Practical TRANSFORMER DESIGN and CONSTRUCTION

By C. ROESCHKE

Part 1. The design and construction of iron core transformers and reactors. Save money by rebuilding obsolete transformers to your own specifications.

IRON core transformers and reactors are fundamental units employed in circuits operating at power and audio frequencies.

It is very desirable for an amateur or serviceman to have a practical understanding of this equipment for three reasons. First, because it is sometimes possible to use a transformer for an application different from that for which it was originally intended. Second, because it is frequently possible to rebuild an available transformer and thus avoid the necessity of buying a new one. Third, because a technician can design and build his own units at very low cost.

This article is intended to provide practical information to aid the technician in building and using equipment of this type.

Power Transformers

Before we go into a description of the actual design applications, let us review the fundamentals of electricity and magnetism which determine the operation of a transformer.

When a power transformer primary is connected to the power lines, the a.c. flux produced by the current flowing in the primary induces voltage across the secondary windings. The voltage appearing across each secondary winding depends on the number of turns of wire contained in the primary and in each secondary. It depends on the ratio between the number of turns in the primary to the number of turns in each individual secondary.

For example, let us assume that the supply voltage is 100 volts a.c. and assume that the primary winding consists of 100 turns of wire. Now, this means that for each primary volt, there is one primary turn, or, one turn per volt. Since there is one turn per volt in the primary, there is also one turn per volt in each secondary. Then if one secondary delivers 300 volts, there must be 300 turns in that secondary winding. It is to be noted here that the potential of 300 volts mentioned is the open circuit, no load, voltage of the winding. When the transformer is fully loaded, this value would drop about 5 or 10 per-cent depending on the regulation characteristic of the unit.

Mathematically, the turns per volt in a given transformer is equal to:

$$\frac{\textit{Number of turns in the winding}}{\textit{Voltage appearing across that winding}}$$

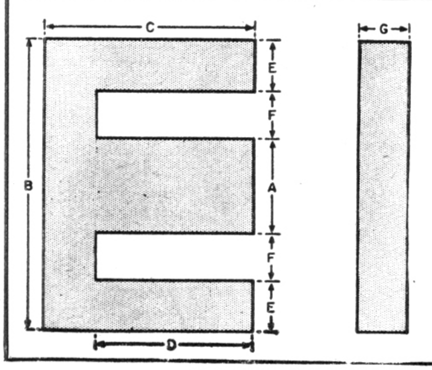
Iron cores are used to concentrate the magnetic flux along the desired paths where it will be most effective. Then, practically all lines of flux are caused to aid in inducing voltages in the secondary coils when alternating current flows in the primary circuit. If an iron core were not used, most of the flux would be lost in air and the power transfer efficiency would be too low for practical use. Such an air core transformer for use at power frequencies would have to be tremendous in size if any appreciable amount of power were to be taken from it.

The core material is not of solid construction, but made up of many flat pieces, called "laminations," which are piled one on top of the other to make up the core of required thickness or "stack." By employing thin laminations to make up the core, eddy current losses in the core are reduced thus minimizing the development of heat and power loss.

Manufacturers have developed for the radio and electronic industries laminations of sizes and shapes most applicable to the required voltage and power handling capacities. These are of the familiar "E" and "I" shaped design. Fig. 1 is a chart showing the

Fig. 1. Table gives various dimensions of most commonly used "E & I" laminations.

LAMINATION SIZE	A	B	C	D	E	F	G
1/2"	0.500"	1.625"	1.062"	0.813"	0.25"	0.312"	0.25"
5/8"	0.625"	1.875"	1.25"	0.938"	0.312"	0.312"	0.312"
3/4"	0.750"	2.250"	1.500"	1.125"	0.375"	0.375"	0.375"
7/8"	0.875"	2.625"	1.750"	1.312"	0.437"	0.437"	0.437"
1"	1.000"	3.000"	2.000"	1.500"	0.500"	0.500"	0.500"
1 1/8"	1.125"	3.375"	2.250"	1.687"	0.562"	0.562"	0.562"
1 1/4"	1.250"	3.750"	2.500"	1.875"	0.625"	0.625"	0.625"
1 1/2"	1.500"	4.500"	3.000"	2.250"	0.750"	0.750"	0.750"



These are only a few of the iron sizes available. Some differ only slightly from the above dimensions. There are, of course, larger laminations having center leg "A" dimensions of 1 3/4", 1 7/8", 2", 2 1/4", etc.

physical dimensions of these laminations.

The various sizes are identified by the width dimension of the center leg. Thus, a lamination having a center leg which is 1 inch wide is called a "1 inch lamination." One with a center leg ½ inch wide is called a "½ inch lamination" or "½ inch iron," etc.

When laminations are placed into a coil to make a power transformer they are "interleaved," that is, the first "E" piece is inserted into the left end of the coil, the second into the right end of the coil, the third into the left end, and this alternating process is continued until all "E" pieces are in place. Then the "I" pieces are inserted into the spaces left between the "E" pieces.

In the actual design of a power transformer there are five principal factors to be determined. They are:

1. Size of lamination required.
2. Cross section core area required.
3. Sizes of wire required.
4. Number of turns of wire required in each winding.
5. Thickness of insulating paper required throughout.

Fig. 2 may be used as a rough guide for determining the lamination size required for a transformer of given power output capacity. Observe that the output power is given in volt-amperes or v.a. This power value is obtained by multiplying voltage by current for each secondary and then adding these values together. As an example, consider a filament transformer having two secondary windings. The first delivers 6.3 volts at 3 amperes and the second secondary delivers 5 volts at 2 amperes. For secondary No. 1, v.a. = 6.3 x 3 = 18.9; for secondary No. 2, v.a. = 5 x 2 = 10.00. Then by adding 18.9 to 10.0 we get 28.9 v.a. which is the total output provided by this transformer. Now, according to Fig. 2, the lamination required would be about 1″ size iron. But this chart is, of necessity, only an approximation since the power output determines the core area required as well as the lamination size. Therefore, a transformer of given output rating might be constructed using 1″ iron with a stack, or core thickness, of 1¼″. This would give a cross section core area of 1¼″. However, you could employ 1¼″ iron with a 1″ stack of laminations which would also give a core area of 1¼″. See Fig. 3 for the method of determining the cross section core area. As indicated, core area is equal to dimension width of center leg times the thickness of stack of laminations.

From this discussion one can see that the matter of design is a "cut and try" process wherein one juggles the size of the coil and core to arrive at a combination that will fit. In the above design, one might find that the coil would not fit into the space provided in the 1″ lamination but would fit nicely into the 1¼″ iron. Let us state here that it is not necessary to actually wind the coil and then try to fit it into a given core. This determination can be made beforehand.

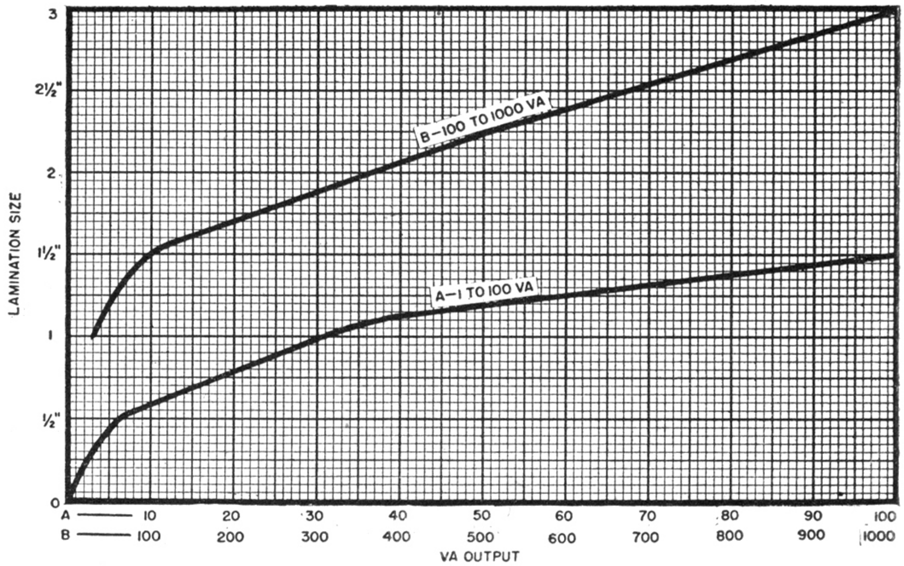


Fig. 2. Approximate volt-ampere (v.a.) output for various lamination sizes. Chart may be used to determine lamination size for transformer of given power output capacity.

