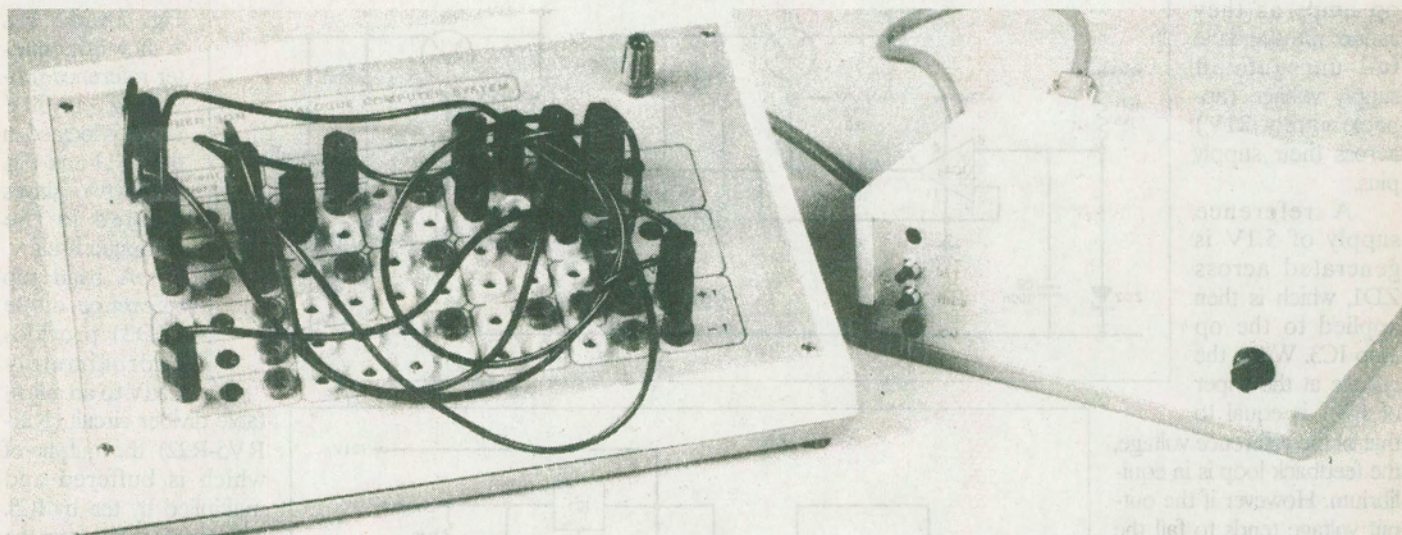# Build an Analog Computer

The first part of a project for a small simple-to-build analog computer circuit for education or experiment.

PAUL CUTHBERTSON

Many of the early analog computers were true monsters, requiring four strong persons to lift them, and then with some difficulty. Fortunately, modern integrated circuits have come to the rescue and we can build a sensible small computer which, although no match for the performance standards and facilities of the bigger ones, represents considerable saving in weight, cost and power consumption.

This computer provides eight summing amplifiers, six coefficient multipliers and four integrators with over and under voltage indication. It is housed in two boxes — the power supply and the computer itself — with a cable connecting the two. The PSU can power a number of other units if the user wishes to install extra connectors for this.

There are controls for SET and HOLD on the power supply. The front panel of the computer is rather more complex. There is an overvoltage indicator, the four integrators, eight summing amplifiers,

six coefficient multipliers and outlets for the +/-10V references.

Such a small system is useful in a school or university laboratory or anywhere that experiments are done on control systems and such.

Mathematicians might like to note that in its present form the computer will solve linear differential equations, but not those which involve a function of two variables. Nor does it provide exponentiation or sinusoidal functions. However, the equipment to do this can be easily designed and if there is sufficient call for it, perhaps a future article may be devoted to such a unit. Even in its present form the system can be usefully employed in a number of ways in the lab.

Construction

Start assembly with the PSU. Mount all the PCB components first. Figure 4(a) shows the component overlay for the PSU board.

If a PCB-mounting transformer is difficult to obtain, a chassis-mount can be used, with wire links running to the ap-

propriate points on the board.

Now solder the smaller components in place, making sure metal film resistors are fitted in the right places. Lastly, fit the transformer and mount the power transistors on their heatsinks. The transistors should be fixed to the heatsinks before inserting and soldering to the board. No insulator is needed.

