Pulse Circuits

What they are, how they work and where they are used in electronic equipment

By Joseph J. Carr

Though you may not recognize them as such in some cases, pulse circuits are very common in modern electronic equipment. Television, for example, would produce only scrambled images without pulses to synchronize the receiver to the studio camera. Too, radar wouldn't be possible without pulses, Morse code CW transmissions are in reality crude pulses, and digital circuits are inherently pulse circuits.

Pulses can be regular or irregular in shape. They can be periodic, aperiodic or single-event. They might look like a distorted sine wave or have a completely non-sinusoidal shape. Consequently, understanding the basic nature of pulses will help you to better understand pulse circuitry and even aid in furthering your understanding of other circuits.

Though pulse circuits once were of interest to a select few people, the widespread use of digital electronics and the need for analog and digital devices needed to generate pulses have radically changed this view. Even if your interest is purely in digital electronics, knowledge of pulse technology will provide a deeper understanding of all electronics.

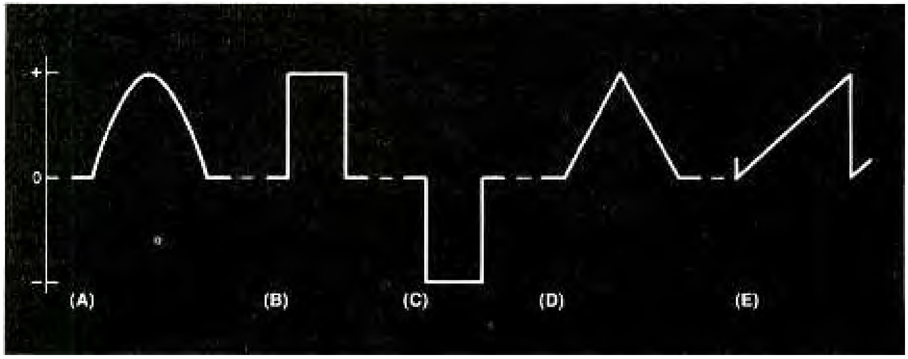

Fig. 1. Typical examples of pulse waveforms: (A) positive half of a sine wave, (B) positive square wave, (C) negative square wave, (D) triangle and (E) ramp.

Some Pulse Shapes

Pulse shapes vary so much that the only true statement that applies to all of them is that they are not sinusoidal. Indeed, as you will shortly see, the pure harmonic-free sine wave is the one wave shape that does not exhibit at least some pulse-like behavior.

Refer now to Fig. 1. In (A) is shown a pulse that is derived from a sine wave but is not a perfect sine shape. In this case, you see a half-wave rectified sine wave that, because of its missing half, now exhibits the behavior of a pulse. Positive- and negative-going square pulses are shown in (B) and (C), respectively. (D) illustrates the wave shape of a triangle or "delta" pulse, while (E) is a drawing of a sawtooth pulse.

Some pulses occur as single events. That is, they occur only once (or in response to a stimulus). Other pulses are repetitive and form "pulse trains," as illustrated in Fig. 2. The pulse train shown in Fig. 2(A) is *periodic* because the pulses occur at regular intervals. *Aperiodic* pulse trains are illustrated in Fig. 2(B) and (C). In these cases, the pulses are repetitive but not periodic because they occur irregularly.

In Fig. 2(B), the duration—interval t_1—of each pulse is the same, but the intervals between pulses are different. In Fig. 2(C), even the durations of the pulses are irregular. Although they are seen on occasion, these waveforms are rather unusual. In most cases, we observe either single pulses or periodic pulse trains in actual electronic gear.

A periodic pulse waveform like that shown in Fig. 3(A) contains a series of equal-duration (t_1), equal-interval (t_2) pulses. The total *period* of the pulse (T) is the sum of duration and interval, or $T = t_1 + t_2$.

With pulse circuits, we often use terminology that is a little different from that used in sine-wave circuits. For example, the "frequency" of the pulse train is often given as the "pulse repetition rate" (PRR), which is also called the "pulse repetition frequency" (PRF). As with frequency, if the waveform is left on continuously, the PRF is the reciprocal of the period.

