

NOISE ENGINEERING
MESSAGE CIRCUIT NOISE
MEASUREMENTS AND EVALUATION

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2. MESSAGE CIRCUIT NOISE CHARACTERISTICS

A. General

2.01 Message circuit noise arises from a variety of sources. It enters the transmission path in many ways and appears in the telephone receiver at levels that may, or may not, be disturbing. In addition to its level or loudness, the frequency content, duration, periodicity of occurrence, similarity to speech, and other characteristics of a noise will combine to determine how disturbing it will be.

2.02 Message circuit noise is usually described as hum, tone, static, frying, hissing, crosstalk, impulses, etc. Because these terms tend to become somewhat ambiguous in use, Appendix 1 gives brief descriptions of their accepted meanings as they relate to noise.

B. Subjective Aspects—Relative Interfering Effect

2.03 An electrical disturbance in a message circuit—that is, any unwanted signal—appears acoustically as noise at the output of the receiver of the telephone set. Such noise may be barely audible, or it may be loud enough to impair the reception of a telephone message. On a message circuit, noise which is coincident with speech results in impairment of the received speech signal. Noise on a message circuit in the absence of speech is often more troublesome. It can cause greater annoyance or increased subjective discomfort to a listener than when speech is present. The interfering effect of noise in either case depends upon the magnitude, duration, and frequency content of the noise and upon its relation to the corresponding characteristics of the desired signal. It is also related to the frequency response of the telephone set and of the typical human ear. Individuals respond differently to noise, depending on their sensitivity. That is, the characteristics of the individual, whether he hears well or poorly, whether his hearing responds to a narrow band or to a wide band of frequencies, his acoustical environment, and other factors affect his response to noise. These are termed the “subjective” aspects of noise. The items concerning the measurable electrical parameters of noise and the telephone system are the “objective” aspects.

2.04 The design of a noise measuring set or system must include consideration of both the subjective and the objective aspects. The set

should simulate the most important qualities of the typical human hearing mechanism, and it must be compatible with the design and performance of the telephone system so its characteristics are not changed when the set is connected. A weighting network that attenuates certain frequencies more than others approximates the objective C-message weighting curve in Fig. 1. The meter movement itself can be made to reach an appropriate fraction of the full value of a noise signal in about the same time as does the auditory response. Other features, including the reference level and the input impedance, make an NMS compatible with performance of the telephone system as a whole. The ensuing paragraphs describe how these various design parameters are determined, and how they are met in present NMSs.

C. C-Message Weighting

2.05 Figure 1 shows the objective C-message weighting curve with permissible tolerances, and Table A gives the weighting coefficient data from which the curve was plotted. This curve describes the combined frequency response of the 500-type telephone set and the hearing of the typical human ear. Studies of subjective aspects indicate that, to have the same interfering effect, low and high frequencies in the voiceband range must be louder than midfrequencies. The C-message weighting curve takes this into account by showing low and high frequencies at levels an appropriate number of decibels below an arbitrary zero at 1000 Hz. Thus, an NMS must attenuate low and high frequencies with respect to 1000 Hz by the amounts shown on the C-message curve to correctly evaluate their interfering effect. The response of practical C-message weighting networks should fall within the limits shown in the table in Fig. 1 to assure reasonable conformity with the objective curve.

2.06 Strictly speaking, the C-message curve is true at only one loudness level. At some different level, the relative interfering effect of the low and high frequencies will change somewhat. However, these changes are small over the range of noise volumes usually encountered in practice. Therefore, the C-message curve introduces negligible error into message circuit noise measurements. This is particularly true when considering the wide variations in the subjective aspects of noise measurements.

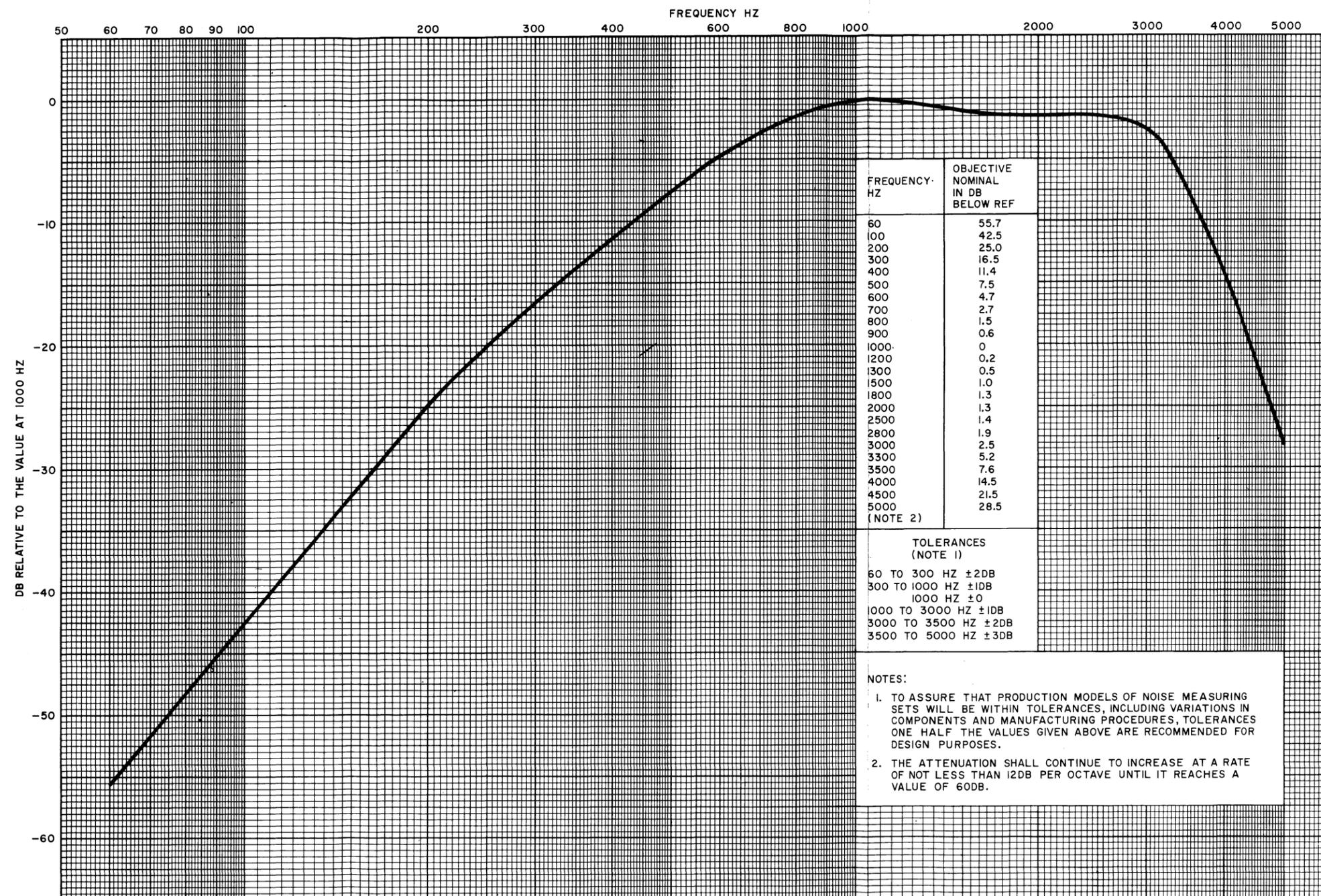


Fig. 1—C-Message Weighting Curve

TABLE A
C-MESSAGE WEIGHTING COEFFICIENTS

FREQUENCY, (HZ)	NOMINAL OBJECTIVE BELOW REFERENCE (DB)	TOLERANCES
60	55.7	60 to 300 Hz ±2 dB
100	42.5	300 to 1000 Hz ±1 dB
200	25.0	1000 Hz 0
300	16.5	1000 to 3000 Hz ±1 dB
400	11.4	3000 to 3500 Hz ±2 dB
500	7.5	3500 to 5000 Hz ±3 dB
600	4.7	
700	2.7	
800	1.5	
900	0.6	
1000	0.0	
1200	0.2	
1300	0.5	
1500	1.0	
1800	1.3	
2000	1.3	
2500	1.4	
2800	1.9	
3000	2.5	
3300	5.2	
3500	7.6	
4000	14.5	
4500	21.5	
5000	28.5	

2.07 Although C-message weighting is the present standard for message circuit type noise measurement, other weightings have been used in the past as described in Appendix 2. Appendix 3 gives a brief description of another weighting used for noise measurements in Europe and other parts of the world. In addition, program and 15-kHz flat weightings are available for noise measurements on broadcasting and on other circuits which pass wider bandwidth than message circuits.