Mount the board into the case with the transformer to the rear and drill the four fixing holes in the case base in line with the mounting holes in the PCB. Drill a hole for the mains cable, fit a grommet and solder the neutral and ground wires directly to the board with the 100mA fuse in line with the live connection.

Bolt the board to the case and after drilling holes and mounting the two switches (SET and HOLD), the LED and the power D- connector, wire them to the board as shown in Fig. 5. The connector blocks are not essential and the wiring can be made directly to the PCB, but removable connectors enable the board to be easily taken from the case for repair or alteration.

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The PSU

The power supply provides +/-7V and +/-15V for any computer unit to use as well as the SET and HOLD signals.

The circuits for positive and negative halves of the PSU are practically identical and are shown in Fig. 1.
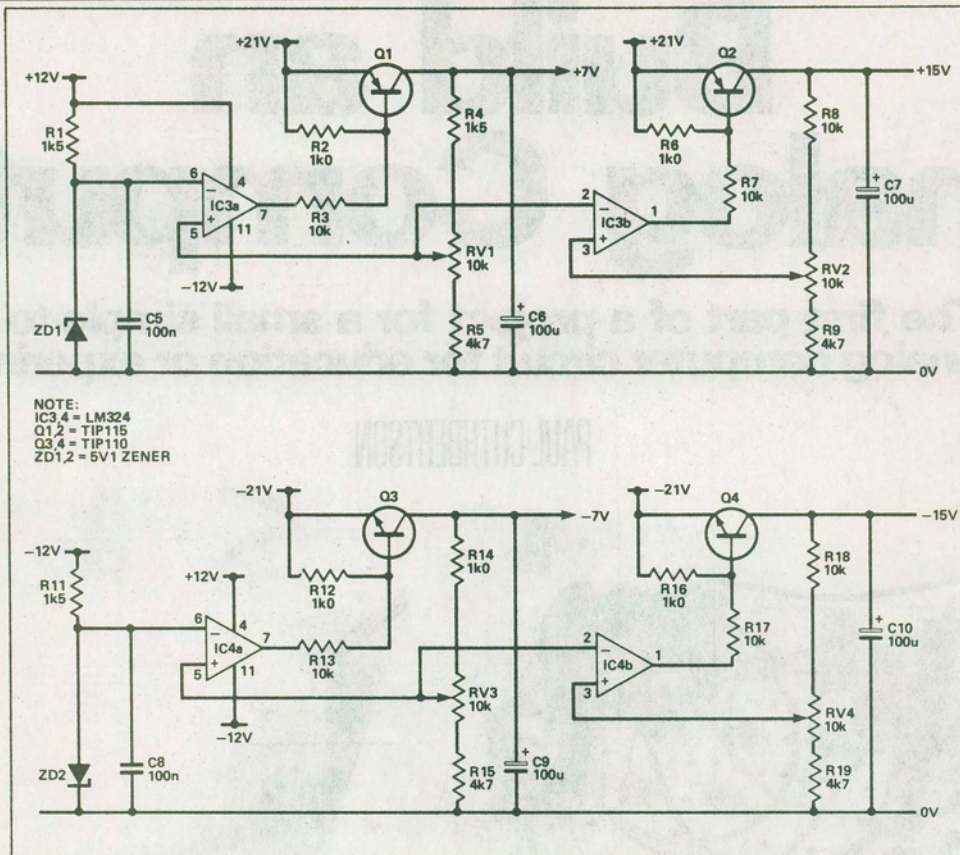
Preregulators, IC1,2 give +/-12V to power the PSU op amps as they cannot withstand the full unregulated supply voltage (approximately 21V) across their supply pins.

A reference supply of 5.1V is generated across ZD1, which is then applied to the op amp IC3. When the voltage at the wiper of RV1 is equal to that of the reference voltage, the feedback loop is in equilibrium. However if the output voltage tends to fall the op amp drives negative, causing more current to flow in the series pass transistor Q1 and thereby raising the output voltage. Similarly if the output voltage rises, the op amp output goes positive, cutting down the current flowing in the pass transistor.

Resistors R2,3 are chosen so the pass transistor is able to cut off when the op amp output is at or near the op amp supply voltage.

Very little current flows in the OV line. It isn't power supply line as such, but provides a 0V reference for signals. This results in quiet, stable operation.

