Using Voltage Comparators

A hands-on look at the popular and readily available LM339

By Robert Witte

First cousin to the ubiquitous op amp, the versatile voltage comparator offers circuit designers and experimenters a convenient means for bridging the worlds of analog and digital circuits. The need for such a bridge grows as more and more digital circuits have built into them or must communicate with external analog elements.

A typical case is the personal computer, which often requires some sort of interface circuit to translate the real world's analog informaton into the digital format it needs. Here, the voltage comparator provides a TTL logic signal that is high when a sensor reaches a particular temperature, pressure, light level, or any other condition that can be monitored electronically. Comparators can be used in a variety of other applications, too, such as monitoring the voltage on a battery and converting from one logic family to another. As you follow the examination of this device, other uses will suggest themselves. Our discussion focuses on the popular LM339 voltage comparator, which is readily available from mail-order houses such as Digi-key for only 88¢, as well as from many local electronics parts stores.

The LM339 offers four separate comparators in a single 14-pin DIP. It can be powered from any +2- to +36-volt dc supply, including batteries, making it suitable for 5-volt logic circuits and portable applications. It is easy to incorporate into circuit designs and is ideal for electronics experimenting.

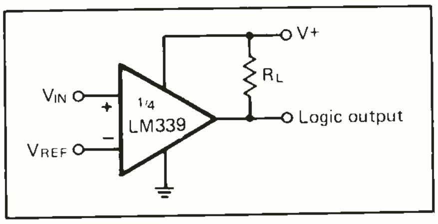


Fig. 1. The basic comparator circuit.

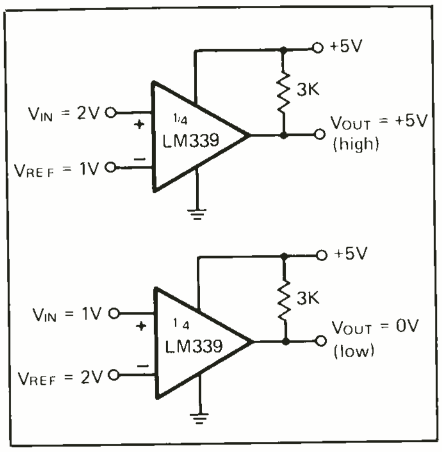
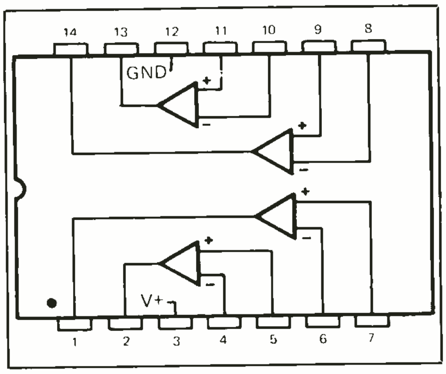


Fig. 2. Depending on input voltage.

Fig. 3. Contained inside a single LM-339 are four comparators.



How It Works

Operation of a compatator is really quite simple. Referring to Fig. 1, if the voltage at the noninverting (+) input, referred to as V_{in}, is greater than the voltage at the inverting (−) input, referred to as V_{ref}, the output is a logic high. However, if V_{ref} is greater than V_{in}, the output is a logic low. Hence, with a 2-volt V_{in} and a 1-volt V_{ref}, output voltage V_{out} will be high (approximately the same as supply voltage V+). On the other hand, if V_{in} is 1 volt and V_{ref} is 2 volts, V_{out} will be low (approximately 0 volt). Both of these conditions are illustrated in Fig. 2.

The LM339 voltage comparator (see pinout diagram in Fig. 3) has an open-collector output, which means that no pull-up resistor is required to make it TTL and CMOS compatible. Since the LM339 is the subject of this article, it is important that you know something about its operating parameters. Its major specifications are as follows:

Supply voltage	2 to 36 volts dc
Supply current	2 mA maximum, 0.8 mA typical
Response time	1.3 μs typical
Output sink current	6 mA minimum, 16 mA typical
Saturation voltage	400 mV maximum, 250 mV typical
Input bias current	100 nA maximum

