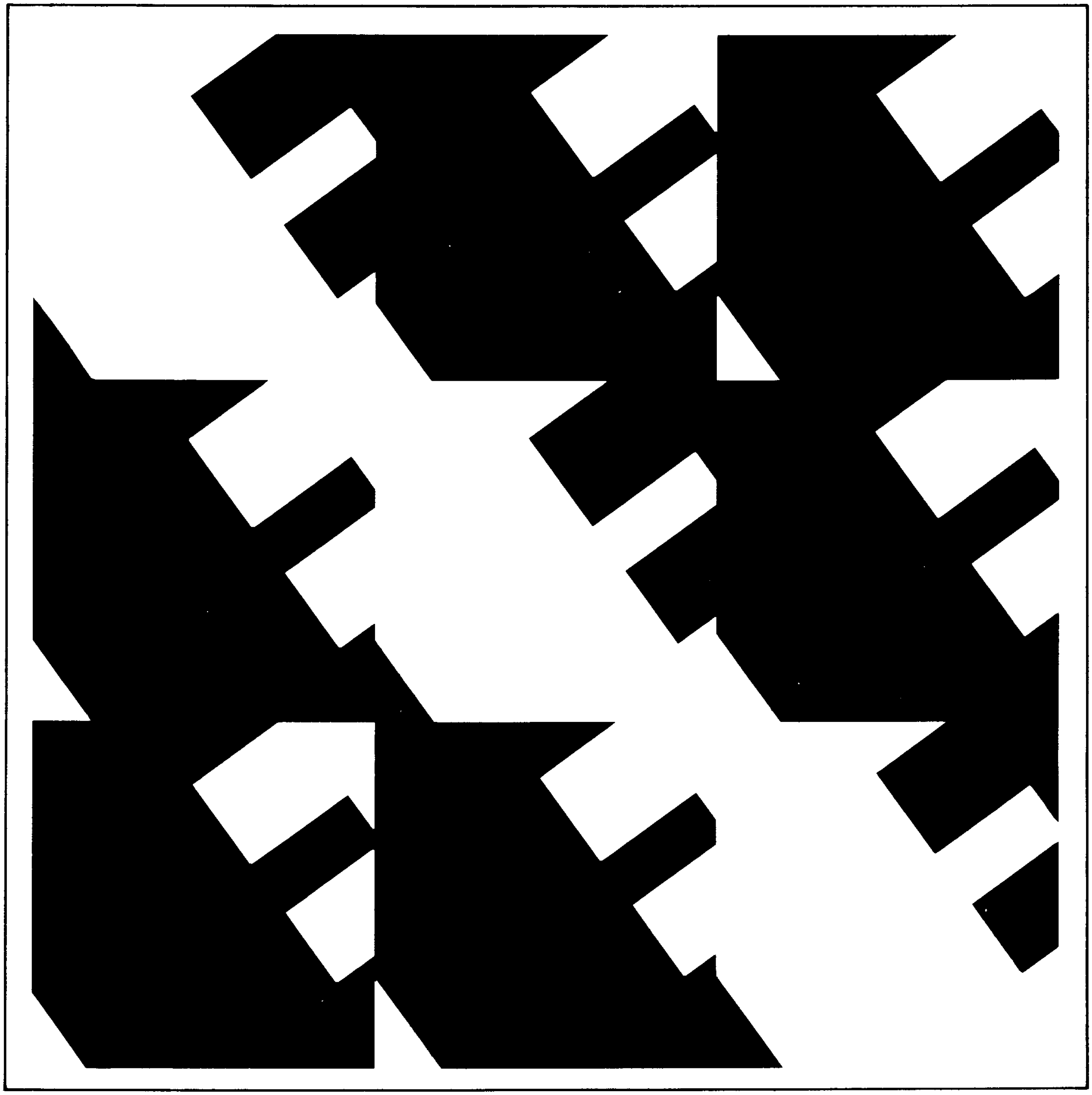
AMERICAN NATIONAL STANDARD

ANSI/IEEE Std 743-1984

# IEEE Standard Methods and Equipment for Measuring the Transmission Characteristics of Analog Voice Frequency Circuits



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Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA
November 14, 1984
SH09308

# IEEE Standard Methods and Equipment for Measuring the Transmission Characteristics of Analog Voice Frequency Circuits

## 1. Introduction

**1.1 Scope.** The purpose of this standard is to establish functional requirements for measuring analog transmission characteristics of voice frequency telecommunication equipment including voiceband and wideband data transmission channels and program circuits, and to establish functional requirements for test equipment needed to make the required measurements.

Section 2 of this standard contains definitions. Section 3 presents a general, somewhat tutorial review of the measurements, while Section 4 presents the details of the standard for each measurement. Section 5 addresses physical characteristics and Section 6 environment.

This standard will be useful for specifying test equipment for measuring the performance of subscriber loops, message network trunks, PBX trunks, tie lines, and other similar facilities.

**1.2 References**

When the documents referred to in this standard are superseded by a revision the revision shall apply.

[1] ANSI/ASTM D21-97-1968, (R1979) Standard Test Methods for Adhesion of Organic Coatings.[1]

[2] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.

[3] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[4] ANSI/IEEE Std 455-1976, IEEE Standard Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voice Band.

[5] ANSI/IEEE Std 488-1978, IEEE Standard Digital Interface for Programmable Instrumentation.

[6] EIA RS-232-C-1969, (R1981) Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange.[2]

[7] EIA RS-449-1977, General Purpose 37-Position 9-Position Interface for Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange.

[8] IEC 320-1981, Appliance Couplers for Household and Similar General Purposes.[3]

[9] IEC 348-1978, Safety Requirements for Electronic Measuring Apparatus.

## 2. Definitions and Abbreviations

**2.1 Definitions.** This section contains only those definitions relating to transmission measurement which are not listed in ANSI/IEEE Std 100-1984 [3].[4]

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[1] ANSI Publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] EIA Publications are available from Electronic Industries Association, 2001 Eye Street, NW Washington, DC 20006.

[3] IEC Publications are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[4] Numbers in brackets correspond to those of the references listed in 1.2.

**C-Message.** A frequency-weighting characteristic, used for measurement of noise in voice-frequency communications circuits and designed to weight noise frequencies in proportion to their perceived annoyance effect in telephone service.

**C-Notch.** The measure of noise on a channel when a signal is present. A very narrow band-elimination filter (notch filter) is used with a C-Message filter to eliminate the holding tone at the measuring end of the circuit. *See also:* **C-Message, holding tone.**

**echo return loss (ERL).** The return loss of a circuit measured with a transmitted signal with a flat spectral distribution between 3 dB frequencies of 560 Hz and 1965 Hz.

**holding tone.** A tone, usually 1004 Hz, transmitted over a communication circuit for performing noise tests on systems using compandors or quantizers or for the measurement of jitter or transients. The tone is transmitted at a predetermined level and filtered out at the noise measuring set. *See also:* **C-Notch.**

**longitudinal balance.** The electrical symmetry of the two wires comprising a pair with respect to ground. *See also:* **longitudinal circuit (telephony).**

**quantizing noise.** The noise introduced during the process of digitally encoding an analog signal.

**singing return loss.** The return loss of a circuit measured with two separately transmitted signals with a flat spectral distribution between 3 dB frequencies of 260 Hz and 500 Hz (SRL Low) and 2200 Hz and 3400 Hz (SRL High). The lower of the two return losses (SRL Low or SRL High) will be the best measure of the margin of the circuit against singing.

**2.2 Abbreviations.** The following abbreviations, commonly used in the communications field, are used in this standard. Listed with each abbreviation is the section of the standard where it is introduced.

| | | |
|---|---|---|
| **dBm:** | Decibels relative to one milliwatt. This is the customary unit worldwide for measurement of communications signal power. | (4.3.1) |
| **dBm0:** | Decibels relative to one milliwatt, referred to a zero transmission level point (0 TLP). | (4.3.1) |
| **dBrn:** | Decibels relative to one picowatt reference noise level. This is the customary North American unit for measurement of noise power in communications signal circuits. | (4.3.2) |
| **dBrnC:** | Decibels relative to one picowatt reference noise level, measured with C-Message or C-Notch frequency weighting. | (4.3.2) |
| **TLP:** | Transmission level point. The symbol TLP is preceded by a number that indicates, for a particular point in a transmission system, the design signal level in dB relative to the level at a reference point (0 TLP). | (4.3.2) |

## 3. General Description of Measurements

### 3.1 Basic Measurements

**3.1.1 Level and Frequency Response.** This is a measurement of signal power at an access point of nominal impedance in a circuit. The impedance may range from 135 Ω to 1650 Ω with 600 Ω and 900 Ω most commonly used. The expected signal levels at the access points usually range from -40 dBm to +10 dBm.

The frequency range of interest for normal speech and voiceband data services may extend from below 60 Hz to above 4 kHz. For program circuits, the frequency range of interest may extend from 20 Hz to 20 kHz. Wideband data circuits further extend this range (see 4.3.1 for measurement standards).

**3.1.2 Noise and Signal-to-Noise Ratio.** Measurements are made with the channel terminated in its nominal impedance. A holding tone of 1004 Hz (see 4.3.1.4) is usually transmitted, then notched out before the noise is measured. The holding tone activates the channel so that harmonic distortion, quantizing noise, phase jitter, and amplitude jitter become part of the noise measurement. If no holding tone is transmitted, the result is a background noise measurement. If a holding tone is transmitted, the result is a noise-with-tone measurement or notched noise measurement. Noise-with-tone measurements give a measure of the noise encountered by a continuous data signal or the noise a listener would hear during a speech burst. Signal-to-noise ratio is a comparison of the received power of the holding tone to the noise-with-tone (see 4.3.2 for measurement standards). Noise measurements are made using one of several frequency weighting networks/filters. These include:

(1) *C-Message.* A filter frequency weighting which weights the noise according to its perceived annoyance to a *typical* listener, of standard telephone service.

(2) *C-Notch.* C-Message weighting with the addition of a narrow stop-band or notch filter centered at 1010 Hz. This measurement is used to make a dynamic evaluation of the effects of noise on voice-grade services.

(3) *3* kHz *Flat.* When used on voice frequency circuits, this filter permits the investigation of the presence of low-frequency noise (power induction, etc). It is a 3 kHz low-pass filter of Butterworth shape rolling off at 12 dB per octave.

(4) *Program.* This filter is used for weighted measurements of noise on program circuits with bandwidths up to approximately 8 kHz.

(5) *15* kHz *Flat.* This filter is used when making unweighted measurements of noise on program circuits. It is a 15 kHz low-pass filter of Butterworth shape rolling off at 12 dB per octave. It is not ordinarily used on voice message circuits.

(6) *50 Kilobit.* This filter is used to measure noise on facilities assigned to 50 kb data service. The equivalent noise bandwidth is approximately 28.2 kHz.

(7) *Psophometric.* This measurement is a frequency weighting technique very similar to C-Message weighting. Psophometric weighting is specified by the CCITT (and therefore not included in this standard) for use in measuring noise on telephone circuits in countries that recognize the CCITT standards.[5]

**3.1.3 Envelope Delay Distortion.** This is the basic measurement of the phase linearity of a channel. Envelope delay, or the derivative of phase with respect to frequency, is measured because of the difficulty in establishing a phase reference and also because some channels, including analog carrier systems, have a time-varying zero-frequency phase intercept.

Envelope delay distortion is related to the differences in transmission time for the various voiceband frequencies over a given line. Such differences in delay will produce intersymbol interference in many data signals (see 4.3.3 for measurement standards).

### 3.2 Transients

**3.2.1 Impulse Noise.** Noise bursts or spikes that are much higher than normal peaks of the background noise or noise-with-tone are considered impulse noise.

An impulse noise measurement is made by counting the number of spikes exceeding a preset threshold. Often it is desirable to measure the amplitude distribution of the noise spikes. This is done by counting the spikes exceeding three different thresholds.

Impulse noise spikes may have extremely sharp rise times and may cause baseband filters to ring. To avoid counting the oscillations due to the ringing, the counter(s) is blanked for a period of time after a threshold has been exceeded.

**3.2.2 Phase and Gain Hits.** A rapid change in phase or gain of a signal is called a phase hit or a gain hit. These hits are measured by monitoring a received tone (holding tone) and counting hits that exceed selectable thresholds for specified durations.

**3.2.3 Dropouts.** A 12 dB reduction in the holding tone level as measured at the start of the measurement interval is defined as a dropout.

### 3.3 Incidental Modulation

**3.3.1 Phase Jitter.** This measurement is the summation of incidental phase modulation and the effects of interference and noise. The phase modulation component of phase jitter typically results from unwanted phase modulation on carrier supplies in frequency division multiplex (FDM) terminals. The modulation frequencies are usually low, consisting of ringing frequency, power-line frequencies and their harmonics. Phase jitter is normally measured by examining phase disturbances on a test tone.

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[5] CCITT publications are available in the US from National Technical Information Service, Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

**3.3.2 Amplitude Jitter.** The summation of incidental amplitude modulation and the effects of interference and noise. Amplitude jitter is usually measured by examining amplitude disturbances on a test tone.

### 3.4 Other Measurements

**3.4.1 Return Loss.** A measure of power reflected back to the originating end of a channel due to impedance mismatches throughout the channel.

Return loss measurements are most important for mixed 4-wire/2-wire systems providing 2-way transmission. Such systems are subject to line echoes. If the return loss is low, large talker or listener echoes, or both, may occur creating what is referred to as the *rain barrel* effect in voice communications and may also cause mutilation of some data signals (see 4.6.1 for measurement standards).

**3.4.2 P/AR.** This acronym represents the measurement of the peak-to-average ratio of a specially designed test signal sent over a channel. It is a measure of intersymbol interference in voiceband data signals. P/AR is designed to evaluate the simultaneous effects of envelope delay distortion, bandwidth reduction, and poor return loss (gain and phase ripples) on high-speed data transmission (see 4.6.2 for measurement standards).

**3.4.3 Intermodulation Distortion.** Nonlinearities such as compression and clipping cause harmonic and intermodulation distortion in a transmitted signal. The extent of this impairment is evaluated by measuring intermodulation products that result from the nonlinearities acting on a multiple-tone transmitted signal (see 4.6.3 for measurement standards).

**3.4.4 Crosstalk.** Undesirable signal coupling between circuits is called crosstalk. It is measured by transmitting a sinusoidal test signal on one channel while measuring the power of the test signal received in a second channel. The difference (in dB) between the transmitted power and the received power is defined as the crosstalk coupling.

**3.4.5 Frequency Selective Level.** Spurious tones may exist on a channel in addition to the intended signal. A frequency selective voltmeter is used to analyze the frequency and amplitude of individual components of an interfering signal to help determine its source, or of a transmitted signal to judge its potentially interfering effects (see 4.6.5 for measurement standards).

**3.4.6 Frequency.** The measurement of the frequency of a transmitted or received signal. It is usually made while setting up a test signal or in conjunction with the measurement of other parameters such as level or envelope delay distortion (see 4.6.6 for measurement standards).

### 3.5 Measurements not Covered in this Standard.

Certain measurements of a more fundamental nature than those previously described would be more valuable if they could be made conveniently. As of this issue, however, no instrumentation exists for making such measurements. Specific requirements for the measurements listed below have not been proposed at this time.

**3.5.1 Phase Modulation.** The requirements for an instrument to measure phase jitter are given in 4.5.1. This measurement indicates the amount of jitter in the zero crossings of a received holding tone in a specified bandwidth. Both random or quantizing noise and true phase modulation (sidebands in pairs about the holding tone) will produce phase jitter.

Since the random noise or quantizing noise can be measured more conveniently with equipment meeting the standards of 4.3.2, it would be more desirable to have an instrument which measures phase modulation rather than phase jitter. High-speed data modems react differently to noise than they do to phase modulation. An instrument which can measure phase modulation is more useful to common carriers for trouble localization than is an instrument which measures phase jitter.

The formula for a carrier that is phase modulated by a single frequency and with additive noise may be expressed by:

$$M(t) = A \cos (2\pi f_c t + K \cos 2\pi f_m t) + n(t)$$

where

$f_c$ = carrier or holding tone frequency
$f_m$ = modulating frequency
$K$ = peak phase deviation due to $f_m$
$n(t)$ = total random noise or quantizing noise

If the peak phase deviation is less than 1 radian, the frequency spectrum of the received signal will then have only a few spectral components spaced above and below the carrier frequency $f_c$, at low multiples of $f_m$.

**3.5.2 Amplitude Modulation.** The requirements for an instrument to measure amplitude jitter are given in 4.5.2. This measurement indicates the amount of jitter in the amplitude of a received holding tone in a specified bandwidth. Random or quantizing noise and true amplitude modulation (sidebands in pairs about the holding tone) will produce amplitude jitter.

Since random noise or quantizing noise can be measured more conveniently with equipment meeting the standards of 4.3.2, it would be more desirable to have an instrument which measures amplitude modulation rather than amplitude jitter. High-speed data modems react differently to noise than they do to amplitude modulation. An instrument which can measure amplitude modulation is more useful to common carriers for trouble localization than is an instrument which measures amplitude jitter.

The formula for a carrier that is amplitude modulated by a single frequency and with additive noise may be expressed by:

$$M(t) = (1 + m \cos 2\pi f_m t) \cos 2\pi f_c t + n(t)$$

where

$f_c$ = carrier or holding tone frequency
$f_m$ = modulating frequency
$m$ = peak modulation index
$n(t)$ = total random noise or quantizing noise

**3.5.3 Absolute Delay.** Envelope delay distortion compares the difference in absolute delay between a reference frequency and other frequencies. The requirements for an instrument to measure envelope delay distortion over the voiceband are given in detail in 4.3.3.

It would be desirable to have an instrument which could measure the absolute delay of a circuit on a straightaway basis to permit prediction of response times on multipoint fast-poll data networks or to measure the difference in arrival times of a single command sent simultaneously to several locations. The measurement precision required for the measurement of absolute delay is at least an order of magnitude less than that required for the measurement of envelope delay distortion.

## 4. Measurements Techniques and Requirements

**4.1 Introduction.** This section presents requirements which shall be adhered to when measuring the performance of analog voice frequency transmission channels. Specific requirements on ranges, accuracies, and stabilities are established and, where appropriate, methods of testing for the requirements are suggested. Also included are suggested general descriptions of the different classes of measuring instruments.

### 4.2 Classes of Instruments

**4.2.1 High-Performance Instruments.** Instruments in this category are designated Class 3 instruments and are intended primarily for laboratory type application or special diagnostic activities, or both, in an operating equipment environment. These instruments offer the highest currently attainable degree of accuracy and stability.

**4.2.2 General-Purpose Instruments.** Instruments in this category are designated Class 2 instruments and are intended primarily for preservice routine maintenance and diagnostic activities. These instruments, therefore, offer a degree of accuracy and stability consistent with the testing requirements and limits for such activities. Unless otherwise indicated, the requirements of this standard refer to the general purpose (Class 2) instruments.

**4.2.3 Reduced-Performance Instruments.** Instruments in this category are designated Class 1 instruments and are intended primarily for field application. Therefore, portability, rugged construction, and ease of operation are a major consideration in their design. These instruments offer accuracy acceptable for basic parameter measurement.

### 4.3 Basic Measurements

**4.3.1 Level and Frequency Response (includes Loss and Linearity).** Received level is measured with a sinusoidal test signal driving the circuit under test. The received level is the power dissipated in a standard impedance by the received tone. The received level is expressed in dBm (dB relative to 1 milliwatt) as follows:

$$\text{Received level in dBm} = 10 \log (10^3 P)$$

where

$P$ = power in watts of the received signal delivered to a standard impedance (usually 600 Ω or 900 Ω); that is, 1 mW = 0 dBm

The loss (more correctly the transducer loss) of the circuit is expressed in dB and is the difference between the power available from the source that is driving the circuit under test (that is, the power the source would deliver to a standard matched impedance (600 Ω or 900 Ω); also called the transmitted level) and the received level.

The transmission level at any point in a transmission circuit or system is the ratio, expressed in dB, of the power of a signal at that point to the power of the same signal at a reference point called the zero transmission level point (0 TLP). Stated another way, the transmission level at any point on a circuit is defined as the design gain or loss, expressed in dB, between that point and an arbitrary point called the zero transmission level point (0 TLP). By design, certain points in the telephone plant have fixed TLPs. For example, if the demodulator output of a properly aligned analog carrier system in a central office is a +7 TLP, this means that a 0 dBm, 1 kHz test signal applied at a 0 TLP will be amplified to +7 dBm at this +7 TLP. Transmission level points for voice frequency and data circuits at analog points in a telephone plant vary from +13 TLP to -16 TLP. The TLP will also effect the expected value for noise measurements, which is normally accounted for by specifying noise limits at 0 TLP. The term dBm0 (dBm at 0 TLP) is used to express the test signal power at any point on a circuit referred to 0 TLP. For example, a -16 dBm0, 1 kHz signal is measured as -16 dBm at a 0 TLP and as -9 dBm at a +7 TLP.

Linearity or tracking refers to loss measurements made at a variety of transmitted levels.

**4.3.1.1 Gain Slope.** The measurement of loss or received level versus frequency while the transmitted level is held constant is referred to as frequency response or attenuation distortion. The term gain-slope refers to the measurement of received level at 404 Hz, 1004 Hz, and 2804 Hz and calculating the difference between levels at 404 Hz and 1004 Hz for 404 Hz gain-slope and the difference between levels at 2804 Hz and 1004 Hz for 2804 Hz gain-slope. Conventionally, + means more loss and - means less loss than the 1004 Hz value. The nominal 4 Hz offset prevents beating problems in level measurements on digital systems with an 8 kHz sampling rate. Gain-slope measurements are typically made at -16 dBm0.

**4.3.1.2 Oscillators, Common Requirements.** The variable-frequency oscillator in this section is distinguished from the fixed-frequency holding tone oscillator in 4.3.1.4. There are certain common requirements for both oscillators.

An oscillator used to measure loss may also be used for the measurement in signal-to-noise ratio, which is described in 4.3.2.

**4.3.1.2.1 Output Level.** The required output level range is +10 dBm to -40 dBm. The output level setability over this range shall be 0.1 dB. At a test frequency of 1 kHz, the output level shall be accurate to ± 0.1 dB between 0 dBm and -19 dBm and accurate to ± 0.2 dB, elsewhere as measured with a precision level measuring set (or equivalent means) with a resolution and accuracy of 0.03 dB. A signal-off capability, while maintaining a constant output impedance, is desirable to provide a quiet termination for noise measurement. Flatness with frequency is covered in 4.3.1.3.3.

**4.3.1.2.2 Frequency Stability.** The frequency should not deviate by more than 0.1% in any one-hour period after an initial warm-up of 5 minutes while still meeting the other requirements for oscillator frequency accuracy.

**4.3.1.2.3 Level Stability.** The level should not vary by more than 0.05 dB in any one-hour period after an initial warm-up of 5 minutes.

**4.3.1.2.4 Total Distortion.** The total distortion including harmonics, noise, and spurious tones, as measured on a distortion analyzer which eliminates only the fundamental tone, shall meet the requirements of Table 1. The bandwidth of the noise and distortion presented to the distortion analyzer may be reduced as shown in Table 1 by means of a low distortion filter between the oscillator and the distortion analyzer.

These requirements should be met over the output level range of +10 dBm to -40 dBm.

