preciate that the oxides and sulphides present were in sufficient quantities to be objectionable although actually of small magnitude.

Through our method of filling no difficulty is encountered in obtaining a completely fused area. A permanent bond, clear to the edge of the cylinder and for about four to six inches into the old charge, results from this procedure, as is shown in figure 5, and by the numerous etched slugs on exhibition in our laboratory.

References 11, 12, and 13 cited in the paper clearly show that certain oxides are to some extent soluble in molten lead. Naturally, it is obvious that it is only on solidification that segregation along boundary lines will take place.

It is well known that the presence of metallic impurities in lead will decrease the tendency to form dross. For instance, lead containing small quantities of copper, tin, or antimony will definitely form less dross for a given time and temperature than lead free from metallic impurities as reported by G. O. Hiers. Thus, if we are to accept Mr. Zickrick's statement that the lead used by D. M. Smith contained more metallic impurities than in use at present by the cable manufacturers, then the tendency to dross, especially under reduced pressure, should have been eliminated at least after the first heat and vacuum treatment.

It is true that the purer the lead the lower will be the tensile properties and the larger will be the grain size and the lower the resistance to fatigue. However, by our technique of sodium treatment, metallic impurities are not removed. The process is a stabilizing one and not a metallurgical refining process. Therefore, the tensile strength of sodium-treated lead is the same as for untreated lead while the resistance to creep is somewhat greater owing to the more uniform and better bonding of the crystals.

The tensile-strength figures given for treated and untreated lead in table I are all very similar and within five per cent, except for the electro plus 0.01 per cent lithium. Tensile tests on strips cut from lead pipes cannot be expected to check any closer than 5 per cent.

The treated electro plus 0.01 per cent lithium lead has a higher tensile strength than the untreated, probably due to the formation of a binary alloy of sodium and lithium.

Regarding figure 7, it is well known that when the creep rate of two leads is compared, the stress at which it is tested must be taken into account. Thus the creep rate of noncopper-bearing lead is much greater than that of copper-bearing lead when tested at 850 pounds per square inch, but the creep rates are equal at some lower stress.

The 500-pound-per-square-inch creep tests of figure 7 and figure 8 are not strictly comparable, one being made on strip and the other on pipe. In the pipe tests the lead is stressed in at least two directions, but in only one direction on the strip tests. The simple pipe formula was used for calculating hoop stress and not the Philadelphia Electric Company formula.

We agree with Mr. Phelps that different results may be obtained when making long-time and short-time tests. We do not consider our tests as short-time tests because, even with the pressure steps used, they have extended over periods of a month or more.

Instruments and Methods of Measuring Radio Noise

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Synopsis: This paper embodies the relevant agreed recommendations of the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA, as to the nature, essential characteristics, and performance of an instrument for the measurement of radio-noise voltages. It further gives detailed descriptions of the recommended practices for measuring radio noise directly from low- and high-voltage apparatus, for making noise measurements along overhead lines, for determining broadcast field-strength levels, and methods of collecting data for the establishment of radio-noise standards.

RADIO-NOISE effects are produced by extraneous electrical fields associated with transient conditions in an electric circuit. In order that apparatus producing these effects can be treated and described in precise terms and the most satisfactory method of radio-noise suppression employed in a given case, it is necessary that there be some means of measuring the radio-noise voltages that are significant in relation to radio reception. It is also desirable that there shall be a national understanding and agreement as to the method of measurement.

The noise voltage produced by electrical apparatus on a given system depends upon the high-frequency voltage generated, the internal impedance of the apparatus, and the character and impedance of the load. This voltage is propagated by conduction, induction, radiation, or a combination of these. All metallic materials, whether used normally for electrical systems or for other purposes, may conduct high-frequency energy.

The radio-noise effect of electrical apparatus on a receiver antenna is influenced by most of the above factors. No definite method has been developed that will permit the calculation of voltage on a receiver antenna when the noise voltage produced by electrical apparatus is known.

Through the co-operative efforts of the Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association, the measurement of radio noise has been placed on an engineering basis. In 1932 this committee adopted specifications for a radio-noise meter and methods of measurement. These were published in NELA Publication No. 32 in 1933. These specifications were revised and published in EEI Publication C9, NEMA Publication 102, and RMA Engineering Bulletin No. 13 in 1935. Due to the advances in the radio art and the increased use of the radio-frequency spectrum, it has been necessary to extend and bring up to date these specifications. All the field data in this paper were taken with a meter built according to the old specifications. However, similar data taken with an instrument according to the new specifications would not be sufficiently different to change the interpretation of the results.

The development of these specifications has resulted in the application of engineering principles to the reduction of radio noise produced by certain types of electrical apparatus. The continuation of this work shows promise of producing more beneficial results in the future.

Radio-Noise Meters

A meter for measuring radio noise should give results which are comparable with the effect of the noise as heard in the loudspeaker of a radio receiver, and at the same time should be accurate and rapid in operation.

Radio noise from different types of apparatus differs in character; some types of noise have high amplitude but are of short duration, whereas others are more nearly sinusoidal in form. Furthermore, the characteristics of the radio receiver upon which the noise impinges will have an effect on the noise characteristics, so that the wave shape of the noise pulse at the output of the receiver may

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differ materially from that at the input.

A noise meter designed to measure the characteristics of the noise pulse as it exists at the input to a radio receiver would be a complex and cumbersome piece of equipment because it would be required to measure noise potentials of the order of microvolts and would have to be capable of amplifying all types of pulse shapes without distortion. Such a device would not be suitable for field measurements and furthermore the results would require correlation with observations of the interfering propensities of the many types of noise.

The most practical type of noise meter is one which is essentially similar to a radio receiver, with indicating means in the output. Such a device may be made convenient to operate, portable, and reliable. The indications of noise intensity for various types of noise on this type of noise meter depend upon the design constants chosen, but it is preferable to have a simple indication such as this type of noise meter provides and then to classify types of noise-making apparatus if necessary, rather than to use a complex noise meter which does not alter the noise pulse, as in the latter case classification of noise types is replaced by correlation of pulse shapes.

Indicating Means

There are three general types of output indicators which may be used:

1. Oscilloscopes
2. Wave-form analyzers
3. Indicating meters

Oscilloscopes and wave-form analyzers are useful for theoretical investigation of noise, but do not provide ready numerical means of expressing results, and are more difficult to use than an indicating meter. Indicating meters are convenient and reliable so are to be preferred for general use.

Frequency Range

The noise meter should cover the entire radio spectrum of interest for reception, which is from approximately 150 kilocycles to at least 100 megacycles. However, the design problems for frequencies above 20 megacycles differ materially from those for frequencies below that value so that it is more practical to design two separate instruments, one for frequencies below 20 megacycles and one for frequencies above 20 megacycles. This discussion will be confined primarily to the meter for frequencies of 150 to 350 kilocycles and 540 to 20,000 kilocycles. The wide frequency range dictates the use of the superheterodyne circuit, and because the intermediate frequency thereof will probably be the RMA standard value of 455 kilocycles, there will be a range on either side of this frequency which will not be covered, namely 350 to 540 kilocycles.

Detectors and Indicating Meters

Since the noise is transmitted through the instrument at radio frequencies, detection is necessary before applying the resultant audio-frequency pulse to the indicating meter. The indicating meter may be arranged to read root-mean-square, average, or peak value of the wave. It is generally recognized that on noise pulses of short duration, meters reading average or root-mean-square do not indicate values as high as those disclosed by listening tests. A peak or quasi-peak indicating device has been found to give meter readings more nearly proportional to the auditory interference experienced. Since a peak-reading meter is desired, the meter may be in the detector circuit, thereby eliminating audio amplification. The use of a meter in the detector circuit has the further advantage that calibration of the device can be made by application of an unmodulated carrier-frequency voltage, thus eliminating the necessity of modulation thereon, and eliminating the necessity of determining the modulation factor.

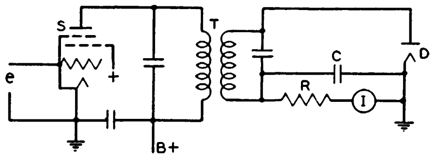

Figure 1. Detector circuit

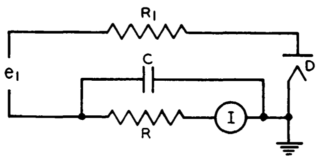

Figure 2. Equivalent detector circuit

A detector for noise measurement should meet special requirements, but with due regard for practical design limitations. A typical diode detector, which is the most satisfactory and reliable type detector, is shown in figure 1. The radio-frequency voltage, e, noise or signal voltage as the case may be, is applied by preceding amplifier circuits to the input of the final intermediate-frequency amplifier tube S. Tube S in turn impresses the voltage on diode D through the intermediate-frequency transformer T. In the diode circuit are a resistance R, a capacitor C, and the current-indicating meter I. Tube S and transformer T can be replaced by an equivalent voltage e_1 and resistance R_1 as shown in figure 2. Capacitor C is charged by e_1, through R_1 and discharges through R. The time constant on charge is then R_1C and on discharge RC.

If voltage e_1 is a suddenly applied potential, capacitor C will charge to 63 per cent $(1-1/\epsilon)$ of e_1 in time R_1C. On discharge the voltage of C will drop to 37 per cent $(1/\epsilon)$ of its initial voltage in time RC. Now if the discharge time constant RC is long in comparison with the charge time constant R_1C, the voltage of C will build up to very nearly the peak value of the applied voltage. In considering the mechanism of build-up of voltage to the peak value, it should be borne in mind that noise voltage consists of a series of impulses, the measured voltage reaching essentially the peak value after the first few impulses. In the very rare case of noise consisting of a single pulse, or pulses with a repetition time longer than the discharge time constant of the metering circuit, a value considerably less than the peak would be indicated. However, experience would tend to show that the disturbing effect of such noises on the listener is less than would be indicated by their peak amplitude.

In determining the time constants of the metering circuit, consideration must be given to meter characteristics, noise characteristics, and to circuit design limitations. An indicating meter which is too rapid in action is expensive and is difficult to read, whereas a meter with too long a time constant makes circuit design difficult. A meter with a time constant of 200 to 400 milliseconds is suitable, the time constant of the meter for this use being considered as the time required for the meter to deflect from zero to an equilibrium position upon the application of a steady current equal to about two-thirds full-scale value. This corresponds to a meter with a natural period of 0.5 to 0.7 second with a damping factor of 10 to 100 determined according to American Standards Association standard methods.

It is desirable that the time constant of the noise meter be determined by the circuit values rather than by indicating-meter constants, because the former are more readily determined and may be held more closely. By making the circuit charge time short and discharge time long in comparison with the indicating-meter time constant, this may be accomplished.

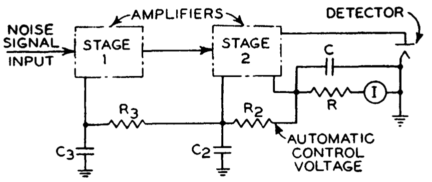

Figure 3. Logarithmic amplifier

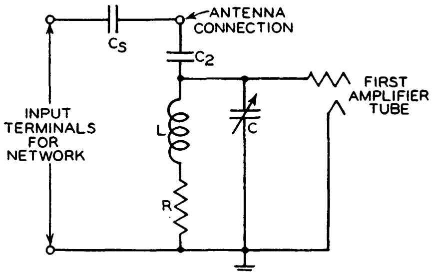

Figure 4. Input circuit

It is difficult to secure an equivalent resistance on charge (R_1 of figure 2) of less than 20,000 to 30,000 ohms with receiving-type vacuum tubes, whereas fixed resistors for discharge (R of figure 2) become difficult to determine accurately and are not stable in value above approximately 5 megohms. This, therefore, in conjunction with the indicating-meter constants determines the permissible range of values for C and for charge and discharge time constants. It should also be borne in mind that the peak voltage is given by IR so that for any value of voltage, the lower we make R, the greater I will become, thus permitting use of a less sensitive indicating meter. In some cases where it is desirable to use a relatively insensitive meter and a high value of R, a d-c amplifier may be used. From the above considerations, a charge time constant of the order of 10 milliseconds and a discharge time constant of the order of 600 milliseconds are indicated.

