Pulse Circuits Revisited

Generating pulses and waveforms from experimental circuits

By Joseph J. Carr

In February, we discussed how pulses and other non-sinusoidal waveforms are composed of a series of harmonically-related sine and cosine waves. Only the pure, undistorted sine wave contains only a single frequency, which we call the "fundamental." All other waveforms have a fundamental—which sets the frequency of the waveform or pulse repetition rate of the pulse train—and a collection of harmonics.

Our objective this month is to look at ways to generate pulses and waveforms using your own experimental circuits. We will consider methods for creating single pulses, pulse trains and square waves using the popular 555 integrated circuit timer, TTL devices and CMOS devices.

Classes of Circuits

In this installment, we will look at two classes of circuits that will accomplish our aims. One is monostable multivibrators, commonly referred to as "one-shot" oscillators. The other is the astable multivibrator.

The monostable multivibrator gets its name from the fact that it has only one stable state. The circuit remains dormant in this state until it is triggered, as illustrated in Fig. 1. When a trigger pulse is received, the monostable multivibrator snaps to an unstable output state, where it remains for a predetermined period of time called "T." When time T expires, the circuit reverts back to its stable or so-called "dormant" state.

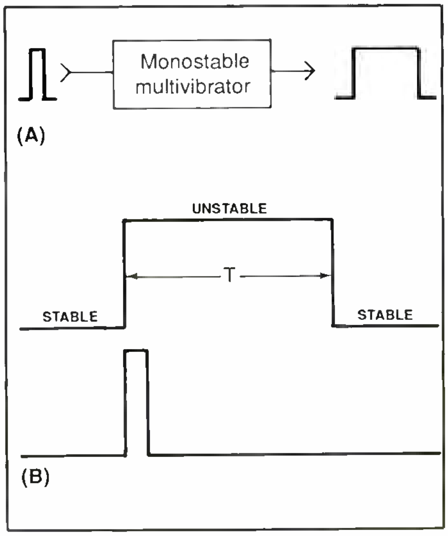

Fig. 1. When trigger pulse is received, output of monostable multivibrator circuit (A) must "time out" before it can respond to another triggering pulse; only two states (B) are possible.

Monostable multivibrator circuits can be further subdivided into "retriggerable" and "non-retriggerable" categories. The difference between these two types of circuits is in whether or not the circuit will accept a trigger pulse prior to expiration of the duration of the pulse.

Shown in Fig. 2(A) is the non-retriggerable response. At time T_1, a trigger pulse is received and the output snaps to a logic high for time T. At time T_2, however, a second trigger pulse is received. The circuit ignores this second trigger pulse because it is already active. At time T_3, the original pulse "times out," which readies the circuit to receive and act upon another trigger pulse. The subsequent trigger at time T_4 reactivates the output to a logic high.

All non-retriggerable monostable multivibrators (which means most such circuits) ignore the trigger input until the time-out period has elapsed. Some circuits will also ignore new trigger pulses until after a post-time-out "refractory period" expires. This period is short and not of significance in modern circuits. However, it was quite significant in the days before integrated circuits.

The usefulness of the non-retriggerable multivibrator is seen in applications like switch and relay contact debouncing circuits. The "bounce" of switch and relay contacts has the effect of applying to the input of a circuit multiple pulses rather than the single one that should be received. By letting the first pulse "fire" a non-retriggerable one-shot multivibrator and making duration time T long enough for secondary "bounce" pulses to die out, a clean contact-closure signal is obtained.

Shown in Fig. 2(B) is the retriggerable monostable multivibrator response. The original trigger pulse occurs at time T_1, at which point the output snaps to logic high for the duration of time T. At time T_2, when a second pulse is received, the circuit "retriggers" for an additional time T. The total duration of the high output state, then, is $T_4 - T_1$, or natural duration time T plus a shorter duration $T_2 - T_1$.

