the GENERAL RADIO Experimenter

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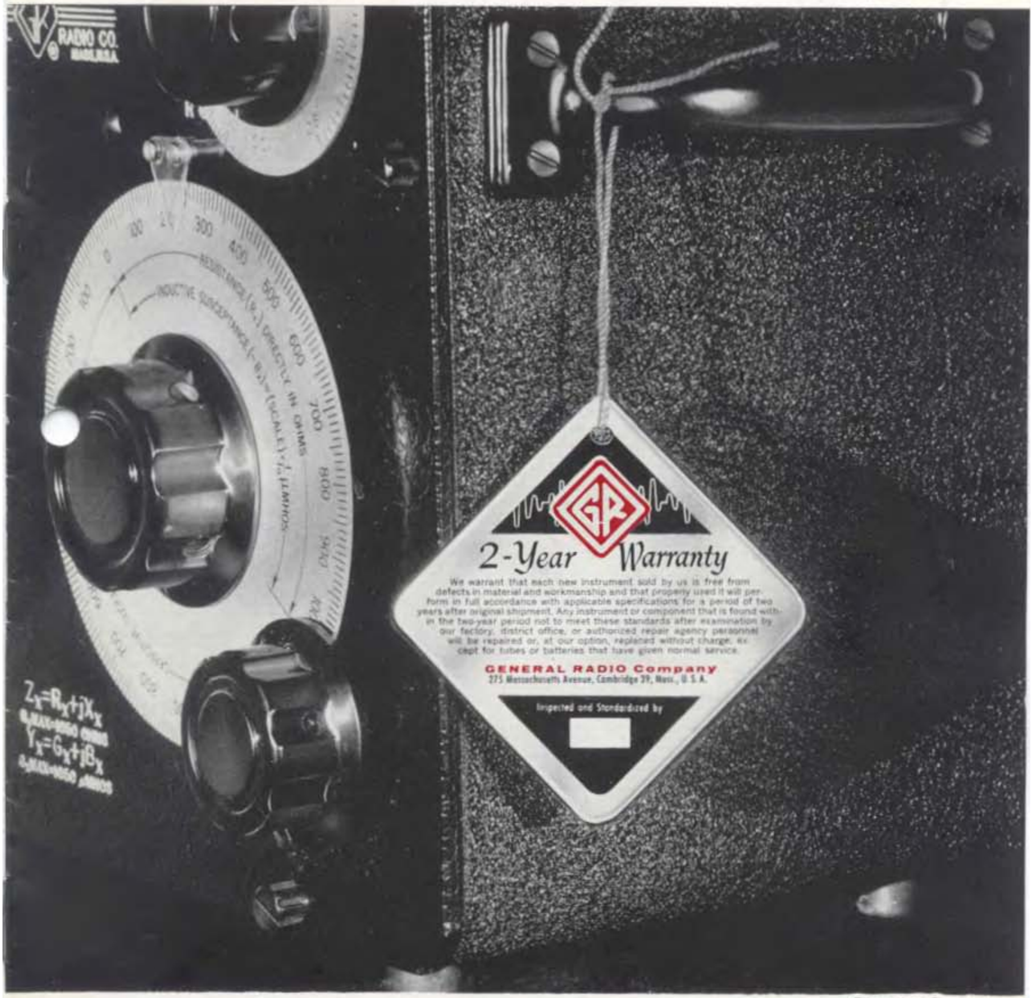
Since 1915 Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 10 MARCH, 1957



We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

GENERAL RADIO Company
275 Massachusetts Avenue, Cambridge 39, Mass., U.S.A.

Inspected and Standardized by

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THE GENERAL RADIO EXPERIMENTER

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COVER

Look for this warranty tag on your electronic test equipment.

G-R INSTRUMENTS ARE BUILT TO LAST

2-Year Warranty

We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

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New Two-Year Warranty Backs Up Well-Established Fact

A full two-year warranty — the first in the electronic instrument industry — now applies to *all* General Radio products shipped after March 1, 1957. This warranty is made possible by the ingredients of high quality that have always characterized GR equipment — circuit design that doesn't cut corners and which provides the extra refinements that assure stable and reliable performance; the use of high-quality components, which cost more but return several times their cost in calibration accuracy and stability; ruggedness of mechanical construction, which assures long life; care in manufacture, through the use of skilled workmen and modern machines; and thorough testing, to better-than-catalog specifications.

