

Bell System

TECHNICAL REFERENCE

TRANSMISSION PARAMETERS
AFFECTING VOICEBAND
DATA TRANSMISSION-
MEASURING TECHNIQUES
MAY 1975



Bell System Data Communications

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**Transmission Parameters
Affecting Voiceband
Data Transmission -
Measuring Techniques**

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1. INTRODUCTION

1.1 Scope

The purpose of this document is to outline the general techniques used by the Bell System in measuring the important transmission characteristics of telephone channels. Many of these characteristics are defined in detail in the AT&T Technical Reference PUB 41008 "Transmission Parameters Affecting Voiceband Data Transmission — Description of Parameters, July, 1974."

The measuring techniques, ranges of measurement, and accuracy requirements described herein are, in general, those currently in use in the Bell System. However, some of the characteristics described are sufficiently new that standard techniques have not yet been established throughout the Bell System. The techniques and measurement parameters for these characteristics are therefore, based upon the best data and engineering judgment available at this time and may be subject to change as knowledge of these characteristics increases.

In addition to a description of the measuring techniques used by the Bell System, this document also presents information on the physical characteristics of voiceband transmission test equipment used by the Bell System. This information is not intended to imply a specification for procurement of equipment but, rather, is an indication of some of the physical requirements imposed upon test equipment used by the Bell System to insure satisfactory performance and life in the operating environment peculiar to a telephone system such as the Bell System.

1.2 Organization

Section 2 provides a brief description of transmission parameters which affect data transmission and general comments on measurement philosophy. Section 3 provides details on the techniques used within the Bell System to measure the parameters listed in Section 2. The requirements of Sections 4, 5, and 6 provide information on the general characteristics of voiceband transmission test equipment used by the Bell System.

1.3 Reason for Reissue

This document is being reissued to indicate requirements for parameter measurements not previously specified, to make additions and corrections to previously-published measuring techniques, and to indicate those new parameter measurement areas where detailed specification may be forthcoming in a later issue.

The holding tone for all measurements requiring a holding tone is now near 1000 Hz as described in Section 2.3. With the exception of the sine wave oscillator, the requirements for the transmitter for a particular measurement will be found in the same section with the receiver requirements.

2. GENERAL INFORMATION

2.1 General Description of Measurement Requirements

Most of the measurement requirements discussed below are for transmission parameters discussed in more detail in AT&T PUB 41008.

- (a) **Level:** The power, at a nominal impedance, of the received signal which results from transmitting a test signal over the facility. (Section 3.1)

Voice frequency transmission measurements are made at several access points within the central offices and on trunk, loop, and station equipment outside of the central offices. The expected signal levels at these access points, may span a range from — 40 dBm to +10 dBm. Test tones are frequently transmitted at data level (— 13 dBm0). The frequency range of interest for circuits handling normal speech and voiceband data services may extend from below 60 Hz to above 4000 Hz. For program circuits the frequency range of interest may extend from 20 Hz to 20,000 Hz. Gain-slope measurements are level measurements made near 400 Hz, 1000 Hz, and 2800 Hz.

- (b) **Background Noise or Noise-With-Tone:** Noise on a facility with no holding tone present or noise remaining after a holding tone has been notched out, as measured through a frequency weighting network. (Section 3.2)

Noise measurements are made using one of several frequency weighting networks. These include:

- (1) **C-Message:** A frequency weighting which evaluates the effects of noise corresponding to its annoyance to the "typical" subscriber of standard telephone service (see Figure 1). This weighting is also used to evaluate the effects of noise on voice-grade data services.
- (2) **C-Notch:** A frequency weighting similar to C-Message weighting except for the addition of a narrow stopband or notch centered at 1010 Hz. See Figure 2.
- (3) **3 kHz Flat:** Used on voice frequency circuits when investigating 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:** For weighted measurements of noise on program circuits of bandwidths up to approximately 8000 Hz. Not used on voice message circuits. See Figure 3.
- (5) **15 kHz Flat** For unweighted measurements of noise on program circuits. Not ordinarily used on voice message circuits. It is a 15 kHz low pass filter of Butterworth shape rolling off at 12 dB per octave.

Noise measurements with a holding tone near 1000 Hz at data level at the transmitting station interface may be used to give a measure of the noise encountered by a continuous data signal or the noise a listener would hear during

a speech burst. The tone is eliminated by a sharp notch filter before C-message weighted noise measurement is made. Quantizing noise, harmonic distortion, and phase or amplitude jitter are among the impairments which can cause the noise-with-tone measurement to be higher than the idle channel noise.

- (c) **Impulse Noise:** Indicated by noise bursts exceeding a selected voltage threshold. (Section 3.3)

An impulse noise measurement is a count of noise hits on a line whose amplitudes exceed a given threshold during a specified time interval. These hits are usually far more disturbing to data transmission than to conversation. To avoid counting the individual damped oscillations in a given hit, the counter is blanked for a short period after the threshold has been exceeded.

- (d) **Envelope Delay Distortion:** Envelope delay is defined as the derivative of the circuit phase shift (in radians) with respect to frequency (radians per second). The deviation of this derivative at any frequency from its value at a prescribed frequency (usually 1800 Hz) is called envelope delay distortion. (Section 3.4)

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.

- (e) **Return Loss:** A measure of the mismatch between the actual transmission circuit impedance and the nominal circuit impedance. (Section 3.5)

Return loss measurements are most important for 2-wire systems providing 2-way transmission. Such systems are subject to line echoes. If the return loss is low, large talker and/or listener echoes may occur creating the "rain barrel" effect in voice communications and causing mutilation of some data signals. Zero or negative return loss at any point along the frequency scale will cause the circuit to oscillate or "sing".

Echo (ERL) and singing (SRL) return loss measurements are made by transmitting band-limited noise of known power and measuring the energy reflected back to the transmitter, or to the receiver for a 4-wire measurement. The ERL measurement places the test signal energy primarily in the center of the voiceband (500-2000 Hz). The SRL measurements place energy near the edges of the channel bandwidth where singing margins are lowest.

- (f) **Phase Jitter:** Undesired phase modulation on a received signal. (Section 3.6)

Phase jitter typically results from unwanted phase modulation on carriers supplied in carrier terminals. The modulating frequencies are often harmonics of 60 Hz or other very low frequencies that are not easily filtered in power supply circuits. In making phase jitter measurements, a holding tone is transmitted over the facility under test. The phase jitter measured at the receiver is the summation of any incidental phase modulation (sidebands symmetrically located around carrier) and random or quantizing noise encountered on the facility.

- (g) **Intermodulation (Nonlinear) Distortion:** A measure of the second and third order nonlinearities. (Section 3.7)

Nonlinearities such as compression and clipping cause harmonic and intermodulation distortion in the transmitted signal. This type of impairment is evaluated by measuring a number of second and third order modulation products which result from the nonlinearity acting on a multiple-tone transmitted signal.

- (h) **P/AR Rating:** The P/AR measurement (peak-to-average ratio of a particular test signal) is designed to be sensitive to envelope delay distortion and gain-bandwidth reduction and largely insensitive to the normal steady interferences or impairments on a channel

such as harmonic distortion, noise, and phase jitter. It is completely immune to the transient phenomena. A shaped pulse with a 10 dB peak to RMS ratio is transmitted over a channel and, after frequency shaping, is processed by circuits which measure the peak-to-average ratio of the rectified envelope of the received signal. (Section 3.8)

Envelope delay distortion measurements are tedious to make and require relatively expensive and complicated test equipment. P/AR permits a weighted, single-number, straightaway measurement related to the effect of envelope delay distortion on intersymbol interference in high speed data sets. Because the P/AR spectrum weights envelope delay distortion in the center of the voiceband more heavily than at the band edges, it may be used to estimate the degree of conditioning of a channel.

Since the envelope delay distortion of a given facility tends to remain invariant or change only slowly with time, P/AR may be used as a benchmark type of measurement which, if recorded at circuit-order time for a channel, can establish on subsequent measurements whether the facilities making up the connection have been changed.

- (i) **Hits and Dropouts:** Rapid changes in the gain or phase of a received signal or loss of signal. (Section 3.9)

These transient phenomena are measured by examining a received holding tone for abrupt changes in its level or phase for an extended period. To separate these effects from impulse noise, a guard interval is normally used. The holding tone may remain at its new level or phase, or return to its original value. For a dropout, the dropout level is determined at the start of the measurement and remains fixed over the measurement interval.

- (j) **Single Frequency Interference:** Spurious steady tones present on the channel in addition to the transmitted signal. (Section 3.11)

A listening test provides a quick way to determine if unwanted tones are present after the transmitted signal, if any, is notched out at the receiving end. Occasional low level tones which may occur from crosstalk of multifrequency signaling, for example, do not fall in this category.

- (k) **Spectrum Analysis:** Resolution of the frequency components of a signal into narrow frequency bands. (Section 3.12)

Either a sweeping narrow-band selective detector must be used to cover the frequency band of interest, or a sampled data technique with sufficient frequency resolution.

- (l) **Frequency:** The reciprocal of the period of a sinusoidal tone or of the carrier in a modulated signal. (Section 3.13)

The measurement must be made in the presence of noise. Frequency shift may be caused by a difference in frequencies of the locally-generated carrier frequencies used for transmitting modulators and receiving demodulators in single-sideband suppressed-carrier transmission systems.

- (m) **Amplitude Jitter:** Undesired amplitude modulation on a received signal. (Section 3.14).

Amplitude jitter is the summation of incidental amplitude modulation (sidebands symmetrically located around the carrier) and random or quantizing noise encountered on the facility.

The extent to which this impairment exists is under investigation.

2.2 New Measurement Techniques

The measurement techniques described in the previous section do not necessarily represent a complete or optimum list. The Bell System is interested ultimately in test equipment which measures those parameters which affect the service to its customers and permits rapid identification of the facility causing the difficulty. For example, a new phase jitter set which could distinguish between the effect of

added noise and incidental phase modulation would permit efficient troubleshooting of tandem facilities.

Time domain test equipment with computer analysis capability could measure the parameters specified in this document by different means and still produce comparable results to test equipment adhering exactly to these specifications.

The requirements for analog and digital displays in Sections 5.2 and 5.3 are not intended to discourage such innovation in displays as proves useful to the personnel performing the transmission tests.

2.3 Holding Tone

It has been a long-established practice in the Bell System to set gain adjustments and measure facility loss at 1000 Hz. The holding tone frequency for measurements has been moved to this frequency range from 2800 Hz in order to be better able to predict its level at various points in an end-to-end connection.

Motor-generator oscillators were used initially to provide the 1000 Hz test tone and more recently transistorized oscillators provided the tone. With the advent of PCM (Pulse Code Modulation) facilities, the use of exactly 1000 Hz as a test tone frequency resulted in beats in the measured level because the tone frequency was one-eighth of the sampling frequency. As a result, 1020 Hz became a popular testing frequency for this application. Commercial holding tone sources should be in the range of 1002 Hz to 1020 Hz, and if crystal controlled, 1004.0 Hz is suggested.

The Bell System will introduce crystal-controlled 1004.0 Hz, -16 dBm0, and low-distortion tone sources for holding and test tone in new measurement systems. These sources avoid the level-beating problems associated with T-Carrier and also permit frequency offset measurement on a straightaway basis.

A band-rejection filter to notch out holding tones described above must have a rejection band of at least 995 Hz to 1025 Hz to account for frequency tolerance in the early tone sources. The center frequency of this rejection band is therefore at 1010 Hz, so the rejection filter will be referred to as a 1010 Hz notch.

Because the sine wave oscillator is routinely available, and because it may be used as a holding tone for so many measurements (noise-with-tone, impulse noise, phase jitter, amplitude jitter, gain hits, phase hits, dropouts and frequency shift) it is accorded a separate Section , 3.10, Oscillators, Sine Wave.

2.4 Test Set Economics

This document does not address the economics of transmission test equipment design, nor does it suggest best combinations of parameters to be measured. It is possible that a test set which failed some of the requirements of this document be acceptable because some important characteristic, such as small size, was critical in some other area, such as outside plant, to which other standards apply.

2.5 Repair and Modification of Equipment

The reputation of a test equipment manufacturer rests on his equipment in use. If repair or modification of the equipment is necessary, the test equipment manufacturer has the greatest interest in seeing the work done quickly and properly.

3. MEASUREMENT TECHNIQUES

This section presents the current Bell System requirements for measurement techniques for the parameters which affect voiceband data transmission. Specific requirements on ranges, accuracies, distortion, and stabilities are established and, in some instances, methods of testing for the requirements are suggested. The accuracy objective given for each type of measurement, after a five minute warm up time, includes the effects of all variable parameters such as calibration errors, flatness, attenuator errors, reading errors, temperature, crosstalk, etc. The level ranges specified in this document refer to rms power of the signal.

3.1 Level

Level measurements are used to determine the loss and attenuation distortion of a circuit. In addition, level measurements of the received level of a signal are used in conjunction with noise measurements to determine the signal-to-noise ratio on the circuit.

Loss and attenuation distortion measurements require the application of a single frequency tone at a specified level at the distant end* of the circuit. Loss on message trunks is generally measured using 1000 Hz at 0 dBm0 applied at the distant end. Attenuation distortion (gain-slope) is measured on message trunks using 404 Hz, 1004 Hz, and 2804 Hz at - 16 dBm0 applied at the distant end. Because of slight measurement errors that occur on T-carrier systems when the measured frequency is a submultiple of the sampling rate, the normal 400, 1000, and 2800 Hz signals are offset upward by 4 Hz where crystal-controlled oscillators are used. Loss and attenuation distortion measurements on data services make use of test signals applied at the data level (- 13 dBm0). The 0 dBm0 level for loss measurements will eventually be lowered to - 16 dBm0.

Level measuring sets can be divided into three general categories according to their advertised frequency response: - Voiceband (up to 4 kHz) Program (up to 15 kHz), and Wideband, (up to at least 20 kHz).

- (a) **Accuracy:** According to the advertised frequency range, the level measuring set shall meet the following accuracy requirements as shown in Table A.

TABLE A

Frequency	Accuracy in dB		
	Voiceband	Program	Wideband
20 Hz to 200 Hz	±0.5	±0.5	±0.5
200 Hz to 4 kHz	±0.2	±0.2	±0.2
4 kHz to 15 kHz		±0.2	±0.2
15 kHz to top of range			±0.5

In addition, the absolute accuracy at 1000 Hz shall be ±0.1 dB for levels between 0 and -19 dBm.

* The distant end of the circuit is taken to mean some access point on the circuit remote from the location of the measuring equipment. dBm0 means dBm at a zero transmission level point (0 TLP). 0 TLP is an expedient used as a standard power level reference point on trunks. For a discussion of TLP, see the text "Transmission Systems for Communications" by Bell Telephone Laboratories, Inc., fourth edition, February, 1970.