With a maximum supply current of 2

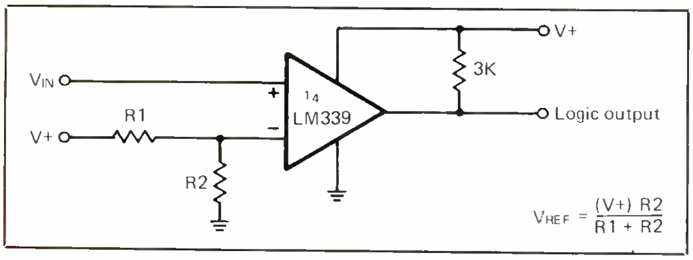


Fig. 4. Shown here is the basic comparator circuit that compares an input voltage (V_{in}) with a reference voltage (V_{ref}), the latter supplied by the voltage-divider R1/R2.

mA, this chip is suitable for low-power applications. Though response time is not as fast as a TTL gate's response time, 1.3 μs is good enough for many circuits.

The output of each comparator in the LM339 can sink 6 mA or more current, which will handle at least one TTL and several CMOS loads. Output saturation voltage is the point at which the output is at logic low. Input impedance is very high, allowing the comparator to draw a mere 250 nanoamperes of current.

Circuit Applications

Basic Comparator Circuit. Shown in Fig. 4 is the basic comparator circuit that compares a V_{in} to a V_{ref}, the latter supplied by bias resistors *R1* and *R2*. This circuit can be used to monitor the voltage from a solar cell to produce a high whenever the voltage exceeds a given value of V_{ref} to indicate the presence of light. This TTL-compatible logic signal can be used to drive an I/O (input/ output) line in a computer. V_{ref} is calculated using the formula $V_{ref} = [(V+)R2]/(R1+R2)$.

Time-Delay Circuit. A time-delay circuit can be built by preceding the comparator with an RC network, as shown in Fig. 5. When the comparator's output goes from 0 volt to V+, the potential on *C* rises exponentially. When the voltage on *C* reaches 70% of V+, the comparator's output switches from low to high. The time it takes for the charge on *C* to reach 70% of V+ delays the change of state in output voltage relative to the input voltage by the time constant of the RC network. For example, if *R* is 100,000 ohms and *C* is 10 microfarads, the time constant (T = RC) and, therefore, time delay is 100,000 ohms × 0.00001 farad = 1 second. The low input current of the comparator permits a wide range of *R* and *C* values to be used.

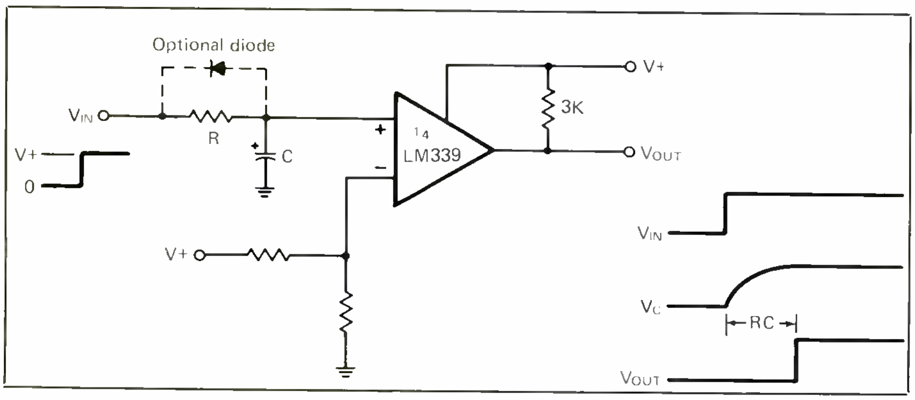


Fig. 5. R and C in this circuit provide a delay in output, as shown in the lower-right. Diode D1 provides an immediate reset when the output goes low.

An optional diode can be added to make the circuit reset as soon as the input voltage goes low. Without this diode, some time will be required for the voltage on *C* to discharge back to zero before the circuit resets.

Window Comparator. By using two comparators, as shown in Fig. 6, you can build a "window" comparator. The object of this arrangement is to have the comparator's output go high if the input is between two predetermined voltages, which we will call V_{hi} and V_{lo}, produced by their respective resistor bias circuits.

In Fig. 6, the upper comparator's output goes high when the input voltage is less than V_{hi}. The lower comparator's output goes high when the input voltage is greater than V_{lo}. The comparators operate independently of each other, though their outputs are tied together to provide a single output condition.

