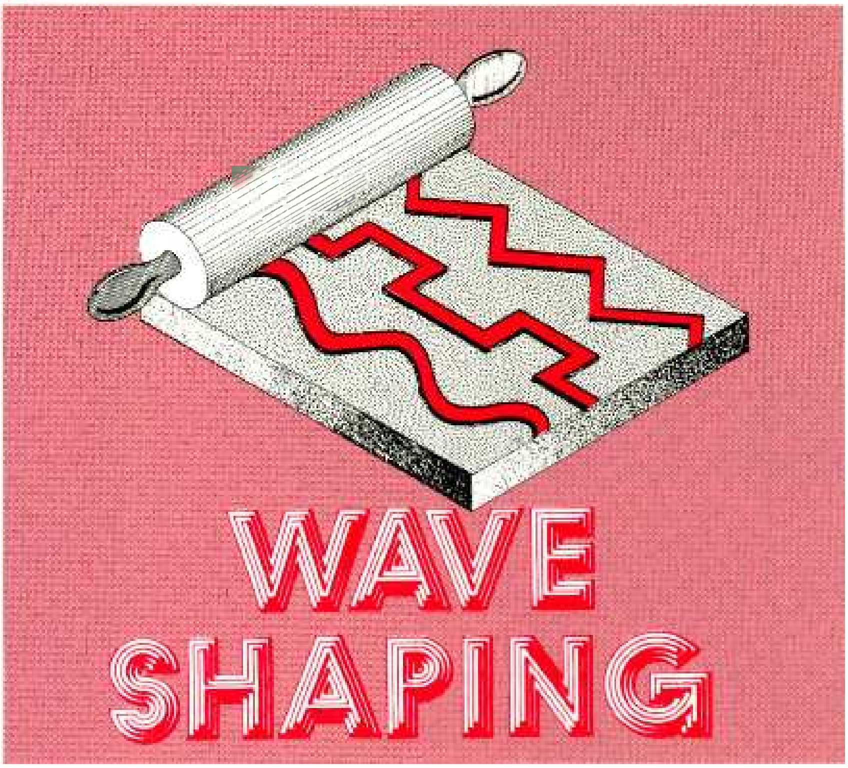

Learn the basics of waveform generation and shaping with bipolar transistor circuits that you can build and put to work.

RAY MARSTON

THE SUBJECT OF THIS ARTICLE IS waveform generation and shaping as performed by various kinds of multivibrator circuits and special-purpose oscillators. It is a continuation of last month's article on transistorized RC and LC oscillator circuits, and the astable multivibrator. Previous articles in this series have covered the basics of the bipolar junction transistor (BJT) and have presented a general roundup of popular BJT circuits starting with those basic transistor amplifiers: common-collector, common-emitter and common-base.

Multivibrator basics

A transistor multivibrator is a cross-coupled, two-stage switching circuit. Each active transistor stage is regeneratively cross-coupled to its companion; thus, one stage automatically turns on as the other turns off, and conversely. This cross-coupling can be arranged to give either stable or semistable switching. When stable cross-coupling is desired, the transistor switch locks permanently into the ON or OFF state until it is forced to change state by an external signal.

When the circuit is cross-coupled in a semistable manner, the transistor initially locks into the ON or OFF state, but then automatically becomes "unlocked" again after a delay period determined by the time constant of the cross-coupling components.

Schematics of the four basic transistor multivibrator circuits most commonly used are shown in Figs. 1 to 4. The Fig. 1 circuit is a manually triggered bistable (two stable state) multivibrator. The base-bias of each transistor is obtained from the collector of the other transistor, so that one transistor automatically turns off when the other turns on, and conversely.

The output can be driven low by briefly turning Q1 off with S1: the circuit locks into this state until Q2 is turned off by S2. At that time the output locks into the high state, and this action can be repeated as long as the circuit is powered.

Figure 2 shows a monostable (one stable state) multivibrator or *one-shot* pulse generator circuit. Its output is normally low, but switches high for a preset period (determined by the vales of C1 and R2) if Q2 is briefly turned off with S1.