- (b) **Bridging:** In addition to meeting the bridging impedance requirements of Section 5.4 c, the level displayed on the set shall be compensated to be that which would have been observed if the bridging impedance were infinite. The front panel of set shall clearly indicate the impedance for which the bridging reading is calibrated. All other requirements of this Section 3.1 apply to the set in the bridging mode.
- (c) **Level Range:** The measuring set shall accommodate an input level range of at least +10 dBm to -40 dBm.
- (d) **Low-Frequency Noise Protection:** In some applications, levels of the ac power frequency (60 Hz) or its harmonics may be encountered which are high enough to effect the accuracy of measurement of loss. A filter having at least 25 dB loss at 20 Hz and 60 Hz and at least 4 dB loss at 180 Hz should be provided. Since the filter can effect the accuracy of loss measurements at low frequencies, its insertion should be controlled by a front-panel switch. The effects of its insertion on loss measurements above 400 Hz should be negligible.
- (e) **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 no measurements are to be made above voiceband, this filter shall be present for all measurements. If measurements are to be made above voiceband, a low pass filter rolling off at least 6 dB per octave with a corner frequency no higher than three times the top of the advertised frequency range should be present for all measurements.
- (f) **Detector:** A average detector shall be used because it is 2 to 3 dB less sensitive to interfering noise than is an rms detector. The displayed reading shall be the rms power of the sine wave.
- A selective detector should not normally be used for level detection because of accuracy and cost considerations. In addition, a selective detector will indicate a lower received level than the standard wideband average detector for a received tone with incidental phase modulation.
- (g) **Display Response Time:** For a suddenly-applied 1000 Hz sine wave, the display shall be within ± 0.1 dB of the final reading within 3 seconds or less, and the overshoot, excluding autoranging, shall be less than 0.2 dB. This same requirement shall be met for a suddenly-applied signal consisting of a 1000 Hz tone with either a +50 V dc or -50 V dc bias.
- (h) **Crosstalk:** Care must be taken in sets which contain an oscillator as well as a receiver to ensure that the oscillator of the test set does not crosstalk into the receiver at a level which causes more than 0.2 dB worst case error. This crosstalk requirement may be tested for such sets as follows:
- (1) Terminate the transmitter of the test set in 600 ohms and set the output level to the lowest possible value. Turn off the transmitter if this is possible.
 - (2) Apply a 1000 Hz test tone from a separate oscillator to the test set receiver so that it reads -39.0 dBm on the receiver.
 - (3) Set the test set transmitter to the highest possible output level.
 - (4) The reading now observed should not differ from -39.0 dBm by more than 0.1 dB as the test set transmitter frequency is varied in the regions around 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz.

- (i) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. This section also gives the longitudinal balance (LB) requirements as a function of the frequency, f_L , of the longitudinal noise. An audio oscillator (M) should be connected to terminals 3 and 4 to provide a metallic signal of frequency f_M and level M dBm. Another oscillator (L) should be connected to terminals 5 and 6 to provide a longitudinal signal of frequency f_L and level L dBm.

With no harmonic relationship between f_L and f_M , the level indication on the set caused by oscillator (M) should change less than 0.2 dBm as a result of applying a longitudinal signal of level L dBm as indicated in the following formula:

$$L = M + LB - 11$$

Example: With f_L at 180 Hz and (M) adjusted so the set reads -20 dBm

$$L = -20 + 50 - 11 = +19 \text{ dBm}$$

- (j) **Precision Level Measurement:** There is a need in the Bell System for a precision level measurement set to verify levels of office tone supplies. The required accuracy for the set is $\pm .03$ dB over a level range of at least +7 dBm to -32 dBm and a frequency range of 400 Hz to 2800 Hz. None of the previous requirements for level measurement sets of Section 3.1 apply except those for Crosstalk (Section 3.1h) where .03 dB shall be substituted for 0.1 dB.

Precision level measurements shall not be made on a bridging basis because of the extreme precision required in the terminating resistor.

3.2 Background Noise

Noise may be measured either with or without a holding tone present. If no holding tone is present, the idle channel noise is measured to a "quiet" 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 to an oscillator (600 or 900 ohm output impedance) with an output frequency between 1002 Hz and 1020 Hz and at a level appropriate for the system under test. The rms noise power is normally measured with a C-Message weighting network after rejection of the holding tone with a sharp notch filter (C-Notched noise measurement). Once the holding tone has been eliminated, the range and accuracy requirements for the two kinds of noise measurement are identical.

Noise-to-ground measurements permit evaluation of the longitudinal (common mode) voltage present on facilities.

- (a) **Accuracy:** The background noise measurement shall be accurate to ± 1 dB over a range of at least 20 dBm to 90 dBm. The noise-to-ground measurement shall be accurate to ± 1.5 dB over a range of at least 50 dBm to 130 dBm.

- (b) **Weighting Network Tolerances:** Bell System standard weighting networks conform to the tolerances shown in the attached Figures 1 through 3 and in Table B. The response at 1000 Hz of all networks, except the 1010 Hz Notch of Figure 2, in a given set should be the same to within a tolerance of ± 0.2 dB.

The combined response of the C-Message Filter (Figure 1) plus the 1010 Hz Notch Filter (Figure 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

$$\text{Loss} = 20 \log_{10} [1 + (f/f_0)^4]^{1/2}$$

where $f_0 = 3\text{kHz}$ or 15kHz . 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 the following table.

TABLE B

Frequency in Hz	Loss in dB	Tolerance in 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 should continue to increase at a minimum of 12 dB per octave until a loss of 60 dB is achieved. At higher frequencies the loss must be at least 60 dB.

- (c) **Noise-to-Ground Input Configuration:** The impedance between the balanced inputs, if shorted together, and ground shall be at least 100,000 ohms. There shall be no dc path to ground for a 200-volt dc longitudinal signal of either polarity.

Under certain conditions with Bell System E-Type Signaling Units, if polarized capacitors are used to block dc current flow, the 100,000 ohm impedance above can cause false signaling. This problem shall be avoided by using a nonpolarized capacitor to block dc current in the Noise-to-Ground mode.

The reading displayed shall correspond to the power dissipated in a 600 ohm resistor with the measured voltage applied.

Because of economic considerations, the Bell System 3-Type Noise Measuring Sets accomplish this function with the user adding 40 dB to the readings. This procedure is not recommended for new sets.

- (d) **Detector:** The detector circuit should measure the rms value of the noise. An approximate, or full-wave "quasi"-rms detector circuit may be used as long as 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, at a 50 Hz rate, of 1000 Hz sine wave, 20 percent of the cycle at full amplitude and 80 percent of the cycle down 8.4 dB from 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 as not to cross an autorange point, if any.

- (e) **Measurement Averaging Time:** The response time for the detector and indicating means shall meet the following limits: Apply gated bursts of 1000 Hz tone to the input of the set gated at a duty cycle of 50 percent, half of the cycle at full amplitude and the other half 8.4 dB down from full amplitude. The levels should be chosen so as to avoid autoranging points, if any. The indicator or digital display device shall show a variation as shown below:

TABLE C

Gating Frequency	Peak-to-Peak Indicator Variation
10 Hz	Less than 1 dB
2 Hz	Equal to or greater than 3 dB

Other damping may be provided on a switchable basis.

- (f) **Loss of Holding Tone:** For the noise-with-tone measurement, there should be some unmistakable indication if the holding tone level suddenly drops below -40 dBm or the lowest level measurement capability of the set.
- (g) **Crest Factor:** So as not to significantly (0.5 dB) clip white noise, the set shall not clip signals at least 8 dB above the highest permissible displayed reading.

(h) **Turnover:** With the 3 kHz Flat weighting, apply a rectangular waveform to the input with a 20 percent duty cycle and a 300 Hz repetition rate, and note the noise reading. Invert the input leads. The new noise reading shall be within 1 dB of the first reading.

(i) **Longitudinal Noise:** Use the test setup of Figure 4 as described in Section 5.10 a. This section also gives the longitudinal balance (LB) requirements as a function of the frequency, f_L , of the longitudinal noise oscillator (L) with output level L dBm. The metallic noise reading shown on the test set should be less than

$$L - LB + 91 - A(f_L) \text{ dBm}$$

where $A(f_L)$ is the loss in dB of the filter weighting as shown in the Appendix at the longitudinal frequency of f_L Hz.

Example: With a 3 kHz Flat filter and an f_L of 3000 Hz, $A(f_L) = 3$ dB. Selecting a level L of -5 dBm, then the observed noise reading on the set should be less than

$$L - LB + 91 - A(f_L) = -5 - 60 + 91 - 3 = 23 \text{ dBm}$$

3.3 Impulse Noise

Impulse noise is defined as that component of a received signal that has been band-limited and exceeds rms noise level in that same band by 12 dB or more. As applied to a voiceband circuit, any excursion of this band-limited signal above a preset threshold should be counted as an impulse. Since within this definition and for operational reasons it is important to have knowledge of the rms noise level, an impulse noise instrument should have this additional measurement capability.

If the test set has hit or dropout counting capability in addition to impulse noise measuring capability with a holding tone, then Section 3.9, Phase Hits, Gain Hits and Dropouts should also be consulted.

(a) **Calibration and Accuracy:** The test set shall be calibrated in dBm to read the peak value of the received signal. For

example, if a 90 dBm (0 dBm) sinusoidal signal is applied to its input terminals, counting shall normally just start with the instrument set at 93 dBm. The accuracy of the threshold setting should be ± 1 dB on balanced circuits and ± 1.5 dB for noise-to-ground measurements.

(b) **Range:** Adjustment of the threshold level in 1 dB steps shall be provided for balanced signals ranging from 30 to 110 dBm and 60 to 140 dBm for impulse noise-to-ground measurements.

(c) **C-Message Weighting:** The Bell System standard weighting network for the measurement of impulse noise without a holding tone is shown in Figure 1, which lists the required tolerances.

(d) **Holding Tone:** In order to provide more meaningful measurements of impulse noise on certain facilities, a holding tone of nominal 1 kHz must be used. The received holding tone level may range from 0 dBm to -40 dBm and the frequency from 995 Hz to 1025 Hz. The set should provide a clear indication of the presence or absence of the holding tone.

Since the impulse noise set is frequently not monitored during the measurement period, it would be desirable to have some resettable means for showing loss of holding tone during the measurement period.

(e) **1010 Hz Notch:** To eliminate the holding tone, a 1010 Hz notch filter shown in Figure 2 shall be provided in tandem with the C-Message Filter of Figure 1. So as to provide uniformity in the response to impulses the notch filter and C-Message filter shall be minimum phase designs without phase equalization sections. The requirements of a., above, shall be met for a 1700 Hz sine wave with, or without, the presence of a 1000 Hz holding tone applied at a level 5 dB above the level of the 1700 Hz sine wave.

- (f) **Detector Response:** The difference in response (count threshold) to a 1000 Hz sine wave, when compared to the response of the same sine wave when delivered in 10 cycle (± 1 cycle) bursts at a repetition rate of 5 bursts per second shall be within ± 0.2 dB. The same requirement shall be met if the input leads are interchanged.
- (g) **Turnover:** The difference between "just counting" levels for positive or negative going 1 ms duration rectangular pulses at a 5 pulse-per-second rate shall not differ by more than 0.2 dB.
- (h) **Counting Rate:** A counting rate of 7 pulses per second shall be provided by designing for a blanking interval of 143 milliseconds ± 5 percent after each count. Higher counting rates may be provided on an optional switch-controlled basis, but in no case should the blanking interval be less than 4 milliseconds (so as not to count individual cycles of a damped oscillation impulse).
- (i) **Timer:** A timer accurate to at least ± 5 percent shall be provided for the convenience of the tester. Periods of 5 minutes, 15 minutes, and continuous should be provided under switch control if the timer is not continuously adjustable.
- (j) **Count Capacity:** A register capacity of at least 999 counts is required.
- (k) **Impulse Noise Distribution Set:** If provision is made for obtaining impulse noise amplitude distributions, then at least three separate storage circuits should be provided, each having a capacity of at least 999 counts. If only three counters are provided, with no switch selection of threshold difference, then the threshold difference between them shall be set at 4 dB. Otherwise, the threshold differences for the individual counts should be capable of being set to at least 2, 4, or 6 dB by means of a switch. The reference level should correspond to the lowest threshold setting.

The registers should display the cumulative distribution function of impulses each subject to the 7 counts per second rate. A single large impulse should cause counts on all registers. Each register should have its own independent blanking interval timing circuit so that an impulse just exceeding any lower threshold should not block other registers from counting on a subsequent, higher impulse within 143 milliseconds of the original impulse. For example, if an impulse exceeding a LOW threshold is followed in 30 milliseconds by an impulse exceeding a MID threshold, one count should be recorded by each counter.

- (l) **Longitudinal Noise:** Use the test setup of Figure 4 as described in Section 5.10 a. This section also gives the longitudinal balance (LB) requirements as a function of frequency. No counts shall be registered on a metallic basis at a threshold of $L-LB+94-A(f_L)$ where $A(f_L)$ is the loss of the weighting filter at the frequency, f_L , of the longitudinal voltage.

Example: For the C-Message weighting where a +10 dDm, 600 Hz, longitudinal voltage is applied, $[A(f_L) = 5 \text{ dB}]$ the threshold is $10-60+94-5 = 39 \text{ dBrn}$.

3.4 Envelope Delay Distortion

Bell System envelope delay distortion measurements are made utilizing an amplitude-modulated test signal which is envelope detected at the receiver to obtain the necessary phase information. A reference path must be provided to obtain a stable reference if other than a loop measurement is to be made. This one-way measurement mode requires that an envelope delay distortion set at the far end of the facility be put in a 'Repeat' mode in which the detected 83-1/3 Hz modulation frequency is modulated on a new transmitted frequency returned via the reference path to the near end. On a 4-wire measurement, such a path is routinely available, but on a 2-wire measurement, a separate path must be provided.

This measurement technique reduces the cost and complexity of the test equipment compared to straightaway envelope delay distortion measuring sets, but requires the separate reference path. Test equipment which can make straightaway envelope delay distortion measurements with a 83-1/3 Hz modulation frequency can permit delay measurements to the accuracy required below, but will require that a compatible set be available at the other end of the facility. Other modulation frequencies such as the CCITT Standard (41-2/3 Hz) may at some time be used by the Bell System, and may be provided on a switchable basis.