**Table 1**
**Oscillator Distortion Requirements**

| Fundamental Frequency $f_0$ (Hz) | Distortion Analyzer 3 dB Bandwidth (Hz) | Total Distortion below Fundamental (dB) |
|---|---|---|
| 100–3000 | 40–12 000 | > 50 |
| 100–$f_{max}$ | 40–4 × $f_{max}$ | > 40 |

$f_{max}$ = specified maximum frequency of the oscillator.

**4.3.1.2.5 Background Noise.** If oscillator levels below - 40 dBm are possible, the distortion requirements in 4.3.1.2.4 may be changed consistent with a noise floor of - 90 dBm.

### 4.3.1.3 Variable Frequency Oscillators

**4.3.1.3.1 Frequency Accuracy.** The accuracy requirement for the oscillator frequency is a function of the manner in which the frequency is displayed.

(1) The frequency accuracy of oscillators whose output frequency is indicated by the operation of one or more switches or pushbuttons is a function of how the sinusoidal tone is generated.

(a) RC or LC oscillators shall be accurate to ± 0.4% of the indicated frequency with the frequency vernier, if any, in the detented position.

(b) Crystal-controlled or frequency-synthesized oscillators shall be accurate to ± 1 Hz from 50 Hz to 9999 Hz (or to the highest advertised frequency below 9999 Hz) and accurate to ± 10 Hz from 10 kHz to 100 kHz (or to the highest advertised frequency below 100 kHz.)

(2) Calibrated dial oscillators shall be accurate to ± 3% of the indicated setting.

(3) If the oscillator frequency is displayed on a four or five digit display as the means for adjusting the oscillator frequency, then the actual frequency shall be within ± 1 least significant digit or 0.01%, whichever is greater. In addition, the frequency shall be adjustable in increments of:

1 Hz (or less) for frequencies of 4 kHz or less
5 Hz (or less) for frequencies ranging from 4 kHz to 10 kHz
10 Hz (or less) for frequencies above 10 kHz.

**4.3.1.3.2 Frequency Range.** The oscillator shall have a frequency range of at least 50 Hz to 3900 Hz.

**4.3.1.3.3 Flatness.** The properly terminated output of the oscillator shall be flat to within 0.2 dB (or less) over the frequency range of 200 Hz to 15 kHz (or to the top of the frequency range, if less than 15 kHz). This measurement shall be made by a precision level measuring set (or other equivalent means) which has an order of magnitude (0.03 dB) more resolution and precision than the 0.2 dB requirement. As the frequency is varied at any output level setting, the maximum and minimum level readings shall not differ by more than 0.2 dB. For frequencies above 15 kHz, a flatness within 0.5 dB shall be measured with a level set (or equivalent) with an accuracy and resolution of 0.1 dB.

**4.3.1.4 Holding Tone Oscillator.** The holding tone oscillator finds most frequent use in the measurement of signal-to-noise ratio (4.3.2), impulse noise with tone, phase hits, gain hits, and dropouts (4.4), phase jitter (4.5.1), amplitude jitter (4.5.2), and frequency shift (4.6.6).

**4.3.1.4.1 Frequency Range.** Acceptable frequencies may range from 1002 Hz to 1020 Hz. Care should be exercised that the tone frequency does not drift below 1002 Hz as a result of the permissible frequency drift.

**4.3.1.4.2 Oscillator for Frequency Shift Measurement.** Because of the requirement to measure frequency shift to ± 0.1 Hz, an oscillator for this use shall be stable to ± 0.005 Hz under all conditions, and have the frequency identified to the nearest 0.1 Hz on the front panel. Crystal-controlled oscillators at 1004 Hz are frequently used as holding tone oscillators for making frequency shift measurements.

**4.3.1.4.3 Spurious Noise.** The holding tone oscillator should have:

(1) 0.2 degree phase jitter or less
(2) 0.2% amplitude jitter or less
(3) No impulsive noise at a level 20 dB below the power of the tone
(4) No phase hits greater than 3 degrees
(5) No gain hits greater than 0.5 dB

All of these tests may be performed using equipment defined in this standard, with (4) and (5) requiring the addition of a controlled amount of phase or amplitude modulation, or both.

### 4.3.1.5 Level Measurement

**4.3.1.5.1 Level Range.** The input level range shall be +10 dBm to - 49.9 dBm.

**4.3.1.5.2 Accuracy.** The level measuring set shall meet the accuracy requirements shown in Table 2 for its specified frequency range.

**Table 2**
**Level Measuring Accuracy Requirements**

| Frequency Range (Hz) | Accuracy (dB) |
|---|---|
| 20 to 200 | ± 0.5 |
| 200 to 15 000 | ± 0.2 |
| 15 000 to $f_{max}$ | ± 0.5 |
| 1002 to 1020 | ± 0.1 (0 to -19 dBm) |

$f_{max}$ = specified maximum frequency of the oscillator.

For auto-ranging detectors, the accuracy shall be checked near auto-ranging points as the input signal is being lowered and raised through the auto-range points.

**4.3.1.5.3 Bridging.** The front panel of the set shall clearly indicate the impedance for which the bridging reading is calibrated. In addition to meeting the bridging impedance requirements of 5.6, the level displayed on the set shall be compensated to be that which would have been observed if the bridging impedance were infinite. All other requirements of 4.3.1 apply to the set in the bridging mode.

**4.3.1.5.4 Low-Frequency Noise Protection.** In some applications, levels of ac power (60 Hz) may be encountered which are high enough to affect the accuracy of the loss measurement. A filter having at least 20 dB loss at 60 Hz and below should be provided. Since the filter can affect the accuracy of loss measurements at low frequencies, its insertion should be controlled by a front-panel switch. The effect of its insertion on loss measurements above 400 Hz should be negligible (less than 0.1 dB).

**4.3.1.5.5 High-Frequency Noise Protection.** Noise above voiceband frequencies is often encountered on voiceband facilities. Interference from AM broadcasting transmitters is an example. A low-pass filter rolling off at 12 dB per octave with a corner frequency no higher than 10 kHz and having more than 60 dB loss at all frequencies above 500 kHz should be provided. If measurements are not to be made above the voiceband, this filter should be present for all measurements. If measurements are to be made above the voiceband, a low-pass filter rolling off at least 6 dB or more per octave with a corner frequency no higher than three times the top of the specified frequency range should be present for all measurements.

**4.3.1.5.6 Detector.** An average detector shall be used since it is 2 dB to 3 dB less sensitive to interfering noise than an rms detector. The displayed reading shall be the rms power of the sine wave.

A frequency selective detector normally should not be used for level detection because of accuracy and cost considerations. If the test set has some alternate means for determining that a test tone signal-to-noise ratio of at least 19 dB (0.05 dB error with an rms detector) is present at the level measuring set input, then an rms detector may be used.

**4.3.1.5.7 Display Respone Time.** For a suddenly applied 1 kHz sine wave, the display shall be within ± 0.1 dB of the final reading within 3 seconds. This requirement shall be met for a signal suddenly applied consisting of a 0 dBm 1 kHz tone with a 50 V dc bias.

**4.3.1.5.8 Crosstalk into Level Detector.** Care shall be taken in test sets which contain an oscillator and a level detector to ensure that the oscillator of the test set does not crosstalk into the level detector at a level which materially affects the level measurement. To test for the presence of such crosstalk the following methods may be used:

(1) Terminate the oscillator of the test set in 600 Ω and set the output level to the lowest possible value. If it is possible, turn off the transmitter.

(2) Apply a 1 kHz test tone from a separate oscillator to the test set level detector so that it reads - 39.0 dBm on the receiver.

(3) With the test set oscillator now turned on, adjust the output to the highest possible level.

(4) The reading now observed should not differ from - 39.0 dBm by more than 0.1 dB as the test set oscillator frequency is varied in the regions close to 500 Hz, 1 kHz, 2 kHz, 3 kHz, and at its highest available transmitting frequency.

**4.3.1.5.9 Crosstalk into Oscillator.** High-level signals on the input to the set could conceivably crosstalk into the oscillator. To ensure that this crosstalk does not materially affect level measurements being made with the oscillator, the following test should be performed:

(1) Set the oscillator to 1 kHz, - 39.0 dBm and 600 Ω as monitored by another level measuring set connected to the oscillator output.

(2) Apply a +10 dBm, 1 kHz tone to the set under test from a separate oscillator.

(3) The observed reading on the separate level measuring set should not differ from - 39.0 dBm by more than 0.1 dB as the separate oscillator frequency is varied in the regions close to 500 Hz, 1 kHz, 2 kHz, 3 kHz, and at the highest advertised receive frequency.

**4.3.2 Noise and Signal-to-Noise Ratio.** This section covers the requirements for the measurement of noise and the requirements for a set which measures signal-to-noise ratio automatically (4.3.2.13).

Noise power is measured in dBrn referenced to one picowatt, as given by the formula:

$$N(\text{in dBrn}) = 10 \log (10^{12} P)$$

where
$N$ = displayed noise reading
$P$ = received noise power, watts

For example, if
$P = 1\ \mu W$,
$N$ = 60 dBrn or (- 30 dBm).

The unit symbol dBrnC (dBrn C-Message) is used for noise measurement with C-Message or C-Notch weighting.

Noise may be measured either with or without a holding tone present. If no holding tone is present, the background noise, or idle channel noise is measured to a *far end* termination which normally consists of a nominal[6] 600 Ω to 900 Ω resistive termination. The rms noise power is measured through an appropriate weighting network. If a holding tone is used, the noise-with-tone measurement is made with an oscillator having a 600 Ω or 900 Ω output impedance, an output frequency between 1002 Hz and 1020 Hz and an output level appropriate for the system under test. The rms noise power is normally measured with a weighting network after rejection of the holding tone with a sharp notch filter (notched noise measurement). The displayed reading for notched noise is the summation of noise on the circuit that is not a function of the holding tone plus any harmonic distortion or quantizing noise that is a result of the holding tone. Amplitude or phase modulation sidebands may fall outside of the notch filter rejection band and thus contribute to the reading.

Noise-to-ground measurements permit evaluation of the longitudinal (common mode) voltage present on facilities. There is no need to make noise-to-ground measurements with a longitudinal holding tone or notch filter present. Noise-to-ground measurements are not normally made where a low impedance to ground is present.

**4.3.2.1 Accuracy.** The noise measurement shall be accurate to ± 1 dB. The noise-to-ground measurement shall be accurate to ± 1.5 dB. These accuracies shall be verified for both sinusoidal and random noise inputs. The accuracy of a C-Notch noise measurement when a holding tone is present is covered in 4.3.2.13.1.

**Table 3**
**3 kHz Flat and 15 kHz Flat Weighting Requirements**

| Frequency (Hz) | Loss (dB) | Tolerance (dB) |
|---|---|---|
| 30 | 0 | ±2.5 |
| 60 | 0 | ±1.7 |
| 400 | 0 | ±0.5 |
| 1000 | 0 | ±0.2 |
| $0.67f_0$ | 0.8 | ±1.0 |
| $f_0$ | 3.0 | ±1.8 |
| $2f_0$ | 12.3 | ±3.0 |

The loss shall continue to increase at a minimum of 12 dB per octave until a loss of 60 dB is achieved. At higher frequencies the loss shall be at least 60 dB.

**4.3.2.2 Weighting Network Tolerances.** Standard weighting networks conform to the tolerances shown in Figs 1 through 4 and in Table 3. The response at 1 kHz of all noise measuring networks, except the 1010 Hz Notch of Fig 2, in a given set shall be the same to within a tolerance of ± 0.2 dB.

The combined response of the C-Message filter (Fig 1) plus the 1010 Hz Notch filter (Fig 2) should be verified by observing the noise reading while employing a low-distortion variable-frequency oscillator to trace the combined filter shape (C-Notch) on a point-by-point basis.

The 3 kHz Flat and 15 kHz Flat filters shall have a Butterworth low-pass filter shape with a 12 dB per octave roll-off. The loss of the filter is given by:

$$\text{Loss} = 10 \log [1 + (f/f_o)^4]$$

where
$f_o$ = 3 kHz or 15 kHz

The total response of the filter and the noise measuring set is not specified below 30 Hz. The nominal values for loss and permissible tolerances are given in Table 3.

The 50 Kilobit filter of Fig 4 is used for the measurement of background noise on wideband data circuits at an impedance of 135 Ω.

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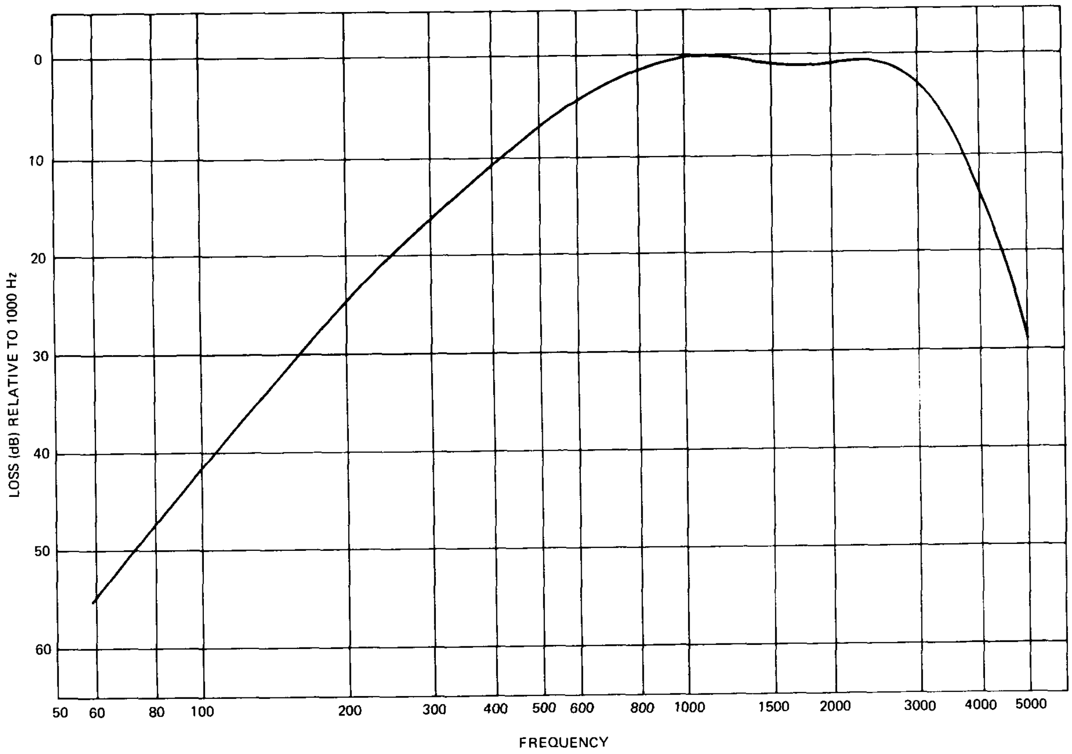
[6] See 5.6.1.1.



Tolerance (NOTE (1))

60 to 300 Hz ± 2 dB
300 to 1000 Hz ± 1 dB
1000 Hz 0
1000 to 3000 Hz ± 1 dB
3000 to 3500 Hz ± 2 dB
3500 to 5000 Hz ± 3 dB

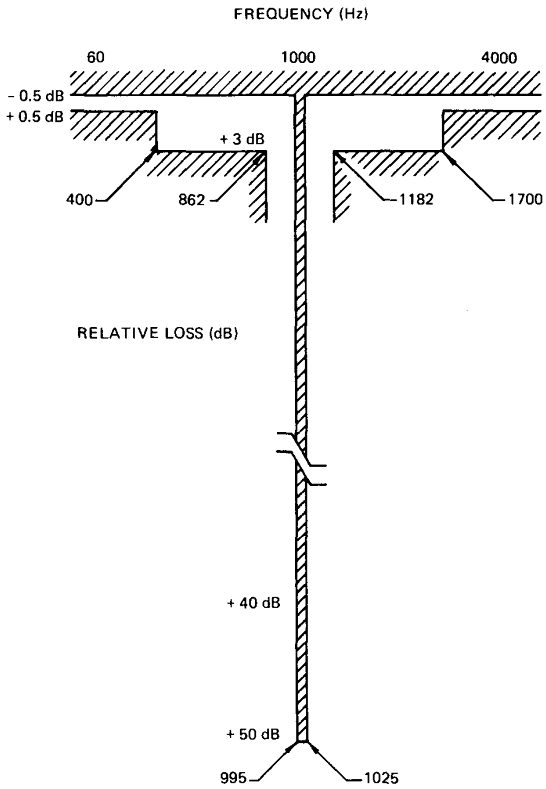
NOTES: (1) To ensure that production models of noise measuring sets will be within tolerances, including variations in components and manufacturing procedures, tolerances one half the values given above are recommended for design purposes.

(2) The attenuation shall continue to increase at a rate of not less than 12 dB per octave until it reaches a value of 60 dB.

(3) See 4.4.3.4 for required pole-zero locations for a C-Message filter for impulse noise measurement.

| Frequency | Design Loss (dB) |
|---|---|
| 60 | 55.7 |
| 100 | 42.5 |
| 200 | 25.1 |
| 300 | 16.3 |
| 400 | 11.2 |
| 500 | 7.7 |
| 600 | 5.0 |
| 700 | 2.8 |
| 800 | 1.3 |
| 900 | 0.3 |
| 1000 | 0 |
| 1200 | 0.4 |
| 1300 | 0.7 |
| 1500 | 1.2 |
| 1800 | 1.3 |
| 2000 | 1.1 |
| 2500 | 1.1 |
| 2800 | 2.0 |
| 3000 | 3.0 |
| 3300 | 5.1 |
| 3500 | 7.1 |
| 4000 | 14.6 |
| 4500 | 22.3 |
| 5000 (NOTE 2) | 28.7 |

Fig 1
C-Message Weighting Characteristic



NOTE: See 4.4.3.4 for additional requirements for a 1010 Hz Notch Filter used for impulse noise measurement.

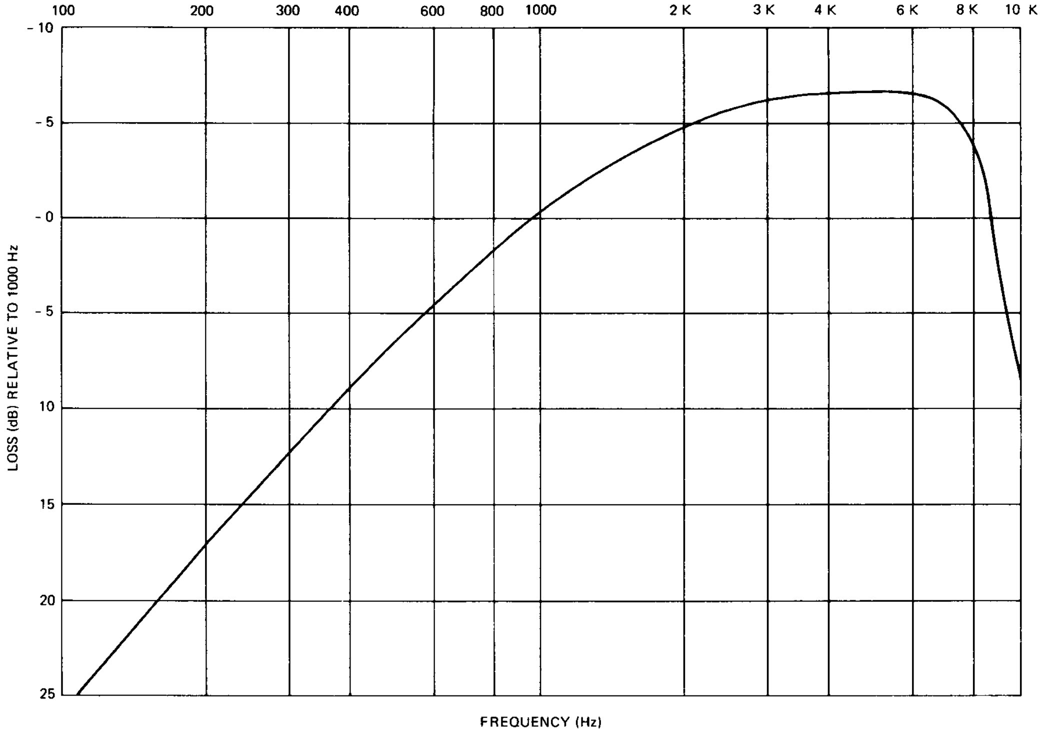
Fig 2
1010 Hz Notch Filter

Table 4
Noise Measurement Ranges

| Filter | Noise (dBrn) | Noise-to-Ground (dBrn) |
|---|---|---|
| C-Message | 10 to 60 | 40 to 110 |
| 3 kHz Flat | 20 to 70 | 50 to 130 |
| 15 kHz Flat, Program | 20 to 70 | |
| C-Notched noise with a holding tone | 20 to 70 | |
| 50 Kilobit | 20 to 70 (135 Ω impedance) | |

**4.3.2.3 Noise Range.** The required measurement range for noise is a function of the type of filter selected as shown in Table 4.

These ranges already take into account the transmission level point (TLP) discussed in 4.3.1. If the set has no level measuring capability, the 3 kHz Flat noise measuring range could be extended to 90 dBrn so as to permit a rough measurement of the holding tone level, so that the tester could compute the ratio of holding tone level to the C-notch noise with an overall accuracy of ± 2 dB.



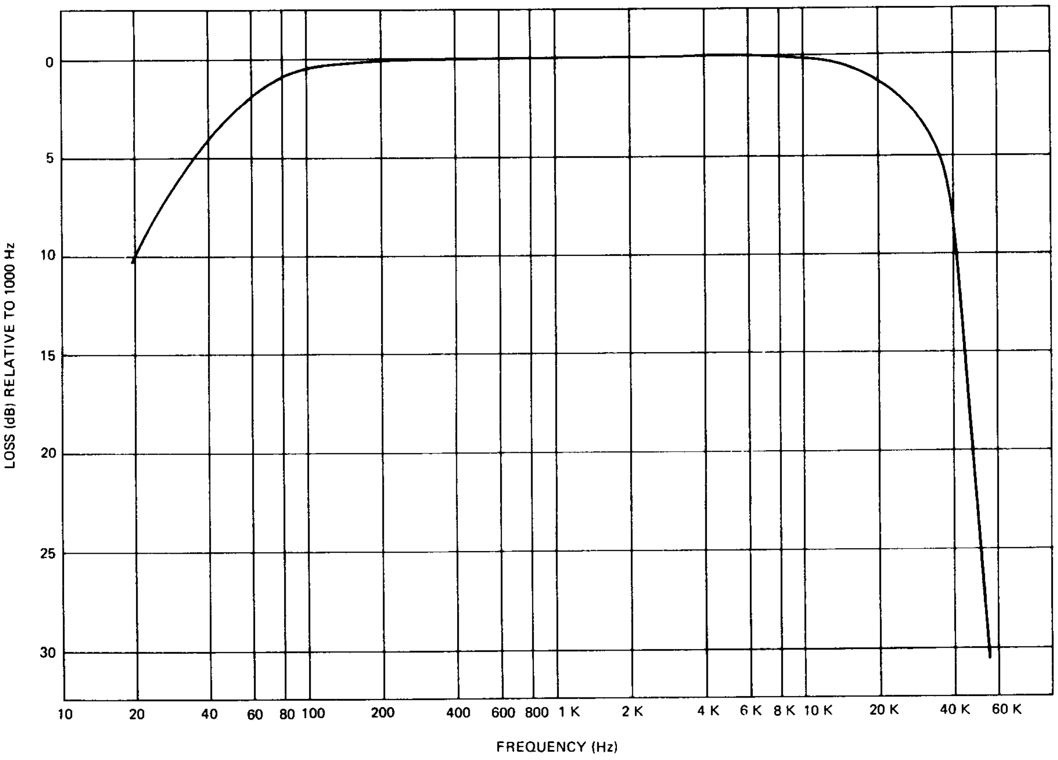
Tolerances [NOTE (1)]
100 to 500 Hz ± 2 dB
500 to 2000 Hz ± 1 dB
2000 to 5000 Hz ± 2 dB
5000 to 8000 Hz ± 3 dB
8000 to 10 000 Hz ± 4 dB

NOTES: (1) To ensure that production models of noise measuring sets will be within tolerances, including variations in components and manufacturing procedures, tolerances one half the value given above are recommended for design purposes.

