Using Op Amps to Generate Signals

A low-cost way to obtain the sine, square, triangle and sawtooth waves called for in many modern analog and digital circuits

By C.R. Fischer

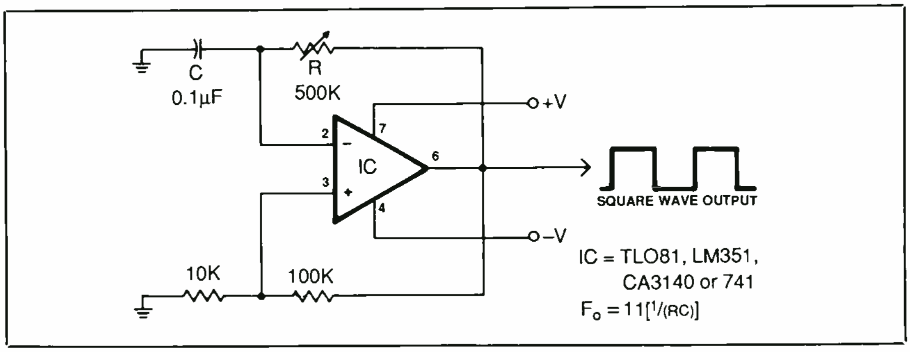

Fig. 1. Simple, low-cost multivibrator.

One or more periodic waveforms are frequently used in many types of electronic circuits to produce a specific function. The circuit can be anything from a simple oscillator for a toy electronic organ to a sophisticated crystal-controlled oscillator to regulate the timing of a microprocessor. Though a variety of specialized integrated circuits are available to fill these needs, the common operational amplifier can in many cases be used to perform the same task. A garden variety op amp is usually cheaper and easier to find, too. Consider also that if the circuit being designed already has several amplifiers elsewhere in it, a dual or quad op amp IC package could be drafted to perform all of the work with a single chip!

Op amps can be used to create special waveforms that would be difficult or too costly to generate by other means. For example, to generate a triangle wave with a digitally based circuit would require a clock oscillator, a counter, RAM or ROM containing the waveform parameters, a digital-to-analog (D/A) converter and a smoothing filter for the D/A output. Of course, a digital waveform generator has capabilities that go far beyond what's possible with the common function generator, but there's also a large difference in price and complexity. And unless you absolutely need the complexity of such a waveform-generating system, using a complex digital waveform generator can be unjustifiably costly.

In this article, we discuss a series of circuits built around op amps to demonstrate how versatile a device it is to use for signal generating purposes. These circuits have all been "proofed" at a workbench and, thus, can be used as needed. But the main objective of this article is to stimulate you to do creative thinking of your own when it comes time to design and build signal-generating circuits. You can certainly build these circuits without knowing op-amp theory, but you can go much further in designing your own circuits by taking a short course in op-amp design. An excellent primer for this is "Using Op Amps" by Robert A. Witte presented in the October 1985 issue of *Modern Electronics.*

Simple Multivibrator

A very inexpensive and versatile multivibrator built around an op amp is shown in Fig. 1. This circuit can be powered by just about any 6-to-18-volt source that has positive and negative buses referenced to ground. In this circuit, *R* and *C* set the output frequency, while the two resistors at the noninverting (+) input to the op amp set the switching thresholds for the circuit. The value of *R* can range from a couple of thousand ohms to several megohms, with the output frequency ranging from less than one cycle per minute to several kilohertz.

Operation of the Fig. 1 circuit is as follows. Assume that the inverting (–) input of the amplifier is at

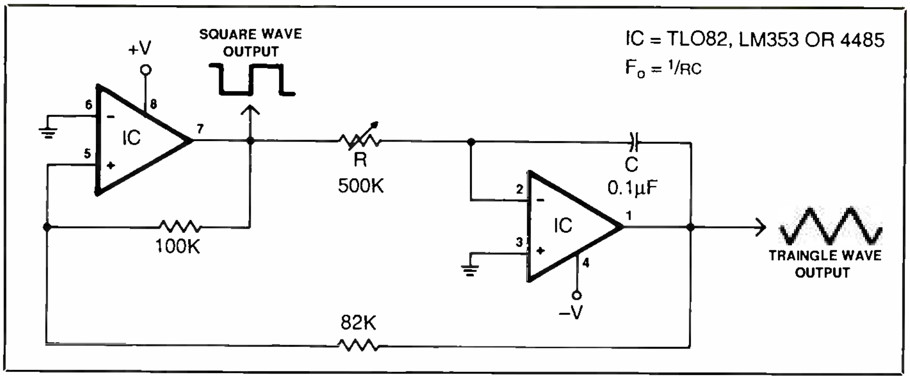

Fig. 2. An oscillator that generates square and triangle waves.

ground potential and the output is at V+. The capacitor begins charging in the positive direction until the voltage at the + input of the op amp is reached. At this time, the output will switch toward V−. The capacitor will then discharge toward the negative supply voltage until the negative threshold point is reached, at which time the cycle repeats. The output of the IC continues this positive/negative charging action for as long as power is applied.

