# AUTO-VIM
# PART I

## A Dual 5–15 Volt Bench Supply with Automatic Voltage and Current Monitors

*by L.B. Cebik W4RNL*

The advent of three and four pin monolithic voltage regulators in both fixed and variable voltage models for two dollars or less each has simplified the construction of bench supplies for the ham shack or experimenter's workshop. A few dollars and a few parts yield perfectly good supplies in the 5 to 15V range, which covers most building and testing needs. Current capabilities depend only on the particular regulator model and the size of the heat sink we choose. It's a snap now to build a well-regulated bench supply!

**Challenges of Convenience**

The new challenge of bench supplies is building in user conveniences. Voltage and current monitoring, for example, are extremely useful. A first glance at the problem, however, suggests the need for at least four meters: a positive voltmeter, a negative voltmeter, a positive ammeter, and a negative ammeter. If the ammeter is to cover more than one range–say, 50 mA and 500 mA full scale–then more manual switching is needed. Short of installing some autoranging, autopolarity DMMs inside the power supply case, the problem of comprehensive power supply monitoring seems either complex or expensive.

Far from it, however. A batch of inexpensive and easily accessible ICs and transistors, along with a few resistors and fewer capacitors, gives comprehensive voltage and current monitoring for most small bench needs. This article describes a half amp bench supply with the following features:

- ± 5 to 15V output with mechanical tracking to within a few hundredths of a volt.
- Automatic voltage monitoring with electronic switching between plus and minus voltages and with manual override for close monitoring of one of the voltages.
- Automatic current monitoring with electronic switching between plus and minus supply loads, again with manual override for close monitoring of one of the current loads.
- Automatic current ranging between 50 mA and 500 mA full scale ranges, regardless of voltage polarity.
- A parts cost of about fifty dollars or less.

Auto-VIM stands for AUTOmatic Voltage and current (I) Monitoring. In addition to providing circuit and construction details on this bench supply, this article supplies enough background to vary the circuits to personal needs. This includes the adaptation of the circuit for use with digital voltmeter circuits. For supply monitoring, I prefer analog meters, but preferences vary according to the type of work prescribed for the bench supplies. In addition, there's a one meter voltage and current monitoring circuit.

**Basic Design Concept**

The basic design of the power supply appears in Figure 1. Since the power supply itself is fairly standard, except for the secondary regulators, which feed a fixed ± 15V to the monitor circuits. A clock (555 or 7555) and flip-flop (4013) provide the control pulses for changing polarity in the two monitors. Connecting the Set and Reset pins of the D-type flip-flop to a switch allows the operator to override the clock and force the circuit to the high-low combination which permits reading either the positive or negative voltages and currents.