As an example of the above, let's

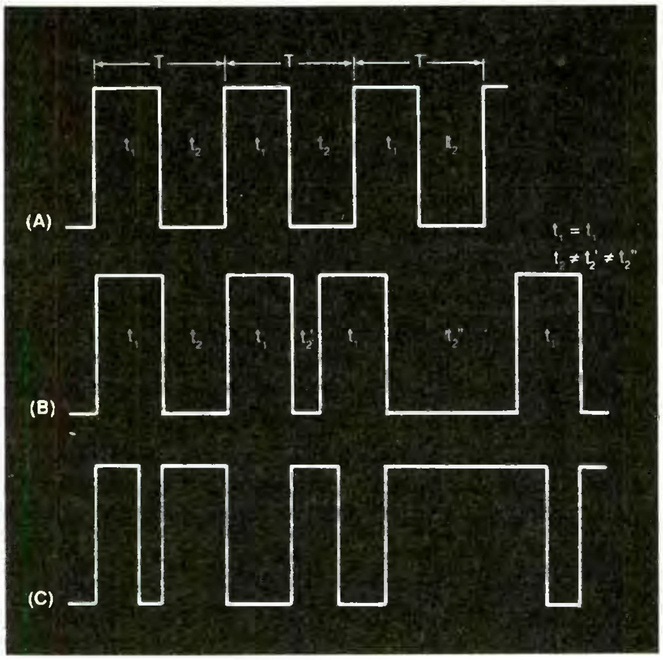

Fig. 2. Periodic (A) pulse train; aperiodic pulse train (B) where time between pulses is irregular; and aperiodic pulse train (C) where both time and pulse widths are irregular.

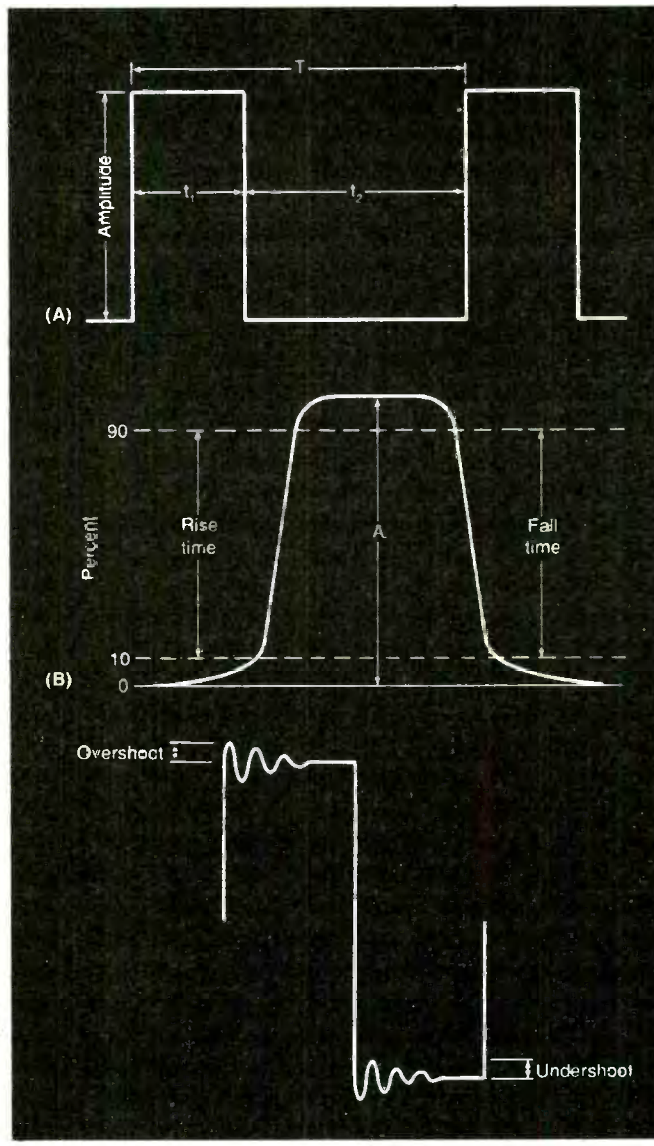

Fig. 3. Total time T between the beginning of any two successive pulses in a periodic pulse train (A) is the same as for any two other pulses in the train; graphic explanation of rise and fall times of a pulse (B); and overshoot "ringing" on a square-wave pulse (C).

say we have a pulse train in which the pulses are on (t_1) for 1 millisecond (ms) and off (t_2) for 5 ms. The period is $T = (t_1 + t_2) = (0.001 \text{ second} + 0.005 \text{ second}) = 0.006$ second. From this, you obtain a PRF of 1/0.005 second = 166.7 pulses per second (pps). In some circuits, the designer may call PRR/PRF "frequency" and express the figure for the repetition rate in Hertz (Hz). Both types of notation are technically correct, but pps is the one traditionally used.