To the engineer using this equipment, G-R quality means added assurance that his measurements are correct, because he knows the G-R reputation for calibrations that *hold* their accuracy over the years. To the firm buying G-R equipment, high quality in basic measuring tools means lower costs in the long run: less time lost for repairs and *longer life with full performance* before replacement is required.

When you buy a G-R product you make an investment in lasting value. Our new warranty tag on all newly purchased instruments shipped after March 1, 1957, will serve as a reminder of this quality.

THE G-R 2-YEAR WARRANTY

We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

NEW VARIAC® HANDLES OVER 1¼ KVA

Type W5L Gives More Watts Per Pound, More Watts Per Dollar

For use in the "line-voltage connection," where the usual overvoltage feature is not needed, the new Type W5L Variac® offers outstanding performance and outstanding economy.

Output voltage of the Type W5L is equal to input line voltage, that is, with 115 volts input, the output can be adjusted from 0 to 115 volts. Loads drawing up to 11 amperes at line voltage can be handled at any output setting, giving an output rating of 1.265 kva.

This increased rating is made possible by the elimination of both the overvoltage feature and 50-cycle operation, which permits the use of a larger wire size for the transformer winding. Size, weight, and mounting dimensions are identical with those of the Type W5.*

For the many uses where output voltages higher than input line voltage are not required, the Type W5L is an outstanding buy. It offers more watts per pound of weight and more watts per dollar than any other variable autotransformer on the market today.

---

* See *Experimenter* for December, 1955.

SPECIFICATIONS

Input Voltage: 115 volts, 60 cycles; can be used on lines from 105 to 125 volts, 60 cycles.

Output Voltage: 0 to input line voltage; dial calibration, 0 to 115 volts, correct at 115 volts input.

Load Rating: 1.265 kva.

Rated Current: 8.5 amperes; may be drawn at any output setting.

Maximum Current: 11.0 amperes; may be drawn at or near input line voltage.

No-Load Loss at 60 cycles: 12 watts

Angle of Rotation: 325 degrees

No. of Turns on Winding: 235

D-C Resistance of Winding: 0.926 ohms at 20° C

Driving Torque: 10 to 20 ounce-inches.

Mounting: Without case, for panel mounting.

Net Weight: 6½ pounds.

Type		*Code Word*	*Price*
W5L	**Variac ® Autotransformer..................**	COTUG	**$17.50**
VB2	**Replacement Brush..........................**		**0.75**
W5LBB	**Variac with Ball Bearings...................**	COTUGBALLY	**24.50**

THE DESIGN OF IRON-CORED CHOKES CARRYING DIRECT CURRENT

The optimum design of inductors with ferro-magnetic cores, having dc superposed on the a-c signal, has never been very satisfactorily systematized. Such chokes are used, for example, as filter chokes in rectifier-type power supplies or as plate chokes in constant-current modulators. In the past, the usual procedure was for each user to make empirical measurements on sample coils, displaying the results as a family of curves of inductance versus d-c bias for a succession of different air gaps. These measurements were usually repeated for each different lamination used. There was no facile method by which normalized data could be presented for a given grade of ferro-magnetic material so that it could be simply used for as many different sizes and shapes of laminations as desired.

This situation was recognized in the early twenties by Mr. C. R. Hanna of the East Pittsburgh works of Westinghouse Electric and Manufacturing Company, and he presented a paper entitled "Design of Reactances and Transformers Which Carry Direct Current" at the Winter Convention of the AIEE in New York City in February of 1927.[1] This paper provided the methods for deriving and presenting succinctly normalized data of the type being considered here. Some Hanna-type curves are published in Federal Telephone and Radio's *Reference Data for Engineers*, but this is the exception rather than the rule. Hanna's contribution has never received the wide usage to which its advantages entitle it.

