MESSAGE CIRCUIT AND C-NOTCHED NOISE

GENERAL INFORMATION

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1. GENERAL

1.01 ➧This section contains general information relative to message circuit and C-notched noise and their effects on voice and data transmission. Its purpose is to provide background information for employees working with noise problems, noise sources, and methods of measuring noise on message circuits. Cross-office noise, PBX line and subscriber loop noise measuring procedures and requirements are covered in the 331-division. Similar procedures and requirements for message trunks are covered in the 660-division. Message circuit noise test limits for data transmission on the Message Telecommunications System (MTS) network are covered in Section 314-205-500.➧

1.02 This revision is required to incorporate general information on message circuit C-notched noise measurement. Revision arrows are used to emphasize the more significant changes. Equipment test lists (ETL) are not affected.

1.03 With use of message circuits for data transmission and nonvoice forms of transmission, it is imperative that personnel responsible for the maintenance of the facilities used in the communications network have a basic knowledge of noise and its control.

1.04 The telephone subscriber is critical of audible noise on the line. Likewise, in nonvoice transmission, the terminal equipment requires that noise be low compared to the signal. Therefore it is essential that noise be controlled. For practical reasons it is impossible to eradicate all noise sources. However, every effort must be made to reduce noise interference as much as possible.

2. MESSAGE CIRCUIT NOISE CHARACTERISTICS

A. General

2.01 An electrical signal in a message circuit will appear acoustically at the output of the receiver of a telephone set or as a signal at the input of a terminal device. If the signal is a good reproduction of the signal inserted at the distant terminal of a message circuit, it is useful as speech, data or other signal format. If the signal is random, has no intelligence, or is unwanted, it is called ***noise.***

2.02 Noise may enter the subscriber loop, the private line, the PBX trunk, the interoffice or intertoll trunk, or any part of a message circuit connection. This message circuit noise may consist of any combination of unwanted frequencies or pops and clicks, whether they contain information or not, that interfere with the reception of speech or data from a normal connection. In practice, measurements with noise measuring sets (NMSs) of narrowly defined characteristics identify the presence and level of message circuit noise.

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

B. ▶C-Message Noise—Voice Transmission

2.04 Message circuit or "C-mess" noise, heard by individuals using the telephone, can be annoying or even troublesome during a conversation because the noise is heard during pauses in the conversation. C-mess noise is a weighted average of the noise within an idle voice circuit as measured by the 3-type NMS equipped with a frequency weighting called "C-message weighting." (C-message weighting is described further in paragraph 2.11.) One well-known method for reducing this noise is through the use of compandors which introduce considerable loss in the circuit when there is no speech present. Noise increases during speech syllables, but is not as annoying subjectively as is the noise heard during pauses. Therefore, compandors are used throughout the Bell System in all short-haul analog and digital carrier systems.

C. C-Notched Noise—Data Transmission

2.05 When data is transmitted on a message circuit, it is the noise present during active transmission (receiving data) and the corresponding signal-to-noise ratio that is most important; the noise during pauses or breaks is of concern only if it exceeds the receiver detection threshold. In systems using compandors or quantizers, the noise increases during active transmission. Therefore, for noise measurement purposes, active-circuit conditions must be simulated on an idle circuit. This is accomplished by transmitting a 1004-Hz tone from the far end of a circuit to activate compandors and other nonlinear elements. If digital devices are present in the circuit, the test tone activates the analog-to-digital (A-D) converters in the digital equipment allowing the resulting quantizing noise to be passed on to the NMS. The 1004-Hz tone is removed at the NMS by means of a very narrow band rejection or "notch" filter. When the tone is removed the remaining noise on the facility plus 1004-Hz harmonics and tone leak-through represent C-notched noise. The ratio of at least 24 dB must be maintained between the 1004-Hz holding tone measured with 3-kHz flat weighting and the noise on the facility measured with C-notched weighting. (C-notched weighting is described further in paragraph 2.14.)◀

D. Definitions of Terms

2.06 Message circuit noise is usually described as hum, tone, static, frying, hissing, crosstalk, impulses, etc. Because these terms tend to become somewhat confusing in use, a brief definition of their accepted meaning as they relate to noise follows.

