WORKING WITH VOLTAGE COMPARATORS

Voltage-comparators and window-comparators are extremely versatile circuits. Here are some practical circuits that you can put to use.

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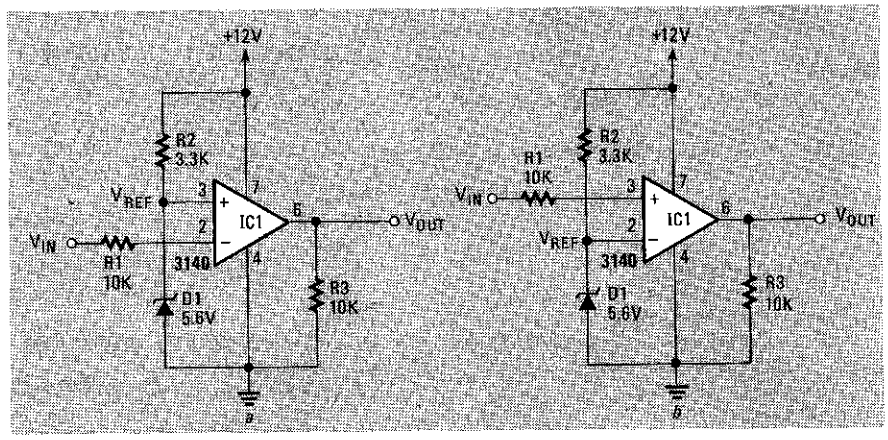

FIG. 1—BASIC VOLTAGE-COMPARATOR CIRCUITS.

WE'RE SURE THAT YOU CAN THINK OF many applications for a voltage comparator: a circuit that abruptly changes its output state when an input voltage crosses a certain reference value. Voltage comparators have plenty of practical applications apart from the obvious ones of over- and under-voltage switches. The number of applications becomes especially apparent when you realize that the voltage can be representing resistance, temperature, light-level, and more.

Voltage comparators can readily be made to activate relays (or alarms, or other circuits) when load currents (or temperatures, light levels, etc.) go outside of—or come within—preset limits. We'll look at some practical circuits in the next few pages.

Basic voltage comparator circuits

The easiest way to make a voltage comparator is to use an op-amp such as the CA3140; two basic configurations are shown in Fig. 1. The 3140 op-amp has a typical open-loop, low-frequency voltage gain of about 100 dB, so its output can be shifted from the high to the low state (or vice versa) by shifting the input voltage a mere 100 µV (microvolts) or so above or below the reference voltage value. The CA3140 can be powered from either a single-ended or split power supply and it provides an output that typically swings to within a couple of volts of its positive rail or to within a few millivolts of its negative (or zero) supply rail. Unlike many other op-amps, the 3140 can accept input voltages all the way down to the negative rail value.

The operation of the circuit in Fig. 1-a is very simple: A fixed reference-voltage (V_{REF}) is generated via the combination of R2 and Zener diode D1. It is applied directly to pin 3, the non-inverting input terminal of the op-amp. The input or test voltage V_{IN} is applied to the inverting input terminal (pin 2) via current-limiting resistor R1. When V_{IN} is below V_{REF} the op-amp output is driven high (to positive saturation), but when V_{IN} is above V_{REF} the output is driven low (to negative saturation). That response is shown graphically in Fig. 2-a.

By simply interchanging the connections to pins 2 and 3, the action of the circuit can be reversed; the op-amp output is normally low, but goes high when V_{IN} exceeds V_{REF}. That circuit is shown in Fig. 1-b, and its response is shown graphically in Fig. 2-b.

There are a few points worth noting about the basic single-supply voltage-comparator circuits in Fig 1. The first point is that the reference voltage can be given any value from zero up to within 2 volts of the positive supply-rail. Thus, either circuit can be made to trigger at any desired value between those limits by simply interposing a potentiometer between a fixed voltage-reference source and the "V_{REF}" pin of the op-amp.

The second point to note is that the voltage-input pin of the op-amp must be constrained to the range from zero volts up to within 2 volts below the positive supply-rail value. Thus, if you want the

FIG. 2—THE ACTION OF THE VOLTAGE comparators shown in Fig. 1 is shown graphically here.

circuit to trigger at some high value of input voltage, you will have to feed the input voltage to a simple voltage divider before the op-amp input.

