The Great Power Supply Issue!

Build the DUAL POWER SUPPLY

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DUAL POWER SUPPLY

By John T. Bailey

Here is a design procedure for constructing a bench-top power supply which is adjustable down to zero volts without loss of regulation and that has a snap-action, current-overload protection circuit!

MY VENERABLE HOMEBREW VARIABLE POWER SUPPLY WAS typical of those in common use during the past ten years. It used the popular LM723 voltage regulator with an external pass transistor for higher-output current. The circuit was conventional, as recommended by the manufacturers of the LM723. However, for my applications, it has two characteristics that I wanted to improve. First, the output-voltage lower limit was about 2 volts; and, second, the over-current *shutdown circuit* was *soft*. That is, as the over-current, trip-set point was approached, the regulation began to suffer. So, what is an experimenter to do? As I did—come up with a design that overcomes those two deficiencies. I called my project the Dual Power Supply. The title may not be original, but the circuit application sure is!

I have chosen a 0- to 20-volt, 400-mA, maximum-design objective to illustrate the design procedure I used. Also, I have furnished the essential calculations to permit design of other output ratings to suit output specifications of different values.

Zero Output

Quite a few circuits for adjusting the output of a regulated power supply down to zero volts are to be found in current technical literature. Some circuits are simple, some quite complex. The simple ones that I tried did permit reduction down to zero-volts output but, surprisingly with some, regulation fell off badly as zero was approached. Then, in Hewlett-Packard's *DC Power Supply Handbook, 1970* I found the answer in principle, but without component values. Basically, H-P's circuit uses a floating reference voltage, referenced to the positive-output terminal rather than to ground. Figure 1 is a block diagram of the circuit. The output voltage is determined by:

(Eq. 1) $$E_O = V_{ref} \times (R2 \div R1).$$

When R2 is 10,000 ohms,

$$E_O = 6 \times (10{,}000 \div 3000)$$
$$E_O = 20\text{-volts DC}.$$

When R2 is 0-ohms,

$$E_O = 6 \times (0 \div 3000) = 0 \text{ volts}.$$

Potentiometer R2 has a linear taper; thus, the output will be a linear function of the rotation of R2. However, an audio taper for R2 provides a much better adjustment of output voltages near zero. Remember, that your eye is on the voltmeter scale when adjustments are made, and that no front-

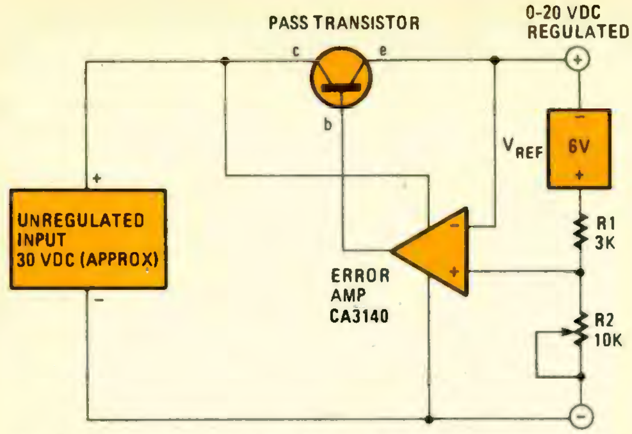


FIG. 1—SIMPLIFIED BLOCK DIAGRAM for one section of the Dual Power Supply. Not shown is the current-sensing resistor and circuitry that eliminates current-overload.

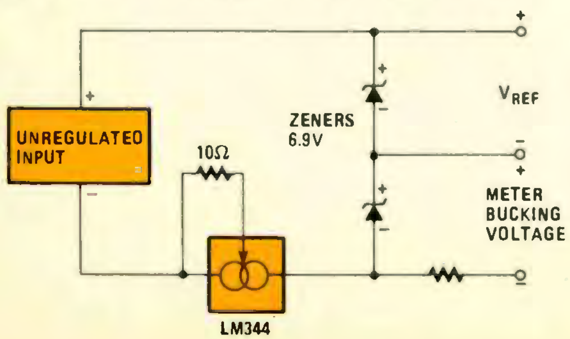
TABLE 1—VOLTAGE CHECK POINTS

Load Conditions (Trip set point = 400 mA)			
No Load	About to Trip	Tripped	
Volts DC to Common from:			Fig. 3
29.9	27.0	29.4	A
18.53	18.27	18.53	B
4.40	4.02	4.37	C
4.06	4.00	4.06	D
−.0157	−.0455	−.0512	E
mA through R10			
14.3	41.4	46.5	

panel scale for the regulated output control is required.