Usefulness of the retriggerable multivibrator circuit is seen in alarm circuits. In medical electronics, for example, these circuits are frequently

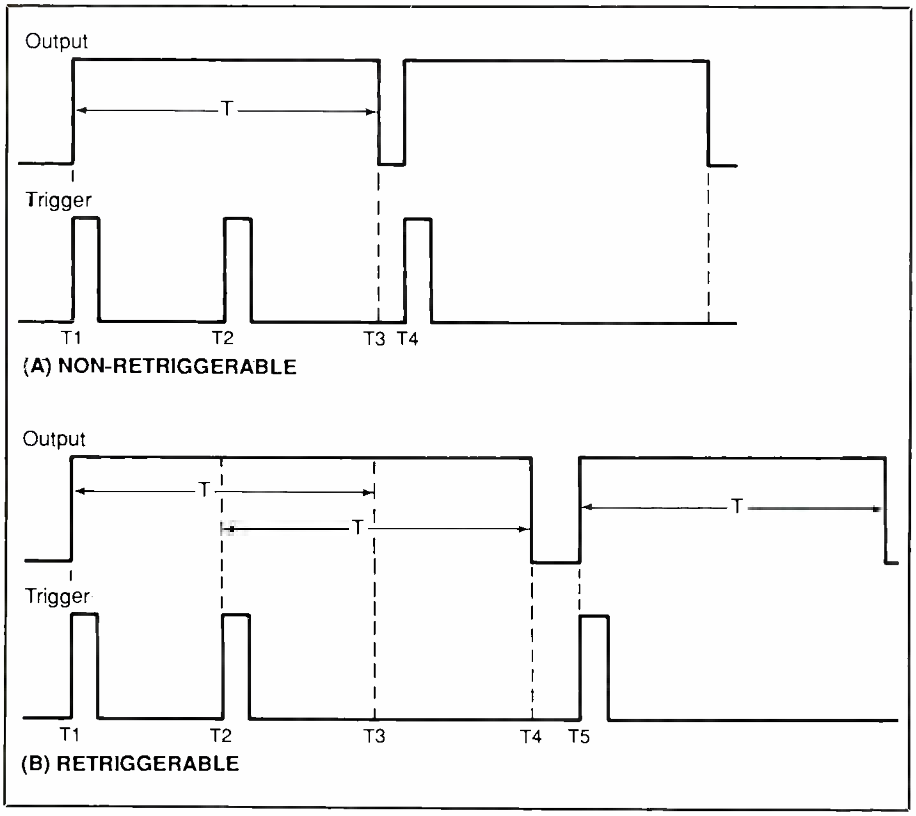

Fig. 2. Responses of non-retriggerable (A) and retriggerable (B) multivibrators.

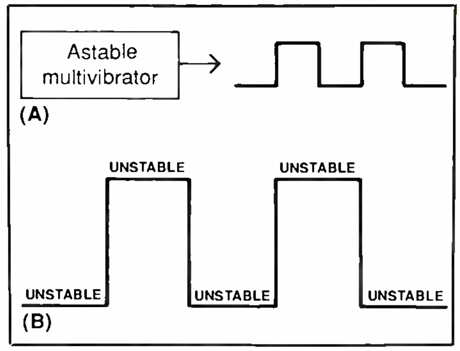

Fig. 3. Output from astable multivibrator (A) alternates between high and low logic states; both states (B) are unstable.

used in respirator alarms. A signal from a transducer is wave-shaped into pulse form and applied to the trigger input of the retriggerable monostable multivibrator. Duration T is set to the limits that the doctor feels indicates that the patient has ceased breathing. If no "breath" signal retriggers the one-shot multivibrator before the circuit times out, the output snaps to logic low and triggers the alarm.

A monostable multivibrator produces only one output pulse for every input trigger pulse. The output pulse of the circuit has a constant duration and amplitude even when the triggering pulse is ragged. Typical uses of the one-shot multivibrator include cleaning up of pulses after transmission (where path losses roll off frequencies and so distort the pulse), "stretching" short-duration pulses, debouncing switch and relay contact closure signals and actuating digital circuits.

An astable multivibrator has no stable states. Its output waveform bounces up and down, as illustrated in Fig. 3, between two possible unstable states. If the durations of the two unstable states are equal, the output from the astable multivibrator resembles the classical square waveform. If the high and low unstable states are unequal in duration, the output waveform resembles a digital pulse train.

Actual Circuits

Monostable multivibrators can be built using TTL, CMOS and other integrated-circuit devices. The popular 555 timer is a particularly useful IC device. In Fig. 4 is shown the use of simple CMOS inverters or noninverting followers. These circuits can be built using such hex chips as the 4049 and 4050 or from NAND or NOR gates wired as inverters.