Multivibrators provide a fairly symmetrical square-wave output, as well as a crude semi-triangle waveform at the inverting input. The triangle waveform is distorted and is, therefore, not suitable for critical applications.

The multivibrator in Fig. 1 has a frequency range from about 40 Hz to about 2.5 kHz with the 500k potentiometer and 0.1-microfarad capacitor specified for *R* and *C* in the feedback circuit to the − input.

A single-polarity power-supply version of the multivibrator circuit can be had by adding a second 10k resistor between the + input of the op amp and the positive supply rail. This resistor biases the + input at about 0.5V+, making it possible to use this circuit in applications where a split power supply isn't available.

Triangle/Square Wave Oscillator

A slightly more elaborate circuit than the one shown in Fig. 1 generates a much cleaner triangle wave. A second amplifier is required to accomplish this, as shown in Fig. 2. This triangle/square-wave oscillator has many uses, such as operation as a sweep generator for AM and FM. In many effects boxes used by rock musicians, this circuit is used to modulate a signal to produce such effects as phasing, flanging and chorusing.

A TL082 op amp is a good choice for the triangle/square-wave oscillator circuit. Thanks to its very-high-impedance FET inputs, the TL082 can use large-value resistors as timing components. If you have to generate very-low frequencies, a large value of resistance and small value of capacitance in the frequency-determining network makes building this circuit easier and more economical than using a large value of capacitance and small value of resistance. In addition, the TL082 has a high slew rate that permits the op amp to be used at higher frequencies with a minimum of distortion.

Using the same timing-component values as in Fig. 1, the Fig. 2 circuit can deliver a respectable range of 1,500:1 (15 kHz to 10 Hz).

A variation of the triangle wave, known as the sawtooth or ramp wave, is needed in certain applications. For example, a ramp wave is frequently used as a sweep generator and in electronic music for its high overtone content.

To change a triangle waveform into a sawtooth waveform, you simply add a pair of diodes to the circuit, as shown in Fig. 3. These diodes force the timing resistor to be in the circuit on only the positive-going portion of the cycle. When *C* discharges, reset time is almost instantaneous. Keep in mind, though, that the diodes affect the output frequency because they put the timing resistor into the circuit for only part of the time.

A square wave is reshaped in a similar way. An assymmetrical square wave, known as a pulse, is used in many types of analog and digital circuits and systems. What's even better is a pulse that has a variable duty cycle (the ratio of on to off time) that can be determined by a control voltage. This type of pulse is put to good use in switching power supplies and for sending analog signals by infrared or radio methods. The signal to be sent is used to modulate the width of the pulse. The pulse train is then used as a carrier. At the

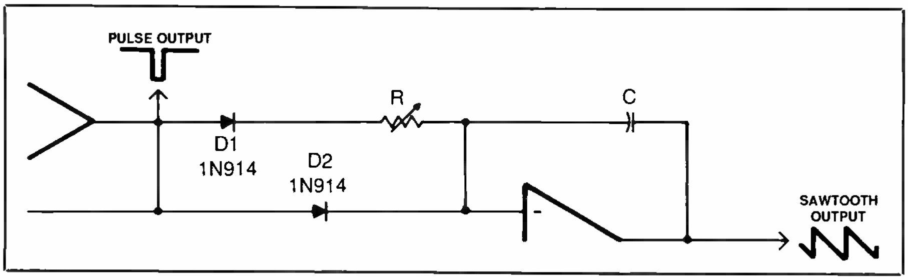

Fig. 3. Modifications show how square/triangle-wave oscillator can be used to output sawtooth waveform.

receiving end, the carrier is removed with a low-pass filter to recover the original signal.

A very simple way to obtain a variable-width pulse signal is illustrated in Fig. 4. If the potential applied to the + input of the op amp is greater in amplitude than the potential at the − input, the comparator output from the op amp will be positive, and vice-versa.

If the triangle waveform is fed into one input and the control voltage is fed to the other input, the comparator's output will change polarity whenever the triangle wave crosses the threshold set by the control voltage. With the control voltage set halfway between the V+ and V− supplies, the output will be a square wave. By changing the setting of the PULSE WIDTH control, duty cycles from 0 to 100% can be obtained.

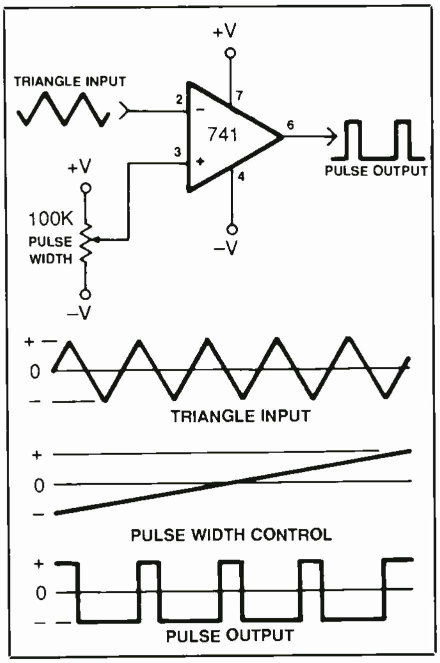

Fig. 4. A third operational amplifier gives square/triangle-wave oscillator independent variable-pulse output.

