Experimenting with the Analog Comparator

By Forrest M. Mims III

In this digital age, analog (linear) electronic circuits are sometimes considered obsolete. Of course, nothing could be further from the truth. Indeed, analog circuits can perform many tasks for which digital circuits are totally unsuited. And, using just a few components, they can perform some tasks that would require highly complex digital circuits like programmable microprocessors.

One of the key analog circuits is the *operational amplifier.* This circuit is a two-input, differential amplifier that uses a feedback resistor from its output to one of its two inputs to control the circuit's voltage gain. When the feedback resistor is omitted, even a very small input signal will cause the output of the amplifier to swing wildly from ground to the maximum possible positive or negative voltage extreme. When used in this fashion, the operational amplifier is considered an analog *comparator.*

The comparator has an amazing number of applications. Because of the comparator's two-state (on/off) mode of operation, many of its applications are digital in nature. In this column, I'll explain how the comparator works and provide some sample application circuits with which you can experiment.

The Basic Comparator

Many different analog comparator integrated circuits are available commercially (in future columns I'll describe some of them). Often, however, you can use a commonly available op amp, such as the 741, in a comparator mode simply by leaving out the usual feedback resistor. Figure 1, for example, shows a basic comparator demonstration circuit made from a 741 integrated circuit and several resistors.

In operation, resistors *R2* and *R3* form a voltage divider that places half the supply voltage, or 4.5 volts, at the 741's inverting (−) input. This is called the *reference voltage.* Potentiometer *R1* functions as an adjustable voltage divider that delivers a variable voltage to the noninverting (+) input of the 741. This voltage is called the *input.*

When the amplitude of the input voltage is below that of the reference, the output of the 741 comparator is low (near ground). Therefore, the

Fig. 1. Shown here is a basic comparator demonstration circuit.

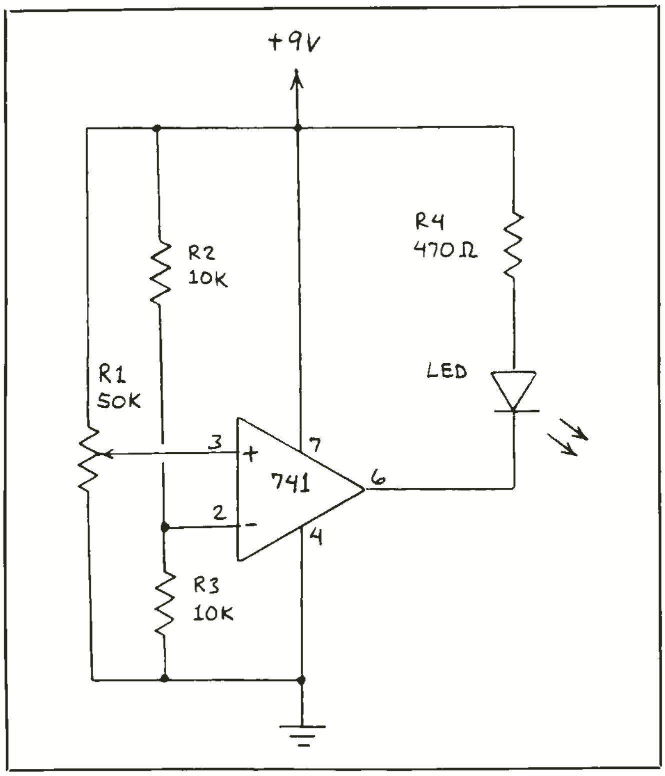
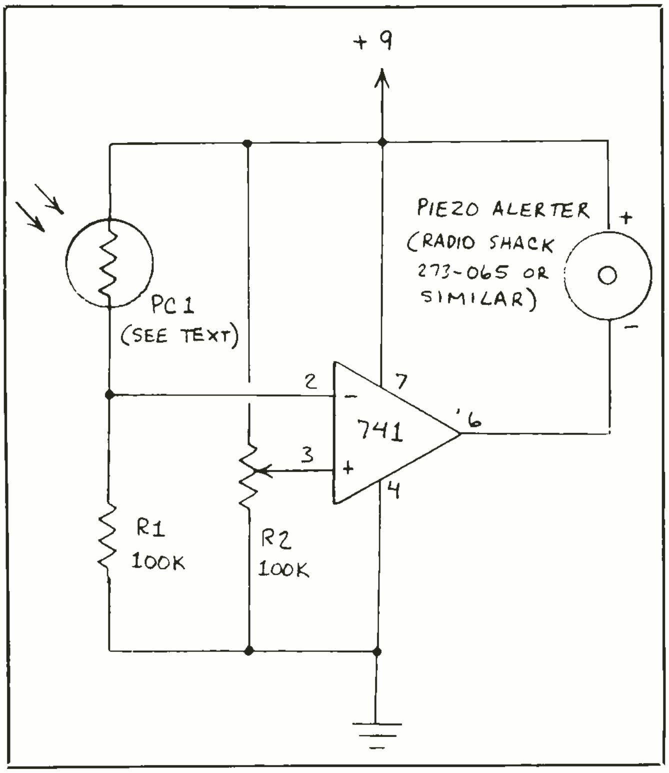


