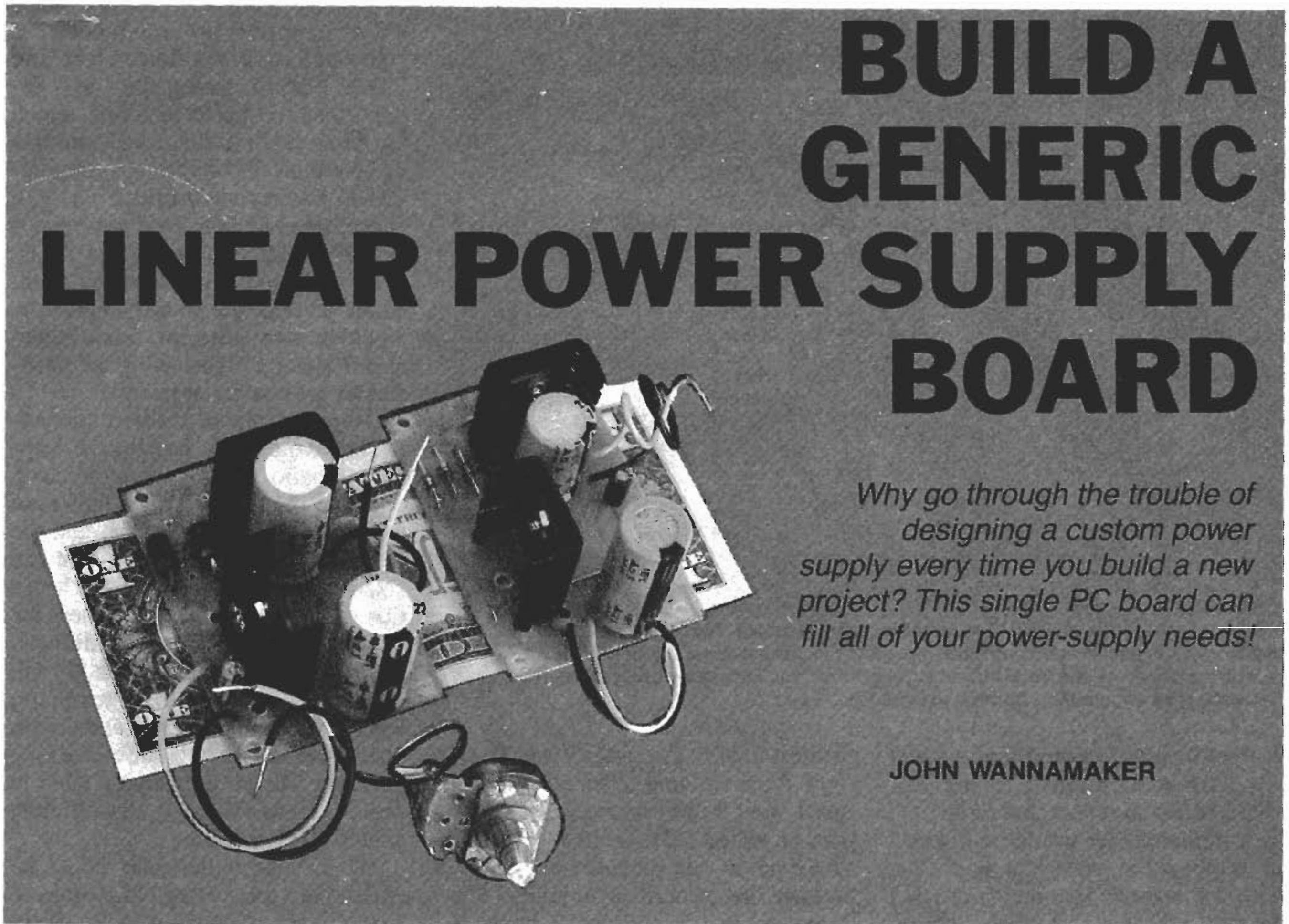
BUILD A GENERIC LINEAR POWER SUPPLY BOARD

Why go through the trouble of designing a custom power supply every time you build a new project? This single PC board can fill all of your power-supply needs!

JOHN WANNAMAKER



ARE YOU TIRED OF LAYING OUT YET ANother PC board for some special power supply? Here's a possible solution to lessen the trauma: the EZ-DC generic power-supply PC board, designed to give you a choice of one or two linear supplies on a single 2 × 3-inch PC board. The layout is very versatile, and while one supply produces a fixed-positive voltage, the other can have any value desired. The choices are:

- Two fixed-positive supplies.
- One fixed-positive, and one adjustable-positive supply.
- One fixed-positive, and one fixed-negative supply.
- One fixed-positive, and one adjustable-negative supply.

Of those configurations, the supplies can be either half-wave or full-wave, when a transformer with a center-tapped secondary is used, or you can build a single full-wave bridge of either polarity. You can also make it adjustable or not, as you prefer. Dual isolated grounds are possible. For the TO-220/221A regulators, there are four different 3-terminal pinout configurations, which made the layout of the EZ-DC quite challenging. Whether or not to rotate the regulator 180° helped reduce the reconfiguration problem to one of selective placement of jumpers.