The cross section core area that must be used is dependent on the power capacity of the transformer, smaller power units having smaller core areas than ones to handle larger amounts of power. Also, the efficiency of the unit and the amount of heat developed in the core depend on a.c. flux density at which the core operates. Transformers designed to operate at high flux density develop more heat in the core while those designed to operate at lower flux density run cooler. Actually, the flux density depends upon the number of turns in the primary winding and the cross section core area. Thus for a given number of primary turns higher flux density will be present if small core area is employed and lower flux density is obtained by using a larger core area.

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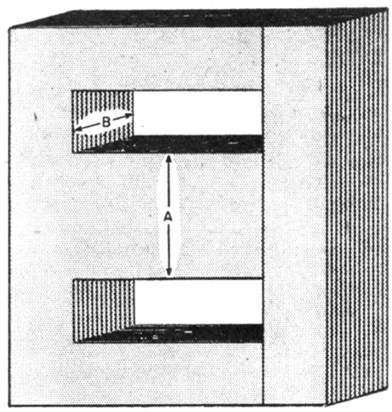
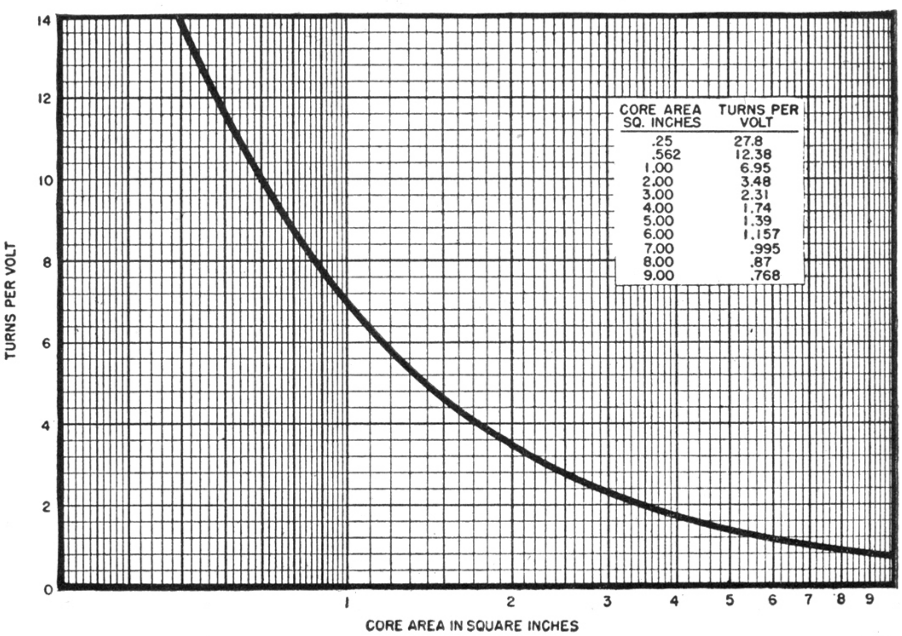


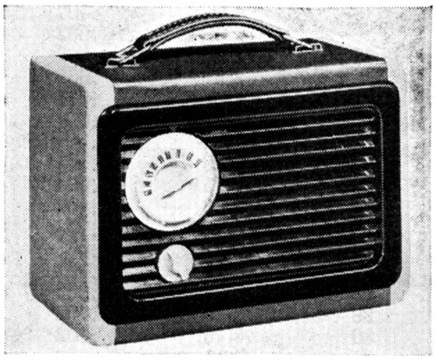
Fig. 3. The cross section area of the core in square inches can be determined by multiplying the thickness of the stack (B) by the width of the center leg (A).

Fig. 4. For 60-cycle operation, the flux density of a power transformer should be approximately 60,000 lines per square inch. Graph is based on this figure and may be used to determine the turns-per-volt value from a given core area.



6½ pounds with batteries. The receiver uses a 1R5, 1S5, 1U4 and 3V4 with a selenium rectifier replacing the usual rectifier tube.

Price and additional details will be



supplied upon request to *John Meck Industries, Inc.,* Plymouth, Indiana.

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Transformer Design

(*Continued from page* 61)

We won't go into mathematical determinations of flux density. It is only necessary to say that for practical work a flux density of 60,000 lines per square inch of core area is satisfactory. By using Fig. 4, one can determine the proper number of turns per volt for given core area which will provide operation at 60,000 lines flux density.

The size of wire to be used for each winding depends only on the magnitude of current flowing in the winding. It is necessary that the wire used be of sufficient cross section area to carry the current without overheating. Listed in the chart of Fig. 5 are the various commonly used wire sizes showing the maximum current-carrying capacity for each size. These values are suitable for good transformer design practice.

Voltage to be developed across each winding determines the number of turns of wire necessary in each winding. The number of turns will also depend on how much space is available in the core to accommodate the finished transformer coil. Because the flux density is determined by the number of turns in the primary in relation to the cross section core area, one could redesign a coil that was too large by reducing the number of turns and using the same size lamination but with more of them to make a larger core area. Thus, by using a larger core area, one could use fewer turns in the winding but still have a low flux density.

Let's go through the actual processes of designing a power transformer. We'll design a filament transformer with the following specifications.

Primary for 115 volts 60 cycles.

Secondary No. 1 for 5.0 volts at 2 amperes.

Secondary No. 2 for 6.3 volts at 3 amperes.

The first step is to find the total v.a.

Wire Size	Amperes	Insulation
10	15	.010"
11	12	.010"
12	9.5	.010"
13	7.5	.010"
14	6.0	.007"
15	4.8	.007"
16	3.7	.007"
17	3.0	.007"
18	2.5	.005"
19	2.0	.005"
20	1.6	.004"
21	1.2	.004"
22	0.92	.004"
23	0.73	.004"
24	0.58	.004"
25	0.46	.003"
26	0.37	.003"
27	0.29	.003"
28	0.23	.002"
29	0.20	.002"
30	0.15	.002"
31	0.11	.0015"
32	.090	.0015"
33	.072	.0015"
34	.057	.001"
35	.045	.001"
36	.036	.001"
37	.028	.001"
38	.023	.0008"
39	.018	.0008"
40	.014	.0008"

Fig. 5. Current carrying capacity of various sizes of enameled wire.

output to be delivered by the two secondaries.

For secondary No. 1, v.a. = 5 x 2 = 10.

For secondary No. 2, v.a. = 6.3 x 3 = 18.9.

Then total secondary v.a. = 10 + 18.9 = 28.9.

The primary circuit v.a. is equal to about 1.4 times the total secondary v.a. or 1.4 x 28.9 = 40.5, approximately. If the primary v.a. is 40.5, then the primary current is equal to

$$\frac{\textit{Primary v.a.}}{\textit{Primary voltage}} = \frac{40.5}{115} = 0.35 \text{ amperes}$$

Now, since the current flowing in each winding is known, the proper wire sizes can be determined. Consulting Fig. 5 reveals that the primary wire size can be No. 26 to carry 0.35 ampere. It also shows that secondary No. 1 can be wound with No. 19 wire for 2 amperes and that secondary No. 2 can be wound with No. 17 wire for 3 amperes.

According to Fig. 2, the lamination size for a unit to deliver 28.9 v.a. is about 1" or 1⅛" iron so we'll try this design with 1⅛" square core. This means that we'll assume a 1⅛" thick stack of 1⅛" iron.

The next step is to determine the turns-per-volt required for our core area of 1⅛" x 1⅛" = 1.265 square inches. We find that the curve of Fig. 4 specifies that a core area of 1.265 square inches requires 5.5 turns-per-volt.