The following tabulation shows several possible combinations of circuit values which result in these time constants for charge and discharge.

R (Megohms)	C (Microfarads)	R_1 (Ohms)
5	0.12	83,000
4	0.15	67,000
3	0.2	50,000
2	0.3	33,000
1	0.6	17,000

If it is desired to measure the signal intensity of a broadcast-station carrier or to use the audio-frequency noise output for listening or other type of indication, the time constant RC should be of the order of 0.1 millisecond, which may be done by appropriate reduction in the value of C when such measurements are required.

SELECTIVITY

Steep-wave-front disturbances involve a broad band of frequencies for their transmission and when transmitted through a selective amplifier undergo a change in shape. The energy content of a high amplitude pulse of short duration is unchanged by a selective amplifier, but its maximum amplitude is decreased and its duration correspondingly increased. Since this shape alteration of sharp pulses takes place in radio receivers in proportion to their selectivity, in order to correlate noise-meter indications with radio reception, it is desirable to have comparable selectivity. The over-all pass band of radio receivers, from antenna to loudspeaker, varies widely, from about 1,500 cycles in the lowest-priced receivers to 6,000 or 8,000 cycles in the case of receivers of high fidelity. Since good-quality receivers merit additional consideration, the noise meter should have somewhat greater pass band than that of the average receiver. The high-frequency end of the pass band is of prime interest, frequencies lower than 60 cycles seldom being of interest in noise studies. The noise meter should then transmit frequencies of 4,000 to 5,000 cycles, which means the selective circuits should have a band width twice as great because of double-side-band considerations.

SENSITIVITY

While it is desirable to have signal intensities of five to ten millivolts per meter from broadcasting stations for good reception, there are many localities where no signal over 500 microvolts per meter is available. A signal-to-noise ratio of 30 decibels for average program to average noise is generally conceded to constitute a minimum ratio for acceptable reception so that the noise meter must be capable of measuring noise voltages of the order of ten microvolts. It is seldom that noise voltages of more than 100 millivolts are of interest, which determines the upper limit of noise-meter calibration. However, such voltages should not undergo any limiting action by the noise meter, nor should such voltages cause generation of spurious responses, so the amplifiers of the noise meter should be capable of handling peak values up to about ten volts input.

METER SCALES

A scale on the indicating meter which is logarithmic in character has several advantages over a linear scale. In the first place it fulfills the psychological conditions of Weber's law and in addition makes the use of fewer attenuator taps possible, with resultant increase in simplicity of construction and use.

The logarithmic characteristic is best secured by electrical means. The deflection law of the meter itself is linear, the angular deflection of the pointer being proportional to the current through the meter.

The automatic-volume-control system as used on radio receivers provides a ready means of obtaining such a characteristic. By the use of remote-cutoff vacuum tubes in the noise-meter amplifier stages, a sufficient amount of control can be applied to each stage to obtain a useful input range of about 40 decibels on each meter scale range without amplifier overload or distortion.

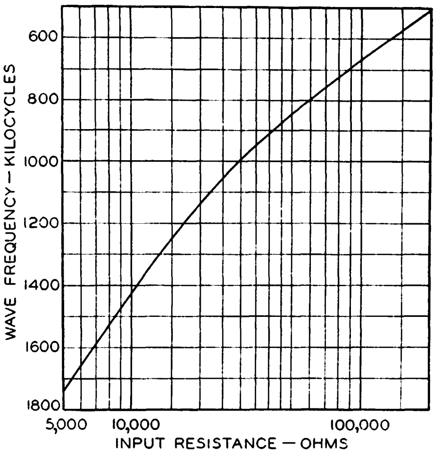

Figure 5. Noise-meter input resistance with circuit of figure 4

In figure 3 is shown the method of obtaining logarithmic indication. The direct current developed by the detector is filtered by R_2C_2 and R_3C_3 to eliminate any intermediate-frequency or noise component and is then applied to bias the amplifier stages. The time constant of the filter should be of the order of 200 milliseconds so that it will not influence the meter indication, the time constant for noise measurement being that of the detector circuit only.

The meter scale is calibrated logarithmically in microvolts or linearly in decibels above one microvolt and the value of noise input in microvolts is thus read directly on the indicating meter.

The meter scale is useful over a ratio of inputs of about 100 to 1 by virtue of the logarithmic system used, but in order to cover the entire desired range of 10 to 100,000 microvolts, multipliers of 10 and 100 should be used. These multipliers are in the form of attenuators for the noise input, and in order that none of the tubes be overloaded, must precede the first tube. The attenuator may be of the resistance type, or may be of the capacitance or mutual inductance type, any one of which can be made to have the desired attenuation independent of frequency.

INPUT CIRCUITS

The input circuits should be suitable for use either with a vertical-rod antenna for measuring noise or signal field intensities or as a voltmeter. In either case the impedance of the input system should be high, so that the voltage existing on the antenna or across a standard coupling network will not be affected by connection of the noise meter. One type of input circuit which fulfills these requirements is shown in figure 4.

The antenna should be a relatively short vertical rod with an effective height of one-half to one meter which means a physical height of approximately twice that value. Such an antenna has an inherent capacitance of 10 to 20 micromicrofarads, and C_s should have the same capacitance so that the input circuit will be tuned correctly when the meter is used either with the antenna connection or as a voltmeter.

The impedance of this type input system is a pure resistance when tuned for maximum response as the *LRC* circuit under such condition becomes an equivalent resistance and inductance in series, the value of the inductive reactance being equal to the capacitive reactance of C_s and C_2 in series. In order to secure a suitable high impedance, a small capacitance C_2 is placed in series with the circuit. The capacitance of C_s and C_2 in series should be of the order of three micromicrofarads. If we assume this to be three micromicrofarads and L to be 166 microhenries, and the power factor of L to be one per cent, at broadcast frequencies, the equivalent resistance of the input circuit as a function of frequency will be as shown in figure 5.

CALIBRATION SOURCE

The noise meter should be battery operated for field use, which means that the gain will change with battery usage as well as due to aging of tubes and effects of atmospheric humidity. In order to make the instrument readings accurate, the gain must be standardized each time the instrument is used. The gain standardization requires the incorporation of a self-contained calibrating source. The primary calibration should be performed by means of a standard signal generator but a comparison standard must also be included in the noise meter itself.

There are three possible types of calibration sources which might be used, an internal radio-frequency oscillator with a meter to indicate its output, the inherent thermal agitation noise voltage of the noise-meter input circuit, or the shot noise from a saturated diode. The latter two are simple to incorporate and depend only upon constancy of resistance of the input circuit. For an input circuit resistance of 10,000 ohms and a band width of 6,000 cycles, the thermal agitation voltage is 1 microvolt at a temperature of 20 degrees centigrade, whereas the shot noise for a current of one milliampere is 14 microvolts, under the same conditions, so is easier to apply.

The shot noise voltage is given by

$$E_s^2 = 31.8 \times 10^{-20} i R^2 F$$

at a temperature of 20 degrees centigrade where

E_s is shot noise voltage
i is current in amperes
R is input circuit parallel equivalent resistance in ohms
F is frequency pass band in cycles

The circuit of figure 6 may be used for the calibration source. *LC* is the input tuned circuit and *R* is a resistance shunted across this circuit during calibration so that the total circuit resistance will be more uniform with frequency. *B* is a battery of sufficient voltage so that the diode draws saturation current. R_1 is a resistor which varies the diode filament temperature until the space current as read by meter *I* reaches the calibration value. Meter *I* may be the output indicator of the noise meter switched to the position shown in figure 6 for calibrating purposes. The amplifier gain is then adjusted to standard value by variation of screen or initial bias potential.

In the design of such instruments, due consideration must also be given to shielding, image-frequency response, and intermediate-frequency response ratios, so that the noise indicated is due only to that existing at the frequency to which the meter is tuned.

Methods for the Measurement of Radio-Noise-Influence Voltage Produced by Electrical Apparatus

The term "noise-influence voltage" will be used hereafter to describe the radio-noise voltage measured at the terminals of electrical apparatus when connected to a coupling network. This term is used in order to make a definite distinction between this voltage and the radio-noise voltage that may appear at the input terminals of a radio receiver. The noise voltage that appears between the antenna and ground will hereafter be referred to as the "noise voltage."

NOISE-INFLUENCE VOLTAGE OF LOW-VOLTAGE DEVICES

The noise voltages produced by low-voltage electrical apparatus are generally caused by the transmission of high-frequency currents along the wires or conductors connected to the apparatus. These currents are due to the electromotive forces produced by the apparatus at its terminals. As such apparatus is generally grounded or has a substantial capacity to ground, the currents will not be confined to the conductors connected to it but will in addition be propagated via ground. It is, therefore, necessary to consider the disturbing currents as consisting of two components, one corresponding to the electromotive force acting between the various conductors, hereafter referred to as the line-to-line noise-influence voltage (E_L) and the other

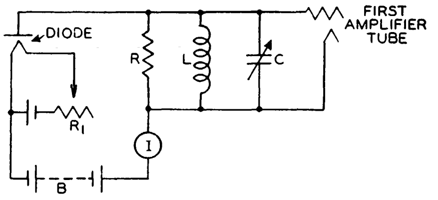

Figure 6. Calibration method

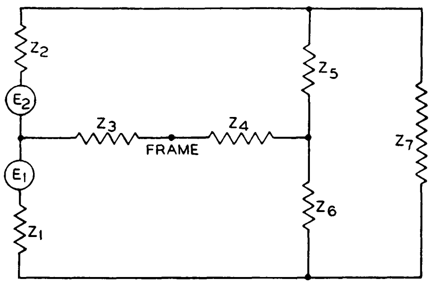

Figure 7. Equivalent circuit showing the various impedances involved when a universal motor is connected to a line

Z_1, Z_2—Impedance of field windings
Z_3—Capacity of field windings and armature to frame
Z_4—Capacity of frame to ground
Z_5, Z_6—Impedance from line to ground
Z_7—Impedance from line to line
E_1, E_2—High-frequency voltage developed at brushes

corresponding to the electromotive force acting between the ground as one pole and the conductors jointly as the other, this being hereafter referred to as the line-to-ground (E_G) noise-influence voltage.

Effect of Variation in Termination on the Noise-Influence Voltage

The amplitude of the noise-influence voltage produced by electrical apparatus is determined by the external terminating impedance as well as its internal impedance. This may be seen by referring to figure 7 which is a simplified circuit for the various impedances involved when a universal motor is connected to a supply line. It will be noted that the line impedance network is represented as a delta system. In service conditions, the voltage induced upon a receiver antenna is associated with the vector sum of the voltages across Z_5 and Z_6. Consequently, any network that is developed should be so designed that the line-to-ground component will be taken vectorially. This can be accomplished readily by a star network as shown by figure 11.

