By JORDAN McQUAY

# ELECTRONIC TRANSIENTS

## The Future Belongs to These Odd-Shaped Waves

PERIODIC waves of electrical energy may have many different shapes. Simplest of these is the pure sine wave. More complex waves may have a large number of harmonic frequencies—voice, music, or random noise. In most audio and radio work the exact shape of these waveforms is unimportant—provided the output of the operating device or equipment is not *too* distorted. Even so-called high fidelity allows for considerable distortion inaudible to the human ear.

In electronic applications — radar, television, and electronic timing, delay, and control circuits—the shape of these waves is very important. They control microsecond action of other circuits and components of the equipment, where accurate timing and measurement often depends entirely upon the wave shape.

Despite their apparent simplicity when viewed on a test oscilloscope, such control waves are usually extremely complex in composition. Simple-appearing waves—such as the saw-tooth, square, and peaked waves, rectangular pulses, and others (Figure 1)—are complex combinations of many waveforms.

Although not sinusoidal, such electronic waves *are* periodic. That is, they repeat themselves at regular time intervals, permitting examination with a synchronized test oscilloscope.

The composition of these periodic, nonsinusoidal waves is important to an understanding of the operation of all electronic circuits. Because these waves, under the guidance and control of the special types of electronic circuits, perform the many functions of timing, modulation, measurement, and delay in radar, television, and general electronics work.

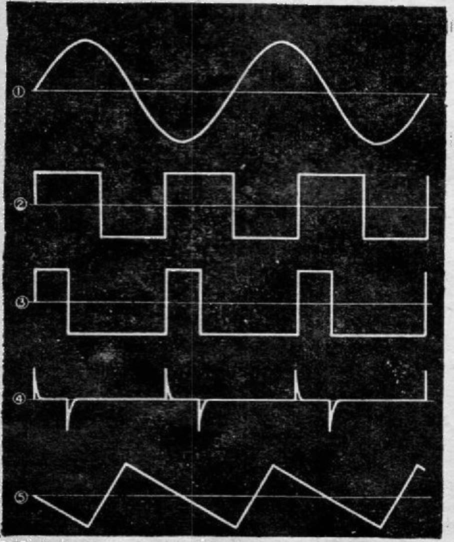

Fig. 1—Types of periodic waves. 1—Sine wave. 2—Square wave. 3—Rectangular wave. 4—Peaked wave-forms. 5—Saw-toothed wave.

### USE OF HARMONICS

All complex, periodic waves have their basis in the pure sine wave, the recurrent sine wave having the same frequency as the complex wave. This is called the fundamental or first harmonic.

Component waves of multiple frequency are known as second, third, fourth, fifth, etc. harmonics. And the waves are designated according to ratio of their recurrence frequency to the fundamental. That is, a frequency three times that of the fundamental is known as the third harmonic, a frequency six times the fundamental as the sixth harmonic, and so on.

By skillfully combining certain harmonics (of different amplitudes) with the fundamental, basic sine wave, a complex wave having almost any given shape can be created by electronic circuits.

The *saw-tooth wave*—familiar as a time base control in test oscilloscopes and certain radar applications—consists of the fundamental wave to which are added harmonics of lower amplitude. When only the second and third harmonics are combined with the basic sine wave, the resultant wave [Figure 2 (4)] begins to assume a saw-tooth form. But the positive and negative peaks are not sharp and the slope is irregular. To obtain an acceptable saw tooth wave [Figure 2 (5)] a great many other harmonics—often as many as eight or nine—must be combined with the fundamental.

A *perfect* saw tooth wave—with sharp edges and a perfectly flat slope—would have to consist of an infinite number of added harmonics. For most radar and electronic purposes, however, saw tooth waves with harmonics up to the eighth or ninth are acceptable.