A similar circuit derives the +/-15V supply. A special feature is that the 15V supply tracks the 7V supply. The 15V supply will not reach its full voltage if the 7V supply is pulled down or has failed for any reason. This protects the CMOS circuitry which uses the 7V supplies but which may be fed from circuits employing the 15V supplies. The tracking is ac-
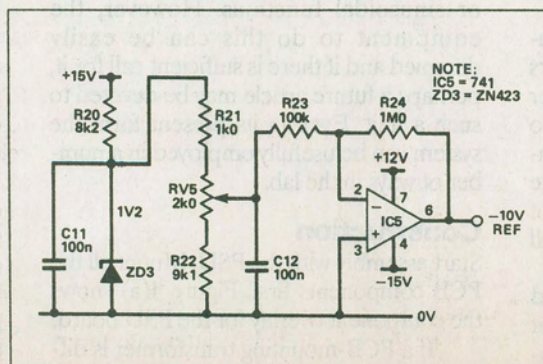
complished by using the feedback signal from the 7V supply as the reference voltage for the 15V supply.

The performance of the supplies as regards load regulation and drift is quite exceptional.

Voltage Reference

The voltage reference are shown in Figs. 2 and 3. Fig. 2 shows the master reference providing -10.00V which is located in the PSU and Fig. 3 the two slaves located in the computer itself.

A band gap reference diode (ZD3) provides approximately 1.26V to an adjustable divider circuit (R21-RV5-R22) the output of which is buffered and multiplied by ten by IC5. This circuit is fed from the +12V and -15V supplies — if the -15V supply should fail then the master reference will be not provide possibly damaging voltages to other circuits.

Note that if the ZN423 or MP5010GN voltage reference diodes are not available, the required 1.2V can be obtained by substituting two silicon diodes (1N914, 1N4148, etc) in series (with the cathodes to the 0V line). This is not a precision reference by any means, and will drift with temperature changes. However, it will allow circuit operation for experimenting.

The positive and negative slave references are an inverting and a non-inverting buffer respectively. Their gains are slightly adjustable (about 1% either side of unity) giving fine control over the reference voltage.
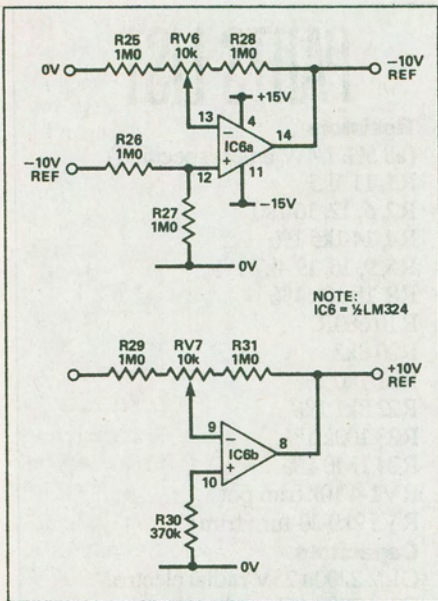
Multipliers

One of the coefficient multipliers is

Fig. 1. The power supply circuit diagram.
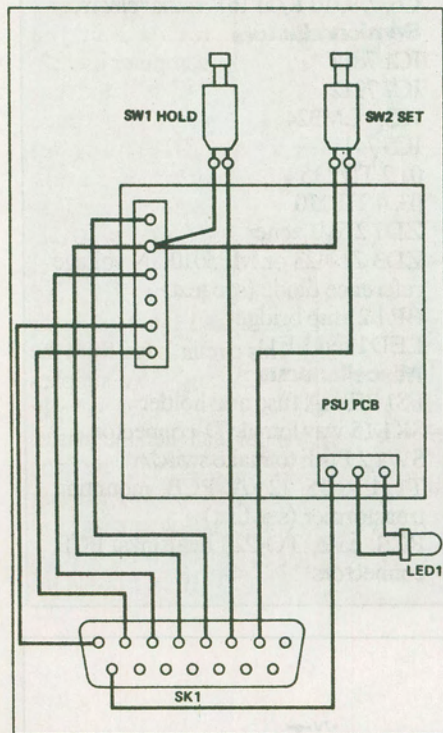
NOTE:
IC3,4 = LM324
Q1,2 = TIP115
Q3,4 = TIP110
ZD1,2 = 5V1 ZENER

NOTE:
IC1 = 7812
IC2 = 7912
BR1 = W005
FS1 = 100mA FUSE

Fig. 2. The -10.00V reference source.

