# Passive Wave-Shaping Circuits

## *Using resistors, capacitors, inductors and diodes to do a job that has traditionally been the task of op amps and other active elements*

**By Joseph J. Carr**

Much has been written about active wave-shaping and wave-generating circuits in which operational amplifiers and other linear IC devices are used to create special waveforms. Did you know, though, that it is also possible to use *passive* circuits to shape waveforms? Resistors, capacitors, inductors and diodes can be used to shape waves at less cost than with active devices.

The use of passive devices in shaping waveforms is due to the nature of pulse signals and the nature of diodes. Since a pulse is made up of a fundamental sine wave and an assortment of harmonics, the mix of which harmonics and how strong each is depends upon the particular waveform generated. Traditionally, wave-shaping circuits have been made up of frequency-sensitive RC, LC and RLC networks that shape and form pulses by altering their frequency content.

We will investigate passive wave-shaping networks and how they can be incorporated into practical circuit designs. You may find here ways of simplifying your own wave-shaping designs or means of designing circuits that can save on the cost of your next project.

### *Action On Square Waves*

Shown in Fig. 1 is the 10-volt peak-to-peak (p-p) square wave of an elderly Heath Model IG-18 sine/square-wave audio signal generator. For these experiments, the frequency of these square waves was set to approximately 400 Hz. Although age has deteriorated the rise time of the leading edges of the square waves generated by this instrument, the signal is adequate for purposes of experimenting.

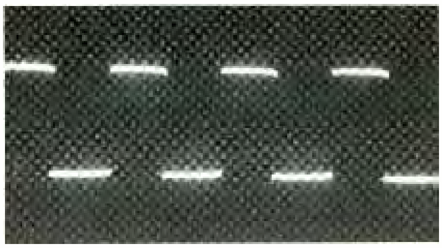


*Fig. 1. Screen photo of a 10-volt peak-to-peak square wave from an old Heath Model IG-18 sine/square-wave audio generator.*

Recall that a square wave consists of a fundamental sine wave plus a collection of odd harmonics. This waveform can be shaped by enhancing or rolling off those harmonics. Of course, if these harmonics are rolled off to too great a degree, the only thing remaining will be a sine wave whose frequency is the fundamental.

When the Fig. 1 square wave is applied to the input of an RC low-pass filter, or "integrator," network like that shown in Fig. 2(A), the output signal appears as shown in Fig. 2(B). Note here that the amplitude of the output signal is somewhat reduced compared to that of the original input signal, the result of losses (attenuation) in the RC network. Also note that the fast rise- and fall-time edges of the input signal have become curved in the output waveform so that it appears much like a capacitor charge/discharge waveform. This wave shape results from rolling off the high frequencies present in the square wave.

The degree to which the edges of the output waveform are rounded depends on the values of *R* and *C* in the network. A high RC product is a lower-frequency low-pass filter and, thus, will have a larger effect on the waveform.

A low-pass filter also serves to mathematically "integrate" an output waveform. As a result, the output of this network represents the time-average of the input waveform. This fact is used to good effect by instrumentation designers.

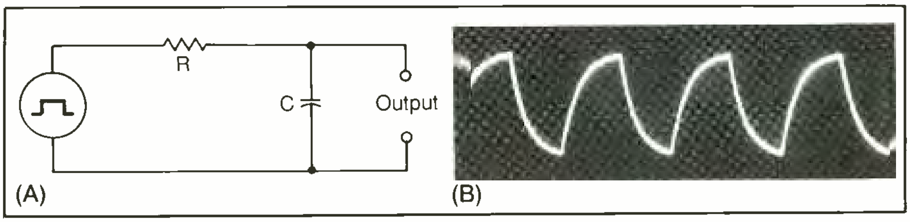



*Fig. 2. An RC low-pass filter or integrator (A) and the output signal that occurs when a square wave is applied to its input (B).*

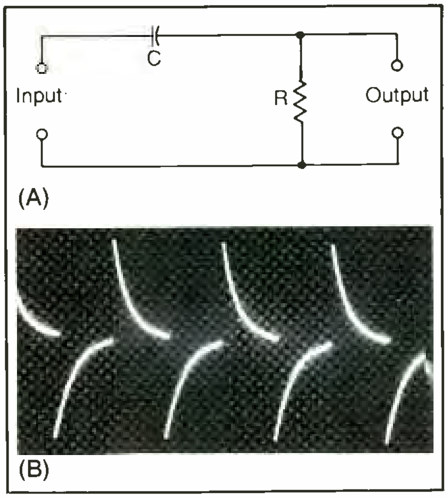



*Fig. 3. An RC high-pass filter or differentiator (A) and the output that occurs when a square wave is applied to its input (B).*