In pulse circuits, "duty factor" relates to the time the pulse is on—t_1 in Fig. 3(A)—and is expressed as a percentage: $DF = [t_1/(t_1 + t_2)] \times 100\%$. Plugging the $t_1 = 1$ ms and $t_2 = 5$ ms figures from the above example into the equation, we have DF = [1 ms/91 ms + 5 ms)] × 100% = 16.7%.

"Rise time" of a pulse is a measure of how fast the pulse makes the low-to-high transition, and "Fall time" is the time required for the pulse to make the high-to-low transition. Unfortunately, pulses often have odd shapes or may have other problems that make the measurements of rise and fall times difficult or even impossible to make.

To overcome this problem (and to standardize the measurement), it has become standard practice to measure pulse rise time as the time required to snap from 10 percent to 90 percent of peak amplitude of the pulse, as illustrated in Fig. 3(B). Conversely, fall time is the period required for the transition from 90 percent to 10 percent of the pulse's peak amplitude.

Perfect square waves are like that shown in Fig. 3(A), and many practical pulse generators produce nearly

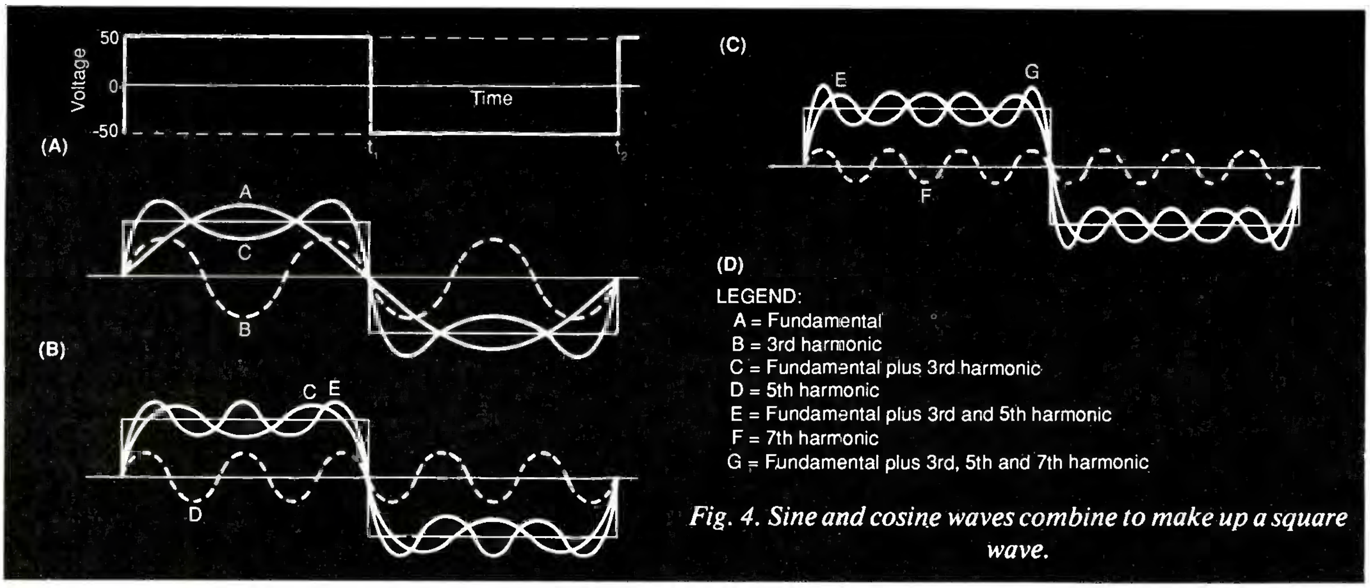

Fig. 4. Sine and cosine waves combine to make up a square wave.

perfect output waveforms. However, sometimes "ringing" occurs on a pulse, as illustrated in Fig. 3(C). A ringing pulse has damped oscillations at the transition points that show up on the waveform as "overshoot" and "undershoot."

There are times when a perfect pulse source exhibits ringing when connected to a circuit but not when connected directly to an oscilloscope's input. In a case like this, the problem might be an unintended LC resonance in the circuit, or it might be more subtle. For example, in one circuit I found ringing that was traced to an oscilloscope probe that had a broken ground wire. The "ground" was being completed through the ac power plug grounds on the scope and signal generator. Restoring the probe's ground eliminated the ringing.

