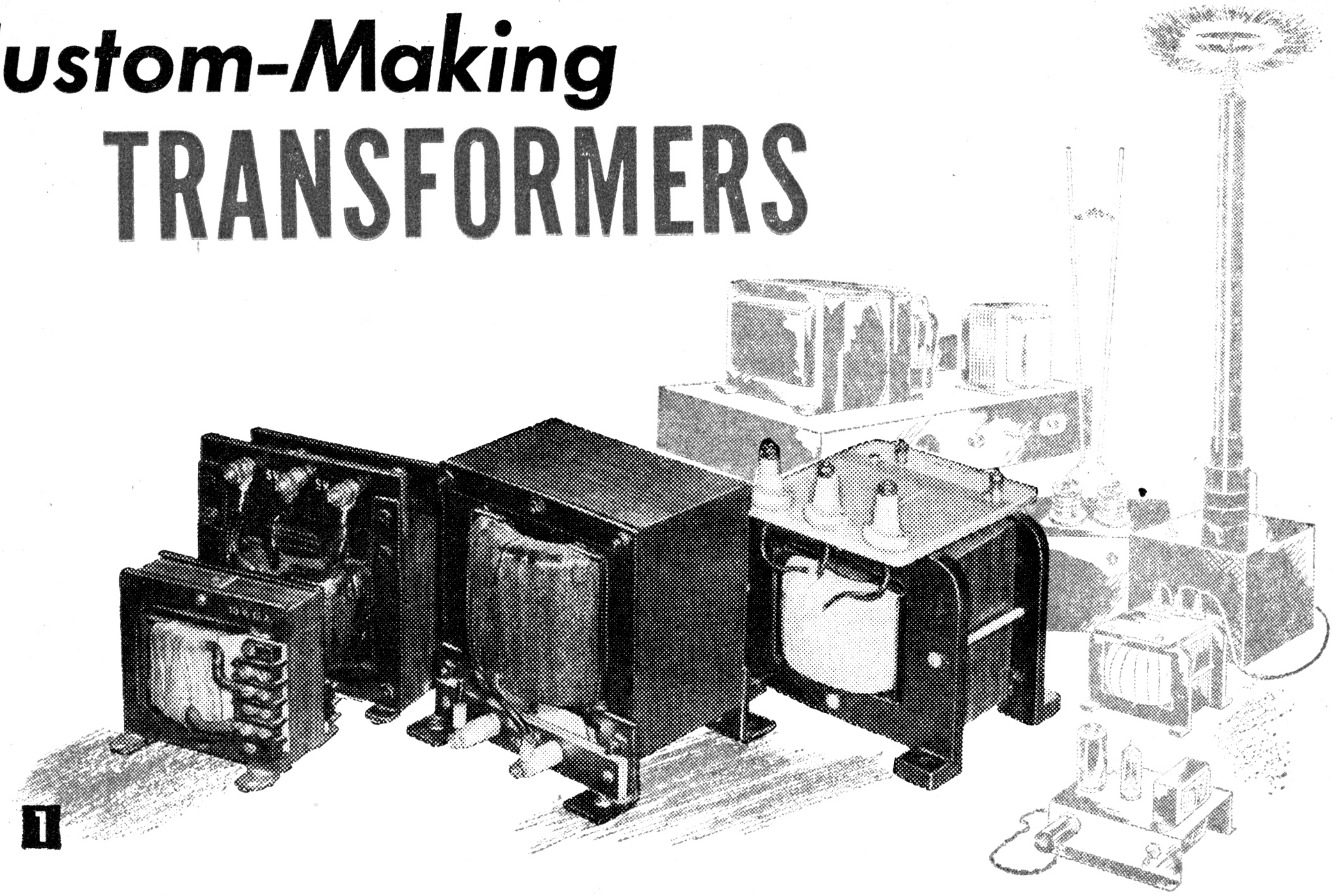
Custom-Making TRANSFORMERS



Transformers built using methods described in this two-part article. Left to right: a 10 V 12 amp filament transformer; a 10 V 25 amp filament transformer; a 3000 V 400 ma. plate transformer; a 2000 V 350 ma. transformer for large Tesla coil.

Part 1. How to make your own special transformers for ham radio, high voltage experiments, welding, plating, and special electronic equipment

By HAROLD P. STRAND
Electrical Editor

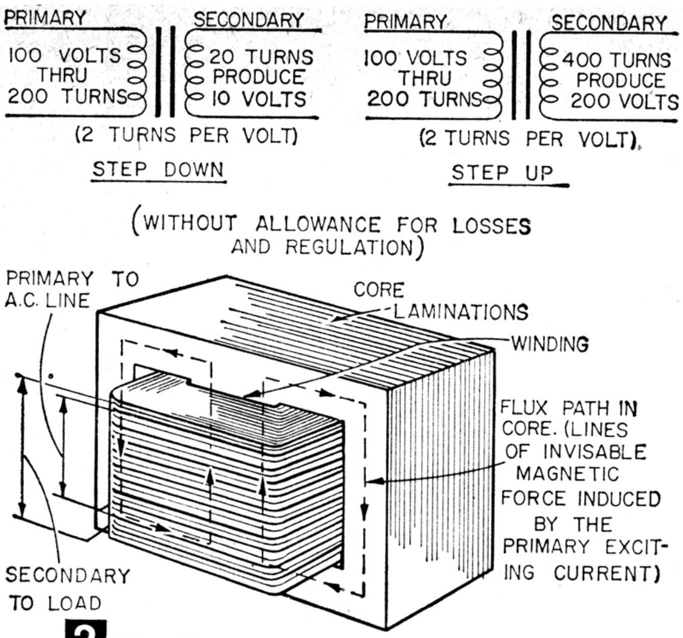
IF YOU need a certain voltage and amperage not available in a stock transformer, you can get exactly what you need by salvaging core metal from a discarded transformer. Then, by winding your own coils, you have a tailor-made job, at a fraction of the cost of having a special transformer made to order.

A transformer consists of a laminated core of special silicon steel (Fig. 2) on which is placed a primary and secondary coil. Depending on design needs, primary and secondary windings can be wound on top of one another as a unit, or placed side by side on the core.

Your first step in design is to decide exactly what transformer output voltage and amperage you need. You determine what size laminated metal core to use, by means of Table A. A formula gives you the wire size and number of turns for the windings. Varnishing, baking and testing completes the job.

Obtaining Laminations. Let's start with the transformer's metal core. We'll assume that you want to get set to make up practically any type of transformer. Usually, large metal stamping companies are not anxious to handle orders for transformer laminations in small lots. But you can pick up old transformers from electrical equipment, radio and TV sets, sometimes for the asking, in repair shops and junk yards. We suggest that you obtain a variety of used or burned out transformers in all sizes.

Suspend the transformers over an incinerator or steel drum, with wires attached to a ½-in. steel rod (Fig. 3). If the transformers have side enclosures, they should be removed before burning, but brackets and clamping parts can be left on. Work away from buildings because the fumes and odor are objectionable. A little fuel oil sprinkled over paper



2 BASIC TRANSFORMER PRINCIPLES

will get a good fire started. Keep the heat up for a half hour by adding more paper and scrap wood. The heat will burn away all old insulation and wrapping material, but will not harm the laminations. In fact, it will tend to anneal the steel, resulting in lower magnetic losses, an important factor in good quality transformers. Quench the fire with a garden hose, and cool the transformers so they can be handled.