With 5.5 turns-per-volt, we must have 5.5 turns of wire for each volt appearing across each winding. Then the primary coil must have 5.5 x 115 = 633 turns of wire. In a like manner, the turns in each of the secondary windings is equal to the voltage of that winding times 5.5. But the open circuit, no load, secondary voltages, must be slightly higher than the values required when the transformer is loaded. Therefore, multiply the load voltage by 1.08 to get the required no load voltage. Then:

For secondary No. 1, we have 5.0 x 1.08 = 5.4 volts, approx., no load.

For secondary No. 2, we have 6.3 x 1.08 = 6.8 volts, approx., no load.

The turns required for each secondary winding is then equal to the open circuit voltage times 5.5 turns-per-volt. Thus:

No. of turns for secondary No. 1 = 5.4 x 5.5 = 29.8 turns, approx.

No. of turns for secondary No. 2 = 6.8 x 5.5 = 37.4 turns, approx.

This means that secondary No. 1 will have 30 turns and secondary No. 2 will have 38 turns because you must use full numbers of turns. A fraction of a turn is not effective. Using 30 turns and 38 turns at 5.5 turns per volt, the actual open circuit voltage will be:

For secondary No. 1, 30/5.5 = 5.45 volts.

For secondary No. 2, 38/5.5 = 6.9 volts.

At this point let us tabulate our data.

Primary: 115 volts at 60 cycles.
Lamination size = 1⅛" iron.
Lamination stack = 1⅛".
Core area = 1⅛" x 1⅛" = 1.265 sq. in.

Secondary No. 1: 5 volts at 2 amps. 30 turns of No. 19 wire.

Secondary No. 2: 6.3 volts at 3 amps. 38 turns of No. 17 wire.

A transformer coil is made up of enameled copper wire, paper insulation between the layers of wire, paper insulation between the separate wind-

Fig. 6. Breakdown voltage of various between-layer insulating materials.

Paper Type	Thickness	Voltage
Cellulose Acetate	.020"	20,000
Cellulose Acetate	.010"	10,000
Cellulose Acetate	.007"	7000
Cellulose Acetate	.003"	3000
Cellulose Acetate	001"	1000
Varnished Cambric*	.005"	2700
Varnished Cambric*	.007"	4000
Varnished Cambric*	.010"	7000
Fibre Paper	.007"	2000
Fibre Paper	.010"	3000
Red Rope Paper	.005"	800
Gummed Kraft Paper	.007"	1000
Gummed Kraft Paper	.003"	500
Kraft Paper**	.003"	300
Kraft Paper**	.004"	500
Kraft Paper**	.005"	650
Kraft Paper**	.010"	1000
Glassine Paper	.0004"	200
Glassine Paper	.0008"	250
Glassine Paper	.001"	350
Glassine Paper	.0015"	450
Glassine Paper	.002"	550
Gummed Glassine Paper	.002"	1000
Oiled Silk	.003"	2000

*(Empire cloth).
**(Not gummed).

Lamination	Thickness	Length
½"	.030"	¾"
⅝"	.030"	⅞"
¾"	.040"	$1\frac{1}{16}$"
1"	.050"	$1\frac{5}{16}$"
1⅛"	.050"	$1\frac{9}{16}$"
1¼"	.060"	1¾"
1½"	.075"	$2\frac{3}{16}$"
2"	.100"	Depend On Actual Dimension of Iron "D Dimension"
2¼"	.125"	
3"	.175"	

These tubes upon which coils are wound are made by winding required number of layers of gummed kraft paper over a form of proper dimensions.

Fig. 7. Thickness and length of coil tube required for various lamination sizes.

ings, gummed tape, lead wire, and the tube upon which the coil is wound. To select the proper insulating paper consult Fig. 5. Here we see that No. 26 wire requires paper between each layer of wire which is about .003" thick and that .005" or .007" thick paper is proper between individual layers of No. 17 and No. 19 wire.

To determine the amount of paper insulation to use between the separate windings, figure that it must withstand voltage equal to twice the voltage across the winding which produces the highest voltage output in the transformer and add 1000 volts to that value. In this transformer, the primary winding has the highest voltage which is 115 volts and so 2 x 115 = 230, plus 1000 = 1230 volts. Data on paper insulation shown in Fig. 6 reveals that two layers of .007" fibre or "empire cloth" will be sufficient between the separate windings.

The coil must be wound on a rigid coil form which can easily be made. At almost any "ten cent" store you can obtain brown gummed "kraft paper" in rolls of various widths. Fig. 7 shows the required thickness for a coil form to be used with each lamination size. Now, this coil form, or tube, must be of proper length so that the coil will fit into the space in the core. Fig. 7 indicates correct coil length (coil form length) for each different sized lamination. Here we see that 1⅛" iron will accommodate a coil form $1\frac{9}{16}$" long. The inside dimension of this tube must be slightly larger than the core and since the core is 1⅛" x 1⅛", we'll add $\frac{1}{32}$" to each of these dimensions making the inside of our tube $1\frac{5}{32}$" x $1\frac{5}{32}$" x $1\frac{9}{16}$" long. The tube should be about .050" thick.

Strips of insulating paper to be used between the layers of wire and also to separate the various windings should be $1\frac{9}{16}$" wide and long enough to go around the coil and overlap about ¾".

Before winding the coil, it is necessary to calculate the size of the coil to determine if it will fit into the core. Fig. 8 shows how many turns of wire can be wound in one layer for coils used in cores of the different sizes. We see here that on 1⅛" iron we can wind 71 turns of No. 26 wire. Therefore, since our primary has 633 turns it will have to be wound in 633 ÷ 71 = 9 layers. But it is possible with this iron size to wind 33 turns of No. 19 wire so only one layer is required for secondary No. 1. Two layers will be required for secondary No. 2.

Here let us add together all of the materials which, when they are wrapped one over the other, go together to make the total coil thickness. This data can be tabulated as follows:

Material	Thickness of Material in Inches
1. Winding tube	.050
2. Primary wire, 9 layers #26 wire (9 x.0168)	.151
3. Primary layer insulation (9 x.003)	.027
4. Primary wrapper (2 x.007)	.014
5. Secondary No. 1 wire, 1 layer #19 wire (.0375)	.0375
6. Secondary No. 1 wrapper (2 x.007)	.014
7. Secondary No. 2 wire, 2 layers #17 wire (2 x.0469)	.094
8. Secondary No. 2 layer insulation (1 x.007)	.007
9. Final coil wrapper (2 x.007)	.014
TOTAL	0.4085"

This figure, 0.4085", is the approximate thickness of the finished coil. Actually, the coil will be considerably larger. This is because when the wire and paper are being wound, they do not lie flat. Even with tight winding, the coil bows out slightly. For this reason, it is necessary to establish a maximum constant for coil size. The space into which this coil must fit in our 1⅛" iron is 0.562" according to Fig. 1, dimension *F*. Our coil has theoretical thickness of 0.4085" which means that theoretically 73 per-cent of the available space is being used. This percentage is calculated thus:

$$\frac{0.4085}{0.562} \times 100 = 73 \text{ per-cent}$$

If this figure had exceeded 82 percent, we would have to redesign our coil to make it small enough to fit. This coil with 73 per-cent build is satisfactory and will fit. We could even use less than a 1⅛" stack of laminations, which would give us smaller core area and therefore require more turns of wire. With a smaller core area, we would have to refer to Fig. 4 to find the "turns-per-volt" required and then redesign the coil.

In a transformer of this type the primary is wound first. When starting to wind, enough of the No. 26 wire is allowed to protrude to function as one lead connection. After the primary has been wound with .003" paper between each layer of wire the end of the wire is anchored, as was the start lead, to be used as the other connection to the coil. Insulating sleeving is used over the end wires to provide insulation for the leads. Next, the .007" paper layers are placed over the primary and the first secondary is wound in similar manner. When the second secondary has been wound, a final over-all paper wrapper is placed around the finished coil. This wrapper can be two or three layers of the brown gummed paper. Remember, when inserting the paper layer insulation, to make the overlap on a side of the coil which is not to be fitted between the legs of the core. This is necessary because if all of the overlaps were put on one of those sides, they would increase the coil size on that side so much as to prevent the coil from being inserted into the core.

