Audio Transformer Applications

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Impedance calculations for transformers are encountered regularly in audio work. The author clarifies relations between impedances in tapped and multi-winding coils.

AUDIO TRANSFORMERS are essential elements of high quality audio systems. The broadcast engineer, to whom quality performance is a prime consideration, uses audio transformers in practically every phase of his work. Modern design, high quality materials, and up-to-date manufacturing processes contribute to the superb performance of present day transformers.

In this connection, the writer recalls some experiences with transformers in the humid climate of the Netherlands East Indies in the early 1930's. Transformers were difficult to obtain and demanded highly developed protective techniques to combat the onslaughts of humidity, termites, fungi and many other threats to the delicate life of the fragile and valuable components.

Radio amateurs spent many evenings comparing, arguing, and defending their latest developed protective techniques, which they claimed were guaranteed to allow a tranformer to remain unattended for fully two months. Regularly removing transformers from the sets and drying them slowly in hot boxes was old stuff—it took more courage to dip the pride of one's collection in a hot bubbling mixture of rosin and beeswax, praying that the latest treatment would not again result in a horribly sticky mess that eventually would seep through the entire set. Reliability was a touchy characteristic then, and not many makes of transformers were able to take both the climate and the protective practices to which they were subjected by the zealous amateurs.

Most readers, however, living in less trying climates, may feel assured that their investment in high quality audio transformers is a safe one, without having to resort to any maintenance program. An investment it will be, however, for good quality transformers are not cheap, and mediocre ones are not worth wasting time and money on if the utmost in performance is your goal.

Specific Uses

Sometimes a transformer is needed that must operate satisfactorily over a wide range of operating levels and over a wide frequency band. An example of such an application is the matching transformer used in certain audio signal generators equipped with an output meter and variable attenuator with 110-db range in 1-db steps. The output of the attenuator is fed into this matching transformer, which provides various output impedances while handling a power range from −60 to +35 dbm over a frequency band from 20 to 20,000 cps and with less than 1 per cent harmonic distortion. The fact that such transformers are produced in commercial quantities at reasonable cost is a good example of the high standards of design and manufacture in the transformer industry.

The application of audio transformers as a rule requires a certain amount of impedance matching. In most cases, little difficulty is encountered with interstage transformers, which normally are selected to operate with a specific set of tubes and therefore are not subject to a change in conditions. With care, good resistance-capacitance coupled circuits may be designed to replace interstage transformers, but it is not so simple to find a substitute for input or output transformers, which are often called upon to accomodate a wide variety of impedances.

Microphones and pickups require a wide range of input values, and loudspeaker voice coils vary with speaker size, type, and manufacturer. Telephone

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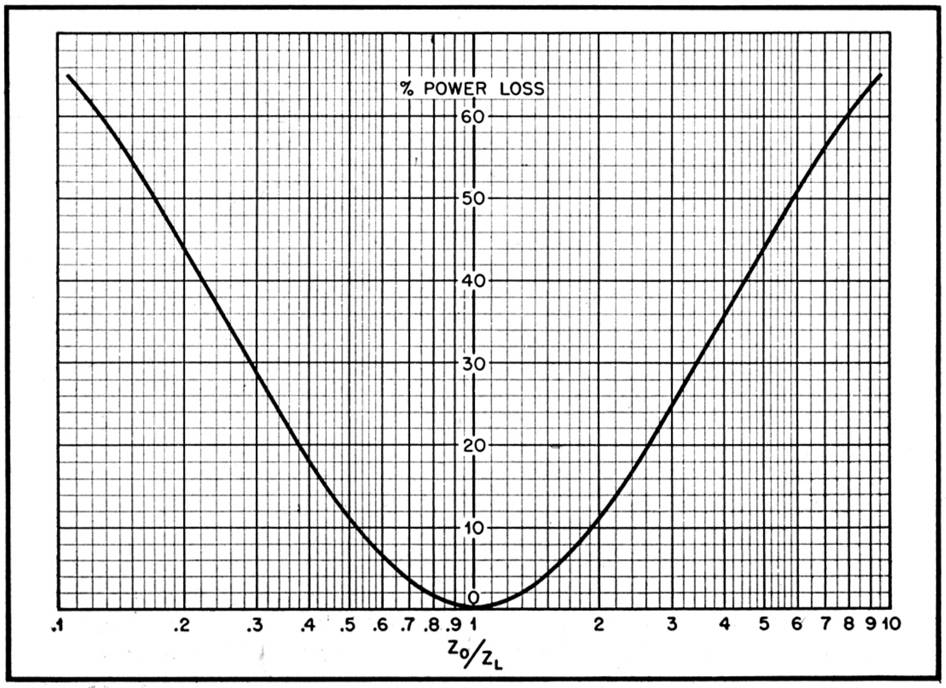
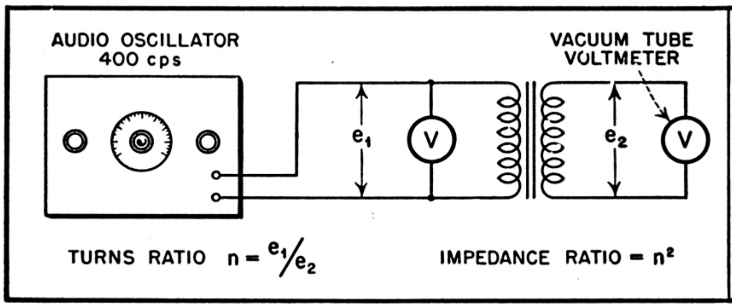