NOTE:
IC5 = 741
ZD3 = ZN423

Fig. 3. The voltage reference buffers.

NOTE:
IC6 = ½LM324

Fig. 4(b). Wiring the socket and switches.

Fig. 5. The multiplier circuit.

NOTE:
IC900 = ¼LM324
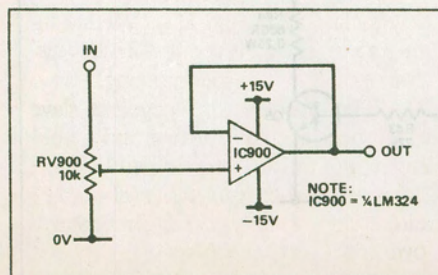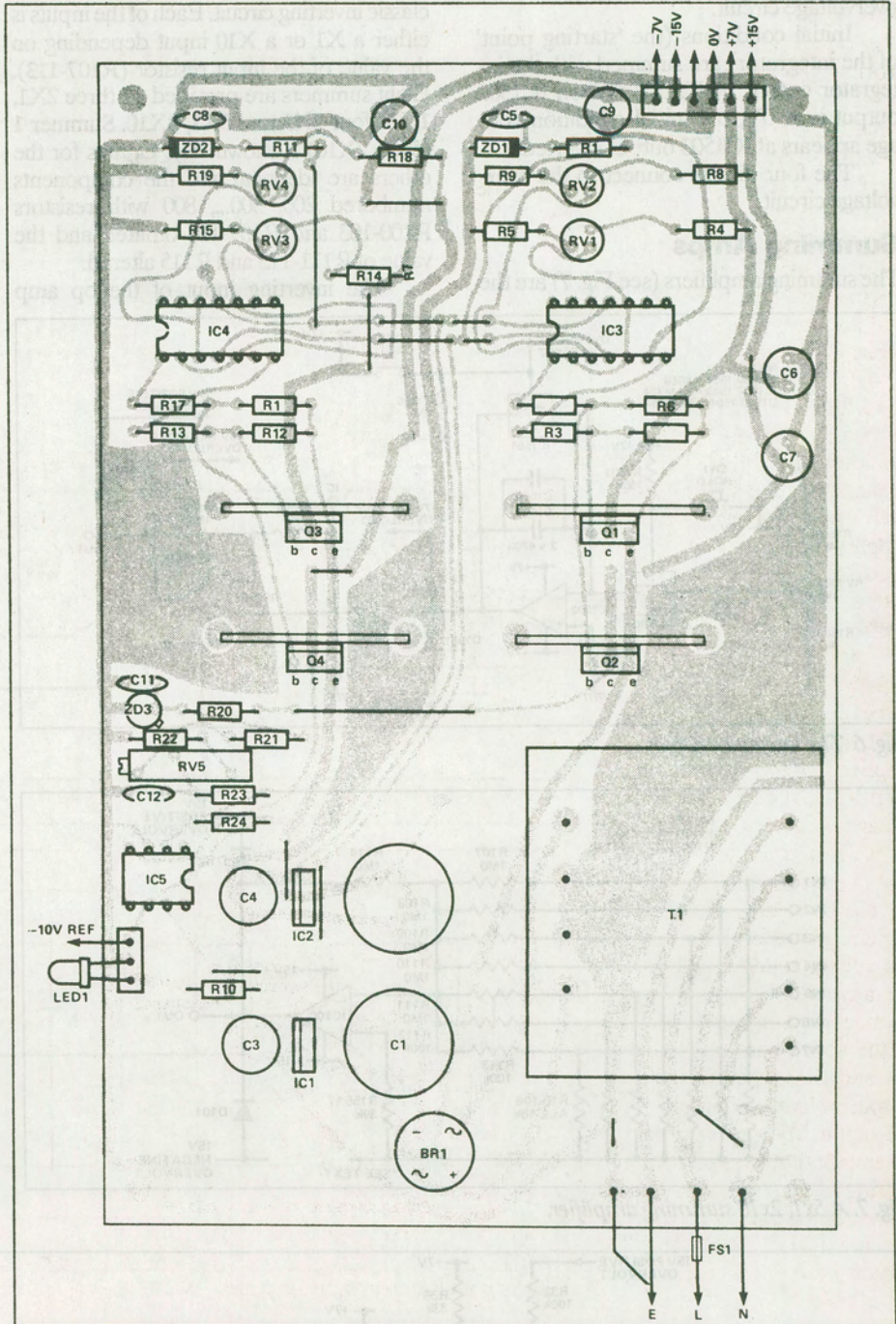
Fig. 4(a). The component overlay for the power supply.