D. Reference Noise Levels

2.08 The reference level for metallic voice frequency noise measurement is defined as 10^{-12} watt of noise power. On the noise scale, this corresponds to 0 dBrn or, in words, "zero decibels reference noise." A small letter "c", when added to the abbreviation, indicates C-message weighting, i.e., "dBrnc." Appendix 4 describes some of the

considerations that led to the choice of this reference noise level.

2.09 In the Bell System, the reference testing power, defined as 0 dBm, is equivalent to 10^{-3} watt at 1000 Hz. Hence, the 1000 Hz equivalent on the noise scale is:

$$0 \text{ dBrn @ } 1000 \text{ Hz} = 10 \log_{10} \frac{10^{-12}}{10^{-3}} = -90 \text{ dBm.}$$

This relationship holds for any frequency in a flat weighted passband, but only at or very near to 1000 Hz in the C-message weighted band. To get the reference level for other specific frequencies, the effect of the weighting curve must be subtracted.

2.10 Noise is rarely a single frequency, and is usually very complex. Therefore, no equivalent ratio based on any single frequency is adequate to express a relationship between 0 dBrnc and 0 dBm. Instead, the ratio of the total power under the C-message weighting curve to the total power in a flat spectrum of the same effective bandwidth and equivalent 1000 Hz amplitude must be evaluated. This has been done by approximate methods, with the result:

$$0 \text{ dBm}_{300-3000 \text{ Hz}} = 88 \text{ dBrnc}_{300-3000 \text{ Hz}}$$

2.11 Voice-frequency noise-to-ground (N_G) measurements are referred to 2.45 millivolts, with no power level specified. Thus, 0 dB (N_G) corresponds to 2.45 millivolts between either or both conductors of a pair and ground when the pair is connected to a 3-type NMS with its function switch in the N_G position. The designation "dBrn" does not apply to noise-to-ground measurements.

2.12 Carrier frequency noise-to-ground measured with the 7A carrier frequency NMS is referred to 11.62 microvolts. Thus, 0 dB carrier frequency noise-to-ground indicates 11.62 microvolts between either or both conductors of a pair and ground when the pair is connected to a 7A carrier frequency

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NMS with its FUNCTION switch in the NG ADD 30 position. 0 dB CFN_G on the 7A carrier frequency NMS is indicated when the attenuator is on -30 dB, the meter is on 0 dB, and the correction of +30 dB has been added as called for in the 7A carrier frequency NMS section:

Carrier frequency N_G = meter dB
+ attenuator dB
+30 dB

The designation "dBrn" does not apply to carrier frequency noise-to-ground measurements.

3. MESSAGE CIRCUIT NOISE MEASURING EQUIPMENT

3.01 The design of an NMS must assure that two noises judged to be equally interfering are assigned the same numerical magnitude. To do this, an NMS must include the following:

- (a) A frequency weighting characteristic
- (b) A time response similar to that of a typical human ear
- (c) A means of combining the weighted components
- (d) A reference level and scale of measurement
- (e) Inputs compatible with the circuits to be tested.

3.02 The 3-type NMS, described in the 103 division of BSPs, meets the following requirements:

(a) The plug-in 497A network (C-message) provides the frequency weighting. Its response approximates the subjective interfering effect of noise in the voice-frequency band for the nominal range of noise levels encountered. The plug-in 497A network, when turned over, provides 3-kHz flat weighting. A dimensionally identical plug-in network provides weightings suitable for program and other services.

(b) The meter itself, by design, requires 200 milliseconds to reach 99% of full-scale deflection. This simulates the time response of a typical human ear.

(c) A square-law type rectifier sums the weighted components. This rectifier includes special design features that permit close approximation of the rms values of many waveforms when the NMS, of which it is a part, is calibrated with a standard sine wave signal. This is called "quasi-rms" rectification.

(d) The meter scale reads from 0 to 12 dBrn in one dB steps, with a single mark to the left of the zero for -10 dBrn. The meter, with an attenuator (85 dB in 5 dB steps) and voltage amplifiers (90 dB from 30 Hz to 15 kHz), provides for noise measurements from below 0 dBrn to above 90 dBrn.

(e) Input impedances match those commonly used in the telephone system. The 3A and 3B NMSs have both 600-ohm and 900-ohm input impedances for terminating a circuit to make noise-metallic measurements. The 3C NMS has a input impedance of 735 ohms. This is the geometric mean between 600 and 900 ohms. The set with this input impedance will measure correctly when calibrated on and used with either 600- or 900-ohm circuits. A 10,000-ohm bridging input in all the 3-type NMSs makes possible noise-metallic measurements on circuits without opening them. The input circuit for noise-to-ground consists of a network which connects both sides of the circuit through approximately 100,000 ohms to ground. This arrangement presents a high impedance to ground and reduces the sensitivity 40 dB to make the indicated noise-to-ground magnitude comparable to the noise-metallic magnitude. (Noise-to-ground is defined in 4.06.)

3.03 The 3-type NMS and similar NMSs measure power indirectly by indicating the voltage drop across a known terminating impedance. The voltage under these conditions is proportional to the square root of the power:

$$\text{Volts} = \sqrt{\text{Power} \times \text{Impedance}}$$

The voltage drops produced by 10⁻¹² watt dissipated in each of the four standard terminating impedances are:

135 ohms	0.0116 millivolt	Used with 7A CF NMS
600 ohms	0.0245 millivolt	Used with 3A and 3B NMSs and 4A Noise analyzer
735 ohms	0.0271 millivolt	Used with 3C NMS
900 ohms	0.0300 millivolt	Used with 3A and 3B NMS

Each of these voltages will produce a 0 dBrn indication on the meter of a correctly calibrated NMS of the correct terminating impedance. Each, under the specified conditions, will correctly indicate power levels referred to 10^{-12} watt.

3.04 In operation, an NMS sums the individual weighted noise components in a single overall measurement in a way to properly indicate the degree of noise interference. The same interfering effect could be determined by actually measuring the frequency and magnitude of each component of noise. Each component so measured would be weighted in accordance with the C-message weighting curve; then all would be combined by "power" summation. This summation is based on the square root of the sum of the squares (rss) of the weighted (C-message) effective (rms) currents or voltages. The result is a good approximation of the rms voltage or current of the complex noise wave shape.

3.05 Noise generally is too complex to be conveniently analyzed by measurement and summation of individual frequency components. However, the technique is very practical and useful for analyzing the influence of 60 Hz harmonics. The 4A frequency analyzer, or an equivalent instrument, will make such a harmonic analysis. Section 103-635-100 describes the 4A frequency analyzer, and the electrical coordination practices tell of its use for message circuit inductive interference analysis.

3.06 The 7A carrier frequency NMS includes all the basic features described in 3.01, and extends message noise measurement into the carrier frequency region. In effect, it works like a single-channel carrier terminal. The set demodulates any noise or signal in the 3-kHz band selected, weights it, using the same 479A plug-in networks

as the 3-type NMSs, and indicates the level in dBrn on a meter. In addition to providing input connections, jacks on the front panel provide for connecting monitoring and external measuring instruments. Section 103-500-100 describes the 7A carrier-frequency NMS.

3.07 Testboards and voice-frequency patching bays may be equipped with either, or possibly both, the SD-95900-01 Transmission and Noise Measuring System and the 3B or the 3CR NMS. Some earlier testboards may still retain the 43A Noise Measuring System. Recent modifications have added C-message weighting to the SD-95900-01 and 43A Noise Measuring Systems.

3.08 The 3B NMS is electrically identical to the 3A, but is arranged for central office battery operation and for rack-mounting.

3.09 The 3C NMS is essentially identical to the 3A, except for some additional features. The added features include a holding bridge and connections for an external dial handset. These should simplify operation by reducing the amount of equipment required at a subscriber station. The 3C NMS makes possible dialing a quiet termination and holding the line for measurement. As noted above, it provides a single compromise terminating impedance of 735 ohms.

3.10 The 3CR NMS, arranged for rack-mounting at testboard locations, contains the basic noise measuring circuit of the 3C NMS. However, the holding bridge, the internal calibrating oscillator, all external binding posts and jacks on the front panel, and the dry battery power supply are absent. The set uses the normal -48 volt central office power supply. The remaining features omitted from the NMS are part of the testboard cord circuits or are available as jack-terminated circuits at the board.

4. BASIC NOISE MEASUREMENTS

A. General

4.01 The 3-type NMSs and the SD-95900-01 system, both equipped with C-message weighting, are the present standard for measuring message circuit noise in the Bell System. The appropriate descriptive sections in the 103-2, 103-5, and 103-6 division layers give detailed information on the use of these sets. This part, therefore, gives more

general information, as well as methods applicable to all message circuit NMSs.