Figure 3 shows an astable (no stable states) multivibrator or free-running square-wave generator. The on and off periods of the square wave are determined by the values of R3 and C1 and R2 and C2.

Figure 4 shows a *Schmitt trigger* or sine-to-square waveform converter. Transistor Q2 switches abruptly from the ON state to the OFF state, or conversely, as the base of transistor Q1 base rises above or falls below the predetermined trigger-voltage levels.

Several different practical astable multivibrator circuits were discussed in last month's article. This article will examine practical versions of three other multivibrators.

Monostable circuits

The monostable multivibrator circuit in Fig. 2 acts as a triggered pulse generator. Normally transistor Q2 is driven into saturation through R2, so the output (taken from transistor Q2's collector) is low. Transistor Q1, which derives its base-bias from transistor Q2's collector through resistor R4, is cut off under this condition, and its collector is at the full supply voltage.

When a START signal is applied to Q2 by momentarily closing switch S1, Q2 switches off, driving the output high and driving Q1 on through R4. Regenerative switching action is caused by the reopening of S1.

Transistor Q2's base is driven negative by the charge on C1, and as soon as the regenerative response is complete, C1 starts to discharge through R2. Eventually its charge falls so low that Q2 turns on again, thus initiating another regenerative response. Now both transistors revert to their original states, and the output pulse terminates, completing the action of the circuit.

Thus, a positive-going pulse is developed at the output of this circuit each time an input trigger signal is applied by momentarily closing switch S1. The pulse period is determined by the values of R2 and C1. The relationship is:

Pulse period = $\approx 0.7 \times R2 \times C1$

Where the pulse period is in microseconds, C is in microfarads, and R is in kilohms.

The circuit in Fig. 2 can be triggered either manually by closing a momentary switch or by introducing an input trigger signal. That trigger signal can be either a negative pulse applied to the base of Q2, or a positive pulse applied to the base of Q1.

Figure 5-*a* is a practical schematic for a manually triggered monostable multivibrator. It can be triggered with momentary switch S1 by feeding a positive pulse to Q1's base through R2. Figure 5-*b* shows the circuit's waveforms.

In Fig. 5, the base-to-emitter junction of Q2 is reverse-biased during the operating cycle by a peak voltage equal to the supply voltage. This means that the maximum supply voltage should be limited to about 9 volts to prevent damage to the transistor. However, a supply voltage greater than the reverse base-emitter breakdown value of Q2 can be applied safely if silicon diode D1 is placed in series with Q2's base, as shown in Fig. 5.

This higher supply voltage provides the same kind of *frequency correction* that was described for the astable multivibrator in last month's article.

The value of timing resistor R3 in the Fig. 5 circuit must be large with respect to R1, but

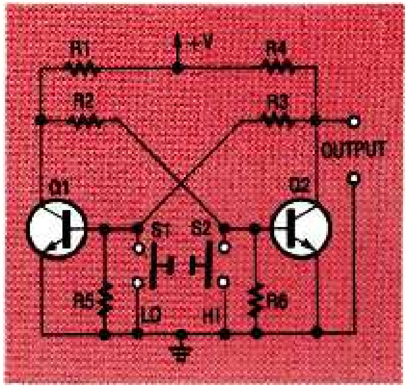

FIG. 1—A BISTABLE MULTIVIBRATOR intended for manual-triggering.

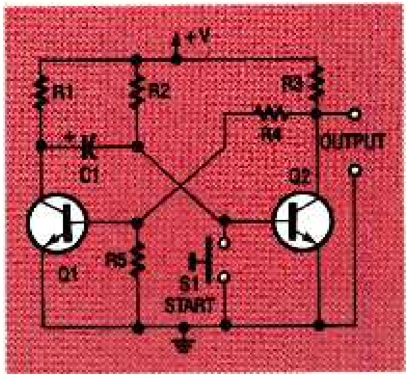

FIG. 2—A MONOSTABLE multivibrator designed for manual triggering.

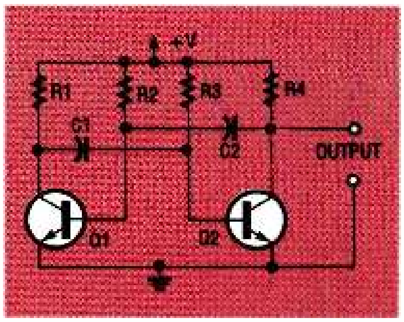

FIG. 3—AN ASTABLE MULTIVIBRATOR or free-running squarewave generator.