The final point to note about the basic voltage-comparator circuits is that they give a non-regenerative switching action, so that the op-amp is driven into the linear (non-saturated) mode when the input voltage is within a few tens of microvolts of V_{REF}. Under that circumstance, the op-amp output generates lots of spurious noise and that output will vary with slowly varying input signals. In some applications, that may be unacceptable. The problem can be overcome by using positive feedback, so that a regenerative switching action is obtained. The feedback signal introduces a degree of hysteresis in the voltage switching levels; the degree of hysteresis is directly proportional to the amount of feedback.

Special voltage-comparator circuits

Figures 3 to 7 show how the three points mentioned above can be put to practical use to make various types of "special"

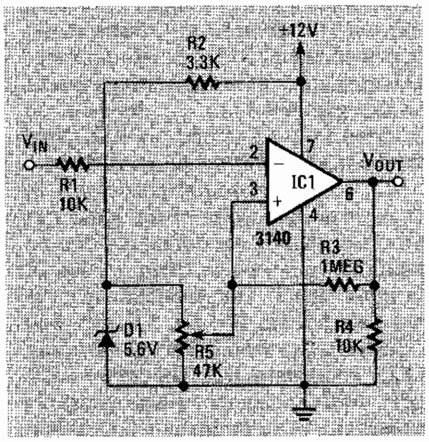

FIG. 3—THIS UNDER-VOLTAGE SWITCH lets you vary the V_{REF} trip point and offers regenerative feedback.

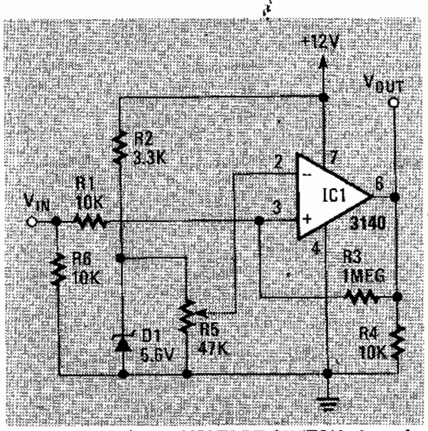

FIG. 4—THIS OVER-VOLTAGE SWITCH also offers regenerative feedback and adjustment of V_{REF}

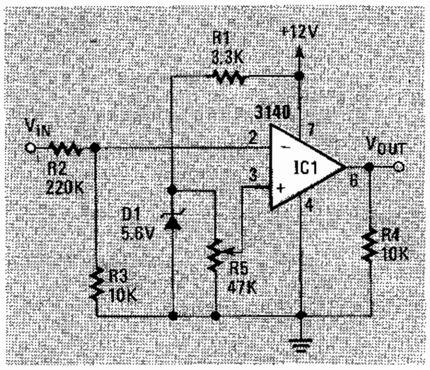

FIG. 5—A VOLTAGE DIVIDER allows us to use the voltage comparator to give high-value, variable-voltage triggering. This circuit does not offer regenerative switching.

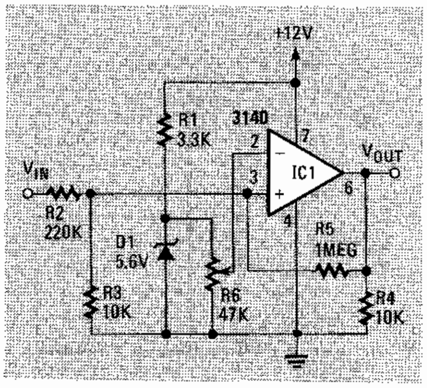

FIG. 6—THIS CIRCUIT, like that in Fig. 5, gives us high-value, variable-voltage switching. It offers regenerative switching.

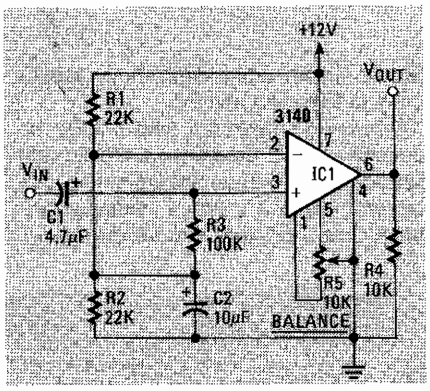

FIG. 7—THIS SINEWAVE-TO-SQUAREWAVE converter needs an input of under 100 mV to provide a 10-volt P-P squarewave output. The circuit can be used to about 15 kHz.

voltage-comparator circuits; plenty of other variations are possible. For example, Figs. 3 and 4 show how the basic comparator circuits can be modified so that the switching voltage can be varied by using a potentiometer (R5) to set the desired reference or trigger voltage at any value in the range 0–5.6 volts and to give regenerative (noiseless, snap-action) switching by feeding part of the op-amp output back to the non-inverting-terminal via R3. Note that in Fig. 4, the circuit's input terminal is terminated via R6 to ensure controlled hysteresis.