Fig. 1. Curve showing power loss due to impedance mismatch between circuits.



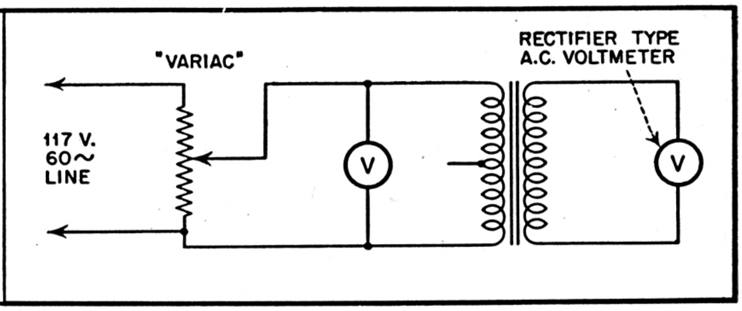


Fig. 2 (left). Simple method of measuring turns ratio of transformers when v-t voltmeter is available. This arrangement is suitable for all types of transformers. Fig. 3 (right). Method of measuring turns ratio of output or speaker coupling transformers.

lines and multiple-speaker installations complicate the picture even more and emphasize the importance of suitable input and output transformers.

Transformer Selection

The selection and application of each type require special considerations, which often are not obvious to the non-professional designer. Transformers are usually designed for a definite application, and optimum performance is obtained only under specified operating conditions. The performance of a unit when applied under different circumstances may differ appreciably from that which is expected. Furthermore, the frequency characteristic of input and output transformers and the available output from the amplifier are definitely affected by incorrect impedance matching. A few cases are described to illustrate some of these effects. 1. A 500-ohm to 8-ohm voice coil matching transformer with a power handling capacity of 20 watts may perform superbly with low losses when driving a heavy duty speaker. However, when used as an input transformer to match an 8-ohm dynamic microphone to a 500-ohm line, unsatisfactory operation may result. The low-level signal may be inadequate to provide sufficient flux excitation in the large core, since the minimum signal level depends on the grade of lamination iron used. Inasmuch as operations under these conditions have not been anticipated in the design, no provision has been made to utilize special costly core materials which are capable of developing adequate flux densities at exceedingly low signal levels. On the other hand, a transformer designed for dynamic microphone matching purposes would transmit the low signal levels efficiently in that service, but would be unable to handle a speaker power level because of core saturation and limited current-carrying ability in its fine wire. 2. When a transformer is used at a different impedance level than the rated value, the frequency response may be affected to a marked degree. Consider for example an output transformer designed to match an 8000-ohm plate-to-plate load to a 500-ohm line, and having a frequency response within 0.5 db from 30 to 15,000 cps. It is desired to use this transformer to match a 5000-ohm plate-to-plate load by reducing the secondary load in the same proportion to about 313 ohms.

