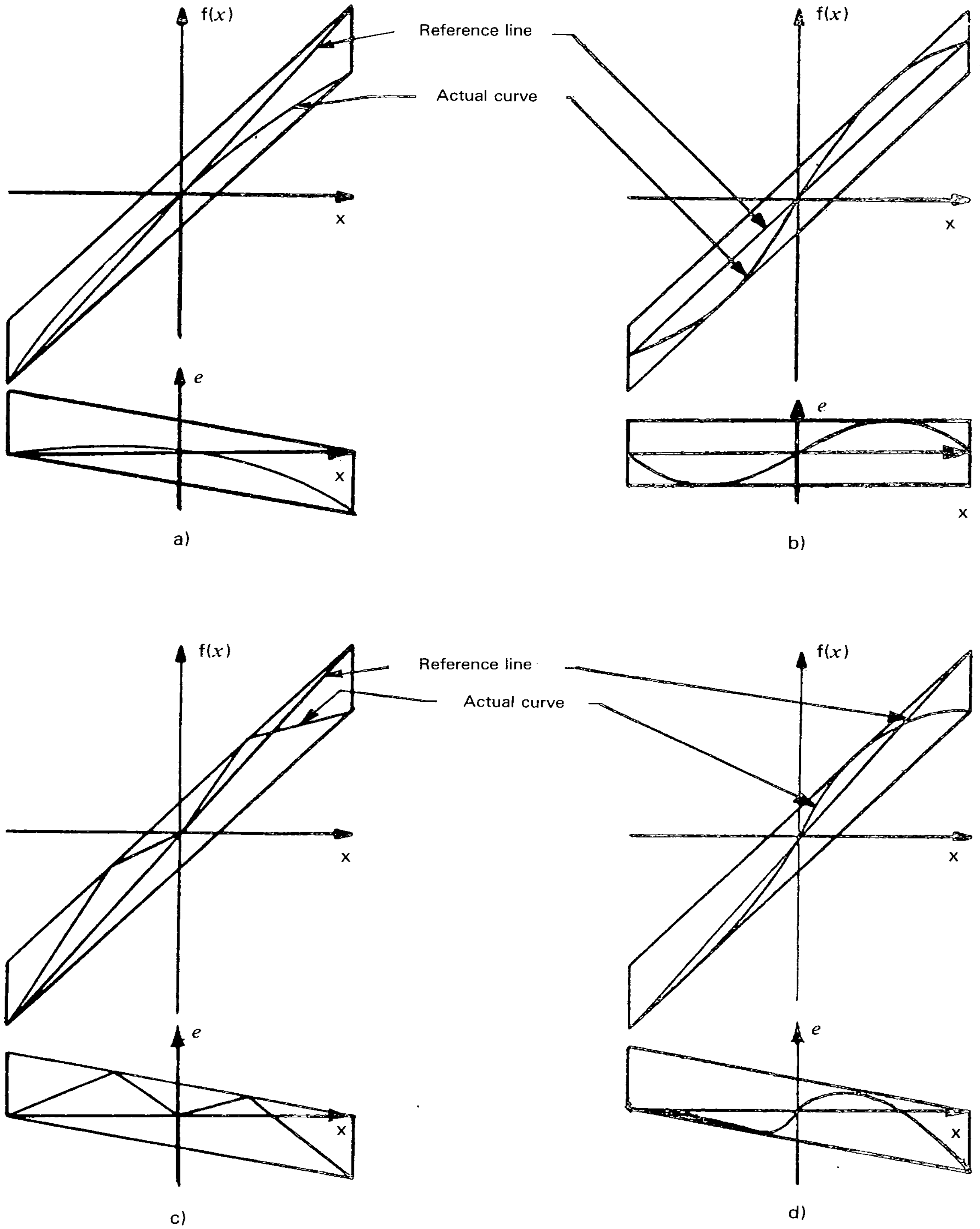


Figure 20 — DC linearity curves

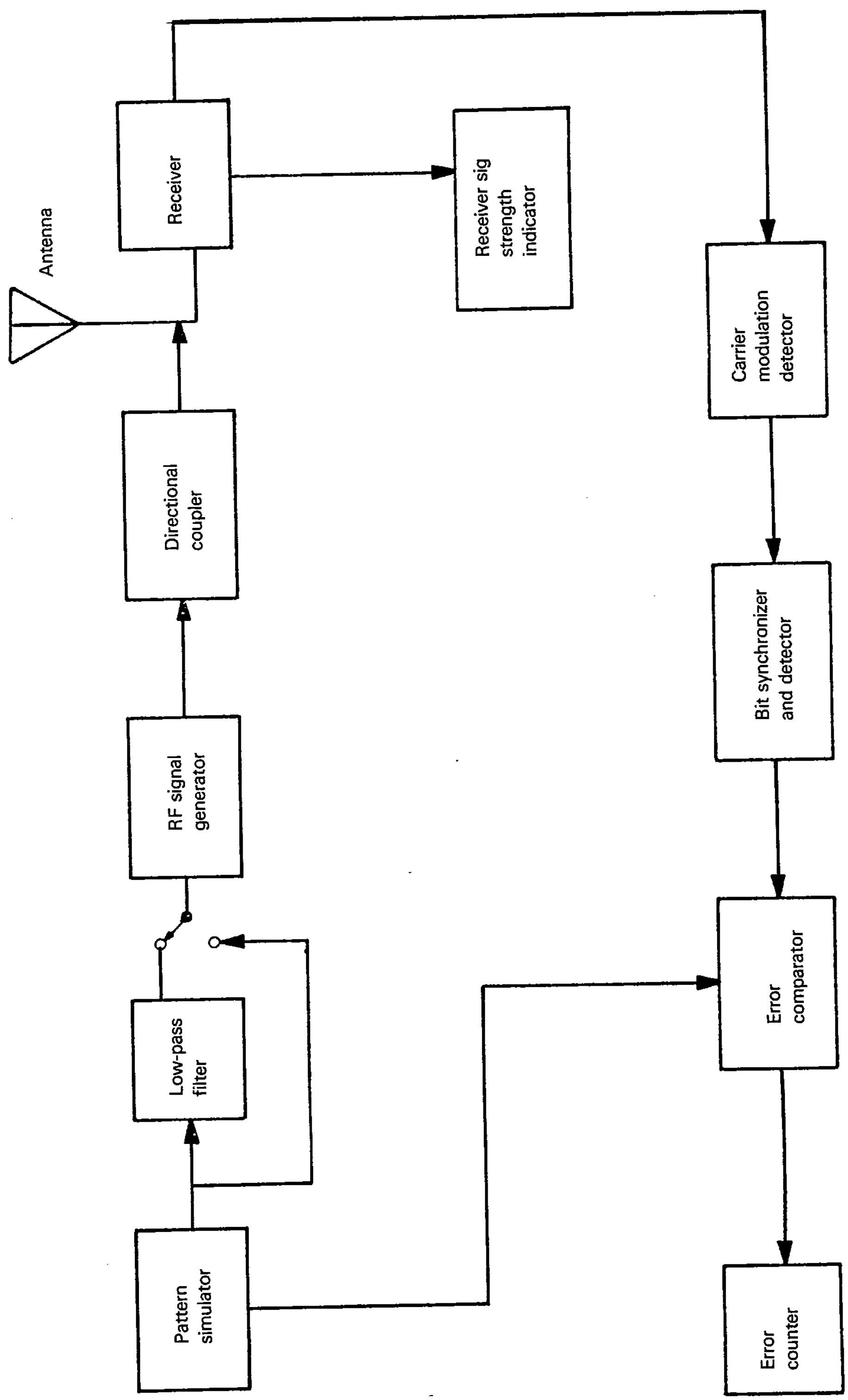
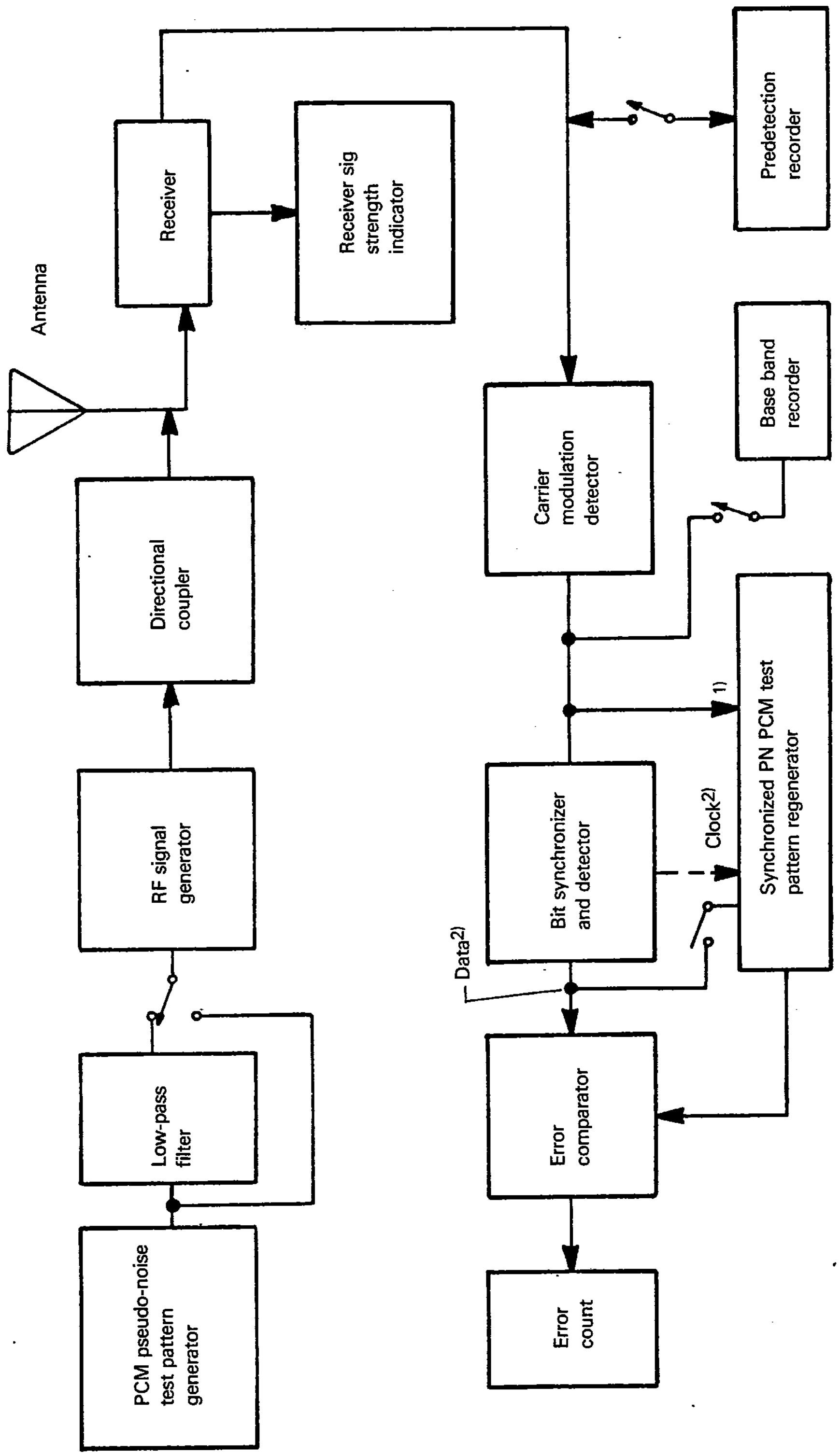


Figure 21 — PCM simulator test method (real time)



1) Use in coherent synchronization.

2) Use in noncoherent synchronization.