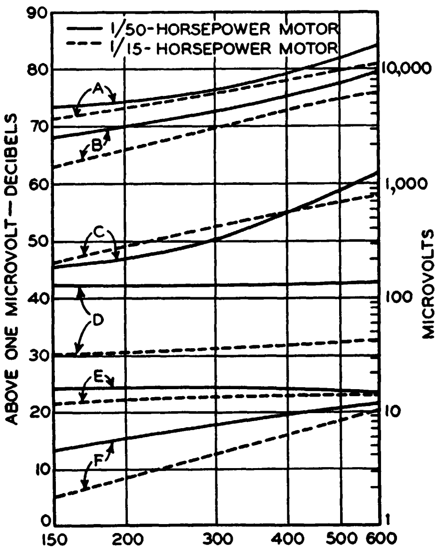

Figure 8. Noise-influence voltage from 1/50- and 1/15-horsepower universal motors with various terminating impedances

A—Line to ground, frame grounded
B—Line to line, frame grounded or ungrounded
C—Line to ground, frame ungrounded
D—Line to line, frame grounded or ungrounded—filtered
E—Line to ground, frame grounded—filtered
F—Line to ground, frame ungrounded—filtered

The noise-influence voltages produced by $^1/_{50}$- and $^1/_{15}$-horsepower motors with terminating impedances of 600–300 and 150 ohms are shown by figure 8. It will be seen that the measured average noise-influence voltages are seven decibels higher with 600 ohms than with 300 ohms and five decibels higher with 300 ohms than 150 ohms in the following conditions:

1. Line-to-line, grounded or ungrounded (not filtered)
2. Line-to-ground, grounded and ungrounded (not filtered)
3. Line-to-ground, ungrounded (filtered)

Where filters are applied to the motors all three impedances give identical line-to-line and line-to-ground (frame grounded) voltages.

Some field tests have indicated that the variation in the impedances of supply lines in homes may vary from 10 to 2,000 ohms with an average around 150 to 300 ohms. Other investigators have measured an average impedance of 80 ohms. The supply-line impedances vary considerably from location to location and are not pure resistances but contain reactive terms. Some of the supply lines that have been measured were resonant in the broadcast band. Lines with impedances that contain reactive terms may increase or decrease the noise voltage from electrical apparatus, depending upon their phase relation with respect to the internal impedance of the apparatus. The impedance of supply lines may vary from day to day. Turning on a lamp may change the line impedance characteristics so as to cause the noise voltage from apparatus to increase or decrease a considerable amount.

Field tests indicate that the impedance of each wire to ground is different, thereby causing a high-frequency unbalanced termination for the apparatus. Laboratory tests have indicated that the minimum noise voltage from electrical apparatus will be obtained when the terminating impedances are balanced with respect to ground. A mathematical analysis of figure 7 will also show this.

This effect was determined by using a circuit as shown by figure 9 where *A*, *B*, and *C* were the terminating resistors and the other network utilized to measure the vector sum of the line-to-ground voltage. When *A*, *B*, and *C* were 200, 300, and 300 ohms respectively, providing a resultant resistance of 150 ohms between lines and between each line and ground, the line-to-ground voltage was 240 microvolts. When *B* was short-circuited, *C* made equal to 600 ohms, and *A* equal to 200 ohms, providing a line-to-line resistance of 150 ohms and 150 ohms from one line to ground, the line-to-ground voltage increased to 1,920 microvolts. This impedance unbalance resulted in a line-to-ground voltage that was three times as great as the line-to-ground voltage obtained with a balanced 600-ohm network. This test probably produced a greater unbalanced condition than will exist in practice. However, it does show the necessity of considering unbalanced systems in the field.

Field measurements on unfiltered devices also indicate that, because of the impedance unbalances of supply systems, the networks used for measuring the noise-influence factor should have impedances greater than the average line impedances measured in the field. Figure 10 shows the ratio between the noise-influence voltage produced by a motor when terminated with a 600-ohm network and as measured on various supply lines. In this figure the ordinates are the average of the voltage measurements taken at three frequencies in 20 residences. It may be seen by this curve that 50 per cent of the cases had 25 per cent or more of the voltage measured on a 600-ohm network. Twenty per cent of the cases had 60 per cent or more of the voltage measured on the 600-ohm network. If this motor had been measured on a 150-ohm network, 50 per cent of the cases would have had a voltage on their supply line that would have been 100 per cent or more of the voltage measured when using a network.

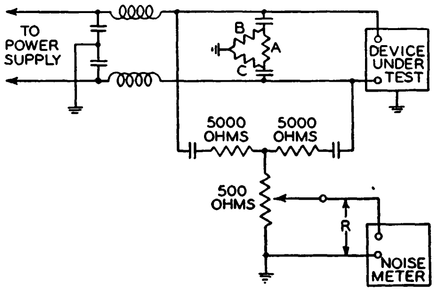

Figure 9. Circuit used to determine the effect of unbalancing the terminating impedance

Circuits Used for the Measurement of Radio-Noise-Influence Voltage at the Terminals of Apparatus Normally Connected to Single-Phase Domestic Supply Lines

The auxiliary devices and detailed methods of measurement contained in this paper have been developed primarily for the 550–1,500-kilocycle broadcast band. It is probable, however, that the same methods can be used for measurements at frequencies higher than this, but since the problem of measurement at these higher frequencies is now in the developmental stage, the scope of this paper, so far as detailed measurement procedure is concerned, is limited to frequencies below 1,600 kilocycles.

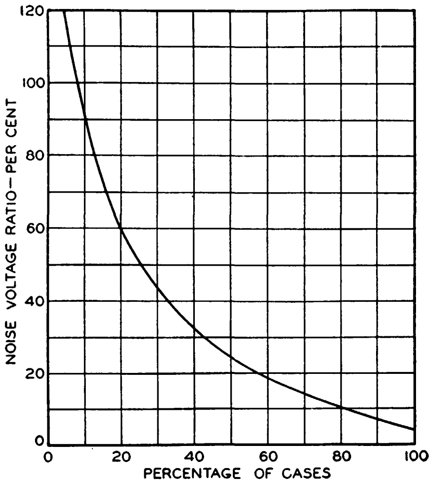

Figure 10. Per cent of noise-influence voltage existing on supply lines

The measurement of noise-influence voltage at the terminals of single-phase low-voltage apparatus such as motors, appliances, etc., is accomplished by a circuit arrangement as shown in figure 11.

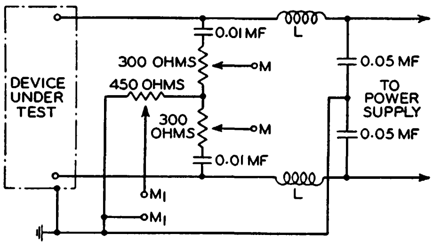

Figure 11. Circuit for the measurement of noise-influence voltage produced at the terminals of single-phase low-voltage devices

M-M—Terminals for line-to-line measurements
*M*1-*M*1—Terminals for line-to-ground measurements
L—Radio-frequency choke coils

Measurement of the line-to-line voltage (E_L) is made by connecting the radio-noise meter across the terminals *M-M*. This voltage may be obtained by measuring the voltage across a known portion (R) of the 600-ohm resistance between lines. This measured voltage is multiplied by $600/R$ to obtain E_L.

Measurement of the line-to-ground voltage (E_G) is made by connecting the radio-noise meter across the terminals M_1-M_1. This voltage may be obtained by measuring the voltage across a known portion (R) of the 450-ohm resistance. The measured voltage is multiplied by $600/R$ to obtain E_G.

This network is constructed with resistors that are noninductive at the radio frequencies employed in the measurements. These resistors may be of the metallized filament or carbon type commonly used in radio receivers. They should preferably be mounted with the coupling capacitors in a nonferrous metallic case. The resistance values should not differ from the specified values by more than five per cent plus or minus. Furthermore, the resistance between one line terminal and the ground terminal should not differ by more than one per cent from the resistance between the other line terminal and the ground terminal. Taps for suitable ratios can be secured by proper selection of resistor units.

It is necessary that the radio noise already existing in the supply circuit independently of the apparatus under test should not be included in the measurements and that the normal impedances existing between the supply lines and ground should not modify, in any essential respect, the characteristics of the measuring circuit. These two results are achieved by inserting in each supply lead between the measuring circuit and the terminals of the supply line a choke having a radio-frequency impedance of not less than 5,000 ohms at the frequency of the test. The chokes must be so designed that any drop in the supply voltage due to the load current of the apparatus does not cause the terminal voltage to fall below the normal rating of the apparatus.

Method of Making Measurements

The frame of the apparatus is normally grounded.

The final reading is the mean of the values measured during a period of not less than ten seconds.

In the case of apparatus having noise-influence voltages of the nature of impulses with long intervals between them, the reading is the mean of the values of ten impulses.

The network should be connected to the supply circuit by a twisted pair of leads 24 inches long and to the noise meter by leads not exceeding 4 inches.

It has been the experience to date that it is necessary to ground the device under test if comparable results in various locations are to be obtained. However, for apparatus that is normally ungrounded in service the grounding of the apparatus may increase considerably its apparent ability to produce noise. Because of the lack of information on this subject it is desirable to include in this paper the precautions that must be taken when measuring ungrounded apparatus.

In order that the capacitance to ground of apparatus tested ungrounded shall be standardized for the purpose of measurement, the apparatus under test should be placed 15 inches above the metallic floor of the test room in an insulated position. The distance to the walls of the room should not be less than 15 inches. The radio-noise meter, networks, and the person in charge of the test should be at a distance greater than 15 inches from the apparatus. If a shielded room is not available, the apparatus should be placed at a height of 15 inches over a grounded metal plate which is not less than seven by seven feet.

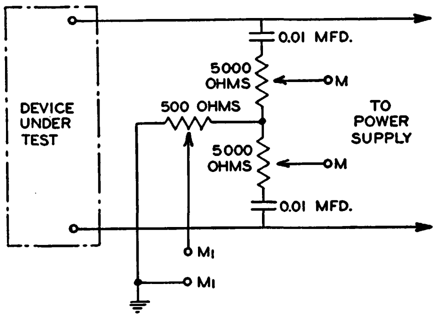

Figure 12. Circuit for the measurement of noise-influence voltage on equipment in the field

M-M—Terminals for line-to-line measurements
*M*1-*M*1—Terminals for line-to-ground measurements

Circuit Used for the Measurement of Noise-Influence Voltage at the Terminals of Low-Voltage Three-Phase Equipment

A network similar to that used on single-phase apparatus may be used for three-phase systems. The network consists of three 300-ohm resistors connected in Y with a 500-ohm resistor connected from the neutral to ground. This arrangement provides a network with 600 ohms between phases, and 600 ohms between ground and all phases in parallel. The line-to-line voltage (E_L) between any two phases may be obtained by measuring the voltage across a known portion (R) of the 600-ohm resistance between the lines. This measured voltage is multiplied by $600/R$ to obtain E_L.

The line-to-ground voltage (E_G) may be obtained by measuring the voltage across a known portion (R) of the 500-

ohm resistance, and multiplying the measured voltage by $600/R$ to obtain E_G.

MEASUREMENT OF RADIO-NOISE-INFLUENCE VOLTAGE ON EQUIPMENT IN NORMAL SERVICE

In normal service the noise-influence voltage of apparatus cannot be measured accurately by the networks previously described because of the possibility of these networks changing the impedance of the load circuit. Consequently, a measuring network having little effect on the impedance of the load should be used. Among those types of apparatus that require different networks are telephone equipment, complicated power switchboards, supply lines, etc.

A network which can be used for measurements on such systems is shown in figure 12. It is to be noted that this circuit is fundamentally the same as the network used for single-phase measurements, differing only in the change of circuit constants and omission of filter chokes.

By connecting the radio-noise meter to terminals M-M, the voltage across a known portion (R) of the 10,000-ohm resistance between lines can be measured. This measured voltage when multiplied by the conversion factor $10{,}000/R$ gives the noise-influence voltage between lines.