Transmitter

- (a) **Amplitude Modulation:** The transmitted test signal shall consist of 50 percent amplitude-modulated signal at a modulation frequency of 83-1/3 Hz. The modulation depth shall be between 45 and 55 percent and the frequency accurate to ± 0.1 percent.
- (b) **Test Signal Distortion:** All harmonics or other spurious outputs from the transmitter individually must be at least 46 dB below the power of the carrier frequency (f_C) with the exception of 83-1/3 Hz and $3 f_C + 83-1/3$ Hz, which must be down 52 dB.
- (c) **Frequency Range:** The carrier frequency shall have a range of at least 300 Hz to 3500 Hz.
- (d) **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.
- (e) **Output Level Range:** The output power shall have a range of at least 0 dBm to -40 dBm. Adjustment shall be in 5 dB steps or less.
- (f) **Flatness:** The output power shall be flat to ± 0.2 dB from at least 300 Hz to 3500 Hz.
- (g) **Compatibility:** Because the transmitter of one envelope delay set may be used

with the receiver of another set, it is necessary that the transmitter exceed the back-to-back delay accuracy of the following section as measured with a flat receiver, in that a maximum of one-half of the permitted back-to-back envelope delay distortion be in the transmitter.

Receiver

- (h) **Accuracy:** The back-to-back measurement accuracy shall be ± 10 microseconds from 600 Hz to at least 3500 Hz and ± 30 microseconds from 300 Hz to 600 Hz.
- (i) **Range:** The set shall have an envelope delay distortion measurement range capability of at least 10,000 microseconds.
- (j) **Input Power:** The receiver shall meet the accuracy requirements for an input power range of at least $+10$ dBm to -40 dBm.
- (k) **Display Response Time:** After the application of a 3000-microsecond step change in delay, the instrument shall indicate within 30 microseconds of the final delay distortion indication within 3 seconds.
- (l) **Frequency Accuracy:** The input 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 input frequency.
- (m) **Amplitude-to-Phase Conversation:** The indicated envelope delay in the back-to-back mode shall not change by more than 5 microseconds for a transmitted level shift of 5 dB.
- (n) **Crosstalk:** The measured envelope delay distortion for a low loss network with at least 1000 microseconds of envelope delay distortion shall not differ by more than ± 10 microseconds if 35 dB of flat loss is inserted in series with the network. This test shall be conducted in the Normal mode.

- (o) **Signal-to-noise Ratio:** The accuracy objectives given above shall be met with a line signal-to-noise ratio as low as 20 dB. The noise level shall be measured with 3 KHz FLAT weighting.
- (p) **Harmonic Distortion to Phase Conversion:** The indicated delay shall not change by more than +5 microseconds when the test signal is subjected to 25 dB of second order distortion and 20 dB of compressive 3rd order distortion. The circuitry creating these harmonic distortions should have no frequency dependent phase or amplitude characteristic within the band of interest.
- (q) **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.
- (r) **Turnover:** The set shall meet all of the requirements of this section if the input leads are interchanged. This permits only a flat delay change.
- (s) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. This section also gives the longitudinal balance (LB) requirements as a function of the frequency, f_L of the longitudinal noise. An envelope delay transmitter should be connected to terminals 3 and 4 to provide the 50 percent amplitude-modulated metallic signal of level M dBm. An oscillator (L) should be connected to terminals 5 and 6 to provide a longitudinal signal of level L dBm. For the most probable trouble frequencies, set f_L to the same frequency as the upper or lower sideband of the AM signal and adjust f_L to the worst case envelope delay bobble. This variation shall be less than 20 us for $L = M + LB - 53$ dBm. This requirement shall also be met at other frequencies including 60 Hz.

Example: For a -20 dBm metallic signal

$$L = -20 + 50 - 53 = -23 \text{ dBm}$$

Repeat Mode

To permit envelope delay distortion measurements with envelope delay measuring sets at each end of the facility, the equipment must be designed so that in the 'Repeat' mode, it can transfer the 83-1/3 Hz envelope of a received envelope delay signal to a new transmitted carrier for transmission back to the originating end. This establishes a phase reference over the loop.

- (t) **Repeat Mode:** 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 have the following capabilities:
 - (1) Ability to display either transmitted or received frequency without loss of phase reference.
 - (2) Ability to display received level so as to be assured at the start of the measurement that the receiver input range capability will not be exceeded.

3.5 Return Loss

Return loss measurements are made on both 2-wire and 4-wire circuits. When return loss measurements are made on a 2-wire circuit, the return loss is the ratio of the transmitted power to the reflected power. On 4-wire circuits with proper terminations, the return loss is this power ratio adjusted for any difference in the expected transmission levels (TLPs) of the sending and receiving sides due to amplifications, pads, or transhybrid loss. Return loss measurements require a quiet termination at the distant end of the circuit. On 2-wire circuits, a hybrid must be included as 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 equipment.

Transmitter

- (a) **Transmitted Signal Weighting Requirements:** Requirements for three signal weightings are given in the following tables. In each case, the applied test signal is derived by passing a wideband random noise signal through

a bandpass weighting network. The noise source should be flat to ± 0.5 dB from 200 Hz to 4000 Hz 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 second will be required to obtain a reasonable estimate of the central value of the noise.

For echo return loss (ERL), measurements, the test signal is obtained by passing a wideband noise source signal through a bandpass filter network meeting the requirements given in Table D.

TABLE D
ERL Filter Response

Frequency Hz	Loss* dB	Tolerance dB
≤ 200	≥ 30	—
300	21.8	± 2.3
560	3	± 0.4
750	0.2	± 0.2
1000	0	± 0.1
1500	0.1	± 0.2
1965	3	± 0.4
2400	10.9	± 1.2
3000	22.9	± 3.0
4000	42.6	± 5.0
≥ 5000	≥ 45	—

* Excluding any flat insertion loss.

For low frequency singing return loss (SRL) measurements, the test signal is obtained by passing a wideband noise source signal through a bandpass filter network meeting the requirements given in Table E.

TABLE E
SRL Filter Response

Frequency Hz	Loss* dB	Tolerance dB
< 100	> 20	—
120	20	—
200	9.5	± 1.1
260	3	± 0.5
360	0	± 0.2
500	3	± 0.5
650	10	± 1.2
1000	20	—
> 1200	> 20	—

* Excluding any flat insertion loss.

For high frequency singing return loss (SRL HI) measurements, the test signal is obtained by passing a wideband noise source signal through a bandpass filter network meeting the requirements given in Table F.

TABLE F
SRL HI Filter Response

Frequency Hz	Loss* dB	Tolerance dB
< 1000	> 30	—
1300	30	—
2000	11.5	± 1.3
2200	3	± 0.5
2700	0	± 0.2
3400	3	± 0.5
3700	10.9	± 1.3
5700	30	—
> 6000	> 30	—

* Excluding any flat insertion loss.

- (b) **Output Level:** To avoid both system overload and background noise, the output level for ERL, SRL, or SRL HI shall be in the range of -2 dBm to -10 dBm, as measured into a 600 ohm resistive termination, with -10 dBm the preferred value.
- (c) **Level Stability:** The transmitter and receiver when used together must meet the accuracy objective of ± 0.5 dB for the periodic recalibration interval specified by the manufacturer. The allocation of drift to transmitter or receiver is the decision of the manufacturer.
- (d) **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 or for the sinusoidal output if an EXTERNAL OSCILLATOR jack is provided.
- (e) **Accuracy and Range:** The overall accuracy shall be ± 0.5 dB or better over a range of 0 to 50 dB return loss.
- (f) **Flatness:** The detector shall be flat to 0.5 dB from 200 Hz to 5000 Hz.
- (g) **Measurement Averaging Time:** The response time for the detector and indicating means shall meet the following limits: Apply gated bursts of 1000 Hz tone to the input of the set gated at a duty cycle of 50 percent, half of the cycle at full amplitude and the other half 8.4 dB down from full amplitude. The levels should be chosen so as to avoid autoranging points, if any.

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

TABLE G

<u>Gating Frequency</u>	<u>Peak-to-Peak Indicator Variation</u>
1.5 Hz	Not more than 1 dB
0.3 Hz	Not less than 3 dB

- (h) **Test Hybrid Standard Impedances:** The return loss of a 2-wire circuit is

measured by comparison with a standard impedance. Nominal standard impedances ('quiet' termination) for Bell System circuits are 600 or 900 (± 1 percent) ohms in series with 2.16 (± 1 percent) μ F. Under certain circumstances, such as cable acceptance testing, neither of the two standard impedances is appropriate for the measurement. In these cases, means for connecting an external standard impedance shall be provided.

- (i) **Test Hybrid Loss:** Return loss measurements on 2-wire circuits require the use of a hybrid in the testing arrangement. The transhybrid loss must be sufficiently high to have little effect on the actual measurement. This loss can be checked as follows:

With the line terminals open circuited or short circuited, the return loss on the 2W-900 ohm position shall be 0 dB ± 0.5 dB. With the line input terminated in 900 ohms (± 1 percent), the return losses shall be within ± 0.4 dB of the following values:

ERL	28.3 dB
SRL	18.9 dB
SRL HI	36.6 dB

- (j) **Meter Display:** If a meter is used as the display device, it must have at least a 10 dB display range with 0.5 dB markings.
- (k) **60 Hz Loss:** To minimize the effects of power line hum, at least 20 dB of loss at 60 Hz shall be provided with less than .5 dB loss at 200 Hz.
- (l) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. This section also gives the requirements for longitudinal balance (LB) as a function of frequency, f_L , of longitudinal noise. An audio oscillator (M) should be connected to terminals 3 and 4 to provide a metallic signal of frequency f_M and level M dBm. Another oscillator (L) should be connected to terminals 5 and 6 to provide a longitudinal signal of frequency f_L and level L dBm. Set the frequency f

within the range of the test set and vary f_L so that there is no harmonic relationship with f_M . The return loss reading with no longitudinal voltage applied should be within 1 dB of the return loss reading with an applied longitudinal voltage of

$$L = M + LB - 6 \text{ dBm.}$$

3.6 Phase Jitter

Phase jitter measurements indicate the cumulative effect of incidental phase modulation and additive tones or noise on the zero crossings of a holding tone. The peak-to-peak deviations in zero crossings of the received signal are detected after band limiting to reduce the effect of additive noise.

For the Bell System, holding tones from 1002 Hz to 1020 Hz are employed, with the eventual standard being a 1004.0 Hz, crystal-controlled oscillator. Incorrect low phase jitter readings will result if a 1000 Hz carrier is employed on a PCM system with a 8000 Hz sampling rate. C-Notched noise measurements should always be made in conjunction with phase jitter measurement to assure that additive noise is not the chief contributor to the phase jitter measurement.

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 demand for an option which permits testing in this range with equal frequency weighting from 4 Hz to 20 Hz. The requirements below would apply with the exception of appropriate scaling in e, f, and k.

For a system maintenance standpoint, it would be desirable to have a test set which could distinguish between incidental phase modulation and additive noise, but the requirements for such a set are not covered by these guidelines.

- (a) **Accuracy:** The displayed reading shall be accurate to ± 5 percent of the indicated value plus ± 0.2 degrees.
- (b) **Level Range:** The set shall accommodate input signal levels from -40 to $+10$ dBm.

- (c) **Frequency Range:** The set shall accommodate input frequencies from 990 Hz to 1030 Hz. If the set can accommodate other carrier frequencies, it should give some indication when that carrier is outside the range of 990 Hz to 1030 Hz.
- (d) **Display Range:** The set should be capable of displaying phase jitter readings from 0.0° to at least 25° .
- (e) **Noise Rejection:** A 3.5 kHz bandlimited white noise signal down 30 dB from a 1000 Hz sine wave carrier shall indicate less than 4 degrees p-p jitter. When a limiter is used in the detection process, this requirement typically dictates a bandpass filter in front of the limiter.
- (f) **Frequency Weighting:** After demodulation, the signal should be weighted such that jitter components in the range of 20 Hz to 300 Hz around the carrier are given full weighting. The weighting characteristic may be measured by applying a pure 1000 Hz tone at a $+10$ dBm level as the carrier and a second pure tone 20 dB lower in level as a source of phase jitter. The table below gives the required phase jitter readings as a function of the difference frequency between the two tones.

TABLE H

Difference Frequency Hz	Phase Jitter Degrees
2	Less than 1
5	Less than 3
10	Less than 8
20—240	11.5 ± 0.7
300	10 to 12.2
500	Less than 3
700	Less than 1

- (g) **Level-to-Phase Conversions:** With the test setup as in the previous test and the second tone at 1100 Hz, flat loss in 10 dB steps up to 50 dB should be inserted by means of an external attenuator. The spread of the readings should not exceed 0.7 degree. All of the

requirements in Table F should also be met at any of the flat loss settings up to 50 dB.

- (h) **Single Frequency Interference:** Apply a 1000 Hz tone to the input of the set at a 0 dBm level. Apply a second tone down 20 dB in level and vary its frequency. For frequencies below 500 Hz, the displayed reading shall be less than 1 degree. For frequencies between 1500 Hz and 4000 Hz, the displayed reading shall be less than 3 degrees. For frequencies above 4000 Hz the displayed reading shall be less than 0.5 degree.
- (i) **Amplitude-to-Phase Conversion:** Apply a 10 percent amplitude-modulated 1000 Hz 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 degree.
- (j) **Measurement Averaging Time:** The detector and indicating circuits should have response averaging time characteristics as follows: apply a gated sine wave phase modulation on a steady 1000 Hz carrier to the test set. The modulation signal should be gated at a duty cycle of 50 percent. The indicator should show a variation as in Table I.

TABLE I

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

- (k) **Peak Detector:** The peak detector should measure white noise at the 2.58σ (99 percent) point. A test for quality of peak detection is as follows:
 - (1) Apply a 0 dBm, 1000 Hz carrier tone to the input of the set along with a second tone A at 1100 Hz which is adjusted in level so as to produce a phase jitter reading of exactly 10.0 degrees.

- (2) Remove tone A and add a third tone B at 1170 Hz which is adjusted in level so as to produce a phase jitter reading of exactly 10.0 degrees.
- (3) Add tone A to the carrier plus tone B without any further adjustments in level. The phase jitter reading shall lie between 18.5 and 19.8 degrees.

- (l) **Time to Display Correct Reading:** The display shall be within 0.7 degree of the final reading in f, at a difference frequency of 100 Hz, within 4 seconds of application of the complete test signal. This speed of response permits accurate readings using a widely available Bell System 1000 Hz tone source which has 9 seconds ON, 1 second OFF duty cycle.
- (m) **Demodulated Carrier:** If the set employs a phase-lock loop, the demodulated carrier from the phase-locked loop should be made available for measurement of frequency offset over the facility. This carrier is free from the interfering effects of noise on the facility.
- (n) **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 cause of jitter.
- (o) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. This section also lists the longitudinal balance (LB) requirements as a function of the frequency, f_L , of the longitudinal noise. Connect a 1000 Hz oscillator and a 1100 Hz oscillator to terminals 3 and 4. Set the 1000 Hz oscillator to provide a level of M dBm and the level of the 1100 Hz oscillator lower in level so as to produce a 10 degree phase jitter reading on the meter. Connect another oscillator (L) to terminals 5 and 6 to act as a source of longitudinal noise of frequency f_L and level of L dBm.