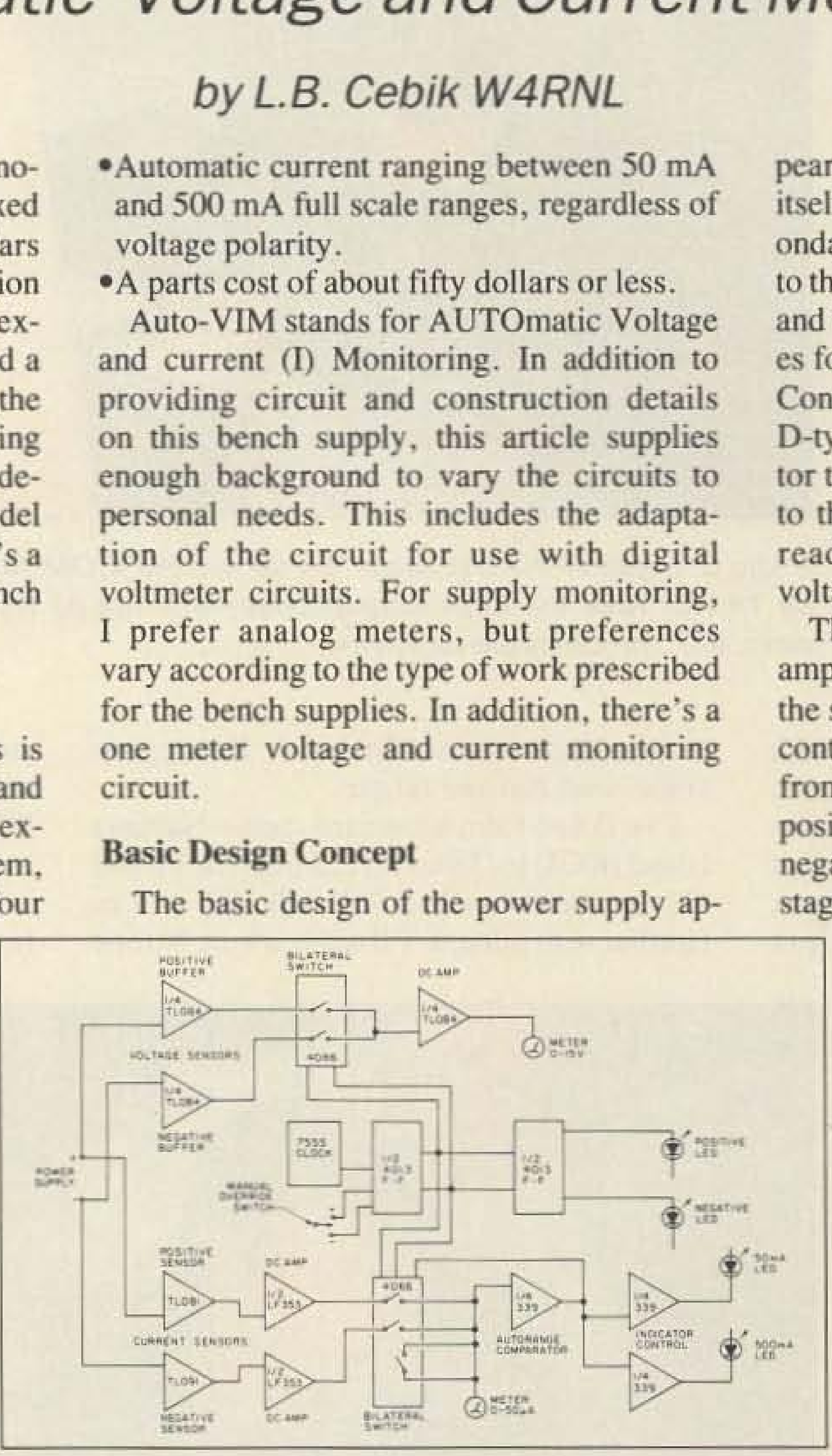

*Figure 1. Block diagram of the voltage and current monitoring system.*

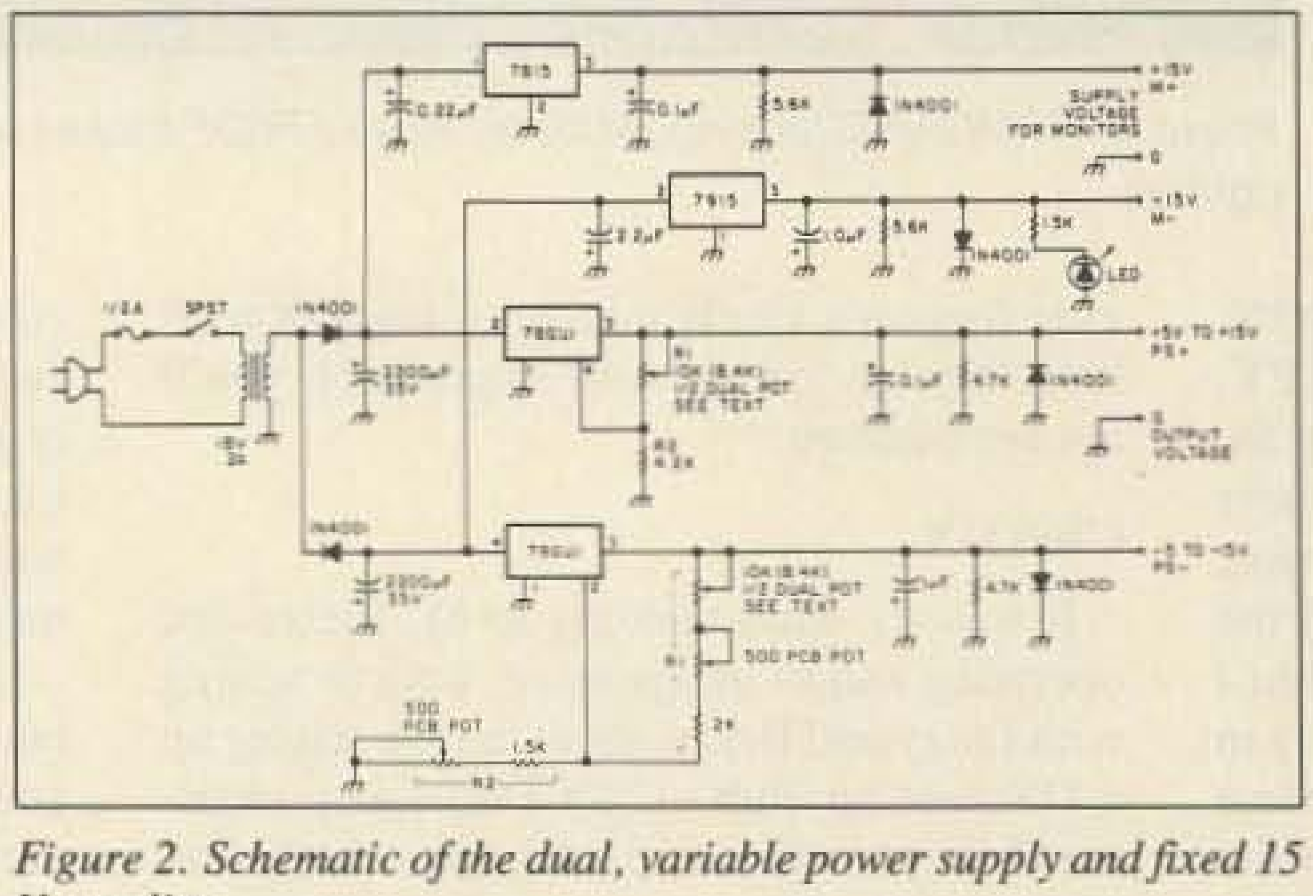

*Figure 2. Schematic of the dual, variable power supply and fixed 15 V supplies.*

The voltage monitor consists of a quad op amp (TL084) used to sense a set fraction of the supply voltage. A bilateral switch (4066) controlled by the flip-flop selects the output from the non-inverting unity gain buffer for positive voltages or the inverting buffer for negative voltages, thus providing succeeding stages with only positive voltages. A non-inverting DC amplifier raises the voltage to a maximum of 10V (well within the linear capabilities of the TL084) for readout by a modified 0-to-15V voltmeter whose external series resistor has been changed to track the DC amplifier output.

The current monitor uses the same flip-flop signals to control another bilateral switch (4066) which feeds voltages from the sensor input stages to the meter. The sensors use both normal Bi-FET (P-channel) and NFET (N-channel) op amps to sense the current drawn from the positive and negative supplies, respectively.

The TL081 and TL091 op amps feed a low level voltage proportional to the current to standard DC op amplifiers (LF353 dual op amp), with the negative voltage inverted so that the meter circuit sees only a positive voltage. Which current-proportional voltage the meter sees is controlled by the 4066. One section of a quad comparator (339) senses the voltage in the meter circuit. Above a certain point (1.2V), it switches in additional meter circuit resistors to increase the range by a factor of ten, thus giving automatic ranging between the 50 mA and 500 mA scales. Unused portions of the

4013 and 339 control panel LEDs indicate polarity and ammeter range.

### Accuracy

Minor inaccuracies introduced by imbalances in the current sensing op amps and calibration errors limit the absolute precision with which the circuits will read out either voltages or currents. Current residuals depend upon the tracking accuracy of the positive and negative supplies, and are minimized by splitting DC amplifier duties between the sensors and the follow-up 353 stage. With careful mechanical adjustment of tracking, these reduce to 2 mA or less (apart from other sources of calibration error).