Since the output of the comparator is an open collector of an npn transistor, either comparator can pull the output low. However, both comparators in Fig. 6 must be high for the output to be high. This is sometimes referred to a "wired-AND" configuration, because the output goes high when the outputs of the upper *and* lower comparators are both high. Notice that V_{in} is connected to the inverting (reference) input of the upper comparator and the bias voltage from the resistor network goes to the noninverting (V_{in}) input. This arrangement causes the logic output of the upper comparator to be inverted with respect to the input.

Zero-Crossing Detector. A sine wave, such as a low-voltage version of the 60-Hz power-line signal, can be converted to a square wave simply by using a zero-crossing detector. This type of circuit, shown in Fig. 7, simply compares the input voltage against ground (0 volt) and outputs a high whenever the input is greater than 0 volt. The circuit is slightly more complicated than this, since the LM339 cannot handle voltages more negative than −0.3 volt.

To keep the voltage from going very negative, a diode is added to the circuit to limit the voltage to some small negative value, typically 0.7 volt for a silicon diode. The 10k and 1k resistors in the Fig. 7 circuit provide additional voltage attenuation.

A good application for the Fig. 7 circuit would be to supply a computer or other digital system with a known signal frequency to be used as the reference for a software-based real-time clock.

Hysteresis

Since the comparator is a very-high gain device, if no special steps are taken, a slowly varying input can cause an erratic output to be generated when V_{in} is close to V_{ref}. Consider a slowly rising V_{in} that typically includes some small amount of noise (Fig. 8). As V_{in} increases, it will pass through the $V_{in} = V_{ref}$ point, causing the output to swing high. As it passes through the $V_{in} = V_{ref}$ point, any noise (or feedback caused by stray capacitance) can momentarily cause the output to rapidly switch between the high and low states. In many circuits, this toggling of the output may be of no concern. However, if the comparator's output drives an edge-sensitive circuit, such as the clock input to a digital counter or flip-flop, erratic operation will result. Consequently, the edge of the signal must be cleaned up to assure stable operation of the circuit.

A small amount of positive feedback—commonly called "hysteresis"—from the output back to the input of the comparator solves this "glitching" problem. This feedback arrangement is illustrated in Fig. 9, where the 1-megohm resistor feeds a small amount of the comparator's output voltage back to its noninverting input. When the output first swings high, the feedback causes the voltage at the noninverting input to increase slightly. This increase is

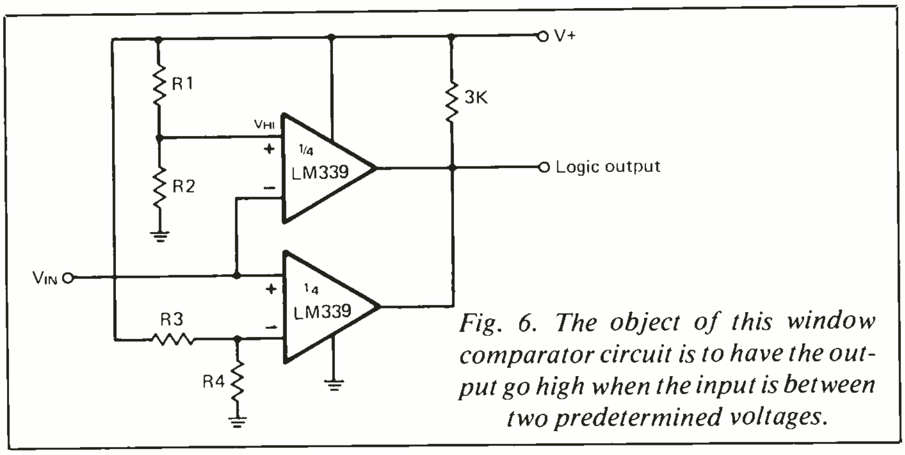


Fig. 6. The object of this window comparator circuit is to have the output go high when the input is between two predetermined voltages.

