The Pass Band of a Transformer-Coupled Amplifier

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A discussion of the transmission characteristics of an audio transformer and the parameters which affect it. The author reduces calculations to a minimum by the use of an abac.

THE DESIGNER is often confronted with the problem of rapidly determining the pass band of a transformer-coupled amplifier. Straightforward application of the pertinent formulas is a time-consuming process even with the aid of a slide rule. It is the purpose of this article to furnish a rapid, direct-reading calculator for the one- and three-decibel attenuation frequencies. The calculator may also be used to select combinations of circuit parameters which afford a specified band width.

To review quickly the equivalent circuits which are used for this type of calculation, refer to *Fig.* 1. In these simplified schematics for an output transformer, primary capacitance, hysteresis, and eddy-current resistance are neglected, and the turns ratio is reduced to unity. The leakage reactance at low frequencies and the shunt inductance at high frequencies are disregarded. Secondary circuit parameters are referred to the primary side by using the turns squared factor.[1]

The relative gain at low and high frequencies as compared with mid-frequency gain depends upon the values of the effective circuit resistance r' and r'' as compared with the corresponding inductive reactances. Thus, at low frequencies r', which is R_p and R_o in parallel, is compared with the primary inductive reactance to determine relative gain. At high frequencies r'', which is R_p and R_o in series, is compared with the leakage inductive reactance.

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[1] F. E. Terman, *Radio Engineers Handbook*, New York: McGraw-Hill Book Co., 1943; pp. 385–388.

Equivalent Circuit Components

Circuit component values corresponding to those in *Fig.* 1 can be measured easily if these data are not available from the manufacturer. The required parameters are primary and secondary winding resistance, primary incremental inductance, leakage inductance, and the turns ratio. Load resistance is generally known and plate resistance is dependent upon tube operation. With this information on hand the equations in *Fig.* 1 can be utilized.

Winding resistance is generally measured with a resistance bridge. Although the a.c. resistance is desired, the d.c. resistance can be substituted in the audio-frequency range. When multiple windings are involved care must be taken to group properly those windings which constitute the complete primary or secondary.

It is important that the primary inductance be measured at a suitable frequency with adequate applied voltage. By this method the measured inductance is more representative of circuit conditions in the lower cut-off region. The usual values are 10 volts applied at 60 cps. This is minimum voltage which will produce a core flux density representative of normal operation for most transformers. The Hay inductance bridge may be used and the transformer secondary should be open-circuited.

If the circuit being designed is single-ended, the d.c. magnetization current must also flow through the primary winding (assuming series feed) when incremental inductance is measured. The amount of current should be the anticipated plate current plus that current drawn through the primary winding by any other element such as the screen grid of a triode-connected pentode.

Leakage inductance is determined by the measurement of primary inductance when the secondary is short-circuited. An inductance bridge may be used. This measurement can be made at any convenient frequency and without passing direct current through the winding.

Finally, the turns ratio is measured by applying an a.c. voltage from a signal generator to the primary and measuring the resulting secondary voltage with a vacuum-tube voltmeter. The signal generator should be adjusted to a mid-band frequency in order to avoid high- or low-frequency attenuation.

Graphical Calculations

The 1- and 3-db attenuation frequencies can be determined rapidly for a given circuit by reference to the nomogram of *Fig.* 2. Low-frequency cutoff can be read on the left portion and high-frequency cutoff on the right portion of the chart. Thus, to determine the low-frequency cutoff, select the value of effective resistance on the r' scale and the value of primary inductance on the L_p scale. Join these points with a straight line and find the 1- and 3-db attenuation frequencies at the intersection of this line with the f scale.

To determine the upper limits of the pass band, enter with the effective resistance r''. Join this point and the leakage inductance value on the L_s scale with a straight line. Once more the attenuation frequencies are found at the intersection of this line with the corresponding f scale.

Both of the above procedures are reversible. In this way a specified frequency can be selected, a straight-edge can be pivoted about this point, and combinations of inductance and resistance observed which will yield the desired frequency.

In the case of push-pull class A and class AB amplifiers, the same procedure can be used provided that the plate resistance is taken as twice the value for a single tube.

When applying this method to pentodes and beam power tubes the calculated upper cutoff may be high due to the large source resistance. In these cases the measured attenuation may be controlled by circuit capacitance rather than source and load resistances as shown in *Fig.* 1. Another precaution

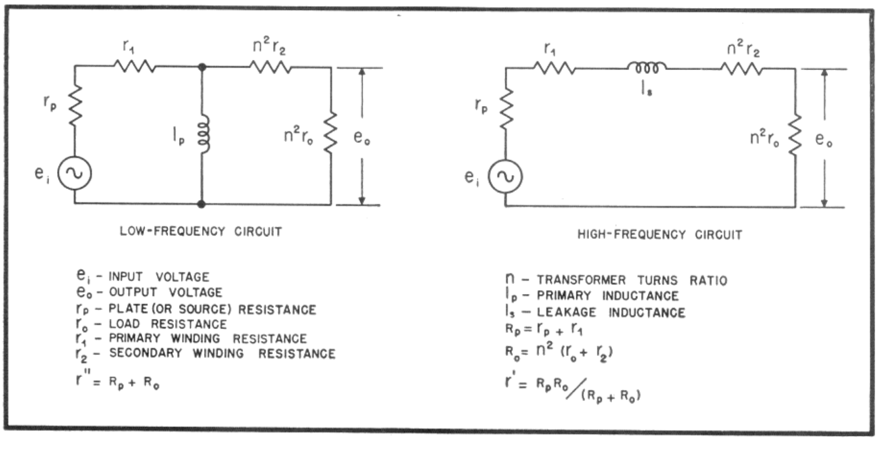

Fig. 1. Equivalent circuits of an audio transformer for low and high frequencies.

which should be kept in mind is that the application of negative feedback will increase the pass band and decrease the amplification of all stages within the feed-back loop.