B. Noise-Metallic (N_M)

4.02 Noise-metallic is the weighted noise power in a metallic circuit at any given point when the circuit is terminated at that point in the impedance of the NMS. As the name implies, it includes the noise currents flowing in the metallic circuit of a loop or trunk, or the noise voltage across such a circuit. Noise-metallic accounts for the annoyance to customers. Thus, noise-metallic measurements are the ones of greatest interest in noise work.

4.03 Bridging or bridged noise measurements are equivalent to noise-metallic, provided that the impedance of the circuit at the point of measurement approximates the impedance at which the measuring set is calibrated. For the 3-type NMSs this is 600 ohms, corresponding to the impedance on the office side of the terminating equipment of most voice-frequency trunks and the impedance on the voice-frequency side of carrier-channelizing equipment. Thus, bridged measurements at most points inside central office buildings will be accurate. However, the impedance of cable circuits departs from the nominal 600 ohms by considerable amounts. The impedance of loaded cables ranges between 700 and 1200 ohms, and that of nonloaded cable ranges from 200 to 500 ohms. Bridged measurements across these impedances with a 3-type NMS calibrated on 600 ohms will be in error by several dB. Table B gives corrections to use for circuit impedances other than 600 ohms. The schematic drawings for the terminating equipment usually include impedance information for outside plant options, to assist in choosing the correct ratios for repeating coils. Where these drawings do not provide impedance information, the appropriate sections in Division 304 provide it for each gauge of cable, both loaded and nonloaded. Appendix 5 gives the procedure by which the values in Table B were obtained.

TABLE B

AMOUNTS NEEDED TO CORRECT BRIDGED MEASUREMENTS WHEN CIRCUIT MEASURED IS NOT 600 OHMS

(For noise measuring sets calibrated on 600 ohms)

CIRCUIT IMPEDANCE	ADD TO VALUE MEASURED
150 to 250 ohms	+5 dB
251 to 350 ohms	+3 dB
351 to 450 ohms	+2 dB
451 to 550 ohms	+1 dB
551 to 650 ohms	0 dB
651 to 850 ohms	-1 dB
851 to 1200 ohms	-2 dB
1201 to 2000 ohms	-4 dB

4.04 In the case of measurements made at 1000 Hz, it is only necessary to subtract 90 from the reading in dBrn to obtain the level in dBm, since there is no weighting effect on a 1000 Hz tone, as shown in Fig. 1. This will result in a negative sign for the dBm, signifying dB below the one milliwatt reference.

$$\text{dBrn} - 90 = \text{dBm}$$

However, this is not true for other frequencies or for measurements of noise or speech. In the case of uniformly distributed noise in the 100-Hz to 3-kHz band, the reference is -88 dBm. That is, C-message weighting will reduce noise in the 100-Hz to 3-kHz spectrum by 2 dB. For example, if 3-kHz flat noise power is -50 dBm, then $88 - 50 = 38$ dBrnc.

4.05 An additional factor may be noted. The fact that -90 dBm of 1000-Hz tone gives rise to a 0 dBrnc reading does not mean that 0 dBrnc equals -90 dBm. The noise meter measures the interfering effect of noise, but it cannot tell the observer what kind of noise is causing the interference or how much of a particular kind of noise is present. 0 dBrnc may equal -90 dBm of 1000-Hz tone, or it may equal -88 dBm of 3-kHz flat (uniformly distributed) noise, or it may equal a certain magnitude of tone at any given frequency. However, the only thing that these three noises

will necessarily have in common is that they cause the same indication on the NMS and are approximately equal in their interfering effect. Hence it is important to monitor with the NMS headphone or with the testboard talking circuit each time a noise measurement is made, in order to observe the character of the noise and to ensure that noise is actually being measured.

C. Noise-to-Ground (N_G)

4.06 Noise-to-ground is a measure of the noise voltage across the 100,000-ohm circuit of a 3-type NMS connected between one or more conductors and ground. In effect, the 3-type NMS connects both sides of the line together through a very high resistance and places them in a series with other resistances to provide a total of 100,000 ohms to ground. This arrangement presents high impedance between the pair and ground and reduces the sensitivity of the NMS 40 dB in order to place the indicated noise-to-ground magnitudes in the same range as the noise-metallic magnitudes.

4.07 An adjustment of 40 dB added to the noise-to-ground measurement will refer it to the voltage equivalent of 10^{-12} watt in 600 ohms. The adjusted measurement will be comparable with metallic measurements in dBrn.

4.08 Noise-to-ground measurements with the 3-type NMS may be used to help evaluate the severity of longitudinal induction from external sources. Such induced voltages may be many times the usual metallic-noise voltages. For example, a flat weighted noise-to-ground reading of 40 dB (attenuator at 40 + meter at 0 = 40) corresponds to .245 volt.

4.09 Flat weighted noise-to-ground measurements with the 3-type NMS frequently indicate low-frequency voltages. These include both 60 Hz and other low-frequency voltages, which are usually not audible. In estimating these components, it is necessary to measure both the weighted (C-message) and the unweighted (3-kHz flat) noise. The difference in dB between these measurements will usually give some indication of the magnitude and frequency of the low-frequency components with respect to other noise on the circuit. The approximate relationship between the more important 60 Hz harmonics and the corresponding differences between their levels when measured with flat weighting

and then with C-message weighting can be estimated from the C-message curve as follows:

60 HZ HARMONIC	FREQUENCY — HZ	ESTIMATED DB DIFFERENCE DBRN — DBRNC
Fundamental	60	More than 45 dB
2nd	120	45 to 32 dB
3rd	180	32 to 16 dB
5th	300	16 to 8 dB
9th	540	8 to 4 dB
11th and higher	660 and above	Less than 4 dB

4.10 Carrier frequency noise-to-ground measurements may help identify disturbing carrier and radio frequency signals originating outside the telephone system. Such signals may originate in airway radio beacons, radio broadcasting stations, power line carriers, diathermy or other medical therapy devices, other carrier systems operated by outside organizations, and other sources. These usually enter cables via unsuppressed drop wires, branching open-wire leads, ineffective shielding caused by cable sheath opens, and missing or high-impedance sheath grounds. The 7A CF NMS simplifies identification of the frequency of disturbing signals by means of its narrowband tuning feature.

D. Longitudinal Induction

4.11 Noise-to-ground measurements, in general, indicate the relative magnitude of longitudinal voltages on the two conductors of a pair, or the relative voltage to ground on a single conductor. In either case, readings should be made with both C-message and 3-kHz flat weightings to make sure that low-frequency voltages are not overlooked.

4.12 Noise-to-ground measurements compared with noise-metallic measurements on the same circuit and with the same weighting provide a means for estimating circuit longitudinal balance. Such balance between the two sides of a message circuit is an important factor. A power system may induce comparatively high voltages to ground on each side of a message circuit. Unless the circuit is well balanced to ground, the induced voltages will cause metallic currents in the message circuit. Even slight unbalances will result in such currents, which then appear as metallic-noise voltages across the terminals of the circuit.

4.13 The ratio of longitudinal voltage on a circuit to the metallic voltage on the same circuit, both with the same weighting, is taken as a measure of its balance. For convenience, balance is expressed in dB as follows:

$$\text{Balance in dB} = 20 \log_{10} \frac{V_G}{V_M}$$

V_G is the noise-to-ground voltage, and V_M is the noise-metallic voltage. Since measurements with the 3-type and other NMSs are in dB, balance in dB is simply the difference between the measured noise-to-ground dB and the noise-metallic dB, with a correction to adjust one to the same reference as the other.

$$\text{Balance in dB} = \text{dB reference adjustment} \\ + \text{dB } N_G - \text{dB } N_M$$

Earlier Bell System Practices express balance as:

$$\text{Balance in dB} = 20 \log_{10} \frac{V_M}{V_G} \\ = (\text{noise-metallic}) \\ - (\text{noise-to-ground} \\ + \text{dB ref. adj.})$$

The numerical value from this expression will be the same, but it will have a negative sign. A more recent proposed standard expression for balance results in a positive sign; therefore, the revised expression is given above to reflect the newer viewpoint.

4.14 The dB reference adjustment for voice-frequency balance measurements is 40 dB

$$\left(40 \text{ dB} = 20 \log_{10} 2.45 \times \frac{10^{-3}\text{V}}{.0245 \times 10^{-3}\text{V}} \right)$$

Voice-frequency balances, measured in this manner, in the order of 70 to 95 dB are typical for well-maintained cable plant. In the voice-frequency range, excellent performance is represented by balance greater than 60 dB, good between 60 and 50 dB, fair between 50 and 40 dB, and poor less than 40 dB.

