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Audio-Frequency Impedance Measurements

By the Engineering Department, Aerovox Corporation

IT is a well-known engineering fact that maximum power is transferred from a generator to a load only when the impedance of the one equals that of the other. However, to bring about this favorable condition in practice, the absolute magnitude of each impedance must be known. Impedance measurement techniques therefore are of considerable practical importance.

Methods of measuring impedance at audio frequencies are especially significant to the electronic technician because of the wide distribution of components for use in the range between 10 and 20,000 cps. Specialization in audio engineering and audio maintenance has increased rapidly in recent years. Furthermore, impedance measurements often are

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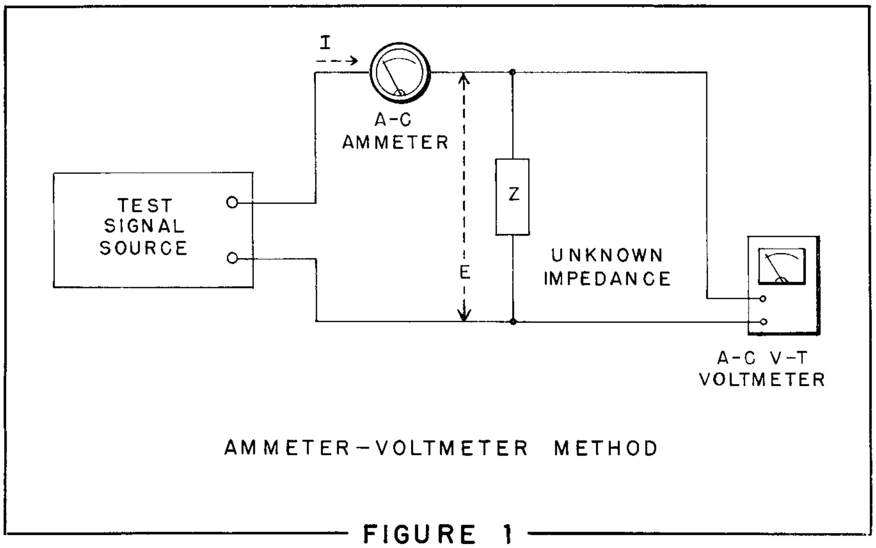


AMMETER—VOLTMETER METHOD

FIGURE 1

more conveniently made at a-f than at r-f positions. Sometimes, but not in every case, a relatively simple measurement of the impedance of a component at an audio frequency will suffice as a one-shot test, although the component may be intended for r-f use. This is especially convenient in a receiving-inspection operation where highly-skilled personnel otherwise might be required for r-f measurements.

Audio-frequency impedance may be measured in a number of ways. It is well to describe several of these methods, since a single type of instrument will not always be available to all persons needing to measure impedance. This article explains the most useful practical methods.

Nature of A-F Impedance

The absolute magnitude of impedance Z is taken as R+jZ, that is, the vector sum of the resistive and reactive components. At very high frequencies, R may differ significantly from the simple d-c resistance, including all of the in-phase loss factors. The reactive component may be capacitive, inductive, or some combination of C and L. Impedance may be calculated from the separately evaluated resistive and reactive components.

Neglecting phase angle considerations; from Ohm's Law for ac, Z = E/I, I = E/Z, and E =IZ. From these relationships, it is seen that impedance may be calculated also from current and voltage levels.

Methods of Measurement

Impedance-measuring methods may be classified broadly as (1) direct, (2) indirect, and (3) comparison. An example of the direct method would be the use of an a-c ohmmeter. An indirect method might be one in which the impedance is calculated from the measured current through and voltage drop across the unknown impedance. In a typical comparison-type measurement, the unknown impedance might be compared with a known resistance either in a bridge test circuit or a simpler setup.

The following Sections describe procedures which fall variously into the three categories just listed.

While it has been customary to make a-f impedance measurements at 400 or 1000 cps, there is nothing sacred about these frequencies. Specifications often prescribe that lower, higher, or a series of frequencies be employed. In some instances, 60 cps, derived from the power line, will suffice and greatly simplifies the signal generator requirement. It should be noted, however, that the accuracy of measurement sometimes suffers at very high audio frequencies (above 5 kc particularly) as a result of stray coupling, unless elaborate shielding is employed in the test circuit. The effects of distributed capacitance also become more pronounced at the higher frequencies.