A *square wave* consists of a fundamental and a number of *odd* harmonics only. When the fundamental is combined with a third harmonic of lower amplitude [Figure 2 (6)], the general "square wave effect" is illustrated. Addition of more *odd* harmonics—the fifth, seventh, ninth, and sometimes the 11th—results in a wave shape more nearly approaching a perfect square. However, a *perfect* square wave is impossible to obtain since it would have

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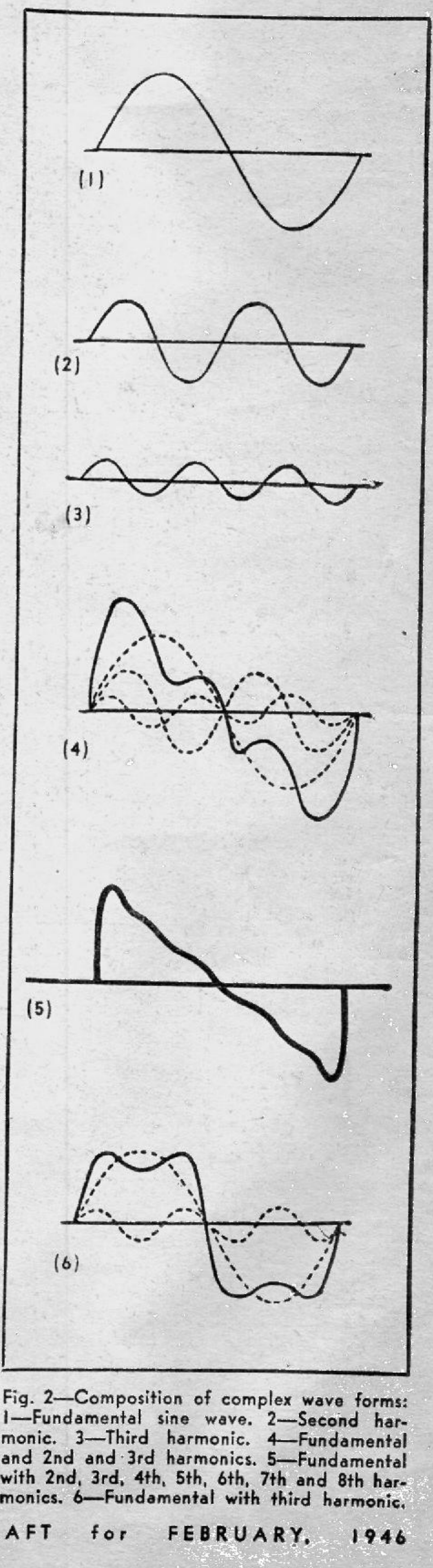

Fig. 2—Composition of complex wave forms: 1—Fundamental sine wave. 2—Second harmonic. 3—Third harmonic. 4—Fundamental and 2nd and 3rd harmonics. 5—Fundamental with 2nd, 3rd, 4th, 5th, 6th, 7th and 8th harmonics. 6—Fundamental with third harmonic.

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to consist of an infinite number of odd harmonics.

Omitting certain odd harmonics in the series and changing the amplitudes of others, results in a variant of the square wave—the *rectangular wave.*

Countless other periodic wave shapes are encountered in electronics. But their shape always depends on the harmonics that are present, their relative amplitudes, and their relative phase relations with each other. The steeper the sides of the final wave shape, the more harmonics it contains.

All of the wave shapes shown in Figure 2 have equal alternations. That is, the positive portion of each wave has mirror symmetry with the negative portion. Sometimes waves are encountered that do not have equal alternations but which are periodic. Again, these waves are the result of combining a fundamental and certain harmonics of given amplitude.

Thus, any shape of recurrent wave may be produced by the careful selection and combination of a fundamental and harmonics of the basic frequency. And, in like manner, any existing wave may be broken down into a fundamental and certain harmonics.

### DISTORTION

This represents distortion of the original, fundamental wave. But it is desirable distortion. The large number of harmonics present in the wave generally is necessary to obtain specifically shaped waves, without which certain types of electronic circuits—such as timing relays, delay and control devices, or others—could not function.

Steep-front waves are widely used in practically all phases of radar, television, and electronics. As such, they represent a highly distorted wave consisting of a great number of harmonics.

For this reason it is impossible to pass such a wave through an ordinary audio or radio circuit. To do so would introduce *unwanted* distortion and loss of shape.