4.15 A procedure similar to that above may be used for estimating balance of carrier frequency lines measured with the 7A carrier

frequency NMS. The dB reference adjustment will be 0 dB in the carrier frequency case, as carrier frequency noise-to-ground is referred to the voltage equivalent for 10^{-12} watt dissipated in 135 ohms, which is the reference for carrier frequency noise-metallic. Determined in this way, balances over 55 dB are considered excellent for carrier frequency lines, between 40 and 55 dB, good, between 30 and 40 dB, fair, and below 30, need improvement.

5. NOISE SOURCES, COUPLINGS, AND SUSCEPTIBILITY

A. General

5.01 A message circuit can never be entirely isolated from external noise sources. It may parallel a power line, it usually lies in close proximity to other similar loops and trunks in cables or in open wire, and it passes through central offices in which switching apparatus creates sizable transients. While not intended, coupling to these sources of interference always exists. The coupling between the source of interference and a message circuit may be capacitive, inductive, or conductive, or combinations of these. Coupling to power lines is usually predominantly inductive, and would be of trivial importance if it were not for the great energy of the disturbing source. Couplings between pairs in cables and in open-wire lines are predominantly capacitive. Transpositions in open-wire pairs effectively reduce inductive interference from power lines and, in addition, help reduce crosstalk. Different rates of twist for adjacent pairs in cables help minimize transfer of noise and crosstalk energy. Further, the use of balanced circuitry for message circuit connections plays an important part in reducing the effects of induced currents and voltages.

B. Noise From External Sources

5.02 Message circuit noise frequently comes from sources external to the telephone plant. Two important external sources are atmospheric static and induction from exposures to power systems. Noise due to static is distributed rather broadly over both the frequencies of the voiceband and the frequencies of the carrier spectrum. This noise varies with time, and is not readily reduced to single-frequency components. Where noise arises due to exposure to power systems, it consists principally of odd harmonics of 60 Hz, with the third (180 Hz), the fifth (300 Hz), and the ninth

(540 Hz) usually predominating. It appears as hum in the message circuit. The hum level is determined by the extent of the power system influence and the degree of balance of the message circuit and terminal equipment. Rectifiers also produce even harmonics which, in the absence of adequate filtering, appear as ripple in the dc. Other external noise sources include diathermy machines, radio stations, and similar apparatus.

C. Noise From Internal Sources

5.03 Message circuit noise comes from many sources within the telephone plant. Noise sources associated with central offices include: (a) the battery supply, (b) relay contacts opening and closing, (c) ringing machines and other tone sources, (d) microphonic contacts, and (e) others. The effects from central office sources are often intensified by any unbalanced wiring to which they connect.

5.04 Outside plant cable pairs become secondary sources of noise by being connected to many central office noise sources. An example is cable pairs that connect to revertive pulsing apparatus which pulses by grounding the tip of the pair. Cable pairs also act as secondary sources of: (a) induction from signaling tones, (b) cable test tones, (c) transmission test tones, (d) tones derived from carrier systems, (e) crosstalk, etc.

5.05 Carrier and radio systems are major sources of certain types of noise, including (a) modulation distortion or intermodulation noise, (b) thermal noise, (c) atmospheric noise, (d) crosstalk, and (e) others. Both carrier and voice-frequency repeatered lines, when unterminated, may go into oscillation, producing tones that interfere with adjacent circuits. Some of these sources are fairly constant and may be analyzed into single-frequency components. Others, such as contact noise and intermodulation noise, vary irregularly with time and cannot be readily analyzed.

D. Couplings

5.06 Noise and crosstalk couplings usually occur at locations where wiring or apparatus of the disturbed circuit is exposed to similar portions of the disturbing circuit. In some cases, the exposure may not be directly from the disturbing circuit or equipment but via some other circuit or group of circuits. These are sometimes described as "tertiary" or "interaction" paths. Such paths

must be coupled to the disturbing as well as to the disturbed circuit. Noise, therefore, travels from the point where it is generated in the disturber, and where it may be a desired signal, via associated wiring to a coupling either directly to the disturbed or via some intermediate circuitry or interaction path. If such a path is involved, the noise travels along its wiring to a coupling to the disturbed circuit. Finally, the noise travels to the receiver of the disturbed telephone set or apparatus via the normal transmission path.

5.07 Couplings between pairs within a cable can introduce noise into telephone interconnections. The following factors govern the amount of inductively and capacitively coupled noise between pairs within a cable:

- (a) Magnitude of the disturbing currents
- (b) Amount of coupling between the disturbing and disturbed circuit
- (c) Susceptibility of the disturbed circuit.

In the case of cables, the exposure may vary from a few feet to many miles. The separation between pairs is small, often only fractions of an inch. The magnitude of couplings between cable pairs is important because of the variety of noise-producing circuits that can be connected to the pairs. Some examples are telemetering circuits, grounded telegraph circuits, metallic telegraph circuits lacking proper waveshaping devices, unfiltered PBX battery supply circuits, poorly balanced subscriber line circuits, unfiltered talking battery supply circuits, revertive pulsing circuits, and many others.

5.08 The magnitude of a coupling depends largely on the separation between conductors in an exposure. The coupling is less as the separation between exposed conductors increases. Likewise, the coupling is less as the exposed length is shortened. And, of course, the converse is true.

5.09 The inductive interference sections describe procedures for estimating the magnitude of the coupling, as well as the resulting interference in outside plant which is exposed to power lines. Likewise, the cable crosstalk sections describe procedures for estimating capacitive couplings in outside plant cables.

5.10 Couplings inside the central office are very difficult to identify. Further, there are no methods available for estimating the magnitude of interference. Where such couplings are suspected, a frequently used technique, described in the central office noise sections, is to measure the change on the disturbed circuit after it has been separated from the circuits that are presumed to be causing the disturbance.

E. Susceptibility

5.11 Susceptibility describes the tendency of any circuit to deliver to connected apparatus unwanted metallic currents or voltages derived from external unconnected sources. Susceptibility is not directly measurable, since the noise or interference that can be measured is only partly due to the circuit's susceptibility. As described previously, the measured noise also includes the magnitude of the interfering signal and the effect of the coupling. All transmission circuits are susceptible to noise, however, to some degree. The susceptibility of a circuit varies with both frequency and bandwidth. Circuits that transmit higher frequencies or greater bandwidth, or both, tend to be more sensitive to noise. Of the three factors causing noise (source, coupling, and susceptibility), susceptibility is perhaps most under control of the designer and the engineer. With reduced susceptibility, careful circuit designs permit successful transmission of very wide bandwidths with acceptable noise levels.

5.12 Control of susceptibility begins with the design of a trunk facility. At this stage the designer may choose: (a) one of several carrier modulation plans (amplitude, frequency, pulse code, etc), (b) a transmission medium (coaxial cable, standard paired cable, radio, open wire, etc.), (c) higher transmission levels, (d) companders, (e) shielding for noise-sensitive components or conductors, (f) apparatus with a high degree of longitudinal balance, (g) filters or other devices to limit bandwidth, (h) longitudinal isolation transformers, and (i) others. Further control of susceptibility is possible when the facility is engineered. The engineer can: (a) select repeater locations that conform to optimum repeater section length, (b) locate the equipment in an area of low noise potential, (c) route cable and wire on racks with minimum exposure to noise, (d) provide decentralized battery filters, (e) provide longitudinal suppression coils, (f) select well-balanced coils, filters, and other supplemental apparatus and, with attention

to detail and good judgement, develop other effective stratagems. Finally, the engineers who lay out the trunk can do much to take full advantage of the features provided by the equipment engineers to keep susceptibility to a minimum.

5.13 Of the methods for reducing circuit susceptibility listed in 5.12, the degree of longitudinal balance is perhaps the most important. Noise voltages and currents in a disturbed circuit are usually longitudinal. Each conductor of a well-balanced pair carries approximately an equal magnitude of noise current in the same direction to the connected termination or load, or they are at approximately equal noise voltages with respect to some reference, usually ground. Longitudinal currents and voltages do not generate noise signals directly, but create potential differences between the conductors of a pair. It is these potential differences between conductors, usually called metallic-noise (sometimes noise-metallic) voltages, that introduce noise directly into voice circuits. Therefore, longitudinal currents and voltages (sometimes called "common mode" currents and voltages) would never appear in the disturbed circuit as noise if they could be kept identical in both conductors of every pair involved and in the halves of any termination or of any connected load. Such perfect equality is impossible to realize. Conductors are never identical; their series resistance may vary slightly and shunt impedances, mainly capacitive, to other conductors and ground tend to unbalance paired conductors.