Figure 22 — Pseudo-noise (PN) autocorrelation method

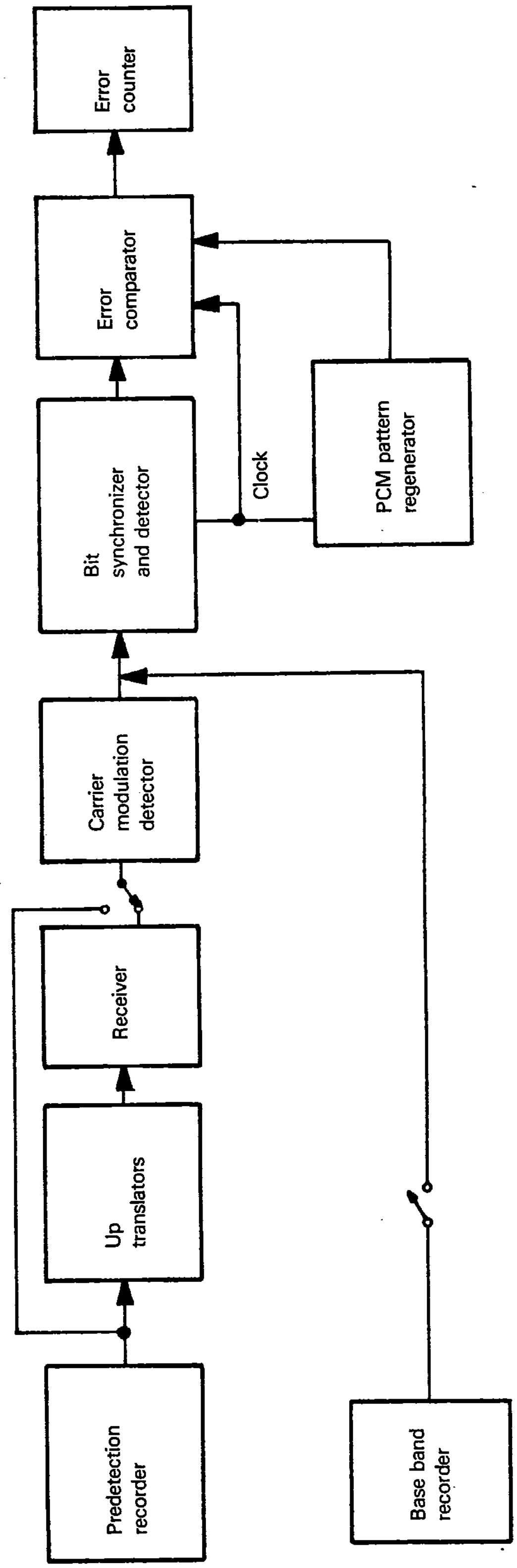


Figure 23 — PCM simulator method (post time)

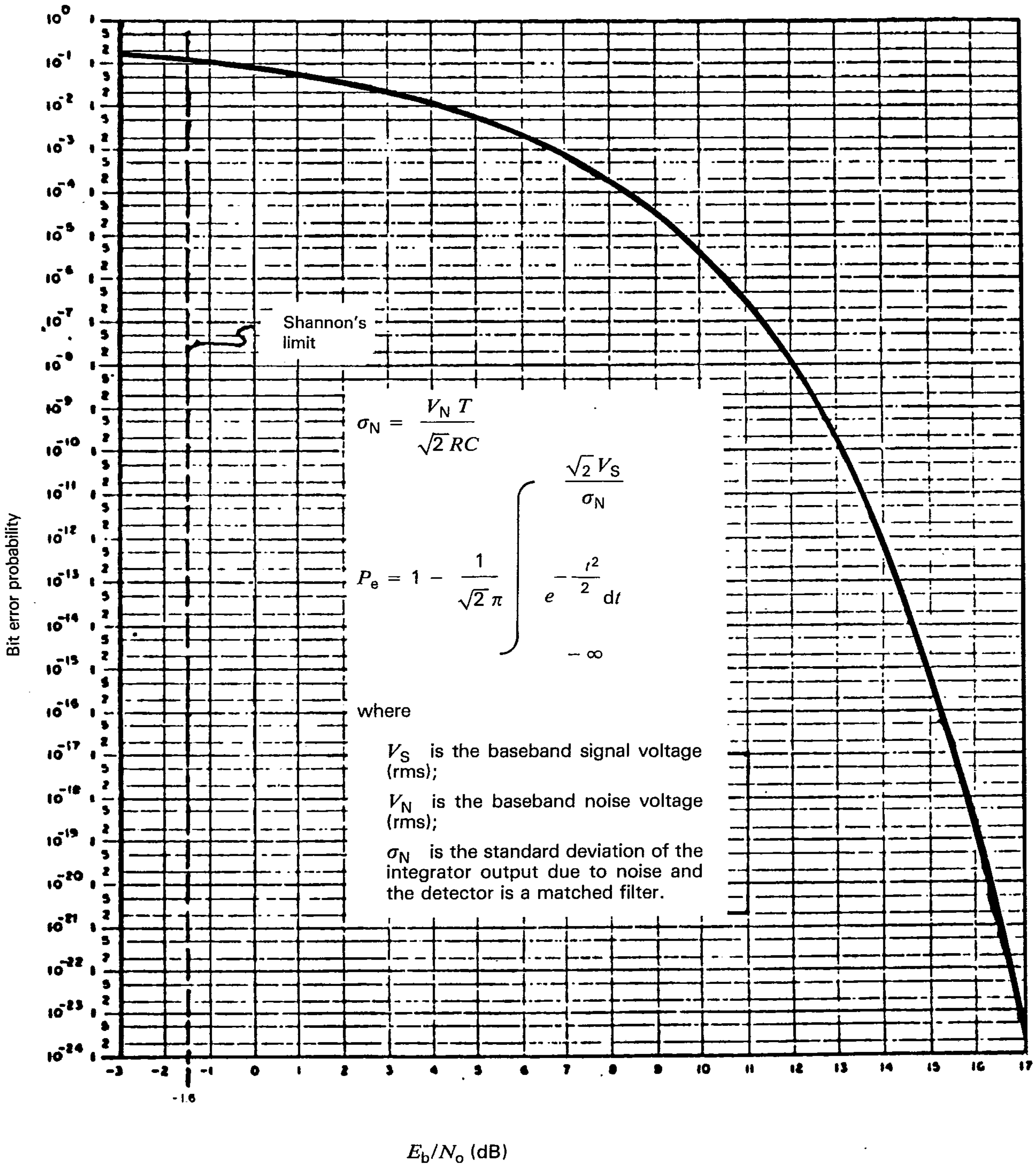


Figure 24 — Optimum theoretical performance for bit error rate versus normalized signal-to-noise ratio

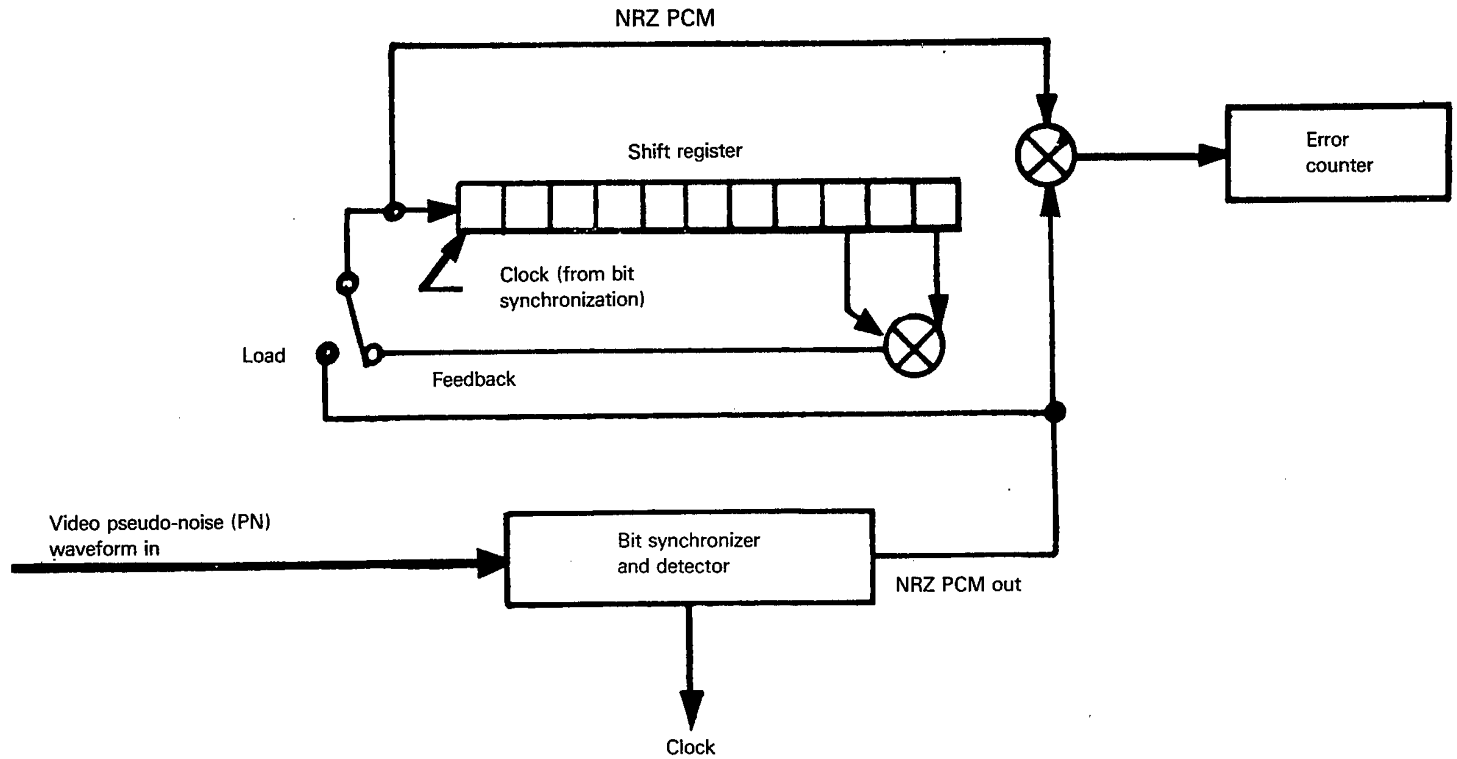
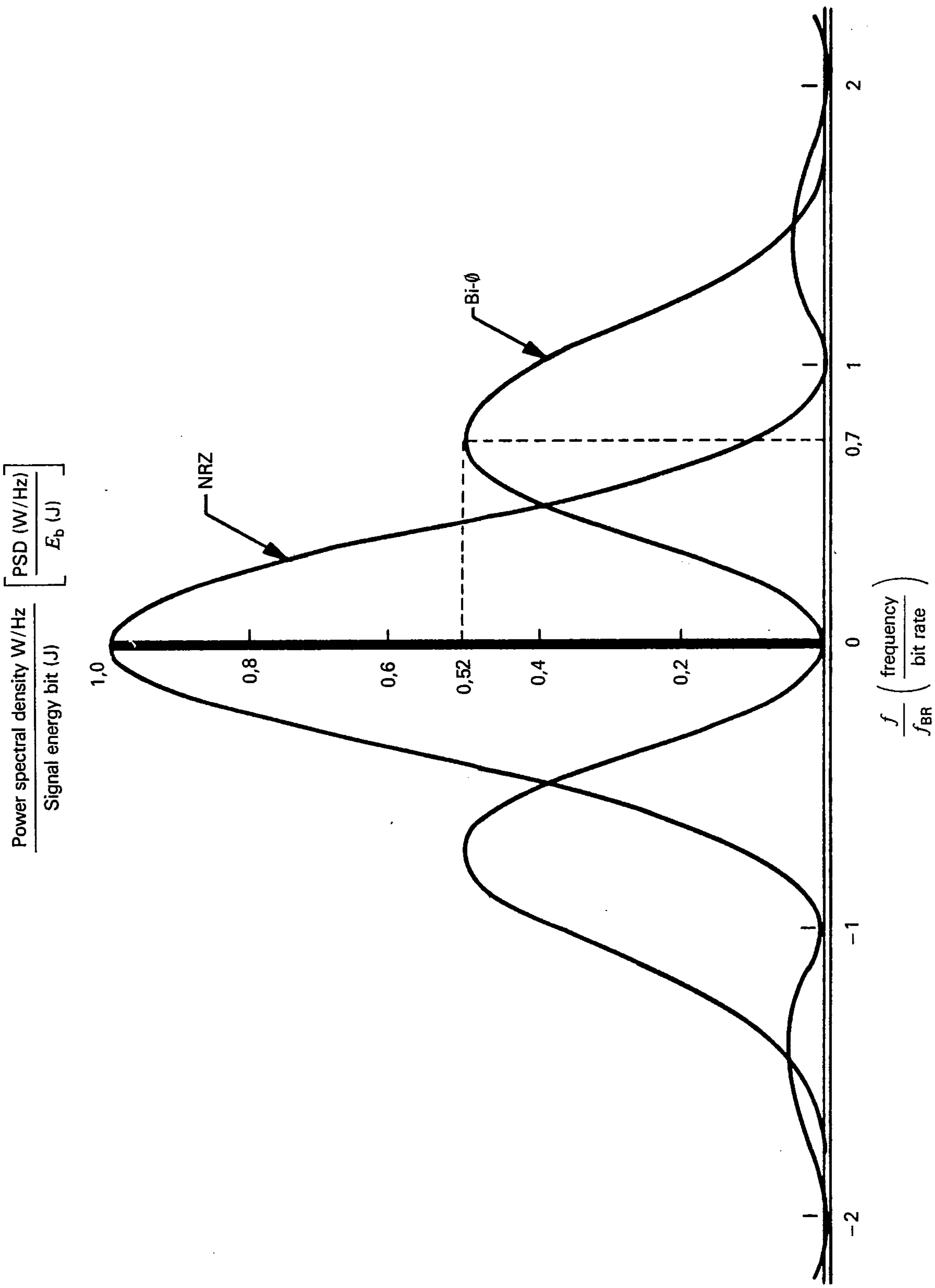