The EZ-DC is a good basis for a bench supply. With two PC boards, you can build two fixed-positive sources, an adjustable-positive source, and an adjustable-negative source, all with or without isolated grounds. Each supply provides for a milliammeter to be inserted at its regulator input. In one supply on each PC board, the meter replaces a jumper. In the other, two adjacent pads are provided for meter leads. The foil connecting the two pads has to be cut with a razor blade or X-acto knife to use the meter; the point is marked by an arrowhead and an "X."

Different power-supply types

- **Separate fixed-positive full-wave supplies with common grounds.** Figure 1 shows a dual, full-wave, fixed-positive supply, using a common ground. Fig. 1-*a* shows the pinouts of the two regulators, Fig. 1-*b* shows the schematic, and Fig. 1-*c* shows the parts placement diagram.

Supply #1, on the lower half of the PC board, is always fixed positive. Supply #2, on the upper half of the PC board, can be varied in configuration, and is, in this case, also fixed positive. Since the center-tapped transformer supplies equal voltages to each regulator, the most efficient arrangement is for both IC's to regulate to identical (or nearly so) voltages, such as +12 and +15 volts.

Where the difference is considerable, as between a +5- and a +12-volt supply, the lower voltage regulator must drop 7 volts more than the higher one, and its load current must be limited accordingly. Since the voltage drop across the regulator is multiplied by the load current to determine the regulator power dissipation, the lower the voltage, the more current that's available. The less power consumed by the regulator, the more that's available to the load.

However, there has to be some drop across the regulator or it won't work. This is nominally 2 volts for the 78XX/79XX fixed-voltage series, and about 2.5 volts for the LM317/LM337 adjustable models. Also, the regulator needs a standby current of

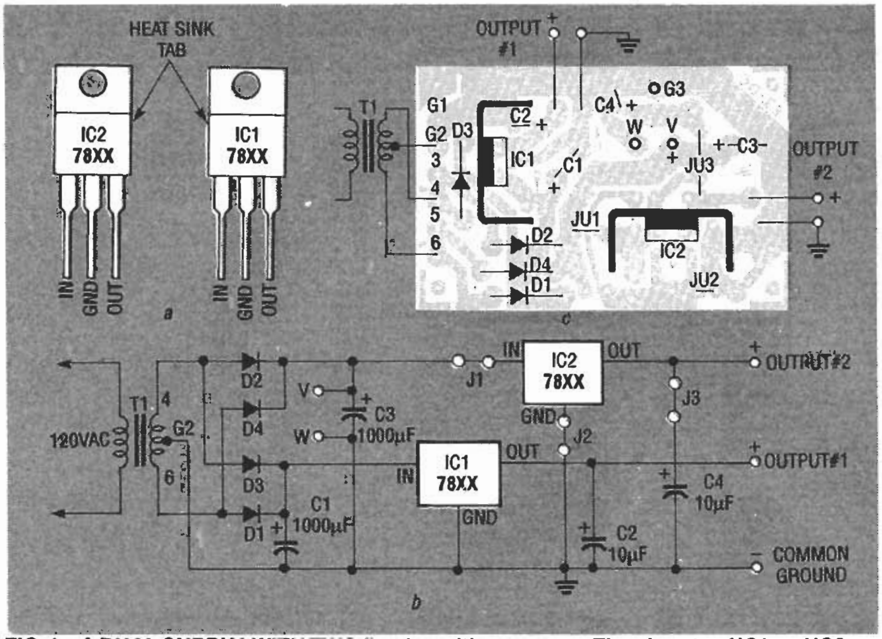


FIG. 1—A DUAL SUPPLY, WITH TWO fixed-positive sources. The pinouts of IC1 and IC2 are shown in (*a*), the schematic is shown in (*b*), and the parts placement diagram is shown in (*c*), with supply #1 on the bottom, and supply #2 on top. This same order of (*a*)–(*c*) is used throughout all succeeding figures, except Figs. 4 and 7.

3–10 milliamps, ignored here. Expect any current monitoring at the provided points to reflect this error.

A milliammeter would be inserted in supply #2 in place of jumper JU1, with the negative terminal connected nearest to the heatsink when monitoring a positive supply. In supply #1, connect the meter to the two pads near the right wing of the lower heatsink. Cut the foil between these two pads at point X as already mentioned. The negative meter lead goes to the pad nearest to IC1. Two pads V and W on both PC board and schematic are unused here. Extra filtering capacitance can be added here for supply #2, or these points can provide unregulated voltage for noncritical circuits. Pay attention to the polarity at point V which depends on the polarity of supply #2; point W is ground.

- **Separate fixed-positive and fixed-negative full-wave supplies.** In Fig. 2, supply #1 is fixed-positive as before. The difference is how supply #2 is jumpered, to accommodate a fixed-negative regulator, like the 79XX/79MXX series; the "M" denotes medium-power versions, which are harder to find. Since load currents of less than 500 milliamps are suggested to prevent overheating, you should try to find the "M" versions, if possible. Again, due to the transformer's equal voltage distribution, equal but opposite polarity regulators would be most efficient. Some general information on selecting the transformer will be given later.