For complete understanding of the matter, reference should be made to Hanna's paper. However, it can be stated that Hanna's information enables one to calculate quickly the airgap which will yield the maximum inductance for a given number of turns on a given magnetic structure with a stated amount of superposed dc at a particular flux density. It may thus be seen that the curves are useful only to give the optimum design for a specific steady-state purpose. They do not contain the information needed, for instance, to design a "swinging" choke in which the inductance at 10 per cent of full-rated direct current is typically about five times what it is at full-rated direct current. For this purpose one would use a family of curves as described in the first paragraph.

Hanna's information (*cf* Figure 3 and Figure 6 of his paper, reproduced here as Figure 1) is presented as a single curve (for each flux density) of stored direct-current energy per unit volume $(\frac{LI^2}{V})$ versus d-c magnetizing force $(\frac{NI}{l})$. Hanna indicated that airgap per unit length for optimum performance by labeled "transverse marks" on the curve. While this conveys the information faithfully, we find that we can read and interpolate with appreciably more ease if a separate curve is provided for

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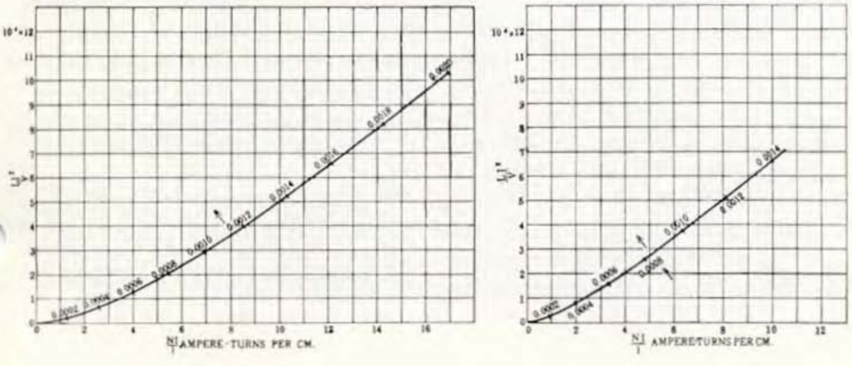
[1] See *Journal of the AIEE*, February, 1927.

Figure 1. Curves of $\frac{LI^2}{V}$ vs. $\frac{NI}{l}$ from Hanna's paper.[1] *(left)* 4% silicon steel; *(right)* Hypernik.



airgap per unit length $(\frac{g}{l})$ versus d-c magnetizing force $(\frac{NI}{l})$.

Behavior of any shape and size of core, with some limitations, can be derived from such data by the use of nothing more than the proper constants pertaining to the core. These constants are the volume of iron and the length of the magnetic path. The latter is necessary to determine the value of the abscissa $\frac{NI}{l}$. The former is necessary when interpreting the value of the ordinate $\frac{LI^2}{V}$.

We have found it advantageous to amplify the information given in the single curve on Figure 3 of Hanna's paper. While he specified in 1927 that his Figure 3 applied to 4 per cent silicon steel, this is not now very specific since a number of the better grades of electrical silicon steels contain around 4 per cent of silicon, and so we are not sure whether it applies to the grade of silicon steel often employed for chokes. Further, we do not know the flux density, *B*, at which Hanna's curves were taken. Even if we did, it would be necessary to have similar curves at several flux densities to take care of all design problems encountered.

This comes about from the fact that the permeability is highly dependent upon the alternating flux density. With no dc present, the permeability follows the familiar course. It starts on a plateau at very low flux densities at a value somewhere between 400 and 500[3], rises with flux density to perhaps 6000, and then falls off to very low values as saturation occurs. With dc present, the behavior is similar, except that the plateau is different and the permeability begins to drop off sooner, because of the d-c polarizing flux. The greater the dc, the sooner the falling off occurs.

THE ATTACHED CHARTS

The large curves herewith represent, respectively, the empirically obtained plots of $\frac{LI^2}{V}$ and $\frac{g}{l}$ against $\frac{NI}{l}$. The measurements were made using coils having cores of U. S. S. Radio Transformer "72" grade silicon steel, No. 26 U. S. gauge (approximately 0.019″), which is an AISI M-19 grade material. Over the past ten years these curves have been used with good results for coils having 26-gauge laminations of AISI M-19 material of other manufacturers also, and 29-gauge (0.014″) AISI M-15 (58 grade) material.