The accuracy of the voltage monitor depends upon the accuracy of the calibration results. Power supply monitors provide general indications rather than specific measurements of test circuit performance. The latter require more precise measurements with the usual array of test bench equipment. Therefore, an accuracy of 10% in general monitors is usually good enough, and 5% accuracy is more than most applications require. Careful construction and calibration permit these circuits to better the 5% mark plus or minus the inherent accuracy of the analog meters themselves (generally 2 to 3%). These figures suggest that the monitor can provide a valuable service to the builder and experimenter. In fact, it has already saved me nearly its own cost in components that did not die in test circuits.

Achieving good circuit results depends on careful component selection and calibration throughout the supply. Ordinary ham shack-VTVMs and DMMs are fine. In fact, the circuit requires only 5% tolerance components at its critical points, plus some care. The care contributes to the circuit's fairly low cost. In order to catch all the salient circuit features, let's explore the major circuit divisions one at a time.

### Variable Dual Power Supply

Figure 2 shows the dual power supply that forms the core of the project. The supply is standard in almost every feature. The 18V, two amp transformer provides ample reserve capacity for the supply at peak loads, despite the simple half-wave rectifiers. The large filter capacitors minimize ripple to the regulators. Tracking with the 78G/79G series four pin regulators is quite simple, compared to others on the market. Moderate size heat sinks for the TO-202 packages will handle the supply's requirements. The remaining components are standard data book recommendations.

The 7815/7915 positive and negative fixed regulators provide the voltage for the monitor components. For the small load involved (under 20 mA exclusive of BEDs, which are set at about 10 mA each), Zener regulation might do, but the fixed three pin regulators are cheap, nearly foolproof, and run cool without heat sinks.

To establish the values of the control components R1 and R2, measure the actual value of the dual 10kΩ potentiometer. Most inexpensive varieties top out at less than 10kΩ. In my case, I found 8420Ω the maximum value. I obtained several pots and chose the unit whose individual maximum values were most nearly equal. The closer the values, the better the tracking of the two supplies.