Sine-Wave Oscillators

A sine wave, fundamentally the simplest of waveforms, resembles the triangle wave, except that it has a curved appearance and there are no sharp points on it. Because it lacks any "edges," a perfect sine wave resonates at a single frequency and has no overtones. Don't expect to be able to generate perfect sine waves. However, it's easy to put together a reasonably clean sine-wave generator without too much trouble.

Dating all the way back to the early days of vacuum tubes, the oldest design for a sine-wave generator is the Wien-bridge oscillator shown in Fig. 5. The easy-to-build circuit oscillates at a single frequency with a slight amount of distortion byproducts. Note that two RC networks are involved in determining the output frequency. Both RC pairs must be matched to within 1 percent or better for the circuit to generate sine waves with minimum distortion.

When operating the Wien-bridge oscillator circuit, you first set the trimpot to maximum resistance before applying power. If the circuit fails to oscillate within a few seconds of being powered, you slowly decrease the trimmer's resistance until a sine-wave output appears.

While the trimmer potentiometer can be "tweaked" so that the circuit's distortion is very low, the amplifier may have insufficient gain to start or maintain oscillation. If a cleaner waveform is required, it's best to set the trimmer for stable oscillation with a slight amount of clipping and to follow the output with an appropriate low-pass filter.

A variable-frequency Wien-bridge oscillator with a few extras thrown in is shown in Fig. 6. Here, the zener diodes keep the amplitude of the sine wave constant and eliminate the need for the trimpot. By changing the value of the 10k resistor between the + input of the op amp and the trimpot that goes to ground, the amplitude of the output can be adjusted to a desired level. A lower resistance raises the amplitude of the output signal, while a larger resistance attenuates it.

In the Wien-bridge oscillator circuits shown in Figs. 5 and 6, the frequency-determining components

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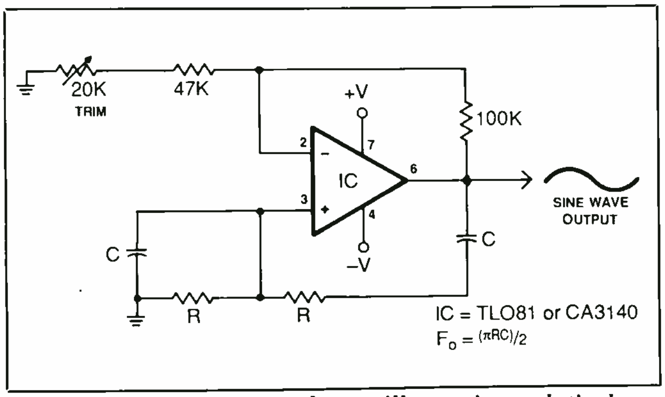

Fig. 5. Simple Wien-bridge oscillator gives relatively pure sine-wave output.

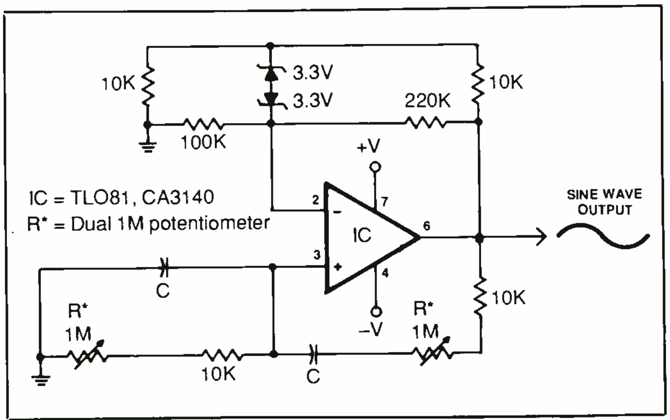

Fig. 6. Variable-frequency sine-wave oscillator.

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must be matched as closely as possible to assure reliable operation. Use of 1-percent metal-film resistors is almost mandatory because of their accuracy and fairly good immunity to drifting off value with changes in temperature. Also, be sure to use only polystyrene, polyester or polypropylene capacitors in this circuit. Ceramic capacitors is a poor choice because they're notorious for drifting off value as temperature changes and they can have values that can vary as much as ± 100 percent of their printed values.

Always use the best-quality dual potentiometer you can find for the variable-frequency Wien-bridge oscillator. If your oscillator stops oscillating when the dual potentiometer is set to either end of its rotation, or the circuit has a limited frequency range, the two sections are probably not matched well enough for practical application in this circuit. **ME**