Basic Electronics
#6

by Ron C. Johnson

Murphy's Law states that whatever can go wrong, will, and at the most inconvenient moment. Those of us who dabble in electronics know that Murphy must have been one of us. On the other hand, sometimes things do go right, but in a round-about way...

Last month I told you we would do some circuit building with op amps to put into practice some of the theory we talked about in the last segment. Well, Murphy intervened, but not in a bad way. We are still going to build a project using op amps (and a few other components) but we'll also build a piece of equipment for your bench that you'll need in order to do more work with op amps — a triple output power supply with tracking positive and nega-

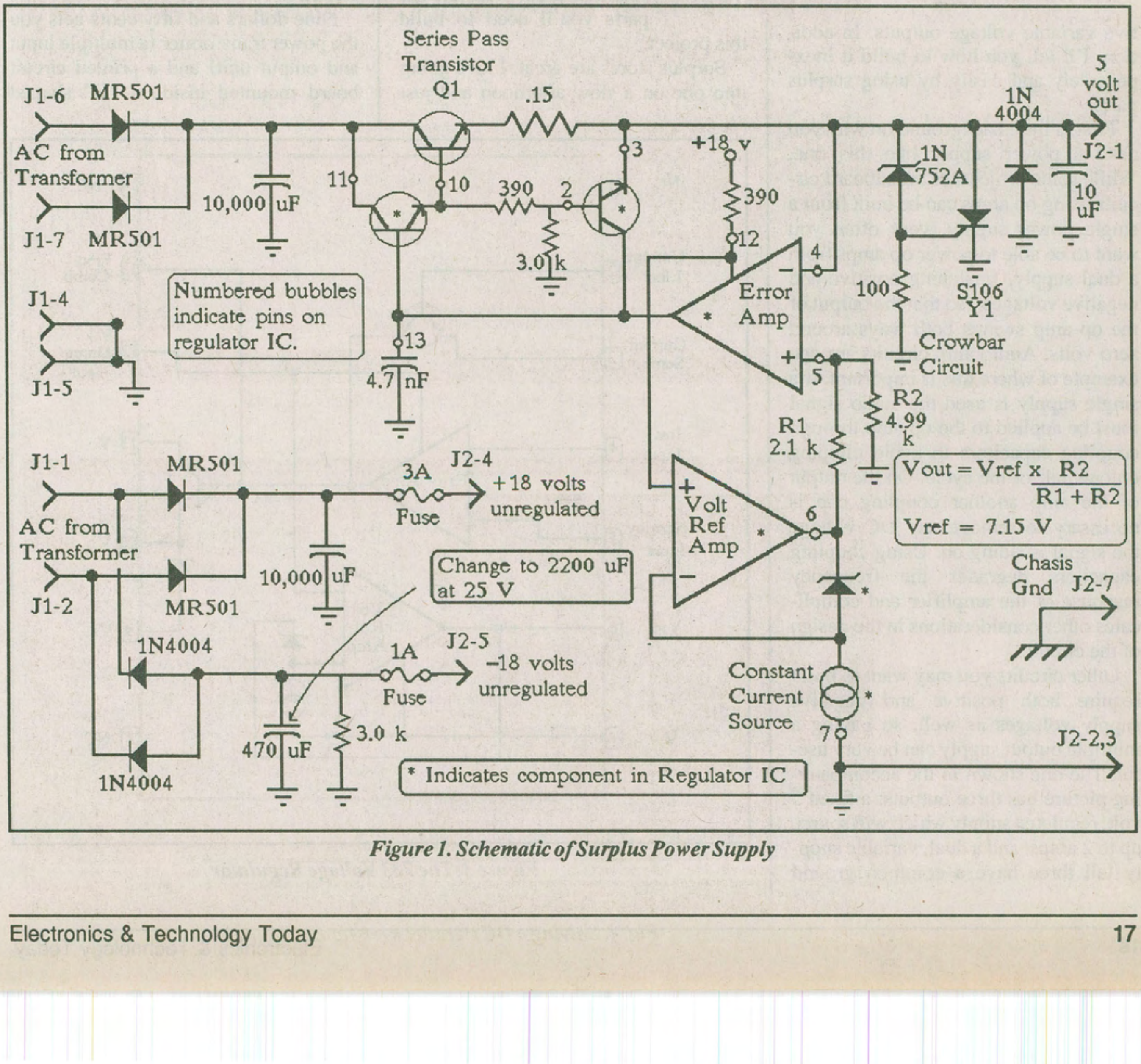

Figure 1. Schematic of Surplus Power Supply

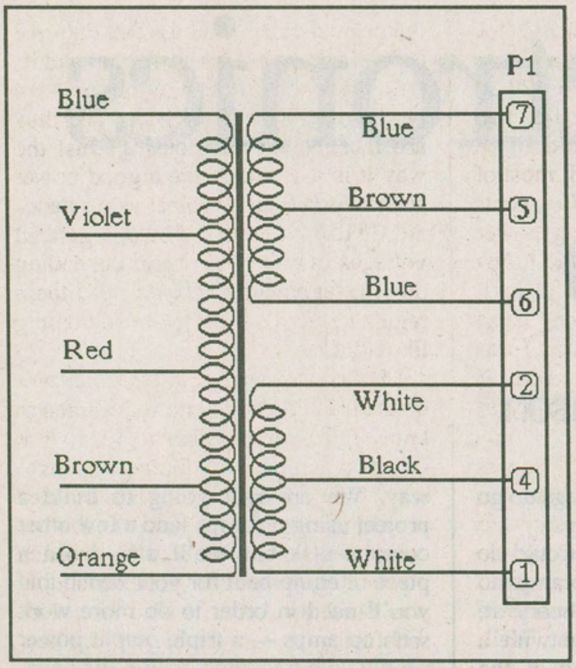

Figure 2. The Step Down Transformer

tive variable voltage outputs. In addition, I'll tell you how to build it inexpensively and easily by using surplus parts.

First, a little background on why you need a power supply like this one. While some projects or breadboard circuits using op amps can be built from a single power supply, very often you want to be able to power op amps from a dual supply, (matching positive and negative voltages), so that the output of the op amp swings both ways around zero volts. Audio amp circuits are one example of where this is important. If a single supply is used the audio signal must be applied to the op amp through coupling capacitors to avoid clipping on one half of the cycle. On the output of the amp another coupling cap is necessary to remove any DC voltage the signal is riding on. Using coupling capacitors degrades the frequency response of the amplifier and complicates other considerations in the design of the circuit.