5.14 Although cable pairs may contain unbalances in themselves in the form of defective splices, slight variations in insulation thickness, etc, it is more often the apparatus connected to the pairs that contributes the major unbalance, especially in the case of voice-frequency circuits. Trouble conditions, such as moisture in a cable, crosses, and inadvertent grounds, also tend to increase susceptibility to noise to a marked degree. These effects are usually of large magnitude and occur as a marked change in performance in a relatively short time interval. Thus, causes of troubles of this sort are usually quite evident. Problems arising from apparatus connected to outside plant pairs are much less evident. Examples of these are listed in the ensuing paragraphs.

5.15 Trunk circuit equipment that may affect susceptibility through poor balance includes:

- (a) Unbalanced composite signaling apparatus

- (b) Incorrectly wired trunk equipment
- (c) Defective, improperly installed, or poorly balanced load coils
- (d) Unbalanced carrier line build-out equipment
- (e) Improperly installed carrier line filters
- (f) Partially operated or dirty protective devices.

5.16 Subscriber loop equipment, when in good condition and correctly installed, provides adequate balance for control of susceptibility to noise usually encountered. However, there are a few equipment arrangements and fortuitously connected pieces of apparatus that do tend to increase susceptibility to noise. Some of these are:

- (a) Tip party identification apparatus required for ANI.
- (b) Party-line ringers connected with two or more on one side of a pair and one or none on the other, or party-line ringers fortuitously located with reference to a noise exposure.
- (c) Foreign attachments connected by the customer to one side of his line, or with unequal impedances connected to the two conductors. Examples are: "phone patches," unauthorized subsets, and extension ringers.
- (d) Wiring errors at the station.
- (e) Coin control circuitry at coin telephone stations.
- (f) Unbalanced class 5 central office and PBX line equipment. Examples are ground start line circuits, some line relays in crossbar offices, etc.
- (g) Unbalanced talking battery supply relays and/or inductors in step-by-step and panel offices.
- (h) Dirty or partially operated protectors.

5.17 Radio and coaxial carrier equipment is, by design, unbalanced at the input. For these systems the signal itself is essentially longitudinal with reference to the waveguide or outer coaxial conductor, which is at or near some nominal ground

potential. Thus, the waveguide or outer coaxial conductor effectively shields against external noise fields. For these reasons, the balance of radio and coaxial carrier equipment influences susceptibility to noise to a lesser degree than equipment of other carrier and voice-frequency systems.

6. TELEPHONE MESSAGE CIRCUIT—NOISE MEASUREMENT CONSIDERATIONS

6.01 Subscriber lines and various categories of trunks make up the telephone network. The most meaningful message circuit noise measurements in this network are those at the subscriber set. Measurements at other points in the network must be adjusted for loss and for other noise between the point of measurement and the customer. Thus, objectives for trunk noise, central office noise, and other parts of the telephone network must include an allowance for this loss and noise.

6.02 Noise objectives are stated differently, depending on the proposed use. If the objective is for engineering or design purposes, it most likely will be given in terms of the 0 level point. The equivalent noise at any other level point may be estimated by adding or subtracting the gain or loss in dB between the 0 level point and the point of interest. Conversely, the noise at any level point can be converted to an equivalent noise at the 0 level point by subtracting the gain or adding the loss.

6.03 In many situations, message circuit noise on a particular circuit may be a combination of noise from several individual contributors. To arrive at the total, such individual contributions can be combined by several procedures. Actual power levels in watts or milliwatts are simply summed arithmetically. If voltage or current values are available, they must be combined by the rms rule. Almost always, however, noise levels are in dBrn or in dBrc. It is tedious to convert these to power, voltage, or current values, combine them by the appropriate procedure, and then reconvert them to dB values. To simplify this procedure, Fig. 2 gives corrections in dB to add to the higher of two noise readings to obtain the combined effect of the two. For many purposes, the values in Table C should be adequate. Figure 2 and Table C apply only to quantities expressed in terms of their rms values. Thus they cannot be used for impulse noise, which is expressed in terms of peak values and time. Also, quantities to be combined must have the same weighting.

TABLE C

SUMMATION ON A POWER BASIS OF TWO UNEQUAL RMS QUANTITIES EXPRESSED IN DB AND WITH SAME WEIGHTING

(Not suitable for quantities measured in terms of peak power, such as impulse noise.)

AMOUNT BY WHICH TWO QUANTITIES DIFFER (DB)	AMOUNT LARGER DB QUANTITY SHOULD BE INCREASED TO OBTAIN SUM (DBRN)
0 — 0.5	3.0
0.6 — 1.6	2.5
1.7 — 3.0	2.0
3.1 — 4.7	1.5
4.8 — 7.2	1.0
7.3 — 12.2	0.5
Over 12.2	0.0

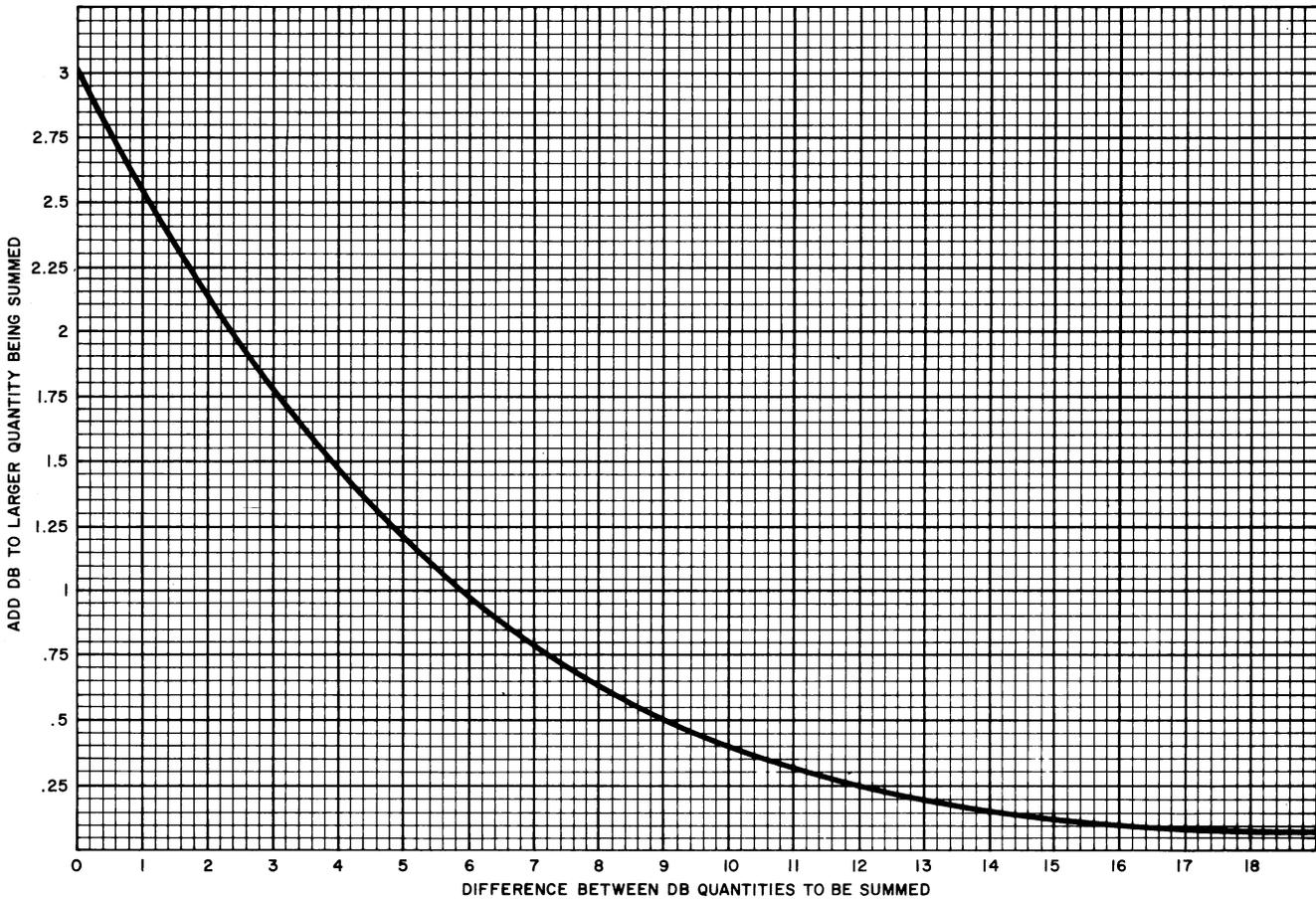


Fig. 2—Factors for Power Summation of dB Quantities

APPENDIX 1

DEFINITIONS OF VARIOUS TERMS USED TO DESCRIBE NOISE

BABBLE

See CROSSTALK.