Figure 25 — Non-coherent pseudo-noise (PN) — PCM synchronizer



NOTE — PSD = Power Spectral Density

Figure 26 — Power spectra for random PCM

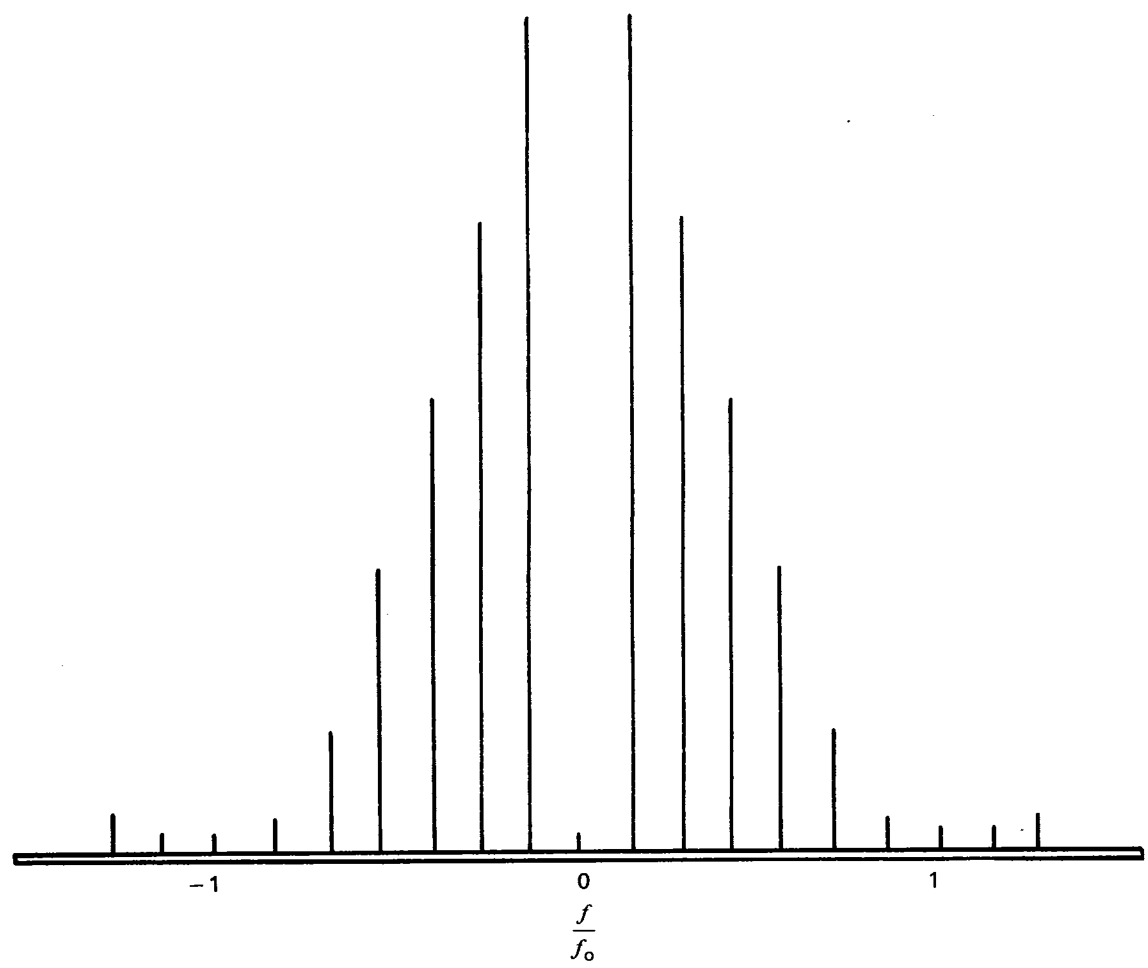


Figure 27 — Spectrum of NRZ-pseudo-noise (PN) sequence of length 7 bits

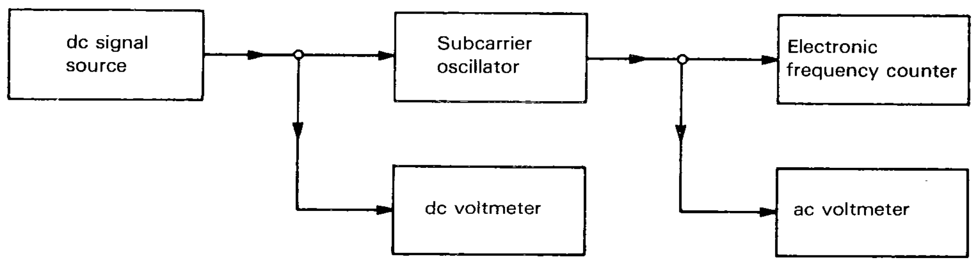


Figure 28 — Equipment configuration for control range(s) test(s)

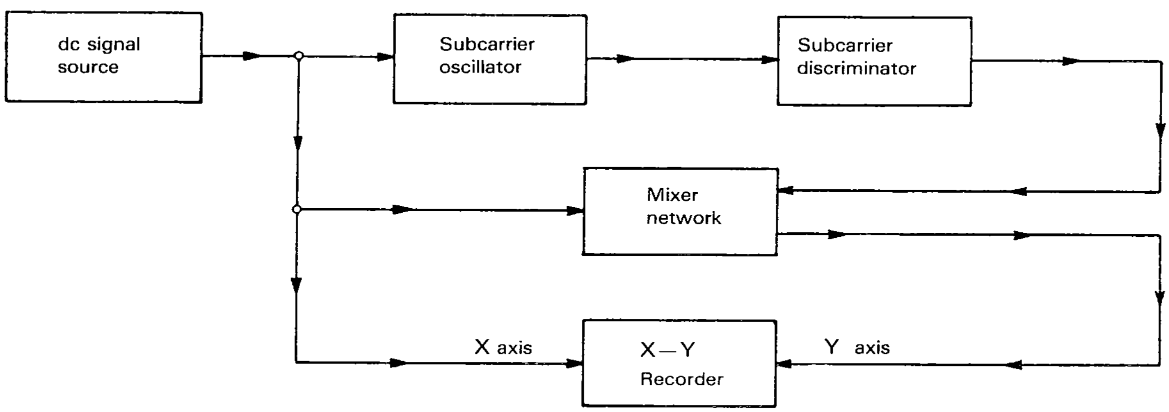


Figure 29 — Equipment configuration for linearity measurement, method no. 1

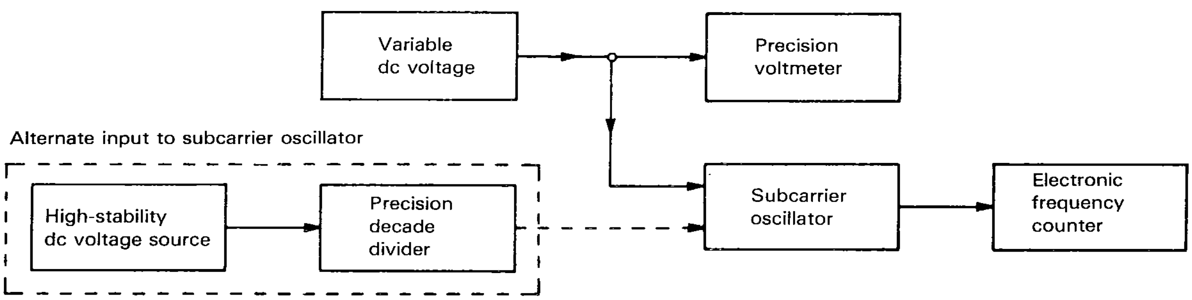


Figure 30 — Equipment configuration for linearity measurement, method no. 2

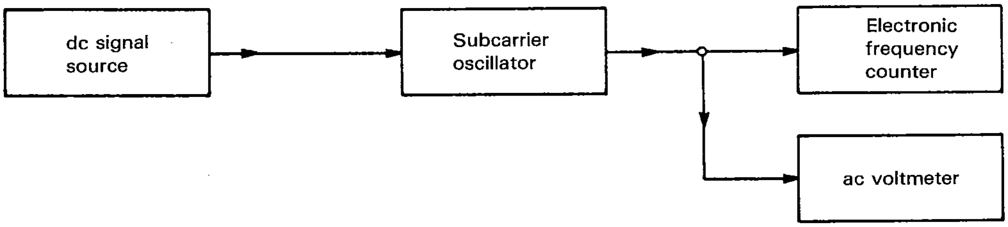


Figure 31 — Equipment configuration for amplitude modulation test

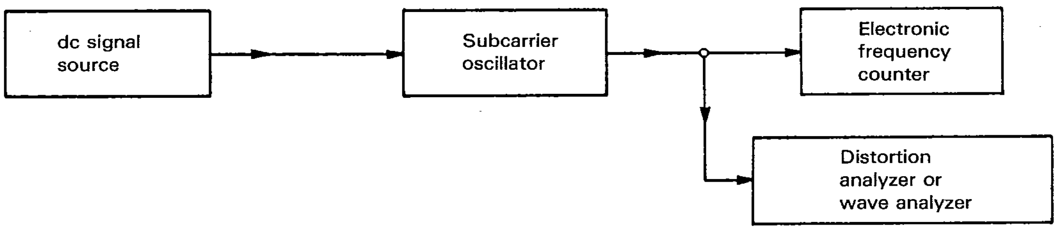


Figure 32 — Equipment configuration for output distortion test

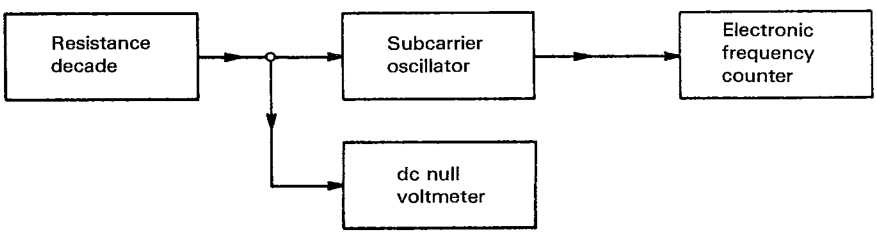


Figure 33 — Equipment configuration for source impedance test

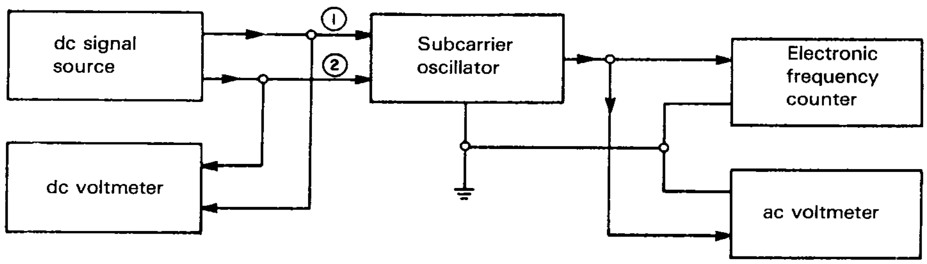


Figure 34 — Equipment configuration for input grounding test

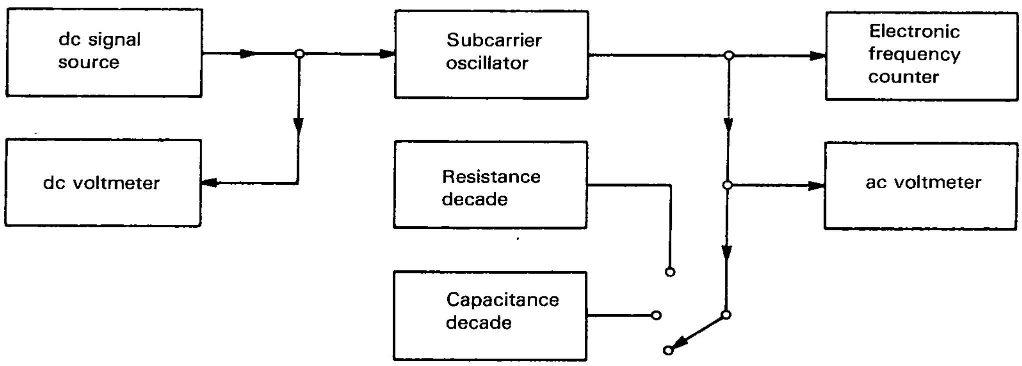


Figure 35 — Equipment configuration for output loading test

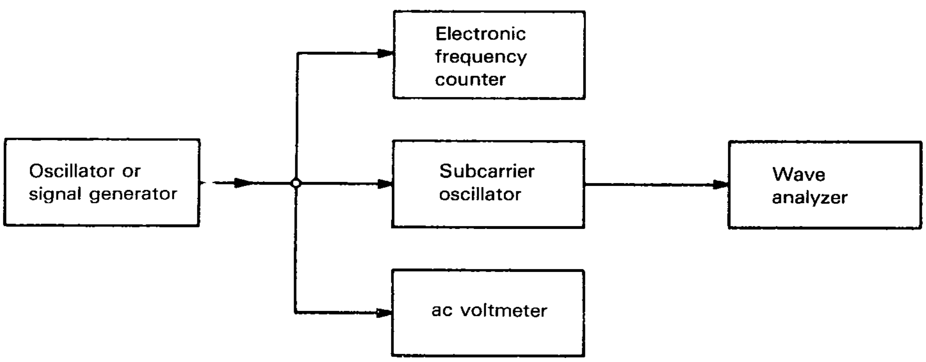


Figure 36 — Equipment configuration for modulation feedthrough test

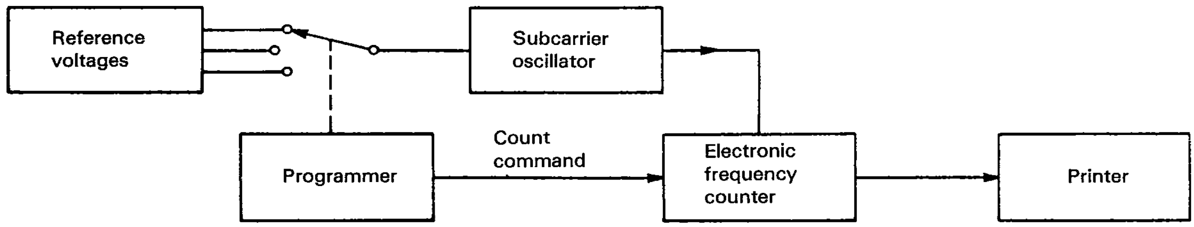


Figure 37 — Equipment configuration for stability versus time test

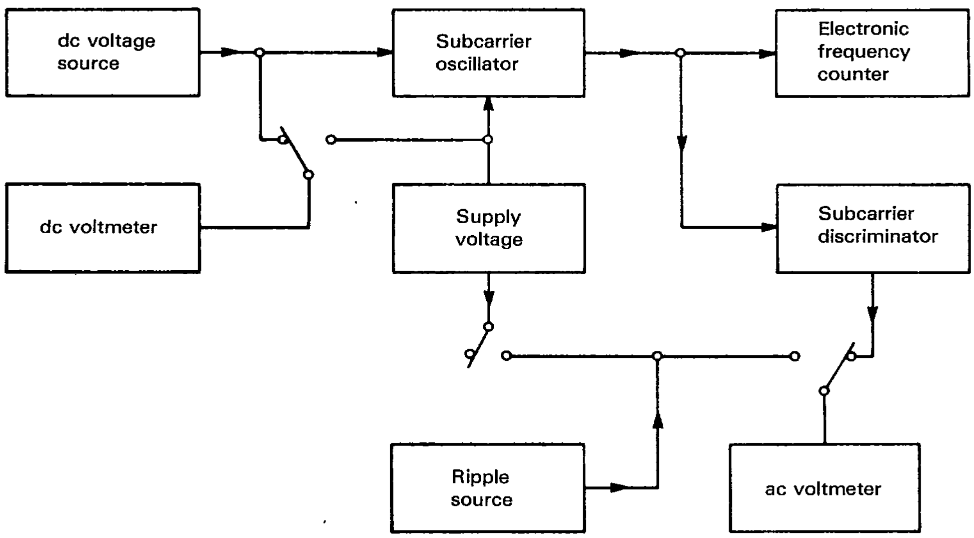


Figure 38 — Equipment configuration for supply voltage variation and ripple tests