shown in Fig. 5. These are simply poten-tiometers with a buffer amplifier on the out-put. The potentiometer is mounted on a small board at the front panel. The op amps are on the main board. The circuits for each are identical and numbered 900-1400.

Integrator

An integrator is shown in Fig. 6. The resis-tors R1500-RV1500- R1501 attenuate the incoming signal by a factor of two to render it safe for use in the analog switch, IC1500.

RV1500 adjusts the time constant of the in-tegrator. When the HOLD pushbutton is released, the analog switch IC1a is closed, allowing a current to flow in R1502, charg-ing the parallel integrating capacitors C1500, 1501 and causing the output voltage of op amp IC1502 to ramp. Pressing HOLD opens IC1a and integration stops, regardless of the input voltage.

Pressing SET close IC1501, shorts the integrating capacitor and discharges it. The SET line also forces a reset of the

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overvoltage circuit.

Initial conditions (the 'starting point' of the integrator) are summed with the integrator output by IC1503. When IC1502 output is at 0V, the initial condition voltage appears at IC1503 output inverted.

The four diodes connect to the overvoltage circuit.

Summing Amps

The summing amplifiers (see Fig. 7) are the classic inverting circuit. Each of the inputs is either a X1 or a X10 input depending on the value of the input resistor (R107-113). Eight summers are provided — three 2X1, 1X10 four 3X1 and 5X1, 2X10. Summer 1 (5X1, 2X10) is shown. The circuits for the others are identical and the components numbered 200, 300..., 800 with resistors R100-103 and R107-110 omitted and the value of R111-113 and R115 altered.
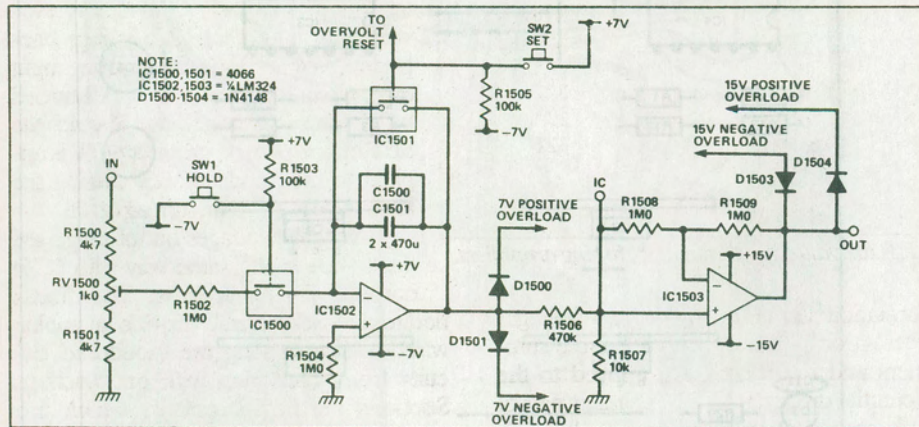
The inverting input of the op amp
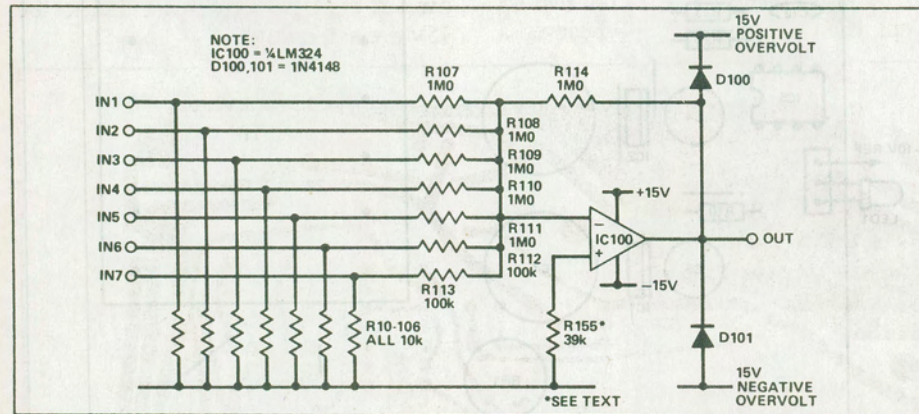