When amplification of such a complex wave is required, the fundamental and *all* harmonics must be amplified equally. In radar and television this led to the development of wide-band or *video* amplifiers, capable of equal amplification of all frequencies from a few cycles to several megacycles. Most coupling stages, also, are required to pass complex waves without discrimination as to frequency, phase, or amplitude of the component harmonics.

In some electronic applications, however, just the opposite is true. Circuits are designed to introduce the intentional distortion. Particularly in radar, this *controlled* distortion is necessary for shaping control waves prior to their application to the final stage of some other component. A typical example of this is the very steep-front, narrow, rectangular pulse required to modulate a radar transmitter during each "pulsing period" of the set's operation.

The behavior of these distortion circuits can best be understood as transient phenomena—or "transients." A measure of the introduced distortion is sometimes known as the *time constant.*

### TIME CONSTANT

Ohm's law states that the voltage across a resistance is equal to the current through it times the value of the resistance. In other words, a voltage is developed across a resistor only when current flows through it. By controlling this flow of current the shape of the voltage wave (across the resistor) can be controlled.

Simplest method of current control is to utilize the charging and discharging properties of a condenser. In a simple R-C circuit [Figure 3], when the switch S is closed the rate of the condenser charge is limited by the amount of resistance R in the circuit. The charging of the condenser is not instantaneous, but of an exponential nature. It takes place within a measurable time, determined by the amount of resistance R and capacitance C.

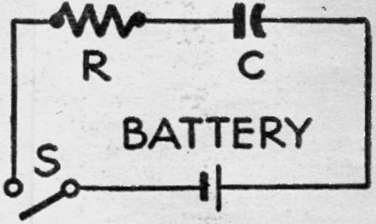

Fig. 3—The simplest wave-forming circuit.

The product of R and C is a measure of the time (in seconds) required for the condenser charge to reach 63 percent of its final or fully charged value. This product (RC) is known as the *time constant* where R is in ohms and C is in farads.

When the condenser [Figure 3] is discharged through the same resistance R, the discharge current will be limited by the resistance. The current decrease will again be exponential, the slope at any time depending upon the values of R and C. The time constant is again a measure of the time required to discharge the condenser.

When the time constant for a given circuit equals 1 (or RC seconds), the charge on the condenser is considered to have reached 63 percent of its final value. When the time constant equals 5 (or 5RC seconds), the condenser is

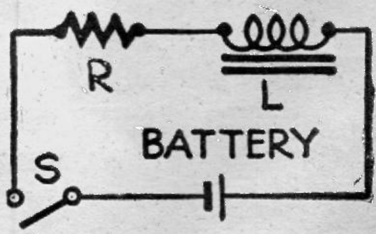

Fig. 4—An inductor changes the wave shape.

considered, for all practical purposes, to be fully charged.

Conversely, in discharging, when the time constant equals 1 (RC seconds), the amount of charge on the condenser is considered to be 37 percent of its final voltage. And when the time constant equals 5 (or 5RC seconds), the condenser is considered to be fully discharged.

Current flow through a resistance can also be controlled by means of inductance-retarding effects. In a simple R-L circuit [Figure 4], when the switch S is closed the battery forces a current through the inductance L. The reactance of the coil retards any change in the flow of current, and the current increases exponentially—the rate depending upon the values of R and L.

The quotient L/R is a measure of the time required for the current to rise to 63 percent of its full value. And this quotient is known as the time constant (in seconds), where R is in ohms and L is in henrys. There is a similar exponential fall of current when the circuit [Figure 4] is discharged through the resistance R, the time constant again being a measure of the time required for current decay.

By utilizing transient current effects of either R-C or R-L circuits, it is possible to influence the distortion and formation of voltage waves—to any desired shape. For instance, the common saw-tooth wave used for the time base of most types of cathode ray tubes is but the charge-discharge wave taken from across a condenser.

Resistance-inductance circuits are occasionally used in electronic delay, timing and counting circuits. But the resistance-capacitance or R-C circuit has wider general use in radar, television, and electronics.

### TRANSIENT EFFECTS

In a given R-C circuit [such as Fig. 3], if the value of either resistance or capacitance is increased, or if both are increased, the circuit will have a longer time constant because the condenser will take longer to charge.

