Measuring up an Audio Transformer

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Proper selection of a transformer for audio applications often requires thorough measurement of its characteristics. The author describes the important measurements needed to determine its adaptability to certain uses.

IN THE PRECEDING ARTICLE[1] the various electrical properties having a bearing on its performance were introduced. This article covers the question of measuring up these electrical properties. A following one will deal with applying the information so gained to obtain the best performance from the transformer. Intelligent application of this method proves far more direct than the "hit and miss" method of trying various values in circuit, and results in ultimate time saving. The latter method may never find the best result.

Audio transformers can be divided into two groups from the viewpoint of the electrical properties contributed by the presence of a core of magnetic material: those in which no d.c. polarizing flows; and those with d.c. polarizing.

No D.C. Polarizing

In components designed for use without d.c. polarizing, the core does not have an air gap, but is made up to give the lowest possible magnetic reluctance for the material used. As a result less turns are used on a winding for the same working impedance, causing the magnitude of core losses to affect performance appreciably. So for these components, core loss should be measured in addition to inductance, and at the same time equivalent harmonic generation should be investigated.

Measuring the impedance of a winding appears quite simple, using a comparison circuit such as that shown at *Fig.* 1. Impedance magnitude is calculated from the ratio between readings V_2 and V_3, while phase can be calculated from the three-voltmeter formula known to power engineers. But in practice, results show inconsistency as different frequencies or amplitudes are explored. Even at the same frequency and amplitude of signal, discrepancies are noted when different values of series resistor are used. So the results are suspect. If an oscilloscope is used to examine the waveform across either the resistor or the winding, the reason will be revealed. Although the applied waveform has been checked as sinusoidal, the transformer magnetizing current is non-linear, with the result that the potential drop across the resistor, and hence also that across the winding, is not sinusoidal; so voltage readings are falsified by the irregular wave shape.

For practical application, only sinusoidal signals are of value, so the next method suggested uses the oscilloscope to trace a pattern when the applied voltage is sinusoidal. The circuit is shown at (A) in *Fig.* 2. The series resistor, *R*, used to obtain the Y deflection, has a value such that its potential drop is small compared to that across the winding. Thus the waveform across the winding is sensibly the same as the input waveform. Use of a 'scope amplifier for the Y deflection produces a trace similar to that shown at (B). To interpret this result, the trace is first transferred to squared paper. Then the ordinates are measured off and used to produce graphs against a time scale: a sinusoidal potential (or more strictly, e.m.f.) wave is plotted and used to locate X points along the time axis; at the same points, the Y ordinates for the original trace are set up, and these points give a magnetizing current curve, as at (C), in both waveform and phase relation to the e.m.f. wave. This waveform can now be analyzed for magnitude and phase of fundamental, and percentage harmonic generated.

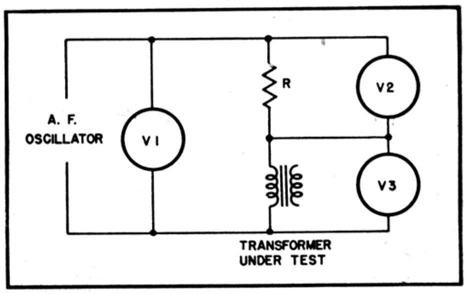

Fig. 1. The simple three-voltmeter method shown here can be used to find magnitude and phase of magnetizing current, but the waveform may invalidate the readings.

With care, time and patience, this method can yield good results. But something more direct is desirable. Without bothering with all the analysis, calibration of trace amplitude will find the magnitude of magnetizing current, and from this a rough approximation of inductance value can be calculated. Inductance varies widely over different amplitudes and frequencies, so this method is accurate enough for finding an inductance value only. But performance is affected more by the loss component of the magnetizing current than by its inductive component.

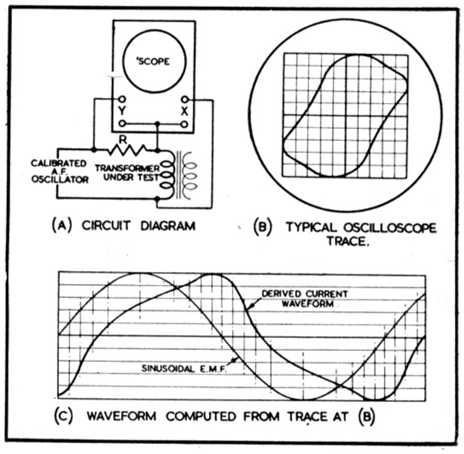

Fig. 2. This method, producing an oscilloscope trace that is graphically analyzed, can yield good results, but the analyses are arduous. Minimum equipment is required.