Figures 5 and 6 show examples of how the circuits can be modified to give high-value, variable-voltage (0–150 volt) triggering by interposing a simple voltage divider (R2 and R3) between the input signal and the input of the op-amp: The circuit in Fig. 5 gives non-regenerative switching, while that in Fig. 6 gives regenerative switching.

Figure 7 shows how the comparator can be used as a sensitive audio converter that converts sinewaves to squarewaves. It can operate from input-signal amplitudes as low as 10 mV peak-to-peak at 1 kHz and can produce decent squarewave outputs from sinewave inputs with frequencies up to about 15 kHz. The converter's input impedance is 100K. The operation of the circuit is rather simple: The voltage divider made up of R1 and R2, and capacitor C2 apply a decoupled reference voltage to pin 2 of the op-amp and an almost identical voltage is applied to signal-input pin 3 via isolating resistor R3. When a sinewave is fed to pin 3 via C1, it swings pin 3 about the pin-2 reference level, causing the op-amp output to transition at the "zero voltage difference" cross-over points of the input waveform and produce a squarewave output. Potentiometer R5 is used to bias the op-amp so that its output is just pulled low with zero input signal applied (so that the circuit operates with maximum sensitivity and stability). Because of the gain-bandwidth product characteristics of the op-amp, circuit sensitivity decreases as input frequency increases.

Window comparators

The voltage-comparator circuits that we have looked at so far give an output transition when the inputs go above or below a single reference-voltage value. It's a fairly simple matter to interconnect a pair of voltage comparators so that an output transition is obtained when the inputs fall between, or go outside of, a *pair* of reference-voltage levels. Figure 8-a shows the basic configuration, which is known as a window comparator.

The action of the circuit is such that the output of the upper op-amp goes high when V_{IN} exceeds the 6-volt V_U (upper limit) reference value, and the output of the lower op-amp goes high when V_{IN} falls below the 4-volt V_L (lower limit) reference value. By feeding the outputs of the two op-amps to R4 via the D1-D2 diode OR gate, we get the situation where the final output is low when V_{IN} is within the limits set by V_U and V_L, but goes high when the input is outside those limits.

By taking the output via a simple inver-

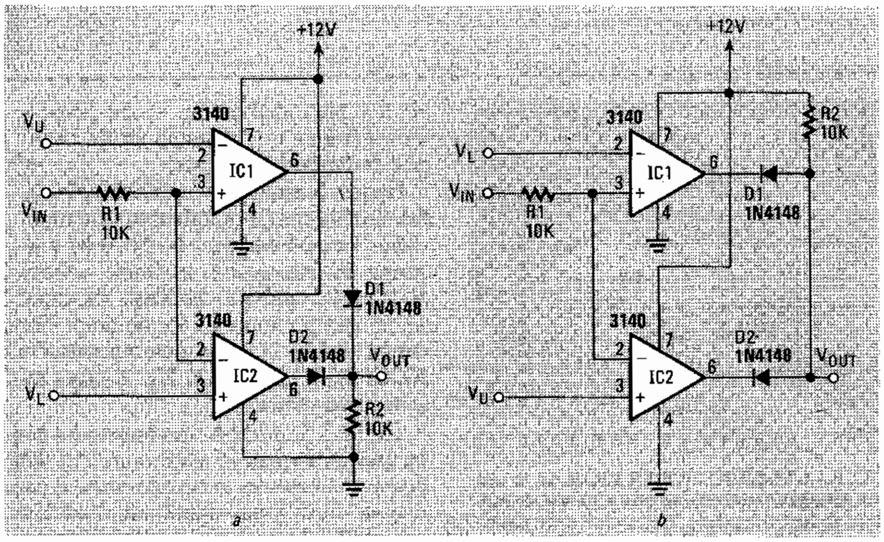

FIG. 8—TWO WINDOW COMPARATORS. When V_{IN} is outside the window determined by V_U and V_L; the output of the circuit in *a* goes high while the output of the circuit in *b* goes low.

