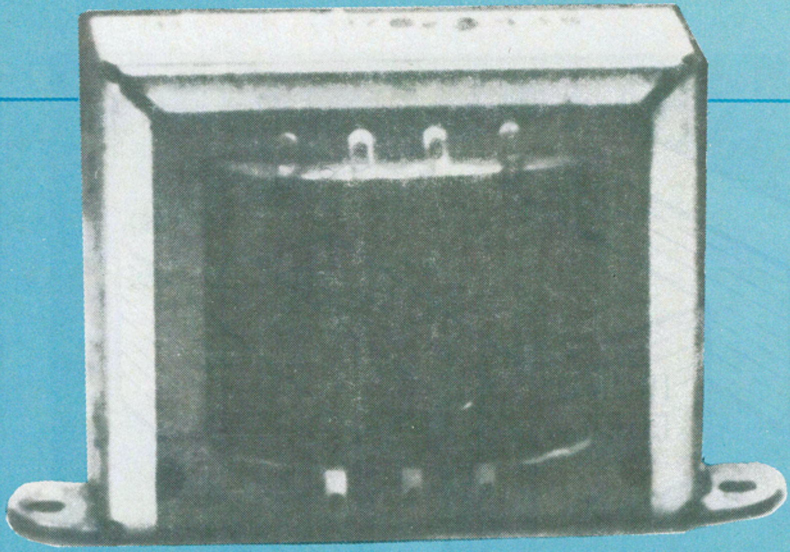
HOW TO



REWIND TRANSFORMERS

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If you can't find the right transformer for your project at the right price, there's an easy solution—rewind one! As this article shows, the job is not as difficult as you might think.

ONE OF THE MOST IMPORTANT PARTS OF A power supply, whether it be for a project or your bench, is the transformer. If you've had much building experience, however, you know that getting the right transformer—one with appropriate voltage and current ratings—can be difficult and/or expensive. That's doubly true if you need something other than a "standard" voltage.

The easiest and most economical way to solve those problems is to rewind a readily available or inexpensive transformer. This article focuses on two aspects of the task: specifications, and the general guidelines for rewinding transformers. Also, we'll look at a practical example—how to rewind a transformer with a rating of 18 volts at 2.5 amps into one with a rating of 7 volts at 4.5 amps.

Manufacturer's specifications

Transformer ratings are usually given in RMS values. A secondary rated at 12.6 volts center-tapped at 1 amp means 12.6-volts RMS is across the entire secondary and that no more than 1-amp RMS can be drawn safely from it. The voltage from either end of the secondary to the center tap is one half the voltage across the entire secondary, or, in this case, 6.3 volts RMS. The current that can be supplied by each part of the secondary simultaneously is equal to the current rating of the entire secondary, or, in this case, the halves of the secondary can supply 1-amp RMS each.

The secondary's output ratings are based on the assumption that a particular RMS voltage will be applied to the primary of the transformer. Favorite values used by manufacturers are 110-, 117-, and 120-volts RMS. Note that while any transformer you buy new will have the ratings stamped either on it or its packaging, surplus or salvaged transformers usually will not. For the remainder of our discussion we will assume that the input to the primary is 117-volts RMS.

Since the maximum power capability of a transformer depends on the cross-sectional area of the iron core, the maximum power that a transformer can deliver is a constant. But any combination of voltage and current is possible provided that the voltage times the current is less than or equal to the transformer's wattage rating. Thus, if the manufacturer rates the secondary for 25.2 volts at 0.5 amps, it means that the transformer can supply 12.6 watts ($P = V \times I = 25.2$ volts $\times$ 0.5 amps = 12.6 watts). It also means that the transformer can handle any combination of voltage and current, so long as the product of the two is less than or equal to 12.6 watts—6 volts at 2.1 amps, for example.

Besides the wattage rating, the cross-sectional area of the wire used in the transformer puts a limitation on the amount of current that it can supply. If a transformer's secondary is rated for 22.5 volts at 2 amps, the manufacturer has told us that the wire used in the secondary will safely supply 2 amps RMS at any voltage, provided the transformer is capable of handling the resulting power.

Finding specifications on your own

If you have a salvaged transformer, information about its voltage, power, and current ratings is usually not available. That information is not that hard to find, however, if you follow these simple steps:

To find the voltage rating of the secondary, first find which wire belong to the primary winding. Most electronics handbooks provide a complete color code for the transformer's wires, but let's sketch out the essentials here.