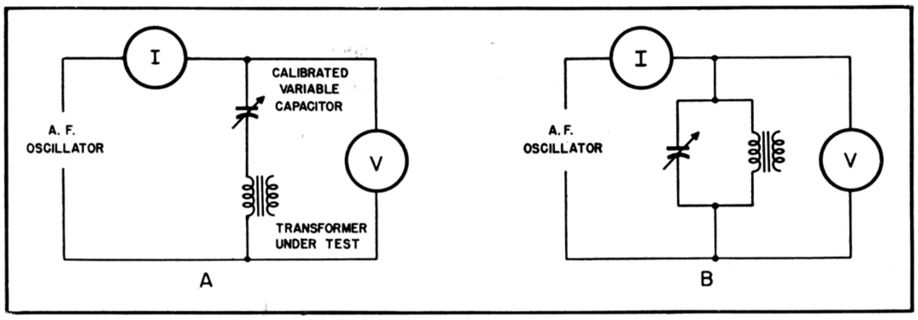

Fig. 3. Circuits such as these for balancing out the inductive reactance to find core losses are also invalidated because of waveform troubles, and other difficulties.

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[1] "How good is an audio transformer," AUDIO ENGINEERING, March, 1952.

Coil loss may be isolated from its reactance by using a series or shunt tuning capacitor to balance out the reactance component, as shown at *Fig.* 3. In the series arrangement, as at (A), the loss current is sinusoidal, so the potential across the coil is not, nor is the potential across the series tuned circuit. This means the result does not conform with practical conditions. In the shunt arrangement, as at (B), the applied voltage is sinusoidal, so practical conditions are reasonably simulated, if satisfactory readings can be obtained. But with both methods of connection, definite readings are difficult to obtain: frequency is set, and the value of capacitor adjusted to obtain minimum V in (A), or minimum I in (B). It would be expected that variation of frequency, as a check for true tuning, would show a rise in V or I on either side of the set frequency; but instead, a new minimum is found in one direction. Never will adjustment of frequency for tune point coincide with adjustment of capacitance. This effect is due to the nature of the loss characteristic with frequency.

A highly successful method of making the measurements uses the bridge circuit of (A) in *Fig.* 4. Arms *ab* and *bc* are essentially the same as shown at (A) in *Fig.* 2, the low value standard resistance being used to obtain current waveform. The other arms are used to separate the fundamental component of magnetizing current from its harmonics, so that its phase can easily be read off from ellipse dimensions. To take the reading, the bridge is balanced for fundamental, so across the null points, *bd*, only harmonic appears. The potential drop across the combination arm *ad* is the same as the fundamental component of that across *ab*, in both magnitude and phase. The complete method is facilitated by the use of a Cossor double-beam oscilloscope, so the two Y quantities can be displayed simultaneously. Alternatively an electronic switching unit could be used.

The complete measuring circuit, including calibrating potentiometers, is shown at (B) in *Fig.* 4. The procedure for taking a reading at a given frequency and amplitude is as follows:

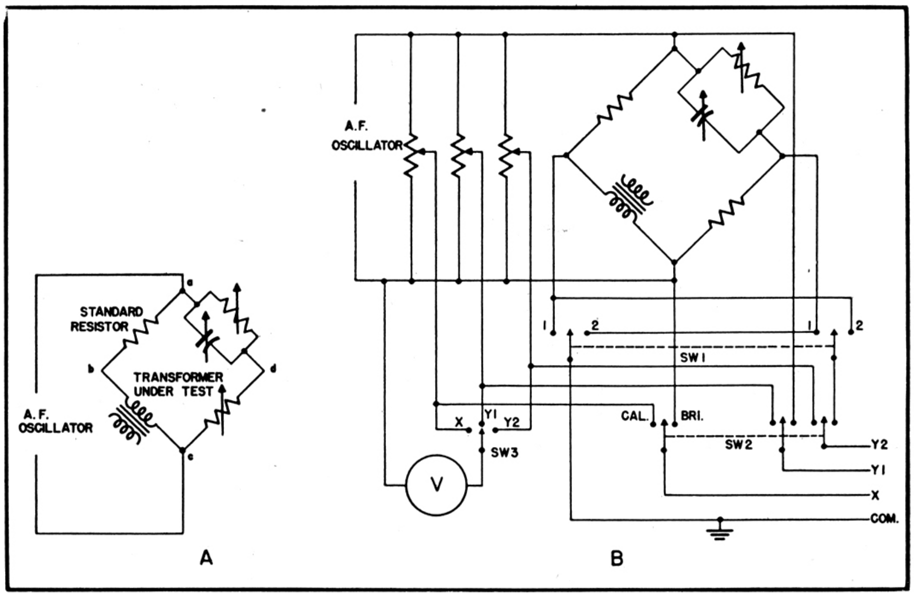

Fig. 4. This complete method, although requiring more equipment, speeds up measurement, and gives accurate results. Either a double beam 'scope, or electronic switching, may be used to display Y_1 and Y_2 traces simultaneously.