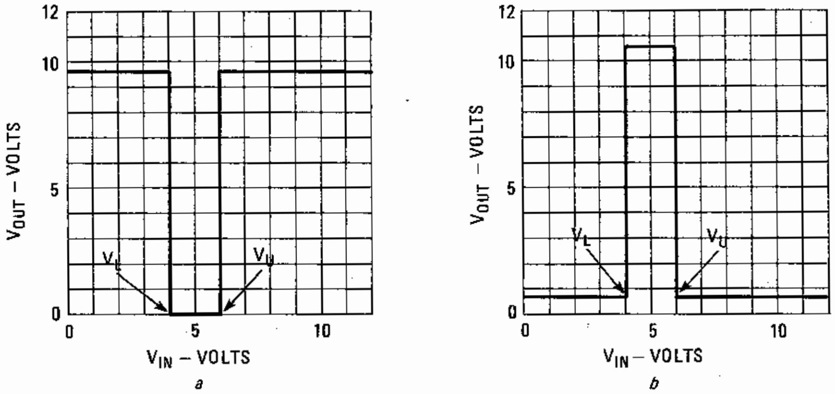

FIG. 9—THE ACTION OF THE WINDOW COMPARATORS shown in Fig. 8-a and 8-b are shown here in *a* and *b* respectively.

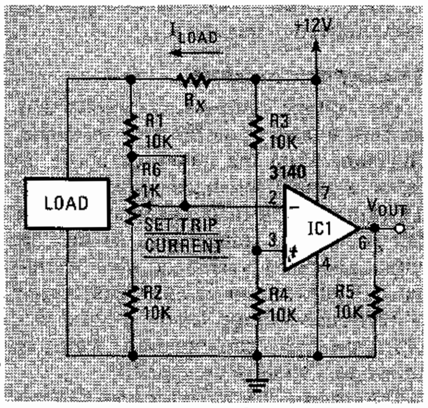

FIG. 10—OVER-CURRENT SWITCH. The output goes high when the load current exceeds a value determined by the setting of R6. By reversing the connections to pins 2 and 3 of IC1, the output will go low to signal the over-current condition.

ter stage, the action of the circuit in Fig. 8-a can be reversed so that its output goes high only when the input voltage is within the "window" limits. Alternatively, the required action can be obtained by transposing the two reference voltages and taking the output via a diode AND gate, as shown in Fig. 8-b. The actions of the two circuits shown in Fig. 8 are shown graphically in Figs. 9-a and 9-b.

Window comparators can readily be made to activate from any parameter that can be turned into an analog voltage, in the same way as a "normal" voltage comparator can. Let's look at some examples.

Analog-activated comparators

Figure 10 shows how a comparator circuit can be made to function as an over-current switch that gives a high output when the load current exceeds a certain value—which you can choose via potentiometer R6. The value of R_X is chosen so that it drops roughly 100 millivolts at the required trip point. Thus, a fixed reference voltage of 1/2 the supply voltage is fed to pin 3 of the op-amp via the voltage divider made up of R3 and R4. A similar but current-dependent voltage is fed to pin 2 via R_X, R1, R6, and R2. In effect, those two sets of components are configured as a Wheatstone bridge—with one side feeding pin 3 and the other side feeding pin 2—and the op-amp is used as a bridge-balance detector. Consequently, the trip points of the circuit are not significantly influenced by supply-voltage variations but are highly sensitive to load-current variations.

By simply transposing the connections to pins 2 and 3, the action of the circuit in Fig. 10 can be reversed so that it functions as an *under-current* switch: The circuit can then be used as a lamp- or load-failure indicator in cars, test gear, etc.

Figure 11 shows the circuit of a sensitive AC over-voltage switch that gives a high output when the input signal exceeds a peak value (6 mV to 111 mV) that is preset via potentiometer R12. The AC input signal is applied to the non-inverting input of variable-gain amplifier IC1. Its gain can be varied from 45 to 850 via R12. Note that the input of IC1 is DC-grounded via R1-R2, so the op-amp responds only to the positive half-cycles of the input signal. Consequently, the output of IC1 is an amplified, half-wave-rectified version of the input signal. That rectified signal is peak-detected via R5, D1, C2, R6, and R7, and is fed to the input of non-inverting voltage comparator IC2. The circuit's output is positive when the voltage across C2 exceeds the value on the junction of R8-R9.