Fig. 6. The integrator circuit.
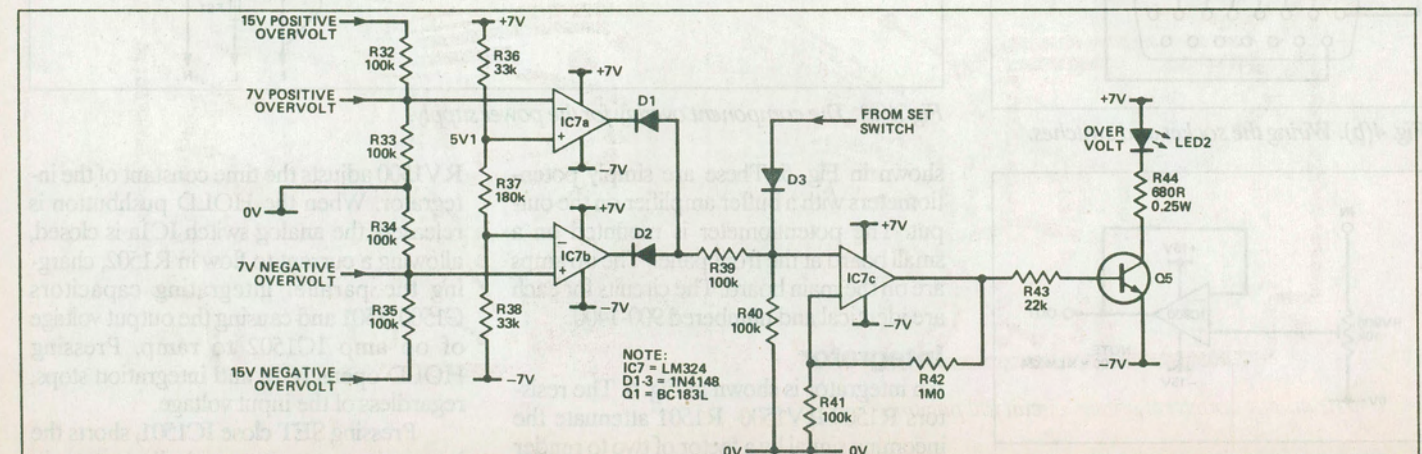

Fig. 7. A 5x1, 2x10 summing amplifier.

Fig. 8. The overvoltage warning circuit.

(C100) is maintained as a virtual ground point. The currents from all the inputs are summed at the inverting input of the op amp. The sum of these current flows in the feedback resistor (R114).

When inputs are unused, offset voltages due to bias currents might be a problem. These tiny currents need an external path to flow in. We need not tie unused inputs to 0V when using the computer, since the grounded 10K (resistors) R101-107 provide a path for the input bias currents to follow.

Looking at it another way, when an input is unplugged, the impedance seen by the op amp input does not change as much as it might, as there is a (relatively) small resistor shorting the other end of the input resistor to 0V. A similar technique is employed at the integrator inputs as well.

The resistor on the non-inverting input (R115) of any op amp is always chosen to be approximately equal to the parallel value of all the input resistors (R107-113). See Table 1 for a list of the values used in these circuits.

The two diodes D100, 102 route the output voltage to the overload detector. More on this later.

Overvoltage

The overvoltage circuit is shown in Fig. 8 and consists of a window comparator and a latch. The potential divider R36-38 develops approximately +5.1V at the non-inverting input IC7 and -5.1V at the inverting input. Two rails carrying in-

SUMMING AMP	INPUT RESISTORS		R107
	1M0	100k	(207 . . .) VALUE
5×1, 2×10	Five	Two	39k
3×1	Three	—	330k
2×1, 1×10	Two	One	82k

Table 1. R107 values for different summing amplifiers.

formation about the maximum voltages present on any of the outputs of the summers and integrators, are applied to the potential divider R32, 33. A similar pair of rails concerned with minimum voltages is applied to the divider R34, 35.