Example

Consider the Triad HSM-89 transformer coupling push-pull KT-66's as Class A triodes to a 16-ohm voice coil. For this application the total plate resistance is 10,000 ohms (twice the single tube value). Primary resistance is 265 ohms and secondary resistance is 0.489 ohms. Primary inductance is approximately 233 henries and leakage inductance is 35.7 millihenries. The turns ratio is 23 and n^2 is 529.

The load resistance referred to the primary is 529(16 + 0.489) or 8720 ohms. The effective resistance r' is $8720 \times 10{,}265/(8720 + 10{,}265)$ or 4720 ohms, and r'' is $8720 + 10{,}265$ or 18,985 (use 19,000) ohms.

Construct a straight line from 4720 on the r'' scale to 0.0357 on the L_s scale. Read 3.2 and 6.3 on the f scale. Thus, the lower 3-db frequency is 3.2 cps and the 1-db frequency is 6.3 cps.

Next, draw a straight line from 19,000 on the r'' scale to 0.0357 on the L_s scale. Read 43,000 and 85,000 on the f scale. Thus, the upper 1-db frequency is 43,000 cps and the 3-db frequency is 85,000 cps.

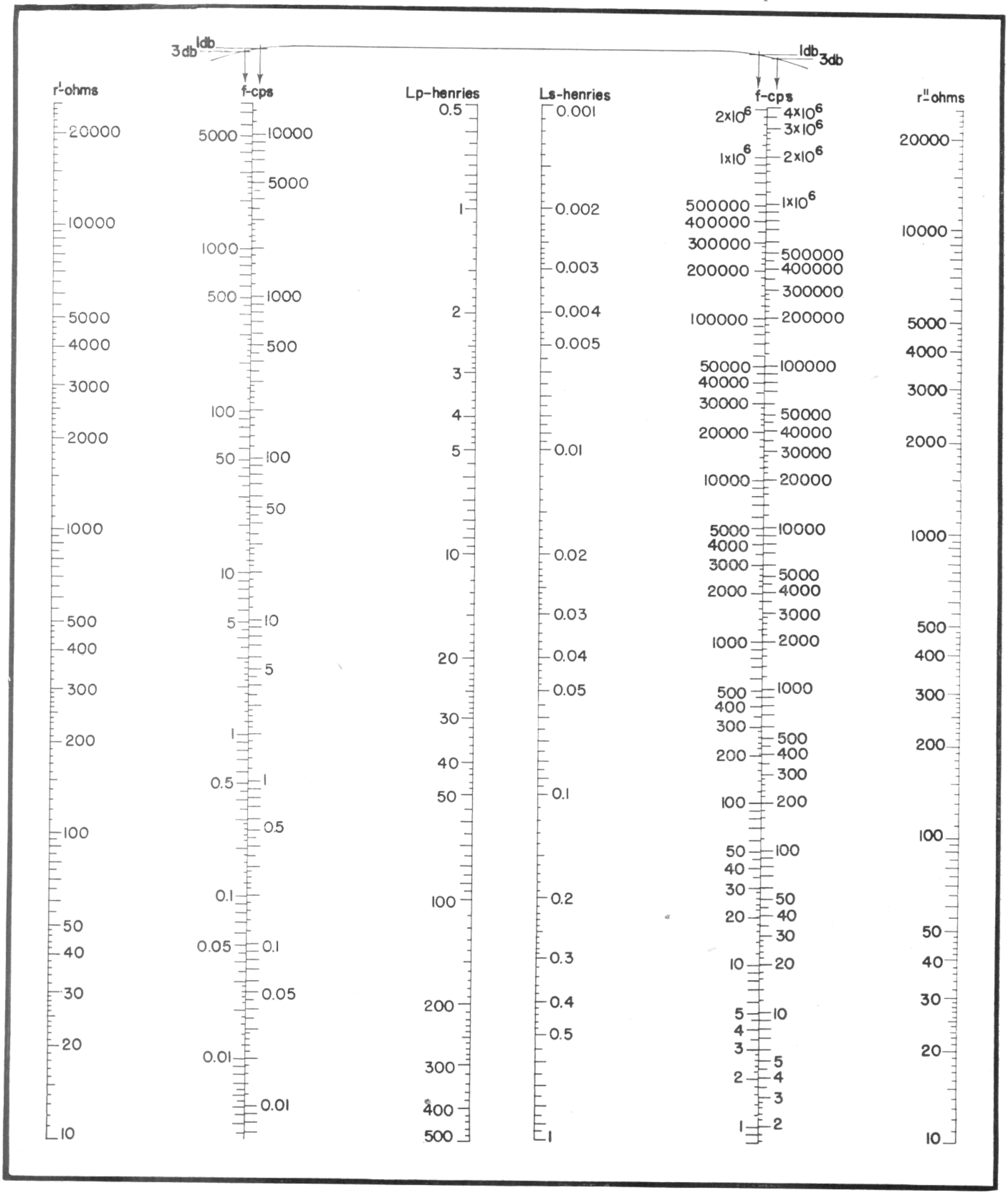

Fig. 2. Nomogram for determining the 1- and 3-db attenuation frequencies of an audio transformer.