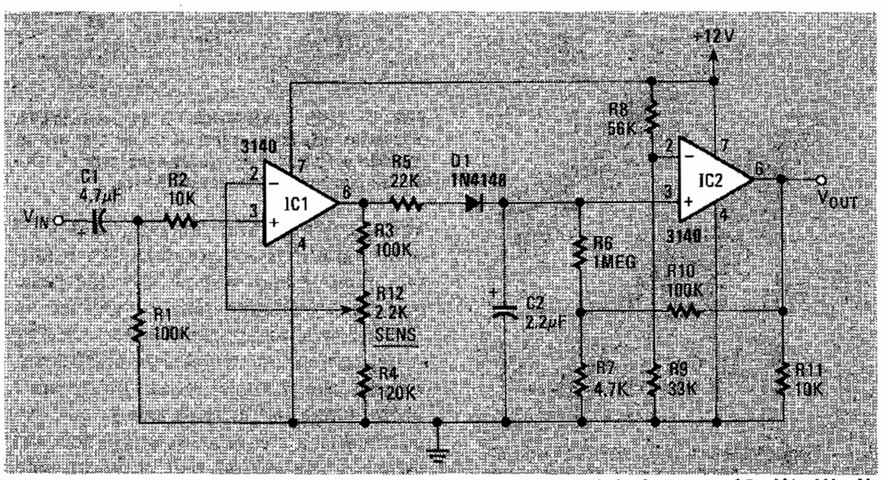

FIG. 11—AC OVER-VOLTAGE SWITCH can be triggered by input signals in the range of 6 mV to 111 mV peak.

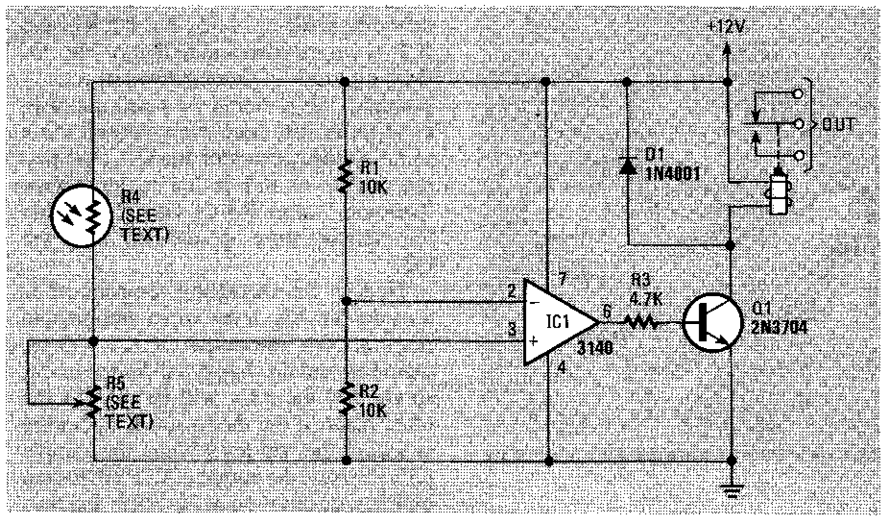

FIG. 12—THIS PRECISION OVER-TEMPERATURE SWITCH will control a relay.