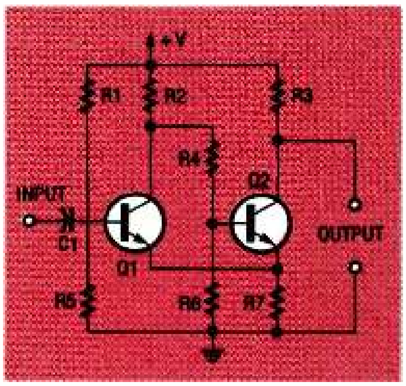

FIG. 4—A SCHMITT TRIGGER circuit is a sinewave-to-square wave converter.

must be less than the product of R5 and the h_{FE} of Q1. The pulse period for Fig. 5 equals 50 milliseconds divided by the value of capacitor C1 in microfarads; it will be 5 seconds with the value of C1 shown.

Long delays

If a Darlington transistor pair is substituted in place of Q2 in Fig. 5, the circuit will be able to provide very long timing periods. That substitution results in a very high effective h_{FE}, and permits the use of large values of R3, as shown in Fig. 6.

The Fig. 6 circuit can be powered from any DC source with an output between +6 and +15 volts to give a pulse output period of about 100 seconds with the values of the resistors and capacitors shown.

Keep in mind that a manually triggered monostable circuit such as those of Figs. 5 and 6 is dependent on the duration of the input trigger signal. The circuits trigger at the moment that a positive-going pulse is applied to the base of Q1 in Fig. 5 or Q3 in Fig. 6. If this pulse is removed before the monostable multivibrator completes its normal timing period, the period will end regeneratively, as previously described.

However, if the trigger signal has not been removed by the time the monostable completes its natural timing period, the timing cycle will end non-regeneratively. This means that the output pulse will have a longer period and falltime than if the trigger signal were removed earlier.

Waveform triggering

Figures 7 and 8 show alternative ways of applying input signal triggering to the monostable pulse generator. In each case, the circuit is triggered by a square-wave input signal with a short rise time. This waveform is differentiated by the differentiation circuit consisting of C1 and R1 to produce a brief trigger pulse.

In the Fig. 7 circuit, the differentiated input signal is rectified by diode D1 to provide a positive trigger pulse on the

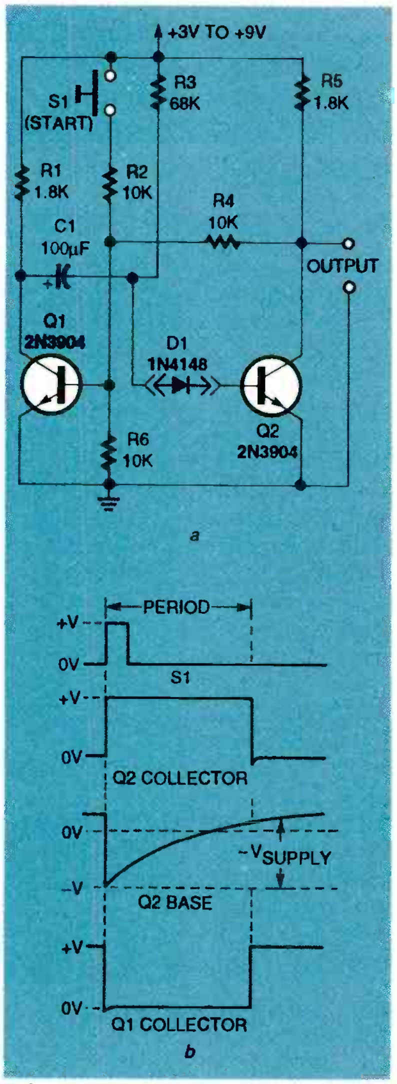

FIG. 5—A MANUALLY-TRIGGERED monostable pulse generator.

base of Q1 each time an external trigger signal is applied. In the Fig. 8 circuit, however, the differentiated signal is fed to the gate of transistor Q1. That change in the circuit makes the trigger signal independent of Q2. Notice that "speed-up" capacitor C3 in Fig. 8 is connected in parallel with feedback resistor R5 to improve the shape of the output pulse.