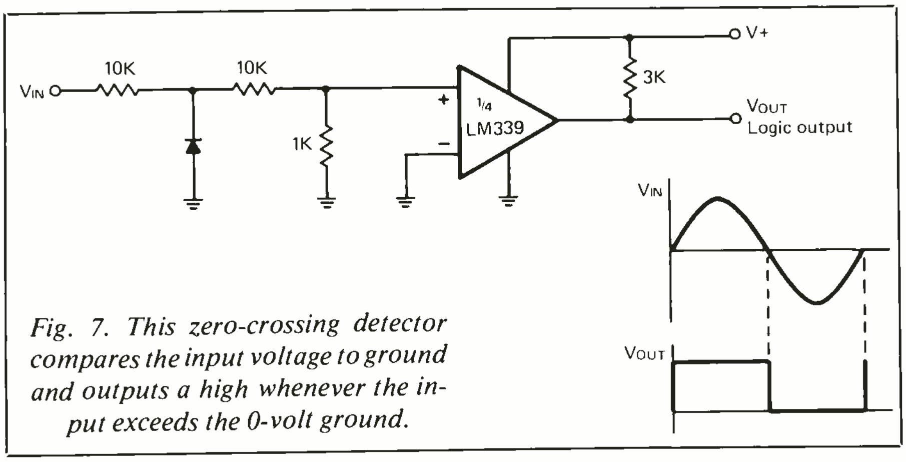


Fig. 7. This zero-crossing detector compares the input voltage to ground and outputs a high whenever the input exceeds the 0-volt ground.

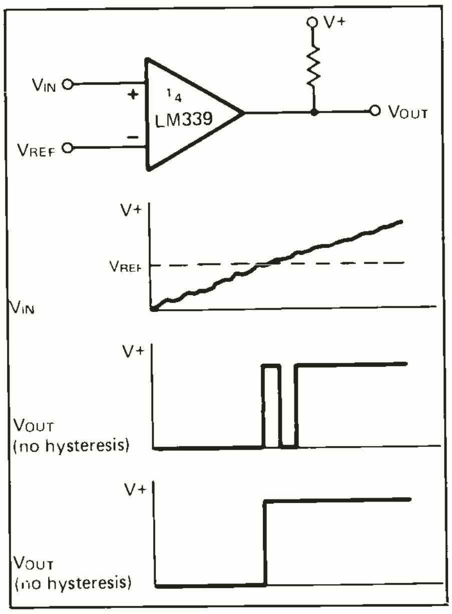


Fig. 8. If no special steps are taken with the very-high-gain comparator, noise can cause the output to be erratic (V_{in}). Adding a small amount of feedback, called "hysteresis," assures stable operation.

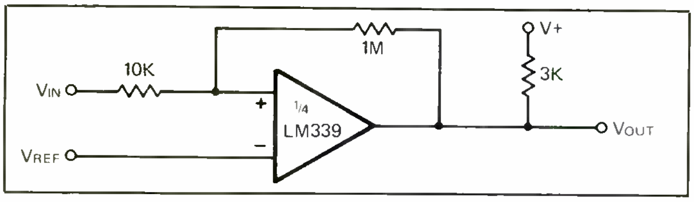


Fig. 9. Hysteresis is obtained simply by installing a resistor between the output and the noninverting input.

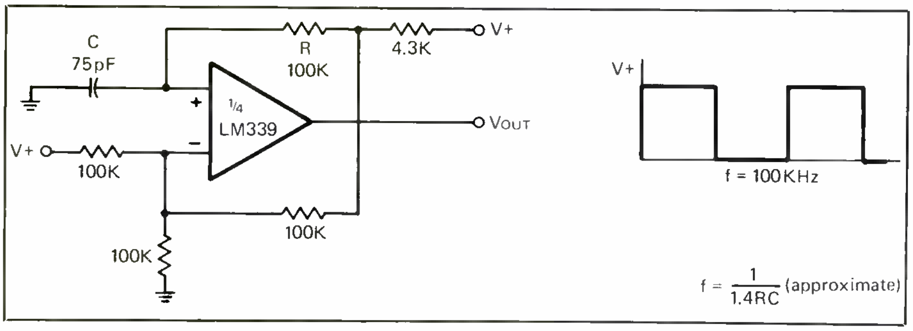


Fig. 10. In this circuit, the comparator operates as a 100-kHz square-wave oscillator. Change R and C values to obtain other frequencies.

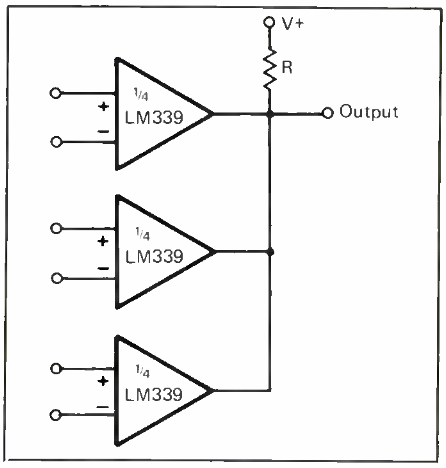


Fig. 11. A wired-AND arrangement.