Fig. 2. This is an adjustable light-dark detection circuit.



LED is switched on. When the input voltage rises above the reference, the output of the 741 suddenly switches on, rising to near the positive supply voltage extinguishing the LED.

If the input voltage is made very close to the switching threshold, the 741 may oscillate in an unstable fashion by rapidly and unpredictably switching on and off. But, practically speaking, the comparator output is either full-off (ground) or full-on (near the positive supply voltage).

Note that the inputs of the comparator are designated inverting (pin 2) and noninverting (pin 3). You can reverse the operation of the circuit in Fig. 1 simply by reversing the two inputs. Be sure to keep this in mind when you experiment with the following circuits.

Adjustable Light-Dark Detector

The basic circuit in Fig. 1 may seem simple, but it can readily be adapted for many applications. Figure 2, for example, shows how to use the basic circuit as an adjustable light-dark detector. This circuit can be used to signal the arrival of dawn (or dusk) and to provide a warning when a refrigerator door has been left open. It can also be used as a simple break-beam object detector. Though the circuit uses a piezoelectric buzzer or alerter, an output relay can be included to control an external motor, lamp or other device.

The circuit's light detector is a low-cost, but highly sensitive, cadmium-sulfide (CdS) photoresistor. The circuit activates the alerter when the photoresistor is illuminated by even a very low light level. After a simple modification is made, the circuit will trigger the alerter when the photodetector is dark. In either case, the circuit consumes only about 0.5 milli-

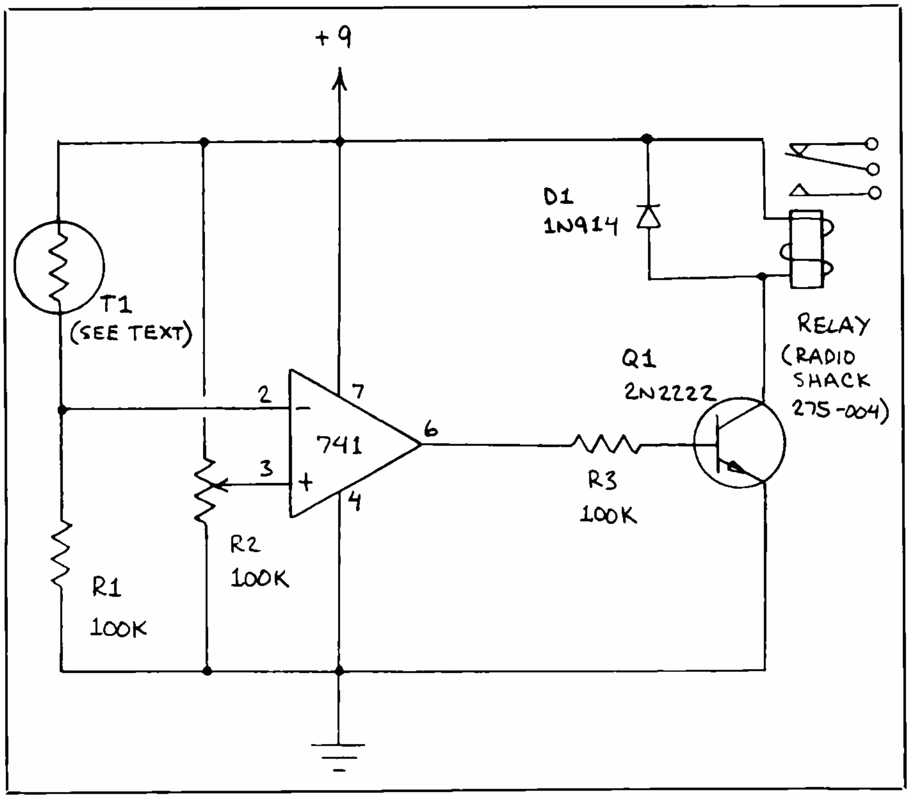


Fig. 3. An adjustable-threshold temperature-controlled relay.