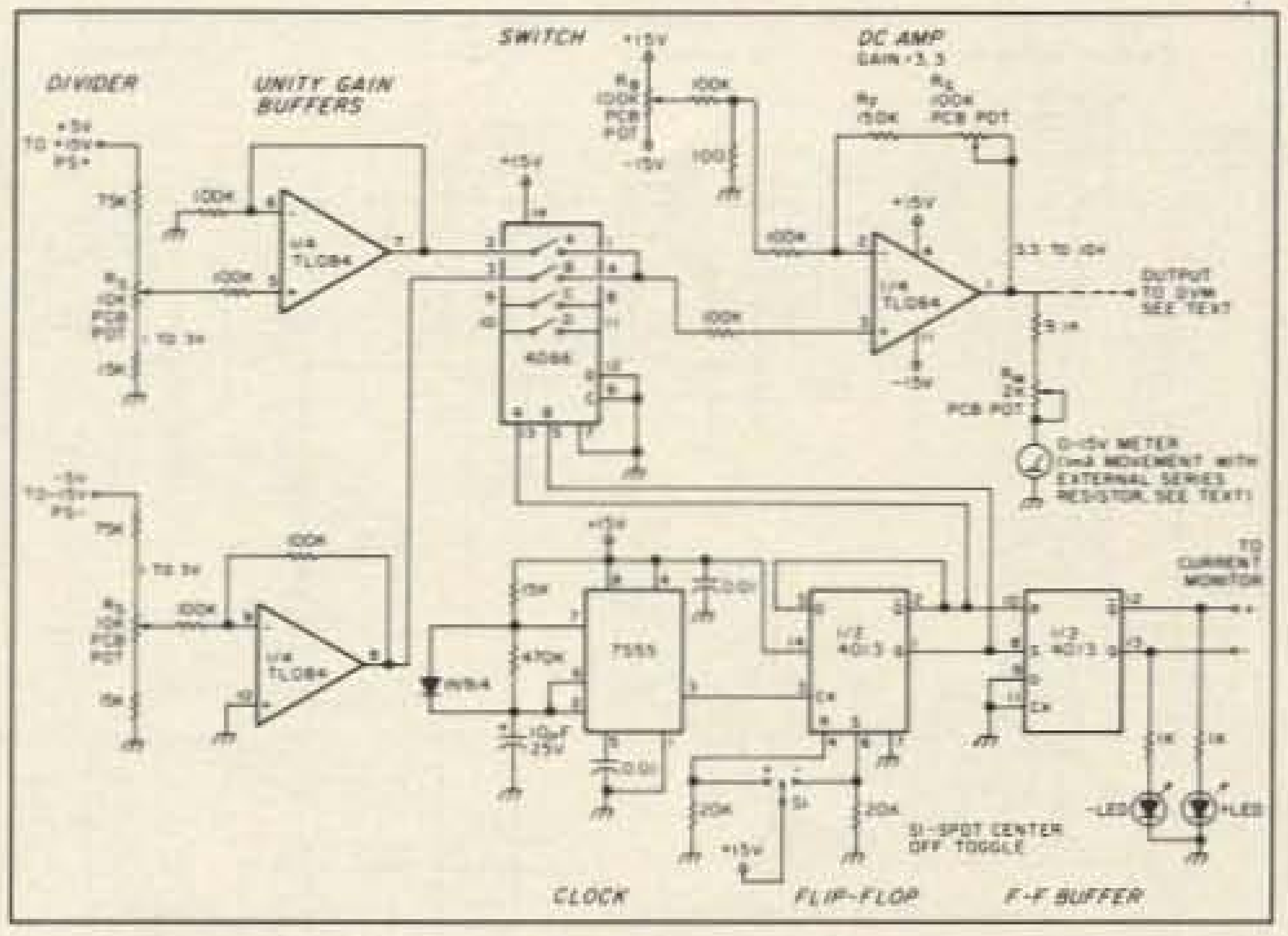


*Figure 3. Schematic of the auto-polarity voltage monitor.*

The rest of the process is a matter of following data book formulas, with a few adjustments. For both regulators, the output voltage (Vo) equals the sum of R1 and R2 divided by R2, with the result multiplied by the control voltage (Vc). For the 78GU1,Vc is 5V, and for the 79GU1 it is 2.23V. The data books recommend a 1 mA control current, which gives 5kΩ and 2.2kΩ for the positive and negative regulator values of R2. With the less than nominal maximum pot value, however, (8420Ω instead of 10 k), 4.2kΩ yielded a positive output range from 5 to 15V with the 78GU1. Applying similar logic to the 79GU1 negative regulator gave a value of 1875Ω for R2 and a series resistor of 2345Ω for the potentiometer leg. Breaking the fixed values into fixed resistors and circuit board trimmer pots yielded the values in Figure 2.

The procedure for calculating the negative regulator values begins with the formula for R1, which equals R2 times the difference between the output voltage (Vo) and the control voltage (Vc), all divided by the control voltage. At minimum output (5V) when the potentiometer is also at minimum, R1 will be 1.25 R2, and at maximum voltage (15V) with the pot also at maximum, R1 will be 5.73 R2. Since the difference between R1 at maximum and minimum is 8400 Ω (the measured range of the pot), 5.73 R2 minus 1.25 R2 will also be 8400 Ω. R2 thus equals 8400 divided by 4.48 (i.e., 5.73 - 1.25), or 1875 Ω. A 1500 Ω fixed resistor plus a 500 ΩPC board trimmer give room for adjustment. Since R1 at minimum (when the pot is at 0 Ω) is 1.25 R2, which we just set at 1875 Ω, then the series resistance for the R1 pot leg of the control circuit will be 2345 Ω. A 2kΩ resistor plus a 500 Ω trimmer again provide room for adjustment.

Calibrating the tracking is easy. Check the positive supply range and later the 4.2kΩ resistor until the output extends from 5 to 15V. When the positive supply voltage range is satisfactory, then set both negative PC board trimmers to midrange. With the dual pot set to minimum value, adjust the trimmer in R2 to let the negative voltage equal the positive voltage (about 5V).

Turning the dual pot to maximum, adjust the trimmer in the R1 leg to let the maximum negative voltage equal the maximum positive voltage. Retrimming both the circuit board pots once more should yield stable results. Now output voltage tracking will depend on how well the dual pot sections track. Even with inexpensive dual pots, the variation should run less than a tenth of a volt between supplies. If the error is greater, but consistently high or low for one supply, then repeat the calibration. If the error varies across the voltage range, a different dual pot may be in order. Careful pot selection can thus save the cost of precision potentiometers and the complexity of electronic tracking circuitry.