Other circuits you may want to build require both positive and negative supply voltages as well, so having a multiple output supply can be very useful. The one shown in the accompanying picture has three outputs: a fixed 5 volt, regulated supply which will source up to 2 amps, and a dual, variable supply (all three have a common ground point). The dual supplies will vary between about 1.2 volts and about 20 volts, one positive, the other negative. These supplies are also regulated and will source up to about 1 amp from either side. An added feature here is the ability to switch between independent control of each voltage or tracking control in which the negative supply tracks the positive supply. This is especially useful in those op amp circuits where you want the supplies to be equal and opposite.

I said that this supply can be built inexpensively by using surplus parts. That's where a positive aspect of Murphy's Law came in: I found a great deal on the parts you'll need to build this project.

Surplus stores are great. I love going into one on a slow afternoon and just poking around through all the quaint and obscure bits and pieces that accumulate on their shelves. Half the fun is just trying to make sense of what some of this stuff is and where it might have come from. Quite often the prices in these places have no relationship to reality. Obsolete junk goes for outrageously high prices (and people buy it for some reason) while the next item goes for some unbelievably low price.

Princess Auto is such a store. These guys have lots of stuff for the avid project builder, and some of it goes for reasonable prices. (They have branches right across Canada, by the way, so you should be able to find one relatively near you. In future segments of my column, "Tech-niques," I'll give you a run down some of the better items on their shelves.) For this project I found a great little power supply module which makes up the heart of the power supply I built.

Nine dollars and fifty cents gets you the power transformer (a multiple input and output unit) and a printed circuit board mounted inside a "U" shaped