Note that a zero-ohms, terminal resistance of R2 (Fig. 1) is required, theoretically, in order to obtain zero-volt output. I found that different makes of potentiometers varied considerably in their minimum resistances; some were as large as 100 ohms. I used a Mallory U18 Midgetrol 10,000-ohm, #1 taper (audio) potentiometer, which had a 4-ohm minimum resistance. Compensation for that small, minimum-resistance value is possible and shall be explained later.

FIG. 2—VOLTAGE-REFERENCE Zener diodes are fired by a constant current source, practically eliminating voltage variance due to line-voltage and load outrages.



In case you want a different maximum output voltage, merely use different values of reference voltage and/or R1 as necessary to satisfy Equation 1. If R2's maximum resistance is a little greater than 10,000-ohms; it can be shunted to reduce it to 10,000-ohms, or you may prefer to leave it unshunted and get a little more than a 20-volts, maximum output. If R2 is less than 10,000-ohms, change R1 to an appropriate lower value to satisfy Equation 1. Of course, a substantial change in the output will require a change in the value of the unregulated input voltage.

For the 20-volt maximum output voltage, I used a no-load, 30-volt unregulated input. That gave me a satisfactory input-output differential to take care of line voltage changes and voltage drops in current-sensing resistors not shown in Fig. 1. A nominal 20-volt AC, secondary-winding in the power transformer (actually 21 volts under no load) produced an input of just under 30-volts DC after bridge rectification.

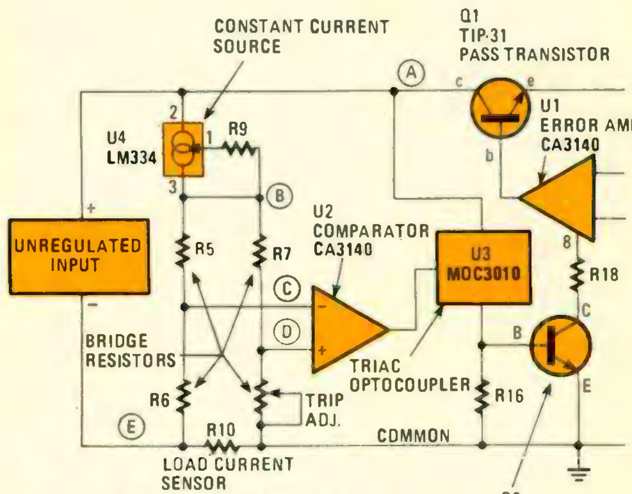


FIG. 3—A BRIDGE NETWORK detects excessive-current across R10 and controls the voltage comparator U2.

It is interesting to note here that the CA3140 op amp used in this circuit (Fig. 1) takes its supply voltage from the unregulated input and that its maximum supply rating is 44-volts DC. That's plenty of latitude! Hence, if the input voltage is increased to more than, say, 40-volts DC to get more than a 20-volt DC output, a resistance divider should be used to maintain the CA3140 op amp DC supply within its maximum rating. Also, if that is done, a pass transistor of a higher wattage rating will be required. The heat dissipation of the pass transistor is greatest at zero output voltage and is equal to the voltage at the collector multiplied by the maximum load current.