Ringing sometimes occurs in digital circuits as the result of a bad printed-circuit design. One of the earliest microcomputers used a motherboard that had 100 parallel traces that were all too long, especially in larger machines. These traces acted like unterminated transmission lines, and the resulting reflections created ringing (and, incidentally, erratic computer behavior!). Terminating the lines in an absorptive resistance usually solved the problem.

The Making of a Pulse

The only "pure" waveform is a harmonic-free, perfectly undistorted sine wave. All other waveforms, in-

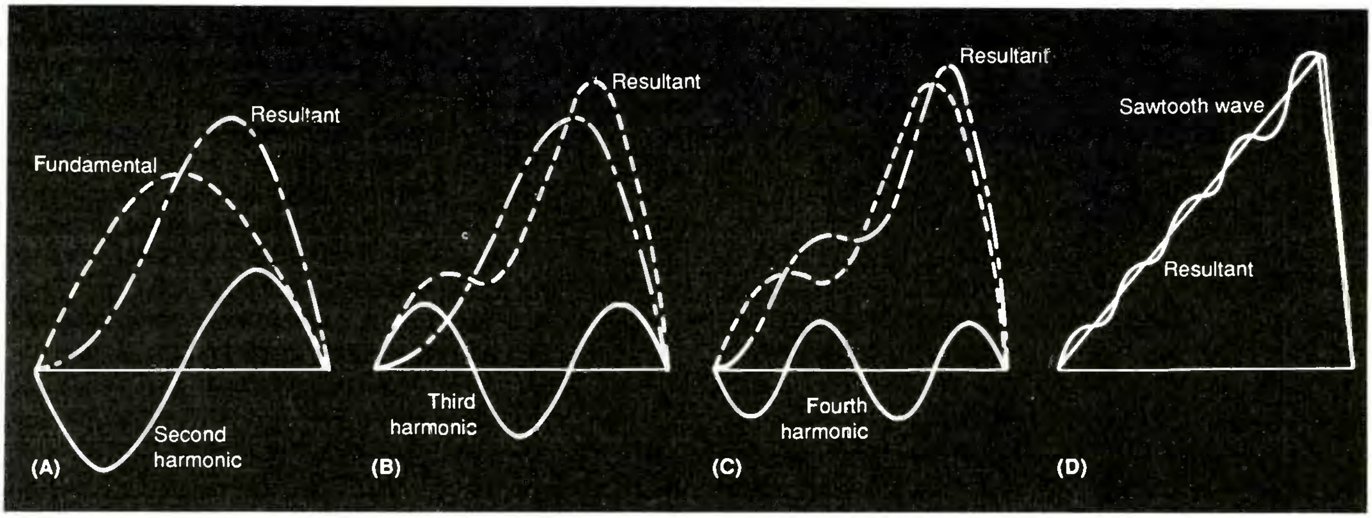

Fig. 5. Graphical depiction of how second, third, fourth and successive harmonics add together to produce a ramp waveform.