The 10 degree phase jitter reading shall vary by less than one degree when oscillator (L) is connected with an output power of

$$L = M + LB - 41 \text{ dBm}$$

Example: Adjust the 1000 Hz oscillator to provide a level of -4 dBm. Choosing f_L in the sensitive range of 700 Hz to 1300 Hz then

$$L = -4 + 50 - 41 = +5 \text{ dBm}$$

3.7 Intermodulation (Nonlinear) Distortion

In the past, nonlinear distortion has been measured by applying a single-frequency tone to one end of a circuit and measuring the second and third-order products with a selective voltmeter or spectrum analyzer. However, this type of measurement does not properly characterize the intermodulation distortion of most telecommunications channels. See PUB 41008 for a discussion of this subject.

The new test signal consists of four equal-level tones. Two of the tones are 6 Hz apart centered at 860 Hz and two are 16 Hz apart centered at 1380 Hz. The total power of the six third-order intermodulation products in a narrow band centered at 1900 Hz is measured and expressed in dB below the received signal. The power of the four second-order intermodulation products in a narrow band centered at 520 Hz is measured as is the power of the four second-order intermodulation products in a narrow band centered at 2240 Hz. These two second-order distortion powers are then averaged and the results expressed in dB below the received signal.

Transmitter

- (a) **Level Accuracy:** The signal output level shall be accurate within ± 1 dB.
- (b) **Level Range:** The output level range shall be at least 0 to -40 dBm. Attenuator increments of 1 dB shall be provided unless a receiver is part of the test set, in which case a vernier is acceptable.

- (c) **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 equal level within ± 0.25 dB. Existing sets with an upper tone pair spacing of 11 Hz produce identical measurements but preclude more rapid receiver response times.
- (d) **Harmonic Distortion:** Any harmonic of any of the four tones shall be at least 35 dB below the tone.
- (e) **Background Interference:** Any noise, distortion or interference falling in the three distortion filter passbands of the receiver as specified below in k, shall be at least 70 dB below the signal. (Long-term objective: 90 dB below signal.)
- (f) **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.
- (g) **Signal-to-Noise Check:** A front panel switch 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.

Receiver

- (h) **Accuracy:** The measurements shall be accurate to within ± 1 dB.
- (i) **Input Level Range:** The receiver shall meet the accuracy and measurement range requirements for an input power range of 0 to -40 dBm.
- (j) **Measurement and Display Range:** The test set shall be capable of measuring and displaying the measurement of second and third-order products from 10 to 55 dB below the signal. (Long-term objective: 10 to 70 dB)

below signal for second-order distortion and 10 to 75 dB below signal for third-order distortion. This wider measurement range is necessary only over the input level range of -5 to -25 dBm.)

- (k) **Filter Specifications:** The six third-order products to be measured fall in the range 1877 to 1923 Hz. The lower 4 second-order products in the range 503 to 537 Hz and the 4 upper second-order products in the range 2223 to 2257 Hz. (This allows for channel frequency offset and transmit signal frequency drift.)

Filters used to recover the products must be wide enough to measure the total power within the overall accuracy requirement of ± 1 dB and must be narrow enough to reject out-of-band noise. The filter bandwidths may be checked by adding a -40 dBm, 3500 Hz band-limited white noise signal to the input of the set in addition to the four-tone signal at -10 dBm. The second and third-order intermodulation products displayed must each be down at least 46 dB.

- (l) **Response to Spurious Tones:** With a spurious tone 15 dB below the total signal power, the second and third-order measurements shall be 55 dB or more below the signal. The requirement shall be met for spurious tones from 50 to 4000 Hz, but not including the frequencies within 300 Hz of 520, 1900, or 2240 Hz. At 60 and 180 Hz the rejection must be at least 25 dB greater than the above requirement.
- (m) **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 Section 3.2 d.
- (n) **Display Response Time:** The instrument shall indicate within 1 dB of the final indication within 10 seconds of the application of a test signal. Four seconds may become the standard.

- (o) **Crosstalk with Transmitter:** Terminate the transmitter of the first test set in 600 ohms and set it to its highest output power. The receiver of this first set shall meet overall accuracy requirements when the received test signal from a second transmitter is 40 dB below the terminated transmitter power of the first transmitter.

- (p) **Self-Check Capability:** A self-contained means should be provided for determining that the receiver is calibrated within ± 1 dB for second and third-order distortions.

- (q) **Loss of Transmitted Signal:** An indication shall be provided for loss of transmitted signal.

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

- (s) **Correction for S/N:** If the observed S/N check reading is X dB greater than the observed distortion reading, then the correct distortion reading is

$$-10 \log [1 - 10^{-.1X}] \text{ dB}$$

greater than the observed reading. The operating instructions shall include this correction curve (see Figure 19 of PUB 41008) or a correction table, unless the test set automatically includes this correction in the observed reading after the S/N Check transmission.

- (t) **Spurious Tone Monitor:** A means should be provided for determining that a spurious tone or noise equal to or greater than the test tone is being received.

- (u) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. Connect an intermodulation distortion transmitter to terminals 3 and 4 to provide a metallic source of level M dBm. Either an oscillator or a 3.5 kHz band-limited white noise generator will be connected to terminals 5 and 6 to provide a longitudinal signal of level L dBm. The oscillator will be used at test frequencies above 4000 Hz or at 60 Hz

with the longitudinal balance (LB) requirements as specified in Section 5.10 b. The longitudinal balance (LB) requirement for the noise source is $LB = 50$ dB.

The second and third-order intermodulation distortion readings displayed should be more than $M - L + LB + 17$ dB.

Example: For the metallic signal $M = -15$ dBm and the longitudinal noise from the noise source at $+10$ dBm, the distortion readings should be above $-15 - 10 + 50 + 17 = 42$ dB.

3.8 P/AR Rating

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 through the system, and each pulse is dispersed by the distortions it encounters. The P/AR receiver measures the absolute peak and full-wave rectified average values of the pulse train and displays their ratio on a zero-suppressed scale. This ratio serves as the basis for the P/AR rating, ie,

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

where

$E(\text{peak})$ = normalized absolute peak value of the pulse train
 $E(\text{fwa})$ = normalized full-wave rectified average 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

$$f_n = (2n-1) 125 + 15.625 \text{ Hz}$$

with $n = 1, 2, \dots, 16$

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.

Transmitter

- (a) **P/AR Line Spectrum:** The relative magnitude and phase of each spectral component of the P/AR line spectrum shall be as specified in the Table J.
- (b) **Line Spectrum Distortion:** All other spurious frequencies up to 4000 Hz from the transmitter must be at least 50 dB below the power of the reference component at 1890.625 Hz, and 40 dB down above 4000 Hz.
- (c) **Line Signal Stability:** The period of the line signal is 64.0 milliseconds, and shall be accurate to ± 0.1 percent.
- (d) **Output Level Range:** The output level shall have a range of at least 0 dBm (true rms) to -40 dBm (true rms).
- (e) **Output Level Resolution:** The output level shall be adjustable in 1 dB increments.

Receiver

- (f) **Accuracy:** The measurement accuracy shall be ± 2 P/AR units for P/AR readings from 30 to 110, and ± 4 P/AR units outside this range.
- (g) **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 unit.
- (h) **Range:** The receiver shall have a P/AR display range of at least 0 to 120 P/AR units.
- (i) **Resolution:** The receiver shall have a P/AR display resolution of 1 P/AR unit.
- (j) **Input Level Range:** The P/AR system shall meet the accuracy requirements over a true rms input level range of 0 to -40 dBm.
- (k) **Turnover:** The P/AR system shall meet accuracy requirements if the input leads are interchanged.
- (l) **Receive Filter:** The received pulse train shall be shaped by only a fourth-order bandpass filter prior to detection. The filter shall consist of two second-order bandpass filters each having a center frequency of 1300.00 Hz and a Q of 2.00 connected in cascade. The Q of the filters in cascade is 3.108. The receiver shaping filter reduces the effects of power-line frequency interference, and spurious high frequency interference.

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 the Table J. The acceptable spectrum tolerances are specified in Table K.

TABLE K

Frequency	Line Spectrum Tolerance		Test Spectrum Tolerance	
	Level (\pm DB)	Phase (\pm DEG)	Level (\pm DB)	Phase (\pm DEG)
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

TABLE J

Frequency HZ	Line Spectrum		Receiver		Test Spectrum	
	Magnitude DB	Phase DEG	Loss DB	Phase DEG	Magnitude DB	Phase DEG
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
1140.625	-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
2390.625	-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

- (m) **Detectors:** The P/AR receiver shall utilize a full-wave rectified average detector and an absolute peak detector.
- (n) **Display Response Time:** The P/AR equipment shall indicate within one unit of the final indication in less than 5 seconds after the input signal is applied to the receiver, or within 3 seconds after a 10-unit drop in the P/AR value of a test circuit.
- (o) **Out-of-Range Indication:** The P/AR equipment shall indicate when the received level is above or below its permissible range.
- (p) **Self-Check Capability:** A self-contained means should be provided for determining that the P/AR system is properly calibrated.
- (q) **Crosstalk:** If the test set has a P/AR transmitter in the same case, terminate the transmitter in 600 ohms 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 can differ by a maximum of one P/AR unit.
- (r) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. Connect a P/AR transmitter to terminals 3 and 4 to provide a metallic signal of level M dBm. Either an oscillator or a 3.5 kHz band-limited white noise source will be connected to terminals 5 and 6 to provide longitudinal noise of power L dBm. The oscillator will be used to test at frequencies above 4000 Hz or at 60 Hz with the longitudinal balance requirements as detailed in Section 5.10 b. The longitudinal balance (LB) requirement for the noise source is $LB = 50$ dB.

The P/AR reading shown on the test set with no longitudinal voltage applied should be within 3 P/AR units of the P/AR reading with an applied longitudinal voltage of

$$L = M + LB - 30 \text{ dBm.}$$

Example: For a P/AR level of -35 dBm and a 60 Hz longitudinal noise source

$$L = -35 + 80 - 30 = +25 \text{ dBm}$$

3.9 Phase Hits, Gain Hits, and Dropouts

These phenomena can be classified as abrupt changes in the phase or amplitude of a received sinusoidal wave which occur so infrequently, or exist for such short periods of time, that they cannot be properly assessed by any of the other measurement of techniques described in this publication.

If a set measures impulse noise as well as hits, then the counting thresholds for each of these transient phenomena should be set at a level which just causes data modem errors. For this condition, surveys of Bell System facilities have shown that dropouts occur less frequently than gain or phase hits, which in turn occur less often than impulse noise. Test show, however, that each dropout causes more data modem errors than each gain or phase hit, which in turn causes more errors than an impulse.

The time constants for agc and phase lock loops specified below roughly approximate those found in many high speed data modems. Other aspects of hit measurement such as post-detection filtering are still under investigation.

Common Requirements

- (a) **Holding Tone:** The measuring set should accept holding tone frequencies between 995 Hz and 1025 Hz with levels within the range of 0 dBm to -40 dBm. If the set can accept other holding tone frequencies, it should give some clear indication that the tone is outside the recommended 995 Hz to 1025 Hz range.
- (b) **Counting Rate:** The maximum counting rate for any of these phenomena shall be 7 counts per second, which shall be accomplished by means of a blanking period of appropriate length after each of the phenomena. There shall be no sharing of such blanking period timers between counters.
- (c) **Turnover:** Interchange of the input leads shall not degrade the accuracy requirements listed below.

(d) **Timer:** A timer accurate to ± 5 percent shall be provided for the convenience of the tester. Periods of 5 minutes, 15 minutes and continuous should be provided under switch control if the timer is not continuously adjustable.

(e) **Counting Hierarchy:** For sets which count dropouts and at least one other type of transient phenomena, the occurrence of a dropout shall block the detection or counting of hits or impulse noise for one-seventh of a second or until the holding tone returns, whichever is longer. The occurrence of a gain or phase hit should block the detection or counting of impulse noise for one-seventh of a second.

Gain and phase hits can occur simultaneously, as in a switch to a protection channel, so these hits should not block one another. An impulse occurring at the start of, or during the guard interval for hit or dropout detection should not be counted if the hit or dropout is counted.

Phase Hits

(f) **Accuracy:** The accuracy of the threshold setting shall be ± 5 percent of the threshold setting plus $\pm .2$ degrees for phase changes occurring in less than 0.2 milliseconds.

(g) **Threshold Settings:** Threshold settings from 10° to at least 45° in 5-degree steps shall be provided.

(h) **Guard Interval:** A guard interval of 4 milliseconds ± 10 percent shall be provided. A phase hit exceeding a threshold by 5 degrees shall not be counted if the holding tone returns to its original phase at any time within 3.6 milliseconds, and shall be counted if the tone returns to its original phase any time after 4.4 milliseconds.

(i) **Loop Recovery Time:** The phase of the test tone should be linearly varied over 100 degrees over a period defined as the rise time. The hit counter shall record a 20° phase hit for this condition if the rise time is 20 milliseconds and no 20° phase

hit if the rise time is 50 milliseconds. The hit counter shall meet this same requirement for a 100 degree phase change of opposite polarity.

(j) **Amplitude to Phase Conversion:** A 10 dB gain hit shall not cause a phase hit to be counted at a 10° threshold.

(k) **Loss of Holding Tone:** If the set does not have a dropout counter, then if holding tone is instantly lost, or instantly lost and replaced by a 3.5 kHz band-limited white noise signal of equal level, no phase hit shall be recorded. There shall also be a maximum of one phase hit recorded with the instantaneous return of the holding tone at the same level.

(l) **Count Capacity:** A register capacity of at least 999 counts is required.

Gain Hits

(m) **Accuracy:** The threshold setting accuracy shall be ± 0.5 dB for a positive or negative gain change occurring in less than 0.2 milliseconds.

(n) **Threshold Settings:** Threshold settings of 2, 3 and 6 dB shall be provided with 4, 8, and 10 dB as possible options.

(o) **Guard Interval:** A guard interval of 4 milliseconds ± 10 percent shall be provided. A gain hit exceeding a threshold by 1 dB shall not be counted if the holding tone returns to its original value within 3.6 milliseconds, and shall be counted if the tone returns to its original level any time after 4.4 milliseconds.