Babble: see ***crosstalk.***

Background: describes the usually accepted noise on any telephone circuit. Background noise should be within measured limits. A low level of background noise is sometimes considered to be a desirable indicaton of a live circuit.

Clatter: occasionally is used to describe the general background noise from central office (CO) sources. It includes dial pulses, pops and clicks, telegraph or teletype thump and the like. Clatter is least noticable under light calling conditions and is most noticeable during the busy period.

Crosstalk: usually describes unwanted speech in message channels. It may consist of intelligible words or 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: frequently originates at base metal contacts carrying current. It resembles the sound of frying.

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, transistors, and to a lesser degree, resistors. Hissing is characteristic of the noise on radio systems.

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: 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 objectional in speech, but are a serious problem with data service and should not be neglected.

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 noise increases as the system load increases.

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 the 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: originally referred to the crackling, popping sound produced especially in AM radio sets by nearby and distant lightning discharges. It now refers to similar sounds heard in telephone receivers, 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: may also be called singing—refers to sound 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: is the classical term for thermal noise. It makes a rushing or hissing sound in a telephone receiver. (See ***hissing.***)

E. Subjective Aspects—Relative Interfering Effect

2.07 Noise of sufficient magnitude coincident with speech or data signals will impair reception of those signals. Noise in the absence of speech may produce a more disturbing effect on a listener than it will when speech is present. Parts of speech destroyed by excessive noise may not be lost entirely. The human mind has the capability of inserting lost syllables (by reasons of redundancy or intersymbol influence); and, unless the noise is of sufficient magnitude and duration, intelligence can be communicated. However, data signals are composed of discrete bits of information and noise interference can completely destroy the message content. Data machines are not affected by idle period noise unless the noise has the characteristics of a data signal which can be reproduced.

2.08 The interfering effect of noise on speech or data signals or the annoyance effect depends upon the magnitude, duration, and frequency content of the noise and its relation to corresponding characteristics of the desired signal. The effect is also related to the frequency response of the telephone set and of the 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 narrowband or to a wideband of frequencies, his acoustical environment, and other factors affect his response to noise. These factors are termed subjective aspects of noise. Data machine reactions are controlled mostly by their sensitivity and frequency response, since environmental conditions have no effect on the machine operation. Interference can come only from the circuit. These factors are termed subjective aspects of noise. The items concerning the measurable electrical parameters of noise and the telephone system are the objective aspects.

2.09 The design of a noise measuring set or system must include consideration of both the subjective and the objective aspects. Measuring sets are divided into two catagories: NMS and impulse counters. Noise measuring sets are used for both speech and data transmission parameters, while impulse counters are used primarily with data services.

2.10 The NMS simulates 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. It includes a weighting network that attenuates certain frequencies more than others on a basis known as C-message weighting. The meter movement itself is designed 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. Impulse counters are designed to count pulses of predetermined magnitude in a given time period. They also use weighting networks. Additional information on impulse counters, their use and objectives, is found in the Bell System Practices applicable to the type of set.

F. C-Message Weighting

2.11 The objective C-message weighting 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 weighting low and high frequencies at levels that are an appropriate number of decibels (dB) below the arbitrary reference value at 1000 Hz. Thus, an NMS must attenuate low and high frequencies with respect to 1000 Hz in accordance with the C-message curve, to correctly evaluate their interfering effect and this is accomplished with the C-message weighting network.

2.12 Strictly speaking, the C-message weighting network is correct at only one level of loudness. 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 network is considered suitable for making message circuit noise measurements.