- **Separate fixed-positive and adjustable-positive half-wave supplies.** Figure 3 shows supply #2 with an adjustable regulator in a half-wave configuration, where both it and the heatsink are rotated 180° from the fixed regulator position. Don't use this version in applications where the load current exceeds 200 milliamps. Extra capacitance at V and W will give a smoother input to the regulator, but strains the transformer and diodes due to the higher half-wave charging currents. The accompanying table in Fig. 3-*d* shows $V_{2(MAX)}$, for different values of R1 and R2.

While current demands could be excessive, the voltage distribution with this arrangement may be advantageous. With one end of the winding grounded, the center tap supplies modest voltage for a low-voltage fixed supply, and the other end provides double that voltage from the adjustable supply. Where higher current is required, the diode and transformer arrangement shown in Fig. 4 is suggested instead.

- **Separate fixed-positive and adjustable-positive full-wave supplies.** The more features you want in any piece of equipment, the more it's going to cost, and the EZ-DC is no exception. The best transformer arrangement, shown in Fig. 4, uses two transformers with center-tapped secondaries, or a single transformer with dual center-tapped secondaries, if you're able to find one. The relevant segment of schematic is shown in Fig. 4-*a*, and the relevant segment of the parts placement diagram is shown in Fig. 4-*b*.

Supply #1 always has the layout shown in Fig. 1, and you can take the layout for supply #2 from any other version you prefer, in any of the figures. For example, copy the upper part of Fig. 2 for a fixed-negative supply (remember to reverse D2 and D4),

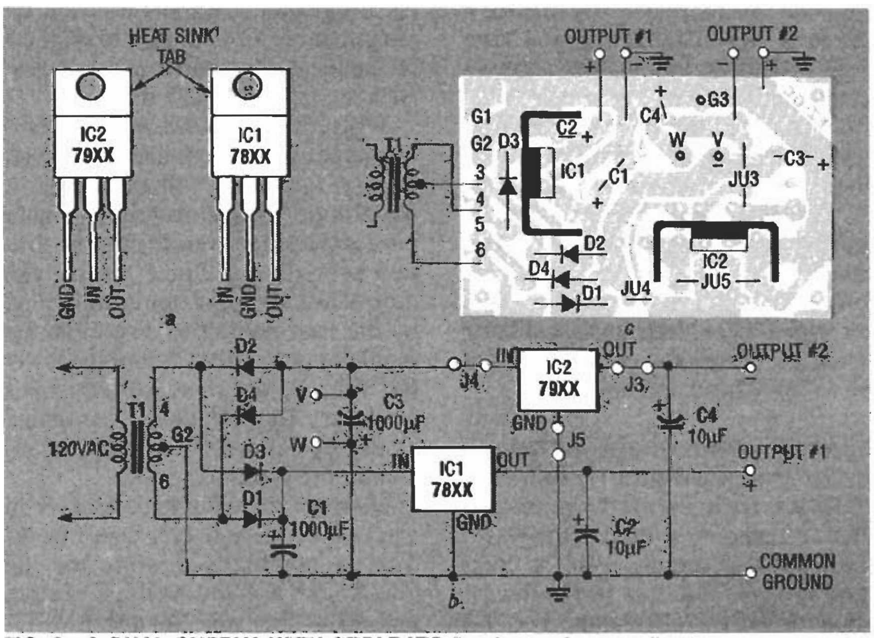
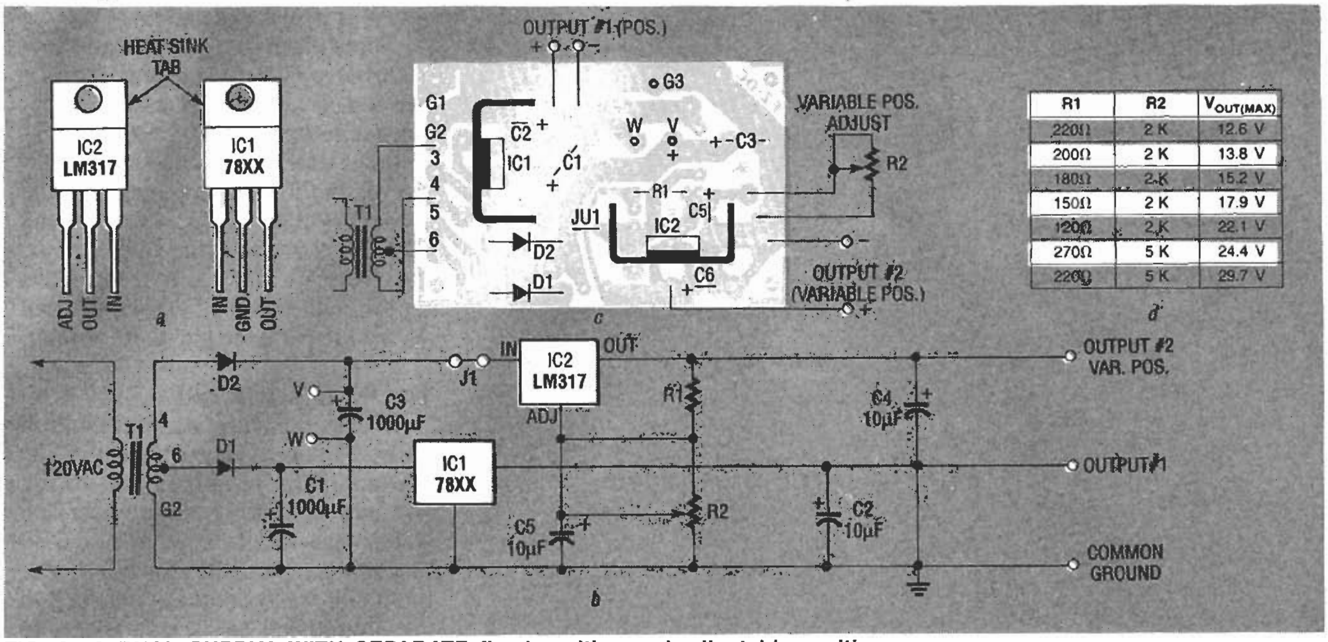