In the expressions used throughout:

A = effective cross-sectional area of core in square inches.

B = max. a-c flux density in lines/in.^{2}.

E = applied a-c voltage in volts, rms.

I = direct current in amperes.

L = inductance in henrys.

N = number of turns.

V = geometric volume of iron in cubic inches (no reduction for stacking factor).[4]

f = frequency in cps.

g = length of airgap, or airgaps, in inches. (Hanna calls this a).

l = length of magnetic path in inches.

For preparing both of these curve sheets, Hanna-type data was taken at 60 cycles with flux densities, *B*, of

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[3] For a material which is variously known as Radio Transformer "72" grade or AISI M-19; Radio signifies a punchable grade rather than one that must be sheared.

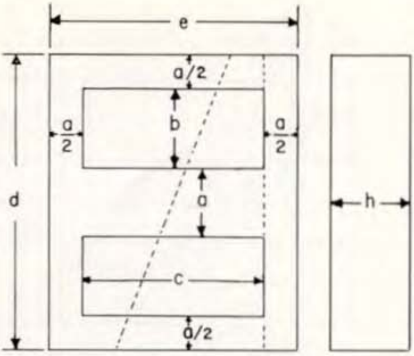
[4] This means that a stacking factor of around 96 per cent for noninterleaved laminations is implicit in the curves for inductance. Stacking factor should have no effect on airgap curves. If laminations much thinner or much thicke are used, so that the stacking factor will be less than or slightly greater than 96 per cent, then appropriate correction should be made to the inductance curves in direct proportion to the stacking factor.

100, 500, 1000, 5000, 10,000, 20,000, and 30,000 lines/in.^{2}.

The $\frac{LI^2}{V}$ curves show the wide spread of inductance values as a function of B. The spread would be still wider if data had been taken for initial a-c permeability. It will be noted, in general, that the curves for higher B lie above those for lower B. For a large part of the distance, the 10- and 20-kiloline curves coincide. The 30-kiloline curve lies above these two near the origin, but shortly goes below them and continues to cross other curves of still lower B's.

The upward-inclined lines crossing the others connect points having the same $\frac{g}{l}$ ratios. These lines are practically straight until saturation sets in. They show that, in general, a given $\frac{g}{l}$ ratio is optimum even when the d-c polarizing flux is increased, provided that the a-c superposed flux is also increased.

The second set of curves (page 9) shows the optimum airgap (in terms of $\frac{g}{l}$, which is specific) as a function of the magnetizing force (in terms of $\frac{NI}{l}$). These curves are derived from those on the prior sheet through the original data. They are supplied in this different form, rather than the way this information appears on Hanna's curves, for two reasons. First, a great deal of confusion is eliminated. Second, these curves are much easier to interpolate for $\frac{g}{l}$ than are Hanna's. The same effects described concerning relative permeabilities and the effects on optimum airgap of higher B's and of saturation can be seen also on these curves.