Thus, the value of either R or C, or both, can be varied to obtain any desired value of charging time.

The terms *long* time constant and *short* time constant are purely relative evaluations.

A *long* time constant means that the time (expressed in RC seconds) is long compared with the time necessary for the impressed or signal voltage to complete half a cycle. If the product of R and C is large enough there will be little or no introduced distortion.

A *short* time constant means that the time (expressed in RC seconds) is short in comparison with the frequency of the impressed or signal voltage. A circuit possessing a short time constant introduces a particularly desirable form of distortion known as *peaking*.

The input wave applied to either R-C or R-L circuits may be of any shape. But the greatest amount of distortion can be obtained in the output when the

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input wave consists of abrupt changes, that is, when the input wave has very steep sides. Most ideal type of input wave is the *assymmetrical square wave.*

Figure 5 illustrates such a signal voltage applied to two kinds of R-C circuits. By earlier definition, the upper circuit has a short time constant (RC=0.001 seconds), the lower circuit has a long time constant (RC=0.1 seconds), both with respect to the frequency of the applied square-wave voltage.

When the voltage E is applied to the short time-constant circuit [upper Figure 5], the condenser is charged to E volts according to the rate of charge permitted by the values of R and C. Polarity of the condenser charge is determined by the polarity of the applied square wave.

As the input voltage changes, the voltage across the condenser, $e_c$, follows the rate of charge and discharge. This wave form is known as the *integrated portion* of the original impressed square wave. Should such a sloping wave, $e_c$, be desired to operate or control an electronic circuit, the voltage wave could be tapped off from across the condenser and fed to other stages or components. This circuit is referred to as an *integrator circuit.*

Of more practical use, however, is the *peaked wave* appearing across the resistance, $e_r$. Such a circuit is referred to as a *differentiator circuit.*

Peaking is an important form of distortion, finding wide use as a trigger impulse. The output voltage, $e_r$, is often applied to limiting or other types of pulse-forming circuits to obtain extremely narrow and precise rectangular impulses.

Thus there are two principal types of distortion in the R-C circuit: integration and differentiation.

Distortion of the input square wave by a short time constant R-C circuit is due to the poor low frequency response of the stage. The square wave has steep sides, and therefore a large number of *odd* harmonics. The highest frequency harmonics cause the impressed wave to be even further removed from the shape of the fundamental sine wave. Reactance of the condenser is greatest for low frequency harmonics, causing an exaggeration of the high frequency harmonics in the resistor output wave, $e_r$.

Although both waveforms, $e_r$ and $e_c$, are available for use, either but only one of the two are ever utilized because of loading effects on the stage. And of the two types of output waves, the voltage, $e_r$, is more generally used.