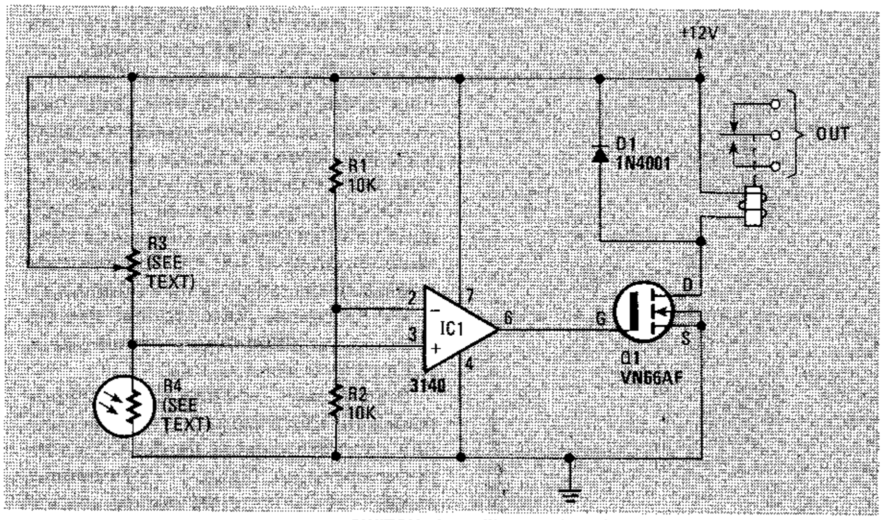

FIG. 13—THIS UNDER-TEMPERATURE SWITCH also will control a relay.

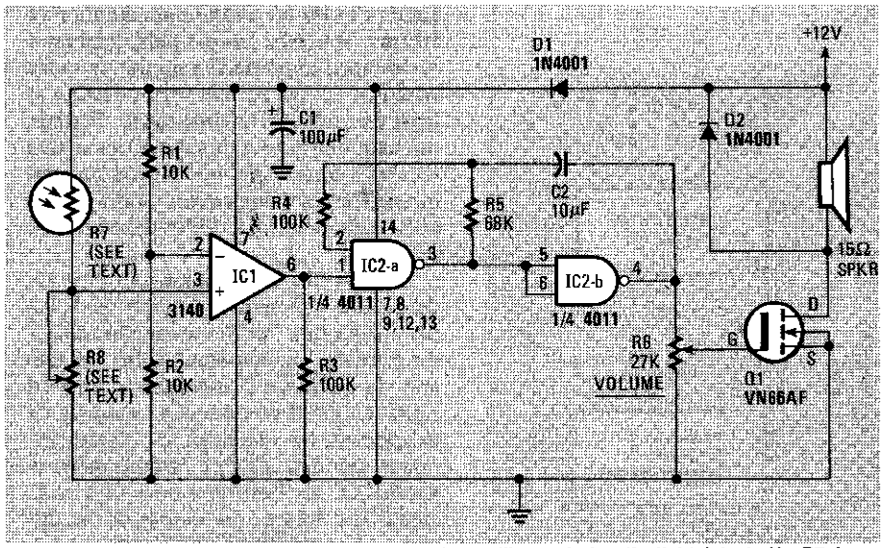

FIG. 14—LIGHT-OPERATED SWITCH. A monotone alarm will sound when the light detected by R7 rises above a value determined by the setting of R8.

Figures 12 to 15 show a variety of ways you can use comparator circuits as light- or temperature-activated switches. For light-sensitive circuits we use a cadmium-sulfide photocell; for temperature-sensitive circuits, we use an NTC (*N*egative-*T*emperature-*C*oefficient) thermistor as the sensing element. The sensing element is used as one arm of a Wheatstone bridge and the op-amp is used as a simple bridge-balance detector. Thus, the trip point of each circuit is independent of supply-voltage variations. In all cases, the sensing element must have a resistance in the range 5K to 100K at the required trip point. The potentiometer is chosen to have the same resistance value as the sensing element at the required trip level.

The circuits shown in Figs. 12–15 also show a variety of ways we can use the output of the op-amp to activate a relay or to generate an acoustic alarm signal. Thus, the over-temperature switch in Fig. 12 has a transistor-driven relay output, while the under-temperature switch in Fig. 13 has a FET-driven relay output. Similarly, the light-operated switch circuit of Fig. 14 generates a monotone alarm output signal in a small speaker, while the dark-operated switch of Fig. 15 generates a low-power pulsed-tone signal in a small acoustic transducer.

Micro-power operation

All of the 3140-based comparator circuits that we have looked at so far are continuously powered; they draw continuous currents of about 4 mA per op-amp. So if you wanted to use a 9-volt battery as a power supply, you'd find it running down after a couple of days of continuous operation. As you can see, the circuits that we've shown you so far are not well suited to battery operation in portable applications. In practice, however, all of those circuits can easily be modified for long-life battery operation by using a micro-power "sampling" technique; the principle behind that technique can be explained very easily with a simple example, as follows.