(p) **Loop Recovery Time:** The amplitude of the test tone should be linearly varied over 4 dB over a period defined as the rise time. The hit counter shall record a 2 dB gain hit for this condition if the rise time is 200 milliseconds and shall not record a 2 dB gain hit if the rise time is 600 milliseconds. The hit counter shall meet this same requirement for a 4 dB gain change of opposite polarity.

- (q) **Loss Holding Tone:** For sets without a dropout counter, if holding tone is instantly lost, or instantly lost and replaced by a 3.5 kHz, band-limited white noise signal of equal level, a gain hit shall be recorded. There shall be no gain hit recorded with the instantaneous return of holding tone at the same level.
- (r) **Count Capacity:** A register capacity of at least 999 counts is required.

Dropouts

- (s) **Accuracy:** A negative gain hit of 12 dB or greater lasting for 4 milliseconds or more is defined as a dropout. The dropout level threshold should be accurate to ± 1 dB.
- (t) **Threshold Setting:** The set should measure the received holding tone level at the start of the timing period and establish a dropout threshold 12 dB below this level, which will then remain fixed for the remainder of the measuring period.
- (u) **Guard Interval:** The holding tone must stay below the 12 dB threshold for at least 4 milliseconds ± 10 percent to be registered.
- (v) **Loss of Holding Tone:** If the holding tone decreases instantly by more than 13 dB and then after 5 milliseconds, returns to its original level instantly, one dropout shall be recorded, even if 3.5 kHz band-limited white noise with a level equal to the original holding tone level is added during the 5 milliseconds.
- (w) **Count Capacity:** A register capacity of at least 99 counts is required.

3.10 Oscillators, Sine Wave

The variable-frequency sine wave oscillator is distinguished in this section from the source of holding tone for measurements such as noise-with-tone and phase jitter. There are certain common requirements for both oscillators.

Common Requirements

- (a) **Output Level:** The output level should be switchable in 1 dB steps from +10 dBm to -40 dBm accurate to ± 0.2

dBm. A 1 dB vernier should be provided. A continuously variable level control over the +10 to -40 dBm range is acceptable if there is a convenient means for monitoring level in the same test set.

- (b) **Frequency Stability:** The frequency should not deviate by more than 0.1 percent per hour after an initial warm-up of 5 minutes.
- (c) **Level Stability:** The level should not vary by more than 0.05 dB per hour after an initial warm-up of 5 minutes.
- (d) **Total Distortion:** The total harmonic distortion plus noise, as measured on a distortion analyzer which eliminates only the fundamental tone should meet the requirements of Table L. The bandwidth of the noise and distortion presented to the distortion analyzer may be reduced as shown in Table L by means of a low-distortion, low-pass filter between the oscillator and the distortion analyzer.

TABLE L

Frequency f_0 in Hz	3 dB Bandwidth in Hz	Distortion Requirement in dB
100 - 1100	4000	≥ 50
1200 - 3000	$4xf_0$	≥ 50
>3000	$4xf_0$	≥ 40

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

- (e) **Background Noise:** If oscillator levels below -40 dBm, are possible, the distortion requirements in the previous section may be changed consistent with a noise floor of -90 dBm.

Variable Frequency Oscillators

- (f) **Frequency Accuracy:** The accuracy requirement for the oscillator frequency is a function of the manner in which the frequency is displayed.
 - (1) Pushbutton oscillators shall be accurate to ± 0.4 percent with the frequency vernier, if any, in its detented or zero position.

- (2) Calibrated dial oscillators shall be accurate to ± 3 percent of the indicated setting.
- (3) A tunable oscillator with a frequency counter in the same case shall be tunable to the nearest 1 Hz. The frequency counter should display the frequency to the nearest 1 Hz and be accurate to ± 1 Hz. The counter update rate should be at least 4 updates per second so as to permit convenient frequency adjustment.
- (g) **Frequency Range:** The oscillator shall have a frequency range of at least 50 Hz to 3900 Hz.
- (h) **Flatness:** The output shall be flat to ± 0.2 dB for frequencies between 200 Hz and 15 kHz, and flat to ± 0.5 dB for other tunable frequencies.

Holding Tone Oscillator

Holding tones from 995 Hz to 1025 Hz will be properly attenuated by the 1010 Hz Notch Filter of Figure 2. Holding tone frequencies within 1 Hz of 1000 Hz will cause measurement problems as described in Section 2.3.

- (i) **Frequency Range:** Acceptable frequencies may range from 1002 Hz to 1020 Hz. Care should be exercised that the tone frequency not drift below 1002 Hz as a result of the permissible frequency drift of b.
- (j) **Crystal-Controlled Oscillators:** Crystal-controlled holding tone oscillators must hold the frequency stable to ± 0.05 Hz under all conditions. The Bell System will use 1004.0 Hz crystal-controlled oscillators.
- (k) **Spurious Noise:** The holding tone oscillator should have:
 - (1) 0.2 degree phase jitter or less
 - (2) 0.2 percent 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

As measured with test equipment described in this publication.

3.11 Single Frequency Interference

Single frequency interference is defined as the presence of spurious or interfering tones with a received signal. It can usually be detected by a simple listening test. 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 in the presence of an applied tone is required to detect spurious tones generated as a result of the applied tone. For such interfering tones, an alternate method may be used employing the noise-with-tone measurement technique. A listening test made after the suppression of the holding tone (Section 2.3) will reveal the presence of any tones or harmonic distortion.

For facilities equipped with compandors, a holding tone should be applied to the circuit to condition compandors to their normal operating point. If the presence of single frequency interference is detected by the listening test a further test using a spectrum analyzer as described in the next section is usually necessary to determine the frequency and level of the interfering tone.

3.12 Spectrum Analysis

Spectrum and/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.

If the spectrum or wave analyzer will be directly connected to transmission facilities, then it must meet the requirements of Sections 4, 5 and 6. If it is internal to a test set with other transmission measurement capabilities, or is only to be connected to the auxiliary outputs of a transmission measuring set, then the analyzer must meet the requirements of Sections 4, 5 and 6, with the exception of Sections 5.4 through 5.10.

- (a) **Level Range:** The analyzer must be able to accept inputs from at least +10 dBm to -90 dBm. The voltages corresponding to these levels should also be indicated.
- (b) **Level Accuracy:** The displayed level must be accurate to ± 1 dB for a single tone input.
- (c) **Frequency Range:** The analyzer shall be able to measure frequencies from at least 20 Hz to 50 kHz.
- (d) **Frequency Accuracy:** If the analyzer has a frequency counter, it should be capable of measuring a tone in the filter passband to ± 2 Hz. If the analyzer does not have a frequency counter, it should have a tone output which permits measuring a tone in the filter passband to ± 2 Hz.
- (e) **3 dB Filter Bandwidth:** The analyzer shall have a 10 Hz ± 30 percent bandwidth at the 3 dB points. If optional bandwidths are provided, 3 Hz, 30 Hz, and 100 Hz are suggested.
- (f) **60 dB Filter Bandwidth:** The filter bandwidth at the 60 dB loss points shall be less than 13 times the 3 dB filter bandwidth above.
- (g) **Sweep:** Some provision shall be made for automatic sweep. If a sweep rate may be chosen which is too fast to permit the ± 1 dB level accuracy for the selected filter bandwidth, then there must be some positive indication of this undesirable condition.
- (h) **AFC:** There should be some provision for locking on a tone which drifts slowly in frequency.
- (i) **Overload:** There shall be some clear indication if the total input signal causes an overload condition.
- (j) **Longitudinal Noise:** Directly — connected analyzers shall meet the requirements of Section 3.2 i when f_L is the same as the indicated center frequency of the filter.

3.13 Frequency Counters

If the frequency counter will be directly connected to transmission facilities, it must meet the requirements of Sections 4, 5 and 6 as well as this section. If the frequency counter is internal to a test set with other transmission measurement capabilities, or is only to be connected to the auxiliary outputs of a transmission measuring set, then it must meet the requirements of Sections 4, 5 and 6 with the exception of Sections 5.4 through 5.10.

- (a) **Level:** The counter must be able to accept inputs from +10 dBm to -40 dBm.
- (b) **Frequency Range:** If the counter is part of a larger test set, it should cover the frequency range of that set. If it stands alone, it shall have a range of at least 20 Hz to 50 kHz.
- (c) **Accuracy:** The counter shall be accurate to ± 1 Hz. If the counter is to be used to display frequency shift, it shall display frequencies up to 9 kHz accurate to ± 0.1 Hz.
- (d) **Update Rate:** The counter shall display a new measurement at a rate of once per second, even if it is displaying frequency to the nearest 0.1 Hz. If the counter is frequently used to display the frequency of a manually-tuned oscillator, it shall display a new measurement at a rate of at least 4 times per second.
- (e) **Noise:** The counter shall meet the accuracy requirements in the presence of a 20 dB signal-to-sine wave or a 20 dB signal-to-noise ratio where the white noise band extends below 200 Hz.
- (f) **Longitudinal Noise:** Use the test setup of Figure 5 as described in Section 5.10 b. This section also gives the longitudinal balance (LB) requirements as a function of the frequency, f_L , of the longitudinal noise. An audio oscillator (M) should be connected to terminals 3 and 4 to provide a metallic signal of frequency f_M and level M dBm. Another

oscillator (L) should be connected to terminals 5 and 6 to provide a longitudinal signal of frequency f_L and level L dBm.

The frequency displayed on the test set with no longitudinal voltage applied should be within 1 Hz of the frequency reading with a longitudinal voltage of

$$L = M + LB - 20 \text{ dBm.}$$

Example: For a longitudinal frequency of 60 Hz and metallic signal of -30 dBm,

$$L = -30 + 80 - 20 = +30 \text{ dBm.}$$

3.14 Amplitude Jitter

The extent to which data sets are affected by this parameter is being studied. The amount of amplitude jitter on Bell System facilities is under investigation.

In keeping with standard definitions, the unit for amplitude jitter should be peak percent. The amplitude jitter should be measured with a peak-to-peak detector calibrated in peak percent. The accuracy of the measurement should be ± 0.2 percent plus 0.05 times the indicated reading. The display range should be from 0.2% to at least 20%.

It is suggested that the specifications of the amplitude jitter set mirror those of the phase jitter set described in Section 3.6. An amplitude jitter set with the same circuits or characteristics (level and frequency range, time constants, post-detection frequency weighting, noise rejection, peak detector) as a phase jitter set, would then produce "equivalent" readings for random noise or single-frequency interference. For example, the test of Section 3.6, f should produce a mid-band reading of 10 percent for amplitude jitter and 11.5 degrees for phase jitter.

With a digital display on a set which measures both amplitude and phase jitter, some means should be provided to observe both readings on an "equivalent" basis to check for noise. Such "equivalent" readings would be easily observed on an analog meter with scales for degrees and percent. 11.5 degrees of incidental phase modulation should produce less than 1 percent phase-to-amplitude conversion in an amplitude jitter set.

4. PHYSICAL CHARACTERISTICS OF TEST EQUIPMENT

This section indicates the general physical characteristics or power requirements of voiceband transmission test equipment used for testing Bell System circuits. Construction practices and component selection shall be such as to ensure 20-year life of the equipment.

4.1 Nonoperating Environment

The equipment shall not be damaged by being subjected to the environment of an unpressurized cargo compartment of a commercial jet for a time commensurate with a cross-country flight. The equipment shall be able to operate after being stored at temperatures of -40 to $+75^\circ\text{C}$ at pressures of 30 inches (sea level) to 5.5 inches (40,000 feet) of mercury.

4.2 Operating Environment

The electrical performance objectives given in Section 3 of this document shall be met when operating at temperatures within the range of 0 to 50°C and relative humidity of 10 to 95 percent, unless otherwise stated. Portable equipment stored in vehicles may reach temperatures from -25°C to 70°C , and test equipment capable of immediate use in a 0°C to 50°C ambient after such storage would be desirable.

4.3 Mechanical Shock

Portable test equipment shall be capable of passing a "bench-handling" shock test. To conduct this test, the set shall be placed on a solid horizontal surface and, using one edge as a pivot, shall be tilted so that the opposite edge is 4 inches above the surface or the test set is at an angle of 45 degrees with the horizontal surface, whichever occurs first, and shall be permitted to drop freely to the surface. The set shall be operating in a normal manner during the test. The set shall not be in a shipping package or transit case when the test is performed. The test surface shall be a rigid horizontal surface such as a concrete or heavy wood floor or a hard wood bench top.

This procedure shall be repeated for all edges of the same face as pivots for a total of four drops. This test shall then be conducted on all faces on which an impact test is physically possible. On faces that are equipped with surface protecting

pads, the height shall be measured from the bottom of the pad. Tests shall not be conducted on faces that are equipped with handles, glass parts, control knobs, or other protrusions which might cause stress concentrations.

After the above tests, the equipment shall operate normally without replacement or internal adjustment of parts. Adjustments of external controls are permitted to return the equipment to normal operation. It is desirable, but not essential that rack-mounted equipment also pass this test.

4.4 AC Power

AC powered equipment shall meet the requirements of this publication for 60 Hz power line voltages of 105 to 129 volts. AC powered equipment shall be provided with a power cord of 3-conductor No. 18 AWG flexible cordage equipped at one end with a parallel blade, grounding type polarized plug (cap) in a manner approved by Underwriters' Laboratories, Incorporated. It is desirable that this plug permit connection of another plug at the outlet box. The cord should be at least 7 feet long and for reasons of safety, should be yellow. AC powered equipment shall be fused for fire protection.

4.5 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 are near end-of-life. 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 rack-mounted test equipment is to be powered from the office battery, the equipment shall function with voltages from -44 volts to -52.5 volts with respect to ground.

Short-duration bursts of high-frequency damped oscillations in excess of 30 volt peak-to-peak have been observed on the office battery in some locations in electromechanical offices.

4.6 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 pushbuttons shall be such that their function is clear in both the In and Out position.

4.7 Finish and Markings

The test equipment case shall be protected by a semigloss finish. The texture of the finish shall be free of dirt and grit and should not show objectionable orange peel effect or other unevenness of coverage.