(2) The attenuation shall continue to increase at a rate not less than 12 dB per octave until the insertion loss is not less than 60 dB.

| Frequency (Hz) | Design Loss (dB) Ref to 1000 Hz |
|---|---|
| 100 | 26.3 |
| 200 | 17.3 |
| 300 | 12.2 |
| 400 | 9.0 |
| 500 | 6.6 |
| 600 | 4.7 |
| 700 | 3.2 |
| 800 | 2.0 |
| 900 | 0.8 |
| 1000 | 0 Ref |
| 1500 | -3.2 |
| 2000 | -4.8 |
| 2500 | -5.6 |
| 3000 | -6.0 |
| 4000 | -6.5 |
| 5000 | -6.5 |
| 6000 | -6.4 |
| 7000 | -5.8 |
| 8000 | -4.0 |
| 9000 | -1.5 |
| 10,000 | 8.5<br>(NOTE 2) |

Fig 3
Program Weighting Characteristic



| Frequency (Hz) | Design Loss (dB) Ref to 1000 Hz | Tolerance (dB) |
|---|---|---|
| 0 | >30 | |
| 50 | 2.7 | ±1.5 |
| 200 | 0.2 | ±0.5 |
| 1000 | 0 (Ref) | ±0.2 |
| 5000 | 0.1 | ±0.5 |
| 10 000 | 0.3 | ±0.5 |
| 15 000 | 0.7 | ±1.0 |
| 20 000 | 1.3 | ±1.0 |
| 25 000 | 2.1 | ±1.0 |
| 30 000 | 3.3 | ±1.5 |
| 35 000 | 5.0 | ±1.7 |
| 40 000 | 7.8 | ±2.0 |
| 45 000 | 14.0 | ±3.0 |
| 50 000 | >22.0 | |
| >55 000 | >30.0 | |

**Fig 4**
**50 Kilobit Weighting Characteristic**

**4.3.2.4 Noise-to-Ground Input Configuration.** The impedance between the balanced inputs when shorted together and ground shall be at least 100 kΩ between 20 Hz and 800 Hz. This requirement is decreased inversely with frequency above 800 Hz. There shall be no dc path to ground for a 200 V dc longitudinal signal of either polarity.

Under certain conditions, such as with E-type signaling units, if a polarized capacitor is used to block dc flow, the 100 kΩ impedance cited above can cause false signaling. This problem shall be avoided by using a nonpolarized capacitor to block dc in the noise-to-ground mode.

The reading displayed shall indicate the power dissipated in a 600 Ω resistor with the measured voltage applied.

**4.3.2.5 Detector.** The detector circuit shall measure the rms value of the noise. An approximate, or full-wave Quasi-rms detector circuit may be used if its output does not differ from a true rms detector by more than ± 0.5 dB for the following input signals:

(1) Random noise

(2) Sine wave

(3) Two nonharmonically related sine waves of equal level, and at least 100 Hz apart.

(4) Gated bursts of a 1.8 kHz sine wave, at a 50 Hz rate, with 20% of the cycle at full amplitude and 80% of the cycle down 8.4 dB from the full amplitude. An rms detector would indicate a drop in level of 5.0 dB compared to the full amplitude sine wave for this case. The 8.4 dB drop in level should be chosen to avoid autoranging points.

**4.3.2.6 Measurement Averaging Time.** The response time for the detector and indicating means shall meet the following limits. With the application of bursts of 1.8 kHz tone to the input of the set, gated at a duty cycle of 50%, with half the cycle at full amplitude and the other half down 8.4 dB from full amplitude, the meter or digital display device shall indicate a variation as shown below. The levels should be chosen to avoid autoranging points.

| Gating Frequency (Hz) | Peak-to-Peak Indicator Variation (dB) |
|---|---|
| 10 | $\leqslant 1$ |
| 2 | $\geqslant 3$ |

For a set having a digital display, it is permissible to adjust the total input power with a 1 dB vernier control to a point where the digital display does not change so as to pass the *less than 1* dB requirement.

**4.3.2.7 Damped Response.** If a set has a DAMPED display capability, then in addition to the requirements of 4.3.2.6 which shall be met in the NORMAL mode, the following requirement shall be met with DAMPED mode. The damping factor is determined by measuring the gating frequency as in 4.3.2.6 which just causes a 3 dB spread in the noise readings in first the NORMAL mode and then in the DAMPED mode. The ratio of these gating frequencies is the damping factor, which shall lie between 2.4 and 4.8.

**4.3.2.8 Display Response Time.** For a suddenly applied random noise signal 20 dBrn or greater, the display shall be within ± 1 dB of the final reading within 3 seconds. This requirement shall be met with a 50 V dc bias on the random noise signal.

**4.3.2.9 Loss of Holding Tone.** A nominal 1 kHz holding tone is necessary to provide more meaningful measurements of noise on certain facilities. For a noise-with-tone measurement, there should be an unmistakable indication if the holding tone level drops below −40 dBm or if the frequency is outside the range of 995 Hz to 1025 Hz.

**4.3.2.10 Holding Tone Level.** The set shall accommodate received holding tone levels from 0 dBm to −40 dBm.

**4.3.2.11 Crest Factor.** To not significantly impair the measurement of noise level, the set shall not compress signals that are at least 8 dB above the highest permissible displayed reading by more than 0.5 dB.

**4.3.2.12 Turnover.** With a 3 kHz Flat weighting filter in place, apply a rectangular waveform of 300 Hz to the input with a 20% duty cycle, and note the noise reading. Invert the input leads. The new noise reading shall be within 1 dB of the first reading.

**4.3.2.13 Signal-to-Noise Ratio**

**4.3.2.13.1 Signal-to-Noise Ratio Display.** If the set measures signal-to-noise (C-Notch only) ratio, then the ratio shall be displayed in decibels in a manner so that it is clearly distinguished from a noise measurement. The level and the noise shall be monitored separately and continually during the measurement period. Each displayed measurement shall be the result of a new measurement of the level (as per 4.3.1.5.2) and the C-Notch noise. The requirements of 4.3.2.1, 2, 9, 10, and 11 apply to the noise measurement. The requirements of 4.3.2.5, 6, and 10 apply, with the addition that holding tone shall be added at the input to produce an in-range signal-to-noise ratio. The set shall continuously display the signal-to-noise ratio in dB and the received sinusoidal tone level in dBm.

**4.3.2.13.2 Signal-to-Noise Ratio Range.** The set shall measure signal-to-noise ratio over the range of 10 dB to 45 dB with an accuracy of ±1 dB over the 10 dB to 40 dB range, and with an accuracy of ±2 dB or better over the 41 dB to 45 dB range.

**4.3.2.13.3 Signal-to-Noise Ratio Display Response Time.** For a suddenly applied random noise signal with holding tone, the reading should be within ± 1 dB of the final reading within 4 seconds.

**4.3.3 Envelope Delay Distortion (EDD).** Common methods of envelope delay distortion (EDD) measurement are based upon measuring the phase shift of the envelope of low-frequency modulation placed on a carrier relative to the modulation placed on a reference-frequency carrier or relative to the original modulation. The North American method uses a separate reference path except for the special case of loop-around measurements. In the latter case, the original modulation source itself serves as reference. The CCITT method (Recommendation O.81) uses an alternate measure-reference carrier frequency to time-share the measure and reference carriers and, therefore, no separate reference channel is required. The CCITT modulation ("split") frequency is 41$\frac{2}{3}$ Hz, whereas the North American method uses 83$\frac{1}{3}$ Hz, with some instances of 25 Hz and other frequencies being encountered.

In addition to the differences in modulation frequency, the technical and operational differences between the North American and CCITT methods are so great that they are incompatible. Since detailed specifications exist for the CCITT method, the following specifications will be confined to only the North American method.

**4.3.3.1 Transmitter**

**4.3.3.1.1 Amplitude Modulation.** The transmitted test signal shall consist of a 50% amplitude-modulated signal at a modulation frequency of 83$\frac{1}{3}$ Hz. The modulation shall be maintained between 45% and 55% and the frequency variation held to ± 0.1%.

**4.3.3.1.2 Test Signal Distortion.** All harmonics or other spurious outputs from the transmitter shall be individually at least 46 dB below the power of the carrier frequency ($f_c$). In addition, 83$\frac{1}{3}$ Hz and 3 $f_c$ + 83$\frac{1}{3}$ Hz shall be down at least 52 dB. Total distortion and spurious output shall be at least 43 dB below the power of the carrier frequency.

**4.3.3.1.3 Frequency Range.** The carrier frequency shall have a range of at least 300 Hz to 3.5 kHz.

**4.3.3.1.4 Frequency Accuracy.** The output frequency shall be within 40 Hz of the indicated frequency. If a frequency counter is present in the envelope delay set, the frequency displayed shall be within 4 Hz of the transmitted frequency.

**4.3.3.1.5 Output Level Range.** The output carrier-frequency power shall have a range of at least 0 dBm to −40 dBm. Adjustment shall be in 5 dB steps or less.

**4.3.3.1.6 Flatness.** The output power shall be flat to ± 0.2 dB from at least 300 Hz to 3.5 kHz.

**4.3.3.1.7 Compatibility.** Because the transmitter of one envelope delay set may be used with the receiver of another set, it is necessary that the delay flatness of the transmitter be better than the back-to-back delay flatness required in 4.3.3.2.1, in that a maximum of one-half of the permitted back-to-back envelope delay distortion may be in the transmitter.

**4.3.3.2 Receiver**

**4.3.3.2.1 Accuracy and Resolution.** The back-to-back measurement accuracy shall be ± 10 $\mu$s or finer from 600 Hz to at least 3.5 kHz and ± 30 $\mu$s from 300 Hz to 599 Hz. The resolution shall be 10 $\mu$s or finer.

**4.3.3.2.2 Range.** The set shall have an envelope delay distortion measurement range capability of at least 10 000 $\mu$s.

**4.3.3.2.3 Input Power.** The receiver shall meet the accuracy requirements for an input-carrier power range of at least +10 dBm to −40 dBm. Some means shall be provided to show if the received signal is not within the useful range of the instrument.

**4.3.3.2.4 Display Response Time.** After the application of a 3000 $\mu$s step change in delay, the instrument shall indicate within 30 μs of the final delay distortion indication with 3 seconds.

4.3.3.2.5 **Frequency Accuracy.** The indicated frequency shall be within 40 Hz of the input frequency. If a frequency counter is present in the envelope delay set, the frequency displayed shall be within 4 Hz of the input carrier frequency.

4.3.3.2.6 **Amplitude-to-Phase Conversion.** The indicated envelope delay in the back-to-back mode shall not change by more than 5 μs for a transmitted level shift of ± 5 dB.

4.3.3.2.7 **Internal Crosstalk.** The measured envelope delay distortion for a low-loss network with at least 1000 μs of envelope delay distortion shall not differ by more than ± 10 μs if 35 dB of flat loss is inserted in series with the network. This test shall be conducted in the back-to-back mode.

4.3.3.2.8 **Signal-to-Noise Ratio.** The accuracy objectives given above shall be met on a back-to-back basis with a line signal-to-noise ratio as low as 24 dB. The noise level shall be measured with a 3 kHz Flat weighting filter. The noise shall be introduced by summing linearly the test signal and a filtered noise source. The noise source shall be flat to ± 0.5 dB from below 60 Hz to above 14 kHz and shall be filtered by tandem 2-pole Butterworth high-pass and low-pass filters with cutoff frequencies of 120 Hz and 6.5 kHz, respectively, to provide a relative response given by:

$$\text{Noise filter response (dB)} = -10 \log \left[1 + \left(\frac{120}{f}\right)^4\right]\left[1 + \left(\frac{f}{6500}\right)^4\right]$$

The filter shall conform to this response within ± 0.5 dB from 85 Hz to 9.2 kHz.

4.3.3.2.9 **Harmonic Distortion to Phase Conversion.** The indicated delay for a test network having at least 500 μs of envelope delay between 1 kHz and 2 kHz and a frequency response flat within ± 0.5 dB from 600 Hz to 3.5 kHz, shall not change by more than ± 5 μs when the received signal is subjected to 25 dB of 2nd order distortion and 20 dB of compressive 3rd order distortion introduced after the test network. The circuitry creating these harmonic distortions should have no frequency dependent phase or amplitude characteristics within the band of interest. Distortion levels are to be established by either a selective level meter or a spectrum analyzer with a 10 Hz resolution bandwidth. Distortion adjustments of the test network are to be made so that the fundamental carrier is 25 dB above the 2nd harmonic and 20 dB above the 3rd harmonic outputs at the receiver input. The test signal applied to the test network input shall conform to the requirements of 4.3.3.1.

Recommended circuits for distortion generation are a high-quality half-wave rectifier for creation of the 2nd order products, a high-quality limiter for the 3rd order products and means for summing these in adjustable ratios with the undistorted input.

4.3.3.2.10 **Self-Check Capability.** A self-contained means should be provided for determining that the envelope delay distortion measuring portion of the instrument is properly calibrated.

4.3.3.2.11 **Turnover.** The set shall meet all of the requirements of this section if the input leads are interchanged. This permits only a constant shift in EDD.

4.3.3.2.12 **Analog Output.** Means should be provided for a dc output proportional to delay for purposes of X-Y chart recording, etc. Means should be provided for ± full-scale calibration and range changing for this output.

4.3.3.2.13 **Drift.** After the specified warm-up period, once the reference zero has been set at the reference frequency, it shall not drift by more than 10 μs in any half-hour period. This applies to the display and the analog output.

4.3.3.3 **Repeat Mode.** To permit envelope delay distortion measurements with envelope delay measuring sets at each end of the facility, the equipment shall be designed so that in the *repeat mode*, it can transfer the $83\frac{1}{3}$ Hz envelope of a received envelope delay signal to a new carrier for transmission back to the originating end. This establishes a phase reference over the loop.

When the set is operating in the *repeat mode*, it shall be capable of meeting the preceding transmitter and receiver requirements where appropriate. In addition, it shall meet the requirements of 4.3.3.3.1 through 4.3.3.3.4.

4.3.3.3.1 **Display of Frequency.** The set shall have the ability to display either transmitted or received frequency without loss of phase reference.

4.3.3.3.2 **Display of Received Level.** The set shall be able to display the received level to ensure that the receiver input range capability is not exceeded at any carrier frequency of interest.

**4.3.3.3.3 Forward Reference Mode.** In the forward reference mode, the originating end sends a modulated fixed-frequency signal to the far end. There the modulation is recovered and used to modulate a variable-frequency carrier that is sent back to the originating end where it is possible to measure the relative delay and amplitude response of the return path as a function of frequency. The variable carrier frequency can be selected by an operator at the far end, set for specific sweep routines, or otherwise programmed.

In some cases, the reference signal level received at the far end is used to control the return frequency. In such applications, it is necessary to ensure that level-to-phase conversion effects that may arise in compandored channels or channels with nonlinear distortion problems do not cause unacceptable errors in delay measurement. To ensure that the test is not a source of such error, the requirements in 4.3.3.2.6 shall be met for a received level shift of ± 5 dB located anywhere over the permissible receive level span. This requirement applies to transmitter and receiver individually and collectively.

**4.3.3.3.4 Return Reference Mode.** In the return reference mode, the originating end sends a modulated, variable-frequency signal to the far end. At the far end, the modulation is recovered and used to modulate a fixed-frequency carrier that is sent back to the originating end where it is used to measure the relative delay of the forward path as a function of frequency. In some cases, both the amplitude and the delay responses of the forward path can be measured by using the received level to control the level of the return references modulated fixed-frequency carrier. This may cause the same problems cited above for the forward reference. It is necessary that level-to-phase conversion effects in the return path not cause unacceptable errors in delay measurements. Therefore, for such use, the requirements of 4.3.3.2.6 shall apply.

## 4.4 Transients

**4.4.1 Description.** This section describes the measurement of two classes of transient phenomena in telephone circuits: impulse noise and rapid changes in phase or gain (including sudden loss of signal). Impulse noise is a large excursion of an input voltage signal level that is not correlated with the transmitted signal (if any) and is higher than the normal peaks of message circuit noise. A rapid change in phase is called a phase hit. A rapid change in received signal amplitude is called a gain hit. The phase or gain may stay at its new value or return to the original value some time later. A dropout occurs when the loss of the circuit increases by 12 dB or more compared to that at the start of the measuring interval.

Transients are usually measured in the presence of a sinusoidal signal called a holding tone as described in 4.3.1.4. For impulse noise measurement, either the holding tone is notched out and the background noise is monitored for peaks exceeding preset thresholds or the holding tone is not used at all. Noise peaks within 12 dB of the measured message circuit noise could be attributed to the message circuit noise rather than to impulse noise. To ensure that impulse noise thresholds are set at least 12 dB above message circuit noise, it is important to have knowledge of the rms noise level. It is, therefore, important that an impulse-noise measuring instrument also be capable of measuring message circuit noise.

A holding tone is always used for the measurement of phase hits, gain hits, and dropouts. The phase and level of the holding tone are monitored for changes exceeding preset thresholds. In any transient measurement, counts of transients exceeding thresholds are accumulated and displayed continuously or for preset measurement time intervals. Surveys of telecommunication facilities have shown that dropouts, phase hits, and gain hits occur less frequently than impulse noise. Tests show, however, that each dropout causes more modem errors than each phase or gain hit, which in turn cause more errors than impulse noise.

To ensure that hit counters have protection against low-frequency noise and noise at the upper end of the voice band, a front-end bandpass filter is required which passes energy near 1 kHz. The detection process for hits measured through this filter shall therefore be different from that of high-speed data sets which utilize all the available passband of a voice channel.

It is the function of the hit counter to approximate the sensitivity of high-speed data sets to hits to permit sectionalization and clearing of troubles on telecommunication facilities. The wide variety of hit wave forms, the effects of noise on measurements, and allowable tolerances in thresholds and measurement circuitry, will generally contribute to different hit counts even on instruments of identical design.

This variability will lead to some confusion among those testing with hit counters of different manufacture. The alternative of specifying the entire hit counting circuitry is under further investigation. Dropout counting requirements in the presence of noise and single-frequency interference are also being investigated.

**4.4.2 Common Requirements.** The following requirements are common to the measurement of all transient phenomena.

**4.4.2.1 Holding Tone.** Transient measuring instruments shall meet the requirements of this section with the received holding tone level between +10 dBm and -40 dBm, the frequency between 995 Hz and 1025 Hz, and at least 20 dB signal to C-Notch noise ratio. Specifications for the transmitted holding tone are given in 4.3.1.4. The test setup shall either display the holding-tone frequency or indicate when the holding-tone frequency is out of range.

**4.4.2.2 Counting Rate.** Except for the requirements of 4.4.2.6.1, the nominal counting rate shall be 8 counts per second. For electromechanical counters the rate shall be 8 counts per second ± 10%. For electronic counters a blanking interval of 125 ms ± 10% shall be provided. The timing of this blanking interval begins when a transient first crosses the preset threshold. Each counter and associated blanking interval shall be independent (see 4.4.2.6 and 4.4.3.7).

As an aid in troubleshooting, an additional faster counting rate may be provided. This is not a quantitative measurement and while in this mode other specifications may be exceeded. This is especially true for phase hits where a longer time may be required for the phase lock loop to fully recover following a large hit. The nominal fast counting rate shall be 100 counts per second with a blanking interval of 10 ms.

**4.4.2.3 Qualification Interval.** A qualification interval of $4 \pm \frac{1}{2}$ periods of the holding tone is necessary to distinguish phase hits, gain hits, and dropouts from each other and also from impulse noise. This qualification interval is also necessary to avoid counting individual cycles of a damped oscillation impulse. This interval begins at the time a transient first crosses the preset threshold. Only those phase hits, gain hits, and dropouts that exceed the threshold for longer than the qualification interval shall be counted. Each counter and associated qualification interval shall be independent (see 4.4.2.6).

**4.4.2.4 Polarity.** Interchange of the input leads of the measuring equipment shall not degrade the accuracy or the dynamic characteristics of the measurements.

**4.4.2.5 Counting Interval.** A timer accurate to at least ± 5% shall be provided for the convenience of the tester. Time periods of 5 minutes, 15 minutes, and 60 minutes, in addition to free running, shall be provided if the timer is not continuously adjustable.

**4.4.2.6 Counting Hierarchy.** Whenever several types of transient phenomena are being measured simultaneously, the following hierarchy applies.

**4.4.2.6.1 Dropouts.** Detection and counting of a dropout shall block the counting of hits or impulse noise for a period of time beginning when the dropout is first qualified and ending one second after the dropout ends. This implies a maximum count of 1 per second.

**4.4.2.6.2 Phase and Gain Hits.** Detection and counting of a phase or gain hit shall not block the counting of impulse noise. Phase and gain hits shall not block one another. When they occur simultaneously, both shall be counted.

**4.4.2.7 Bandpass Filter for Hit and Dropout Counter.** In order to provide some immunity to single frequency interference and noise, it is recommended that an input bandpass filter precede hit and dropout detection circuits. Although the number of poles and type of filter used are not critical, the rise time (and therefore the bandwidth) is critical. The filter and detection circuit designs shall be such that the requirements for single-frequency interference in 4.4.4.4, 4.4.5.4, and 4.4.6.3 and the requirements for amplitude and duration limits in 4.4.4.8 and 4.4.5.8 are all satisfied.

**4.4.3 Impulse Noise.** An impulse is counted when the received signal exceeds a preset threshold, provided the impulse is not blocked by a dropout (see 4.4.2.6.1).

**4.4.3.1 Threshold Setting Range.** Adjustment of the threshold level in 1 dB steps shall be provided for balanced (metallic) signals ranging from 30 dBrn to 110 dBrn and for impulse noise-to-ground measurements, ranging from 60 dBrn to 140 dBrn.

**4.4.3.2 Threshold Accuracy.** The test set shall be calibrated in dBrn to read the peak value of the received signal. The accuracy of the threshold setting shall be ± 1 dB for balanced impulse noise measurements, and ± 1.5 dB for impulse noise-to-ground measurements. With the tandem connection of the C-Message and notch filters described in 4.4.3.4(1) and (2), the counting threshold for a steady sinusoidal input shall be checked as follows: Apply a 0 dBm, 1.8 kHz tone to the input of the set (which will be attenuated by 1.5 dB in the filters) and verify that counting does not occur with a 92 dBrn threshold and that continuous counting occurs at a 91 dBrn threshold.

**4.4.3.3 Count Capacity.** A register with a capacity of at least 998 counts shall be provided. A means for indicating overflow shall be provided.