Now you can remove the laminations (Fig. 4). If you have an "E and bar" type transformer, pull alternately from each side. Another kind of core has one-piece laminations (Fig. 5B) with a joint open at one side. Take it apart by carefully lifting the side pieces first. Then pull the laminations alternately from each side, one at a time. Clean the metal with a stiff brush, and wipe clean with cloth.

Planning Core Size is easy. You need a mass of metal in the center big enough to provide an adequate path for the magnetic flux in relation to the volt-ampere rating of the transformer. The window opening must be big enough to take the wound coil. Table A lists transformers from 5 to 500 volt amperes. The core area minimum figures refer to the width of the center leg, times the thickness of the stacking in inches (Fig. 5A). You need not follow the table exactly. A variation of 20% plus or 5% minus is allowable.

Theoretically, the best core would have a square cross-sectional area, for example 1.5 x 1.5-in. In practice, many coils will not fit in such a stack. Your core should not vary from the square more than by a factor of 1.75 for the best designs. For example, it would measure 1-in. by a maximum of 1.75 in. But if a certain required coil size would not fit into such a stacking, you might have to exceed the 1.75 ratio.

This will happen when your coils have un-

TABLE A—TRANSFORMER CORE AREAS

Approximate cross sectional area in inches for Silicon steel transformer laminations.

Output in volt-amperes	25 cycles	50 cycles	60 cycles
5	0.6	0.3	0.25
10	1.0	0.5	0.4
15	1.2	0.6	0.5
20	1.4	0.7	0.6
25	1.8	0.8	0.7
50	2.8	1.4	1.2
75	4.0	2.0	1.8
100*	4.8*	2.4*	2.2*
125	5.2	2.6	2.4
150	5.6	2.8	2.6
200	6.0	3.0	2.8
250	6.8	3.4	3.2
300	7.6	3.8	3.6
350	8.0	4.0	3.8
400	8.4	4.2	4.0
500	9.6	4.8	4.6

* Text example.

usually large numbers of turns, or where large size wire is being used. In such cases, use more stacking or larger laminations and then recalculate the winding with the larger core area; this in turn will result in a smaller coil with less turns. When designing transformers, you may have to recalculate several times with different core dimensions, before you can be certain that the finished coil will fit into the core space.

Window Opening. The second important design factor to consider is the length times the width of one of the rectangular openings in a lamination (Fig. 5A). A good transformer design is thus the best combination of three factors: core size, window opening area, and coil size. Common rectangular cores can be mounted either horizontally or vertically (Fig. 7A, B). In some amplifier circuits where two transformers are to be mounted close together on a chassis, their cores are placed at right angles to each other. This reduces the flux linkage between them to minimize hum and other bad effects.

Building a Transformer. Let's run through a typical design problem and build a transformer. We're making a rectifier unit that runs on 120-*ac* line voltage. The circuit requires 16.5 volts at 5 amps. So we multiply secondary voltage (16.5) times secondary amperage (5), to get the volt-amp rating (82.5 v.a.), which is equal to watts. This, of course, is provided that the future load of the equipment is non-inductive.

In Table A you will find that the nearest core size is 100 v.a., calling for 2.2-sq. in. core area. This area is an average and we can be under 5% or over 2%. From our stock of salvaged laminations, we select a suitable group with a center leg width of the "E", 1.25-in. Stacking these laminations to 1.75-in. thick, and multiplying the two dimensions, (Fig. 5A) we get 2.18 sq. in. The window opening measures ⅝-in. x 1⅞-in. or an area of 1.17 sq. in.—the space into which the coil cross section must fit.

Now calculate the coil windings (Fig. 7C).

Heavy Formvar Diameter (Nominal)	Wire size in B&S Gage	Cross-sectional area (bare) in circular mils	Turns per square inch with average insulation, layer wound
.1055	10	10,380	90
.0942	11	8,226	112
.0842	12	6,529	140
.0753	13	5,184	177
.0673	14	4,109	220
.0602	15	3,260	276
.0538	16	2,580	346
.0482	17	2,052	428
.0431	18	1,624	534
.0386	19	1,289	665
.0346	20	1,024	835
.0310*	21*	812*	1,042*
.0377	22	640	1,310
.0249	23	511	1,600
.0223	24	404	1,980
.0200	25	320	2,470
.0179	26	253	3,090
.0161	27	201.6	3,870
.0145	28	158.8	4,830
.0131	29	127.7	5,920
.0116	30	100	7,430
.0104	31	79.21	9,120
.0094	32	64	10,000
.0084	33	50.41	13,900
.0075	34	39.69	17,700
.0067	35	31.36	22,200
.0060	36	25	27,700

TABLE B—WIRE SIZES AND TURNS PER SQUARE INCH

* Text example.

Volt-amperes required (83) are divided by line voltage (120), to get the amperage which must flow through the primary circuit. But since small transformers usually operate at 85% efficiency in transferring electromagnetic energy from primary to secondary, we must add 15% more current to compensate. This totals .79, or .8 amp (with decimal rounded off).

Figuring for constant duty, a value of 1,000 circular mills per ampere is satisfactory. In wire Table B, #21 wire has 812 c.m. area. Therefore you point off three decimal places to the left for the current carrying capacity, .812. For intermittent duty, or if the transformer is to be used only at partial load, one smaller size wire, #22, can be used.

Your next step is to find out how many turns of wire will be required for the primary. The formula is:

$$N = \frac{10^8 \times E}{4.44 \times f \times A \times B_m}$$

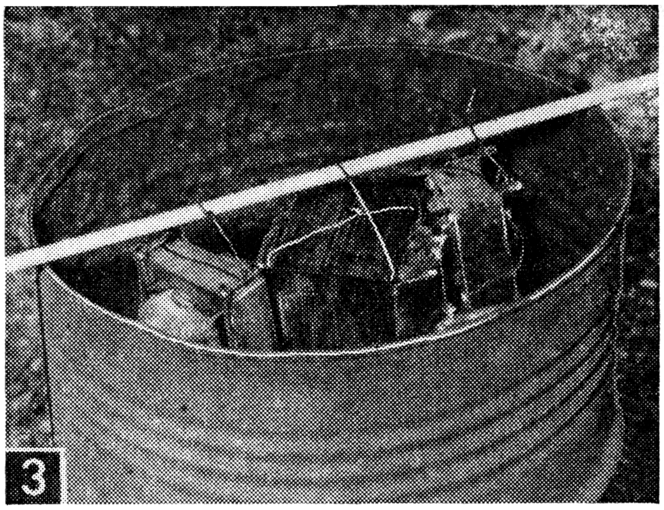
N is number of turns, E is counter electromotive force (line volts), 4.44 is a multiplying factor, f is frequency in cycles per second, B_m is maximum flux density in lines per sq. in., A is area of core in sq. in.