The line-to-ground noise-influence voltage is obtained by connecting the radio-noise meter at points M_1-M_1 across a known portion (R) of the 500-ohm resistor. When the lines are considered jointly, their resistance to ground is 3,000 ohms; thus the conversion factor for the line-to-ground measurement is $3{,}000/R$.

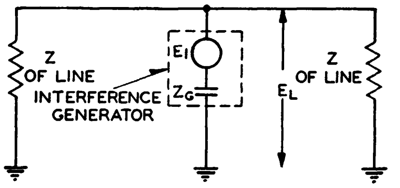

Figure 13. Schematic circuit of a typical high-voltage interference generator

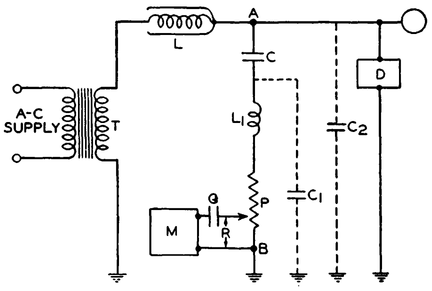

Figure 14. Circuit for the measurement of the noise-influence voltage produced by high-voltage devices

T—Testing transformer

L—Radio-frequency choke, not less than 20,000 ohms at frequency at which measurement is made

M—Radio-noise meter

C—Coupling capacitor, not less than 0.0025 microfarad

G—Dummy antenna

D—Device under test

P—Potentiometer or tapped resistor, 600 ohms resistance, nonreactive

L_1—Inductance between capacitor and potentiometer; ten microhenries, approximately

C_1—Stray capacitance on potentiometer side, not over 50 micromicrofarads

C_2—Stray capacitance on bus side, not over 60 micromicrofarads

RADIO-NOISE-INFLUENCE VOLTAGE OF HIGH-VOLTAGE APPARATUS

The radio-noise voltage produced by high-voltage apparatus is influenced by the same means as the low-voltage devices. It is propagated in the same fashion and the difficulties of determining the radio-noise effect on receivers are as great if not greater than that from low-voltage devices. Consequently, it is necessary, as it is on the low voltage, to measure the noise-influence voltage from this type of apparatus on a standard network.

The noise-influence voltage produced by high-voltage equipment depends upon the internal impedance of the apparatus and the line impedance. An interference generator and its load impedance is shown by figure 13. All high-voltage apparatus generally has an impedance to ground at broadcast frequencies that is larger than the line impedance to ground. Because of this condition, the line impedance affects the transmission line-to-ground voltage E_G. For open-wire lines the impedance Z is between 400 and 600 ohms unless the line is shorter than 10 or 12 wave lengths.

A circuit similar to figure 14 has been used by a number of manufacturers to determine the noise-influence voltage of line apparatus, such as insulators, bushings, and fuse cutouts.

Because of the effect of the distributed capacitances of the high-voltage conductor and coupling capacitor it is necessary to limit these distributed capacitances to the values shown in figure 14 in order that the error be kept under ten per cent at 1,000 kilocycles, where the majority of the measurements are made.

A simplified circuit to show the effect of these distributed capacitances on the voltage measured is shown by figure 15. It is the same as figure 14 except the impedance of the choke coil and transformer has been neglected. If the choke coil in series with the transformer has the impedance specified, this part of the system can be neglected.

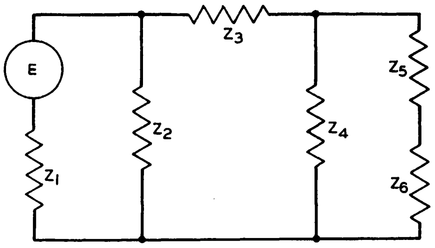

Figure 15. Equivalent circuit of figure 14

E—Voltage produced by device

Z_1—Internal impedance of device

Z_2—Impedance of stray capacitance C_2

Z_3—Impedance of coupling capacitor

Z_4—Impedance ofs tray capacitance C_1

Z_5—Impedance of series inductance

Z_6—Terminating resistance

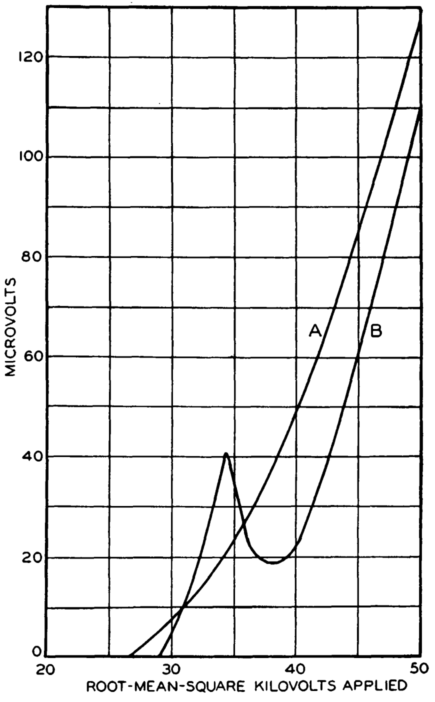

Figure 16. Effect of power-supply wave form

A—Corrected wave form

B—Distorted wave form

The voltage appearing across the resistance R figure 14 (Z_6 figure 15) is:

$$E_{Z_6} = E\frac{Z_2Z_4Z_6}{Z_{11}Z_{22}Z_{33} - Z_{11}Z_4^2 - Z_{33}Z_2^2}$$

where:

$Z_{11} = Z_1 + Z_2$

$Z_{22} = Z_2 + Z_3 + Z_4$

$Z_{33} = Z_4 + Z_5 + Z_6$

From the foregoing, it will be noted that stray capacitances will introduce errors, which must be given consideration in the design of a circuit such as shown by figure 14. If it is assumed that the voltage that would be measured with a pure resistance of 600 ohms across the device ~~is~~ E_R, then the error in per cent introduced by the system as shown by figure 14 is $\frac{E_R - E_{Z_6}}{E_R}100$.

Effect of Power-Supply Wave Form on the Noise-Influence Voltage

Tests in the laboratory have shown that supplying a distorted 60-cycle voltage wave to the testing transformer will produce erroneous measurements. Curve *A* of figure 16 shows the noise influence produced by a treated pin-type insulator when the testing transformer was supplied by a system that contained a high percentage of harmonics. The source of voltage for this test was such as to result in a change in both the phase relationship and per cent magnitude of the various harmonic components for various values of root-mean-square voltage readings.

Correcting curve *A* to agree with the measured crest voltage readings did not materially improve the appearance of this curve.

The testing transformer was then supplied from a motor generator set and the curve *B* as shown by figure 16 was obtained.

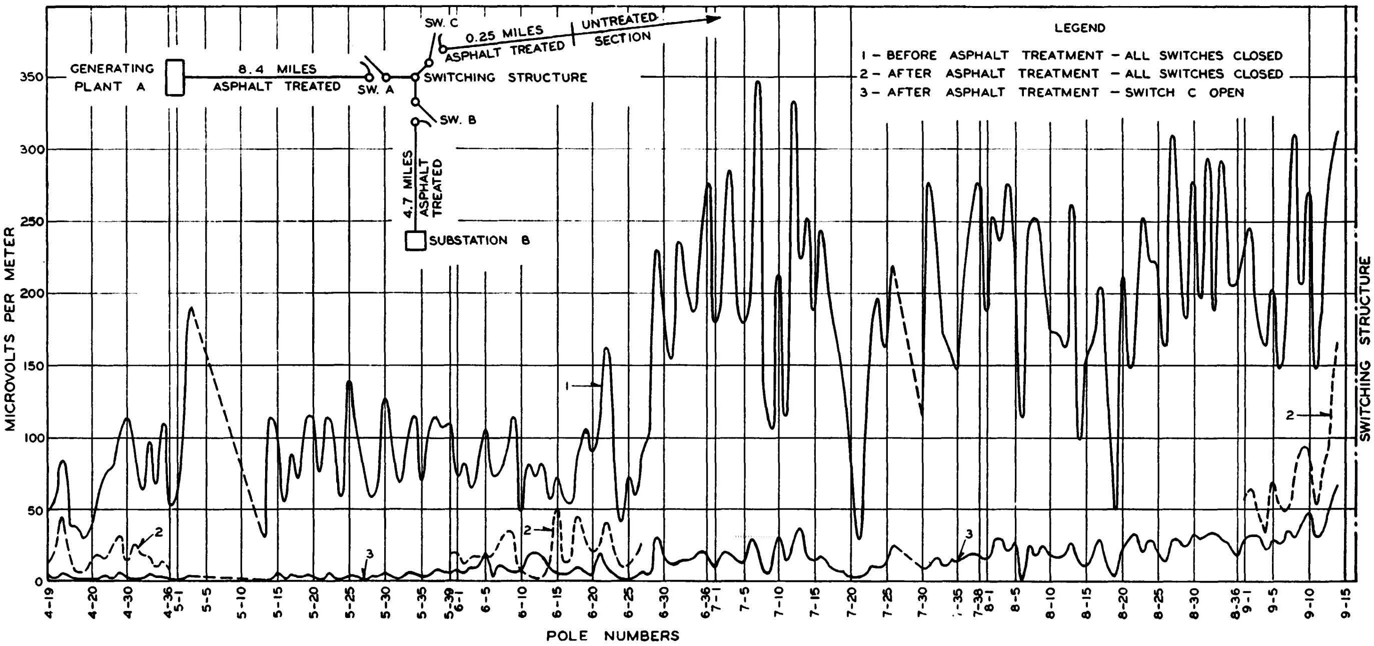

Figure 17. Noise measurements along a transmission line—case I

Field Applications

In the preceding paragraphs radio-noise meters and methods of measurement have been described in detail. With the instruments available, and with the development of a suitable measuring technique, definite progress can be made by those engaged in the investigation and mitigation of noise phenomena.

Power companies and other agencies which have used noise-measuring equipment in the field have found it to be valuable in a number of ways, some of which are enumerated as follows:

1. Investigation and analysis of complicated noise problems on transmission and distribution systems.
2. Quantitative determination of noise characteristics of electrical apparatus and appliances for the purpose of determining their suitability from a noise standpoint.
3. Analyses of situations where special devices have been applied for mitigating noise effects.
4. Accumulation of data for establishing acceptable noise levels. Examples of the foregoing applications are given in the following paragraphs:

Measurement of Noise Along Transmission Lines

Figures 17 and 18 show, in graphical form, measurements made along 66-kv pin-type transmission lines where asphalt emulsion was applied to the heads of the insulators so as to close all voids between the surface of the insulator and the energized conductor and tie wires. Figure 17 covers a situation where measurements were made over a 5-mile section of the line before and after the asphalt application. A total of approximately 13 miles of line was treated between the generating station marked *A*, and the substation marked *B*. At a point 8.4 miles from the generating station there is a switching structure from which point a tap line extends for approximately 20 miles to another generating station. Except for approximately one-quarter of a mile from the tap structure, this line was not treated with asphalt at the time the measurements were made.

The explanation of the higher noise level in the sixth to ninth miles lies in the fact that this particular pole line carries both 66- and 11-kv circuits arranged in vertical configuration with the 66-kv circuit occupying one side of the pole and the 11-kv circuit the other side. Measurements were taken with the noise meter placed in a car with the antenna rod mounted on the side window. As a result, the 11-kv circuit was nearest the car up to pole 6-27 and probably shielded the higher-voltage circuit to some extent, while beyond this point the conditions were reversed. In making the measurements the car was always headed in a direction such that the rod would be on the side toward the pole line. Measurements were taken at each pole at an approximate distance of 20 feet transverse to the center of the line, and care was exercised to maintain this separation at the various pole locations.