Panel markings shall be permanent, well defined, and legible. Depressed markings shall be obtained by engraving, etching, steel stamping, or other equivalent technique and subsequently filled with a contrasting color. Alternatively, markings may be embedded within a thick organic surface coating and obtained by a screen or other type printing process. The permanence of markings shall be determined as follows:

- (a) **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 the American Society for Testing Materials DOCUMENT ASTM D2197 "Adhesion of Coatings of Paint, Varnish, Lacquer, and Related Products" loaded with a 4000-gram load.
- (b) **Abrasion Resistance:** The markings shall remain legible and there shall be no wear-through to the base after 1000 turns in a Taber Abraser machine. The wheels shall be CS17 Calibrase with 1000-gram load. The abramer wheels shall be properly dressed before each test.
- (c) **Chemical Resistance:** The finish and markings shall be resistant to 1, 1, 1 - trichloroethane when tested at 77°F and 50 percent relative humidity as follows: lightly and uniformly rub a wad of cotton (approximately 1 inch diameter) moistened with the chemical over an area approximately 1 inch by 2 inches for 15 seconds. The cotton shall not be

discolored nor shall the wiped area be discernible from the surrounding area after a 30-minute recovery period.

4.8 Shielding

The test set should have electrical shielding to protect against errors due to stray electric or magnetic fields. This may be accomplished through use of a metal case and panel. If meters are mounted on the metal panel and the test set has a metal case, means shall be provided for grounding this case to the panel.

It might be necessary that the meter be shielded to prevent radiation into or out of the set. This may be accomplished by use of a metal case and dial plate or a built-in shield within the test set case. Metal parts of the meter shall be bonded to one of the terminals of the meter, or to a third (grounded) terminal.

4.9 Rack-Mounted Equipment

If test equipment is rack-mounted, it should conform, or have option brackets which permit it to conform to the mounting dimensions of the appropriate frame. Certain requirements for maximum protrusion in front of or behind the frame must be met. Terminal connections should be of an approved solderless wirewrap type. Western Electric Company should be consulted if information on the above is required. Equipment above or below the rack-mounted test equipment could block convection air currents.

4.10 Portability

To provide easy handling, tests sets should have a single handle placed on the case of the set (not the cover) such that the set may be moved or carried comfortably. The set, plus cover and power cord or batteries should weigh no more than 33 pounds. If the set comes in more than one part, then each part should meet the above requirement and the parts should stack conveniently.

4.11 Identification of Equipment

The name of the test equipment shall appear on the outside of the set, or its cover, so that it may be easily identified while in a storage position.

If a set is modified such that it passes a requirement of this document which it used to

fail, or vice-versa, there should be a clear change in the set designation so as to make its rapid identification possible.

4.12 Safety

The following section specifically prohibits certain conditions which can be hazardous to personnel using the equipment. Hazards not listed such as X-Ray radiation, ultrasonic sound generation, dangerous mechanical configuration, etc, should also be avoided.

- (a) **Hot Surfaces:** External metal surfaces, including those which are painted or covered with thin plastic coatings, exposed to operating personnel must not have an operating temperature rise of more than 70°F over an ambient temperature of 70°F.
- (b) **Grounded Case:** For ac-powered equipment with an external metal case, the case shall be securely connected to frame (green-wire) ground.
- (c) **Leakage Current:** The leakage current from any exposed, ungrounded metal surface of the test set into a 10,000 ohm load to ground shall be less than 0.2 ma for the condition of 110V ac applied to the 110V ac power input and 30V ac applied longitudinally between the balanced input and (green-wire) ground or the balanced output and ground. Auxiliary input or output jacks do not have to meet this requirement.
- (d) **Power Cord Strain Relief:** If the ac power cord is not designed to be disconnected for storage, then a strain relief device shall be provided to mechanically secure the ac cord to the test set.

This strain relief shall be capable of resisting a 35 pound pull at any angle to the surface through which the ac cord enters without displacement of the cord.

5. ELECTRICAL CHARACTERISTICS OF TEST EQUIPMENT

This section indicates the general electrical characteristics of voiceband transmission test equipment. Certain sections apply only if the equipment will be directly connected to the transmission facility.

5.1 Display of Incorrect Results

Care should be exercised in the design of test equipment such that the display of incorrect results is avoided.

- (a) If input ranges can be 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.
- (b) If the presence of a holding tone is necessary for a measurement, its absence shall be clearly indicated.
- (c) 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.
- (d) 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 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.

5.2 Digital Displays

In the past, most test equipment used by the Bell System utilized analog (meter) display arrangements. Recently, however, the use of digital displays has become more prevalent. This section gives some specific requirements for the display device and also discusses the factors which affect the usefulness of the digital display for transmission measurements.

- (a) For measurements (level, frequency) where it is likely that manual adjustments (gain, oscillator frequency) will be made while observing the display, the refresh shall be at least 4 times per second so as to permit convenient adjustments.

- (b) Analog displays (meters) permit convenient estimation of both the peaks and mean value of a noisy signal for such measurements as background noise. No single digital display refresh rate permits convenient display of both peaks and mean value so a compromise refresh rate 2 to 3 times per second is suggested for such measurements. The readability of a noisy signal on a digital display at faster refresh rates is poor.
- (c) The refresh rate or display design should be such that there be no noticeable change in the display for digits that have remained unchanged between refresh intervals.
- (d) The autorange circuits, if any, shall be fast enough that the time to display of the correct reading meets the requirements for the particular measurement, if given, in Section 3, Measurement Techniques.
- (e) Provisions shall be available for checking that all characters can be displayed.
- (f) It is often desirable to have an independent output, such as Binary Coded Decimal (BCD), for obtaining hard copy, telemetry of results, or computer operation.
- (g) If there are multiple entry points into a rack-mounted measuring system, provisions should be made in the display device to indicate the input position being serviced, or alternatively, to indicate the measuring system is busy.
- (h) The point at which a display changes from one number to the next should be at the one-half unit point. The display should go from 1 to 2 at 1.5, for example.

5.3 Analog Displays

If a 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 noise measuring instrument has an input attenuator with 10 dB steps, at least a 10 dB range on the meter must be marked in 1 dB increments.

If the test set has supports or feet suggesting usage in more than one position, the analog meter must be mechanically balanced so as not to degrade the test set accuracy in any of these positions.

5.4 Input and/or Output Impedances

Measurements on balanced voice frequency circuits are ordinarily made on a bridged (high impedance) or a terminated basis. Except as noted below, the requirements apply to either transmitters or receivers.

- (a) **Terminated Impedance:** The impedance of set shall be a nominal 600 or 900 ohms with a return loss of 30 dB over the frequency range of the test set as specified in Section 3 for the measurements the set performs. For test sets with reduced frequency ranges (phase jitter, 700 Hz to 1300 Hz) where the requirement of 30 dB is not met for the range from 200 Hz to 4000 Hz, the user shall be cautioned about the use of the set as a terminating resistance for other measurement sets.
- (b) **Transmitter Impedance:** In the event that a transmitter cannot be tested in the preceding section because its output signal cannot be eliminated, then the return loss can be calculated through knowledge of the test set's impedance. The return loss can be measured using a selective detector as the detector in a bridge circuit. The impedance of the test set, $Z(j\omega) = R(\omega) + jX(\omega)$, is in general, frequency dependent, and can be determined at individual frequencies using the bridge circuit. The formula for the return loss is:

$$RL(\omega) = 10 \log_{10} \frac{[R_T + R(\omega)]^2 + [X(\omega)]^2}{[R_T - R(\omega)]^2 + [X(\omega)]^2} \quad (c)$$

where R_T is the nominal resistance of 600 or 900 ohms, and $R(\omega)$ and $X(\omega)$ are the resistive and reactive parts of $Z(j\omega)$. $RL(\omega)$ should meet the requirements of the preceding section.

- (c) **Bridging Impedance:** The bridging impedance of the set, when connected across a 600-ohm oscillator driving a 600-ohm level measuring set, shall cause less than 0.2 dB loss as observed on the level measuring set. The oscillator frequency should be varied over the frequency range of the test set as specified in Section 3 for the measurements the set performs.
- (d) **Impedance to Ground:** There shall be no dc path from either input or output terminal to ground. The ac impedance from the balanced inputs (when shorted together) to ground shall be greater than 20,000 ohms for frequencies below 4000 Hz, and can decrease at 6 dB per octave above 4000 Hz. Output terminals shall meet this same requirement.

5.5 Line Holding

It may be necessary to hold up certain supervisory relays in the telephone office with a dc hold current in order to maintain transmission over the facility. The requirements below hold for any terminating resistance provided.

- (a) **Passive Holding:** A dc holding resistance of 200 ohms will assure holding wherever a subscriber set would hold.
- (b) **Electronic Holding:** If electronic dc holding is provided, it shall draw a minimum current of 23 milliamperes under the condition of 46 volts of either polarity applied to the input terminals through an external 1700 ohm resistor. The hold circuit should not draw more than 40 milliamperes under the limiting case of 53 volts applied to the input terminals through a 400 ohm resistor.
- (c) **Holding Return Loss:** The addition of dc holding shall not cause the test set to fail the requirements of 5.4 a, with the

exception that the 30 dB requirement may be relaxed by 6 dB per octave below 300 Hz. This requirement shall be met for all dc voltages less than 53 volts fed to the input terminals through a 400 ohm resistor.

- (d) **Effect on Measurements:** The hold circuit of a test set shall not degrade the accuracy of any of the measurements which the test set performs for the case of all dc voltages less than 53 volts fed to the input terminals through a 400 ohm resistor.
- (e) **Dialing:** It is desirable for sets which have holding capability to provide for the convenient connection of a handset with a dial.

5.6 High Voltage Protection

The test set should be protected against high voltages which can occur on the facilities being measured. The test set shall be turned on during these tests, and work properly at their conclusion.

- (a) **Longitudinal Voltages:** The presence of longitudinal voltages of 200 volts rms (dc or ac at 60 Hz) should cause no damage to the measuring set. This requirement may be reduced at 6 dB per octave for frequencies greater than 60 Hz.
- (b) **DC Blocking:** In certain metallic, low-frequency telegraph or alarm loops as much as 260 volts dc may appear across the balanced input terminals. A set which may be used to test this kind of service should have 300 volts dc blocking capability, otherwise the requirement is 150 volts dc blocking.
- (c) **Lightning:** The input circuitry should be capable of withstanding a lightning-created spike which may be simulated by a 600-volt spike having a 10-us rise time and a 1000-us decay time applied through a 6 ohm resistor across the balanced input terminals or from either terminal to ground.

5.7 Effect of Power Line Transients and Radiated Interference on the Equipment

- (a) **Battery-operated Sets:** A battery-operated set shall meet all of its accuracy requirements while an ac-powered electric drill of at least 1/5 horsepower is running continuously within 3 feet 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.
- (b) **AC-powered Sets:** The requirements of a shall be met when the 1/5 horsepower electric drill is plugged in approximately 6 feet from the outlet supplying to the test set.
- (c) **Stacking of Sets:** Test sets of the same type when stacked on top of one another and powered from the same ac outlet shall meet all accuracy requirements 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 should not cause a count.

5.8 Radiation from the Equipment

- (a) So as not to interfere with nearby receivers or other sensitive equipment, the test set shall not exceed the radiation requirements of Table M, when the field strength is measured at a distance of 100 feet from the test set.

TABLE M

Frequency of Radiation in kHz	RMS Field Strength in uV/meter (10 kHz band)
10 – 24	1000
24 – 1600	24000/f (kHz)
above 1600	15

- (b) To permit the use of a voiceband transmission test set as a termination for a paralleled noise measuring set, the power output from the receiver terminals, or from the transmitter terminals when in an XMT OFF position shall be less than 10 dBm with the 3 kHz Flat shaping.

5.9 Longitudinal Balance

All test equipment, inputs or outputs, should have a longitudinal impedance balance of at least 80 dB at 60 Hz and 70 dB at 540 Hz. At other frequencies below 4 kHz, all test equipment inputs or outputs, excluding noise measuring sets, should have a longitudinal balance of at least 50 dB. For frequencies greater than 4 kHz, the longitudinal balance requirement decreases at the rate of 6 dB per octave up to a maximum test frequency which corresponds to the highest stated receiver or transmitter frequency capability.

For noise measuring sets, at frequencies other than 60 Hz or 540 Hz, the longitudinal impedance balance requirement is at least 60 dB below 4 kHz and decreases at a rate of 6 dB per octave above 4 kHz up to a maximum test frequency of 20 kHz.

It is necessary that these requirements be met for longitudinal voltages of at least 30 volts rms at 60 Hz decreasing with an increase of frequency at the rate of 6 dB per octave until a level of 0.78 volts rms is reached at 2300 Hz. This level should then be maintained for higher frequencies.

The test procedure in parts a and b is the IEEE longitudinal impedance balance test proposal to the CCITT for receivers. For transmitters, a modification of this test is described in parts c and d.

- (a) Refer to the test setup shown in Figure 4 for the longitudinal balance test of a receiver. With proper calibration, the test circuit can be made to measure balances in the order of 80 dB. The calibration procedure includes both a capacitor and a resistor calibration.

- (1) Short-circuit terminals 1, 2, and GND to an external ground.

- (2) Adjust the oscillator at L to +20 dBm and a frequency of 60 Hz.
- (3) Adjust R3 so that C is less than -80 dBm. If the responses of C is too sensitivie to a change in R3, R1 and R2 should be more closely matched, permitting a larger R3.
- (4) Change the position of S1 and note C. If C remains less than -80 dBm, then the capacitors have a balance greater than 100 dB.
- (5) If C is greater than -80 dBm, then shunt small values of additional capacitance onto either C1 or C2 and repeat steps (3) and (4) until C remains less than -80 dBm for S1 in either position.
- (6) Remove the short-circuit from terminals 1, 2, and GND and add a 3 ohm potentiometer between terminals 1 and 2 with the center arm connected to GND and the external ground. This small resistance is used to create a known longitudinal imbalance. With the oscillator adjusted to +20 dBm at L at a frequency of 60 Hz, adjust the 3 ohm potentiometer to obtain a reading of -60 dBm at M.
- (7) Without changing the 3 ohm potentiometer, adjust R3 so that an identical reading at M is obtained for switch S1 in either position. The resistors and the entire circuit should have a balance of greater than 100 dB.
- (8) To verify the calibration of the circuit at this point, leave S1 in either position and reverse the connections of the 3 ohm potentiometer at terminals 1 and 2 with the center arm still connected to GND. If the circuit is calibrated and the setting of the potentiometer not disturbed, the voltage M should remain within ± 1 dB. If not, then repeat steps (1) through (8).