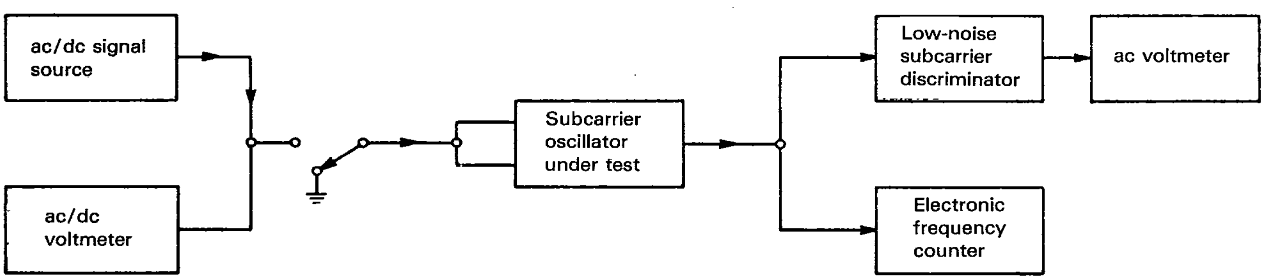


Figure 39 — Equipment configuration for common-mode rejection test

Annex B

Magnetic tape recorder/reproducer information and use criteria

(This annex does not form part of the standard.)

B.1 Configurations not as yet included in this International Standard

B.1.1 Extended wide-band DR recording (see 5.1.1.1)

Systems have been demonstrated using special heads and modified electronics, and special high-output magnetic tape, which will give direct recording down to wavelengths of 1 μm (40 μin) or lower (a bandwidth of at least 1,5 MHz at 1 524 mm/s (60 in/s) without serious degradation of system signal-to-noise ratio. If field experience proves these systems reliable over a reasonable operating time, economies in tape use could result.

B.1.2 High-density PCM (see 6.3.8)

Several methods for recording serial PCM data at bit-packing densities of 800 bits/mm (20 000 bits/in) or greater have become available. The encoding methods are designed to avoid the need for very low frequency response by ensuring the presence of an adequate number of flux transitions, while at the same time attempting to constrain the overall bandwidth required, although nominal bandwidth is not necessarily the only criterion. The methods include the techniques known as delay modulation ("Miller code") and enhanced-NRZ as well as the Bi-phase formats defined in figure 1.

For these systems wide-band DR instrumentation recorders are employed but special record and reproduce electronics are required. Such systems appear attractive for recording large quantities of PCM data and consideration is being given to the preparation of International Standards in this area.

B.2 Head polarity (see 4.5.7)

The requirement that a positive pulse at a record amplifier input generate a south-north-north-south magnetic sequence and that a south-north-north-south magnetic sequence on tape produces a positive pulse at the reproduce amplifier output still leaves two interdependent parameters unspecified. These are

a) polarity inversion or non-inversion in record and/or playback amplifiers, and,

b) record or playback head winding sense.

For purposes of head replacement it is necessary that these parameters be determined so that an unsuspected polarity inversion on-tape or off-tape will not occur after heads are replaced.

B.3 Record level (see 5.1.3.4)

Normal record level is established as the level of a sinusoidal signal of 0,1 upper band edge frequency which, when recorded, results in an output signal having 1 % third harmonic distortion. This level will seldom be optimum for data recording. Signals having noise-like spectral distribution, such as FM/FM telemetry signals, contain high crest factors and should be recorded well below the 0 dB normal record level. Other signals may have to be recorded above the normal record level to give optimum performance in the data system.

Crossplay of tapes from older low- and intermediate-band DR machines on wide-band DR machines will exhibit bias signal output due to the higher resolution of the wide-band reproduce heads and the relatively low bias frequencies employed.

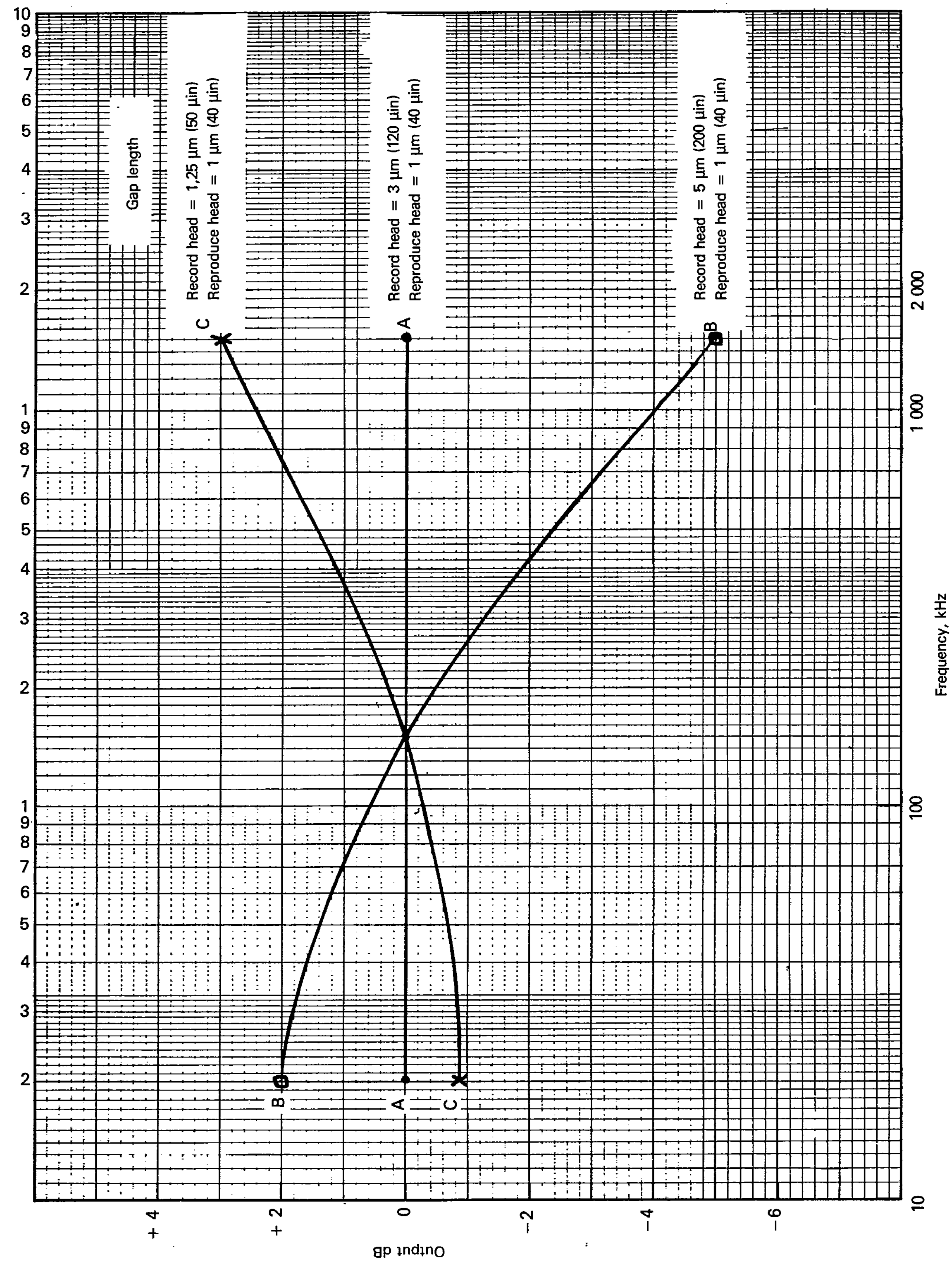
B.4 Tape crossplay considerations (wide-band DR) (see 5.1.3.3)

Figure 40 illustrates the typical departure from optimum frequency response that may result when crossplaying wide-band tapes which were recorded with heads employing different record head gap lengths. Line AA is the idealized output versus frequency plot of a machine running with wide-band 1,5 MHz DR response at 3 048 mm/s (120 in/s). Record bias and record level were set up per this International Standard, using a 3 μm (120 μin) record head gap length and a 1 μm (40 μin) reproduce head gap length. Lines BB and CC represent the output response curves of the same tapes recorded on machines with 5 μm (200 μin) and 1,25 μm (50 μin) record head gap lengths, respectively. Each of these recorders was set up individually per this International Standard. The tapes were then reproduced on the machine having a 1 µm (40 µin) reproduce head gap length without readjusting its reproduce equalization.

The output curves have been normalized to zero decibels at the 1/10th upper band-edge frequency for the purpose of clarity. The normalized curves may be expected to exhibit a plus or minus 2 dB variance in relative output over the pass band. The tape recorded with the shortest gap length heads will provide the greatest relative output at the upper band-edge.

Because of the fact that the recorder/reproducer setup procedures do not establish a uniform recorded flux density on the tape for different heads, it is recommended that crossplay of tapes between different machines be undertaken with great care.

One method of normalizing the record-playback transfer function is to record a calibration signal sequence on each tape leader so that equalization and gain of the reproduce amplifiers may be properly adjusted during the reproduce process. First, an upper band-edge sinusoidal signal should be recorded on at least one odd-numbered and one even-numbered track for adjustment of reproduce-head azimuth. Then it is recommended that a 1/10 upper band-edge sinusoidal signal set at normal record level followed by a band-limited white noise signal set 6 dB below normal record level be recorded on each track. Gain is adjusted using the sinusoidal signal and equalization is adjusted with the recorded white noise. It is important that the noise generator signal be low-pass filtered at the upper band-edge of the recorder/reproducer response being employed. Most reproduce amplifier inputs are not band-limited, and out-of-band noise contributes to front end saturation or overload effects which will result in excessive intermodulation noise in the desired pass band.



(Tape speed : 3 048 mm/s (120 in/s)

Figure 40 — Effect of record head gap length on frequency response (wideband 1,5 HMz DR)

Annex C

Additional notes for the testing of magnetic tape recorder/reproducers

(This annex does not form part of the standard.)

C.1 Types of test procedures

Several versatile test procedures applicable to component tests have evolved from telemetry systems testing. Among these are noise power ratio (NPR) tests useful in defining frequency multiplex system performance. Where possible, use of these devices in testing recorder/reproducer systems should be considered. The use of pseudo-noise (PN) generators for bit error rate testing has been described in A.6.2.

C.2 Flutter spectrum measurement

C.2.1 This is an extension of the measurements described in A.2.3. C.3 below contains application notes on the use of flutter spectrum data.

C.2.2 Procedure

Carry out the measurement as follows :

a) Connect equipment as shown in figure 41 (see also table 23).

b) Record test frequency, f_0, at normal record level. The frequency f_0 should be less than 75 % of the frequency of the first null in the playback characteristic (playback velocity/gap width) and several times greater than the frequency of the highest flutter component of interest.

c) Rewind tape and play back into discriminator and spectrum analyzer.

If the spectrum analyzer output meter is true rms, it should be noted on the results and the spectrum plotted as 20 log [(rms flutter in Hz/f_0)/Hz] versus 10 log (frequency in hertz) over the frequency range of significant flutter components. At 1 524 mm/s (60 in/s) for example, the frequency range will be from several hertz to 20 kHz. If the spectrum analyzer output meter is a statistical meter, the spectrum should be run at the one sigma, two sigma and three sigma levels and all three plotted as 20 log {[(1, 2, 3) sigma flutter in Hz/f_0]/Hz} versus 10 log (frequency in hertz).

d) Calibration. If the flutter analyzer is not calibrated internally, this can be done by the method shown in figure 41. A known frequency deviation is supplied from the test oscillator and compared with the resulting meter reading.

e) In playback mode, utilize servo speed control as required.