4.4.3.4 Filters

(1) *C-Message Weighting.* If a C-Message filter is required only for measurement of noise as described in 4.3.2, then the gain versus frequency plot of Fig 1 is a sufficient specification. Many filter pole-zero locations will meet the requirements of Fig 1, but different pole-zero locations will yield different peak responses for voiceband impulses. For this reason, a C-Message filter for impulse noise measurement shall conform to more specific requirements. The C-Message filter shall have the following pole-zero locations.

zeros (radians): $0, 0, 0, 0, \infty, \infty, \infty, \infty, \infty$
poles (radians): $-1502 \pm j1267$,
$-2439 \pm j5336$,
$-4690 \pm j15\,267$,
$-4017 \pm j21\,575$

(2) *1010* Hz *Notch Filter.* If a 1010 Hz Notch filter is required only for measurement of noise-with-tone as described in 4.3.2, then the gain versus frequency plot of Fig 2 is a sufficient specification. Many filter pole-zero locations will meet the requirements of Fig 2, but different pole-zero locations will yield different peak responses for voiceband impulses. For this reason a 1010 Hz Notch filter used for impulse noise measurement shall conform to more specific requirements. In particular, the notch transfer function shall consist of three complex pole pairs and three real frequency zero pairs. One suitable design is a stagger-tuned set given by:

zeros (radians): $\pm j6202, \pm j6346, \pm j6494$
poles (radians): $-197 \pm j5640, -1310 \pm j6209,$
$-249 \pm j7132$

Other suitable designs include Butterworth 3rd-order band-reject responses meeting the magnitude requirements of Fig 2.

In all cases, it is essential that the filter steady-state response meet the requirements of Fig 2 and the time-domain response requirements of the following paragraph.

**4.4.3.5 Filter Response to a Standard Impulse.** Apply the standard impulse, B, of Fig 5, at a rate of twice per second, to the impulse noise counter with the C-Message weighting filter and the 1010 Hz Notch filter in tandem. With the attenuator set at 0 dB and the count threshold set to 83 dBrn the counter shall count each impulse applied and no counts shall be recorded at a threshold setting of 85 dBrn.

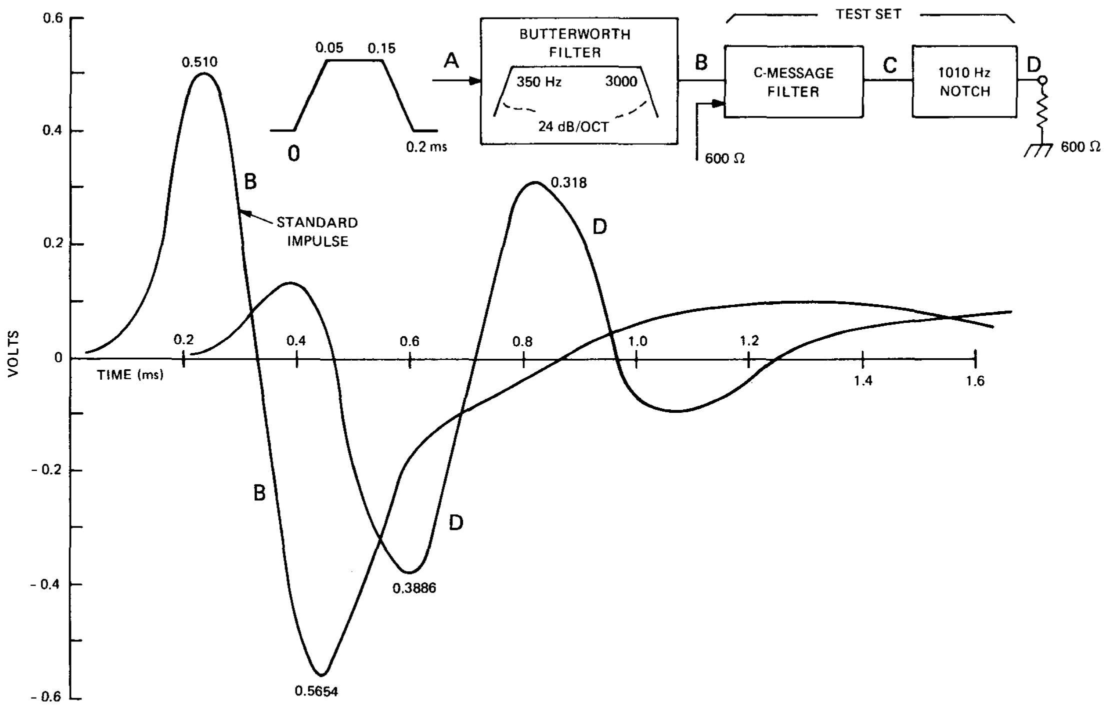
When the rate of impulses is changed from twice per second to a rate of one every five seconds for each of the above thresholds the above counting criteria shall be met.

With appropriate gain or loss following the Butterworth filter of Fig 5, the impulse noise counter shall meet the accuracy objective of 4.4.3.2 over a threshold setting range of 30 dBrn to 110 dBrn.

**4.4.3.6 Turnover.** There shall be no difference in the response of the impulse noise counter if the signal, A, of Fig 5 is applied to the input of the impulse noise counter in a normal manner or with the input leads reversed.

**4.4.3.7 Impulse Noise Distribution Set.** If provision is made for obtaining impulse noise amplitude distributions, then at least three separate storage registers shall be provided, each having a capacity of at least 998 counts. A means for indicating overflow on each register shall be provided.

If only three registers are provided, with no provision for selection of threshold differences,



| At Point D | Peak | Threshold |
|---|---|---|
| 0 dBm SINE WAVE | $\sqrt{0.60}\sqrt{2} = 1.095$ V | 93.0 dBrn |
| Standard Impulse after C-Notch | 0.3886 V | 84.0 dBrn |

**Fig 5**
**Test Configuration for a Standard Impulse**

the threshold difference between them shall be set at 4 dB. Otherwise, the threshold differences for the individual registers shall be capable of being set to at least 2 dB, 4 dB, and 6 dB. The reference level shall correspond to the lowest threshold setting.

The registers shall display the cumulative distribution function of impulses, each subject to the 8 counts-per-second rate. Each register should have its own independent blanking-interval timing circuit so that an impulse just exceeding any lower threshold will not block other registers from counting on a subsequent higher impulse within the 125 ms ± 10% of the original impulse. For example, if an impulse exceeding a LOW threshold is followed in 30 ms by an impulse exceeding a MID threshold, one count should be recorded on the LOW register and one on the MID register. An impulse exceeding the LOW threshold, followed in 100 ms by an impulse exceeding the MID threshold, followed in 100 ms by an impulse exceeding the LOW threshold, should register as one MID count and two LOW counts.

**4.4.3.8 Overload Characteristics.** An impulse 6 dB greater than the highest available counter threshold shall register on all counters for any threshold setting.

**4.4.3.9 Operation Without Holding Tone.** Provisions shall be made to allow impulse noise counting without holding tone.

**4.4.3.10 Loss of Holding Tone.** For a set which has no dropout counter, if the holding tone drops below - 40 dBm for a period longer than 125 ms then:

(1) No impulses shall be counted during the interval beginning 125 ms after the tone drops below - 40 dBm and ending when the

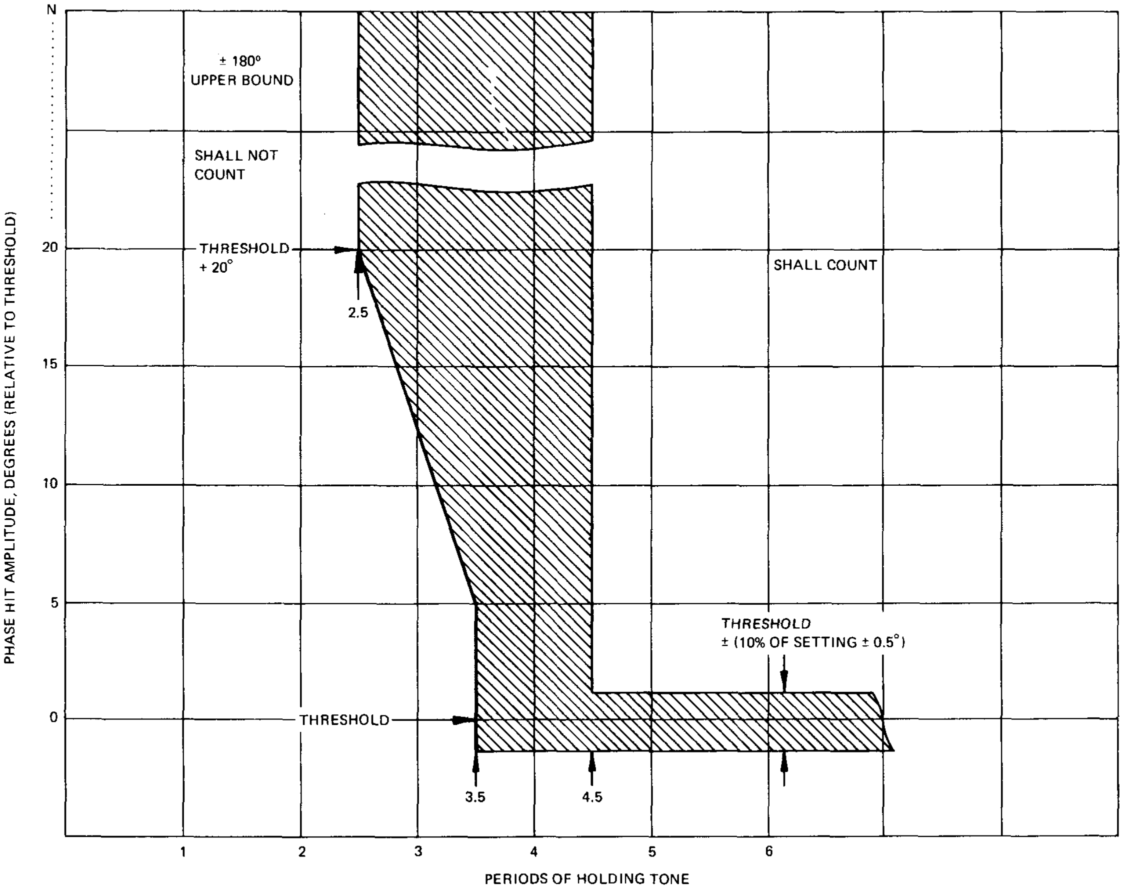


**Fig 6**
**Phase Hit Amplitude and Duration Limits**

tone has returned to a level above -40 dBm for 125 ms.

(2) An indicator shall signify loss of holding tone. The indicator should remain latched until reset.

4.4.4 **Phase Hits.** A phase hit is counted when a change in phase of the holding tone exceeds a preset threshold for a period of time longer than the qualification interval. This may be a positive or negative phase change.

4.4.4.1 **Threshold Setting Range.** Threshold settings from 5° to 45° in 5° steps shall be provided.

4.4.4.2 **Threshold Accuracy.** The accuracy of the threshold settings shall be ± (10% of the setting plus an additional 0.5°), for phase changes of either polarity occurring within a 0.2 ms transition time.

4.4.4.3 **Count Capacity.** A register capacity of at least 998 counts with an overflow indicator shall be provided.

4.4.4.4 **Single-Frequency Interference.** To check for single-frequency interference protection, perform the following tests.

(1) Set the phase hit threshold to 10°. Apply a -20 dBm, 1004 Hz holding tone with 25°, 5 ms phase hits occurring once per second.

(2) Add a 300 Hz tone at -30 dBm to the holding tone with phase hits. All of the 25° phase hits (and no extra) shall be recorded at the 10° threshold.

(3) Remove the 300 Hz tone and add a 120 Hz tone at -22 dBm. All of the 25° phase hits (and no extra) shall be recorded at the 10° threshold.

(4) Remove the 120 Hz tone and add a 3100 Hz tone of -30 dBm. All of the 25° phase hits (and no extra) shall be recorded at the 10° threshold.

**4.4.4.5 Amplitude-to-Phase Conversion.** A 10 dB gain hit shall not cause a phase hit to be counted at the 10° threshold.

**4.4.4.6 Qualification Interval.** A phase hit exceeding a threshold by 5° shall not be counted if the holding tone returns to its original phase within 3.5 periods of the holding tone and shall be counted if the tone returns to its original phase after 4.5 periods of the holding tone.

**4.4.4.7 Loop Recovery Time.** If the phase of the test tone varies linearly for 100° in either direction over a period defined as the rise time, a 20° phase hit shall be counted for a 20 ms rise time and shall not be counted for a 50 ms rise time. This roughly approximates the performance of high-speed modems.

**4.4.4.8 Phase Hit Amplitude and Duration Limits.** Figure 6 is a graphical representation of the amplitude and duration requirements that shall be met for phase-hit measuring instruments. The instrument shall not count phase hits for conditions below and to the left of the shaded area and shall count all phase hits above and to the right of the shaded area when tested with a 1004 Hz holding tone. This requirement shall be met for thresholds of 5° through 45° over the range of hit inputs of -180° to +180°.

**4.4.5 Gain Hits.** A gain hit is counted when a change in the amplitude of the holding tone exceeds a preset threshold for a period of time longer than the qualification interval. This may be an increase or a decrease in amplitude.

**4.4.5.1 Threshold Settings.** Threshold settings of 2 dB, 3 dB, and 6 dB shall be provided. In addition optional settings of 4 dB, 8 dB, and 10 dB may be provided.

**4.4.5.2 Threshold Accuracy.** The accuracy of the threshold settings shall be ± 0.5 dB, for gain changes of either polarity occurring within a 0.2 ms transition time.

**4.4.5.3 Count Capacity.** A register capacity of at least 998 counts with an overflow indicator shall be provided.

**4.4.5.4 Single-Frequency Interference.** To check for the single-frequency interference protection, perform the following tests.

(1) Set the gain hit threshold to 3 dB. Apply a -20 dBm, 1004 Hz holding tone with -6 dB, 5 ms gain hits occurring once a second.

(2) Add a 300 Hz tone of -30 dBm to the holding tone with gain hits. All of the -6 dB gain hits (and no extra) shall be recorded at the 3 dB threshold.

(3) Remove the 300 Hz tone and add a 120 Hz tone at -22 dBm. All of the -6 dB gain hits (and no extra) shall be recorded at the 3 dB threshold.

(4) Remove the 120 Hz tone and add a 3100 Hz tone at -30 dBm. All of the -6 dB gain hits (and no extra) shall be recorded at the 3 dB threshold.

**4.4.5.5 Phase-to-Amplitude Conversion.** A 180° phase hit shall not cause a gain hit to be counted at the 2 dB threshold.

**4.4.5.6 Qualification Interval.** A gain hit exceeding a threshold by 1 dB shall not be counted if the holding tone returns to its original value in 3.5 periods of the holding tone, and shall be counted if the tone returns to its original level after 4.5 periods of the holding tone.

**4.4.5.7 Loop Recovery Time.** If the amplitude of the test tone varies linearly for 4 dB in either direction over a period defined as the rise time, a 2 dB gain hit shall be counted for a 200 ms rise time and shall not be counted for a 600 ms rise time. This requirement roughly approximates the performance of high-speed modems.

**4.4.5.8 Gain-Hit Amplitude and Duration Limits.** Figure 7 is a graphical representation of the amplitude and duration requirements that shall be met for gain-hit measuring instruments. The instrument shall not count gain hits for any conditions below and to the left of the shaded area and shall count all gain hits above and to the right of the shaded area when tested with a 1004 Hz holding tone. This requirement shall be met for thresholds of 2 dB through 6 dB over the range of hit inputs of -12 dB to +7 dB.

**4.4.6 Dropouts.** A dropout is counted when the level of the holding tone decreases by at least 12 dB for a period of time longer than the qualification interval. The dropout measuring set shall measure the received holding tone level at the start of the measuring interval and establish a dropout threshold 12 dB below this level. This threshold will remain fixed during the remainder of the measuring period.

**4.4.6.1 Threshold Setting and Accuracy.** One threshold shall be provided at 12 dB ± 1 dB.

**4.4.6.2 Count Capacity.** A register capacity

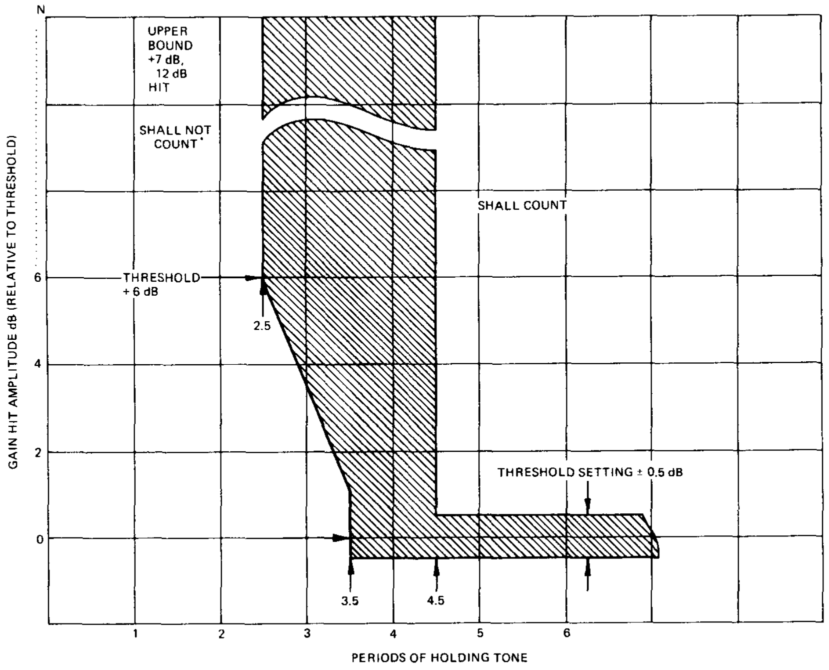


Fig 7
Gain Hit Amplitude and Duration Limits

of at least 98 counts with an overflow indicator shall be provided.

4.4.6.3 **Single-Frequency Interference.** To check for single-frequency interference protection, perform the following tests.

(1) Apply a -20 dBm, 1004 Hz holding tone and start the dropout detection. Apply -20 dB, 5 ms gain hits to the holding tone once every 2 seconds.

(2) Add a 300 Hz tone at -30 dBm to the holding tone with hits. All of the -20 dB gain hits (and no extra) shall be recorded as dropouts.

(3) Remove the 300 Hz tone and add a 120 Hz tone at -22 dBm. All of the -20 dB gain hits (and no extra) shall be recorded as dropouts.

(4) Remove the 120 Hz tone and add a 3100 Hz tone at -30 dBm. All of the -20 dB gain hits (and no extra) shall be recorded as dropouts.

### 4.5 Incidental Modulation

4.5.1 **Phase Jitter.** Phase jitter measurements indicate the cumulative effect of incidental phase modulation and additive tones or noise on the phase of a holding tone (see 4.3.1.4 for holding-tone requirements). The peak-to-peak deviations in phase of the received signal are detected after band limiting to reduce the effect of additive noise.

The most commonly found single-frequency components of phase jitter are 20 Hz (ringing current), 60 Hz (commercial power) and the 2nd through 5th harmonics of these. Since the peak phase deviation caused by ac components of phase modulation rarely exceeds 0.2 radians (low-index phase modulation) only one pair of significant sidebands is produced for each sinusoidal component. Hence, a bandwidth of approximately 600 Hz centered about a carrier near 1 kHz suffices to recover the major suspected sinusoidal phase modulation without incurring large amounts of uncorrelated interference.

Since noise can cause what would appear to be a significant amount of phase jitter, a C-Notch weighted noise measurement should always be made in conjunction with phase jitter measurements. Also, because quantizing noise can cause a significant phase jitter reading, care is needed in the choice of the carrier frequency and in the filtering to suppress the effect of noise on the measurement.

Incorrect phase jitter readings (lower than true value) will result if a 1000 Hz carrier is employed on a pulse code modulation (PCM) system with an 8 kHz sampling rate (see 4.3.1.4).

Instances of phase jitter in the region from 4 Hz to 20 Hz have been noted on some facilities. Since some data sets are affected by this low-frequency jitter, there may be a need for an option which permits testing in this range with equal frequency weighting in the total band of 4 Hz to 300 Hz.

4.5.1.1 **Accuracy.** The displayed peak-to-peak reading shall be accurate to ± 5% of the measured value ± 0.2°.

4.5.1.2 **Level Range.** The set should accommodate input signal levels from −40 dBm to +10 dBm. The set also should have means to indicate when the signal is outside of this range.

4.5.1.3 **Frequency Range.** The set shall accommodate input frequencies from 990 Hz to 1030 Hz. The set should give some indication when the signal is outside the range of 990 Hz to 1030 Hz.

4.5.1.4 **Display Range.** The set should be capable of displaying phase jitter readings from 0.0° to at least 25° peak-to-peak.

4.5.1.5 **Noise Rejection.** A band-limited white noise signal down 30 dB from a 1 kHz sine-wave carrier shall indicate less than 4° peak-to-peak jitter. For purposes of this test, the band-limited white noise signal shall be flat to within ±1 dB from 250 Hz to 3.5 kHz with asymptotic slopes of −12 dB per octave. When a limiter is used in the detection process, this requirement typically dictates a bandpass filter in front of the limiter.

4.5.1.6 **Frequency Weighting.** After demodulation, the signal shall be weighted so that jitter components in the selected band are given equal weighting. The weighting characteristics may be measured by applying a pure 1 kHz tone at a 0 dBm level as the carrier and a second pure tone 20.0 dB lower in level as a source of phase jitter.

For purposes of this test, a pure tone is defined as a signal source that meets the requirements of a holding tone oscillator as specified in 4.3.1.4. Tables 5 and 6 give the jitter reading limits as a function of the difference in frequency between the two tones.

Table 5
Frequency Weighting Band of 20 Hz to 300 Hz

| Difference Frequency (Hz) | Phase Jitter Degrees Peak-to-Peak |
|---|---|
| 2 | < 1.0 |
| 5 | < 3.0 |
| 10 | < 8.0 |
| 20–240 | 10.8 to 12.2 |
| 300 | 10.0 to 12.2 |
| 500 | < 3.0 |

Table 6
Frequency Weighting Band of 4 Hz to 300 Hz

| Difference Frequency (Hz) | Phase Jitter Degrees Peak-to-Peak |
|---|---|
| 0.4 | < 1.0 |
| 1 | < 3.0 |
| 2 | < 8.0 |
| 4 | 9.2 to 12.2 |
| 8–240 | 10.8 to 12.2 |
| 300 | 10.0 to 12.2 |
| 500 | < 3.0 |

4.5.1.7 **Single-Frequency-Interference.** Apply a 1 kHz tone to the input of the set at a 0 dBm level. Add in a second tone down 20 dB in level and vary its frequency. For frequencies below 300 Hz, the displayed reading shall be less than 1°. For frequencies between 1.5 kHz and 4 kHz the displayed reading shall be less than 3°. For frequencies above 4 kHz, the displayed reading shall be less than 0.5°.

4.5.1.8 **Level-to-Phase Conversion.** With the test setup as in the previous test and the second tone at 1.1 kHz, change the composite level over the range of +10 dBm to −40 dBm without a change in the ratio of the test-tone and the second tone amplitudes. The spread of the readings shall not exceed 0.7°.

4.5.1.9 **Amplitude-to-Phase Conversion.** Apply a 10% amplitude-modulated 1 kHz carrier to the input of the set at a 0 dBm level. As the modulation frequency is varied from 2 Hz to 900 Hz, the displayed jitter indication shall be less than 1°.