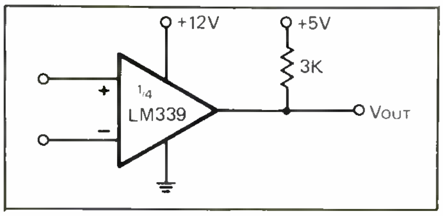


Fig. 12. How to make a comparator powered from +12 volts compatible with the requirements of TTL logic.

greater than the noise present and keeps the comparator's output from switching back to low. Thus, the output switches low to high with a good clean edge. Similarly, the high-to-low transition is also kept glitch-free.

Oscillator Circuit. A comparator can also be configured as a square-wave oscillator, as shown in Fig. 10. This is really a simple time-delay circuit whose output is fed back to its input. Assuming the output is initially high, the capacitor at the inverting input charges up until the voltage exceeds the potential applied to the noninverting input (67% of V+). At this point, the output swings low and the capacitor starts discharging. The comparator would instantly switch back to low but for the fact that the voltage at the noninverting input is simultaneously changed to 33% of V+, due to the 100k feedback resistor. As the voltage on the capacitor decreases, it will become less than the voltage at the noninverting input, causing the comparator's output to swing to high and repeat the process.

The Fig. 10 circuit, taken directly from the manufacturer's data sheet, produces a 100-kHz square-wave output. It can be modified to oscillate at other frequencies by changing the value of *R* and *C*, using the formular $F_{o(approx.)} = 1/1.4RC$.

Open-Collector Output. By not committing the collector of the output npn transistor in each comparator in the LM339, the manufacturer has made it possible to provide the user with several design advantages. The major advantage is that the open-collector output can be adapted to diverse applications. For example, when the comparator is powered by a 5-volt source, a single pull-up resistor with a value of about 3000 ohms can produce a TTL- and CMOS-compatible logic signal. Multiple open-collector outputs can be connected together in a wired-AND configuration (Fig. 11), but keep in mind that all comparator ouputs must be high before the wired-AND signal actually goes high. Note in the wired-AND circuit that only one pull-up resistor is required.

A major advantage of the open-collector is its ability to handle different supply voltages in different parts of a circuit. Typically, +12 volts might be required in the analog and +5 volts in the digital portions of a project. Using an open-collector solves the match. Figure 12 shows that a comparator used to sense some analog signal can be powered from a +12-volt supply but deliver a 5-volt logic signal simply by connecting the pull-up resistor to the +5-volt supply. The reverse situation is illustrated in Fig. 13, which shows how the comparator's output signal can be greater than the voltage powering the comparator. Here the comparator translates a 5-volt logic signal to a 12-volt signal. The comparator's output can exceed the power supply

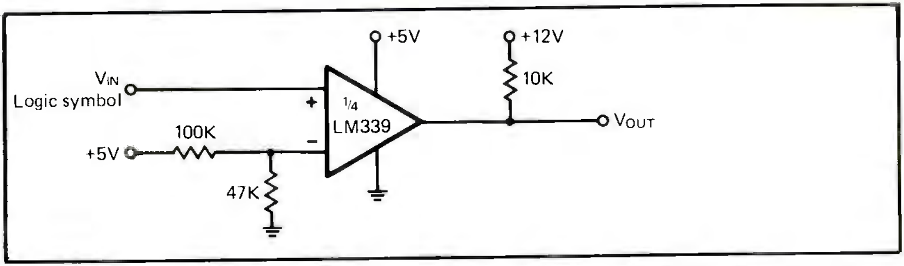


Fig. 13. A comparator's output can also be greater than its supply voltage.

voltage, but only up to the maximum specified supply voltage (+36 volts for the LM339).

Summing Up

Since the LM339 contains four separate comparators, it is ideal for digital applications. Conveniently, two LM339s can supply a full byte-wide (8-bit) bus with appropriate signals in a computer.

Although the LM339 does not usually require careful power supply bypassing, it is still a good idea to practice good circuit layout techniques. That is, keep component leads and circuit board traces (or wires) short to minimize stray capacitance and other forms of coupling, and be sure to ground all unused pins of the comparators.

In this article, we have merely laid the groundwork for using voltage comparators. If you want more information on the LM339, consult the *Linear Databook* published by National Semiconductor Corp. **ME**