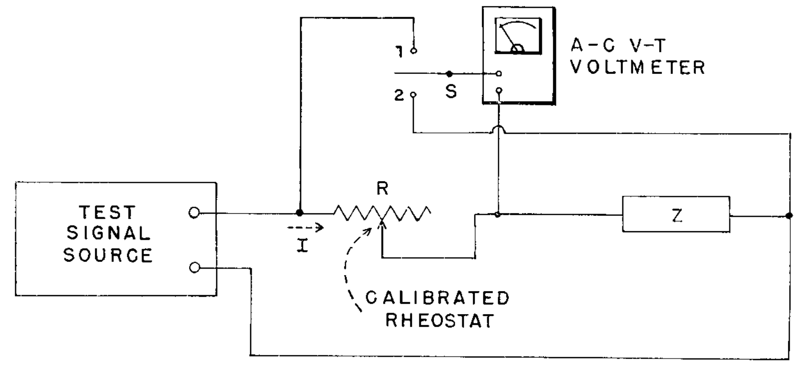
In each impedance-measurement procedure in which current and voltage amplitudes are checked, current and voltage waveform both should be examined for purity. If appreciable harmonic distortion is present, the signal voltage must be reduced to restore the sinusoidal shape (and the sensitivity of the indicating meters increased proportionately), otherwise significant errors will be introduced.

Ammeter-Voltmeter Method. This is a relatively simple method, employing readily-available instruments. It is convenient to use this scheme either in the laboratory or shop. The circuit is shown in Figure 1.

A test-signal voltage, E, is applied to the unknown impedance, Z. The test-signal source must be capable of passing a suitable current through the impedance with negligible distortion. The current level, I, is indicated by a low-resistance ammeter, and the voltage (E) across the impedance by an a-c vacuum-tube voltmeter. It is essential that the voltmeter current be negligible with respect to the current through the unknown impedance and the output impedance of the signal source. This will reduce the error of measurement by minimizing the current drawn by the voltmeter. A v-t voltmeter is recommended to measure the voltage across the impedance, since the high input resistance of this type of instrument renders its loading negligible.

The unknown impedance is calculated from the measured current and voltage values: $Z = E/I$; where Z is in ohms, E in volts, and I in amperes.

The test-voltage amplitude should be held to the lowest value which will give accurately-readable meter indications. This has several advantages: (1) distortion is reduced, especially when an iron-cored component is under test, (2) heating in the component is prevented or minimized, and (3) loading of the signal source is reduced. When sensitive instruments are available, it is best to use a low-level signal, a-c v-t millivoltmeter, and a-c milliammeter or microammeter. It is inadvisable, however, to reduce the signal amplitude to such an extent that stray pickup deflects the millivoltmeter.



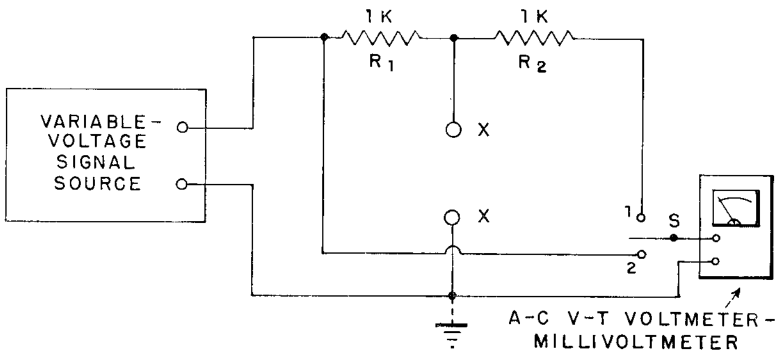
VARIABLE—RESISTANCE METHOD

FIGURE 2

Variable-Resistor Method. In this scheme, the unknown impedance is compared with an accurately-known resistance. The latter is made continuously variable, in order to provide a range of measurement. Figure 2 shows the circuit.

The test-signal source forces a current, I, through the calibrated resistor (R) and the unknown impedance (Z) in series. This current produces a voltage drop, $E_1 = IR$, across the resistor, and a similar voltage drop, $E_2 = IZ$, across the impedance. The resistive voltage drop is indicated by the v-t voltmeter when changeover switch S is set to its Position 1, and the voltage drop across the impedance is read when S is at Position 2.

