Experimenter's Corner

By Forrest M. Mims

THE ANALOG COMPARATOR

THE ANALOG comparator is a circuit that compares an input voltage to a reference voltage and changes the state of its output when the input exceeds the reference. This decision-making ability has many important applications, several of which we will examine here.

A simple analog comparator can be made by using an operational amplifier without a feedback resistor. The role that a feedback resistor usually plays is to pass some of the amplified signal back to the inverting input of the op amp, thus reducing the amplifier's gain. Without the gain limitation imposed by a feedback resistor, the op amp operates at its maximum ("open-loop") gain. A small input voltage will then cause the output of the op amp to change state immediately. The resulting voltage swing is so dramatic that the comparator can be considered a switching circuit.

The operation of a noninverting analog comparator is shown in Fig. 1. A known reference voltage is applied to the comparator's inverting (−) input, and an unknown voltage to its noninverting (+) input. The LED indicates the status of the comparator's output.

In operation, the output of the comparator is at −V when the input voltage is more negative than the reference voltage which in this case is ground. The LED indicates this by glowing. When the input voltage is more positive than the reference voltage, the comparator output switches from −V to +V and the LED is extinguished. Because the reference is ground, a very small positive voltage will trigger the comparator. In both cases, the voltage difference is measured in millivolts.

Comparator Demonstration Circuit. Unless you have previously worked with analog comparators, you will probably want to take a few minutes to breadboard the simple demonstration circuit shown in Fig. 2 before trying any of the circuits that will be described later.

The comparator in this circuit is a 741 op amp without a feedback resistor. A variable input voltage is provided by *R1*, a potentiometer operated as a voltage divider. Resistors *R2* and *R3* form a fixed voltage divider that provides a reference at half the supply voltage.

When the input voltage is below the reference voltage, the LED glows to indicate that the comparator's output is low (at ground). The LED switches off to indicate the comparator's output is high (at +9V) as soon as the input voltage exceeds the reference voltage. With the values shown in Figure 2, *R1*'s wiper will be at the center of its rotation when the comparator switches, assuming that *R1* is a linear potentiometer.

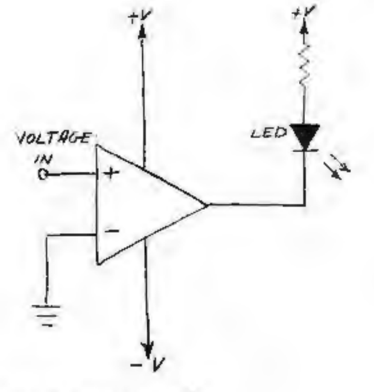

Fig. 1. Operation of a basic comparator circuit.

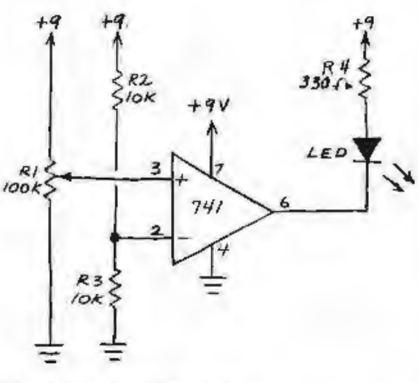

Fig. 2. Schematic of a demonstration comparator circuit.

Sine- to Square-Wave Converter. One of the simplest applications for a comparator is the sine- to square-wave converter shown in Fig. 3. The reference voltage is ground so the comparator switches its output to its maximum positive value when the sine-wave voltage exceeds ground potential. Similarly, the comparator output switches to its maximum negative value when the sine-wave voltage is at or below ground potential. The result is a square wave with the same period as the sine wave.

Peak Detector. Another simple but useful comparator application is the peak detector. As its name implies, the peak detector retains the maximum amplitude of a fluctuating input voltage for subsequent readout and analysis. Suitable transducers connected to the input of a peak detector permit the determination of such parameters as maximum wind velocity, temperature, light intensity, vehicle speed, and many others.

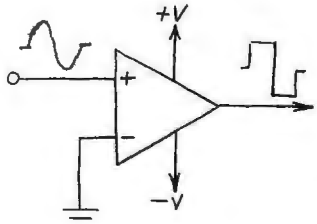

Fig. 3. Comparator as sine-wave to square-wave converter.

Figure 4 shows a basic peak detector circuit that you can easily assemble. To understand its operation, assume that *C1* is initially *discharged* (i.e., the RESET switch has been momentarily closed). This means that the reference voltage at the inverting input of the comparator is 0 and that a positive input voltage will immediately switch the output of the comparator to +9 volts. The comparator output will then begin to charge *C1* until the voltage across the capacitor equals the input voltage. As soon as the two voltages are equal, the comparator output immediately drops to ground potential and *C1* stops charging.