4.5.1.10 **Measurement Averaging Time.** The detector and indicating circuits for the 20 Hz to 300 Hz frequency weighting shall have response averaging time characteristics as follows: apply a gated sine-wave phase modulation on a steady 1 kHz carrier to the test set. The modulation signal shall be gated at a duty cycle of 50%. The indicator shall show a variation as shown here:

| Gating Frequency (Hz) | Indicator Variation |
|---|---|
| 5.0 | $\frac{2\,(\mathrm{Max} - \mathrm{Min})}{\mathrm{Max} + \mathrm{Min}} < 10\%$ |
| 1.0 | $\frac{2\,(\mathrm{Max} - \mathrm{Min})}{\mathrm{Max} + \mathrm{Min}} > 40\%$ |

4.5.1.11 **Detector**

4.5.1.11.1 **Peak-to-Peak.** The detector shall be a true peak-to-peak detector. Do not use a two-times-peak detector.

4.5.1.11.2 **Response to White Noise.** The detector should measure white noise at the 2.58 sigma (99%) point.

4.5.1.11.3 **Two-Tone Response.** A test for the quality of peak detection is as follows:

(1) Apply a 0 dBm, 1000 Hz carrier tone to the input of the set together with a second tone at 1100 Hz which is adjusted in level to produce a phase-jitter reading of exactly 10.0°.

(2) Remove the 1100 Hz tone and add a tone at 1170 Hz with another oscillator which is adjusted in level to produce a phase-jitter reading of exactly 10.0°.

(3) Add the 1100 Hz tone, at its previously-adjusted level, to the carrier plus the 1170 Hz tone. The phase-jitter reading shall lie between 18.5° and 19.8°.

4.5.1.12 **Time to Display Correct Reading.** When the 20 Hz to 300 Hz weighting is used, the display shall be within 0.7° of the final reading in 4.5.1.6 at a difference frequency of 100 Hz, within 4 seconds of application of the complete test signal. When the 4 Hz to 300 Hz weighting is used, the time to display the correct reading shall be within 25 seconds of application of the complete test signal.

4.5.1.13 **Demodulated Carrier.** If the set employs a phase locked loop, the demodulated carrier from the phase locked loop should be made available for measurement of frequency offset over the facility. This carrier is relatively free from the interfering effects of noise on the facility.

4.5.1.14 **Demodulated Phase Jitter.** The test signal, after phase demodulation and frequency weighting, should be made available on an external jack to permit analysis of the jitter signal.

4.5.2 **Amplitude Jitter.** Amplitude jitter measurements indicate the cumulative effect of incidental amplitude modulation and additive tones or noise on the envelope of a holding tone (holding-tone requirements are found in 4.3.1.4). Peak-to-peak deviations in the envelope of the received signal are detected after band limiting to reduce the effect of additive noise.

The most commonly found single-frequency components of amplitude jitter are 60 Hz (commercial power) and its 2nd through 5th harmonics. A bandwidth of approximately 600 Hz centered about a carrier near 1 kHz suffices to recover the major suspected amplitude jitter without incurring large amounts of uncorrelated interference.

Since group delay distortion and frequency response of a channel can cause amplitude jitter to be created from phase jitter, and vice versa, it is recommended that amplitude jitter be measured in conjunction with phase jitter. Comparison of amplitude jitter measurements with phase jitter measurements can be an effective tool in the diagnosis of channel impairments.

Since noise can cause what would appear to be a significiant amount of amplitude jitter, a C-Notch weighted noise measurement always should be made in conjunction with amplitude jitter measurements. Also, because quantizing noise can cause a significant jitter, care shall be exercised in the choice of the carrier frequency and in the filtering to suppress the effect of noise on the measurement.

Incorrect amplitude jitter readings (lower than true value) will result if a 1000 Hz carrier is employed on a PCM system with an 8 kHz sampling rate. (See 4.3.1.4).

Instances of amplitude jitter in the region from 4 Hz to 20 Hz have been noted on some facilities. Since some data sets may be affected by this low-frequency jitter, there may be a need for an option which permits testing in this range with equal frequency weighting in the total band of 4 Hz to 300 Hz.

4.5.2.1 **Accuracy.** The displayed reading shall be accurate to ±5% of the measured value ±0.2% peak.

4.5.2.2 **Level Range.** The equipment should accommodate input signal levels from - 40 dBm to +10 dBm. The set should have means to indicate when the signal is outside of this range.

4.5.2.3 **Frequency Range.** The set shall accommodate input frequencies from 990 Hz to 1030 Hz. The set should give some indication when the signal is outside of this range.

4.5.2.4 **Display Range.** The set should be capable of displaying amplitude jitter readings from 0.0% peak to at least 25% peak.

4.5.2.5 **Noise Rejection.** A bandlimited white noise signal down 30 dB from a 1 kHz sine-wave carrier shall indicate less than 4% peak jitter. For this test, the bandlimited white noise signal shall be flat to within ±1 dB from 250 Hz to 3.5 kHz with asymptotic slopes of - 12 dB per octave.

4.5.2.6 **Frequency Weighting.** After demodulation, the signal should be weighted so that jitter components in the selected band are given full weighting. The weighting characteristics may be measured by applying a pure 1 kHz tone at a 0 dBm level as the carrier and a second pure tone, 20.0 dB lower in level, as a source of amplitude jitter. For this test, a pure tone is defined as a signal source that meets the requirements of a holding tone oscillator as specified in 4.3.1.4. Tables 7 and 8 give the jitter reading limits as a function of the difference frequency between the two tones.

**Table 7**
**Frequency Weighting Band of 20 Hz to 300 Hz**

| Difference Frequency (Hz) | Amplitude Jitter % Peak |
|---|---|
| 2 | < 0.9 |
| 5 | < 2.6 |
| 10 | < 7.0 |
| 20-240 | 9.4 to 10.6 |
| 300 | 8.7 to 10.6 |
| 500 | < 2.6 |

**Table 8**
**Frequency Weighting Band of 4 Hz to 300 Hz**

| Difference Frequency (Hz) | Amplitude Jitter % Peak |
|---|---|
| 0.4 | < 0.9 |
| 1 | < 2.6 |
| 2 | < 7.0 |
| 4 | 8.0 to 10.6 |
| 8-240 | 9.4 to 10.6 |
| 300 | 8.7 to 10.6 |
| 500 | < 2.6 |

4.5.2.7 **Single-Frequency Interference.** Apply a 1 kHz tone to the input of the set at a 0 dBm level. Add in a second tone down 20 dB in level and vary its frequency. For frequencies below 300 Hz the displayed reading shall be less than 0.9% peak and for frequencies between 1.5 kHz and 4 kHz the display reading shall be less than 2.6% peak. For frequencies above 4 kHz, the displayed reading shall be less than 0.5% peak.

4.5.2.8 **Level-to-Amplitude Jitter Conversion.** With the test setup as in the previous test and the second tone at 1.1 kHz, change the composite level over the range of +10 dBm to - 40 dBm without a change in the ratio of the test-tone and the second tone amplitudes. The spread of the readings shall not exceed 0.6% peak.

4.5.2.9 **Phase-to-Amplitude Conversion.** Apply 11.5° peak-to-peak phase modulated 1 kHz carrier to the input of the set at a 0 dBm level. As the modulation frequency is varied from 2 Hz to 900 Hz, the displayed jitter indication shall be less than 0.9% peak.

4.5.2.10 **Measurement Averaging Time.** The detector and indicating circuits for the 20 Hz to 300 Hz frequency weighting should have response averaging time characteristics as follows: apply a gated sine-wave amplitude modulation on a steady 1 kHz carrier to the test set. The modulation signal should be gated at a duty cycle of 50%. The indicator should show a variation as follows:

| Gating Frequency (Hz) | Indicator Variation |
|---|---|
| 5.0 | $\frac{2\,(\text{Max} - \text{Min})}{\text{Max} + \text{Min}} < 10\%$ |
| 1.0 | $\frac{2\,(\text{Max} - \text{Min})}{\text{Max} + \text{Min}} > 40\%$ |

**4.5.2.11 Detector**

**4.5.2.11.1 Peak-to-Peak.** The detector shall be a true peak-to-peak detector. Do not use half-wave or a peak detector.

**4.5.2.11.2 Response to White Noise.** The detector should measure white noise at the 2.58 sigma (99%) point.

**4.5.2.11.3 Two-Tone Response.** A test for the quality of peak detection is as follows:

(1) Apply a 0 dBm, 1000 Hz carrier tone to the input of the set together with a second tone at 1100 Hz which is adjusted in level to produce an amplitude jitter reading of exactly 10.0%.

(2) Remove the tone at 1100 Hz and add a tone at 1170 Hz with another oscillator which is adjusted in level to produce an amplitude jitter reading of exactly 10.0%.

(3) Add the tone at 1100 Hz at its previously-adjusted level, to the carrier plus the tone at 1170 Hz. The jitter reading shall lie between 18.5% and 19.8%.

**4.5.2.12 Time to Display Correct Reading.** When the 20 Hz to 300 Hz weighting is used, the display shall be within 0.6% peak of the final reading in 4.5.2.6 at a difference frequency of 100 Hz, within 4 seconds of application of the complete test signal.

When the 4 Hz to 300 Hz weighting is used, the time to display the correct reading shall be within 25 seconds of application of the complete test signal.

**4.5.2.13 Demodulated Amplitude Jitter.** The test signal, after amplitude demodulation and frequency weighting, should be made available at an external jack to permit analysis of the jitter signal.

### 4.6 Other Measurements

**4.6.1 Return Loss.** Return loss is the ratio, in decibels, of the power incident upon a transmission system discontinuity to the power reflected from the discontinuity. Return loss measurements are made on both 2-wire and 4-wire circuits. The 4-wire return loss at frequency ($f$) is given by:

$$\mathrm{RL}\,(f) = 10 \log \frac{\text{transmitted power } (f)}{\text{received power } (f)}$$

The 2-wire return loss at frequency ($f$) is given by:

$$\mathrm{RL}\,(f) = 10 \log \frac{\text{transmitted power } (f)}{\text{reflected power } (f)}$$

The 2-wire return loss at frequency ($f$) can be calculated by:

$$\mathrm{RL}\,(f) = 20 \log \left| \frac{Z(\mathrm{f}) + Z_{\mathrm{ref}}(f)}{Z(f) - Z_{\mathrm{ref}}(f)} \right|$$

where

$Z(f)$ = impedance of the circuit under test at frequency ($f$)

$Z_{\mathrm{ref}}(f)$ = reference impedance at frequency ($f$)

Return loss measurements require a suitable termination at the distant end of the circuit. On 2-wire circuits, a hybrid is a necessary part of the measuring system to permit application of the transmitted signal and measurement of the reflected power. Measurements on 4-wire circuits do not require the use of a hybrid in the measuring system.

The result of a single frequency return loss measurement shall specify the measurement frequency. Return loss as a measure of impedance match is usually specified as the minimum for any frequency within a specified band.

Average return loss over a specified band of frequencies may be measured using a sweep frequency signal generator. The average return loss over the band is a power average. If the quantity available for averaging is voltage proportional, then the sum of squares averaging followed by log conversion should be used. If the quantity, RL($f$) expressed in decibels, is to be averaged, an antilog-average-log operation may be used to obtain the power average in decibels. Alternatively, a nonlinear circuit which approximates power averaging, analogous to the quasi-rms detector described in 4.3.2.5, may be used if accuracy specifications for the set are met.

Echo return loss (ERL) is the return loss of a circuit measured with a transmitted signal whose spectral distribution is defined in Table 9.

Singing return loss is the return loss of a circuit measured with two separately transmitted signals whose spectral distributions are defined in Table 10 (SRL Low) and Table 11 (SRL High).

These three measurements may be made either with a swept-frequency signal or a band-limited noise signal. When they are made with a signal source consisting of noise limited to the

### Table 9
### ERL Filter Response
### (Frequency Weighting)

| Frequency (Hz) | Relative Loss (dB) | Tolerance (dB) |
|---|---|---|
| ⩽ 200 | ⩾ 30.0 | — |
| 300 | 21.8 | ±2.3 |
| 560 | 3.0 | ±0.4 |
| 750 | 0.2 | ±0.2 |
| 1000 | 0.0 | ±0.1 |
| 1500 | 0.1 | ±0.2 |
| 1965 | 3.0 | ±0.4 |
| 2400 | 10.9 | ±1.2 |
| 3000 | 22.9 | ±3.0 |
| 4000 | 42.6 | ±5.0 |
| ⩾ 5000 | ⩾ 45.0 | — |

Return loss transmitters have designated this response as ERL. This response should continue to be designated as ERL.

### Table 10
### SRL Low Filter Response
### (Frequency Weighting)

| Frequency (Hz) | Relative Loss (dB) | Tolerance (dB) |
|---|---|---|
| ⩽ 100 | ⩾ 20 | — |
| 120 | 20 | ±3.0 |
| 200 | 9.5 | ±1.1 |
| 260 | 3 | ±0.5 |
| 360 | 0 | ±0.2 |
| 500 | 3 | ±0.5 |
| 650 | 10 | ±1.2 |
| 1000 | 20 | ±3.0 |
| ⩾ 1200 | ⩾ 20 | — |

Most return loss transmitters have designated this response as SRL. This response should be designated as SRL Low.

### Table 11
### SRL High Filter Response
### (Frequency Weighting)

| Frequency (Hz) | Relative Loss (dB) | Tolerance (dB) |
|---|---|---|
| ⩽ 1000 | ⩾ 30 | — |
| 1300 | 30 | ±4.0 |
| 2000 | 11.5 | ±1.3 |
| 2200 | 3 | ±0.5 |
| 2700 | 0 | ±0.2 |
| 3400 | 3 | ±0.5 |
| 3700 | 10.9 | ±1.3 |
| 5700 | 30 | ±4.0 |
| ⩾ 6000 | ⩾ 30 | — |

Most return loss transmitters have designated response as SRL HI. This response should be designated as SRL High.

bands indicated in Tables 9, 10, and 11, a power average is immediately available because all measurement frequencies are present simultaneously. When these three measurements are made with a swept sinusoidal signal, the power average shall be weighted according to Tables 9, 10, and 11, respectively.

The midband frequencies measured by ERL are most important to end-to-end subjective echo quality for voice communications, and stringent requirements have been established for ERL. SRL Low and SRL High have less stringent requirements designed to protect against circuit instability. Before the availability of test equipment which had singing return loss capability, amplification was added in 4-wire circuits until singing occurred, normally at a frequency covered by the present SRL Low or SRL High band. Singing point for a 4-wire circuit is the single-frequency return loss at that critical frequency. Singing point and the singing-return loss measurements for the band which contains the critical frequency have been found to be essentially the same.

Although the following specification implies a shaped transmitted spectrum and wide-band receiver, the specification should not be interpreted to preclude the use of a stepped or swept measurement, or frequency shaping in the receiver in place of a shaped transmitted spectrum. The overall performance of such systems shall be equivalent to that which is contained in the following specification. In addition, any flat noise spectrum should be band-limited to 4000 Hz.

#### 4.6.1.1 Transmitter

**4.6.1.1.1 Transmitted Signal Weighting Requirements.** Three signal weighting filter responses are given in Tables 9, 10, and 11. In each case, the applied test signal is derived by passing a wideband random or pseudorandom noise signal through a bandpass weighting network. The noise source should be flat ±0.5 dB from 200 Hz to 4 kHz as measured with a selective detector with approximately a 100 Hz bandwidth (3 dB) and no more than a 400 Hz bandwidth at the 60 dB points. A selective detector meter damping time constant of at least 0.7 seconds will be required to obtain a reasonable estimate of the central value of the noise. (If a pseudo-random or frequency step generator is used, its line spacing shall be 50 Hz or less, and if the flatness specification above is not met, such lack of flatness shall be compensated for in the bandpass filters.)

For echo return loss (ERL), low-frequency singing return loss (SRL Low) and high-frequency singing return loss (SRL High) measurements, the test signal is obtained by passing a wideband noise source signal through a bandpass filter network meeting the requirements given in Tables 9, 10, and 11.

4.6.1.1.2 **Output Level.** To avoid both system overload and background noise, the output level for ERL, SRL Low, or SRL High shall be in the range of - 2 dBm to - 10 dBm, as measured across a resistive termination. The preferred value is - 10 dBm.

4.6.1.1.3 **Level Stability.** The transmitter and receiver when used together shall meet the accuracy objective of ±0.5 dB for the periodic recalibration interval specified by the manufacturer. The allocation of drift between transmitter and receiver is the decision of the manufacturer.

4.6.1.1.4 **Harmonic Distortion.** The total harmonic distortion plus noise at the output shall be down at least 30 dB for each of the three transmitted signals and for the sinusoidal output, if an *external oscillator* jack is provided.

4.6.1.2 Receiver

4.6.1.2.1 **Accuracy and Range.** The receiver accuracy shall be ±0.5 dB or better over a range of 0 dB to 50 dB return loss for 4-wire measurements and ±0.5 dB or better over a range of 0 dB to 40 dB return loss for 2-wire measurements.

4.6.1.2.2 **Measurement Averaging Time.** The response time for the detector and indicating means shall meet the following limits: apply gated bursts of 1 kHz tone to the input of the set gated at a duty cycle of 50%, half of the cycle at full amplitude, and the other half may be chosen to avoid receiver autoranging points.

The indicator or digital display means shall show variation as below:

| Gating Frequency | Peak-to-Peak Indicator Variation |
|---|---|
| 1.5 Hz | Not more than 1 dB |
| 0.3 Hz | Not less than 3 dB |

4.6.1.2.3 **Meter Display.** If a meter is used as the display device, it shall have at least a 10 dB display range with 0.5 dB markings.

4.6.1.2.4 **60 Hz Loss.** A filter shall be provided at the input to the return loss set to minimize the effects of power-line hum. The filter shall have at least 20 dB of loss at 60 Hz, with less than 0.5 dB loss at 200 Hz.

4.6.1.2.5 **Transhybrid Loss Compensation.** In order to compensate for transhybrid loss on 4-wire return loss measurements, gain shall be provided in the receiver in 0.1 dB or 0.2 dB steps from 0 dB to at least 29.8 dB.

4.6.1.3 Test Hybrid

4.6.1.3.1 **Standard Impedances.** The return loss of a 2-wire circuit is measured by comparing it to a standard impedance. Nominal impedances are 600 Ω or 900 Ω (±1%) in series with 2.16 μF (±3%). Since under certain circumstances, such as cable acceptance testing, neither of the two standard impedances is appropriate for the measurement, means for connecting an external standard impedance shall be provided.

4.6.1.3.2 **Loss.** Return loss measurements on 2-wire circuits require the use of a hybrid in the testing arrangement. The transhybrid loss shall be sufficiently high to have little effect on the actual measurement. This loss can be checked by causing a deliberate mismatch between an external 900 Ω resistor and the internal 900 Ω resistor with a series 2.16 μF capacitor. With the line terminals either open circuited or short circuited, the return loss indicated on the 2 W- 900 Ω position of the test set shall be 0 dB ±0.5 dB. With the line input terminated in 900 Ω (±0.25%), the indicated return losses shall be within ±0.4 dB of the following values:

| | |
|---|---|
| ERL | 28.3 dB |
| SRL Low | 18.9 dB |
| SRL High | 36.6 dB |

4.6.2 **P/AR.** The P/AR system consists of a transmitter and a receiver connected to opposite ends of a voiceband transmission system. The transmitter generates a precisely controlled complex pulse train of known peak-to-average ratio. In passing through the system, the pulses are dispersed by the distortion they encounter. The P/AR receiver measures the absolute peak and full-wave rectified average values of the pulse train and displays ratio of these values on

### Table 12
### Filter Transfer Characteristic and P/AR Test Spectrum

| | Line Spectrum | | Receiver | | Test Spectrum | |
|---|---|---|---|---|---|---|
| Frequency (Hz) | Magnitude (dB) | Phase (degree) | Loss (dB) | Phase (degree) | Magnitude (dB) | Phase (degree) |
| 140.625 | -33.737 | -173.73 | 50.498 | 173.73 | -74.780 | 0.0 |
| 390.625 | -15.881 | -161.24 | 31.518 | 161.24 | -37.945 | 0.0 |
| 640.625 | -14.556 | -143.95 | 20.377 | 143.95 | -25.478 | 0.0 |
| 890.625 | -15.181 | -114.31 | 10.629 | 114.31 | -16.355 | 0.0 |
| 1140.626 | -16.303 | - 55.37 | 2.112 | 55.37 | - 8.960 | 0.0 |
| 1390.625 | -11.937 | 30.19 | 0.610 | - 30.19 | - 3.092 | 0.0 |
| 1640.625 | - 3.961 | 86.41 | 5.493 | - 86.41 | 0.0 | 0.0 |
| 1890.625 | - 0.000 | 113.78 | 10.505 | -113.78 | - 1.050 | 0.0 |
| 2140.625 | - 0.438 | 128.62 | 14.520 | -128.62 | - 5.503 | 0.0 |
| 2390.626 | - 3.104 | 137.78 | 17.741 | -137.78 | -11.390 | 0.0 |
| 2640.625 | - 6.512 | 144.00 | 20.402 | -144.00 | -17.459 | 0.0 |
| 2890.625 | -10.082 | 148.52 | 22.662 | -148.52 | -23.289 | 0.0 |
| 3140.625 | -13.658 | 151.95 | 24.624 | -151.95 | -28.828 | 0.0 |
| 3390.625 | -17.240 | 154.67 | 26.361 | -154.67 | -34.146 | 0.0 |
| 3640.625 | -20.892 | 156.87 | 27.917 | -156.87 | -39.355 | 0.0 |
| 3890.625 | -24.722 | 158.70 | 29.330 | -158.70 | -44.597 | 0.0 |

a zero-suppressed scale. This ratio serves as the basis for the P/AR rating, that is,

$$\mathrm{P/AR} = 100\left(2\ \frac{\mathrm{E\ (peak)}}{\mathrm{E\ (fwa)}} - 1\right)$$

where

E(peak) = normalized absolute peak value of the pulse train

E(fwa) = normalized full-wave rectified averaged value of pulse train

A P/AR rating of 100 signifies no pulse degradation

The P/AR system is designed to measure the simultaneous effect of envelope delay distortion, bandwidth reduction, and poor return loss (gain and phase ripples) on intersymbol interference of voiceband data signals. The P/AR measurement is largely insensitive to noise and nonlinear distortion, and unaffected by frequency shift or transient phenomena.

The spectrum of the transmitter output, termed the P/AR line signal, consists of 16 components at frequencies of:

$f_n = (2n - 1)\,125 + 15.625$ Hz

with

$n = 1, 2, \ldots 16$

The absence of even harmonics produces a pulse train with half-wave symmetry, thus minimizing the influence of system nonlinear distortion on the P/AR measurement.

4.6.2.1 Transmitter

**4.6.2.1.1 P/AR Line Spectrum.** The relative magnitude and phase of each spectral component of the P/AR line spectrum shall be as specified in Table 12.

**4.6.2.1.2 Line Spectrum Distortion.** All spurious outputs from the transmitter at frequencies up to 4 kHz shall be at least 50 dB below the power of the reference component at 1890.625 Hz. Spurious components above 4 kHz shall be down at least 40 dB.