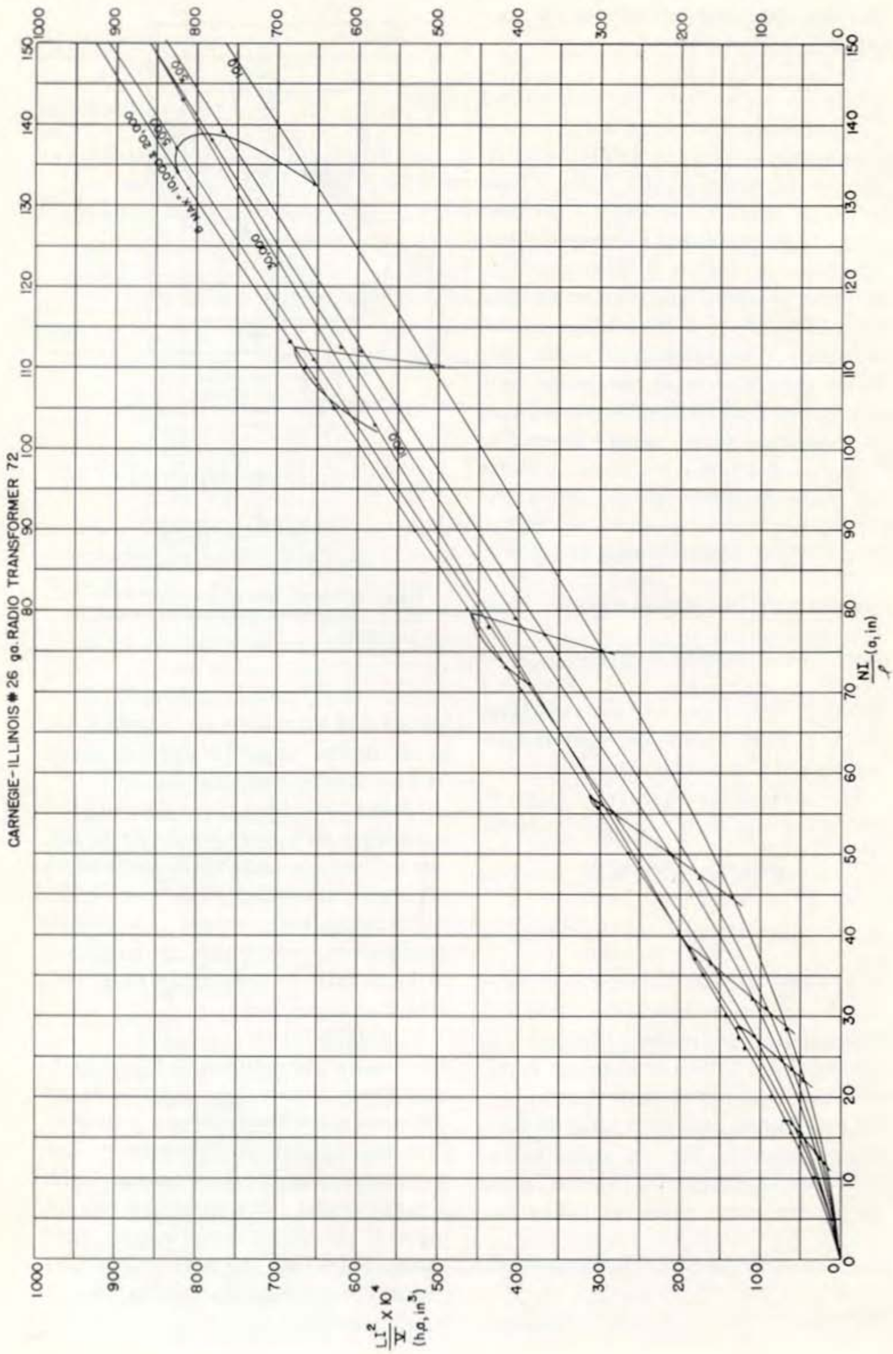


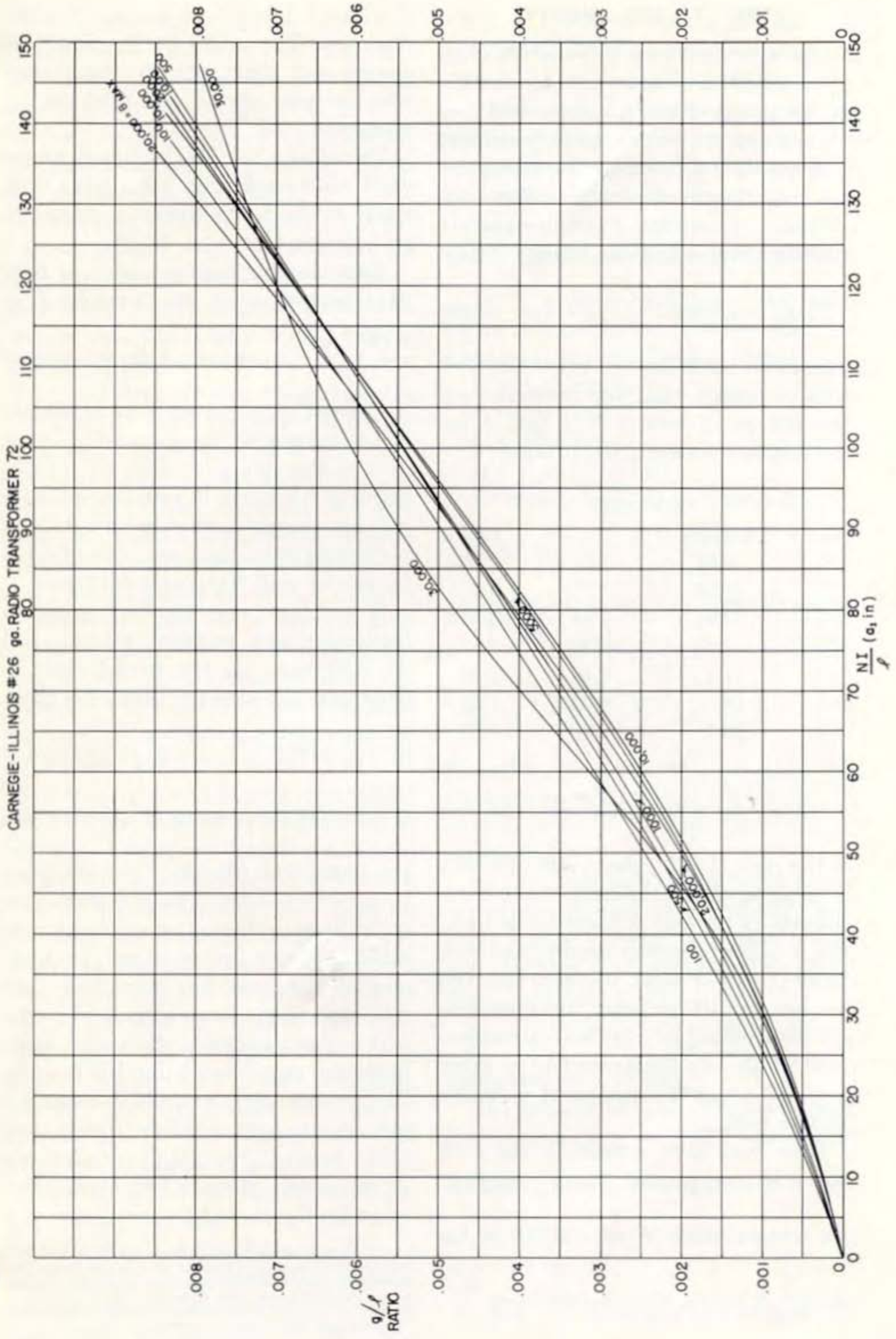
Type	a	h	b	c	e	d
746	11/32	21/32	1/4	3/4	35/32	1 3/16
745	3/8	3/8	9/16	13/16	1 3/16	1 7/8
345	3/4	3/4	17/32	1 1/8	1 7/8	2 9/16
485	15/16	15/16	21/32	1 19/32	2 17/32	3 3/16
365	1 1/16	1 1/16	29/32	2 1/8	3 3/16	3 15/16
685	1 3/8	1 3/8	1 1/16	2 3/8	3 3/4	4 7/8
565	1 5/8	1 5/8	1 1/4	2 7/8	4 1/2	5 3/4

Figure 2. Dimensions of standard General Radio laminations used as examples in this article.

Dimensions of the seven standard GR lamination structures are shown in Figure 2. They are convenient examples for use here because they constitute a series which is roughly geometric, the volume changing in steps which are roughly 2 to 1, as may be seen in Table 1, Column 2.

It should be obvious that all that needs to be done to apply this data to any other lamination is to establish dimensions for the structure analogous to those of Figure 2, deduce from them parameters analogous to those of Table I, and proceed. This procedure was followed in the calculation of a modulation choke, for which the core weighed almost 100 pounds, with complete success on the first trial.