C.3 Measurement of flutter and time base error (see also A.2.3, A.2.5 and A.2.6)

a) Since the speed of the tape relative to the record and playback heads is not exactly constant, a time base error in the played back data results. Assume that the average speed of the tape relative to the heads is s_0. The instantaneous speed $s(t)$ can be written :

$$s(t) = s_0 + q(t) \qquad \ldots (10)$$

The quantity $q(t)$ is generally called flutter. Since distance along the tape (measured relative to the playback head) corresponds to time, the instantaneous time base $\gamma(t)$ can be written

$$\gamma(t) = t + \eta(t) \qquad \ldots (11)$$

where

$$\eta(t) = \int \frac{q(t)}{s_0} \, dt \qquad \ldots (12)$$

The quantity $\eta(t)$ is called the instantaneous time base error.

b) In order to measure flutter a sinusoid of fixed frequency f_0 is recorded on the tape. One method of measurement consists of playing the recorded sinusoid back through a calibrated discriminator. "Peak-to-peak" flutter can be estimated by the limits of excursion on an oscilloscope display of the discriminator output. This datum is useful relative to certain types of flutter compensation for FM sub-carriers. However, this gives no particular information on the flutter spectrum from which the time base error spectrum can be derived. The spectrum can be utilized conveniently to evaluate tracking error in bit synchronizers, etc., when phase-lock loops are used for clock recovery.

c) If the output of the calibrated discriminator is expressed in terms of instantaneous frequency deviation $\Delta f(t)$, then by differentiating equation 12 with respect to time

$$\frac{q(t)}{s_0} = \frac{\Delta f(t)}{f_0\,\eta(t)} \qquad \ldots (13)$$

The spectral density of $q(t)$ is called the flutter spectrum, and can be obtained by use of a spectrum analyzer on the discriminator output (see C 2). The time base error spectrum, i.e. the spectrum of $\eta(t)$, is obtained from that of $q(t)$ by dividing $(2\,\pi f)^2$. Sometimes a set of low-pass filters (or a tunable low pass filter) is used to measure points on the cumulative spectrum from which the spectrum can be estimated.

d) A method of estimating time base error given in A.2.5 utilizes a cathode ray display of the recorded sinusoid of frequency f_0. Sometimes a band-pass filter is used to reduce the additive noise. The sweep is triggered on say a positive zero crossing and the zero crossings observed a length of time T s later. There will be a spread of zero crossings due to the time base error in the tape. Call Δt the departure from the average crossing time in seconds. Let the two-sided spectrum of $\eta(t)$ be $G\eta(f)$ s²/Hz.

Then the spectrum Δt is given by use of the time delay operator exp $(-j2\pi fT)$ to give

$$G_{\Delta t}(f) = [1 - e^{-j2\pi fT}]^2\, G_\eta(f) = 4 \sin^2 \pi fT \cdot G_\eta(f) \text{ s}^2/\text{Hz} \qquad \ldots (14)$$

or

$$\sigma^2_{\Delta t}(T) = 4 \int_{-\infty}^{\infty} \sin^2 \pi fT \cdot G_\eta(f)\, \mathrm{d}f \text{ s}^2 \qquad \ldots (15)$$

In terms of the flutter spectrum $G_n(f)$, equation (15) becomes

$$\sigma^2_{\Delta t}(T) = T^2 \int_{-\infty}^{\infty} \frac{\sin^2 \pi fT}{(\pi fT)^2}\, G_\eta(f)\, \mathrm{d}f \text{ s}^2 \qquad \ldots (16)$$

Note that $\sigma^2_{\Delta t}(T)$ is a function of the time T between the start of the sweep and the time the zero crossings are observed. Since $\sin^2 \pi fT = 1/2\,(1 - \cos \pi fT)$, equation 15 can be integrated to give

$$\sigma^2_{\Delta t}(T) = 2\,[\sigma^2_\eta - R_\eta(T)] \text{ s}^2 \qquad \ldots (17)$$

where σ^2_η is the variance of $\eta(t)$, it being assumed that the tape servo removes the dc component of $\eta(t)$, and $R_\eta(T)$ is the autocorrelation of the process $\eta(t)$. If it is assumed that there are no important sinusoidal or dc components in $G_\eta(f)$, then $R_\eta(T) \Rightarrow 0$ as $T \Rightarrow \infty$, so that

$$\sigma^2_{\Delta t}(T \to \infty) \approx 2\,\sigma^2_\eta \qquad \ldots (18)$$

or

$$R_\eta(T) \approx 1/2\,[\,\sigma^2_{\Delta t}(T \to \infty) - \sigma^2_{\Delta t}(T)] \qquad \ldots (19)$$

e) If appreciable sinusoidal components are present in $\eta(t)$, then $R_\eta(T)$ has sinusoidal components of the same frequency with respective amplitudes equal to the power in each of the sinusoidal components in $\eta(t)$. A Fourier analysis of $\sigma^2_{\Delta t}(T)$ would reveal these components. For such analysis it would be convenient to utilize a portion of $\sigma^2_{\Delta t}(T)$ for large T so that the rapid variation of the nonperiodic part of $\sigma^2_{\Delta t}(T)$ is not present.

Having determined $R_\eta(T)$, the spectrum $G_\eta(F)$ of $\eta(t)$ can be determined by the Fourier transform of $R_\eta(T)$. Unless the $R_\eta(T)$ determined from the data can be approximated satisfactorily by a function of T which is convenient for performing the integration, it is necessary to accomplish the transform numerically.

C.4 Utilization of time base error data in predicting errors in clock accuracy (see also A.2.3 and A.2.5)

a) In PCM bit synchronizers, the time base error must be tracked by the phase-lock-loop (PLL) sufficiently well to hold the untracked time base error to a small fraction of the bit period, otherwise the bit detector performance against noise is degraded. See, for example, A.O. Rocke and P. Mallory, *Bit error rate in the presence of untracked time base fluctuation*, Proceedings ITC/68. In order to reduce the untracked time base error, it is necessary to increase the closed loop bandwidth of the PLL; but this allows the loop to track larger amounts of additive noise and also increases the signal power required for locking the loop. Thus there is a trade-off between performance against time base error and performance against additive noise.

b) Because the time base errors in tape result from tape speed variations relative to the head, the spectrum is limited in frequency range because of the inertia of the tape and its elasticity. Thus for high PCM bit rates, the time base error $\eta(t)$ remains essentially constant over a single bit period. In this case, assuming that the probability density function of the untracked time base error as well as of the additive noise is known, then the performance of the bit detector can be calculated. For example, figure 42 shows calculated bit error probability versus E/N_0 assuming white Gaussian additive noise of two-sided spectral density N_0 and bit energy E with rms untracked time base error σ_x assumed to be Gaussian distributed.

The model for this calculation is an ideal NRZ bit stream with a matched detector, for example integrate and dump. If the time base error $\eta(t)$ is not essentially constant over a bit period, then the calculation is more complicated.

c) The mean square value of the untracked time base error σ_ε^2 from the PLL can be conveniently calculated by equation

$$\sigma_\varepsilon^2 = \int_{-\infty}^{\infty} |Y_\varepsilon(j2\pi f)|^2 G_\eta(f)\mathrm{d}f \qquad \ldots (20)$$

where $Y_\varepsilon(j2\pi f)$ is the closed loop error transfer function of the phase-lock-loop. If it is assumed that the loop bandwidth is sufficiently large so that the tracking error is small compared to $\pi/2$ radians, then linear PLL theory can be applied. If the PLL is second order with damping ratio 0,7, the phase error transfer function can be approximated as in figure 43 where f_n is the natural undamped frequency of the closed loop in hertz. Figure 44 is a TBE spectrum plotted in units of decibels below one second, i.e. 20 log s/Hz versus frequency. A 40 kHz tone was recorded on track 2 at 1 524 mm/s (60 in/s) using Scotch 888 tape on two machines namely, Ampex FR 600 and Ampex FR 607. Both machines have the same type drive. The standard 17,0 kHz speed-control signal was used on track 7. The triangle points were obtained with a Minneapolis-Honeywell spectrum analyzer Model 9050 and the dots and the crosses with a MICOM Model 8300 W flutter meter set for 2 sigma duty cycle. The 2 sigma readings were divided by two to provide a comparison with the MH analyzer which has a mean square output. The triangles and dots were taken on the FR 607 and the crosses on the FR 600. The agreement is quite good above 100 Hz. Below 100 Hz there is some variation presumably because of varying tape tension, bearing and reel effects, skew, etc. In addition, the rms value of sinusoidal components, as obtained by dividing the 2 σ readings on the MICOM by two, will be too low by about 3 dB because of the functioning of the MICOM duty cycle method of metering. It should be noted that the time between the triangles and dots measurements is about six months.

The data approximate a − 12 dB/octave line from about 2 Hz, where the transport servo appears to corner, to about 3 kHz where the spectrum appears to "bottom out". At still higher frequency the spectrum rises, presumably because of the combined effects of noise added prior to the discriminator, unsupported tape resonance, and other effects. The FR 600 and 607 are high mass machines; low mass machines or combinations will corner at higher frequencies.

The one-sided TBE spectrum can be approximated by

$$G(f) \approx 10^{-7}/4f^4 \qquad \ldots 21$$

over the range $2 \leqslant f \leqslant 3\ 000$ Hz.

In the following it is assumed for purposes of illustration that we may neglect the spectrum beyond 3 kHz.

Also, it is assumed that the TBE power spectrum of figure 44 goes to zero below 2 Hz because of tape servo. Using these approximations for the TBE spectrum, the mean square untracked time base error, σ_ε^2 affecting the data channel output is given approximately by

$$\sigma_\varepsilon^2 = (f_n - 2)\ 10^{-7}/4f_n^4 + \frac{10^{-7}}{4}\int_{f_n}^{3kHz} \frac{\mathrm{d}f}{f^4}\ \sec^2 \qquad \ldots (22)$$

if $2 \leqslant f_n \leqslant 3\ 000$ Hz, then

$$\sigma_\varepsilon^2 \approx 10^{-7}/3f_n^3\ \sec^2 \qquad \ldots (23)$$

This, if $f_n = 100$ Hz, then $\sigma_\varepsilon^2 \cong 3 \times 10^{-14}\ \sec^2$.

d) If it is desired to use the $R_\eta(T)$ from equation 19 to calculate σ_ε^2, this can be done by computing the autocorrelation of the untracked time base error $R_\varepsilon(0)$ from the formula

$$R_\varepsilon(T) = R_\eta(T) * h(T) * h(-T) \qquad \ldots (24)$$

where $h_\varepsilon(t)$ is the weighting function of the error transfer function of the PLL and the symbol * stands for convolution. This can be done as follows :

$$R_{\eta\varepsilon}(T) = \int_0^\infty R(T-\beta)h(\beta)\mathrm{d}\beta \qquad \ldots (25)$$

$$R_\varepsilon(0) = \int_0^\infty R_{\eta\varepsilon}(t)h(t)\mathrm{d}t \qquad \ldots (26)$$

and

$$\sigma_\varepsilon^2 = R_\varepsilon(0) \qquad \ldots (27)$$

e) The weighting function $h_\varepsilon(t)$ is given by the inverse Fourier transform of $Y_\varepsilon(j2\pi f)$. Thus it is seen that if that Δt data obtained as outlined in A.2.5 is to be utilized to directly determine the time base error it is necessary either to Fourier transform the $R(T)$ from equation 19 and then use equation 20 or it is necessary to perform the convolutions of equations 25 and 26. Thus it is evident that considerably more numerical analysis is required to utilize the ΔT data than the spectrum analyzer data. Further analysis and test are required to determine the necessary precision of the Δt data.

C.5 Noise error and flutter measurement

a) As shown in the following discussion, under certain conditions, if the system parameters; carrier-to-noise ratio, carrier frequency, and flutter bandwidth are known, the error due to noise can be predicted. The same equation can be used as a guide in selecting the carrier frequency.

b) According to FM theory the presence of noise at the input of an ideal discriminator results in an error-producing noise output. If the carrier-to-noise ratio exceeds the threshold value, and if the noise is white noise, the magnitude of the error-producing output (Schwartz, Mischa, *Information transmission modulation and noise*, McGraw-Hill Book Co., Inc., New York, N.Y., pp 302-304 (1959)] is :

$$\delta_{\mathrm{rms}} = \frac{1}{\sqrt{6}} \frac{N_\mathrm{c}}{S_\mathrm{c}} \frac{f_\mathrm{f}}{f_\mathrm{c}} \qquad \ldots (28)$$

where

δ_{rms} is the output error due to noise in terms of fractional equivalent flutter;

$N_\mathrm{c}/S_\mathrm{c}$ is the noise-to-carrier ratio in rms voltage; noise measured over a bandwidth of $(f_0 - f_\mathrm{m})$ to $(f_0 + f_\mathrm{m})$;

f_f is the flutter bandwidth in hertz;

f_c is the carrier frequency in hertz.

For peak-to-peak readings on a 2_σ basis

$$\delta_{2\sigma} = 4\,\delta_{\mathrm{rms}} \qquad \ldots (29)$$

C.6 Speed test procedures : modified reproduce head method (developed by D.F. Tinari, NASA, GSFC) (see also A.2.2)

C.6.1 General

C.6.1.1 In order to carry out a complete speed calibration it is necessary to obtain three measurements as follows :

a) actual tape speed (V_{act});

b) operating tape tensile force;

c) tape elongation under operating tensile force.