If a subsequent input voltage exceeds the charge stored in *C1*, the comparator output will again go high and allow *C1* to charge to the new peak voltage. This tracking process ensures that *C1* always retains the peak voltage applied to the input. When you want to track a new (lower) peak voltage, close the RESET switch to discharge *C1*.

The peak detector circuit is subject to drift because *C1* will gradually lose its charge. Diode *D1* prevents discharge through the comparator, but discharge can take place through the output circuitry or through the dielectric leakage of the capacitor. For these reasons, it is important to use a low-loss polystyrene or Mylar capacitor for *C1* and a high-impedance monitoring circuit.

Last month's installment of this column described a simple high-input-impedance voltage follower you can use to interface the peak detector to a low-impedance device such as a panel meter or VOM. Without the high-impedance buffer, *C1* will quickly discharge when you attempt to measure the voltage across it.

The Window Comparator. The comparator circuits described thus far

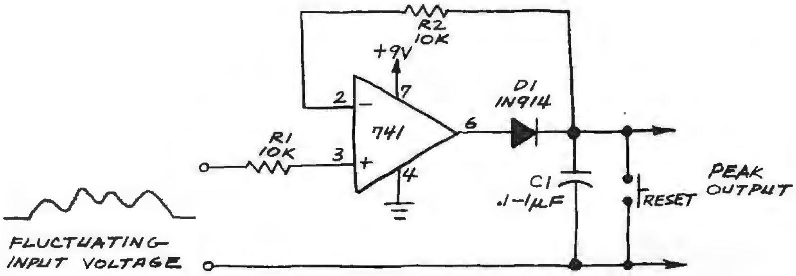

Fig. 4. Schematic of a simple peak detector.

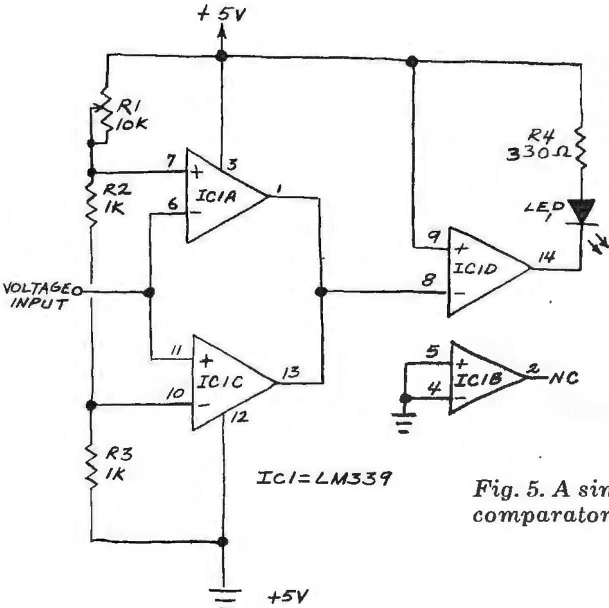

Fig. 5. A simple window comparator circuit.

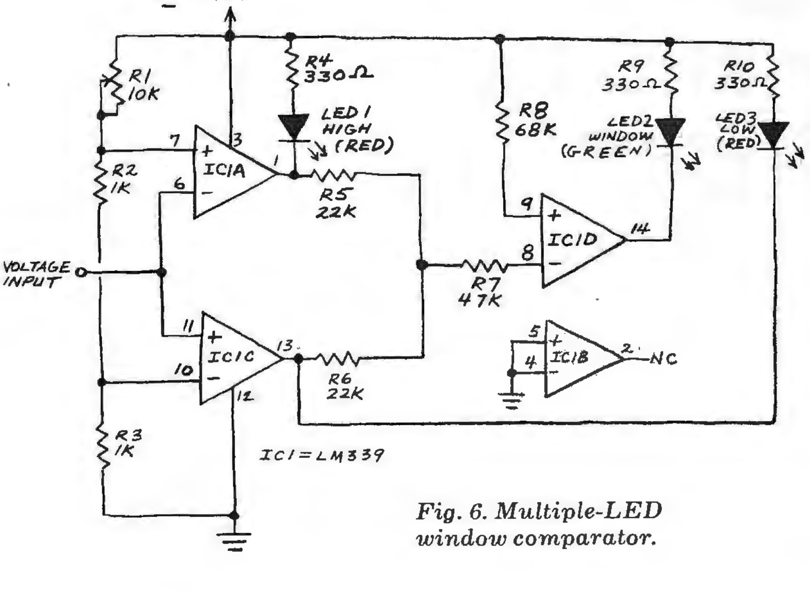

Fig. 6. Multiple-LED window comparator.

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operate in the noninverting mode. That is, they generate an output identical in polarity to the input voltage. However, a comparator can be operated in the inverting mode by simply reversing the two inputs. This makes possible many additional applications, one of which is called the limit or window comparator.