**4.6.2.1.3 Line Signal Period Stability.** The period of the line signal is 64.0 ms, and shall be accurate to ±0.1%.

**4.6.2.1.4 Output Level Range.** The output level shall have a range of at least 0 dBm to - 40 dBm (true rms).

**4.6.2.1.5 Output Level Resolution.** The output level shall be adjustable in 1 dB increments or finer.

4.6.2.2 Receiver

**4.6.2.2.1 Accuracy.** The measurement accuracy shall be ±2 P/AR units for P/AR readings from 40 to 110, and ±4 P/AR units outside this range.

**4.6.2.2.2 Accuracy Verification.** The P/AR system measurement accuracy shall be verified by the following procedure.

(1) Measure the loss and phase of passive test networks at each spectral frequency of the P/AR signal.

(2) Calculate the *objective* P/AR rating of the test networks using a computer. A listing of a Fortran IV subroutine that calculates the P/AR rating is given in the Appendix.

(3) Measure the P/AR ratings of test networks.

(4) The measured and objective P/AR values shall differ by no more than ±2 units.

**4.6.2.2.3 Range.** The receiver shall have a P/AR display range of at least 0 to 120 P/AR units.

**4.6.2.2.4 Resolution.** The receiver shall have a P/AR display resolution of 1 P/AR unit.

**4.6.2.2.5 Input Level Range.** The P/AR system shall meet the accuracy requirements over a true rms input level range of 0 dBm to −40 dBm.

**4.6.2.2.6 Turnover.** The P/AR system shall meet accuracy requirements if the input leads are interchanged.

**4.6.2.2.7 Receive Filter.** The pulse train shall be shaped by a fourth-order bandpass filter in the receiver prior to detection. The filter shall consist of two second-order bandpass filters each having a center frequency of 1.3 kHz and a Q of 2.00 connected in cascade. The Q of the filters when connected in cascade shall be 3.108. The receiver shaping filter reduces the effects of power-line frequency interference, and spurious high frequency interference.

Table 13
Spectrum Tolerances

| | Line Spectrum Tolerance | | Test Spectrum Tolerance | |
|---|---|---|---|---|
| Frequency | Level (±dB) | Phase (± degree) | Level (±dB) | Phase (± degree) |
| 140.625 | 0.80 | 5.0 | 8.0 | 7.0 |
| 390.625 | 0.30 | 3.0 | 0.5 | 5.0 |
| 640.625 | 0.20 | 2.0 | 0.4 | 3.0 |
| 890.625 | 0.20 | 0.5 | 0.4 | 1.0 |
| 1140.625 | 0.20 | 0.4 | 0.3 | 0.6 |
| 1390.625 | 0.10 | 0.4 | 0.15 | 0.6 |
| 1640.625 | 0.10 | 0.4 | 0.15 | 0.6 |
| 1890.625 | 0.00 | 0.4 | 0.05 | 0.6 |
| 2140.625 | 0.10 | 0.4 | 0.15 | 0.6 |
| 2390.625 | 0.10 | 0.4 | 0.15 | 0.6 |
| 2640.625 | 0.20 | 0.5 | 0.30 | 1.0 |
| 2890.625 | 0.20 | 1.0 | 0.30 | 2.0 |
| 3140.625 | 0.30 | 3.0 | 0.40 | 4.0 |
| 3390.625 | 0.30 | 4.0 | 0.50 | 5.0 |
| 3640.625 | 0.30 | 5.0 | 0.50 | 7.0 |
| 3890.625 | 0.50 | 5.0 | 0.80 | 7.0 |

The output of the receive filter is termed the P/AR test signal. The receive filter transfer characteristic, and the P/AR test spectrum shall be as specified in Table 12. The acceptable spectrum tolerances are specified in Table 13.

**4.6.2.2.8 Detectors.** The P/AR receiver shall utilize a full-wave rectified average detector and an absolute peak detector.

**4.6.2.2.9 Display Response Time.** The P/AR receiver shall indicate within one unit of the final indication in less than 5 seconds after the input signal is applied, or within 3 seconds after a 10-unit drop in the P/AR value of a test circuit.

**4.6.2.2.10 Out-of-Range Indication.** The P/AR equipment shall indicate when the received level is above or below its permissible range.

**4.6.2.2.11 Self-Check Capability.** A self-contained means should be provided for determining that the P/AR system is properly calibrated.

**4.6.2.2.12 Crosstalk.** If the test set has a P/AR transmitter in the same case, terminate the transmitter in 600 Ω and set it to its highest output level. From a separate P/AR transmitter obtain a test signal through a network with a P/AR between 50 and 80, first at the maximum and then at the minimum received level by means of an attenuator. The two P/AR readings should not differ by more than one P/AR unit.

**4.6.3 Intermodulation Distortion.** Intermodulation distortion can be broadly defined as the generation of signal components from the transmitted signal that add to the transmitted signal, usually in an undesired manner. Second and third order products are usually the most significant.

A test signal is used which consists of four equal-level tones. Two of the tones are nominally 6 Hz apart centered at 860 Hz and the other two are nominally 16 Hz apart centered at 1380 Hz. The total power nominally due to the six 3rd order intermodulation products in a narrow band centered at 1.9 kHz is measured and expressed in dB below the received signal. The power nominally due to the four 2nd order intermodulation products in a narrow band centered at 520 Hz and the power nominally due to the four 2nd order intermodulation products in a narrow band centered 2240 Hz are also measured.

These two 2nd order distortion product powers are then averaged and the result expressed in dB below the received signal. Alternatively, it is permissible to measure one-half the total power in the combined 520 Hz and 2240 Hz bands and to express the result in dB below the received signal.

Second order intermodulation distortion is defined as follows:

$$\text{Intermod}_{2nd} = 20 \log(V_{4T}/V_{2nd}) \text{ (dB)}$$

where

$V_{4T}$ = rms voltage in the 4-tone signal

$$V_{2nd} = \sqrt{\frac{V_5^2 + V_{22}^2}{2}}$$

where

$V_5$ = rms voltage in the frequency band centered at 520 Hz

$V_{22}$ = measured rms voltage in the frequency band centered at 2240 Hz

Third order intermodulation distortion is defined as follows:

$$\text{Intermod}_{3rd} = 20 \log \frac{V_{4T}}{V_{19}} \text{ (dB)}$$

where

$V_{4T}$ = measured rms voltage in the 4-tone signal

$V_{19}$ = measured rms voltage in the frequency band centered at 1900 Hz

#### 4.6.3.1 Transmitter

**4.6.3.1.1 Level Accuracy.** The composite signal output level shall be accurate within ±1 dB.

**4.6.3.1.2 Level Range.** The output level range shall be at least 0 dBm to -40 dBm. Attenuator increments of 1 dB or smaller shall be provided unless a level indicator is part of the test set, in which case a vernier is acceptable.

**4.6.3.1.3 Spectrum.** The transmitted signal shall consist of four equal-level tones. Two of the tones shall be 6 ±1 Hz apart centered at 860 ± 1 Hz and two of the tones shall be 16 ±1 Hz apart centered at 1380 ± 1 Hz. The tones shall be of equal level within ± 0.25 dB.

**4.6.3.1.4 Harmonic Distortion.** Any harmonic of any of the four tones shall be at least 35 dB below the tone.

**4.6.3.1.5 Background Interference.** Any noise, distortion, or interference falling within the three distortion filter passbands as specified in 4.6.3.2.4, shall be at least 70 dB below the signal. (Long-term objective: 90 dB below signal.)

**4.6.3.1.6 Probability Density Function.** The probability density function of the transmitted signal shall be that of four independent sinusoidal oscillators even if the tones are synthesized from a single source.

**4.6.3.1.7 Signal-to-Noise Check.** A front-panel means shall be provided to determine the contribution of noise to the measurement by disabling either the two tones centered at 1380 Hz or the two tones centered at 860 Hz and increasing the other two tones by 3 ±0.25 dB.

**4.6.3.2 Receiver.** The following requirements shall be met.

**4.6.3.2.1 Accuracy.** The measurements shall be accurate to within ±1 dB.

**4.6.3.2.2 Input Level Range.** The receiver shall meet the accuracy and measurement range requirements for an input power range of 0 dBm to -40 dBm.

**4.6.3.2.3 Measurement and Display Range.** The test set shall be capable of measuring and displaying the measurement of 2nd and 3rd order products from 10 dB to 70 dB below the signal level.

**4.6.3.2.4 Filter Specifications.** The six 3rd order products to be measured fall in the range of 1877 Hz to 1923 Hz. The lower four 2nd order products in the range of 503 Hz and 537 Hz and the four upper 2nd order products in the range of 2223 Hz to 2257 Hz. (This allows for frequency shift in the channel and transmit signal frequency drift.)

Filters used to recover the products shall be wide enough to measure the total power within the overall accuracy requirements of ±1 dB and shall be narrow enough to reject out-of-band noise. The filter bandwidths may be checked by adding a 3.5 kHz band-limited white noise signal (see 4.3.3.2.8), at a level of -40 dBm to the input of the set in addition to the 4-tone signal at -10 dBm. The 2nd and 3rd order intermodulation products displayed shall each be down at least 46 dB from the power of the -10 dBm tone signal. The effect of a reading of $X$ dB of 2nd order distortion should be down at least $X$ +25 dB in the 3rd order distortion channel and vice versa.

**4.6.3.2.5 Response to Spurious Tones.** With a spurious tone 15 dB below the total signal power, the 2nd and 3rd order measurements shall be 55 dB or more below the

4-tone signal. This requirement shall be met for spurious tones from 50 Hz to 4 kHz, but not including frequencies within 300 Hz of 520 Hz, 1900 Hz, or 2240 Hz. At 60 Hz and 180 Hz, the rejection shall be at least 25 dB greater than the above requirement.

**4.6.3.2.6 Detectors.** The intermodulation products shall be measured with an average or an rms detector. An approximate or quasi-rms detector circuit may be used if it meets the requirements of 4.3.2.5.

**4.6.3.2.7 Display Response Time.** The instrument shall indicate within 1 dB of the final indication within 10 seconds after the application of a test signal. After this initial period, the display shall be updated at least once every five seconds on the basis of continuing measurements of both the received 4-tone level and the intermodulation products.

**4.6.3.2.8 Crosstalk with Transmitter.** The receiver shall meet overall accuracy requirements when its associated transmitter is set to its highest output level and terminated in 600 Ω, and a second transmitter set 40 dB below this level is used as a signal source for intermodulation measurement.

**4.6.3.2.9 Self-Check Capability.** A self-contained means should be provided to ensure that the receiver is calibrated within ±1 dB for 2nd and 3rd order distortions.

**4.6.3.2.10 Improper Received Signal Level.** An indication shall be provided for received test signals outside of the input level range of 0 to - 40 dBm.

**4.6.3.2.11 Monitor of Signal to Noise (S/N) Check.** A means should be provided for determining that a signal-to-noise check signal is being received.

**4.6.3.2.12 Correction for Signal to Noise (S/N).** Generally, the readings observed with the 2-tone S/N check will be higher than for the 4-tone signal, so the correct reading is less than that for the 4-tone test signal. The operating instructions shall include a suitable correction curve or correction table, unless the test set automatically makes the correction in the observed reading after the S/N check transmission.

**4.6.3.2.13 Spurious Tone Monitor.** A means should be provided to determine if a spurious tone or noise equal to or greater than the test tone is being received. Frequencies closer than ±100 Hz about 860 Hz and 1380 Hz are excluded from this requirement.

**4.6.4 Crosstalk.** Crosstalk is measured with a sinusoidal test signal driving one circuit and the received level measured on a second parallel circuit. Crosstalk coupling (crosstalk loss) is expressed in decibels (dB) and is the difference between the transmitted level in one circuit and the received level in another circuit. Measurements are usually made at an impedance of 600 Ω or 900 Ω.

**4.6.4.1 Oscillator-Transmitter.** See 4.3.1.2 and 4.3.1.3.

**4.6.4.2 Measuring Set-Receiver.** See 4.6.5.

**4.6.5 Frequency-Selective Level.** Frequency-selective level measurement is the technique of analyzing individual components of signals to determine frequency, level, or interference within a band of frequencies.

Frequency-selective level meters or wave analyzers should be used if single-frequency-interference is heard, if higher frequency interfering tones are suspected, or if tone levels are to be measured in the presence of other tones or noise of sufficient magnitude to interfere with accuracy of the measurement.

**4.6.5.1 Level Range.** The useful input range shall be at least +10 dBm to - 90 dBm. Dynamic range shall be 60 dB with 75 dB being desired.

**4.6.5.2 Level Accuracy.** The displayed level shall be accurate to ±1 dB for a single tone input. The response from the band center to the 3 dB point shall be monotonic within 0.3 dB.

**4.6.5.3 Frequency Range.** The selective level meter shall be able to measure frequencies from 20 Hz to 4 kHz. Higher frequency ranges may be desirable in some applications.

**4.6.5.4 Frequency Accuracy.** If the analyzer has a frequency counter, it should be capable of measuring a tone in the filter passband to an accuracy of ±2 Hz. If the analyzer does not have a frequency counter, it should have a tone output which permits the use of another frequency counter to measure a tone in the filter passband to an accuracy ±2 Hz.

**4.6.5.5 Filter Bandwidth 3 dB.** The analyzer shall have a 10 Hz ± 30% bandwidth at the 3 dB points. If optional bandwidths are provided, 3 Hz, 30 Hz, and 100 Hz are suggested.

**4.6.5.6 Filter Bandwidth 60 dB.** The bandwidth of each filter at the 60 dB loss points shall be less than 13 times the filter 3 dB bandwidths given above.

4.6.5.7 **Sweep.** Provision should be made for automatic sweep. If the sweep rate chosen is too fast to permit ± 1 dB level accuracy for the selected filter bandwidth, then there shall be some positive indication of this undesirable condition.

4.6.5.8 **AFC.** There should be some provision for locking on a tone which drifts slowly in frequency.

4.6.5.9 **Overload.** There shall be some clear indication if the total input signal causes an overload condition.

4.6.6 **Frequency Measurement.** The frequency measurement capability of an instrument shall meet the following specifications. Requirements for an optional frequency shift measurement capability are added in those sections where they differ from the frequency measurement capability.

4.6.6.1 **Level.** The frequency measuring set shall be capable of accepting inputs from +10 dBm to - 50 dBm.

4.6.6.2 **Frequency Range.** If the frequency measuring set is part of a larger test set, it shall cover the frequency range of that set. If it stands alone, it should have a range of at least 20 Hz to 50 kHz. For frequency shift measurement, the set shall have a range of at least 400 Hz to 1999.9 Hz.

4.6.6.3 **Accuracy.** The frequency measuring set shall be accurate to ±1 Hz for frequencies up to 10 kHz. It shall be accurate to ±10 Hz for frequencies above 10 kHz and up to 100 kHz. It shall display frequency up to 10 kHz with an accuracy of ±1 Hz. For frequency shift measurement, the display shall be accurate to ±0.1 Hz for frequencies up to 1999.9 Hz.

4.6.6.4 **Update Rate.** The frequency measuring set shall display a new measurement at the rate of once per second. If the frequency measuring set is often used to display the frequency of a manually-tuned oscillator to 1 Hz, it shall display a new measurement at a rate of at least 4 times per second.

4.6.6.5 **Interference and Noise.** The frequency measuring set shall meet the accuracy requirements in the presence of single-frequency interference or noise with a signal-to-interference or signal-to-noise ratio of 20 dB. The single-frequency interference requirement shall be met for any interference frequency within the measurement range of the set. The noise requirement shall be met for band-limited white noise as follows:

(1) Voiceband instruments: noise bandwidth as defined in 4.3.3.2.8.

(2) Wideband instruments: noisee bandwidth extending from 50 Hz to the highest frequency that the set can measure.

4.6.6.6 **Display Response Time.** The response time of the measuring set display is a function of the required accuracy.

(1) For a suddenly applied 1 kHz sine wave with a 20 dB signal-to-white noise (50 Hz to 4000 Hz) ratio, the display shall be within the stated accuracy within:

- 30 seconds for frequency shift measurement
- 3 seconds for frequency measurement

(2) For an intantaneous 100 Hz frequency shift, or of a sinusoidal tone, the display shall be within the stated accuracy within:

- 15 seconds for the frequency shift measurement
- 2 seconds for frequency measurement

## 5. Test Equipment Characteristics

### 5.1 Physical Characteristics

5.1.1 **Shock and Vibration Test Requirements.** Upon completion of each test the instrument shall meet its required specifications. In addition, the instrument shall not have any mechanical damage which could interfere with or be detrimental to the operation of the instrument.

5.1.1.1 **Shock Tests (Packaged).** Drop tests shall be peformed on the instrument in its packing (shipping or designated transit) container. The height of the drop test is based on the gross weight of the package (see Table 14). The impact surface shall be concrete. The unit shall be dropped once on each face and once on each corner.

5.1.1.2 **Shock Tests (Unpackaged).** If the instrument is advertised as a portable unit it shall meet the requirements of Table 14. The drops shall be made once on each rest surface and once on each corner adjacent to a rest surface. The impact surface shall be concrete.

5.1.1.3 **Vibration Tests (Packaged).** In its packing (shipping or designated transit) container the instrument shall be vibrated as indicated in Table 14. The tests shall be per-

Table 14
Shock and Vibration Test Requirements

| Instrument Condition | Test | Requirement |
|---|---|---|
| Packaged | Shock (drop) | <20 lb: 30 in high, each face and corner<br>20–50 lb: 24 in high, each face and corner<br>50–100 lb: 21 in high, each face and corner<br>100–200 lb: 18 in high, each face and corner |
| Unpackaged (Portable Only) | Shock (drop) | <10 lb: 12 in high, once each rest surface and 6 in high once each corner adjacent to rest surface<br>10–33 lb: 6 inch high, once each rest surface and 3 in high once each corner adjacent to rest surface |
| Packaged | Vibration | once for each axis:<br>swept from 5 Hz to 100 Hz at a rate of 0.1 octave/min at 0.5 G (1.0 G for overseas)<br>swept from 100 Hz to 500 Hz at a rate of 0.25 octave/min at 1.5 G with a dwell at peak response for 15 min |
| Unpackaged (Portable Only) | Vibration | Same as packaged vibration above |

formed along each of the three orthogonal axes.

Along each axis the peak response frequency of the unit shall be determined and the unit shall be vibrated at the specified frequencies for a minimum of 15 minutes at the G level indicated in Table 14.

**5.1.1.4 Vibration Test (Unpackaged).** If the instrument is defined as a portable instrument, it shall meet the requirements of 5.1.1.3 without being in a packing container.

**5.1.2 Finish and Markings.** The test equipment case shall be protected by a suitable finish. The texture of the finish shall be free of dirt and grit and shall not show objectionable orange peel effect or other unevenness of coverage. Panel markings shall be permanent, well defined, and legible. The permanence of markings shall be determined as follows.

(1) **Adherence.** The finish and markings shall not be removed from the base metal nor show any separation of coats when tested using the conditioning and apparatus described in ANSI/ASTM D21-97-1968 (R1979) [1], Adhesion of Coatings of Paint, Varnish, Lacquer, and Related Products loaded with a 4000 g load.

(2) **Abrasion Resistance.** The markings shall remain legible and there shall be no wear-through to the base metal after 1000 turns in a Taber Abraser machine, or equivalent. The wheels shall be CS17 Calibrase with 1000 g load. The abraser wheels shall be properly dressed before each test.

(3) **Chemical Resistance.** The finish and markings shall be resistant to 1, 1, 1 — trichloroethane when tested at 25 °C and 50% relative humidity as follows: lightly and uniformly rub a wad of cotton [approximately 1 inch (2.5 cm) in diameter] moistened with the chemical over an area approximately 1 inch (2.5 cm) by 2 in (5 cm) for 15 seconds. The cotton shall not be discolored nor shall the wiped area be discernible from the surrounding area after 30 minutes recovery period.

**5.1.3 Knobs and Controls.** All controls shall be located where they are easily accessible. They shall be engineered for convenience and suitability of operation. In general, concentric knobs shall be avoided unless the intent of such knobs is obvious. Markings for push buttons shall be such that their function is clear in both the IN and OUT position.

**5.1.4 Portability.** To provide easy handling, test sets should have a single handle placed on the case of the set (not the cover) so that the set may be moved or carried comfortably. The set, plus cover and power cord or batteries should weigh no more than 15 kg (33 lb). If the set is more than one part, then each part should meet the above requirement and the parts should stack conveniently.

5.1.5 **Rack-Mounted Equipment.** Rack-mounted test equipment shall not rely on cooling from convection air currents which can be blocked by other equipment above or below it.

### 5.2 Identification of Equipment

5.2.1 **Markings.** The name and model number of the test equipment and also the name of the manufacturer shall appear on the outside of the set, or on its cover so that it may be easily identified while in a storage position.

5.2.2 **Updated Markings.** If a set is modified to change its original form or function or in any way alter its suitability for an intended measurement, the set designation should be clearly changed to indicate its new use and make rapid and positive identification possible.

### 5.3 Safety Requirements

5.3.1 **Safety Standards.** Detailed safety requirements are beyond the scope of this standard. National or local authority may require conformance to safety standards applicable in the location where the equipment will be used. In the absence of such standards, equipment shall conform to the International Electro-Technical Commission, IEC 348-1978 [9].

5.3.2 **Third-Wire Ground.** All ac-line powered equipment shall be provided with a third-wire safety ground in accordance with the referenced standards (IEC Safety Class 1 or equivalent). This requirement is waived where local authority requires the use of double insulation (IEC Safety Class II).

### 5.4 Operating Power

5.4.1 **AC Line Power.** Equipment designed to operate from ac line power shall meet the performance requirements of this standard and of the individual equipment specification while operating with power line frequencies of 50 Hz or 60 Hz and voltages between 100 V and 129 V or between 200 V and 250 V. Equipment that is switchable between these two ranges shall be equipped with an appliance inlet connector in conformance with IEC 320-1981 [8]. Equipment intended for one voltage range only may be equipped with the appliance inlet connector or may have a permanently attached 3-conductor AWG 18 flexible cord equipped with a 3-contact polarized plug or cap suitable for the intended voltage range.

5.4.2 **Battery Power.** Power may be supplied by batteries, which may be rechargeable. There shall be some provision for indicating when the batteries need recharging or replacing. If the batteries are not rechargeable they shall be of a type readily obtainable locally. If they are rechargeable, a means of recharging shall be provided with the equipment.

If test equipment is to be powered from the office battery, the equipment shall meet the specification of this standard with central office battery voltages from -42.5 V to -56.5 V with respect to ground.

### 5.5 Presentation of Measurement Results

5.5.1 **Analog Displays.** If an analog meter is used as the output display, the spacing of the meter markings shall be proportional to the approximate accuracy of the meter at that point, and there shall be an area of the meter where the markings permit readings accurate to the specifications for the given measurement. For example, if a measuring set with ±1 unit accuracy has a range switch with ten-unit steps, at least a ten-unit range on the meter shall be marked in increments of one unit or less.

If the equipment has supports or feet suggesting usage in more than one position, the meter shall be balanced so as not to degrade the measurement accuracy in any of these positions.

#### 5.5.2 Digital Displays

5.5.2.1 **Resolution.** The resolution of a digital display, or the unit value of the least significant digit, shall be commensurate with the specified accuracy of the measurement being displayed. The resolution shall be at least as fine as the maximum permissible error in either direction. A one unit resolution is required to display ±1 unit accuracy. Because of the decimal nature of the display, a one unit resolution is also required to display lower accuracy, such as ±5 units, even though this resolution is much finer than the measurement accuracy. On the other hand, display of extra nonsignificant digits should be avoided.