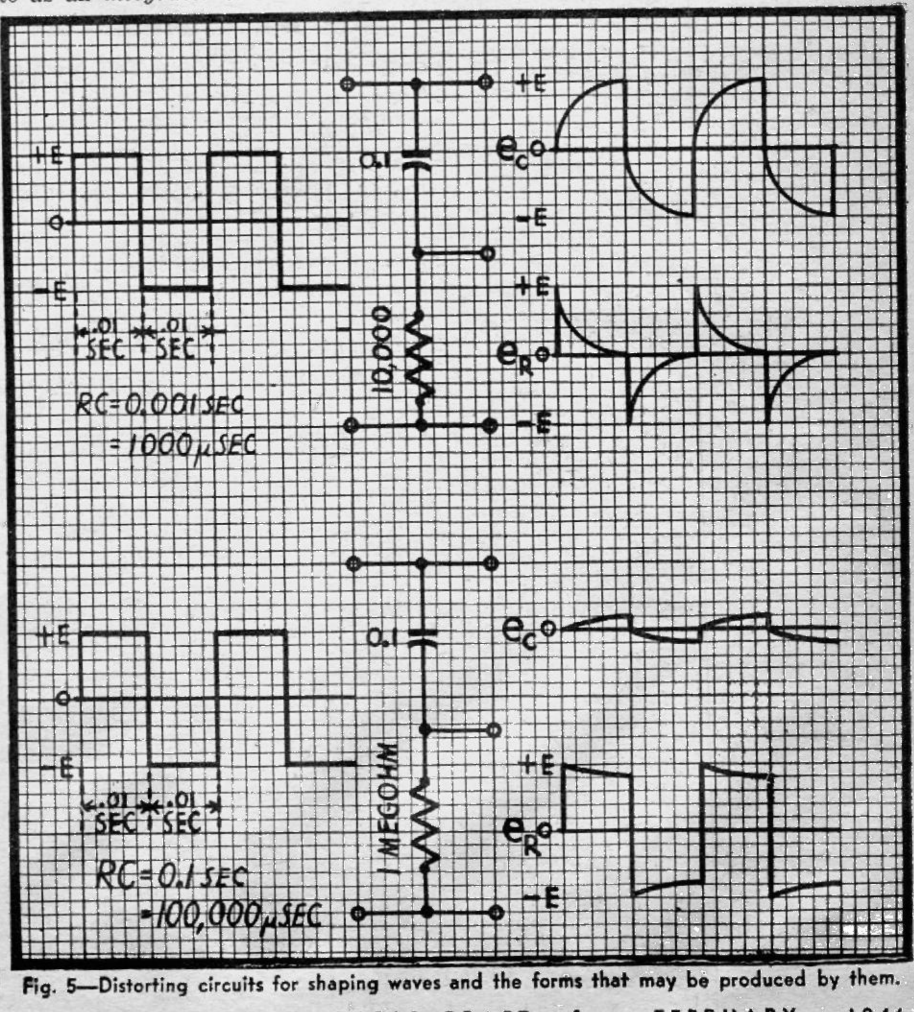

Fig. 5—Distorting circuits for shaping waves and the forms that may be produced by them.

A long time-constant circuit [lower Fig. 5] also provides two waveforms, but of somewhat different nature. In this circuit the time constant is ten times the required time for a half cycle of the impressed square-wave voltage. When this voltage E is applied to the circuit, the condenser does not charge to its full value during an alternation. Before it has time to charge fully, the polarity of the impressed voltage is reversed.

The wave across the condenser, $e_c$, is of little use because of its diminished amplitude.

The integrated voltage across the resistance, $e_r$, is almost a duplicate of the impressed square wave. If the time constant for this particular circuit were 40 or 50 times that of the signal frequency, the voltage across the resistor would be almost identical with the input voltage. And the condenser voltage, $e_c$, would have no perceptible change.

Since practically the entire voltage drop of the R-C circuit [lower Fig. 5] is across the resistance, this explains the wide use of long time-constant circuits as coupling devices between stages of resistance-coupled amplifiers. Careful selection of R and C values is necessary, since improper selection might result in a short time-constant circuit introducing unwanted distortion.

Wave shapes other than square waves may be applied to either long or short time-constant circuits, resulting in various wave forms in the differentiated or integrated output. For instance, a rectangular wave may be integrated to obtain a saw-tooth voltage wave.

However, a pure sine wave suffers *no* distortion when passing through either a long or short time-constant circuit, since one of the important mathematical properties of a sine wave is that it may be differentiated any number of times without changing its shape.

Besides the important distortion effects of R-C and R-L circuits, the time constant of such simple circuits is the basis for all electronic delay and timing circuits. The delay action depends upon the R-C or R-L values, and the time required for a current to build up or decrease. The retarding action of these circuits can be utilized to achieve either postponed control actions or to measure required time intervals.

These circuits permit delayed action of both electrical and mechanical devices, control of circuits during prescheduled intervals of time, and other electronic functions.

In radar and television applications, selected impulses containing very high-order harmonics are used to synchronize the operating of many components.

## CORRECTION

An error occurred in the article "Elements of Radar" on page 169 of the December issue. In the 24th line, second column, the time for a pulse to travel 3270 yards should have been 10, not 50 microseconds. The time for the full circuit would of course be 20 microseconds instead of 100 as stated.

British amateurs were permitted to return to the air on a limited number of frequencies, by an order dated January 8, 1946. Power up to 100 watts is permitted. Equipment taken into custody in 1939 will be returned to the hams of Great Britain within the next few weeks.