CARNEGIE-ILLINOIS # 26 ga. RADIO TRANSFORMER 72
$\frac{LI^2}{V} \times 10^4$ (h, a, in^3)
1000
900
800
700
600
500
400
300
200
100
0
$\frac{NI}{\ell}$ (a, in)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
100
500
1000
5000
20,000
B MAX = 10,000 & 20,000


CARNEGIE-ILLINOIS #26 ga. RADIO TRANSFORMER 72
g/ℓ RATIO
NI/ℓ (a, in)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
.001
.002
.003
.004
.005
.006
.007
.008
30,000
20,000 = B max
10,000
1000
500
250
100
20,000
5000
10,000
1000
20,000
250
100

HOW TO USE CHARTS

Suppose you wish an iron-cored coil to give at least a certain inductance with an a-c signal of given voltage and frequency applied, with a given polarizing dc present, and having a d-c resistance not more than a certain value. You may also have some idea which lamination structure you would like to use.

First, calculate $\frac{LI^2}{V}$ and find where this value lands on the curve for a B which is about what you guess the a-c flux will be. Values of V, l, and A for the laminations are given in Table I.

TABLE I

Core	V (*in.*^{3})	l (*in.*)	A (*in.*^{2})
746	0.67	2.69	0.238
745	1.46	3.75	0.375
345	2.71	4.81	0.540
485	5.49	6.38	0.844
365	11.4	8.19	1.35
685	18.0	9.63	1.81
565	29.1	11.00	2.53

If the $\frac{LI^2}{V} \times 10^4$ comes near the top of the plot, that is, above 700, the iron is being worked very hard, the d-c resistance of the coil is likely to be high, and a larger core may need to be used. If, on the other hand, it comes near the bottom, say 100 or below, the opposites are true; that is, the iron is underworked, the d-c resistance will be quite low, and a smaller core could perfectly well be used.

Once you have settled on the core you wish to use, enter the first chart at the proper value of $\frac{LI^2}{V} \times 10^4$ on the chosen B curve, thus determining $\frac{NI}{l}$. Since both I and l are known, N is determined. The tables for the structure chosen will then indicate the largest wire size that can be used, and the d-c resistance.

Unless the d-c resistance is above what can be tolerated, the design is all right. If the d-c resistance is too high, try a larger core.

Next check the actual value of B to be expected, using the formula $E = \frac{4.44\ BANf}{10^8}$, in which A is the area of the center-leg cross section in square inches multiplied by a stacking factor of 0.96, the values of which (A) can be found in the table. If your first-guess B was not too good, go over any steps in the computation that would be affected by having used the wrong B curve.

If you are now satisfied with the lamination size, number of turns, and d-c resistance, use the second chart to determine the airgaps. Enter the chart at the appropriate $\frac{NI}{l}$, go to the proper B curve, and read value of $\frac{g}{l}$, from which g is found immediately by multiplying by l from the table. This gap is the sum of the gaps in the center and in an outside leg. Divide by two to get the thickness of nonconducting shim to be put into each of the three airgaps in a coil.

If a single airgap in the center leg is used, the outer legs being interleaved, the optimum airgap should be about 1.5 mils larger (see "Those Iron-Cored Coils Again", Part II, *General Radio Experimenter*, January 1947) than the g given by the curve.[5]

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[5] A center-leg airgap is not possible in the 745 or 565 cores (which are EI-shaped). Likewise, all EI's and many other lamination shapes are not adaptable to a center-leg gap because of their geometries. The other GR standard laminations are either F's, or double E's with slanted shear line, and lend themselves to center-leg gaps.

In this case, however, the inductance is likely to be reduced by something like 20% from the values indicated by the curves on the first chart. This seems to be the penalty paid for the extra stability and freedom from external field of the center-leg airgap design.

The extra stability results from the mutual friction of the interleaved outside legs of the laminations. This is sufficiently great that some laminations can be removed from one side only of the coil in order to adjust the inductance to a desired value without having to clamp or bind into place those remaining. Freedom from external field is a matter of geometry, with the airgap only in the center leg of the coil and with the outside legs providing some magnetic shielding to outside space.