ampere in its standby mode and about 4.5 milliamperes when the alerter is sounding.

Comparing the two circuits, note that the photoresistor in Fig. 2 has replaced *R2* in Fig. 1. Therefore, the photoresistor and *R1* in Fig. 2 form a light-dependent voltage divider. Potentiometer *R2*, which forms a second adjustable voltage divider, permits the reference voltage at the + input of the 741 to be altered.

When the sensitive surface of the photoresistor is illuminated, its resistance is very low, typically a few hundred ohms. Therefore, the voltage appearing at pin 2 of the 741 can approach the supply voltage when the photoresistor is brightly illuminated. The 741 will switch on as soon as the voltage at pin 2 exceeds the reference voltage from *R1* that is applied to pin 3. The alerter will then be actuated.

When the light level at the sensitive surface of the photoresistor is decreased, its resistance is increased. Indeed, the resistance may reach a million ohms or more when the light level is very low. When this occurs, the voltage at pin 2 approaches ground. In any case, when the light level falls to a point where the voltage at pin 2 falls below the reference voltage, the comparator will switch off. The trigger point, of course, can be conveniently altered simply by changing the setting of *R2*.

Incidentally, this operating mode can be reversed simply by exchanging the photoresistor and *R1* in Fig. 2. The circuit then switches off when the photoresistor is illuminated and on when the photoresistor is dark.

The alerter in Fig. 2 can easily be replaced by a relay that can control external lamps, motors and other devices. The circuit in Fig. 3 shows how.

Adjustable Temperature Detector

The photoresistor in the Fig. 2 circuit can be replaced by a thermistor to transform the circuit into an adjustable-threshold, temperature-sensing alarm. Properly calibrated, the circuit can function as a freeze detector.

In operation, the output from the comparator at pin 6 is connected via *R3* to *Q1*, which functions as a switch that turns on and off a low-voltage relay. When the comparator's output is high, *Q1* switches on and, in turn, allows current to flow through the relay coil. Transistor *Q1* can be a 2N2222 or any other general-purpose silicon switching transistor. The relay is Radio Shack's No. 275-004.

Some electronics parts suppliers stock thermistors. You can mail-order purchase them if they are not available locally. Check the ads in this and other electronics magazines. Some of the many thermistor manufacturers include Keystone Carbon Co. (Thermistor Division, 1935 State St., St. Marys, PA 15857); Fenwal Electronics (63 Fountain St., Framingham, MA 01701; Thermometrics, Inc. (808 U.S. Highway #1, NJ 08817); and Omega Engineering, Inc. (One Omega Dr., Box 4047, Stamford, CT 06907).

Many different kinds of thermistors are available. For best results, select a thermistor that has a room-temperature resistance of from 25 to 50 kilohms or so. I prefer to use glass-bead thermistors, since they are very small and can be safely calibrated in water. But they are more expensive than other types of thermistors.

If the thermistor you select can be calibrated in water, you can easily adjust the circuit to trigger at the freezing point of water simply by inserting the thermistor in crushed ice or snow. You can set other calibration points with the help of a thermometer. Just adjust the temperature of a small cup of water to the desired point, insert the thermistor, and calibrate *R2*.

Sine- to Square-Wave Converter

The sine wave is among the most important waveforms in electronics. The comparator is well-suited for transforming the ubiquitous sine wave into square and other kinds of waves. As you can see in Fig. 4, this manipulation of waveforms can be achieved with the simplest possible comparator circuit. This circuit can also be used to clip that portion of a signal that rises above or below any preset level.