In Fig. 4(A) is shown the schematic diagram of a positive-edge-triggered one-shot multivibrator circuit that can produce either positive- or negative-going output pulses. If you need only one direction of pulse, however, feel free to omit the other device.

The Fig. 4(A) circuit operates by nature of the fact that CMOS circuits change state when the input potential crosses a point midway between the positive and negative supply voltages. If only one supply is used, such as V+ only, the transition point occurs at 0.5V+.

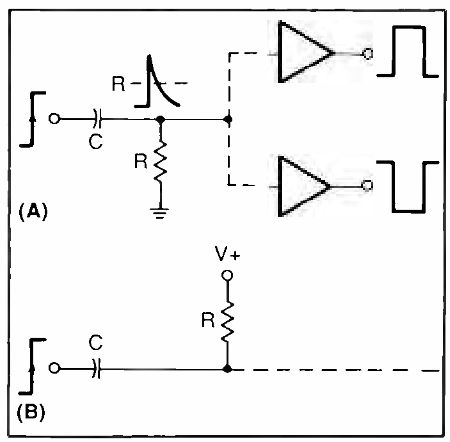

Fig. 4. Positive-edge-triggered one-shot multivibrator can produce positive- and negative-going output pulses (A) when bipolar power supply is used; with single-ended power supply reference end of resistor tied to V+ (B), circuit can be made to respond to negative-going-edge triggering.

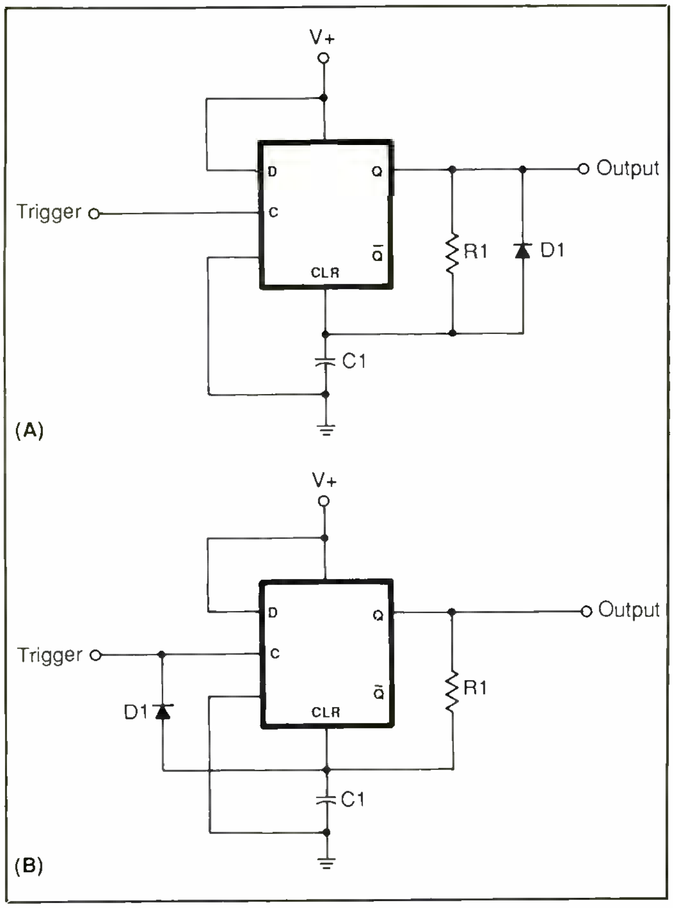

Fig. 5. Two versions of monostable multivibrator built around 4013 CMOS D-type flip-flop: (A) non-retriggerable and (B) retriggerable.

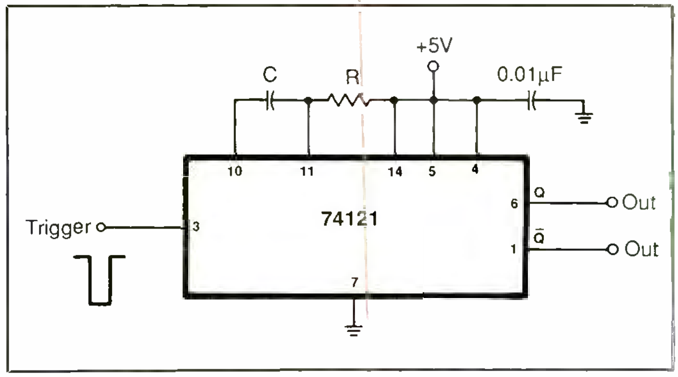

Fig. 6. One-shot multivibrator built around specialized 74121 TTL-logic device.