Now, it is only necessary to assemble the coil and core together and the transformer is finished except for adding the required mounting brackets.

The design operations described above can be used to design any type of power transformer used in radio work.

In designing a plate transformer the size of wire to be used in the high voltage rectifier secondary is determined by the value of direct current which is to be drawn after rectification. (This applies to full-wave rectification. For half-wave rectification, use wire size twice as large.)

If a winding is to be put on in several layers and is to be center tapped, construction will be easier if you employ an even number of layers. This makes the center tap lead connection fall at one end of a layer.

Before winding a transformer you have designed, it would be a good idea to disassemble completely one or two power transformers to see more clearly the various details of construction. This is suggested because it is difficult to describe the various ways in which leads are brought out of a coil.

Remember to insulate well where all lead connections are made inside a coil. Also use insulation under end wires which are brought up along the sides of the coil to be soldered to leads at the top. Start- and finish-leads of the same winding must be insulated for each other, from other windings and from the turns in the same winding.

Defective transformers can be bought for a few cents each and they provide inexpensive core material and mounting shells. In building your own transformers your only real expense is for enameled wire and paper insulation.

When the coil and core have been assembled, this assembly should be heated to about 250 degrees Fahrenheit and held at this temperature for about 30 minutes. This is done to remove moisture. After the preheat, it should be immersed in hot wax for another 30 minutes and then removed and allowed to drain until cooled. As an alternative it could be immersed for 30 minutes in a baking-type varnish after being preheated. Then it should be baked for about 30 minutes at 250 degrees Fahrenheit. The oven for preheating and baking can be of simple construction but must be well ventilated to allow fumes and moisture to escape.

(To be continued)

Fig. 8. Number of turns of wire per layer that can be wound on various lamination sizes.

WIRE SIZE	LAMINATION SIZES							
	1/2"	5/8"	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 1/2"
10				9	10	11	12	16
11				10	11	12	14	17
12		8	10	12	13	14	16	20
13	6	8	10	13	15	16	18	22
14	7	9	11	15	17	18	21	26
15	8	10	12	16	19	21	24	30
16	9	12	14	19	22	24	27	33
17	10	13	16	21	25	28	30	36
18	11	14	17	23	27	30	34	41
19	13	16	20	25	30	33	37	45
20	14	17	22	28	33	37	42	51
21	16	20	25	31	38	41	46	57
22	17	23	29	35	42	46	51	62
23	19	26	31	39	45	50	56	68
24	22	29	34	45	52	58	64	79
25	25	34	41	50	57	62	71	88
26	27	37	45	57	65	71	81	102
27	31	42	49	63	73	81	93	114
28	36	47	57	71	84	93	107	132
29	39	51	63	80	94	103	119	145
30	44	58	70	88	107	117	133	161
31	52	66	80	100	121	132	147	183
32	60	73	88	110	130	144	163	206
33	70	85	100	125	146	163	186	232
34	78	95	113	138	163	181	205	250
35	90	112	132	160	188	211	238	293
36	99	122	142	173	211	234	264	336
37	110	134	161	194	233	260	292	365
38	122	149	176	215	257	286	325	
39	138	165	203	252	281	316	362	
40	160	193	247	284	338	371	422	

The number of turns of wire per layer shown above allows proper margin at each end of the coil. To find number of turns per layer for any size iron, first decide on coil length, then, subtract about 1/4" to allow for margins. This gives space remaining for winding. Divide this space by the diameter of wire to get number of turns per layer.

Destry Scott, New York model, listens to invisible particles as they fly from a piece of radioactive material and are made to "talk" in this unit which also records their flight. The new counter, developed by General Electric Company, uses a Geiger tube in conjunction with a new ultra-high-speed "electrical impulse" counter. This instrument makes the unseen particles "click" over a loudspeaker and at the same time records their flight and number on the meters located on the front panel. This decade scaling unit can count impulses being emitted from material as fast as the speed of light.

ERRATUM

The values for R_{21} in Fig. 2 and R_{26} in Fig. 3 on page 48 of the April issue were inadvertently omitted. These may each be 13,000 ohms unless voltage drop is excessive in which case lower values may be used. These values are not critical. In Fig. 3, a standard ganged condenser may be used. Rotors of C_1, C_7, C_{11} may all be grounded to chassis. In doing this remove rotor connection of C_1 and C_7 from coil terminals.

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Practical TRANSFORMER DESIGN and CONSTRUCTION

Part 2. Complete details for designing and constructing your own iron core reactors.

By C. ROESCHKE

LAST month we discussed the design and construction of various types of power transformers used in the radio field. This month data relative to the proper design of filter chokes will be covered.

Iron core reactors are used primarily because they provide a smaller size unit for a given value of inductance at power or audio frequencies.

The points to consider in the design of such a choke or reactor are:

1. Magnitude of inductance (in henries) required
2. Magnitude of direct current which will flow in the coil during operation
3. Iron size required to provide unit having desired inductance

Obviously, the unit can not be designed until the amount of inductance required has been established. This is, of course, determined from the anticipated operation of the circuit in which the choke is to be used.

Similarly, the value of direct current which will be flowing in the coil depends on the circuit operation.

Fig. 9 has been worked out to be used for filter choke design calculations. The filter chokes referred to here are those used in power supplies for receivers or transmitters.

The iron size required for a given value of inductance will depend primarily on the magnitude of the direct current involved. This is because coils which carry large currents must be wound with large size wire. To use a given number of turns of large wire, you must, of course, use a large size lamination which has enough room for the coil. Also, the iron size employed for chokes carrying high direct current must be large to avoid saturation of the core by this high current.

Fig. 9. Simplified chart that can be used in designing filter chokes.

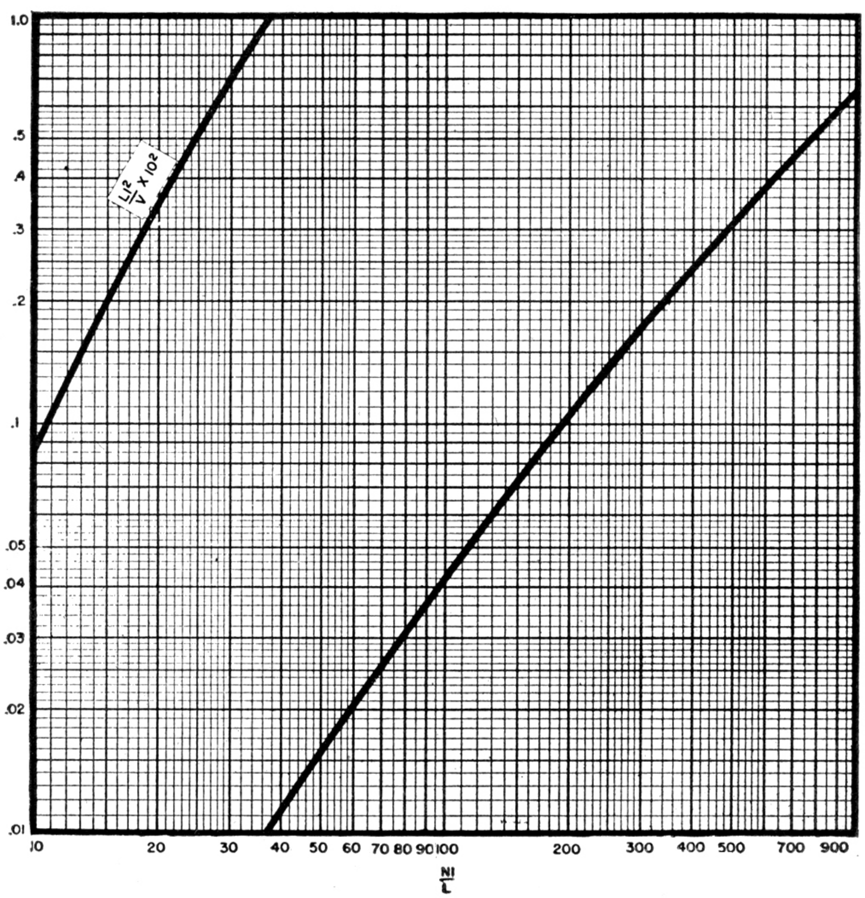


Fig. 13 gives the data on the lamination size required for various filter chokes and will serve as a rough guide in design work.

