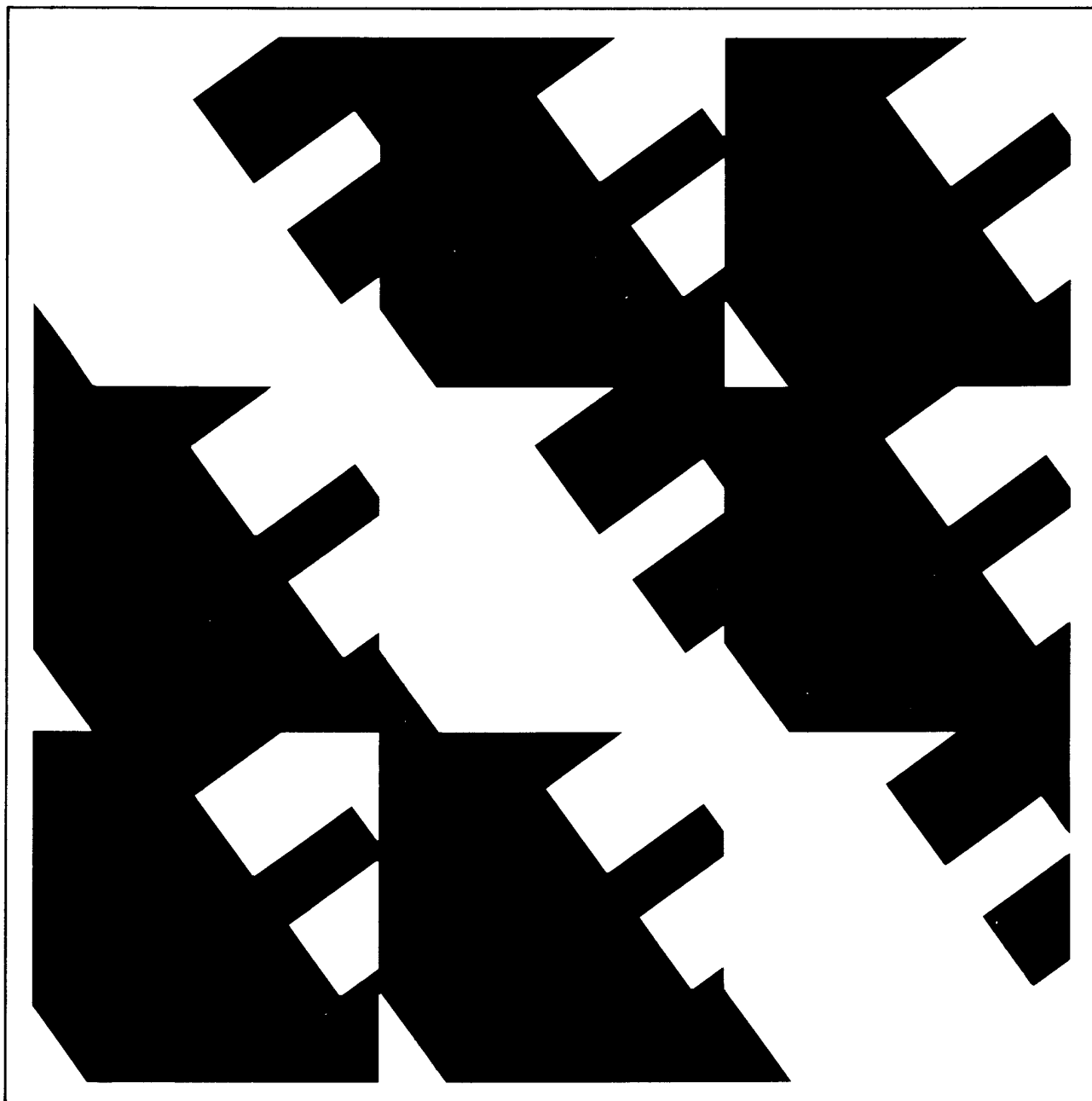


IEEE Standard Methods and Equipment for Measuring the Transmission Characteristics of Analog Voice Frequency Circuits



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When the documents referred to in this standard are superseded by a revision the revision shall apply.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

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

[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

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 companders 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)

dBm: 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)

dBmC: 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 trans-

mitted, 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.

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 measur-

ing 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 pre-service 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 $\times f_{\max}$	> 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 push-buttons is a function of how the sinusoidal tone is generated.

(a) RC or LC oscillators shall be accurate to $\pm 0.4\%$ 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 $\pm 3\%$ 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 Response 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

$$P = 1 \mu\text{W},$$

$$N = 60 \text{ dBrn or } (-30 \text{ dBm}).$$

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 nominal⁶ 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

⁶ See 5.6.1.1.

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.

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.