5.5.2.2 **Round Off.** The worst-case rounding error in the display shall be included in determining the accuracy of the measurement. Normally, the point at which a display changes from one number to the next should be at the one-half unit point. For example, the display should go from one to two at 1.5. The worst-case rounding error will then be 0.5 unit. This round-off rule is essential in the case of a one-unit resolution for ±1 unit accuracy.

If a different round-off rule is used, such as simply discarding less significant digits, the rounding error may be as great as one full unit. This is acceptable if the specified accuracy is, for example, ±5 units, but is not acceptable for ±1 unit accuracy.

5.5.2.3 **Update Rate.** When it is likely that the user will make a manual adjustment while observing the result on a digital display, a fast real-time response is essential for convenient adjustment. For this purpose, the measurement shall be made and the result displayed at least four times per second. Liquid crystal displays shall respond to the four per second rate at the lowest specified operating temperature unless a statement to the contrary is included in the equipment specifications.

For other measurements of continuous quantities, the display of new measurement data shall occur at least once per second. The results of measurements such as event counts shall be displayed as they are completed. The result of each measurement shall be held and displayed until the next measurement result is received, or until occurrence of a manual reset, timeout, or some other deliberate erasure or blanking as may be determined by the set manufacturer.

5.5.2.4 **Damping and Fluctuation.** No digital display, regardless of the update rate, has the ability of an analog display (meter) to permit convenient estimation of the peaks and mean value of a fluctuating measurement. A compromise update rate of two or three times per second may be used for such measurements.

5.5.2.5 **Autorange.** Autorange circuits, if any, shall be fast enough that the time to display the correct reading meets the requirements for the particular measurement in Section 4, if given.

5.5.3 **Output Interfaces.** Provision of analog and digital output interfaces, for remote display or acquisition and storage of measurement results, is recommended. In the absence of applicable standards, analog output interfaces shall conform to good engineering practice. Digital output interfaces shall conform to EIA RS-232-C-1969 (R1981) [6], EIA RS-449-1977 [7], ANSI/IEEE Std 488-1978 [5], corresponding CCITT (International Telegraph and Telephone Consultative Committee), or ISO (International Organization for Standardization)[7] standards, or a combination of the above.

5.5.4 **Audible Monitor.** A simple listening test is a valuable adjunct to quantitative measurements in the audio frequency range because it will often reveal the reason for an unsatisfactory measurement result. The human ear can detect an interfering tone in the audio range if its level is within 3 dB of a single tone or random noise. A listening test will reveal the presence of single frequency interference, which can then be measured as described in 4.6.5. During noise-with-tone measurement, a listening test made after suppression of the holding tone will reveal the presence of single frequency interference, harmonic distortion, impulse noise, or hits.

For these reasons, wherever applicable, equipment for measuring analog voice frequency transmission characteristics shall include either a built-in loudspeaker monitor or means for connecting external headphones. A loudspeaker monitor or headphone jacks should be provided with a volume control having an OFF position, or a volume control and separate ON/OFF switch.

5.5.5 **Display of Incorrect Results.** Care shall be exercised in the design of test equipment to prevent the display of incorrect results. For example,

(1) If input ranges are exceeded, there shall be some kind of out-of-range indication. For example, a digital display could show only a + for overrange, and only a - for underrange

(2) If the presence of a holding tone is necessary for a measurement, its absence shall be clearly indicated

(3) Changing a step attenuator or a scale factor shall not permit a steady-state incorrect reading to be displayed, unless warning of such is indicated on the front panel by some means

(4) If the power of a transmitted signal may be monitored other than by manual connection of an appropriate receiver, the power displayed shall be that which would be dissipated in a resistance equal to the nominal transmitter

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[7] ISO standards are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

output impedance. (The displayed power shall not be a function of the impedance connected to the transmitter terminals.) This prevents a tester from varying the transmitter power output for different frequencies to match a frequency-variable facility input impedance.

### 5.6 Functional Requirements

**5.6.1 Input and Output Impedances.** Measurements on balanced audio frequency circuits are ordinarily made on a bridged or terminated basis. For bridged measurement, the input impedance shall be high enough to minimize the effect of the measuring equipment on the circuit being measured. For terminated measurement, the input impedance should be designed to match the nominal impedance of the circuit being measured.

Transmitters of test signals used on balanced audio frequency circuits should provide output impedance which matches the circuit under test.

**5.6.1.1 Terminated Impedance.** Terminated input or output impedance is usually 600 Ω or 900 Ω for voice frequency circuits and 135 Ω for program or wideband data circuits. Other impedances may be provided for specific requirements. Some applications may require separate send and receive impedance selection.

**5.6.1.1.1 Accuracy.** Signal and noise measurement levels are expressed in terms of the power which would be dissipated in a precise nominal termination. If the terminating impedance differs from nominal, the set can still be calibrated to read correctly with a nominal source impedance, but there will be an error if the source impedance also differs from nominal. Accuracy of terminating impedance is expressed in terms of return loss measured against the nominal impedance, because high return loss will ensure minimum sensitivity to errors caused by source impedance deviation from nominal. The value of return loss, at frequency ($f$), is given by

$$\text{Return loss } (f) = 20 \log \left| \frac{Z_{\text{ref}} + Z(f)}{Z_{\text{ref}} - Z(f)} \right| \text{ dB}$$

Where $Z(f) = R(f) + jX(f)$ is the actual phasor impedance at frequency ($f$). $Z_{\text{ref}}$ is the nominal impedance, and is a pure resistance when measuring return loss of test equipment input and output terminating impedance. (This should not be confused with the termination used for measurement of Echo Return Loss or Singing Return Loss, which is 600 Ω or 900 Ω in series with 2.16 μF. See 4.6.1.3.1.

**Table 15**
**Input and Output Impedance**

| Nominal Impedance (Ω) | Frequency Range | Return Loss (dB) |
|---|---|---|
| 600 or 900 | 200 Hz to 4 kHz | ⩾ 30 |
| 135 or 150 | 800 Hz to 16 kHz | ⩾ 30 |
| 135, 150, 600, or 900 | Full operating range of the set | ⩾ 15 |

**5.6.1.1.2 Return Loss.** The return loss of input and output impedance against the nominal impedance shall be as shown in Table 15.

**5.6.1.1.3 Reduced Frequency Range.** For test sets with reduced frequency ranges, if the 30 dB requirement is not met for the range from 200 Hz to 4 kHz, the user shall be cautioned about the use of the set as a termination for other measurement sets.

**5.6.1.1.4 Calculation of Transmitter Return Loss.** If the return loss of transmitter output impedance cannot be measured directly because the set's output signal cannot be eliminated, the return loss can be calculated from a knowledge of the set's phasor output impedance as given in 5.6.1.1.1. The phasor output impedance can be measured by using a bridge circuit having a selective detector. The detector is tuned to the bridge measurement frequency while the set's output is tuned to another frequency rejected by the detector.

**5.6.1.2 Bridging Input Impedance.** Bridging input is intended to have negligible effect on the circuit being measured. Bridging loss is defined as the change in level which occurs when the set is connected to a test circuit having nominal source and terminating impedance (that is, the set is connected to an impedance of one-half circuit nominal).

$$\text{Bridging loss } (f) = 20 \log \left| 1 + \frac{Z_{\text{CKT}}}{2Z(f)} \right| \text{ dB}$$

where

$Z_{\text{CKT}}$ = nominal circuit impedance
$Z(f)$ = actual bridging input impedance at frequency $f$

Bridging loss for Class II and III instruments shall not exceed 0.2 dB over the specified operating frequency range of the set. In addition the set shall be calibrated so that the total error including the effect of bridging loss is within the accuracy specification given in Section 4 for the intended measurement. See 4.3.1.5.3.

5.6.1.3 **Impedance to Ground.** There shall be no dc path from either input or output terminal to ground. The ac longitudinal impedance, measured from the balanced input or output terminals (shorted together) to ground, shall be greater than 20 000 Ω for frequencies below 4 kHz. Above 4 kHz, the requirement decreases in inverse proportion to frequency.

5.6.2 **Line Holding and Signaling.** It may be necessary to operate and hold supervisory relays in line type telephone circuits which supply a dc holding current in order to establish and maintain transmission integrity over the circuit.

The following parts describe telephone circuit characteristics and requirements which shall be met for line holding:

5.6.2.1 **Voltage versus Current.** Transmission test equipment may be used to test a variety of circuit types and may be connected to the circuit at locations that subject the test equipment to a wide range of voltages and currents. The most common circuit encountered consists of a nominal 48 V office battery in series with some dc line resistance, with a minimum of 20 mA required between tip and ring to hold the office relay. With some facilities it may be necessary to pass currents up to 26 mA to ensure seizing the line. To ensure holding these circuits, the dc drawn by the test set holding circuit shall be at least 20 mA with 42.5 V dc of either polarity applied to the input through an external 1700 Ω resistance. Additionally, the hold current shall not drop below 20 mA for any combination of open circuit voltage between 42.5 V dc and 105 V dc, and any resistance up to 1700 Ω.

Other voltages and currents may be encountered. The voltage supplies may be nonlinear, but the dc V-I characteristic describing them will fall within the boundaries indicated by the IL MAX and IL MIN limits shown on Fig 8.

In a small, indeterminate number of instances, residential line service may be provided by a subscriber line carrier system which may provide a tip to ring open circuit voltage as low as 7.8 V dc. This voltage is generated at or close to the point of the telephone set installation on/at the customer premises and therefore does not have to provide current over a long central office loop. These circuits will normally hold with a current flow of 16 mA. The probability of having to make comprehensive transmission measurements on these carrier derived circuits is very low and therefore would not necessarily be subject to the restraints of 5.6.2.6.

5.6.2.2 **Holding Timing.** After a line is seized and dialing has been completed, operation of panel controls on the set shall not interrupt the hold current for a period exceeding 100 ms.

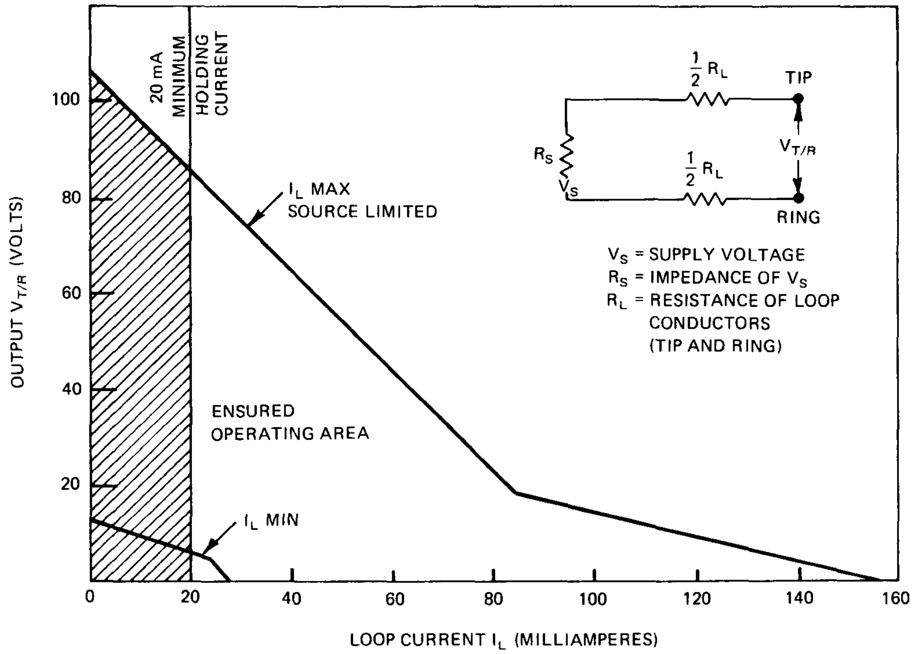
5.6.2.3 **Dialing.** It is desirable for sets which have holding capability to provide for the convenient connection of a handset with a dial.

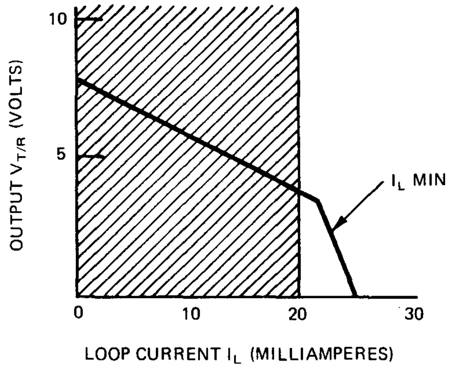
5.6.2.4 **Ground Start.** Loop signaling ground start circuits require a momentary ground applied to the Ring (R) conductor to operate the supervisory relays. This is accomplished by providing up to 600 Ω resistive path between ring and ground until tip ground or the initial dial tone is received from the central office. At that point, the holding current previously specified is sufficient to maintain operation of the relays.

Provisions may be made for supplying a momentary ground start signal in the test set.

5.6.2.5 **Loop Reverse Battery Signaling Circuits.** These circuits require that the terminating end of the loop furnish battery and ground to the conductors. In the idle condition the ring (R) conductor shall be negative with respect to the tip (T) conductor. Battery supply voltage should be between -42.5 V dc and -56.5 V dc. The total loop plus central office resistance will range from a minimum of 500 Ω to be a maximum of 2450 Ω. A minimum of 16 mA is required to hold reverse battery circuits. Provisions may be made for furnishing the ground and battery supply.

5.6.2.6 **Effect on Measurement.** The hold circuit, when connected to 53 V source of either polarity through an external 330 Ω dc resistance, shall not degrade the accuracy of any measurement that the test set performs. It also shall not cause the test set to fail any of the general requirements, except that the return loss requirement of 30 dB may be relaxed by 6 dB per octave for frequencies below 300 Hz.





| | LIMITS | |
|---|---|---|
| VOLTS OPEN CIRCUIT | CURRENT mA SHORT CIRCUIT | $R_S + R_L$ Ω |
| $I_L$ MAX: 105.0 | 107.0 | 981.3 |
| 52.5 | 157.0 | 334.4 |
| $I_L$ MIN: 42.5 | 25.1 | 1693.0 |
| 7.8 | 41.1 | 189.8 |

Fig 8
Line Holding Current Requirements

In addition, when connected to a 42.5 V source through 1700 Ω, the hold circuit shall not degrade the accuracy of any measurement made at a level below − 9 dBm.

**5.6.3 Longitudinal Balance.** All test equipment inputs and outputs shall have a longitudinal balance of at least 90 dB at frequencies between 50 Hz and 120 Hz, with the requirement decreasing 20 dB per decade from 120 Hz to the maximum operating frequency of the set.

Longitudinal balance in the voice frequency band shall be measured in accordance with ANSI/IEEE Std 455-1976 [4]. The same method may be extended to higher frequencies for measurement outside the voice band.

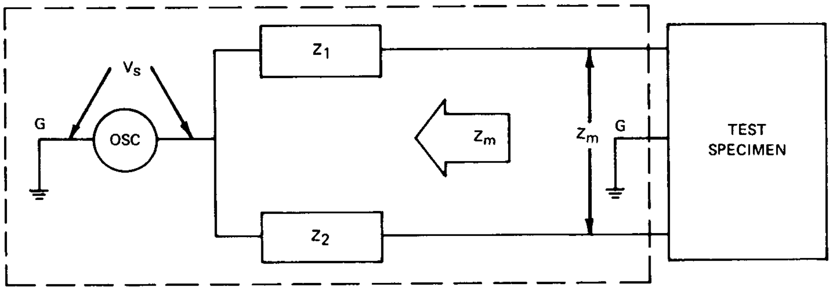


Fig 9
Standard Driving Test Circuit of
ANSI/IEEE Std 455-1976 [4]

**5.6.4 Effect of Longitudinal Voltages on Measurement Accuracy.** The presence of longitudinal voltages at the input terminals can affect measurement accuracy of test sets due to the combined effect of longitudinal imbalance, common mode response, and nonlinearity of the input circuits. Test sets shall be capable of normal operation in the presence of a standard longitudinal voltage source whose rms magnitude is given by the expression

$$V_s = \frac{1500}{f} \text{ Volts}$$

for any frequency, $f$ in hertz, from 50 to 500 000. In addition, the presence of this standard longitudinal voltage shall not degrade the accuracy of the measurement the set performs except as provided below.

This requirement shall hold for all permissible levels, frequencies, and operating conditions of the test set (such as dc holding current).

If the test set is to be tested in the bridging mode, an external terminating resistance shall be added across the input terminals.

**5.6.4.1 Test Configuration.** To test for conformance with this section, the standard longitudinal voltage source is applied to the set input terminals through the standard driving test circuit as defined for longitudinal balance measurement in ANSI/IEEE Std 455-1976 [4]. A source of signal or noise for the measurement in question is also connected to the set input terminals. With the standard longitudinal voltage source turned OFF but the drive circuit connected, the set measurement in question is made. The standard longitudinal voltage source is then turned ON and stepped or swept through its frequency range. The resulting change in set measurement shall be within the limits specified below for each frequency sweep.

Figure 9 shows for reference the standard driving test circuit of ANSI/IEEE Std 455-1976 [4]. The impedances $Z_1$, $Z_2$, and $Z_m$ include the series reactance of dc blocking capacitors and the shunt impedance of dc supply circuits.

The values are:

$$Z_m = 736\ \Omega \pm 5\% \ \angle 0^\circ \pm 4^\circ$$

$$Z_1 = Z_2 = 368\ \Omega \pm 5\% \ \angle 0^\circ \pm 4^\circ$$

Means shall be provided for precisely balancing $Z_1$ and $Z_2$. An Appendix to ANSI/IEEE Std 455-1976 [4] describes one implementation of the standard driving test circuit, including means for introducing dc bias through the driving test circuit to the test specimen and also a method for balancing $Z_1$ and $Z_2$.

Figure 10 shows the overall test configuration for testing the effect of longitudinal voltage. The capacitors C1 and C2 and transformer T1 provide a means for driving the set under test with an appropriate metallic test signal. These components may be omitted if the output of the signal source is suitably blocked, balanced, and isolated.

The impedance $Z_m$ has the effect of double-terminating the measurement circuit. The output level of the signal source shall be set, in the presence of this double termination but with the standard longitudinal voltage source OFF, to produce a measurement indication by the set under test as specified for each of the tests of 5.6.4.2.

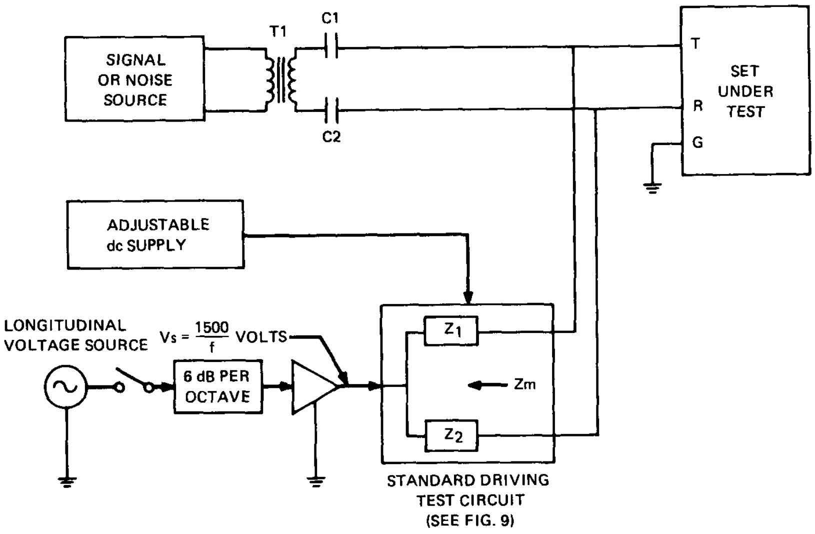


Fig 10
Equipment Configuration for Longitudinal Voltage Tests

**5.6.4.2 Specific Requirements.** All of the requirements below shall be met with dc voltages applied to any line holding circuits (see 5.6.2). The specific requirements for maximum error caused by the presence of the standard longitudinal voltage source of Fig 10, for the various measurements covered in Section 4, are as follows:

**5.6.4.2.1 Level Measurement.** Use the test configuration of Fig 10. The signal source shall have an ouptut impedance equal to the nominal input impedance of the set under test. With no harmonic relationship between the frequencies of the test oscillator and the standard longitudinal voltage source, for any level measurement above −50 dBm, switching on the standard longitudinal voltage source (at longitudinal frequencies of 120 Hz and above) shall not cause a level measurement change of more than 0.1 dB. For longitudinal frequencies below 100 Hz, the no greater than 0.1 dB change requirement shall be met for level measurements above −40 dBm.

**5.6.4.2.2 Noise Measurement.** Use the test configuration of Fig 10. For this test, the signal source of Fig 10 is replaced by a terminating impedance equal to the nominal input of the set under test. With either 3 kHz Flat or 15 kHz Flat weighting selected and the standard longitudinal voltage source switched ON, the equivalent noise reading of the set under test shall not exceed 30 dBrn.

When the noise weighting networks of Figs 1 through 4 are selected, the permissible reading of the set under test is further reduced by the network weighting factor at the longitudinal test frequency. For example, with a C-Message loss of 25 dB at 200 Hz the maximum permissible reading of the set under test when the standard longitudinal voltage source is switched on is 30 − 25 = 5 dBrnC.

If the maximum permissible equivalent noise reading is below the sensitivity of the set under test, then the test shall be conducted in the same manner as for level measurement in 5.6.4.2.1. The requirement is that for any measurement reading of a signal source 10 dB or more above the maximum permissible equivalent noise reading resulting from the standard longitudinal voltage source, switching ON the standard longitudinal voltage source shall not cause the observed reading to change by more than 0.5 dB (1 dB in the case of a digital readout with only 1 dB resolution).

**5.6.4.2.3 Envelope Delay.** Use the test configuration of Fig 10. The signal source for this test is an envelope delay transmitter providing a 50% amplitude-modulated metallic signal at a level of - 3 dBm. When the standard longitudinal voltage source is turned on, at any frequency within its range, the variation in envelope delay measurement shall not exceed the accuracy limitations of 4.3.3.2.1. Particular attention should be paid to the effect of longitudinal frequencies at the upper and lower side-bands of the AM signal.

5.6.4.2.4 **Impulse Noise.** Connect the test circuit of Fig 10 as for noise measurement (5.6.4.2.2). For any threshold setting higher than 30 dBrn, the presence of the standard longitudinal voltage shall cause no impulse counts.

5.6.4.2.5 **Phase Hits.** Connect the test circuit of Fig 10. The signal source for this test shall be a 1 kHz holding tone at - 40 dBm with 5 ms, 10° phase hits occurring once a second. With the threshold set at 20°, no phase hits shall be recorded in the presence of the standard longitudinal voltage.

5.6.4.2.6 **Gain Hits.** Connect the test circuit of Fig 10. The signal source for this test shall be a 1 kHz holding tone at - 40 dBm with 5 ms, 2 dB gain hits occurring once a second. With the threshold set at 3 dB, no gain hits shall be recorded in the presence of the standard longitudinal voltage.

5.6.4.2.7 **Dropouts.** Connect the test circuit of Fig 10. The signal source for this test shall be a 1 kHz holding tone at - 40 dBm. After establishing the dropout threshold with this tone, apply 5 ms, 11 dB negative gain hits to this holding tone occurring once a second. No dropouts shall be recorded in the presence of the standard longitudinal voltage.