The under-temperature switch shown in Fig. 13 monitors temperature continuously and draws about 5 mA of quiescent current (with the relay off). In reality, however, temperature is a slowly-varying parameter and thus does not need to be monitored continuously—it can be efficiently monitored by briefly inspecting or sampling it. We can sample it by connecting the supply power and looking at the op-amp output only once every second or so. If the sample periods are very brief (say 300 microseconds) relative to the sampling interval (1 second), the *mean* current consumption of the monitor can be reduced by a factor equal to the interval/period ratio (in this example, by a factor of 3300). Thus, by using the sampling technique, we can reduce the 5-mA consumption of circuit in Fig. 13 to a *mean* value of 1.6 µA.

Figure 16 shows the basic circuit of a "micro-power" or sampling version of the under-temperature switch we saw in Fig. 13. It operates the relay when the temperature of the thermistor falls below a preset value but it draws a mean quiescent

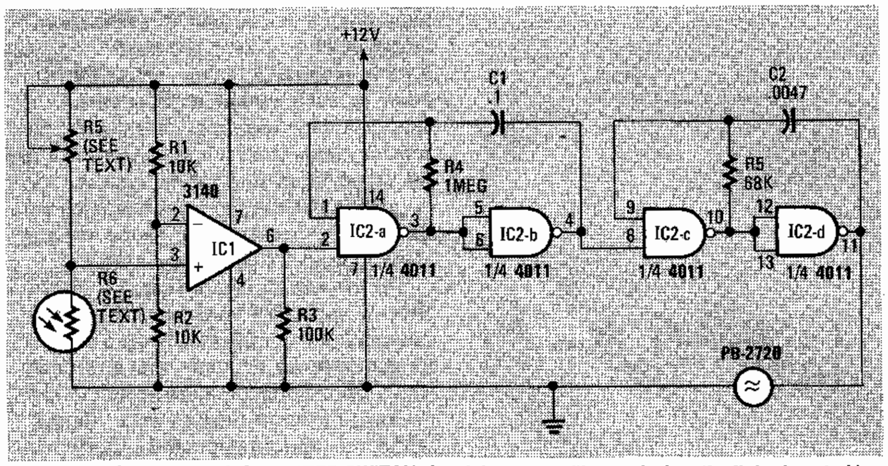

FIG. 15—ANOTHER LIGHT-OPERATED SWITCH. A pulsing tone will sound when the light detected by R6 falls below a value determined by the setting of R6.

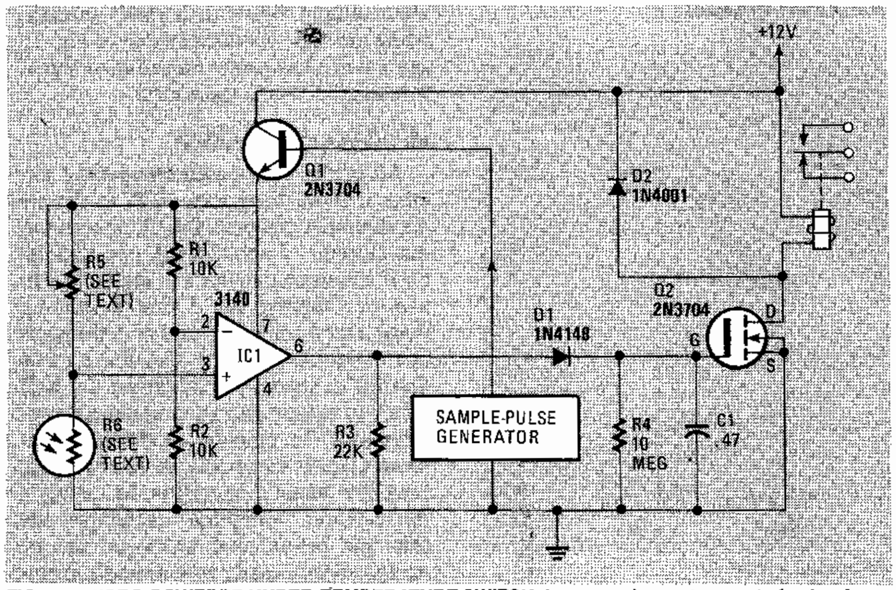

FIG. 16—MICRO-POWERED UNDER-TEMPERATURE SWITCH draws a quiescent current of only a few microamps.