BACKGROUND

Background describes the usually accepted noise on any telephone circuit. Background noise should be within measured limits, and is usually considered a desirable indication of a live circuit.

CLATTER

Clatter occasionally is used to describe the general background noise from central office operation. It includes dial impulses, low pops and clicks, telegraph or teletype "thump," and the like. Clatter is least under light calling conditions and is most noticeable during the busy period.

CROSSTALK

Crosstalk usually describes unwanted speech in message channels. It may describe intelligible words and phrases, but may also be present as unintelligible "BABBLE" from multiple sources. BABBLE may include modulation products of carrier frequency crosstalk, and may also include intermodulation products. Signaling tones, data, etc, transmitted at voice frequencies also appear as crosstalk in message circuits.

FRYING

Frying frequently originates at base metal contacts carrying current. It resembles the sound of frying.

HISSING

Hissing describes the effect of thermal noise. Sometimes the words "rushing" or "shushing" might stand for the same effect. Thermal noise originates in all parts of the telephone system, especially in components working at elevated temperatures, such as electron tubes and, to a lesser degree, resistors. Hissing is characteristic of the noise on radio systems.

HUM

Hum usually describes the audible effect of the harmonics of 60 Hz. Hum may also apply to dial tone and to other sustained low-frequency sounds occasionally heard as noise. When more than one 60-Hz harmonic is present, as frequently happens in the case of inductive interference, they may "beat" to produce variations in amplitude, pitch, or both.

IMPULSES

Impulses are the very sharp clicks that rise substantially above the other noise. Although it takes the typical human ear about 200 milliseconds to sense the full amplitude of a sound, many impulses last long enough to be very bothersome in speech transmission. Impulses lasting substantially less than 200 milliseconds are less objectionable in speech, but are a large problem with data services and should not be neglected.

INTERMODULATION

Intermodulation describes a number of noise sounds produced by the many complex frequencies present in carrier and radio systems. These sounds may resemble babble, hiss, and even at times be impulse-like. Intermodulation increases as the system load increases.

MICROPHONICS

Microphonics are usually low-pitched bell-like sounds generated at contacts under light pressure or within electron tubes. In both cases, the part reproduces vibrations present in its supporting structure. BANJO noise resulting from operation of crossbar switches is a type of microphonic noise. It sounds like the twang of a banjo string.

STATIC

Static originally referred to the crackling, popping sound produced especially in AM radio sets by nearby and distant lightning discharges. It now

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refers to similar sounds heard in the telephone receiver, regardless of origin. Sources of static, in addition to atmospheric noise, include high-voltage discharges in electrical equipment and possible central office clatter. It may arise as direct induction at voice frequencies, or may be demodulated from higher frequencies by radio- or carrier-channelizing equipment.

TONE (SINGING)

Tone refers to sounds produced by higher audible frequencies. Howling repeaters frequently introduce

tones into the transmission path. Two or three tones of closely related pitch or frequencies may "beat" to produce variations in pitch, amplitude, or both.

WHITE NOISE

White noise is the classical term for thermal noise. It makes a "rushing" or "hissing" sound in a telephone receiver. See HISSING.

APPENDIX 2

NOISE WEIGHTINGS USED WITH OLDER TELEPHONE INSTRUMENTS

The introduction of new telephones having improved response characteristics has from time to time changed the relative interfering effect of frequencies in the voiceband. Such a change occurred with the introduction of the 500-type telephone set. Each event in this sequence dictated a need for a new noise scale that would more adequately interpret the new relative interfering effect. The C-message weighting curve is only a later revision of several which preceded it. In 1930, a network included in the 1A noise amplifier represented the first message weighting curve. The 144 line weighting followed in 1935 with the introduction of the 2A noise measuring set (NMS). In 1945, a modification of the 2A and 2B NMSs arranged them for F1A weighting. Finally, the 3A NMS introduced C-message weighting in 1960. The early weightings were sharply peaked near 1000 Hz to include the response of the older wall-type and deskstand telephone sets with receiver and transmitter separate. The F1A transmitter and HA1 receivers introduced with the 300-type telephone sets added considerable bandwidth.

Hence, the F1A line and HA1 receiver weightings included the effect of this improved response. Sets using F1A transmitter and HA1 receiver are now largely replaced with the newer sets represented by C-message weighting. The earlier sets for which 144 weighting was designed are, for all practical purposes, entirely removed from plant. Thus, the 144 and F1A weightings and the 2B NMS no longer have any application. Figure 1 shows these curves for reference purposes. The curve for the 1A noise amplifier was, to all intents and purposes, the same as 144 weighting. The differences in the frequency response of the F1A and C-message weighting give different responses to differing types of noise. Because of this, a single conversion factor may give misleading results. Table A lists a number of types of noise, together with the appropriate conversion factor for each. For general use where the type of noise is not identified, a noise-metallic correlation factor of 6 dB or a noise-to-ground correlation factor of 10 dB should be used.

TABLE A

APPROXIMATE CORRELATION BETWEEN dB_a AND dB_{rn}

TYPE OF NOISE	NOISE-METALLIC			NOISE-TO-GROUND*		
	MEASURED WITH			MEASURED WITH		
	2B-NMS F1A dB _a	3A-NMS C-MESS dB _{rn}	CORR FACTOR dB	2B-NMS F1A dB _a	3A-NMS C-MESS dB _{rn}	CORR FACTOR dB
General message circuit type noise	20	26	6	20	30	10
Flat 3 kHz band-limited thermal noise	20	26	6	20	30	10
Power harmonics consisting of 180-300 and 540 Hz	20	25	5	20	29	9
Impulse-type noise	20	26	6	20	30	10
Modulation product noise	20	27	7	20	31	11
Central office switching noise	20	26	6	20	30	10

* The correlation factor for noise-to-ground is higher than that for noise-metallic because of the difference in the voltage divider ratio in the input circuit of the two sets.