In operation, the sine wave (or signal) is applied to the noninverting input of the comparator. When the reference voltage applied to the inverting input is ground, the output of the comparator remains at ground until the positive (rising) voltage of the sine wave *exceeds* ground potential. The output then suddenly switches to its maximum positive value and remains there until the voltage of the wave falls to ground potential. The comparactor then suddenly switches off. When the voltage falls below ground potential, the output voltage suddenly switches to its maximum negative value, where it remains until the waveform voltage again reaches ground potential.

It should be obvious that this operating mode transforms a sine wave into a square wave. What is not obvious, however, is that the amplitude of the square wave at the output can be much greater than that of the sine wave at the input. This occurs when the supply voltage exceeds the input voltage by about 1 volt or more. Therefore, it's important to adjust the supply voltage and possibly the amplitude of the input signal if true clipping of the sine wave is required.

The frequency response of the circuit in Fig. 4 depends largely upon the quality of the 741. The 741 I used in a breadboard version of the circuit had a peak response of 42.5 kHz at the −3-dB (half-amplitude) points. Other operational amplifiers or comparators can provide a much wider frequency response.

Interesting effects can be had by connecting the noninverting input of the 741 to potentiometer *R1* instead of ground. This permits the reference voltage and, consequently, the circuit's operation to be altered. For instance, when the reference voltage is *increased* above gound, the positive half of the output wave narrows and increases in amplitude while the negative half becomes broader and decreases in amplitude. The reverse occurs when the reference voltage is *reduced* below ground.

Potentiometer *R1* also permits the shape of the output square wave to be transformed into either a positive or negative triangle wave with a clipped peak. If *R1* is adjusted to provide a sharp peak, the comparator becomes unstable and oscillates.

The circuit in Fig. 4 will work when powered by a single polarity supply (pin 4 connected to ground instead of −V). However, the comparator will then respond to only the positive side of the incoming signal.

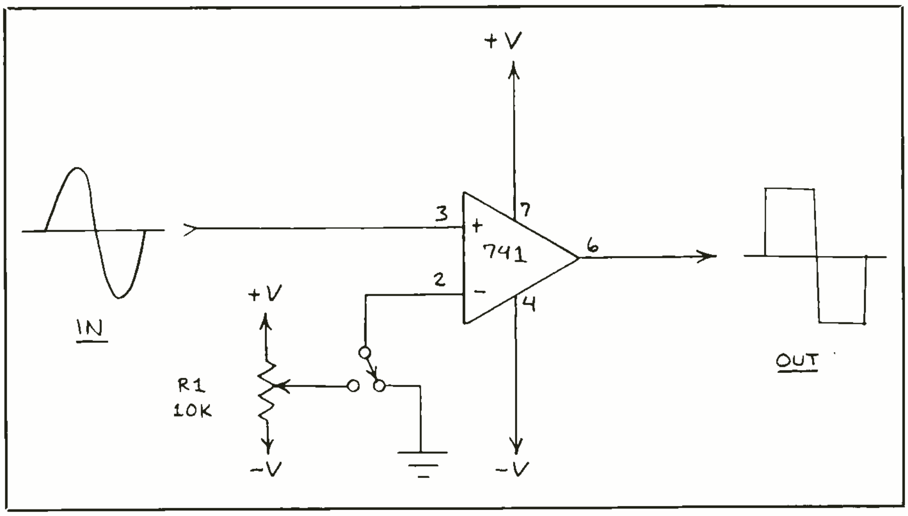


Fig. 4. This circuit demonstrates how a sine wave is converted to a square wave with a comparator.

Incidentally, while experimenting with the circuit in Fig. 4, I applied a square wave to the input. The output was a trapezoid wave with sloping sides. When the amplitude of the input signal was adjusted to match that of the output, a substantial delay could be observed in the arrival of the maximum positive and negative excursions of the trapezoid.

For instance, when the frequency of the incoming wave was 10 kHz, the duration of both the positive and negative peaks of the incoming square waves was 50 microseconds. The positive peak of the trapezoid trailed the positive leading edge of the square wave by 20 microseconds. The negative peak of the trapezoid trailed the negative leading edge of the square wave by 32 microseconds.

This delay, which also occurs when other waveforms are processed by the circuit, has several possible applications. One is the conversion of a single-phase digital clock for a logic circuit into a two-phase clock.