- (9) The value of M, with the 3 ohm potentiometer connected to terminals 1 and 2, should remain within 1 dB for a frequency range of the oscillator from 60 Hz to 1000 Hz. Remedies for any of the above problems may include using larger size wire, making sure the wire lengths are equal, twisting the wires, and using lower power factor capacitors.
- (10) As indicated in Figure 4, a high impedance, high longitudinal balance voltmeter is required. Since the voltmeter used in calibrating the capacitors and resistors was bridging very low impedances, the use of a medium impedance, medium longitudinal balance voltmeter would still result in a test circuit having a balance of 100 dB. A quick check of the longitudinal balance of the voltmeter can be accomplished by removing the 3 ohm potentiometer or the short-circuit from terminals 1, 2, and GND and connecting the tip and ring of the voltmeter to terminals 1 and 2. To obtain the best balance when using the voltmeter for any test, use a battery-operated type and isolate the voltmeter by not connecting the voltmeter ground to GND or any external ground. Using the balanced test circuit, the oscillator at 60 Hz to 1000 Hz, L equal to +20 dBm, and S1 in either position, the indication of the meter under test should be less than -80 dBm. This test gives an indication of the balance of the voltmeter only.
- (11) Using the configuration in (10), with the voltmeter still connected, switch S2 can be closed to determine if the dc conditioning circuit affects the test circuit balance. The indication of the voltmeter should also be less than -80 dBm under the same conditions as in (9).

- (b) Assuming that the test circuit in Figure 4 has been calibrated as in part a, the longitudinal balance of the test set can now be found. The requirements were stated in the introduction of this section. These requirements should hold for all permissible levels, frequencies and operating conditions of the test set (such as dc holding current). Note that if the test set is to be tested in the bridging mode, an external terminating impedance must be added equal to the value of the resistance for which the bridging mode is calibrated.

The test procedure is as follows. Connect the tip and ring of the test set to terminals 1 and 2. Connect the test set ground to GND and the external ground. With the oscillator at an appropriate frequency and level, read the value of L and M in dBm. The longitudinal balance of the test set is L - M dB, or if the voltage readings were made where V_L and V_M are the longitudinal and metallic voltages, respectively, the longitudinal balance is

$$LB = 20 \log_{10} \left[\frac{V_L}{V_M} \right]$$

- (c) The longitudinal balance test for a transmitter requires the use of a selective detector instead of the voltmeter to distinguish the converted longitudinal signal, caused by a bad longitudinal balance, from the metallic signal generated by the test set transmitter. If the selective detector has a high longitudinal balance and a high input impedance, the test setup in Figure 4 can be used. The calibration procedure in part a would be followed exactly. Part d describes the test procedure.

If the selective detector has an unacceptable longitudinal balance or input impedance, the test setup shown in Figure 5 can be used. Side D of the transformer T1 should be terminated in 1200 ohms. The calibration procedure is

the same as in part a except for the following modifications. Leave the selective detector disconnected and connect only a 600 ohm resistor to terminals 3 and 4. Also connect a local ground to terminal 4. Proceed as in part a by using the voltmeter described in Figure 5 to calibrate the circuit.

- (d) If the test setup in Figure 4 is to be used for the case of the balanced selective detector, the test procedure of part b is followed with these precautions. To assure that the transmitter does not affect the selective detector measurement, the following test can be made. A 1 dB increase in the signal level output of the test set transmitter should show less than a 0.1 dB change in the level reading on the selective detector. The longitudinal balance test should be made while the transmitter output is at the lowest possible level.

If the test setup in Figure 5 is to be used for the case of the unbalanced selective detector, use the test procedure above (which also includes the part b procedure) with these exceptions. The selective detector is connected to terminals 3 and 4 with a build-out resistance to make the input impedance 600 ohms. The metallic voltage measured, D , will be different from M by the insertion loss of the transformer, L dB. Therefore, the longitudinal balance will be $L-D-I$.

5.10 Effect of Longitudinal Voltages on Measurement Accuracy

The measurement accuracy of test sets should not be affected by the presence of longitudinal voltages except for errors that arise due to balance requirements. It is necessary that this requirement be met for longitudinal voltages of 30 volts rms at 60 Hz decreasing with an increase of frequency at the rate of 6 dB per octave until 2300 Hz where for higher frequencies the level remains at 0.775 volts rms (0 dBm into 600 ohms).

The requirements given in this section should 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 (equal to 600 ohms or other nominal impedance) must be added across terminals 1 and 2.

- (a) To test noise or impulse noise measuring sets, use the circuit in Figure 4 and calibrate it as in part a of Section 5.9. The test procedure and specific requirements for noise or impulse noise sets are included in their respective sections under Section 3, Measurement Techniques. In each requirement, a longitudinal balance, LB , is required in a formula. For noise or impulse noise sets, LB is 80 dB for 60 Hz, 70 dB at 540 Hz, 60 dB for other frequencies below 4 kHz and decreasing at a rate of 6 dB per octave above 4 kHz up to a maximum of 1 MHz.
- (b) For sets requiring a holding tone or received signal for proper operation, use the circuit in Figure 5 and calibrate it as in part c of Section 5.9. The metallic source must have an output impedance of 600 ohms. The metallic source, connected to terminals 3 and 4, may be one of the following:
- (1) Oscillator (M) at a frequency of f_M and a level M dBm measured across terminals 1 and 2.
 - (2) Transmitter (M) compatible with the test set receiver at a level M dBm measured across terminals 1 and 2.
 - (3) Two tone source consisting of oscillators (M_A) and (M_B) at frequencies f_A and f_B , respectively, with their outputs combined through a split pad. The power contribution of each is M_A and M_B dBm measured across terminals 1 and 2.

The longitudinal source, connected to terminals 5 and 6, may be one of the following: (The source output impedance is not important.)

- (4) Oscillator at a frequency of f_L and a level L dBm.
- (5) Gaussian noise source with a bandwidth of 100 Hz to 3500 Hz at the dB points and decreasing 12 dB per octave outside those points. Noise source has a level of L dBm.

The test procedure and specific requirements for measuring sets other than noise and impulse noise measuring sets are included in their respective sections under Section 3, Measurement Techniques. In most requirements, the longitudinal balance, LB, required is 80 dB at 60 Hz, 70 dB at 540 Hz, 50 dB for other frequencies below 4 kHz, and decreases at a rate of 6 dB per octave above 4 kHz up to a maximum of 1 MHz.

5.11 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 starting at 10 kHz and having more than 60 dB loss at all frequencies above 500 kHz shall be provided, except if this filter would interfere with measurement accuracy. For this case, a filter rolling off at 12 dB octave shall be provided at as low a frequency as is practical.

5.12 Tone Sweeping Capabilities

- (a) **Resolution:** In test sets that provide an automatic frequency sweep of the loss or delay signal, a sweep rate should be provided which permits reading the maxima and minima of a transmission characteristic to the stated accuracy of the set on the normal output display (meter or digital readout, for example). In particular, an observed point-by-point characteristic of a narrow (300 Hz) 2 dB loss bump, or 100 us delay bump, should agree with the sweep characteristic within 0.2 dB or 10 us. If alternate means

of display such as X-Y plotters are considered, then slower or variable triangular sweeps should be provided. The plot may then be examined for hysteresis which would be indicative of a frequency sweep rate too rapid for the plotter.

- (b) **SF Skip:** Since many of the transmission facilities to be measured may employ 2600 Hz SF (single frequency) signaling, care must be exercised in the use of tone sweeping features. On circuits employing SF signaling, transmission of signals between 2450 Hz and 2750 Hz should usually be avoided in order to prevent the connection from being disconnected.
- (c) **Echo Suppressor:** Switched connections in excess of 1500 miles normally employ echo suppressors. For full-duplex operation, these suppressors can be disabled by the application of at least 750 ms of tone between 2000 Hz and 2300 Hz. Once disabled, the echo suppressor will be held disabled by the presence of any signal between 800 Hz and 2800 Hz provided any interruptions in the signal are less than 50 ms in duration.
- (d) **4 kHz Pilots:** If a sweeping tone is to be used on N3 carrier facilities, the baseband sweep should stop at 3980 Hz maximum so as to prevent interference with the 4 kHz pilot tones.

5.13 Four-Wire Operation

If a test set can both transmit and receive test signals for a measurement, and has two sets of balanced terminals, it shall be capable of simultaneously transmitting and performing the measurement.

6. MISCELLANEOUS

6.1 Instruction Material

Instruction material to ensure satisfactory operation and maintenance should include:

- (a) Picture or line drawing of the front panel.
- (b) Complete performance specifications.

- (c) Detailed instructions on operation.
- (d) Theory of operation with block diagrams.
- (e) Schematic diagram, including typical voltages and waveforms.
- (f) Parts list, including manufacturer's name and part ordering information.
- (g) Part locating diagrams, including terminal identification of all multiterminal devices.
- (h) Printed wiring board component and path locating diagrams.
- (i) Routine maintenance and calibration procedures.
- (j) Troubleshooting procedures.
- (k) Minor repair procedures.

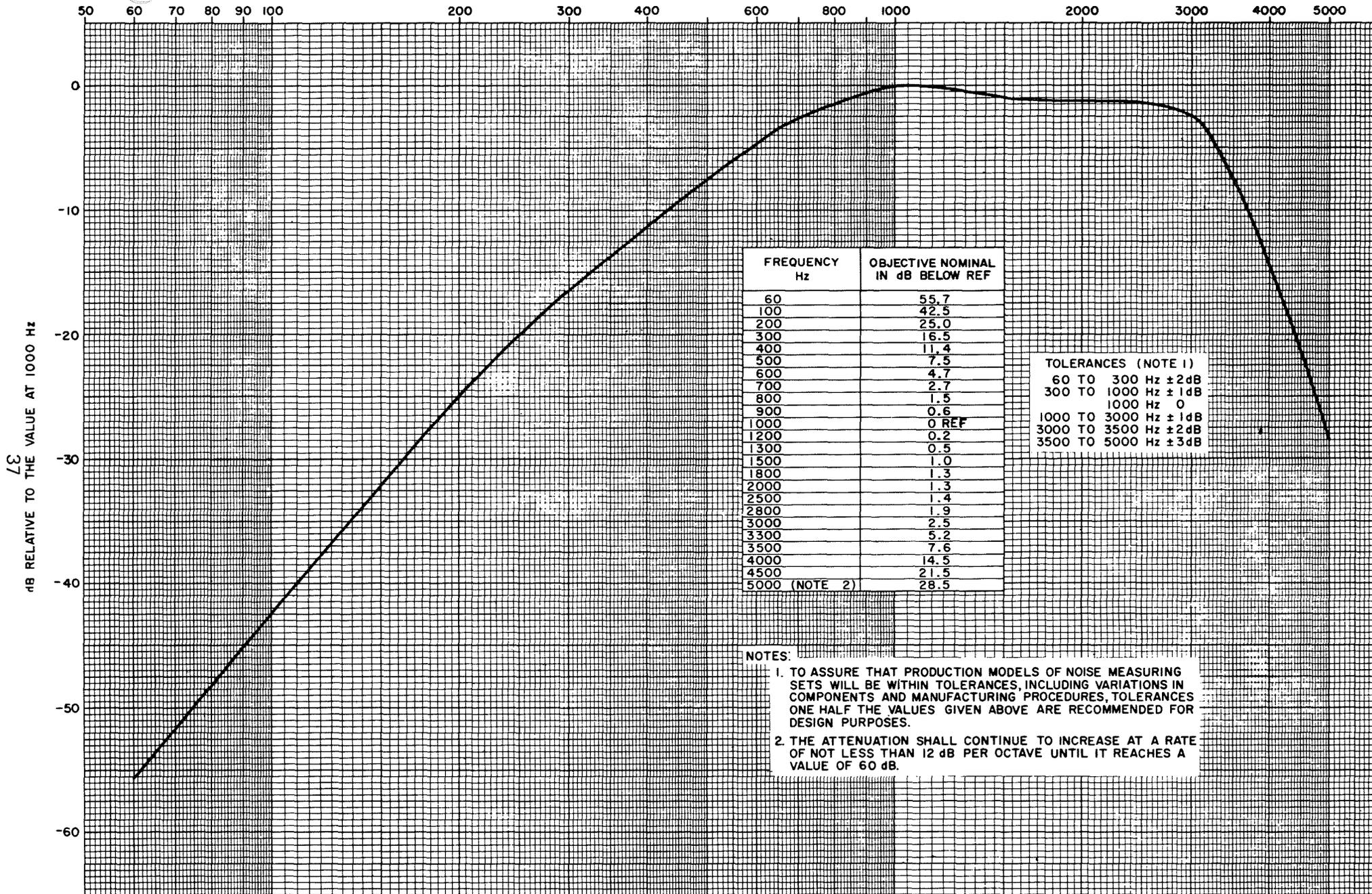
6.2 Ease of Use

In addition to desirable features mentioned earlier, headphone or loudspeaker monitoring of

the received signal is helpful. Detected signal outputs for plotters are frequently useful. Internal provisions for calibration or verification that the set is working properly build confidence in 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:

- (a) Confusing instruction material.
- (b) Interactive front panel controls.
- (c) Ambiguous switch designations.
- (d) Proliferation of controls or calibrations.
- (e) Handle not over center of gravity of set.
- (f) Small readouts or designations.
- (g) Noisy fan.
- (h) Loose, but necessary, accessories without provisions for storage.