As the photographs show, construction is not critical. Perfboard works very well when placing one set of stand-off pillars under the transformer mounting wings, rather than at the corners of the board. Use heat sink grease between the variable regulators and their finned sinks. Also note that the pinouts of corresponding positive and negative regulators differ. Do not let local QRM cause a reversal here! My experience says that at least one of the regulators will fry at first test.

My perfboard construction techniques make use of T-46 pins for off-board connections. In this project, there are many board-to-board and board-to-panel connections, so have a good supply of pins and plan their placement carefully. Since, as the photos show, the project will fill the case, be sure that no pins interfere with cabinet screws.

### Voltage Monitor

The voltage monitor makes use of some automatic metering principles previously reported in *73*, but updates them to eliminate the need for measuring the forward voltage drop of diodes and for taking the drop into account when designing the power supply section. By using op amps to sense a portion of the positive and negative voltages, it's possible to control the voltage and not exceed the op amp limits, while still making accurate measurements. The trade-off for this convenience is the need to calibrate the circuit carefully.

As in the earlier voltmeter circuit, it begins with a timing clock (7555 or 555). The clock circuit provides short square wave pulses, as the on-time is controlled by the 15kΩ resistor. The diode shunts the 470kΩ resistor during capacitor charge, but the discharge goes through the resistor, extending the off-time to about 3 seconds. The 4013 flip-flop provides alternate 3 second periods for reading positive and negative values. The builder can alter the 470kΩ resistor to change the read periods, or insert a 500kΩ circuit board trimmer pot in series with a 330kΩ resistor to provide for an adjustable period.