FIG. 2—A DUAL SUPPLY, WITH SEPARATE fixed-negative and fixed-positive sources. The organization of (*a*)–(*c*) is that of Fig. 1, but supply #2 has been made negative by reversing D2, D4, C3, and C4, and using a 79XX for IC2 in stead of a 78XX.



R1	R2	$V_{OUT(MAX)}$
220Ω	2 K	12.6 V
200Ω	2 K	13.8 V
180Ω	2 K	15.2 V
150Ω	2 K	17.9 V
120Ω	2 K	22.1 V
270Ω	5 K	24.4 V
220Ω	5 K	29.7 V

FIG. 3—A DUAL SUPPLY, WITH SEPARATE fixed-positive and adjustable-positive sources. Supply #2 is now made adjustable-positive, changing the jumpers as indicated, changing IC2 to an LM317, adding potentiometer R2, and shifting the other parts as shown. Also, only D1 and D2 are used, and the secondary of T1 is rewired. The accompanying table in (*d*) shows $V_{2(MAX)}$, for different values of R1 and R2.

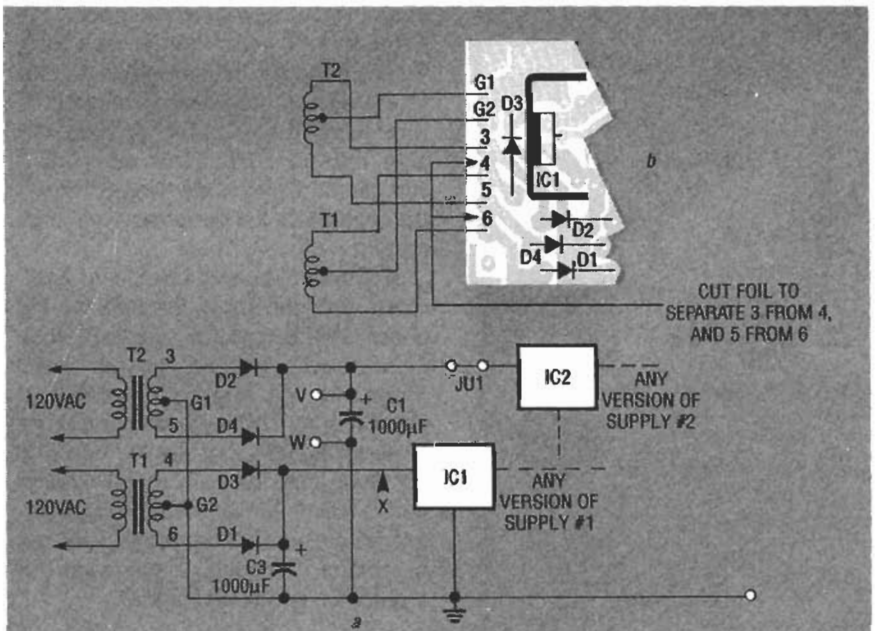


FIG. 4—DUAL FULL-WAVE RECTIFICATION for a fixed-positive supply #1, using either two single-secondary transformers, or a single dual- secondary version; (*a*) is the relevant segment of schematic, (*b*) is relevant segment of the parts placement diagram. Only the lower half of the PC board (supply #1) is shown; you can design the upper half (supply #2) as you wish. For example, copy the upper half of Fig. 3 for an adjustable-positive supply, or the upper par of Fig. 5 if you want an adjustable-negative dupply (remember to reverse D2 and D4).

or the upper part of Fig. 3 for an adjustable-positive supply, or. If you'd rather calculate your own values than use those provided in the table accompanying Fig. 3, use the following formula:

$$V_2 = 1.25 \text{ volts} \times [1 + (R2/R1)].$$

For best results, keep: R1<240 ohms. There's no way to control the minimum output, which should be about 1.25 volts.

• **Separate fixed-positive and adjustable-negative half-wave supplies.** A version with dual half-wave supplies, one fixed-positive and the other adjustable-negative, is shown in Fig. 5. It's got the same limitations as the version shown in Fig. 3. For the greater current a full-wave supply can provide, use the rectifier arrangement shown in Fig. 4 (reversing D2 and D4), with the layout shown in Fig. 5. If you use a transformer with no center tap, Dl is connected as shown by the dashed lines. In that case, jumper pad 3 to pad 5 with JU7, and remove the connection to pad 6.