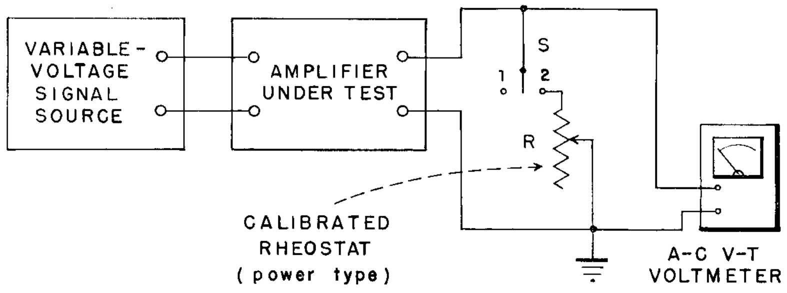
The ratio of the voltage drops depends upon the setting of R. When R is set exactly equal to Z; $E_1 = E_2$, since IR then equals IZ. The voltmeter deflection then remains unchanged as switch S is thrown back and forth between 1 and 2. At this point, the unknown impedance, Z, may be read directly from the resistance calibration of R, since if $IR = IZ$, then $Z = R$.



T-NETWORK METHOD

FIGURE 3

The test-signal voltage must be restricted to a level which will not force excessive current through R and Z, and the voltmeter range accordingly must be selected to give a deflection in the upper portion of the instrument scale. The actual voltage value does not enter into the



MEASURING AMPLIFIER OUTPUT IMPEDANCE

FIGURE 4

determination of the impedance, however, the instrument serving only as a balance indicator. The accuracy of this widely-used method of impedance measurement is governed by the closeness with which the value of R is known. In many laboratories, the variable resistor is built up with one or more precision decade boxes.

It is important that the meter be of the high-input-resistance, vacuum-tube type, otherwise the R and Z components will be excessively loaded by the instrument in many instances and accuracy of the measurement will suffer.

A-C Bridge Method. When an a-c bridge is available and will give the equivalent resistance component (R) as a direct reading (when its separate resistance balance is adjusted for null), this value may be used with the reactive magnitude (X), computed from the inductance or capacitance value obtained from the reactive balance of the bridge to *calculate* impedance.

This method may be employed with equal success in determining the impedance of devices which are essentially capacitive or essentially inductive. The bridge is adjusted in the conventional manner.

After determining the inductance (L) of a component, the reactance is determined from the relationship: $X_L = 6.28fL$. Similarly, the capacitive reactance may be determined from the relationship: $-X_c = -1/6.28fC$. Using the indicated equivalent resistance, the unknown impedance may be calculated: $Z = (R^2+X^2)^{1/2}$.

Because the bridge method necessitates at least two calculations and since many bridges give no reading of equivalent resistance (but, instead, of D, Q, or power factor which require still another calculation to obtain the value of R), this impedance-measuring scheme is less popular than some others. The technician should be acquainted with it, however, since on occasion the bridge may be the only instrument immediately available for the purpose.

T-Network Method. In Figure 3, the unknown impedance is connected to terminals X-X to form a simple T-network with the non-inductive fixed resistors, R_1 and R_2. The output voltage of the signal source is continuously variable. An a-c vacuum-tube millivoltmeter is connected to the output of the measuring circuit through the spdt changeover switch, S. When S is at Position 1, the meter indicates the output voltage of the T-network; and when S is at Position 2, the meter reads the input voltage.

This scheme is employed in the following manner: (1) Connect an accurately-known non-inductive resistance (R_3), say some value between 10 and 100 ohms, to terminals X-X. (2) Throw switch S to Position 2 and adjust the signal voltage to give full-scale deflection (E_1) on a selected range. (3) Throw S to Position 1 and note the deflection (E_2) of the meter. (4) Connect the unknown impedance to terminals X-X in place of the test resistor, R_3, and readjust the signal voltage to give the same output voltage E_2 that was obtained with the resistor. (5) Throw switch S back to Position 2 and read the new input voltage (E_3). (6) Calculate the unknown impedance: $Z = R_3/(E_1/E_3)$.

This is a convenient method for checking the impedance of components in most laboratories and shops and in the field. An audio oscillator and audio v-t voltmeter-millivoltmeter constitute the instrumentation and usually are readily available.