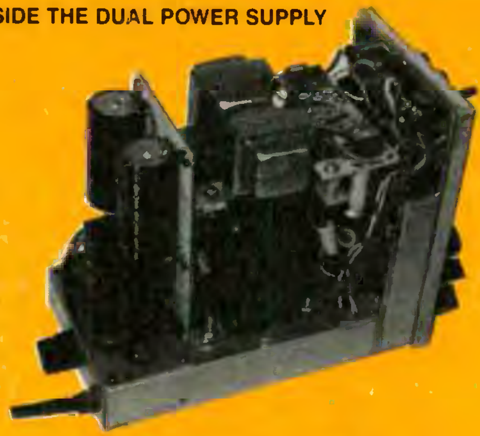
Reference Voltage

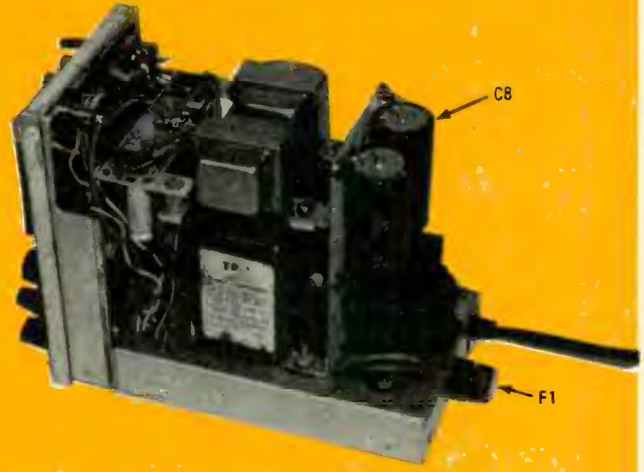
As with all other circuits using reference voltages, the quality of the reference is a major factor in determining overall performance of a regulated supply; regulation will be degraded if the reference is not steady. I used Zener diodes under constant-current bias for my reference voltage as shown in Fig. 2. The LM334 is the constant-current source, set to 6.8 mA by the 10-ohm resistor. The formula for constant current using the LM334 is:

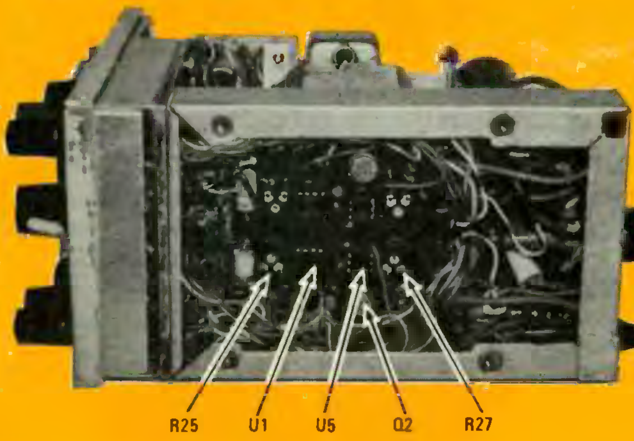
$$I = 67.7 \div R$$
$$I = 67.7 \div 10 = 6.8$$

where I is given in milliAmperes.

INSIDE THE DUAL POWER SUPPLY







THREE VIEWS of the author's Dual Power Supply are shown here. A quick inspection will reveal the dual nature of the project by the duplication of identical parts almost as mirror images in many instances. Author compacted the parts within, and on, a small chassis to reduce bench-top space. The two small transformers were connected to provide transformer T2 shown in Fig. 4. That proves the power of the junkbox! You may want to package the Dual Power Supply in a larger cabinet, or install it under your workbench as a built-in supply where there's plenty of space.

Constant current operation improves the Zener diodes' stability and minimizes the adverse effect of varying input voltages applied due to change in line voltage. The function of the meter-bucking Zener diode will be explained later. Note that the reference voltage indicated in Fig. 2 is 6.9 volts, whereas it is shown as 6 volts in Fig. 1. That is due to my 10,000-ohm potentiometer having only a 9,000-ohm maximum resistance, which compensation was provided by increasing the reference voltage to 6.9 volts DC.

Over-Current Shutdown

The conventional *shutdown* circuit for protection against excessive-output current, or accidental load short circuits, uses a shutdown transistor, which removes the base current to the pass transistor when the voltage across a current-sensing resistor turns the shutdown transistor *on*. That scheme works, but it doesn't provide snap-action turn-on of the transistor. Hence, as the load current approaches the base turn-on voltage of the shutdown transistor, regulation of the power supply begins to fall off. What I desired was a snap-action shutdown circuit that would maintain regulation right up to the over-current set point, and would hold the supply voltage off until the overload is removed. Also, I wanted both the output voltage and current to drop to zero on shutdown.