Both the circuits in Figs. 7 and 8 provide an output pulse period of about 110 microseconds with the values of resistors and capacitors shown. This period can be varied from a fraction of a microsecond to several seconds with a suitable choice of values for capacitor C2 and resistor R4.

The circuits in Figs. 7 and 8 can be triggered by sine or other non-rectangular waves if they are conditioned by a Schmitt trigger or similar sinewave-to-squarewave converter circuit. (The Schmitt trigger circuit is discussed later in this article.)

Bistable circuits

Figure 9 is practical schematic for the manually-triggered bistable multivibrator shown in Fig. 1 and described earlier. This circuit is also known as a R-S (reset-set) flip-flop and, like a toggle switch, it is also an elementary digital memory. Its output can be SET to the high state by momentarily closing switch S2. (Alternatively a negative pulse can be applied to the base of Q2.)

The circuit then "remembers" this state until it is RESET to the low state by a momentary closing of S1 (or by applying a negative pulse to the base of Q1). The

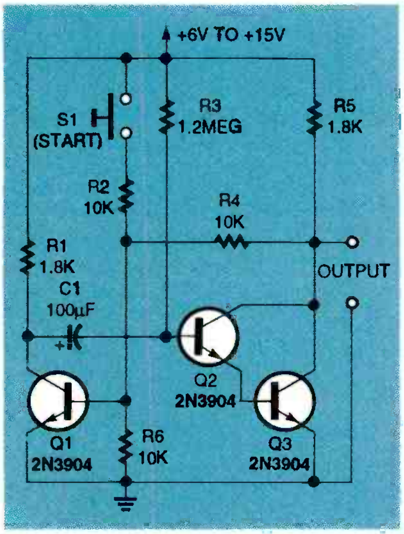

FIG. 6—A LONG-PERIOD (100-SECOND) monostable circuit.

circuit then "remembers" this new state until it is again set by S2. This cycle can be continued indefinitely as long as power is applied.

The circuit in Fig. 9 can be modified to provide a divide-by-two or counting function by including two *steering* diodes (diodes D1 and D2) and associated components, as shown in Fig. 10.

The Fig. 10 circuit changes state each time a negative-going trigger pulse is applied. If, for example, the input pulses are derived from a squarewave input signal, the circuit will generate a squarewave output signal at half the input frequency.

The circuit generates a pair of output signals that are 180° out of phase, shown here as Q1 and Q2. The introduction of CMOS IC versions of the bistable counter circuit have largely eliminated any need for the construction of these circuits from discrete components.

Schmitt trigger

The last member of the multivibrator family to be discussed here is the Schmitt trigger circuit. It is a voltage-sensitive switching circuit that changes its output state when the input signal exceeds or falls below preset upper and lower threshold levels. Figure 11 shows how the Schmitt trigger converts sinewaves to square waves.

The Schmitt trigger circuit is emitter-coupled and has cross-coupling between the base and collector of transistor Q1, which provides the required regenerative switching. Capacitor C2 speeds up the switching action by shunting R4. The sinewave input signal is superimposed on a DC voltage. (The voltage is determined by trimmer potentiometer R8 and resistors R1 and R2) that is applied to the base of Q1.

A practical Schmitt trigger needs a sinewave input signal with an amplitude of at least 0.5

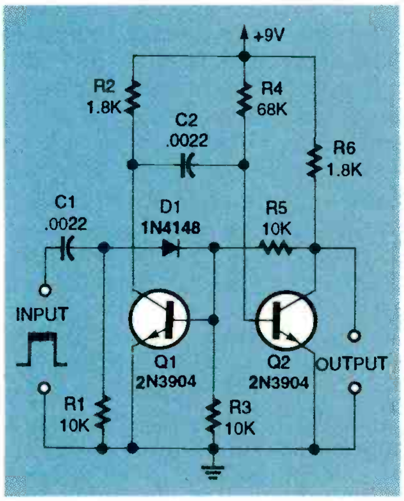

FIG. 7—A WAVEFORM-TRIGGERED monostable circuit.