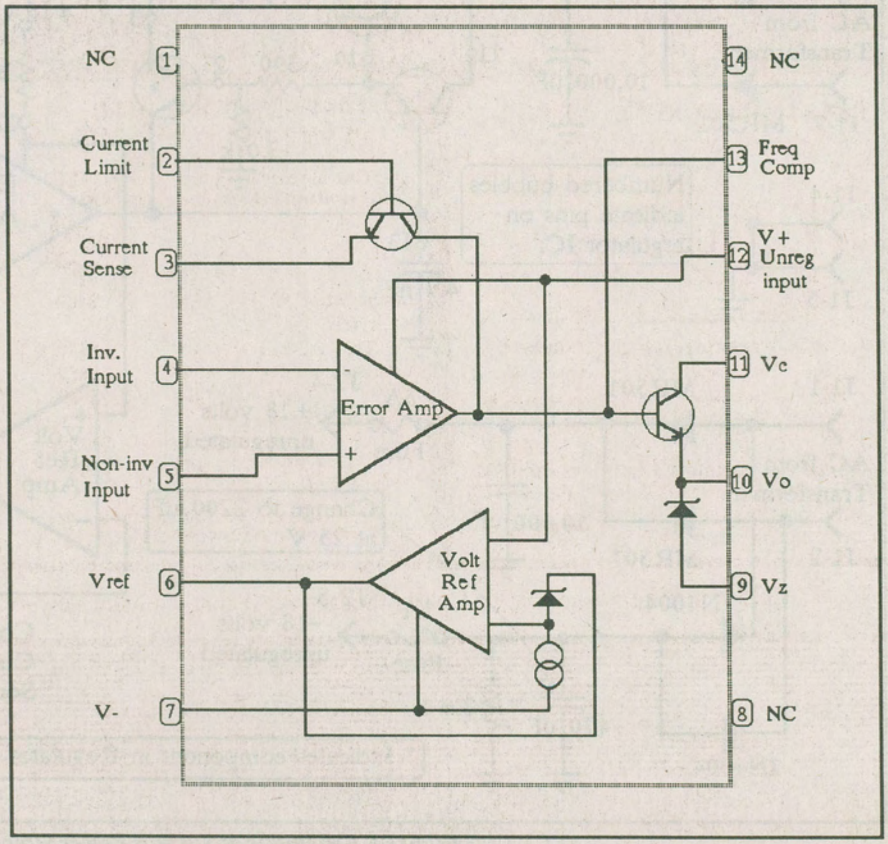

Figure 3. The 723 Voltage Regulator

metal housing. The information printed on the housing indicates that it was made by "Sierracin Power Systems" from Chatsworth, California (Assembled in Mexico) beyond which I have no idea what its original purpose was. (But I checked and they have lots of them in stock.) The rest of the printing on the housing tells the specifications of the power supply: +5 VDC, 2.2 amps; +18 VDC, 2 A pk, 1A Avg; -15 VDC, .1 A. It also tells how to pair up the wires on the input side of the transformer to use it with various line voltages.

On closer examination and testing I determined that the positive and negative supplies were unregulated and had on board fuses to limit their current to somewhere above the maximum value given on the housing. There appeared to be one integrated circuit with a part number I didn't recognise, an SCR on the top of the board, and a transistor under the board, sandwiched against the housing to heatsink it. There were two 10,000 µf capacitors and one 470 µf capacitor and four large and two smaller rectifier diodes on board.

I probably don't have to tell most of you that nine dollars and fifty cents doesn't go very far in buying power supplies these days. In fact, the transformer alone would cost you at least twice that from most suppliers. Even though I wasn't sure exactly what I was getting I knew I had to be a good deal if it worked at all so I decided to try to make something out of it.

If you decide to run out to Princess Auto and buy one of these things you will find that they are easy to get up and running. If you just want a simple power supply for a project there is no need to make any modifications to it. The power transformer came with a plug-in connector on the end of the secondary wires, which plugs right onto the printed circuit board. (See Figure 2 for a diagram of the transformer and its output connector.) The output pins are on the other side of the board and they are labelled on the housing. Just the way it is it would make a good power source for a digital project using standard TTL logic levels. The unregulated voltages may be a problem depending on your application. If you need them regulated you'll have to do something like I did.

My first step was to find out what was on the printed circuit board. I wanted to know if it was possible to fix it if it failed sometime in the future and also to see why the negative supply was rated at only .1 amp. This was too low an output for what I wanted in a bench power supply but the positive supply was rated for 1 amp which would be satisfactory for most of my applica-

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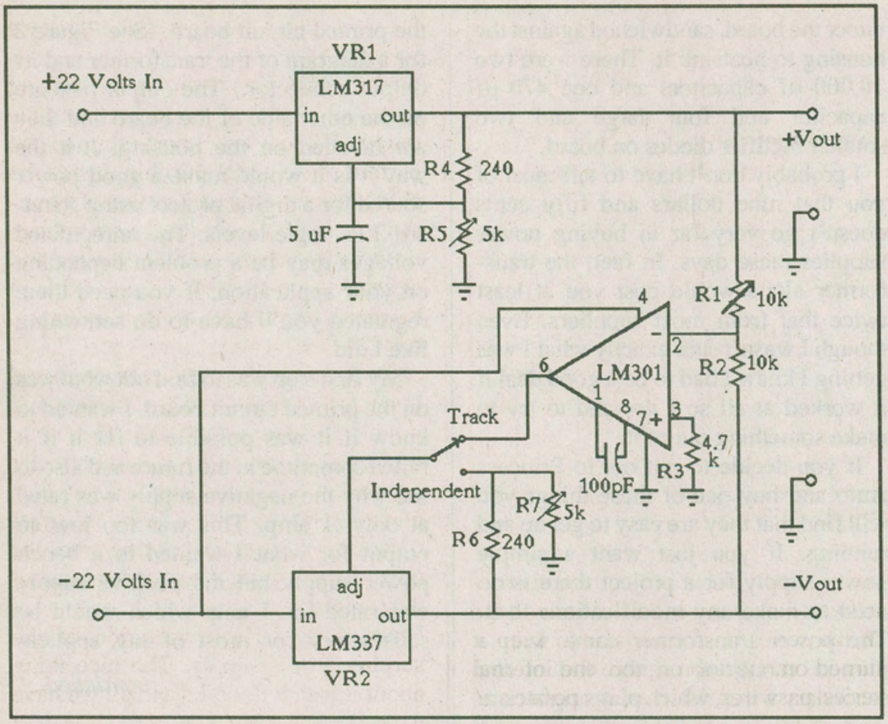

Figure 4. The Dual Tracking Regulator

tions. After tracing circuits on the board and attempting to determine what the "house numbered" parts were, I finally came up with the schematic shown in Figure 1.