2.13 C-Message Weighting is the present Bell System standard for message circuit type noise measurement. Other weightings have been used in the past and may be encountered in obsolete equipment. ➧3-kHz FLAT➧ networks are available for measurement of unweighted noise. Program and 15-kHz weightings are available for noise measurements on broadcasting and other circuits which pass wider bandwidths than message circuits. Wideband circuits may require weighting networks that are peculiar to wideband transmission requirements. ➧Weighting characteristic curves are illustrated in Section 103-611-101.➧

G. ➧C-Notched Weighting

2.14 The C-notched weighting characteristic has the C-message frequency weighting with a

50-dB attenuation notch, 30-Hz wide centered at 1010 Hz. The notch attenuates typical holding tones from 995 Hz through 1025 Hz. Outside the notch, the weighting has the same loss-frequency shape as C-message weighting, thus the name C-notched weighting. The C-notched characteristic curve is illustrated in Section 103-611-101.◀

3. ▶MESSAGE CIRCUIT NOISE REQUIREMENTS

3.01 Message circuit noise requirements and investigative procedures for central offices, PBX lines, subscriber loops and trunks are covered in several divisions of Bell System Practices. The noise requirements for trunks are in some cases system oriented and in other cases application oriented. If requirements cannot be met, the majority of the techniques used to reduce C-message circuit noise will also reduce C-notched noise. In digital (T-type) carrer systems, methods used to improve distortion measurements will improve C-notched noise. The relationship between the various divisions of practices and the 331- division may be seen from the following discussion.

A. Trunks

3.02 C-message and C-notched noise requirements for message trunks vary according to facility type and mileage. C-message noise requirements for the MTS networks are covered in Section 660-403-500. C-notched noise limits and signal-to-C-notched noise ratio in dB for data transmission on the MTS network are covered in Section 314-205-500. Noise requirements for the switched special services (SSS) network are covered in the 311- division (to be revised).

B. Central Office (CO), PBX Lines and Subscriber Loops

3.03 C-message noise requirements and test methods for central offices, PBX lines and subscriber loops are covered in the 331- division. Currently, there are no equivalent C-notched noise requirements specified.◀

4. MESSAGE CIRCUIT NOISE MEASURING EQUIPMENT

4.01 The design of an NMS must ensure 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 for combining the weighted components

(d) A reference level and scale of measurement

(e) Inputs compatible with the circuits to be tested.

4.02 The 3-type NMS, when arranged for C-message ▶or C-notched◀ weighting, meets these requirements as follows (sections in the 103-6 layer of Bell System Practices contain additional information).

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

(b) ▶The plug-in KS-21567 L1 network provides C-notched weighting. Its response approximates the interfering effect of noise in the voice-frequency band on data transmission. The response provides a 50-dB attenuation "notch" to remove the 1004-Hz holding tone transmitted from the far end. The network when turned over provides 3-kHz flat weighting. The two sides of the filter provide convenient means for making signal-to-C-notched noise ratio measurements. (See Table A.)◀

(c) The meter is designed to reach 99 percent of full-scale deflection in 200 milliseconds. This simulates the time response of a typical human ear.

(d) 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

TABLE A

PLUG-IN NETWORKS AVAILABLE FOR USE IN 3-TYPE NMS

DESIGNATION	CODE	APPLICATION
C-MESSAGE/3-KHZ FLAT	497A	C-Message Circuit Noise
PROGRAM/15-KHZ FLAT	497B	Program Channel
1004-HZ NOTCH/3-KHZ FLAT	KS-21567 L1	C-Notched Noise

standard sine wave signal. This is called quasi-rms rectification.

(e) The meter scale reads from 0 to 12 dBrn in 1-dB steps, with a single mark to the left of the zero for -10 dBrn. With an internal attenuator capable of 85 dB in 5-dB steps and voltage amplifiers having a total of more than 90-dB flat gain (30 Hz to 15 kHz), noise measurements can range from below 0 dBrn to above 90 dBrn.