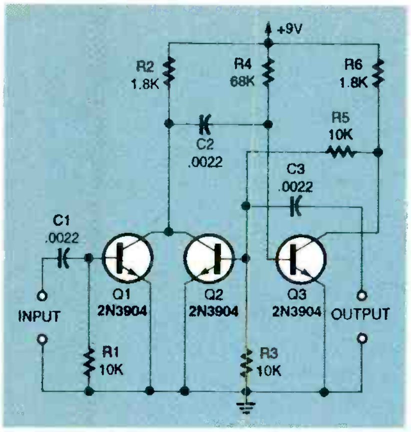

FIG. 8—A MONOSTABLE CIRCUIT with gate-input triggering.

volts, rms. The squarewave output signal symmetry varies with the input signal amplitude, so R8 must be adjusted to optimize that symmetry. The Schmitt trigger performs satisfactorily as a sinewave-to-squarewave converter at frequencies up to a few hundred kilohertz. The device produces squarewave output signals whose rise times are only a fraction of a microsecond.

Sawtooth generators

The astable multivibrator shown in Fig. 3 is one of a variety of circuits that can generate sawtooth waveforms. For example, it can generate negative-going sawtooth waves at the bases of both transistors Q1 and Q2. As a result, the astable multivibrator can be considered as another *free-running sawtooth generator*.

Similarly, the monostable multivibrators shown in Figs. 5 to 8 each generate a negative-going sawtooth on the base of Q2 during their active phases. They can be considered as *triggered sawtooth generators*.

Practical versions of Figs. 5 to 8 generate slightly nonlinear sawtooth waveforms because each of their timing capacitors charge exponentially (rather than linearly) through their timing resistors. This abberation can be easily overcome by replacing each timing resistor with a constant-current generator capable of generating linear waveforms.

A timing circuit based on the 555-type integrated circuit timer offers the best way to generate positive-going triggered sawtooth waveforms. However, if you want to generate free-running, positive-going sawtooth waveforms, this can be done with a unijunction transistor or UJT, connected in the circuit shown in Fig. 12.

The UJT is a three-terminal transistor whose terminals are identified as *emitter* (E), *base 1* (B1), and *base 2* (B2). A UJT is connected as shown in Fig. 12 as Q1 with its B2 positive with respect to B1, and with the input applied to its emitter terminal.

The emitter of the UJT Q1 presents a very high impedance until the input (emitter) voltage reaches a specific *firing* voltage. At that time, UJT Q1 switches abruptly to the ON state. When it is on, the emitter presents a low input impedance, and it draws a significant amount of current from the input circuitry. However, if this input current falls below a certain threshold value, UJT Q1 automatically switches back to its high input impedance state.

In Fig. 12, capacitor C1 charges exponentially towards the positive supply voltage through trimmer potentiometer R4 and R1 until the voltage on C1 reaches the firing value of the UJT Q1. At that time, the Q1 switches on and rapidly discharges C1. As soon as C1 is discharged, Q1 turns off again, so C1 starts to recharge again through R4 and R1.

This circuit generates a stable but nonlinear sawtooth waveform that van be varied from 25 Hz to 3 kHz by R4, with the value of capacitor C1 shown. Transistor Q2 and Q3 are connected as a Darlington emitter-follower

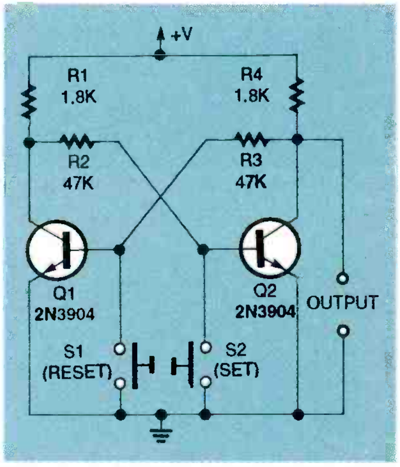

FIG. 9—A SWITCH-TRIGGERED FLIP-flop (R-S) bistable multivibrator.