B_m (maximum flux density) is the value of the flux or magnetic lines of force set up in the core by the primary exciting current (Fig. 8). If the density is too high, the transformer will heat excessively and waste power. Various values are selected by a designer according to the use. In some electronic transformers it may be as low as 20,000; in some cases a density of 80,000 has been used, especially for intermittent duty. A value of 60,000 lines is a good average for small power transformers.

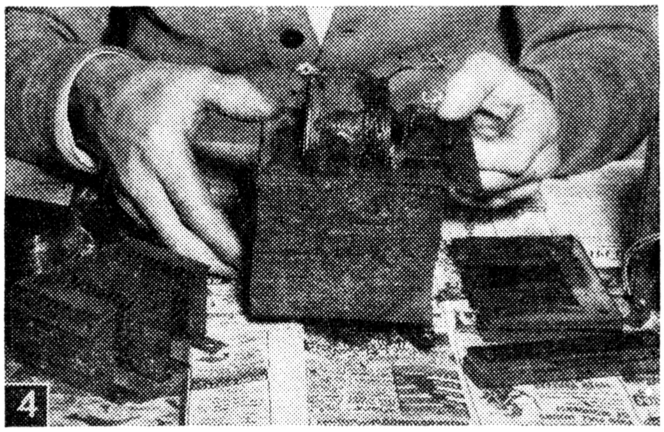
$$\text{Thus turns} = \frac{100{,}000{,}000 \times 120}{4.44 \times 60 \times 2.18 \times 60{,}000} = 344$$

We now have the primary winding calculated as having 344 turns of #21 wire which would operate with little temperature rise.

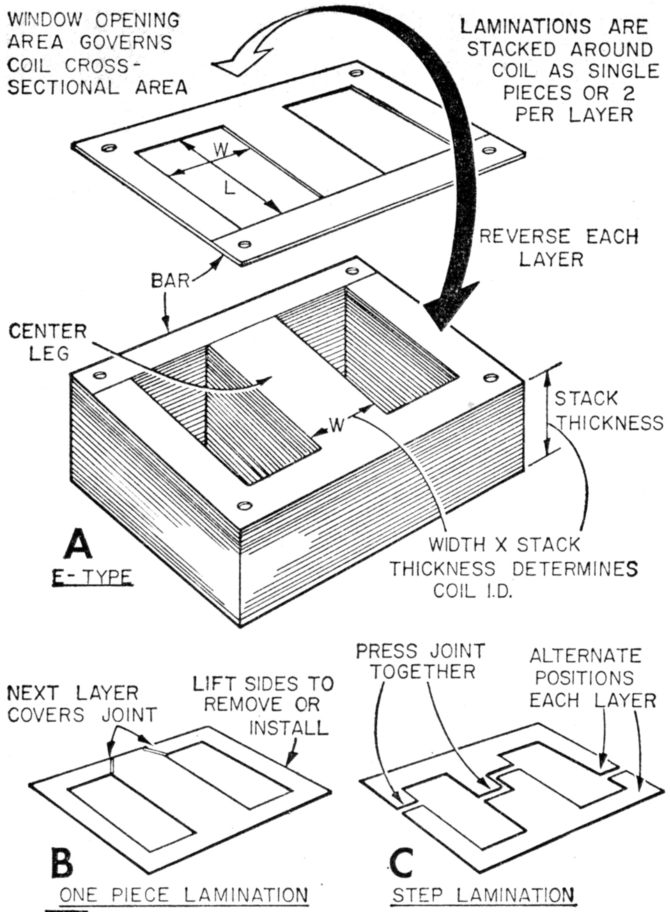
Now figure the turns-per-volt in the primary to determine how many turns will be required in the secondary. Divide primary turns (344) by line voltage (120), which is 2.87 turns per volt. As 16.5 secondary volts are required, multiply by 2.87, resulting in 47.3 turns. There will be some iron and copper losses, however, which average about 4%, and there will also be a normal voltage drop when the load is added so, if we want the stated voltage at full load, about 2% more turns must be added—or a total of 6% additional turns. The exact values of losses and regulation (the % difference between no load voltage and full load voltage) are difficult to estimate in advance. In commercial applications where the voltage under load must be exact, it is often necessary to construct a second pilot model after tests on the first one show more or less is involved in the loss and regulation factors. In our case the



Burning a half hour will loosen the insulation and wrappings so that core laminations can easily be removed.

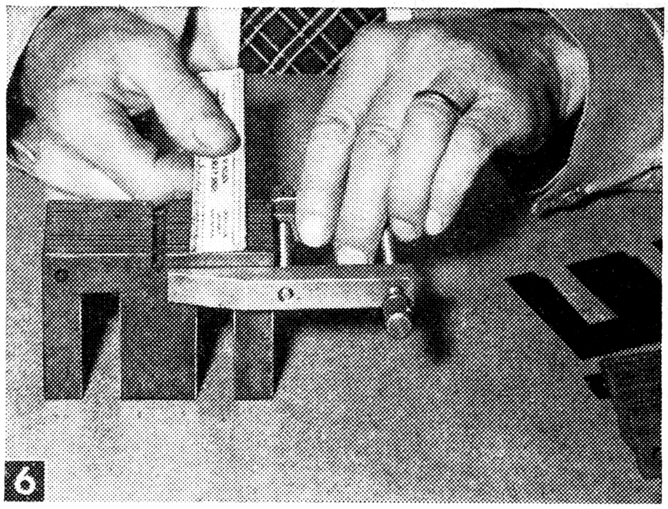


The heat has reduced the insulated wire to bare copper and laminations that are easily pulled out.



5 PUNCHED TRANSFORMER LAMINATIONS

STACKED LAMINATIONS ARE #26-#29 GAGE, SILICON TRANSFORMER STEEL. FOR 60-400 CYCLES, USE #29 GAGE TO LOWER LOSSES. (#29 MAY BE USED ON LOWER FREQUENCIES)

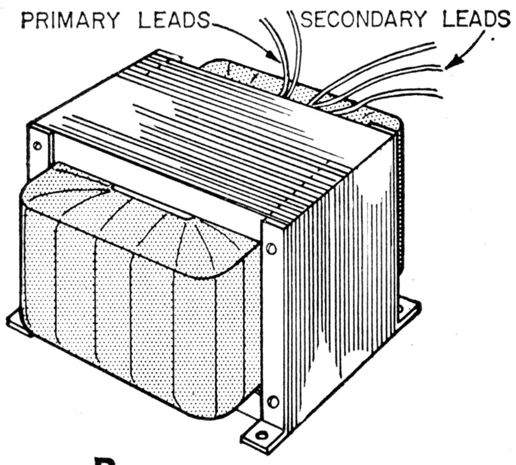


6 **Clamp the stack of transformer laminations tightly together when you measure thickness. The thickness x the center leg width is the cross sectional area of core.**