From these data, one computes the effective tape speed (V_{eff}), and the transport under test is then adjusted to operate at a required actual tape speed (V_{act}) so that the effective tape speed (V_{eff}) equals the standard tape speed (V_{std}) (see table 26 and 4.3.1).

C.6.1.2 The test method described herein calculates the required quantities under normal operating conditions, using magnetic tape of the user's choice. Changes in temperature and humidity from those existing when speed calibration was performed will affect the calibration accuracy. Therefore, normal precautions should be taken to ensure that the tape has reached equilibrium with an unchanging environment. Likewise, when a different tape having significantly changed elastic properties is used, recalibration may be necessary (for example a speed calibration for tape base thickness of 25,4 μm (0.001 in) may differ from a speed calibration for a base thickness of 38,1 μm (0.001 5 in).

C.6.1.3 For definitions of V_{act}, V_{eff} and V_{std} see clause 3 and A.2.2.

C.6.2 Test equipment

C.6.2.1 Electronic test equipment :

a) A variable frequency pulse generator having a minimum range of 1 to 80 Hz. Only moderate accuracy and stability are required.

b) An electronic counter capable of making time interval measurements : oscillator stability better than 0,05 %; oscillator frequency 320 kHz or higher (for a tape speed of 3 048 mm/s (120 in/s), and a six- or more decimal-digit display is required. Ability to measure time interval over n periods is desirable.

C.6.2.2 Mechanical test equipment :

a) Modifications are required to a pair of interlaced reproduce heads meeting the requirements of this International Standard. The odd numbered head is shimmed up from its normal position on the base plate so that some of the tracks on each head are in line.

The spacing between the gaps to be used for the test (measured along the path of the tape) is optically adjusted to 38,100 0 mm ± 1,3 μm (1.500 00 in ± 50 μin). This corresponds to less than ± 1 μs error at 1 524 mm/s (60 in/s). This special head assembly must mount directly in place of a normal head assembly without changing the gap spacing. If the head cannot be optically adjusted, accurately measure the gap spacing, and record the measurement for subsequent use in computations.

NOTE — If the pairs of record and reproduce heads are themselves interlaced, i.e. if the sequence of heads is record No. 1, reproduce No. 1, record No. 2, reproduce No. 2, then the even numbered head should be shimmed.

b) A travelling microscope capable of image resolution better than 1,3 μm (50 μin) with a travel of 38,100 0 mm (1.500 00 in) and a calibrated motion of a few micrometres (milli-inches) are required. For best repeatability of measurements, the 38,100 0 mm (1.500 00 in) indexing of the microscope should be accomplished using Johannsen blocks.

c) A device such as a hand-held spring scale shall be used for applying tensile force to the tape. It shall have an accuracy which can be calibrated to 1 % or better and a range of at least 8,9 N (32 ozf).

d) A tape signal developer consisting of a liquid suspension of carbonyl iron powder or an equivalent preparation is needed to make pulses recorded on tape visible. Various commercial prepartions are available.

e) The above listed test equipment, electronic and mechanical, must be assembled at the test location to carry out a full speed calibration (all three quantities). However, to determine only actual speed or constancy of tape speed, assuming tape tensile force is unchanged, only the modified head assembly, pulse generator, and electronic counter are needed.

C.6.3 Initial procedure

The initial procedure shall be as follows :

a) Mount the modified head assembly on the unit to be tested.

b) Connect the test equipment to the recorder as shown in figure 45.

c) Thoroughly erase the tape to be used for the test and load on the transport. The tape should be allowed to come to equilibrium with the environment in which it will be used. A 24-hour exposure to the operational environment followed by one pass on the transport to be tested is recommended.

C.6.4 Measurement of actual tape speed

Carry out the measurement as follows :

a) With the tape unit under test adjusted normally in all respects, record pulses at a slow enough repetition rate to allow each pulse to traverse the head gap spacing before the next pulse appears (see table 26). Using the electronic counter, determine the time interval T required for the pulse to travel from the leading to trailing gap. Note the variation in the resulting count, and increase the number (n) of periods averaged until a sufficiently small percent variation is observed. Perform the measurement near the beginning, middle and end of a reel. It is not necessary to use bias in recording the pulses.

b) The actual tape speed V_{act} is determined by the formula :

$$V_{act} = \frac{38,100\,0}{T} \text{ mm/s} = \frac{1.500\,00}{T} \text{ in/s} \qquad \ldots (30)$$

where the time interval T is measured in seconds.

C.6.5 Operating tape tension measurement

With the tape unit moving an unrecorded tape under normal conditions, record the shortest pulse feasible using both reproduce heads simultaneously. Stop the tape and "develop" the two recorded pulses [see C.6.2.2 b)]. Place the tape under the travelling microscope with one end fixed. Apply tensile force to the tape, using the spring scale, until the spacing of the magnetic marks equals the previously measured gap spacing of the head assembly. Note the reading in newtons (ounce force). The tape is now under its operating tensile force. Perform the measurement near the beginning, middle and end of a reel. Bias is not used when the reproduce heads are used for recording.

Table 26 — Speed test record frequency

Standard tape speed (V_{std}) mm/s (in/s)	Maximum pulse repetition frequency pps	Equivalent minimum time interval between pulses s	Time interval tolerance for specified accuracy µs	
			0,2 %	0,5 %
3 048 (120)	80	0,012 5	± 25	± 62,5
1 524 (60)	40	0,025 0	± 50	± 125
762 (30)	20	0,050 0	± 100	± 250
381 (15)	10	0,100	± 200	± 500
190,5 (7 1/2)	5	0,200	± 400	± 1 000
95,2 (3 3/4)	2,5	0,400	± 800	± 2 000
47,6 (1 7/8)	1,25	0,800	± 1 600	± 4 000
23,8 (15/16)	0,625	1,60	± 3 200	± 8 000

C.6.6 Measurement of tape elongation under operating tension

Using the same tape described above, apply standard tensile force ± 2 % (see 4.5.8) and note the new spacing between magnetic marks. The coefficient (K) for fractional elongation of tape in proportion to a change in tensile force can be determined by the following formula :

$$K = \frac{\Delta l}{l} \cdot \frac{1}{\Delta t} \qquad \ldots (31)$$

where

l is the gap spacing under operating tensile force (nominally 38,100 0 mm) (1.500 00 in);

$l + \Delta l$ is the gap spacing under standard tensile force in millimetres (inches);

i.e. Δl = change in gap spacing;

t is the operating tensile force in newtons (ounce force);

$t + \Delta t$ is the standard tensile force in newtons (ounce force).

i.e. Δt = change in tensile force.

Assuming that the tape acts as an elastic medium over a limited range of tensile force, this provides a means of estimating tape length change. For 12,7 mm (0.500 in) wide tape typical values of K are about 360×10^{-6}/N (100×10^{-6}/ozf), for tape with a base thickness of 38,1 μm (1.5×10^{-3} in) and 648×10^{-6}/N (180×10^{-6}/ozf) for tape with a base thickness of 25,4 μm (1.0×10^{-3} in).

C.6.7 Effective tape speed

The effective tape speed (V_{eff}) can be computed from the above as follows :

$$V_{eff} = V_{act} \frac{\text{gap spacing for standard tensile force}}{\text{gap spacing for operating tensile force}}$$

$$= V_{act} \frac{l + \Delta l}{l} = V_{act} (1 + K \Delta t) \qquad \ldots (32)$$

where the standard tensile force is that used in C.6.6.

The effective speed should equal the corresponding standard speed. Effective tape speed should be used in computing tape speed error :

$$\text{Tape speed error} = \frac{V_{eff} - V_{std}}{V_{std}} 100\ \% \qquad \ldots (33)$$

C.6.8 Required actual tape speed

The actual tape speed required for a given operating tensile force in order to obtain a standard effective tape speed (V_{std}), i.e. one of the speeds listed in table 26, can be determined as follows :

$$V_{act} = V_{std}/[1 + K\,(\text{operating tensile force} - \text{standard tensile force})]$$

$$= V_{std} \frac{1}{1 + K\Delta t} \qquad \ldots (34)$$

where K and the tensile forces have the same units as given in C.6.6.

C.7 Frequency response — Direct recording

See also A.3.2 and table 23.

Procedure :

a) Set up equipment as indicated in figure 46.

b) Set band-pass filter in the white noise generator to give desired base-band width for the tape speed to be used.

c) Set rms value of noise voltage and bias to normal record levels as in A.3.1.

d) Set spectrum display band spread to correspond to bandwidth selected in b). Select spectrum display IF bandwidth, sweep rate and low pass filter in accordance with manufacturer's recommendations for the band spread selected. Set display gain to desired value and record all settings.

e) For this test, it is permissible and convenient to record and play back simultaneously into the spectrum display.

f) Photograph spectrum display.

g) As a check, remove (or attenuate 40 dB) the signal and photograph the spectrum of the noise out of the playback amplifier, without changing the spectrum display settings used in d).

C.8 Intermodulation and signal-to-noise ratio NPR (noise power ratio) test method

See also A.3.4 and table 23.

Procedure:

a) Connect test equipment as shown in figure 47.

b) Check back-to-back performance of NPR test equipment to determine that it is functioning correctly. If pre-detection mode is to be used, measure NPR with VCO and discriminator back-to-back, having set rms level into VCO to correspond to the desired rms carrier deviation.

c) Set nominal levels of bias, record and play back. Equalize gain for tape playback speed to be used. Select pre-detection or post-detection mode. Set the high and low pass filters in the NPR generator to the desired values.

d) For this test it is permissible and convenient to record and play back simultaneously into the NPR signal analyzer.

e) For each test condition in b) above, measure and record the ratio (NPR) of the power in the selected band-pass filter in the NPR analyzer for notch out and notch in. Call this ratio A. Now remove test signal (or attenuate 40 dB) and measure and record the change in the notch ratio. Call this ratio B.

In terms of signal and noise :

$$A = \frac{S + N_0 + N_i}{N_0 + N_i} \qquad \ldots (35)$$

where

S is the "signal power" in a notch;

N_0 is the background noise in the notch;

and

N_i is the intermodulation power in the notch.

$$B = \frac{N_0 + N_i}{N_0} \qquad \ldots (36)$$

The noise power ratio NPRI due to intermodulation only is then

$$\text{NPRI} = \frac{S + N_i}{N_i} = \frac{AB - 1}{B - 1} \qquad \ldots (37)$$

If $S + N_0 \geqslant N_i$, then :

$$\text{NPRO} = \frac{S + N_0}{N_0} = AB \qquad \ldots (38)$$

The quantity NPRO is the signal-to-noise power ratio for background noise alone.

f) The NPR method can be used to obtain the results of A.3.2, A.3.8, A.3.9 and A.4.3. The procedure is as follows :

1) Set up as in b) above. Select an NPR receiver band-pass filter in the centre of the base-band to be used. Leave the corresponding notch filter out. Set the coarse attenuation in the NPR receiver to 10 dB and the fine attenuation to 0 dB. Adjust the continuously variable attenuator in the NPR receiver to bring the galvanometer to the reference line. This standardizes the gain.

2) Now select other NPR band-pass filters and measure their outputs relative to the standardized band-pass filter output by using the attenuation. Record the data and plot as a function of band-pass filter frequency. This gives the record/reproduce gain characteristic.

C.9 Multispeed reproduce transfer levels and equalization — Direct recording

See also A.3.8.

Procedure :

a) Use the equipment configuration of figure 46.

b) Place bulk erased tape of the type recommended on the recorder.

c) Set band-pass filter in the white noise generator to give desired base-band width for the tape speed to be used. Call this bandwidth W. Record at normal record rms voltage level with bias level.

d) Rewind and play back at all specified speeds of the machine without repositioning the output level control. Set frequency band spread on spectrum display to cover output spectrum for each reproducer speed. Photograph spectrum for each reproducer speed and record rms output voltage. Record on each photograph the display sensitivity in kHz per mm, the IF bandwidth (insofar as possible the IF bandwidth should be selected in proportion to tape reproducer speed), and the display gain.

C.10 Record transfer characteristics

See also A.3.9.

Procedure :

a) Use the equipment configuration of figure 46.

b) Place recorder manufacturer's recommended bulk erased tape on the recorder.

c) Record and reproduce at 1/8 the highest tape speed on the machine a band of white noise extending to the maximum frequency specified for this speed. This should be recorded and reproduced at the normal rms levels. Reproduce level shall be adjusted so that level changes between speeds will not cause the reproduce amplifier to saturate. On machines with azimuth adjustable reproduce heads, adjust azimuth for maximum output of the upper band-edge frequency. Photograph spectrum display and record rms output voltage plus all spectrum analyzer parameters.

d) Rewind the tape and erase it. Record a frequency band extending to a maximum frequency eight times that used in step c) above at the highest speed of the machine.

e) Reproduce the tape recorded in step d) at 1/8 the highest tape speed of the machine. On machines with azimuth adjustable reproduce heads, adjust azimuth for maximum upper band-edge output. Photograph spectrum display and record rms output voltage plus all spectrum analyzer parameters.

f) The deviation from ideal recording is defined as the difference between the response curves obtained in steps c) and e).