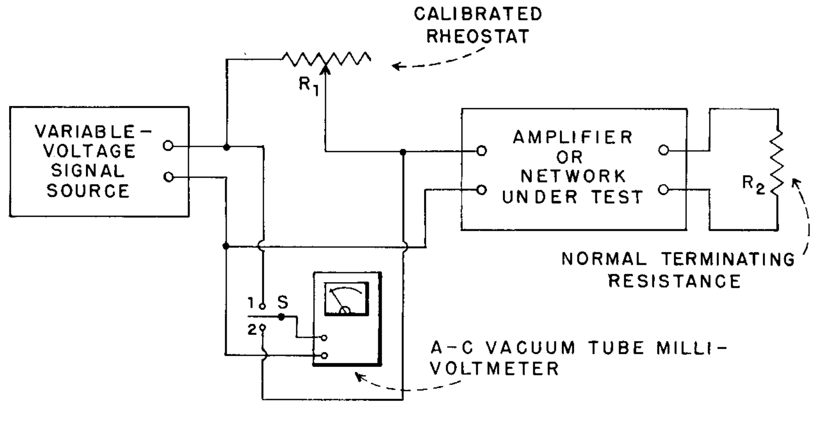
Checking Amplifier Output Impedance. The schemes described up to this point permit impedance checking only of passive components, except that the *input* impedance of an active system, such as an amplifier, might also be checked with most of the methods. Other methods must be employed for checking the output impedance of an active component or system while in operation.

Figure 4 shows a setup for measuring the output impedance of an audio amplifier in operation. A variable-voltage signal source, such as an audio oscillator or signal generator, supplies a test signal to the amplifier input terminals. The amplifier output terminals are connected to an a-c vacuum-tube voltmeter.

A calibrated variable resistor, R, is connected in parallel with the amplifier output circuit when the spdt switch, S, is thrown to its Position 2. For good safety factor, the wattage rating of this resistor must be at least twice the maximum power output of the amplifier.

With switch S at Position 1 and the amplifier controls set to a desired test position, the test-signal amplitude is adjusted for full-scale deflection of the meter. This is the open-circuit output voltage of the amplifier corresponding to the input-signal amplitude employed. Switch S then is thrown to its Position 2, and rheostat R adjusted to drop the meter reading to ½ its original value. At this point, the resistance setting of R equals the output impedance of the amplifier.

The scheme is based upon the fact that resistance R and the output impedance of the amplifier are in series. When R is made equal to Z (usually resistive in an amplifier), a 2-to-1 voltage divider is formed, so that the voltage across R becomes ½ the open-circuit voltage.



MEASURING INPUT IMPEDANCE

FIGURE 5

Checking Generator Output Impedance. The output impedance of an audio oscillator, signal generator, or power generator may be measured with the aid of a circuit similar to Figure 4. The only difference is that the generator is connected directly to the measurement circuit instead of through an amplifier.

The test procedure is the same as that explained in the previous Section for measuring amplifier output impedance.

Series-Resistor Method for Input Impedance. The input impedance of an amplifier or a-f network may be measured with the circuit shown in Figure 5. The a-c vacuum-tube millivoltmeter is arranged, with the spdt changeover switch (S), to read the signal voltage at the output of the signal generator (switch S at Position 1) and at the input of the amplifier (S at Position 2). A calibrated rheostat, R_1, is connected between the generator and amplifier, and the latter is terminated in its normal output impedance or resistance, R_2.

With switch S at Position 1, the generator signal-voltage amplitude is read with the v-t millivoltmeter. Switch S then is thrown to its Position 2, and the rheostat adjusted to give a voltage reading equal to ½ that deflection. At this point, the amplifier input impedance is equal to the resistance setting of R_1, on the assumption that the input impedance is resistive. The reason for this is that R_1 and the input resistance form a voltage divider. When R_1 and the input resistance are equal, the voltage division ratio is 2:1, so that the voltage at the output of R_1 is ½ the input voltage.

It should be noted that the output resistance of each of the common circuits employed in transistor amplifiers is sensitive to generator resistance. For this reason, when checking the input impedance of transistor amplifiers, the presence of R_1 must be taken into account when selecting the value of R_2. Resistance R_1 becomes a part of the output resistance of the signal generator and tends to increase the output resistance of the transistor amplifier.

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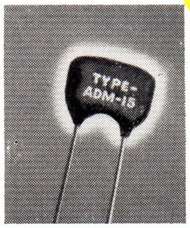

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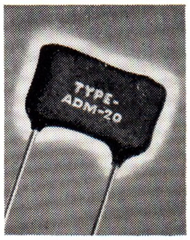

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