A window comparator can be made from three-fourths of an LM339 quad comparator as shown in Fig. 5. This chip was the subject of the January 1977 Experimenter's Corner. Unlike the 741, the LM339 is specifically designed to operate with a single-polarity power supply.

In operation, *IC1C* functions as a noninverting comparator, but *IC1A* operates as an inverting comparator. Potentiometer *R1* and fixed resistors *R2* and *R3* form a divider chain that delivers slightly different voltages to the two comparators. These voltages define the upper and lower limits of the circuit's switching "window," which can be changed easily by varying *R2* and *R3*.

The output of each comparator in the LM339 is an uncommitted collector. This means two or more outputs can be tied together to achieve a logic OR function without using diodes or a logic gate.

When the input voltage is less positive than *IC1C*'s reference voltage, the output collector of this comparator is low. When the input voltage is more positive than *IC1A*'s reference voltage, its output collector is low. When either output is low, the other is pulled low, causing a LED connected between the two outputs and the positive power supply to glow.

If the input voltage falls in the window region between the two reference voltages, the output of each comparator is high. This will cause a LED connected to the outputs to be darkened.

It's usually desirable for an indicator to light when a desired condition is met. The third comparator in Fig. 5 serves this purpose by inverting the output of the window comparator. The LED then glows only when the input voltage falls within the window region.

An even more useful version of the circuit is shown in Fig. 6. Here, the third comparator is employed as a NAND gate. Three LED's connected to the outputs of all three comparators provide a HIGH/WINDOW/LOW indication. For best results, use a green LED for the WINDOW indicator and red LED's for the HIGH and LOW indicators. The green LED will glow when the input voltage is within the window. The red LED's will indicate that the input voltage is either above or below the window. The LED's should be mounted in a vertical row with the HIGH LED on top, the WINDOW LED in the middle, and the LOW LED on the bottom.

If you use three different colors for the LED's, the circuit will tell you whether the input voltage is above, below, or in the window no matter how the LED's are mounted. A red LED connected to the output of *IC1A*, for instance, would indicate a HIGH voltage. A yellow LED at *IC1C* would indicate a LOW voltage. Finally, a green LED at *IC1D* would indicate an input voltage within the WINDOW.

Incidentally, the comparator used as a NAND gate in Fig. 6 can be replaced by a conventional TTL 7400 NAND gate. In fact, the first breadboard version of the circuit I assembled used a 7400. Similarly, the third comparator in Fig. 5 can be replaced by one of the inverters in a 7404 hex inverter or an npn transistor and a 10,000-ohm base resistor. Keep this in mind when building a window comparator in a complex circuit that includes digital logic chips. A 7400 with an unused gate will allow you to eliminate the extra resistors required by the comparator NAND gate.

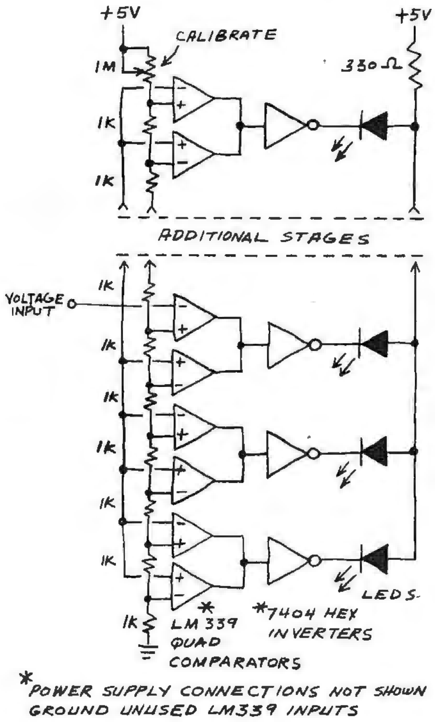

Fig. 7. A moving-dot voltage indicator.

Moving-Dot Voltage Indicator. The window comparator shown in Fig. 5 can be easily expanded to provide a moving dot LED voltage indicator and Fig. 7 shows one possible configuration suggested by Bill Cikas of Rockford, IL.

Regular readers of this column might recall the moving-dot voltage indicator described in the October 1978 installment. Bill's circuit requires three functional blocks per dot while my earlier circuit uses 2.5 per dot. On the other hand, Bill's circuit requires one less IC (7) than mine (8). It's also more straightforward and easier to troubleshoot.

Solid-State Oscilloscope Update. The solid-state oscilloscope described in previous columns has resulted in more letters than any previous topic covered in "Experimenter's Corner." In fact, the moving-dot voltage indicator in Fig. 7 is actually the vertical section of a solid-state scope designed and built by Bill Cikas.

I'll have more to say about this and other experimental solid-state scopes in a future column. In the meantime, I would like to hear from other experimenters who have successfully assembled and operated all-solid-state oscilloscopes. Please include a stamped, self-addressed envelope for a reply. ◇