I discovered that the 5 volt regulator on the board was controlled by the DIP integrated circuit, and though its numbering was unfamiliar it wasn't difficult to trace its connection to the transistor on the bottom of the board. Again, the transistor was "house numbered" but, using my trusty Fluke 77 I determined that it was an NPN power transistor connected as a series pass transistor. I was somewhat familiar with the LM723 voltage regulator chip which is often used in conjunction with series pass transistors in regulator circuits so I looked up its pin-out in a linear data book. Lo and behold, the external circuitry around the chip on the board looked just like the applications in the data book. The regulator on this board was just a renumbered 723. (See Figure 3 for a pin configuration diagram.)

I pursued tracing the circuit and drawing it out and found a couple of interesting things. The 5 volt supply has a "crowbar circuit" in it. This is interesting in itself and should be noted if you build your own supply. A crowbar circuit senses the output voltage of the power supply using a zener diode, and if it exceeds the 5.6 volts of the 1N752A, the gate of a power SCR receives a voltage pulse which turns on the SCR, shorting the power supply output to ground. In order for this to be effective (rather than catastrophic and dangerous) the input side of the power transformer must be appropriately fused. The regulator circuit does have current limiting (as we'll see shortly) but, if the series pass transistor were to fail in a shorted condition, current limiting wouldn't help. This whole circuit is there to protect the circuitry in the circuit to be powered, from receiving a voltage level over 5.6 volts, which could stress, or destroy TTL logic circuitry.

Pursuing the task of tracing the regulator circuitry I also found the reason for the .1 amp specification for the negative supply. As shown in Figure 1 the negative supply uses the same centre-tapped windings of the transformer as the positive 18 volt supply. For the negative supply, however, 1N4004 rectifier diodes were used (good for about 1 amp) and the filter cap was a 470 µF capacitor. The output of this had a 1 amp fuse in line. The limiting factor here is the 470 µF capacitor. If currents exceeding .1 amp were required of the supply, the capacitor would not be large enough to smooth the output acceptably. As you will note from the diagram. I chose to remove the 470 µF and replace it with a 2200 µF capacitor which is still much smaller than the 10,000 µF cap used in the positive supply but should be sufficient for my application.

While we're still looking at Figure 1, an explanation of the operation of the circuit using the 723 regulator would be in order. The 723 is one of those integrated circuits (like the 555 timer), which incorporates several devices on one chip to facilitate a common function. The same function could be obtained using separate op amps and transistors but this chip makes the operation much more convenient. On board the chip an NPN transistor is used to drive the base of the external series pass transistor. Actually, if you only want to