The output pad is closer to the heatsink than you might prefer, but all patterns have multiple output points. Examine the foil pattern and select your own output pad. Always select a ground nearest the filter capacitor's ground connection to minimize hum, and use separate grounds for each supply.

• **Separate fixed-positive full-wave supplies with isolated grounds.** The arrangement for isolating the grounds between full-wave recitifiers is shown in Fig. 6. While this version has dual fixed-positive supplies, that needn't be the case. Use any version for supply #2 you want, but watch the diode polarities. Cut the foil at the "Z" by the ground foil, and then the transformer secondary pads, isolating 3 from 4, and 5 from 6.

Arrowheads on the foil side show the exact points to cut. If you connect the supplies in series, the total output voltage is the sum of both. You can assume both regulators to be passing identical currents, but not necessarily dissipate the same power, since their regulator drops may differ.

positive supply and must all be reversed if yours is negative.

- **Separate fixed-positive and adjustable-positive supplies from a car battery.** Figure 8 assumes that you use a standard +5-, +6-, or +8-volt regulator for IC1, and an adjustable version for IC2; the output of the second regulator is adjusted by R1 and R2. The accompanying table in Fig. 8-*d* gives V_2 to within 50 millivolts for different values of R1 and R2, but you can also use the previous formula.

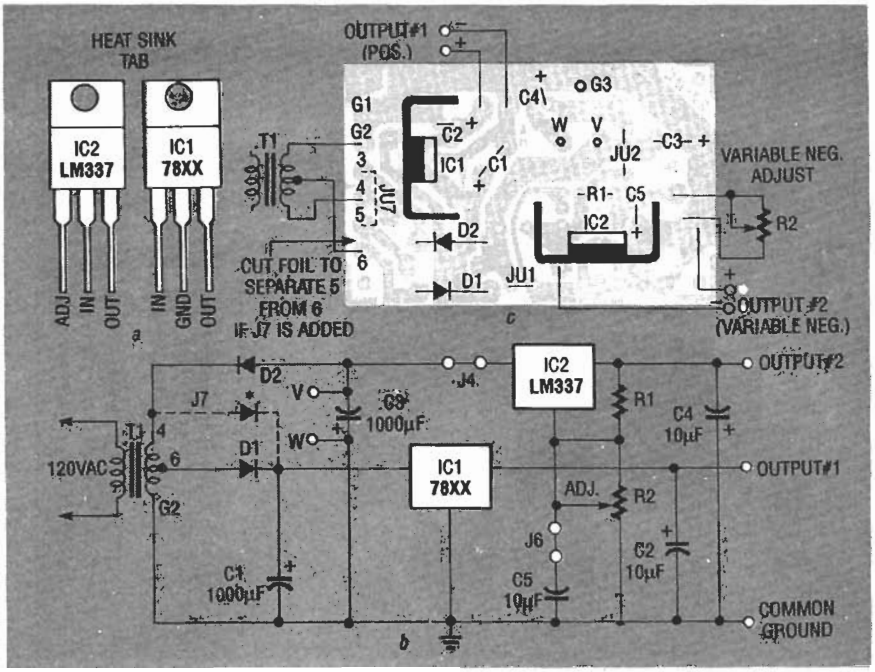


FIG. 5—A DUAL SUPPLY, WITH COMBINED fixed-positive and adjustable-negative sources; it has the same limitations as Fig. 3. For greater current, use the full-wave approach of Fig. 4, with the layout shown here. The D1 shown using dashed lines is connected this way for a transformer with no center tap. In that case, jumper pad 3 to pad 5 with JU7, removing the connection to pad 6.