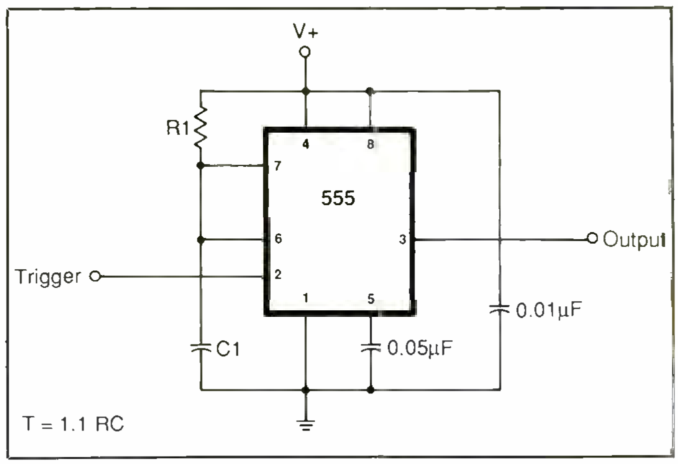

Fig. 7. Circuit for using 555 and 7555 IC timer chips as monostable multi-vibrators.

The RC network acts as a differentiator so that the square input step-function used as a trigger signal forms the decaying output signal shown. The output snaps to logic high as soon as the input signal crosses point "A" in a positive-going direction and remains high until the newly charged capacitor discharges back to point "A," which causes the output to snap back to logic low. The duration of the output pulse is approximately T = 0.7RC, with T expressed in seconds.

The same circuit shown in Fig. 4(A) becomes negative-edge triggered by lifting the "cold" or ground end of resistor *R* and connecting it to the V+ rail. A significant limitation of this version of the circuit is that the input trigger must remain active—logic high in this case—for a period of time that is longer than the duration of the output pulse.

Two versions of the monostable multivibrator built around the 4013 D-type flip-flop are shown in Fig. 5. The rules of operation for the D-type flip-flop are as follows:

(1) The level on the D input to the flip-flop is transferred to the Q output when clock input C is at logic high;

(2) The not-Q output is the complement, or opposite, of the Q output (that is, is Q = high, not-Q = low);

(3) A logic high applied to clear input CLR forces the Q output to low and the not-Q output to high.

The non-retriggerable multivibrator circuit shown schematically in Fig. 5(A) has its D input permanently tied to logic high by nature of it being connected to the V+ rail. When a trigger pulse forces clock input C high, the high on the D input is transferred to the Q output, making this output also high.

The high on the Q output causes capacitor *C1* to begin charging at a rate determined by the value of resistor *R1*. When the potential across *C1* reaches V+/2, the CLR input is activated, forcing the Q output low again. However, now diode *D1* is forward-biased by the potential on the capacitor; so *C1* rapidly discharges into the low Q output. Again, T = 0.7R1C1.

Shown in Fig. 5(B) is the retriggerable version of the Fig. 5(A) circuit. In this case, the discharge diode is connected from the CLR input of the D-type flip-flop to the trigger input. Retriggering occurs by bringing the trigger input to logic high and then back to logic low.

One-shot multivibrator circuits built using CMOS devices suffer from a couple of problems. Unless either specified B-series CMOS ICs or Schmitt-trigger CMOS devices are used, the rise and fall times of the output pulse will suffer. Also, very-short durations are difficult to achieve with most CMOS devices. In these cases, however, you may be able to turn to TTL devices.

TTL devices produce both shorter durations (in the nanosecond range) and faster rise times. You can use the same type of inverter-based one-shot multivibrator circuits in TTL as we discussed above for CMOS devices. Of course, you may prefer to opt for specialized multivibrator chips instead of TTL devices.

Shown in Fig. 6 is the schematic diagram of the specialized 74121 TTL-logic one-shot multivibrator. Also available are 74122 and 74123 TTL devices that can be used, though they operate in a slightly different manner to the 74121. Don Lancaster's *TTL Cookbook* gives the pinouts and rules of operation for the other TTL one-shot multivibrators. When assembling the Fig. 6 circuit, use a value of greater than 10 picofarads for capacitor *C* and keep the value of resistor *R* between 2,000 and 40,000 ohms. Output duration of this circuit is approximately 0.7RC.