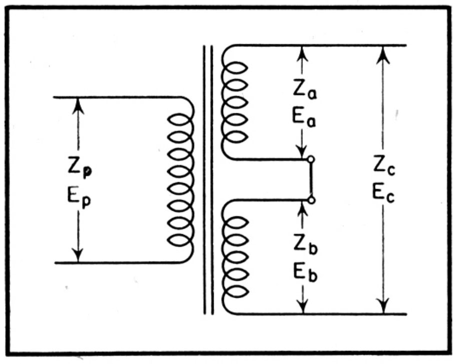


Fig. 4. Coil arrangement using two separate windings connected in series.

The inductance of the primary is sufficient to maintain only 0.5 db loss at 30 cps when shunting a 8000-ohm generator. The effect of reduced generator impedance by a ratio of 8:5 is such that the primary inductance is now sufficient to maintain 0.5 db loss at only 20 cps. On the other hand, the effect of leakage reactance, which controls the high-frequency response, is increased by the ratio 8:5 and the response of the transformer will be down 0.5 db at 10,000 cps. The reverse holds when the transformer is used in a higher impedance level circuit. Similar conditions exist in input transformers. 3. The effect of power loss due to mismatching is shown in *Fig.* 1, where power loss is plotted in per cent against the ratio of optimum output impedance Z_o to actual load impedance Z_L. The following example illustrates an application of the graph. An amplifier is available with 8- and 16-ohm taps, and it is desired to determine which one to use to connect a 12-ohm voice coil. The 8-ohm connection gives a ratio of Z_o/Z_l of 8/12 or 0.667 and from *Fig.* 1 a loss of 4 per cent. The 16-ohm connection results in a ratio of 16/12 or 1.33 and a loss of only 2.5 per cent, indicating the more desirable connection.*

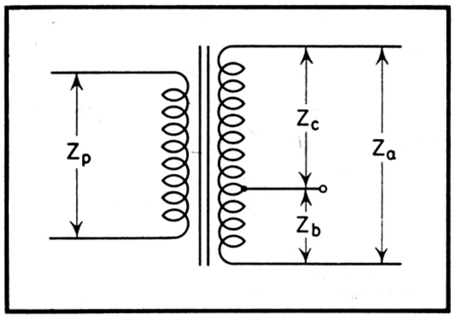


Fig. 5. Coil arrangement for single tapped secondary.

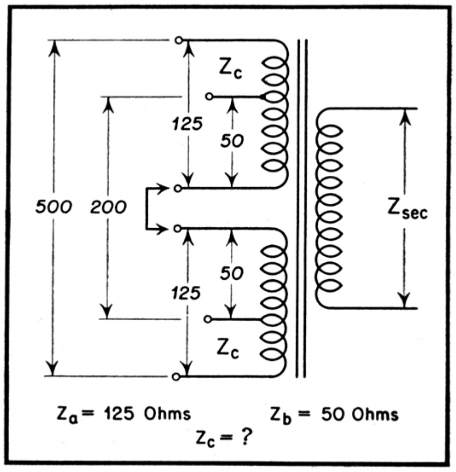


Fig. 6. Typical input transformer connections. Two 125-ohm windings connected in series provide a 500-ohm winding; similarly, two 50-ohm windings in series equal a 200-ohm winding.

In the first part of this acticle, transformer applications involving known impedance values have been considered. Most designers and experimenters are limited in selecting suitable transformers to commercially available lines, which include a great many with tapped or multiple windings. The values available at the taps may not always provide as close a match as would be desirable, and one may won-

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(*Note that this applies only when maximum power output is the primary consideration. Ed.)

however, largely because few people have taken the trouble to equalize it properly. *Figure* 8 shows the equalizer used to obtain the curve for the QT-3J in *Fig.* 7. This may be built into an octal base and substituted for the plug-in preamplifier when desired.

BIOGRAPHY

1 "Versatile Phonograph Preamplifier," Paul W. St. George and Benjamin B. Drisko, AUDIO ENGINEERING, March, 1949.
2 "Flexible Dual Control System," Howard T. Sterling, AUDIO ENGINEERING, Feb. 1949.
3 "Feedback Preamplifier For Magnetic Pickups," Richard S. Burwen, AUDIO ENGINEERING, February, 1948.