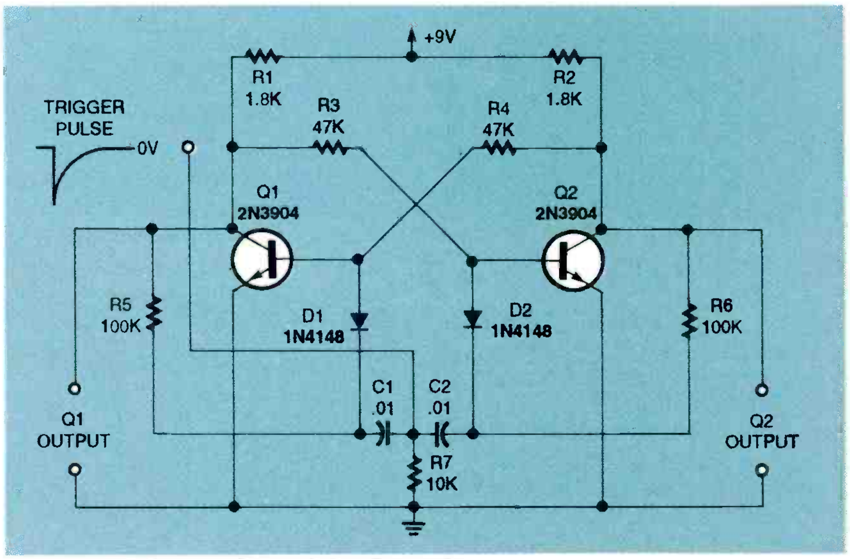

FIG. 10—A DIVIDE-BY-TWO BISTABLE circuit.

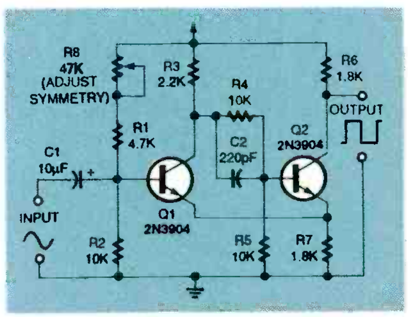

FIG. 11—SCHMITT TRIGGER sinewave-to-squarewave converter.

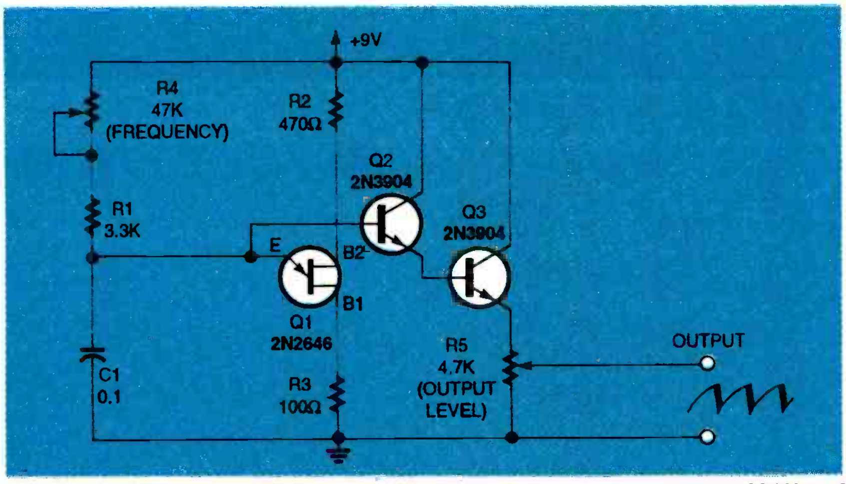

FIG. 12—A NONLINEAR SAWTOOTH GENERATOR that works over a range of 25 Hz to 3 kHz.