5.6.4.2.8 **Phase Jitter.** Connect the test circuit of Fig 10. The signal source for this test shall provide two test signals at 1 kHz and 1100 Hz. Set the 1 kHz oscillator to a level of - 15 dBm, and the 1100 Hz oscillator to a level which produces a 10° phase-jitter reading on the meter. Now switch on the standard longitudinal voltage source at any frequency within its range. The 10° phase-jitter reading shall not change by more than 1°.

5.6.4.2.9 **Amplitude Jitter.** Connect the test circuit of Fig 10. The signal source for this test shall provide two test signals at 1 kHz and 1100 Hz. Set the 1 kHz oscillator to a level of - 15 dBm, and the 1100 Hz oscillator to a level which produces a 10% amplitude jitter reading on the meter. Now switch on the standard longitudinal voltage source at any frequency within its range. The 10% amplitude jitter reading shall not change by more than 1%.

5.6.4.2.10 **Return Loss.** For 4-wire return loss measurement, connect the test circuit of Fig 10. Set the signal source to - 60 dBm. Note the apparent return loss reading on the set under test. Now switch ON the standard longitudinal voltage source. The reading shall not change more than 1.5 dB.

For 2-wire return loss measurement, connect the longitudinal driving test circuit as shown in Fig 10 to the LINE or 2-wire transmit/receive terminals of the set under test. The signal source of Fig 10 is omitted. Connect a resistance which is adjustable over a range of approximately ±10% around 736 Ω to the external standard terminals of the set under test. The set will now read the return-loss of the longitudinal driving test circuit metallic impedance against the adjustable resistor. Adjust the resistor to obtain the highest return loss reading the set is intended to measure (but not more than 50 dB). When the standard longitudinal voltage source is turned ON at any frequency within its range, the reading shall not change more than 1.0 dB.

5.6.4.2.11 **P/AR.** Connect the test circuit as shown in Fig 10. The metallic signal source for this test shall be a P/AR transmitter sending an undistorted P/AR signal at a level which depends on the frequency of the standard longitudinal voltage source, as follows:

| Longitudinal Source Frequency | Received Level of the P/AR Signal Source (Longitudinal Source Turned Off) |
|---|---|
| 50 — 800 Hz | - 38 dBm |
| 800 — 2700 Hz | - 20 dBm |
| 2.7 kHz — 1 MHz | - 30 dBm |

The received P/AR value shall not change by more than 3 P/AR units as the standard longitudinal voltage source is varied in frequency from 50 Hz to 1 MHz and in voltage as shown in Fig 10.

5.6.4.2.12 **Intermodulation Distortion.** Connect the test circuit of Fig 10 using a metallic signal source meeting the requirements of 4.6.3.1. Adjust the output level of this intermodulation test signal source for a received signal level of - 10 dBm on the set under test.

When the standard longitudinal voltage source is turned on, the observed second and third order intermodulation distortions shall be at least 50 dB down when the longitudinal source frequencies are set to 520 Hz, 1900 Hz and 2240 Hz. For other frequencies that are not closer than 300 Hz to 520 Hz, 1900 Hz or 2240 Hz, distortion products shall be at least 70 dB below the input signal.

5.6.4.2.13 **Frequency Selective Level.** Connect the test circuit of Fig 10. For this test, the signal source is replaced by a terminating impedance equal to the nominal input impedance of the test set. Tune the selective detector to 15 kHz or the highest test frequency of the set if lower than 15 kHz. The observed level reading shall remain below -56 dBm when the standard longitudinal voltage is applied. This requirement shall be met for tuned frequencies down to the lowest advertised frequency limit of the set.

5.6.4.2.14 **Frequency Measurement.** Connect the test circuit of Fig 10. The signal source for this test shall be a tone of frequency $f$ at a level of -46 dBm. The observed frequency, $f$, shall not change by more than 1 Hz when the standard longitudinal voltage is applied. The frequency of the signal source, $f$, shall be varied to include the low end through the high end of the advertised frequency measurement range.

**5.6.5 Effect of External Interference.** The test set should be protected against errors caused by power line transients and radio frequency signals or noise which may be radiated or longitudinally conducted into the set.

5.6.5.1 **Battery-Operated Sets.** A battery-operated set should meet all of its accuracy requirements while an ac powered electric drill of at least 0.2 hp is running continuously within 3 ft of the set. The set should be measuring a proper signal at its lowest threshold or most sensitive range. The input leads to the set should be shielded. If the set measures transient phenomena, then no counts should be registered when the drill is turned ON or OFF.

5.6.5.2 **AC Powered Sets.** The requirements of 5.6.5.1 should be met when the 0.2 hp electric drill is plugged in to an outlet on the same bus approximately 6 ft from the outlet supplying power to the test set.

5.6.5.3 **Stacking Sets.** Test sets of the same type when stacked on top of one another and power from the same ac outlet shall meet all accuracy requirements when operating at their most sensitive ranges. All sets shall have proper input signals and a common ground. In addition, for sets measuring transient phenomena, turning an adjacent similar set ON or OFF shall not cause a count.

5.6.5.4 **High-Frequency Noise Protection.** Facilities close to AM broadcasting transmitters will often pick up the AM signals both metallically and longitudinally. Transmission measuring sets covered by this standard should be designed to minimize the effects of this interference on the accuracy of measurements. The tests which follow for susceptibility to metallic and longitudinal AM broadcast signals are for sets which do not make measurements above voiceband frequencies. Such sets should have a low-pass filter in the measuring path with a corner at 10 kHz, a slope of at least 12 dB per octave, and a loss greater than 60 dB for all frequencies above 500 kHz.

While specific requirements are not given in this section for the low-pass filter for sets which measure parameters above voiceband frequencies, the performance of such a set for the tests which follow is likely to be of interest to a user. The requirements below shall be met with dc voltages applied to any line holding circuits (see 5.6.2).

(1) To test the susceptibility of a voiceband set to metallic AM broadcast interference, use the test setup of Fig 10, but with the standard longitudinal voltage source removed. Add the outputs of a 1004 Hz tone source and an amplitude modulation rf signal generator at the input to transformer T1 in such a manner that the output level of either may be reduced to zero without changing the effective 600 Ω drive impedance seen looking toward these sources from the input to transformer T1. With the output of the amplitude modulation rf signal generator reduced to zero, adjust the level of the 1004 Hz source for a level indication of -49.9 dBm on the voiceband set under test (600 Ω input impedance). Bridge a high-frequency, high-impedance voltmeter across the input to the set under test and note the observed voltage.

(2) Set the output level of the 1004 Hz source to zero. Set the carrier frequency of the amplitude modulation source to 1 MHz and adjust it for 50% amplitude modulation with a 1300 Hz modulation frequency. Using the bridged high-frequency voltmeter, adjust the

output level of the amplitude modulator for a voltage reading 100 times (40 dB) larger than that observed for the 1004 Hz source in (1).

(3) Remove the bridged high-frequency voltmeter and apply the 1004 Hz tone at the level set in (1). The observed level reading shall remain at 49.9 dBm as the carrier frequency is varied from 0.5 MHz to 1.6 MHz.

(4) Remove the amplitude modulator used as the source of metallic interference in (1)-(3) above and use it to replace the standard longitudinal voltage source in Fig 10. Set its output level to zero. Use the 1004 Hz oscillator as the source of metallic test signal for the set under test, and adjust its level for a level reading of -49.9 dBm on the set under test.

(5) Connect the high-frequency, high-impedance voltmeter between an input terminal of the set under test and ground. Adjust the level of the amplitude modulator (with a carrier frequency of 1 MHz and 50% amplitude modulation at 1300 Hz) for a reading of 0.775 V rms (0 dBm in 600 Ω). Remove the high-frequency, high-impedance voltmeter. The level reading shall remain at -49.9 dBm as the carrier frequency of the longitudinal 1300 Hz amplitude-modulated signal is varied from 0.5 MHz to 1.6 MHz.

(6) Successful completion of these tests indicates suppression of high-frequency interference, and that nonlinearities do not exist which would demodulate the 1300 Hz amplitude-modulated signal in the broadcast band.

### 5.7 Miscellaneous Requirements

5.7.1 **Warm-up Time.** The time required, after a test set is first turned on, before specified accuracy is assured shall be specified by the manufacturer. This time should not exceed five minutes when the instrument is at ambient temperature. The manufacturer shall specify the warm-up time when the instrument is used with an initial 25 °C change to room temperature.

5.7.2 **Extraneous Output from the Equipment**

5.7.2.1 **Electromagnetic Interference.** So as not to interfere with nearby receivers or other sensitive equipment, the test set shall meet the radiation requirements of applicable standards.

5.7.2.2 **Undesired Output when Used as Circuit Termination.** To permit the use of a voice-band transmission test set as a termination for a paralleled noise measuring set, the noise power output from the receiver terminals, or from the transmitter terminals when in an XMT OFF position, shall be less than 10 dBrn, measured with 3 kHz Flat weighting.

5.7.2.3 **Conducted Outputs.** For any signal input or output port, the power in any 10 kHz band up to 1 GHz conducted out of either terminal shall be less than -55 dBm. The measurement shall be made as follows: both terminals of the port shall be terminated with 100 Ω to ground and the power measured from either terminal to ground. Good rf measurement techniques shall be employed. This requirement applies only in cases not previously addressed in other parts of the text.

5.7.3 **(SF) Single Frequency Skip.** On circuits employing single frequency (SF) signaling, transmission of a tone at or near 2600 Hz will cause disconnection of the circuit. For test sets which have tone sweeping capabilities, a switchable means should be provided for blocking transmission of tones between 2450 Hz and 2750 Hz during a tone sweep on circuits with SF signaling.

5.7.4 **4 kHz Pilots.** For testing on N3 carrier facilities, transmitted sweep should stop at 3980 Hz maximum so as to prevent interference with 4 kHz pilot tones.

5.7.5 **Ease of Use.** Detected signal outputs for plotters are frequently useful. Internal provisions for calibration or verification to show that the set is working properly will build confidence in the users of a set.

The requirements of the previous sections, if met, do not guarantee that the transmission test set will be useful. Good human engineering is the best precaution. Among the pitfalls that should be avoided are:

(1) Confusing instruction material
(2) Interactive front-panel controls
(3) Ambiguous switch designations
(4) Proliferation of controls or calibration adjustments
(5) Handle not over center of gravity of set
(6) Small readouts or designations
(7) Noisy fan
(8) Loose but necessary accessories without provisions for storage

5.7.6 **Instruction Material.** Instruction material to ensure satisfactory operation and maintenance should include:

(1) Photograph or line drawing of the front panel
(2) Complete performance specifications

(3) Detailed instructions on operation
(4) Theory of operation with block diagrams
(5) Schematic diagrams, including typical voltages and waveforms
(6) Flow chart of the test set measurement functions, where applicable
(7) Parts list, including manufacturer's name and part ordering information
(8) Part locating diagrams, including terminal identification of all multiterminal devices
(9) Printed wiring board component and path locating diagrams
(10) Routine maintenance and calibration procedures
(11) Troubleshooting procedures
(12) Minor repair procedures

**5.7.7 Calibration.** A set specified as meeting the accuracy requirements of this standard shall meet the accuracy requirements when the set is received. It shall continue to meet the stated accuracy requirements until passing of the time period designated by the manufacturer as the recalibration interval.

## 6. Environment

**6.1 Scope.** This section provides the operating and nonoperating environmental requirements of voiceband transmission test equipment. The test equipment requirements are categorized by the intended use of the set, and the prevailing environmental conditions at such use locations.

**6.2 Nonoperating Environment.** The equipment shall meet its specified performance and accuracy requirements after being stored for a minimum period of 12 hours under the following nonoperating conditions.

(1) Temperature: -40 °C to +75 °C.
(2) Relative humidity: 10% to 90% noncondensing.
(3) Altitude: up to 15 000 m.

A 20 minute warm-up period following a 2 hour stabilization period at +15 °C to +25 °C is allowed before performance tests are made.

**6.3 Operating Environment.** The equipment shall meet the specified performance and accuracy requirements under the following operating conditions:

(1) Temperature: 0 °C to 50 °C.
(2) Relative humidity: 10% to 90% noncondensing.
(3) Altitude: up to 5000 m.

Portable test sets shall be capable of being turned on without damage at temperatures down to -30 °C.

**6.4 High-Voltage Protection.** The test set should be protected against high voltage which can be encountered on the facilities being measured. The test set should be turned on during these tests, and work properly at their conclusion.

**6.4.1 Longitudinal Voltages.** Damage to the measuring set shall not result from the presence of a longitudinal voltage of 250 V dc or 250 V rms at 50 Hz or 60 Hz, or less. Above 60 Hz, the voltage requirement decreases in inverse proportion to frequency.

**6.4.2 Metallic Voltages.** The inputs and outputs of test equipment used on balanced audio frequency circuits shall not provide a dc metallic path of less than 100 kΩ resistance except through hold circuits as described in 5.6.2. It is necessary that the set withstand dc voltages which may be present. In certain metallic, low-frequency telegraph or alarm loops as much as 260 V dc may appear across the balanced input terminals. A set which may be used to test this kind of service should have 300 V dc blocking capability; otherwise, the requirement is 150 V dc blocking capability.

In addition, the set should be capable of withstanding, without damage, an ac ringing voltage of 150 V rms at frequencies of 15.3 Hz to 68 Hz, applied through a resistance of 400 Ω for a repeated cycle to 2 seconds ON, 4 seconds OFF, or until ring-trip occurs. Ring-trip may be accomplished by drawing holding current as described in 5.6.2.1.

When a dc metallic path is present in the set, as through a hold circuit, the set shall not be damaged when its input is connected to a source of 150 V dc of either polarity applied through a resistance of 400 Ω.

**6.4.3 Lightning.** The test set shall be capable of withstanding, without damage, a simulated lightning-created transient surge across any pair terminals or from any terminal to ground. The surge voltage may be simulated by a surge generator having an internal impedance of 10 Ω and being capable of delivering a 1000 V, 10 (maximum) times 1000 (minimum) waveform to a noninductive 600 Ω resistor.

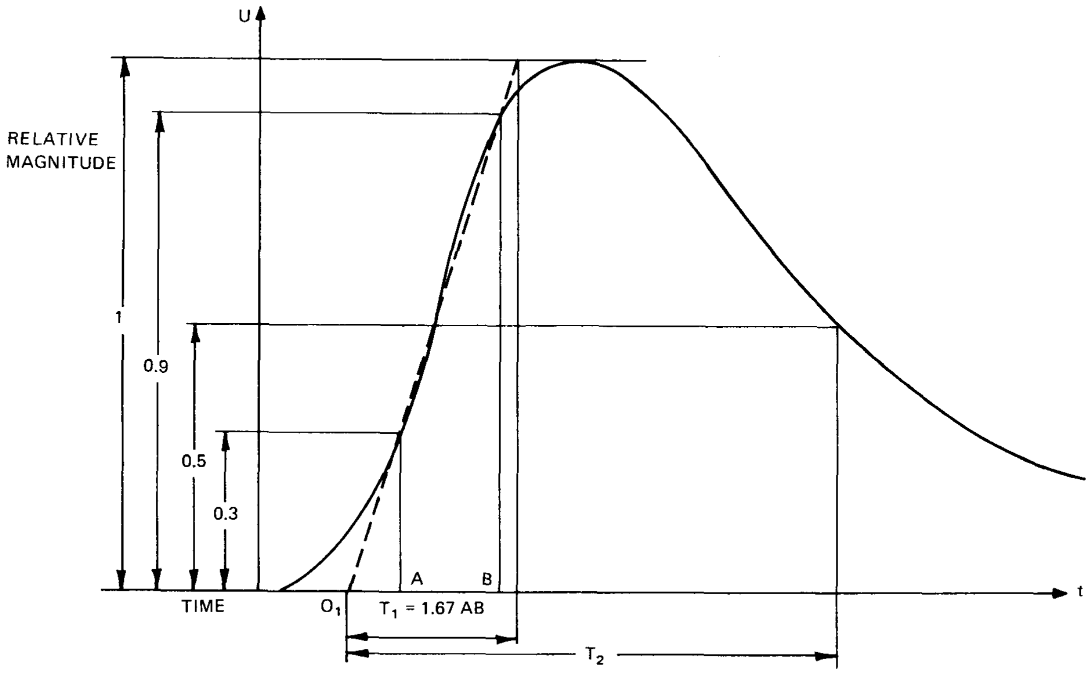


**Fig 11**
**Definition of Standard Waveform for Simulating Lighting-Induced Voltages**

6.4.3.1 Referring to Fig 11, the designation of current or voltage impulse using a combination of two numbers as 10 times 1000 is the standard IEEE numerical representation of a wave shape. The first, (T1 in Fig 11) an index of the wave front, is the virtual duration of the wave front in microseconds. The second, (T2 in Fig 11) an index of the wave tail, is the time in microseconds from virtual zero to the instant at which the voltage has decreased to one-half of the crest value on the wave tail.

6.4.3.2 The virtual duration of a wave front as defined in ANSI/IEEE Std 4-1978 [2] is as follows:

(1) For voltage waves with front durations of less than 30 μs, either full or chopped on the front, crest or tail; 1.67 times the time for the voltage to increase from 30% to 90% of its crest value.

(2) For voltage waves with wave front durations of 30 μs or more; the time taken by the voltage to increase from actual zero to maximum crest value.

6.4.3.3 The virtual zero time is the intersection with the zero voltage axis of a straight line drawn through the points on the leading edge of the wavefront 30% and 90% of its crest value.

## Appendix

(This Appendix is not a part of the IEEE Std 743-1984, IEEE Standard Methods and Equipment for Measuring the Transmission Characteristics of Analog Voice Frequency Circuits.)

## Fortran IV Subroutine that Calculates the P/AR Rating[8]

```
      SUBROUTINE PARR (XLOSS, PHASE)
C
C     CALCULATION OF THE ENVELOPE P/AR RATING.
C
C     THIS SUBROUTINE CALCULATES THE ENVELOPE P/AR RATING GIVEN THE LOSS
C     AND PHASE DATA AT EACH P/AR SPECTRUM FREQUENCY COMPONENT.
C
C     THE P/AR TEST SIGNAL IS REPRESENTED BY A TRUNCATED FOURIER SERIES
C     CONSISTING OF SIXTEEN (16) SPECTRAL COMPONENTS. THE SPECTRAL
C     FREQUENCIES ARE AT ODD MULTIPLES OF 125 Hz  IN ADDITION, EACH COM-
C     PONENT IS OFFSET BY 125./8 = 15.625 Hz
C
C     XLOSS IS A ONE-DIMENSIONAL VARIABLE WHOSE ELEMENTS ARE THE LOSS IN
C     DECIBELS AT THE P/AR SPECTRAL COMPONENTS STARTING AT 140.625 Hz AND
C     ENDING AT 3890.625 Hz.
C     PHASE IS A ONE-DIMENSIONAL VARIABLE WHOSE ELEMENTS ARE THE PHASE
C     IN DEGREES AT THE P/AR SPECTRAL COMPONENTS STARTING AT 140.625 HZ
C     AND ENDING AT 3890.625 HZ.
C
C     THE P/AR TEST SIGNAL ENVELOPE IS CALCULATED AT N EQUALLY
C     SPACED SAMPLE POINTS OVER ONE PERIOD.
C
C     THE FULL-WAVE AVERAGE OF THE P/AR TEST SIGNAL ENVELOPE IS FOUND BY
C     NUMERICAL INTEGRATION USING SIMPSON'S RULE.
C
C     THE PEAK OF THE P/AR TEST SIGNAL ENVELOPE IS FOUND BY TWO SUCCESSIVE
C     SECOND-ORDER INTERPOLATING POLYNOMINAL CURVE FITTINGS USING
C     ESTIMATES OF THE ENVELOPE PEAK AND ADJACENT ENVELOPE VALUES.
C
      DIMENSION XLOSS (16),PHASE(16),TSDB(16),A(16),B(16),E(70),PK(3)
C
C     P/AR TEST SPECTRUM IN DECIBELS:
      DATA TSDB(1),TSDB(2),TSDB(3)/-74.780,-37.945,-25.478/
      DATA TSDB(4),TSDB(5),TSDB(6)/-16.355,-8.960,-3.092/
      DATA TSDB(7),TSDB(8),TSDB(9)/0.00,-1.050,-5.503/
      DATA TSDB(10),TSDB(11),TSDB(12)/-11.390,-17.459,-23.289/
      DATA TSDB(13),TSDB(14),TSDB(15)/-28.828,-34.146,-39.355/
      DATA TSDB(16)/-44.597/
```

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```
C
            PI=3.1415926
            TWOPI=6.2831853
            NC=16
            N=64
            FN=N
            N1=N+1
C
            DO 5 I=1,NC
            ADB=TSDB(I)-XLOSS(I)
            A(I)=100.*10.**(ADB/20.)
      5     B(I)=PHASE(I)*PI/180.
C
C           CALCULATION OF THE P/AR TEST SIGNAL ENVELOPE
            DO 10 J=1,N
            X=0.
            Y=0.
            C=TWOPI*FLOAT(J)/FN
C
            DO 15 I=1,NC
            PH=B(I)+C*FLOAT(I)
            X=X+A(I)*COS(PH)
     15     Y=Y+A(I)*SIN(PH)
C
            E(J)=SQRT(X*X + Y*Y)
     10     CONTINUE
C
C           CALCULATION OF THE FULL-WAVE AVERAGE OF THE P/AR TEST SIGNAL
C           ENVELOPE
            FWA=0.
            DO 16 J=2,N,2
     16     FWA=FWA+2.*E(J-1)+E(J)
C
            FWA=2.*FWA/3./FN
C
C           CALCULATION OF THE PEAK OF THE P/AR TEST SIGNAL ENVELOPE.
            PK(1)=0.
            E(N+1)=E(1)
            E(N+2)=E(2)
            DO 25 J=2,N1
            IF(E(J)-PK(1)) 25,25,20
     20     K=J
            T=J
            PK(1)=E(J)
     25     CONTINUE
C
            DEL=(E(K+1)-E(K-1))/2./(2.*PK(1)-E(K+1)-E(K-1))
```

```
C
          DO 35 K=2,3
          X=0.
          Y=0.
          T=T+DEL
          C=TWOPI*T/FN
C
          DO 30 I=1,NC
          PH=B(I)+C*FLOAT(I)
          X=X+A(I)*COS(PH)
   30     Y=Y+A(I)*SIN(PH)

C
          PK(K)=SQRT(X*X+Y*Y)
   35     CONTINUE
C
          PEAK=PK(2)+(PK(1)-PK(3))**2/8./(2.*PK(2)-PK(1)-PK(3)+.0001)
C
C         PO, AND FO ARE THE UNDISTORTED PEAK AND FWA VALUES OF THE P/AR
C         TEST SIGNAL ENVELOPE.
          PO =423.6377
          FO=101.6241
C
          PEAKN=100.*(PEAK/PO)
          FWAN=100.*(FWA/FO)
C
          PAR=200 .*(PEAKN/FWAN)-100.
C
C         OUTPUT CONTROL:
C
          PRINT105
  105     FORMAT('-',11X,'ENVELOPE P/AR RATING:')
          PRINT106,PEAK,FWA
  106     FORMAT('0',11X,'ENVELOPE PEAK=',F8.4,2X,'ENVELOPE FWA=',F8.4)
          PRINT107,PEAKN,FWAN,PAR
  107     FORMAT('0',11X,'NORMALIZED   PEAK=',F7.2//12X,'NORMALIZED  FWA=',
     1     F7.2//12X,'P/AR RATING=',F7.2)
C
          RETURN
          END
```