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:

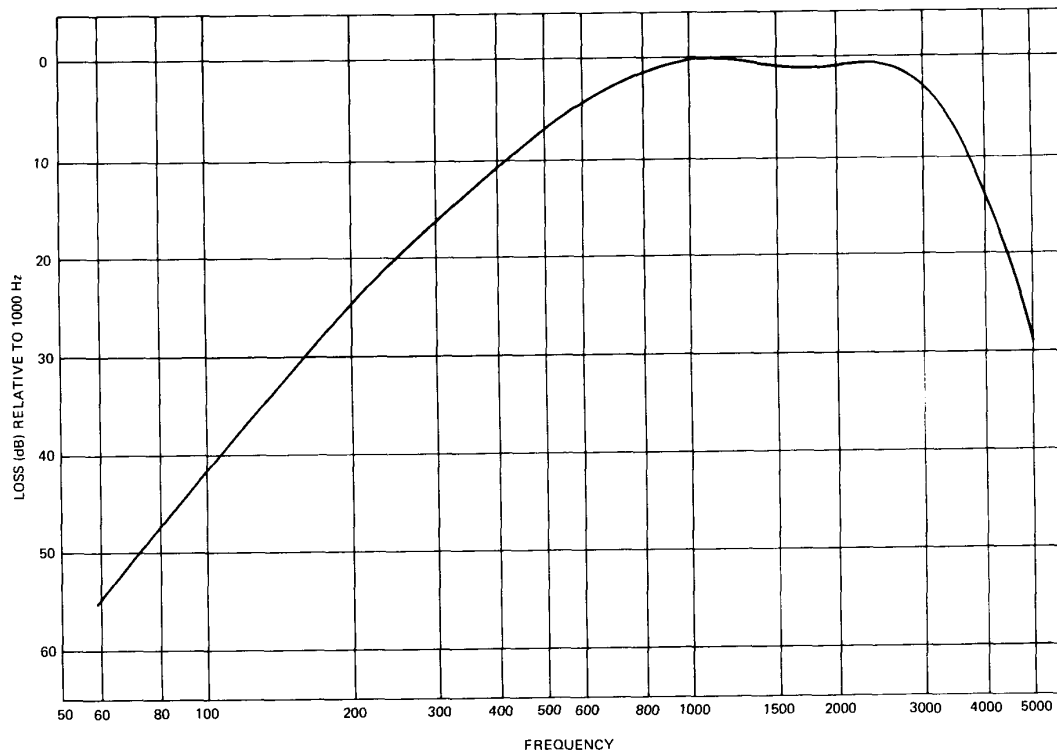
$$\text{Loss} = 10 \log [1 + (f/f_0)^4]$$

where

$$f_0 = 3 \text{ kHz or } 15 \text{ kHz}$$

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 wide-band data circuits at an impedance of 135 Ω .



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

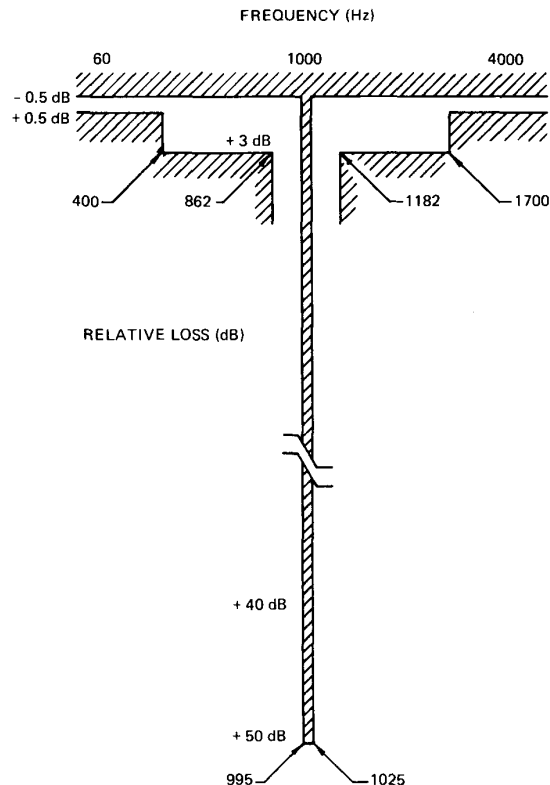
NOTES: (1) To ensure that production models of noise measuring sets will be within tolerances, including variations in components and manufacturing procedures, tolerances one half the values given above are recommended for design purposes.