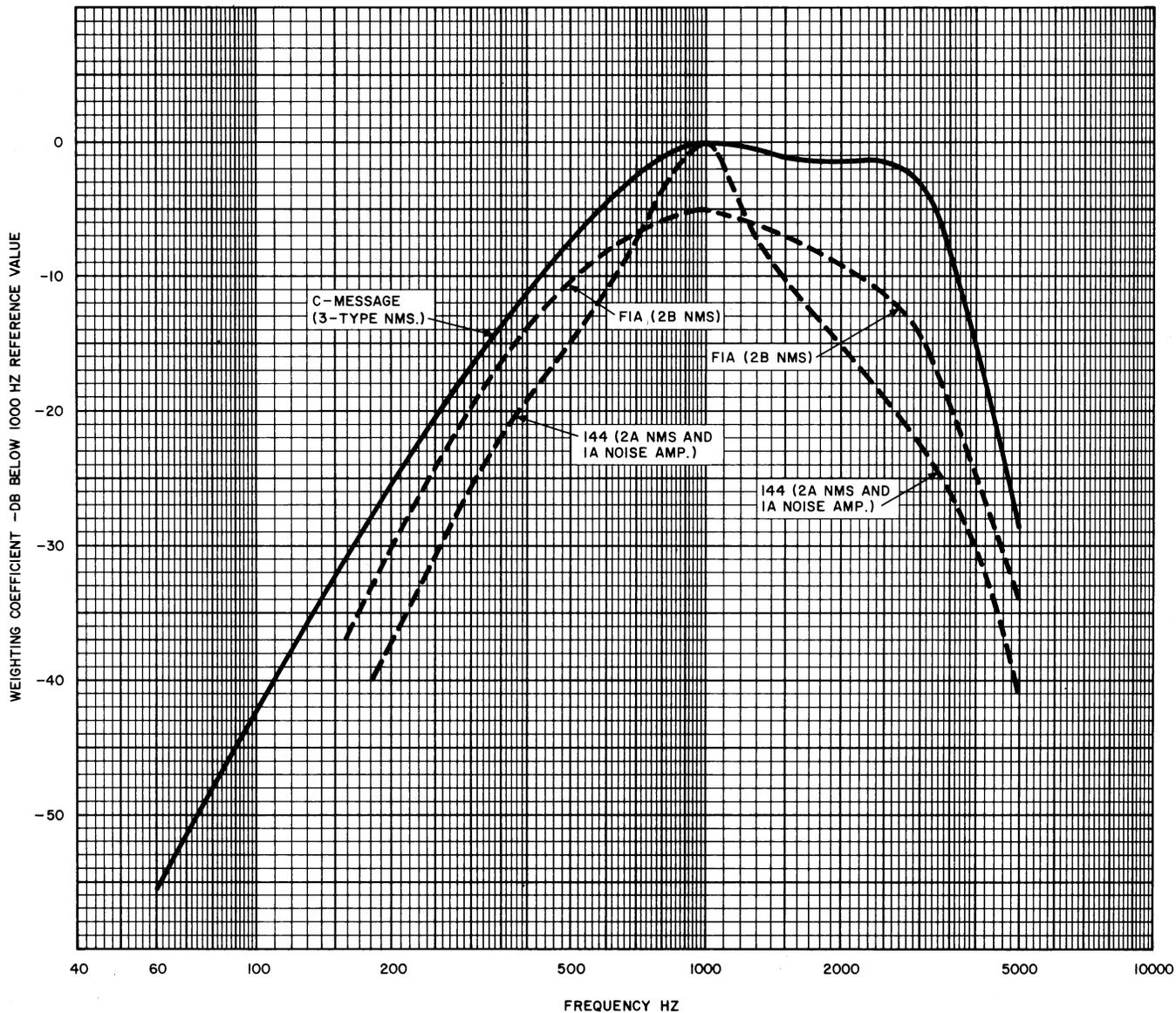


Fig. 1—C-Message and Earlier Weighting Characteristics Compared

APPENDIX 3

OTHER NOISE WEIGHTINGS AND REFERENCE LEVELS

Telephone sets manufactured in Europe and used in other parts of the world respond somewhat differently than Bell System sets. As a result, a different message weighting simulates the combined effect of these sets and the subjective characteristics of the users. Procedures similar to the ones used to develop C-message weighting have resulted in a weighting characteristic called "psophometric" (Greek for "noise measure"). Reference frequency for the psophometric curve is 800 Hz, instead of 1000 Hz. Calibration of the psophometer [European or CCITT noise measuring set (NMS)] is in millivolts across 600 ohms, rather than in dB. Figure 1 compares the 1960 CCITT psophometric weighting characteristic curve with the C-message curve.

Since the psophometer is essentially a millivoltmeter and is calibrated as such, its indications must be converted to dB before they can be compared with those of a 3-type NMS. The following relationship relates both psophometric millivolts (mVp) and dBrnc in terms of dBm:

$$\text{dBrn} - 90 = 20 \log_{10} (\text{mVp}) - 57.8$$

Rearranging the expression will permit converting mVp to dBrnc:

$$\text{dBrn} = 20 \log_{10} (\text{mVp}) + 32.2$$

or

$$\text{dBrn} = 90 - 20 \log_{10} \frac{775}{(\text{mVp})}$$

The resulting dBrn will be psophometrically weighted, rather than C-message weighted. Likewise, if a measurement in dBrn were to be converted to

millivolts, the weighting of the dBrn would carry over. The result would be mV C-message weighted or mV 3-kHz flat weighted, but not mVp.

As Fig. 1 shows, the differences between C-message and psophometric weightings are not great. Considerations similar to those described for C-message weighting under Reference Noise Levels (see 2D) apply to psophometric weighted measurements. Thus, if one milliwatt of noise, uniformly distributed in the 100- to 3000-Hz band, is applied to a 600-ohm termination, the voltage across it, when measured by psophometer with 1960 CCITT weighting and read as, or converted to, dBm should compare with the direct measurement of the same noise with a 3-type NMS as follows:

3-type NMS (C-Message Weighting)	88 dBrnc*
CCITT psophometer (1960 weighting) dB equivalent	-2 dBm*

*Both figures rounded to simplify practical computations. The original figures are 88.5 dBrnc and -2.5 dBm, respectively.

Recognizing that the relationship will change for other noise spectra, the following approximate conversion factors are suggested for general comparison that will be within the limits of accuracy of most noise measurements:

CCITT 1960 WEIGHTING	=	3-TYPE NMS C-MESSAGE WEIGHTING
0 dBm	=	90 dBrn
-90 dBm	=	0 dBrn

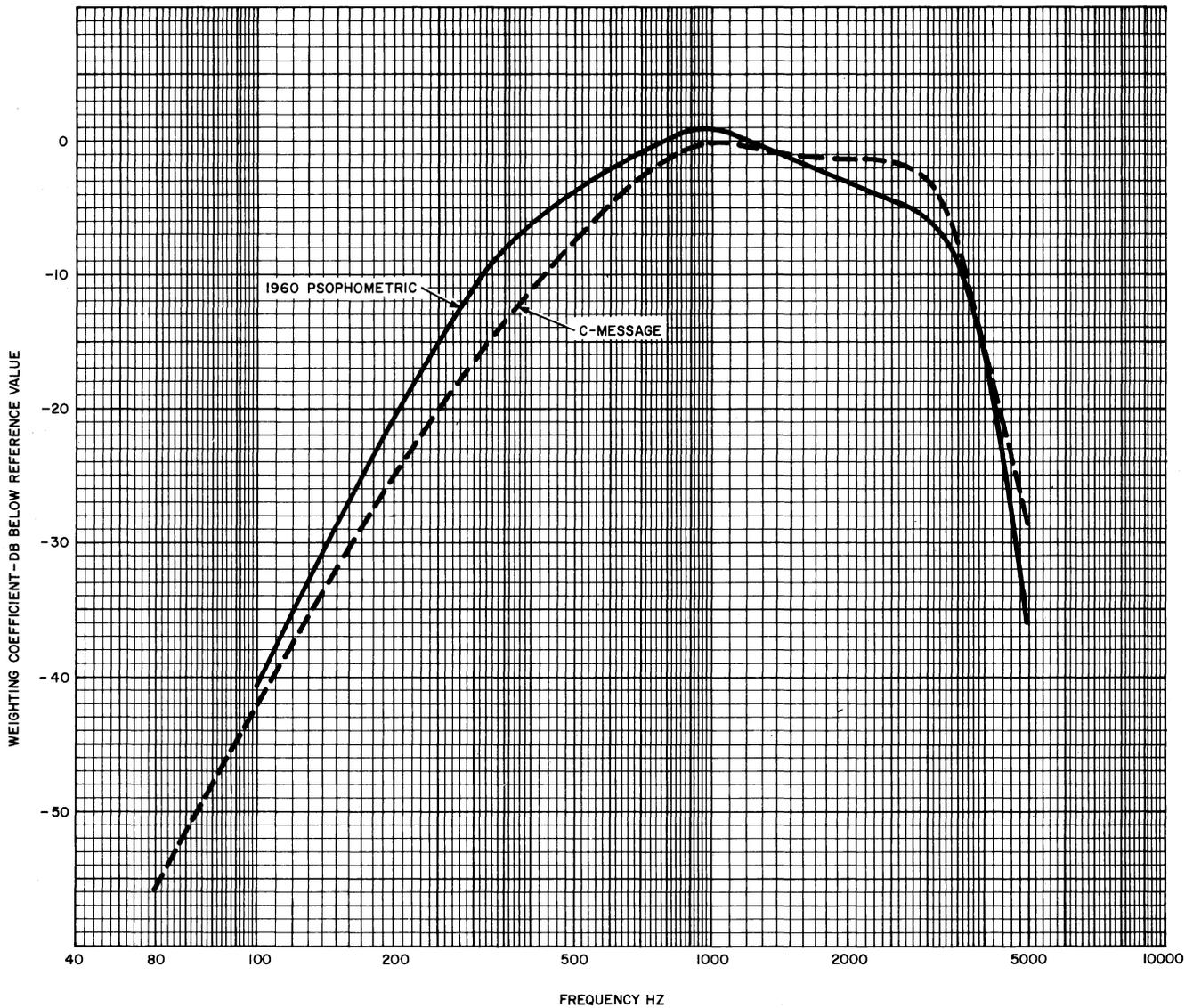


Fig. 1—C-Message and Psophometric Weightings Compared

These conversion factors include the effect of the difference between the reference frequencies used (800 Hz in the CCITT psophometer, 1000 Hz in the 3-type NMSs).

$$-90 + 31 = -59 \text{ dBm}$$

For example, noise measured with a 3-type NMS at 31 dB_{rnc} should read about:

This, when converted to millivolts, would approximate the reading on a CCITT psophometer with 1960 weighting.

APPENDIX 4

DEVELOPMENT OF REFERENCE NOISE LEVEL

Noise was first measured by comparing the sound made by the noise of interest in a standardized receiver to the sound in the same receiver when connected to a calibrated 1A noise source. A potentiometer on the 1A or 3A noise shunt provided for adjusting the loudness of the standard noise. This potentiometer was calibrated from 0 to 10,000 noise units, with 0 being inaudible. When the tester judged that the two sounds made by the standardized receiver were of equal intensity, the position of the potentiometer would indicate the number of noise units. A table then showed the degree of transmission impairment that would result from the number of noise units measured.