Since the installation of the noise meter in the car would be expected to affect the measurements as compared to operating the noise meter with a standard rod as a unit on the ground, an antenna

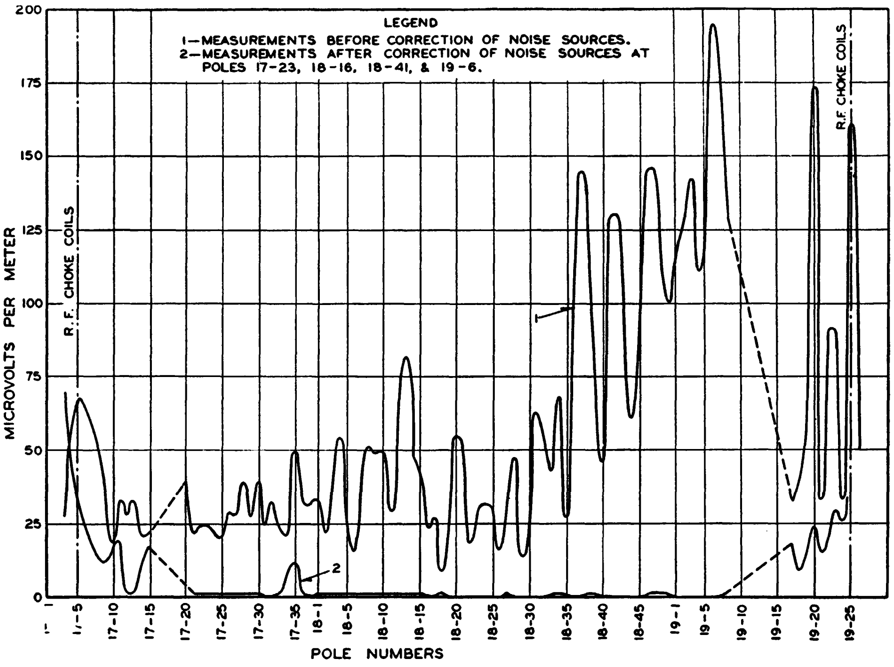

Figure 18. Noise measurements along a transmission line—case II

factor was secured in the following manner: A pole location was selected and a measurement made with the equipment installed in the car. A mark was placed on the road directly under the rod antenna, after which the instrument was removed and the car run ahead approximately 50 feet. The instrument was then placed on the ground in a position so that the rod was in the same vertical line as when mounted on the car, after which another measurement was taken. The second measurement divided by the first, gave an antenna factor for the particular frequency used and all measurements made with the measuring equipment in the car were multiplied by this factor. Aside from the quantitative results obtained in reducing the noise level the measurements indicated that a higher noise level existed in the eighth and ninth miles and beyond, probably due to inadequate asphalt coatings, and that the closing of switch *C* on the untreated tap line, raised the noise level all along the asphalted section, thus showing the results of noise propagation along the line from a distant source.

Figure 18 shows a somewhat different situation than the one just described. In this case a smaller section of line was treated with asphalt emulsion, with the addition of line-type radio-frequency choke coils installed at each end of the treated section, to attenuate the noise generated in the adjacent untreated sections. About two years after this job was completed, the noise along this line attained very high levels with the result that measurements were made along the line as shown on curve 1. These measurements indicated a source of noise at pole 19-6 with less severe disturbances originating at other points. Due consideration, however, had to be given to the possibility of reflections from the choke coils. It developed that an insulator at pole 19-6 was found to have cracks in two of the shells which gave rise to severe noise. Incidental cases were found also at poles 17-23, 18-16, and 18-41. The correction of these conditions resulted in curve 2, which indicates a very low noise level for this type of line. In making these measurements the same precautions were taken with respect to lateral distance from the line and the determination of an antenna factor as outlined in the discussion of figure 17.

MEASUREMENTS OF LOW-VOLTAGE APPLIANCES

In the measurement of radio noise produced by low-voltage electrical appliances, it is desirable to utilize the information in such a way that it will be possible to rate these devices according to their radio-noise effects when operated in a home or place of business. This feature applies also to noise levels of high-voltage equipment and their relation to reception in the home, but the data on this phase of the subject, at present, are somewhat meager. This discussion, consequently, while applying in principle to all classes of apparatus, will refer specifically to the use of appliances in the home.

In analyzing any case involving interference with radio reception, the question of signal-to-noise ratio must be given consideration. In applying the reasoning prompted by this conception of the problem, it follows that reception can be improved either by increasing the signal level or by reducing the noise. Obviously there are limits beyond which each of

Table I. Radio-Noise Measurements, Low-Voltage Motor Appliance

		Noise-Influence Voltage*			Residence Measurements					Noise Voltage on Antenna (Per Cent)		
		Line-Ground								Noise-Influence Voltage Line-Ground		
Kilocycles	Station	Grounded	Ungrounded	Line-Line Grounded	Line-Ground†	Noise Voltage on Antenna	Signal Voltage on Antenna	Signal-to-Noise Ratio (Decibels)	Quality Reception	Grounded	Ungrounded	House Wiring, Line-Ground
610	*M*	1,200	160	208	585	107	396	11.4	*E*	8.9	66.6	18.3
660	*N*	1,280	170	188	612	97	140	3.0	*F*	7.6	58.2	15.8
710	*O*	1,310	184	166	610	79	860	20.8	*C*	6.0	42.9	12.7
760	*P*	1,200	207	145	370	30	1,240	32.3	*A*	2.5	14.5	8.1
830	*Q*	1,120	223	123	153	13	290	27.0	*B*	1.2	5.8	8.5
860	*R*	1,120	220	117	125	10	350	30.8	*A*	0.9	4.6	8.0
1,020	*S*	1,270	240	84	93	6	352	36.2	*A*	0.5	2.5	6.4
1,170	*T*	1,370	305	84	40	9	435	34.2	*A*	0.7	3.0	22.5
1,200	*U*	1,380	318	85	25	9	198	27.4	*B*	0.7	2.8	36.0
1,440	*V*	1,500	255	130			12,300		*A*			
Average		1,275	228	133	290	40				3.1	17.5	13.8

* In accordance with figure 11. † In accordance with figure 12.

Table II. Measurements of Signal and Noise Voltage on Antenna Systems

Kilocycles	Station	Signal: Conventional	Signal: Noise Reducing	Noise: Conventional	Noise: Noise Reducing	Signal-to-Noise Ratio (Decibels): Conventional	Signal-to-Noise Ratio (Decibels): Noise Reducing	Improvement, Noise Reducing Over Conventional
610	*M*	336	450	35	15.5	19.5	29.1	9.6
660	*N*	310	143	43	12	17.1	21.5	3.4
710	*O*	930	695	51	9.5	26.1	37.1	11.0
760	*P*	1,790	1,230	62	8	29.2	43.5	14.3
830	*Q*	530	570	89	7	15.5	38.0	12.5
860	*R*	450	336	106	8	12.5	32.1	19.6
1020	*S*	470	2,400	90	59.5	14.1	32.0	17.9
1170	*T*	560	1,570	102	33.5	14.9	33.5	18.6
1440	*V*	260	120	126	34.5	6.0	11.0	5.0

these factors cannot go, these being dictated by geographical location, local conditions, the status of the art, and other considerations. While opinions differ to some extent, a number of measurements have indicated that where the signal-to-noise ratio is 30 decibels or greater, satisfactory reception is obtained. With decreasing values of signal-to-noise ratio, reception becomes increasingly unsatisfactory, finally reaching a point where all program reception is impossible when the signal-to-noise ratio is zero decibels or lower.

Table I shows a tabulation of a number of measurements made under various conditions on a motor-driven electrical appliance. The data include measurements made from line to ground (E_G) and from line to line (E_L) in accordance with the circuits shown in figures 11 and 12. All measurements of noise in the residence were made at frequencies adjacent to the broadcast-station channels, the noise at the latter frequencies being obtained by interpolation. Other measurements include the noise voltage from the customer's house wiring to ground, noise on the customer's antenna, signal on the antenna, signal-to-noise ratio in decibels, and quality of reception. The latter item is intended to indicate the reaction of the listener to various signal-to-noise ratios, and it has been found convenient to express these aural effects as follows:

A—Entirely satisfactory

B—Very good, background unobtrusive

C—Fairly satisfactory, background plainly evident

D—Background very evident, but speech easily understood

E—Speech understandable only with severe concentration

F—Speech unintelligible

By referring to table I it will be noted that a definite relation can be established between the noise-influence voltage and the results in a residence for a particular appliance. It has been found that even with the same appliance, results will vary in other residences. The data collected by the Joint Co-ordination Committee on Radio Reception of the EEI, NEMA, and RMA show that the relationship between noise measured at the factory and on the customer's antenna varies over a very wide range. This is due to such factors as the coupling between the antenna and supply system, the electrical characteristics of the house wiring system, the susceptibility of the radio receiver to noise pickup by means other than the antenna connection, and finally, the field intensity of the radio station being received. Through the accumulation and analysis of a considerable amount of data, eventually it will be possible to determine generally acceptable noise-influence voltages for appliances and other electrical apparatus. In making a study of this character it must be recognized that it is not economically feasible, and in many cases practically impossible, to select limiting noise-influence voltages which will satisfy all conditions and locations. As a result, limits that may be acceptable generally will have to be recognized as taking care of a certain percentage of cases rather than all cases.

Measurements on Antenna Systems

In the foregoing paragraphs, reference has been made to the signal-to-noise ratio and to the coupling between the antenna and house wiring system. One method of increasing the signal-to-noise ratio is by reducing this coupling by means of a noise-reducing antenna system of suitable design and proper installation. Quantitative data to compare one antenna arrangement with another may be obtained by measuring both signal and noise separately on the two antenna systems and determining the signal-to-noise ratios for each antenna arrangement. Since the proper functioning of most noise-reducing antenna systems requires that the pickup section of the antenna be located beyond the intense portion of the noise field, the noise meter can be used to advantage in determining the best location for the antenna. This may be accomplished by making a survey at various points on the premises, using the noise meter and its associated antenna rod. The final results can then be checked after the antenna is installed.

An example of the data which may be secured and the results which can be obtained, is shown in table II. In this installation, the conventional antenna was an inverted L type with a 60-foot flat top and a lead-in located 40 feet from the overhead line carrying the disturbance. The noise-reducing antenna consisted of a vertical wire 37 feet long located 100 feet from the overhead line carrying the disturbance. A coupling transformer was mounted near the ground level at the lower end of the vertical antenna with a 12-inch lead to a ground pipe. From this point a twisted-pair transmission line, laid on the ground for the test, ran to the radio set in the house where another coupling transformer was installed directly at the antenna and ground terminals of the set. The conventional antenna was removed during the period of making measurements on the noise-reducing antenna. As in the case of table I, noise measurements were made at other frequencies and interpolated for the broadcast channels.

It will be noted that the signal-to-noise ratio was increased in varying degrees from 3.4 to 19.6 decibels when using the noise-reducing antenna and that on the basis of approximately 30 decibels signal-to-noise ratio, seven out of the nine stations involved were received satisfactorily with the noise-reducing antenna, while only one could be placed in that category with the conventional antenna arrangement. These data are given to indicate the application of the noise meter to a given situation rather than to show the maximum attainment possible with a noise-reducing antenna system. Under more favorable conditions with respect to antenna location and other factors, a much greater increase in signal-to-noise ratio would be a likely possibility.

Discussion

J. J. Smith (General Electric Company, Schenectady, N. Y.): The specifications for an instrument for measuring radio noise and the description of the methods of measurement given by the authors in this paper should be of considerable help to those who have to study the problem of radio interference. It is hoped that this work done under the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA will tend to produce a uniformity in the methods used by different workers and encourage measurements along the standard procedure.