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der how to determine the impedance values between taps, and the impedance of unequal windings in series. This would be a simple matter were the actual number of turns known, but this is usually not the case.

There are two methods by which the impedances that are available from a given transformer may be determined. If an audio oscillator and a vacuum-tube voltmeter are available, the turns ratio may be measured directly. Apply a known voltage from the oscillator to one winding and measure the voltage with the high-impedance vacuum-tube voltmeter at the desired terminals, as in *Fig.* 2. The impedance ratio is then the square of the voltage ratio.

By measuring and recording the values at various taps, a convenient set of data on that particular unit may be obtained.

With output transformers, a rough check may even be made using only a multirange rectifier-type meter with 1000-ohm-per-volt sensitivity and the regular 117-volt 60-cps line, as shown in *Fig.* 3. This method is not recommended for input transformers because of the load presented by the voltmeter.

If the impedance values are known at several taps or of separate windings, a simple calculation may give the desired answer more quickly. A few formulas have been derived which are fairly easy to remember, and values are obtained without reference to the primary impedance. To illustrate this, the following simplified derivation is presented. Note that the primary impedance is used as a common factor, and subsequently drops out.

Assume a transformer having three windings, *p*, *a*, and *b*, corresponding voltages E_p, E_a, and E_b, and impedances Z_p, Z_a, and Z_b, with the arrangement shown in *Fig.* 4. It is desired to derive an equation for Z_c representing Z_a and Z_b wired in series, observing "aiding" polarities.

$$E_a/E_p = \sqrt{Z_a/Z_p}$$

$$E_a = Z_p\sqrt{Z_a/Z_p}$$

$$= E_p\sqrt{Z_a} / \sqrt{Z_p}$$

Similarly

$$E_b = E_p\sqrt{Z_b} / \sqrt{Z_p}$$

and

$$E_c = E_p\sqrt{Z_c} / \sqrt{Z_p}$$

$$E_c^2 = E_p^2\, Z_c / Z_p$$

$$Z_c = E_c^2\, Z_p / E_p^2$$

Now

$$E_c = E_a + E_b$$

$$= E_p\,(\sqrt{Z_a} + \sqrt{Z_b}) / Z_p$$

From above

$$Z_c = E_c^2 + Z_p / E_p^2$$

Substituting and solving

$$Z_c = (\sqrt{Z_a} + \sqrt{Z_b})^2$$

$$Z_c = Z_a + Z_b + 2\sqrt{Z_a\, Z_b} \quad (1)$$

Similar derivation for the value between taps of a winding as shown in the diagram of *Fig.* 5 yields the following formula:

$$Z_c = Z_a + Z_b - 2\sqrt{Z_a\, Z_b} \quad (2)$$

These formulas have been of great use to the writer and it is hoped that they may serve the reader equally well.

The following examples are given to illustrate their application:

1. An amplifier has to be matched to a 600-ohm load. The output transformer has a 500-ohm winding and a winding tapped at 2, 4, 6 and 8 ohms. The 500-ohm winding in series with the 4-ohm section will give, using formula (*1*):

$$Z_c = 500 + 4 + 2\sqrt{500 \times 4}$$

$$= 504 + 2\sqrt{2000}$$

$$= 504 + 89.44 = 593.44 \text{ ohms}$$

The 6-ohm section together with the 500-ohm winding will yield:

$$Z_c = 500 + 6 + 2\sqrt{500 \times 6}$$

$$= 506 + 2\sqrt{3000}$$

$$= 506 + 109.6 = 615.6 \text{ ohms}$$

The 4-ohm section apparently would be the better choice.

2. The 20-ohm dynamic microphone has to be matched to an amplifier while the input transformer has two tapped windings as shown in *Fig.* 6. The known values would result in considerable mismatch and the value of the unknown section is investigated:

$$Z_c = 125 + 50 - 2\sqrt{50 \times 125}$$

$$= 175 - 2\sqrt{6250}$$

$$= 175 - 158 = 17 \text{ ohms}$$

This match is obviously closer than would be possible using only the known values and best results are obtained by using both Z_c sections in parallel.

In closing, the writer wishes to call attention to the fact that two equal impedances in series will give a value four times that of the single winding and that one half of a winding presents an impedance of one-fourth of the total winding.