The two black wires on the transformer lead to the primary and are where the 117-volts RMS line-voltage is applied. The wires to each secondary have a different color set. The wires to one secondary, for instance, may use a red color set—two solid red wires and another red wire with a different color stripe. The striped wire is the center tap of the secondary. If a secondary does not have a center tap, only two wires will be found in that color set. With the primary and secondaries identified, you simply use an AC voltmeter to find the voltages required.

To do that, hook the transformer up to your household power line and measure the voltages on each winding. **Be very careful** in performing this step. The best way to go about it is to wire a plug to the primary, attach the AC voltmeter to the winding you want to measure, and make sure that there are no exposed or touching bare wires before plugging in the transformer. To find the voltage simply plug in the transformer and read the voltage on the meter. Take enough measurements so that you know the voltage across each secondary, the voltage to each center tap, and the voltage applied to the primary. For safety, be sure to disconnect the power before you switch the meter leads.

Photo courtesy of Amecon Inc.

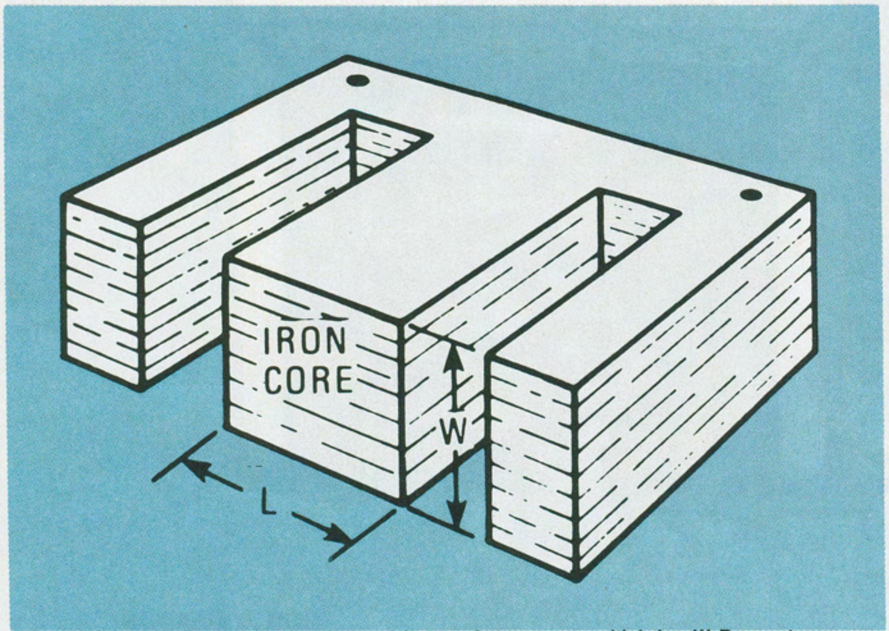


FIG. 1—TO FIND THE cross-sectional area of the transformer core, multiply L × W. Be sure to measure L and W in inches

TABLE 1

Cross-Sectional Area (Square Inches)	Power (Watts)
1	45
1.25	50
1.75	75
2	120
2.25	150
2.75	230
3	275
3.25	330
3.75	440
4	520

To find the power rating of the transformer, first find the cross-sectional area of the core by multiplying L × W as shown in Fig. 1. Be sure to measure L and W in inches so the cross-sectional area is calculated in square inches. Then, using Table 1, find the approximate wattage rating that corresponds to the cross-sectional area.

It is possible to reuse the wire from the original secondary for the new secondary. If the rating of that wire is not known, and there is only one secondary, the maximum current that the wire can safely handle is equal to the power capability of the iron core divided by the voltage of the winding. When there is more than one secondary, you would be better off to use the cross-sectional area of the wire used in each secondary to determine its current-handling capability (more on that later).

Rewinding a transformer

Since rewinding a primary is a job that should be avoided if at all possible (suggestions for handling that messy task will be given later on), the best transformers to rewind are those in which the primary is wound closest to the iron core. Transformers with a high-voltage secondary often have that winding wrapped next to the core, the primary wrapped on the outside of the high-voltage secondary, and finally the low-voltage secondaries as the outermost layer. Transformers with only one low-voltage secondary (less than 110 volts) usually have the primary wound closest to the core and the secondary on the outside. There is no way of knowing where the secondaries are until you disassemble the transformer.

The first step in rewinding a transformer is to determine what size transformer you need. To calculate the power that is required, multiply the voltage you need by the current you need.