Transmission impairment was determined in dB by subjective tests of speech in the presence of noise. Essentially, in these tests speech without noise was attenuated until it was judged equally intelligible as similar speech in the presence of calibrated noise. The effective attenuation in dB was used as a measure of the noise transmission impairment.

TABLE A
NOISE EVALUATION

NOISE TRANSMISSION IMPAIRMENT (DB)	NOISE UNITS	DB ABOVE REFERENCE NOISE
0	0 to 200	0 to 29
1	201 to 300	29 to 32
2	301 to 400	32 to 35
3	401 to 550	35 to 38
4	551 to 700	38 to 40
5	701 to 850	40 to 42
6	851 to 1000	42 to 43
7	Over 1000	Over 43

In Table A, "dB above reference noise" refers to measurements with the 1A noise amplifier. This instrument was the first direct-reading amplifier-type

noise measuring device. It was used in conjunction with testboard-mounted transmission measuring sets. Since this equipment was calibrated in dB, a reference noise value was required. A combination of field experience and laboratory study resulted in the definition: "**Reference noise** is any circuit noise which gives the same meter reading as one micro-microwatt of 1000-Hz power. This corresponds approximately to a sound in the receiver of a telephone set which could just be heard in a quiet residence." The receiver referred to was the 144-type used with deskstand and old-style wall-type telephones built on a wooden mounting. It is likely, too, that the residential rooms referred to were, on the whole, quieter than similar rooms today.

Later, the same 10^{-12} watt reference was standardized as 0 dBrn for 144 line and receiver weightings, as provided in the 2A and 2B noise measuring sets (NMSs).

The improved response of the 300-type telephone sets created a need for a major revision in noise weighting. The new weighting was designated "F1A", an acronym for the F1 transmitter and HA1 receiver units used in the 300-type telephone set. To have kept the 10^{-12} watt reference at the time F1A weighting was developed would have meant that the 2B NMS would have to be replaced by a more sensitive instrument. Instead, the 2B NMS was modified. Since this reduced the sensitivity, the reference was changed to -85 dBm at 1000 Hz or to -82 dBm in the 3-kHz voiceband. To avoid confusion, the designation dBrn was replaced by dBa (dB adjusted).

The design of the 3A NMS presented an opportunity to review the noise reference level. The completely new design made possible increased sensitivity. Therefore the older reference of 0 dBrn = 10^{-12} watt was reinstated. This reference is related to the older usage in name only. As Fig. 1 of Appendix 1 shows, C-message weighting differs greatly from 144 weighting. Thus, the old designation dBrn does not apply directly. Therefore, to avoid any implications of similarity, a small letter "c"

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follows the letters *dBrn*, which becomes *dBrnc*, or the legends "3 kHz Flat," "program," or "15 kHz Flat" are added to avoid ambiguity:

dBrn—3 kHz Flat

dBrn—Program

dBrn—15 kHz Flat

The designations "3 kHz Flat" and "15 kHz Flat" appear as "3 KC Flat" and "15 KC Flat" in most references prior to this. In this and in future discussions the new designations will be used to conform with the internationally adopted usage.

APPENDIX 5

IMPEDANCE CORRECTION FOR BRIDGED MEASUREMENTS

When a noise measuring set (NMS) calibrated for use at a specified impedance is set for bridging measurements, the results will be cor-

rect only if the circuit being measured is at the specified impedance.

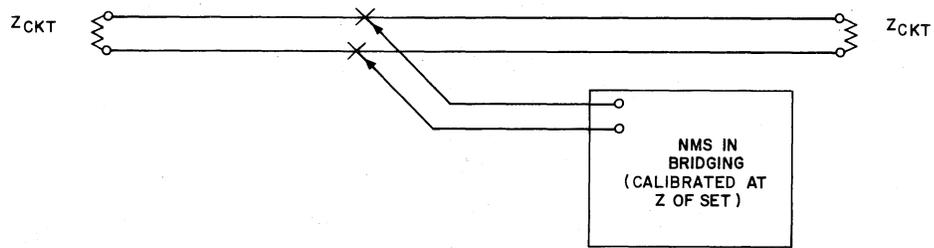


Fig. 1 — Bridging Measurement

If $Z_{Ckt} \neq Z_{Set}$:

$$\text{Correction in dB} = 10 \log_{10} \frac{Z_{Set}}{Z_{Ckt}}$$

To avoid logarithms of fractional numbers when

$$Z_{Set} < Z_{Ckt}$$

use: correction dB = $-10 \log_{10} \frac{Z_{Ckt}}{Z_{Set}}$

Fig. 2 shows these corrections for $Z_{Set} = 600$ ohms and $Z_{Set} = 900$ ohms.

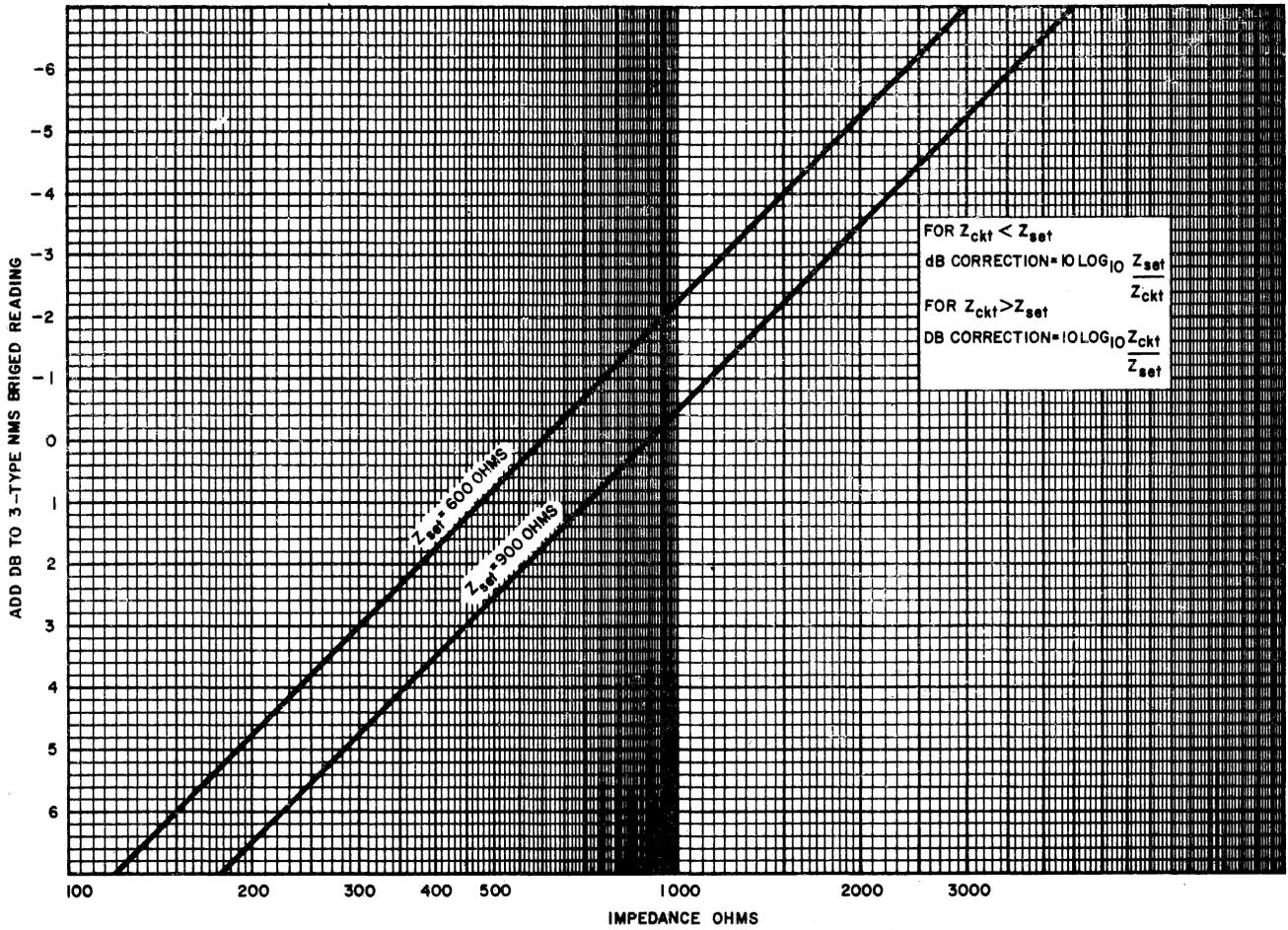


Fig. 2—3-Type NMS—Bridging Measurements—Corrections When Circuit Measured Is Other Than 600 or 900 Ohms