In many cases of investigation of complaints of radio interference due to power equipment the only type of measurement made is to listen with a radio set. The data thus obtained, however, are not of great assistance since they tell only the relative value of the interference and the radio signal and do not give the actual value of either.

The signal field strength available for radio reception varies considerably from place to place. Thus, as far as radio reception is concerned, in a locality where the field strength is of the order of thousands of microvolts a given piece of power equipment might be used without affecting radio reception. However, when the same piece of equipment is used in a locality where the field strength of the radio signal is of the order of a few microvolts it might make reception difficult. Thus it is evident that the field strength at the point of reception is an important part of the radio-interference problem, and it is only by having a definite measure of its magnitude and also a knowledge of the magnitude of the noise-influence voltage produced by the device that the best solution can be obtained.

Another advantage of this new meter is that it is expected it will be available at a lower cost than the meters previously used. This should result in its being more widely used and thus assist in obtaining data on both the signal strengths at the point of reception and the noise-influence voltage of the electrical apparatus in the same location together with the resulting radio reception.

Similar work on studies of the problem of radio interference has been going on in Europe and a committee (CISPR) of the International Electrotechnical Commission has developed standards for a radio-noise meter quite similar to the one described in this paper. However, there are certain differences and I should like to ask the authors what these differences are and the reasons why it did not appear desirable to make the two meters the same.

Charles M. Burrill (nonmember; RCA Manufacturing Company, Inc., Camden, N. J.): The "quality of reception" ratings listed in table I are based on a subjective scale of values devised by the writer in 1934 for use in an unpublished research on broadcast reception at ultrahigh frequencies. This scale has been found useful within the RCA organization in a number of radio-noise and interference investigations. However, the figures in table I are the first to be published comparing ratings on this subjective scale with signal-to-noise ratios determined objectively with a radio-noise meter.

In 1936 we made a few tests to correlate the readings of a quasi-peak noise meter with our "quality of reception" ratings. The results of these tests were communicated to the Joint Co-ordination Committee on Radio Reception of RMA, NEMA, and EEI, but it was not possible to make at that time a sufficient number of the time-consuming listening tests to warrant the publication of definite conclusions. It is gratifying to note the agreement between our figures and those given in table I, despite the fact that different noise meters and different noises were involved.

We found average quality ratings corresponding to the signal-to-noise ratios given in the following table:

Signal-to-noise ratio (decibels)	+28	+8	+3	
Quality	*B*	*B*	*B*	
Signal-to-noise ratio (decibels)	−10	−20	−34	−47
Quality	*C*	*C*	*D*	*E*

All but the first three ratings in table I are entirely consistent with the above values. The first three ratings correspond to considerably poorer quality of reception than would be expected from our data. I believe the explanation of this is, that we used a noise of a more impulsive nature than the noise of an average commutator motor, and that our noise meter may have given to brief high peaks of noise relatively more weight than the instrument used in obtaining the data of table I.

The above partial agreement and partial disagreement, and the necessity for explanations are typical of experience when quantitative studies of interference are attempted. They illustrate why standardization of method is the greatest need in this field. The work reported in the present paper is a splendid and important contribution toward filling this need.

AUTOMATIC-GAIN-CONTROL TIME CONSTANTS

In the radio-noise meter described in the paper, in which a logarithmic scale is obtained by "automatic gain control" action, the function of the indicating meter is twofold; first, to measure a change in output, and second, to measure a change in gain which is produced by the change in output through feedback. The input corresponding to a given indication depends on both of these. If now the time constants determining the transient response of the gain-changing circuit are not the same as those determining the transient response of the indicating meter, the actual response of the instrument to noise will be a complicated function of *both* sets of time constants.

For example, if in figure 3 of the paper the time constants R_2C_2 and R_3C_3 are made 200 milliseconds as suggested in the paper, and if the charging time of C is ten milliseconds, then the response to a single isolated noise peak will be substantially as though the automatic-gain-control circuit did not exist, for C will be charged before the gain control has time to act. If this is the performance desired, then at least the time constants of the automatic-gain-control circuits should be as carefully standardized as those determining the indicating-meter action. It should be mentioned, however, that with a slow automatic-gain-control circuit there is serious danger of overloading the intermediate-frequency amplifier on impulsive noise peaks.

I believe that the time constants of the automatic-gain-control circuits should be made the same as those determining the response of the indicating meter, so that the instrument will have a truly logarithmic scale for both impulsive and sustained noises. This is accomplished by making the time constants R_2C_2 and R_3C_3 small compared with the charging time constant of C, or ten milliseconds. Some tests have indicated that this is a practical possibility.

INTERNAL CALIBRATING SOURCE

There is another possible internal calibrating source not mentioned in the paper, which I believe has received too scant consideration. In fact such a source, a relaxation oscillator, was used in a commercial radio-noise meter built in accordance with the 1932 specifications of the Joint Coordination Committee ("Radio Noise Meter and its Application," C. R. Barhydt, *General Electric Review*, volume 36, 1933, page 201). The method of calibration there used may not have been very satisfactory. However, I believe that the relaxation oscillator, properly designed, will be found at least as satisfactory as the shot-noise generator, and perhaps preferable to it.

There is an advantage, not mentioned in the paper, in using for a comparison standard of calibration a typical noise wave form rather than a sine wave. By so doing, changes in selectivity of the instrument are compensated for, exactly for noise wave forms of the type used, partially for other wave forms. The compensation cannot be obtained exactly for all forms of noise, because at one extreme, the peak value with noise pulses which completely overlap is proportional to the square root of the band width, whereas at the other extreme, the peak value with nonoverlapping noise pulses is directly proportional to the band width ("A Study of the Characteristics of Noise," V. D. Landon, IRE *Proceedings*, volume 24, 1936, page 1514).

Shot noise has a wave form at the one extreme, corresponding to complete overlapping of the noise pulses in the receiver, whereas a relaxation oscillator with a low repetition frequency produces a noise wave form at the other extreme, that of no overlapping. By increasing its repetition frequency the relaxation oscillator may be made to give an intermediate type of wave form, if desired.

In a large number of cases, actual noise wave forms consist of pulses repeated at twice the commercial power-line frequency (120 cycles per second), a rate too slow to cause overlapping in most receivers. Thus, a noise wave form with a repetition frequency of 120 cycles per second such as can be obtained with a relaxation oscillator, would seem more typical of radio noise than hiss such as shot noise, and therefore preferable for use in calibration.

The shot noise of a tube is very small, so that a radio-noise meter must be very sensitive if shot noise is to be used for its calibration without additional complications. This may prove a rather severe limitation to the use of shot noise for calibration, particularly for low-priced instruments.

The shot noise generated by a saturated tungsten-filament diode may be determined very accurately by measuring the average space current, although generally a correction for the finite internal resistance of the diode must be applied unless the external resistance is low. Unfortunately, a tungsten-filament tube cannot be operated from batteries suitable for a portable instrument. Thoriated-tungsten or oxide-coated-filament tubes, which must be used instead, are much more uncertain as to saturation and noise. It seems doubtful to me whether the shot noise from such a tube can be determined any more reliably by measuring its space current than the noise generated by a properly designed relaxation oscillator can be determined by measuring its supply voltage.

The International Special Committee on Radio Interference (CISPR), working in Europe, has been investigating the design of a standard radio noise generator, and a paper describing some of their results with a relaxation oscillator used for this purpose has recently been published ("Étude et Applications d'un Générateur Stable de Tensions Perturbatrices Radiophoniques. Perturbateur Type," G. Coffin and G. Marchal, *L'Onde Électrique*, volume 17, number 204, December 1938, pages 562–74).

J. L. Clarke (Bell Telephone Company of Canada, Montreal, Que.): The authors have not mentioned whether any means have been provided in their measuring set to make the noise field audible. It has been our experience when measuring noise including several discrete and readily identifiable sounds that it is very helpful to be able to sort out the observations when one or another of the more prominent sounds is present. We have found that the addition of an audio stage and loudspeaker to the measuring set is very helpful in this connection.

W. F. Grimes (Radio Interference Engineering Bureau, Inc., Los Angeles, Calif.): The paper by C. V. Aggers and his associates presents a very complete description of instruments and methods of measurement available for the laboratory study of radio noise. Some results of comparative laboratory and field tests are also given.

It appears that the radio and electrical industries are confronted with two general problems involving the reduction of radio noise. First, the manufacturer of electrical apparatus, as is shown by the paper, has recognized the necessity for the development of radio-noise-free products. Much work has been done to devise methods which permit reproduction of laboratory results in the measurement of radio-noise-influence voltages. Second, as pointed out in the paper, measurements now made in the laboratory cannot be satisfactorily reproduced in the field due to the electrical constants of supply circuits and other such factors.

The routine investigation of radio noise in the field is in existence today on a very limited basis. So far as is known, little or no quantitative field work is being done. Funds which have been made available for field investigations, with few exceptions, have been appropriated for the immediate benefit of broadcast and electric-utility customers. This has meant the establishing of a service free to the radio listener through which improvement in radio-receiving conditions could be accomplished.

In conclusion, it would seem that closer co-operation is necessary between the manufacturers and the field agencies serving the radio listener.

When instruments and methods of measurement are devised which will permit the interpretation of laboratory results in terms of expected radio-listener satisfaction, apparatus will be produced and purchased for the direct improvement of radio reception.

W. N. Goodwin, Jr. (Weston Electrical Instrument Corporation, Newark, N. J.): In the paper reference is made, somewhat briefly, to the characteristics of the indicating instrument. It is thought that a more complete discussion of these characteristics and why the particular constants were adopted might possibly be of general interest.

In noise measurements and also in indicating sound volume, such as broadcasting-program material, the indicating-instrument pointer is continuously fluctuating, and measurements are made by estimating averages of the pointer indication, or by noting peak readings.

In view of this condition, the first question considered by the committee was whether the instrument should be overdamped, critically damped, or underdamped.

This was studied by computing the deflection-time characteristics for specific cases of the three types of motions, from the following equations of motion. These were developed and the interesting properties of the quantity n discovered by the present writer in the early years of his career as an instrument engineer.

$$\frac{\theta}{\phi}=1-\frac{\epsilon^{-\frac{2\pi nt}{T_0}}}{\sqrt{n^2-1}}\sinh\left[\frac{2\pi t}{T_0}\sqrt{n^2-1}+\sinh^{-1}\sqrt{n^2-1}\right] \quad (1)$$

$$\frac{\theta}{\phi}=1-\left[\frac{2\pi t}{T_0}+1\right]\epsilon^{-\frac{2\pi t}{T_0}} \quad (2)$$

$$\frac{\theta}{\phi}=1-\frac{\epsilon^{-\frac{2\pi t}{T_0}}}{\sqrt{1-n^2}}\sin\left[\frac{2\pi t}{T_0}\sqrt{1-n^2}+\sin^{-1}\sqrt{1-n^2}\right] \quad (3)$$

where θ = deflection at any time t, resulting from the application of a constant electromotive force to the instrument circuit, which will produce a final deflection of an angle ϕ; T_0 is the undamped period of the instrument; and n the ratio of the actual to the critical damping coefficients, which the writer has designated "specific damping coefficient."

Equation 1 applies to the aperiodic or overdamped condition, equation 2 to the critically aperiodic condition, and equation 3 to the periodic, or underdamped condition.

Equation 1 may be considered the general equation from which equations 2 and 3 may be derived by making $n=1$ or $n<1$ respectively. When this substitution is made in equation 2 it becomes indeterminate and is evaluated in the usual manner by differentiation. Equation 3 becomes imaginary and is transformed by the relations, $\sinh^{-1} j\alpha = j\sin^{-1}\alpha$ and $\sinh jx = j\sin x$.