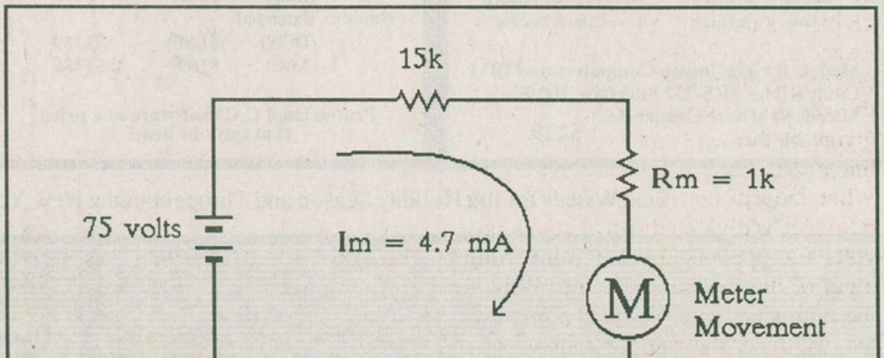

Figure 5. Original Meter Configuration

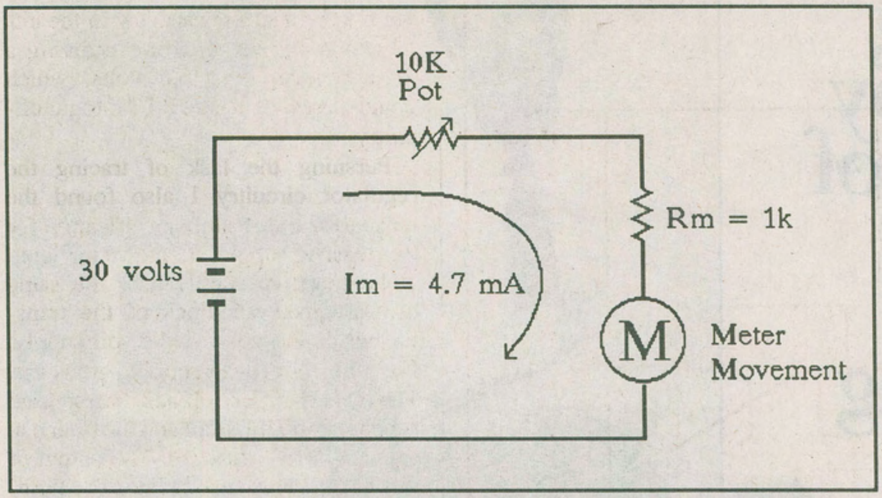

Figure 6. Revised Meter Configuration

regulate up to 150 mA, no external transistor is necessary. The internal transistor mentioned will do the job. The base of the internal pass transistor is driven by the output of an op amp. This op amp is being used in a DC mode with the inverting input tied to the 5 volt supply output line to sense any fluctuations in voltage output. If the output voltage decreases the inverting input will cause the op amp output to increase driving the pass transistor harder, turning it more fully on and allowing more current to reach the load. This should in turn increase the output voltage, all of which constitutes regulation.

The non-inverting input of the op amp is tied to the output of another op amp on the regulator chip. This op amp uses a combination of a current source and a zener diode to provide an extremely stable reference voltage (7.15 volts according to the specs) which can be used for comparison. A voltage divider consisting of two precision resistors, R1, (2.1 k), and R2, (4.99 k), determine the actual output voltage of the regulator according to a formula given in the application notes in the linear data book (shown on Figure 1). What happens here is that the 7.15 volt reference is divided down to about 4.51 volts and applied to the non-inverting input of the feedback op amp. Why is the reference lower than the 5.00 volts we want on the supply output, you might ask? The answer is in the base-to-emitter voltage drop of the external series pass transistor. The output of the feedback op amp must be kept more positive than the output voltage in order to overcome the .6 volt junction voltage of the series pass transistor to keep it turned on. (We can ignore the internal series pass transistor as it operates as part of the op amp circuit and its B-E junction is already overcome.) Adding the series pass junction voltage, .6 volts, to the 4.51 volt reference gives about 5.1 volts on the output which is what we want.

The 723 achieves current limiting by using a .15 Ω resistor in line with the output voltage and connecting to the current sense pin of the chip. Inside the chip, the base-emitter junction of a transistor is biased according to the voltage dropped across the .15 Ω resistor and dependent on the 390 Ω and 3.0 k Ω resistors connected to the transistor's base. If the voltage across the .15 Ω resistor rises above a predetermined level, the current sense transistor's B-E junction is forward biased. This turns on the transistor, which has its collector connected to the op amp output. The current sense transistor "robs" the pass transistor of its drive coming from the op amp decreasing the current output of the regulator.

So much for the operation of the surplus power supply. The nice thing about it is that it works and all we have to do is connect it up properly. The next step in this project was to come up with a regulator circuit for the dual supply portion. First, I replaced the 470 µF capacitor on the negative supply with a