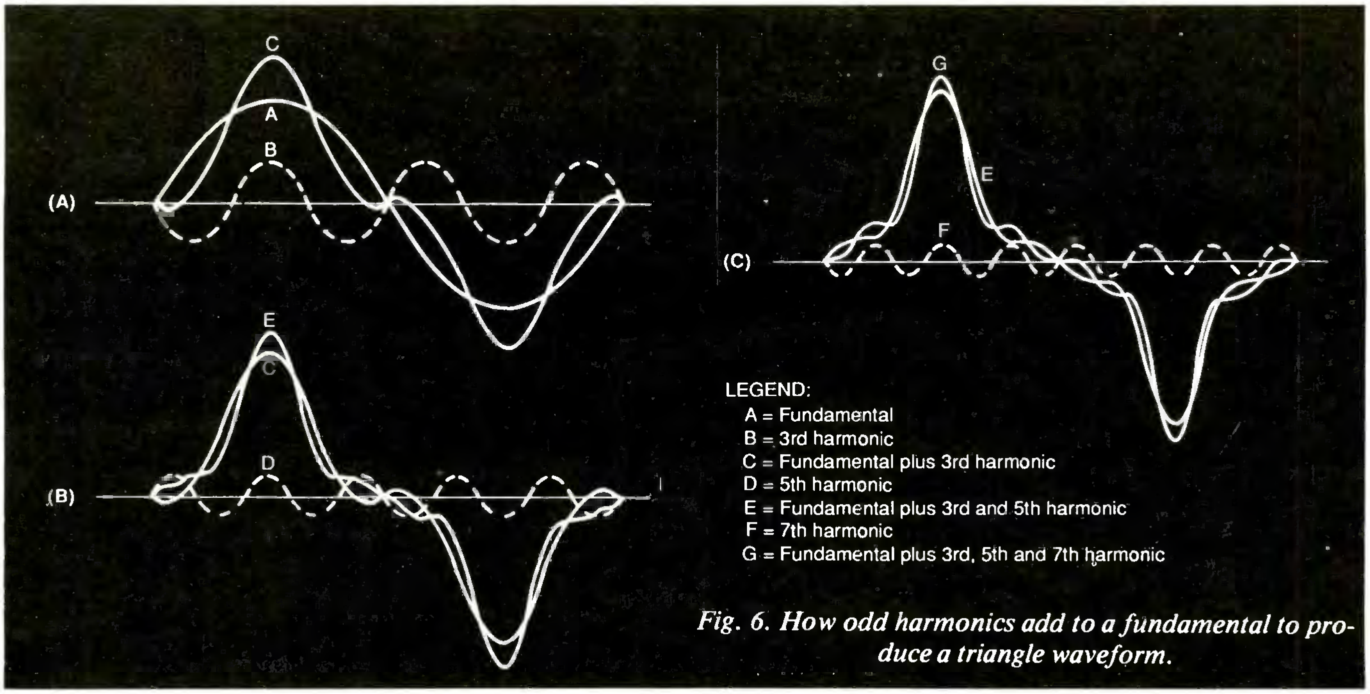

Fig. 6. How odd harmonics add to a fundamental to produce a triangle waveform.

cluding pulses, are made up of a series of harmonically-related sine and cosine waves. Any mathematician can tell you that the list of those sines and cosines form the "Fourier spectrum" of the pulse.

You don't need to dive into heavy mathematics to understand the situation. Figure 4 illustrates how the sines and cosines combine to make up a square wave. The fundamental frequency of the square wave is the lowest-frequency sine wave in the mix, while the others are harmonics of this fundamental. Figures 5 and 6