The three curves derived from the equations are shown in figure 1 of this discussion. Curve 1 shows the overdamped condition where the specific damping coefficient $n=1.5$, curve 2 shows the critically damped condition where $n=1$, and curve 3 the underdamped condition where $n=0.825$, and the damping factor is 100, resulting in an overswing of one per cent.

The curves were computed upon the basis that the deflections of corresponding instruments reached to within one per cent of their steady-state deflection in the same time.

It will be noted that the velocity of the slightly underdamped instrument is much more uniform from zero to full-scale deflection than for the other two conditions.

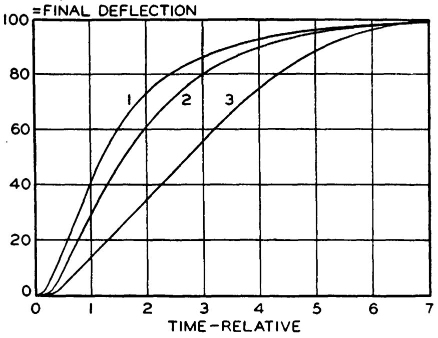

Figure 1

In the latter, the velocity is high in the lower part of the scale and diminishes rapidly in the upper part.

It is quite evident that an instrument, having a movable system giving a uniform velocity throughout its motion for a given current, would result in more correct estimates of averages and peaks than one varying in velocity. This has been proved by actual experience for a number of years in instruments for similar purposes, namely, for volume control in broadcasting. Furthermore, it results in far less eye fatigue to the reader.

For these reasons the committee adopted the slightly underdamped instrument for the noise meter.

The next question considered was that of speed of response. If the pointer action is too rapid, the eye cannot follow it; and if too slow it does not adequately follow the fluctuations in the current and gives erroneous indications. By actual tests it was found that an instrument having an undamped period of not less than 0.5 and not greater than 0.7 second, slightly underdamped, gave very satisfactory results, especially when connected into the noise-meter circuit which itself has definite time constants.

The committee thought it desirable, in order to keep the cost of the instrument within reasonable limits, to permit considerable tolerance in its constants, and for this reason specified that the undamped period may be from 0.5 to 0.7 second, and its damping factor from 10 to 100. Consideration was given to the question as to the best method of specifying response time based upon the constants just referred to. An instrument having moment of inertia, damping, and spring control does not have a time constant similar to that possessed by a resistance-capacity circuit, or to a body heated at a constant rate, namely, the time which will reduce the exponent of ϵ in the exponential function to unity, equivalent to the time required for the quantity to reach about 63 per cent of its final value. The reason for this is that the deflection of the instrument is not only an exponential function with time but also a trigonometric or hyperbolic function, as shown in the equations given above. It would be possible, of course, to assume the time constant to be the time required to produce 63.2 per cent of final deflection as in the heat and electrical problems, but as it has no fundamental basis as it has in the latter cases, it has no especial virtue.

The time quantity which seemed to be the most practical for specifying the characteristic of the instrument, in addition to the damping, is the time required to deflect under constant electromotive force and circuit resistance from rest at zero to the final steady-current position on its first excursion. This value of time is a simple function of the damped and undamped periods and of the damping constants, any of which may be computed if the others are known, and is independent of the final scale deflection. These relations are shown in figure 2 of this discussion, in which ordinates are angles of deflection, and abscissas are angles proportional to time; 2π being the angle for a complete period; and π for the half period. The angle ϕ is the steady deflection and the motion is represented by the line OA. The angle α is the phase angle of the system, equal to $\sin^{-1}\sqrt{1-n^2}$ given in equation 3. The time to complete a full period, that is through the time angle 2π, is T, where T is the damped period, and $T=T_0/\sqrt{1-n^2}$. The time angle for the deflection to A is therefore $(\pi-\alpha)$, and the time to reach A from zero is then

$$t_0=\left(\frac{\pi-\alpha}{2\pi}\right)T=\left(\frac{\pi-\alpha}{2\pi}\right)\frac{T_0}{\sqrt{1-n^2}}$$

which is the value of time by which the indicating instrument used in the noise meter is specified.

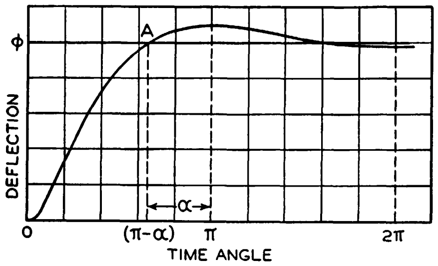

Figure 2

This time value for any completed instrument may be measured in several ways, for example, (1) by direct observation, using a high-speed electric stop watch; (2) by taking a motion picture of the motions of the pointer from which the time can be computed; (3) by applying an interrupted direct current, having the off and on times equal, and varying the speed of interruption until a maximum deflection of the pointer results. Then the time of a complete period, off and on, is equal to the damped period T, from which the specified time can be calculated from the equations given above.

Table I

Undamped Period T_0 (Seconds)	Damped Period T (Seconds)	Damping Factor k	n	Deflection Time (Milliseconds)
0.5	0.62	10	0.592	217
0.5	0.885	100	0.825	357
0.7	0.87	10	0.592	304
0.7	1.24	100	0.825	500

Table I of this discussion gives the various constants of instruments having undamped periods from 0.5 to 0.7 second and damping factors from 10 to 100, computed from the above equations.

C. W. Frick (General Electric Company, Schenectady, N. Y.): The measuring circuits described in the paper have been in use for a number of years with radio-noise meters according to the old specifications. In the testing of low-voltage devices both the line-to-line and the line-to-ground radio-influence voltages are measured. The following test illustrates relations which may be found between these quantities, depending on the conditions. It also shows reasons for making the two measurements. A commutator motor was set up with choke coils in the lines, each coil having 1,700 ohms reactance at 1,000 kilocycles. The frame of the motor was grounded. First the motor was tested on the standard circuit of figure 11 of the paper. The noise-influence voltage was 2,500 microvolts line-to-line (V_L) and 4,000 microvolts line-to-ground (V_G). Referring to the equivalent circuit in figure 7 of the paper, it appears that the internal voltages E_1 and E_2 taken with respect to ground are approximately equal in magnitude and in the same direction but not in phase, since when the line impedances are equal V_L is proportional to the vector difference of E_1 and E_2 and V_G is proportional to one-half their vector sum. A later test indicates the assumption of equal magnitudes for E_1 and E_2 to be reasonable.

Next the device was connected in a circuit similar to figure 9 of the paper to try the effect of equal and unequal impedances between supply lines and ground. A delta network of 200 ohms between lines and 300 ohms from each line to ground, as in the paper, was used for the first condition. Noise voltage between lines was measured directly and noise voltage from line to ground was measured on the network of figure 12 connected as in figure 9. This gave 620 microvolts line-to-line and 1,080 microvolts line-to-ground. These values are approximately one-fourth of those measured according to figure 11, this ratio being the same as the ratio of the resistances of the networks which were 600 and 150 ohms respectively. This shows that the radio-frequency currents were controlled by the line chokes.

The next measurement was made with unequal impedances between lines and ground. One side of the line was connected to ground and a 150-ohm resistor was connected across the line. The measuring network of figure 12 was left in place. The noise voltages then became 1,250 microvolts line-to-line and 630 microvolts line-to-ground. It may be noted that the line-to-ground voltage is half the line-to-line voltage which it should be in this test because the network of figure 12 measures half the vector sum of the voltages between lines and ground and here the voltage on the grounded side is zero.

It appears from these results that the junction between E_1 and E_2 in figure 7 is practically grounded, probably through capacitances and the grounded frame. Then when one side is grounded it eliminates the voltage on that side from the circuit. The voltage across the line was the same with the ground on either side which would indicate that E_1 and E_2 are nearly equal in magnitude. In the case of equal impedances the line-to-ground voltage was proportional to half the vector sum of E_1 and E_2 or approximately proportional to either E_1 or E_2. In the case of one side grounded only one of these was acting and the voltage to ground was only half as large.

If the phases of E_1 and E_2 had been different the result would have been different. If they had been equal and opposite in direction instead of in the same direction, they would have tended to cancel each other out in the line-to-ground voltage when the impedances from line-to-ground were equal. However, when one side was grounded, eliminating either E_1 or E_2 from the circuit, the cancellation effect would not exist and the line-to-ground voltage would be about the same as in the test. Thus if E_1 and E_2 were opposite in phase the line-to-ground voltage would increase as it did in the test described in the paper. In the test described here, however, it decreased.

If E_1 and E_2 are opposite in phase, their effect is additive between lines. In such a case consideration of the test results indicates that under conditions of unequal impedances between lines and ground the line-to-ground voltage would not exceed half the value measured between lines provided the impedance of the line is not higher than the impedance of the network. The two quantities measured are useful for analyzing effects such as these.

In table I of the paper which gives an example of radio-noise data taken on a device and data taken in a home, the figures in the last three columns appear to be ratios between these two sets of measurements, but it is not clear what they are. It would be desirable for the authors to add an explanation of these figures and to show their use.

Further explanation would also be desirable in the case of figure 16. Can the shape of the curve for distorted voltage be explained? If the authors consider it necessary to take precautions to avoid errors attributed to voltage distortion, it would be desirable to state what these precautions should be.

Charles J. Miller, Jr. (The Ohio Brass Company, Barberton): The radio-noise meter described by the authors certainly has several desirable characteristics over those formerly available. The use of a logarithmic output meter with a range of 100 to 1 will certainly reduce the amount of work necessary for measuring radio-influence voltages on all types of devices. The new meter will be direct reading, a decided improvement over the substitution method of measurement.

In connection with the proposed detector circuit and indicating meter, a tabulation of suitable combinations of R, C, and R_1 is given. The lowest value of R given is one megohm. Since this resistance is in series with the indicating meter, the sensitivity of this meter will have to be very high. The most sensitive portable meter with which the writer is familiar has a full scale deflection for 20 microamperes flowing through it. If used with the one-megohm resistor, the voltage across the capacitor C would have to be 20 volts to produce a full-scale reading. What is the maximum voltage that can be satisfactorily applied to the capacitor C, considering all the limitations imposed by vacuum tubes available, and what indicating-meter sensitivity is practical for this application?

The coupling circuit for use with high-voltage devices imposes three new limitations over the previous circuit. These are the upper limits placed upon stray capacitances on the bus side and potentiometer side of the circuit and the lower limit of 2,500 micromicrofarads for the coupling capacitor. A formula is given whereby one may calculate from the constants of the circuit, Ez_6, the voltage appearing across the resistance potentiometer. A second formula is given whereby the per cent error may be calculated if the load impedance into which the device is looking is different from a pure resistance. It is possible to determine all the constants of an existing circuit by measurements. While it is fully recognized that it is desirable to use a circuit meeting all the requirements, is it not practical to compute the error introduced by an existing circuit, whose parameters are known, and then to use this factor to correct all readings taken on that circuit in order to make them comparable with values that would be obtained on an ideal circuit?

E. T. Hughes (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): In 1930 the Joint Co-ordination Committee on Radio Reception of EEI, NEMA, and RMA was appointed to study methods for improving radio reception and in particular to consider the steps necessary to co-ordinate this newer use of electricity with some of its other uses for light, heat, power transmission, and communication.

A major problem has been in the development of radio-noise test circuits for the laboratory measurement of radio-noise-influence voltages. A test circuit which could determine directly the radio-noise voltage to be expected on any receiver antenna from any electrical apparatus on test would be desirable. However, no definite method has been developed that will permit the calculation of the radio noise on a receiver antenna when the radio-frequency voltage produced by electrical apparatus is known. Therefore the solution to the problem has been to develop measuring circuits which will permit measuring the radio-noise-voltage output of electrical apparatus with a radio-frequency load simulating the load impedance of the power system. At the present state of the art the radio noise produced by any equipment can only be expressed in units measured, utilizing the coupling networks recommended by the joint co-ordination committee.