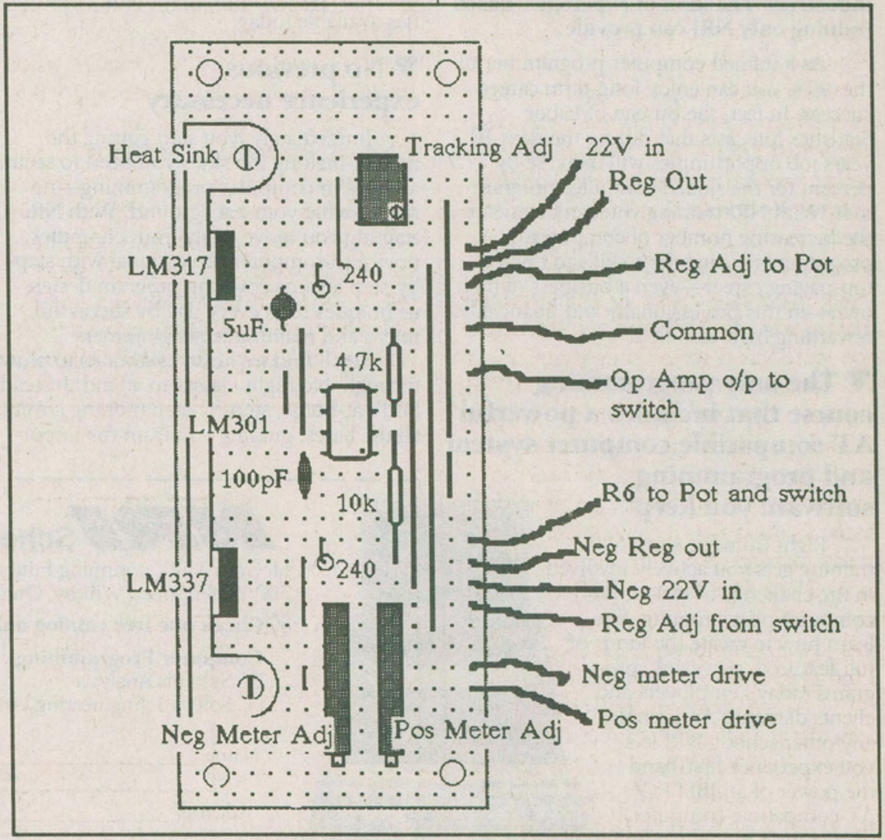

Figure 7. Add-On Regulator Board

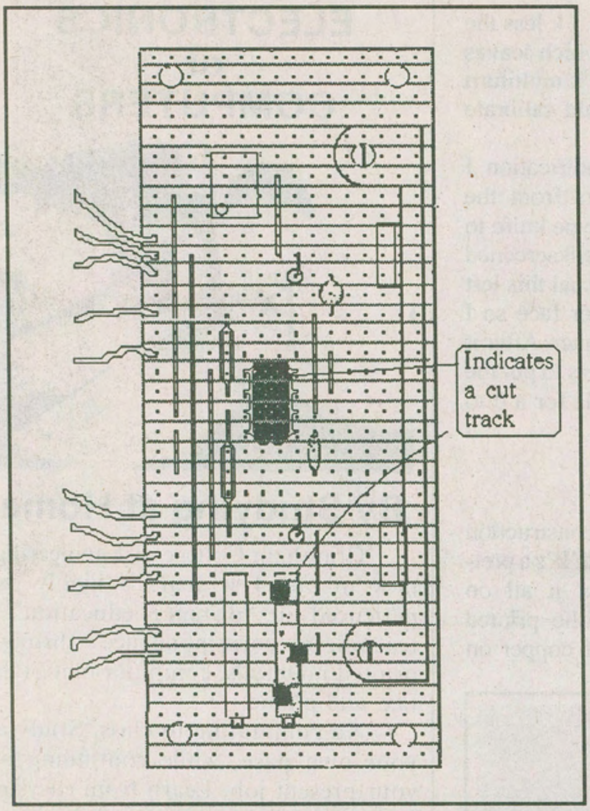

Figure 8. Rear View of Board Indicating Cut Tracks

2200 µF of about the right physical size. I also replaced the on-board fuse with a 1.6 amp slow blow. This is pushing the capabilities of the rectifier diodes, which are rated at about 1 amp but they could easily be replaced with higher rated rectifiers. (I found when measuring the actual output of these supplies that their nominal voltage was closer to 22 volts than what was specified on the housing.)

What about a variable regulator? I could have used a similar circuit to the one on the 5 volt supply but made it variable using a potentiometer. This would have involved a fair amount of circuit construction, so I looked further. (In fact, it wouldn't be hard to buy two more of these modules and modify them to be variable, giving you a total of three independent supplies, but I wanted to keep the project relatively inexpensive.)

I decided to build two simple variable regulators using a LM317 adjustable positive regulator and a LM337 adjustable negative regulator and add an op amp circuit which would allow me to switch to a tracking type of operation. The schematic is shown in Figure 4. Individually, the regulators use voltage dividers consisting of a 240 ohm resistor and a 5 k potentiometer to set a reference voltage on the adjust pin of the three-terminal device. Adjusting the potentiometer will give a voltage output range from 1.2 volts to about 20.5 volts.

If higher voltages were required another transformer could be used to increase the unregulated DC level. It also occurred to me that a different combination of input leads on the transformer could be connected to the 120 VAC (probably the combination for 100 VAC in). This would decrease the turns ratio thereby increasing the output of the transformer, although I haven't yet tried it...

The tracking feature of this circuit is accomplished by using an LM301 op amp to sense the level of the positive power supply, invert it and set the reference level for the negative voltage regulator. When in tracking mode, the switch disconnects the potentiometer reference and connects the output of the op amp to the regulator. Sensing the positive power supply output is done using a voltage divider made up of a 10 k resistor and a 20 k multiturn potentiometer, connected from the positive output to the negative output. Adjusting the pot allows you to match the levels very closely. The centre of the voltage divider is connected to the inverting input of the op amp while the non-inverting input is connected to ground through a 4.7 k resistor.

The op amp accomplishes its task by comparing the voltage level on the voltage divider to ground (on non-inverting input). Because the voltage divider is essentially two 10 k resistors, its output should be 0 volts. If the positive supply increases (because of adjusting the positive control pot) the inverting input will see an increased voltage. This will be inverted and amplified by the gain of the op amp (very high because there is no feedback loop) giving a negative voltage on the op amp output. This negative voltage sets the reference for the negative voltage regulator. As the negative supply increases (in a negative direction) an equilibrium will be established.