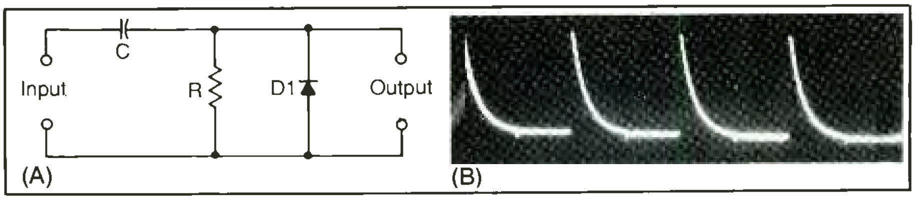



*Fig. 5. A diode connected across output of a differentiator circuit to clip negative peaks (A) and output signal that results from its inclusion in circuit (B).*

Figure 3(A) illustrates an RC high-pass filter, also referred to as a "differentiator." In this circuit, the elements are the same as those used in the low-pass filter arrangement shown in Fig. 2(A). However, their respective roles are reversed. In this case, the high frequencies are not attenuated as much as are the low frequencies. Therefore, the square wave becomes tilted in favor of the high frequencies. Put another way, the output waveform is "peaked up," as shown in Fig. 3(B), which shows the output waveform with a characteristically fast rise time and an exponentially decaying fall time. This waveform, called a "differentiating square wave," is used for applications such as counting or triggering other circuits.

A problem with using the straight differentiated square wave for either triggering or counting purposes is that it has two separate peaks, one in the positive and the other in the negative directions. To be used effectively, this waveform must be modified to eliminate one polarity's peaks. For this wave-shaping task, we turn to the ordinary diode.

Figure 4 shows the current-versus-voltage (I-vs.-V) characteristic for a diode. When the applied voltage is such that the anode (A) is negative with respect to the cathode (K), the diode is cut off and no current flows through it, which is the reverse-biased condition. In theory, current flow through the diode is zero. (In real diodes, however, there is always a tiny leakage current ($I_{leak}$) in the reverse direction. As a general rule, the smaller the leakage current, the better the diode, and the higher the "reverse resistance" as measured on an ohmmeter.

When the diode is forward biased such that its anode is positive with respect to its cathode, the diode conducts current freely. Below a certain junction potential, referred to as $V_g$, conduction is nonlinear. Above $V_g$, the diode's action begins to obey Ohm's Law. The value of the junction potential is 0.2 to 0.3 volt for germanium diodes like the 1N43, 1N60, etc., and 0.6 to 0.7 volt for silicon diodes like the 1N914, 1N4148, and others like them.

As a result of the diode's characteristics, we know that a diode: conducts in only one direction; is linear above the junction potential; and does not conduct current when reverse biased. Knowing these things, let us connect the diode into a circuit and observe what occurs.

Figures 5(A) and 6(A) show a "clamping diode" connected across the output of the differentiating RC network shown in Fig. 3(A). In the case of Fig. 5(A), the diode is connected such that it is reverse biased by positive output voltage excursions

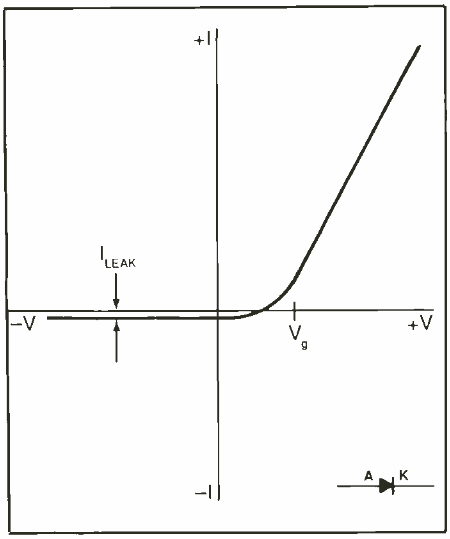



*Fig. 4. The current-versus-voltage transfer characteristic of a diode.*

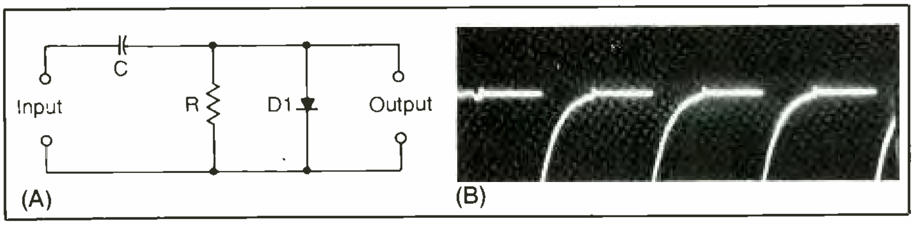



*Fig. 6. A diode connected across output of a differentiator circuit to clip positive peaks (A) and output signal that results from its inclusion in circuit (B).*