There is another advantage to using a center-leg gap for a rectifier-filter choke which is encased in a magnetic can. A very bothersome problem was solved by this fairly simple expedient of substituting one center-leg airgap for three gaps, one in each leg. It was found that this choke, at the input of a choke-fed rectifier filter and having, consequently, a high a-c ripple component across it, was aurally very noisy in the 1/32″-thick cold-rolled steel case in which it was mounted. The noise was found to emanate from the vibrating sides of the case, which are close to the lamination structure adjacent the ends of the center leg. All other curative expedients failed, such as tight wedging, resilient padding, or high-temperature treatment to flow the potting compound into the lamination structure. With three airgaps the a-c magnetizing force required at the gaps in the outer legs, added to that required for the iron in the U-portion from one end of the center leg out and around to the other, constitutes the majority of the total. With a single center-leg airgap, this magnetizing force at the ends of the center leg is markedly reduced (say, around 3 to 1 in a typical instance). Its attractive force for the magnetic sides of the case is reduced by the square of this figure (or almost 10 to 1).

EXAMPLE OF A DESIGN CALCULATION

Let us take an example. The input choke of a particular rectifier filter had some such requirements as these:

L = 15 henrys
I = 140 ma
R = 200 ohms
core desired — 485

First calculation is for stored energy.

$$\frac{LI^2}{V} \times 10^4 = \frac{15 \times 0.14^2 \times 10^4}{5.49} = 535$$

Using the curve for $B = 1000$, this gives a $\frac{NI}{l} = 97.5$. From this:

$$N = \frac{97.5 \times 6.38}{0.14} = 4440$$

Referring to tables of turns for this lamination, this is a full core of No. 29 enamel wire. D-C resistance is 180 ohms.

So far, everything is all right in accordance with the specifications. Now check actual B-Max., assuming a 200-volt signal of 120-cycle frequency from the full-wave rectifier.

$$200 = \frac{4.44B \times 0.844 \times 4440 \times 120}{10^8}$$

From this $B = 10{,}000$.

The guess of 1000 for B was not good. If the curve for $B = 10{,}000$ is used, 525 for stored energy corresponds to $\frac{NI}{l} =$ 90. For this value $N = 4100$ turns and $R = 166$ ohms.

Using $\frac{NI}{l}$ of 90 and the $B = 10{,}000$

curve on Chart 2, $\frac{g}{l} = 0.00455$. This means that $g = 29$ mils. Each gap should be half of this, or 14.5 mils. A figure of 15 will be near enough.

The specifications for the coil, therefore, will be these:

4100 turns of No. 29 enameled wire wound on a 485 core with three gaps of 15 mils each.

Actually, in this instance, it was necessary, to prevent noisy steel cans as a result of the external field of the coils, to make this input choke with a single center-leg airgap. To get the data for this coil, an inductance 20 to 25% larger must be used in the calculations and 1.5 mils added to the g given by the curves.

— P. K. McElroy

This method and data for coil design have been in use at General Radio for several years. The author is indebted to James K. Clapp, Charles E. Rice, and the late Hammond H. Hollis for the original measurements on which the charts are based.

SHOW BUSINESS

RADIO ENGINEERING SHOW

New York Coliseum **March 18–21, 1957**

General Radio Company exhibits are in Booths 3302–3306 and 2319. See the *Experimenter* for February for complete details.

1957 NARTB CONVENTION

The Conrad Hilton **Chicago** **April 7–11, 1957**

Again this year, at the convention of the National Association of Radio and Television Broadcasters, General Radio will be in Booth No. 1 with a display of station monitors (including the new TV monitor), modulation and distortion meters, line-voltage control devices, instruments for the measurement of antennas and lines, harmonic measuring equipment, sound-level meters, and other items of interest to broadcast engineers.

These engineers will be on hand to discuss your measurement problems.

William R. Thurston Charles A. Cady Joseph E. Belcher

SOUTHWESTERN IRE CONFERENCE AND ELECTRONIC SHOW

The Shamrock Hilton **Houston** **April 11–13, 1957**

At the Ninth Annual Southwestern IRE Conference, with which is combined the Second Annual Simulation Conference, General Radio products will be shown in Booth Nos. 63, 64, and 65. Engineers in attendance will be:

John C. Gray Frank J. Thoma William M. Ihde

General Radio Company

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