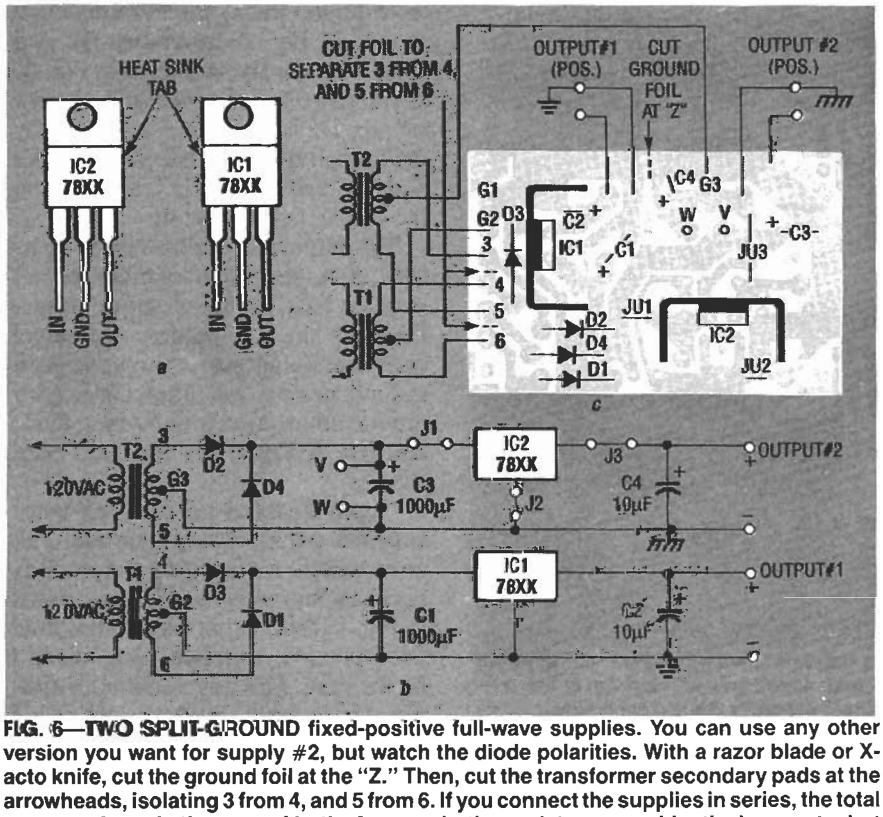


FIG. 6—TWO SPLIT-GROUND fixed-positive full-wave supplies. You can use any other version you want for supply #2, but watch the diode polarities. With a razor blade or X-acto knife, cut the ground foil at the "Z." Then, cut the transformer secondary pads at the arrowheads, isolating 3 from 4, and 5 from 6. If you connect the supplies in series, the total output voltage is the sum of both. Assume both regulators pass identical currents, but don't necessarily dissipate identical power, since their regulator drops may differ.

- **A single full-wave bridge supply.** The connections for a full-wave bridge are shown in Fig. 7. Figure 7-*a* shows the relevant segment of the schematic, and Fig. 7-*b* shows the relevant segment of the parts placement diagram. Don't forget JU8 where an electrolytic would normally go. Again, use the top of the PC board for any version, whether positive, negative, fixed, or adjustable—but note the the diodes are shown for a

The PC board layout

To ensure that the wide ground foil holds hum to under 1 millivolt, the best soldering layout was sacrificed; you may need to use more heat and solder than usual. Use 4-40 or 6-32 machine screws in the corner holes for mounting. One corner is attached to the ground foil as a metal spacer to electrically connect the PC board to a metal chassis. If you don't want to use it, cut it away.

The heatsinks are electrically connected to the middle pin of each regulator. For a fixed-positive model, it's ground, but it's different in each case; for example, it's the unregulated input in the adjustable-negative model. A little heatsink silicone grease will help transfer about 20% more heat, and can be worthwhile—especially if the regulators are sourcing very high current.

If you use the recommended heatsinks with the three through-the-PC board tabs, be careful you don't bend them underneath and cause a short. Space was left hoping to avoid this, but watch it. The regulators are fairly close to the edges of the PC board to possibly heatsink to a metal cabinet with a screw. Measure the tab's potential, to be sure it's grounded, and use insulation if needed. If you want full 1-A load current, use a fan.

Selecting components

Don't consider the following the last word on how to select power-supply parts. This is an abbreviated method to keep you from going very wrong with practical advice from personal observations. The transformer is a good starting point because they're "iffy," at best. Consider the secondary voltage; for example, a 10-volt secondary. With little or no load, you may measure up to 12 volts. If the line voltage is 5% high, you'll measure 12.6 volts. Isn't that reasonable with

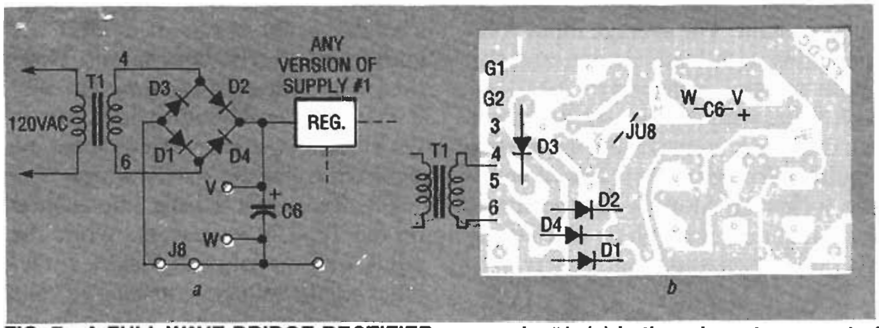
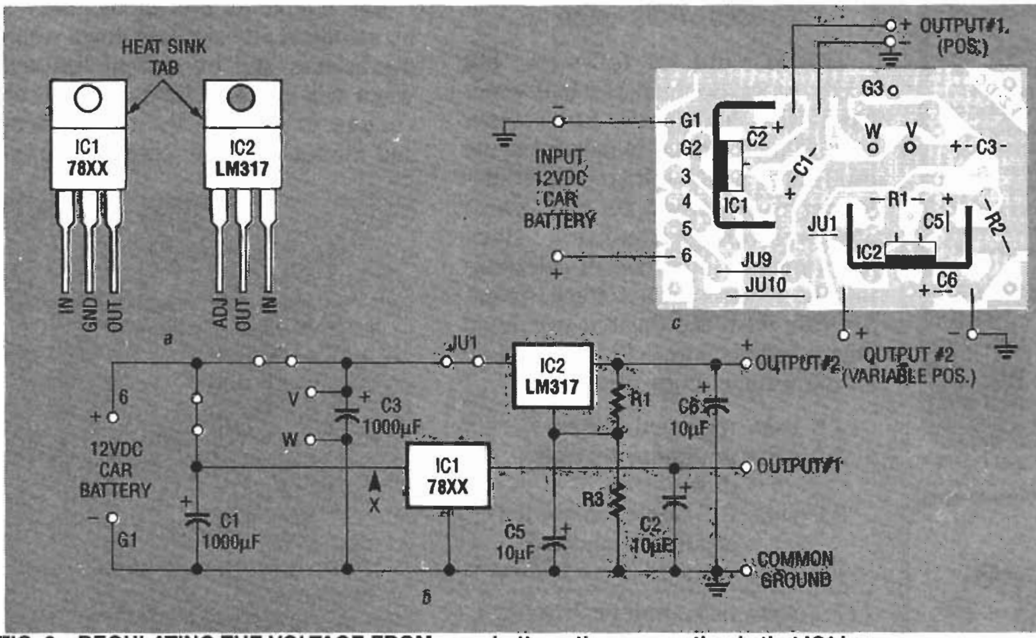