1. With *Sw₂* in the CAL position and *Sw₃* in the X position (the X potentiometer may be at or near its maximum), the input from the A.F. oscillator is adjusted at the required frequency to the correct voltage on the instrument scale, and the gain of the X amplifier or potentiometer on the 'scope set to produce a display of predetermined width on a squared transparency.

2. Switching over Sw_2 to BRI with Sw_1 in position 1, the input from the oscillator is adjusted until the trace is the same width again. The bridge circuit values, and the gains of the two Y amplifiers are now adjusted to make the two patterns fall between the same two horizontal rulings, as shown at (A) in *Fig.* 5, the one from Y_2, taken from the null point, touching each line in three places.

3. Sw_1 is moved to position 2, giving the traces shown at (B), and the dimensions of the ellipse used to determine the phase angle of the fundamental as indicated.

4. Return Sw_2 to CAL position, and adjust the three potentiometers to give the pattern shown at (C), the essential features of which are: (a) the Y deflection amplitudes are both the same as in patterns (A) and (B); (b) the phase relation between X and Y deflection voltages is zero, because both traces are straight lines. The cross pattern is due to phase reversal of one half of the double beam; use of an electronic switch will produce two sloping lines that coincide when correctly adjusted.

5. Sw_3 is turned into its other two positions, and the voltage drop across the standard resistor, due to fundamental and harmonic components of magnetizing current, are read. From this the magnitude of the current is obtained by Ohm's law, and the harmonic percentage calculated from the ratio of the readings.

Considerably greater gain will be required of the Y_2 amplifier, than of the Y_1. If an electronic switch is used, it may be well to incorporate an extra stage in the Y_2 circuit, performing the dual purpose of giving the extra gain, and phase reversal, so the result is the same as using a double-beam 'scope.

Another interesting and useful check is to make the same measurements with a 90-deg. phase shift in the lead to the X deflection. *Figure* 6 shows a suitable phase-shift network. (D), (E), and (F) show the corresponding patterns for this modification. The 90-deg. phase shift is accurately set up by adjustment, using pattern (F), until the two ellipses coincide to form a circle. The interesting feature of this is the fact that one of the traces at (D) is the actual hysteresis loop (with H vertically and B horizontally, instead of the usual way). The useful part is that a check on phase is available by using a different ellipse.

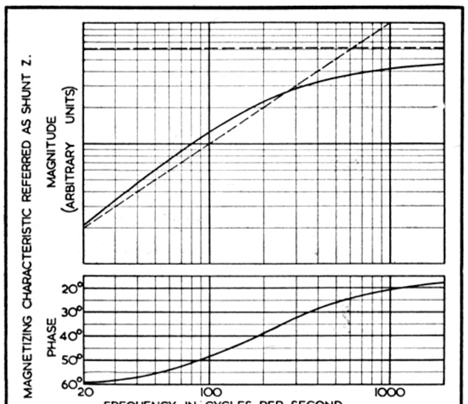

Fig. 7. Recommended method of plotting the results. The sloping dotted line represents pure inductance for comparison. The horizontal dotted line is loss due to eddy currents in the core.

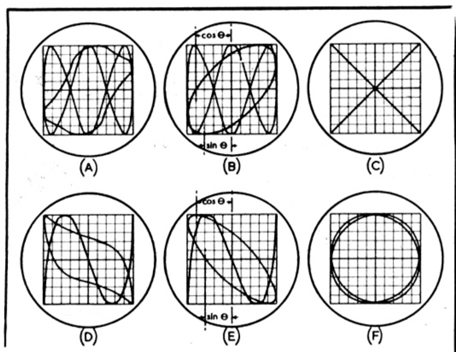

Fig. 5. Typical traces obtained using the method of Fig. 4. Significance and use of each is explained in the text.

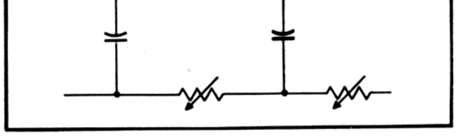

Fig. 6. This phase shift network enables the alternative traces of Fig. 5 to be displayed, giving the actual hysteresis loop, and a check on phase angle result. Exact 90-deg. phase shift requires adjustment for each frequency of measurement, using the method explained in the text.