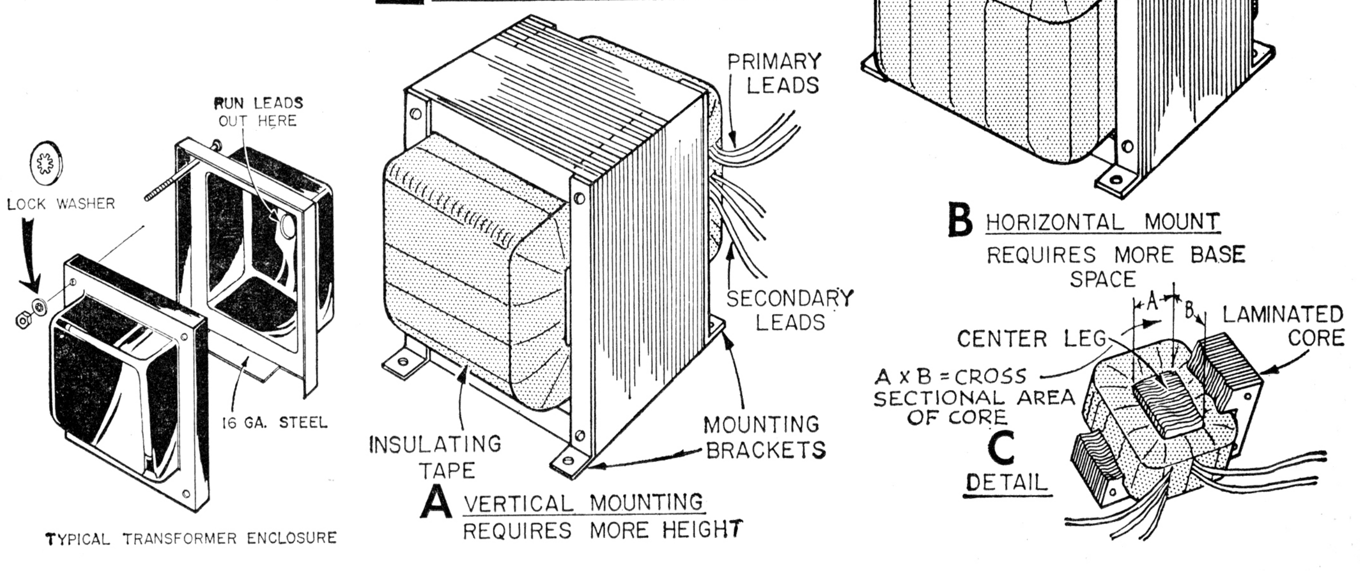
voltage is not too critical, so the addition of 6% is sufficient in the calculated turns, making 50.1 (50) turns for the secondary winding. This winding will be tapped at 25 turns.

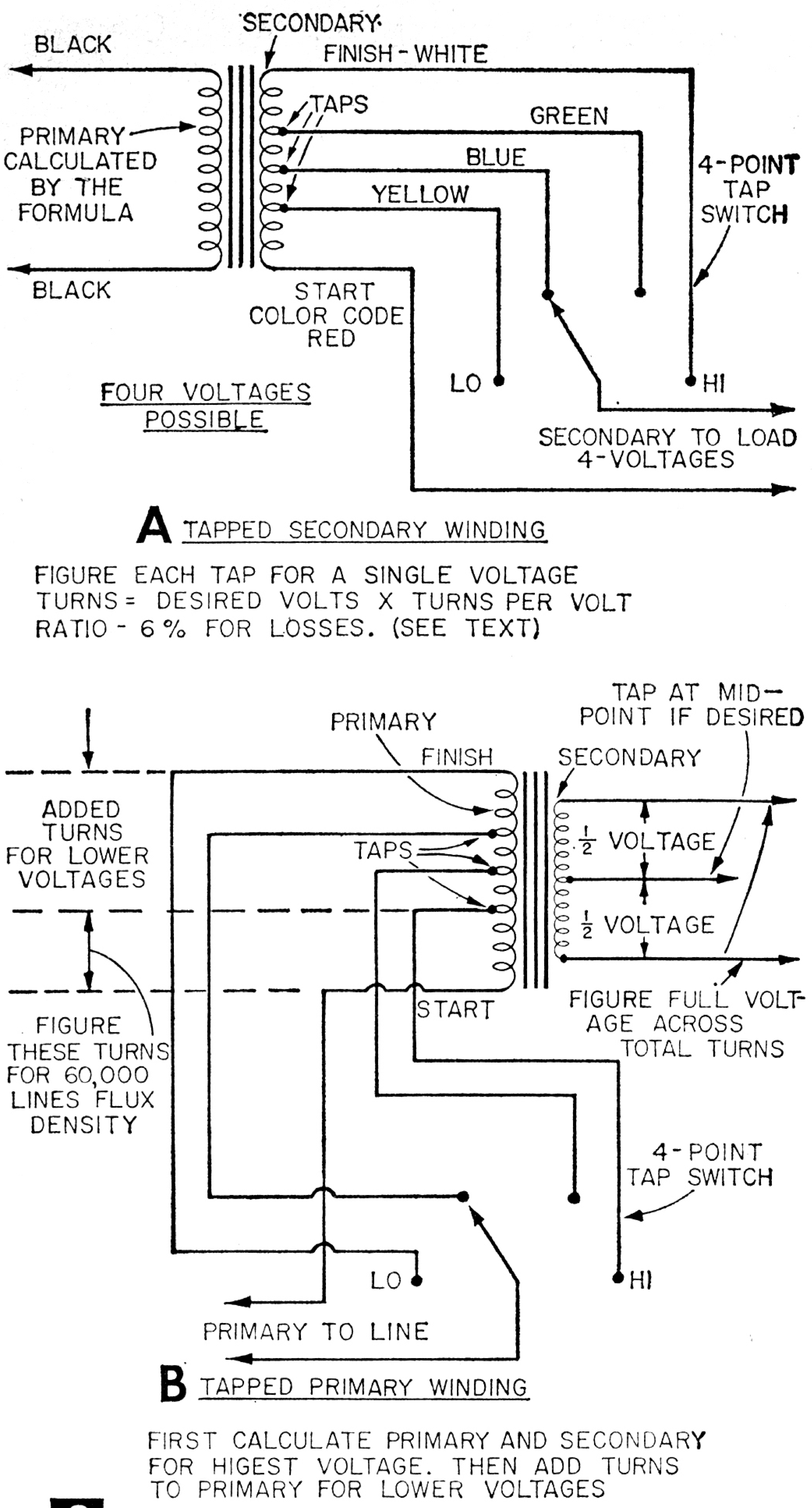
The wire size of this winding is the next consideration. The transformer winding is to carry a current of 5 amperes. Table "B" lists #13 wire with 5184 circular mils, or as having 5.184 amp capacity at 1000 circular mils per amp. Since this is heavy wire to wind, use two wires wound on together, three sizes smaller, or #16, which will have the same area and be easier to wind. (For intermittent duty, you could use one #15 wire.) Formvar magnet wire is recommended for its tough enamel insulation and minimum required space.