FIG. 7—A FULL-WAVE BRIDGE RECTIFIER as supply #1; (*a*) is the relevant segment of schematic, (*b*) is the relevant segment of the parts placement diagram. Remeber to reverse D1–D4 for a fixed-negative version. The connections for a full-wave bridge are shown in Fig. 7, and don't forget to add JU8. You can also make supply #2 on top any version, whether positive, negative, fixed, or adjustable.



R1	R2	V_{OUT}
220Ω	270Ω	2.8 V
220Ω	330Ω	3.1 V
220Ω	470Ω	3.9 V
220Ω	560Ω	4.4 V
220Ω	680Ω	5.1 V
220Ω	820Ω	5.9 V
220Ω	1 K	6.9 V
220Ω	1.2 K	8.0 V
150Ω	910Ω	8.8 V
220Ω	1.5 K	9.7 V

d

FIG. 8—REGULATING THE VOLTAGE FROM a car battery; the assumption is that IC1 is a standard +5-, +6-, or +8-volt regulator, and that IC2 is adjustable, but set to a non-standard value by R1 and R2. The accompanying table in (*d*) gives V_2 to within 50 millivolts for different values of R1 and R2, but you can use the formula given in the text.

no load? What's the figure at full load? Try several yourself and see.

In ten transformers sampled, only one was precisely correct at rated load. The average high was 7.56% off, the worst was 12.7%, and these were at the rated 120-volt primary input. Those sampled came from a variety of suppliers, most with a rating of 1 amp or higher. If you order a transformer, you can't be sure what you'll get until you measure it. Since you're dealing with peak value, it may look even worse. What you thought would be merely 14.14 volts may more likely be 15–17.8 volts peak.

The peak value is important, because the electrolytics need to be rated accordingly and the regulator drop is partly dependent on it. Also, a center tap may not always be at the exact electrical center of the secondary winding; about 3% error was the worst observed. Assuming a transformer secondary voltage 20% above its rated value is realistic, but don't depend on it. As for RMS current, rate the transformer at 1.2 times the maximum expected load current for full-wave center-tapped, and 1.8 times for a bridge.

The diode voltage ratings should be twice the peak transformer voltage. While you might get by with diodes rated at the maximum load current, you should use ones with *at least* double that limit, for safety, especially for half-wave. The diode will dissipate heat through its leads and the PC board foil, so short leads are best.

The only generalization that can be made about the voltage drop across a diode is that it increases with current under forward bias. Thus, not quite all the peak transformer voltage is perceived by the electrolytic. Close to rated current, a diode drops about 0.8 volts, and 0.5 volts at low currents. Since the diode normally conducts to recharge the electrolytic, assume a worst-case drop of 1.2 volts. This is the figure to use with either half-wave or full-wave center-tap. With a bridge, two diodes conduct in series, so two drops must be added, for a worst-case of 2.4 volts.

The electrolytic perceives the secondary voltage, minus the diode drop(s). Unless you're right on the edge of a electrolytic's voltage rating, ignore the diode drop(s) and use electrolytics rated at least equal to peak transformer voltage. In practice, electrolytics are built for safety, so one with a 25-volt rating won't explode if 25.01 volts is used. How much you can get away with depends on the specific electrolytic or individual luck, so don't try it unless desperate. The current into and out of the capacitor causes heating; an electrolytic of large diameter will heat more than two smaller ones with the same capacitance when in parallel, due to less surface area per microfarad.

For an infinitely large capacitor, a constant voltage would be observed at the regulator's input. Most fixed regulators function properly with a 2-volt drop, and 2.5 volts for adjustable versions, so select the electrolytic to get as close to these regulator drops as possible.