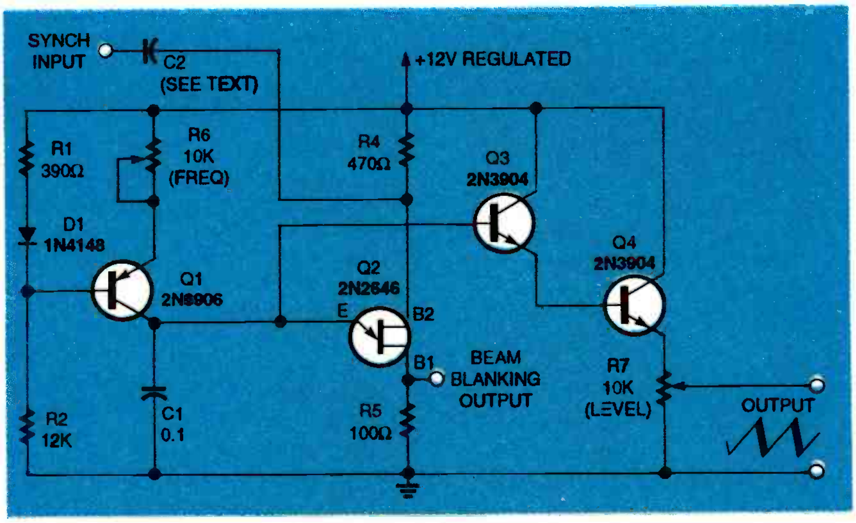

FIG. 13—THIS LINEAR SAWTOOTH GENERATOR can function as a oscilloscope timebase generator and can blank the CRT beam.

buffer stage. This arangement makes a low-impedance sawtooth waveform available at an output terminal taken from the wiper of output level potentiometer R5.

The linear sawtooth generating circuit in Fig. 12 can be modified to become an oscilloscope timebase generator. The modified circuit is shown in Fig. 13. Capacitor C1 is charged by a constant-current source. In this circuit, Q1 functions as a temperature-compensated, constant-current generator. It current can be varied from 35 to 390 microamperes by adjusting frequency trimmer potentiometer R6.

The linear sawtooth is available as a variable output whose amplitude can be varied by setting level potentiometer R7. The

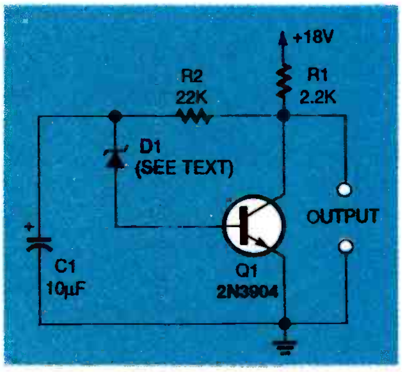

FIG. 14—A WHITE-NOISE GENERATOR has many applications.

output between R7 and ground can be fed via a coaxial cable to the external timebase jack of an oscilloscope.

Positive "flyback" pulses taken between resistor R5 and B1 of UJT Q2 at the beam-blanking output can be used to blank the oscilloscope beam if taken through a high-voltage blocking capacitor.

The operating frequency of the Fig. 13 circuit can be varied from 60 to 700 Hz with R6 if all of the component values are as shown. Other frequency ranges can be obtained by substituting other values for capacitor C1. The timebase generator can be synchronised to an external signal by feeding the external signal to UJT Q2 through the synch input capacitor C2.

This external signal, which must have a peak amplitude between 200 millivolts and 1.0 volt, effectively modulates the supply voltage (and thus the trigger point) of UJT Q2. It causes UJT Q2 to fire in synchronism with the external trigger signal.

Capacitor C2 must have a lower impedance than resistor R4 at the sync signal frequency. Also, capacitor C2 must have a working voltage that is greater than the external voltage from which the external signal is applied. If the sync signal has a rectangular form with short rise and fall times, the value of C2 need only be a few hundred picofarads.

White-noise generator

"White noise" is another useful waveform. It is a signal that contains a full spectrum of randomly generated frequencies, each having equal mean power when averaged over a unit of time. White noise is useful for testing audio and radio frequency amplifiers, and it is widely used to mask background noise to serve as a sleeping aid.

Fig. 14 is the schematic for a simple, practical white-noise generator. In operates on the principle that all reverse-biased Zener diodes inherently generate white noise. In Fig. 14, R2 and D1 are connected in a negative-feedback loop between the collector and base of common-emitter amplifier Q1. Negative feedback stabilizes the DC working levels of the generator. Capacitor C1 serves to decouple alternating current from the circuit.