The final problem is to estimate the size of the finished coil to make sure it will fit in the lamination window openings (Fig. 7C). To do this, refer to Table "B" in the "turns per sq. in." column. We are using 344 turns of #21, so divide 344 by 1042, resulting in .33. Figure the 50 turns of double #16 singly first, then the result doubled: 50 divided by 344 is .14 times 2 equals .28. Add this to .33 for a total of .61. To this must be added a figure which represents the approximate space taken by the insulation between primary and secondary, between secondary turns if any, and out-



7 SMALL TRANSFORMER DESIGN





8 VARIABLE VOLTAGE TAPS.

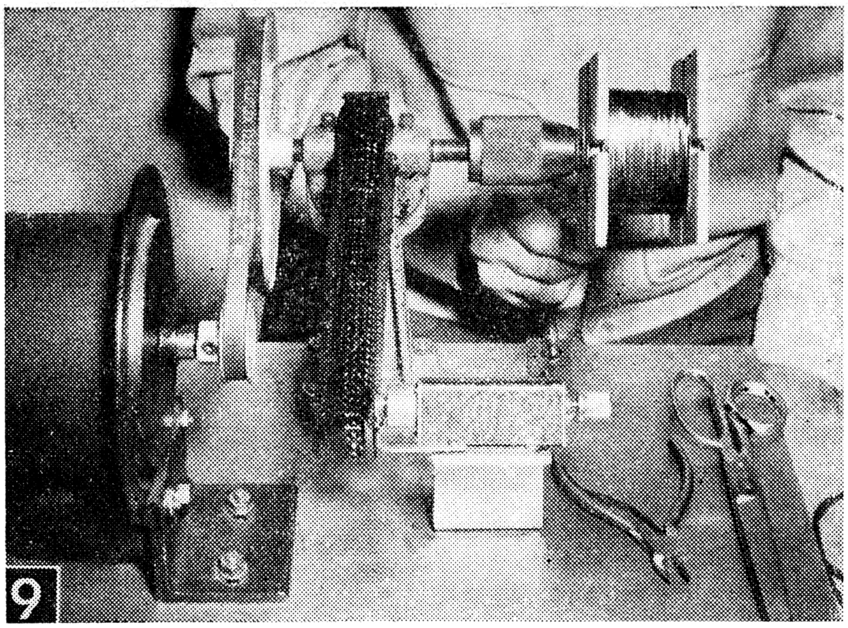
side taping of coil. Another factor is that the turns may not be wound in flat layers, but may be "random" wound, which is easier for the amateur. This type of winding, while satisfactory, takes up more space. Therefore, an estimate of 25% must be added to the figures previously obtained as the probable total space required for the finished coil. This totals .76 sq. in. As the window opening in the core (5/8 x 1 7/8 in.) is 1.17 sq. in., the coil should fit in place if it is neatly and tightly wound.

Transformer designs which must be quite exact, usually include a stacking factor for the core, since a stack of laminations 2-in. high does not necessarily have the same area as 2-in. of solid steel. Therefore, .9, another multiplier, is added to the row of figures below the line in the formula. For practical purposes, however, this figure can be omitted in most cases.

A transformer is often needed which has several output voltages, obtained with a multi-point switch or so-called tap switch. There are two ways of doing this. You can design the secondary winding with taps at the turns to deliver the desired voltages, each of which can be calculated by the methods already described, and bring out leads at these points (Fig. 8). Or the primary winding can be tapped. This is especially desirable when the size wire in the secondary is large and it is impossible to make taps there without adding considerable bulk. To tap the primary, first calculate the primary winding by the method described for single-voltage transformers. Then, figure the number of turns for the secondary for the *highest* voltage required, using the primary turn-per-volt ratio as the multiplier plus the added percentage for losses and regulation. This will establish the number of secondary turns. In order to get several lower voltages, more turns must be added to the primary with taps at each of the points to be determined.

Supposing that we wish to have 24, 18, 12 and 10 volts through the use of a tap switch on the primary. A particular transformer with a certain core, for example, is figured to require 350 primary turns for a 60,000 flux density. Dividing this by the line voltage (120), we get a turn-per-volt ratio of 2.9. Multiplying this by the highest secondary voltage (24), the turns for the secondary—with 6% added for losses and regulation—will be 73.77 (74) turns. 18 volts will be the next objective, so 70 is divided by 18 which is 4.1. Multiply this by line voltage (120) and the result is 492 primary turns as the next tapping point. Repeat this procedure for each secondary voltage and the last figure obtained will be the total primary turns required, with the point for each tap indicated (Fig. 9B). With so many primary turns, the coil when wound, will be comparatively large, so careful selection of the laminations must be considered to provide a suitable space for the coil. When the transformer is operating on the tap which produces the highest secondary voltage (24), the flux density in the core will be at its highest—60,000 lines. The taps which cut in *more* primary turns will *reduce* the secondary voltage and the exciting current and hence the flux, so the transformer will not be in danger of overheating on any of the taps. If you tapped the basic 350 turns in an attempt to get variable secondary voltage, the result would be an increase in flux density for each tap used, and the flux density would reach a point where the core would overheat, and the line current become excessive. . . .

Part 2 will show you how to make a winding form and begin the winding of a coil for a transformer based on the calculations we have made.



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This homemade machine makes transformer and coil winding easy. Speed is controlled by a foot pedal.

Custom Making
TRANSFORMERS

Part 2. Completing and testing the transformer. How to make a form for transformer winding and a simple bake oven

By HAROLD P. STRAND
Electrical Editor

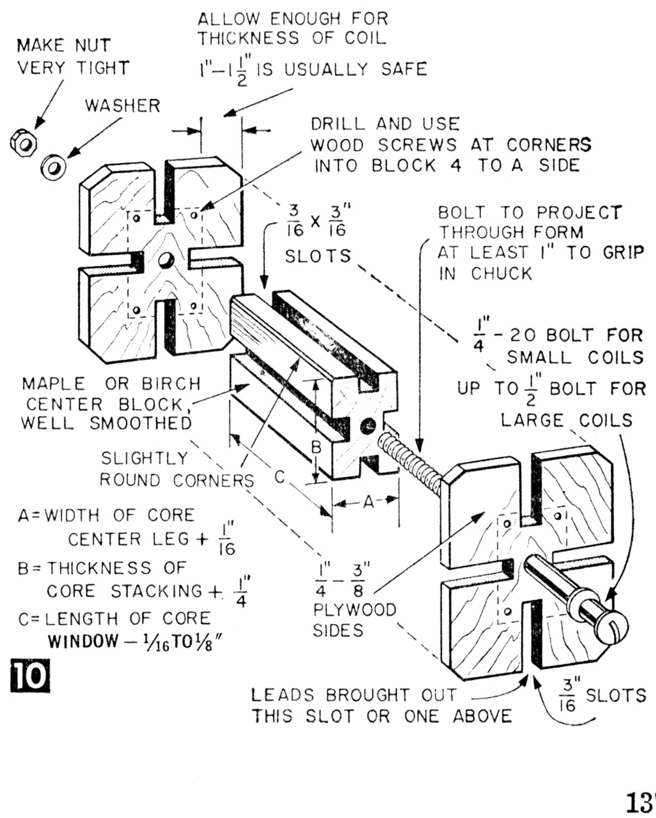
PART 1 described the steps in designing cores and coils for making your own special transformers for rectifiers, plating, ham radio as well as high voltage and electronic experiments.

Laminations were salvaged from discarded transformers, and complete calculations were shown for designing a special rectifier transformer which is to step down 120 line voltage to 16.5 volts at 5 amperes. The continuous duty primary coil was calculated to require 344 turns of #21 Formvar magnet wire; the secondary winding requires 50 turns of two #16 Formvar magnet wires wound together in parallel, with a center tap at the 25th turn. The basic procedure which follows can be used to wind any kind of similar transformer.