One more circuit had to be designed before I put it all together in a working prototype — meters for the variable supplies. Again I made use of the surplus equipment available at Princess Auto by obtaining a couple of inexpensive panel meters (about eight bucks). These meters are not used. They are brand new and come in shrink wrapped packaging with some instructions on

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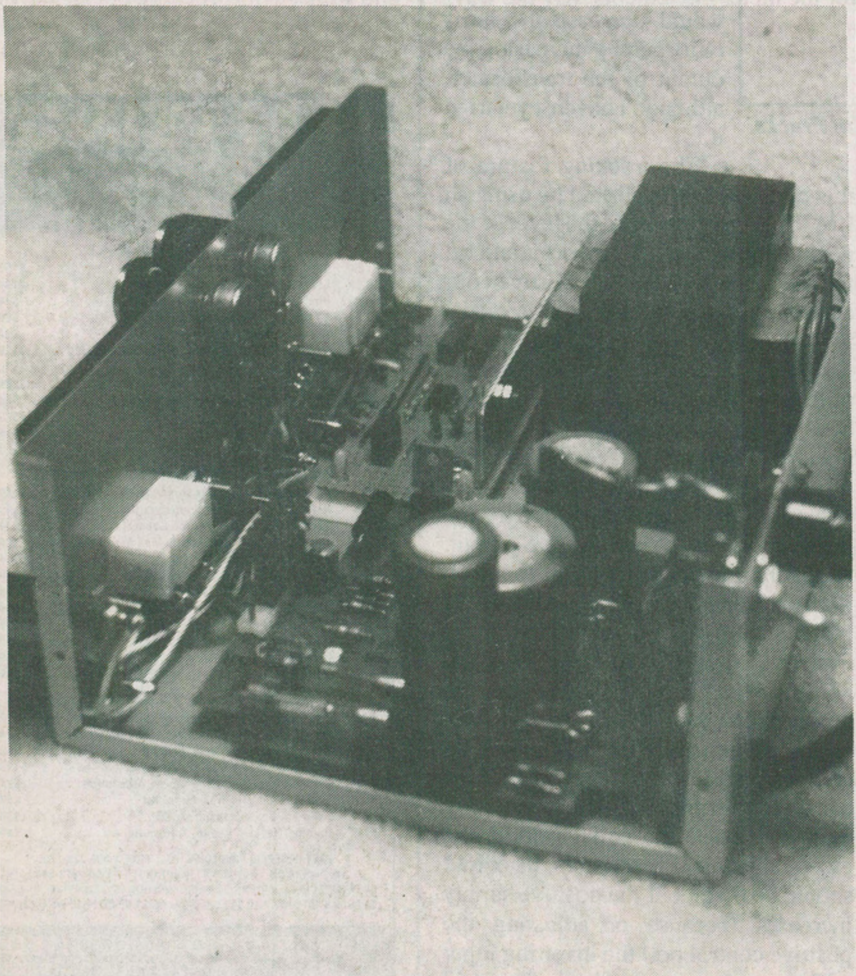
the back. There are several sizes, shapes and ranges but I found that most of them had scales higher than what I wanted so I had to change the series resistance to scale them differently and then change the lettering on the front of the meter.

The meter movements I used were about 6 cm by 6 cm and were scaled for 0 to 75 volts DC. A 15 k precision resistor was included with each one to scale it for 75 volts full scale. With that information in mind I recalculated the resistance needed to scale them for 0 to 30 volts full scale. (See Figures 5 and 6) I used my ohmmeter to measure the resistance of the meter coil itself and found it to be very close to 1 k. With 75 volts applied and a 15 k resistor in series the full scale current would be 4.7 mA. Recalculating for 30 volts at the same current showed that I would need a series resistance of about 6.3 k less the internal resistance of 1 k which leaves 5.3 k. I decided to use a 10 k multiturn potentiometer so that I could calibrate the meter more easily.

To finish the meter modification I removed the plastic covers from the meters and used a scalpel-type knife to carefully scrape away the silkscreened lettering on the scale. As usual this left a obvious spot on the meter face so I sprayed it with a plastic lacquer. After it dried I used Letraset transfers to put the proper numbers on the scale for a 0 to 30 volt indication.

Construction

Figures 7 and 8 show the construction details of the regulator board. It's a pretty simple circuit so I put it all on Veroboard which is phenolic printed circuit board with strips of copper on



Interior of Completed Power Supply

one side and a grid of holes on .1 inch centres. I found an old piece of aluminum to use as a heatsink which had mounting tabs ideal for bolting it directly to the board. I mounted the regulator chips on the board and bolted them to the heatsink saving the extra wiring required to mount them off board on the power supply chassis. It is important to isolate the regulators using mica insulators and plastic washers as the tabs of the regulators are connected to pins on the chip and are at different potentials.

Besides the conductors between the pins of the op amp track had to be cut in only three places (as shown in Figure 8). Several jumpers are required to interconnect components. In addition to the tracking adjustment potentiometer, the two meter adjustment pots were mounted on the board.

Now that all the circuits were complete I went searching for the rest of the hardware required to put the project together. I obtained a metal box from the local Radio Shack and mounted the power transformer and surplus power supply inside without its housing. One thing to note here is that the series pass transistor on the bottom of the board must be isolated from the chassis with the appropriate mica insulator. The plastic washer which extends through the hole in the transistor came with it. Always check with an ohmmeter before powering up a project like this to make sure that there is isolation.