The results of such a series of measurements can be analyzed and presented in any desired form. Probably a plot of impedance and phase angle, of which a typical example is shown at *Fig. 7,* is the most convenient. If desired, the measurements can be taken at different amplitudes, as well as at different frequencies, so the effect of amplitude on response can be seen. Harmonic content can be similarly plotted.

With D.C. Polarizing

Components designed for use with d.c. polarizing require more turns to produce the necessary inductance, so core loss due to a.c. magnetization is usually small enough to have negligible effect on performance. Inductance value does not vary so widely with amplitude and frequency of signal, but is principally dependent on d.c. polarizing current.

For measuring inductance with d.c. polarizing, the bridge circuit of *Fig.* 8 gives satisfactory results. The polarizing current is adjusted to a specific value, and then the bridge is balanced. The value of inductance is given by

$$L = R_1R_2C$$

The resistor R_3 serves to balance the core losses in the inductor under test, and generally is used only to help find

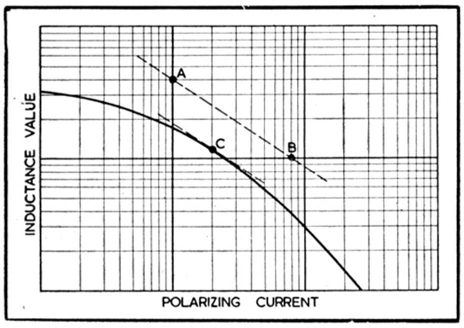

Fig. 9. By plotting inductance against current on log/log paper, the intended operating point can be located, and a useful record made for later reference.

the bridge null. If, however, the effective shunt loss resistance due to core losses is required, it is given by

$$R_p = \frac{R_1R_2}{R_3}$$

If the inductance for various values of polarizing current is plotted, for small currents compared with that for which the core gap was intended, change of current will have only small effect on inductance; at larger values, it will cause the inductance to fall off more rapidly. If the design value of polarizing current is not known, a good method of finding it approximately is to plot inductance and current on log/log paper, as shown at *Fig.* 9. By connecting two points on the paper representing 4:1 inductance ratio and 1:8 current ratio, for example (A) and (B), find the 2/3-power slope. The designer's operating point is approximately where the inductance/current curve is tangential to this slope, as at (C). It is never economic to work at currents appreciably higher than this point, because inductance could

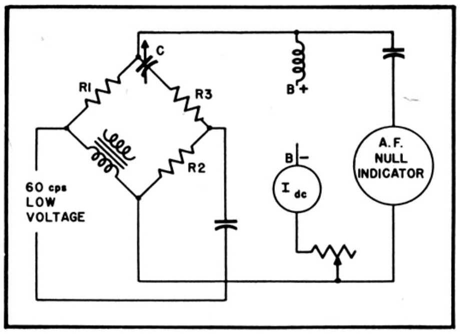

Fig. 8. Bridge circuit suited for measurement of inductance when there is d.c. polarizing current.

be improved by widening the air gap.

Leakage Inductance

This property is not directly dependent upon the core, but on the dimensions of the flux leakage paths through the windings themselves, so it will not possess any non-linear properties, nor will it vary with d.c. polarizing, if any.

It can be measured by an inductance bridge method. To make this measurement, one winding is short-circuited, and the leakage inductance measured at the terminals of the other winding. The measured value will be the leakage inductance referred to the winding at whose terminals it is measured.

An alternative method of determination is by resonance. Care must be taken to avoid invalidation of the result by winding capacitances. However, as winding capacitances cannot be measured independently, it is useful to determine the two quantities together, as outlined in the following section.

Winding Capacitances

Physical-interwinding or winding-to-ground capacitances can be measured by means of a capacitance bridge in the normal way, but this does not give the value effective in normal transformer working. The values that matter are the effective capacitances in shunt with each winding, referred to the whole winding, and that between "hot" points on the two windings. As stated in the previous article, capacitance between such hot points should be avoided—it is mentioned here only to emphasize the necessity for ensuring it *is* avoided.

As affecting winding capacitances, there are two important methods of connection: (1) single ended, in which one end of the winding is connected to ground, or has zero signal potential; (2) push-pull, in which the center tap of the winding has zero signal potential.

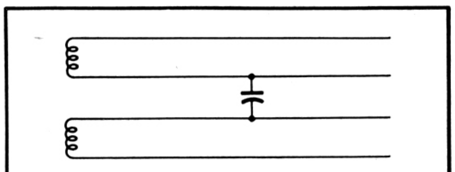

Fig. 10. In a simple transformer, the lumped interwinding capacitance is between the ends of the windings adjacent to each other. Where possible these ends should be operated as zero signal points.