The following calculations show all steps in the design of a filter reactor, assuming that a choke of these specifications is required: Inductance, 5 hy; Direct current in coil 200 ma.

By consulting Fig. 13, we see that the approximate lamination size is 1⅛″ iron so we shall try to design this unit using 1⅛″ laminations with a stack of 1⅛″.

Fig. 5* indicates that No. 29 wire will carry the 200 ma. direct current.

Now, let us try to use about 2500 turns of wire. We shall have to check to see if a coil of this size will fit into the 1⅛″ iron. According to Fig. 8,* we can wind 103 turns per layer of No. 29 wire on a coil for 1⅛″ iron, which means that 25 layers will be required for the 2500 turns. Let us calculate the size of this coil:

Tube thickness	.050″
25 Layers of .002″ Paper	.050″
25 Layers of #29 Wire	.305″
Outside Wrapper (2 of .007 Paper)	.015″
	0.420″

The space available in the core (dimension F of Fig. 1*) is 0.562. Our coil build is

$$\frac{0.42}{0.562} \times 100 = 75 \text{ per-cent}$$

which means that the coil will fit nicely.

We do not yet know if this unit will provide the required inductance of 5 henries. Therefore, our final step is to calculate what the inductance of this unit will actually be.

* Figs. so designated appeared in Part 1 of this article published in the June issue of Radio News.

First, we calculate NI/l where: N = number of turns in the coil; I = direct current flowing in coil (amperes); l = length of magnetic path of core in inches.

The length of the magnetic path in cores using various size laminations is shown in Fig. 11.

$$\frac{NI}{l} = \frac{2500 \times 0.2}{6.75} = \frac{500}{6.75} = 74.2$$

Here we shall employ the graph of Fig. 9 to find $\frac{LI^2}{V}$ where: L = inductance in henries; I^2 = direct current in amperes, squared; V = volume of core in cubic inches. This is the total volume of all of the core.

This graph shows that when NI/l = 74.2 then LI^2/V = .0275, approximately. By transposition in this equation we see that $L = .0275V/I^2$ and this is the formula we use to find the inductance L of our choke.

Thus:

$$L = \frac{.0275 \times 8.55}{0.2^2} = 5.87 \text{ henries}$$

This is a satisfactory design and the actually measured inductance would be within 10 or 15 per-cent of this value depending on the characteristics of the iron used.

At this time, assume that we also want a choke having an inductance of 7 henries at 200 ma. d.c. Since we have a design which gives us 5 hy. at 200 ma. we can arrive at a design for 7 hy. merely by adding more iron in the core. By juggling our formula, we can find the volume of core required for 7 henries.

Since $L = \frac{.0275V}{I^2}$ we see that

$$V = \frac{LI^2}{.0275}$$

Then $V = \frac{7 \times 0.2^2}{.0275} = \frac{7 \times .04}{.0275} = 10.2$ cubic inches (approx.)

which is the volume of core required for inductance of 7 henries. It is only necessary then to increase the number of pieces of iron in the core to make the stack dimension large enough to provide 10.2 cubic inches of volume. In this design our stack would then be about 1 7/16" instead of 1⅛".

Fig. 14 is used in the following manner to calculate what amount of wire will be required in a coil and to estimate the d.c. resistance.

A and *B* are inside dimensions of the winding tube.

Assume that A = 1⅛", B = 1 7/16" and that the coil is wound with 2500 turns of No. 29 wire. Also, assume that 25 layers were required. Then, dimension *K* is equal to:

1.125"	dimension A
.050"	tube thickness
.050"	25 layers of .002" paper
.300"	25 layers of #29 wire
1.525"	

(*Continued on page* 136)

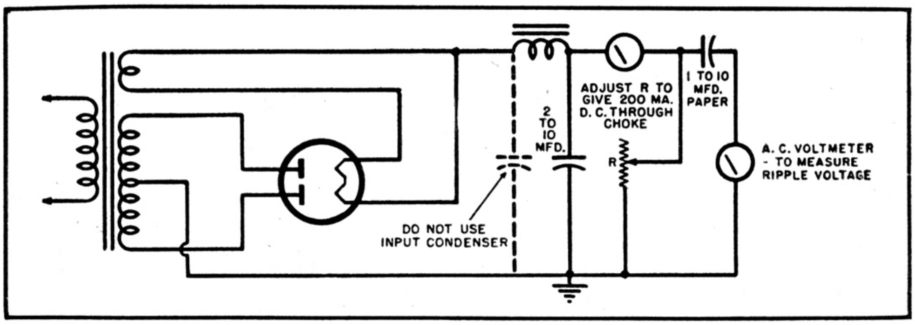


Fig. 10. Test circuit that can be used to determine proper core gap experimentally.

IRON SIZE	LENGTH OF MAGNETIC PATH
½"	3.0"
⅝"	3.75"
¾"	4.5"
⅞"	5.25"
1"	6.0"
1⅛"	6.75"
1¼"	7.5"
1⅜"	8.25"
1½"	9.0"

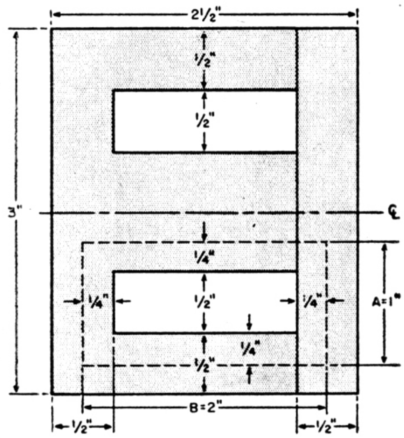
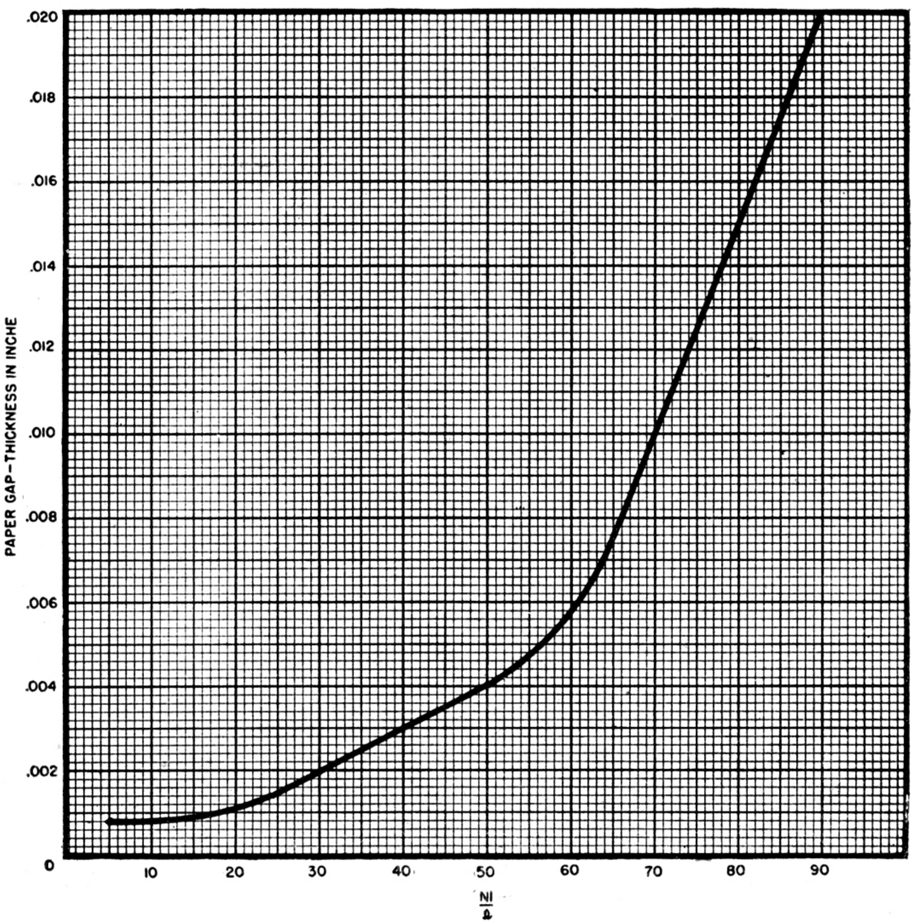


Fig. 11. Diagram shows method of measuring length of magnetic path. The dotted line is the mean path and equal to A + A + B + B or, as in this case, 1 + 1 + 2 + 2 or 6". Table gives magnetic path lengths of various standard sizes of laminations.