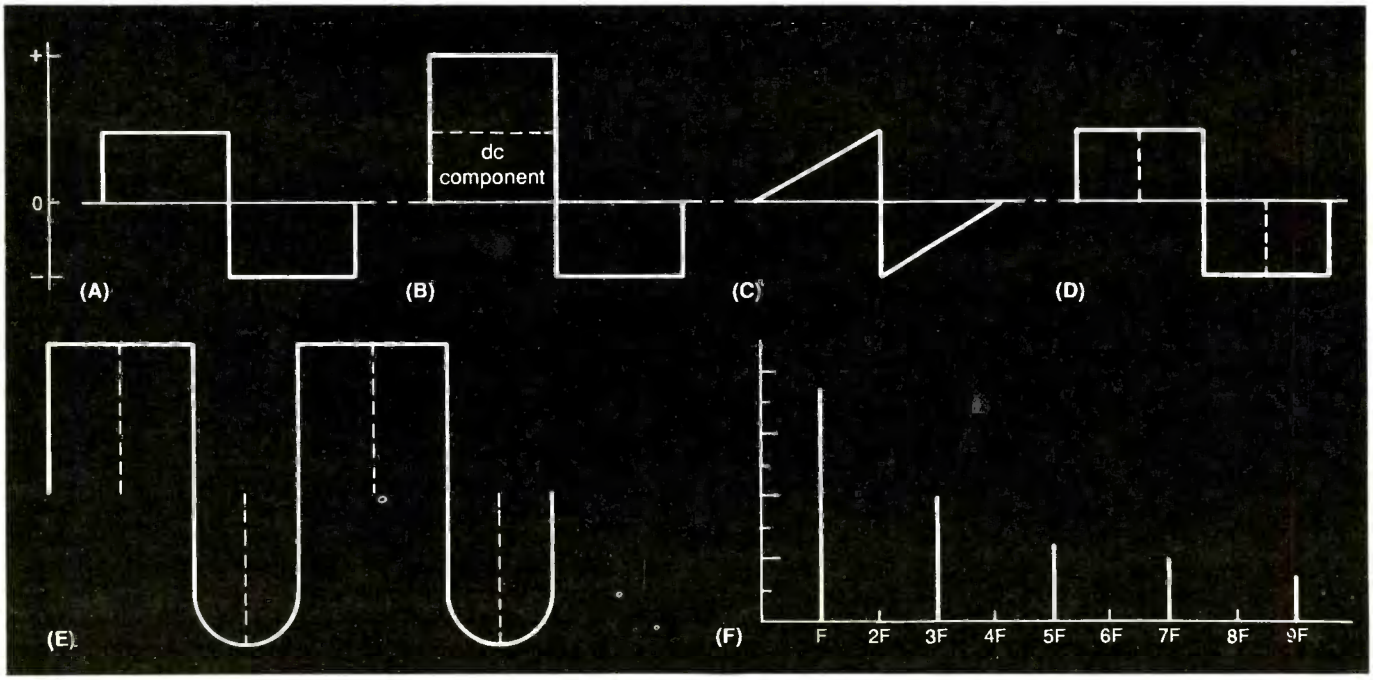

Fig. 7. Symmetry gives a clue to any pulse waveform's frequency content. A variety of pulse waveforms are illustrated in (A) through (E), while (F) depicts the Fourier frequency spectrum for a typical square wave.

show how other waveforms are similarly made up of sine and cosine waves that are harmonically related to each other.

The "symmetry" of any given waveform is a clue to the frequency content of the pulse. "Baseline symmetry" is shown in Fig. 7(A). In this example, the wave is the same shape and amplitude above and below the zero baseline. In contrast, the square wave in Fig. 7(B) is non-symmetrical about the baseline. In this pulse, there is a dc component that makes the positive amplitude greater than the negative amplitude. Another example of baseline symmetry is the sawtooth waveform in Fig. 7(C).

"Half-wave symmetry" is also illustrated in Fig. 7(A) and Fig. 7(C). This is evidenced by the fact that the negative portion is a mirror image of the positive-going portion of the waveform. "Quarter-wave symmetry" is shown in Fig. 7(D) and Fig. 7(E). In Fig. 7(D), the waveform also exhibits half-wave symmetry, while in Fig. 7(E) it does not.

Several things can be deduced from observing the symmetry of pulses:

(1) Baseline symmetry indicates that no dc component is present;

(2) Quarter-wave symmetry indicates that odd harmonics (1st, 3rd, 5th, etc.) are in-phase with the fundamental sine wave;

(3) Half-wave symmetry indicates that there are probably no even harmonics (2nd, 4th, 6th, etc.) present.

A Fourier series chart, such as shown in Fig. 7(F), for any given pulse shape. Figure 7(F) illustrates the Fourier spectrum for a square wave. Note that the square wave has baseline, half-wave and quarter-wave symmetry; so you can conclude that there are no even-order harmonics and that the odd-order harmonics (3F, 5F, 7F, and so on) are in-phase with the fundamental (F). An actual square wave has many more than just the few harmonics, but only a few are shown in Fig. 7(F) for the sake of simplicity.