Tests for winding capacitance must be made with the correct zero signal points on both windings connected to ground.

Where one or both windings are of the push-pull type, there can be no ambiguity about connection. In transformers with both windings for single ended connection, the internal construction usually consists of two simple windings, so arranged that one end of each is close to the other, shown diagrammatically at *Fig.* 10. These ends should be the zero signal points in their respective windings. Many manufacturers clearly indicate the correct method of connection, and in open types inspection can give the necessary information; but where neither means of identification is available, measurement of winding capacitance should include tests to find the correct method of connection.

The low-impedance winding of a transformer should be connected to an A.F. oscillator, one side of each winding being connected to ground; search is made for the resonant frequency between leakage inductance and capacitance, which is effectively a series circuit, producing a dip in input terminal voltage, or a peak in input current; having found the resonant frequency, try connecting the opposite side of the high-impedance winding to ground (the high-impedance winding is open circuited for these tests); if the resonant frequency is raised, the second method of connection is correct, otherwise the first was correct.

Next the correct connection for the low-impedance winding can be found by connecting the high-impedance winding to the A.F. oscillator, keeping its correct side grounded, and finding the resonances for the low-impedance winding (now open circuit) with leakage inductance, with its alternative ground connections. With high turns ratios, this test may be indefinite, if not impossible, but under these circumstances which side of the low-impedance winding is grounded is unimportant; although, in a practical circuit, phasing may matter. For lower turns ratios, the test will still be less definite than for the high-impedance winding, but should prove adequate.

Having thus found the correct method of connection, by inspection or test, the final stage consists in setting the transformer up, correctly connected, as a step-up transformer, and again checking the actual resonant frequency; additional capacitance is then added in shunt with the high-impedance winding untii the resonant frequency is halved. The effective self capacitance of the high-impedance winding will then be one third of the added capacitance value.

Once the effective winding capacitance is known, the leakage inductance can be calculated quite simply from the resonance formula. The value given will be leakage inductance referred to the high-impedance winding. Referred to the low-impedance winding, it will be divided by the square of the turns ratio.

Some transformers may be required for "universal" use, that is, for some

[*Continued on page 80*]

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[*from page 26*]

purposes a winding may be connected single ended while for others a push-pull connection may be required. For such a case, the tests may be made with both methods of connection to find effective capacitance. Leakage inductance will not be affected by changing the grounded point, but capacitance will.

Integrated distributed capacitance effects, set up between individual layers of the same winding, will not change with method of connection, but effects due to lumped capacitance from end layers to core, the other winding, or to screens, if used, will change considerably with method of connection. No fixed rule can be stated as to which method of connection will give the smallest effective capacitance, because this depends on the arrangement of the windings. Some methods of construction give minimum effect with zero signal point at one end, and others with it at the center. Good designs naturally take this effect into consideration, so connecting in a way other than that for which the transformer was intended will generally be found to increase effective winding capacitance.

Southwest Audio

Texas-TV Stores, San Antonio distributor is staging an Open House Week from Nov. 3 to Nov. 8, and the important part (to Æ readers) will consist of an Audio Show at which the products of over 35 manufacturers will be demonstrated. Believed to be the first such show to be held in the Southwest, this exhibit will introduce the new Altec 604C loudspeaker, the Pilot line of tuners and amplifiers, the Stephens transformerless amplifier, the Weathers FM pickup and the Gately Superhorn in addition to other well known products.

The Audio Show will be held in the new Texas-TV Sound Rooms—a group of air-conditioned, sound-proof studios of varying acoustic properties to match the different kinds of listening conditions. Latest type of acoustic construction has been employed in making these studios as completely up-to-date as the art permits, according to Jeff Smith, Texas-TV manager, and former New York network and recording engineer.

This showing is only one of many similar audio exhibits which are rapidly appearing throughout the country—distributor-planned and staged on a more or less permanent basis to offer their customers an opportunity to see how they can adapt standard audio components to their own requirements and listening conditions.

Once the urge for good quality is felt, the customers are sure to demand more places where they may see and hear before making their final selections.

Erratum

M. V. Kiebert, Jr., author of the preamplifier story in the September issue advises us of an error in the schematic on page 23. The V_3 cathode resistor should be 4700 ohms instead of the 47,000 shown. The correct value is given in the text. However, we agree that with two values given, it is difficult to choose the right one with any degree of assurance.