Using Table 1 you can approximate the core size you need. If the core size is not given in a catalogue, the total power capability of a transformer can be found simply by adding the power rating of each secondary.

After you get the transformer, check the voltages using the technique we discussed earlier. The next step is to disassemble the unit. Take out the screws and anything else holding the transformer together. Usually the laminations are soaked in a special enamel and then baked. That is done to keep the transformer from buzzing and to seal it from the environment; it also makes the laminations hard to remove. As each lamination is removed, the enamel holding it must be broken off; when doing so it is very easy to damage the transformer's wires, so great care must be taken.

The first few laminations are hardest to remove. To break the enamel seal, take a very small screwdriver and slip it between the outside edges of the lamination you're removing. If you ruin a few laminations at first, don't worry—you won't be able to get all of them back in anyway when the transformer is reassembled. Set the transformer on a piece of plywood so that the lamination that you are removing projects over the edge as shown in Fig. 2. Working alternately at either end of the exposed lamination, lightly tap the screwdriver until the enamel on the inside of the core breaks loose. Then remove the lamination.

After a few laminations are removed, one of the "I"-shaped laminations can be

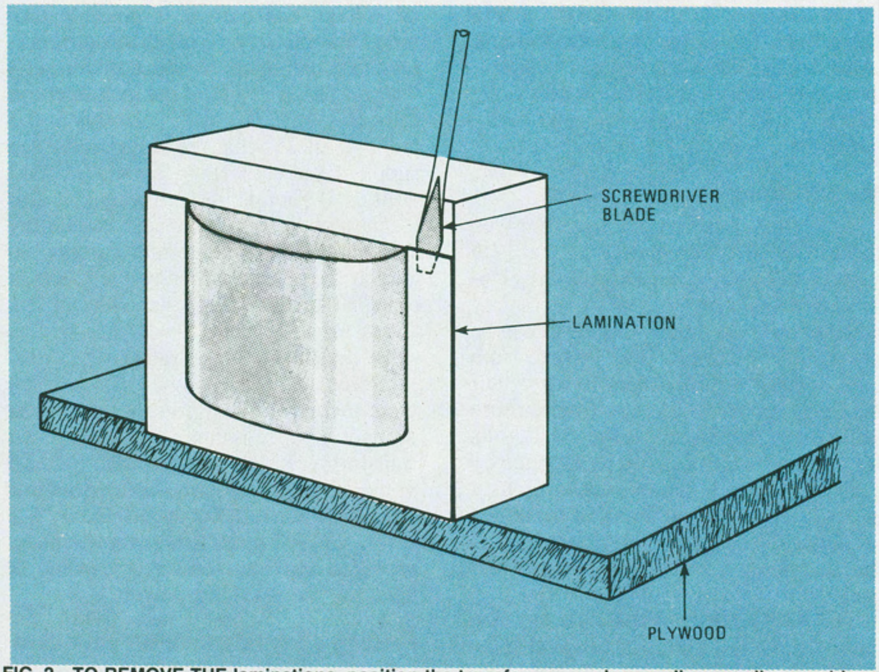


FIG. 2—TO REMOVE THE laminations, position the transformer as shown, slip a small screwdriver under the first lamination, and tap lightly with a hammer.

used to break the enamel seal on the remainder—the ones inside the coil—as shown in Fig. 3. You will still have to tap lightly with a hammer, but the "I" piece will be easier to use and cause less damage than a screwdriver.

After removing the laminations, the next step is to unwind the secondary. As you unwind the wire, count the number of turns. When the secondary is completely unwound, calculate the turns-per-volt by dividing the turns counted by the voltage previously measured on the secondary. For example, if the output from the secondary is 12.6 volts RMS and it has 40 turns, the turns-per-volt ratio is 3.175. When there is more than one secondary, the turns-per-volt ratio for each should be the same. If not, you have miscounted. In that case, use the average of the different values.

If the voltage measurements were made with something other than 117-volts RMS applied to the primary, you need to adjust the turns-per-volt value. Or, if the line voltage in your house was 112-volts RMS when you measured the secondary voltage, but most times your line voltage is 120-volts RMS, you may want to calculate the turns-per-volt value with 120 volts RMS applied to the primary. The following formula allows you to do that:

$$T_T = \frac{E_{MEAS}}{E_{NEW}} \times T_C$$

where T_C is the calculated turns-per-volt, E_{MEAS} is the voltage applied to the primary when the values were measured for the T_C calculation, E_{NEW} is the voltage you are recalculating for, and T_T is the turns-per-volt ratio with E_{NEW} applied to the primary.