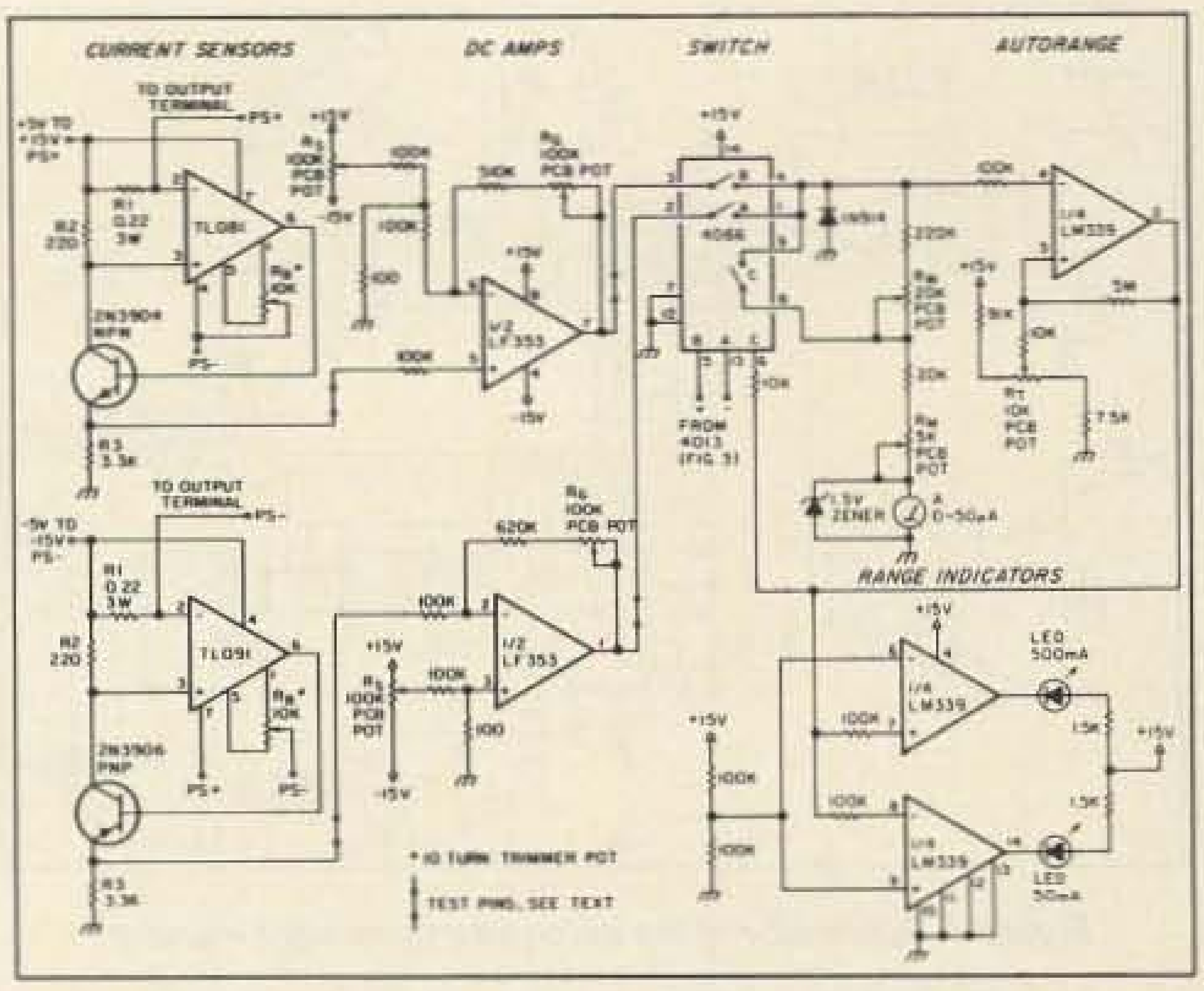


*Figure 4. Schematic of the auto-polarity, auto-ranging current monitor.*

The 4013 D-type flip-flop is in a standard divide-by-two circuit. Be sure to bypass pin 14 to ensure good action. Some combinations of clocks and flip-flops will miss some or even all beats without it. The extra portion of the two-section chip keys the indicator LEDs and provides clocking pulses to the current monitor. The Set and Reset pins (6 and 4) are grounded for clocked operation through 20kΩ resistors. Setting either high with the single pole, double throw, center off toggle switch will override the clock, locking the readout either positive or negative, along with its indicator LED.

If complement-Q controls the positive readout, then a high Reset line locks the circuit for continuous positive readout. Likewise, a high Set pin locks the Q output high for continuous negative readout. Returning the switch to center allows the clock to take over, and the circuit will cycle with the next clock pulse. Thus, There is a simple but effective manual override for the automatic circuit whenever we wish to closely monitor any one of our voltage or current readings.

The voltage sensors consist of unity gain buffers following a simple resistive voltage divider network. Feeding between one-tenth to one-third of the voltage to the buffers ensures that the voltage will never rise to near the op amp supply voltage. Near that point, op amps cease to amplify linearly, and accuracy deteriorates. For this circuit, the network provides 20% of the supply voltage to the buffers. The positive voltage buffer is non-inverting, while the negative buffer inverts. The result is that the rest of the circuit always gets a positive voltage. The circuit is similar to one developed by Pepper (*Radio-Electronics*, March 1983, page 64).

Following the buffers is the 4066 bilateral switch, whose individual switches close when their associated control pins go High according to the output from the flip-flop. The 4066 is an improved version of an earlier switch chip and shows a resistance of only about 80Ω per switch section. This low resistance is insignificant for these circuits. A DC amplifier follows the switch to set the voltage fed to the meter circuit.

For some applications, the builder may wish to use separate DC amplifiers for each buffer and install them ahead of the 4066 switch. A gain of 3.3 provides a maximum of 10V for an analog meter, well within the op amp limits. For use with digital voltmeter circuits, adjust the gain of this amplifier according to need. For example, with an original one-tenth sample at the resistor divider and a unity gain amplifier at this point, the circuit will show .5 to 1.5V for power supply settings of 5 to 15V (either polarity). Digital measurement would thus require only a change in decimal point position.