Next I added a power switch and a fuse in the rear of the chassis. Let me warn you, as always, **BE CAREFUL** when constructing any project where 120 VAC power is used. Cover all exposed conductors which are associated with the line voltage and **ALWAYS** use a three-prong plug and line cord, connecting the green, ground wire to the chassis.

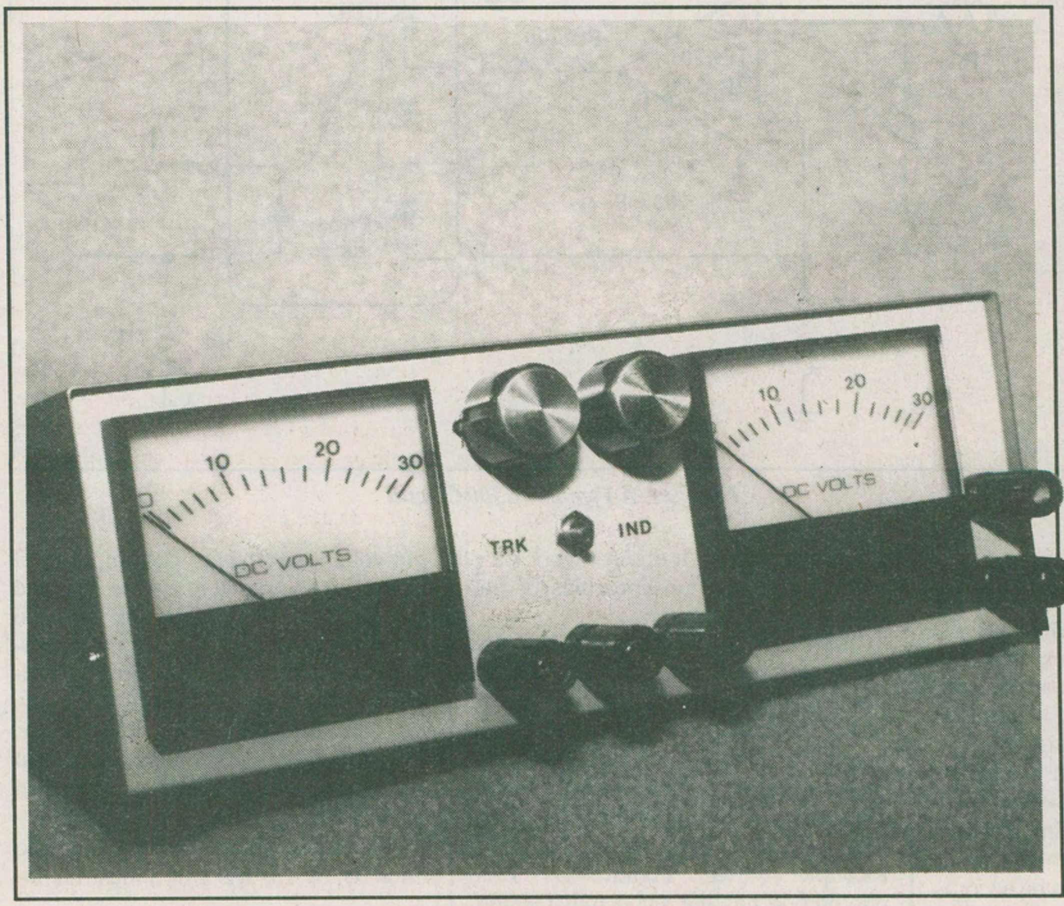
On the front of the chassis I cut holes for the meter movements. (By the way, a nibbler tool, available at most electronic suppliers including Radio Shack, is very useful for this task.) Then I drilled holes for two control pots, a switch and five binding posts.

The most labour-intensive part of the job is the point to point wiring required to connect the veroboard regulator to the front panel control pots, the switch, the binding posts and the meter movements. I found a connector which would plug onto the output pins of the surplus power supply board which makes this board easily removable. As usual, care and attention to your soldering techniques will probably save you headaches later on.

Eventually the moment of truth arrived; the moment when I had to flip the power switch and hope the smoke didn't curl up out of the circuitry. To my satisfaction everything operated quite well. At least there were no catastrophes. Using my Fluke 77 again I checked the output in tracking mode and adjusted the tracking pot so that the two outputs were equal but opposite. I then adjusted the meter pots so that the meters indicated the same as my Fluke.

One note here: The meter movements were obviously not the highest quality. In addition to being fairly clunky in their response, I had some trouble getting them to retain their mechanical zero, probably due to some stickiness in their operation. Even so, they give a fairly good indication of the supply's output and, for precise adjustment another meter can be used.

All in all, Murphy seemed to help us with this one. We ended up with a pretty good supply at a reasonable cost and learned something about op amps at the same time. Moreover, we now have a supply which will be useful in future breadboarding and experimentation. ❐



Completed Power Supply