By using a comparator driving a Triac optocoupler, my shutdown objectives are easily achieved. Figure 3 shows the basic shutdown circuit.

A resistive-bridge arrangement, with an adjustable circuit in one arm, feeds a differential voltage to the comparator, which trips when the voltage drop across the current-sensing resistor reaches the trip value. The comparator output pulses the optocoupler's internal LED on momentarily, the optocoupler's Triac turns on, and, via a switching transistor, takes the error amplifier's shutdown pin to a low state. That action removes any base current to the pass transistor so that the supply's output voltage and current both fall to zero, and stay there until the overload is corrected and the reset button is activated.

Table 1 shows the voltages measured in the snap-action over-current circuitry of Fig. 3 under three conditions: (1) No load, (2) full load just before tripping, and (3) after tripping. Just before tripping, the bridge arm voltage to the comparator's inverting input (C in Fig. 3) is slightly larger than voltage D applied to the comparator's non-inverting input. When the trip-value current of 400 mA is exceeded, the comparator output goes high to about 25 volts. That voltage, via R15 (refer to Figs. 3 and 4), causes the internal LED of U3 to illuminate the Triac in U3, which then turns on, permitting about 32 mA to flow from the unregulated input point through the shunted trip indicators, D13, R14, the saturated Triac, and R16. The drop across R16 turns Q2 on via R17, thus grounding R18. Hence, pin 8 of U1 is taken low via R18 and base drive to Q1 is removed. That action reduces the output voltage and current to zero. Of course, with the load current reduced to zero the voltage drop across R10 drops to a low value, and the comparator inputs return to their normal values. The current through the Triac, however, remains latched on until the fault is corrected and RST (reset) switch S2 is depressed. Listed at the bottom of Table 1 are the currents flowing through R10 as calculated from the drops measured across it.