(f) Input impedances match those commonly used in the telephone system. The 3A and 3B NMSs have both 600- and 900-ohm input impedances for terminating a circuit to make noise-metallic measurements. The 3C NMS has an input impedance of 735 ohms. This is a compromise between 600 and 900 ohms so that a set with this input impedance will measure correctly within about ±1 dB when calibrated on and used with either 600- or 900-ohm circuits. (It may provide an incorrect answer if used as a termination for any other purpose.) 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 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 paragraph 5.04.)

4.03 The 3-type NMS and similar NMSs measure weighted 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} watts (0 dBrn) dissipated in each of the four most common 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 weighted power levels referred to 10^{-12} watt.

4.04 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 waveshape.

4.05 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 or other tones. The 4A frequency analyzer, or an equivalent instrument, will make such an analysis. The 103-635 layer of Bell System Practices describes the 4A frequency analyzer.

4.06 The 7A carrier frequency NMS includes all the basic features described in paragraph 4.01, 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 497A plug-in network as the 3-type NMS, 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. The 103-5 layer includes a section on the 7A carrier-frequency NMS.

4.07 Testboards and voice-frequency patching bays may be equipped with either, or 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. Modifications provide C-message weighting in the SD-95900-01 and 43A Noise Measuring Systems. Unmodified systems will give incorrect answers.

4.08 The 3B NMS is electrically identical to the 3A but is arranged for CO battery operation and for rack mounting.

4.09 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 simplify operation by reducing the amount of equipment required at a subscriber station. The 3C NMS makes it possible to dial up a quiet termination and hold the line for measurement. As noted above, it provides a single compromise terminating impedance of 735 ohms and may not be used for any other purpose requiring a precision termination.

4.10 The 3CR NMS, arranged for rack-mounting at testboard locations, contains the basic noise measuring circuit of the 3C NMS and has the same restrictions. 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 CO 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.

5. BASIC NOISE MEASUREMENTS

A. General

5.01 The 3-type NMS and the SD-95900-01 system, equipped with C-message ◆or C-notched◆ 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 (Nm)

5.02 ***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 is an annoyance to customers. Thus, ***noise-metallic measurements are the ones of greatest interest in noise work.***

5.03 ***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 voice-frequency side of carrier-channelizing equipment. Thus, bridged measurements at these points inside CO buildings will be accurate. However, the impedance of most voice-frequency trunks is 900 ohms. Also, cable circuits depart from the nominal 600 ohms by considerable amounts. The impedance of a loaded cable pair 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 at 600 ohms may 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 the 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.

TABLE B

AMOUNTS NEEDED TO CORRECT BRIDGED MEASUREMENTS WHEN CIRCUIT MEASURED IS NOT 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

Note: For noise measuring sets calibrated on 600 ohms

C. Noise-to-Ground (NG)

5.04 ***Noise-to-ground*** is a measure of the noise voltage between one or more conductors and 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. Adding 40 dB to the NMS reading will produce the proper value for comparison with metallic measurements in dBrn.

5.05 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 frequently differing by 60 dB or more.

5.06 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. The frequency of these components can be estimated by subtracting the C-message reading from the flat reading and comparing the difference 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

5.07 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 devices, other carrier systems operated by outside organizations, and other sources. These usually enter cables because of unsuppressed drop wires, branching open-wire leads, ineffective shielding caused by cable sheath discontinuities, open splices, 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

5.08 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.

5.09 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, there will be a difference in voltages in the two sides, causing currents in the message circuit. Even slight imbalances will result in such currents, which produce noise voltages across the terminals of the circuit.

5.10 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 in the above expression 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 (NMS reading plus 40 dB) and the noise-metallic dB.

5.11 Voice-frequency balances, measured in this manner, can be found as high as 70 to 95 dB in 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.

5.12 A procedure similar to that above may be used for estimating balance of carrier frequency lines measured with the 7A carrier frequency NMS. (When reading N_G with the 7A set, the result does not need correction.) 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.