Since no electrolytic has infinite capacitance, the regulator voltage isn't constant. The average input voltage varies with load current, and the ripple voltage increases in peak-to-peak value with current. At its lowest value during worst-case ripple, the regulator drop must be at least 2 volts. The following formula for the minimum required electrolytic size in μF is a good approximation:

$$C_{filter} = 6000 \times I_{load}/V_{rippple}.$$

For example, if maximum load current is 0.5 amp, and ripple voltage is 2 volts P-P, the minimum electrolytic size is:

$$C_{filt} = 6000 \times 0.5/2 = 1500\ \mu F.$$

This is valid for full-wave, but needs to be doubled for half-wave. Now, work backwards, from output back to transformer, to determine the minimum peak voltage the transformer has to deliver. For now, ignore any over-voltage condition, since that's mainly important in determining the electrolytic's voltage rating. Starting with the desired regulated output voltage, say +12 volts, add up all the voltage drops present:

12.0 volts	regulated output
2.0 volts	minimum regulator drop
2.0 volts	P-P ripple (somewhat arbitrarily selected)
+1.2 volts	worst case diode drop
17.2 volts	minimum peak voltage from transformer secondary

Multiplying this sum by 0.7071 gives 12.16 volts, the minimum tolerable RMS secondary voltage. This works well with a normal 12.6-volt secondary, but with only a 3% cushion for a low line-voltage condition. With the extra voltage the transformer provides, it should be efficient—for a linear supply. If the figures are too high for a standard transformer, consider using extra capacitance to achieve smaller ripple.

If you can select the transformer from several already on hand, or can afford a little extra cost, a transformer with twice the anticipated current rating could mean an extra volt or more in the secondary voltage. A higher secondary voltage will manifest itself as a higher regulator drop, causing more heating for any given load. This problem is insoluble when using an adjustable regulator to provide from 1.25–25 volts.

A clean 27.5 volts would have to be available at the regulator input to accommodate the highest output. However, when adjusted downward to only 2 volts, the regulator drop increases to 25.5 volts. Output current must be reduced to prevent overheating.

Finally, here's a little information on the TO-220 regulators. While the adjustable models can handle somewhat higher voltage, consider 35 volts as a maximum for all. This includes the fixed versions from 5–15 volts, inclusive. This same 35-volt figure was kept in mind as a capacitor rating when considering component sizes.

The regulators protect themselves by automatically shutting down when overheated, and by current limiting when shorted. This limit may still be enough to damage the transformer and diodes. You can consider a regulator as a 1.5-watt device with no heatsinking, a 5-watt device with fairly good heatsinking, and a 12-watt device with excellent heatsinking and air circulation.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise indicated.

R1—150–270 ohms (see Figs. 3 and 8)
R2—2000- or 5000-ohm cabinet-mounted potentiometer
R3—270–1500 ohms (see Fig. 8)

Capacitors

C1, C3, C6—1000 μF, 16 volts, electrolytic
C2, C4, C5—10 μF, 30 volts, electrolytic

Semiconductors

D1–D4—1N4004 or 1N5404 silicon rectifier diode or equivalent
IC1, IC2—78XX, 79XX, LM317, and/or LM337 3-terminal TO-220 voltage regulators (see text)

Miscellaneous: one or more copies of the PC board (see PC Service), suitable cabinet, red and black banana jacks, one or more 3-terminal regulator heatsinks (JAMECO part number 6030B), 1⁄32-inch and ⅛-inch drill bits, wire, solder.

To get a rough idea of safe operation, let one operate under worst-case conditions for five minutes, and then applying a tiny drop of room-temperature water to the top of the its heatsink tab. Even if a heatsink is attached, apply the water only to the top of the tab—awkward, but possi-

(Continued on page 58)

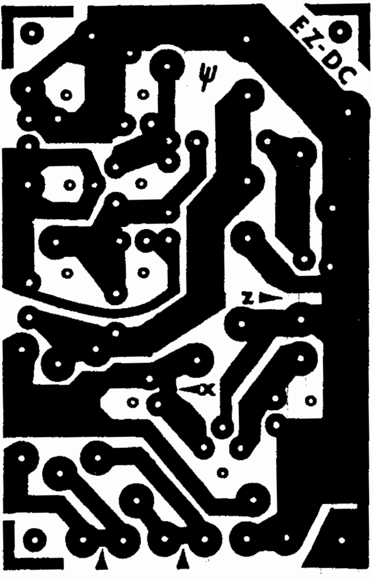
GENERIC POWER SUPPLY

continued from page 46

ble. If the water dries smoothly, from the edges inward, or forms fine bubbles, you're probably safe. However, if the water boils off immediately, there's trouble. It's not a terribly scientific method, but it's free. Check a second time, waiting a full minute after drying for heating recovery.

The 78XX/78MXX versions are fixed-positive models. For example, a 7812 is a positive 12-volt model that can provide at least 1 amp of output current—but only when the regulator drop is low enough to avoid overheating. The suffix "T" specifies a TO-220 case, but catalogs often omit this and specify the case type elsewhere. The 79XX/79MXX versions are fixed-negative models. The LM317/LM317M models are adjustable-positive, and the LM337/LM337M are adjustable-negative. They're all very reliable, and can take considerable abuse. **R-E**

PC SERVICE



2 INCHES

BUILD A GENERIC POWER SUPPLY using this PC board.