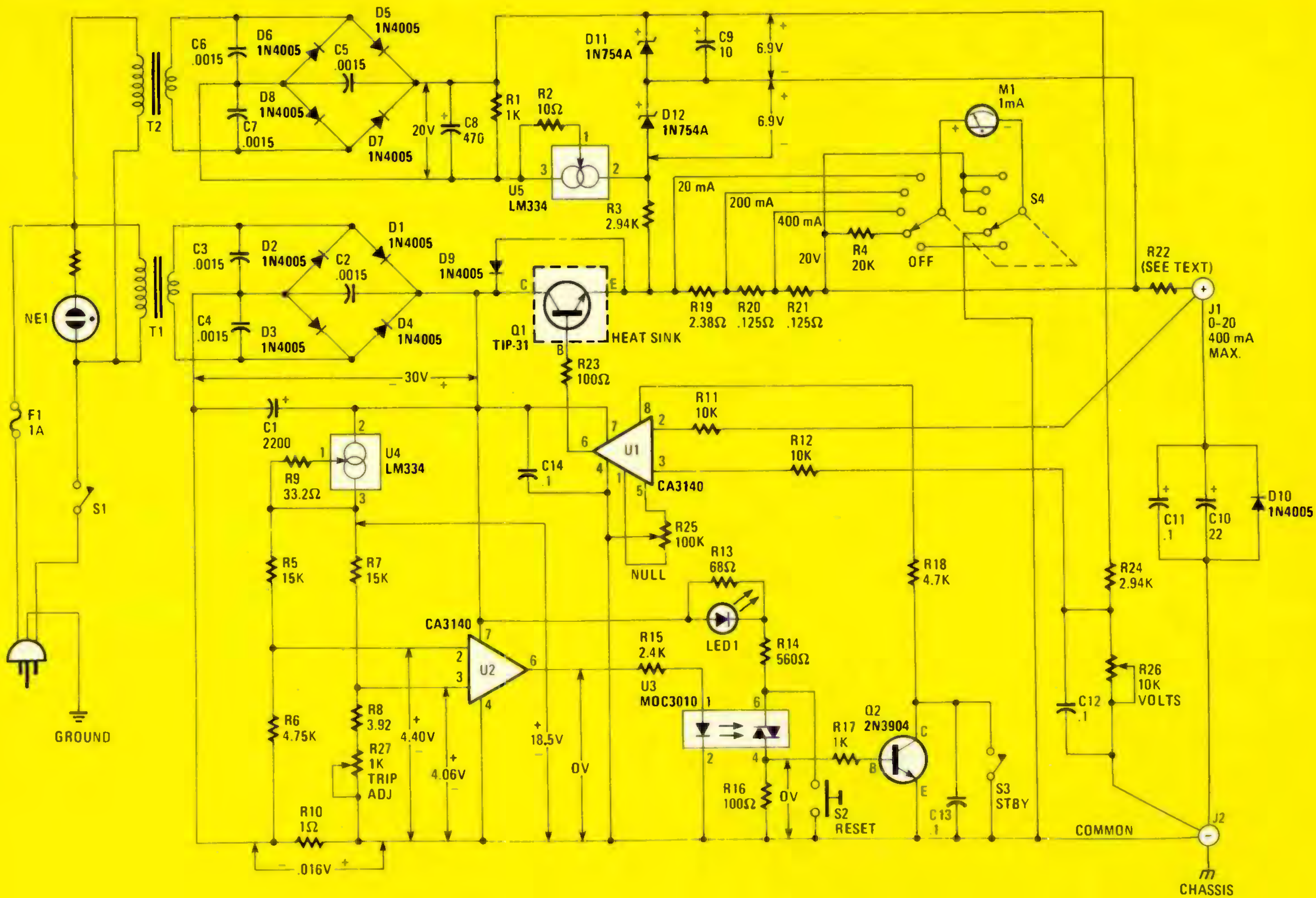


FIG. 4—HERE IS ONE-HALF of the Dual Power Supply. Since both halves are identical, build two from this drawing and package them in one cabinet. In fact, if you wish, you could build a *quad* power supply—it's all up to you. For each power supply you build, use an electrically-isolated chassis ground return so that the supplies can be connected in series using a common tie-point as ground for a dual regulated power supply.

With no external load, the current through R10 (Figs. 3 and 4) is about 14.3 mA. That current represents the currents drawn by U1, U2, and the circuit's resistive dividers. With a 400-mA external load, the current through R10 increases to 414-mA. Under trip conditions, the no-load internal current is increased by the Triac (U3) latched current to a total of 46.5 mA. The measured resistance of my R10 was 1.1 ohms.

Full Schematic Diagram

Figure 4 shows the actual schematic diagram used in my prototype providing an output of 0 to 20 volts at 400 mA maximum. Critical component values are shown as measured; circuit voltages are indicated at points on the schematic diagram, and in the Tables, where they will be of help in duplicating this prototype, or in designing another power supply of a different rating. Measurements were made using a 3½-digit DMM.

Load Regulation

It is possible to get the output voltage to actually rise with an increase in load current, or to obtain perfect regulation at any selected output voltage. That characteristic can be achieved by inserting a small resistance in the path to the positive output terminal, as represented by R22 in Fig. 4. When the load current increases, the voltage drop across R22 increases linearly. That voltage drop is of the proper polarity to add to the reference voltage, so the effective reference voltage increases with increases in load current. Reference to Eq. 1 reveals that there will be an increase in output voltage, which counteracts the normal decrease in output voltage under increased-load current conditions. The required resistance value of R22 is very small and must be determined by trial. Just a few inches of small-gauge magnet wire is all that is needed. The gauge of the wire must be able to carry the current that passes through it without heating up.

Using magnet-wire-wound current shunts, a 1-mA meter and a double-pole, five-throw (DP5T) rotary switch S4, output voltages and three current ranges can be monitored. The current ranges chosen were 20, 200, and 400 mA. With a 30-volt unregulated input to Q1, a 400-mA maximum output can be handled by a heat-sinked TIP-31 transistor with a reasonable safety factor. Also, 400 is a multiple of 20, the maximum output voltage, thus simplifying the meter dial markings.