(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

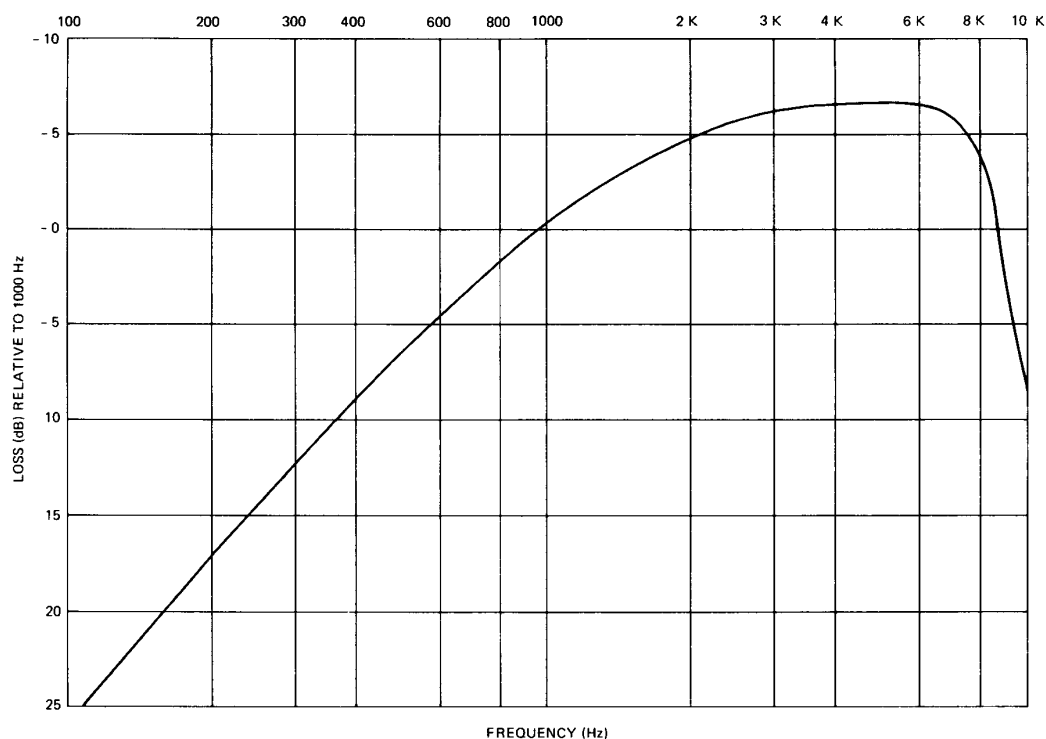
Table 4
Noise Measurement Ranges

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

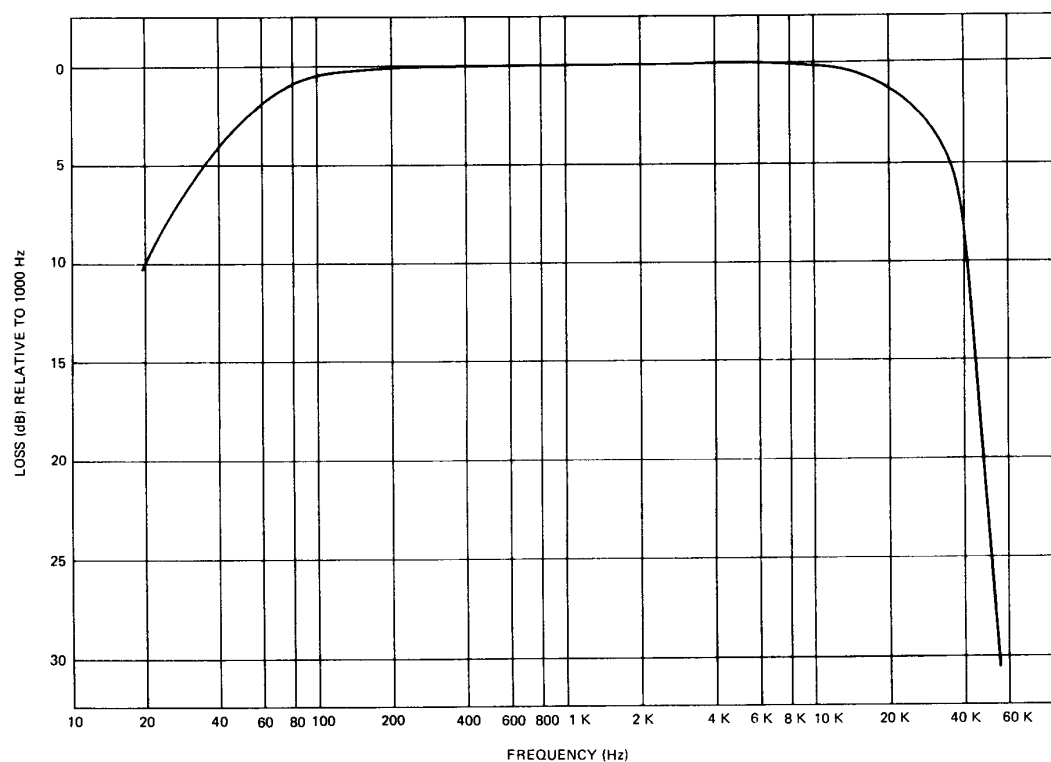
NOTES: (1) To ensure that production models of noise measuring sets will be within tolerances, including variations in components and manufacturing procedures, tolerances one half the value given above are recommended for design purposes.

(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

(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 k Ω 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 k Ω 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	≤ 1
2	≥ 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 dBm 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 re-