Start by making the winding form (Fig. 9) with a center block cut slightly larger than the core center of your transformer laminations. The grooves and the slots in the coil form (Fig. 10) are used for temporarily binding completed turns of wire with cord. Sand the wood smooth, slightly rounding the corners, and then coat with shellac. When dry, sand lightly and apply paste wax to make it easy to remove the coil after winding.

The home-made machine (Fig. 9) includes a variable-speed foot pedal which controls a vacuum cleaner motor. If you plan to make a number of transformers, or coils, you will save time by building an electrical coil winding machine (such as the one shown in Craftprint 265, $1). Otherwise, you can chuck the winding form in a lathe that has slow speeds, or rig up a hand crank. For any winding method, you need a positive way to count turns, such as a mechanical counter tied in with sprockets and chain.

To insulate the coil from the laminations first place a turn of lapped .007 Duro insulating paper around the form. Fit the paper tightly with 1/16-in. brought up on all sides (Fig. 12). Secure with a strip of Scotch masking tape. Then slip a length of spaghetti tubing over the end of your #21 Formvar magnet wire, for the starting lead of the primary. Allow at least a foot of this wire and bring the spaghetti in through one of the side slots into the coil form about 1/4-in. Secure the loose end of the



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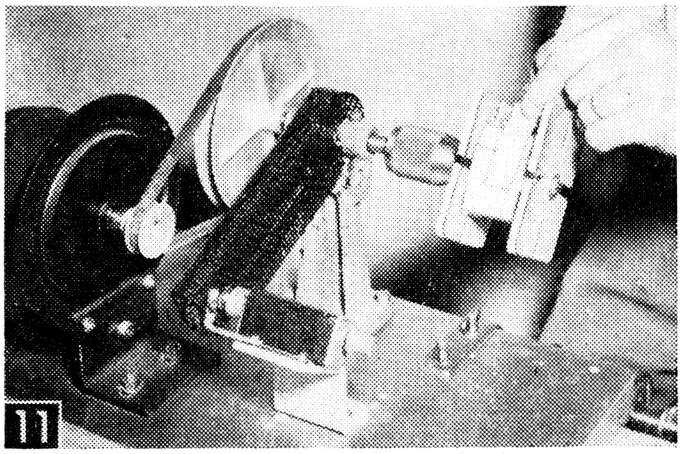
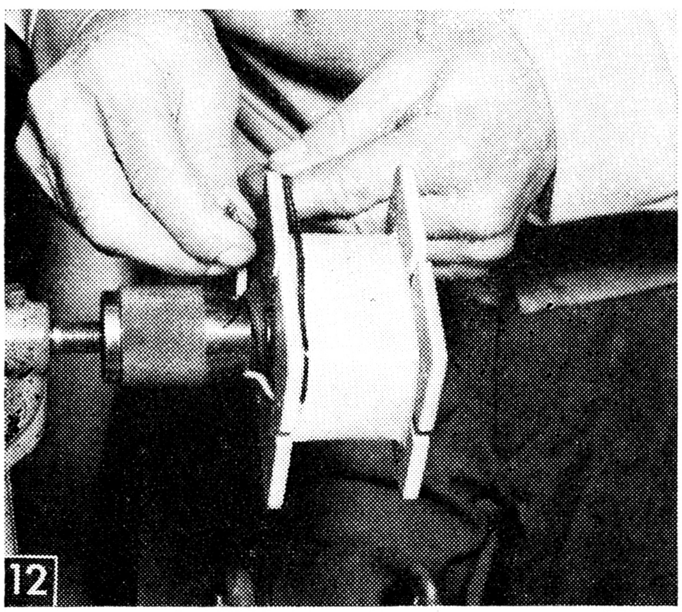
wire by taking a few turns around the bolt on the chuck side of the form. Set your counter at zero and wind back and forth as evenly as possible to avoid unnecessary wire crossings. When the counter reads 344, cut about a foot beyond the last turn, slip on spaghetti tubing, and bring the lead out through the same slot used at the start. Again, secure the lead with paper Scotch tape and a few turns taken around the bolt.

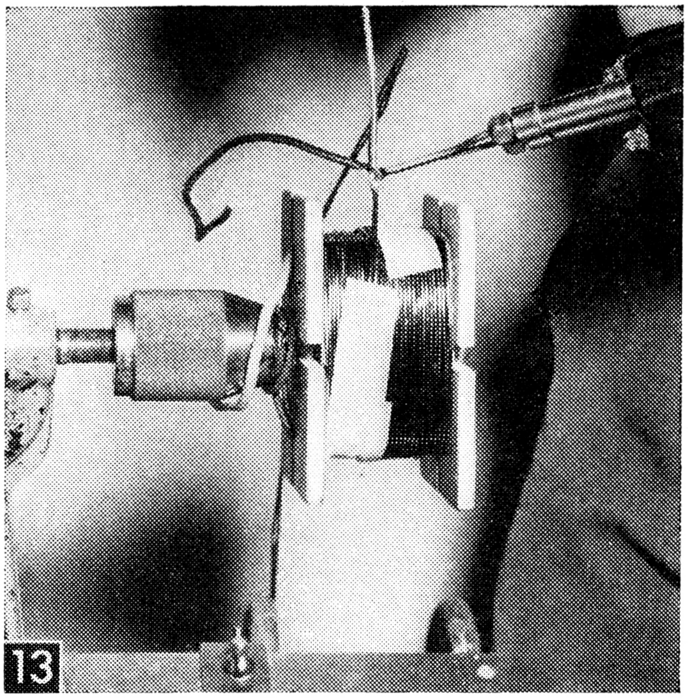
Start the secondary winding with a turn of .007 Duro insulating paper placed over the primary. Follow the same procedure as before (Fig. 11). But after you slip the spaghetti tubing over the lead of your pair of #16 secondary wires, run them through the opposite slot on the coil winding form. Set counter to zero and wind 25 turns, flat and even because your space in the laminations is limited. After the 25th turn, use tape around the turns to temporarily hold them in place. Scrape ⅝-in. insulation from both wire ends and solder on a flexible #16 insulated lead (Fig. 13). Insulate with a folded piece of the .007 Duro paper and secure with paper



Use Duro insulating paper, brought up at the sides and fastened with tape to insulate the coil from the laminations.



When primary winding is finished, bring out the leads and wrap around the mounting bolt. The paper insulates primary from secondary winding.



With tape temporarily holding the windings, solder a flexible lead wire to make your first tap.

masking tape. Then wind another 25 turns, cut the wires, slip on spaghetti, and bring the last lead out the same slot used to start the secondary winding.

Now you are ready to remove the coil from the form. Make a fish wire and thread some strong cord through the slots (Fig. 14). Gently tap the windings with a block of wood and tightly bind the coil with secure knots. Unchuck, tap out the coil block, and check the coil size with a lamination. Coils have a tendency to spread out at the center after removal from the form, but can be compressed slightly with tape, or in a vise with two blocks of wood.