With no external load there will be an internal current apparent on the 20-mA range. This *error* current will not be noticed on the 200- or 400-mA ranges. It is due to regulatory action of the error amplifier, U1, which must allow Q1 to pass just enough current to make the voltage-drop across R24 equal to the Zener voltage of D11. When that equality is achieved the output voltage is zero because the Zener voltage and the drop across resistor R24 are in series, are equal, and are of opposite polarity. The *error* current is, of course, the Zener voltage divided by the value of resistor R24 in ohms, or about 2.3 mA, and is a constant regardless of the setting of R2. It is bucked out by an equal opposite current produced by the lower Zener diode and series resistor shown in Fig. 2.

A standby LOAD switch, S3, is connected across Q2. The function of S2 is to provide manual shutdown of the supply's voltage and current output. That action is more convenient in some applications than turning off the supply's power switch. Capacitor C13, across S3, was found necessary to prevent triggering of U3, the optocoupler, when S3 is opened after being closed to shut down the supply manually.

The 10-µF capacitor, C9, across the reference Zener diode, D11, minimizes Zener noise.

The protective diodes are included in the Dual Power Supply. Capacitor C10 across the output protects the power supply against reverse voltages, which might be applied by an active load. Diode D9 across pass transistor Q1 is included for the same reason.

Performance

Specific figures for load and line regulation will not be offered because my instruments for determining such figures do not have sufficient resolution to be meaningful. In other words, the power supply's regulation is so good that I can't measure it. Tables 2 and 3 present performance data as well as I could measure them with a 3½-digit DMM. Whereas those tables show perfect regulation, it should be noted that the normal resolution of a 3½-digit DMM creates that illusion. A 4½ DMM, or better, is required to measure more precisely. Nevertheless, excellent load and line regulation is obvious.

TABLE 2
REGULATION VS. LOAD

Line = 115 Volts	
Load (mA)	
0	400
Output Volts (DC)	
18.48	18.48
11.13	11.13
4.80	4.80
1.181	1.181
.1670	.1670
.0945	.0945

TABLE 3
REGULATION VS. LINE

Load = 400 mA		
Line Volts (AC)		
103.5	115.0	126.5
Output Volts (DC)		
17.56	17.56	17.56

Ripple on the output voltage at full load was so small that, on my scope's 10-mV/cm range, it was barely perceptible and what could be seen may have been caused by hum pickup on the test leads.

Construction

Mechanical layout is not critical. Neither is the wiring critical, except that it is important that connections from R11 and R26 go right to the output terminals as shown in Fig. 4. Those are the voltage-sensing leads and have to be connected as shown, to monitor the voltage as close as possible to the external load for good regulation.

The meter I used, from my junkbox, had a plastic cover, which created a minor problem. It tended to acquire a static charge, so that the pointer wouldn't always return to zero when it should. Passing a finger across the cover, or tapping it, to overcome jewel friction would create a sizeable and unpredictable offset. That annoying condition was eliminated by brushing on a thin coat of Sta-Puf, a laundry liquid for

PARTS LIST FOR DUAL POWER SUPPLY

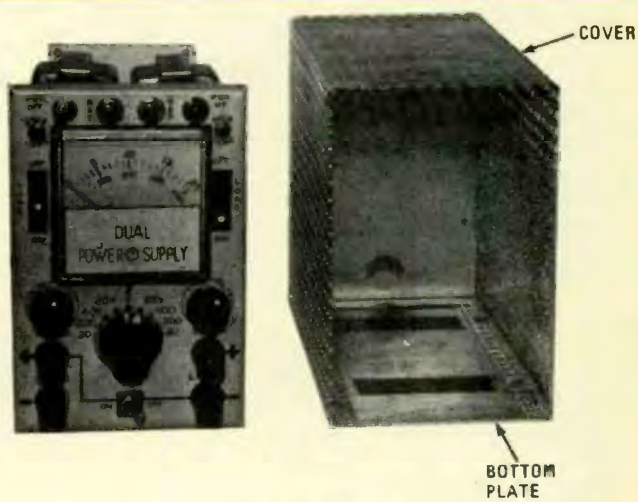
SEMICONDUCTORS
D1-D10—1N4005 600-PIV, 1-A rectifier diode (Radio Shack 276-1104 or equivalent)
D11, D12—1N754A 6.8-volt, 400-mW Zener diode
LED1—Light-emitting diode, T-1, red miniature
Q1—TIP-31 NPN transistor (Radio Shack 276-2017 or equivalent)
Q2—2N3904 NPN transistor (Radio Shack 276-1603 or equivalent)
U1, U2—CA3140 bi-FET op amp, RCA (Jameco Electronics)
U3—MOC3010 Triac output, 250-volts, 100-mA optocoupler (Radio Shack 276-134 or equivalent)
U4, U5—LM334 current-source integrated circuit (Radio Shack 276-1734 or equivalent)