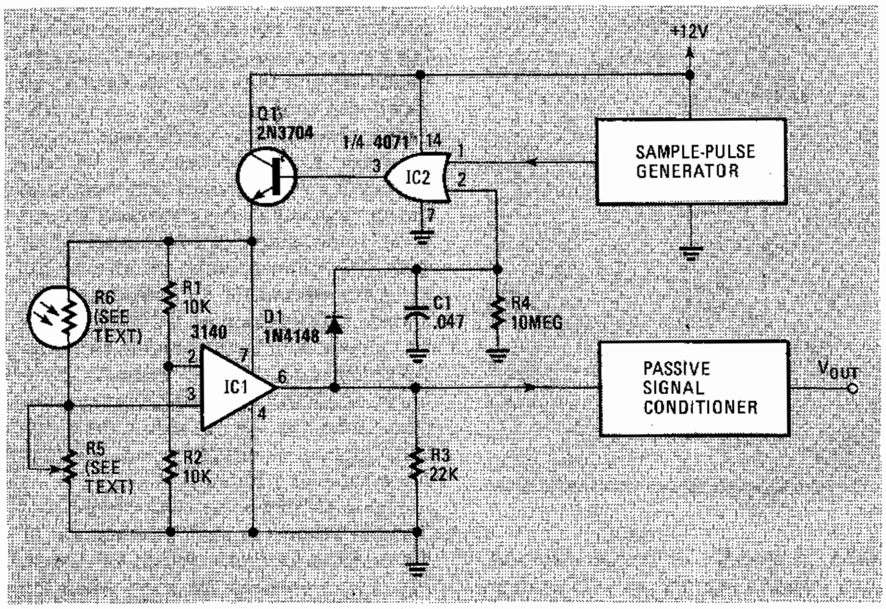

FIG. 17—THIS CODED-LIGHT-BEAM DETECTOR uses a modified version of the sampling technique to monitor for the presence of a coded light-signal.

current of only a few μA. The monitor network, made up of R5, R6, R1, R2, and IC1, is almost identical to that of Fig. 13. But instead of being continuously powered, it is powered via a 300-microsecond pulse just once every second via a sample-pulse generator and Q1. Note that the output of IC1 is led to temporary "memory" store R4-C1 via D1, and that the memory store operates the relay via Q2.

Thus, if the thermistor temperature is outside the trip level when the sample pulse arrives, the output of IC1 will remain low and no charge will be fed to C1, so Q2 and the relay will be off. On the other hand, if the thermistor temperature is within the trip level when the sample pulse arrives, the output of IC1 will switch high for the duration of the pulse and thus rapidly charge C1 up via D1 and drive the relay on via Q2.

The circuit in Fig. 16 illustrates the basic principles of the micro-power sampling technique. In reality the sampling interval and pulse width used (and, thus, the reduction in mean power consumption) will depend on the specific application. If, for example, you wish to monitor transient changes in light or sound levels and know that these transients have minimum durations of 100 ms, you may have to use a 50-ms sampling interval and (say) a 500 μs sample pulse. In that case the mean consumption of your circuit will be reduced by a factor of 100.

In some cases, you may have to slightly modify the operating principle of the sampling circuitry to obtain the desired micropower operation. Figure 17, for example, shows how the principle may be adapted to make a coded-light-beam detector, in which the "code" light signal is modulated at 1 kHz for a minimum duration of 100 ms. Thus, the sample-pulse generator is designed to produce a minimum pulse width of 1.2 ms so that it can capture at least one full 1-kHz code cycle. Further, the sampling interval is set at 60 ms so that part of a tone burst will always be captured. The sampling circuitry thus gives a 50:1 reduction in monitor-current consumption.

Thus, in the circuit shown in Fig. 17, the sample generator repeatedly feeds 1.2 ms "inspection" pulses to the 3140 detector circuitry via one input of the OR gate and via Q1 to see if any trace of a coded signal exists: If no trace of a coded signal is detected, the output of the op-amp remains low and another sample pulse is applied 60 ms later. If a trace of a code signal *is* detected, the output of the op-amp switches high and the resulting pulse is "captured" and applied to the remaining input of the OR gate. That temporarily applies full power to the 3140 circuitry so that the code signal can be completely inspected via the passive signal conditioning circuitry. **R-E**