Since the DC amplifier is non-inverting, the feedback resistor network of Rf and Rg is easily altered. Keeping the 100kΩ trimmer and the 100kΩ input resistor, Rf then equals 100kΩ times the difference of the desired gain and 1, with another 100kΩ subtracted for the trimmer pot. Unlike the unity gain buffers, which require no offset balancing, the DC amplifier shows a remnant offset voltage which detracts from accuracy. The external balance circuit at the inverting input terminal provides easy adjustment for no output when the 100kΩ input resistor to the non-inverting terminal is grounded rather than connected to the 4066.

The analog meter circuit uses a Radio Shack 0-to-15V voltmeter which comes with an external series resistor of about 15kΩ. This circuit replaces the series resistor with another combination to drive the 1 mA meter movement. Since the op amp output voltage corresponds to the sensed voltage, 10V from the DC amplifier equals 15V at the resistor divider terminal. Ten volts at 1 mA requires a 10kΩ series resistor, which is shown as 9.1kΩ plus a 2kΩ trimmer pot for calibration.

Construction is not critical here either, since only DC and slowly timed pulses are involved. Use IC sockets for construction ease. As with the supply board, use pins liberally for off-board connections. The 3 x 3 ½-inch perfboard squares shown in the photos easily hold the circuitry with room to spare. Be sure to place the trimmer pots in easy access areas for calibration after mounting the board in the cabinet. Since lead length makes no difference, mounting all trimmers along the top edge of the board will ease later calibration.

### Voltmeter Calibration

Calibration of the voltmeter is a cinch. Balance the DC amplifier by grounding the 100kΩ input resistor at the switch (4066) end and adjusting the trimmer marked Rb until the output is zero. Adjust the input voltage setting trimmers so that the voltage to the buffers is one-fifth (or the desired fraction) of the power supply voltage. Using a convenient voltage, adjust the DC amplifier gain trimmer, Rg, so that the output is 10V (or the desired amount) for 15V from the power supply. Finally, set the meter trimmer, Rm, so that the meter shows 15V for 15V from the power supply. The only other cautions concern the flip-flop. Identify the positive and negative control lines and be sure that the manual override switch and indicator LEDs correspond correctly to these lines. Identify the positive and negative control lines for the current measuring circuit so that the meters will read together.

### Current Monitor

Although voltage monitoring circuits are growing more common in bench supplies, there's still little useful current monitoring. A single meter for gross current measurement provides little help for monitoring low current circuits, while a sensitive meter pegs long before the supply nears its maximum rated output. Automatic monitoring of both positive and negative current drain appears only in expensive industrial and lab equipment in the $2,500-and-up class. A simple, reliable, and effective current monitoring circuit, however, has long had a place in the data books.

The current monitor in Auto-VIM owes much to National Semiconductor's Linear Databook circuit for routinely converting current drain to a voltage output without resorting to ultra-precise resistor matching.

The sensor circuits in Figure 4 use different op amps to sense positive and negative current flow. The TL081 (or LF351) Bi-FET op amp uses P-channel inputs which work with input voltages close to the positive supply value, but fail as the input voltage approaches the negative supply voltage. By contrast, the newer TI NFET op amp, the TL091, with its N-channel inputs, shows precisely the opposite characteristics. Between the two, we obtain separate but parallel sensors for positive and negative supply currents.

The transistors, whose base current is controlled by the op amp output, control the voltage seen at the 3.3kΩ resistor. In fact, the circuits provide an output voltage per mA of line current equal to .001 times the product of R1 and R3 divided by R2. The circuit shown provides .0033V per mA, or 1.65V at 500 mA. Sensor circuit output is positive for the TL081/2N3904 combination and negative for the TL091/2N3906 duo. Although most data book circuits show FETs rather than transistors used with the FET input op amps, the bipolar transistors work better at the 5V end of the power supply range. Note the 10-turn trimmer pots marked Rb, which will receive attention during circuit calibration.

A DC amplifier follows each sensor to increase the voltage to a level desired for measurement. As with the voltage monitor, the negative amplifier inverts while the positive does not, thus yielding positive voltages for the bilateral switch. Each amplifier has a gain of 6.7 so that the metering circuit will see 12V at 500 mA, which is within the linear range of the op amps and within the switching range of the 4066. Each section of the LF353 includes an offset balancing circuit to decrease errors introduced by remnant voltage outputs. *(to be continued)*