RESISTORS
R1—1000-ohm, 1-watt, 10% fixed
R2—10-ohm, ⅛-watt, 1%, film
R3, R24—2,940-ohm, 1%, film
R4—20,000-ohms, 1%, film
R5, R7—15,000-ohm, 1%, film
R6—4750-ohm, 1%, film
R8—3,920-ohm, 1%, film
R9—33.2-ohm, 1%, film
R10—1-ohm, 1-watt, 5%, wire-wound
R11, R12—10,000, ⅛-watt, 10%
R13—68-ohm, ⅛-watt, 10%
R14—560-ohm, 2-watt, 10%
R15—2,400-ohm, ⅛-watt, 10%
R16, R23—100-ohm, ⅛-watt, 10%
R17—1000-ohm, ⅛-watt, 10%
R18—4700-ohm, ⅛-watt, 10%
R19—2.38-ohm (made from #40-gauge magnet-wire wound on 1000-ohm, ¼-watt resistor form
R20, R21—125-ohm (made from #28-gauge magnet-wire wound on 1000-ohm, ¼-watt resistor form
R22—(See text)
R25—100,000-ohm, ⅛-watt, miniature trimmer potentiometer (Radio Shack 217-338 or equivalent)
R26—10,000-ohm,audio-taper miniature potentiometer (Mallory U18 Midgetrol, #1-taper)
R27—1000-ohm, ⅛-watt, miniature, trimmer potentiometer (Radio Shack 217-333 or equivalent)

CAPACITORS C1—2200-µF, 50-WVDC, electrolytic
C2-C7—.0015-pF, 1000-WVDC, ceramic-disc
C8—470-µF, 35-WVDC, electrolytic
C9—10-µF, 16-WVDC, tantalum
C10—22-µF, 35-WVDC, electrolytic
C11-C14—1-µF, 50-WVDC, Mylar

SWITCHES S1—SPST, 3A, 125-VAC, miniature, toggle
S2—SPST, normally-open, momentary-pushbutton
S3—SPST switch, toggle
S4—2-position, 6-throw, non-shorting, rotary (use only 5 positions)

ADDITIONAL PARTS AND MATERIALS
F1—1-A, type-3AG fuse
J1, J2—Multi-way binding post, one red, one black
M1—DC panel meter, 1-mA, 2¼-in. square
NE1—Indicator part of type-3AG fuse holder
T1—Power transformer; 117-VAC pri.; 20-VAC, 1.2-A sec. (Signal #PC40-600 or equivalent)
T2—Power transformer; 117-VAC pri.; 6-VAC, .15-A sec. (Signal #241-3-16 or equivalent)
Heat sink, two 8-pin IC sockets, one 6-pin IC socket, knobs, line cord, chassis, case, hardware, rubber feet, decals, etc.



A HOME-BUILT front panel, cover and bottom plate was made to fit a standard chassis that the author had available. Metal screen used to make cover provides ample ventilation for project.

fabric softening and static cling control, on the inside of the cover. The coating is still working after six months.

A suitable heat sink is required for Q1, the series-pass transistor. In my prototype I used a flat piece of 3/32-inch thick aluminum that was 3½-inch square, which was mechanically and thermally connected to the chassis. The TO-220 tab of Q1 is internally connected to the transistor collector element, so a mounting screw through the tab hole must be electrically isolated from the heat sink. I used two extruded fiber washers to accomplish that purpose. In addition, a piece of mica ⅝-inch by ⅞-inch with thermal grease on each side was used between Q1 and its heat sink. Figure 5 shows the mounting arrangement. That electrical isolation isn't required if, instead, the heat sink is isolated from the chassis by means of insulating standoffs.