Normally the outputs of the two op amps IC7a, b are positive. Whenever a

voltage greater than about 10.2V plus one diode drop appears on the 15V overvolt rail or a voltage greater than about 5.1V plus one diode drop is applied to the 7V overvolt rail, the op amp IC7a will go negative, pulling down the inverting input of IC7c via D1 and R39. The output of IC7c will swing positive, turning on 05 and LED2.

Due to the hysteresis (positive feedback) applied by R41, 41, IC7c stays latched in the positive condition, even when the output of IC7a swings back positive. R40 ensures the inverting input of IC7c stays at 0V when not disturbed by an overvolt condition. Should the SET button now be pressed, +7V is applied to the anode of D3, causing the latch IC7c to be reset, turning off 05.
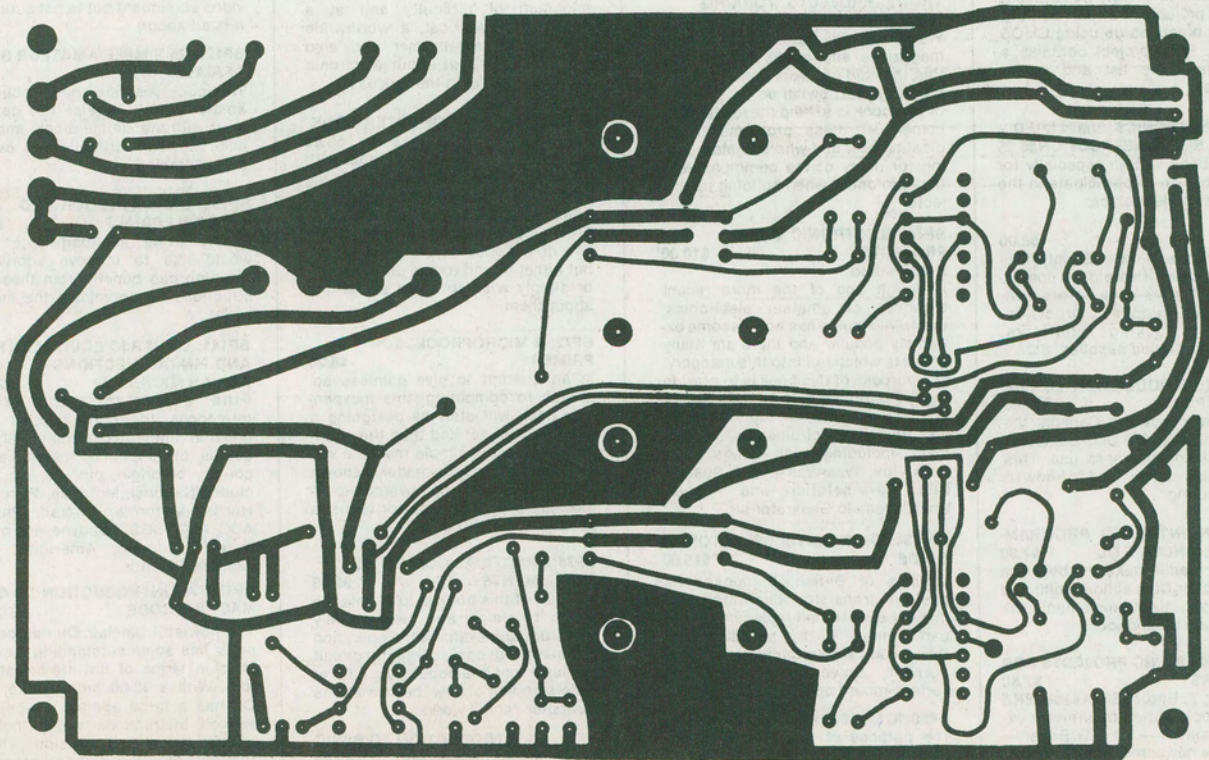
Negative voltages out of range are dealt with in the same way with IC7b output swinging negative. The diodes tied to the overvolt rails provide an analog wired-0R, preventing the monitored circuits from interfering with one another. Sections of the integrators which are powered from +/-7V (and cannot be expected to attain 10V) are tied to the 7V overvolt rails. All others are tied to the 15V overvolt rails. ■

The analog computer printed circuit foil pattern.