Use cotton coil tape, the kind specially sold for this purpose, to wrap the coil. Pull it tight each turn, and overlap the tape half its' width. Avoid bunching tape excessively at the corners, which might interfere with the laminations. When you come to a tie cord, cut it, and continue taping (Fig. 15). Run the cotton tape tightly around the leads and sew with needle and thread to keep tight. Also secure the ends of the tape with sewing.

COIL WINDING—SOURCES OF SUPPLY

Formvar Magnet Wire*

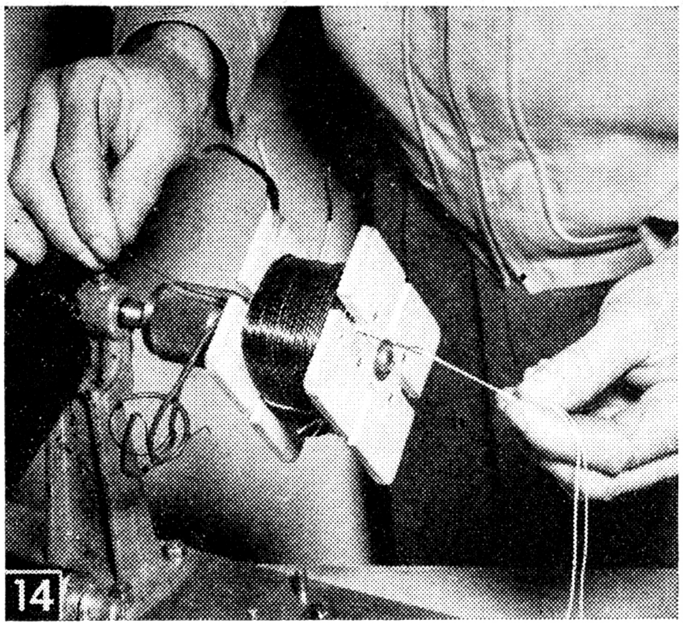
1-lb. spools; Allied Radio, 100 N. Western Ave., Chicago 80, Ill. 5 lb. #21, 10-lb., #16 minimum orders; Huse Liberty Mica Co., Lynfield Street, Peabody, Mass.

Insulation*

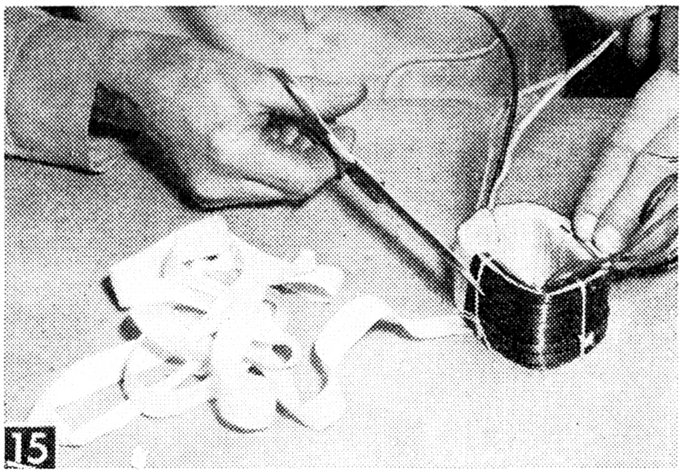
Duro insulating paper .007 or .010″ thick in 24 x 46″ sheets; cotton coil tape, .007 x ¾″ wide rolls; clear baking varnish, 1 gal. cans.; Huse Liberty Mica Co.
Spaghetti tubing, heat-resistant; assorted sizes available most electronic supply houses. Assorted bundle, 8″ lengths, Allied Radio Cat. No. 49 T220. ($ .25)
Scotch masking tape, paper; hardware and paint stores.

Flexible Insulated Lead Wire

Braided, heat resisting type; electrical and electronic supply houses.
*Many of these items in small quantities can be purchased through motor winding shops.



Use a small fish made of a short piece of wire to thread through the slots to tie the finished windings.



Pull each turn of the cotton coil tape tightly, and avoid bunching the tape at the corners.

Before you can install the laminations, the coil must be dipped in heat-reactive clear coil baking varnish, and baked. First be sure the coil is free of moisture, dirt etc. Use a can with enough varnish to completely submerge the coil. Wait 20 minutes or until all bubbling ceases, and then hang it up over the can to drain.

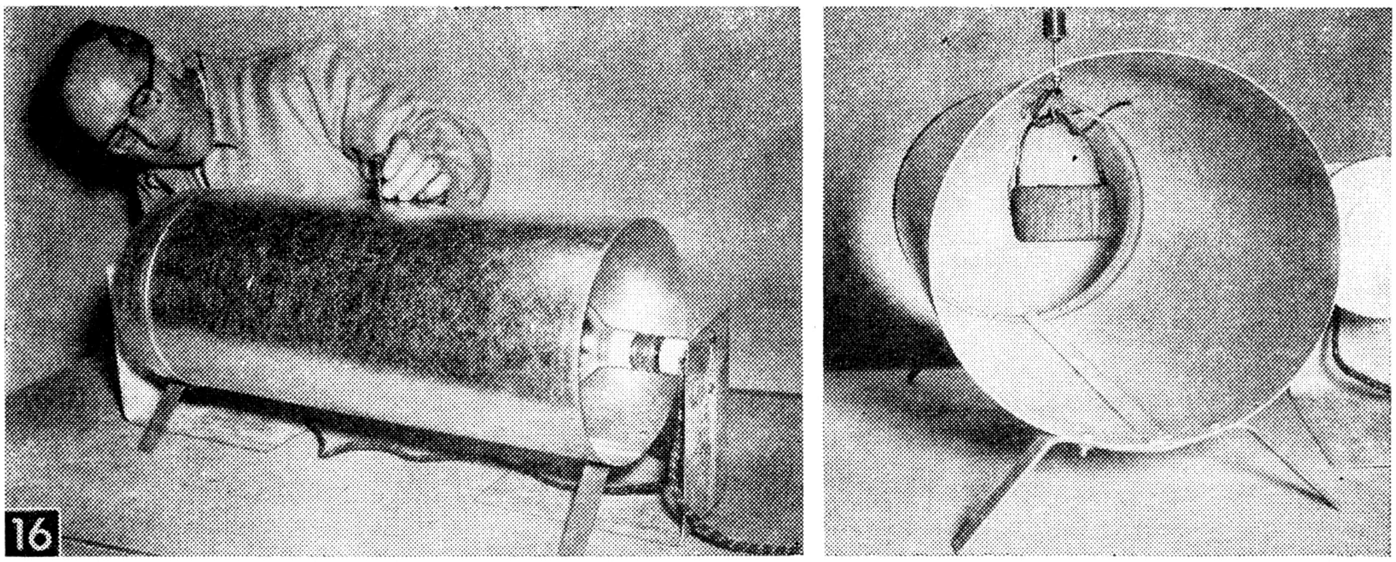
The Baking Oven (Fig. 16) uses two 250-watt infra-red lamps and has a hook fitted through the center of the large galvanized stove pipe for turning the coil during baking. Use asbestos cord for the leads to the lamps, and bind the asbestos fibers with carpet thread to prevent fraying. The infra-red heat rays penetrate down through the windings to the bottom layer, and so baking time will vary with the size of coil and make of varnish. Two or three hours should be enough, provided that you turn the coil a few times.