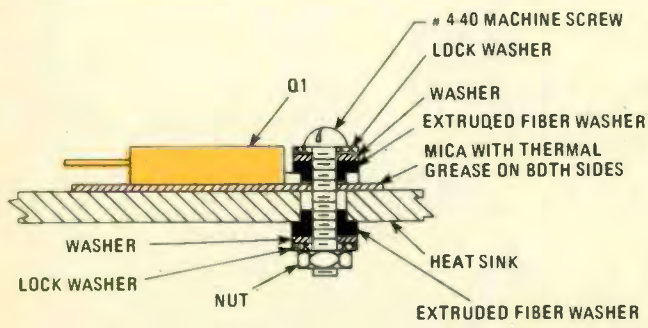


FIG. 5—PASS TRANSISTOR Q1 requires a suitable heat sink, due to the amount of heat it dissipates. The author mounted Q1 on the metal chassis thereby requiring electrical isolation.

Adjustments

There are only two adjustments to be made before operation. The first one is to null the error amplifier, U1. With a digital voltmeter across the Dual Power Supply's output ter-

(Continued on page 92)

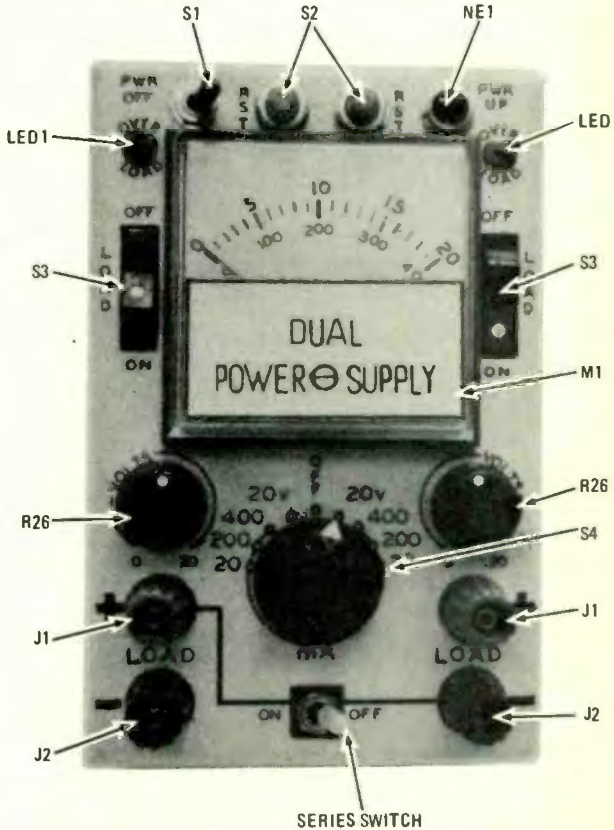
DUAL POWER SUPPLY

(Continued from page 26)

minals and the voltage output VOLTS potentiometer, R26, set to zero (it actually will have a few ohms at the *zero* resistance setting) adjust the NULL potentiometer, R25, for zero output as shown on the DMM. It will be found that the output can be varied from a small negative voltage to a small positive voltage, and that the adverse effect of a few ohms of terminal end resistance of R26 will be nullified. The other adjustment is the overload set point. Connect a suitable load resistor to the output terminals and adjust the output voltage until the desired trip current is indicated on the current meter. Then adjust the current TRIP ADJ potentiometer, R27, until the comparator trips.

This article is, basically, a design article giving data on how to design and construct a power supply with two improved features to specifications of your choice. The prototype referred to herein was built using the circuit of Fig. 4, but with a variation. What I built was a Dual Power Supply consisting of two identical and separate power supplies in one case. Using a front panel switch, the two supplies can be connected in series to give a total of 40 volts. The power transformer, again from my junk box, had two 20-volt secondary windings, thus eliminating the need for two large components. The case measures 5¾ high × 3½ wide × 7½-inch deep, however you need not pack its contents in so small a case.

By using the design data in this article it should be easy to duplicate the performance of my chosen specifications, or to design a power supply to your requirements. ■



DUAL MEANS DUAL CONTROLS—and that's what you see on the unit's front panel. SERIES SWITCH is not in Fig. 4. It is used to strap the power supplies in series. See text.