The next step is to determine the number of turns you need by multiplying the turns-per-volt calculated above by the voltage you want. In the above example, if you want 6-volts RMS, then you need 19 turns (6 volts × 3.175 turns-per-volt). Keep in mind that the wire you use must be capable of handling the maximum current you desire.

The amount of current that a wire can handle, whether used for the primary or secondary, depends on the wire's cross-sectional area. The easiest way to determine its current-handling capability is to use one of the wire tables found in most complete electronics handbooks. Measure the wire's diameter in mils, using either a micrometer or a wire gauge, and using the table find the maximum current that the wire is rated to handle. The cross-sectional area of a wire is measured in a unit called the *circular mil* (a circular mil is equal to the cross-sectional area of a wire with a diameter of one mil) and wire tables often include that data for a given wire diameter or gauge. Generally speaking, a cross-sectional area of 600 mils per ampere is satisfactory for small

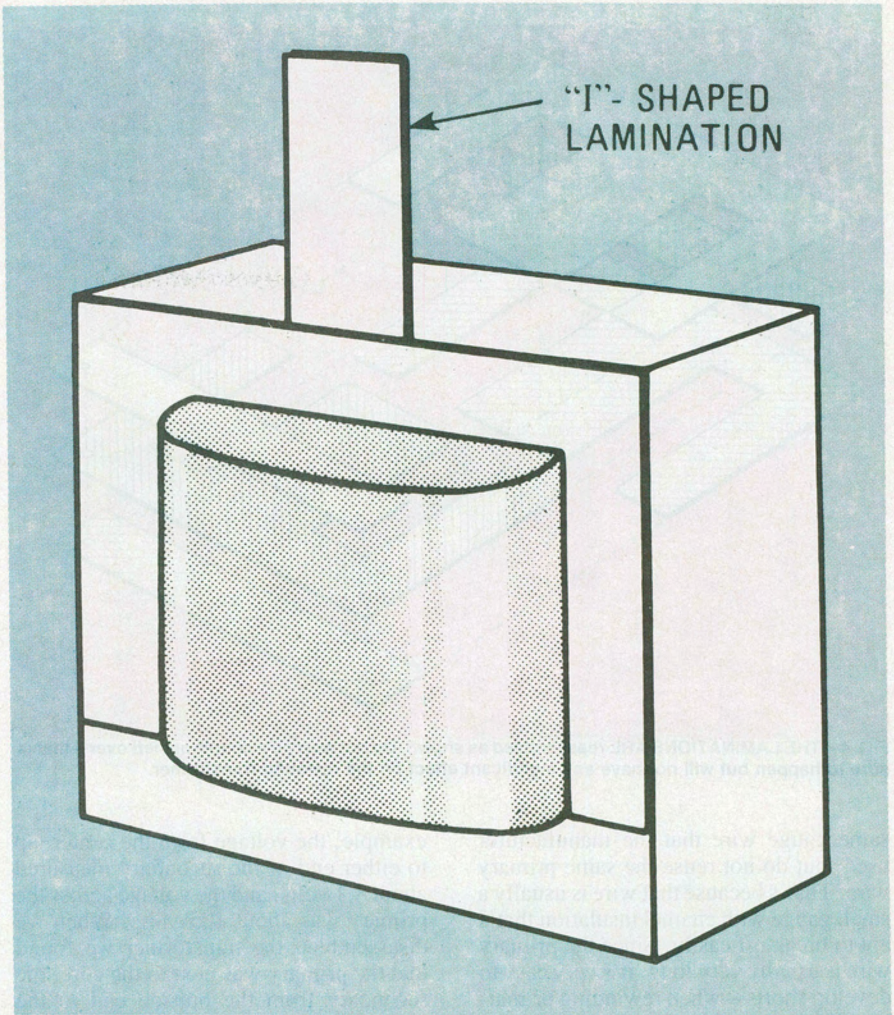


FIG. 3—AFTER A FEW laminations are removed, one of the "I"-shaped laminations can be used in place of the screwdriver.

transformers, although areas of 500 to 1000 mils are commonly used. If you are unsure about how heavy a wire you require, it is best to remember that the larger the cross-sectional area, the cooler the transformer will operate; so choose as heavy a wire as is practical.

It's best to use new wire for the new secondary, but, as we previously mentioned, if you're careful the old secondary's wire may be serviceable. Bend old wire as little as possible, and do not use it if there are any spots where the enamel has flaked off.