Assemble the laminations as soon as the coil is cool. You can insert two laminations per layer at once, but be sure to alternate the direction of the "E" for each layer (Fig. 17). When the stack is complete, insert the longer "E" pieces (keepers) which generally are used to cover the last laminations. If such keepers were not part of your original core assembly, disregard. They are not essential.

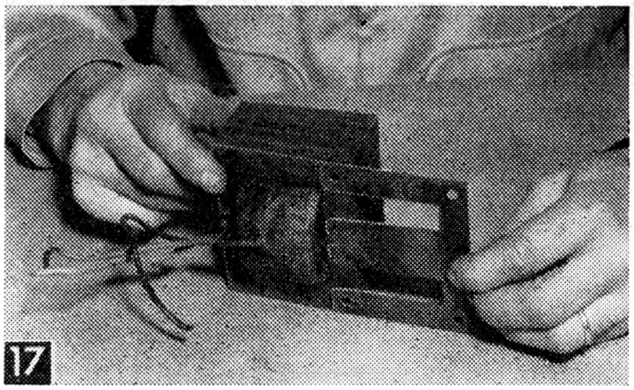
Now insert core assembly bolts through the laminations and tighten temporarily. Drive Bakelite or fiber wedges into the spaces between the winding and "E" legs to pre-

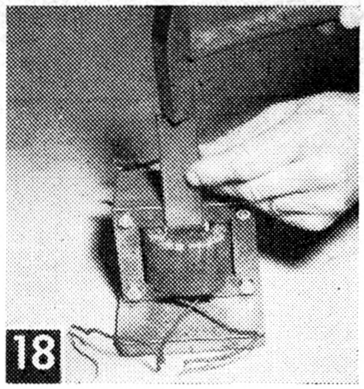
MATERIALS LIST—BAKING OVEN

Amt. Req.	Size and Description
1	10 x 24″ length, galvanized stove pipe
2	1 x 25 x 1/8″ strips, mild steel (legs)
2	1/16 x 6 x 18″ pieces aluminum, or galv. sheet steel. (bend 90° for lamp brackets)
1	1/8 x 6″ steel rod (coil support)
1	3/4 x 1″ Bakelite rod (coil support knob)
4	6-32 x 1/2″ rh machine screws and nuts (leg stove pipe assembly)
4	6-32 x 3/4″ rh machine screws, washers and nuts (lamp socket assembly)
4	8-32 nuts, (rod-hook assembly)
2	250-watt infra-red lamps
2	lamp sockets, porcelain surface type
12′	#16 braided asbestos-covered appliance cord
1	a-c plug

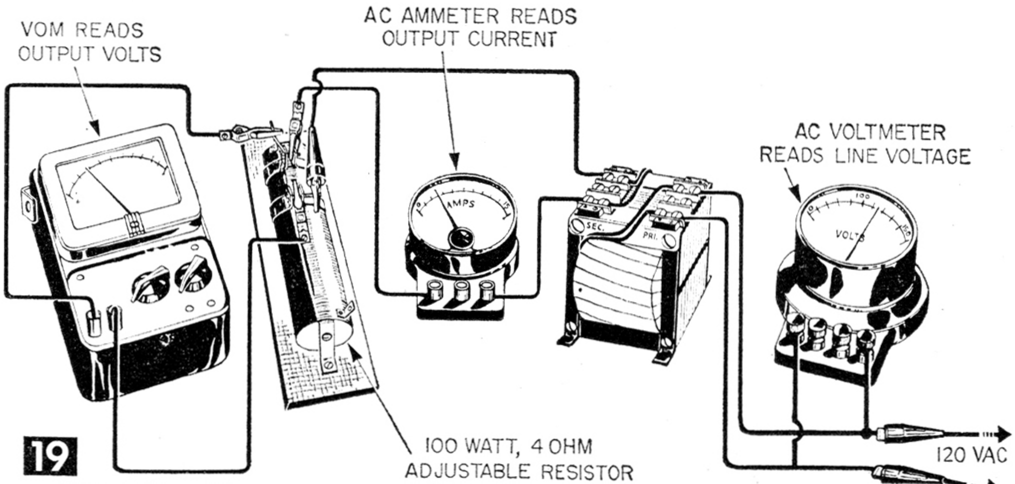


Use a 10-inch stovepipe and two 250-watt infrared lamps to make the oven. With the knob you can turn the coil during baking.





Left. Assemble the laminations alternating the E each layer. Usually longer E pieces cover the ends. Right. Fiber wedges driven into the open center spaces prevent vibration of the laminations.



FINAL LOAD TEST

vent the laminations from vibrating. Square up your laminations and drive the joints together with a hammer, with the assembly resting on a steel block (Fig. 18).

Terminal strips are a practical necessity on this type of experimental transformer (Fig. 19), because you can make and break connections quickly. Use Jones #3-140 barrier terminal strips, and make two sheet metal brackets that just clear the top of the laminations. Complete construction by bolting the terminal assembly, the laminations, and transformer mounting brackets together. Carefully clean the ends of your lead wires and loop around the terminal screws, or solder permanently.

Insulation Tests. A high voltage transformer, such as the Test Transformer described in S&M Handyman's Electrical Guide, Vol. 1, is generally used to check for grounds, or electrical leakage to core. A commercial "Megger" insulation tester, will also tell you whether you have perfect insulation. Make the test by applying the high voltage between one primary terminal and frame, and one secondary terminal and frame. Also test across one primary terminal and one secondary terminal. Apply the high voltage for only an instant and of course, never between terminals of either winding. The leakage will show on the test transformer lamp, or on a megger, the meter will register value of insulation resistance.

Make the No-Load Test by connecting an ammeter in series with one line wire to the primary. A well designed transformer should draw hardly any current with no load on the secondary. Our transformer read .160 amps, which is a satisfactory value. A high current would indicate insufficient primary turns, or that there are shorts between turns. Either fault requires rewinding of the coil.

A final test is with a secondary load. For our model, we used an adjustable 100-watt resistor (Fig. 19) capable of carrying the output amperage (5 amps) with a 4-ohm resistance. Connect the resistor with an ammeter in series with one side of the secondary, and a voltmeter in parallel. Also connect a voltmeter across the line. An a-c ammeter to indicate line current, connected in series with one of the primary leads, would also be helpful. Adjust resistor band so secondary ammeter reads exactly 5 amps. Secondary voltage on our model read 16.4 volts, and reading primary amps, we found that full load current was exactly .75 amps. We found the finished transformer voltage was within 1% of our original calculations in Part 1, (using the right line voltage for the test.)

You can use the method demonstrated in this article to wind any low voltage transformer. When you build high voltage transformers, you will need to use many turns of fine wire, which usually require insulation between layers to prevent breakdown. On factory winding machines, the insulation is applied automatically over perfectly even layers. On a hand winding machine, use a turn of paper every 500 turns to break up the otherwise continuous winding. Transformers up to 3,000 volts can be built by this method. As an added precaution with high-voltage types, thoroughly impregnate the coils and bake and varnish twice. Also, especially with high voltage transformers, use your infra-red oven to pre-bake the coil for 10 minutes to dry out any moisture that otherwise might be sealed in by the varnish.