Fig. 12. Graph used to determine approximate thickness of gap to be placed in core.



Transformer Design

(Continued from page 59)

Dimension L is equal to:

1.437″ dimension B
.050″ tube thickness
.050″ 25 layers of .002″ paper
.300″ 25 layers of #29 wire

1.837″

The length of a mean turn of wire is then equal to $K + K + L + L$ or $1.525 + 1.525 + 1.837 + 1.837 = 6.724''$. The total length of wire is equal to the length of a mean turn times the actual number of turns in the coil which is

$$\frac{6.724'' \times 2500}{12} = \frac{16{,}800''}{12} = 1400 \text{ feet}$$

The resistance of No. 29 copper wire is 83.44 ohms per 1000 feet. Then this coil of 1400 feet of wire has resistance of 1.4 x 83.44 = 117 ohms, approximately.

The weight of No. 29 copper wire is 0.383 pound per 1000 feet. Then this coil of 1400 feet of wire has 1.4 x 0.383 = 0.537 pound of wire in it.

SPECIFICATIONS	IRON	STACK
4.5 hy. @ 80 ma. d.c. ..	3/4″	3/4″
5 hy. @ 110 ma. d.c. ..	7/8″	7/8″
5 hy. @ 200 ma. d.c. ..	1 1/8″	1 1/8″
7 hy. @ 250 ma. d.c. ..	1 3/8″	1 3/4″
10 hy. @ 110 ma. d.c. ..	1″	1″
18 hy. @ 100 ma. d.c. ..	1″	1 3/8″
20 hy. @ 200 ma. d.c. ..	1 1/2″	1 3/4″
30 hy. @ 20 ma. d.c. ..	3/4″	1″
35 hy. @ 60 ma. d.c. ..	1″	1″

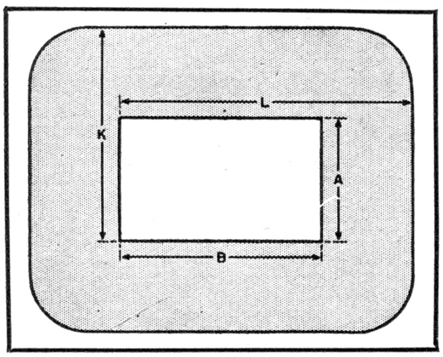
Fig. 13. Approximate core sizes for chokes of various specifications.

The approximate thickness of the gap to be placed in the magnetic core is shown in Fig. 12. NI/l for our choke is 74.2 and this graph indicates that the air gap should be about .012″. This curve will give only approximate values because of variations in different kinds of iron. The proper core gap can be determined experimentally by using the test circuit of Fig. 10. Adjust the load R so that the proper direct current is flowing through the choke. Then simply try different thicknesses of paper in the core gap until you obtain lowest a.c. ripple voltage across the load. Fig. 15 shows how the core is assembled and how the paper gap is placed in the core.

Filter chokes are easy to build because they consist of only one winding. With the information contained herein, you can design and construct your own.

(To be continued).

Fig. 14. Dimensions used in calculating amount of wire needed in a coil.



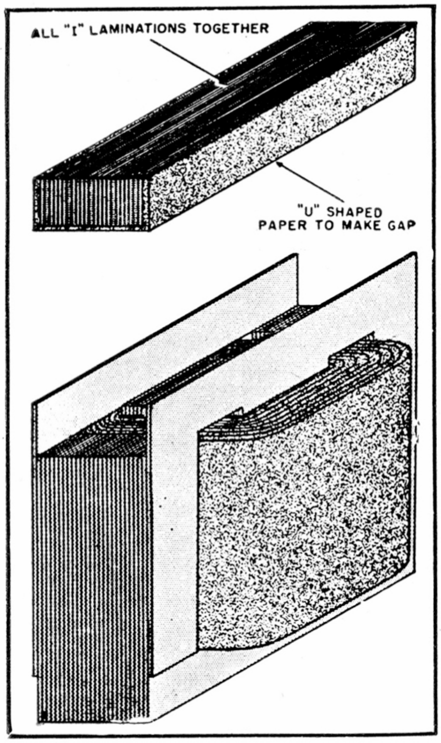
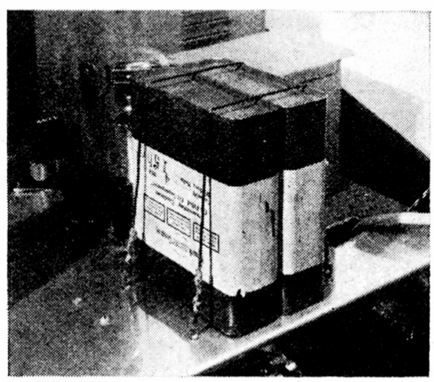


Fig. 15. How core for filter choke is assembled when paper gap is required.

MOUNTING SURPLUS FILTER CONDENSERS

MANY of the excellent surplus filter condensers now on the market are a bit awkward to handle because they are not provided with either mounting feet or rings. The photo shows a simple and inexpensive method of mounting that has proved very satisfactory in transmitter construction.

Holes with plenty of clearance are drilled in the chassis for the terminals and their stand-off insulators. Four No. 25 holes are made also, next to the cans, to take ordinary spade lugs. Short lengths of stranded aerial wire are looped over the condensers and through the lugs, and the latter are then tightened from the underside of the chassis. The condensers are very rigidly supported, yet can be removed in a few seconds merely by loosening the nuts of the spade lugs. . . . . . D. J. B.



Practical TRANSFORMER DESIGN and CONSTRUCTION

By C. ROESCHKE

Part 3. Concluding article covering the design and construction of iron core transformers and reactors.

IN THIS final article on transformer design we will discuss the design and construction of a plate modulation transformer, and an audio output transformer. Several valuable hints on the practical construction of transformers are also included for the assistance of the builder.

A modulation transformer, like any audio power transformer, is designed to match the output impedance of one piece of equipment to an input impedance of a second piece of equipment. This matching is done to insure maximum power transfer and satisfactory frequency response.

When a load is connected to the secondary winding of an audio transformer, there is reflected into the primary circuit an impedance which is determined by the turns ratio of the transformer. This is the ratio of the number of turns in one winding to the number of turns in the other winding.

Mathematically, the turns ratio is equal to the square root of the ratio of the two impedances, or *turns ratio* $= \sqrt{Z_1/Z_2}$.

For example, consider a transformer which is to work out of a 5000 ohm circuit into a load of 50 ohms. Then

$$\textit{Turns ratio} = \sqrt{\frac{\textit{Primary Impedance}}{\textit{Secondary Impedance}}}$$

$$= \sqrt{\frac{5000}{50}} = \sqrt{100} = 10$$

This means that the primary winding must have ten times as many turns as the secondary to match the 5000 ohm primary circuit to the 50 ohm secondary load.

For the purpose of design demonstration, assume that a plate modulation transformer is required for the following conditions of operation.

1. Modulator output is push-pull pentodes requiring load impedance of 10,000 ohms and that each tube draws 60 ma. plate current.
2. Audio output power to be 7.5 watts.
3. The Class C r.f. amplifier to be plate modulated draws plate current of 70 ma. at 420 volts.
4. Voice frequencies are to be used.