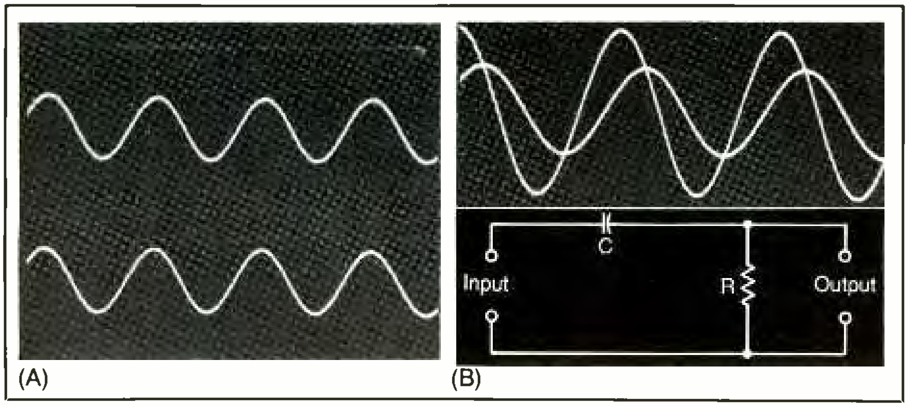



*Fig. 7. A sine-wave signal applied to both inputs of a two-channel oscilloscope with the waveforms in-phase with each other (A) and input and output waveforms from an attenuator superimposed on each other (B).*

and is forward biased by negative output excursions. The result is the waveform shown in Fig. 5(B). Here we see the same type of differentiation as before on positive peaks, but now the negative peak of the output waveform has been clipped.

If you are eagle-eyed, you can see a small "pip" on the Fig. 5(B) trace at the point where each negative excursion would have begun if the signal had not been clipped. This pip is the result of the junction potential of the diode. The experiment to make these photos used a network containing a 1N60 germanium diode, which had a 0.2- to 0.3-volt junction potential, which is the approximate amplitude of the pips shown in both Fig. 5(B) and Fig. 6(B).

Exactly the opposite situation is illustrated in Fig. 6(B). In this case, the Fig. 6(A) circuit was arranged to clamp the positive-going spike so that only the negative spike remains. Otherwise, operation of the Fig. 5(A) circuit is identical to that of the Fig. 6(A) circuit.

Using a diode to clamp the spike is one way to ensure that only correct triggering signals get to a circuit. Otherwise, operation of such circuits as one-shot multivibrators, voltage-to-frequency (V/F) converters and others would be difficult to predict when two pulses arrive at their inputs.

## *Sine-Wave Response*

Figure 7 shows a sine wave applied to both inputs of a two-channel oscilloscope. In Fig. 7(A), the two waveforms are in-phase, rising and falling in step with each other. However, when the sine wave is applied to either high- or low-pass RC filters, two things occur. The first is that the output waveform shown as the bottom trace will be attenuated. The second is that the relative phase between the waveforms shifts. This effect is illustrated in Fig. 7(B). To better show the effect, the two waveforms are shown superimposed on each other in Fig. 7(B). Note that the smaller-amplitude is the output waveform and that it lags the input waveform by almost 90 degrees. Thus, you can conclude that even in sine-wave circuits, passive RC networks are useful as phase shifters. A well-known oscillator circuit, called appropriately enough the "phase-shift oscillator," is based on this principle.

Connecting a diode in shunt—or in series—with the ac sine-wave signal produces a half-wave output. This fact is used to advantage in power-supply circuits. Figure 8(A) shows the circuit of a diode clamp across an ac signal line. This type of circuit is occasionally used in CB and other communications equipment to limit the percentage of modulation to a maximum value. In this application, two diodes are connected in parallel and opposite polarity to clip alternate halves of the modulating signal waveform.