The Zener diode acts as a

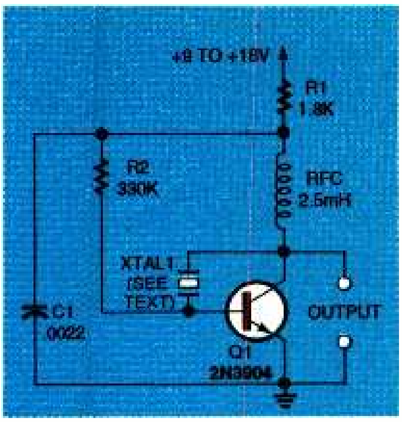

FIG. 15—A PIERCE OSCILLATOR with a parallel-mode crystal.

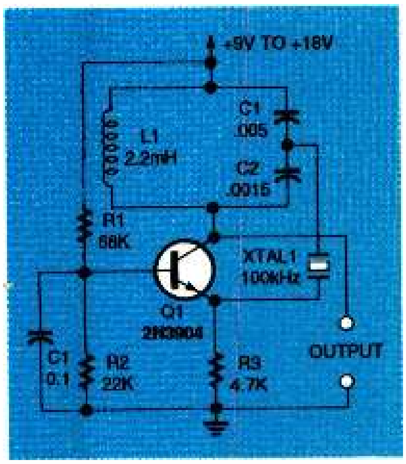

FIG. 16—A 100-kHz COLPITTS oscillator with a series-mode crystal.

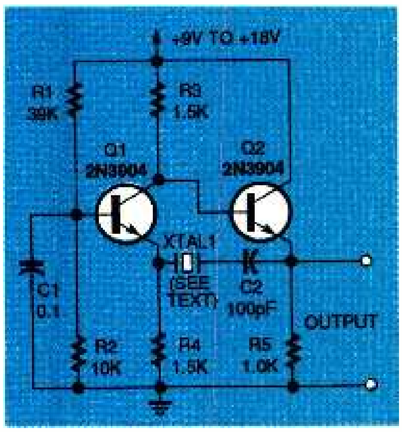

FIG. 17—THIS 50-kHz to 10-MHz oscillator will work with most series-mode crystals.

white-noise source that is in series with the base of transistor Q1. The Zener noise is amplified by the transistor to a useful level of about 1 volt peak-to-peak. Any Zener diode rated for 5.6 to 12 volts should work well in this circuit. Try different Zener diodes and compare the white-noise output.

Crystal oscillators

Crystal oscillator circuits generate accurate, stable frequencies because they include precisely cut piezoelectric quartz crystals which function as high precision electromechanical resonators or tuned circuits. The crystals in these circuits typically have Qs of about 100,000, and they can provide as much as 1000 times greater frequency stability than can conventional inductive-capacitive (LC) tank-circuit oscillators.

A piezoelectric crystal's operating frequency of a few kHz to 100 MHz is determined by its mechanical dimensions. The crystal, can be cut to provide either series or parallel resonant operation. Series-mode crystals present a low impedance at resonance, while parallel-mode crystals present a high impedance at resonance.

Figure. 15 is a practical schematic for a crystal oscillator that is designed for a parallel-mode crystal. The circuit is actually a Pierce oscillator, and it will oscillate with most 100-kHz to 5-MHz parallel-mode crystals without any circuit modification.

Figure 16 shows an alternative 100-kHz oscillator that was designed for a series-mode crystal. It is known as a Colpitts oscillator.

Its tank circuit, consisting of L1, C1, and C2, is designed to resonate at the same frequency as the crystal. However, the tank circuit component values must be changed if any other crystal frequencies are desired.

Figure 17 is the schematic for a useful two-transistor oscillator that will work with most 50 kHz to 10 MHz series-resonant crystals. In this circuit, Q1 is connected as a common base amplifier, and Q2 is an emitter follower. The output signal (from Q2's emitter) is fed back to the input (Q1's emitter) through C2 and the series-resonant crystal. This is a versatile oscillator circuit that will work even with a low-cost, marginal crystal. Because of that, the circuit can form the heart of a simple crystal tester. Ω