The secondary load resistance is equal to the r.f. amplifier d.c. plate voltage divided by the r.f. amplifier plate current. In this case then: $R = 420/.07 = 6000$ ohms

To calculate turns ratio:

$$\textit{Turns ratio} = \sqrt{\frac{10{,}000}{6000}} = 1.29$$

Therefore, the primary must have 1.29 times the number of turns used in the secondary.

When a transformer is employed in the plate circuit of a vacuum tube, it is necessary that it be designed to reflect the proper load impedance for the tube. In addition, the primary inductance will determine the low frequency response of that audio stage. For this reason, Fig. 16 is included to indicate proper primary inductance for good low frequency response at 50 cycles or 150 cycles. Fig. 9 ** can be used to calculate the primary inductance. Since our modulator tubes are pentodes and we are interested only in voice frequencies, we see in Fig. 16 that the primary inductance should be about 10 henrys.

Fig. 5* shows that the primary could be wound with No. 34 wire to carry 60 ma. and the secondary can be wound with No. 33 wire for 70 ma.

For convenience we shall use No. 33 for both windings.

This transformer is to handle 7.5 watts so, according to Fig. 17, we can try to design it with 1″ laminations and a stack of 1″.

Let us tabulate the data we have so far:

Primary impedance = 10,000 ohms
Primary d.c. = 60 ma.
Primary inductance = 10 hy.
Primary wire size = No. 33
Secondary impedance = 6000 ohms
Secondary d.c. = 70 ma.
Secondary wire size = No. 33
Core size = 1″ stack of 1″ laminations
Turns ratio = 1.29

First let us try 2700 turns, center tapped, for the primary winding. Then the secondary must have 2700/1.29 = 2090 turns. Next we calculate the coil size as explained previously and find that the build is 81 per-cent which means that the coil will fit into the core.

The primary is for push-pull tubes and therefore must be center tapped at 1350 turns. Since "B+" is connected to the center tap, the direct current flows in opposite directions in each half of the winding which means that the core saturation effect is cancelled out as far as the primary is concerned. But the secondary has 70 ma. d.c. flowing through its entire length in one direction and this must be considered in the calculation of inductance.

Then for the secondary, $NI = 2090 \times .07 = 146$. But we are interested in the primary inductance so let us convert this effect into the primary. Thus:

Since $NI = 146$
Then $2700 \times I = 146$
And $I = 146/2700 = .054$ amp.

This means that 54 ma. flowing in the 2700 turns primary would give the same core saturation effect that 70 ma. flowing in the secondary would give. For this reason we shall use the figure 54 ma. in our primary inductance calculation.

(*Continued on page* 123)

Fig. 16. Primary inductance required for good response at low frequencies.

FOR TRIODE TUBE			FOR PENTODE TUBE		
D.C. Plate Resistance Ohms	Inductance for 50 cycles	Inductance for 150 Cycles	Load Impedance* Ohms	Inductance for 50 Cycles	Inductance For 150 Cycles
800	3.5 hy.	1.0 hy.	2500	8.5 hy.	3.0 hy.
1000	4.5 hy.	1.5 hy.	4000	13.0 hy.	4.0 hy.
1500	6.5 hy.	2.0 hy.	5000	16.5 hy.	5.0 hy.
2000	8.5 hy.	3.0 hy.	6000	20.0 hy.	6.0 hy.
3000	13.0 hy.	4.5 hy.	7000	25.0 hy.	7.0 hy.
5000	20.0 hy.	5.5 hy.	8000	27.0 hy.	8.0 hy.
10,000	40.0 hy.	15.0 hy.	10,000	33.0 hy.	10.0 hy.
			15,000	50.0 hy.	15.0 hy.

* This is plate-to-plate impedance for push-pull tubes.

* Figs. so designated appear in Part 1 of this article published in the June issue of Radio News.
** Figs. so designated in Part 2 of this article published in the July issue of Radio News.

Transformer Design

(*Continued from page 60*)

Then $\frac{NI}{l} = \frac{2700 \times .054}{6} = \frac{146}{6} = 24.3$

And from Fig. 9** if $\frac{NI}{l} = 24.3$

then $\frac{LI^2}{V} = 0.5 \times 10^{-2} = .005$

By transposition if $\frac{LI^2}{V} = .005$ then

$L = \frac{.005\ V}{I^2}$ (V = 6 cu. in.), or

$L = \frac{.005 \times 6}{.054^2} = 10.3$ henrys (primary inductance).

Therefore this design is satisfactory.

In Fig. 12** we see that when $NI/l = 24.3$ the paper gap in the core should be about .0015″ thick.

Audio Output Transformer

Here let us assume that our audio amplifier employs the same output tubes as used in the modulator described before, which means that the following conditions exist:

Output tubes—P.P. pentodes (10,000 ohm load)

Plate Current—60 ma. for each tube

Output Watts—7.5

Lowest Frequency—150 cycles (voice frequencies)

Required Primary Inductance—10 hy.

Here we have the same primary circuit requirements which existed when we designed the previous modulation transformer. Therefore, we can use the same core size and primary winding.

Assume that at times this amplifier will feed into a 500 ohm line and that at other times it will drive a loudspeaker having an 8 ohm voice coil. Then two secondary windings will be needed; one for a 500 ohm load and one for an 8 ohm load.

Turns ratio $= \sqrt{\frac{10{,}000}{500}} = \sqrt{20} =$ 4.47 for 500 ohm winding, and

Turns ratio $= \sqrt{\frac{10{,}000}{8}} = \sqrt{1250} =$ 35.3 for 8 ohm winding.

With 2700 turns in the primary we find that the 500 ohm winding must have 2700/4.47 = 604 turns. Similarly, the 8 ohm winding must have 2700/35.3 = 76.5 turns (use 77 turns).

Now, we want to be able to put the full 7.5 watt output either into the 500 ohm load or into the 8 ohm load. Then, the wire used in each of these secondary windings must be heavy enough to carry such current. At 7.5 watts, the current in the 500 ohm winding is:

$W = I^2 Z$

Then: $I^2 = \frac{W}{Z}$

And $I = \sqrt{\frac{W}{Z}}$

$I = \sqrt{\frac{7.5}{500}} = \sqrt{.015} = 0.122$ amp.

or 122 ma. and the current in the 8 ohm winding is:

$I = \sqrt{\frac{W}{Z}} = \sqrt{\frac{7.5}{8}} = \sqrt{.937} = 0.968$ amp.

Fig. 5* indicates that the 500 ohm winding must be wound with No. 30 wire to carry 0.122 amp. and the 8 ohm winding must have at least a No. 22 wire to carry 0.968 amp.

The coil size calculation shows a build of 83 per-cent which is satisfactory.

Since the only direct current is in the primary winding where it flows in opposite direction in each half of the coil, the core does not have to have a gap. The laminations can be interleaved as in a power transformer core. Thus our design is a follows:

Core 1″ iron 1″ stack—laminations interleaved

Primary—2700 turns No. 33 wire, center tapped

500 ohm winding—604 turns No. 30 wire

8 ohm secondary—77 turns No. 22 wire

Only one secondary is to be used at one time.

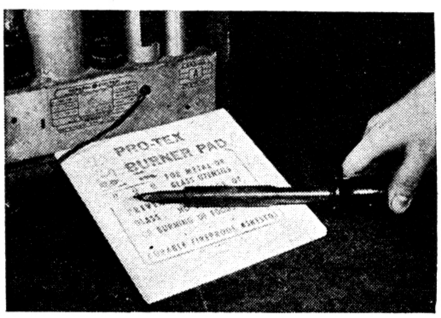
Practical Hints

When the approximate specifications of a transformer are known, it is a simple matter to determine its construction in more accurate detail.

ASBESTOS PAD IN SERVICE KIT

An asbestos pad of the type shown takes but little space in the tool kit or on the work bench and will be found very useful when soldering.

The iron may be placed directly on the pad or the pad may be used between the iron barrel and the radio cabinet when soldering with the chassis in place, to prevent damage to the cabinet. . . . . H. L.



After this has been done, it is then possible to know how that unit may be used for different applications or how, by slight modification, it can be made to perform an entirely different function.