A modified circuit in which a biasing voltage is applied in series with the diode is shown in Fig. 8(B). In this configuration, the diode is forward biased by +5 volts dc. The result is a +5-volt offset to the half-wave output signal, as illustrated in Fig. 8(C). The sine wave has a peak-to-peak value of 25 volts; therefore, the half-

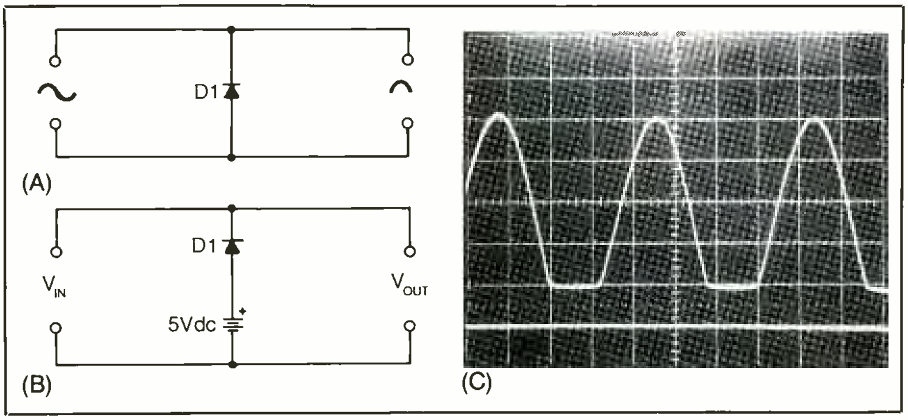



*Fig. 8. A circuit with a diode clamp across an ac signal line (A); the same circuit with a battery used to provide a dc offset (B); and the output waveform from the circuit using dc offset (C).*

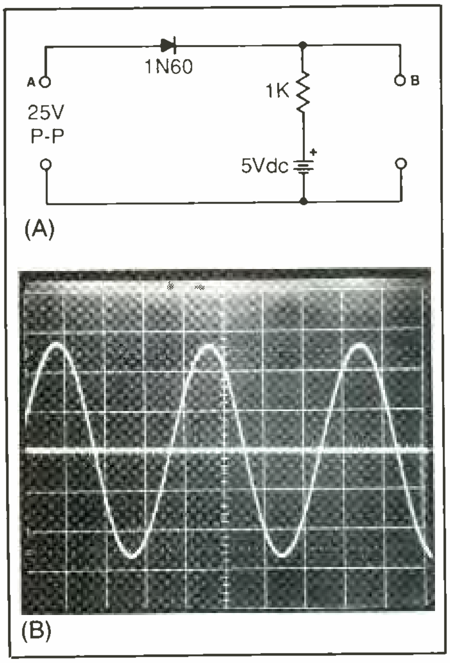



*Fig. 9. A circuit in which a germanium diode is connected in series with the signal line with 5-volt dc bias applied in series with a 1,000-ohm resistor (A). With a 25-volt peak-to-peak sine wave (B) applied to circuit's input, what waveforms will appear at points A and B? (See text for answer)*

wave amplitude is 25 volts − 5 volts, or 20 volts.

You can set the trip point and exact output characteristic by selecting the amount of the bias voltage, whether to forward- or reverse-bias the diode, and exact circuit configuration.

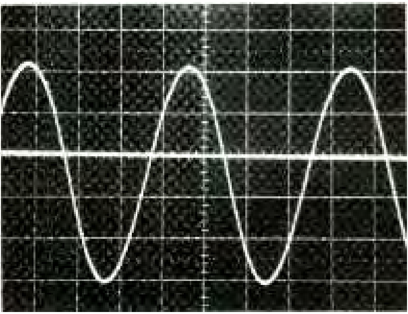
Here is a little quiz that will test what you have learned about passive wave-shaping circuits. Shown in Fig. 9(A) is a circuit in which a 1N60 germanium diode is connected in series with the signal line. A 25-volt p-p, 400-Hz ac signal like that shown in Fig. 9(B) is applied to the input of the circuit. If the bias voltage is +5 volts *dc* and it is connected in series with a *1*,000-ohm resistor, what waveforms can be expected at points A and B? Assume that the junction potential is negligible compared to the peak amplitudes. The answers to this question appear on page 85.



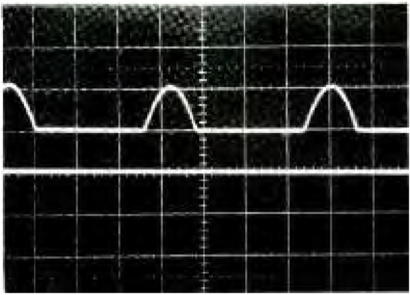
"YOU'RE RIGHT . . . I MISS THE VCR, TOO."

## The Solution

Here is the solution to quiz question given on page 29. The waveforms that should appear at points A and B in the Fig. 9 circuit would be as shown in the upper and lower photos, respectively.



(A)



(B)