C MESSAGE WEIGHTING CHARACTERISTIC

FIGURE 1

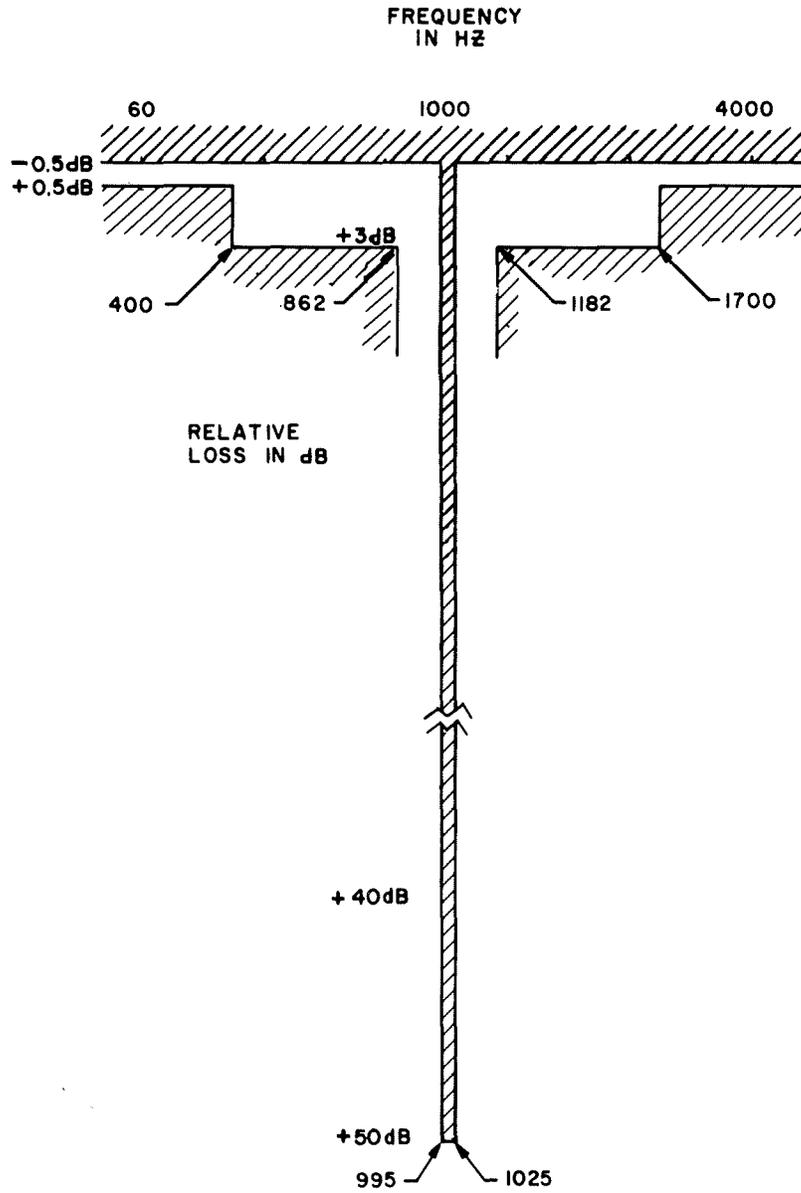
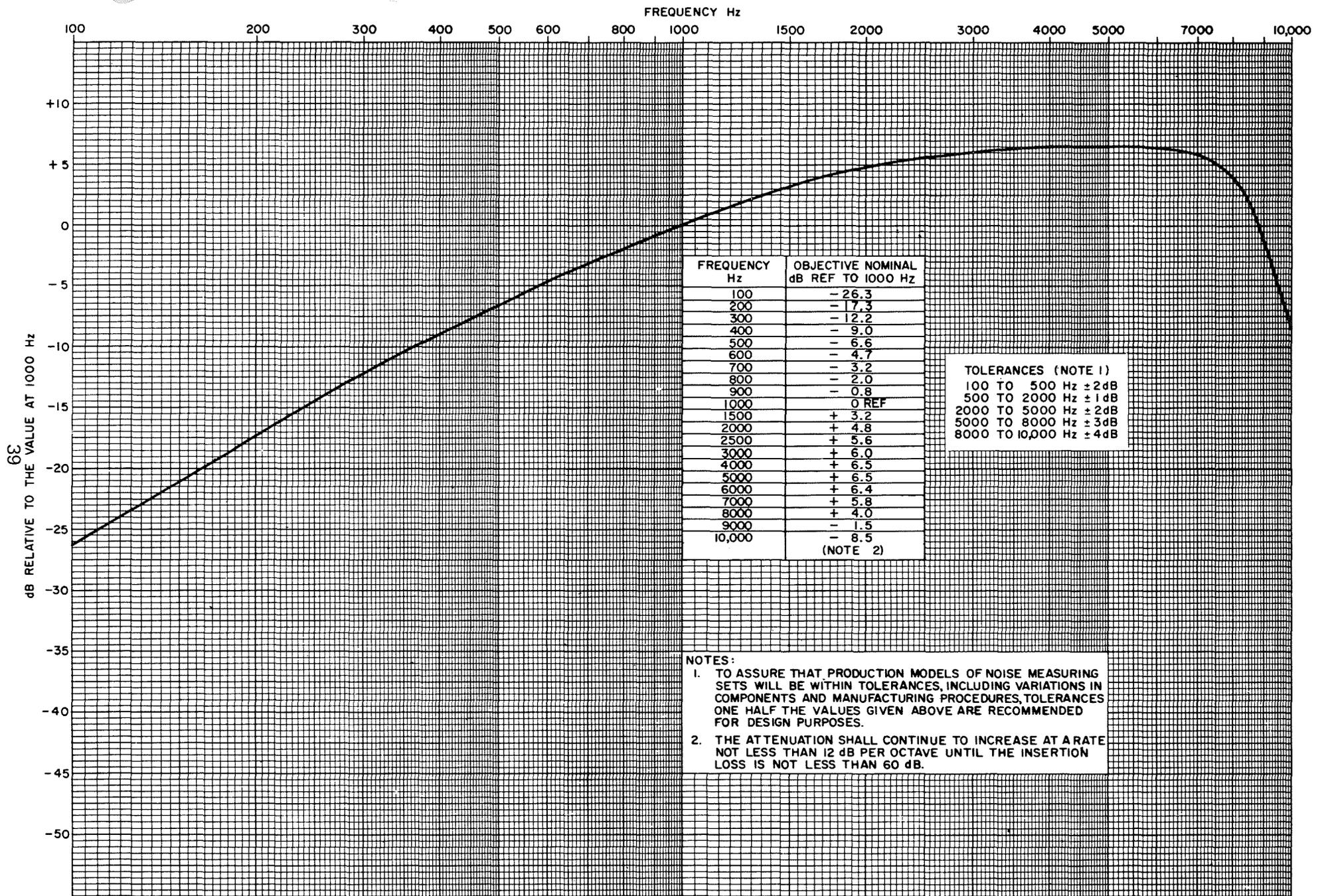
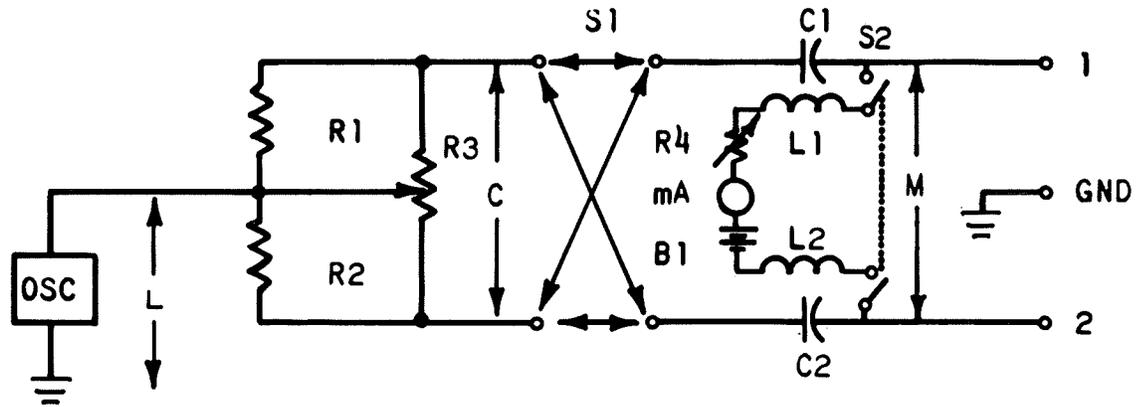


FIGURE 2 1010 HZ NOTCH FILTER



PROGRAM WEIGHTING CHARACTERISTIC

FIGURE 3

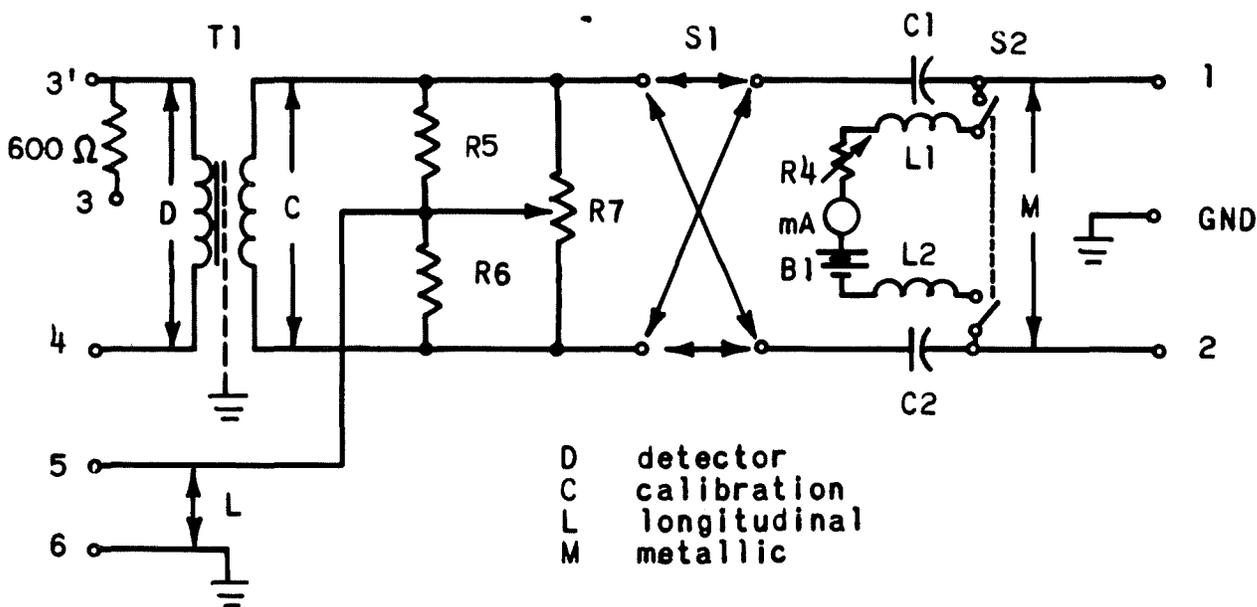


C calibration
 L longitudinal
 M metallic

NOTES:

- R1, R2 - $370\Omega \pm 1\%$
- R3 - $250\text{ k}\Omega$
- R4 - $50\text{ k}\Omega$ POTENTIOMETER TO CONTROL DC CURRENT
- C1, C2 - $100\mu\text{F}$, WITHIN $0.4\mu\text{F}$ OF EACH OTHER
- L1, L2 - APPROX. 10H , WILL RETAIN HIGH AC IMPEDANCE WITH 100 mA AC CURRENT
- S1 - DPDT SWITCH TO INTERCHANGE TIP AND RING
- S2 - SWITCH CONNECTS DC SUPPLY
- B1 - DC VOLTAGE SOURCE
- mA - DC MILLIAMMETER
- C, L, M - POWER IN dBm REFERENCED TO TERMINATING IMPEDANCE MEASURED WITH A RMS RESPONDING VOLTMETER HAVING BRIDGING IMPEDANCE $> 20\text{ K}$ AND A LONGITUDINAL BALANCE $> 100\text{ dB}$.
- OSC - SINE WAVE OSCILLATOR AT A FREQUENCY OF f_L HZ, OUTPUT IMPEDANCE IS NOT IMPORTANT

Fig. 4 - Longitudinal Test Setup



NOTES:

R4 - 50 KΩ POTENTIOMETER TO CONTROL DC CURRENT

R5, R6 - 1000Ω ±1%

R7 - 250 KΩ, LARGER IF R5 AND R6 ARE WELL MATCHED

C1, C2 - 100 μF, WITHIN 0.4 μF OF EACH OTHER

L1, L2 - APPROX. 10H, WILL RETAIN HIGH AC IMPEDANCE WITH 100 mA DC CURRENT

S1 - DPDT SWITCH TO INTERCHANGE TIP AND RING

S2 - SWITCH CONNECTS DC SUPPLY

T1 - TRANSFORMER WITH LONGITUDINAL BALANCE > 100 dB AND INSERTION LOSS < 1 dB OVER PROPER FREQUENCY RANGE AND IMPEDANCES, ELECTROSTATIC SHIELD IS SHOWN, TURNS RATIO 1:1

B1 - DC VOLTAGE SOURCE UP TO 60 VOLTS

mA - DC MILLIAMMETER

D, C, L, M - POWER IN dBm REFERENCED TO TERMINATING IMPEDANCE MEASURED WITH A RMS RESPONDING VOLTMETER HAVING A BRIDGING IMPEDANCE > 20 KΩ AND A LONGITUDINAL BALANCE > 100 dB

Fig. 5 - Longitudinal Test Setup With Transformer

APPENDIX

SUBROUTINE PARR (XLOSS, PHASE)

CALCULATION OF THE ENVELOPE P/AR RATING.

THIS SUBROUTINE CALCULATES THE ENVELOPE P/AR RATING GIVEN THE LOSS AND PHASE DATA AT EACH P/AR SPECTRUM FREQUENCY COMPONENT.

THE P/AR TEST SIGNAL IS REPRESENTED BY A TRUNCATED FOURIER SERIES CONSISTING OF SIXTEEN (16) SPECTRAL COMPONENTS. THE SPECTRAL FREQUENCIES ARE AT ODD MULTIPLES OF 125. Hz. . IN ADDITION, EACH COMPONENT IS OFFSET BY $125./8 = 15.625$ Hz. .

XLOSS IS A ONE-DIMENSIONAL VARIABLE WHOSE ELEMENTS ARE THE LOSS IN DECIBELS AT THE P/AR SPECTRAL COMPONENTS STARTING AT 140.625 Hz, AND ENDING AT 3890.625 Hz.

PHASE IS A ONE-DIMENSIONAL VARIABLE WHOSE ELEMENTS ARE THE PHASE IN DEGREES AT THE P/AR SPECTRAL COMPONENTS STARTING AT 140.625 Hz. AND ENDING AT 3890.625 HZ.

THE P/AR TEST SIGNAL ENVELOPE IS CALCULATED AT N EQUALLY SPACED SAMPLE POINTS OVER ONE PERIOD.

THE FULL-WAVE AVERAGE OF THE P/AR TEST SIGNAL ENVELOPE IS FOUND BY NUMERICAL INTEGRATION USING SIMPSON'S RULE.

THE PEAK OF THE P/AR TEST SIGNAL ENVELOPE IS FOUND BY TWO SUCCESSIVE SECOND-ORDER INTERPOLATING POLYNOMIAL CURVE FITTINGS USING ESTIMATES OF THE ENVELOPE PEAK AND ADJACENT ENVELOPE VALUES.

DIMENSION XLOSS (16),PHASE(16),TSDB(16),A(16),B(16),E(70),PK(3)

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/

PI = 3.1415926

TWOPI = 6.2831853

NC = 16

N = 64

FN = N

N1 = N + 1

```

C          DO 5 I=1,NC
          ABD =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
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.
C      PO = 423.6377
C      FO = 101.6241
C
C      PEAKN = 100.*(PEAK/PO)
C      FWAN = 100.*(FWA/FO)
C
C      PAR = 200.*(PEAKN/FWAN)-100.
C
C      OUTPUT CONTROL:
C
C      PRINT105
105    FORMAT('-',11X,'ENVELOPE P/AR RATING:')
C      PRINT106,PEAK,FWA
106    FORMAT('0',11X,'ENVELOPE PEAK =',F8.4,2X,'ENVELOPE FWA =',F8.4)
C      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
C      RETURN
C      END

```