C.11 Frequency response — Single-carrier FM

See also A.4.3.

Procedure :

a) Use the equipment configuration of figure 46.

b) Select the noise bandwidth to correspond to the pass-band specified in table 13.

c) Record and reproduce at nominal input and bias voltage (if used) levels at the desired tape speeds.

d) Photograph the output spectrum and record all spectrum analyzer parameter settings.

C.12 Multispeed reproduce transfer levels — Single-carrier FM

See also A.4.10.

The objective and procedure in this test are the same as those of C.9 except that the recorder/reproducer is operated in the FM mode.

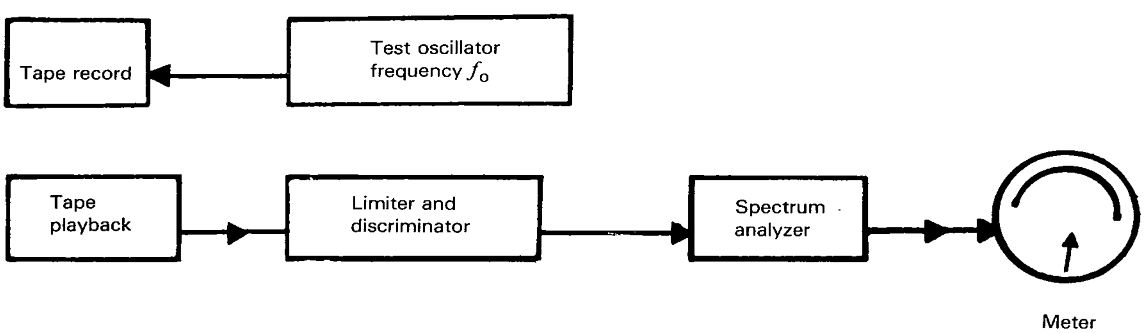
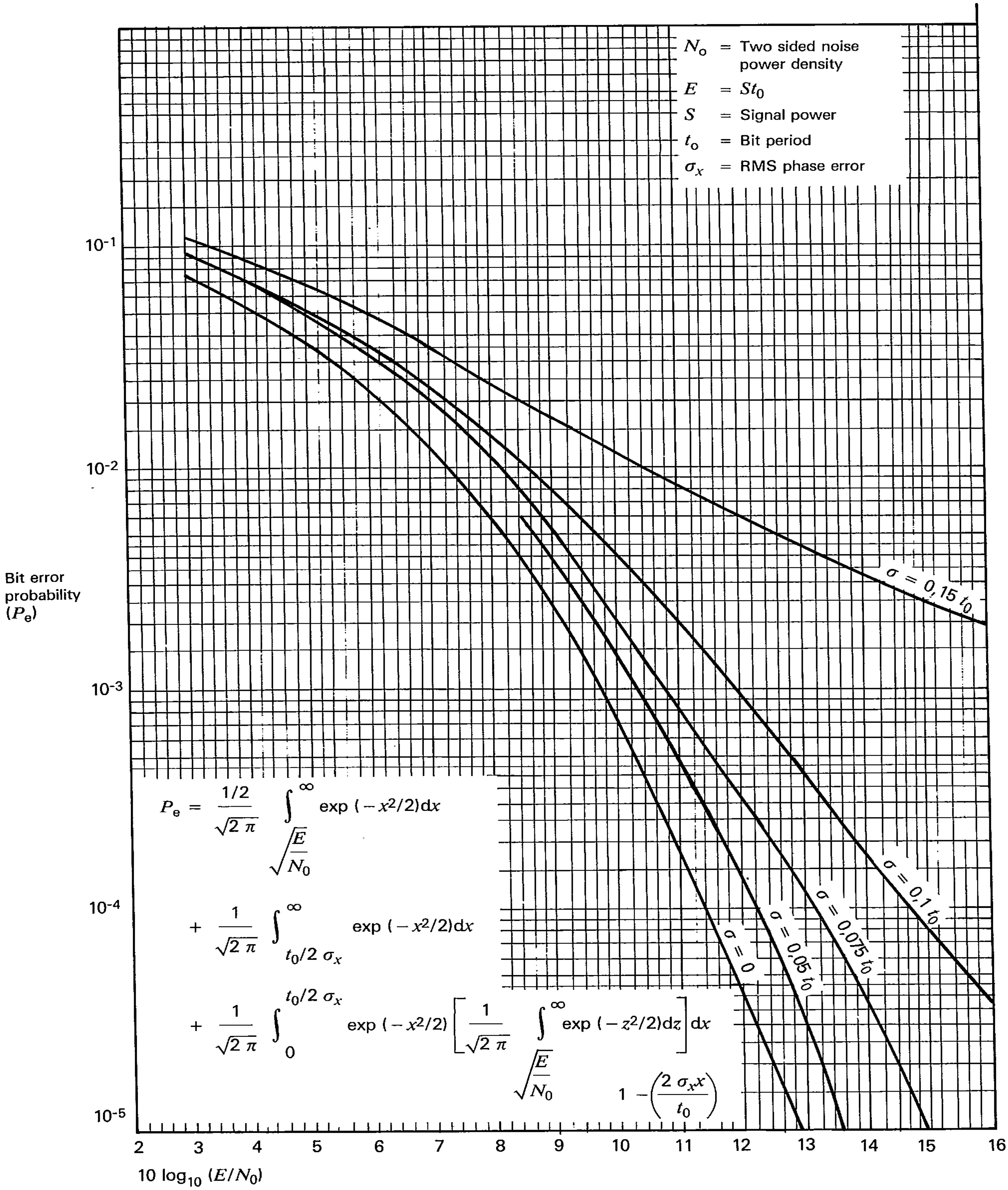


Figure 41 — Equipment configuration for flutter spectrum measurement



$$P_e = \frac{1/2}{\sqrt{2\pi}} \int_{\sqrt{\frac{E}{N_0}}}^{\infty} \exp(-x^2/2)\mathrm{d}x + \frac{1}{\sqrt{2\pi}} \int_{t_0/2\sigma_x}^{\infty} \exp(-x^2/2)\mathrm{d}x + \frac{1}{\sqrt{2\pi}} \int_0^{t_0/2\sigma_x} \exp(-x^2/2) \left[\frac{1}{\sqrt{2\pi}} \int_{\sqrt{\frac{E}{N_0}}\,1-\left(\frac{2\sigma_x x}{t_0}\right)}^{\infty} \exp(-z^2/2)\mathrm{d}z \right] \mathrm{d}x$$

Figure 42 — Bit error probability as a function of untracked Gaussian time base error