Suppose that a combination plate and filament power transformer is at hand which has 2.5 volt filament windings. It is a relatively simple job to remove the coil from the core and to remove the 2.5 volt filament windings. In a power transformer of this type, the filament windings are always on the outside of the coil. They are wound after all of the other windings have been completed and they consist of only a few turns. Assume that the 2.5 volt windings consisted of 5 turns of wire and that one wishes to replace them with 6.3 volt windings to operate modern tubes. Then 5 turns/2.5 volts = 2 turns per volt. Then the new 6.3 volt windings would have 2 x 6.3 = 12.6 turns (use 13 turns). In this way, by thus determining the "turns per volt" in a transformer, one can replace any windings with new ones for different voltage output. It is not necessary to wind extra turns here for higher open circuit voltage to compensate for regulation because that was done when the transformer was originally designed for 2.5 volts. Now, if one of the old 2.5 volt windings had been wound with No. 19 wire, one could see in Fig. 5 * that it had been designed to supply 2.5 volts at 2 amperes (No. 19 wire will carry 2 amperes). Then 2.5 volts x 2 amps = 5.0 v.a. This means that the new 6.3 volt winding which is to replace the old winding could also deliver 5.0 v.a. or 6.3 volts at 0.795 amp. (6.3 x 0.795 = 5.0 v.a. For the current of 0.795 ampere No. 23 wire could be used.

Many times it is not desirable to remove any winding in a power transformer to determine the "turns per volt." Frequently, this information can be obtained without even removing the coil from the core. The procedure is as follows:

Wind 10 or 15 turns of light insulated wire around the center leg of the core at one end of the coil. These few turns will fit into the space between the end of the coil and the core. Now, apply the proper a.c. voltage to the primary and measure the open circuit voltage developed across the temporary winding. Then, "turns per volt" is equal to:

$$\frac{\text{Number of turns in temporary winding}}{\text{Voltage across temporary winding}}$$

Assume that a plate transformer is available which can supply plate voltage at 500 v.a. Also assume that one intends to draw only 480 v.a. of plate power from it and that it does not have any filament winding secondaries. It would then not be necessary to use a separate filament transformer to operate some of the tubes in the equipment. One could add a filament winding to this plate transformer because it is able to supply 20 v.a. more power. Thus, a 6.3 volt winding might

LAMINATION SIZE	AUDIO POWER (in watts)
½"	1.0
¾"	3.0
1"	5.0
1⅛"	10.0
1¼"	20.0
1½"	30.0
1¾"	60.0
2"	100.0
2½"	250.0
3"	500.0

Fig. 17. Approximate lamination size for audio transformers to handle various amounts of audio power.

be added to deliver 3.17 amps. (6.3 volts x 3.17 amps. = 20 v.a.).

The wire would not have to be removed from the coil to add the new winding. It is only necessary to find the "turns per volt" by the method shown above. Then, the new filament winding could be wound in the space at the end of the coil. For 3.17 amps. No. 17 wire could be used. Instead of using enameled wire for this winding, use insulated wire of the type used for lead wire (silk or cotton covered). Use enough turns to give 1.08 x 6.3 = 6.8 volts open circuit to provide 6.3 volts under load. A good amount of extra insulation should be employed to insulate this winding from the coil and core. Insulate for twice the highest voltage in the transformer, plus 1000 volts.

The procedure described above to find the "turns per volt" in a power transformer can be applied to find the number of turns in the windings of an audio transformer as well. When checking an audio transformer, it is well to use as many turns as possible in the temporary winding. Apply about 2 volts a.c. to the temporary winding and measure the voltages developed across the various windings in the transformer. Then, since the "turns per volt" in the temporary winding is known, the number of turns in the other windings may be calculated. After the number of turns in each winding is known, one can then find the impedance ratio and primary inductance.

For example, assume that an output transformer of unknown characteristics is to be analyzed. Also, assume that a temporary winding has been inserted which has 20 turns. Suppose that, when 2 volts a.c. was applied to this winding, voltages across the two transformer windings were 6 volts and 200 volts. Because 2 volts was applied across 20 turns in the temporary winding, "turns per volt" = 20/2 = 10. Now, this means that there are ten turns for each volt in the other two windings. Therefore, the first winding has 10 x 6 or 60 turns and the second winding has 10 x 200 = 2000 turns. (The above voltage measurements should be made with a relatively high resistance voltmeter). Since the transformer has a winding of 2000 turns and one of 60 turns, the turns ratio = 2000/60 = 33.3. The impedance matching ratio is equal to the turns ratio squared. Therefore, for this transformer, the impedance ratio is 33.3^2 or 1115, approximately. Because the impedance ratio is 1115, the impedance reflected into the primary will be 1115 times the load connected to the 60 turn secondary. Thus, if 2 ohms is connected across the secondary, the reflected primary impedance will be 1115 x 2 = 2230 ohms.

Suppose a load of 6 ohms were used. Then the primary impedance is 1115 x 6 = 6690 ohms. Here the question arises, "What impedances are correct for this unit?" To solve this problem it is necessary to make some primary inductance calculations. First, we might find out if it could be used to match a tube such as a 2A3 tube to a speaker voice coil. The 2A3 tube draws about 60 ma. plate current and requires a load of about 2500 ohms. This transformer with an impedance ratio of 1115 would reflect 2230 ohms from a 2 ohm speaker and about 2700 ohms from a 2.5 ohm speaker. Either of these values would be satisfactory for a 2A3 tube if the primary inductance is proper for that tube.

Fig. 16 shows that at 50 cycles a triode with 2500 ohms load requires primary inductance of about 10 henrys. Now, with all factors at hand, the primary inductance may be calculated and if it is found to be 10 henrys or more it can be used with a 2A3 tube. Of course, the primary wire size must be able to carry 60 ma.

When the number of turns of wire in each winding has been determined it is then possible to find out what the wire sizes are. There are two ways to do this. One method is to remove the outer wrapper of the coil and measure the diameter of the wire near where it is soldered to the leads. The other method is based on the fact that sometimes the leads coming out of the coil are merely the ends of the wire of the winding. This is only true if the wire size is about No. 27 or larger because smaller wire is not strong enough mechanically to be used for leads. Frequently, an output transformer is constructed with about No. 25 or larger wire for the secondary and the ends serve as leads. In this case, if there are only two windings in the coil, you could measure the secondary wire size and calculate the size of primary wire. Now, if it were found that the coil had 2000 turns in the primary with 60 turns in the secondary and measurement showed the secondary to be No. 24 wire, a wire size could be assumed for the primary and calculate the size of the coil. The calculation showing the largest coil size that would fit into that core would indicate the correct primary wire size. Obviously, it is necessary to know the primary wire size in an output transformer to be certain that it will carry the tube plate current. (Wire sizes are measured with a micrometer caliper.)

When the number of turns in a filter choke have been found by the method described, using a temporary winding, its inductance may be calculated with various assumed values of direct current. However, one must determine the wire size used in the choke to know what maximum direct current can be allowed to flow in it. To do this, assume a wire size and calculate the coil size for a maximum of 85 per-cent build.

The following notes will help in analyzing an unknown audio transformer:

1. If there is a gap in the core, the unit must have been designed to have d.c. in one or more of the windings. This means that it is to work from a single output tube if the primary is not center tapped, or that it might be an output transformer for push-pull Class "B" tubes, or that it is a modulation transformer.

2. If the core is "interleaved," it was designed to have no d.c. saturation. This means that it might be a line-to-line transformer or a line-to-grid transformer, or a line-to-voice coil transformer, or be for push-pull class "A" or "A_1" tubes.

3. The number of turns in the windings can be taken as a rough indication of the impedance each winding was intended to match.

NO. OF TURNS IN WINDING	IMPEDANCE
10—100	1 to 16 ohms, approx.
200—800	100 to 600 ohms, approx.
1000—4000	1000 to 20,000 ohms, approx.

4. An "output" tube-to-voice coil transformer" can be easily changed to match a different voice coil impedance. The secondary winding is usually wound over the primary and consists of only a few turns which can be removed and replaced with the desired number of turns.

The design data given throughout this entire discussion is quite conservative and is intentionally so. This was done to provide information for designing and constructing transformers of good quality.