TTL one-shot multivibrator devices are somewhat sensitive to electrical noise and, thus, are a little difficult to work with. Consequently, some experts recommend using either CMOS devices or a 555 timer unless you need very short durations.

In Fig. 7 is shown the schematic diagram of a circuit for using the 555 and 7555 timer chips as monostable multivibrator circuits. The circuit is timed by the values of *R1* and *C1*, and output duration is calculated using the formula T = 1.1R1C1. An advantage of this circuit is that it is compatible with TTL if V+ is +5 volts. The circuit possesses a relatively high drive capability. It is also compatible with CMOS circuits that operate with a variety of solid-state and other components.

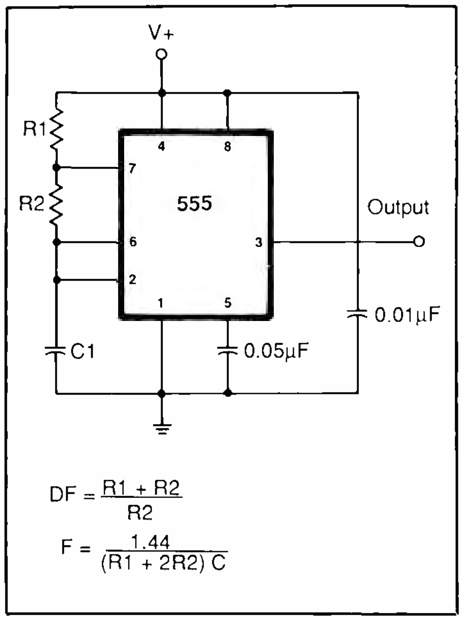

Fig. 8. Astable configuration for 555 and 7555 timer chip circuit.

Shown in Fig. 8 is the astable configuration of the 555/7555 devices. In this case, the circuit is similar to a one-shot multivibrator that is self-triggered. The output frequency of the circuit is calculated from the formula F = [1.44/(R1 + 2R2)C1]. The duty factor (duty cycle) of the circuit is the ratio of high to low times and is calculated from the formula T = (R1 + R2)/R2.

Pulse-Generator Circuit

A pulse-generator circuit must be able to develop an output train of pulses with variable duty factor. One of the easiest ways to obtain a wide-range pulse generator is to connect an astable multivibrator in cascade with a monostable multivibrator, as illustrated in Fig. 9. The RC network between the two stages is used to differentiate the astable output pulses.

By making the frequency of the astable circuit adjustable, you gain control over the pulse repetition rate. Similarly, pulse width is set by making the duration of the one-shot multivibrator stage adjustable. If desired, the output of the astable multivibrator stage can be brought out to a front-panel connector and used as a square-wave signal source.

Summing Up

Pulse circuits are useful to both digital and analog circuit enthusiasts. Understanding the nature of pulses and pulse circuits goes a long way toward understanding much of electronics. This knowledge is useful to a wide range of amateur and professional electronics people alike. **ME**

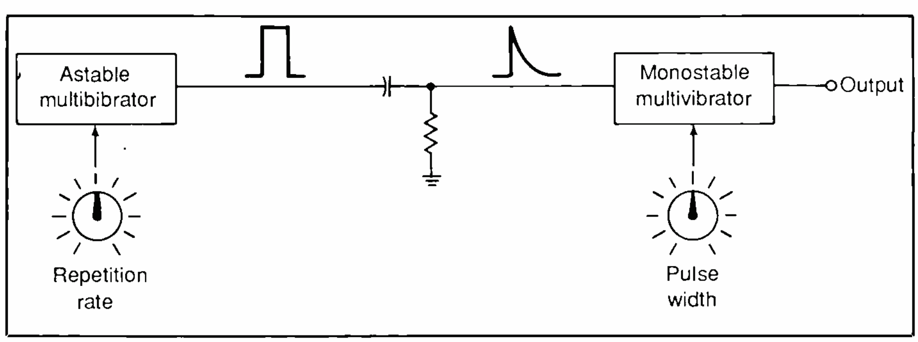

Fig. 9. Pulse generator circuit built using an astable multivibrator in cascade with monostable multivibrator.