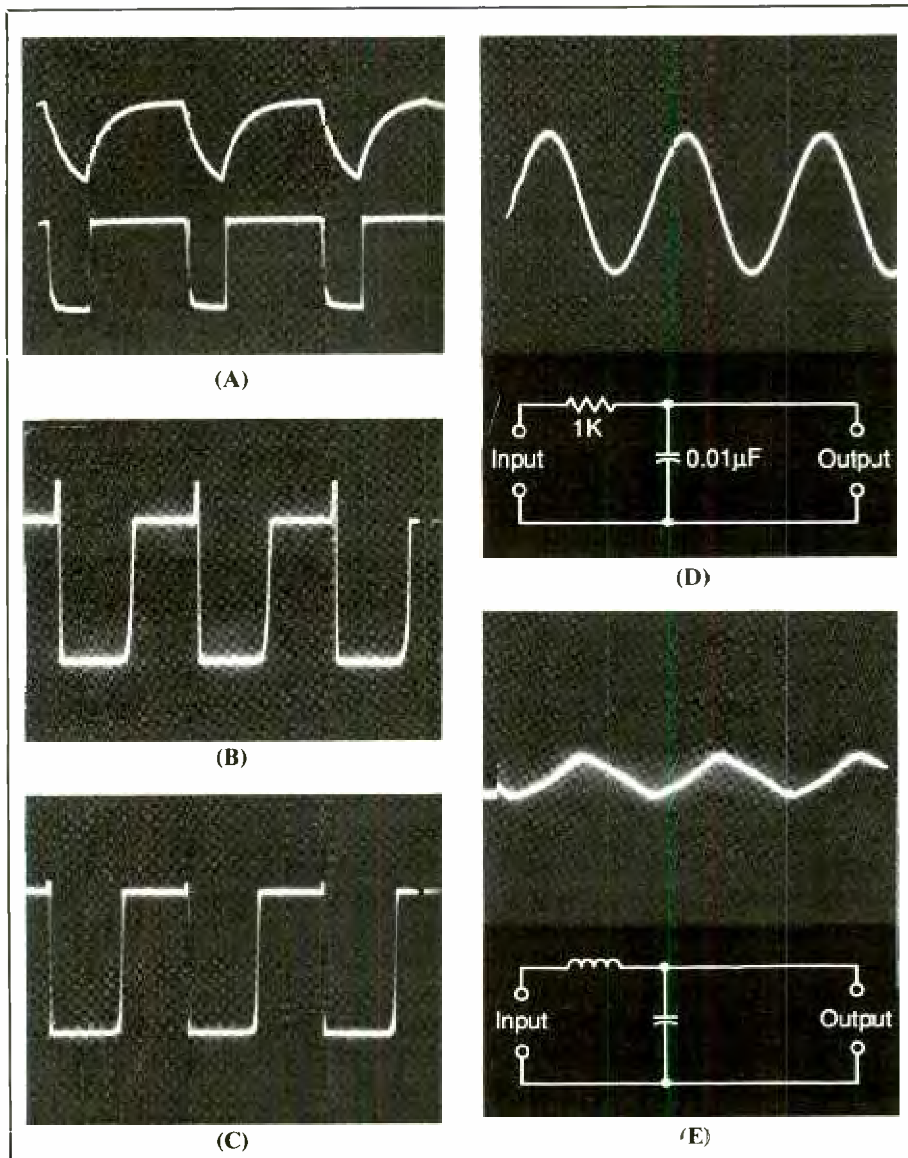

Fig. 8. The 1.5-MHz TTL-level pulse in (A) was applied to a number of circuits and the result monitored with an oscilloscope: with 100-pF and 0.01-µF capacitors connected across the generator's output (B) and (C); through a low-pass RC filter (E).

Why would one care if a pulse is made up of a fundamental and harmonics? The answer is that this determines how a circuit will react to the pulse. You need to know something of the pulse shape in order to set the bandwidth of a circuit. For example, an electrocardiograph (ECG) signal has a fundamental of less than 1 Hz, but the amplifier it drives must be capable of passing 100 Hz because the Fourier components (harmonics) are present in significant amplitude out to this frequency.

Figure 8 shows several situations in which a 1.5-MHz pulse from a TTL generator it applied to various circuits. For the sake of comparison, the output of the pulse generator is shown in Fig. 8(A).

When a 100-picofarad capacitor is connected across the output of the

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generator, the trace shown in Fig. 8(B) was the result. Note here that a little undershoot "ringing" occurred. When the capacitance was increased to 0.01 microfarad, the result was the lower trace shown in Fig. 8(C). Note here the rounding that occurred (compared with the upper trace). This capacitance resulted from rolling off the higher harmonics, leaving only a few harmonics to form the pulse. The "sharpness" of the rise and fall times is dependent upon the higher harmonics.

In Fig. 8(D) is shown the result of a low-pass RC filter consisting of a 1,000-ohm series resistance and a shunt capacitance of 0.01 microfarad. With this arrangement, both the sharpness and amplitude of the pulse decreased substantially over what they were in the previous case.

It is possible to roll off enough harmonics that the square-wave pulse takes on a sine-wave shape. In Fig. 8(E) is shown the result of making an L-section low-pass filter from a 100-microhenry inductor and a 100-picofarad capacitor. Almost all of the harmonics are removed from the pulse; hence, the square wave looks more like a sine wave—which is why the low-pass filter on a ham or CB set prevents TVI (television interference).

This concludes our discussion on pulse shaping. By knowing what pulses are and how they are generated and affect the circuits in which they are used, you will greatly increase your understanding of modern electronics, especially in the digital area. ME