6. NOISE SOURCES, COUPLINGS, AND SUSCEPTIBILITY

A. Noise From External Sources

6.01 Message circuit noise frequently comes from sources external to the telephone plant. Two important external sources are: atmospheric static and induction from exposure to power systems. Noise due to static is distributed rather broadly over both the frequencies of the voice band and the frequencies of the carrier spectrum, 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.

B. Noise From Internal Sources

6.02 Message circuit noise comes from many sources within the telephone plant. Noise sources associated with COs 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 CO sources are often intensified by any unbalanced wiring to which they connect.

6.03 Outside plant cable pairs become secondary sources of noise by being connected to many CO 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.

6.04 Carrier and radio systems are mmajor 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.

C. Couplings

6.05 Noise and crosstalk couplings usually occur at locations where wiring or apparatus of the disturbed circuit is exposed to 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, 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.

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

(a) Magnitude of the disturbing currents

(b) Magnitude 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 magnitudes 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.

6.07 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.

6.08 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.

6.09 Couplings inside the CO may be 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 CO 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.

D. Susceptibility

6.10 ***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.

6.11 Control of susceptibility of a trunk facility begins with the design. 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) compandors,

(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 judgment, develop other effective stratagems.

Finally, the engineers or others who lay out the trunk can do much to take full advantage of the features provided by the designer and by the equipment engineers to keep susceptibility to a minimum.

6.12 Of the methods for reducing circuit susceptibility listed in paragraph 6.11, control of longitudinal balance is perhaps the most important. Noise voltages and currents in a disturbed circuit are usually longitudinal. If the conductors of a well-balanced pair carry approximately the same longitudinal noise current there is little difference of potential between the pairs and thus little noise across the terminal device. It is potential difference between conductors, usually called ***metallic-noise*** (sometimes ***noise-metallic)*** voltages, that generate noise heard in the telephone receiver. Perfect balance is impossible to realize. Conductors are never identical; their series resistance and shunt impedances may vary slightly and tend to unbalance paired conductors.

6.13 Although cable pairs may contain imbalances 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 imbalance especially in the case of voice-frequency circuits. Trouble conditions, such as moisture in a cable, crosses, and inadvertent grounds, can increase susceptibility to noise to a marked degree. These effects are usually of large magnitude and can cause as a marked change in performance in a relatively short time interval. Troubles of this sort are usually quite evident because they affect several pairs. Problems arising from apparatus connected to outside plant pairs are much less evident. Examples of these are listed in the ensuing paragraphs.

6.14 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.

6.15 Subscriber loop equipment, when in good condition and correctly installed, provides adequate balance for control of susceptibility to noise. However, there are a few equipment arrangements and 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 unequally divided between the two sides of the pair, 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 CO and PBX line equipment. Examples are: ground start line circuits, some line relays in step-by-step offices, etc

(g) Unbalanced talking battery supply relays and/or inductors in step-by-step and panel offices

(h) Dirty or partially operated protectors.

6.16 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.

7. NOISE MEASUREMENT CONSIDERATIONS

7.01 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 include an allowance for this loss and noise.

7.02 Noise objectives are stated in various ways, depending on the proposed use. If the objective is for engineering or design purposes, it most likely will be given in terms of the zero level point. The equivalent noise at any other level point may be estimated by adding the gain to or subtracting the loss from the noise at the zero transmission level point to obtain the objective at the point of interest. Conversely, the noise at any level point can be converted to an equivalent noise at the zero level point by subtracting the gain or adding the loss.

7.03 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. Usually, noise levels are in dBrn or in dBrnc. 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, Table B gives corrections in dB to add to the higher of two noise readings to obtain the combined effect of the two. Table C applies 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 WEIGHT

AMOUNT BY WHICH TWO dB 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

Note: Not suitable for quantitites measured in terms of peak power, such as impulse noise