The two basic circuits which have resulted from these considerations have proved to be well adapted for laboratory work because it has been possible for investigators in different laboratories to obtain comparable results in tests on the same apparatus.

By the use of the high-voltage test circuit it has been possible for the NEMA members to recommend certain levels for various high-voltage equipments. These levels have been obtained by making measurements on new equipment and on equipment which was returned from the field. The establishment of permissible levels of radio-noise-influence voltage for all classes of apparatus will require a somewhat different approach to the problem through field tests on different systems throughout the country.

Field tests are now being conducted in the Pittsburgh area to aid in the establishment of levels for low-voltage appliances. An appliance will be tested for radio-noise-influence voltages in the laboratory, then installed in several different homes where the noise voltage on the antenna will be measured. Knowing the effective height of the installed antenna, the signal-to-noise ratio desired, and broadcast station field strength, then the tolerable noise-influence voltage will be:

$$V=\frac{Se}{R}$$

where

V = tolerable noise influence voltage
S = antenna noise factor
e = broadcast station field strength level
R = signal to noise ratio

It is expected that from these tests the antenna-noise factor for an average home may be determined.

A second set of tests has been planned on a 6,900-volt distribution system. These tests are intended to determine the attenuation, effect of reflection, the amount of radiated field, and the field intensity perpendicular to the line in terms of the actual high-frequency voltage on the transmission line. The attenuation of the noise voltage through distribution transformers will also be studied.

A comparison between the work on this subject here and abroad may be of interest to some. The noise meter conforming to the new committee specifications is very similar to the one adopted by England, France, Germany, Italy, and Belgium. The low-voltage coupling networks used in the United States are different in that we have adopted a star network compared to a delta circuit used abroad. Both networks, however, give comparable results when the impedances are the same. The joint co-ordination committee has adopted 600-ohm networks whereas the European network is 150 ohms. The reasons for adopting 600 ohms have been outlined in the paper.

The continuation of the work of the joint co-ordination committee shows promise of producing more beneficial results in the future and by universal adoption and use of this instrument and method of measurement, radio-noise levels for all types of equipment can be established.

C. V. Aggers, D. E. Foster, and C. S. Young: The supplementary information contained in the various discussions is a valuable contribution to the problem, making the paper a comprehensive description of the art of measuring radio noise.

J. J. Smith has raised the question as to why the instrument described in the paper differs from the specifications developed by the CISPR. The CISPR specifications call for a time constant on charge of 1 millisecond and on discharge of 160 milliseconds. The other differences between the instrument in the paper and the CISPR specifications are of a minor nature and will in general cause no difference in performance between the two instruments. In developing the specifications for detector time constants, consideration was given to the CISPR specifications. However, as pointed out in our paper, it is difficult to secure a charge time constant of 1 millisecond with available tubes and difficult to hold this value in production, whereas it is relatively easy to secure a 10-millisecond charge time constant and a time constant of such value may be more readily held in production of noise meters. The discharge time constant specified by the CISPR is of the same order as that of the indicating meter, and hence the indicating-meter time constant will have a large effect on the results obtained. By the use of the long time constant of 600 milliseconds suggested in our paper, a much wider permissible range of time constants for the indicating meter is provided, and indicating meters of more desirable characteristics may be secured. Furthermore, as pointed out in the paper, by largely eliminating the influence of the indicating meter, the effective discharge time constant becomes that of the circuit, and this may be more readily duplicated in production than the time constant of the meter. The ratio of charge to discharge in the CISPR specifications is larger than that of the meter described in our paper, and therefore the CISPR meter will give a higher indication on wave forms of the sharply peaked type. On wave forms approaching the sinusoid, the difference in indication between the CISPR and the joint co-ordination committee specifications will be of the order of one per cent, a relatively minor factor considering the other possible variations.

We feel that the time constants suggested in our paper will give more constant, reliable results and permit more uniformity in production of noise meters than those adopted by the CISPR.

C. M. Burrill points out that with the automatic-volume-control time constant suggested in our paper, the response on a single-pulse type of noise will depend in some degree on the time constants of the automatic-volume-control circuit. The response of the instrument will not be the true peak value on a single pulse or widely separated repetitive pulses, not only because of automatic-volume-control time constants, but also because of the detector time constants chosen. As pointed out in the reply to Doctor Smith's discussion, the detector time constants were chosen to provide reliable and consistent results with practical tubes and circuits, rather than to provide idealized response to all types of noise. Furthermore, as pointed out in our paper, the disturbing effect of pulse types of noise appears to be less than would be indicated by their peak amplitude. It is felt that the correlation of the meter indication on such types of noises with their disturbing effects will be satisfactory with the time constants described and may in fact be better than when the time constants are chosen to give indications nearer the actual peak values. Mr. Burrill's suggestion of short automatic-volume-control time constants would be satisfactory provided adequate attenuation is provided by the automatic-volume-control filter having the short time constants he suggests. The automatic-volume-control filter must be such as to prevent the audio-frequency component of the noise present in the detector circuit from being applied to the amplifiers and there producing a modulation effect. An automatic-volume-control filter of short time constant with adequate attenuation of the audio-frequency component is considerably more complex, that is, must include more filter stages for the same attenuation, than one with a longer time constant.

Relaxation oscillators were considered in drawing up specifications on the noise meter, but experience to date with this type of oscillator was, in the opinion of the majority of the committee, such as to indicate that relaxation oscillators are not as reliable or uniform nor as readily checked in instrument use. The determination of the output of the relaxation oscillator by measurement of the supply voltage is an indirect method, and therefore not as accurate as measuring the current in a saturated diode. The advantage of a noise calibration source of a type to eliminate the selectivity influence in calibration mentioned by Mr. Burrill was also a factor influencing the committee's choice of a saturating diode as a noise source. Mr. Burrill is correct in stating that the theoretical shot noise from oxide-coated-filament tubes, such as are practical for portable noise meters, is not as readily determined as that m tungsten-filament tubes. However, the noise meter described, oxide-coated-filament tubes are satisfactory, since they are used as a transfer standard, the initial calibration being in terms of an unmodulated sine-wave voltage. When so calibrated, it is felt that the oxide-coated-filament diode is a practical and uniform transfer standard readily determined by measurement of the space current. The difference between tungsten and oxide-coated, or thoriated-tungsten-filament tubes is that the latter two types do not have a sharp, definite saturation characteristic but saturate more gradually. Under such circumstances, the impedance of the diode must be taken into account. This impedance need not be specifically determined for the use described in our paper, since it is implicitly included in the initial calibration process.

C. J. Miller's comment emphasizes the point mentioned in our paper that a d-c amplifier may be employed to permit the use of a less sensitive meter. The use of a d-c amplifier and relatively insensitive meter is a more practical design combination than an attempt to secure a charge time constant of ten milliseconds with a resistor lower than one megohm. Battery-type tubes such as are required for portable noise meters have a rather high effective resistance when used to drive a diode and therefore consideration was not given to resistors of less than one megohm. All through the design of the instrument practical tube and circuit considerations were kept in mind in an endeavor to provide an instrument to give readily reproducible results.

The influence of capacitances in the measurement of high-voltage devices is perhaps more readily taken into account than might be indicated by Mr. Miller's comments. Such circuit capacitances are very important in television and have been studied by many investigators of late. The principles developed for television may be used in connection with other circuits where the stray capacitances are important, such as in this case the noise-measurement circuits. Among the several technical papers dealing with this problem, are the following:

"Analysis and Design of Video Amplifiers," S. W. Seeley and C. N. Kimball *RCA Review*, January 1939.

"Transient Response of Multistage Video Frequency Amplifiers," A. V. Bedford and G. L. Friedendall, IRE *Proceedings*, April 1939.

These papers describe the principles and methods involved when uniform response characteristics are necessary over a range of the order of four megacycles, which is even greater than is required in the case of noise measurements.

J. J. Clarke inquires regarding means of making the noise audible. The provision for audible indication of the noise is a decided help in identifying the type of noise or in identifying broadcast stations when the equipment is used for field-intensity measurements. As pointed out in our paper, when the audio-frequency noise output is used for listening, the detector time constant should be of the order of 0.1 millisecond, which may be accomplished through the use of a switch reducing the value of the capacitor by a factor of 100 for listening purposes.

The specifications for the 150 to 18,000-kilocycle noise meter include a paragraph which states that a switch shall be provided to substitute for the weighting detector circuit a conventional second-detector circuit for carrier field-intensity measurements or to supply audio-frequency output which can be used for monitoring analysis with other apparatus.

Mr. Grimes pointed out the need for closer co-operation between the manufacturers and the field agencies. This has been one of the crying needs since the advent of radio but these two groups cannot co-ordinate their activities until standards on instruments and methods of measuring radio noise have been established. It will be only through the co-operation of these groups that sufficient data will be collected which will permit the interpretation of laboratory results in terms of expected radio noise.

It was pointed out by Mr. Hughes in his discussion that a series of field tests are contemplated in an attempt to obtain some conception of the correlation factor between laboratory measurements and field measurements. It is encouraging to note that such a program is under consideration. A number of such programs should permit the establishment of satisfactory radio noise levels for all types of apparatus.

The data included in Mr. Frick's discussion emphasizes the necessity for making both the line-to-line and line-to-ground measurements on low-voltage apparatus as well as choosing some definite terminating impedances for measuring the radio-noise-influence voltage.

The phase relation of E_1 and E_2 in figure 7 varies a great deal between types of machines and somewhat on even the same design of machines. The data shown in the paper is representative of what may be expected from a definite type of machine.

Mr. Frick stated that his tests indicated the junction between E_1 and E_2 in figure 7 is practically grounded. In practically all small commutating machines, the capacity of the windings to the frame is relatively small. There is also the impedance of the field winding between the interference generator and ground so that it would be practically impossible that the junction between E_1 and E_2 be at ground potential.

We wonder if Mr. Frick has not misinterpreted his results because if the measurement is made by figure 12 and one side of the line is grounded, the V_G could be only half of the line-to-line voltage. In other words, the line-to-line measurement is actually the line-to-ground measurement because one side of the line is grounded. The value of 1,250 microvolts appears to be correct because in the previous measurement he obtained 1,080 microvolts line-to-ground. The grounding of one side should increase this value of 1,080 as was obtained by Mr. Frick.

Mr. Frick questions table I. The caption of the last three columns was omitted in the preprint. These columns give the noise voltage on the antenna in per cent of the noise-influence voltage line-to-ground and house wiring. The collection of this type of data by various investigators will permit the establishment of noise levels for such apparatus, for instance, at 610 kilocycles (table I) the noise voltage on the antenna is 8.9 per cent of the noise-influence voltage line-to-ground with the frame grounded. If, for example, it could be determined that an average of ten per cent of the noise-influence voltage produced by low-voltage devices would be obtained at the input to the radio receiver, then it would be possible to determine the permissible radio-noise-influence voltage of a device which would permit satisfactory radio reception with any available broadcasting field-strength level.

The distorted wave shape shown by figure 16 was due to drawing leading current through the induction regulator. In the case discussed, it was necessary to eliminate the induction regulator and energize the transformer from a motor generator set. From tests to date it appears as if it will be desirable to limit the total distortion of the voltage wave to five per cent.

Mr. Goodwin's discussion is a very valuable contribution on this subject as he has covered thoroughly many of the factors given consideration while preparing the specifications of the indicating meter for the radio-noise meter.