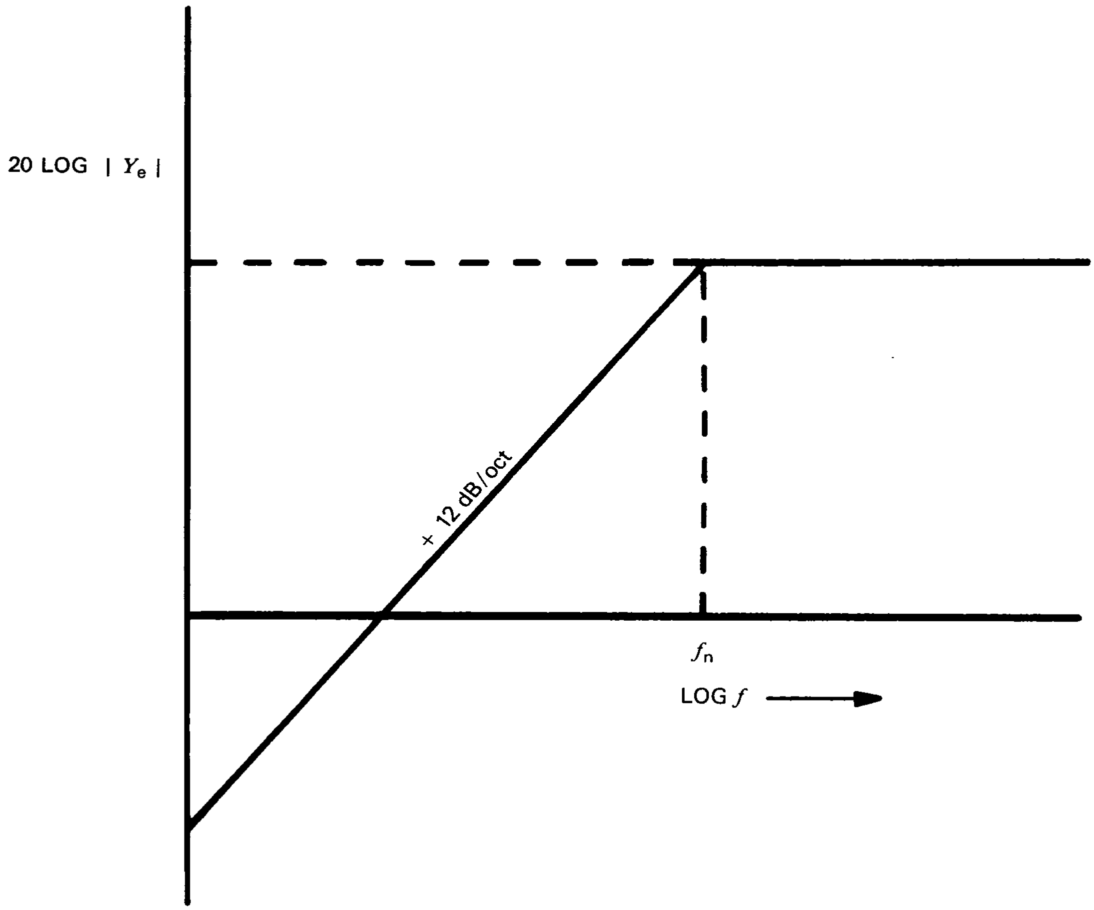


Figure 43 — Approximate phase error transfer function

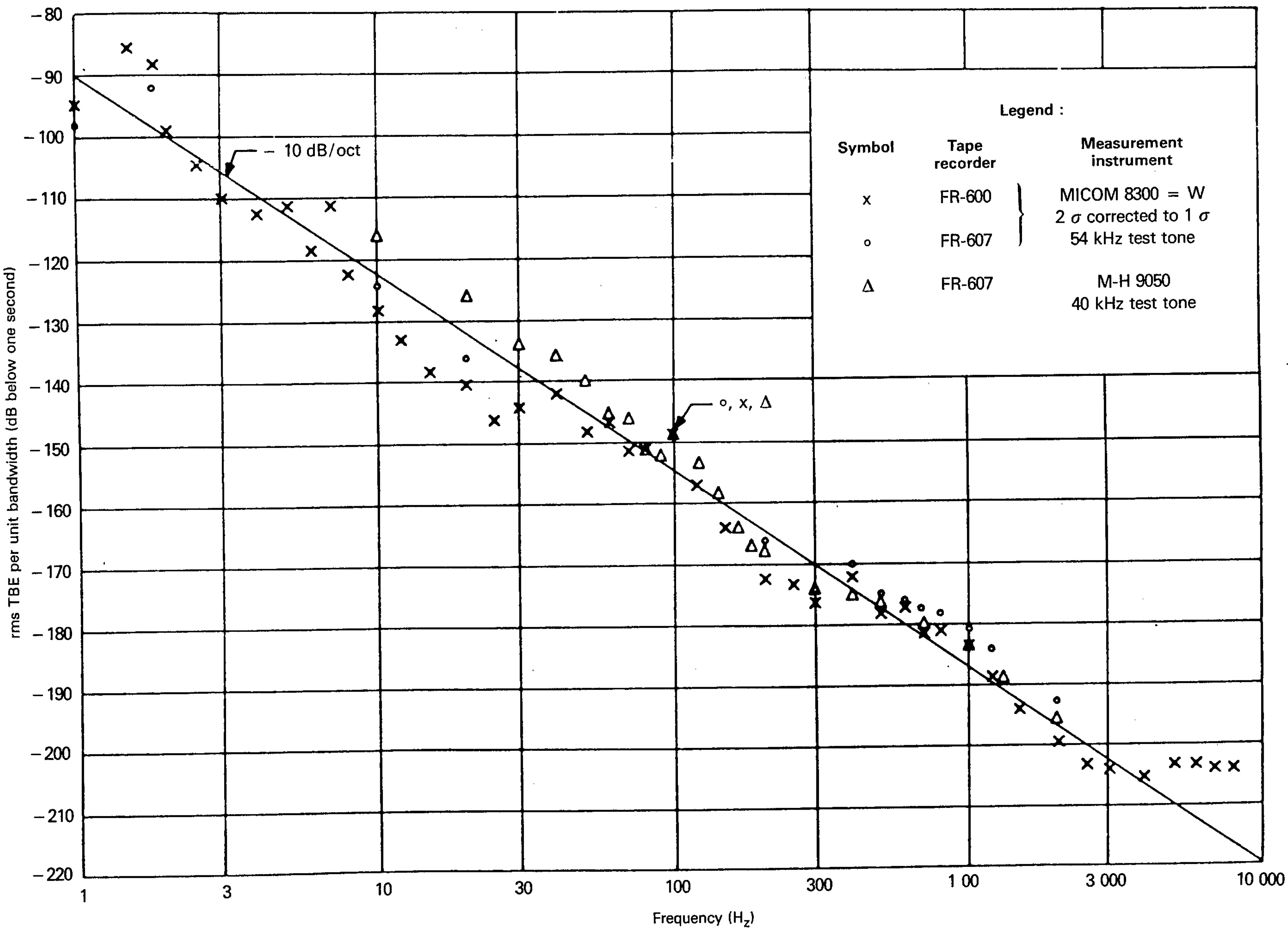
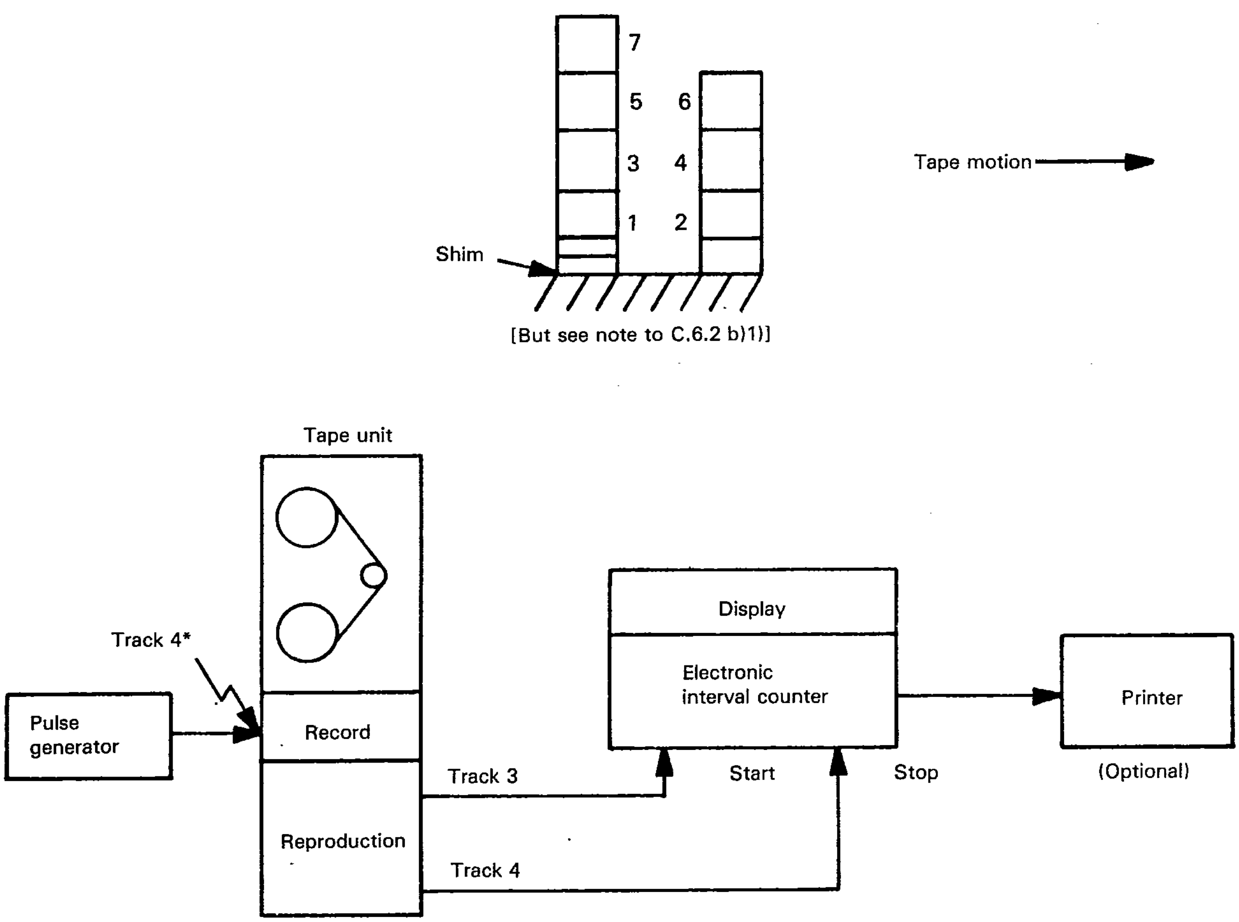


Figure 44 — Measured time base error spectrum



* In 7-track systems pulses may be recorded on tracks 2, 4 or 6. Reproduced signals are then obtained from tracks 1 and 2, 3 and 4, or 5 and 6 respectively. Similar combinations may be used for systems having different number of tracks.

If the record and reproduce head assemblies are interlaced [see note to C.6.2 b)1)], recording must be on odd-numbered tracks.

Figure 45 — Typical 7-track configuration for actual tape speed measurement

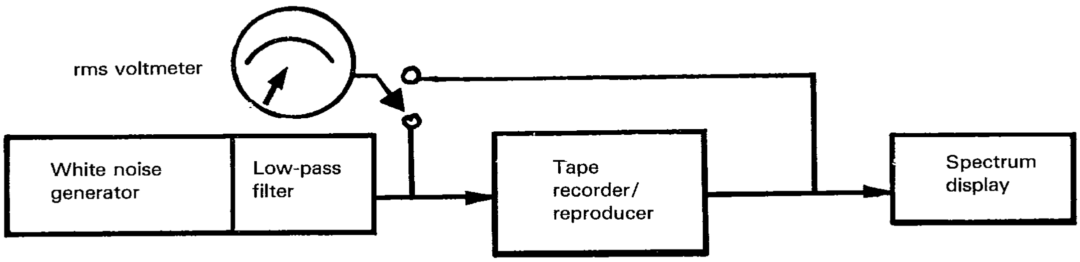


Figure 46 — Equipment configuration for frequency response measurement

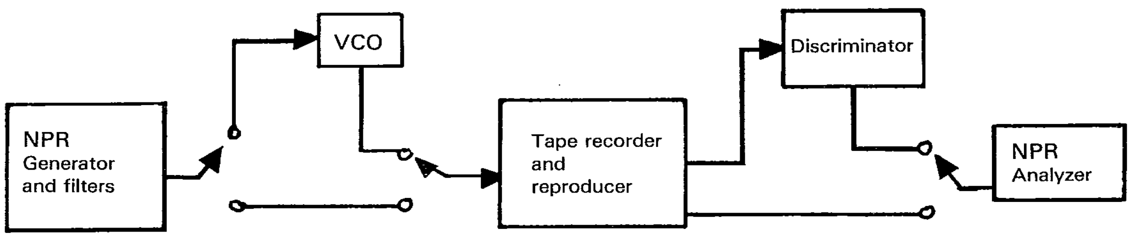


Figure 47 — Equipment configuration for NPR test

Annex D

PCM standards — Additional information and recommendations

(This annex does not form part of the standard.)

D.1 Bit rate versus receiver intermediate-frequency bandwidth (3 dB points) (only applicable to radio frequency telemetry systems). See 6.3.4.2) b)

D.1.1 Receiver intermediate-frequency (IF) bandwidth should be selected from those listed in table 20. Only those discrete receiver intermediate-frequency bandwidths listed should be used for a data channel. IF bandwidth is optional below 12 000 Hz. The selections in table 20 have been made on the consideration that automatic tracking of radio-frequency (RF) carrier drift or shift will be used in the receiver; however, Doppler shift consideration may require wide intermediate-frequency/discriminator bandwidths for the AFC system.

D.1.2 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 1 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.

D.1.3 It is recommended that the period between assured bit transitions be a maximum of 64-bit intervals to assure adequate bit synchronization.

D.2 Suggested PCM synchronization patterns

See 6.3.2.3.

It is suggested that an *N*-bit frame-synchronization pattern be selected under the criterion that the probability of false synchronization with the pattern displaced be minimized. Examples of synchronization patterns meeting the criterion are given in table 27.

Table 27 — Examples of PCM synchronization patterns

Length N bits	Synchronization pattern
7	101 100 0
8	101 110 00
9	101 110 000
10	110 111 000 0
11	101 101 110 00
12	110 101 100 000
13	111 010 110 000 0
14	111 001 101 000 00
15	111 011 001 010 000
16	111 010 111 001 000 0
17	111 100 110 101 000 00
18	111 100 110 101 000 000
19	111 110 011 001 010 000 0
20	111 011 011 110 001 000 00
21	111 011 101 001 011 000 000
22	111 100 110 110 101 000 000 0
23	111 101 011 100 110 100 000 00
24	111 110 101 111 001 100 100 000
25	111 110 010 110 111 000 100 000 0
26	111 110 100 110 101 100 010 000 00
27	111 110 101 101 001 100 110 000 000
28	111 101 011 110 010 110 011 000 000 0
29	111 101 011 110 011 001 101 000 000 00
30	111 110 101 111 001 100 110 100 000 000
31	010 101 101 010 010 110 100 110 101 011 1

Annex E

Use criteria for frequency division multiplexing

(See 6.1)

(This annex is not part of the standard.)

E.1 General

The successful application of the frequency division multiplexing 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 annex are offered in this context, as a guide for orderly application of the standards which are presented in 6.1.

It is the responsibility of the system designer to select the range of performance that will meet his data measurement requirements and at the same time permit him to operate within the limits of the standards. A designer or user must also recognize the fact that even though the standards for frequency-division multiplexing encompass a broad range of performance limits tradeoffs such as data accuracy for data bandwidth may be necessary. Nominal values for such parameters as frequency response and rise time are listed to indicate the majority of expected use, and should not be interpreted as inflexible operational limits. It must be remembered that system performance is influenced by other considerations such as hardware performance capabilities. In summary, the scope of the standards together with the use criteria are intended to offer flexibility of operation and yet provide realistic limits.

Much of the information in the sections which follow is only applicable to radio-frequency telemetry systems, but some is relevant or adaptable to other instrumentation systems using frequency-division multiplexing. In particular, section E.5 discusses aspects of recording FDM signals on magnetic tape.

E.2 FM subcarrier performance

The nominal and maximum frequency response of the sub-carrier channels listed in tables 18 and 19 is 10 % and 50 %, 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 to conform with the specific data response requirements for the channel. As a rule, the rms signal/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 18 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 to 90 % rise time for a step function of the channel input signal; however, deviations from these values may be encountered due to variations in subcarrier components in the system.

E.3 FM subcarrier performance tradeoffs in radio-frequency telemetry systems

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 for 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 system designer's problem is to determine acceptable tradeoffs between the number of subcarrier channels and acceptable subcarrier-to-noise ratios.

Studies have shown that proportional bandwidth channels with centre frequencies up to 165 kHz and constant-bandwidth channels with centre 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 at all of the discriminator outputs with the receiver input near radio frequency threshold. Intermodulation caused by the radio link components carrying the composite multiplex signal limits the channel's performance under large signal conditions.

With subcarrier deviation ratios of four, channel data errors of the order of 2 % rms were observed. Data channel errors of the order of 5 % 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 %. Some channels showed peak-to-peak errors as high as 30 %. 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 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 thermal noise performance of an FM/FM channel above threshold is as follows :

$$\left(\frac{S}{N}\right)_{\mathrm{d}} = \left(\frac{S}{N}\right)_{\mathrm{c}} \left(\frac{3}{4}\right)^{\frac{1}{2}} \left[\frac{B_{\mathrm{c}}}{F_{\mathrm{ud}}}\right]^{\frac{1}{2}} \left(\frac{f_{\mathrm{dc}}}{f_{\mathrm{s}}}\right) \left(\frac{f_{\mathrm{ds}}}{F_{\mathrm{ud}}}\right)$$

where

$\left(\frac{S}{N}\right)_{\mathrm{d}}$ is the discriminator output signal-to-noise ratio (rms voltage ratio);

$\left(\frac{S}{N}\right)_{\mathrm{c}}$ is the receiver carrier-to-noise ratio (rms voltage ratio);

B_{c} is the carrier bandwidth (receiver intermediate-frequency bandwidth);

F_{ud} is the subcarrier discriminator output filter — 3 dB frequency;

f_{s} is the subcarrier centre frequency;

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

f_{ds} is the subcarrier peak deviation.

If the RF carrier power is such that the thermal noise is greater than the intermodulation noise, the above relation provides estimates accurate to within a few decibels.

The FM/FM composite multiplex signal used to modulate the radio-frequency carrier may be a proportional-bandwidth format, a constant-bandwidth format, or a combination of the two types provided only that guard bands allowed for channels used in a mixed format be equal to or greater than the guard band allowed for the same channel in an unmixed format.

E.4 FM 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 18 and 19 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 18 and 19, 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 pre-emphasis of the upper subcarriers, the lower subcarriers may experience intermodulation interference due to difference frequencies of the high-frequency (and high-amplitude) channels.

See also E.5.

E.5 Magnetic tape recording

The number of FM subcarriers which may be recorded simultaneously on one track on magnetic tape is limited by the output signal/noise ratio that is acceptable for the application in hand. As channels are added, it is necessary to reduce the recording level for each individual channel, to keep the overall multiplex within normal record level. This lowers the subcarrier-to-noise performance at the discriminator inputs, and the user has to determine an acceptable tradeoff between the number of subcarrier channels and acceptable subcarrier-to-noise ratios.

Some improvement is possible by taking into account the probability distribution of subcarrier amplitudes when combined in random phase, and there may be some relative advantage in using pre-emphasis at the shortest recorded wavelengths.

Degraded performance may result if proportional-bandwidth subcarrier channel 1 is recorded on a wide-band DR machine having a low frequency cut-off of 400 Hz, and such recording should be avoided if possible.

The use of magnetic tape recorders for recording a subcarrier multiplex may also degrade the data channel accuracy 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 is employed and a reference frequency is recorded with the subcarrier multiplex.