Peak Detector

Often, it's important to measure the maximum amplitude of an event such as rainfall, wind velocity, light level, temperature, revolution rate and many others. If a transducer is available that converts an event to be measured into a proportional voltage, then the simple comparator circuit in Fig. 5 will detect and store for several minutes the maximum amplitude of the signal from the transducer.

The circuit in Fig. 5 is called a peak detector. Digital circuits are available that can perform the same function, but they are far more complex and costly. Furthermore, they require an analog-to-digital (A/D) conversion stage in order to measure the input voltage.

The peak detector in Fig. 5 is placed in operation by pressing *S1* to discharge *C1* and reset the system. Since this removes any charge stored in *C1*, the reference voltage coupled back to the inverting input at pin 2 of the 741 via *R2* is 0. Any signal voltage applied to the input terminals of the circuit will immediately switch the 741 on, since the signal voltage will exceed the reference voltage. Capacitor *C1* will then begin charging to the supply voltage through *D1*.

When the charge on *C1* exceeds the input voltage at pin 3, the 741 immediately switches off and *C1* stops charging. At this point, the amplitude of the charge stored in *C1* equals the input voltage. If the input voltage rises above that stored in *C1*, the comparator will again switch on and *C1* will again begin charging until the voltage level exceeds the reference. The comparator will then switch off.

As you can see, the peak detector automatically tracks the input voltage and stores its peak value. At any time, a new cycle can be initiated simply by pressing *S1* to discharge *C1* and reset the system.

Reverse-biased diode *D1* prevents *C1* from discharging through the comparator. The circuit, however, is not perfect, since *C1* will not long re-

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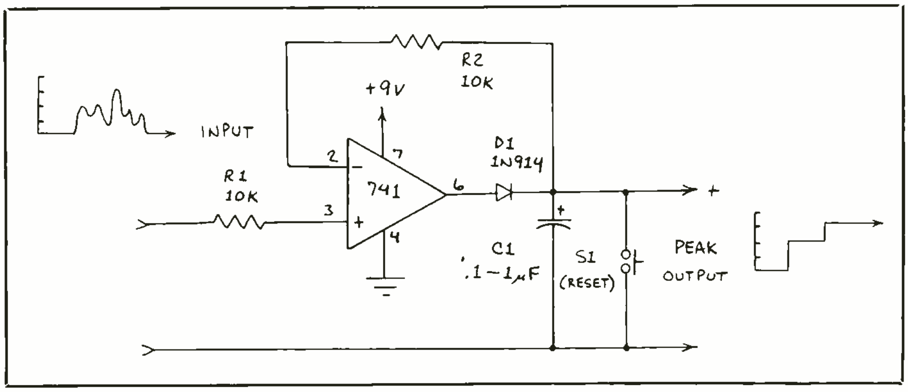
Fig. 5. This circuit uses a comparator as a peak-voltage detector.



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tain its charge if it is not of high quality or if a low-impedance voltmeter is used to monitor the level of its charge. The circuit will, however, hold a charge for several minutes or even much longer if a good quality, low-loss Mylar or polystyrene capacitor is used for *C1*. It's also important to monitor the output voltage with a high-impedance voltmeter to prevent *C1* from being inadvertently discharged.

Going Further

The comparator applications discussed here are among the simplest. Many other applications are available, and you can find representative circuits in semiconductor applications manuals and books about linear integrated circuits. I'll include additional comparator applications in a future column. **ME**

Reader Question

I find infrared diodes work very well for intrusion alarms, particularly across windows, where they can be left on continuously. I put a plastic lens, used for threading needles, in front of the IR emitter. But I don't think this is a rugged enough system for outdoors use, where light fluctuations are greater, distances are longer, and the lens would get dirty. Therefore, I wonder if lasers would work better outdoors. If so, what direction would I take with lasers?
Gary Novak
Highmore, SD

In principle, both helium-neon and diode lasers might work better outdoors. But AlGaAs infrared-emitting diodes will provide a more reliable, less costly system. For high output power, drive the diodes with hefty current pulses. For optimum sensitivity, use a pin photo-diode detector. This detector has a linear response over a very wide range of light levels and will, therefore, work outdoors in daylight. You'll need an infrared filter if direct or reflected sunlight strikes the detector. For more information about infrared-emitting diodes and photodiodes, see The Forrest Mims Circuit Scrapbook *(McGraw-Hill, 1983).*