Once the proper wire has been chosen, the next step is to wrap the secondary. Wrap the wire without leaving any space between turns to get the maximum number of turns in the minimum amount of space. Put wax paper, duct tape, or some other type insulation capable of withstanding the maximum voltage of any one winding between each layer. The outside of the last layer should be covered extra well and taped tightly for both your and the transformer's protection.

The last step is to reassemble the transformer. Fig. 4 shows how to fit the "I"- and "E"-shaped laminations together. Most likely, there will be two to four "I" and "E" laminations left over—you will not be able to squeeze those laminations back into the core, but that will not substantially affect the power rating of the transformer.

Rewinding a primary

Rewinding a primary becomes necessary if the primary on the transformer you have chosen is not wound closest to the iron core. That task is not recommended, but the information is included here for the industrious.

After the turns-per-volt ratio has been calculated, the number of turns on the primary can be determined by multiplying the turns-per-volt ratio by the primary voltage. Using the example of the previous section and assuming the turns-per-volt was calculated with a primary voltage of 117 volts, the primary requires 371 turns (117 volts × 3.175 turns-per-volt). The alternative to that procedure is to actually count the turns of the primary, which may lead to errors.

Under the secondary's and primary's wire there is usually a cardboard or plastic form. Wrap the new primary and secondary on that form so that the laminations will fit into the new windings. Use the

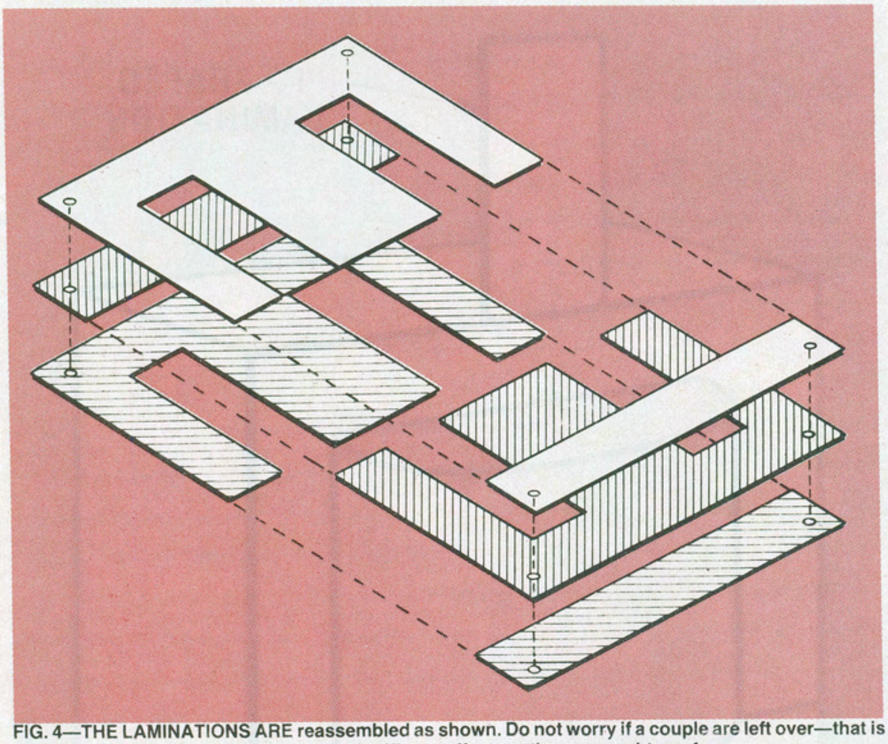


FIG. 4—THE LAMINATIONS ARE reassembled as shown. Do not worry if a couple are left over—that is sure to happen but will not have any significant effect on the rewound transformer.

same gauge wire that the manufacturer used, but do not reuse the same primary wire. That's because that wire is usually a small gauge with enamel insulation that's apt to break off easily. Since the primary wire is usually very long, it's very easy to develop shorts—when rewinding primaries, doing a lot of work for nothing is not that uncommon.

A practical example

Let's look at how we can rewind a transformer to deliver 8-volts DC at about 5 amps to a 5-volt regulator. That allows about 3 volts across the regulator. Also, for the purposes of this example, let's assume that we will use a bridge rectifier so that the transformer current rating would only need to be about 5 amps, since both halves of the AC cycle are used.

Using those specifications we get a pretty clear picture of exactly what kind of transformer is required. With a bridge rectifier a center tap is not needed on the secondary, but a bridge rectifier drops the transformer output voltage (voltage getting to the filter) by about 1.4 volts. The peak-value output of the transformer, therefore, has to be approximately 9.4 volts (8 volts + 1.4 volts). That means that the transformer's power rating has to be about 47 watts (9.4 volts × 5 amps).

The transformer we'll choose to rewind has a secondary rated at 18 volts at 2.5 amps. Therefore, that transformer has a power rating of 45 watts, which is close enough for our purposes.

As the transformer is disassembled, make notes of its characteristics. First thing to do is to take the voltage measurements. For the transformer chosen for the example, the voltage from the center tap to either end of the secondary measured about 8.1 volts, and the voltage across the primary was about 105 volts. When we disassembled the transformer we found that the primary was next to the core, the secondary from the outside end to the center tap had 51 turns in two layers, and that the wire from the center tap to the other end of the secondary was shorter but had the same number of turns. Given those measured values, the turns-per-volt ratio was 6.3 (51 turns ÷ 8.1 volts). Using the correction formula, adjust that turns-per-volt ratio for 117 volts applied to the primary. The corrected turns-per-volt ratio is therefore 5.65—105 volts ÷ 117 volts) × 6.3 turns-per-volt.

Knowing that, we can calculate the number of turns required for the secondary by multiplying the turns-per-volt by the voltage desired. The 9.4 volts peak translates to 6.65-volts RMS (9.4 volts ÷ $\sqrt{2}$) so 37.7 turns are needed (5.667 turns-per-volt × 6.65 volts). If the line voltage that the transformer is to be used with is normally below 117 volts, such as 105 volts, for instance, round the number of turns up to 40.

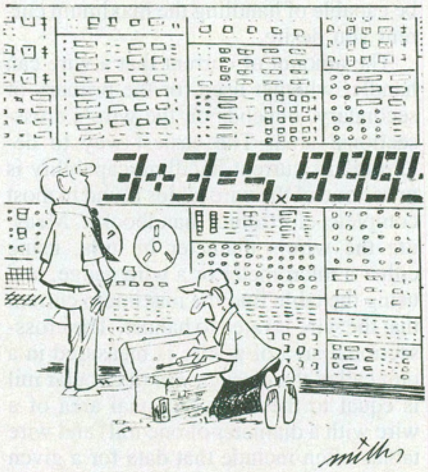
Continuing with our example, since we are using a new transformer, it is reasonable to assume that the secondary wire will be in excellent condition and can be reused. But as we stated earlier, while the wire is rated for 2.5-amps RMS, we want a transformer capable of handling 5-amps RMS. The wire can still be used, however, if two secondaries—wound for the same voltage and in parallel—are used. With two parallel secondaries, the transformer can handle the 5-volts RMS and no additional wire needs to be bought.

Cut the original secondary wire at the center tap. Use the shorter length of that wire for one secondary, wrapping it on top of the primary in two layers of twenty turns each—duct tape should be placed between the layers. For the other secondary, wrap the longer length of wire on top of the first secondary in the same manner—two layers of twenty turns each. Start that outer secondary winding at the same place you started the first secondary and be sure to wind it in the same direction. The two secondaries must be wound in the same direction. Otherwise, the net effect of paralleling them is 0 volt.

The transformer is then reassembled, but before it can be used its specifications must be re-rated. Using the number of turns of the secondary divided by the turns-per-volt ratio at 117 volts, the output voltage of the transformer is 7.06-volts RMS with 117 volts applied to the primary (40 turns ÷ 5.667 turns-per-volt). The current rating is not as easy to calculate. Let's look at the problem from a power standpoint. The maximum power from the transformer is 45 watts. The maximum DC voltage is less than 9.98 volts (7.06 volts × $\sqrt{2}$), assuming full-wave rectification. The maximum DC current that can be drawn is, therefore, 4.5 amps (45 watts ÷ 9.98 volts). For half-wave rectification you would divide that value in half.

The approach outlined here can be expanded to multiple-voltage secondaries with one more bit of information. The sum of the power required by each secondary must be equal to or less than the power capability of the transformer itself.

One big advantage of winding your own transformers is the ability to compensate for house voltages that are slightly high or slightly low. You can also buy transformers that are on sale without worrying about the output voltage. You only need be concerned about the power that the transformer can handle safely. **R-E**



"Well, now, if you insist on looking for mistakes, why, of course, *you're most likely to find one or two."*